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BASIC EMC PUBLICATION
PUBLICATION FONDAMENTALE EN CEM

**Specification for radio disturbance and immunity measuring apparatus and methods –
Part 1-5: Radio disturbance and immunity measuring apparatus – Antenna calibration
sites and reference test sites for 5 MHz to 18 GHz**

**Spécification des méthodes et des appareils de mesure des perturbations
radioélectriques et de l'immunité aux perturbations radioélectriques –
Partie 1-5: Appareils de mesure des perturbations radioélectriques et de l'immunité aux
perturbations radioélectriques – Emplacements d'étalonnage d'antenne et
emplacements d'essai de référence pour la plage comprise entre 5 MHz et 18 GHz**



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INTERNATIONAL ELECTROTECHNICAL COMMISSION
INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE

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

**Part 1-5: Radio disturbance and immunity measuring apparatus –
Antenna calibration sites and reference test sites for 5 MHz to 18 GHz**

FOREWORD

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International Standard CISPR 16-1-5 has been prepared by CISPR subcommittee A: Radio-interference measurements and statistical methods.

This second edition cancels and replaces the first edition published in 2003, and its Amendment 1 (2012). It constitutes a technical revision.

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*.

This edition includes the following significant technical changes with respect to the previous edition:

- site validation methods for other sites covered in CISPR 16-1-6 are added;
- smaller step sizes are specified for swept-frequency measurements;
- the minimum ground plane size is increased;
- other miscellaneous technical and editorial refinements are included.

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

FDIS	Report on voting
CISPR/A/1086A/FDIS	CISPR/A/1097/RVD

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

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

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

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

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The contents of the corrigendum of August 2020 have been included in this copy.

INTRODUCTION

This standard describes validation procedures for Calibration Test Sites (CALTS) that are used to calibrate antennas in the frequency range 5 MHz to 18 GHz. The associated antenna calibration procedures are described in CISPR 16-1-6.

Due to problems with suppressing ground reflections in the frequency range 30 MHz to 200 MHz, the main function of a reflecting ground plane is for the calibration of dipole, biconical, and hybrid antennas over the frequency range for which their H-plane patterns are uniform. The free-space antenna factor, F_a , for dipole antennas may be measured in a free-space environment above 200 MHz. Because of the difficulty of reducing reflections from objects that surround an antenna, and in particular the ground surface, a flat metal ground plane is used to ensure reproducibility of results and to enable the ground reflected signal to be precisely removed mathematically.

Requirements for the construction of a CALTS are given in Annex A. The specifications and validation procedures for a CALTS are given in Clause 4. The most precise way of validating a CALTS is to use calculable dipole antennas, which are the basis of the validation procedure in this standard. The design principles of calculable antennas are given in Annex B, and the theory and methods for calculating site insertion loss (SIL) are given in Annex C and Annex D.

Validation procedures for other antenna calibration sites are given in Clause 5 through Clause 7. Where an antenna calibration method utilizes the ground reflection, a CALTS is required. The validation methods are summarized in Table 1 with reference to the associated antenna calibration methods in CISPR 16-1-6.

All site validation methods involve the measurement of SIL between two antennas. It is critical that the validation of the site itself not be unduly compromised by reflections from antenna supports; see A.3 for associated guidance.

Table 1 – Summary of site validation methods by subclause number

Calibration site(s)	CISPR 16-1-5 validation method(s) Subclause	CISPR 16-1-6:2014 calibration method(s) Subclause	Frequency range MHz	Antenna type(s)	Polarization	Notes
1 CALTS for monopoles	4.10	G.1	5 to 30	Monopole	VP	With tolerance of ± 1 dB
2 CALTS or SAC ^a	4, 7.2	8.4	30 to 1000	Biconical, LPDA, hybrid	HP	SSM
3 CALTS or SAC	4	9.2.2	30 to 300	Biconical, hybrid, dipole	HP or VP	At large height or with absorber on ground
4 FAR	5.3.2	9.2.2	30 to 300 60 to 1000	Biconical, hybrid, dipole Biconical, dipole	HP	
5 REFTS CALTS	4.7 4.9	9.3	30 to 300	Biconical, hybrid	VP	
6 Free space	6.1	9.4.2 9.4.3	200 to 18000	LPDA, hybrid, horn	VP	HP with greater height
7 Free space	6.2	9.4.4	200 to 18000	LPDA, hybrid, horn	VP (or HP)	With absorber on ground
8 FAR	5.3.3	9.5	1000 to 18000	Horn, LPDA	HP or VP	
9 FAR	5.3.2	9.2 and 9.4	140 to 1000	LPDA, hybrid	HP or VP	
10 CALTS	4.6	B.4, B.5	30 to 300	Biconical, dipole	HP	
11 Transfer of properties of a validated site to a site not validated by methods in other clauses	7.1 (excluding 5.3 FAR)	A.9.4	30 and above	Any, but not monopole or loop	HP or VP	Use primarily for SAM and FAR, for particular antenna types and frequencies, except 5.3
^a A CALTS is well specified as being free of reflecting obstacles, and if the antenna supports have negligible reflections the ground plane itself is likely to provide results that agree with the theoretical performance to better than 0,5 dB. However for a Semi Anechoic Chamber (SAC), it is important that the entire allowed acceptance criterion of 1 dB is not taken up by wall reflections, leaving no latitude for other uncertainty components such as reducing reflections from masts and cables.						

SPECIFICATION FOR RADIO DISTURBANCE AND IMMUNITY MEASURING APPARATUS AND METHODS –

Part 1-5: Radio disturbance and immunity measuring apparatus – Antenna calibration sites and reference test sites for 5 MHz to 18 GHz

1 Scope

This part of CISPR 16 specifies the requirements for calibration sites in the frequency range 5 MHz to 18 GHz used to perform antenna calibrations according to CISPR 16-1-6. It also specifies the requirements for reference test sites (REFTS) that are used for the validation of compliance test sites (COMTS) in the frequency range 30 MHz to 1000 MHz according to CISPR 16-1-4.

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

Measurement instrumentation specifications are given in CISPR 16-1-1 [1]¹ and CISPR 16-1-4. Further information and background on uncertainties in general is given in CISPR 16-4 [3], which can also be helpful in establishing uncertainty estimates for the calibration processes of antennas and site validation measurements.

2 Normative references

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

CISPR 16-1-4:2010, *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/AMD 1:2012

CISPR 16-1-6:2014, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-6: Radio disturbance and immunity measuring apparatus – EMC antenna calibration*

IEC 60050 (all parts), *International Electrotechnical Vocabulary* (available at <<http://www.electropedia.org>>)

3 Terms, definitions and abbreviations

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050, as well as the following apply.

NOTE Full terms for abbreviations not already given in 3.1 are listed in 3.2.

¹ Numbers in square brackets refer to the bibliography.

3.1.1 Antenna terms

3.1.1.1

antenna

transducer that converts the guided electromagnetic energy of the feed line into a radiated wave in space and vice versa

Note 1 to entry: In the context of this standard, for antennas for which a balun is intrinsic to the functioning of the antenna, the term “antenna” includes the balun.

3.1.1.2

biconical antenna

symmetric antenna formed by two conical radiating elements having a common axis, and adjacent vertices at which they are fed

Note 1 to entry: For use in the VHF band, biconical antennas are usually made of two conical-shaped wire cages. Often each cage has a cross-bar connecting the centre conductor and one of the peripheral wires to remove a narrowband resonance. Such shorting cross-bars can affect the characteristics of the antenna above 215 MHz. For more details, see also A.4.3 of CISPR 16-1-6:2014.

3.1.1.3

broadband antenna

antenna having acceptable characteristics over a wide range of radio frequencies

3.1.1.4

calculable antenna

dipole-like antenna of which the antenna factor of a single antenna, and the site insertion loss between a pair of antennas, may be calculated using either analytical or numerical (method of moments) techniques based on the dimensions, load impedance and geometrical parameters, and that can be verified by measurement

Note 1 to entry: An example of a calculable antenna is that specified in Annex B. Another example is a simple loop antenna.

Note 2 to entry: Effects of the balun are typically accounted for by *S*-parameters measurements of the balun network, or the balun structure can be modelled.

3.1.1.5

horn antenna

antenna consisting of a waveguide section in which the cross-sectional area increases towards an open end, which is known as the aperture

Note 1 to entry: Rectangular-waveguide pyramidal horn antennas are popular in the microwave frequency range above about 1 GHz. Double-ridged-waveguide horn antennas (DRH; sometimes also referred to as DRG horn, for double-ridged-guide) cover a very wide frequency range. The mainlobe of some DRH antennas splits into several beams at higher frequencies.

3.1.1.6

hybrid antenna

antenna consisting of a wire-element log-periodic dipole array section and a broadband dipole section

Note 1 to entry: The longest element of the LPDA section (see 3.1.1.7) is typically resonant at approximately 200 MHz, and the boom is lengthened at the open-circuit end to feed the connected broadband dipole (e.g. biconical or bowtie) section. Over the range 30 MHz to 200 MHz, the broadband dipole exhibits a performance similar to a biconical antenna, notably in the variation of height-dependent antenna factor.

Note 2 to entry: A common-mode choke is typically used at the open-circuit end (i.e. rear) of the boom to minimize parasitic (unintended) RF currents on the outer conductor of the coaxial cable flowing into the measuring receiver.

3.1.1.7

log-periodic dipole array antenna **LPDA antenna**

antenna comprising an array of linear dipole elements whose dimensions and spacings increase logarithmically with frequency from the tip to the rear end of the antenna

3.1.1.8

resonant dipole antenna **tuned dipole antenna**

antenna consisting of two straight collinear conductors of equal length, placed end to end, separated by a small gap constituting a balanced feed, with each conductor approximately a quarter-wavelength long such that at the specified frequency the input impedance of the antenna measured across the gap has zero reactance when the dipole is located in free space

Note 1 to entry: A resonant dipole antenna is also a calculable antenna (see 3.1.1.4). In this standard the term "linear dipole" implies "two straight collinear conductors," in contrast to the biconical dipole, or array of dipoles as in the LPDA antenna.

3.1.1.9

standard antenna **STA**

antenna for which the AF is calculated or measured precisely

Note 1 to entry: Precision is attainable by a calculable antenna such as specified in 4.3. Alternatively an STA may be an antenna of a type similar to the AUC that has been calibrated to lower uncertainties than required for the AUC, e.g. by the three antenna method.

Note 2 to entry: An STA is used for measurements by the standard antenna method (see 4.3.5, etc. of CISPR 16-1-6:2014). An STA is mechanically robust such that reproducibility of AF to better than $\pm 0,2$ dB is maintained with continuous use of the STA. Balance and cross-polar criteria applicable to the STA are found in 6.3.2 and 6.3.3 of CISPR 16-1-6:2014.

3.1.1.10

balun

device for transforming an unbalanced transmission line to a balanced transmission line and vice versa

Note 1 to entry: A balun is used, for example, to couple balanced antenna elements to an unbalanced feed line, such as a coaxial cable. A balun may exhibit inherent impedance transformation differing from unity.

3.1.1.11

test antenna

combination of the resonant dipole antenna and the specified balun

Note 1 to entry: The definition is for the purposes of this standard only (see also 3.1.1.8 resonant dipole antenna, and 3.1.1.12 wire antenna). The test antenna is described in 4.3.

3.1.1.12

wire antenna

a specified structure consisting of one or more metallic wires or rods for radiating or receiving electromagnetic waves

Note 1 to entry: A wire antenna does not contain a balun.

Note 2 to entry: In the context of this standard, a wire antenna connected to a balun is called a "test antenna" (see 3.1.1.11).

3.1.1.13

antenna factor

F_a

ratio of the electric field strength of a plane wave incident from the direction corresponding to the mechanical boresight (i.e. the main axis of the antenna) to the voltage induced across a specified load connected to the antenna, measured in a free-space environment

Note 1 to entry: The abbreviation AF is used as a general term to denote antenna factor, whereas F_a denotes the boresight AF in free-space. AF is affected by the load impedance (typically 50 Ω) connected to the antenna, and is frequency dependent. AF can be affected by mutual coupling of the antenna to the ground plane, and is directivity dependent. For more details see the definitions and 4.2 in CISPR 16-1-6:2014.

Note 2 to entry: The AF has the physical dimension in dB relative to 1/m [dB(m⁻¹)]. In radiated emission measurements, if F_a is known, the strength of an incident field, E , can be calculated from a reading, V , of a measuring receiver connected to the antenna as follows:

$$E = V + F_a$$

where E is in dB(μ V/m), V is in dB(μ V) and F_a is in dB(m⁻¹).

3.1.2 Measurement site terms

3.1.2.1

calibration site

any site at which an antenna is calibrated

Note 1 to entry: Calibration sites include a CALTS (see 3.1.2.2) on which the ground reflection is intentionally used, a FAR (see 3.1.2.5), and an open-area calibration site (see Clause 6) at which the antennas are high enough above the ground to reduce the ground reflection. For each of these, any reflections from all directions meet the appropriate site acceptance criteria for antenna calibration.

3.1.2.2

calibration test site

CALTS

calibration site with a metallic ground plane and tightly specified site insertion loss in horizontal electric field polarization

Note 1 to entry: A CALTS is used for the measurement of height dependent AF, and to measure free-space AF by the standard site method.

Note 2 to entry: A CALTS can also be validated for: a) vertical polarization using the method of 4.7 (see also 3.1.2.7 definition of REFTS); and b) use for other specific CISPR 16-1-6 calibration methods using the methods of 4.9 and 4.10 (see also Table 1).

3.1.2.3

compliance test site

COMTS

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

Note 1 to entry: Requirements for a COMTS, including those for site validation, are specified in CISPR 16-1-4.

3.1.2.4

free space

environment where it has been shown that the effect of any obstacle, including the ground, on the radiated signals passing directly between two antennas is below a specified uncertainty contribution for the measurement of F_a

3.1.2.5

fully-anechoic room

FAR

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

Note 1 to entry: A FAR suitable for antenna calibration has a tighter field uniformity specification compared with that for EMC radiated disturbance measurement specified in CISPR 16-1-4. If ambient RF interference prevents the required signal to noise ratio, the FAR should be built inside a shielded enclosure. The site acceptance criteria are given in the FAR validation methods in this standard.

3.1.2.6

ideal open-area test site

ideal OATS

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 1 to entry: An ideal OATS is a theoretical construct that is used in the calculation of the theoretical normalized site insertion loss for ground plane sites.

Note 2 to entry: For an ideal OATS the absolute value of the reflection coefficient of the ground plane is $r = 1$, and the phase difference of the incoming and reflected EM waves at the ground plane is $\phi = \pi$ radians for horizontal polarization, and zero radians for vertical polarization.

3.1.2.7

reference test site

REFTS

test site with metallic ground plane and tightly specified site insertion loss in horizontal and vertical electric field polarizations

3.1.3 Other terms

3.1.3.1

measuring receiver

signal measuring instrument, such as a stepping receiver, a spectrum analyzer, or the receiving part of a network analyzer, that fulfils the selectivity and linearity requirements of the relevant calibration method

Note 1 to entry: The term measuring receiver may also imply the full functions of a vector network analyzer. In this standard, the term signal means an RF sinusoidal signal with constant amplitude. For the purposes of antenna calibration and site validation, this definition is a modification of that found in CISPR 16-1-1 [1] and CISPR 16-2-3 [2].

3.1.3.2

null

node in signal level resulting from the vector sum of the direct and ground-reflected signals at the receive antenna and with the level being considerably lower than the in-phase sum of these signals

Note 1 to entry: The dip in signal level on boresight for some DRH antennas is sometimes referred to as a null. This definition does not apply to such dips.

Note 2 to entry: IEC 60050-726:1982, 726-02-07 defines standing-wave minimum, with synonym node (of a standing wave), as the location in a propagation medium where the vectorial sum of a specified field quantity of two waves creating a standing wave is a minimum.

3.1.3.3

site attenuation

SA

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

Note 1 to entry: The terms site insertion loss (see 3.1.3.4) and site attenuation describe essentially the same measurement, however the term site attenuation (SA) is used in the context of finding the minimum site insertion loss (SIL) between a pair of antennas when one antenna is scanned in height above a ground plane.

3.1.3.4**site insertion loss****SIL**

transmission loss between two polarization-matched antennas when a direct electrical connection via cables and attenuators between the signal generator output and the measuring receiver input is replaced by a transmit antenna and a receive antenna placed at specified positions on a calibration site

Note 1 to entry: In this standard, the symbol $A_{i\ c}$ signifies the theoretical SIL in dB, and the symbol $A_{i\ m}$ signifies measured SIL in dB.

Note 2 to entry: The symbol A_i uses A as the conventional symbol for attenuation, with the subscript i denoting insertion; for A_i the subscript is not to be confused with usage in this standard of i as an index symbol, e.g. $i = 1, 2, 3$.

Note 3 to entry: The SIL, A_i , in dB is given by the difference between the received voltages, V_{DIRECT} and V_{SITE} , in dB(μV) that are measured with direct connection and with antennas connected, respectively:

$$A_i = V_{\text{DIRECT}} - V_{\text{SITE}}$$

SIL is defined as a loss factor, so that the antenna geometry giving minimum SIL (see also 3.1.3.3 site attenuation) means the maximum signal is being received.

3.2 Abbreviations

The following abbreviations, not already given in 3.1, are used in this standard.

AF	antenna factor
AUC	antenna under calibration
DRH	double-ridged horn antenna
EM	electromagnetic
EMC	electromagnetic compatibility
EUT	equipment under test
HP	horizontal polarization
MoM	method of moments
NSA	normalized site attenuation
NSIL	normalized site insertion loss
OATS	open-area test site
RF	radio frequency
RSM	reference site method
RSS	root sum square
SAC	semi anechoic chamber
SAM	standard antenna method
SSM	standard site method
TAM	three antenna method
VNA	vector network analyzer

VP vertical polarization

VSWR voltage standing wave ratio

4 Specifications and validation procedures for CALTS and REFTS from 5 MHz to 1 000 MHz

4.1 General

This clause specifies the requirements and a validation procedures for a site suitable for the calibration of antennas above a conducting flat metal plane in the frequency range of 5 MHz to 1 000 MHz. A calibration site meeting these requirements in horizontal polarization is referred to as a CALTS. A CALTS that meets the requirements in vertical polarization may be used as a REFTS. The validation of a CALTS in VP for the calibration of monopole antennas is described in 4.10.

NOTE 1 Although a CALTS and a REFTS are validated by the same methods, a CALTS is used for antenna calibration, whereas a REFTS is used as a reference for validation of a COMTS. Consequently a REFTS may have a less tight acceptance criterion than a CALTS.

NOTE 2 A method for validating a CALTS in VP is given in 4.7.3. The primary validation in HP proves that the ground plane is sufficiently flat and conducting, and this validation applies equally for HP and VP. However in VP there can be larger reflections from antenna supports and cables, therefore validation in VP is needed to support antenna calibrations that use VP.

NOTE 3 For sites at which the SSM is only used to calibrate LPDA antennas, i.e. which are directional, dipole antennas are not essential for site validation. Use of the reference site method (i.e. see CISPR 16-1-4) with a pair of LPDA antennas is suitable. However, a site that is validated by dipoles will be well within the site acceptance criterion required for the SSM performed with pairs comprised of three LPDA antennas.

A method for the validation of a SAC for antenna calibration purposes using the RSM (RSM is described in CISPR 16-1-4) is given in 7.2.

The annexes to this standard contain informative material for a CALTS, and for a calculable dipole to be used in the CALTS validation procedures. They give an analytical model in detail for calculating theoretical site insertion loss (SIL) using resonant dipole (tuned dipole) antennas, together with numerical examples, and a checklist for the validation procedure. The annexes also describe method of moments (MoM) computations of the SIL of a pair of broadband calculable dipole antennas, from which AF can be derived.

NOTE 4 The implementation of Clause 4 is considerably aided by the use of for example the CAP2010 software [24], as described in C.2.

4.2 Antenna calibration test site (CALTS) specification

4.2.1 General

The CALTS comprises the following main components:

- an electrically conducting flat metal plane (the reflecting plane);
- an electromagnetically obstruction-free area surrounding the reflecting plane.

In addition, the following ancillary equipment is needed:

- two antenna masts supporting the antennas;
- the cables to be connected to these antennas; and
- electronic equipment, such as an RF signal generator and a measuring receiver, or a VNA.

The normative specification for a CALTS is given in 4.2.2 (with the associated acceptance criterion in 4.5.3), while Annex A contains a number of informative specifications as guidance

to construct and situate a CALTS in such a way that the acceptance criteria will be met. Annex A also gives details of additional stringent CALTS validation test methods (i.e. A.4).

4.2.2 Normative specification

A CALTS shall comply with the acceptance criterion given in 4.5.3. A subset of the frequency range 30 MHz to 1 000 MHz may be used if the CALTS is only used for antenna calibration in that subset.

Compliance at the 24 frequencies from 30 MHz to 1 000 MHz of Table 3 (see 4.4.3.1), measured by calculable dipoles (see 4.4.4), establishes that the ground plane is of sufficient size, flatness and conductivity, and sufficiently free of reflections from obstacles at those 24 frequencies. Compliance at all other frequencies required for antenna calibration, either by calculable dipoles or by the reference site method (RSM) according to 4.4.5, establishes whether or not abnormalities exist in the electrical characteristics of the CALTS, e.g. reflections from obstacles such as buildings, wires, fences and trees, and also antenna masts and cables.

Where vertical polarization is used for the calibration of antennas or reference SIL measurements, the CALTS shall comply with the acceptance criterion in 4.7.3.5.

NOTE 1 A more stringent test of site validation is given in A.4, in which a null signal is recorded in a search either of antenna height or frequency.

NOTE 2 In the CALTS validation procedure, equipment is used that is also subject to normative specifications, i.e. see 4.3 and 4.4.

NOTE 3 The CALTS validation report (see 4.8) will contain information on how compliance with the requirements is maintained, so that the CALTS is deemed to comply with the requirements during its actual use.

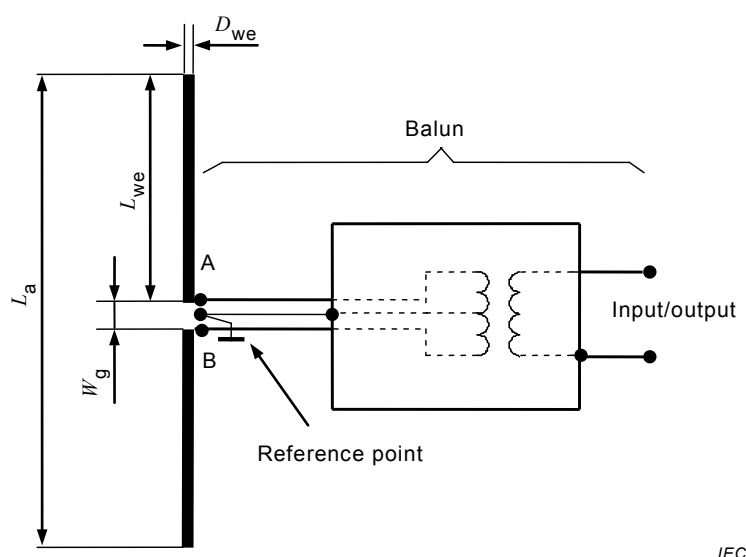
4.3 Test antenna specification

4.3.1 General

Antennas that can be accurately modeled are needed for the (numerical) computation of the theoretical site insertion loss A_{ic} used in the validation procedure. Therefore, the test antenna shall be a dipole connected to a balun with specified properties. The normative test antenna specifications are given in 4.3.2. An example of the construction of a test antenna is given in Annex B.

The test antenna consists of a balun and two collinear wire elements (conductors) each having a diameter D_{we} and length L_{we} . These elements are connected to the two feed terminals (A and B in Figure 1) at the balun. The gap between these feed terminals has a width W_g . The tip-to-tip length L_a of the antenna is given by $L_a = 2L_{we} + W_g$. The centre of the test antenna is in the middle of the feed-terminal gap on the centre-line of the two collinear wire elements.

The balun has an unbalanced input/output (transmit/receive antenna) port and a balanced port at the two feed terminals A and B. As an example, in Figure 1 the purpose of the balun is indicated schematically by the balance/unbalance transformer.



NOTE The centre of the test antenna is in the middle of the gap on the centre-line of the two wire elements.

Figure 1 – Schematic diagram of the test antenna

4.3.2 Details of the required characteristics of the test antenna

In the following list, a quantity ΔX represents the maximum tolerance allowed in the antenna structure with respect to a parameter value X . The quantitative data specifications for these tolerances are summarized in Table 2.

Table 2 – Maximum tolerances for $d = 10$ m

Parameter (X)	Maximum tolerance (ΔX)	Subclause
L_a	$\pm 0,002\ 5\ L_a$ or $\pm 0,001$ (m) if $L_a < 0,400$ (m)	4.3.2 d)
D_{we}	$\pm 0,002\ 5\ D_{we}$	4.3.1
Z_{AB}	VSWR $\leq 1,10$	4.3.2 e) 1)
A_b	$\pm 0,3$ dB ^a	4.3.2 e) 2)
ϕ_b	$\pm 4^\circ$ ^a	4.3.2 e) 3)
d	$\pm 0,04$ m	4.4.2.3
h_t	$\pm 0,01$ m	4.4.2.4
h_r	$\pm 0,01$ m	4.4.2.5
f	$\pm 0,001f$	4.4.3.2
^a The tolerances on A_b and ϕ_b are yet to be verified but may be relaxed when proven by experimentation or modeling to have an effect $< 0,05$ dB on A_i . Alternatively, the uncertainties on A_i may be quantified for higher values of A_b and ϕ_b .		

- The test antenna shall have identical wire elements of length L_{we} which can be disconnected from the balun to enable the balun parameters to be validated, and to allow the balun heads of the two antennas used in site insertion loss measurements to be connected together.
- With λ signifying wavelength, the tip-to-tip length $L_a(f, D_{we})$ of the approximately $\lambda/2$ wire antenna is determined by the condition that, at the specified frequency f and in free space, the absolute value of the imaginary part of the input impedance at the feed terminals is smaller than $1\ \Omega$.

NOTE 1 If the wire elements have a constant diameter and if $D_{we} \ll L_a$, then $L_a(f, D_{we})$ is calculated from Equation (C.3), or using MoM computations (see C.2.3).

NOTE 2 If the diameter is not a constant, e.g. when a telescopic antenna is used, $L_a(f)$ is calculated using MoM (see C.2.3). The telescopic elements are tuned in such a way that the elements having the largest diameter are used first (see Figure 2), and the MoM computations can account for this approach.

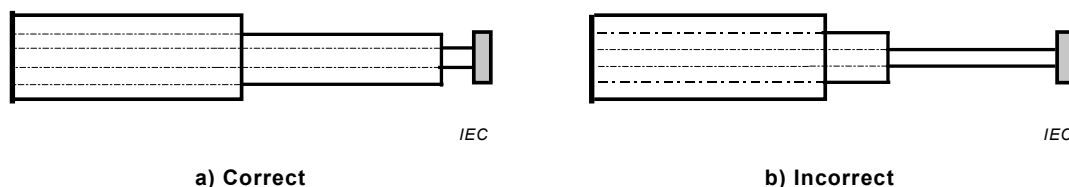


Figure 2 – Adjustment of a telescopic wire element to the length L_{we}

NOTE 3 The analytical formulation of C.1 applies only to SIL for resonant wire elements. The MoM formulation of C.2 agrees to less than 0,1 dB with the analytical calculation of SIL for resonant elements above an ideal ground plane or in free space, but for thin wires the agreement is better than 0,05 dB (see C.1.1). The MoM formulation has been applied to a fixed length wire element over a broad bandwidth [12], [23]. The accuracy of linear elements has been proved (see NOTE 4), but the elements could be of other designs, such as open structure (i.e. non cage) biconical elements, if it can be proven that these give the same or better performance.

- c) The feed-terminal gap shall be small enough that an agreement of less than 0,4 dB is achieved between measured and theoretical SIL between two resonant dipoles of the same length.

NOTE 4 The condition of $SIL < 0,4$ dB has been proved to be met using a gap of $W_g = 9$ mm from 30 MHz to 599 MHz and $W_g = 3$ mm from 600 MHz to 1 GHz.

- d) If the tip-to-tip length $L_a(f)$ of the actual wire antenna is within ΔL_a of the length $L_a(f)$ specified for that antenna (see Table 2), that length is presumed to be validated when the width of the feed-terminal gap complies with item c).
- e) The balanced port of the balun shall have:
- 1) an impedance Z_{AB} with a VSWR less than the maximum tolerance specified in Table 2, when the unbalanced port is terminated in the impedance Z_e (see NOTE 6) presented to it by the external circuitry (the antenna feed cable);
 - 2) an amplitude balance with respect to the balun reference point better than ΔA_b dB (see Table 2), when both feed terminals are terminated in an impedance $Z_{AB}/2$ with respect to the balun reference point;
 - 3) a phase balance of $(180^\circ \pm \Delta \phi_b)$ (see Table 2), when both feed terminals are terminated in an impedance $Z_{AB}/2$ with respect to the balun reference point.

NOTE 5 Connectors at the balun ports enable RF measurements to be made at the three balun ports. For example, SMA push-on connectors at the wire feed ports can be used.

NOTE 6 The impedance Z_e presented by the external circuitry is usually 50Ω , and which is the preferred value. Z_{AB} is the impedance at the port on the balun at A and B attaching to the two halves of the dipole element in Figure 1. The preferred value of this impedance is $Z_{AB} = 100 \Omega$ (real), i.e. the addition of 50Ω for each of the terminals A and B.

NOTE 7 The amplitude and phase balance requirements ensure that the signals at the feed terminals A and B are sufficiently equal in amplitude and opposite in phase with respect to the balun reference point. When the balanced port meets these requirements, the isolation between the two feed terminals will be more than 26 dB when the unbalanced port is terminated in the impedance Z_e .

NOTE 8 As far as practical, the balun components are oriented to present the minimum co-polarized reflecting surface to the wire antenna.

NOTE 9 The components of the balun are electrically shielded, so that their (parasitic) properties cannot be influenced by the surroundings. The balun reference point and the ground terminal of the output/input port are connected to that shield. An example balun is a 3 dB hybrid coupler with anti-phase outputs.

- f) The balun properties required in 4.3.2 e) may be determined from S -parameter measurements and, partly, from insertion loss measurements. Provided the balun properties are incorporated in the A_i calculation, the head-to-head connection of the

baluns in 4.4.4.2.1 and 4.4.4.2.3 (i.e. for insertion loss; see Figure 3) may be replaced by a cable-to-cable connection referenced to the balun inputs, when the full set of balun S -parameters are known.

NOTE 10 The port mismatches presented to the baluns by the generator and the receiver are sufficiently minimized using padding attenuators, where necessary.

NOTE 11 S -parameters and insertion loss measurements are described in B.3.1 and B.3.3, respectively.

- g) In the CALTS validation procedure, if test antennas and/or test equipment is used with Z_{AB} and/or Z_e differing from the preferred values of 100 Ω and 50 Ω , respectively, this should be explicitly mentioned in the validation report (see 4.8).

4.4 Antenna calibration test site validation procedure

4.4.1 General

In the CALTS validation procedure, the measured site insertion loss A_{im} is compared with the theoretically calculated site insertion loss A_{ic} of an ideal OATS (see 3.1.2.6). The procedure thus verifies whether a CALTS sufficiently meets the properties assumed in the SIL calculations.

The properties of ground plane flatness and size, reflection coefficient magnitude, and influence of surroundings constituting an ideal OATS are verified simultaneously in a SIL measurement procedure using fixed antenna heights (see 4.4.4), after which the measured and calculated SIL results are compared.

The properties of ground plane flatness and size, phase difference of incoming and reflected waves, and influence of surroundings constituting an ideal OATS may additionally be verified simultaneously in a scanned frequency or scanned height measurement procedure (see A.4).

In the following subclauses, a quantity $\pm \Delta X$ represents the maximum tolerance allowed in the validation procedure of a parameter value X . The quantitative specifications for the tolerances are summarized in Table 2.

4.4.2 Test set-up

4.4.2.1 The centres of the test antennas, the antenna masts, and the antenna coaxial cables are positioned in a plane perpendicular to the reflecting plane, and centrally located on the reflecting plane.

NOTE 1 The centre of the test antenna is defined in 4.3.1 (see also Figure 1).

4.4.2.2 The collinear wire elements are positioned parallel to the reflecting plane (i.e. horizontal polarization) throughout these tests (i.e. perpendicular to the (vertical) plane mentioned in 4.4.2.1).

At the lower end of the frequency range, e.g. 30 MHz to 40 MHz, the relatively long wire elements can droop, thus influencing the measurement results. This influence may be eliminated by physically propping up the wire elements, or the influence shall be accounted for in the calculation of the theoretical site insertion loss.

4.4.2.3 The horizontal distance between the centres of the test antennas is

$$d = 10,00 \text{ m} \pm \Delta d \text{ m} (\Delta d \text{ per Table 2}).$$

4.4.2.4 The height of the centre of the transmit antenna above the reflecting plane is

$$h_t = 2,00 \text{ m} \pm \Delta h_t \text{ m} (\Delta h_t \text{ per Table 2}).$$

4.4.2.5 The height of the centre of the receive antenna above the reflecting plane shall be adjustable to the heights $h_r \pm \Delta h_r$, as specified in Table 3 (4.4.3.1) and Table 2 (4.3.2).

4.4.2.6 The coaxial cables connected to the baluns of the transmit and receive antennas run perpendicular to the wire elements and parallel to the reflecting plane, over a distance of at least 1 m from the wire elements. After that, the cables may drop vertically down to the reflecting plane and (preferably) continue to run underneath the reflecting plane, or on top of that plane perpendicularly to the wire elements until they reach the edge of the plane. When the cables run partly underneath the reflecting plane, the conductive sheath of the cable should be bonded (360° around) to the reflecting plane at the penetration point through that plane.

Where unbalance is known or suspected, ferrite loading of the coaxial cables connected to the baluns is advised to reduce common mode coupling. A method of quantifying the effect of the cable reflection is given in A.2.3 of CISPR 16-1-6:2014, the outcome of which may be a lesser distance than 5 m or an uncertainty to be added to the antenna calibration results.

NOTE 2 Use of cables with low transfer impedance can minimize influence on the measured results of the induced cable sheet currents through that impedance.

NOTE 3 When the basic test set-up provisions of 4.4.2 are used for testing vertically polarized antennas, e.g. per 4.7, similar cable layout considerations generally apply; see also 4.7.3.3.

4.4.2.7 The RF signal generator and RF measuring receiver shall not be elevated above the level of the reflecting plane if they are within 20 m from the antennas.

4.4.2.8 The RF signal generator shall have good frequency and output level stability throughout the duration of the site insertion loss measurements; see also 4.4.4.2.3.2.

A warm-up time (normally indicated by the equipment manufacturer, e.g. one hour) of the RF signal generator and RF measuring receiver may be included in the measuring procedure, for a sufficient long-term stability of the equipment.

4.4.2.9 The RF measuring receiver shall have its linearity calibrated over a dynamic range of at least 50 dB; see also 4.4.4.2.1.3. The associated uncertainty of the measuring receiver linearity is denoted as ΔA_r (i.e. used in 4.5.2.2); a reasonable value for the measuring receiver linearity uncertainty is 0,2 dB.

If the linear dynamic range is less than 50 dB then a substitution method may be followed, using a calibrated precision attenuator as described in 4.4.4.3.2.

4.4.3 Test frequencies and receive antenna heights

4.4.3.1 Further to the normative specification of 4.2.2, the site validation measurements described in 4.4.4 shall be carried out at a minimum of the 24 frequencies cited in CISPR 16-1-4 over the range 30 MHz to 1 000 MHz, i.e. listed in Table 3, using the fixed heights of the centre of the receive antenna h_r (m) above the reflecting plane as also listed in Table 3. For the calibration of antennas using the methods of CISPR 16-1-6, site validation measurements shall also be carried out using the swept-frequency measurements described in 4.4.5.

Table 3 – Frequency and fixed receive antenna height data for SIL measurements at 24 frequencies, with $h_t = 2$ m and $d = 10$ m (specified in 4.4.2.3 and 4.4.2.4)

Frequency MHz	h_r m	Frequency MHz	h_r m	Frequency MHz	h_r m
30	4,00	90	4,00	300	1,50
35	4,00	100	4,00	400	1,20
40	4,00	120	4,00	500	2,30
45	4,00	140	2,00	600	2,00
50	4,00	160	2,00	700	1,70
60	4,00	180	2,00	800	1,50
70	4,00	200	2,00	900	1,30
80	4,00	250	1,50	1 000	1,20

4.4.3.2 The frequency of the RF signal generator providing the signal for the transmit antenna shall be adjusted to within Δf (see Table 2), of a test frequency specified in Table 3 or in A.4.

4.4.3.3 If narrow-band noise, such as that originating from broadcast transmitters, impedes accurate measurement at a frequency specified in 4.4.3.1 and A.4, a usable test frequency as close as possible to that specified frequency shall be chosen.

The rationale for a deviation from a specified frequency shall be recorded in the validation report (see 4.8).

4.4.4 SIL measurements

4.4.4.1 General

Subclause 4.4.4 describes the three measurements, designated as Measurement 1, Measurement 2, and Measurement 3, needed to determine the measured SIL, A_{im} (see 4.4.3.1 for acceptance criteria), at the specified frequencies. The SIL being considered is between the feed terminals of the transmit antenna (A and B in Figure 3 and Figure 4) and the terminals of the receive antenna (C and D in Figure 3 and Figure 4).

Where a full set of balun S -parameters is available (as described in 4.3.2 f), they should be incorporated in the computation of the theoretical SIL (see C.2.4); this approach enables lower uncertainties to be obtained. In this case, the measured SIL is derived using a cable connection between the two cable/balun interfaces (schematic shown in Figure 3).

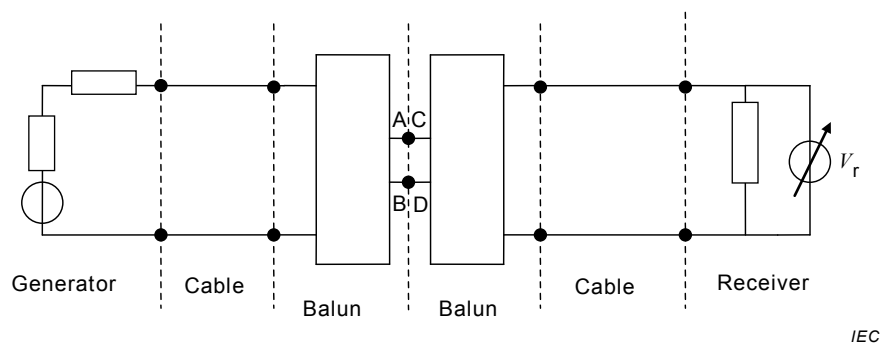


Figure 3 – Determination of $V_{r1}(f)$ or $V_{r2}(f)$

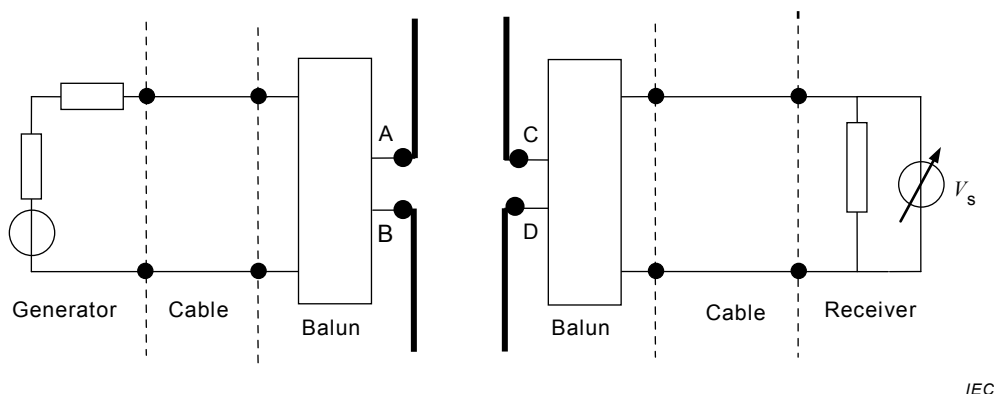


Figure 4 – Determination of $V_s(f)$ with the wire antennas in their specified positions

4.4.4.2 Measurements 1, 2, 3 for determining SIL

4.4.4.2.1 Measurement 1

4.4.4.2.1.1 At a specified frequency f , the reference voltage $V_{r1}(f)$ is determined.

This voltage is used to account for the attenuation of the signal between the RF signal generator output port and the feed terminals of the transmit wire antenna and, similarly, between the feed terminals of the receive wire antenna and the receiver input port.

4.4.4.2.1.2 $V_{r1}(f)$ is determined as follows.

The wire elements of the test antennas are disconnected from their balun, and the two baluns are connected head-to-head with a short connection whose insertion loss shall be accounted for – see Figure 3.

4.4.4.2.1.3 The level of the RF signal generator is set to give a receiver reading at least 60 dB above the noise level of the receiver. The receiver reading is recorded as $V_{r1}(f)$. All readings are in decibels.

The noise level of the receiver may be reduced by reducing the receiver bandwidth. However, if the RF signal generator and RF measuring receiver are not frequency-locked, as in the case of a tracking generator and spectrum analyzer, the receiver bandwidth should be sufficiently wide that a possible drift of the frequency of the RF signal generator signal does not influence the measurement results.

NOTE A signal in Measurement 1 of at least 34 dB above receiver noise yields an acceptable uncertainty; see also 6.2.3 of CISPR 16-1-6:2014. In Table C.1 the SIL at 1 000 MHz is 42,71 dB, so the attenuation including cables and attenuators is likely to be at least 60 dB; if this signal is less than 34 dB above receiver noise, the antenna separation can be reduced to a minimum of 22 and/or the uncertainty due to noise can be increased.

4.4.4.2.1.4 If the S -parameter method indicated in 4.4.4.1 is followed, the complete test antennas are disconnected, and the two antenna cables are interconnected, when determining $V_{r1}(f)$ and $V_{r2}(f)$ in 4.4.4.2.3.

4.4.4.2.1.5 The amplitude setting of the RF signal generator used in 4.4.4.2.1 at a particular frequency remains unchanged throughout the measurements associated with 4.4.4.2.2 and 4.4.4.2.3.

4.4.4.2.2 Measurement 2

The baluns are disconnected from each other, and the wire elements are connected to their baluns (see Figure 4). The elements of the specified length $L_a(f)$ are selected. The test antennas are brought into position, as specified in 4.4.2 and 4.4.3. All other conditions in the test set-up are the same as in 4.4.4.2.1.

NOTE Fixed length elements of constant diameter are preferred. Telescopic elements have varying diameter and will lead to larger uncertainties in the calculation of A_i [see 4.3.2 b) NOTE 2].

At the specified test frequency f , and with the antennas in their specified position, the receiver reading is recorded as $V_s(f)$. Care should be taken to assure that the emitted field does not exceed levels permitted by local regulatory jurisdictions.

4.4.4.2.3 Measurement 3

4.4.4.2.3.1 For Measurement 3, the reference voltage measurement per 4.4.4.2.1 is repeated at the same specified test frequency; the result is recorded as $V_{r2}(f)$.

4.4.4.2.3.2 If $V_{r1}(f)$ and $V_{r2}(f)$ differ by more than 0,2 dB, the stability of the test set-up shall be improved and the preceding Measurements 1, 2 and 3 shall be repeated.

4.4.4.2.3.3 A cause of instability can also be the temperature dependence of the coaxial cable attenuation, especially under direct sunlight exposure. The minimum time between the measurements of $V_{r1}(f)$ and $V_s(f)$, and of $V_{r2}(f)$, shall be used.

4.4.4.3 Determining SIL results

4.4.4.3.1 From the results of Measurements 1, 2, and 3, the measured SIL, $A_{im}(f)$, is given by the Equation (1).

$$A_{im}(f) = V_{ra}(f) - V_s(f) \quad (\text{dB}) \quad (1)$$

where $V_{ra}(f)$ is the average of $V_{r1}(f)$ and $V_{r2}(f)$.

4.4.4.3.2 Where the dynamic range of the RF measuring receiver does not comply with 4.4.2.9, the following substitution method may be used, provided that the full set of balun S -parameters is available, and the balun properties are incorporated in the calculation of the theoretical SIL.

- Determine and record the receiver reading $V_s(f)$, as described in 4.4.4.2.2 (Measurement 2).
- Replace the test antennas by a calibrated precision attenuator, and connect both antenna cables to this attenuator. Adjust the insertion loss caused by the attenuator to a level $A_{im1}(f)$ such that the same receiver reading $V_s(f)$ as determined under step a) is found. Record $A_{im1}(f)$ and its associated measurement uncertainty $\Delta A_{im1}(f)$.
- To demonstrate the stability of the test set-up (as mentioned in 4.4.2.8), repeat step b) to determine $A_{im2}(f)$ after a period of time approximating the total time between the reading of $V_s(f)$ in step a) and $A_{im1}(f)$ in step b). If $A_{im2}(f)$ differs by more than 0,2 dB from $A_{im1}(f)$, the stability of the test set-up shall be improved, and steps a), b) and c) repeated.
- If the test set-up is sufficiently stable, the measured site insertion loss $A_{im}(f)$ is given by

$$A_{im}(f) = A_{im,a}(f) \quad (\text{dB}) \quad (2)$$

where $A_{im,a}(f)$ is the average value of $A_{im1}(f)$ and $A_{im2}(f)$.

4.4.4.3.3 If no provisions have been taken to avoid droop of the wire elements of both test antennas, the site insertion loss A_{im} shall be corrected (see 4.4.2.2).

4.4.5 Swept frequency SIL measurements

4.4.5.1 General

Validation of a calibration site on which antennas will be calibrated at smaller frequency intervals than listed in Table 3 (e.g. swept frequency) shall be performed by swept-frequency measurements using a pair of calculable dipole antennas. Table A.1 gives an example of four dipoles used to cover 30 MHz to 1 000 MHz. The maximum frequency intervals shall be as shown in Table 4. Alternatively the validation may be performed by the RSM of CISPR 16-1-4, for which the reference site shall have a $T_{SIL}(f) < 0,7$ dB for use in Equation (5) (see 4.5.3), when measured according to the procedure used with Table 3. Swept-frequency validations can better reveal reflections from structures such as antenna supports and cables, and any nearby scatterers, such as buildings.

Table 4 – RSM frequency steps

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

For swept-frequency SIL measurements, the SIL between two calculable dipole antennas is measured using a separation distance of 10 m. The antennas are horizontally polarized and placed at heights given in Table 5. The terms Antenna 1 and Antenna 2 in the column headings signify a pair of near-identical antenna elements suitable for the frequency range given in each row of Table 5. As the frequency is swept, the relative phase of the direct signal between the antennas and the ground reflected signal changes, leading to signal nulls (defined in 3.1.3.2). The accuracy of a site validation result is reduced in a null, but there is sufficient accuracy down to a level of 10 dB below the received signal maximum that is closest in frequency to the frequency of the null. An example plot of normalized SIL (NSIL) is shown in Figure 5 [based on the equation for the field strength parameter $e_0(i,j|H)$ in 7.4.1.2.1 of CISPR 16-1-6:2014], with both horizontally polarized Hertzian dipoles at a height of 2 m.

NOTE Normalized site insertion loss (NSIL) is SIL minus the AFs of the two antennas.

The frequency ranges in Table 5 are based on the set of four dipoles listed in Table A.1. For other dipole designs with different subdivisions of 30 MHz to 1 000 MHz, other heights may be optimal, i.e. with signal levels at the ends of the band close to the level of the maximum. For this reason, in Table 5 the 600 MHz to 1 000 MHz range is shown also subdivided into two ranges, rows 5, 6, as an alternative to the single range of row 4. Using a lowest height of 1 m is avoided in an attempt to move further away from the base of the mast where there is a lot more material; it is preferable to not have a motor at the base of the mast. The NSIL for rows 1, 2, 3, 5, and 6 of Table 5 is plotted in Figure 6, demonstrating avoidance of nulls.

Table 5 (informative) – Antenna heights for SIL measurements

Row no.	Frequency range MHz	Antenna 1 height m	Antenna 2 height m
1	30 to 100	4	4
2	100 to 300	2	2,35
3	300 to 600	1,5	1,4
4	600 to 1000	1,5	1,97
5	600 to 750*	1,5	1,1
6	750 to 1000*	1,5	1,8

*Rows 5 and 6 are for alternative to the 600 MHz to 1000 MHz of row 4.

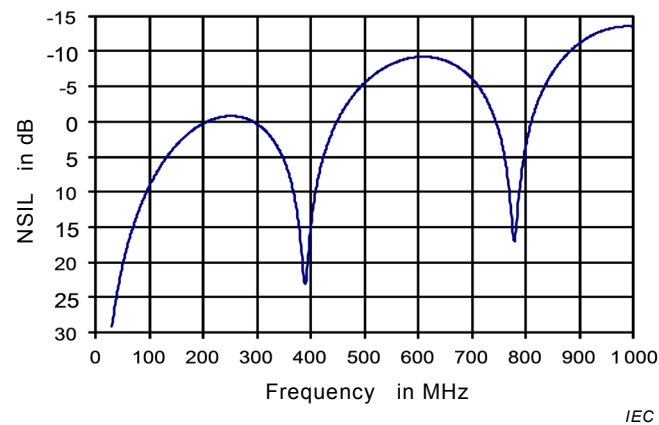


Figure 5 – Example NSIL: horizontal polarization, antenna height 2 m, separation 10 m

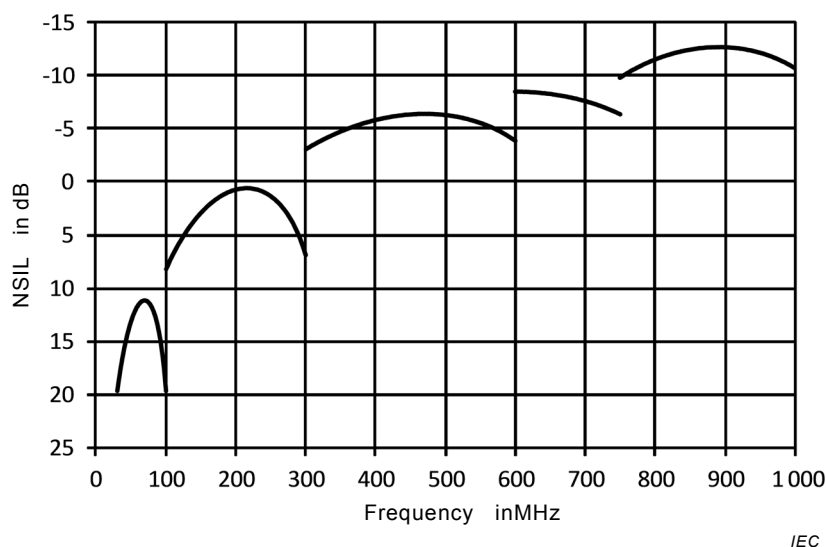


Figure 6 – NSIL of the four pairs of calculable dipoles at 10 m separation and using the alternative heights for the 600 MHz to 1 000 MHz pair according to Table 5

The main purpose of the swept-frequency SIL measurements is to prove the site performance on its own, rather than including the masts, which do not have any reflectivity specification; masts made of thin walled dielectric tubing and minimal metal parts should be used. In contrast, the validation results of a COMTS in CISPR 16-1-4 include the influence of antenna supports and cables, and in the layout required for radiated disturbance testing.

4.4.5.2 Procedure

Two different measurements are made of the received voltage, V_R .

- The first reading of V_R (i.e. V_{DIRECT}) is taken with the two coaxial cables disconnected from the two antennas, and connected to each other via an adaptor.
- The second reading of V_R (i.e. V_{SITE}) is taken with the coaxial cables reconnected to their respective antennas. For both of these measurements, the signal source voltage is kept constant. Preferably, a VNA should be used.
- The SIL is given by Equation (3). All terms are in dB.

$$A_{\text{im}} = V_{\text{DIRECT}} - V_{\text{SITE}} \quad (3)$$

- The measured SIL, A_{im} , is compared to the theoretical SIL, A_{ic} , calculated using C.2.4.1 for the antenna heights, separation and polarization at each frequency. The CALTS complies with the site insertion loss validation criterion if, at all frequencies used for antenna calibration, the acceptance criterion is $T_{\text{SIL}}(f) = 1,0$ dB, where $T_{\text{SIL}}(f)$ is subject to measurement uncertainty per Equation (5) (see 4.5.3).
- At frequencies where the difference between measured and theoretical SIL exceeds $\pm 1,0$ dB (likely to stand out as resonant features in a frequency plot of SIL), single frequencies shall be selected for further investigation.
 - At each selected frequency, the SIL and the height for the maximum signal shall be recorded. The SIL shall be calculated using the same antenna geometry.
 - The reason for the difference of greater than $\pm 1,0$ dB shall be investigated. An initial solution would be to increase the distance between the antenna and the mast and/or feed cable. Potential deviations caused by the antenna supports and feed cable shall be investigated exhaustively (i.e. see 4.4.6), before considering potential problems with the calibration site.

A more sensitive measurement of site performance is to note the frequency at which a null occurs and apply the tolerance criteria of A.4; see also the associated reference in 4.2.2 to the optional tests of A.4.

4.4.6 Identifying and reducing reflections from antenna supports

As mentioned in e.g. NOTE 2 of 4.1, reflections from antenna supports can be the cause of a site not meeting the acceptance criteria, rather than deficiencies of the site itself (see also A.2.3 of CISPR 16-1-6:2014). A single strong source of reflection can be identified from a clear ripple in swept-frequency SIL measurement results. The distance from the antenna to a reflecting surface behind the antenna is given by $R = 300/(2\Delta f)$ in m, where Δf is the frequency interval in MHz between two adjacent peaks of the ripple; this is an approximation dependent on the phase change at the reflecting surface.

The magnitude of the reflection can be reinforced in a set-up where similar antennas are mounted at the same distance from similar masts. An investigation may conclude that the mast is too reflective, even when the antenna is moved 2 m or so in front of the vertical section of the mast. Reflections are usually not obvious below 600 MHz, but the nearer to 1 000 MHz, the greater the area of the mast reflecting surface becomes as a proportion of wavelength, which increases the magnitude of the reflection.

One solution is to use RF-transparent polystyrene foam blocks to support the antennas. The validation report shall state what measures needed to be taken to isolate the site reflections, and what uncertainty can be caused by the masts. Whereas the supplier of the site and the customer (e.g. a calibration laboratory) need to know how compliant the site is in isolation, the customer (e.g. a calibration laboratory) also needs to know that the site with including the antenna supports is compliant, i.e. preferably with masts of a practical design.

The issue of mast reflections is less likely to be a problem with directive antennas, such as LPDA and horn antennas. Reflections are mostly seen when using vertically polarized dipole-like antennas (i.e. with uniform H-plane patterns).

4.5 Antenna calibration test site acceptance criteria

4.5.1 General

A CALTS is deemed to be satisfactory when, at all frequencies at which antenna calibrations that require a CALTS are subsequently to be performed, the measured SIL results (see 4.4.3.1) are within a certain margin of the calculated theoretical values. The margin is given in 4.5.3. Apart from the uncertainties in the various measurement data, this margin also takes into account the tolerances allowed in the measurement set-up.

As explained in 4.5.2, the uncertainty margin consists of a portion that shall be calculated using the theoretical model, and a portion that is directly coupled to the uncertainty in the voltage measurements from which the measured site insertion loss is determined.

4.5.2 Measurement uncertainties

4.5.2.1 The measurement uncertainty ΔA_{im} in the measured SIL, A_{im} , as defined in Equation (1) in 4.4.4.3.1 is given by

$$\Delta A_{im} = \sqrt{(\Delta A_r)^2 + (\Delta A_t)^2} \quad (\text{dB}) \quad (4)$$

where

ΔA_r is given by ΔA_r , in dB, in 4.4.2.9, or by $\Delta A_{im1}(f)$, in dB, in 4.4.4.3.2, whichever subclause is applicable;

ΔA_t in dB, accounts for the sensitivity of the site insertion loss to the parameters

tolerances (maximum values as given in Table 3).

The $k = 2$ (95 % level of confidence) values of ΔA_r and ΔA_t shall be used in Equation (4).

NOTE 1 ΔA_t ($k = 2$) can be calculated using the model given in Annex C.

4.5.2.2 If the tolerances of the parameters comply with those given in Table 2 (see 4.3.2), ΔA_t ($k = 2$) = 0,2 dB may be used for the entire frequency range from 30 MHz to 1 000 MHz. In that case, ΔA_t calculations need not be performed, nor the results of the calculations reported in the CALTS validation report. Table 2 gives the maximum tolerances; the total tolerance of 0,2 dB is an example. The user-estimated total, which may be less, shall be used for application to Figure 7 (see 4.5.3).

NOTE 2 A rationale for ΔA_t ($k = 2$) = 0,2 dB is given in C.1.4.3.

4.5.3 Acceptance criteria

In this subclause, the parameter values to be used in the calculations are the actual values realized in a measurement. The actual parameter values are assumed to be determined with a sufficiently small measurement uncertainty so that the conclusion that a parameter value is within the maximum tolerance range as given in Table 2 is justifiable.

EXAMPLE 1 If the specified distance between the antenna centres $d = 10,00$ m (see 4.4.2.3) and during the actual SIL measurements that distance equals $d_a = 10,01$ m, the latter value is used in the calculations. However $(d - d_a)$ is always to be smaller than 0,04 m (see Table 2).

The CALTS complies with the site insertion loss validation criterion if, at all frequencies used for antenna calibrations, the acceptance criterion is $T_{\text{SIL}}(f) = 1,0$ dB, where $T_{\text{SIL}}(f)$ is subject to measurement uncertainty in Equation (5) (referring to Figure 7).

$$|A_{ic}(f) - A_{im}(f)| < T_{\text{SIL}}(f) - \Delta A_{im}(f) \quad (5)$$

where,

- $A_{ic}(f)$ is the theoretical SIL, in dB, at the specified frequency, calculated according to C.2.4 using the actual geometrical parameter values L_a , d , h_t , and h_r ; example $A_{ic}(f)$ values are given in Table C.1;
- $A_{im}(f)$ is the measured SIL, in dB, following from Equation (1) (see 4.4.4.3.1) or Equation (2) (see 4.4.4.3.2 d); see also 4.4.4.3.3 about droop at tips of wire antennas);
- $\Delta A_{im}(f)$ is the SIL measurement uncertainty ($k = 2$), in dB, as derived in 4.5.2.2;
- $T_{\text{SIL}}(f)$ is the allowed tolerance in SIL, in dB.

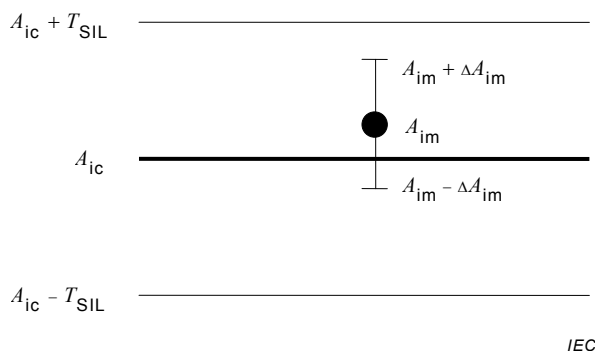


Figure 7 – Relation between the quantities used in the SIL acceptance criterion

The emphasis on need for a ground plane is in the frequency range 30 MHz to 300 MHz. Reflections from antenna supports and cables are significantly less in this range compared to frequencies above 300 MHz. Also it is easier to achieve the antenna performance described in the NOTE in the range 30 MHz to 300 MHz. In this range it is desirable to achieve $T_{\text{SIL}}(f) < 0,7$ dB, to more easily achieve an uncertainty of F_a of less than 1 dB. The reason for a criterion as large as 1,0 dB is to allow for larger reflections from antenna supports and cables up to 1 000 MHz. Because the main purpose of site validation is to test the performance of the ground plane and its environment, a lower criterion should be aimed for where the influence of antenna supports and cables is less.

NOTE Calculable broadband dipole antennas are capable of validating a CALTS to an agreement between measured and theoretical SIL of $\leq 0,3$ dB [23]. This will enable lower uncertainties for F_a .

EXAMPLE 2 If $\Delta A_t (k = 2) = 0,2$ dB and $\Delta A_r (k = 2) = 0,2$ dB, applying Equation (4), $\Delta A_{i,m} (k = 2) = 0,3$ dB. The maximum acceptable difference between calculated and measured site insertion loss can be reduced by using a receiver with a lower value of $\Delta A_r (k = 2)$, by decreasing the tolerances of the various parameters and by considering the actual value of $\Delta A_t (k = 2)$.

EXAMPLE 3 At 30 MHz, a 4,8 m long dipole droops by 16 cm at the tips. $A_{i,m}$ is corrected by adding 0,27 dB, 0,13 dB and 0,08 dB when the dipole is at heights of 1 m, 2 m and 4 m respectively, to properly compare $A_{i,m}$ with $A_{i,c}$. These are corrections for the dipole dimensions in Table C.1 and modelled using NEC (see C.2).

4.6 Calibration site with a metal ground plane for biconical antennas and tuned dipole antennas over the frequency range 30 MHz to 300 MHz

This subclause provides a procedure for validating a calibration site for the calibration of biconical and dipole antennas over the frequency range 30 MHz to 300 MHz by averaging height-dependent antenna factor, $F_a(h,p)$, over a range of heights by the TAM or the SAM, as described in B.4 of CISPR 16-1-6:2014. In an antenna calibration, the two horizontally polarized antennas are separated by 10 m; one antenna is raised as high as 6 m above a flat metal ground plane, and the other is set at 1 m or 2 m height as described in Table B.1 and Table B.2 in B.4 of CISPR 16-1-6:2014. See Figures A.2 and A.3 of CISPR 16-1-6:2014 for an example of F_a obtained by this method.

Compliance of the calibration site shall be determined by the SIL measurements performed in accordance with the following requirements.

- a) SIL measurements shall be performed over the frequency range 30 MHz to 200 MHz using the set-ups in Table 6, and at 250 MHz and 300 MHz in accordance with 4.4.4. The theoretical values of the SIL, $A_{i,c}$, in Table 6 are examples calculated with lossless baluns in the same way as in Table C.1. The SIL results shall comply with the acceptance criterion specified in 4.5.3. Preferably swept-frequency measurements should be made, following 4.4.5.
- b) Antenna-height scan measurements (see A.4.2) and frequency scan measurements (see A.4.3) are optional; see 4.2.2 NOTE 1.

This validation method includes and extends the method of 4.4.4. Guidance on an uncertainty budget can be obtained from Table B.3 of CISPR 16-1-6:2014.

Table 6 – Antenna set-up for the SIL measurement of the calibration site using horizontally polarized resonant dipole antennas (see also 4.4.4 for SIL at 250 MHz and 300 MHz)

Frequency f , MHz	Separation distance d , m	Transmit antenna height h_t , m	Receive antenna height h_r , m	Theoretical SIL A_{ic} , dB
30	10,0	2,0	6,0	17,40
35	10,0	2,0	6,0	18,44
40	10,0	2,0	6,0	19,78
45	10,0	2,0	6,0	20,37
50	10,0	2,0	6,0	20,11
60	10,0	2,0	6,0	20,54
70	10,0	2,0	6,0	21,39
80	10,0	2,0	6,0	21,12
90	10,0	2,0	6,0	22,74
100	10,0	2,0	6,0	24,62
120	10,0	1,0	5,0	26,83
140	10,0	1,0	5,0	27,13
160	10,0	1,0	5,0	27,03
180	10,0	1,0	5,0	27,81
200	10,0	1,0	5,0	29,35

4.7 Validation of a REFTS

4.7.1 General

Guidance on the construction of a REFTS is given in Annex A. A REFTS shall be validated with SIL measurements for both horizontal and vertical polarizations. The test antenna for SIL measurements is specified in 4.3. In horizontal polarization, SIL measurements shall meet the requirements of 4.7.2. In vertical polarization SIL measurements shall meet the requirements of 4.7.3. Alternatively, a REFTS may be validated by the RSM of CISPR 16-1-4. Requirements for a site validation report are given in 4.8.

4.7.2 Validation for horizontal polarization

4.7.2.1 General

Follow the procedures of 4.4 and 4.5 for measurements and analysis of results.

4.7.2.2 Acceptance criterion for horizontal polarization

The theoretical site insertion loss, $A_{ic}(f)$, is calculated according to C.2.4. Example $A_{ic}(f)$ values are given in Table C.1. The acceptance criterion is given by Equation (5), over the frequency range of 30 MHz to 1 000 MHz, with $T_{SIL}(f) = 1,0$ dB. The measurement uncertainty ΔA_{im} shall be evaluated for the use of Equation (5) according to 4.5.2.

4.7.3 Validation for vertical polarization

4.7.3.1 General

The following precautions are applicable to vertically polarized antennas, in addition to the requirements for horizontally polarized antennas.

4.7.3.2 Antenna mounting and antenna mast requirements

The antenna separation shall be 10 m. The height of the centre of the transmit antenna shall be 2 m, except at 30 MHz, 35 MHz and 40 MHz, where the height shall be 2,75 m. The frequency and the receive antenna heights shall be chosen according to Table 7.

Table 7 – Antenna heights

f MHz	h_t m	h_r m	f MHz	h_t m	h_r m	f MHz	h_t m	h_r m
30	2,75	2,75	90	2,0	1,15	300	2,0	2,6
35	2,75	2,4	100	2,0	1,0	400	2,0	1,8
40	2,75	2,4	120	2,0	1,0	500	2,0	1,4
45	2,0	1,9	140	2,0	1,0	600	2,0	1,4
50	2,0	1,9	160	2,0	1,0	700	2,0	1,0
60	2,0	1,5	180	2,0	1,0	800	2,0	1,0
70	2,0	1,5	200	2,0	1,0	900	2,0	1,6
80	2,0	1,15	250	2,0	3,1	1 000	2,0	1,6

h_t and h_r are transmit and receive antenna heights, respectively.

The bottom tip of the antenna shall be at least 0,25 m above the ground plane. The antenna mast should be made of low-density dielectric material (wood or dielectric with $\varepsilon_r \leq 2,5$, low loss, and cross section as small as possible, yet retaining mechanical strength); the mast shall be demonstrated to have minimal effects on the antenna response. Effects of the mast and horizontal boom on the antenna factor shall be evaluated by measuring the transmission loss between two antennas with the mast position varied relative to the antenna, varying the distance between the antenna and the vertical part of the mast.

Effort shall be made to minimize the influence of the antenna mast, e.g. by increasing the distance between the antenna and the vertical part of the mast by mounting the antenna on a horizontal boom.

NOTE For guidance on minimizing reflections from masts, see A.2.3 of CISPR 16-1-6:2014.

4.7.3.3 Cable layout

Cables can act as parasitic reflectors when aligned with the antenna elements, which can change the SIL on the order of ± 1 dB if a cable drops as close as 0,5 m to the rear element of the antenna. Effects of the cables can be evaluated by varying this horizontal distance until the effects on SIL are negligible; see 4.4.2.6. At the distance finally chosen for the measurement, any influence caused by the cables will then be masked by uncertainties of the REFTS. Clamp-on ferrites placed on the cable can reduce this effect, especially where the antenna has a poor balun. Cables should extend horizontally behind the antenna (orthogonal to the antenna elements) for a minimum of 2 m for a REFTS, before dropping to the ground.

4.7.3.4 Ground plane size

Depending on the ratio of the separation distance between the antennas and the distance to the edges of an OATS ground plane, a non-negligible edge diffraction effect may occur. The presence of diffraction effects can be observed as a regular ripple superimposed on the data from a swept-frequency SIL measurement. The ripple appears pronounced in regions of maxima of the SIL data (i.e. signal null). If the ground plane is large enough, the ripple can be reduced by placing the antennas such that the measurement path is on the short axis, rather than the long axis, of the test site. Edge diffraction may also be reduced by enlarging the ground plane using additional wire mesh connected to the perimeter of the ground plane, and into the earth/ground, but the earth/soil shall be very damp for this to be effective.

4.7.3.5 Acceptance criterion for vertical polarization

The theoretical SIL, $A_{ic}(f)$, is calculated according to C.2.4. Example $A_{ic}(f)$ values are given in Table C.5. The acceptance criterion is given by Equation (5) over the frequency range of 30 MHz to 1 000 MHz with $T_{SIL}(f) = 1,5$ dB. The measurement uncertainty ΔA_{im} shall be evaluated for Equation (5) according to 4.5.2.

4.8 Validation report for CALTS and REFTS

4.8.1 General

Throughout 4.8 the term CALTS also applies to REFTS. The provisions of 4.8 are not applicable for 4.9 and 4.10.

This validation report is a means to trace and guarantee the compliance with the CALTS requirements set in this standard.

4.8.2 Validation report requirements

The CALTS validation report shall address a number of items, each of them dealing with a validation aspect of the CALTS. Each item and the justification for inclusion in the validation report are described in this subclause. A summarizing checklist for the items to be addressed is provided in Annex E.

a) General information

General information such as the CALTS location, responsible owner, etc. shall be given.

If the site validation is carried out by other parties/organizations, then these parties/organizations shall be indicated.

The CALTS configuration shall be described, as well as its ancillary components using drawings, photographs, part numbers, etc.

In addition, the date(s) of the validation actions and the issue date of the validation report shall be given. The names of the responsible persons for the editing and authorization of the validation report shall be visible on a cover page, including their signatures.

b) Assessment of the validity period and limiting conditions

It is stated that the validity shall be demonstrated prior to using a site for the calibration of the antennas (see 4.2.2).

Therefore, it is important to indicate the period of anticipated validity of the CALTS under consideration. As the CALTS may be either an indoor or outdoor facility, the anticipated validity of the CALTS may differ and may be affected by different factors such as environmental changes, ageing of cables or ageing of the absorber. It is the responsibility of the facility owner to assess and declare the period of validity of the CALTS validation.

In relation to this validity assessment, items or aspects shall be identified which may be subject to change during the course of use of the facility: for example for outdoor ranges the environment, trees, snow, ground humidity, etc. In general, the performance stability of cabling, equipment, antennas and antenna masts is of importance. Also environmental conditions, ageing of instruments or absorber and validity of calibration of equipment may determine the period of validity of the CALTS.

Quick measurement aids or visual inspection procedures may be incorporated to assess continuously the validity/similarity of the CALTS performance.

Specific environmental or configuration conditions or limitations shall be stated explicitly.

c) Test antenna description and validation

This item of the validation report deals with the demonstration of compliance with the antenna requirements.

The test antennas (elements and baluns) shall comply with the normative specifications given in 4.3.2 and the applicable values given in Table 2.

Each of the normative specification items shall be checked for compliance either by inspection or measurement. The compliance verification results shall be available in an annex or in a separate document (photographs, measurement results, calibration results, supplier statements, etc.).

d) The test set-up

This item of the validation report deals with the evidence on the test set-up. The test set-up shall comply with the normative specifications given in 4.4.2 and the applicable values given in Table 2.

Each of the normative specifications shall be checked for compliance either by inspection or measurement. The compliance verification results shall be available in an annex or in a separate document.

e) Validation measurements

The results of the SIL validation measurements carried out in accordance with the procedure given in 4.4.4, and at the test frequencies and antenna heights given in Table 3, shall be described in this section of the validation report. In addition, the results of either the antenna height scan measurements (see A.4.2) or the frequency scan measurements (see A.4.3) shall be reported in this item, if these optional measurements are carried out. Also the results of the validation of a REFTS in vertical polarization given in 4.7.3 shall be described.

f) Calculation of site antenna attenuation and tolerances

This item in the validation report shall indicate whether the antenna length is calculated using the procedures from Annex C or using different numerical procedures. The results of the SIL calculations and the results of the total measurement uncertainty calculations shall be presented in this item using default values, or calculated values in case of deviations with the tolerances in Table 2.

g) Acceptance criteria calculations

In this item of the validation report, the results of the calculated and measured values of the SIL, and the corresponding allowed tolerances and uncertainties, will be used in Equation (5) to determine acceptance as a function of frequency. Similarly, acceptance with either the height criterion [Equation (A.1)] or the frequency-scan criterion [Equation (A.3)] will be determined, if the associated optional measurements are carried out.

h) Final statement of compliance

Provided the measured SIL complies with Equation (5) at all frequencies, and either the height or the frequency scan criteria conditions are met, then the CALTS under consideration may be declared compliant with the CALTS requirements, taking into account the period of validity and the stated limiting conditions and configurations given in item b). If the height-scan or the frequency-scan criteria conditions of A.4 are also met, the results can be deemed as giving further confidence to support the SIL results.

4.9 Site validation for the calibration of biconical and dipole antennas, and the biconical part of hybrid antennas in vertical polarization

This subclause provides a procedure for validating a CALTS for the calibration of biconical antennas, and the biconical part of hybrid antennas, over the frequency range 30 MHz to 300 MHz, in accordance with 9.3 of CISPR 16-1-6:2014. Determination of the transition frequency for hybrid antennas is described in 6.1.2 of CISPR 16-1-6:2014; see also 5.3.2 of this standard.

For a description of the antenna layout, in which the AUC is illuminated by a field from a monocone antenna, see 9.3.2 of CISPR 16-1-6:2014. Guidance on the construction of a monocone antenna is given in A.2.4 of CISPR 16-1-6:2014. Having the monocone more than 10 m away ensures that the field will be very uniform across the horizontal aperture of the AUC (which has a diameter of approximately 0,5 m); therefore the variation across the horizontal aperture is not measured.

To measure the field variation across the vertical aperture, a small biconical antenna of 0,44 m maximum tip-to-tip length is scanned in height from 1 m to 2,6 m, in 20 cm increments. The antenna shall have an unbalance of less than $\pm 0,5$ dB, according to the balun test of 4.4.2 of CISPR 16-1-4:2010/AMD1:2012. The antenna is placed where the AUC would be, as described in 9.3.2 of CISPR 16-1-6:2014, paying special attention to the minimum distance between the AUC and the vertical part of the mast, and to the minimum distance of 5 m to the vertical part of the antenna cable. Using a VNA to sweep from 30 MHz to 300 MHz, S_{21} is recorded at each height. All of the S_{21} data sets are normalized to the reading at the middle height of 1,8 m. At any given frequency, the difference between the normalized results shall be less than $\pm 1,5$ dB. In general there is a field taper, with S_{21} decreasing with increase in the height of the small biconical antenna. The uncertainty considerations are similar to those of the method of 6.1, because both methods are for measurement of field variation over a height scan.

If the difference in S_{21} exceeds 1,5 dB, possible reflections from the antenna mast shall be investigated. The distance between the small biconical and the mast shall be increased, or the mast replaced by a less reflective one. The reflection from the antenna cable can be investigated by determining whether increasing the 5 m distance to the antenna is beneficial. If neither of these actions lead to compliance, obstacles such as buildings and trees are too near to the antennas, and/or the ground plane is too small. The final set-up that achieves the $\pm 1,5$ dB criterion shall be used for the calibration of the AUC.

Figure F.1 gives an example of field taper across the vertical aperture that is within the specified tolerance. Figure F.2 gives an example of the closeness of the AF measured by this method to that measured in a distinctly different way, i.e. using horizontal polarization and averaging the AF measured at several heights according to B.4.2 of CISPR 16-1-6:2014.

A site validation according to 4.7.3 over the frequency range 30 MHz to 300 MHz should also be performed, but using an acceptance criterion of 1,2 dB. Whereas the preceding method is based on differences, 4.7.3 is an absolute method and will give confidence that the site is of sufficient quality.

4.10 Validation of a CALTS using vertical polarization from 5 MHz to 30 MHz for the calibration of monopole antennas

4.10.1 General

Monopole antennas are calibrated by the plane wave method over the frequency range 5 MHz to 30 MHz, as described in G.1 in CISPR 16-1-6:2014. The plane wave method is useful for the validation of dummy antennas used for the ECSM in 5.1 of CISPR 16-1-6:2014. A CALTS for monopole calibration may differ from the CALTS for dipoles described in Clause 4. The validity of the site is determined by meeting the criterion for validation, which is the agreement between the measured and theoretical calculation of SIL between two monopoles.

Two monopoles are set up, spaced 15 m apart centrally along the long axis of the ground plane. Suitable monopole dimensions are 1 m length and 5 mm radius. The monopole is fitted with a type N male adaptor at one end. See C.2.5.2.1 for the adjustment of the monopole length to account for the adaptor. The monopoles are connected to a type N female bulkhead connector in the ground plane, whose other end under the ground plane is connected to the signal source or receiver. The SIL is measured between the antennas over the frequency range 5 MHz to 30 MHz in 1 MHz steps. The SIL is calculated by the method of C.2.4.2.

Differences between the calculated SIL and the measured SIL greater than 0,5 dB indicate unwanted reflections from objects around the site, such as buildings, fences or trees, or a ground plane that is too small. This difference shall not exceed 1 dB, which would signify that the error caused by the site to the measured AF would not exceed 0,5 dB. If the site error can be reduced, the uncertainty in AF caused by the site can be reduced correspondingly.

NOTE 1 In CISPR 16-1-6 the frequency range for monopole calibration is 9 kHz to 30 MHz. Below approximately 5 MHz the high impedance of these passive monopoles restricts the available signal so this validation is performed only from 5 MHz to 30 MHz, which is the frequency range for the plane wave method in G.1 of CISPR 16-1-6:2014.

NOTE 2 For the calibration of monopole antennas by the method in G.1 of CISPR 16-1-6:2014, a monopole STA is specified; its AF can be calculated by the method of C.2.5.2.1.

4.10.2 Uncertainty evaluation

An example uncertainty budget is given in Table 8 for the SIL measured between two identical monopole antennas. Away from the lowest frequencies, increased padding attenuation may be used, therefore reducing the mismatch value. To estimate uncertainty of the differences between the calculated SIL and the measured SIL, assume an uncertainty of 0,2 dB for the SIL calculated by NEC.

Table 8 – Example measurement uncertainty budget for SIL between two monopole antennas

Source of uncertainty or quantity X_i	Value dB	Probability distribution	Divisor	Sensitivity	u_i dB	Notes
VNA linearity	0,15	Rectangular	$\sqrt{3}$	1	0,087	–
Connector repeatability	0,05	Normal	1	1	0,050	–
Mismatch	0,20	U-shaped	$\sqrt{2}$	1	0,141	–
Antenna separation, 2 cm error at 15 m	0,01	Rectangular	$\sqrt{3}$	1	0,005	–
NEC simulation	0,20	Rectangular	$\sqrt{3}$	1	0,120	
Combined standard uncertainty					0,211	
Expanded uncertainty ($k = 2$)					0,42	

5 Validation methods for a FAR from 30 MHz to 18 GHz

5.1 General

This clause provides several procedures for validating a fully anechoic room (FAR).

- a) The first procedure in 5.2 applies to antenna calibrations above 1 GHz and up to 18 GHz, as described in 9.5 of CISPR 16-1-6:2014; this procedure describes how to determine a quiet-zone and the acceptance criterion [4], [5].
- b) The second procedure is in 5.3.2, and it applies to LPDA antennas from 30 MHz to 1 GHz.
- c) Subclause 5.3.3 provides three additional alternative methods for antenna calibration FAR site validation.
 - 1) FAR site validation for use with SAM for selected antennas in 30 MHz to 1 GHz;
 - 2) The S_{VSWR} procedure, for subsequent calibration of LPDA antennas from 1 GHz to 18 GHz;
 - 3) FAR site validation using time-domain measurements above 500 MHz.

A FAR is used for antenna calibration above 1 GHz, in which the radiated electromagnetic waves propagate as in free space and ideally only the direct ray from the transmit antenna reaches the receive antenna. All indirect and reflected waves shall be minimized with the use of absorbing material on all walls, the ceiling and the floor (see the NOTE). The EM shielding of the FAR shall ensure that any outside EM radiation entering the room, which can have an effect on the calibration signal at the receive antenna, shall be at a level at least 30 dB below the level of the calibration signal (see 6.2.4 of CISPR 16-1-6:2014).

NOTE A guideline for meeting the acceptance criterion is for the absorbing material to have a reflectivity at normal incidence of better than –40 dB at 1 GHz and above. For directive antennas, the reflectivity specification can be relaxed based on the antenna directivity, apart from the end walls to which the antennas are pointing.

Antennas used for site validation above 1 GHz shall be linearly polarized and directional. A pair of horns may be used for measurements from 2,8 m to 3,2 m, but from 0,8 m to 1,2 m a horn and LPDA antenna pair shall be used to avoid large standing waves between the horns. Typically DRH antennas are used because they cover the frequency range 1 GHz to 18 GHz.

5.2 Validation procedure from 1 GHz to 18 GHz

5.2.1 Power transfer between two antennas

The aim is to create a free-space environment inside an anechoic chamber for the purpose of calibrating antennas. When the transmit antenna radiates, the signals at every point along the axis between the two antennas are a combination of the direct signal from the transmit antenna and reflected signals from the chamber surfaces and other reflecting objects, including the receive antenna. The deviation in the level of these signals from those of the antennas in free space depends on many factors, such as frequency, chamber size, quality and coverage of absorbers, antenna type, and reflections from antenna supports. This deviation in level contributes directly to the overall measurement uncertainty of antenna calibrations in a FAR.

A quiet zone should be determined for a particular antenna pair that is used in antenna calibration, with the aim of achieving a near perfect free-space environment. The quiet zone is a part of the chamber (typically around the centre) in which specifications with respect to field uniformity are met, and in which the antenna pairs are to be placed when the AUC is calibrated.

The power accepted by the receive antenna is designated as P_r , and the power delivered to the transmit antenna is P_t . Because the change in antenna gain is small over the range of separation distances used, it may be assumed that the field strength varies inversely proportionally to the distance, d , from the antenna. Therefore, when only direct signals radiated by a stable transmitter arrive at the receive antenna, the value of $P_r d^2$ is assumed to be a constant along the antenna axis for a particular frequency in an ideal reflection-free chamber. Any residual variations in $P_r d^2$ with frequency are assumed to be caused by undesirable reflections in the chamber. These variations appear as a ripple in a plot of amplitude versus distance for a given frequency, and can be used to estimate the imperfection of the chamber. The measurements may be made using a VNA, for which the transmission loss ratio S_{21} in dB is equivalent to P_r/P_t in dB. A plot of $[S_{21} + 20\lg(d)^2]$ against the separation distance, d , will reveal the chamber reflections as a ripple, the peak-to-peak magnitude of which is compared to the acceptance criterion given in 5.2.4. To obtain a sufficient number of peaks in the ripple, the antenna shall be moved a minimum distance of 1λ either side of the separation distance that is used for antenna calibration, in steps of no greater than $\lambda/8$.

NOTE The analysis of the results is more rigorous and considerably simplified by using fine distance increments. Fine increments ensure that a ripple can be formed at each frequency. If the increment is too large, measurements would have to be made at many more frequencies, and the results plotted and inspected to select the frequencies where ripples were strong.

5.2.2 Measurement procedure for validation from 1 GHz to 18 GHz

To validate a chamber to be used for antenna calibration using the TAM described in 9.5.1.3 of CISPR 16-1-6:2014, the same antenna types shall be used. One antenna is placed at one end of the anechoic chamber and its main beam is directed along the main axis of the chamber. A paired antenna mounted on a moving carriage is placed on the same axis at the designated distance from the transmit antenna, as shown in Figure 8.

The measurand is the magnitude of the peak-to-peak ripple in a plot of signal level against antenna separation distance, formed by the interaction of the chamber reflections with the

direct signal between the antennas. Vertical polarization is preferred, because the beamwidth in the vertical plane is narrower, and typically the floor and any walk-on absorber are the closest surfaces to the antennas; this also assumes that the subsequent calibration of antennas is done using vertical polarization.

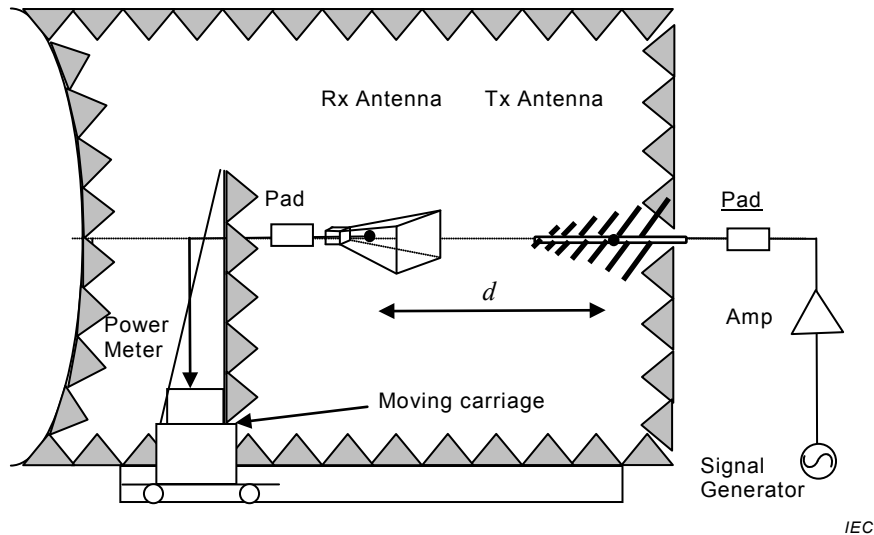


Figure 8 – Set-up of site validation for EMC antenna calibrations above 1 GHz in a FAR, also showing distance between antenna phase centres

The validation is performed only at the largest separation distance required for antenna calibrations, under the assumption that the closer the antennas are the smaller will be the wall reflections in proportion to the direct signal between the antennas. Typically the largest distance is 3 m. It is important that the antenna supports are adequately covered by absorber, otherwise reflections from the supports would have a larger effect at 1 m than at 3 m. If in doubt, and if the chamber is to be used for 1 m calibrations, some exploratory validation measurements at 1 m shall be made.

For a validation over the range 2,8 m to 3,2 m, a pair of horns may be used. However, because of the dominating standing wave between horns at shorter distances, for the range 0,8 m to 1,2 m, a pair comprising one horn and one LPDA antenna shall be used. Another factor is errors caused by the large variation in phase centre of some DRH antennas. For an example of a particular DRH/LPDA antenna pair, the peak-to-peak magnitude of the ripple was measured to be less than 0,2 dB for 3 m separation, which includes chamber reflections, indicating that any standing wave between the antennas is not significant.

This validation method is valid for the frequency range of 1 GHz to 18 GHz, but may be applied just in any sub-range that is to be used for antenna calibration. The frequency increment shall be no greater than 0,5 GHz.

NOTE CISPR 16-1-6 recommends that LPDA antennas be calibrated using two horn antennas by the TAM. If a calibration is performed using an LPDA/LPDA pair, strictly speaking the chamber is validated only by an LPDA/LPDA pair, because they will incur more chamber reflections due to their wider beamwidths. Alternatively, a component is added to the uncertainty budget to allow for greater chamber reflections.

Either a full two-port calibration of the VNA shall be made, or well matched padding attenuators shall be used on the antenna ports. A curved right angle adaptor (with low return loss) may be used to avoid the pad and cable being visible behind the antenna aperture, as viewed from the centre of the other antenna.

If all measurements are made in one session in which the VNA and cables remain undisturbed, it is not necessary to measure $S_{21 \text{ cable}}$ with the antenna cables connected together; if more than one session, then $S_{21 \text{ cable}}$ shall be measured for each session.

results subtracted from the antenna measurement results, $S_{21 \text{ antennas}}$. The receive antenna is moved along the main axis, and $S_{21 \text{ antennas}}$ measured.

Minimum movement of the cables should be ensured and tightness of all connectors checked, because changes in received signal strength due to these factors can be of similar magnitude to the chamber reflections being diagnosed. Assuming that the lowest frequency is 1 GHz, the antenna is moved over a minimum range of 2,8 m to 3,2 m between the tips of the antennas. The distance increment shall be no greater than $\lambda/8$, which at 18 GHz implies an increment of 0,002 m. An automated scanner should be used, with its exposed parts covered with appropriate absorber. As the separation distance is increased, absorber should be placed on the exposed floor.

5.2.3 Analysis of results

The S_{21} data are to be converted into plots at each frequency of signal level against distance, following the steps given in this subclause. As the distance between the antennas is increased, the signal level is assumed to fall off inversely proportional to distance. Although there is a change in horn gain with distance, this is small enough to be ignored, especially at 3 m distance. The term d is the separation distance between the front face of the horn antenna and the tip of the LPDA antenna.

The separation distance, d , shall be corrected for the phase centres of the antennas, as described in the following analysis steps. Because the precise phase centres of the antennas can be unknown, the plots of signal level against distance can have an excessive gradient, making it less easy to quantify the magnitude of any peak-to-peak ripple. The plots may be made more horizontal by applying an experimental correction to the distance.

For the LPDA antenna, a simplified correction for the phase centre using Equation (7) may be made. DRH antennas do not have such simply predictable phase centres; however this validation procedure provides the data for determining the phase centres, and is described in 7.5.3.2 of CISPR 16-1-6:2014.

- a) At every frequency, measure $S_{21 \text{ cable}}$ once, then measure $S_{21 \text{ antennas}}$ for each separation distance. Calculate SIL relative to distance, i.e. $A_{im}(d)$, as shown in Equation (6). It may not be necessary to measure $S_{21 \text{ cable}}$, as explained in 5.2.2, because the $A_i(d)$ at all distances are normalized by the $A_{im}(d)$ at 3 m distance in b).

$$A_{im}(d) = S_{21 \text{ cable}} - S_{21 \text{ antennas}} + 20 \lg(d) \quad (6)$$

- b) Assume the data from a) are presented in a spreadsheet whose first column is frequency, and subsequent columns are $A_{im}(d)$ at each distance. Transpose the data so that the first column is the separation distance, d , and the subsequent columns are $A_{im}(d)$ at each frequency. This layout is more intuitive for applying the phase centre corrections which are frequency dependent, and it sets the data in the right format for plotting $A_{im}(d)$ at each frequency against separation distance. Normalize all the rows to the centre distance, in this case 3 m, i.e. $[A_{im}(d) - A_{im}(d_{3m})]$. To each column of data at a given frequency, apply a distance correction for phase centre using Equation (7), where $d_{1f \text{ radome}}$ is the distance from the tip of the LPDA to its phase centre at a given frequency. Equation (7) is the simplified equation for phase centre; refer to 7.5.2.2 in CISPR 16-1-6:2014 for explanation of $d_{1f \text{ radome}}$. Because great precision in the antenna separation is not required to obtain a measurable ripple, it is assumed that the length of the LPDA antenna is the estimated active length, d_{LPDA} , across the frequency range over which the measurement is made, unless information is available about the actual position of the dipole elements.

$$d_{1f \text{ radome}} = \frac{f_{\max}^{-1} - f^{-1}}{f_{\max}^{-1} - f_{\min}^{-1}} d_{\text{LPDA}} \quad (7)$$

where $f_{\max}$ and $f_{\min}$ are the maximum and minimum design frequencies of the antenna, and f is the frequency at which the correction is required.

- c) Plot $A_{im}(d)$ against d at all frequencies on one graph. If the median line through an individual plot at a given frequency is not horizontal, this is an indication that the corrections in a) for separation and b) for LPDA phase centre are incomplete.

NOTE 1 By experimentation, a correction can be applied to all values of $A_{im}(d)$ at that frequency, i.e. to the frequency column in the spreadsheet. When the plot becomes horizontal, the correction can give useful information about the phase centres of the antennas, or the variation of gain with distance particularly if the validation is centred about 1 m separation. A correction that increases the separation signifies that the phase centre is behind the front face of the horn. In cases where the peak-to-peak magnitude is small, e.g. 0,2 dB for a horn-LPDA pair, this process can be unreliable. This process is more reliable where there is a clear standing wave between the antennas, as is the case for horn-horn pairs. It is noted also that computer modelling by Harima [26] indicates that large variations with frequency of the phase centre of DRH antennas can occur.

- d) By inspection of the plots, estimate the peak-to-peak magnitude of the ripple at each frequency. If the plot is not quite horizontal, a straight line should be drawn through its centre, and the adjacent maxima and minima measured from this straight line. Over the separation range, the largest adjacent maximum-minimum value is compared to the acceptance criterion. Example plots of $A_{im}(d)$ against distance at a sample of frequencies are shown in Figure 9. The LPDA phase centre corrections applied to Figure 9 varied from 0,27 m at 1 GHz to 0,0 m at 18 GHz. A single correction of 0,12 m behind the front face of the horn was applied at all frequencies; probably this should be larger at 1 GHz and 2 GHz.

NOTE 2 The data of Figure 9 was taken in 0,02 m increments in the range 2,8 m to 3,2 m, and clearly the increment is too coarse above 6 GHz for peaks and nulls to form. However 1,5 cycles are developed at 1 GHz, which indicates this can be sufficient range. The largest spread is at 1 GHz and 2 GHz, which is partly caused by the wider beamwidth of the DRH antenna at the lowest end of its specified frequency range.

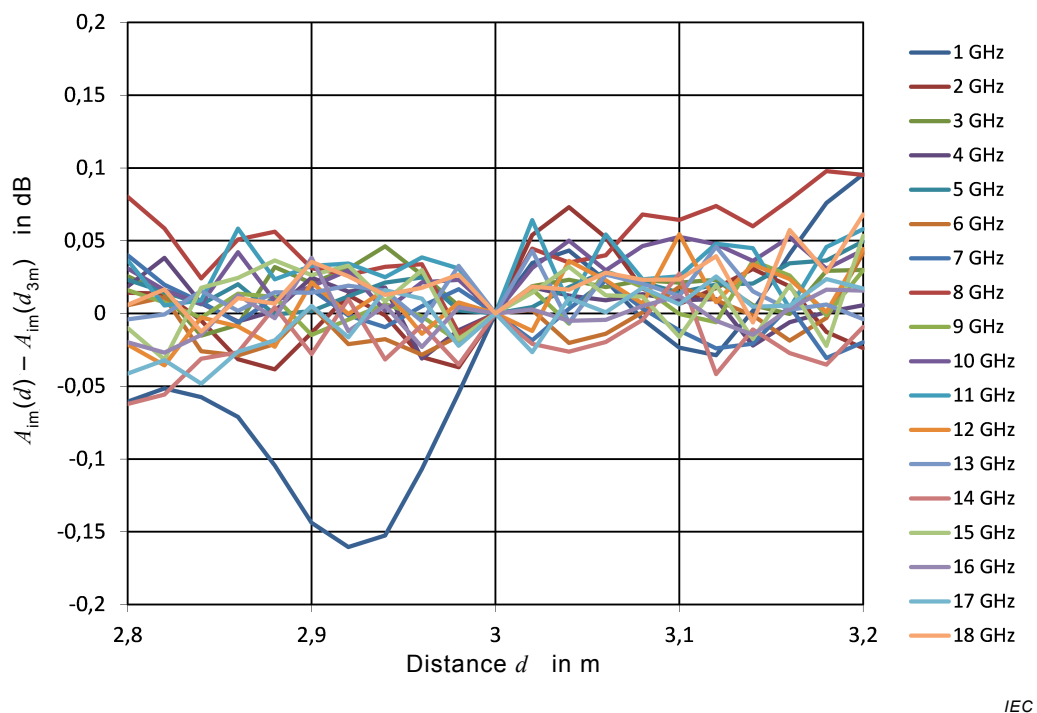


Figure 9 – Example plots of $[A_{im}(d) - A_{im}(d_{3m})]$ in dB against distance in m at 1 GHz to 18 GHz in 1 GHz steps, corrected for LPDA and horn phase centres

5.2.4 Acceptance criterion

The “quietness” of the quiet zone is dependent on the reflection levels from the walls, floor and ceiling of the FAR, and other reflecting objects. The lowest frequency band of the chamber shall be given a more careful examination, because typically the absorber reflectivity is higher at lower frequencies.

The acceptance criterion is a peak-to-peak variation of $A_{im}(d) \leq 0,5$ dB over one cycle attributable to the wall reflections (i.e. between adjacent peaks in Figure 9). The quiet zone

shall be achieved over the required distance. Half the achieved maximum peak-to-peak variation of $A_{im}(d)$ is used as the uncertainty contribution for site imperfections, in the overall measurement uncertainty of AF.

5.2.5 Chamber performance versus polarization

For a perfect FAR, the measurement results of two polarization matched antennas should show no difference whether the antennas are horizontally or vertically polarized. But for a non-perfect FAR, there are likely to be differences. Optionally the measurements are repeated with the antennas horizontally polarized, and plots of $A_{im}(d)$ compared against d for the two polarizations. Differences between the two plots can be helpful in revealing where improvements can be made to the chamber reflectivity.

5.2.6 Uncertainty

Table 9 shows an example of an uncertainty budget. The uncertainty is of the peak-to-peak ripple. Half the magnitude of the peak-to-peak ripple is used as an uncertainty component for antenna factor of antennas calibrated in the chamber. The ripple assumes constant antenna gain and no antenna-to-antenna mutual coupling, so these are essential components in the budget. The measuring receiver stability is included in the repeatability component.

Table 9 – Example measurement uncertainty budget for FAR validation method at and above 1 GHz

Source of uncertainty or quantity X_i	Value dB	Probability distribution	Divisor	Sensitivity	u_i dB	Notes ^a
Measuring receiver linearity	0,1	Rectangular	$\sqrt{3}$	1	0,06	1)
Uncertainty of phase centre correction	0,1	Rectangular	$\sqrt{3}$	1	0,06	2)
Antenna separation error of 15 mm in 3 m	0,05	Rectangular	$\sqrt{3}$	1	0,03	3)
Gain variation with distance, based on 3 m	0,1	Rectangular	$\sqrt{3}$	1	0,06	4)
Antenna mutual coupling	0,2	Rectangular	$\sqrt{3}$	1	0,12	5)
Mismatch	0,1	U-shape	$\sqrt{2}$	1	0,06	6)
Repeatability	0,05	Normal	2	1	0,03	7)
Combined standard uncertainty on above 1 GHz chamber validation, $u_{\text{Site Val}}$ in dB					0,16	
Expanded uncertainty ($k = 2$), $U_{\text{Site Val}}$ in dB					0,33	

^a The number of each item corresponds with the Note numbers below.
See also Annex E of CISPR 16-1-6:2014 for additional uncertainty component descriptions.

Notes:

- 1) Uncertainty associated with a VNA.
- 2) This is the error in the antenna phase centre prediction at a given frequency. The phase centre contribution is applicable to LPDA and hybrid antennas; see 7.5.2.2 of CISPR 16-1-6:2014 for details.
- 3) This error is estimated for a difference in position of less than 15 mm of the two antennas. The calculation of the magnitude of the error uses the separation distance between the antennas.
- 4) Variation of horn antenna gain with distance. At a distance of 1 m from the horn aperture, for a 1 GHz to 18 GHz DRH antenna the variation is up to 1 dB reduction in gain. Therefore the field cannot be assumed to fall off inversely proportional to distance. Unless the gain is known at all distances, this should be included as an uncertainty term.
- 5) Mutual coupling between two antennas shows as a ripple in a plot of SIL versus distance for a change of antenna separation of at least $\lambda/2$. The amplitude of this ripple should be included as an uncertainty. The mutual coupling depends on the antenna mismatch. This ripple can be larger than that caused by multiple reflections from the chamber, but it is the latter which is tested against the acceptance criterion.
- 6) The mismatch uncertainty between the transmit antenna and receive antenna and the cables is to be considered. The maximum contributions are to be included in the uncertainty calculation, for the transmitting and receiving side.

7) The repeatability contribution includes the set-up errors (e.g. antenna heights, antenna distance, and antenna positioning). It also includes connector repeatability, and movement of cables. A set of 10 calibrations should be performed, including a complete tear-down and set up, to obtain a reliable value.

5.3 Validation of a FAR for the calibration of antennas by alternative methods

5.3.1 General

While 5.2.2 describes the validation of a FAR above 1 GHz, 5.3.2 describes the validation of a FAR to use for subsequent antenna calibrations from 30 MHz to 1 GHz. This also assists with determination of the transition frequency for hybrid antennas, described in 6.1.2 of CISPR 16-1-6:2014. Subclause 5.3.3 describes an alternative method to 5.2.2, for the calibration of LPDA antennas above 1 GHz. Finally, time-domain measurements for FAR site validation above 500 MHz are described in 5.3.4.

5.3.2 Validation of a FAR from 30 MHz to 1 GHz

This subclause covers the validation of a FAR for the calibration of the following antennas by the SAM:

- a) biconical and hybrid antennas from 30 MHz to 300 MHz, as described in 9.2 of CISPR 16-1-6:2014, and
- b) dipole antennas from 60 MHz to 1 000 MHz.

The reason for a lowest frequency of 60 MHz in b) is that a dipole length of 2,4 m can be accommodated in most FARs, reducing the number of lower frequencies that have to be done on a CALTS.

Over the frequency range 30 MHz to 1 GHz, a sufficiently uniform field can be achieved in a FAR whose field uniformity when measured according to the FAR validation procedure of CISPR 16-1-4, i.e. using a mini-biconical transmit antenna, meets an NSA criterion of $\pm 2,5$ dB (see NOTE 2 and NOTE 3). The validation measurement volume is a cylinder that just encloses the AUC (e.g. the largest elements on a hybrid) and the receive antenna is at a distance of X m from the centre of the volume, where X is the separation distance used for the antenna calibration set-up given in 9.2.2 of CISPR 16-1-6:2014. Usually the minimum variation of field uniformity is obtained with the axis between the antennas in the centre of the room.

The distances required from the FAR walls, as well as ground and ceiling, depend on the antenna directivities in the E-plane and H-plane (see definitions 3.1.1.16 and 3.1.1.17 of CISPR 16-1-6:2014). There shall be a minimum distance of 1 m between the extremities of the absorber and the extremities of the antennas.

Meeting the NSA acceptance criterion of $\pm 2,5$ dB will enable uncertainties in the measurement of antenna factor as low as $\pm 1,2$ dB to be achieved for a hybrid antenna. Assessment of the suitability of the FAR to achieve lower uncertainties may be investigated by employing the comparison method of 7.1.

NOTE 1 Normalized site attenuation (NSA) is SA minus the AFs of the two antennas.

NOTE 2 The NSA criterion of $\pm 2,5$ dB is a relaxed value from a more desirable value of ± 2 dB, achievable by e.g. national measurement institutes (NMIs). It is intended to revert to ± 2 dB when justified by data from other laboratories.

NOTE 3 Absorber reflectivity criteria are described in N20) in E.2 of CISPR 16-1-6:2014.

5.3.3 Alternative validation of a FAR for the calibration of LPDA antennas above 1 GHz

For frequencies above 1 GHz, a sufficiently uniform field can be achieved in a FAR that has been validated by the S_{VSWR} method of CISPR 16-1-4, using an antenna separation of 3 m and an acceptance criterion $S_{VSWR,dB} \leq 2$ dB. Due to the small size of the active region of the

AUC above 1 GHz, a single location is validated. For the calibration of the antennas, their separation distance is assumed to be less than 3 m, e.g. 2,5 m between the centre of an LPDA and the LPDA part of hybrid antennas, as illustrated in Figure 10 (see 6.1.1).

The validation applies for the subsequent calibration by the TAM or the SAM of LPDA and hybrid antennas of the type that was used as the receive antenna for the validation.

5.3.4 Alternative validation of a FAR applying time-domain measurements above 500 MHz

For frequencies above 500 MHz, a FAR may be validated using the time-domain option of a VNA. The time domain option compares the direct path of propagation between two antennas to the multipath reflections. The source of the reflections can be identified and assigned to e.g. a mast, absorber-lined wall, or imperfection of a FAR. The measurement uncertainty is derived from the levels of the direct beam relative to the RSS of the multipath reflections.

Due to the small size of the active region of an AUC, a single location is validated. For the calibration of the antennas, their separation distance is assumed to be less than 3 m, e.g. 2,5 m between the centres of the antennas, as illustrated in Figure 10 (see 6.1.1).

All common antenna types, such as biconical, LPDA, standard gain horn, or DRH antennas may be used for this validation. For each combination of antenna types, e.g. DRH and LPDA, or LPDA and biconical, a single validation shall be done in the FAR, because the sensitivity for reflections differs for each combination of different antenna designs due to the differing typical antenna radiation patterns.

6 Validation methods for sites used for the calibration of directive antennas

6.1 Validation of the calibration site minimizing ground reflection by a height ≥ 4 m

6.1.1 Measurement procedure

This subclause provides a procedure for validating an outdoor site for subsequent use in calibrating EMC LPDA, hybrid and horn antennas above 200 MHz and up to 18 GHz, as described in 9.4 of CISPR 16-1-6:2014. A ground plane is not required, but the site shall be free of reflections from obstacles following the same principles applicable to a CALTS; also it need not cover as much area as does a CALTS.

If the site does not have a ground plane or surface with a stable reflection coefficient, this validation procedure shall initially be carried out before each use of the site to calibrate antennas, until such time as the worst case reflection is identified, and hence the minimum antenna height. The reflection coefficient of the ground can vary according to the amount of moisture and vegetation, and reflections from any proximate trees can vary.

Besides ground reflectivity, the height required for the undesirable ground reflections to be acceptable is dependent on the separation and directivities of the pair of antennas, and whether they are horizontally or vertically polarized. Vertical polarization is preferred, as shown in Figure 10, because the E-plane pattern is more directive than the H-plane pattern, giving less signal pointing towards the ground. For a specific target uncertainty, the required antenna height is found by starting with a low height (e.g. 2 m) then increasing the height of the antennas in tandem, in steps of a maximum of $\lambda/8$, while monitoring the SIL.

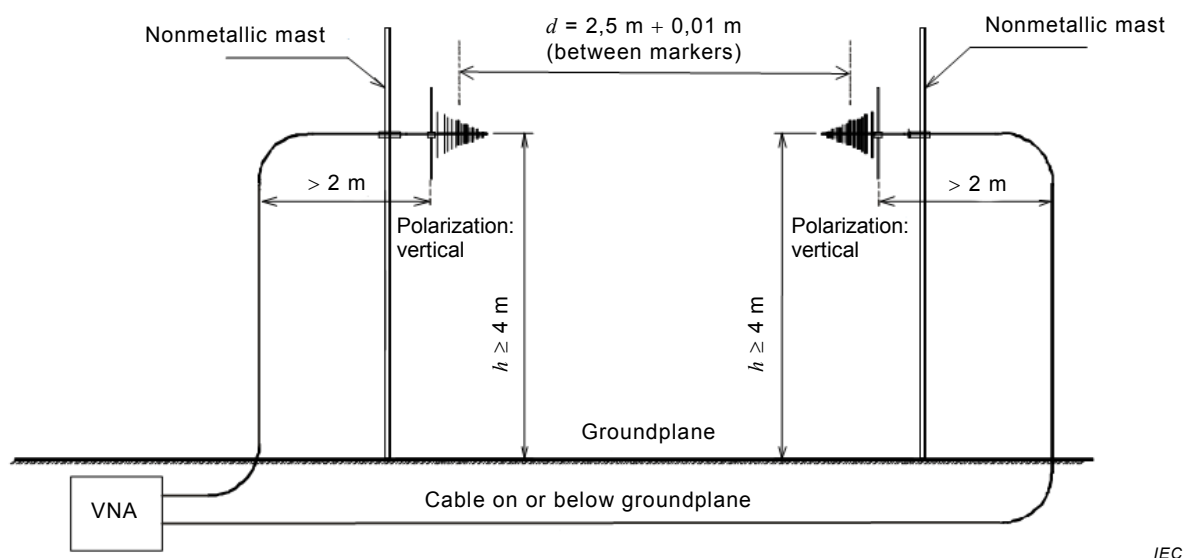


Figure 10 – Example of antenna set-up for an LPDA antenna calibration in the frequency range above 200 MHz

The aim is to cover a sufficient range in height to generate a clear sinusoidal ripple in the SIL, as shown in the example trace in Figure 11, from which the peak-to-peak magnitude can be found. For example above 1875 MHz, a step of 0,02 m over a minimum height traverse of 0,2 m may be used. The ripple is predominantly the result of a main reflection from the ground interacting constructively and destructively with the signal directly between the antennas; however effects of reflections from the environment, such as buildings and trees, will be superimposed on the trace. A tolerance for the site is a peak-to-peak ripple of less than 0,2 dB. This height and separation for that antenna pair in that location constitutes the calibration site. Figure 11 shows that the variation of the SIL is below 0,2 dB at a height of more than 5 m.

However, reflections from tall buildings giving a constant reflection with change in antenna height would not show up by this method. The worst case is a reflective surface in the boresight of the transmit antenna. Figure 12 shows a horn transmitting to an omni-directional antenna. For such reflections to contribute an uncertainty of less than 0,2 dB, the difference in the distances travelled by the transmitted signal, A, to the omni antenna, and the reflected signal, B, to and from the building to the omni antenna, shall be greater than 42 m. In other words, for the boresight scenario in Figure 12 a perfectly reflecting building shall be $> 42 \text{ m}$ from the horn antenna. The distance to the building may be less if the receive antenna has a null in the backward direction. For buildings and metal fences, for example, parallel to the boresight direction, a similar analysis should be carried out, taking into account the radiation patterns of the antennas.

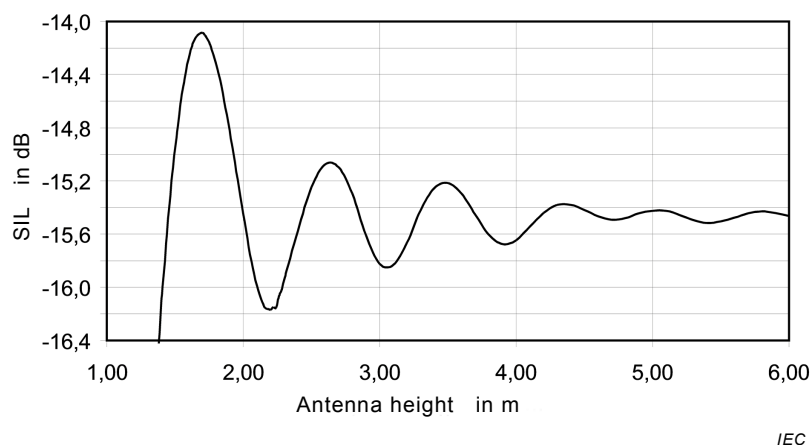


Figure 11 – Example of SIL versus antenna height measured at 200 MHz with two LPDA antennas in vertical polarization at 2,5 m distance between their midpoints above the reflecting ground plane of an OATS

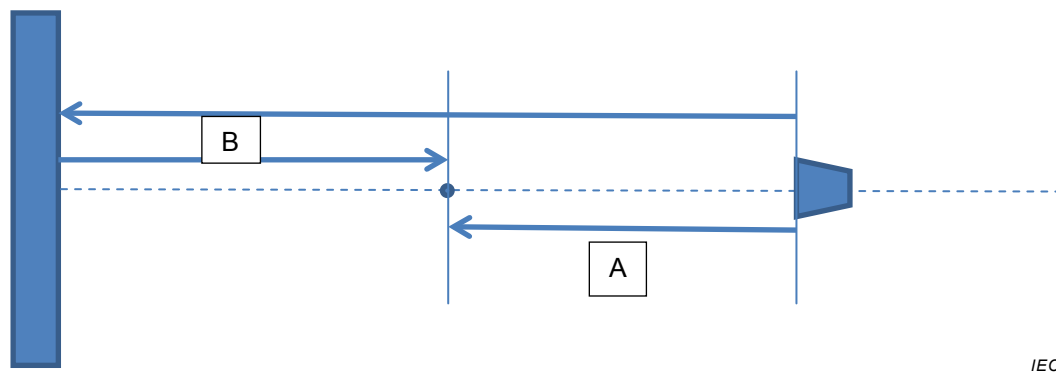


Figure 12 – Illustration of distances of transmit horn to omni-directional receive antenna and reflective building, and transmitted signal paths A and B

6.1.2 Uncertainties

The measurand is the variation of the received signal as the antennas are scanned in height. An example uncertainty budget is given in Table 10.

Table 10 – Example measurement uncertainty budget for the site validation method in 6.1.1

Source of uncertainty or quantity X_i	Value dB	Probability distribution	Divisor	Sensitivity	u_i^a dB	Note ^c
Measuring receiver noise	0,02	Rectangular	$\sqrt{3}$	1	0,012	1)
Reproducibility of antenna height at which the criterion is reached	0,1	Normal	1	1	0,1	
Cable attenuation variation due to temperature or flexing	0,15	Rectangular	$\sqrt{3}$	1	0,087	2)
Ambient RF interference, assuming an ambient signal/receiver noise ratio of at least 20 dB	0,086	Rectangular	$\sqrt{3}$	1	0,050	3)
Linearity error for low level signals, typically < -70 dBm ^b	0,08	Rectangular	$\sqrt{3}$	1	0,046	4)
Combined standard uncertainty, u_c					0,15	
Expanded uncertainty ($k = 2$), $U_{\text{Site Val}}$ in dB					0,30	
^a The sensitivity coefficient, c_i, by virtue of the additivity of the model, is unity for all components. A frequency accuracy of ≤ 10 ppm is assumed. ^b 0,08 dB was in the VNA specification and is an example only. ^c The number of each item corresponds with the Note numbers below. See also Annex E of CISPR 16-1-6:2014 for additional uncertainty component descriptions. Notes: 1) For receiver noise, see 6.2.4 of CISPR 16-1-6:2014. 2) Variation of cable attenuations in the time between the reference attenuation (direct connection) measurement and SIL measurement (with antennas). This may be assumed if the calibration is not performed under extreme environmental conditions (e.g. OATS with temperature changes of more than 5 °C during the calibration process). The minimum cable bend radius should be available from the cable manufacturer. Assess the effect of cable bending through repeat measurements. 3) It is assumed that narrowband ambient signals may be skipped, and the AF at these frequencies may be calculated by interpolation. For receiver noise, see 1). 4) For receiver linearity, see 6.2.3 of CISPR 16-1-6:2014.						

6.2 Validation of the calibration site minimizing ground reflection by use of absorber

Alternatively the antennas may be placed at a lower height (e.g. 2,5 m) with absorber on the ground between the antennas. The absorbing material should have a reflectivity of less than -40 dB at normal angle of incidence across the frequency range of calibration. Assuming an antenna separation of 2,5 m between their mid-points, an area of absorber of 2,4 m length centrally between the antennas and a minimum of 1,8 m width should be used. The same principle of site validation as described in 6.1 may be used.

Alternatively, the measurements may be done in a large fully-anechoic room (FAR). In this case, for site validation the variation of SIL needs to be monitored in two directions: a) using antenna height variation until the minimum of SIL variation versus height is reached (similar to the validation method in 6.1.1), and b) using a variation of the horizontal antenna positions in tandem of the two antennas until the minimum of SIL variation is reached. The distance required from the FAR walls as well as ground and ceiling will again depend on the antenna directivities in horizontal and vertical polarizations, similarly to 5.2. To ensure the effectiveness of absorber on the end walls, the monitoring will be repeated along the axis between the antennas.

7 Site validation by comparison of antenna factors, and application of RSM to evaluate the uncertainty contribution of a SAC site

7.1 Use of SAM for site validation by comparison of antenna factors

This subclause describes the conditions for validating a specific calibration site by comparing AFs measured on it to AFs measured on a site that has been validated by an independent method. A site validated in this way is suitable for use for antenna calibration by the SAM (see also A.9.4 of CISPR 16-1-6:2014). This technique can ensure a considerable cost saving in procuring a calibration site, because the site only needs to provide the EM field environment sufficient to calibrate a particular antenna type. In other words, the site does not need to be over-specified to meet the less focused acceptance criteria of the methods in Clauses 4, 5, and 6. The methods of 5.3 are excluded as validated independent alternative methods.

This technique is particularly suitable for manufacturers who test many of the same model of antenna. However, the site does need to be proved for each model of antenna intended to be calibrated. Small variations in mechanical dimensions of antennas are tolerated; see 8.3.3 of CISPR 16-1-6:2014 for guidance. Clause 6 of this standard has a principle similar to 9.4 of CISPR 16-1-6:2014, in that the site is validated by height scanning a specific pair of antennas.

As an example, this technique of site validation by comparison is beneficial if a calibration laboratory has a CALTS but wants to additionally do some calibrations indoors. The F_a measured in a FAR may be compared to the F_a measured on the CALTS. If the laboratory does not have a CALTS, it can get reference F_a from another calibration laboratory that is able to measure results with low uncertainties.

Another advantage of this technique, i.e. seeing how well F_a agrees with a reference F_a , is that the calibration method can be adapted. For example, in 9.2.2 of CISPR 16-1-6:2014 biconical antennas are calibrated by the SAM using an antenna separation of ≥ 4 m. This reduction from 10 m was found experimentally acceptable by this comparison technique, with the benefit that a smaller FAR may be used.

This technique is useful to extend the frequency range of a calibration site that has already been validated. One example is a requirement to calibrate a horn antenna down to 900 MHz in a FAR that was validated for horn antenna calibrations above 1 GHz. Instead of repeating the validation method down to 900 MHz, an alternative is to obtain a reference F_a for the horn antenna, then see how well the F_a measured in the FAR agrees.

A suitable indoor free-space environment can be achieved in a large enough space in which the extremities of the antenna are at least 1 m away from any absorber lined surface. The AUC and paired antenna shall be separated by at least 1λ , but because biconical antennas are electrically short below 50 MHz, a separation of 5 m is found to work well at frequencies as low as 30 MHz. Larger separations are desirable, because the closer the antennas are, the more sensitive is the resultant AF to the positions of the antennas. Also, when choosing to minimize the room size, the less absorber there is, the more sensitive is the resultant AF to the positioning of the antennas and their mutual coupling to metal surfaces. The best results are achieved when the STA is the same antenna model as the AUC, and is replaced in the same location of the AUC, to a tolerance of better than ± 5 mm in all three Cartesian axes, for frequencies below 1 GHz.

The uncertainty of the measured F_a is obtained by arithmetically adding to the uncertainty of the reference F_a the difference between them, plus a margin for the reproducibility of this process. This added uncertainty can be reduced by repeated comparison measurements of a given type of antenna then using the standard deviation of the results.

This method of validating a site relies strictly on obtaining the same antenna factors, within the desired tolerance, for a given model of antenna. It relies on the site not changing, for the

subsequent calibrations by the SAM of the same model of antenna, with small variations allowed as stated in the second paragraph of this subclause. If there are any changes, including to the layout of any component such as the antennas, masts, and cables, the initial validation shall be repeated.

This method of validating a site is not suitable for antennas with imperfections, e.g. poor balun imbalance that can affect the performance of an antenna within and between calibrations. The validation process can be more intensive than for sites specified to conform to regular validation methods. It is suitable for operators who need to calibrate many of the same model of antenna.

7.2 Application of RSM to evaluate the measurement uncertainty contribution of a calibration site comprising a SAC

Site validation by the comparison of AFs using the SAM is considered in 7.1. Site validation can also be done by comparing the AFs using TAM or SSM measured on a CALTS with those measured on a calibration site to be validated; this can be achieved using RSM in horizontal polarization. This subclause describes the conditions for validating a calibration site comprising a SAC by the use of the RSM basic procedure that is described in CISPR 16-1-4. The resulting contribution of measurement uncertainty of a calibration site validated by this method is usually higher than the contribution of a CALTS.

A site validated using this method is suitable for use for antenna calibration using the SSM (see CISPR 16-1-6). This technique of validation can ensure a considerable cost saving in procuring a calibration site in a SAC, because the site only needs to be validated using broadband antennas of limited size to calibrate a particular antenna type; the site does not need to be over-specified to meet the less focused acceptance criteria of the methods in Clauses 4, 5, and 6.

NOTE The uncertainty of AFs measured in 10 m SACs used as calibration sites can be on the order of 1,5 dB.

This technique of site validation by using a transfer function – in this case by the A_{APR} (see e.g. Clause 5 of CISPR 16-1-4:2010, AMD1:2012) – is beneficial if a calibration laboratory does not have a CALTS but wants to do calibrations in a SAC. The laboratory can get the reference A_{APR} from another calibration laboratory, e.g. a national measurement institute, which is able to provide results with low uncertainties.

This validation procedure is applicable for horizontal polarization using common antennas like biconical, LPDA, or hybrid types. The validation procedure shall be done for typical antenna characteristics, as they can differ significantly due to characteristic antenna patterns. As an example, higher directivity or different front-to-back-ratio in radiation patterns can affect interactions differently, e.g. of walls, masts, or cables.

Usually a SAC has limited dimensions and unique characteristics due to size, geometry and material of the absorber-lined chamber itself. Therefore a small SAC cannot be qualified as a CALTS with tuned dipole antennas. Regardless, a reasonable way to qualify and quantify a SAC is the RSM that may be applied using a transfer function (i.e. antenna pair as a transfer standard) that has been calibrated on a CALTS/REFTS with a low associated measurement uncertainty.

The procedure, which basically consists of antenna pair measurements with one antenna at a height of 2 m and the paired antenna being scanned from 1 m to 4 m height at 10 m distance, shall be carried out on a suitable measurement axis in the absorber-lined chamber. Suitable here means that the site attenuation of the axis deviates as little as possible from that of an ideal OATS. The experimental determination of the suitable axis can be supported with considering existing measurements of the NSA of the absorber-lined chamber. The A_S measured in a SAC can be compared to the theoretical $A_{S\text{ ref}}$ (see 5.4 of CISPR 16-1-4:2010, AMD1:2012) by using the A_{APR} calibrated on a CALTS or REFTS.