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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

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National foreword

This British Standard is the UK implementation of EN 55016-1-4:2010+A1:2012. It is identical to CISPR 16-1-4:2010, incorporating amendment 1:2012 and corrigendum December 2010. It supersedes BS EN 55016-1-4:2010, which is withdrawn.

The start and finish of text introduced or altered by amendment is indicated in the text by tags. Tags indicating changes to IEC text carry the number of the IEC amendment. For example, text altered by IEC amendment 1 is indicated by [A1⟩ ⟨A1]

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A list of organizations represented on this subcommittee can be obtained on request to its secretary.

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Date	Text affected
30 June 2011	Implementation of CISPR corrigendum December 2010: Modification to equation B.2
30 April 2013	Implementation of CISPR amendment 1:2012 with CENELEC endorsement A1:2012

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English version

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
(CISPR 16-1-4:2010)

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 (CISPR 16-1-4:2010)

Anforderungen an Geräte und Einrichtungen sowie Festlegung der Verfahren zur Messung der hochfrequenten Störaussendung (Funkstörungen) und Störfestigkeit - Teil 1-4: Geräte und Einrichtungen zur Messung der hochfrequenten Störaussendung (Funkstörungen) und Störfestigkeit - Zusatz-/Hilfseinrichtungen - Gestrahlte Störaussendung (CISPR 16-1-4:2010)

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CENELEC

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Foreword

The text of document CISPR/A/885/FDIS, future edition 3 of CISPR 16-1-4, prepared by CISPR SC A, Radio-interference measurements and statistical methods, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 55016-1-4 on 2010-06-01.

This European Standard supersedes EN 55016-1-4:2007 + A1:2008 + A2:2009.

This EN 55016-1-4:2010 includes the following significant technical change with respect to EN 55016-1-4:2007 + A1:2008 + A2:2009: 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*.

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

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2011-03-01
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2013-06-01

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard CISPR 16-1-4:2010 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following note has to be added for the standard indicated:

[1] IEC 61169-8 NOTE Harmonized as EN 61169-8.

Foreword to amendment A1

The text of document CISPR/A/995/FDIS, future amendment 1 to edition 3 of CISPR 16-1-4, prepared by SC A "Radio-interference measurements and statistical methods" of IEC/TC CISPR "International special committee on radio interference" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 55016-1-4:2010/A1:2012.

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• latest date by which the document has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2013-05-16
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The text of the International Standard CISPR 16-1-4:2010/A1:2012 was approved by CENELEC as a European Standard without any modification.

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

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.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
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	EN 55016-1-1	-
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	EN 55016-1-5	2004
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	EN 55016-2-3	-
CISPR/TR 16-3		Specification for radio disturbance and immunity measuring apparatus and methods - Part 3: CISPR technical reports	-	-
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	EN 55016-4-2	-
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	EN 61000-4-20	-

CONTENTS

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, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 3: CISPR technical reports*

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 ±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
[A1⟩ quasi free-space test site ⟨A1]
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
[A1) shielded enclosure in which all surfaces except the metal floor are covered with material that absorbs electromagnetic energy (i.e. RF absorber) in the frequency range of interest (A1]

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 [A1) a FAR (A1] in which the EUT is positioned

NOTE In this volume, the [A1) quasi free-space condition (A1] is met and this volume is typically 0,5 m or more from the absorbing material of [A1) a FAR (A1].

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}

3.1.22
antenna factor
AF
F_a
ratio of the electric field strength of an incident plane wave to the voltage induced across a specified load (typically 50 Ω) connected to the antenna

NOTE 1 F_a is affected by the load impedance connected to the antenna radiating elements, and is frequency dependent. For a biconical antenna this impedance could be up to 200 Ω. For antennas with no balun the impedance is equal to the load impedance, typically 50 Ω.

NOTE 2 Usually, the AF is defined for the plane wave incident from the direction corresponding with the maximum gain of the antenna and at a specified point of the antenna.

NOTE 3 The AF has the physical dimension of inverse metres (m^{-1}) and measured data are normally expressed in dB(m^{-1}). In radiated emission measurements, if F_a is known, the strength of an incident field, E, can be estimated from a reading, V, of a measuring receiver connected to the antenna as follows:

$$E = V + F_a$$

where E is in dB(μV/m), V is in dB(μV) and F_a is in dB(m^{-1}).

3.1.23
antenna factor, free-space
$F_{a\ fs}$
AF of an antenna located in a free-space environment

NOTE $F_{a\ fs}$ is a measurand for uncertainty calculation for antenna calibration. For NSA measurements $F_{a\ fs}$ is an input quantity for uncertainty calculation.

3.1.24
antenna pair reference site attenuation
A_{APR}
set of site attenuation measurement results for both vertical and horizontal polarizations using a pair of antennas separated by a defined distance at an ideal open-area test site, with one antenna at a specified fixed height above the ground plane, and the other antenna scanned over a specified height range in which the minimum insertion loss is recorded

NOTE 1 A_{APR} is a measurand for uncertainty calculation.

NOTE 2 A_{APR} measurements are used for comparison to corresponding site attenuation measurements of a COMTS to evaluate the performance of the COMTS.

3.1.25
antenna reference point
midpoint of an antenna from which the distance to the EUT or second antenna is measured

NOTE The antenna reference point is either defined by the manufacturer using a marker on LPDA antennas or by the calibration laboratory.

3.1.26
ideal open-area test site
open-area test site having a perfectly flat, perfectly conducting ground plane of infinite area, and with no reflecting objects except the ground plane

NOTE An ideal OATS is a theoretical construct that is used in the definition of the measurand A_{APR} and in the calculation of the theoretical normalized site attenuation A_N for ground plane sites.

3.1.27
reference test site
REFTS
open-area test site with metallic ground plane and tightly specified site attenuation performance in horizontal and vertical electric field polarizations

3.2 Abbreviations

[A1) The following are abbreviations used in this standard that are not already given in 3.1. (A1]

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
[A1) RSM	Reference site method (A1]
SA	Site attenuation

[A1) *Text deleted* (A1]

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 µA/m. In logarithmic units H is in dB(µA/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 dB(µA/m) or µA/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 dB(µV/m), i.e. assuming that the ratio of the E and H components is 120 π Ω or 377 Ω. Calculations for H are as follows:

$$H = \frac{E}{377\ \Omega} \tag{1}$$

where H is typically in µA/m and E in µV/m.

For measurements in dB:

$$H = E - 51{,}5 \tag{2}$$

where H is in dB(µA/m) and E in dB(µV/m).

The impedance used in the above conversions, Z = 377 Ω, with 20 log Z = 51,5 dB(Ω), is a constant originating from the calibration of field strength measuring equipment indicating the magnetic field in µV/m [or dB(µV/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 µV/m. In logarithmic units, E shall be expressed in dB(µV/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 dB(µA/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 ±1 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.

[A1]

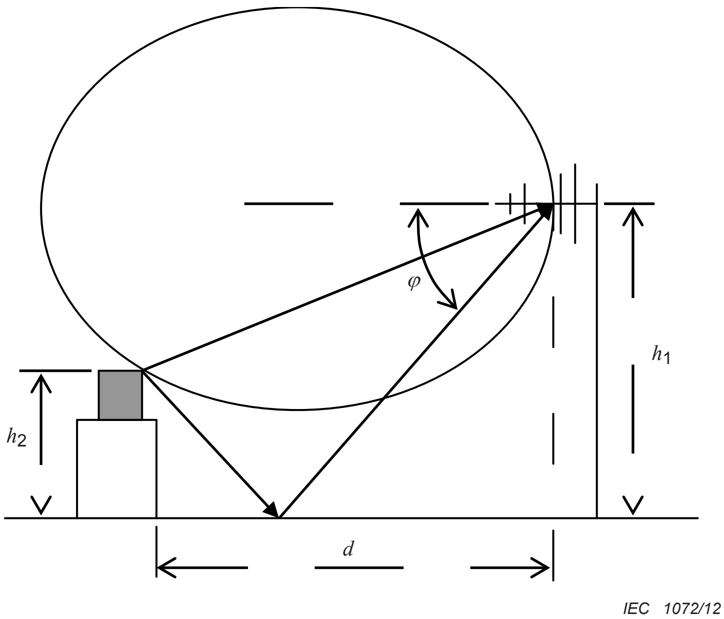


Figure 1 – Schematic of radiation from EUT reaching an LPDA antenna directly and via ground reflections on a 3 m site, showing the half beamwidth, φ , at the reflected ray [A1]

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:

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

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

A1⟩ h_2 ⟨A1 is the height of the equipment under test;

A1⟩ h_1 ⟨A1 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 A1⟩ a correction with associated ⟨A1 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.

A1⟩ *Note deleted* ⟨A1

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(μV), 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 ± 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 ±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 [A1⟩ FAR ⟨A1] with the receiving antenna at its usual location and the transmitting antenna in the centre of the test volume of that [A1⟩ FAR ⟨A1]. The [A1⟩ FAR ⟨A1] should comply with the ±4 dB [A1⟩ site validation criterion ⟨A1].

NOTE 3 The measuring site of which the ground plane forms a part, or the [A1⟩ FAR ⟨A1], should comply with their respective [A1⟩ site validation ⟨A1] 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 A1 quasi free-space conditions A1, a A1 high-quality fully anechoic room A1 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 ±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:

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

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

[A1) An environment is required that assures valid, repeatable measurement results of disturbance field strength from an EUT. For an EUT that can only be tested at its place of use, other provisions shall be utilized (i.e. see details on in-situ measurements in CISPR 16-2-3). (A1]

5.2 OATS

5.2.1 General

[A1) An OATS is an area characterized by cleared level terrain and the presence of a ground plane. To meet the validation requirements of this standard, a metallic ground plane is recommended. Such a test site shall be free 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 of an OATS for disturbance field-strength measurements in the range of 30 MHz to 1 000 MHz. The site validation procedures for an OATS are given in 5.4.4 and 5.4.5. Annex F explains the basis for the acceptability criterion. ⟨A1

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).

A1⟩ For this ellipse, the length of the path taken by the undesired indirect ray reflected from any object on the perimeter is twice the length of the path taken by the direct ray 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. ⟨A1

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 A1⟩ measurement distance. ⟨A1

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.

A1⟩

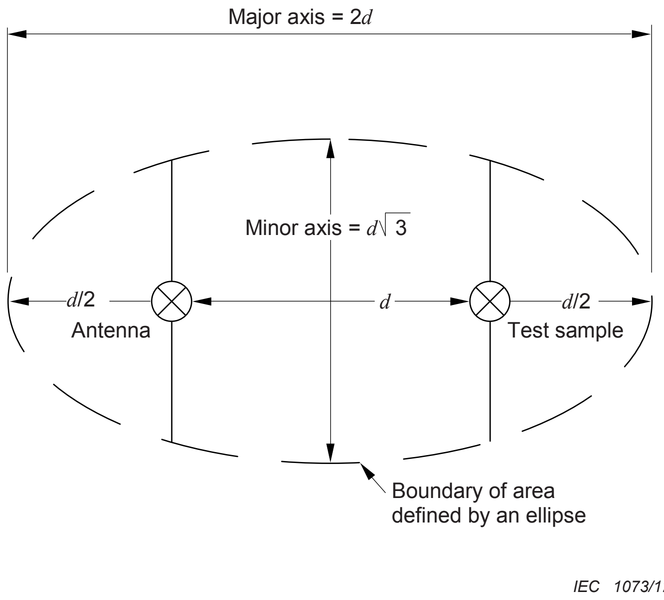


Figure 2 – Obstruction-free area of a test site with a turntable (see 5.2.3) ⟨A1

A1⟩

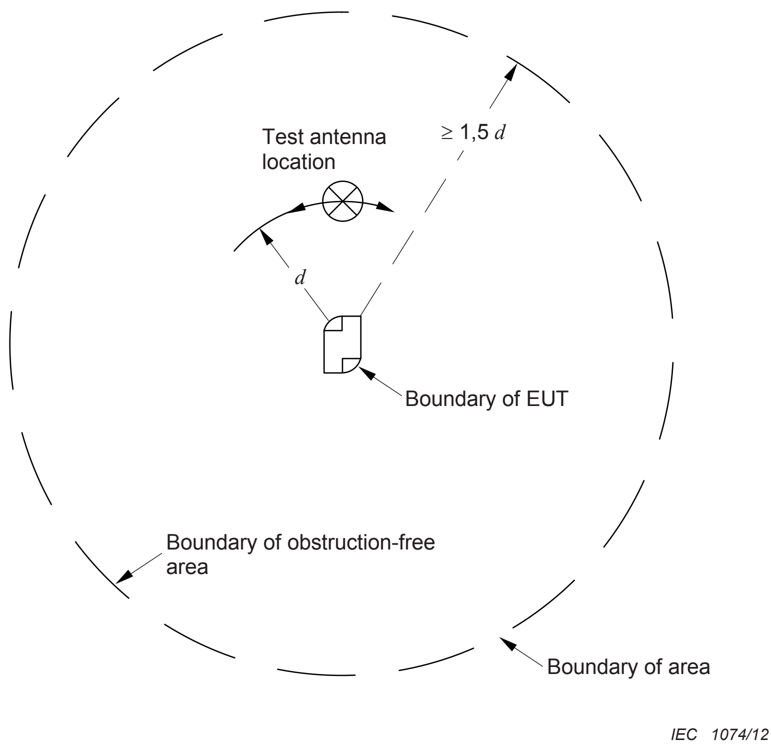


Figure 3 – Obstruction-free area with stationary EUT (see 5.2.3) ⟨A1

5.2.4 Ambient radio frequency environment of a test site

A1⟩ The ambient radio frequency levels at an OATS shall be sufficiently low compared to the levels of measurements to be performed. The quality of the site in this regard may be evaluated under four categories, listed below in order of merit: ⟨A1

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.

A1⟩ NOTE A measured ambient level of 20 dB or more below the emission limit is considered optimum. ⟨A1

5.2.5 Ground plane

A1⟩ The OATS ground plane can be at earth level or elevated on a suitably sized platform or horizontal rooftop site. A metal ground plane is preferred, but for certain equipment and applications, product publications may recommend other site types. Adequacy of the metal ground plane will be dependent on whether the test site meets the site validation requirements of 5.4. If metallic material is not used, caution is required to select a site that does not change its reflective characteristics with time, weather conditions, or effects due to buried metallic material such as pipes, conduits, and non-homogeneous soil. Such sites generally give different SA characteristics compared to those with metallic surfaces. ⟨A1

A1⟩ *Text deleted* ⟨A1

5.3 A1⟩ Suitability of other test sites ⟨A1

5.3.1 A1⟩ Other ground-plane test sites ⟨A1

A1⟩ There are many different test sites and facilities that have been constructed and used to make radiated emission measurements. Most are protected from the weather and the adverse effects of the radio frequency ambient. In a SAC, all walls and the ceiling are equipped with appropriate absorbing material. The floor consists of a metallic ground plane to emulate an OATS. A SAC isolates the receiving antenna from the RF ambient environment, and permits EUT testing independent of weather conditions.

Whenever construction material encloses a ground-plane test site, it is possible that the results of a validation measurement at a single location, as specified in 5.4.5, are not adequate to show acceptability of such an alternative site.

To evaluate suitability of an alternative ground-plane test site, the procedure of 5.4.6 shall be used, which is based on making multiple validation measurements throughout a volume occupied by the EUT. These validation measurement results shall all be within a tolerance of ± 4 dB for a site to be judged suitable as an equivalent to an OATS.

NOTE SACs typically meet the site quality categories listed in 5.2.4. ⟨A1

5.3.2 A1⟩ Test sites without ground plane (FAR) ⟨A1

A1⟩ A fully-absorber-lined shielded enclosure, also known as a fully-anechoic room (FAR), can be used for radiated emission measurements. When a FAR site is used, appropriate radiated emission limits shall be defined in relevant standards (generic, product or product family standards). Compliance of an EUT with the requirements for the protection of radio-services (limits) shall be evaluated at FAR sites using similar methods as for tests done at an OATS. ⟨A1

A1 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 by appropriate placement of absorbing material on all walls, ceiling and floor of a FAR. Like a SAC, a FAR isolates the receiving antenna from the RF ambient environment, and permits EUT testing independent of weather conditions.

NOTE FARs typically meet the site quality categories listed in 5.2.4. A1

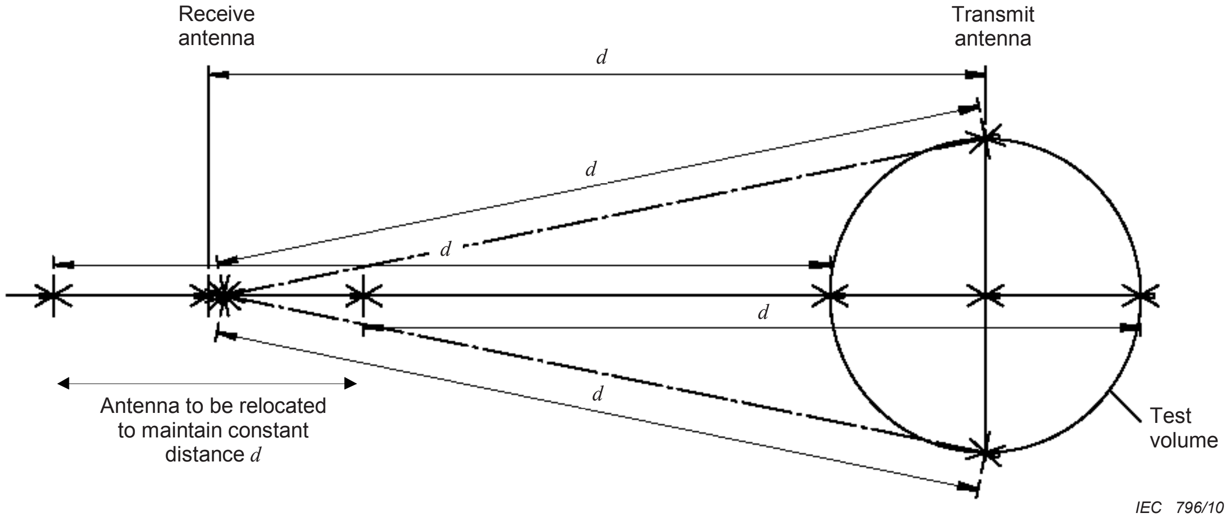


Figure 6 – Typical antenna positions for alternative test site – Vertical polarization NSA measurements

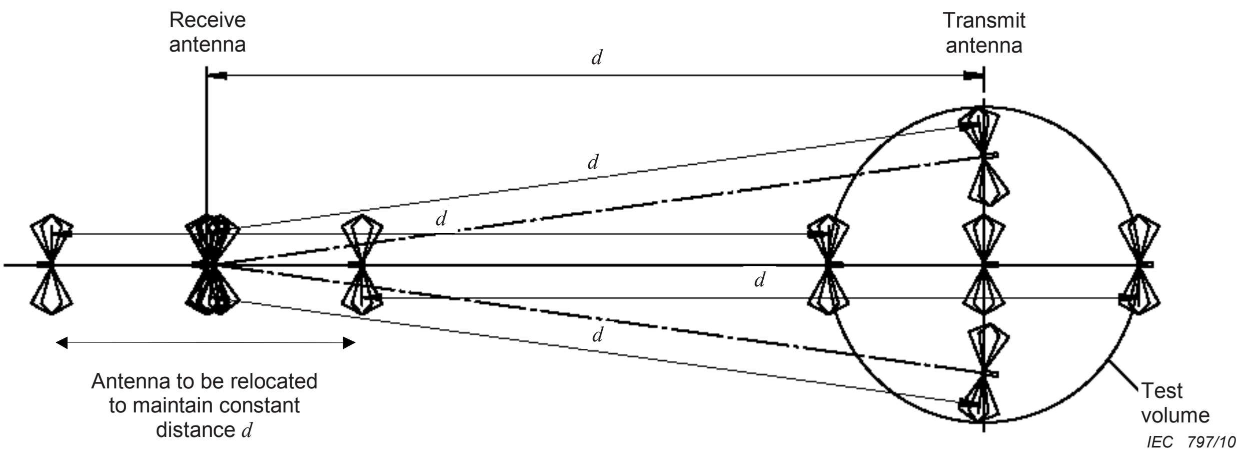
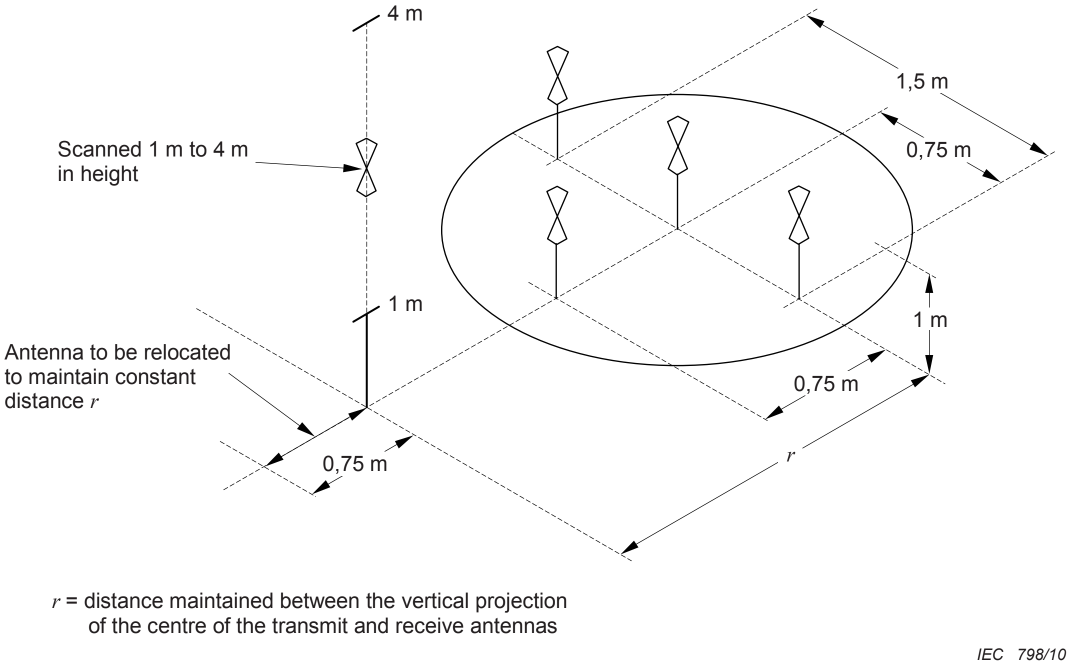
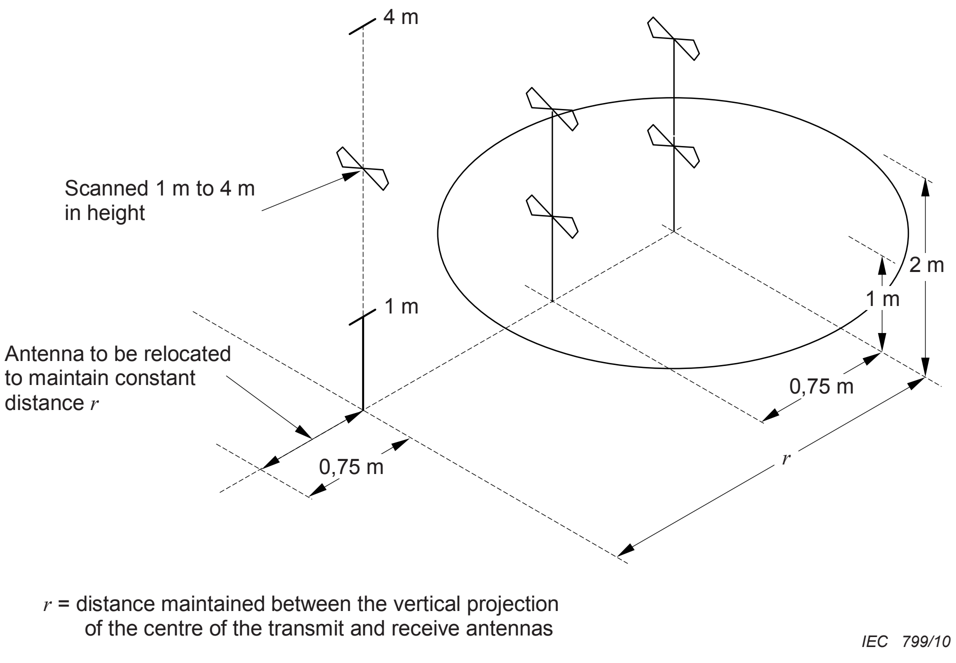


Figure 7 – Typical antenna positions for alternative test site – Horizontal polarization NSA measurements



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

5.4 A1 Test site validation A1

5.4.1 A1 General A1

A1 Three methods for site validation are defined in this standard:

- NSA method with tuned dipoles;
- NSA method with broadband antennas;
- Reference site method (RSM) with broadband antennas.

Validations for test sites with a ground plane (i.e. OATS and SAC) are introduced in 5.4.2 and 5.4.3, followed by detailed procedures for the RSM in 5.4.4 and for the NSA method in 5.4.5. Validation of a SAC and a weather-protection enclosed OATS requires additional measurements as described in 5.4.6.

Table 7 summarizes the site validation methods applicable for these specific test site types. As shown in this table, two or three site validation methods are described for each of these test site types. These methods are deemed to be equivalent for the purposes of this standard; meaning compliance with the validation criterion can be evaluated using only one method. Furthermore, no one of these documented methods is defined as the reference method.

Table 7 – Site validation methods applicable for OATS, OATS-based, SAC and FAR site types

Test site type	Applicability of site validation methods		
	Tuned dipoles NSA	Broadband antennas NSA	Broadband antennas RSM
OATS	Yes	Yes	Yes
OATS with weather protection	No	Yes	Yes
SAC	No	Yes	Yes
FAR	No	Yes	Yes

A1

5.4.2 A1 Overview of test site validations A1

A1 The validation of a test site is performed using two co-polarized antennas. The validation shall be performed separately for both horizontal and vertical polarizations.

SA is obtained from the difference of:

- the source voltage level, V_i, applied to a transmitting antenna;
- the maximum received voltage level, V_R, measured on the terminals of a receiving antenna during a specified antenna height scan.

The voltage measurements are performed in a 50 Ω system.

The measured SA of an OATS (as in 5.2) and other ground-plane test sites (as in 5.3.1) is compared to the SA characteristics obtained at an ideal OATS – this is the definition of the measurand for test site validations. The result of this comparison is the SA deviation, ΔA_S, in dB; see Equations (26) and (27). The site is considered suitable when the SA deviation results are within a tolerance of ± 4 dB.

If the ± 4 dB tolerance is exceeded, the test site configuration shall be investigated as described in 5.4.5.3.

NOTE The basis for the 4 dB site acceptability criterion is given in Annex F. A1

A1 Additionally, SA deviations shall not be used to correct field-strength measurement data for an EUT. The procedures of 5.4 shall be used only for test site validations. A1

5.4.3 A1 Principles and values of the NSA method for OATS and SAC A1

A1 NSA values calculated at specific frequencies are provided in Tables 8 and 9 for tuned dipole antennas, and Table 10 for broadband antennas. The quantities d, h_1, h_2, f_M and A_N, which are used in these tables, are identified at the end of Table 8.

NOTE 1 NSA values for frequencies other than shown in the Tables 8, 9, and 10 can be obtained using linear interpolation between the tabulated values.

NOTE 2 The spacing d between the log-periodic dipole array antenna pairs is measured from the projection on the ground plane of the mid-point of the longitudinal axis of each antenna.

NOTE 3 The spacing d between biconical antennas, is measured from the element centre-line axes at the feedpoint.

For measurements in each polarization, the NSA method requires two different measurements of the received voltage, V_R; Figures 29 and 30 illustrate the set-ups for these measurements. A1

Table 8 – Theoretical normalized site attenuation, A_N – recommended geometries for tuned half-wave dipoles, with horizontal polarization

Polarization	Horizontal	Horizontal	Horizontal	Horizontal
d	3 m [a]	10 m	30 m	30 m
h_1	2 m	2 m	2 m	2 m
h_2	1 m to 4 m	1 m to 4 m	1 m to 4 m	2 m to 6 m
f_M MHz	A_N dB(m²)			
30	11,0	24,1	41,7	38,4
35	8,8	21,6	39,1	35,8
40	7,0	19,4	36,8	33,5
45	5,5	17,5	34,7	31,5
50	4,2	15,9	32,9	29,7
60	2,2	13,1	29,8	26,7
70	0,6	10,9	27,2	24,1
80	–0,7	9,2	24,9	21,9
90	–1,8	7,8	23,0	20,1
100	–2,8	6,7	21,2	18,4
120	–4,4	5,0	18,2	15,7
140	–5,8	3,5	15,8	13,6
160	–6,7	2,3	13,8	11,9
180	–7,2	1,2	12,0	10,6
200	–8,4	0,3	10,6	9,7
250	–10,6	–1,7	7,8	7,7
300	–12,3	–3,3	6,1	6,1
400	–14,9	–5,8	3,5	3,5
500	–16,7	–7,6	1,6	1,6
600	–18,3	–9,3	0	0
700	–19,7	–10,6	–1,4	–1,3
800	–20,8	–11,8	–2,5	–2,4
900	–21,8	–12,9	–3,5	–3,5
1 000	–22,7	–13,8	–4,5	–4,4

d is the horizontal separation between the projection of the transmit and receive antennas on the ground plane;

h_1 is the height of the centre of the transmit antenna above the ground plane;

h_2 is the range of heights of the centre of the receive antenna above the ground plane, in m. The maximum received signal in this height scan range is used for NSA results;

f_M is the frequency;

A_N is the NSA

[a] The mutual impedance correction factors (see Table 11) for horizontally polarized tuned half-wave dipoles spaced 3 m apart should be used in Equation (26).

A1⟩ **Table 9 – Theoretical normalized site attenuation, A_N – recommended geometries for tuned half-wave dipoles, vertical polarization**

	d = 3 m [a] h_1 = 2,75 m		d = 10 m h_1 = 2,75 m		d = 30 m h_1 = 2,75 m	
f_M MHz	h_2 m	A_N dB(m^2)	h_2 m	A_N dB(m^2)	h_2 m	A_N dB(m^2)
30	2,75 to 4	12,4	2,75 to 4	18,8	2,75 to 6	26,3
35	2,39 to 4	11,3	2,39 to 4	17,4	2,39 to 6	24,9
40	2,13 to 4	10,4	2,13 to 4	16,2	2,13 to 6	23,8
45	1,92 to 4	9,5	1,92 to 4	15,1	2 to 6	22,8
50	1,75 to 4	8,4	1,75 to 4	14,2	2 to 6	21,9
60	1,50 to 4	6,3	1,50 to 4	12,6	2 to 6	20,4
70	1,32 to 4	4,4	1,32 to 4	11,3	2 to 6	19,1
80	1,19 to 4	2,8	1,19 to 4	10,2	2 to 6	18,0
90	1,08 to 4	1,5	1,08 to 4	9,2	2 to 6	17,1
100	1 to 4	0,6	1 to 4	8,4	2 to 6	16,3
120	1 to 4	–0,7	1 to 4	7,5	2 to 6	15,0
140	1 to 4	–1,5	1 to 4	5,5	2 to 6	14,1
160	1 to 4	–3,1	1 to 4	3,9	2 to 6	13,3
180	1 to 4	–4,5	1 to 4	2,7	2 to 6	12,8
200	1 to 4	–5,4	1 to 4	1,6	2 to 6	12,5
250	1 to 4	–7,0	1 to 4	–0,6	2 to 6	8,6
300	1 to 4	–8,9	1 to 4	–2,3	2 to 6	6,5
400	1 to 4	–11,4	1 to 4	–4,9	2 to 6	3,8
500	1 to 4	–13,4	1 to 4	–6,9	2 to 6	1,8
600	1 to 4	–14,9	1 to 4	–8,4	2 to 6	0,2
700	1 to 4	–16,3	1 to 4	–9,7	2 to 6	–1,0
800	1 to 4	–17,4	1 to 4	–10,9	2 to 6	–2,4
900	1 to 4	–18,5	1 to 4	–12,0	2 to 6	–3,3
1 000	1 to 4	–19,4	1 to 4	–13,0	2 to 6	–4,2

[a] The mutual impedance correction factors (see Table 11) for vertically polarized tuned half-wave dipoles spaced 3 m apart should be used in Equation (26).

⟨A1

[A1] **Table 10 – Theoretical normalized site attenuation[a], A_N – recommended geometries for broadband antennas**

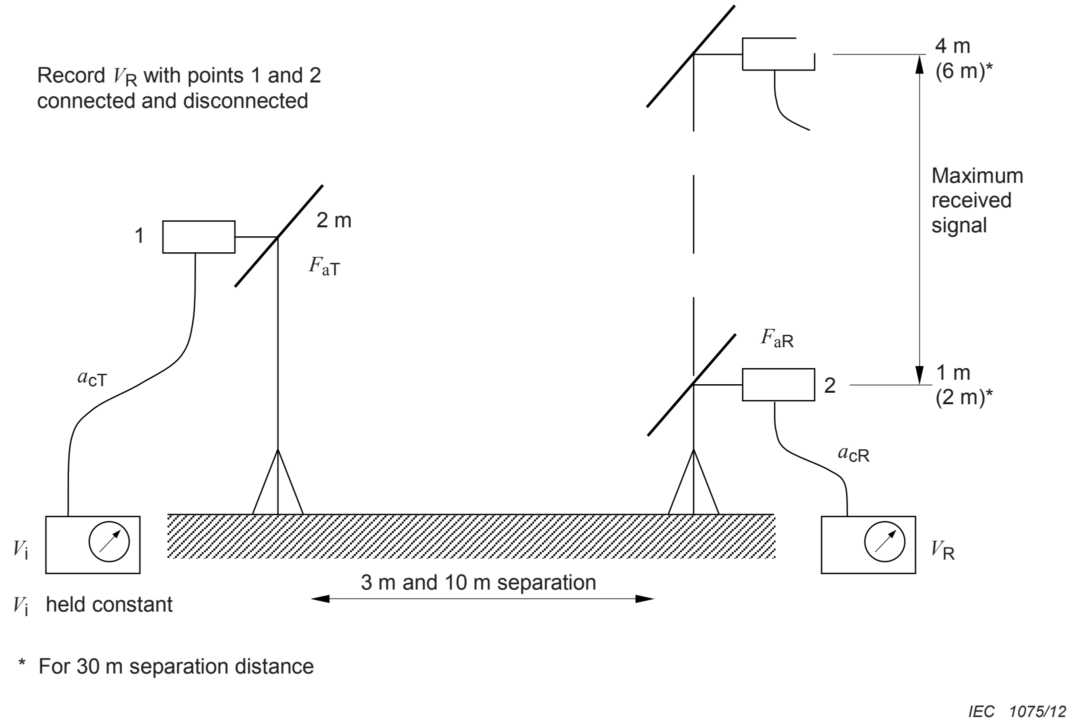
Polarization		Horizontal						Vertical					
d	m	3	3	10	10	30	30	3	3	10	10	30	30
h_1	m	1	2	1	2	1	2	1	1,5	1	1,5	1	1,5
$h_{2,min}$	m	1	1	1	1	1	1	1	1	1	1	1	1
$h_{2,max}$	m	4	4	4	4	4	4	4	4	4	4	4	4
f_M MHz		A_N dB(m^2)											
30		15,8	11,0	29,8	24,1	47,8	41,7	8,2	9,3	16,7	16,9	26,0	26,0
35		13,4	8,8	27,1	21,6	45,1	39,1	6,9	8,0	15,4	15,6	24,7	24,7
40		11,3	7,0	24,9	19,4	42,8	36,8	5,8	7,0	14,2	14,4	23,5	23,5
45		9,4	5,5	22,9	17,5	40,8	34,7	4,9	6,1	13,2	13,4	22,5	22,5
50		7,8	4,2	21,1	15,9	38,9	32,9	4,0	5,4	12,3	12,5	21,6	21,6
60		5,0	2,2	18,0	13,1	35,8	29,8	2,6	4,1	10,7	11,0	20	20
70		2,8	0,6	15,5	10,9	33,1	27,2	1,5	3,2	9,4	9,7	18,7	18,7
80		0,9	–0,7	13,3	9,2	30,8	24,9	0,6	2,6	8,3	8,6	17,5	17,5
90		–0,7	–1,8	11,4	7,8	28,8	23,0	–0,1	2,1	7,3	7,6	16,5	16,5
100		–2,0	–2,8	9,7	6,7	27	21,2	–0,7	1,9	6,4	6,8	15,6	15,6
120		–4,2	–4,4	7,0	5,0	23,9	18,2	–1,5	1,3	4,9	5,4	14,0	14,0
140		–6,0	–5,8	4,8	3,5	21,2	15,8	–1,8	–1,5	3,7	4,3	12,7	12,7
160		–7,4	–6,7	3,1	2,3	19	13,8	–1,7	–3,7	2,6	3,4	11,5	11,6
180		–8,6	–7,2	1,7	1,2	17	12,0	–1,3	–5,3	1,8	2,7	10,5	10,6
200		–9,6	–8,4	0,6	0,3	15,3	10,6	–3,6	–6,7	1,0	2,1	9,6	9,7
250		–11,7	–10,6	–1,6	–1,7	11,6	7,8	–7,7	–9,1	–0,5	0,3	7,7	7,9
300		–12,8	–12,3	–3,3	–3,3	8,8	6,1	–10,5	–10,9	–1,5	–1,9	6,2	6,5
400		–14,8	–14,9	–5,9	–5,8	4,6	3,5	–14,0	–12,6	–4,1	–5,0	3,9	4,3
500		–17,3	–16,7	–7,9	–7,6	1,8	1,6	–16,4	–15,1	–6,7	–7,2	2,1	2,8
600		–19,1	–18,3	–9,5	–9,3	0,0	0,0	–16,3	–16,9	–8,7	–9,0	0,8	1,8
700		–20,6	–19,7	–10,8	–10,6	–1,3	–1,4	–18,4	–18,4	–10,2	–10,4	–0,3	–0,9
800		–21,3	–20,8	–12,0	–11,8	–2,5	–2,5	–20,0	–19,3	–11,5	–11,6	–1,1	–2,3
900		–22,5	–21,8	–12,8	–12,9	–3,5	–3,5	–21,3	–20,4	–12,6	–12,7	–1,7	–3,4
1 000		–23,5	–22,7	–13,8	–13,8	–4,4	–4,5	–22,4	–21,4	–13,6	–13,6	–3,5	–4,3

[a] 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.

Other values are found via linear interpolation.

[A1]

A1



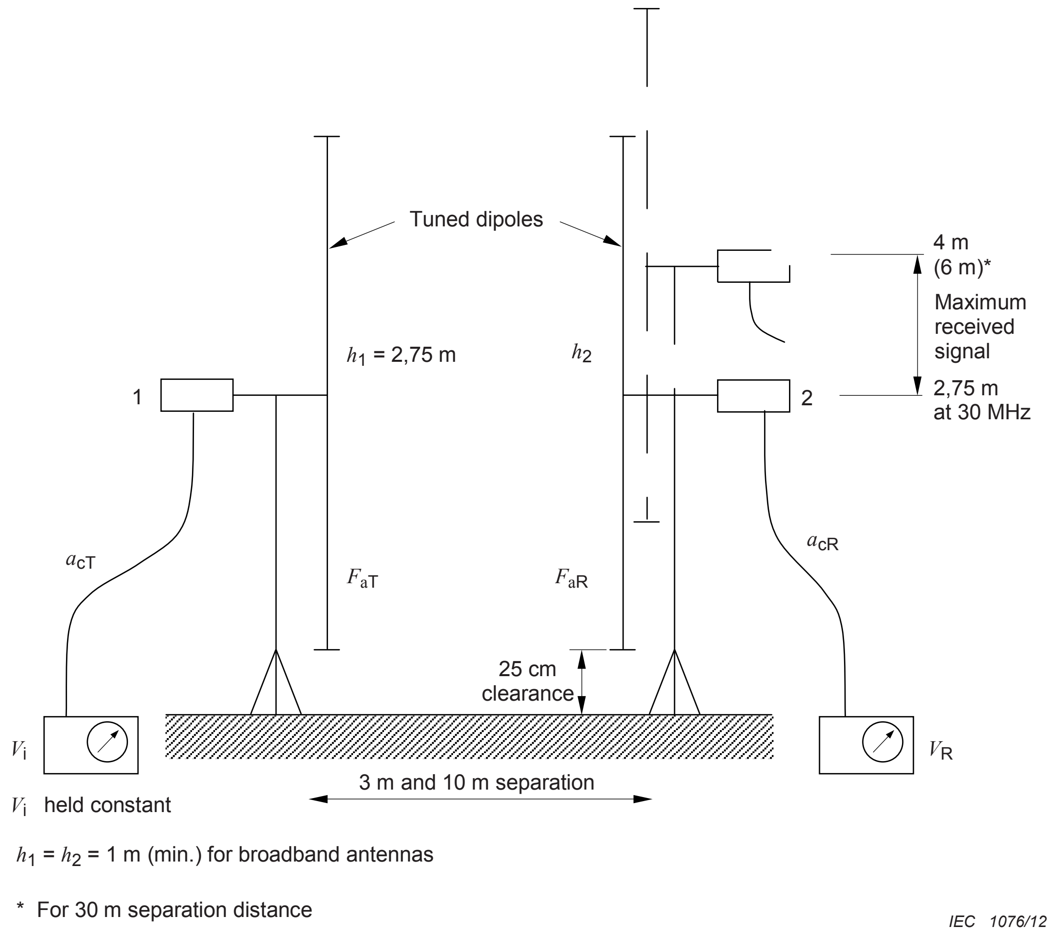
Key

a_{cR}	receive antenna cable loss
a_{cT}	transmit antenna cable loss
F_{aR}	receive antenna factor
F_{aT}	transmit antenna factor
V_i	source voltage
V_R	received voltage

Figure 29 – Configuration of equipment for measuring site attenuation in horizontal polarization

A1

A1



Key

a_{cR}	receive antenna cable loss
a_{cT}	transmit antenna cable loss
F_{aR}	receive antenna factor
F_{aT}	transmit antenna factor
h_1, h_2	see Table 9
V_i	source voltage
V_R	received voltage

Figure 30 – Configuration of equipment for measuring site attenuation in vertical polarization using tuned dipoles

The first reading of V_R (V_{DIRECT}) is taken 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 is measured when the receive antenna is scanned in height (1 m to 4 m, for 3 m and 10 m separation distances; either 1 m to 4 m, or 2 m to 6 m, for 30 m separation distances). For both measurements, the signal source voltage, V_i, is kept constant. The measured results, along with NSA (A_N), are used in Equation (26) to obtain the SA deviation results. All terms are in dB. A1

A1⟩ $$A_s = V_{DIRECT} - V_{SITE} - F_{aT} - F_{aR} - A_N - \Delta A_{TOT} \quad (26)$$

where

ΔA_S is the SA deviation;

F_{aT} is the transmit antenna factor;

F_{aR} is the receive antenna factor;

A_N is the NSA, according to Tables 8, 9 and 10, as appropriate;

ΔA_{TOT} is the mutual impedance correction factor.

F_{aT} and F_{aR} shall be calibrated as free-space antenna factors; see 5.4.5.4.

Note that the first two terms represent the actual measurement of SA, i.e. in the classical view SA is equal to V_{DIRECT} – V_{SITE}, which is the insertion loss of the propagation path with the inclusion of the properties of the two antennas used.

Theoretical values for the mutual impedance correction factor, ΔA_{TOT}, for tuned half-wave dipoles are given in Table 11 for the recommended site geometry of 3 m separation, horizontal and vertical polarization. For other set-up geometries, e.g. 10 m or 30 m, or if broadband antennas are used, correction for mutual impedance is not required.

Table 11 – Mutual impedance correction factors for NSA test using resonant tunable dipoles spaced 3 m apart

f_M MHz	ΔA_{TOT} – Total correction factor dB	
	Horizontal polarization d = 3 m h_1 = 2 m h_2 = 1 m to 4 m	**Vertical polarization** d = 3 m h_1 = 2,75 m h_2 = (see Table 8)
30	3,1	2,9
35	4,0	2,6
40	4,1	2,1
45	3,3	1,6
50	2,8	1,5
60	1,0	2,0
70	–0,4	1,5
80	–1,0	0,9
90	–1,0	0,7
100	–1,2	0,1
120	–0,4	–0,2
125	–0,2	–0,2
140	–0,1	0,2
150	–0,9	0,4
160	–1,5	0,5
175	–1,8	–0,2
180	–1,0	–0,4

NOTE 1 The values for the resonant dipoles were calculated using the method of moments and the numerical electromagnetic code (NEC) or the MININEC computer system [3], [4], [9].

NOTE 2 These correction factors do not completely describe antenna factors measured above a ground plane, e.g. at heights of 3 m or 4 m, because these antenna factors differ from free-space antenna factors at the lower frequencies. However, the values are sufficient to indicate site anomalies.

NOTE 3 Users are cautioned that some half-wavelength dipoles, or antennas with non-typical baluns, may exhibit different characteristics than the antenna described in 5.4.5.4. ⟨A1

[A1) For the respective method used, the validation criterion shall be satisfied at:

- the frequencies given in Table 8 if tuned dipoles are used;
- all frequencies in the desired frequency range, if broadband antennas are used (swept frequency NSA method – see 5.4.5.2).

To confirm the absence of voltage drift due to temperature changes in measurement devices or cables, re-measure V_{DIRECT} after a suitable time period to confirm stability of results.

Table 10 lists NSA values for broadband antennas, such as biconical and log-periodic dipole arrays, for both horizontal and vertical orientation relative to the ground plane. Table 8 lists NSA values for tuned half-wave dipoles oriented horizontally relative to the ground plane. Table 9 lists NSA values for tuned half-wave dipoles oriented vertically relative to the ground plane. Note that Table 9 has restrictions for the scan height h_2, to address that the lowest tip of the receive dipole is kept 25 cm or more from the ground plane.

NOTE 4 The reason Tables 8, 9, and 10 differ is that different geometrical parameters are chosen for a broadband antenna and a tuned half-wave dipole, due primarily to the spatial restrictions needed for the latter.

Accurate antenna factors are necessary in measuring NSA. Linearly polarized antennas are required. A 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 given in 5.4.5.4.

If ΔA_{S} is greater than ± 4 dB, the following items shall be re-checked:

a) measurement procedure;

b) accuracy of antenna factors;

c) drift in signal source or accuracy of receiver or spectrum analyzer input attenuator, and

d) readings from the measurement devices.

If no errors are found for the parameters in a), b), c) and d), then the site shall be considered to be at fault, and detailed investigation of possible causes of site variability shall be made. Annex F describes the errors that can occur in NSA measurements.

Note that because vertical polarization is generally a more stringent measurement condition, site anomalies would typically be investigated using this more sensitive metric rather than horizontal polarization NSA results. Key items to investigate include:

1) size and construction inadequacy of the ground plane;
2) objects at the perimeter of the site that may cause undesired reflections;
3) reflections from all-weather cover;
4) discontinuity in the ground plane at the turntable circumference, for configurations where the turntable surface is conductive and at the same height as the site ground plane;
5) thickness of any dielectric ground plane covers; and
6) openings in the ground plane, e.g. for stairways to underground control rooms. (A1]

[A1) 5.4.4 Reference site method for OATS and SAC

5.4.4.1 General

The RSM is another method for validating the suitability of a test site, using broadband antennas. As with the NSA method, the evaluation of V_{DIRECT} and V_{SITE} is required. These (A1]

A1⟩ results are obtained using exactly the same geometry and polarization as specified for the NSA method. For a weather-protection-enclosed OATS or a SAC, the configurations are:

- 3 m or 10 m test distance;

NOTE 1 Although RSM may be applied to 30 m sites, it is impractical due to the limited number of appropriate reference sites.

- 1 m and 2 m transmit antenna heights for horizontal polarization, and 1 m and 1,5 m for vertical polarization;
- 1 m to 4 m receive antenna height scan range.

The main difference between the RSM and NSA methods is in the calculation of SA deviations, using the equation:

$$A_{\mathrm{S}} = V_{\mathrm{DIRECT}} - V_{\mathrm{SITE}} - A_{\mathrm{APR}} \tag{27}$$

Rather than using transmit and receive antenna factors and the calculated NSA (A_{N}) values, measured results for the antenna-pair reference SA (A_{APR}) are used.

NOTE 2 A_{APR} does not involve antenna factors, but comprises coupling between the antennas, including the effects of coupling of each antenna to the ground. Furthermore, the radiation patterns of the antennas are included, different from the NSA method where the radiation patterns are approximated as being those of Hertzian dipoles.

For a weather-protection enclosed OATS and a SAC, four data sets are required, i.e. two antenna heights with two polarizations. For each additional distance, polarization and antenna height, a different A_{APR} is needed, as shown in the example template of Table 12.

Table 12 – Example template for A_{APR} data sets

Frequency MHz	**Antenna pair reference site attenuation, A_{APR}** dB			
	Horizontal		Vertical	
	h_1 = 1 m	h_1 = 2 m	h_1 = 1 m	h_1 = 1,5 m
30	…	…	…	…
31	…	…	…	…
32	…	…	…	…
…	…	…	…	…

When using a network analyzer or a stepped-frequency receiver to perform an RSM measurement, the frequency steps of Table 13 shall be used.

NOTE 3 RSM is a swept frequency method. Table 13 defines the maximum step size.

NOTE 4 When using a continuously-tuned receiver or a spectrum analyzer for an RSM measurement, the frequency step size definition of Table 13 does not apply. ⟨A1

A1 **Table 13 – RSM frequency steps**

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

Frequencies for the RSM measurement shall be identical to the frequencies of the antenna-pair reference SA calibration.

The ΔA_S criterion, see Equation (27), shall be satisfied at the frequencies given in Table 13.

5.4.4.2 Antennas not permitted for RSM measurements

For the purposes of this standard, hybrid antennas shall not be used for RSM site validation measurements.

NOTE 1 When specific SAC sites are validated using biconical and hybrid antennas, a large deviation in the results has been observed. The main reason for deviations is the different distance between the phase centres of the antennas, e.g. 10 m for biconical antennas and approximately 11,2 m for typical hybrid antennas. To avoid such reproducibility issues, hybrid antennas should not be used.

NOTE 2 Hybrid antennas typically are not used for site validation because of the larger uncertainties in positioning of these typically larger and bulkier antennas, especially for a 3 m test site where the overall combined length of the two hybrid antennas may be nearly 3 m.

NOTE 3 Better performance for a SAC is typically obtained with standard antennas (biconical or LPDA) for a lower ΔA_S; adjustment of SAC design parameters to achieve site validation compliance using hybrid antennas is strongly discouraged. In order to purchase a SAC with better performance than the standard requires, the manufacturer should be asked to fulfil e.g. ΔA_S = 3,5 dB.

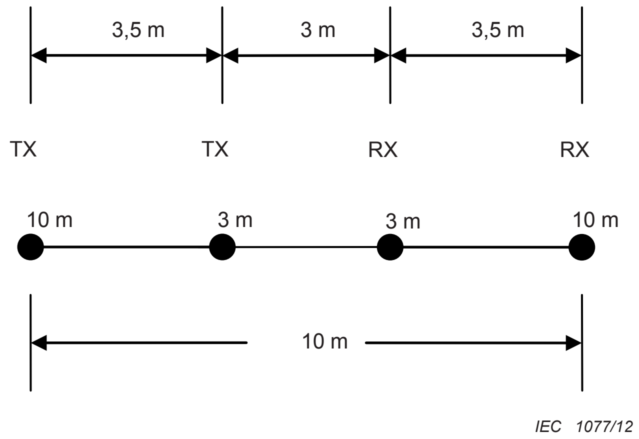
5.4.4.3 Determination of the antenna pair reference site attenuation on a REFTS

One approach to measuring A_{APR} is to use a reference test site (REFTS), which has performance established according to procedures described in CISPR 16-1-5. A second approach is given in 5.4.4.4.

For a test distance of 10 m, identical positions on the REFTS shall be used to determine A_{APR} as were used for the REFTS validation according to CISPR 16-1-5 procedures.

For a test distance of 3 m, measurements shall be made on the axis drawn between transmit and receive position as were used for the REFTS validation according to CISPR 16-1-5 procedures (see Figure 31). A1

[A1⟩



Key

TX = transmit antenna
RX = receive antenna

Figure 31 – Test point locations for 3 m test distance

The following procedure shall be used to determine A_{APR}:

a) determine V_{DIRECT};

b) place the transmit antenna in horizontal polarization at a height of 1 m;

c) place the receive antenna in the same polarization at a distance d;

d) determine V_{SITE} during the 1 m to 4 m height scan of the receive antenna;

e) calculate A_{APR} as follows:

$$A_{APR} = V_{DIRECT} - V_{SITE} \tag{28}$$

f) repeat steps b) to e) for transmit antenna height of 2 m with horizontal polarization, and then for transmit heights of 1 m and 1,5 m with vertical polarization.

5.4.4.4 Determination of the antenna pair reference site attenuation using an averaging technique on a large OATS

Another method to determine A_{APR} is by measurements on a large OATS (see the following paragraphs in this subclause for the criteria to be large). Deviations of the SA from the ideal behavior are caused by the limited area and flatness of the ground plane, and reflections from objects in the near vicinity such as buildings and trees. Also reflections from the edges of the ground plane can cause a sinusoidal ripple in the measured SA, predominantly for vertical polarization measurements. By varying the location of the antenna pair on the ground plane, the magnitude and the phase of the ripple will also change.

To minimize these effects, the SA is measured at several antenna pair positions, and an average value is calculated. This average value will converge to the SA of an ideal site.

NOTE 1 A similar technique is given in reference [28].

The OATS shall meet the following requirements:

- minimum ground plane size of 30 m by 20 m;
- deviation from flatness less than ± 10 mm;
- without protective layer (dielectric) on the metal ground plane. ⟨A1]

A1) The following procedure shall be used to determine A_{APR}:

a) Identify paired test points on the OATS, according to the scheme shown in Figure 32. All nine points for each antenna shall be located on the ground plane. If a weather-protection cover is present on the OATS, the minimum distance between any test point and any part of the cover shall be greater than 3 m. Measurement locations inside the cover are prohibited.

NOTE 2 It is recommended that the local grid (coordinate system) be placed at some non-zero angle relative to the (straight) edges of the ground plane, likewise at some non-zero angle relative to welded seams. An example of such a layout is given in Figure 33.

Under the following conditions, the use of less than nine test positions (18 points) shall be allowed.

1) where compliance was shown in the past:

If compliance with the standard deviation $s \leq 0{,}3$ dB criterion [see Equation (30)] was shown for at least one pair of antennas for each frequency subrange within the past 24 months, the following minimum numbers of antenna-pair test positions shall be allowed:

- one position (centre) for biconical antennas, in horizontal polarization;
- three positions (centre, plus two other positions) for biconical antennas, in vertical polarization;
- one position (centre) for log periodic antennas, in both polarizations.

2) where compliance can be shown with fewer points:

- if the compliance criterion is met with fewer than nine points it is permissible to use that number of points.

NOTE 3 For determining the most accurate A_{APR}, the use of all nine antenna-pair positions is recommended.

b) Number the selected test positions from 1 to N (N less than or equal to nine).

c) Place the antennas at position 1.

d) Measure $A_{\text{APR},1}$ for all required heights and polarizations at all frequencies listed in Table 13.

e) Repeat step d) for all other positions.

f) Calculate the average of the measured $A_{\text{APR},i}$ expressed in dB:

$$A_{\text{APR}} = \frac{1}{N}\sum_{i=1}^{N} A_{\text{APR},i} \qquad (29)$$

g) Calculate the standard deviation of the A_{APR} in dB:

$$s(A_{\text{APR}}) = \sqrt{\frac{1}{N(N-1)}\sum_{i=1}^{N}\left(A_{\text{APR},i} - A_{\text{APR}}\right)^2} \qquad (30)$$

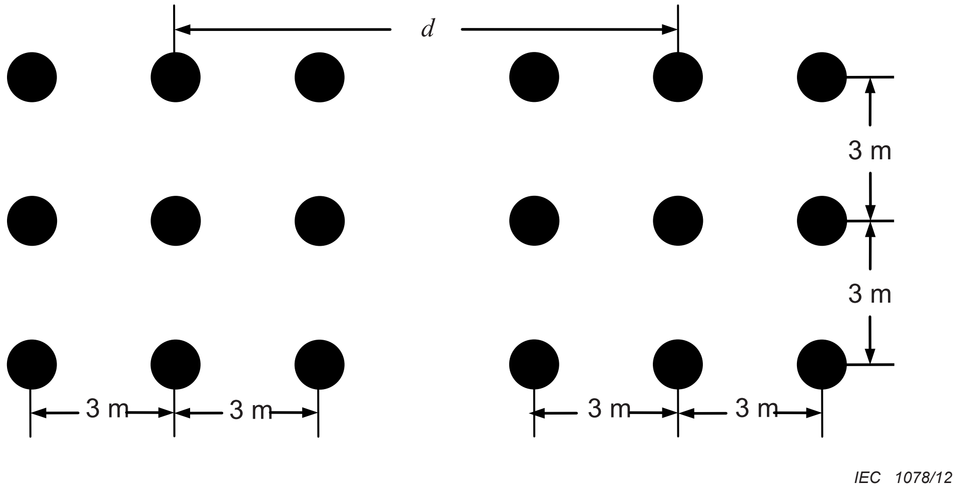
The calibrated A_{APR} values shall be deemed acceptable to use for subsequent COMTS validation if $s \leq 0{,}6$ dB at all measured frequencies.

If $N \geq 2$, Equation (30) shall be used to calculate the accuracy of $s(A_{\text{APR}})$ needed for an uncertainty calculation. If $N = 1$, $s = 0{,}6$ dB shall be assumed.

Special care shall be taken that no common offset (systematic effect) in the data for all selected positions is introduced. Such an effect could be due to influence of the antenna mast. For some antenna masts, a significant coupling between the metallic cover of the motor (A1

A1 box and the antenna can occur. The magnitude of this influence shall be investigated by changing the distance between the antenna and the motor cover d_{Ant} (see Figure 34), and repeating A_{APR} measurements with these new configurations. This influence shall be included in the uncertainty calculation.

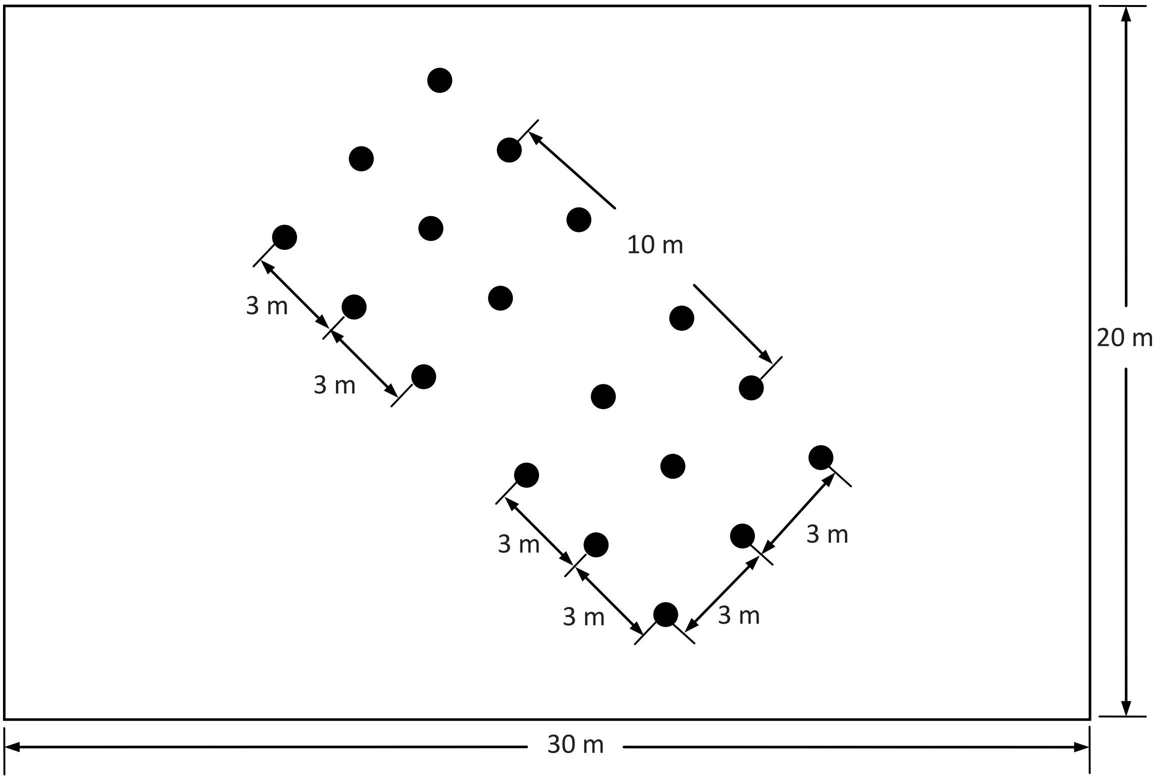
Another cause for a common offset can be reflections from the antenna cable. To minimize this influence, the cable shall be extended horizontally for at least 2 m behind the antenna before routing down to the ground. Clamp-on ferrites shall be used on the cables to reduce surface currents. This influence factor shall be included in the uncertainty calculation as well.



d is the distance between the projections of the two antenna reference points

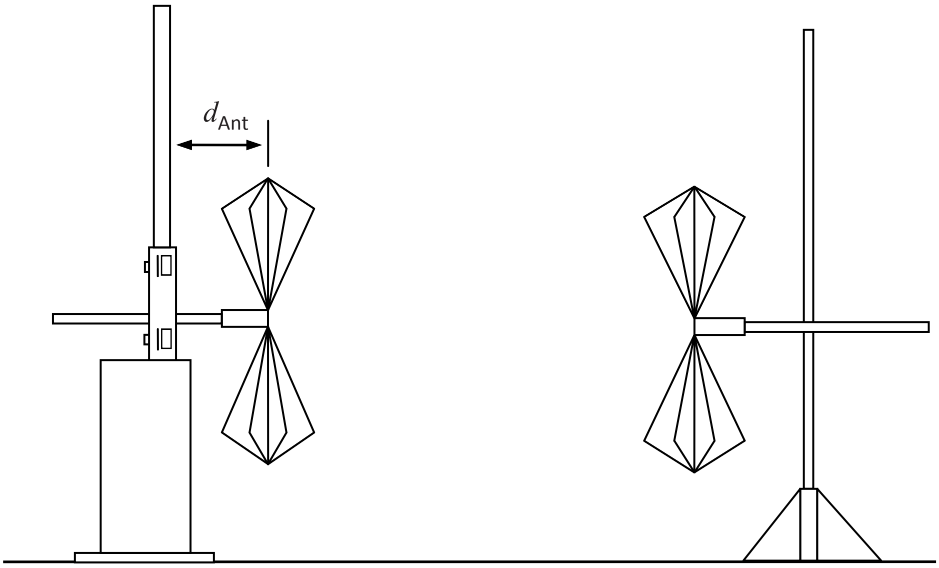
Figure 32 – Paired test point locations for all test distances A1

A1



IEC 1079/12

Figure 33 – Example of paired test point selection for a test distance of 10 m



IEC 1080/12

Figure 34 – Illustration of an investigation of influence of antenna mast on A_{APR} A1

A1 5.4.5 Validation of an OATS by the NSA method

5.4.5.1 Discrete frequency method

5.4.5.1.1 Measurement set-up

Refer to Figures 29 and 30 in 5.4.3 for specific test set-up details. The signal generator is connected to the transmit antenna with an appropriate length of transmission line. The transmit antenna is placed at the desired location. The transmit antenna height is set to h_1 (see Tables 8, 9, and 10 for the values of h_1) and the desired polarization is selected. If a tunable dipole is used, the length is adjusted for the required frequency. For broadband antennas, the antenna heights shall be $h_1 = h_{2\text{min}} = 1$ m.

The receive antenna is mounted on a mast that allows scanning over the height range $h_{2,\text{min}}$ to $h_{2,\text{max}}$, placed at a distance d from the transmit antenna, and connected to the measuring receiver or spectrum analyzer via a suitable length of cable. The same polarization as that for the transmit antenna is selected; if a tunable dipole is used, the antenna is adjusted to the required frequency. The 25 cm ground clearance is maintained for vertically oriented tuned dipoles (see Table 9).

For all NSA measurements using tunable dipoles, these antennas shall be tuned for each frequency, including those between 30 MHz and 80 MHz.

5.4.5.1.2 Measurement procedure

The following steps shall be used for each frequency indicated in Tables 8, 9, and 10. The measurements are first made for antennas horizontally aligned and then for antennas vertically aligned with the transmit antenna height set at h_1.

(1) Adjust the output level of the signal generator to give a received voltage display well above ambient and measuring receiver or spectrum analyzer noise.

(2) Raise the receiving antenna on the mast through the h_2 scan range as specified in Tables 8, 9, and 10, as appropriate.

(3) Record the maximum signal level; this value is V_{SITE} for Equation (26) (see 5.4.3).

(4) Disconnect the transmit and receive cables from their antennas. Connect these cables directly together with a straight-through adapter.

(5) Record the signal level with the transmit and receive cables connected. This value is V_{DIRECT} for Equation (26).

(6) At each frequency and for each polarization, enter the values from steps (3) and (5) in Equation (26).

(7) Insert the transmit and receive antenna factors at the measurement frequency in Equation (26).

(8) Insert the mutual impedance correction factor ΔA_{TOT} from Table 11, which applies only for the specific geometry of vertical and horizontal polarization using tunable dipoles separated by 3 m. For all other geometries, $\Delta A_{\text{TOT}} = 0$.

(9) Solve Equation (38) for A_{N}, which is the NSA for the measurement frequency and polarization used.

(10) Subtract the value in step (9) from the appropriate NSA contained in Tables 8, 9, and 10, as appropriate, to obtain ΔA_{S}.

(11) If the ΔA_{S} results from step (10) are less than ± 4 dB, the site is deemed to be acceptable at that frequency and polarization.

(12) Repeat steps (1) through (11) for the next frequency and polarization combination.

NOTE For both discrete- and swept-frequency NSA measurement methods, an impedance mismatch at the output of the signal source or at the input of the measuring receiver or spectrum analyzer may result in reflections which could cause errors. This should be avoided by use of padding attenuators of 10 dB, i.e. one at the output end of A1

A1⟩ each transmitting and receiving antenna cable. These attenuators should remain in the cables during the entire NSA measurement process.

5.4.5.2 Swept frequency method

5.4.5.2.1 Measurement set-up

The set-up is similar to that contained in 5.4.5.1, except that only broadband antennas are used. No restrictions on vertical polarization antenna height scan are necessary due to the physically small size of such broadband antennas. The antenna heights shall be $h_1 = h_{2min} = 1$ m.

5.4.5.2.2 Measurement procedure

The following steps should be made using automatic measuring equipment having a peak hold (‘max. hold’), storage capability, and tracking generator. In this method, both receive antenna height h_2 and frequency are scanned or swept over the required height and frequency ranges. The frequency ranges are usually determined by the type of broadband antenna used. The frequency sweep speed shall be much greater than the antenna height scan rate. Set the transmit antenna height to h_1.

(1) Adjust the output level of the tracking generator to give a received voltage display well above ambient and scanning receiver or spectrum analyzer noise.

(2) Raise the receiving antenna on the mast to the maximum height of the scan range, as specified in Table 10.

(3) Set the spectrum analyzer to sweep the desired frequency range. Ensure that the spectrum analyzer is adjusted so that a similar signal up to 60 dB higher can be displayed on the same amplitude scale. This will accommodate the levels to be recorded in step (5).

(4) Slowly lower the receiving antenna to the minimum height of the scan range, as specified in Table 10 for the appropriate site geometry. Store or record the maximum received voltage display V_{SITE} in dB(μV). (The time it takes to lower the antenna should be much longer than the frequency sweep time.)

(5) Disconnect the transmit and receive cables and connect them directly together with a straight-through adapter. Store or record the resulting voltage display V_{DIRECT} in dB(μV).

(6) At each frequency, subtract the voltage measured in step (4) from the voltage measured in step (5). Also subtract the antenna factors of the transmit and receive antennas, F_{aT} in dB(m^{-1}) and F_{aR} in dB(m^{-1}), respectively (antenna factors as a continuous function of frequency can be obtained by using simple linear curve fitting on a set of discrete antenna factor values). The result is the measured A_N over the range of frequencies used, which should be plotted. Also plot the theoretical NSA for an ideal site shown in Table 10.

(7) The differences ΔA_S found shall fall within the ± 4 dB criterion.

NOTE For NSA measurement methods, an impedance mismatch at the output of the signal source or at the input of the measuring receiver or spectrum analyzer may result in reflections which could cause errors. This should be avoided by use of padding attenuators of 10 dB, i.e. a 10 dB attenuator between each transmitting and receiving antenna connector and the corresponding antenna cables. These attenuators should remain in the cables during the entire NSA measurement process.

5.4.5.3 Possible causes for exceeding site acceptability limits

If the deviation ΔA_S using Equation (26) [or Equation (27) when the RSM is used] exceeds the ± 4 dB criterion, investigate as follows.

First check the measurement system calibrations. If the signal generator and measuring instrumentation do not drift during the measurements, the prime suspects are the antenna factors. Antennas may also be defective. If these are all acceptable, repeat the measurement. If the differences are still greater than ± 4 dB, the site and the surrounding area are suspect. The vertical SA should in general be the most sensitive to site anomalies. If so, use that measurement as the basis for tracking down the problem. Possible problems include ⟨A1

A1⟩ inadequate ground plane construction and size, reflecting objects too close by (fences, buildings, light towers, etc.), degraded performance of all-weather enclosures due to inadequate construction and maintenance techniques, and such long-term effects as penetration of residue from airborne conductive contaminants.

5.4.5.4 Antenna calibration

The antenna factors of broadband antennas used to make SA measurements should be traceable to a national standard. Manufacturers' antenna factors may not be sufficiently accurate to achieve good agreement between measured and calculated NSAs.

NOTE 1 A separate new standard on antenna calibration (i.e. proposed CISPR 16-1-6) is under development by CISPR/A/WG1.

Antenna factors usually account for losses due to the balun. If a separate balun is used, its effects shall be accounted for. Experience has shown that variations of antenna factors with geometry and polarization are generally negligible for the types of broadband antennas commonly used for EMC measurements below 1 GHz (e.g. biconicals, thick dipoles and log-periodics) as long as the transmit antenna is at least 1 m above the ground plane. If antenna factor variations are suspected because of the use of unusual antennas or measurement geometries, or from effects such as mutual coupling, or transmission line scattering for vertically polarized antennas, especially at a 3 m measurement distance, the antenna factors should first be measured using these geometries.

Normally, the SA is measured using a 50 Ω system, i.e. the signal generator and measuring receiver have an impedance of 50 Ω, and the radiation impedances of the transmitting and receiving antennas are balanced and matched via a balun.

Manufacturer's antenna factors are normally also specified for an impedance of 50 Ω, i.e. the conversion factor for a no-loss matching of the 50 Ω impedance to the radiation impedance of the antenna, and if applicable, the loss of the balun used is also contained in the given antenna factor.

If tuned half-wave dipoles are used, their free-space antenna factors can be calculated, using the following equation:

$$F_\text{a} = 20\lg\left(\frac{2\pi}{\lambda}\right) + 10\lg\left(\frac{73}{50}\right) = 20\lg(f) - 31{,}9 \text{ in dB(m}^{-1}\text{)} \qquad (31)$$

where f is in MHz.

NOTE 2 In practice, the antenna factor will be affected by the height of the dipole antenna above ground due to the mutual impedance of the dipole and its image in the ground.

The average balun loss for a well-designed tuned half-wave dipole is approximately 0,5 dB. Equation (31) then becomes:

$$F_\text{a} = 20\lg(f) - 31{,}4 \text{ in dB(m}^{-1}\text{)} \qquad (32)$$

This balun loss shall be measured by connecting the transmit and receive dipole balun portions back-to-back before they are installed in their housings. The loss per balun is one-half of the total measured loss, assuming both baluns are equivalent.

It is important to check that the calculated F_a values are representative of the values for the particular tuned dipoles used for the NSA measurements. The simplest check is to measure the VSWR with the antennas assembled and the dipole elements tuned to resonance. The antenna shall be placed at least 4 m above the ground, higher if possible, to minimize ⟨A1

A1 antenna to ground coupling, and its elements tuned to resonance using the measurements shown in Table 9. It is sufficient to check the VSWR of the antennas at spot frequencies in the low, middle and high ends of their frequency ranges.

Below 100 MHz, the function of the baluns may also be checked by removing the elements, placing a 70 Ω resistor across the terminals of the element mounting block, and measuring the VSWR of the terminated balun. The VSWR should be less than 1,5 to 1.

5.4.6 Validation of a weather-protection-enclosed OATS or a SAC

For an OATS with a weather-protection enclosure, or a SAC, a single site attenuation measurement is insufficient to pick up possible reflections from the construction materials and/or the RF-absorbing materials comprising the walls and ceiling of the facility. For these sites a “test volume” is defined as that volume traced out by the largest EUT or system to be tested as it is rotated about its centre location through 360°, such as by a turntable. Evaluating horizontal and vertical polarizations, such as illustrated in Figures 35 and 36, may require a maximum of 20 separate SA 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 for horizontal, 1 m and 1,5 m for vertical).

These measurements are performed 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 materials on the walls and EUT periphery is less than 1 m, the centre of the antenna is moved towards the central position so that the extreme tip of the antenna is either at the periphery, or is 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 conditions.

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

   NOTE 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 an EUT can be located near these interfaces, additional SA measurements are necessary.

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 high.

d) If the test volume is no larger than 1 m deep by 1,5 m wide by 1,5 m high, including a set-up table if used, horizontal polarization measurements need only be made at the centre, front and rear positions, but at both 1 m and 2 m heights. If the condition of item a) applies, the rear position may be omitted. This will require a minimum of eight measurements: four positions with vertical polarization (left, centre, right, and front) for one height, and four positions with horizontal polarization (centre and front) for two heights; see Figures 37 and 38. A1

A1 The receive antenna shall be re-positioned to maintain the appropriate separation along a line towards the turntable centre (see Figures 35, 36, 37, and 38). The test site is considered suitable for performing radiated emission testing if all measurements prescribed above meet the requirements of 5.4.2.

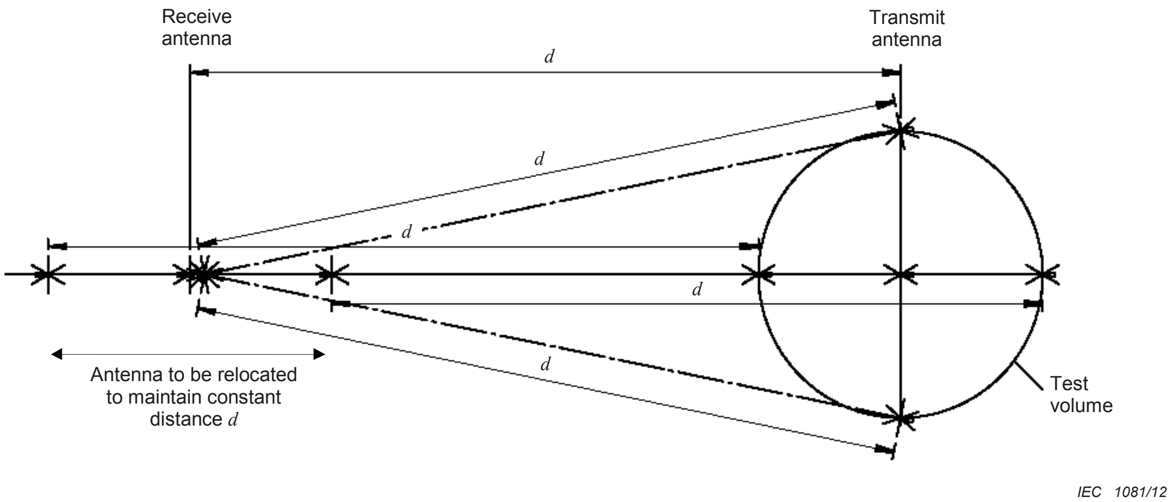


Figure 35 – Typical antenna positions for a weather-protected OATS or a SAC – Vertical polarization validation measurements

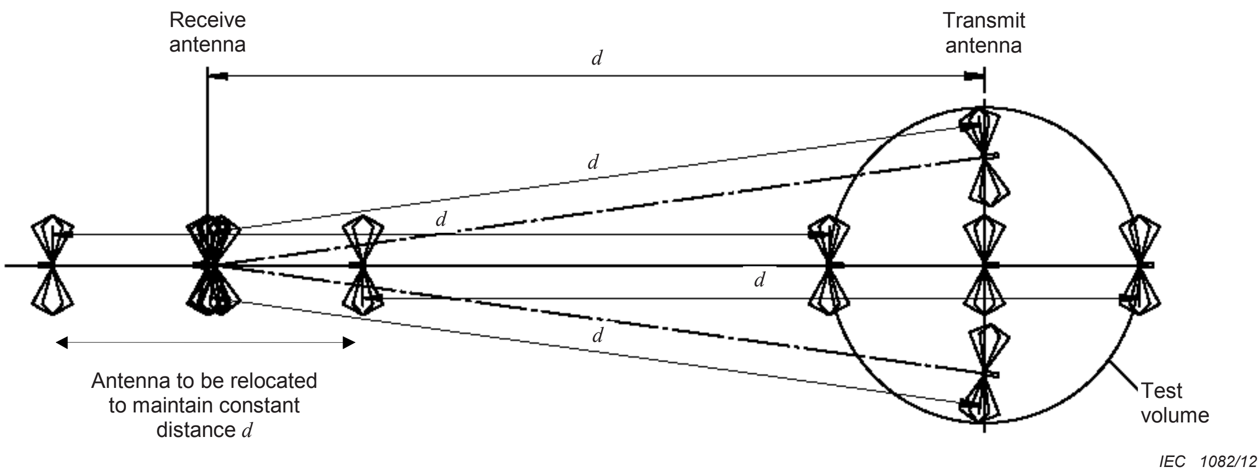
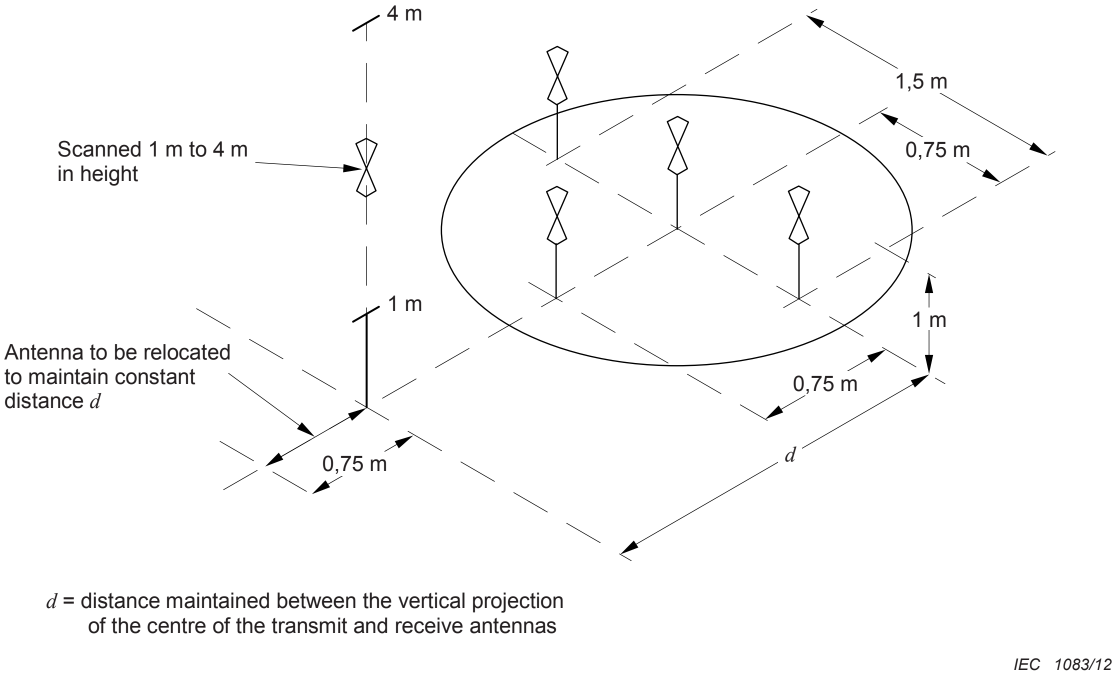


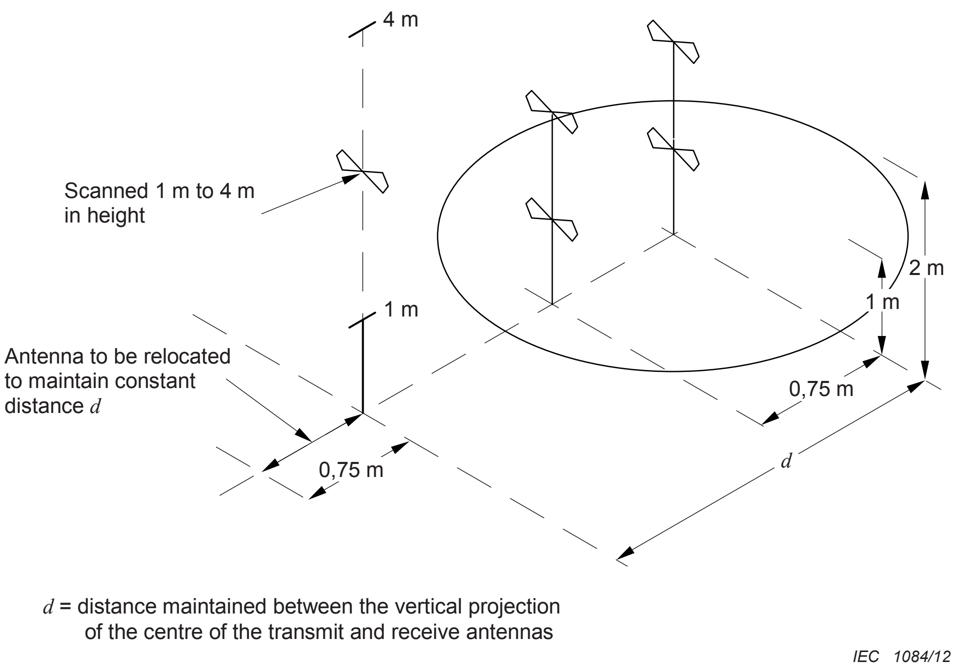
Figure 36 – Typical antenna positions for a weather-protected OATS or a SAC – Horizontal polarization validation measurements A1

[A1>



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 37 – Typical antenna positions for a weather-protected OATS or a SAC – Vertical polarization validation 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 38 – Typical antenna positions for a weather-protected OATS or a SAC – Horizontal polarization validation measurements for a smaller EUT <A1]

A1 5.4.7 Site validation for FARs

5.4.7.1 General

The NSA shall satisfy the requirement of 5.4.7.4 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 14 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 emission testing.

Table 14 – 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 shielded room construction materials and/or absorbing materials lining the walls, floor, ceiling and turntable of a FAR.

Therefore FAR site validation measurements shall be performed at fifteen measurement positions for both horizontal and vertical antenna polarizations of the transmit antenna in the test volume (see Figure 39):

– 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, typically a small biconical antenna.

NOTE 1 The maximum dimension of the transmit antenna should not exceed 40 cm for a 3 m test distance; at larger distances, the tip-to-tip length of the biconical antenna can be a maximum of 44 cm for a cage design, or 50 cm if it is the collapsible type or a spun cone.

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

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

The same antennas used to measure the SA of a FAR, shall be used to measure the reference SA at a quasi free-space test site (5.4.7.2). The receive antenna used during the FAR 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 polarizations, and for all transmitting antenna positions in the test volume, the height position of the receiving antenna in a FAR shall remain fixed at the middle level of the test volume, as shown in Figures 39 and 40. Tilting the antennas is necessary to align the boresight axes of both antennas in one measurement axis along the line between the test points. The distance between the antenna reference point (defined by antenna calibration) and the front position of the test volume is A1

[A1] $d_{nominal}$. 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 $d_{nominal}$ constant. The measurement axis is the line between the transmit antenna and the receive antenna, along which $d_{nominal}$ is established. For all positions and polarizations, the receiving antenna and the transmitting antenna shall face one another with the elements of both antennas parallel (using tilting – see Figure 40). Any antenna masts and supporting floors shall be in place during the site validation measurements.

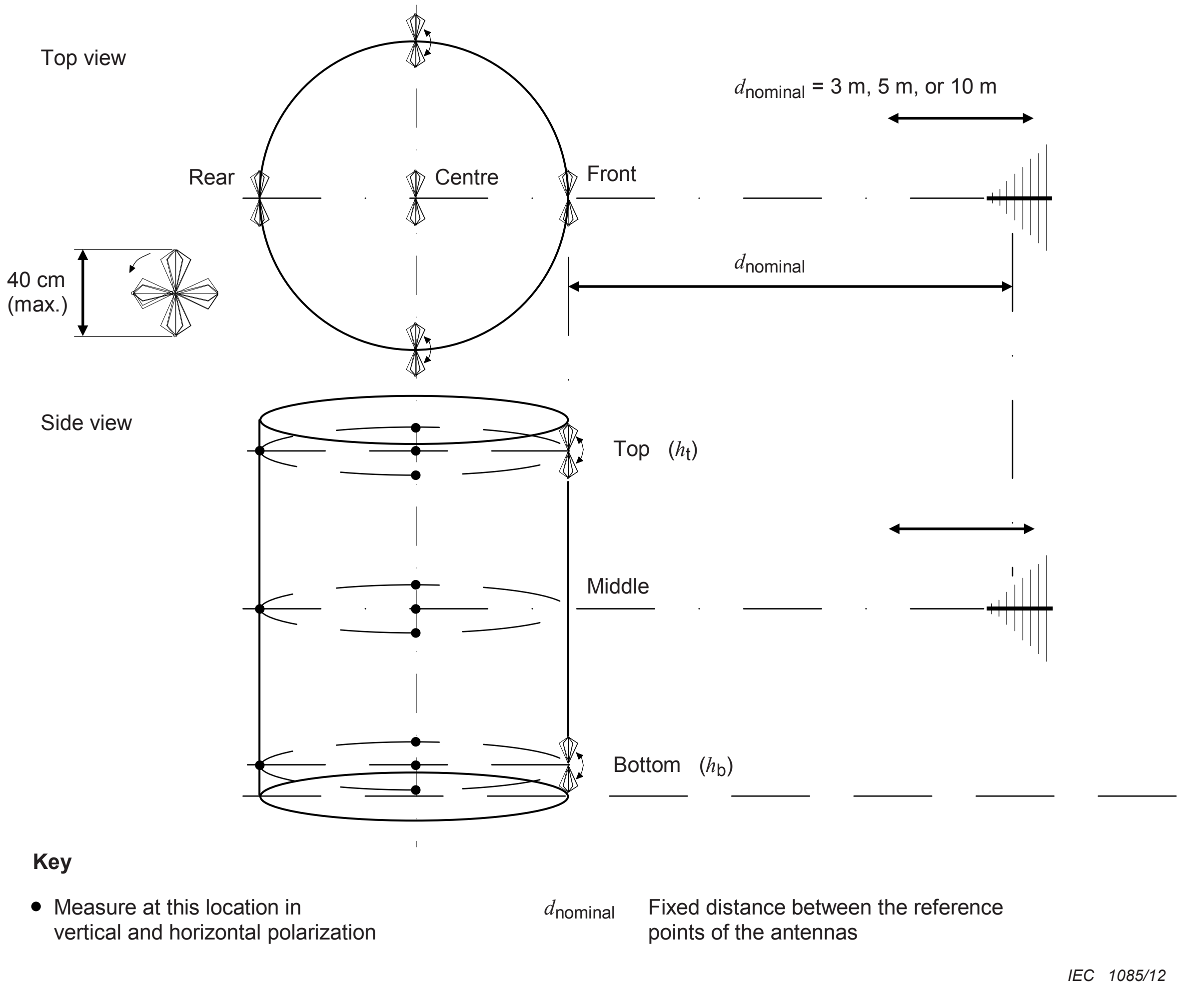


Figure 39 – Measurement positions for FAR site validation

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 along the measurement axis.

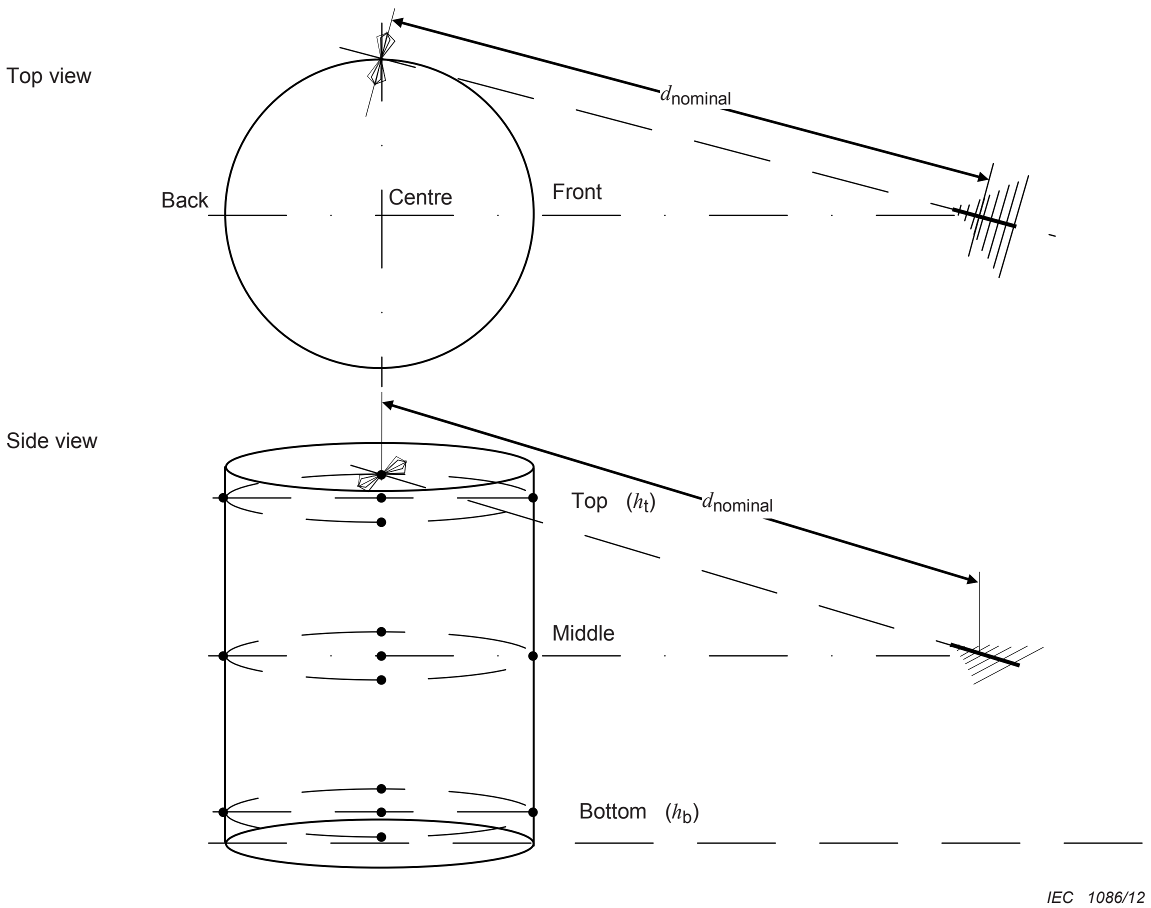
$d_{nominal}$:
- is the EUT test distance associated with the limit;
- is the fixed antenna distance in the site validation measurements;
- is the antenna separation used during measurement of the reference SA if the RSM is used.

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

– "Middle" (h_m) position: where possible, along a virtual axis positioned at mid-height and mid-width of a FAR; [A1]

[A1] – "Top (h_t)" and "Bottom (h_b)" positions: half of h_{max} (see Table 14) minus half of the transmit antenna dimension (e.g. 20 cm for a 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; the distance shall be at least 0,5 m, to avoid EUT to absorber coupling.



NOTE Horizontal antenna polarizations, top right position.

Figure 40 – Example of one measurement position and antenna tilt for FAR site validation

The maximum step size for discrete-frequency measurements shall be as listed in Table 15:

Table 15 – Frequency ranges and step sizes for FAR site validation

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

Two methods are acceptable for FAR site validation:

a) the RSM (5.4.7.2), which is required for test distances less than 5 m; or

b) the NSA method (5.4.7.3), which is preferred for test distances greater than or equal to 5 m. [A1]

A1) NOTE 3 At separations less than 5 m, antenna mutual coupling cannot be neglected. Additionally it is impractical to determine A_{APR} at distances larger than 5 m.

The site validation measurement methods are intended to provide 0 dB deviation from the SA that would result on an ideal site. The site validation criterion is defined in 5.4.7.4. Any means to reduce measurement uncertainty can be utilized, as long as these do not contradict the defined set-up and procedures or mask any site deficiencies, e.g. shall not inappropriately smooth resonant responses in results.

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

– For a vertically-polarized antenna, shielded cables shall 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 FAR. Another possibility is the use of clip-on ferrites on the cables. Another alternative for reducing the influence of RF cables is by instead using 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 (i.e. such that the receiver reading changes less than ± 0,5 dB when the antenna is rotated through 180° with respect to its boresight axis. Antenna balance verification methods are described in 4.5.4).
– Separate biconical and LPDA antennas for FAR validation may be used (different antenna types below and above 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 instead if the mechanical dimensions are sufficiently small relative to the test distance.

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

5.4.7.2 RSM

The RSM accounts for antenna near field effects and field taper, which can have a significant influence on results at 3 m test distance involving a biconical receive antenna. Whilst these effects are present in the NSA method, they can largely be corrected for. The reference SA A_{APR} is measured at the nominal distance, $d_{nominal}$, between the transmit antenna and the receive antenna.

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

a) V_{DIRECT} is the reference level measured by the receiver in dB(μV) with the cables connected directly together, which is normally done once before a series of volumetric tests;
b) V_{SITE} is the level measured by the receiver in dB(μV) with antennas in place;
c) the SA deviation (ΔA_S) relative to the antenna pair reference SA (A_{APR}), in dB, is calculated using Equation (33).

$$A_S = V_{DIRECT} - V_{SITE} - A_{APR} \tag{33}$$

For accurate site validations at distances less than 5 m, it is recommended that a dedicated pair of antennas (transmit and receive antennas) be used to determine the reference SA. A quasi free-space test site, defined in 3.1.12, is required. A quasi free-space test site includes two non-metallic antenna masts (constructed from wood or plastic with $\varepsilon_r \leq 2,5$, low loss, and diameter at minimum while retaining mechanical strength), which allow the placement of antennas at a sufficient height above ground level (Figure 41). One method to realize the ± 1 dB SA performance of the reference site is to choose the height (h) of the antennas as follows: (A1

A1 $$h \geq d \times \frac{8}{3}$$ (34)

where d is the antenna separation in m.

A height of $h = d \times 8/3$ is recommended to suppress the influence of the ground; alternatively a suitable coverage area of RF absorbers effective for frequencies down to 30 MHz shall be placed on the ground.

NOTE At 3 m separation and 30 MHz, there is a significant effect from the near-field component ($1/d^2$) that alone contributes an error of 0,8 dB for a height of d × 5/3, as verified by the UK National Physical Laboratory (NPL). For a reference SA with an uncertainty of less than ± 0,5 dB, a height of d × 8/3 is recommended when absorber is not placed on the ground.

The test distance at the reference site shall be equal to the actual distance d_{nominal} between the antennas to be used subsequently in a FAR. The antennas are polarized vertically (horizontal polarization shall not be used because of stronger interference with the ground-reflected signal), providing a good approximation to free-space conditions. Clearance from buildings, trees, etc., shall be greater than $d \times 8/3$, due to their influence on vertically polarized antenna measurements.

Care shall 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 41, or instead using RF-optical links. The quality of the reference set-up directly influences the subsequent FAR evaluation results. The antenna-pair reference SA (A_{APR}) is determined in three steps, as follows:

a) $V_{\text{DIRECT RS}}$ is the reference level measured by the receiver in dB(µV) with the cables connected together;

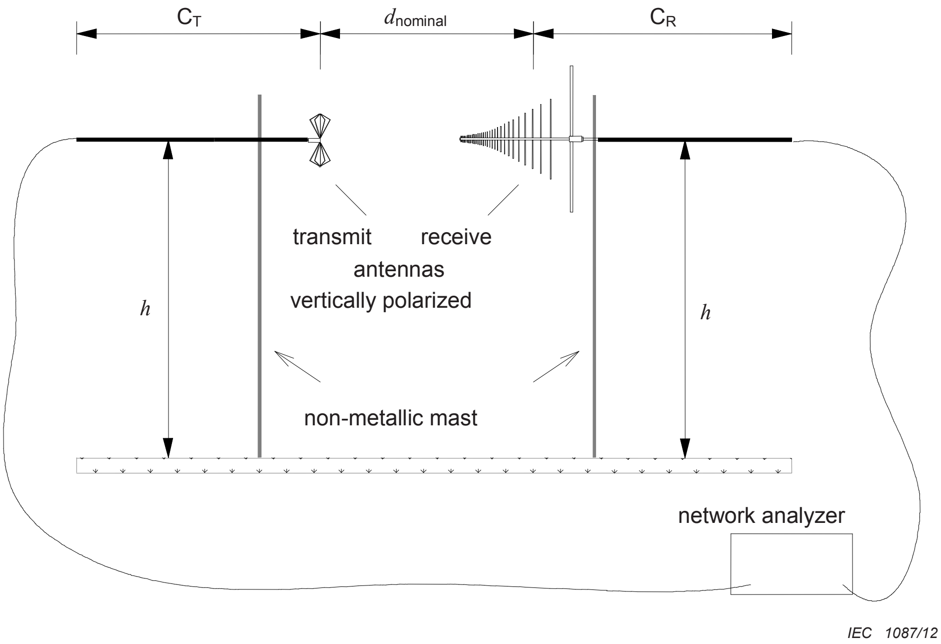
b) $V_{\text{SITE RS}}$ is the level measured by the receiver in dB(µV) with the antennas installed at the required distance d_{nominal}.

c) the A_{APR} in dB is calculated according to Equation (35):

$$A_{\text{APR}} = V_{\text{DIRECT RS}} - V_{\text{SITE RS}}$$ (35)

For 3 m site validation, a height of at least 4 m above ground shall be used for the antenna pair, which is a typical capability of remotely controllable antenna masts used for EUT 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 demonstrated that a quasi free-space condition is fulfilled (i.e. SA measurement results within ± 1 dB of the ideal response at any frequency). For site validation with $d > 3$ m, the equation $h > d \times 8/3$ is used to determine the set-up configuration, or an alternative set-up that has been demonstrated to fulfil the ± 1 dB reference SA can be used. A1

A1



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 SA is obtained separately for all geometries of Figure 41.

Figure 41 – Typical quasi free-space reference SA measurement set-up

5.4.7.3 NSA method

This subclause describes the NSA method applied to FARs. The antenna geometry is given in 5.4.7.1. 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 free-space sites, no antenna height scanning is applied, which is denoted by the term “site insertion loss” (see 3.1.18).

For a free-space environment, A_S (in dB) can be approximated by Equation (36) [22]:

$$A_S = 20\lg\left(\frac{5Z_0}{2\pi}\times\frac{d}{\sqrt{1-\frac{1}{(\beta d)^2}+\frac{1}{(\beta d)^4}}}\right) - 20\lg(f_M) + F_{aR} + F_{aT} \qquad (36)$$

where

F_{aR}, F_{aT}	are the antenna factors of the receive and transmit antennas in dB(m^{-1});
d	is the distance between the phase centres of both antennas in m;
Z_0	is the system impedance (i.e. 50 Ω);
β	is defined as $2\pi/\lambda$; and
f_M	is the frequency in MHz. A1

[A1] The theoretical NSA ($A_{\text{N theo}}$) in dB(m²) is defined as SA with respective antenna factors subtracted, thus:

$$A_{\text{N theo}} = 20\lg\left(\frac{5Z_0}{2\pi} \times \frac{d}{\sqrt{1-\frac{1}{(\beta d)^2}+\frac{1}{(\beta d)^4}}}\right) - 20\lg(f_{\text{M}}) \quad (37)$$

Below 60 MHz at a 5 m distance, or below 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 14, for comparison with the theoretical NSA values of Figure 42 and Equation (37). Near field correction factors are specific to the antennas, test distance, and test volume used; while these factors can be obtained by using a numerical modelling code such as NEC [4], sufficiently low uncertainties are obtained by the use of Equation (37). Alternatively, the RSM of 5.4.7.2 provides cancellation of near field terms if the same antennas and frequencies are used for both the reference SA measurement and subsequent FAR validation.

For measurement distances of 10 m and 30 m, the near-field terms in Equation (37) may be omitted, and the equation simplifies as follows:

$$A_{\text{N theo}} = 20\lg\left(\frac{5Z_0 d}{2\pi}\right) - 20\lg(f_{\text{M}}) \quad (38)$$

If simplified Equation (38) is used instead of Equation (37), 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 to less than ± 0,3 dB, Equation (37) should be used. [A1]

A1

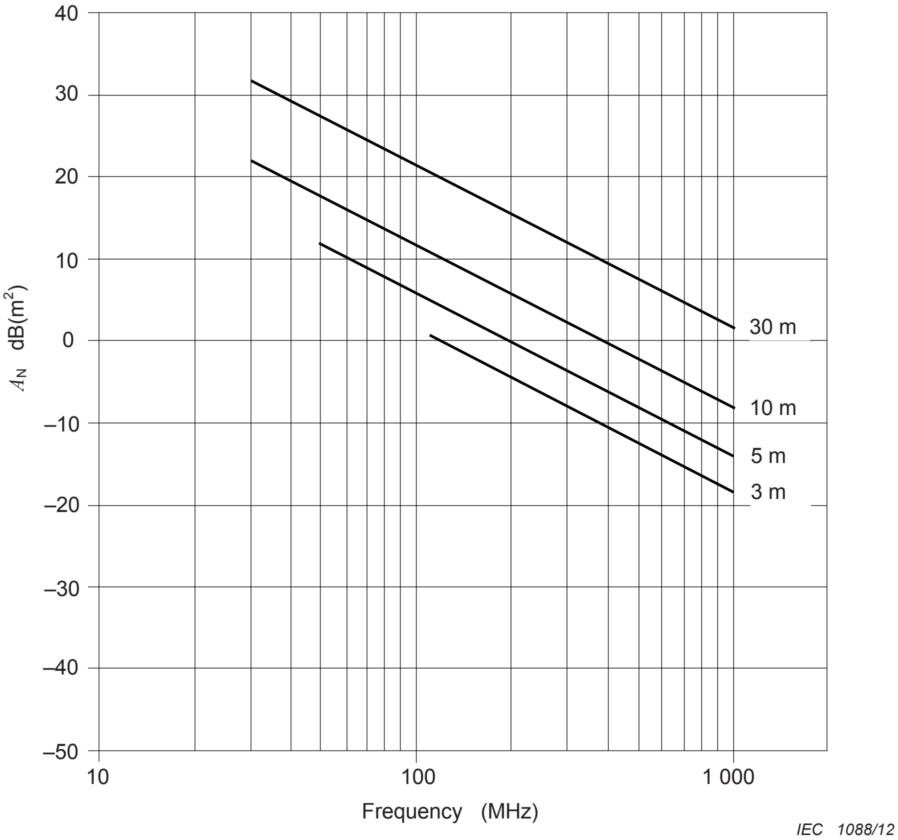


Figure 42 – Theoretical free-space NSA as a function of frequency for different measurement distances [see Equation (38)]

NOTE 1 Frequencies below 110 MHz for 3 m measurement distances, and below 60 MHz for 5 m measurement distances, include near field effects. These are calculated for each individual test site.

The free space antenna factors of the transmit and receive antennas are required for this procedure. Site validation for each measurement position shall be performed in three steps as follows.

a) V_{DIRECT} is the reference level measured by the receiver with the cables connected directly together;

b) V_{SITE} is the level measured by the receiver with the antennas in place;

c) the SA deviation (ΔA_S) is calculated in dB as follows:

$$A_S = V_{\text{DIRECT}} - V_{\text{SITE}} - A_{\text{N theo}} - F_{aT} - F_{aR} \qquad (39)$$

where $A_{\text{N theo}}$ is calculated using Equation (38), and the result is compared with the applicable criterion, as specified in 5.4.7.4.

NOTE 2 The distance d between the reference points of the transmit and receive antennas (defined during 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 should be compensated by the ratio of the effective distance to d_{nominal}. Because an antenna calibration is not defined for the nominal test distance, the variation in effective measurement distance due the variation of phase centre locations when LPDA antennas are used should be applied as a correction. The additional uncertainty due to this correction and due to any mutual coupling of the antennas can be avoided by using the RSM. A1

[A1⟩ 5.4.7.4 Site validation criteria for FAR sites

The SA deviation ΔA_S shall be less than ± 4 dB for both horizontal and vertical polarizations and for each measurement position and measurement frequency range. ⟨A1]

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 [A1⟩ site validation measurement (see 5.4) ⟨A1] 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 [A1⟩ NSA/RSM measurements (see 5.4) ⟨A1] 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).

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

where

$V_{R,with}(f)$ is the maximum voltage at the receive antenna at a specific frequency, expressed in dB(μV), 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(μV), 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).

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

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.

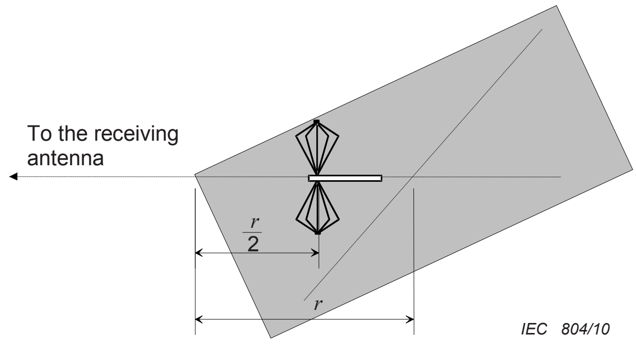


Figure 14 – Position of the antenna relative to the edge above a rectangle set-up table (top view)

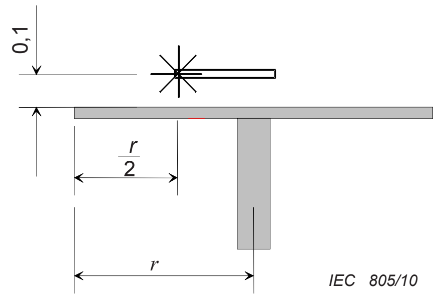


Figure 15 – Antenna position above the set-up table (side view)

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 $V_{\mathrm{R,with}}$) 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 m^3 to large units 1,7 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.

Dimensions in millimetres

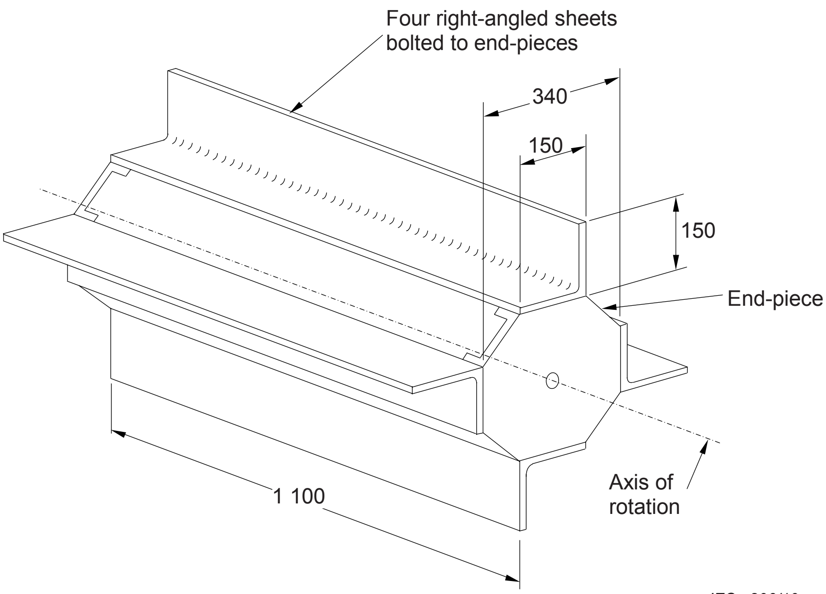


Figure 16 – Example of a typical paddle stirrer

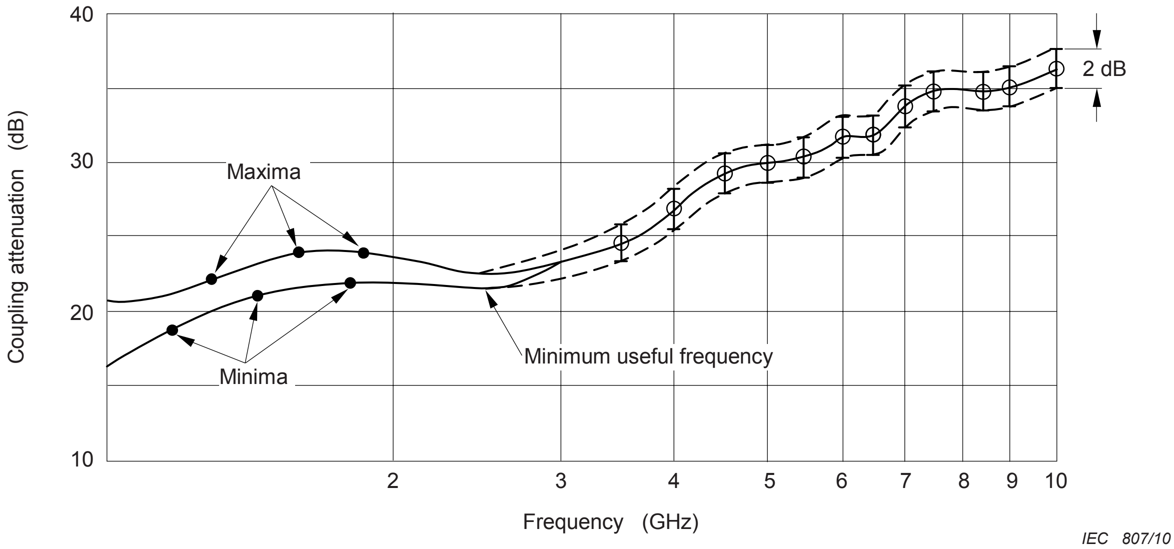
6.2.3.4 Rotating speed

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

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

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

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

NOTE 1 When decibels are employed, $S_{\mathrm{VSWR,dB}}$ 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 $S_{\mathrm{VSWR,dB}}$ 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:

$S_{\mathrm{VSWR}} \le 2:1$, or $S_{\mathrm{VSWR,dB}} \le 6{,}0\ \mathrm{dB}$,

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.

a) 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° ± 15° and 180° ± 15°, respectively.

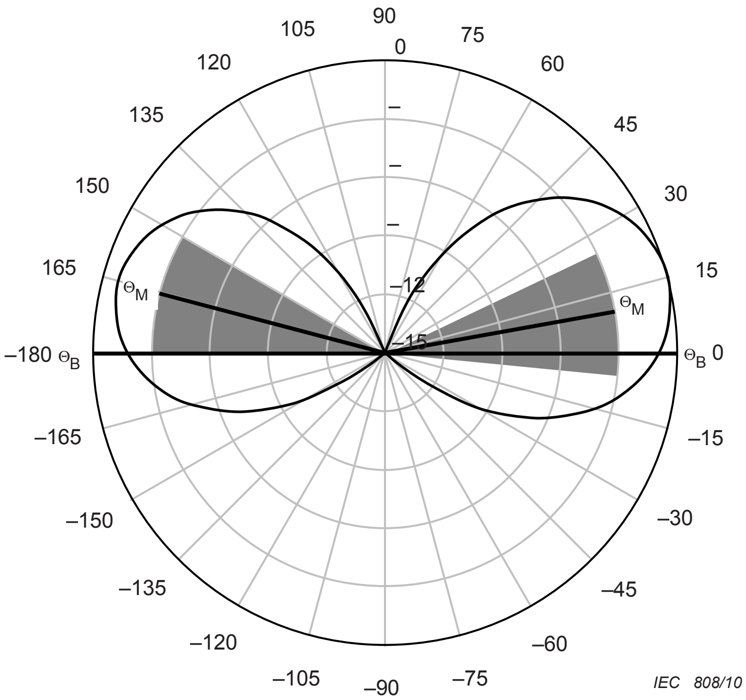
b) Draw the so-called forbidden area symmetrical to the main lobe directions on both sides of the pattern[2)] where amplitude is ≤ –3 dB for ±15°.

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

c) 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° ± 15° and 180° ± 15° respectively. The shaded areas represent the "forbidden area" where amplitude would be ≤ -3 dB for ± 15° 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.

a) Average the radiation pattern data (in dB) over the range of ±135° (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.

b) The pattern shall not exceed the following deviations from the ±135°-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 ±135°, it is desirable for the *H*-plane pattern not to show a null at ±180°, 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 ±135°.

Figure 19 shows an example pattern that meets the preceding H-plane requirements.

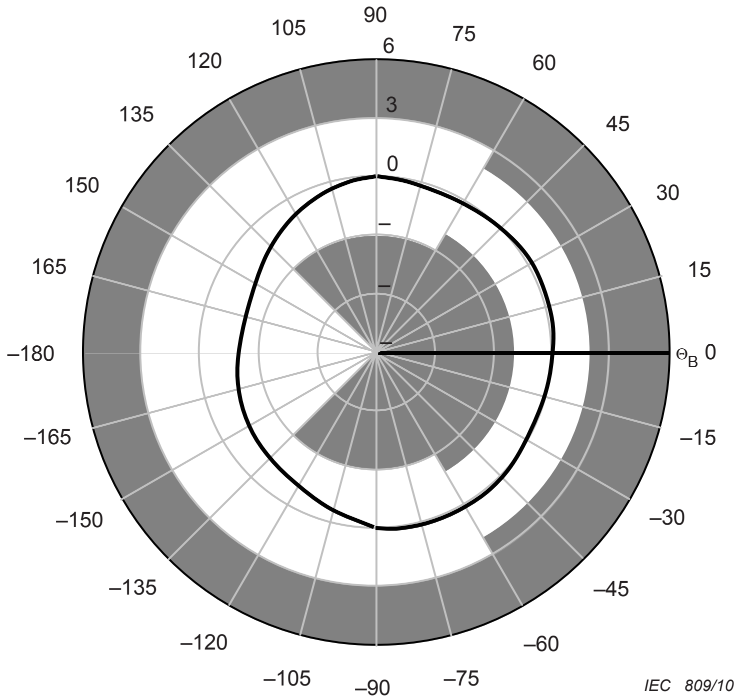


Figure 19a – Transmit antenna *H*-plane radiation pattern – 1 GHz to 6 GHz

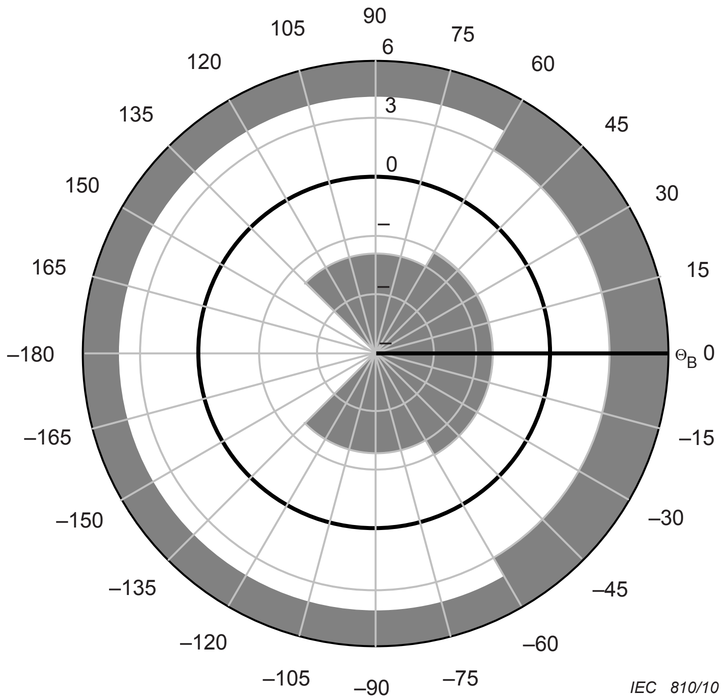


Figure 19b – Transmit antenna *H*-plane radiation pattern – 6 GHz to 18 GHz

NOTE The example plot is for an antenna that meets the H-plane requirements. The shaded areas represent the maximum permissible deviations stated in this subclause. This example antenna meets the requirements because the pattern does not enter the shaded regions.

Figure 19 – Transmit antenna *H*-plane radiation pattern (this example is for informative purposes only)

8.3.3.1.3 Test equipment for the reciprocal S_{VSWR} procedure (i.e. 8.3.3.4)

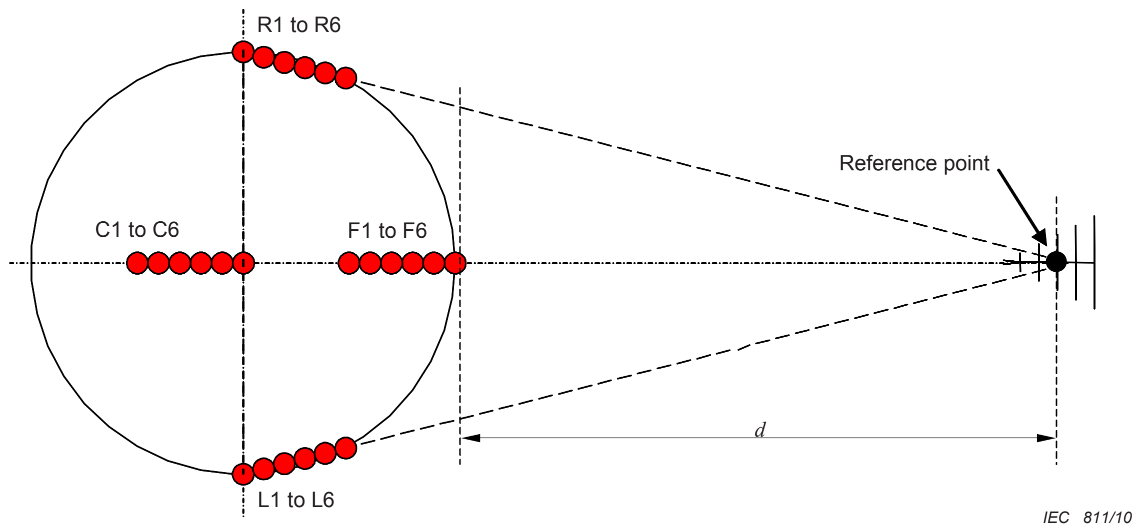
The antenna used to transmit [A1] into [A1] the test volume shall be the same type as used later for emissions measurements. The isotropic field probe used shall be omnidirectional with anisotropy of no more than 3 dB.

8.3.3.2 Required positions for site validation testing

8.3.3.2.1 General

The site validation test shall be performed for a volume in the shape of a cylinder. The bottom of the cylinder is established by the surface that is used to support the EUT. The top of the cylinder is chosen as the maximum height that an EUT and its vertical overhead cabling would occupy. The diameter of the cylinder is the largest diameter required to accommodate an EUT including cables. For cables that leave the test volume, a 30 cm section of these cables shall be assumed to establish the dimensions of the volume. To accommodate floor-standing equipment that cannot be raised above the supporting surface, test-volume illumination for a height of up to 30 cm from the bottom of the test volume is allowed to be obstructed by absorber placed on the ground plane. According to the procedure of 8.3.3.3, the S_{VSWR} is evaluated by placing the receive antenna at the position for which the volume shall be validated, and varying the transmit source location across the defined positions. Alternatively, using the reciprocal S_{VSWR} procedure of 8.3.3.4, the positions described in this subclause are used for the placement of the field probe in the test volume.

The required locations to perform the S_{VSWR} measurements are dependent upon the dimensions of the test volume. Details of the conditional test position requirements are given in 8.3.3.5. The S_{VSWR} is evaluated for each required location and polarization by a sequence of six measurements along a line to the reference point of the receive antenna. All of the possible required locations are illustrated in Figure 20 and Figure 21, including the conditional locations described in 8.3.3.5. The sequence of six measurements along the line to the receive antenna is indicated by dots in these figures.



Key
d test distance

Figure 20 – S_{VSWR} measurement positions in a horizontal plane (see 8.3.3.2.2 for description)

8.3.3.2.2 Descriptions of S_{VSWR} measurement positions in a horizontal plane (Figure 20)

This subclause describes how the S_{VSWR} measurement positions are found in a horizontal plane illustrated in Figure 20.

a) Front positions 1 to 6 (F1 to F6): The front positions are on a line from the centre of the test volume to the receive antenna reference point. To locate these positions, first locate F6 at the front extent of the test volume, on the measurement axis spaced away at the test distance, d from the reference point of the receive antenna.

   F5 to F1 are measured relative to F6 as follows, moving away from the receive antenna:

   1) F5 = F6 + 2 cm away from the receive antenna
   2) F4 = F6 + 10 cm away from the receive antenna
   3) F3 = F6 + 18 cm away from the receive antenna
   4) F2 = F6 + 30 cm away from the receive antenna
   5) F1 = F6 + 40 cm away from the receive antenna

b) Right positions 1 to 6 (R1 to R6): These positions are located relative to position R6. R6 is found by determining the right extent of the test volume (position R1), then moving on a line toward the receive antenna reference point 40 cm (see Figure 20).

   Positions R5 to R1 are measured relative to R6 as follows, moving away from the receive antenna:

   1) R5 = R6 + 2 cm away from the receive antenna
   2) R4 = R6 + 10 cm away from the receive antenna
   3) R3 = R6 + 18 cm away from the receive antenna
   4) R2 = R6 + 30 cm away from the receive antenna
   5) R1 = R6 + 40 cm away from the receive antenna

c) Left positions 1 to 6 (L1 to L6): These positions are located relative to position L6. L6 is found by determining the left extent of the test volume (position L1), then moving on a line toward the receive antenna reference point 40 cm (see Figure 20).

   Positions L5 to L1 are measured relative to L6 as follows, moving away from the receive antenna:

   1) L5 = L6 + 2 cm away from the receive antenna
   2) L4 = L6 + 10 cm away from the receive antenna
   3) L3 = L6 + 18 cm away from the receive antenna
   4) L2 = L6 + 30 cm away from the receive antenna
   5) L1 = L6 + 40 cm away from the receive antenna

d) Centre positions 1 to 6 (C1 to C6): These positions are located relative to position C6. Position C6 is at the centre of the test volume. Positions C1 to C6 are required to be tested when the test volume diameter is greater than 1,5 m (see 8.3.3.5).

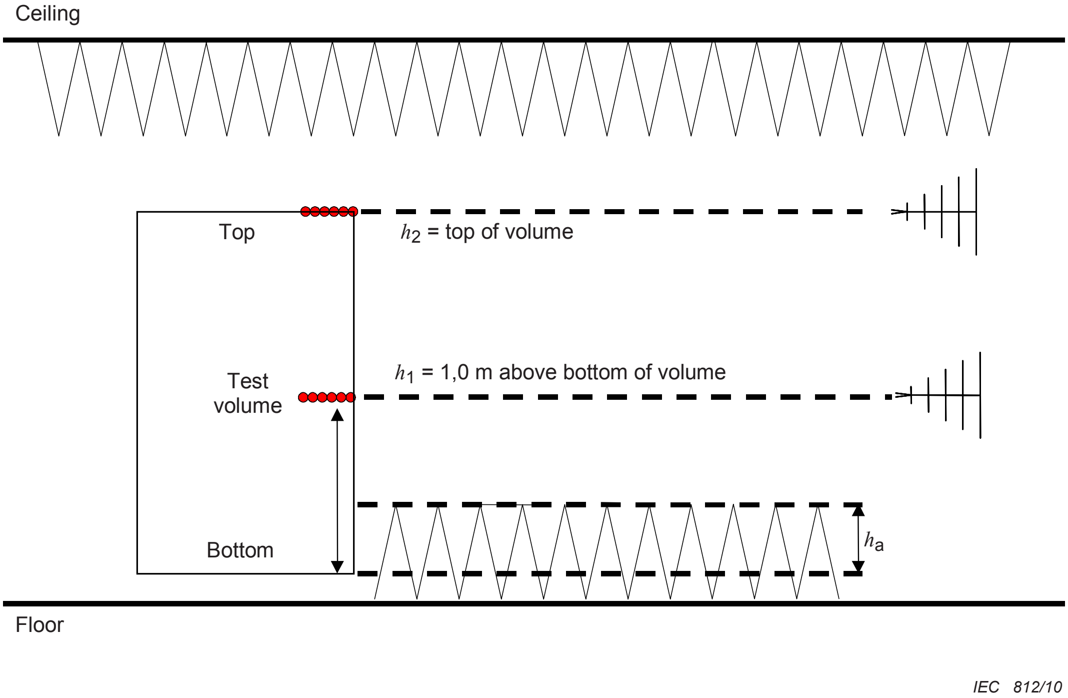
   C5 to C1 are measured relative to C6, moving away from the receive antenna as follows:

   1) C5 = C6 + 2 cm away from the receive antenna
   2) C4 = C6 + 10 cm away from the receive antenna
   3) C3 = C6 + 18 cm away from the receive antenna
   4) C2 = C6 + 30 cm away from the receive antenna
   5) C1 = C6 + 40 cm away from the receive antenna

8.3.3.2.3 Descriptions of S_{VSWR} additional measurement positions (Figure 21)

In addition to the locations indicated in Figure 20, an additional S_{VSWR} test plane at the top of the test volume may be required depending upon the height of the test volume. Figure 21 illustrates the additional height requirement for S_{VSWR} measurements. The test at the second height is to be performed at the front position only.

Table 5 provides a summary of the test positions. In Table 5, the positions are grouped according to height (h_1, h_2) and location (front, left, right, centre). For each location, a reference position is designated for use in the calculations required by Equation (22). The positions are designated as P_{mnopq}, where the subscripts correspond to the position names as listed in the first column of Table 5.



Key

h_a the portion of the test volume that is obstructed by absorber placed on the floor (30 cm maximum)

h_1 height located at the middle of the test volume, or 1,0 m above the bottom of the test volume, whichever is lower

h_2 height located at the top of the test volume and required to be tested when h_2 is separated by at least 0,5 m from h_1 (see 8.3.3.5 for details)

Figure 21 – S_{VSWR} positions (height requirements)

Table 5 – S_{VSWR} test position designations

Position name	Location	Height	Polarization	Reference position for d_{ref} [see Equation (22)]	Location relative to reference position
Front positions (Front, h_1) at first height					
F1h1H	Front	h_1	Horizontal	F6h1	+40 cm away from the receive antenna
F1h1V	Front	h_1	Vertical	F6h1	+40 cm away from the receive antenna
F2h1H	Front	h_1	Horizontal	F6h1	+30 cm away from the receive antenna
F2h1V	Front	h_1	Vertical	F6h1	+30 cm away from the receive antenna
F3h1H	Front	h_1	Horizontal	F6h1	+18 cm away from the receive antenna
F3h1V	Front	h_1	Vertical	F6h1	+18 cm away from the receive antenna
F4h1H	Front	h_1	Horizontal	F6h1	+10 cm away from the receive antenna
F4h1V	Front	h_1	Vertical	F6h1	+10 cm away from the receive antenna
F5h1H	Front	h_1	Horizontal	F6h1	+2 cm away from the receive antenna
F5h1V	Front	h_1	Vertical	F6h1	+2 cm away from the receive antenna
F6h1H	Front	h_1	Horizontal	F6h1	= Reference position (Front, h_1)
F6h1V	Front	h_1	Vertical	F6h1	= Reference position (Front, h_1)
Centre positions (Centre, h_1) at first height (if required - see 8.3.3.5)					
C1h1H	Centre	h_1	Horizontal	C6h1	+40 cm away from the receive antenna
C1h1V	Centre	h_1	Vertical	C6h1	+40 cm away from the receive antenna
C2h1H	Centre	h_1	Horizontal	C6h1	+30 cm away from the receive antenna
C2h1V	Centre	h_1	Vertical	C6h1	+30 cm away from the receive antenna
C3h1H	Centre	h_1	Horizontal	C6h1	+18 cm away from the receive antenna
C3h1V	Centre	h_1	Vertical	C6h1	+18 cm away from the receive antenna
C4h1H	Centre	h_1	Horizontal	C6h1	+10 cm away from the receive antenna
C4h1V	Centre	h_1	Vertical	C6h1	+10 cm away from the receive antenna
C5h1H	Centre	h_1	Horizontal	C6h1	+2 cm away from the receive antenna
C5h1V	Centre	h_1	Vertical	C6h1	+2 cm away from the receive antenna
C6h1H	Centre	h_1	Horizontal	C6h1	= Reference position (centre, h_1)
C6h1V	Centre	h_1	Vertical	C6h1	= Reference position (centre, h_1)

Table 5 *(continued)*

Position name	Location	Height	Polarization	Reference position for d_{ref} [see Equation (22)]	Location relative to reference position
Right positions at first height					
R1h1H	Right	h_1	Horizontal	R6h1	+40 cm away from the receive antenna at the right extent of the volume
R1h1V	Right	h_1	Vertical	R6h1	+40 cm away from the receive antenna at the right extent of the volume
R2h1H	Right	h_1	Horizontal	R6h1	+30 cm away from the receive antenna
R2h1V	Right	h_1	Vertical	R6h1	+30 cm away from the receive antenna
R3h1H	Right	h_1	Horizontal	R6h1	+18 cm away from the receive antenna
R3h1V	Right	h_1	Vertical	R6h1	+18 cm away from the receive antenna
R4h1H	Right	h_1	Horizontal	R6h1	+10 cm away from the receive antenna
R4h1V	Right	h_1	Vertical	R6h1	+10 cm away from the receive antenna
R5h1H	Right	h_1	Horizontal	R6h1	+2 cm away from the receive antenna
R5h1V	Right	h_1	Vertical	R6h1	+2 cm away from the receive antenna
R6h1H	Right	h_1	Horizontal	R6h1	= Reference position (Right, h_1)
R6h1V	Right	h_1	Vertical	R6h1	= Reference position (Right, h_1)
Left positions at first height					
L1h1H	Left	h_1	Horizontal	L6h1	+40 cm away from the receive antenna at the left extent of the volume
L1h1V	Left	h_1	Vertical	L6h1	+40 cm away from the receive antenna at the left extent of the volume
L2h1H	Left	h_1	Horizontal	L6h1	+30 cm away from the receive antenna
L2h1V	Left	h_1	Vertical	L6h1	+30 cm away from the receive antenna
L3h1H	Left	h_1	Horizontal	L6h1	+18 cm away from the receive antenna
L3h1V	Left	h_1	Vertical	L6h1	+18 cm away from the receive antenna
L4h1H	Left	h_1	Horizontal	L6h1	+10 cm away from the receive antenna
L4h1V	Left	h_1	Vertical	L6h1	+10 cm away from the receive antenna
L5h1H	Left	h_1	Horizontal	L6h1	+2 cm away from the receive antenna
L5h1V	Left	h_1	Vertical	L6h1	+2 cm away from the receive antenna
L6h1H	Left	h_1	Horizontal	L6h1	= Reference position (Left, h_1)
L6h1V	Left	h_1	Vertical	L6h1	= Reference position (Left, h_1)

Table 5 *(continued)*

Position name	Location	Height	Polarization	Reference position for d_{ref} [see Equation (22)]	Location relative to reference position
Front positions at second height (if required – see 8.3.3.5)					
F1h2H	Front	h_2	Horizontal	F6h2	+40 cm away from the receive antenna
F1h2V	Front	h_2	Vertical	F6h2	+40 cm away from the receive antenna
F2h2H	Front	h_2	Horizontal	F6h2	+30 cm away from the receive antenna
F2h2V	Front	h_2	Vertical	F6h2	+30 cm away from the receive antenna
F3h2H	Front	h_2	Horizontal	F6h2	+18 cm away from the receive antenna
F3h2V	Front	h_2	Vertical	F6h2	+18 cm away from the receive antenna
F4h2H	Front	h_2	Horizontal	F6h2	+10 cm away from the receive antenna
F4h2V	Front	h_2	Vertical	F6h2	+10 cm away from the receive antenna
F5h2H	Front	h_2	Horizontal	F6h2	+2 cm away from the receive antenna
F5h2V	Front	h_2	Vertical	F6h2	+2 cm away from the receive antenna
F6h2H	Front	h_2	Horizontal	F6h2	= Reference position (Front, h_2)
F6h2V	Front	h_2	Vertical	F6h2	= Reference position (Front, h_2)
NOTE These S_{VSWR} measurements may be performed in any sequence.					

8.3.3.3 S_{VSWR} site validation – standard test procedure

In the following procedure, the positions are designated as P_{mnopq}, where the subscripts correspond to the position names as listed in the first column of Table 5. The measured signal, M, is the received E-field or voltage measurement at each position, and is similarly denoted by subscripts as M_{mnopq}. For example, P_{F1h1H} is the position F1, at height 1, horizontal polarization, and its measured signal (in dB) is referred to as M_{F1h1H}.

a) Locate the transmit source with its reference point at front position 6, height 1, in horizontal polarization (P_{F6h1H}). Locate the receive antenna, also in horizontal polarization, at the test distance d, measured from the source to the reference point of the receive antenna. Note that the receive antenna height shall be located at the same height as the transmit source for all measurements.

b) Verify that the received signal displayed will be at least 20 dB above the ambient and above the measuring receiver or spectrum analyzer displayed noise across the entire frequency range to be measured. If not, it may be necessary to use different equipment (antennas, cables, signal generator, preamplifier) and/or use partial frequency ranges as appropriate to maintain a level of 20 dB above the displayed noise floor.

c) Record the measured signal level, M_{F6h1H} at each frequency. Swept measurement or stepped frequency increments may be used. If stepped increments are used, the frequency increment shall be 50 MHz or less.

d) Repeat steps a) and b) with the transmit source at the other five positions shown in Table 6 (see 8.3.3.6) for the front, height 1, horizontal polarization. In total, there will be six measurements for front, height 1, horizontal polarization (M_{F1h1H} through M_{F6h1H}) varying in separation distance from the receive antenna by the increments shown in Table 5.

e) Change the polarization of the transmit source and receive antenna to vertical and repeat the above procedure for positions P_{F1h1V} through P_{F1h6V} in order to obtain M_{F1h1V} through M_{F1h6V}.

f) For all measurements, normalize the measured E-field or voltage data to the distance of the reference position shown in Table 5, using Equation (22):

$$M'_{\text{mnopq}} = M_{\text{mnopq}} + 20\log\left(\frac{d_{\text{mnopq}}}{d_{\text{ref}}}\right)\ \text{dB} \qquad (22)$$

where

d_{mnopq} is the actual separation distance for the measurement location;

d_{ref} is the separation distance measured to the reference position;

M_{mnopq} is the measured signal (E-field or receiver voltage) in dB. Note that each measurement location has a different reference position corresponding to position 6, as indicated in Table 5 for P_{mnopq};

M'_{mnopq} is normalized measured E-field or voltage data relative to the distance of the reference position shown in Table 5.

g) Using Equation (20) or Equation (21), calculate the S_{VSWR} for horizontal polarization. Using Equation (21), $S_{\text{VSWR,dB}}$ can be obtained by subtracting the minimum received signal, $M_{\text{min,dB}}$, from the maximum received signal, $M_{\text{max,dB}}$, after distance corrections have been applied [i.e. step f)] for the six positions. Repeat the calculation for readings obtained using vertical polarization.

h) The S_{VSWR} for each polarization shall fulfil the acceptance criteria of 8.3.2.

i) Repeat steps a) to h) for the left and right positions of the test volume. Note that when the transmit source antenna is moved to the left or right, its boresight direction shall be aimed towards the receive antenna. However, the receive antenna shall remain facing towards the centre (not aimed at the side positions), which is the same direction it will be facing later during measurements performed on EUTs.

j) If required by 8.3.3.5, repeat the above procedure for the measurements at the centre position, and for the measurements required at the second height. When measurements are performed at the second height, the receive antenna shall be at the same height as the transmit antenna.

8.3.3.4 S_{VSWR} site validation – reciprocal test procedure using an isotropic field probe

For shielded facilities (i.e. fully-anechoic or semi-anechoic chambers), it is permitted to evaluate S_{VSWR} using an isotropic field probe placed at the required locations of Table 5 and illuminating the test volume with the same antenna that is used later as the receive antenna for emissions testing. For the purposes of this standard, this method is termed the “reciprocal” method of S_{VSWR} determination. In this S_{VSWR} reciprocal procedure, the antenna to later be used as the receive antenna in EUT emissions testing is termed the “transmit” antenna, because it will be used to transmit to a probe located in the test volume. The isotropic field probe is required to fulfil the radiation pattern specifications of 8.3.3.1. The probe shall be capable of being aligned with the polarization of the transmit antenna, i.e. the location and orientation of the sensing elements within the probe shall be known.

The reciprocal S_{VSWR} site validation test procedure using an isotropic field probe is as follows.

a) Place the field probe at the front position 6, height 1, in horizontal polarization (P_{F6h1H}). Place the transmit antenna at the test distance d as measured from the perimeter of the test volume to the reference point of the antenna. The transmit antenna height shall be at the same height as the probe for all positions.

b) Verify that field strength magnitude is sufficient to allow proper functioning of the probe. For guidance on the equipment and procedures necessary to establish appropriate field strengths, refer to the manufacturers operating specifications for the probe (adequate sensitivity and measurement uncertainty). In addition, the transmit system and probe system should be checked for linearity, and harmonics shall be suppressed to a level of at least 15 dB below the primary signal. Use of a directional coupler is recommended to monitor forward power during the test, because variations in the output power level will produce variations in the test results. It is important to provide stable output signals, because any signal variation due to instability of the signal source (e.g. bad cable connections, variations with warm-up time of the preamplifier, etc.) will result in additional variations of the results (i.e. artificially high S_{VSWR} results).

c) Record the measured signal level, M_{F6h1H}, at each frequency. Swept measurement or stepped frequency increments may be used. If stepped increments are used, the frequency increment shall be 50 MHz or less.

d) Repeat step c) with the field probe at the other five positions shown in Table 6 (see 8.3.3.6) for the front, height 1, horizontal polarization. In total, there will be six measurements for front, height 1, horizontal polarization (M_{F1h1H} through M_{F6h1H}) varying in separation distance from the receive antenna by the increments shown in Table 5.

e) Change the polarization of the field probe and antenna to vertical, and repeat the above procedure for positions P_{F1h1V} through P_{F1h6V}, in order to obtain M_{F1h1V} through M_{F6h1V}.

f) For all measurements, normalize the obtained data using Equation (22).

g) Using Equation (20) or Equation (21), calculate the S_{VSWR} for horizontal polarization. Using Equation (21), $S_{\text{VSWR,dB}}$ can be obtained by subtracting the minimum received signal, $M_{\text{min,dB}}$, from the maximum received signal, $M_{\text{max,dB}}$, after distance corrections have been applied [i.e. step f)] for the six positions. Repeat the calculation for the readings obtained using vertical polarization.

h) The S_{VSWR} for both polarizations shall fulfil the acceptance criteria of 8.3.2.

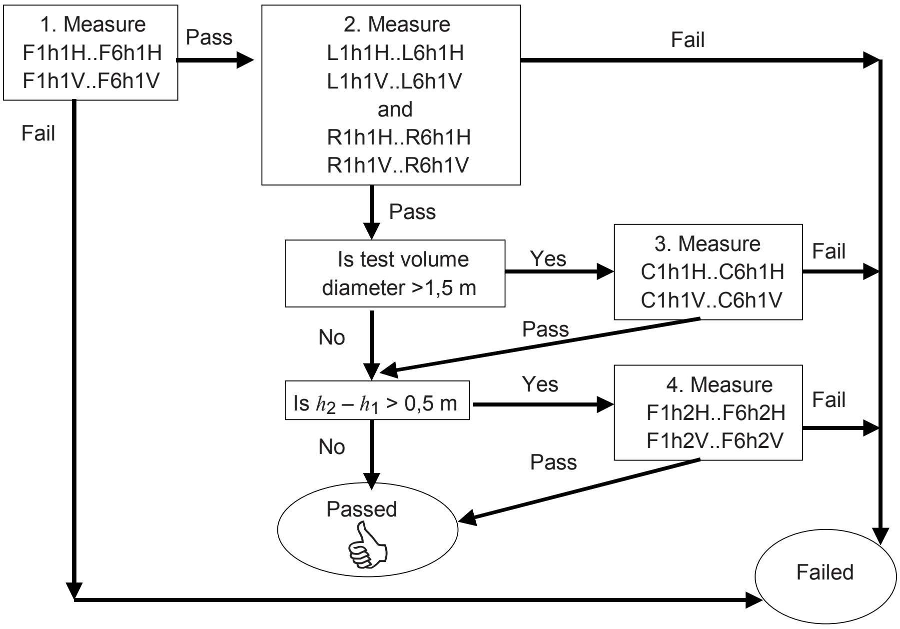
i) Repeat the above procedure for the left and right positions of the test volume. Note that for this reciprocal S_{VSWR} procedure the probe may be adjusted to maintain a constant direction facing at the reference point of the transmit antenna. However, the transmit antenna shall remain facing toward the centre of the volume (not aimed at the side positions) in the same direction it will be facing during later measurements of EUTs.

j) If required by 8.3.3.5, repeat the above procedure for the measurements at the centre position, and for any measurements required at the second height. When measurements are performed at the second height, the probe shall be at the same height as the transmit antenna.

8.3.3.5 Conditional test position requirements

As indicated in Figure 20, Figure 21 and Table 5, additional test positions are required to be tested depending upon the size of the test volume. Figure 22 presents a flow chart specifying when these additional measurements are required.

When additional test positions are required, S_{VSWR} is to be determined at each test frequency from each group of six measurements independently for horizontal and vertical polarization using the procedures of 8.3.3.3 or 8.3.3.4.



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NOTE The measurements are not required to be performed in the sequence shown, and may proceed in any order such that all the required data is obtained.

Figure 22 – Conditional test position requirements

8.3.3.6 S_{VSWR} site validation test report

Table 6 lists a summary of all of the possible required S_{VSWR} measurements and calculations (normalized), including the results from the required positions and the conditional positions of 8.3.3.5.

The S_{VSWR} calculations and reporting requirements apply for each test frequency.

Table 6 – S_{VSWR} reporting requirements

Location	Height	Polarization	Type	S_{VSWR} dB
Front	h_1	Horizontal	Required	= Max $M'_{F1h1H} \cdots M'_{F6h1H}$) – Min ($M'_{F1h1H} \cdots M'_{F6h1H}$)
Front	h_1	Vertical	Required	= Max ($M'_{F1h1V} \cdots M'_{F6h1V}$) – Min ($M'_{F1h1V} \cdots M'_{F6h1V}$)
Right	h_1	Horizontal	Required	= Max ($M'_{R1h1H} \cdots M'_{R6h1H}$) – Min ($M'_{R1h1H} \cdots M'_{R6h1H}$)
Right	h_1	Vertical	Required	= Max ($M'_{R1h1V} \cdots M'_{R6h1V}$) – Min ($M'_{R1h1V} \cdots M'_{R6h1V}$)
Left	h_1	Horizontal	Required	= Max ($M'_{L1h1H} \cdots M'_{L6h1H}$) – Min ($M'_{L1h1H} \cdots M'_{L6h1H}$)
Left	h_1	Vertical	Required	= Max ($M'_{L1h1V} \cdots M'_{L6h1V}$) – Min ($M'_{R1h1V} \cdots M'_{L6h1V}$)
Centre	h_1	Horizontal	Conditional	= Max ($M'_{C1h1H} \cdots M'_{C6h1H}$) – Min ($M'_{C1h1H} \cdots M'_{C6h1H}$)
Centre	h_1	Vertical	Conditional	= Max ($M'_{C1h1V} \cdots M'_{C6h1V}$) – Min ($M'_{C1h1V} \cdots M'_{C6h1V}$)
Front	h_2	Horizontal	Conditional	= Max ($M'_{F1h2H} \cdots M'_{F6h2H}$) – Min ($M'_{F1h2H} \cdots M'_{F6h2H}$)
Front	h_2	Vertical	Conditional	= Max ($M'_{F1h2V} \cdots M'_{F6h2V}$) – Min ($M'_{F1h2V} \cdots M'_{F6h2V}$)

8.3.3.7 Limitations of the S_{VSWR} site validation method

The measurement points chosen for 8.3.3.2 and contained in the preceding procedures are intended to provide an overall measure of the S_{VSWR} of the test site across the frequency range of 1 GHz to 18 GHz. Note however that the peak S_{VSWR} may not always be captured using the procedures of 8.3.3.3 or 8.3.3.4 at any specific frequency f. Therefore, statements about S_{VSWR} compliance based on measurements at any single frequency should be avoided. However, the peak found by the above procedures within adjacent octaves (0,5f to $2f$) is typically representative of the worst case S_{VSWR} for all frequencies inclusive in the band.

In cases where more accuracy of the S_{VSWR} result is desired at a single frequency, the above method can be improved by measuring more than six locations along the lines shown Figure 20 and Figure 21. The additional data collection points should be spaced unequally, and chosen based on a distance translation of the source antenna (or field probe in the reciprocal S_{VSWR} method) using quarter-wavelength steps at the frequency of interest.

8.4 Alternative test sites

Any measurement site that achieves free-space conditions is a possible alternative test site.

9 Common mode absorption devices

9.1 General

Common mode absorption devices (CMADs) are applied on cables leaving the test volume during a radiated emission measurement. CMADs are used in radiated emission measurements to reduce variations in the measurement results between different test sites, due to possible differing values of common mode impedance and symmetry at the point where cables leave the test site (e.g. turntable centre). The basic characteristics of CMADs can be expressed in terms of S-parameters. Derived performance quantities such as insertion loss or reflection coefficient can be determined from these S-parameters. This clause specifies the measurement method for the verification of the S-parameters of a CMAD.

9.2 CMAD S-parameter measurements

S-parameters measured in a test jig, as described in 9.3, are used to characterise the properties of a CMAD. The values of the complex S-parameters are evaluated at the reference planes indicated in Figure 23. The reference method for the measurement of S-parameters with the highest possible accuracy uses a vector network analyzer (VNA) and the TRL calibration method, as described in 9.4.

9.3 CMAD test jig

A test jig used for measuring the S-parameters of a CMAD under test shall have a cylindrical metal rod above a metal ground plane, as shown in Figure 23. The metal rod between the vertical flanges of the test jig consists of three sections: one section forming a transmission line in the jig between the two reference planes, and two adaptor sections between the reference planes and the adaptor ports.

The effects on the measurement of a CMAD from the adaptor sections and the adaptor ports can be eliminated by using the TRL calibration method described in 9.4, providing a low uncertainty for the final measurements. Any type of adaptor may be used for the measurements of 9.4. Examples of adaptors are shown in Figures 26 to 28 (see 9.6).

The diameter d of the cylindrical rod shall be 4 mm. The height above the ground plane, h, is defined by the dimensions of the CMAD. Typical values are 30 mm, 65 mm, and 90 mm. The measurement shall be performed at the height defined by the construction of the CMAD. The distance between the reference plane and the vertical flange of the jig (adaptor section), L_{A}, shall be at least $2h$ (see Figure 23). The distances between the reference planes and the

CMAD ends, D_A and D_B, should be as small as possible, but not larger than h. The metal ground plane of the test jig shall be greater than (L_{jig} + 4h) in length and greater than 4h in width.

The characteristic impedance, Z_{ref}, is given by the internal diameter of the line, d, (defined to be 4 mm), and by the height of the centre of the rod above the ground plane, h:

$$Z_{ref} = \frac{Z_0}{2\pi} \cosh^{-1}\left(\frac{2h}{d}\right) \text{ in } \Omega \qquad (23)$$

where

Z_0 is the free-space impedance (i.e. 120 π) in Ω;

d is the test conductor diameter, defined to be 4 mm;

h is the height of the centre of the test conductor above the ground plane.

EXAMPLE Typical values of Z_{ref} for various heights h are:

h = 30 mm >> Z_{ref} = 204 Ω

h = 65 mm >> Z_{ref} = 248 Ω

h = 90 mm >> Z_{ref} = 270 Ω

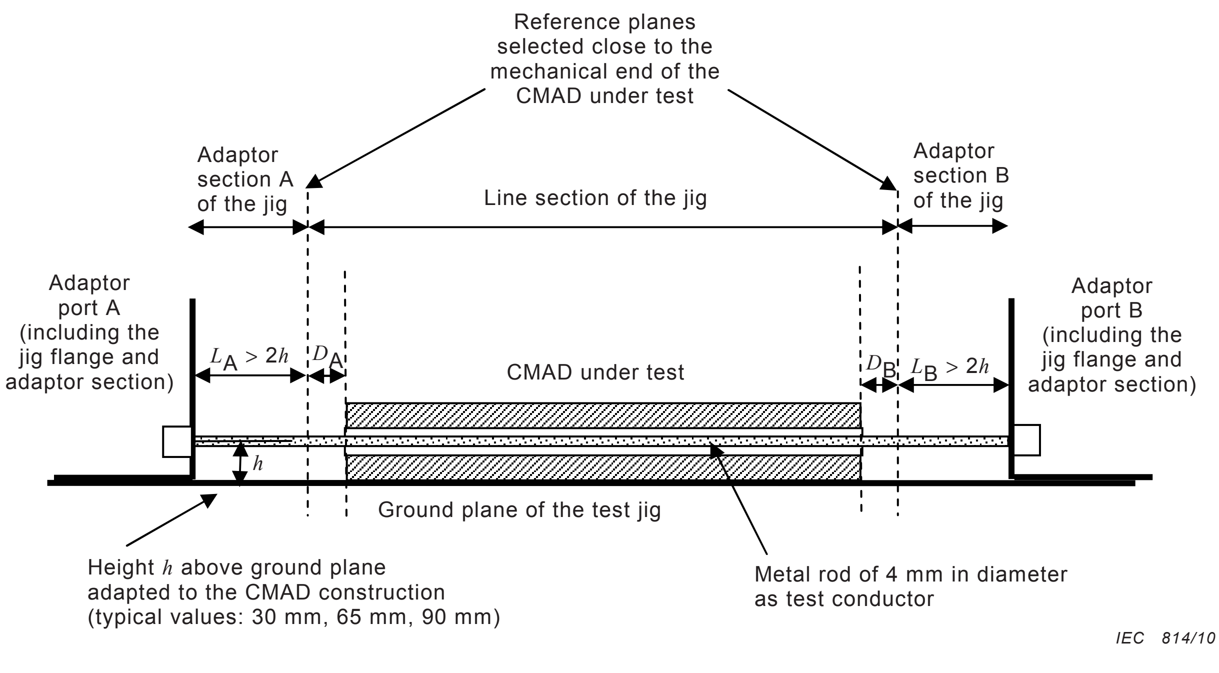


Figure 23 – Definition of the reference planes inside the test jig

9.4 Measurement method using the TRL calibration

The through-reflect-line (TRL) calibration method is recommended for measuring the S-parameters of CMADs. Use of this calibration procedure allows selection of the reference plane inside the test jig such that it is in close proximity to the location where the CMAD under test will be placed and hence distances D_A and D_B can be minimized (see Figure 23). The calibration requires a metal rod (termed "line") with the same diameter and height as the transmission line section of the jig. The characteristic impedance and length of the line section have to be known exactly, and are introduced into the calibration data used by the firmware of the VNA or by external correction calculations.

The length of the line section, used for a TRL calibration process, determines the frequency range in which the TRL calibration can be performed. This frequency limitation results from the mathematical procedure used in the TRL calibration method, where at some frequencies a divide-by-zero (or very small values) condition is possible and shall be avoided.

If the length of the "line" reference is L, the frequency range shall be limited to between low and high frequencies f_L and f_H as follows:

$$f_L = 0{,}05\frac{c}{L} \quad (24)$$

$$f_H = 0{,}45\frac{c}{L} \quad (25)$$

where c is 3×10^8 m/s. A "line" length of 0,6 m is appropriate for calibration in the frequency range 30 MHz to 200 MHz. If the measurement has to be extended to higher frequencies, a second "line" calibration is necessary. A second calibration with a "line" length of 0,12 m would be appropriate for the frequency range 150 MHz to 1 000 MHz.

Four calibration configurations are necessary for the TRL calibration method, as follows.

a) "reflect" (port A): Measuring the complex value S_{11} of the adaptor section and adaptor without any other connection (simulating an open-circuit condition) [Figure 24 a];
b) "reflect" (port B): Measuring the complex value S_{22} of the adaptor section and adaptor without any other connection (simulating an open-circuit condition) [Figure 24 b];
c) "through": Measuring the complex values S_{11}, S_{12}, S_{21}, S_{22} with the two adaptor sections directly connected together (without the line section in between) [Figure 24 c];
d) "line": Measuring the complex values S_{11}, S_{12}, S_{21}, S_{22} with the line section introduced [Figure 24 d]

These calibration measurements yield 10 complex numbers for each frequency point. If the VNA includes a firmware for TRL calibration, it will use these reference measurements to calculate the proper corrections for the TRL measurement. If the VNA does not support the TRL calibration, the necessary corrections may be made independent of the VNA according to the procedure described in CISPR/TR 16-3.

The properties of the adaptor sections and adaptor ports outside of the calibration planes do not need to be known for the TRL calibration; rather, these are measured in the calibration procedure and are compensated correctly by the TRL calibration. Different types of adaptors may be used. It is recommended to use the same type of adaptors and the same length of the adaptor section on both ends of the test jig. It is also recommended that the two adaptor sections are the same length, i.e. that $L_A = L_B$.

After calibration, the CMAD under test is introduced into the line section of the test jig. The adaptor sections and adaptors have to be exactly the same as used for the calibration. The length of the metal rod can be different from the length of the "line" used for the calibration, but the diameter (4 mm) and the height above the ground plane shall be the same as used for the calibration. The metal rod inside the CMAD should be positioned as accurately as possible in the centre of the CMAD opening. The length of the metal rod can be selected such that the reference plane corresponds with the physical ends of the CMAD (i.e. D_A as small as possible). Typical CMADs have a length of 0,6 m. In this case, the 4 mm line section can be used for calibration covering the frequency range of 30 MHz to 200 MHz, as well as for the measurement of the CMAD (also including the frequency range above 200 MHz, calibrated by a shorter line section). The measurement results for a CMAD under test using the VNA measurement corrected by the TRL calibration is a set of the four S-parameters referenced to the characteristic impedance of the transmission line section (empty jig), $Z_{0,\mathrm{jig}}$.

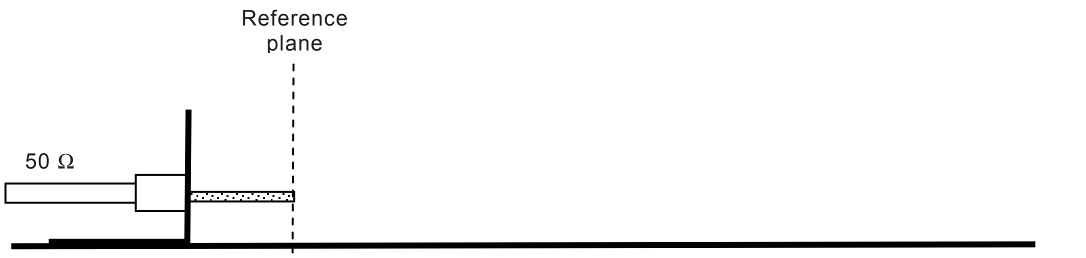


Figure 24a – Configuration for the calibration measurement "reflect port A"

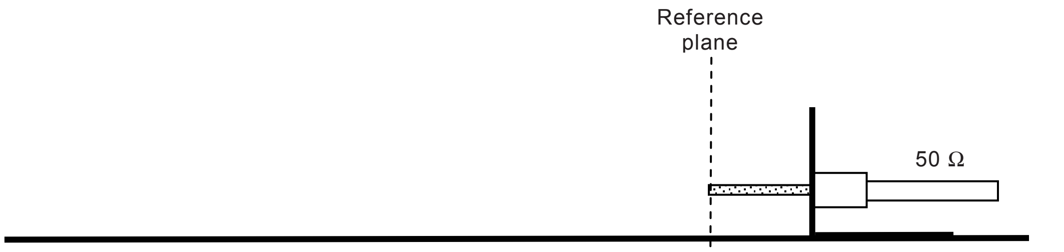


Figure 24b – Configuration for the calibration measurement "reflect port B"

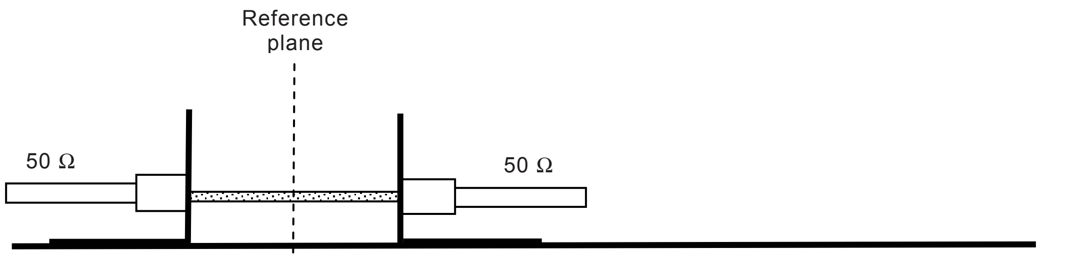


Figure 24c – Configuration for the calibration measurement "through"

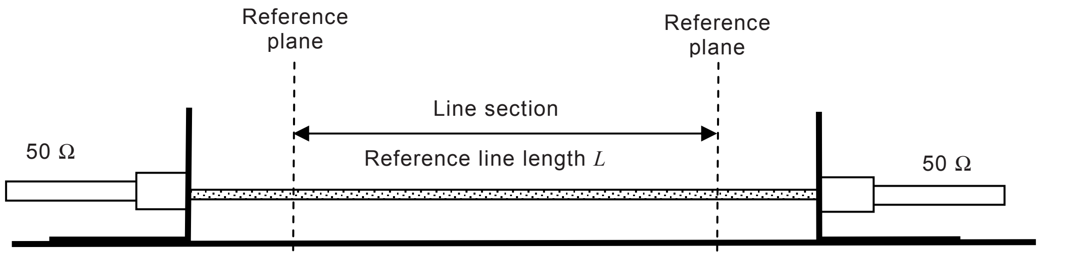


Figure 24d – Configuration for the calibration measurement "line"

NOTE The length L of the reference line for the calibration needs not to be the same as the length used for the measurement of the CMAD. The length of the reference line for the calibration procedure is be selected according to the frequency range needed.

Figure 24 – The four configurations for the TRL calibration

9.5 Specification of ferrite clamp-type CMAD

Ferrite clamp-type CMADs are used during radiated measurements below 1 GHz for the purpose of reducing compliance uncertainty. The characteristics of a CMAD are measured according to provisions of 9.1 to 9.3 and referenced to the characteristic impedance of the empty jig $Z_{0,\text{jig}}$.

A comparison of available ferrite clamp-type CMADs has shown that a magnitude of S_{21} less than 0,25 is required to provide sufficient decoupling. These values can be achieved with CMADs having a magnitude of S_{11} as shown in Figure 25.

Ferrite clamp CMADs shall meet the following specifications:

a) the magnitude of S_{21} shall be less than 0,25 in the frequency range 30 MHz to 200 MHz;
b) the magnitude of S_{11} shall be within the following limit range in the frequency range 30 MHz to 200 MHz:
   – upper limit 0,75 at 30 MHz and 0,55 at 200 MHz (decreasing linearly with the logarithm of the frequency);
   – lower limit 0,6 at 30 MHz and 0,4 at 200 MHz (decreasing linearly with the logarithm of the frequency).

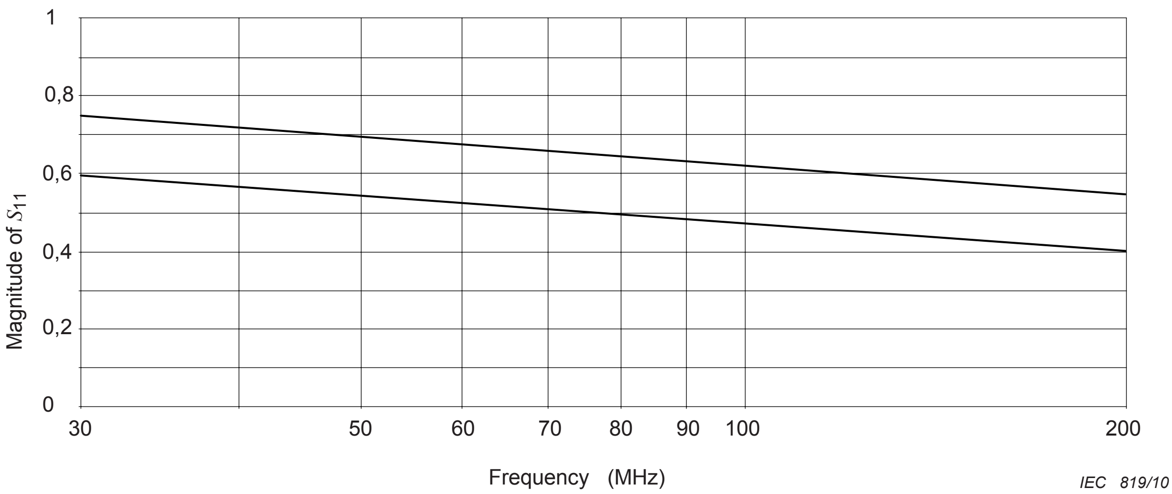


Figure 25 – Limits for the magnitude of S_{11}, measured according to provisions of 9.1 to 9.3

A specification in the frequency range from 200 MHz to 1 000 MHz is not required, because radiated emission measurements are not seriously affected by cable termination conditions at these frequencies.

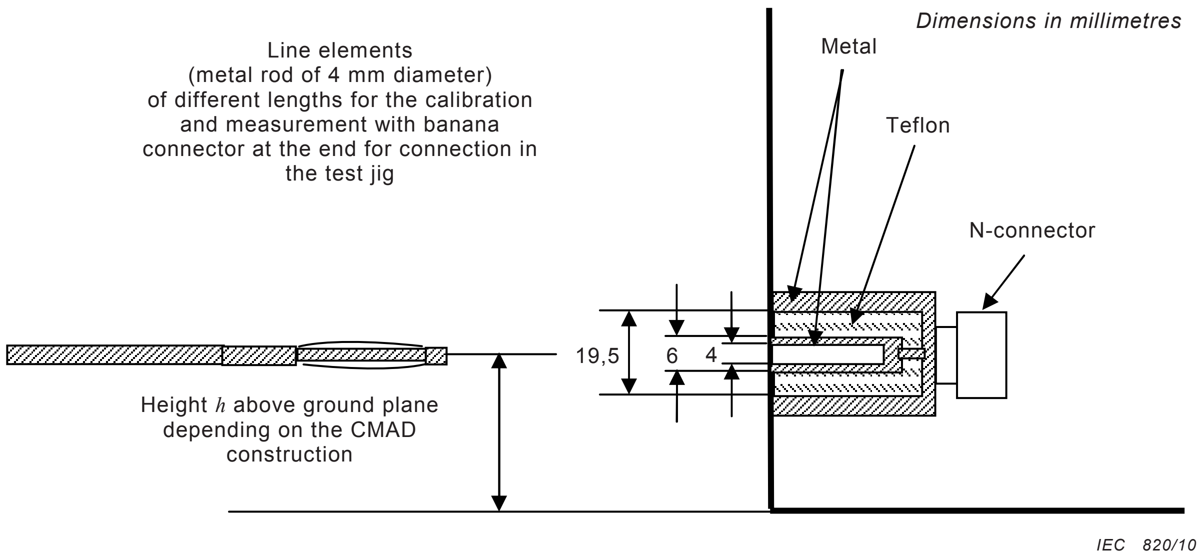
[A1⟩ A rationale for using S-parameters for the specification of ferrite-type CMADs is provided in CISPR/TR 16-3. ⟨A1]

9.6 CMAD performance (degradation) check using spectrum analyzer and tracking generator

The complex S-parameters of a CMAD cannot be measured without using a VNA. However, VNA instruments may not be available in all EMC test laboratories. For laboratories that do not have access to VNA instruments, a simpler method to check the functioning of a CMAD is defined in this subclause, using a spectrum analyzer with tracking generator. This instrumentation set-up measures only the magnitude of the insertion loss, but this measured value will not be directly related to the S-parameters measured at the reference planes shown in Figure 23. Nonetheless, an EMC laboratory can periodically repeat the same insertion loss measurement with their in-house test set-up, using the exact same conditions (impedance and geometry of the test set-up), and record and compare the history of the results to decide whether the CMAD is still in acceptable condition. Degradation of CMAD performance can be detected in this way. If some degradation becomes apparent, a reference measurement shall be performed using a VNA with the TRL calibration method of 9.4.

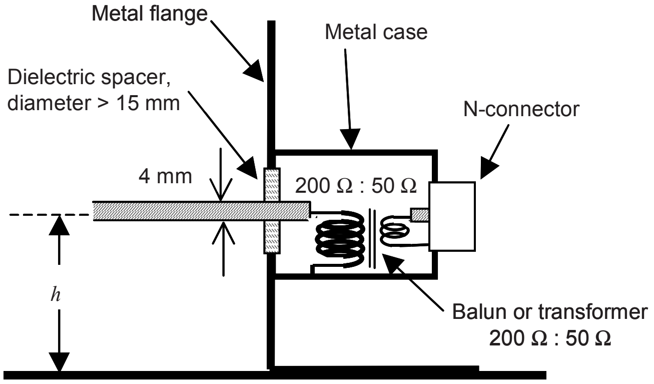
Any adaptor construction (Figures 23 and 24, Figures 26 to 28) can be used for this performance/degradation check. To avoid resonance effects in cables between test jig and measurement instrument, it is necessary to include two 10 dB attenuators close to the test jig connection during this performance check.

a) When 50 Ω adaptors are used (Figure 26), the insertion loss measurement for the performance/degradation check is the difference in dB between attenuation measurements for the following two configurations:
   1) configuration 1: direct connection of the two attenuators without the test jig;
   2) configuration 2: the two attenuators connected to the test jig with the CMAD included.
b) If matching adaptors (Figure 27 or Figure 28) are used, the insertion loss measurement for the degradation check is the difference between the attenuation measured for the following two configurations:
   1) configuration 1: the two attenuators connected to the test jig without the CMAD (empty jig);
   2) configuration 2: the two attenuators connected to the test jig with the CMAD included.



NOTE The bottom sides of the vertical flange are electrically bonded to the metallic ground plane.

Figure 26 – Example of a 50 Ω adaptor construction in the vertical flange of the jig

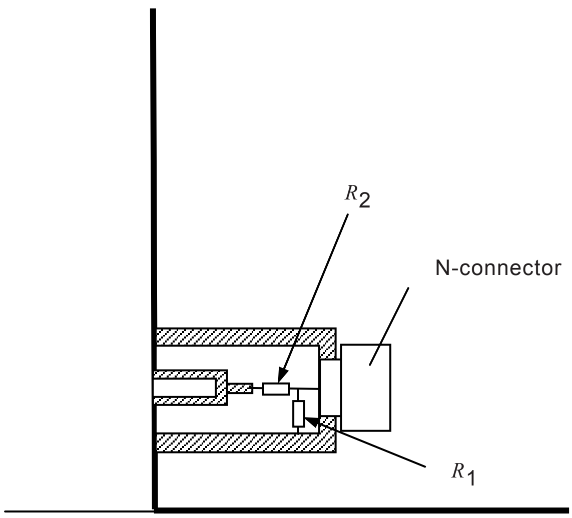


NOTE If the centre tap of the balanced port is connected to the balun case, it should be disconnected.

Figure 27 – Example of a matching adaptor with balun or transformer

$$R_1 = 50\sqrt{\frac{Z_{0\_jig}}{Z_{0\_jig} - 50}} \quad \Omega$$

$$R_2 = \sqrt{Z_{0\_jig}(Z_{0\_jig} - 50)} \quad \Omega$$



h mm	Z_{0_jig} Ω	R_1 Ω	R_2 Ω
30	204	57,6	177,3
65	248	56,0	221,6
90	270	55,4	243,7

IEC 822/10

Figure 28 – Example of a matching adaptor with resistive matching network

Annex A
(normative)

Parameters of antennas

A.1 General

Various CISPR publications specify particular antennas to be used in making measurements. Other types of antennas can be used provided the results are equivalent to those obtained with the specified antenna. The comparison of these antennas to the specified antennas will be aided by listing appropriate parameters. These parameters shall be specified as part of any CISPR acceptance of a new antenna type. Antenna manufacturers shall also use this information as guidance in specifying the most useful aspects of antennas used for radiated emissions measurements. Manufacturers are recommended to supply generic information on each antenna model including the following parameters: free-space antenna factor into a 50 Ω system, return loss, radiation patterns at sufficient frequency intervals to indicate significant changes (which include beamwidth information), and frequency dependent uncertainty values to account for the deviation from free-space antenna factor caused by mutual coupling to a ground plane when the antenna is scanned in height between 1 m and 4 m.

A.2 Preferred antennas

A.2.1 General

If there is an alleged non-compliance to the E-field limit, the value measured by a low-uncertainty antenna is preferred. A low-uncertainty antenna is one with which the field strength on a CISPR test set-up can be measured with a lower uncertainty than is required for other antennas that meets the field strength accuracy criterion of 4.2. The low-uncertainty antennas are described in A.2.3.

A.2.2 Calculable antenna

The calculable standard dipole antenna achieves the lowest uncertainty for E-field measurements. The antenna factor can be calculated for free-space and at any height and polarization above a well-defined ground plane. The principle of the calculable standard dipole is described in CISPR 16-1-5, in which only the resonant condition is described. However, using widely available numerical electromagnetic modelling, the antenna factor for a single dipole length can be calculated over a broad frequency band with uncertainties less than ±0,3 dB. For example, for a measurement at 30 MHz, the dipole that is resonant at 80 MHz can be used. The principle can be extended to multi-wire antennas, which cover an even broader bandwidth.

A.2.3 Low-uncertainty antennas

Low-uncertainty antennas are the biconical and LPDA antennas, whose basic parameters are described in the next paragraph. They are broadband and have reasonable sensitivity, i.e. their antenna factors are not too high. Calculable dipoles can be used and potentially have the lowest uncertainty. The cross-polar response shall meet requirements in 4.5.5 and any balun shall meet the requirements indicated in 4.5.4. The antenna factor shall be determined by a calibration laboratory that provides traceability to national standards, and is selected to minimize the uncertainty of antenna factor determination.

Approved types are the biconical antenna used over the frequency range 30 MHz to 250 MHz and the LPDA antenna over the range 250 MHz to 1 GHz. The reasons for this cross-over frequency are that the LPDA antenna has a phase centre error due to its length, which is reduced by starting at 250 MHz, and most biconical antennas are affected by a resonance above 290 MHz, and exhibit radiation pattern distortion above 260 MHz, unless the open structure elements (portable or collapsible) are used. The cross over frequency between biconical and LPDA antennas can be between 200 MHz and 250 MHz, with a slight increase in phase centre uncertainties associated with LPDA antennas below 250 MHz. The hybrid antenna, which covers the whole frequency band 30 MHz to 1 000 MHz, is not a preferred type because the uncertainties are higher than for biconical and LPDA antennas, mainly because of the greater length of the antenna, especially when used at a distance of 3 m from the source (as opposed to 10 m).

The low-uncertainty biconical antenna has a an element tip-to-tip length of approximately 1,35 m ± 0,03 m (depending on balun width), six wire elements emanating in a cone shape, with a broadest diameter of approximately 0,52 m. The balun shall be a 200 Ω design (200 Ω to 50 Ω transformer ratio), which ensures better sensitivity at 30 MHz, and lower mutual coupling with the environment.

NOTE The biconical antenna is based on the original shown in MIL STD 461A [8] , designed to operate from 20 MHz to 200 MHz. The collapsible element version gives better performance than the closed “cage” element version above 250 MHz.

The low-uncertainty LPDA is designed to have a lowest frequency of 200 MHz (i.e. the longest element is resonant at 200 MHz, approximately 0,75 m) and a length of 0,75 m ± 0,12 m, between the longest and shortest elements, the latter being resonant above 1 GHz. The reason for not having the longest element at 250 MHz is that it is not bounded by an array and the radiation pattern is distorted. The antenna length of 0,75 m distinguishes it from antennas of twice the length that achieve a higher gain but will have a greater phase centre error, and antennas of less than 0,6 m in length that are not likely to have an antenna factor that increases smoothly and monotonically with frequency (with any sharp rises in antenna factor deviating by no more than 1,5 dB from a regression line across the whole frequency range).

A.3 Simple dipole antennas

A.3.1 General

If a laboratory is not able to get an antenna calibrated, an alternative is to use a dipole antenna, either in the form of a calculable dipole or a tuned dipole. A tuned dipole is relatively simple to construct and gives a low uncertainty for field strength measurement comparable to the antennas described in Cause A.2. The antenna factors of a tuned dipole shall be verified either by a laboratory that provides traceability to national standards and tries to minimise the uncertainty of antenna factor determination, or by measuring the site insertion loss between a pair of similar dipoles above a ground plane (that conforms to Annex D) and comparing it with the calculated coupling, allowing for the loss of the baluns - see Annex C of CISPR 16-1-5. A drawback of the tuned dipole is its long length at the lower end of the frequency range, for example it is 4,8 m long at 30 MHz, which at a measurement distance of 3 m will result in errors caused by amplitude and phase gradients. Also a dipole is most sensitive to its surroundings when it is tuned, so that the mutual impedance with its image in the ground plane can change the antenna factor by up to 6 dB for a horizontally polarized 30 MHz dipole scanned in height from 1 m to 4 m above a ground plane. For this reason, a shortened dipole tuned to 80 MHz is recommended for use below 80 MHz.

A.3.2 Tuned dipole

A practical and simple design of a tuned dipole comprises a half-wavelength-resonant dipole with a series-parallel coaxial stub balun. The tip-to-tip dipole lengths are approximately 0,48 wavelengths, depending on the radius of the dipole element. Free-space antenna factors can be computed from the following equation, which gives the factor in decibels. This does not include the balun loss, for which an averaged value of 0,5 dB can be added to the antenna factor, and this loss factor shall be verified.

$$F_{\mathrm{a}}(\mathrm{dB}) = 20\log(f_{\mathrm{M}}) - 31{,}4$$

where f_{M} is the frequency in MHz.

Because the tuned dipole is more sensitive to its surroundings than a broadband antenna (except at its resonant frequency, excluding LPDAs) it is unlikely that the overall uncertainty in the use of a tuned dipole will be less than that of the low-uncertainty antennas of 4.5.2.

A.3.3 Shortened dipole

A dipole shorter than one half-wavelength may be used provided:

a) the total length is greater than 1/10 -wavelength at the frequency of measurement;

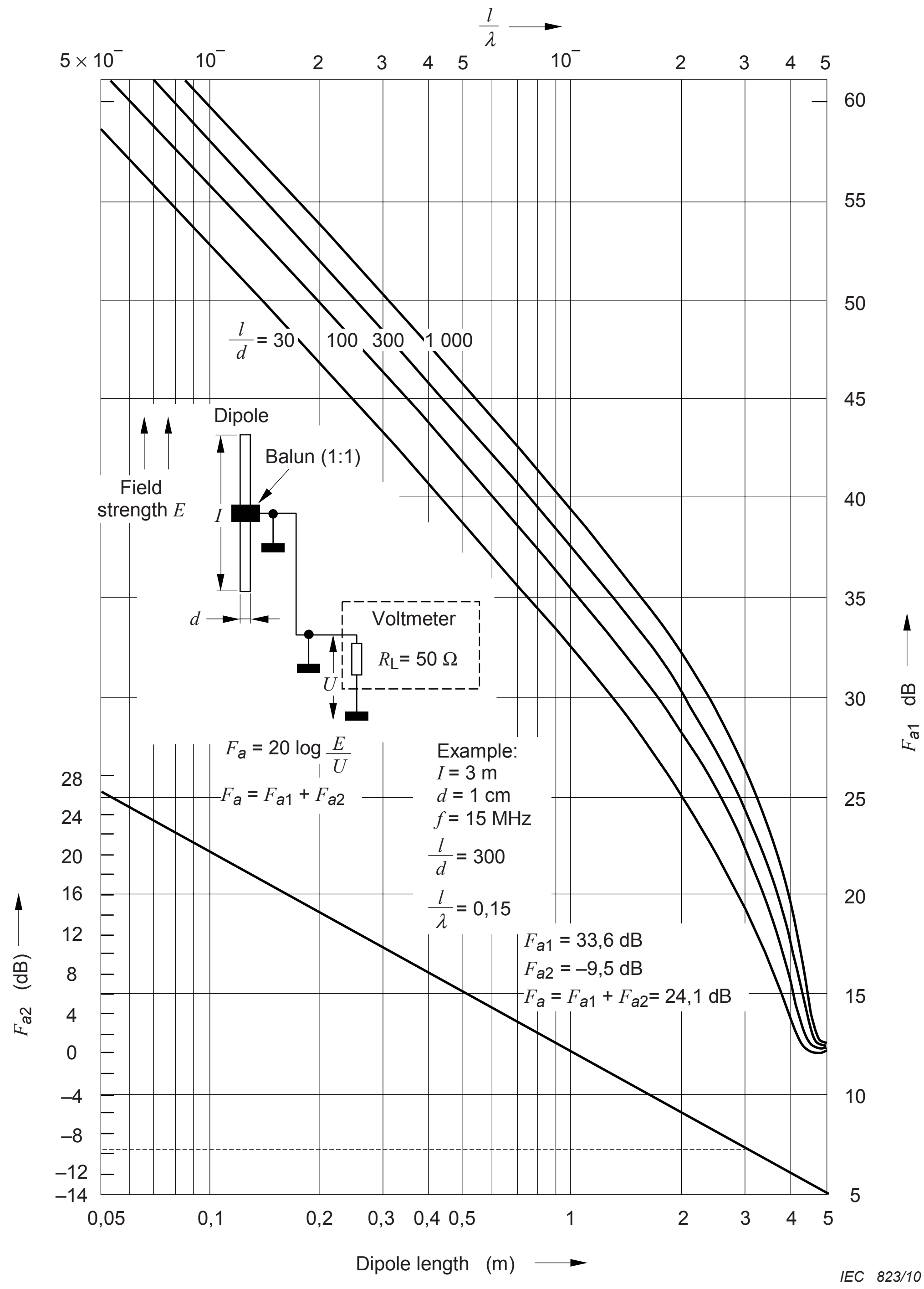
b) it is connected to a cable sufficiently well matched at the receiver end to ensure a return loss at the cable input of greater than 10 dB. The calibration shall take account of the return loss;

c) it has a polarization discrimination equivalent to that of a tuned dipole (see 4.5.3). To obtain this, a balun may be helpful;

d) for determination of the measured field strength, a calibration curve (antenna factor) is determined and used in the measuring distance (i.e. at a distance of at least three times the length of the dipole);

NOTE The antenna factors thus obtained should make it possible to fulfil the requirement of measuring uniform sine-wave fields with an accuracy not worse than ± 3 dB. Examples of calibration curves are given in Figure A.1, which shows the theoretical relation between field strength and receiver input voltage for a receiver with input impedance of 50 Ω, and for various l/d ratios. In this figure, the balun is considered as an ideal 1:1 transformer. It should be noted, however, that these curves do not account for the losses of the balun, the cable, and any mismatch between the cable and the receiver.

e) in spite of the sensitivity loss of the field-strength meter due to a high antenna factor attributed to the shortened length of the dipole, the measuring limit of the field-strength meter (determined for example by the noise of the receiver and the transmission factor of the dipole) shall remain at least 10 dB below the level of the measured signal.



NOTE See Note in A.3.3 item d).

Figure A.1 – Short dipole antenna factors for R_L = 50 Ω

A.4 Broadband antenna parameters

A.4.1 General

Broadband antennas used for CISPR measurements are those antennas that are linearly polarized and are intended for use over a wide frequency range. This does not prevent the use of antennas with limited length adjustment or the addition of antenna element sections. The input impedance of such antennas typically is a complex quantity. Other parameters that can be specified are described below.

A.4.2 Antenna type

A.4.2.1 General

The following subclauses describe the physical parameters of broadband antennas that should be provided. Note that some parameters may not apply to every antenna.

A.4.2.2 Antenna style of fixed or variable length or diameter

If the antenna has a variable length, specify the number of sections that are added or subtracted to change the basic fixed length.

NOTE Fully-tunable antennas are not considered to be broadband and hence would not be specified herein. The diameter of a loop antenna is generally not variable.

A.4.2.3 Depth to width ratio or loop diameter

Provide dimension in metres. For a log periodic array, for example, the length of the boom along the measurement axis and the width of the largest element would be provided.

A.4.2.4 Active or passive antenna

A broadband antenna is considered an active antenna if it contains amplifiers, preamplifiers, and other non-linear active devices which amplify the signal and/or shape the frequency response.

A.4.2.5 Mounting arrangement

Provide any special mounting requirements beyond those that can be accommodated by a typical tripod or antenna positioner.

A.4.2.6 Connector type

Specify BNC, N, SMA, etc. as appropriate. Specify the pin depth tolerance and state that it should be verified with a pin-depth gauge.

A.4.2.7 Balun type

Specify if the balun is discrete, distributed, tunable, etc. Specify the balun transformer ratio.

A.4.3 Specification of the antenna

A.4.3.1 Frequency range

Specify the frequency range in megahertz or kilohertz where the antenna operates within its characteristics. If there is a defined fall-off characteristic in decibels per octave at either end of the range, so specify.

A.4.3.2 Gain and antenna factor

A.4.3.2.1 Gain

Specify typical or actual gain in decibels relative to an isotropic radiator (dBi).

A.4.3.2.2 Antenna factor

Specify typical or actual antenna factor in decibels per metre. Antenna calibration procedures are under consideration (see also A.4.4), and are being prepared for CISPR 16-1-5.

Both gain and antenna factor should be measured using the calibration procedure in A.4.4.

A.4.3.3 Directivity and pattern for linear polarisation

Specify antenna pattern and directivity in degrees with a polar plot in both the E- and H-planes at a sufficient number of frequencies that show any significant change with frequency. For antennas with relatively low directivity (e.g. less than 6 dBi), specify the front-to-back ratio in decibels. If omnidirectional, for example having a Hertzian dipole pattern, so state.

A.4.3.4 VSWR and impedance

Indicate the minimum return loss and nominal input impedance in ohms. Additionally, the minimum return loss can be expressed as maximum VSWR.

A.4.3.5 Active antenna performance

For antennas with active amplified gain, specify the intermodulation product levels, the electric and magnetic field strength immunity level from outside disturbances, and any appropriate check to determine overload or improper operation.

A.4.3.6 Power handling

For immunity testing transmit use, specify maximum and transient power handling capability, in watts.

A.4.3.7 Other conditions

Specify the temperature and humidity range in which the antenna is operated, and any precautions if used in an unprotected area exposed to the weather.

A.4.4 Antenna calibration

A.4.4.1 Method of calibration for emission measurements

Identify the method used for calibration, i.e.:

a) calculated (indicate formula used);
b) measured (specify the method or standard used, or the traceability to a national calibration laboratory, and whether antennas are calibrated individually).

NOTE For immunity measurements, field strength calibrations are generally made using a calibrated receiving antenna or a field probe located at the position of the EUT being subjected to the radiation. Hence, calibrations are not required for the transmit antenna.

A.4.4.2 Frequency interval

Indicate the frequencies in megahertz or kilohertz used during the calibration process; if a swept frequency procedure is used, so state.

A.4.4.3 Accuracy of calibration

Specify the uncertainty of the calibration in ± decibels. Indicate the worst case uncertainty, and the portion of the frequency band where that occurs.

A.4.4.4 Correlation with preferred or specified antennas

If the antenna is to be substituted for (used in place of) a preferred or specified antenna cited in a CISPR publication, indicate all correlation factors in decibels to equate the broadband antenna results to those of the preferred or specified antenna. Also indicate any conversion factor used, e.g. to convert from magnetic field intensity or vice versa, or for any other conversion to a measurement unit other than a field strength quantity.

A.4.4.5 Units

Specify calibration in units that are necessary to make magnetic or E-field strength emission measurements.

A.4.5 Antenna user information

A.4.5.1 Antenna use

Provide a description of the use of the antenna. Ensure that any special precautions or limitations are cited to reduce the chance of misuse.

A.4.5.2 Physical limitations

Indicate if there are any physical limitations in using the antenna such as the following:

a) minimum height above the ground plane;

b) preferred polarization with respect to the ground plane;

c) special use, i.e. use as a receive antenna or a transmit antenna only. Normally, this is limited to the power-handling capability of the balun for passive antennas, or the non-bidirectional characteristics for active antennas. State if power handling is limited by arcing across non-welded antenna element connections;

d) simple ohmic check to determine continuity integrity of antenna;

e) minimum separation of the closest antenna element to the EUT being measured.

Annex B
(normative)

Monopole (1 m rod) antenna performance equations and characterization of the associated antenna matching network

B.1 Description

B.1.1 Introduction of the monopole (1 m rod) antenna system

Monopole (rod) antennas are typically used at frequencies below 30 MHz, but are sometimes used at higher frequencies. Because of the long wavelength associated with the low frequency range, methods used to calibrate or characterize antennas at higher frequencies are not applicable. The techniques defined in this annex are applicable for frequencies up to 30 MHz. Using due care, this method has been used commercially with small (less than 1 dB) error.

NOTE This annex is based on [12].

The primary method for traceability of antenna factor to national standards is to illuminate the whole antenna by a plane wave. An alternative method, capacitor substitution of the monopole element, is contained in this annex. Although it is possible to determine the antenna factor by the capacitor substitution method, it requires expert knowledge to achieve the true antenna factor to within ±1 dB during the actual calibration process. This is especially the case when designing jigs for types of antenna whose monopole element is not attachable by a coaxial connector. Finally, care in the use of the capacitor substitution method is required especially at frequencies above 10 MHz, and for active antennas.

B.1.2 Monopole (rod) antenna performance equations

The following equations are used to determine the effective height, self-capacitance and height correction factor of rod or monopole antennas of unusual dimensions.

The equations are valid only for cylindrical rod antennas shorter than $\lambda/8$ [9].

$$h_{\mathrm{e}} = \frac{\lambda}{2\pi} \tan\left(\frac{\pi h}{\lambda}\right) \tag{B.1}$$

$$C_{\mathrm{a}} = \frac{55{,}6h}{\ln(h/a)-1} \times \frac{\tan(2\pi h/\lambda)}{(2\pi h/\lambda)} \tag{B.2}$$

$$C_h = 20\log(h_{\mathrm{e}}) \tag{B.3}$$

where

h_{e} is the effective height of the antenna (m);

h is the actual height of the rod element (m);

λ is the wavelength (m);

C_{a} is the self-capacitance of the rod antenna (pF);

a is the radius of the rod element (m);

C_h is the height correction factor (dBm).

Other details concerning Equation (B.1) are available in [12], [13], [14], and for Equation (B.2) in [14], [15], [16], [17], [18],[19].

B.2 Matching network characterization method

B.2.1 General

The equivalent capacitance substitution method uses a dummy antenna in place of the actual rod element. The primary component of the dummy antenna is a capacitor equal to the self-capacitance of the rod or monopole. This dummy antenna is fed by a signal source and the output from the matching network or base unit of the antenna is measured using the test configuration shown in Figure B.1. The antenna factor, F_a, in dB(1/m), is given by Equation (B.4).

$$F_a = V_D - V_L - C_h \quad \text{(B.4)}$$

where

V_D is the measured output of the signal generator [dB(μV)];

V_L is the measured output of the matching network [dB(μV)];

C_h is the height correction factor (for the effective height) [dB(m)].

For the monopole (1 m rod) antenna commonly used in EMC measurements, the effective height (h_e) is 0,5 m, the height correction factor (C_h) is –6 dBm and the self-capacitance (C_a) is 10 pF.

NOTE See B.1.2 to calculate the effective height, height correction factor and self-capacitance of rod antennas of unusual dimensions.

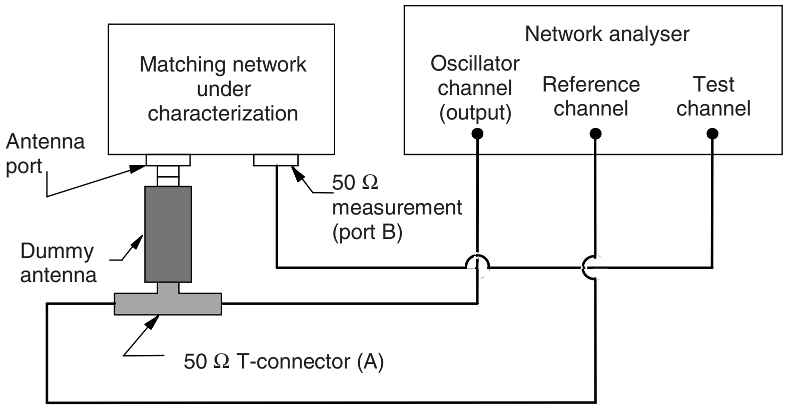
Either of two procedures shall be used: the method of B.2.2, the network analyzer, or the method of B.2.3, the signal generator and radio-noise meter method. The same dummy antenna is used in both procedures. See Clause B.3 for guidance in making a dummy antenna. Measurements shall be made at a sufficient number of frequencies to obtain a smooth curve of antenna factor versus frequency over the operating range of the antenna, or 9 kHz to 30 MHz, whichever is smaller.

B.2.2 Network analyzer procedure

The network analyzer method for characterizing an antenna matching network is described in this subclause.

a) Calibrate the network analyzer with the cables to be used in the measurements.
b) Set up the matching network to be characterized and the measuring equipment as shown in Figure B.1.
c) Subtract the signal level [in dB(μV)] in the test channel from the signal level [in dB(μV)] in the reference channel and subtract C_h (i.e. –6 dB for a 1 m rod) to obtain the antenna factor [in dB(1/m)].

NOTE Attenuator pads are not needed with the network analyzer because the impedances of the channels in the network analyzer are very nearly 50 Ω, and any errors are corrected during network analyzer calibration. Attenuator pads may be used, if desired, but including them complicates the network analyzer calibration.



NOTE 1 Place the dummy antenna as close to the EUT port as possible. Place the T-connector as close to the dummy antenna as possible. Use the same length and type of cables between the T-connector and the reference channel input, and the T-connector and the 50 Ω measuring port test channel.

NOTE 2 Attenuator pads are not needed with a network analyzer and are not recommended.

Figure B.1 – Method using network analyzer

B.2.3 Measuring receiver and signal generator procedure

This subclause describes the method for characterizing a matching network using a measuring receiver and a signal generator.

a) Set up the matching network to be characterized and the measuring equipment as shown in Figure B.2.

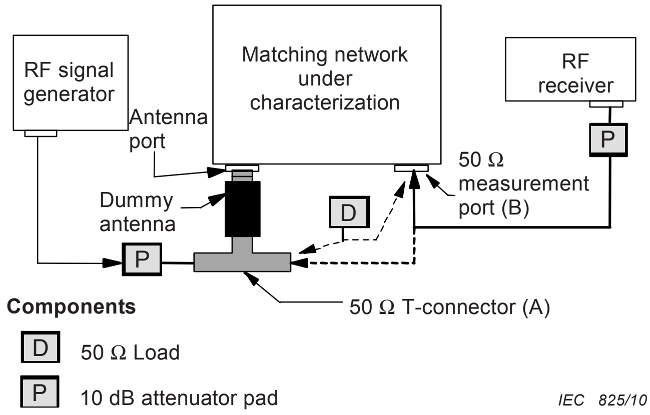
b) With the equipment connected as shown and a 50 Ω termination on the T-connector (A), measure the received signal voltage V_L [in dB(μV)] at the RF port (B).

c) Leaving the RF output of the signal generator unchanged, transfer the 50 Ω termination to the RF port (B) and transfer the receiver input cable to the T-connector (A). Measure the drive signal voltage V_D [in dB(μV)].

d) Subtract V_L from V_D, and subtract C_h (i.e. –6 dB for a 1 m rod) to obtain the antenna factor [in dB(1/m)].

The 50 Ω termination shall have a very low standing-wave ratio (SWR, less than 1,05:1). The radio-noise meter shall be calibrated and have a low SWR (less than 2:1). The output of the signal generator shall be frequency and amplitude stable.

NOTE The signal generator need not be calibrated, because it is used as a transfer standard.



NOTE 1 Place the dummy antenna as close to the EUT port as possible. Place the T-connector as close to the dummy antenna as possible.

NOTE 2 If the VSWR of receiver and signal generator is low, pads may not be needed or may be reduced to 6 dB or 3 dB.

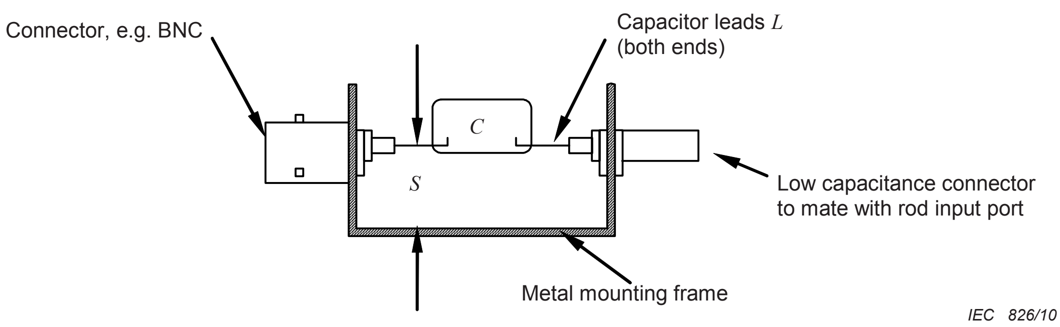
NOTE 3 The dummy antenna may incorporate other matching components to control VSWR at its input and signal generator level at measuring ports.

Figure B.2 – Method using measuring receiver and signal generator

B.3 Dummy antenna considerations

The capacitor used as the dummy (simulated) antenna shall be mounted in a small metal box or on a small metal frame. The leads shall be kept as short as possible, but no longer than 8 mm, and spaced 5 mm to 10 mm from the surface of the metal box or frame. See Figure B.3.

The T-connector used in the antenna factor measurement set-up may be built into the dummy antenna box. The resistor pad to provide impedance matching to the generator may also be built into the dummy antenna box.



Components

C antenna capacitance (C_a) calculated from Equation (B.2), 5 % tolerance, silver mica

S lead spacing, 5 mm to 10 mm (10 mm from all surfaces if enclosed in a box)

L lead length, as short as possible but not greater than 8 mm (total lead length not greater than 40 mm, including both capacitor leads and length of rod port connector)

Figure B.3 – Example of capacitor mounting in dummy antenna

B.4 Application of the monopole (rod) antenna

A monopole rod antenna is typically designed to be used with a counterpoise or to be mounted on a ground plane. To obtain correct field strength values, the manufacturer's instructions or recommendations regarding the use of the counterpoise or ground plane should be followed.

If the antenna uses a telescoping rod element, the element shall be extended to the length specified in the manufacturer's instructions.

Many measurement standards specify that the counterpoise of a monopole (rod) antenna shall be bonded to the ground plane or test-bench ground plane. The requirements of the measurement standard shall be met.

Annex C
(normative)

Loop antenna system for magnetic field induced-current measurements in the frequency range of 9 kHz to 30 MHz

C.1 General

This annex sets forth information and data concerning the loop antenna system (LAS) to measure the current induced in the LAS by the magnetic field emitted by a single EUT, positioned in the centre of the LAS, in the frequency range of 9 kHz to 30 MHz. Subclause 4.7 of this publication, and CISPR 16-2-3, refer to this LAS. See also [11].

A description of the LAS is given, as well as the method of validation of the antennas of the LAS. Conversion factors are given to relate magnetic field induced current data to magnetic field data that would have been obtained when the same EUT was measured using a single-loop magnetic field antenna positioned at a specified distance from that EUT.

C.2 Construction of the loop antenna system (LAS)

The LAS (see Figure C.1) consists of three mutually perpendicular large-loop antennas (LLAs), described in Clause C.3. The entire LAS is supported by a non-metallic base.

A 50 Ω coaxial cable between the current probe of an LLA and the coaxial switch, and between this switch and the measuring equipment, shall have a surface transfer impedance smaller than 10 mΩ/m at 100 kHz and 1 mΩ/m at 10 MHz. This requirement is met when using, for example, double-braided shield RG 223/U coaxial cable.

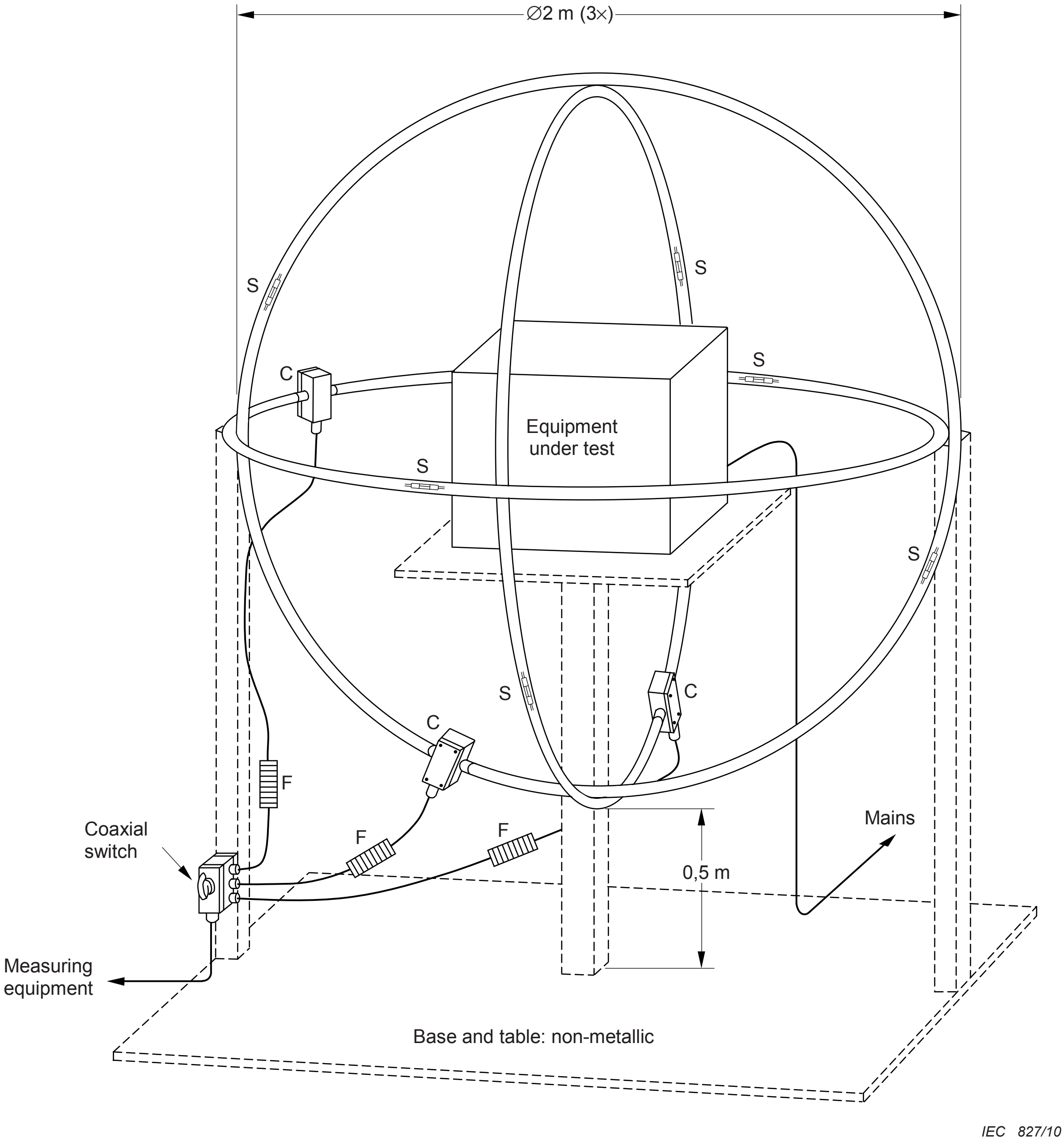
All connectors shall have surface transfer impedance comparable with that of the coaxial cable. This requirement is met, for example, when using good quality BNC collet-lock type connectors (see [1]).

All cables shall be equipped with ferrite absorbers, F in Figure C.1, providing a common-mode series resistance of $R_s > 100\ \Omega$ at 10 MHz. This requirement is met when constructing the ferrite toroid from, for example, twelve rings of type 3E1 from Ferroxcube (minimum size: 29 mm outer diameter by 19 mm inner diameter by 7,5 mm height).

C.3 Construction of a large-loop antenna (LLA)

A large-loop antenna (LLA) of the LAS is constructed from coaxial cable of which the surface transfer impedance has been specified in Clause C.2. In addition, the resistance of the inner conductor of the LLA shall be sufficiently low (see Note 1). Both requirements are met, for example, when using double-braided shield RG 223/U coaxial cable.

To keep the loop in its circular shape and to protect the slit construction, as in the example of Figure C.2, the cable is inserted in a thin walled non-metallic tube with inner diameter of approximately 25 mm. Other non-metallic constructions serving the same purposes may be used.



Components

S antenna slit

C current probe

F ferrite absorber

Figure C.1 – The loop-antenna system, consisting of three mutually perpendicular large-loop antennas

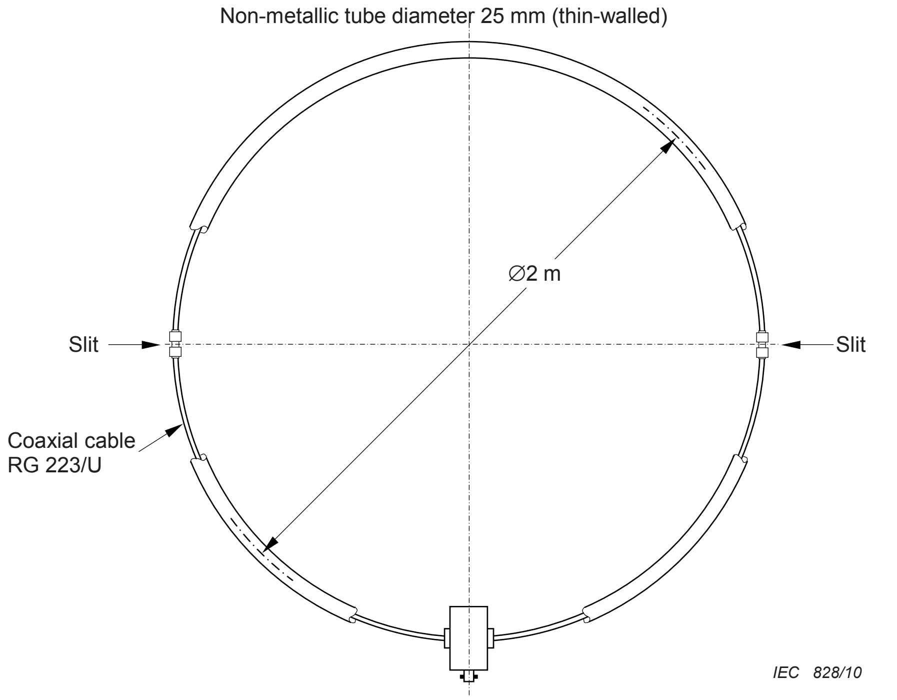


Figure C.2 – A large-loop antenna containing two opposite slits, positioned symmetrically with respect to the current probe C

The loop diameter has been standardized to be D = 2 m. If necessary, e.g. the case of large EUT, D may be increased. However, in the frequency range up to 30 MHz, the maximum allowable diameter is 4 m. Further increase of the diameter would result in non-reproducible resonances of the LAS response at the high-frequency end of the measuring range.

It should be noted that by increasing the diameter, its sensitivity to ambient noise increases proportionally to the diameter, and its sensitivity to wanted signals is inversely proportional with the diameter squared.

An LLA contains two opposite slits, positioned symmetrically with respect to the current probe of the LLA (see Figure C.2). Such a slit, made in the outer conductor of the coaxial antenna cable as shown in Figure C.3, shall have a width of less than 7 mm. The slit is bridged by two parallel sets of 100 Ω resistors in series. The centre of each series circuit is connected to the inner conductor of the coaxial antenna cable.

At each side of the slit, the outer conductor of the coaxial antenna cable may be bonded to a strap of printed circuit board material with two copper rectangles, separated by at least 5 mm, in order to obtain a rigid slit construction (see Figure C.4).

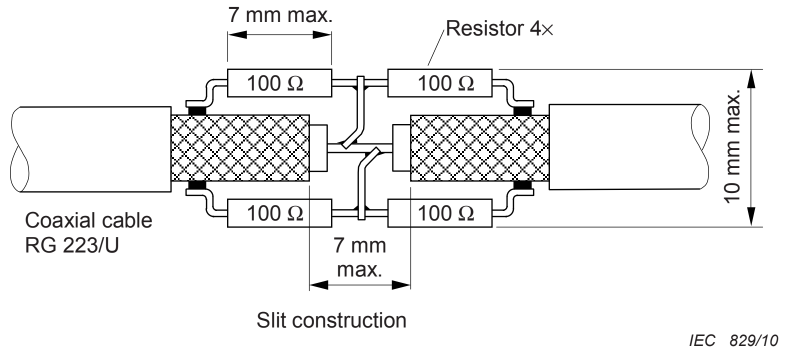


Figure C.3 – Construction of the antenna slit

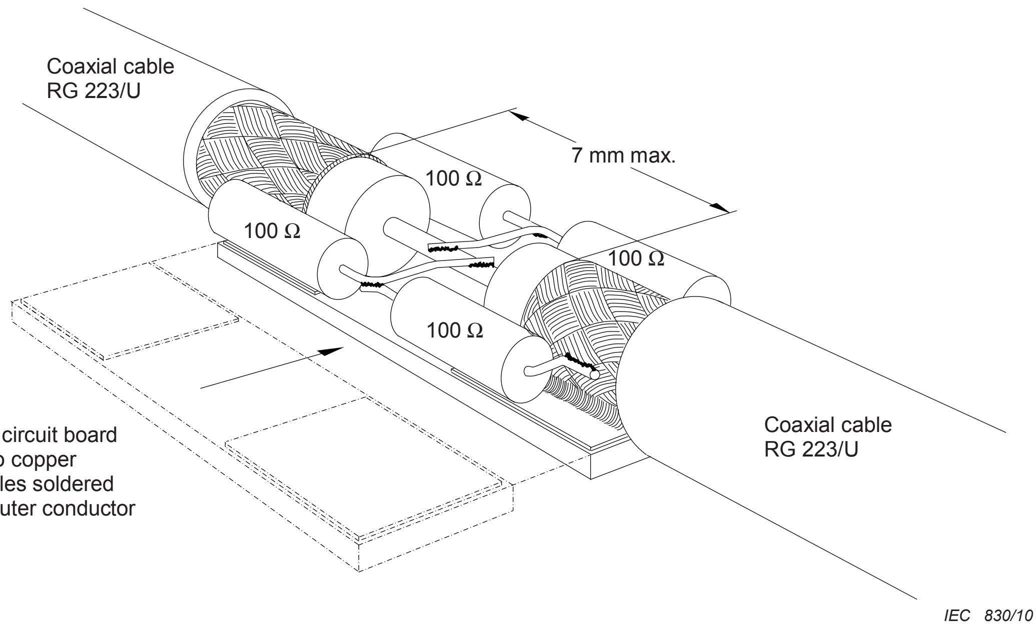


Figure C.4 – Example of antenna-slit construction using a strap of printed circuit board to obtain a rigid construction

The current probe around the inner conductor of the coaxial antenna-cable shall have a sensitivity of 1 V/A over the frequency range of 9 kHz to 30 MHz. The insertion loss of the current probe shall be sufficiently low (see Note 1).

The outer conductor of that cable shall be bonded to the metal box containing the current probe (see Figure C.5). The maximum dimensions of this box are the following: width 80 mm, length 120 mm and height 80 mm.

NOTE 1 To obtain a flat frequency response of the LLA at the lower end of the frequency range of 9 kHz to 30 MHz, the insertion loss R_c, of the current probe should be much smaller than $2\pi f L_c$ at f = 9 kHz, where L_c represents the inductance of the current probe. In addition, $(R_c + R_i) << X_i = 2\pi f L$ at 9 kHz, where R_i is the resistance of the inner conductor of the loop and L is the loop inductance. This inductance is about 1,5 µH/m of circumference, hence for the standardized LLA, $X_i \approx 0,5\ \Omega$ at f = 9 kHz.

NOTE 2 To avoid unwanted capacitive coupling between the EUT and the LAS, the distance between the EUT and components of the LLA should be at least 0,10 times the loop diameter. Particular attention should be paid to the leads of an EUT. Cables should be routed together and leave the loop volume in the same octant of the cell, no closer than 0,4 m to any of the LAS loops (see Figure C.6).

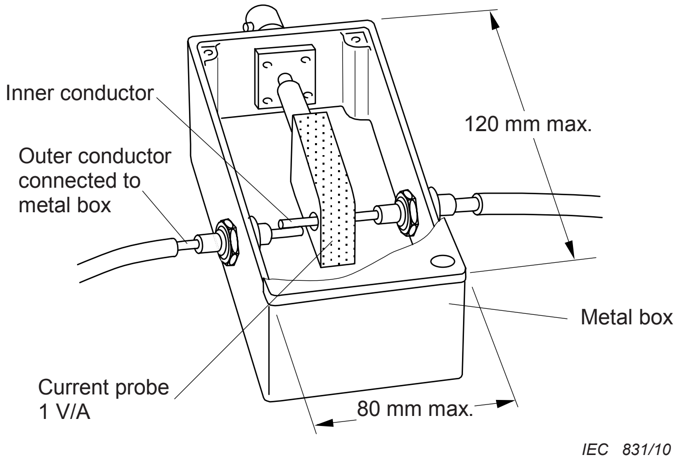


Figure C.5 – Construction for the metal box containing the current probe

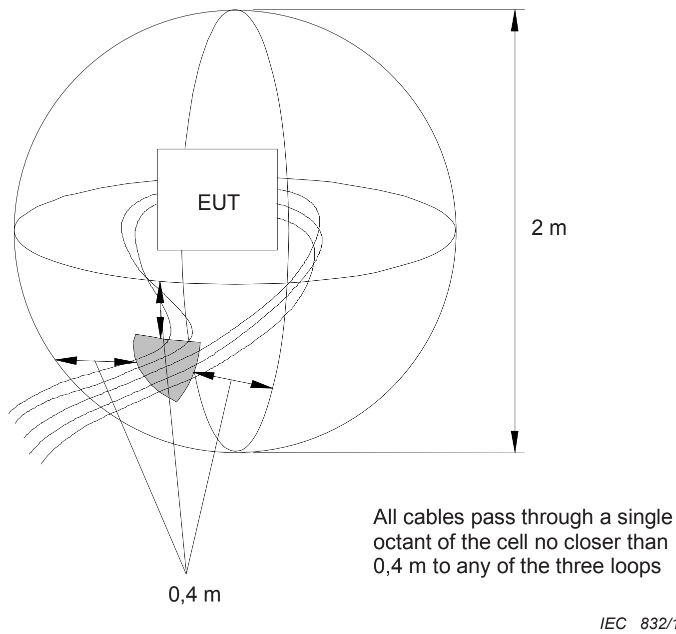


Figure C.6 – Example showing the routing of several cables from an EUT to ensure that there is no capacitive coupling from the leads to the loop

C.4 Validation of a large-loop antenna (LLA)

The validation and calibration of a large-loop antenna (LLA) of the loop antenna system is carried out by measuring the current induced in the LLA by the balun-dipole connected to a 50 Ω RF generator, described in Clause C.5. The magnetic field emitted by that dipole allows verification of the magnetic field sensitivity of the LLA. The E-field emitted by the balun-dipole shows that the E-field sensitivity of the LLA is sufficiently low.

The induced current shall be measured as a function of frequency in the range of 9 kHz to 30 MHz at the eight positions of the balun-dipole in Figure C.7. During this measurement, the balun dipole is in the plane of the LLA under test.

In each of the eight positions, the validation factor [expressed in dB(Ω) = 20 log(V_{go}/I_l)] of the open circuit voltage of the RF generator (V_{go}) and the measured current (I_l) shall not deviate more than ±2 dB from the validation factor given in Figure C.8.

The validation factor given in Figure C.8 is valid for a circular LLA with a standardized diameter D = 2 m. If the diameter of a circular LLA differs from D = 2 m, the validation factor for the non-standardized LLA can be derived from the data given in Figure C.8 and Figure C.11 (see Clause C.6).

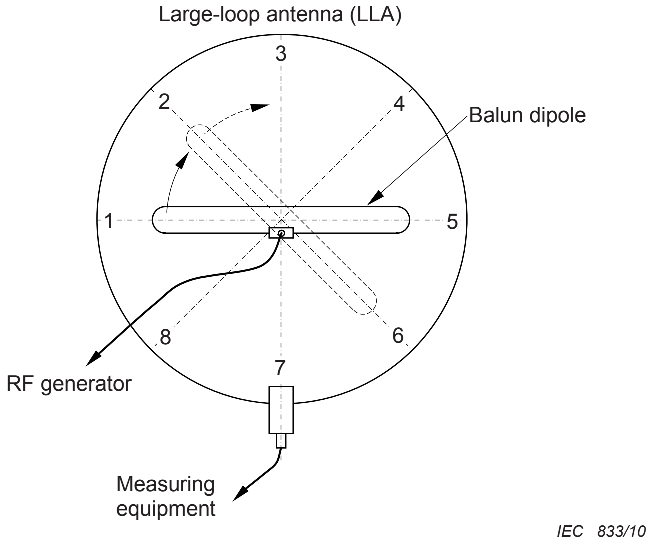


Figure C.7 – The eight positions of the balun-dipole during validation of the large-loop antenna

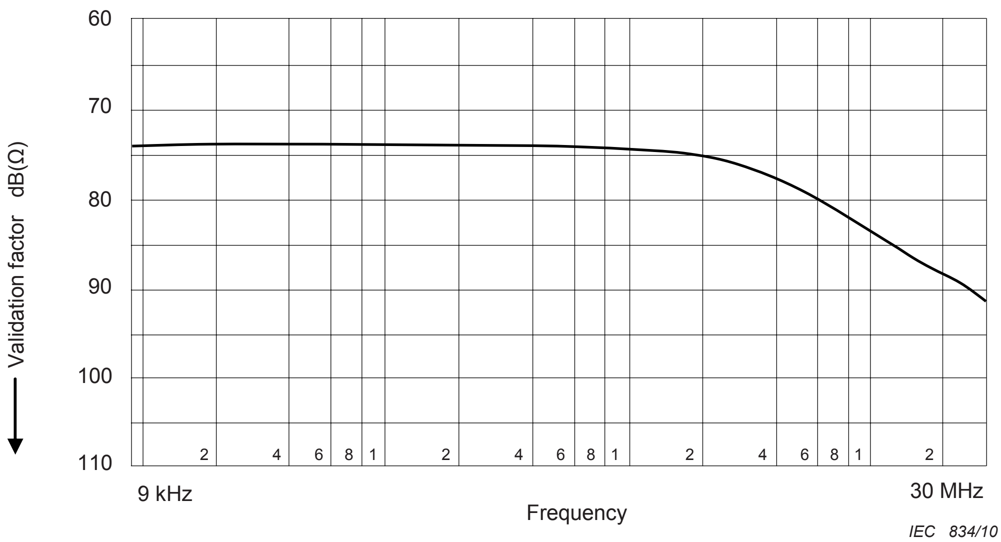


Figure C.8 – Validation factor for a large loop-antenna of 2 m diameter

C.5 Construction of the balun-dipole

The balun-dipole, Figure C.9, has been designed to emit simultaneously a magnetic field, which should be measured by the LLA, and an E-field, which should be rejected by the LLA.

The balun-dipole is constructed from RG 223/U coaxial cable. It has a width W = 150 cm and a height H = 10 cm (cable centre to cable centre distances), as depicted in Figure C.9.

A slit in the outer conductor of the coaxial cable divides the dipole in two halves. One half of this dipole, the right-hand half in Figure C.9, is short-circuited near the slit as well as near the connector. Short-circuited means that the inner and outer conductors of the coaxial cable are electrically bonded together. This half is connected to the reference-ground of the BNC connector. The inner conductor of the coaxial cable, forming the left-hand half of the dipole in Figure C.9, is connected to the centre-pin of the BNC connector and its outer conductor to the reference ground of that BNC connector.

A small metal box is used to screen the connections near the dipole connector. The outer conductor of the two halves of the coaxial dipole cable are bonded to this box, as is the reference ground of the BNC connector.

To obtain a rigid construction, the dipole is supported by a non-conductive base.

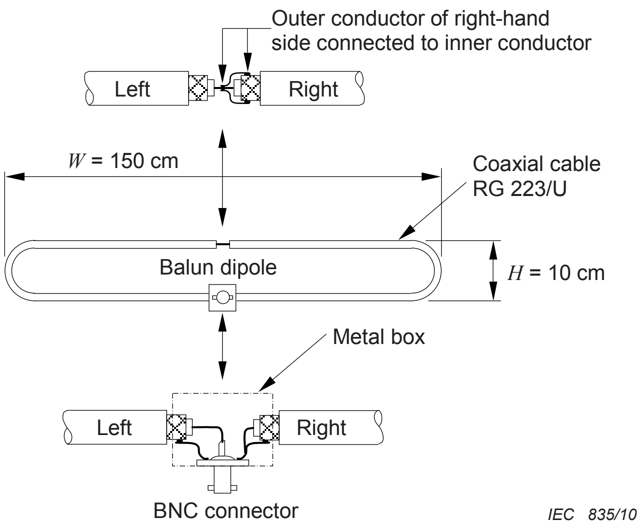


Figure C.9 – Construction of the balun-dipole

C.6 Conversion factors

This clause deals with the factor that converts the current (I) induced in the LLA by the EUT into a magnetic field strength H at a specified distance from the EUT (see Figure C.10). It also deals with the factor which converts the current measured in an LLA with a non-standardized diameter to a current which would have been measured using an LLA with the standardized diameter of D = 2 m (see Figure C.11).

The conversion factor in Figure C.10 applies to a source of magnetic field positioned in the centre of the LLA with its dipole moment perpendicular to the plane of that LLA. It should be noted that with the loop antennas specified in 4.3, the loop antenna is always positioned in a vertical plane and the EUT is only rotated around its vertical axis. Hence, in that case only the horizontal dipole moments, i.e. the dipole moments parallel to the ground plane, are measured. Consequently, in the case of a vertical dipole moment, the conversion factor cannot be used to compare results of both measuring methods. However, the factor can be used when in the magnetic field measuring method the loop antenna would be positioned in a horizontal plane, or when in that method the EUT would be tilted through 90°, so that the relevant vertical dipole moment is changed into a horizontal one.

If the actual position of a disturbance source inside an EUT is at a distance less than 0,5 m from the centre of the standardized LAS, the measuring results differ by less than 3 dB from those with that source in the centre.

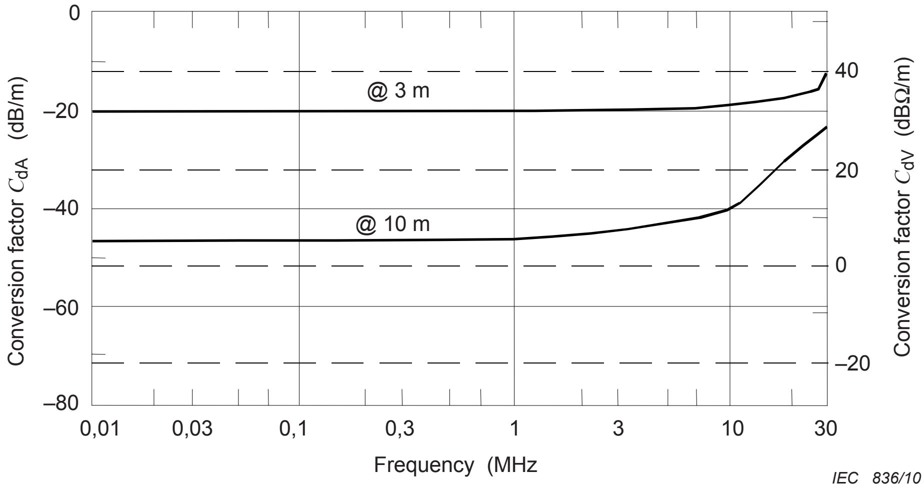


Figure C.10 – Conversion factors C_{dA} [for conversion into dB(μA/m)] and C_{dV} (for conversion into dB(μV/m)) for two standardized measuring distances d

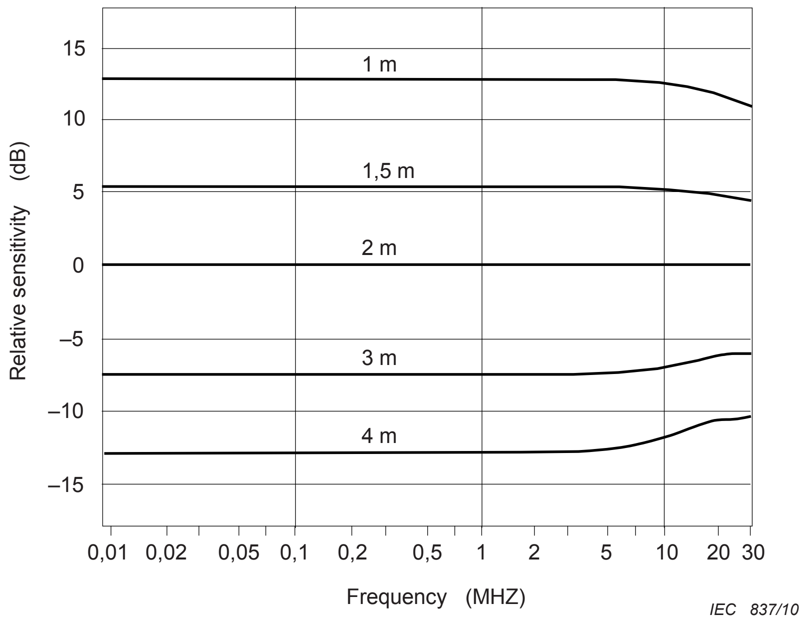


Figure C.11 – Sensitivity S_D of a large-loop antenna with diameter D relative to a large-loop antenna having a diameter of 2 m

The relation between the magnetic field strength H in dB(μA/m) measured at a distance d and the current I in dB(μA) is:

$$H = I + C_{dA}$$

where C_{dA} is the current-to-field conversion factor in dB(m^{-1}) for a certain distance d when expressing H in dB(μA/m); see also the note below.

In general, the conversion factor is frequency-dependent; Figure C.10 presents C_{dA} for standardized distances of 3 m and 10 m. For the standardized distance d = 30 m, the conversion factor is under consideration.

The ratio S_D in decibels, of the current measured in a LLA with a diameter D, in metres, and the current which would have been measured with an LLA having the standardized diameter D = m, are given in Figure C.11 for several values of D. Using this ratio, the equation given above can be written as:

$$H = I - S_D + C_{dA}$$

where H is expressed in dB(µA/m), I in dB(µA), S_D in dB and C_{dA} in dB(m^{-1}).

NOTE For disturbance calculations, CISPR uses the magnetic field strength H in dB(µA/m) instead of dB(µV/m). In this context, the relation between H expressed in dB(µA/m) and E expressed in dB(µV/m) is given by:

$$E = H + 51{,}5$$

where E is expressed in dB(µV/m) and H in dB(µA/m). The constant 51,5, in dB(Ω), is explained in the Note in 4.3.2.

For convenience, the conversion factor C_{dV} converting I in dB(µA) into E in dB(µV/m) is also given in Figure C.10.

The following examples explain the use of the three equations above and of Figures C.10 and C.11.

a) Given: measuring frequency f = 100 kHz, loop diameter D = 2 m, current in loop I = X dB(µA).

   Then using the first equation and Figure C.10, it follows that:

   at d = 3 m: H [dB(µA/m)] = X [dB(µA)] + C_{3A} [dB(m^{-1})]= (X – 19,5) dB(µA/m)

   at d = 3 m: E [dB(µV/m)] = X [dB(µA)] + C_{3V} [dB(Ω/m)] = [X + (51,5 – 19,5)] dB(µV/m)

b) Given: measuring frequency f = 100 kHz, loop diameter D = 4 m, current in loop I = X dB(µA).

   Then using Figure C.11 it follows that the same EUT would have induced a current:

   I [dB(µA)] = X – S_3 (dB) = (X + 13) dB(µA)

   in the LLA with the standard diameter D = 2 m.

c) Given: validate an LLA with diameter D = 3 m.

   Then the validation factor is found by subtracting, at each frequency, S_3, the value of the relative sensitivity as given in Figure C.11, from the validation factor as given in Figure C.8. Hence, if the measuring frequency is 100 kHz, the validation factor for the LLA with D = 3 m equals [73,5 – (–7,5)] = 81 dB(Ω).

Annex D
(normative)

Construction details for open area test sites in the frequency range of 30 MHz to 1 000 MHz
(see Clause 5)

D.1 General

[A1⟩ Subclauses 5.2.1 through 5.2.5 provide major construction considerations for open area test sites. Additional details that are helpful in assuring a well-constructed site and an all-weather enclosure are described in this annex. The best way to assure the suitability of these construction practices is to perform site validation measurements, as described in 5.4. ⟨A1]

D.2 Ground plane construction

D.2.1 Material

Metal is the recommended ground plane material for field strength test sites. However, for practical reasons, metallic ground planes cannot be specified for measurement of all equipment. Some examples of metallic ground planes include solid metal sheets, metal foil, perforated metal, expanded metal, wire cloth, wire screen and metal grating. The ground plane should have no voids or gaps with linear dimensions that are an appreciable fraction of a wavelength at the highest measurement frequency. The recommended maximum opening size for screen, perforated metal, grating or expanded metal type ground planes is 1/10 of a wavelength at the highest frequency of measurement (about 3 cm at 1 000 MHz). Material comprised of individual sheets, rolls, or pieces should be soldered or welded at the seams preferably continuously but in no case with gaps longer than 1/10 wavelength. Thick dielectric coatings, such as sand, asphalt, or wood on top of metal ground planes may result in unacceptable site attenuation characteristics.

D.2.2 Roughness

The Rayleigh roughness criterion provides a useful estimate of maximum allowable r.m.s. ground plane roughness (see Figure D.1). For most practical test sites, especially for 3 m separation applications, up to 4,5 cm of roughness is insignificant for measurement purposes. Even more roughness is allowed for 10 m and 30 m sites. The site validation procedure in [A1⟩ 5.4 ⟨A1] shall be performed to determine whether the roughness is acceptable.

D.3 Services to EUT

Electrical service or mains wiring to the EUT should be run under the ground plane to the maximum extent possible and preferably at right angles to the measurement axis. All wires, cables, and plumbing to the turntable or mounting of the EUT should also be run under the ground plane. When underground routing is not possible, service to the EUT should be placed on top of, but flush with, and bonded to the ground plane.

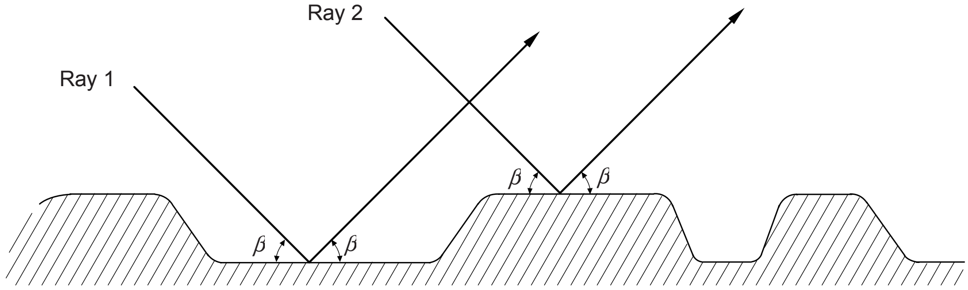


Figure D.1 – The Rayleigh criterion for roughness in the ground plane

[A1⟩ Table D.1 – Maximum roughness for 3 m, 10 m and 30 m measurement distances ⟨A1]

Measurement distance [A1⟩ d ⟨A1] m	Source height, h_1 m	Maximum receiving antenna height, h_2 m	Maximum r.m.s. roughness b	
			In wavelengths	At 1 000 MHz cm
3	1	4	0,15	4,5
10	1	4	0,28	8,4
30	2	6	0,49	14,7

The values of b are calculated according to the formula:

$$b = \frac{\lambda}{8 \sin \beta}$$

D.4 Weather-protection enclosure construction

D.4.1 Materials and fasteners

Up to 1 000 MHz, thin sections of fibreglass and most other plastics, specially treated woods, and fabric material will not cause appreciable attenuation of EUT emissions. Moisture absorption in some materials (e.g. wood and nylon), however, can cause transmission losses that are particularly critical if EUT emissions are measured through such material. Care should be taken to ensure that air-deposited conductive particles and standing water and ice do not build up on the structure or within the material forming the structure. Inspections should be made periodically for foreign objects that might lodge on the structure, causing measurement errors.

Use of metal above the ground plane should be kept to a minimum. Use of plastic or fabric fasteners is highly recommended. Any anchors, pilings, or similar foundations should be far enough removed from the test area so as not to affect the measurement.

D.4.2 Internal arrangements

All structural members should be non-reflective. Any blowers or ducts for heating, cooling or air support should be outside the test area or outside the structure, unless they are made of non-conductive material or run below a metallic ground plane or well below a non-metallic ground plane. Temperature and humidity control may be required for the operation of the equipment. Any insulation or windows should be free of metal backing or framing. Any safety rails or stairs should also be non-conductive if located above the ground plane.

D.4.3 Size

The size of a weather protection enclosure will depend upon the size of the EUT and whether or not the entire antenna range is to be enclosed or only the area over the EUT, the area over the measuring set, or the area enclosing the receive antenna positioner and the highest extent of the receiving antenna when making vertical polarization measurements.

D.4.4 Uniformity with time and weather

It is recommended that periodic normalized site attenuation measurements be made in order to detect anomalies caused by degradation of the all-weather protection due to weather conditions (e.g. moisture absorption) or contamination of enclosure materials. This measurement also checks the calibration of RF cabling and test instrumentation. A six-month interval is generally adequate unless physical signs indicate material degradation sooner, i.e. material changes colour due to air-borne contaminants.

D.5 Turntable and set-up table

A turntable and a table for supporting the EUT are recommended for convenience in measuring electromagnetic emissions from all sides of the EUT. The turntable contains the rotation assembly, and the set-up table is used for positioning the EUT on the test site. The following three set-up and turntable configurations are considered in this clause.

– For turntables with rotation assembly below the ground, the rotating surface (top) shall be flush with and electrically-connected to the ground plane. The rotating top carries the actual set-up table.
  - For table-top equipment, the height of the set-up table shall be 0,8 m ± 0,01 m, and the set-up table is placed such that its centre in the horizontal plane is at the centre of the turntable which is the unit performing the rotation. The set-up table shall be removed for the [A1) site validation (A1] measurement.
  - For floor-standing equipment, the EUT is to be insulated from the conductive surface of the turntable (which is flush with the ground plane). The height of the insulating support shall be up to 0,15 m, or as required by the product committee. The insulating support is not required when non-metallic roller casters are provided by the product. The insulating support shall be removed for the [A1) site validation (A1] measurement.

– For turntables with the rotation assembly integrated into the set-up table and placed on the turntable (which is flush with the ground plane) or on the ground plane without turntable, the set-up table shall have either a height of 0,8 m ± 0,01 m for table-top equipment, or a height not exceeding 0,15 m for floor-standing equipment. The set-up table shall be removed for the [A1) site validation (A1] measurement.

– In a FAR, the height of the EUT set-up table is not defined and depends on the performance of the absorbing material and test volume of the FAR. The set-up table shall be removed for the [A1) site validation (A1] measurement.

[A1) NOTE An EUT/system that includes a support table as part of the configuration under test should use the support table supplied with the system, not the generic set-up table at the test site. (A1]

D.6 Receiving antenna mast installation

The receiving antenna should be mounted on a non-conducting support which will allow the antenna to be raised between 1 m and 4 m for measurement distances of 10 m and less, and between 1 m and 4 m, or between 2 m and 6 m for distances greater than 10 m. The cable shall be connected to the antenna balun such that for horizontally polarized antennas, the cable is orthogonal to the axis of the antenna elements at all antenna heights in order to maintain balance with respect to ground.

The cabling from the receiving antenna balun should drop vertically to the ground plane approximately 1 m or more to the rear of the receiving antenna. From that point, it should be kept on or under the ground plane in a manner so as not to disturb the measurement. The cable between the antenna and disturbance analyzer should be as short as practical to ensure acceptable received signal levels at 1 000 MHz.

For vertically polarized dipole-type antennas, the cabling to the measuring receiver should be maintained horizontal, i.e. parallel to the ground plane, for a distance of approximately 1 m or more to the rear of the receiving antenna (away from the EUT) before dropping to the ground plane. An antenna boom approximately 1 m in length will suffice. The remaining cable routing to the analyzer is the same as for the horizontally-polarized case.

For both cases, the antenna factor calibration should not be affected by the presence of the antenna positioners and disposition of the coaxial cabling attached to the antenna.

A1⟩ Annex E (Void) ⟨A1

Annex F
(informative)

Basis for 4 dB site acceptability criterion
(see Clause 5)

F.1 General

This annex shows the basis for the acceptability criterion of ±4 dB for the normalized site attenuation measurements required in [A1⟩ 5.4 ⟨A1].

F.2 Error analysis

The error analysis in Table F.1 applies to the normalized site attenuation measurement methods given in [A1⟩ 5.4 ⟨A1]. The total estimated errors are the basis for the ±4 dB site acceptability criterion consisting of approximately 3 dB measurement uncertainty and an additional allowable 1 dB for site imperfections.

The error budget in Table F.1 does not include uncertainties in the amplitude stability of the signal generator, tracking generator, or any amplifiers that may be used, nor does it include the potential errors in measurement technique. The output level of most signal and tracking generators will drift with time and temperature, and the gain of many amplifiers will drift as temperature changes. It is imperative that these sources of error be held to an insignificant amount or corrected in making the measurements, otherwise the site may fail to meet the acceptability criterion due to instrumentation problems alone.

Table F.1 – Error budget

Error item	Measurement method	
	Discrete frequency method dB	Swept frequency method dB
Antenna factor (Tx)[a]	±1	±1
Antenna factor (Rx)[a]	±1	±1
Voltmeter	0	±1,6[b]
Attenuator	±1	0
Site imperfections	±1	±1
Totals	±4	±4,6

[a] At frequencies above 800 MHz, F_a errors may approach ±1,5 dB.
[b] From the operating instructions.

From the operating instructions for some automatic spectrum analyzer, for example, if everything is done to remove or compensate every potential error as much as possible the remaining amplitude errors are:

1) ±0,2 dB calibrator uncertainty,
2) ±1,0 dB frequency response flatness,
3) ±1,0 dB input attenuator switching,
4) ±0,4 dB RF and IF gain uncertainty.

This gives a total potential error of ±2,6 dB. This does not include ±0,05 dB/K temperature drift. In practice, when performing substitution type measurements, the errors associated with the frequency response flatness and input attenuator switching are usually 1 dB less, so that the total error band for the spectrum analyzer as a two-terminal voltmeter is ±1,6 dB or less, which is used in Table F.1.

Many attenuators have far poorer absolute accuracy, but some are better. The total error budget could thus be increased or decreased in the discrete measurements. If an external attenuator is used with the automatic spectrum analyzer in the swept frequency measurements this error budget is also increased.

These error budgets do not contain errors from time and temperature induced drifts of the gains, output levels, or amplitude responses of the test equipment. Such errors may exist and steps shall be taken to avoid them by making the measurements as rapidly as possible.

In practice, the errors accounted for above seldom are all in the same direction. Meeting the ±4 dB criterion for a well constructed and located site may actually allow more than ±1 dB site anomaly variation from ideal.

[A1› Annex G
(informative)

Examples of uncertainty budgets for site validation of a COMTS using RSM with a calibrated antenna pair

G.1 Quantities to be considered for antenna pair reference site attenuation calibration using the averaging technique

The measurand A_{APR} is calculated as:

$$A_{\mathrm{APR}} = V_{\mathrm{DIRECT}} - V_{\mathrm{SITE}} + \delta V_{\mathrm{M1}} + \delta V_{\mathrm{M2}} + \delta V_{\mathrm{M3}} + \delta V_{\mathrm{SDAPR}} + \delta V_{\mathrm{NL}} + \delta V_{\mathrm{NF}} + \delta V_{\mathrm{SRTX}} + \delta V_{\mathrm{SRRX}} + \delta V_{\mathrm{AM}} \quad \text{(G.1)}$$

Table G.1 – Antenna pair reference site attenuation calibration using the averaging technique

Input quantity	X_i	Uncertainty of x_i dB	Uncertainty of x_i Probability distribution function	$u(x_i)$ dB	c_i	$c_i u(x_i)$ dB
Receiver reading	V_{DIRECT}	± 0,5	Rectangular	0,29	1	0,29
Receiver reading	V_{SITE}	± 0,5	Rectangular	0,29	1	0,29
Mismatch:						
generator-receiver	δV_{M1}	± 0,1	U-shaped	0,07	1	0,07
generator-antenna	δV_{M2}	± 0,2	U-shaped	0,14	1	0,14
antenna-receiver	δV_{M2}	± 0,2	U-shaped	0,14	1	0,14
Standard deviation of mean A_{APR}	$\delta V_{\mathrm{SDAPR}}$	± 0,6	Normal (k=1)	0,6	1	0,6
Receiver corrections:						
Nonlinearity	δV_{NL}	± 0,1	Normal (k=2)	0,05	1	0,05
Noise floor proximity	δV_{NF}	± 0	Normal (k=2)	0	1	0
Secondary radiation of antenna cable:						
Transmit antenna	δV_{SRTX}	± 0,3	Rectangular	0,17	1	0,17
Receive antenna	δV_{SRRX}	± 0,3	Rectangular	0,17	1	0,17
Antenna Mast	δV_{AM}	± 0,15	Rectangular	0,09	1	0,09

The expanded uncertainty is: $U = 2\ u_c(A_{\mathrm{APR}})$ = 1,37 dB

G.2 Quantities to be considered for antenna pair reference site attenuation calibration using the REFTS

The measurand A_{APR} is calculated as:

$$A_{\mathrm{APR}} = V_{\mathrm{DIRECT}} - V_{\mathrm{SITE}} + \delta V_{\mathrm{M1}} + \delta V_{\mathrm{M2}} + \delta V_{\mathrm{M3}} + \delta V_{\mathrm{REFTS}} + \delta V_{\mathrm{NL}} + \delta V_{\mathrm{NF}} + \delta V_{\mathrm{SRTX}} + \delta V_{\mathrm{SRRX}} + \delta V_{\mathrm{AM}} \quad \text{(G.2)}$$ ‹A1]

A1 Table G.2 – Antenna pair reference site attenuation calibration using REFTS

Input quantity	X_i	Uncertainty of x_i		$u(x_i)$	c_i	$c_i u(x_i)$
		dB	Probability distribution function	dB		dB
Receiver reading	V_{DIRECT}	± 0,5	Rectangular	0,29	1	0,29
Receiver reading	V_{SITE}	± 0,5	Rectangular	0,29	1	0,29
Mismatch:						
generator-receiver	δV_{M1}	± 0,1	U-shaped	0,07	1	0,07
generator-antenna	δV_{M2}	± 0,2	U-shaped	0,14	1	0,14
antenna-receiver	δV_{M2}	± 0,2	U-shaped	0,14	1	0,14
REFTS influence	δV_{REFTS}	± 1	Rectangular	0,58	1	0,58
Receiver corrections:						
Nonlinearity	δV_{NL}	± 0,1	Normal (k=2)	0,05	1	0,05
Noise floor proximity	δV_{NF}	± 0	Normal (k=2)	0	1	0
Secondary radiation of antenna cable:						
Transmit antenna	δV_{SRTX}	± 0,3	Rectangular	0,17	1	0,17
Receive antenna	δV_{SRRX}	± 0,3	Rectangular	0,17	1	0,17
Antenna Mast	δV_{AM}	± 0,15	Rectangular	0,09	1	0,09

The expanded uncertainty is: $U = 2\ u_c(A_{APR})$ = 1,34 dB

G.3 Quantities to be considered for COMTS validation using an antenna pair reference site attenuation

The measurand ΔA_S is calculated as:

$$A_S = V_{DIRECT} - V_{SITE} - A_{APR} + \delta V_{M1} + \delta V_{M2} + \delta V_{M3} + \delta V_{NL} + \delta V_{NF} + \delta V_{SRTX} + \delta V_{SRRX} \qquad (G.3)$$ A1

A1 Table G.3 – COMTS validation using an antenna pair reference site attenuation

Input quantity	X_i	**Uncertainty of x_i** dB	Probability distribution function	$u(x_i)$ dB	c_i	$c_i u(x_i)$ dB
Receiver reading	V_{DIRECT}	± 0,5	Rectangular	0,29	1	0,29
Receiver reading	V_{SITE}	± 0,5	Rectangular	0,29	1	0,29
Antenna pair reference SA	A_{APR}	± 1,4	Normal (k=2)	0,7	1	0,7
Mismatch:						
generator-receiver	δV_{M1}	± 0,1	U-shaped	0,07	1	0,07
generator-antenna	δV_{M2}	± 0,2	U-shaped	0,14	1	0,14
antenna-receiver	δV_{M2}	± 0,2	U-shaped	0,14	1	0,14
Receiver corrections:						
Nonlinearity	δV_{NL}	± 0,1	Normal (k=2)	0,05	1	0,05
Noise floor proximity	δV_{NF}	± 0	Normal (k=2)	0	1	0
Secondary radiation of antenna cable:						
Transmit antenna	δV_{SRTX}	± 0,3	Rectangular	0,17	1	0,17
Receive antenna	δV_{SRRX}	± 0,3	Rectangular	0,17	1	0,17

The expanded uncertainty is: $U = 2\, u_c(\Delta A_S)$ = 1,54 dB A1

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