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TECHNICAL REPORT

INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE

Specification for radio disturbance and immunity measuring apparatus and methods – Part 4-5: Uncertainties, statistics and limit modelling – Conditions for the use of alternative test methods

CISPR TR 16-4-5:2006-10+AMD1:2014-07+AMD2:2021-10 CSV(en)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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CISPR TR 16-4-5 edition 1.2 contains the first edition (2006-10) [documents CISPR/A/665/DTR and CISPR/A/685/RVC], its amendment 1 (2014-07) [documents CISPR/A/1050/DTR and CISPR/A/1069/RVC] and its amendment 2 (2021-10) [documents CIS/A/1321/DTR and CIS/A/1324/RVDTR].

In this Redline version, a vertical line in the margin shows where the technical content is modified by amendments 1 and 2. Additions are in green text, deletions are in strikethrough red text. A separate Final version with all changes accepted is available in this publication.

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

CISPR 16-4-5, which is a technical report, has been prepared by CISPR subcommittee A: Radio-interference measurements and statistical methods.

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

A list of all parts of the CISPR 16-4 series, published under the general title *Specification for radio disturbance and immunity measuring apparatus and methods – Part 4: Uncertainties, statistics and limit modelling*, can be found on the IEC website.

The committee has decided that the contents of the base publication and its amendments 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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SPECIFICATION FOR RADIO DISTURBANCE AND IMMUNITY MEASURING APPARATUS AND METHODS –

Part 4-5: Uncertainties, statistics and limit modelling – Conditions for the use of alternative test methods

1 Scope

This part of CISPR 16-4 specifies a method to enable product committees to develop limits for alternative test methods, using conversions from established limits. This method is generally applicable for all kinds of disturbance measurements, but focuses on radiated disturbance measurements (i.e. field strength and total radiated power), for which several alternative methods are presently specified. These limits development methods are intended for use by product committees and other groups responsible for defining emissions limits in situations where it is decided to use alternative test methods and the associated limits in product standards.

2 Normative references

IEC 60050-161:1990, *International Electrotechnical Vocabulary (IEV) – Chapter 161: Electromagnetic compatibility*

CISPR 16-1-1:2019, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-1: Radio disturbance and immunity measuring apparatus – Measuring apparatus*

~~CISPR 16-4-1:2003, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 4-1: Uncertainties, statistics and limit modelling – Uncertainty in standardized EMC tests*~~

CISPR 16-4-2:~~2003~~2011, *Specification for radio disturbance and immunity measuring apparatus and methods ~~–~~ Part 4-2: Uncertainties, statistics and limit modelling – ~~Uncertainty in EMC measurements~~ Measurement instrumentation uncertainty*
CISPR 16-4-2:2011/AMD1:2014
CISPR 16-4-2:2011/AMD2:2018

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-161 and the following apply.

3.1
established test method
test method described in a basic standard with established emissions limits defined in corresponding product or generic standards. An established test method consists of a specific test procedure, a specific test set-up, a specific test facility or site, and an established emissions limit

NOTE The following test methods have been considered to be established test methods in CISPR:

– conducted disturbance measurements at mains ports using an AMN in the frequency range 9 kHz to 30 MHz; ~~test~~ this method is defined in CISPR 16-2-1~~:2003, Clause 7~~;

– radiated disturbance measurements ~~up~~ in the frequency range 30 MHz to 1 GHz at 10 m distance on an OATS or in a SAC; ~~the test~~ this method is defined in CISPR 16-2-3~~, 7.2.1~~;

– radiated disturbance measurements ~~up~~ in the frequency range 1 GHz to 18 GHz at 3 m distance on an FSOATS; ~~the test~~ this method is defined in CISPR 16-2-3~~, 7.3~~.

3.2
alternative test method
test method described in a basic standard without established emissions limits. The alternative test method is designed for the same purpose as the established test method. An alternative test method consists of a specific test procedure, a specific test set-up, a specific test facility or site, and a derived emissions limit that was determined by the application of the proposed method stated in this document

3.3
established limit
limit having "many years" of good protection of radio services.

NOTE An example is radiated field strength measured on OATS, developed to protect radio services as described in CISPR 16-3.

3.4
derived limit
limit applicable for the alternative test method, derived by appropriate conversion from the established limit and expressed in terms of the misbrands

3.5
conversion factor *K*
for a given EUT or type of EUT, the relation of the measured value of the established test method to the measured value of the alternative test method

NOTE The terms measured and calculated are used interchangeably at various places in this document to describe actual laboratory tests and computer simulations.

3.6
reference quantity *X*
the basic parameter which determines the interference potential to radio reception. It may be independent of the parameters presently used in established standards

NOTE The goal for both the established and alternative test methods is to determine the reference quantity (*X*) for all frequencies of interest. For both established and alternative test methods, the test results may deviate from the reference quantity values. The specification of the reference quantity when applying methods of this document should include applicable procedures and conditions to calculate (or measure) this quantity

3.7
inherent uncertainty
u_{inherent}
uncertainty caused solely by the difference in EUT characteristics and the ability of the measurement procedure to cope with them. It is specific to each test method and remains, even if the measurement is performed perfectly, i.e., the standards compliance uncertainty is zero and the measurement instrumentations uncertainty is zero

3.8
intrinsic uncertainty of the measurand
$u_{\mathrm{intrinsic}}$
minimum uncertainty that can be assigned in the description of a measured quantity. In theory, the intrinsic uncertainty of the measurand would be obtained if the measurand was measured using a measurement system having negligible measurement instrumentation uncertainty.

[CISPR 16-4-1:2009, ~~definition 3.6~~ 3.1.6, modified – Deletion of notes]

3.9
EUT type
grouping of products with sufficient similarity in electromagnetic characteristics to allow testing with the same test installation and the same test protocol.

3.10
standards compliance uncertainty
SCU
parameter, associated with the result of a compliance measurement as described in a standard, that characterizes the dispersion of the values that could reasonably be attributed to the measurand

[IEC 60050-161:1990, 311-01-02, modified, deletion of the notes]

3.11
EUT volume
cylinder defined by EUT boundary diameter and height that fully encompasses all portions of the actual EUT, including cable racks and 1,6 m of cable length (for 30 MHz to 1 GHz), or 0,3 m of cable length (for 1 GHz and above)

NOTE 1 The test volume is one of several criteria limiting the EUT volume.

NOTE 2 The EUT volume has a diameter D (boundary diameter) and a height h.

4 Symbols and abbreviated terms

The following abbreviations are used in this technical report. Note that the symbol k is used for four different quantities.

ATM alternative test method (e.g. subscript in D_{ATM})

D deviation

ETM established test method (e.g. subscript in D_{ETM})

f index number of an individual measured frequency

F number of measured frequencies in the considered frequency range

FAR fully anechoic room

i index number of ~~one~~ an individual EUT ~~(e.g., of a number of EUTs)~~

j index number of an individual test lab

~~*K* conversion factor~~

~~*k* coverage factor~~

k $= 2\pi/\lambda$, wave number (in this document, k is used in the electrical size ka, where a is the EUT radius)

$k(f)$ linear conversion factor

$K(f)$ logarithmic conversion factor

k coverage factor

k Boltzmann's constant

L limit

M measurement (or calculation) result

N number of EUTs

OATS open-area test site

RC reverberation chamber

RRT round robin test

s standard deviation

SAC semi-anechoic chamber

SCU standards compliance uncertainty

T number of test labs

U	expanded uncertainty
u	standard uncertainty
v	volume
X	reference quantity
Δ	difference of two values or quantities
$\bar{x}$	mean value of a set of values *x* (e.g., $\bar{D}$)

5 Introduction

Over the years, several test ~~procedures~~ methods and test set-ups for radiated ~~emissions testing~~ disturbance measurement have been described in basic standards. One particular combination of test method and test set-up also having defined ~~emissions~~ disturbance limits is the open area test site (OATS) method, which has proven to be successful for the protection of radio services. ~~In general~~ Since the first edition of this document, limits have ~~not~~ been defined for ~~the~~ other~~,~~ – alternative – test methods, e.g., fully anechoic rooms~~,~~ and TEM waveguides, but not for reverberation chambers.

Each alternative method can be used to get measurement results related to ~~emission of the~~ disturbance from an EUT. Although each method gives ~~an emission~~ a disturbance level from ~~the~~ an EUT, the different methods ~~may~~ might capture the EUT ~~emission~~ disturbance differently. For example, considering radiated ~~emission~~ disturbance measurements, different methods may capture different EUT radiation pattern lobes, ~~differing numbers~~ a different number of lobes, or the test facility ~~may~~ might alter the EUT radiation pattern producing a different apparent ~~emission~~ disturbance level. Therefore the limits defined for the established test method cannot be applied directly to the alternative test methods. Consequently, ~~a~~ procedures ~~is~~ are needed ~~for how~~ to derive limits to be used for the results of alternative test methods.

The specification ~~for~~ of such ~~a~~ procedures ~~should~~ considers the general goal of disturbance measurements~~. The aim of the disturbance measurement~~, which is to verify whether ~~the~~ an EUT satisfies or violates certain compliance criteria. Past experience has shown that using the present system of ~~the~~ established test methods and ~~the~~ associated limits yields a situation without many cases of interference due to conducted disturbance or radiated ~~emissions~~ disturbance. Applying ~~the~~ an established test method with ~~the~~ its associated limits will fulfill the protection requirement with a high probability. To preserve this situation, the most important requirement for the use of alternative test methods is ~~as follows~~ the following:

– Use of an alternative test method in a normative standard shall provide the same protection of radio services as the established test method.

This requirement can be met by developing ~~a procedure for deriving emission~~ procedures to derive disturbance limits for ~~the~~ alternative test methods from the existing limits of the established test methods. Such ~~a~~ procedures shall relate the results ~~of the~~ from an alternative test method to those ~~of the~~ from an established test method. Using the relations derived in this ~~relation~~ document, the limits of the relevant established test method can be converted into limits for the alternative test method. The measured values of the alternative test method can then easily be evaluated against the converted limits. Such ~~a~~ procedures will provide a similar amount of protection, even though an alternative test method is used.

The limit~~s~~ conversion procedures ~~should~~ consider the preceding goal of ~~emissions~~ disturbance measurements ~~as described above~~. The results of standard ~~emissions tests~~ disturbance measurements can be considered as an approximation of the interference potential of an EUT. Depending on the characteristics of ~~the~~ an EUT (e.g., radiation pattern characteristics for radiated disturbance test methods), and ~~on~~ the ~~measurement~~ test set-up, the measured value ~~differs~~ deviates from the actual interference potential of the EUT. This deviation can be divided into two parts: 1) a systematic deviation, which can be interpreted as a bias of the test method~~,~~; and 2) a random deviation depending on the characteristics of different EUTs, which can be interpreted as an uncertainty of the test method. Each ~~emissions~~

disturbance test method contains both quantities, and consequently the established test method does too. In the following clauses, a procedure based on these two quantities for comparing an alternative test method with the established test method is described. To determine these quantities, the abstract term "interference potential" needs to shall be expressed in terms of a physical quantity. For the purposes of this report document, this physical quantity is called the "reference quantity" X. More Other details about correlation comparison of test methods using a reference quantity can be found in [1][1].

The significance of a reference quantity is under discussion (see Magdowski [16]). It is not used in the derivation of limits for an alternative test method based on measurements (see Clause 7 of CISPR TR 16-4-5:2006/AMD1:2014), and in the derivation of limits for disturbance measurements using a reverberation chamber (i.e. in this document).

6 Procedure to derive limits for an alternative test method

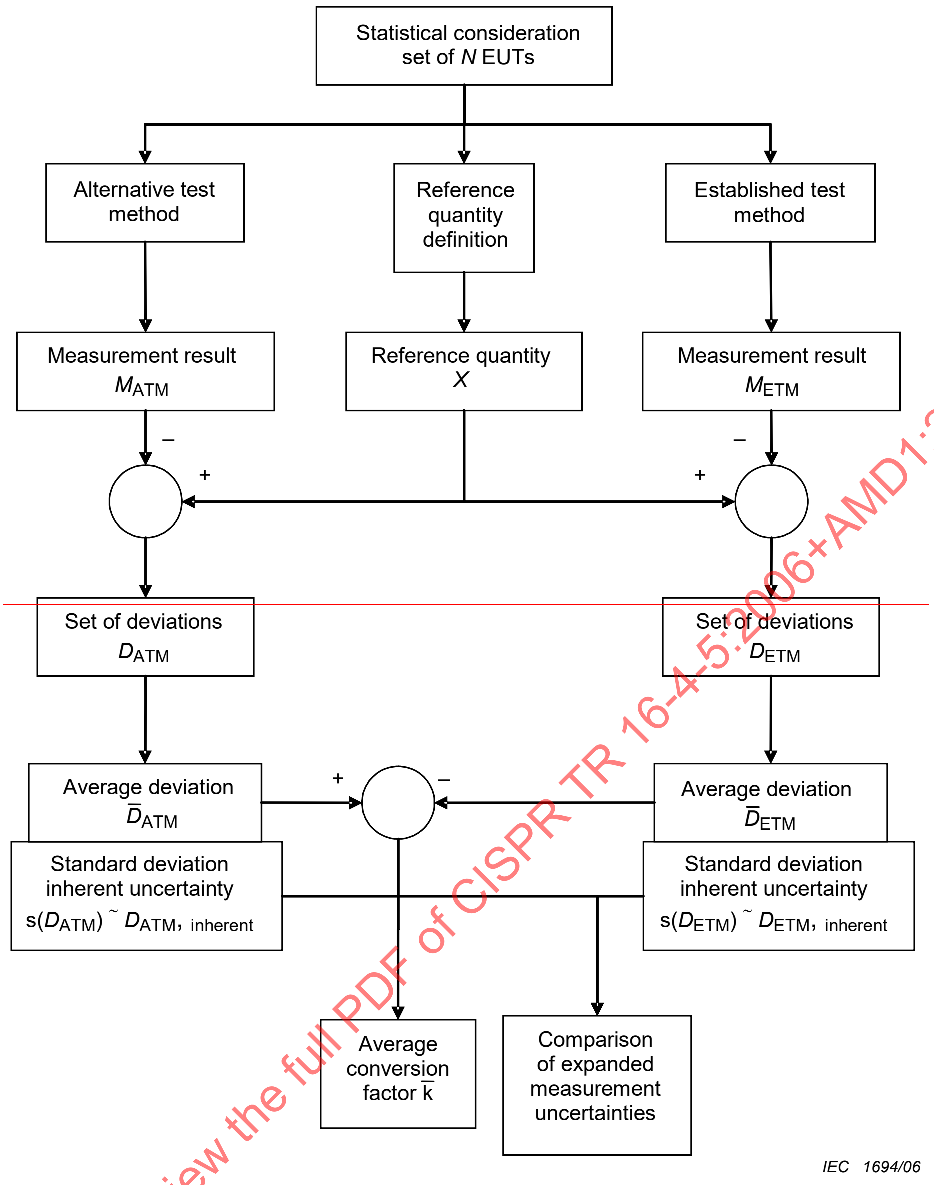
6.1 Overview

A procedure to derive limits for an alternative test method based on the limits of an established test method is described in the following paragraphs. Figure 1 shows a summary of the estimated quantities needed for the correlation process. Figure 2 shows a flowchart for the correlation process using these quantities. The nine-step conversion process below can be accomplished using numerical simulations, measurements, or a combination of simulations and measurements. Calculable or reference EUTs are invaluable for this conversion procedure. In the following subclauses, as part of the conversion process the quantities shown in Figure 1 and Figure 2 are combined into several equations. A summary of the equations is given in Table 2. A summary of the steps in the conversion procedure is shown in Table 1.

Table 1 – Summary of steps in conversion procedure

1	Select the reference quantity
2	Describe the test methods and measurands
3	Determine the deviations of the measured quantities from the reference quantity
4	Determine the average values of the deviations
5	Determine the standard uncertainties of the test methods
6	Verify the calculated values
7	Apply the conversion

1 Figures in square brackets refer to the Bibliography.


Statistical consideration set of N EUTs
Alternative test method
Reference quantity definition
Established test method
Measurement result M_ATM
Reference quantity X
Measurement result M_ETM
–
+
+
–
Set of deviations D_ATM
Set of deviations D_ETM
Average deviation D̄_ATM
+
–
Average deviation D̄_ETM
Standard deviation inherent uncertainty s(D_ATM) ~ D_ATM, inherent
Standard deviation inherent uncertainty s(D_ETM) ~ D_ETM, inherent
Average conversion factor k̄
Comparison of expanded measurement uncertainties
IEC 1694/06

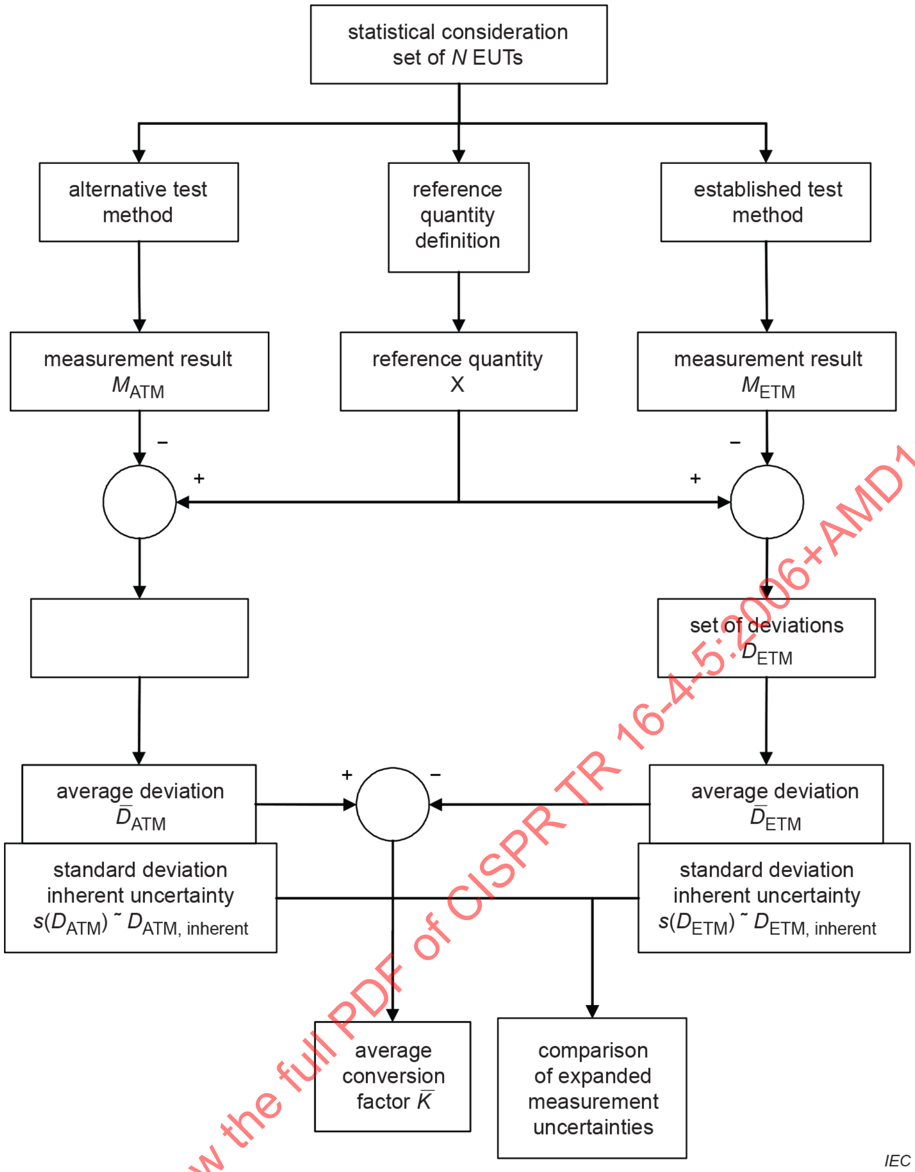
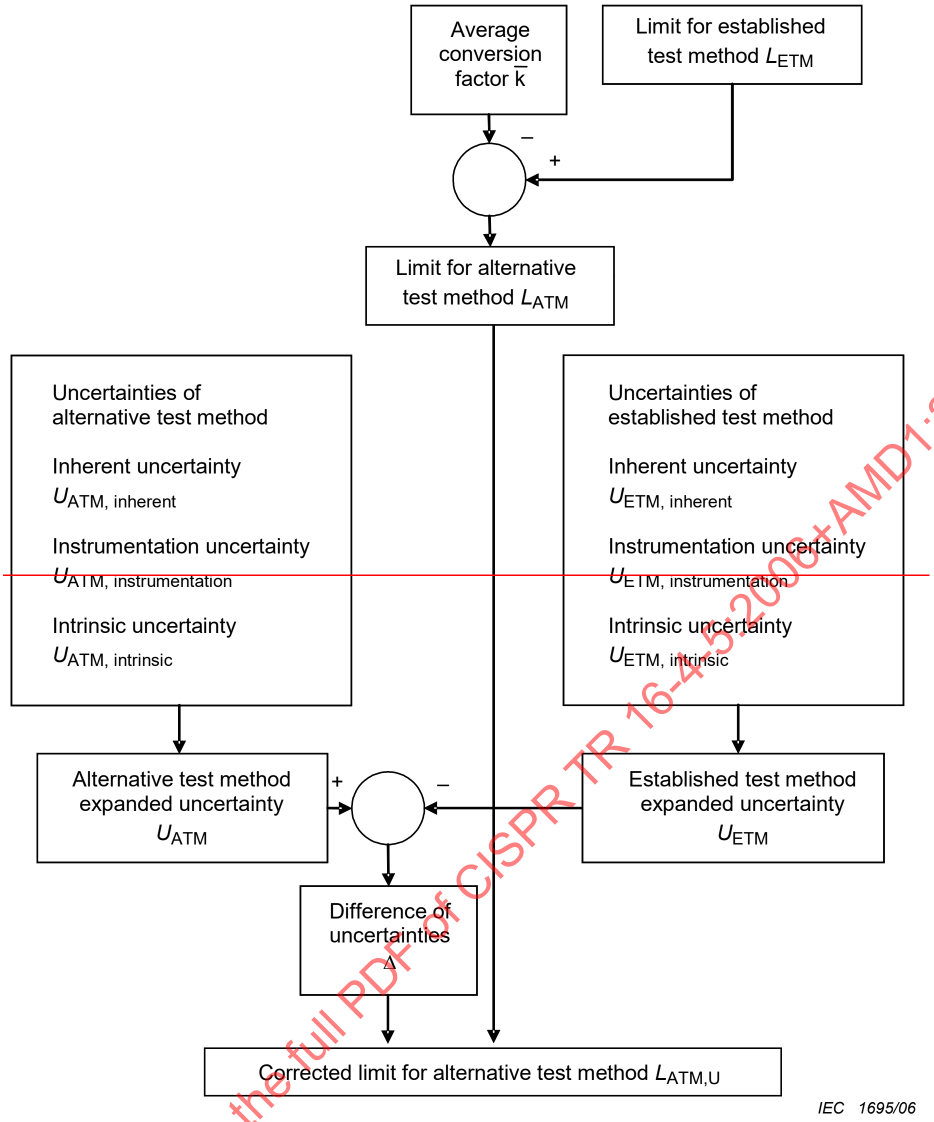


Figure 1 – Overview of quantities to estimate for use in conversion procedure


Average conversion factor k̄
Limit for established test method L_{ETM}
–
+
Limit for alternative test method L_{ATM}
Uncertainties of alternative test method
Inherent uncertainty $U_{ATM, inherent}$
Instrumentation uncertainty $U_{ATM, instrumentation}$
Intrinsic uncertainty $U_{ATM, intrinsic}$
Uncertainties of established test method
Inherent uncertainty $U_{ETM, inherent}$
Instrumentation uncertainty $U_{ETM, instrumentation}$
Intrinsic uncertainty $U_{ETM, intrinsic}$
Alternative test method expanded uncertainty U_{ATM}
+
–
Established test method expanded uncertainty U_{ETM}
Difference of uncertainties Δ
Corrected limit for alternative test method $L_{ATM,U}$
IEC 1695/06

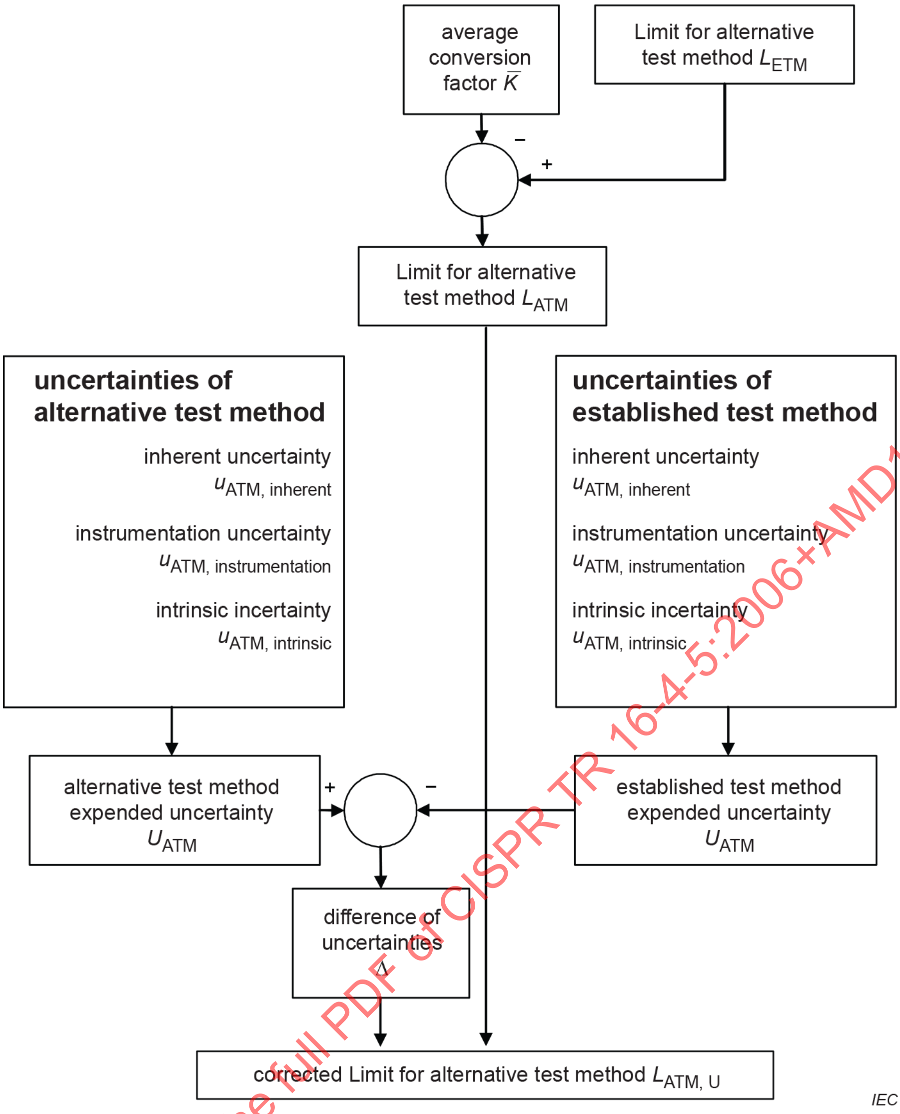


Figure 2 – Overview of limit conversion procedure using estimated quantities

Table 2 – Overview of quantities and defining equations for conversion process

Quantity	Meaning	Equation no.
$D_{ATMi}(f)$	the deviation from the reference quantity of the measurement result of EUT *i* as produced by the alternative test method	(1)
$D_{ETMi}(f)$	the deviation from the reference quantity of the measurement result of EUT *i* as produced by the established test method	(2)
$\overline{D}_{ATM}$	the average deviation of the alternative test method	(3)
$\overline{D}_{ETM}$	the average deviation of the established test method	(4)
$u_{ATM,inherent}$	the inherent uncertainty of the alternative test method	(5)
$u_{ETM,inherent}$	the inherent uncertainty of the established test method	(6)
u_{ATM}	combined standard uncertainty of the alternative test method	(7)
U_{ATM}	the expanded uncertainty of the alternative test method	(8)
u_{ETM}	combined standard uncertainty of the established test method	(9)
U_{ETM}	the expanded uncertainty of the established test method	(10)
$K_i(f)$	frequency dependent conversion factor for EUT *i*	(11)
$\overline{K}(f)$	the average of the conversion factors	(12), (13), (14)
$L_{ATM}(f)$	the limit line of the alternative test method equivalent to the limit of the established test method, without consideration of the uncertainties	(15)
Δ	difference of expanded uncertainties	(16)
$L_{ATM,U}$	the limit to be used for alternative measurements	(17)
USC,XTM	standards compliance uncertainty for the test method X, where X is either “E” for established test method or “A” for alternative test method	(26)
DK	deviation of the single calculated conversion factor $K_i(f,j)$ from the average conversion factor $\overline{K}(f)$	(20), (21)
DXTM	deviation of the single measured value $M_{XTM,i}(f,j)$ from the average for the measured values $\overline{M}_{XTM,i}$	(24), (25)
MXTM,i(f,j)	measured value depending on EUT, lab, and frequency	(18), (23)
Emax	Maximum field strength of an EUT in μV/m measured using the ETM, i.e. at d = 10 m at an OATS/SAC from 80 MHz to 1 000 MHz, and at d = 3 m at a FSOATS/FAR from 1 GHz to 18 GHz	(35)
PT	Power transmitted from an EUT in pW measured using the reverberation chamber test method (ATM), and virtual powera) producing the field-strength maximum Emax measured using the ETM	(35)

a) The virtual power is the power generating E_{max} assuming the EUT directivity is estimated in this document.

6.2 Select the reference quantity *X*

The first step is to select the reference quantity *X*. It should be selected on the basis of a quantity that can possibly cause interference to a radio service, and selection of a reference quantity also depends on the type of EUT.

For the types of EUTs investigated in Annex B, as an example the maximum electric field strength determined on a sphere of a certain radius around the EUT has been selected as the reference quantity for radiated emission measurements in the frequency range of 30 MHz to 1 GHz. In the frequency range below 30 MHz, depending on the frequency subrange and the coupling model, the reference quantity may be the vertical component of the electric field strength, the magnetic field strength, or the asymmetric voltage. In general, the reference quantity and the actual measurands will not necessarily have the same units.

6.3 Describe the test methods and measurands

The measurand shall be described for both the alternative and the established test methods. In addition, the test set-up geometry, the methods of measurement for EUT emissions, and any analysis methods producing the final measurement results shall be described. This description is necessary for an understanding about how the test method works and to give a basis for comparison of the two test methods. In most cases this description is explicit or implicit in the standards that specify the test methods.

6.4 Determine the deviations of the measured quantities from the reference quantity

Each test method provides results, each of which deviate from the reference quantity *X*. The deviation depends on the characteristics of the test set-up as well as on the characteristics of the EUT. Considering a certain EUT *i*, a frequency dependent deviation can be determined for both alternative and established test method.

For a given EUT *i* the deviation of the alternative test method, in a logarithmic scale, is given as

$$D_{\mathrm{ATM}i}(f) = X_i(f) - M_{\mathrm{ATM}i}(f) \quad (1)$$

where

i	is the index of the EUT;
f	is the frequency;
$D_{\mathrm{ATM}i}(f)$	is the deviation from the reference quantity of the measurement result of EUT *i* as produced by the alternative test method;
$X_i(f)$	is the reference quantity defined in 6.2 for the EUT *i*, and
$M_{\mathrm{ATM}i}(f)$	is the measurement result given by the alternative test method for the EUT *i*.

The results of the established test method will deviate from the reference quantity as well. The deviation of the established test method is analogously given by the equation

$$D_{\mathrm{ETM}i}(f) = X_i(f) - M_{\mathrm{ETM}i}(f) \quad (2)$$

where

$X_i(f)$, f, i	are the same as in Equation (1);
$D_{\mathrm{ETM}i}(f)$	is the deviation from the reference quantity of the measurement result of EUT *i* as produced by the established test method;
$M_{\mathrm{ETM}i}(f)$	is the measurement result given by the established test method for the EUT *i*.

6.5 Determine the average values of the deviations

The deviations given by Equations (1) and (2) will differ for different EUTs. In order to obtain more universal results, varying characteristics of EUTs shall be considered, for example as shown in Annex A. Considering a range of *N* EUTs leads to a set of *N* values for the deviation *D* for both alternative and established test methods. From this set of *D* the average can be easily determined. See Annex A for more details about EUT considerations and variations.

An estimate of the mean of the deviation of the alternative test method is given by

$$\overline{D}_{\mathrm{ATM}} = \frac{1}{N}\sum_{i=1}^{N} D_{\mathrm{ATM}i} \tag{3}$$

where

D_{ATM} is the set of deviations of the alternative test method;

$\overline{D}_{\mathrm{ATM}}$ is the average deviation of the alternative test method;

N is the number of EUTs considered, and shall be as large as possible for statistical reasons;

i is the index of any one EUT;

$D_{\mathrm{ATM}i}$ is the deviation from the reference quantity of the measurement result of EUT i, as produced by the alternative test method [Equation (1)].

An estimate of the mean of the deviation of the established test method is given by

$$\overline{D}_{\mathrm{ETM}} = \frac{1}{N}\sum_{i=1}^{N} D_{\mathrm{ETM}i} \tag{4}$$

where

D_{ETM} is the set of deviations of the established test method;

$\overline{D}_{\mathrm{ETM}}$ is the average deviation of the established test method;

N, i are the same as in Equation (3);

$D_{\mathrm{ETM}i}$ is the deviation from the reference quantity of the measurement result of EUT i, as produced by the established test method [Equation (2)].

6.6 Estimate the standard uncertainties of the test methods

The methods comparison procedure must consider uncertainties, as are associated with every measurement result. Because the results from the established test method itself have uncertainties, care must be taken that these uncertainties are not transferred to results from the alternative test methods as part of the conversion procedure. Otherwise, the use of alternative test methods would be burdened with uncertainties that are characteristics of the established test method.

The uncertainty of emission measurements consists of several components. On one hand, the measurement equipment contributes several uncertainties, as documented in CISPR 16-4-2. On the other hand the test set-up combined with the radiation characteristics of the EUT causes an inherent uncertainty, u_{inherent}. For example, in radiated emissions measurements, for some types of EUT radiation patterns, an OATS test (established test method) may fail to capture the radiated emission peak lobe. Deviations between the results of a test method and the reference quantity depend on the radiation characteristics of the EUT, but the radiation characteristics of an arbitrary EUT are not known *a priori*. The resulting uncertainty u_{inherent} can be estimated only if the behaviour of EUTs with different characteristics is examined. Analogously to as in 6.4, the deviations from the reference quantity of a set of N EUTs can be used for estimating the standard deviation as a measure for the inherent uncertainties.

Using the formula for experimental standard deviation, the inherent uncertainty of the alternative test method is given by:

$$u_{\mathrm{ATM,inherent}} = s(D_{\mathrm{ATM}}) = \sqrt{\frac{\sum_{i=1}^{N}(D_{\mathrm{ATM}i} - \overline{D}_{\mathrm{ATM}})^2}{N-1}} \tag{5}$$

where

$u_{\text{ATM,inherent}}$ is the inherent uncertainty of the alternative test method;

$s(D_{\text{ATM}})$ is the experimental standard deviation of the set D_{ATM};

N, i, D_{ATM}, $D_{\text{ATM}i}$ are the same as in Equation (3).

Analogously, the inherent uncertainty of the established test method is given:

$$u_{\text{ETM,inherent}} = s(D_{\text{ETM}}) = \sqrt{\frac{\sum_{i=1}^{N}(D_{\text{ETM}i} - \overline{D}_{\text{ETM}})^2}{N-1}} \quad (6)$$

where

$u_{\text{ETM,inherent}}$ is the inherent uncertainty of the established test method;

$s(D_{\text{ETM}})$ is the experimental standard deviation of the set D_{ETM};

N, i, D_{ETM}, $D_{\text{ETM}i}$ are the same as in Equation (4).

6.7 Estimate the expanded uncertainties of the test methods

The expanded measurement uncertainty is obtained from the multiplication of the combined standard uncertainties by a coverage factor k. The combined standard uncertainty of the alternative test method u_{ATM} can be calculated from

$$u_{\text{ATM}} = \sqrt{u_{\text{ATM,m}}^2 + u_{\text{ATM,intrinsic}}^2 + u_{\text{ATM,inherent}}^2} \quad (7)$$

where

$u_{\text{ATM,m}}$ is the combined standard uncertainty of the alternative test method contributed by measurement instrumentation;

$u_{\text{ATM,inherent}}$ is the inherent uncertainty of the alternative test method, according to Equation (5);

$u_{\text{ATM,intrinsic}}$ is the intrinsic uncertainty of the alternative test method.

Using the coverage factor k, the expanded uncertainty of the alternative test method is estimated:

$$U_{\text{ATM}} = k \cdot u_{\text{ATM}} \quad (8)$$

where

U_{ATM} is the expanded uncertainty of the alternative test method;

k is the coverage factor;

u_{ATM} is the combined standard uncertainty of the alternative test method according to Equation (7).

Analogously the combined standard uncertainty of the established test method u_{ETM} can be obtained,

$$u_{\text{ETM}} = \sqrt{u_{\text{ETM,m}}^2 + u_{\text{ETM,intrinsic}}^2 + u_{\text{ETM,inherent}}^2} \quad (9)$$

where

$u_{\text{ETM,m}}$ is the combined standard uncertainty of the established test method contributed by measurement instrumentation;

$u_{\text{ETM,inherent}}$ is the EUT-dependent uncertainty of the established test method, according to Equation (6);

$u_{\text{ETM,intrinsic}}$ is the intrinsic uncertainty of the established test method.

The expanded uncertainty of the established test method is given by

$$U_{\text{ETM}} = k \cdot u_{\text{ETM}} \tag{10}$$

where

U_{ETM} is the expanded uncertainty of the established test method;

k is the coverage factor;

u_{ETM} is the combined standard uncertainty of the established test method according to Equation (9).

6.8 Calculate the average conversion factor

For each EUT i a frequency dependent conversion factor $K_i(f)$ can be calculated using

$$K_i(f) = D_{\text{ATM}i}(f) - D_{\text{ETM}i}(f) \tag{11}$$

where

$D_{\text{ATM}i}(f)$ is the deviation from the reference quantity of the measurement result of EUT i, as produced by the alternative test method [Equation (1)];

$D_{\text{ETM}i}(f)$ is the deviation from the reference quantity of the measurement result of EUT i, as produced by the established test method [Equation (2)].

The average conversion factor can be calculated from the average deviations of the alternative and the established test methods:

$$\overline{K}(f) = \overline{D}_{\text{ATM}}(f) - \overline{D}_{\text{ETM}}(f) \tag{12}$$

where

$K(f)$ is the set of conversion factors;

$\overline{K}(f)$ is the average of the conversion factors;

$\overline{D}_{\text{ATM}}(f)$ is the average deviation of the alternative test method from the reference quantity, in dB;

$\overline{D}_{\text{ETM}}(f)$ is the average deviation of the established test method from the reference quantity, in dB.

Substituting the averages by Equations (3) and (4) gives:

$$\overline{K} = \overline{D}_{\text{ATM}} - \overline{D}_{\text{ETM}} = \frac{1}{N}\sum_{i=1}^{N} D_{\text{ATM}i} - \frac{1}{N}\sum_{i=1}^{N} D_{\text{ETM}i} \tag{13}$$

Using Equations (1) and (2), the average conversion factor can be expressed in terms of the measurement results of the set of EUTs:

$$\overline{K} = \frac{1}{N}\sum_{i=1}^{N}(X_i - M_{\text{ATM}i}) - \frac{1}{N}\sum_{i=1}^{N}(X_i - M_{\text{ETM}i}) = \frac{1}{N}\sum_{i=1}^{N}(M_{\text{ETM}i} - M_{\text{ATM}i}) \quad (14)$$

where $\overline{K}$ is the same as in Equation (12) and $M_{\text{ETM}i}$ and $M_{\text{ATM}i}$ are the same as in Equation (1) and Equation (2).

6.9 Verify the calculated values

In many cases it is necessary to obtain both the deviations from the reference quantity, and their average and standard deviation values, from numerical simulations. It is strongly recommended to verify such calculations by measurements.

6.10 Apply the conversion

If the limit lines defined for the established test method are to be converted into limit lines for an alternative test method, the results from Equations (8), (10), and (12) or (14), respectively, are needed.

A limit line of an established test method can be converted into limit conditions for an alternative test method using the average conversion factor:

$$L_{\text{ATM}}(f) = L_{\text{ETM}}(f) - \overline{K}(f) \quad (15)$$

where

$\overline{K}(f)$ is the frequency-dependent average conversion factor according to Equation (12);

$L_{\text{ETM}}(f)$ is the frequency-dependent limit of the established test method;

$L_{\text{ATM}}(f)$ is the limit line of the alternative test method equivalent to the limit of the established test method, without consideration of the uncertainties.

To complete the process, the uncertainties of both alternative and established test methods have to be taken into account. Defining a difference, Δ, between the uncertainty of the alternative test method, U_{ATM}, and the uncertainty of the established test method U_{ETM}, i.e.,

$$\Delta = U_{\text{ATM}}(f) - U_{\text{ETM}}(f) \quad (16)$$

implies a rule for how to handle the measurement uncertainties. If the uncertainty of the alternative test method is larger than the uncertainty of the established test method, it shall be used to correct the limit of the alternative test method:

$$L_{\text{ATM},U} = \begin{cases} L_{\text{ATM}} - \Delta & \text{if } \Delta > 0 \\ L_{\text{ATM}} & \text{if } \Delta \le 0 \end{cases} \quad (17)$$

where $L_{\text{ATM},U}$ is the limit to be used for alternative measurements.

7 Measurement-based procedure to derive limits for an alternative test method based on measurement results

7.1 General

As presented in Clause 6, the conversion factor $\overline{K}$ of alternative disturbance measurement methods is based on the concept of the availability of models of the measurement methods under consideration, the considered EUTs, and the application of an independent reference quantity *X*. In this way, the inherent uncertainties of the two methods under comparison are determined, and these uncertainties plus the intrinsic uncertainties of the measurand and the measurement instrumentation uncertainties (MIUs) are taken into account in determining the limit for the ATM [see Equations (7), (9) and (16)].

Because the independent reference quantity is not always available, the conversion factor $\overline{K}$ can be estimated by direct comparison of the measurement results [see Equation (14)]. The uncertainty of each measurement procedure~~s~~ is estimated by the standards compliance uncertainty (SCU). The uncertainty of the conversion factor is determined by the SCUs of the ETM and ATM, as well as by the different characteristics of the EUTs. The limit L_{ATM} is determined according to Equation (15) using the conversion factor $\overline{K}$. The limit $L_{ATM,U}$ takes into account the difference between the SCUs of the ATM and ETM, as well as the uncertainty caused by the different characteristics of the EUTs.

The condition for the estimation of the conversion factor by measurements is that at least five independent sets of data for each EUT are obtained through a round robin test (RRT), and *N* representative EUTs are used for the RRT. To assure statistical independence of the sets of data, the RRT involves at least five test houses. For simplicity, it is assumed here that each set of data is provided by a different test house. Outliers are identified and removed from the sets of data if no correction is possible.

7.2 Application of practical measurement results to determine the conversion factors

7.2.1 The conversion factor

The conversion factor K_i in the considered frequency range can be calculated for each of the *F* measured frequencies, for each of the *N* EUTs and for each of *T* labs.

$$K_i(f,j) = M_{ATM,i}(f,j) - M_{ETM,i}(f,j) \quad \text{in dB} \tag{18}$$

The average conversion factor $\overline{K}(f)$ is calculated using Equation (19).

$$\overline{K}(f) = \frac{1}{NT}\sum_{i=1}^{N}\sum_{j=1}^{T} K_i(f,j) \quad \text{in dB} \tag{19}$$

The uncertainty of the average conversion factor $\overline{K}(f)$ can be estimated by the deviation $D_{K,i}(f,j)$ of each calculated conversion factor $K_i(f,j)$ from the average conversion factor $\overline{K}(f)$ and the standard deviation s_K of $D_{K,i}(f,j)$.

$$D_{K,i}(f,j) = \overline{K}(f) - K_i(f,j) \quad \text{in dB} \tag{20}$$

The experimental standard deviation can be calculated by

$$s_K = \sqrt{\frac{1}{(NTF)-1}\sum_{i=1}^{N}\sum_{j=1}^{T}\sum_{f=1}^{F}[\overline{D}_K - D_{K,i}(f,j)]^2} \quad \text{in dB} \tag{21}$$

where $\overline{D}_K$ is the average of all $D_{K,i}(f,j)$.

The resulting expanded uncertainty U_K of the conversion factor is

$$U_K = 2s_K \quad \text{in dB} \tag{22}$$

7.2.2 Estimation of SCU by measurement

For the estimation of the SCU, the average for the measured values of all T test labs for each EUT i is calculated using Equation (23).

$$\overline{M}_{\mathrm{XTM},i}(f) = \frac{1}{T}\sum_{j=1}^{T} M_{\mathrm{XTM},i}(f,j) \quad \text{in dB} \tag{23}$$

where XTM is either ETM or ATM.

For each frequency f and for each EUT i, the deviation $D_{\mathrm{XTM},i}(f,j)$ between the measured values' average $\overline{M}_{\mathrm{XTM},i}(f)$ and each measured value $M_{\mathrm{XTM},i}(f,j)$ is calculated using Equation (24).

$$D_{\mathrm{XTM},i}(f,j) = \overline{M}_{\mathrm{XTM},i}(f) - M_{\mathrm{XTM},i}(f,j) \text{ in dB} \tag{24}$$

The experimental standard deviation of all these deviations $D_{\mathrm{XTM},i}(f,j)$ can be calculated by

$$s = \sqrt{\frac{1}{(NTF)-1}\sum_{i=1}^{N}\sum_{j=1}^{T}\sum_{f=1}^{F}[\overline{D}_{\mathrm{XTM}}(f) - D_{\mathrm{XTM},i}(f,j)]^2} \quad \text{in dB} \tag{25}$$

where $\overline{D}_{\mathrm{XTM}}(f)$ is the average of all $D_{\mathrm{XTM},i}(f,j)$.

The uncertainty that causes this deviation depends on the measurement equipment and the measurement procedure. This uncertainty is the SCU, and it is estimated by

$$U_{\mathrm{SC,XTM}} = 2s \quad \text{in dB} \tag{26}$$

7.2.3 Applying the conversion factor

The limit of an established test method can be converted into limit conditions for an alternative test method using the average conversion factor [see Equation (15)] and the measurement uncertainties of ETM and ATM [see Equations (16) and (17)].

Equations (16) and (17) take into account the instrumentation uncertainty. The inherent and intrinsic uncertainty of the measurand is considered by using a reference quantity X in estimating the conversion factor $\overline{K}(f)$. If $\overline{K}(f)$ is estimated by measuring the influence of all uncertainties, then the instrumentation uncertainty, the uncertainty of the measurement procedure, and the uncertainty caused by the different radiation characteristics of the EUTs are all taken into account. Therefore the difference Δ_{meas} of the uncertainties of the ATM and ETM is:

$$\Delta_{\mathrm{meas}} = U_{\mathrm{ATM}} - U_{\mathrm{SC,ETM}} \quad \text{in dB} \tag{27}$$

For the estimation of the uncertainty U_{ATM} [see Equation (32)], the uncertainty of the conversion factor U_K is investigated. The amount of the uncertainty U_K of the conversion factor can be estimated by:

$$U_K^2 = U_{\text{SC,ETM}}^2 + U_{\text{SC,ATM}}^2 + U_{\text{EUT}}^2 \qquad (28)$$

where

$U_{\text{SC,ETM}}$ is the SCU of the ETM,

$U_{\text{SC,ATM}}$ is the SCU of the ATM, and

U_{EUT} is the uncertainty that is caused by the different radiation characteristics of the EUTs, which is estimated by Equations (29) to (31).

The different characteristics cause a unique conversion factor for each EUT. The difference between the conversion factors is estimated by the deviation $D_{K,\text{EUT}}$ between the average conversion factor $\overline{K}(f)$ and the average conversion factor for each EUT $\overline{K}_i(f)$.

$$D_{K,\text{EUT}}(f) = \overline{K}(f) - \overline{K}_i(f) \qquad (29)$$

$D_{K,\text{EUT}}$ has standard deviation

$$s_{\text{EUT}} = \sqrt{\frac{1}{(NF)-1}\sum_{i=1}^{N}\sum_{f=1}^{F}[\overline{D}_{K,i} - D_{K,\text{EUT}}(f)]^2} \qquad (30)$$

where $\overline{D}_{K,i}$ is the average of all $D_{K,\text{EUT}}(f)$.

The uncertainty U_{EUT} is estimated by

$$U_{\text{EUT}} = 2s_{\text{EUT}} \text{ in dB.} \qquad (31)$$

The uncertainty U_{ATM} is determined by the uncertainty $U_{\text{SC,ATM}}$ of the ATM and the uncertainty U_{EUT} caused by the EUTs. Therefore U_{ATM} can be estimated by

$$U_{\text{ATM}} = \sqrt{U_{\text{EUT}}^2 + U_{\text{SC,ATM}}^2}\,. \qquad (32)$$

Therefore, using Equation (27) the application of Equation (17) becomes

$$L_{\text{ATM},U} = L_{\text{ATM}} - \Delta_{\text{meas}} \text{ if } \Delta_{\text{meas}} > 0\text{, and} \qquad (33)$$

$$L_{\text{ATM},U} = L_{\text{ATM}} \text{ if } \Delta_{\text{meas}} \le 0 \qquad (34)$$

It should be considered that $U_{\text{SC,ETM}}$ in Equation (27) is estimated in accordance with CISPR 16-4-1, which estimates generally the U_{SC} for 3 m test site results in the frequency range 30 MHz to 300 MHz to be 15,5 dB; for the conditions of the RRT and the terminated cables, U_{SC} may be reduced to 11 dB. CISPR 16-4-1 gives no value for the $U_{\text{SC,ETM}}$ of the 10 m test site results, but the value can be expected to be in the order of about 10 dB.

8 Derivation of limits for the use of reverberation chambers as ATM for radiated disturbance measurements based on a statistical analysis of all essential factors

8.1 Conversion factor

Measurement of radiated power from an EUT using the RC method is described in IEC 61000-4-21 [22]. This clause attempts to provide rules to derive disturbance limits for the radiated power measured using the RC test method based on existing limits for radiated field strength measured using the ETM. Radiated field strength and radiated power of an EUT are related via the EUT directivity, and EUT directivity depends on frequency and EUT volume. Because the type of an EUT and its directivity are typically unknown for generic and product standards, this clause uses a statistical estimate based on assumptions described by Krauthäuser [19]. For comparison and easier understanding, the conversion factors using a short dipole as a model are described in D.2.

With reference to Annex D, conversion factors

– from OATS/SAC to RC for 80 MHz to 1 000 MHz, and

– from FSOATS/FAR to RC for 1 GHz to 40 GHz.

are introduced.

NOTE The start frequency of 80 MHz is selected because IEC 61000-4-21:2011, Table B.2 [22] on field uniformity requirements starts at 80 MHz. Because there are RCs with lower or higher lowest useable frequencies (LUFs), 80 MHz can be replaced by "LUF." The highest frequency of 40 GHz is selected because that is under consideration to be the highest frequency for all CISPR documents pending agreement by NCs.

The linear conversion factor *k*(*f*) is defined as in Equation (35)

$$k(f) = E_{\max}^2 / P_{\mathrm{T}} \tag{35}$$

where

$E_{\max}$ is the maximum field strength of an EUT in µV/m measured using the ETM;

P_{T} is the power transmitted from an EUT in pW measured using the RC test method.

The unit of $k(f)$ is $\mathrm{V^2/m^2W}$ or Ω/m^2. To convert into logarithmic quantities, Equation (35) can be written as Equation (36):

$$\begin{aligned} \lg P_{\mathrm{T}} &= \lg E_{\max}^2 - \lg k(f), \text{ or} \\ 10 \lg P_{\mathrm{T}} &= 20 \lg E_{\max} - 10 \lg k(f) \end{aligned} \tag{36}$$

The logarithmic conversion factor *K*(*f*) is defined as in Equation (37):

$$K(f) = 10 \lg k(f) \tag{37}$$

The logarithmic conversion factor can be used to convert radiated disturbance limits L_{ETM} in dB(µV/m) into limits of the disturbance power L_{ATM} in dB(pW) measured in an RC as shown in Equation (38) (see also Equation (15) in 6.10).

$$L_{ATM}/\text{dB(pW)} = L_{ETM}/\text{dB}(\mu\text{V/m}) - K(f) \quad (38)$$

The logarithmic conversion factor $K(f)$ has the unit dB(Ω/m^2).

8.2 Measurement uncertainty

Equation (7) and Equation (9) of 6.7 provide the combined standard uncertainties of ATM and ETM results with contributions designated in subscripts as: "m" for the instrumentation uncertainty, "intrinsic" for the intrinsic uncertainty of the measurand, and "inherent" for the inherent uncertainty of the method.

$$u_{XTM} = \sqrt{u_{XTM,m}^2 + u_{XTM,intrinsic}^2 + u_{XTM,inherent}^2}$$

where X in the subscript terms denotes either E or A (i.e. ETM or ATM).

For the effect of the measurement uncertainties of ETM and ATM on the disturbance limit, the expanded uncertainties are compared (see Equation (16) in 6.10). The expanded uncertainty of the conversion factor in Annex D (2σ in Table D.2, Table D.3,Table D.4,Table D.6, Table D.7 and Table D.8) takes into account the inherent uncertainties of the ETM ($U_{inherent,ETM}$) and ATM ($U_{inherent,ATM}$). The inherent uncertainty is an indicator of the ability of a measurement procedure to account for differences in EUT characteristics. A three-dimensional (3D) spatial scan would provide the lowest uncertainty for capturing the maximum field strength radiated by an EUT, but none of the ETMs are ideal in that respect. However, the RC ATM does capture the radiated power of an EUT across all directions. Consequently, the inherent uncertainty of the RC ATM is zero whereas the inherent uncertainties of the ETMs are non-zero.

In addition to the uncertainty of the conversion factor, the actual EUT size can deviate from the EUT size assumed for the conversion factor calculation in Annex D, which justifies a contribution U_{EUT}.

As can be seen from Table H.1 of CISPR TR 16-4-1:2009, the SCU $U_{ETM,SC}$ of the ETM (OATS/SAC with d = 10 m) is on the order of 10 dB, whereas $U_{XTM,m}$ is around 5 dB according to CISPR 16-4-2. Thus,

$$U_{ETM,SC} = \sqrt{U_{ETM,intrinsic}^2 + U_{ETM,m}^2}$$

and consequently

$$U_{ETM,intrinsic} = \sqrt{U_{ETM,SC}^2 - U_{ETM,m}^2} = 8{,}7\ \text{dB}$$

This means that the intrinsic uncertainty of the ETM is much larger than the uncertainty of the conversion factor K, so Equation (28) of 7.2.3 does not apply for Annex D. The intrinsic uncertainty is largely dependent on cable layout and cable termination, which is an important topic for the reproducibility of measurement set-ups. By future standardization of cable layout and cable termination, intrinsic uncertainty and standards compliance uncertainty can be minimized.

At present values of SCU (and intrinsic uncertainty) are not available for the ETM above 1 GHz, as well as for the RC ATM below and above 1 GHz. This does not mean that the RC method should be precluded for radiated disturbance measurements usage; there is no reason to assume that the SCU of the RC method results will be larger than the SCU of the ETM results. Product committees should provide appropriate investigations and measurements for establishing the SCU.

In addition to any deviation from the EUT size for the conversion factor, the EUT type can be different from that assumed for the conversion; e.g. with different cable arrangement and cable termination. This means that Equation (32), Equation (33), and Equation (34) of 7.2.3 also apply for the use of an RC disturbance measurement method as an ATM.

Details on instrumentation contributions to uncertainty for RC disturbance measurement results is given in D.4.

Annex A
(informative)

Remarks on EUT modelling

As discussed in 6.5 and 6.6, the characteristics of an EUT directly influence the measurement results, and thus influence the deviations from the reference quantity. Considering the example of radiated emission measurements, the radiation pattern of the EUT influences the probability of capture for a maximum emission using the peak search procedure of an open-area test site or a fully-anechoic room measurement. To obtain more universal results, it is necessary to consider multiple EUTs having different radiation characteristics for use in determining conversion parameters. This annex describes general considerations about EUT modelling for use in investigations about emission measurement methods.

A.1 Types of EUTs

Certain characteristics of EUTs typically have the most influence on the radiation behaviour. It is useful to categorize EUTs with equivalent primary characteristics into several EUT types, which can then be considered and investigated independently. One general classification is to group EUTs into the following three types, based on the test set-up:

a) tabletop equipment without cables;

b) tabletop equipment with cable(s);

c) floorstanding equipment.

A.2 Application of statistics

Each EUT category of Clause A.1 consists of many different devices and operating and performance characteristics. To best cover these widely-varying characteristics, applying statistical methods is helpful. With a statistical approach, universally valid values for average conversion parameters and the uncertainties can be obtained. The uncertainty resulting from the unknown radiation characteristics of an EUT, u_{inherent}, can only be determined by considering a range of different EUTs and analysing the resulting data statistically. An example of such a statistical approach is given in Annex B.

Annex B
(informative)

Examples of application of the test method comparison procedure

B.1 Example 1 – Measurements at 3 m-separation in fully anechoic room compared to 10 m-separation measurements on open-area test site

In the following subclause headings, numbers in parentheses refer to subclauses in the main body of this document.

B.1.1 Small EUTs without cables

B.1.1.1 Select the reference quantity *X* (see 6.2)

The protection requirement is to minimize the risk that the disturbance field strength radiated by an EUT interferes with radio services. A measure for this interference potential of the EUT is the electric field strength emitted by the EUT. Because the EUT final-use set-up in general is unknown or is variable, it is necessary to search for the maximum field strength in all directions from the EUT and for all polarisations. Therefore the reference quantity is selected to be the maximum far-field electric field-strength emitted under free space conditions, independent of direction or polarisation. At a distance from the EUT of d_{ref} = 10 m and for the frequency range and EUT sizes considered here, far-field conditions can be assumed. Figure B.1 displays this scheme for defining the reference quantity. It is noted that in reality it is difficult or nearly impossible to perform such measurements, but this set-up and reference quantity is very amenable to numerical simulations. This reference quantity definition is applicable in the frequency range of 30 MHz to 1 GHz.

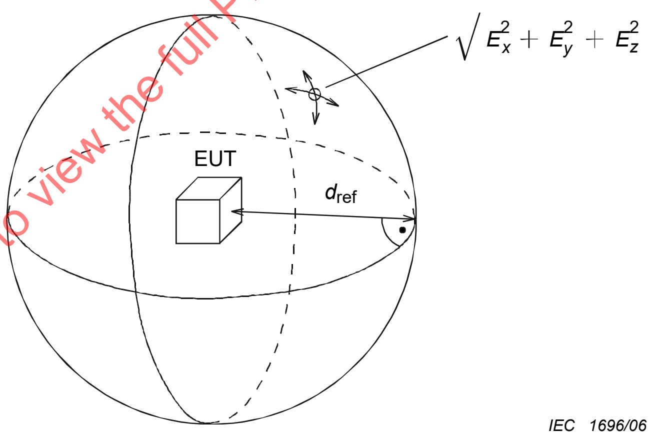


Figure B.1 – Example reference quantity

B.1.1.2 Describe the test methods and measurands (see 6.3)

Alternative test method – 3 m fully anechoic room (FAR): Figure B.2 shows the EUT and antenna set-up for a fully anechoic room measurement for frequencies of 30 MHz to 1 GHz. The receiving antenna is located at a distance d_{far} = 3 m from the EUT. The antenna is positioned at a fixed height corresponding to the vertical centre of the EUT. To detect the maximum field strength, the EUT is rotated in azimuth in the horizontal plane, and both horizontal and vertical polarisations of radiated field are measured. The FAR is a shielded enclosure with absorbing material on the walls, ceiling, and floor. Therefore, ideally the antenna receives only the direct emission radiated from the EUT.

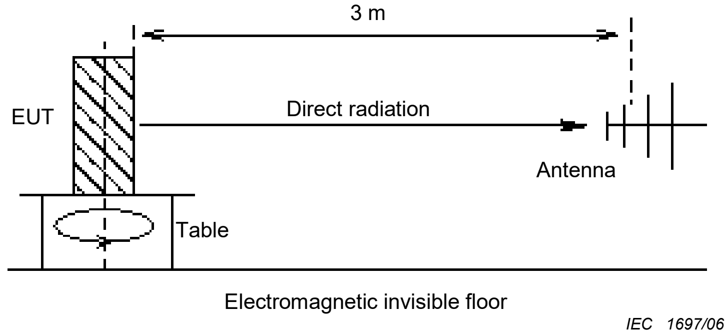


Figure B.2 – EUT and antenna set-up for fully anechoic room emission measurement

Established test method – 10 m open-area test site (OATS): Figure B.3 displays the measurement set-up for an open-area test site for the frequency range of 30 MHz to 1 GHz. The receiving antenna is located at a distance d_{oats} = 10 m to the EUT. To detect the maximum field strength, the EUT is rotated, and the antenna height is varied between 1 m and 4 m. The set-up is placed on a conducting ground plane. The perimeter and surroundings of the OATS and set-up is free of any reflecting objects, therefore ideally the antenna receives only the direct radiation and the ground reflected signal.

Semi-anechoic rooms that meet the CISPR normalized site attenuation (NSA) site-validation criteria can be used to perform compliance tests, and therefore semi-anechoic room could be selected as the established test method instead. The example results shown below remain applicable in this case, because the estimation of the inherent uncertainty assumes conditions of an ideal test site. Considered ideally, a semi-anechoic room and an open-area test site would both ideally provide free-field reflection-free (except ground) conditions.

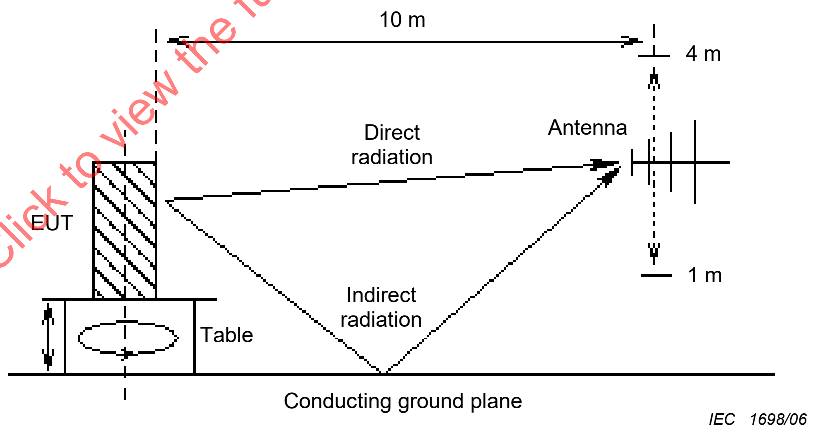


Figure B.3 – EUT and antenna set-up for open-area test site measurement

B.1.1.3 Determine the deviations of the measured quantities from the reference quantity (see 6.4)

The results of the measurement depend strongly on the radiation characteristics of the EUT. Therefore an investigation on the characteristics of the different measurement set-ups must include a wide range of differently radiating EUTs. In the following a statistical model for tabletop EUTs without external cables is used.

In general, any EUT radiation pattern can be approximated by superposing the radiated fields from elementary radiators, such as electrically-short dipoles. Therefore, a quantity of electrically-short dipoles with varying characteristics (direction of axis, amplitude, phase shift, position) will generate statistically different radiation patterns. An example arrangement is shown in Figure B.4. Specifically, the EUT model used here is based on the following concepts: a certain number of dipoles are located inside a certain volume, and their positions, directions and excitations are varied statistically to generate a statistical distribution of radiation characteristics. This statistical EUT model is one practical and reasonable approach among others to simulate tabletop equipment.

Four different virtual-EUT volumes [(30 cm)^3, (60 cm)^3, (90 cm)^3, (120 cm)^3] were simulated to investigate the effect of different EUT models on the resulting emissions. These volumes can be considered to represent the maximum volumes of typical tabletop EUTs. The number of elementary radiators applicable to represent real-world EUT characteristics is indeterminable, thus the ideal number of radiators to be located in the chosen volumes is unknown. Therefore, effects for varying numbers of elementary radiators is investigated. Effects expected from a variation of the numbers of radiators are as follows:

for one radiator, the behaviour of a dipole is modelled;

an increasing number of radiators leads to increasingly complex radiation patterns;

an infinite number of radiators will behave like one equivalent dipole.

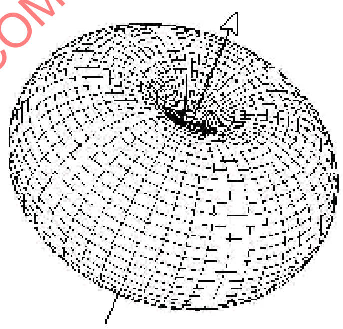
Simulations done for 1, 2, 5, 10, 30, and 50 radiators mainly show the following three characteristics:

the results for 1 or 2 radiators produces the worst-case results only for some frequencies;

the results for 10, 30, or 50 are the worst case for nearly the entire frequency range;

the differences between the results for 10, 30, and 50 radiators are very small, for example compared to the differences between the results for 10 and 2 radiators.

From these observations it can be concluded that simulations with more than 50 radiators probably will not give different results. Therefore the results of the carried out simulations are taken in order to get a safe approximation of the worst case.



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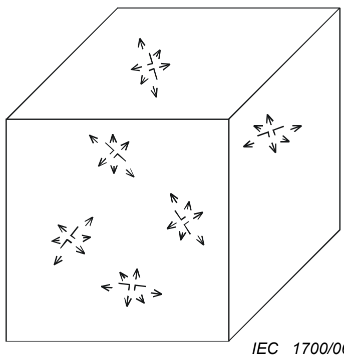


IEC 1700/06

Figure B.4 – Radiation characteristics of elementary radiator (left), and scheme of EUT-model (right)

For each pair of volume and number of radiators, a set of N = 1 000 individual EUTs are generated.

NOTE 1 In general, the number of individual EUTs should be as large as possible. On the other hand, the simulation time has to be finite. A number of 1 000 individual EUTs is deemed to be a reasonable compromise: Based on nonparametric statistics theory, a number of 1 000 individuals enables a confidence level of 99,9% for the estimations of the bounds of interval holding 95% of the simulated values. These bounds are important values to estimate the standard deviation and thus the inherent uncertainty. For more details, see [2] or Chapter 3 of [1].

For each EUT i of such a set, e.g. of the set belonging to a volume of (30 cm)^3 with 5 radiators, the reference quantity X_i and the field strengths $E_{\mathrm{FAR(3m)}i}$ for FAR and $E_{\mathrm{OATS(10m)}i}$ for OATS are calculated, which are equivalent to measured field strength values.

NOTE 2 Because the statistical EUT model yields individual EUTs with larger horizontal or larger vertical field components, the calculated field strengths are determined the same way as in real-world measurements: The maximum value is taken, independent from its polarisation. As a consequence, the polarisation of the field strength values varies statistically, and the derived conversion covers both horizontal and vertical polarisations.

From these results, the deviations for the alternative test method from 6.4, Equation (1),

$$D_{\mathrm{ATM}i} = D_{\mathrm{FAR(3m)}i} = X_i - E_{\mathrm{FAR(3m)}i} \tag{B.1}$$

where

$E_{\mathrm{FAR(3m)}i}$ is the field-strength for 3 m FAR test method for EUT i,

X_i, $D_{\mathrm{ATM}i}$, i are the same as in 6.4 Equation (1),

$D_{\mathrm{FAR(3m)}i}$ is the deviation from the reference quantity X of the 3 m FAR test method result for EUT i,

and for the established test method according to 6.4, Equation (2),

$$D_{\mathrm{ETM}i} = D_{\mathrm{OATS(10m)}i} = X_i - E_{\mathrm{OATS(10m)}i} \tag{B.2}$$

where

$E_{\mathrm{OATS(10m)}i}$ is the field-strength for 10 m OATS test method for EUT i,

X_i, $D_{\mathrm{ETM}i}$, i are the same as in 6.4 Equation (2),

$D_{\mathrm{OATS(10m)}i}$ is the deviation from the reference quantity X of the 10 m OATS test method result for EUT i,

are calculated.

B.1.1.4 Determine the average values of the deviations (see 6.5)

For both alternative and established test methods, the average deviations can be calculated using Equation (3) and Equation (4) from 6.5, respectively. This is done for every set of 1 000 EUTs:

$$\overline{D}_{\mathrm{ATM}} = \overline{D}_{\mathrm{set,\,FAR(3m)}} = \frac{1}{1000}\sum_{i=1}^{1000} D_{\mathrm{FAR(3m)}i} \tag{B.3}$$

$$\overline{D}_{\mathrm{ETM}} = \overline{D}_{\mathrm{set,\,OATS(10m)}} = \frac{1}{1000}\sum_{i=1}^{1000} D_{\mathrm{OATS(10m)}i} \tag{B.4}$$

where

$\overline{D}_{\text{set, ATM}}$ is the average deviation of the alternative test method for the set of 1 000 EUTs;

$\overline{D}_{\text{set, ETM}}$ is the average deviation of the established test method for the set of 1 000 EUTs;

$\overline{D}_{\text{set, FAR(3m)}}$ is the average deviation of the 3 m FAR test method for the set of 1 000 EUTs;

$\overline{D}_{\text{set, OATS(10m)}}$ is the average deviation of the 10 m OATS test method for the set of 1 000 EUTs;

$D_{\text{FAR(3m)}i}$, $D_{\text{OATS(10m)}i}$, i are the same as in Equations (B.1) and (B.2), respectively.

In order to estimate the worst-case emissions, for each volume the maximum average deviation for both test methods is determined using

$$\overline{D}_{\text{max vol, FAR(3m)}} = \max_{\text{number of radiators}} \overline{D}_{\text{set, FAR(3m)}}; \quad \overline{D}_{\text{max vol, OATS(10m)}} = \max_{\text{number of radiators}} \overline{D}_{\text{set, OATS(10m)}} \qquad \text{(B.5)}$$

where

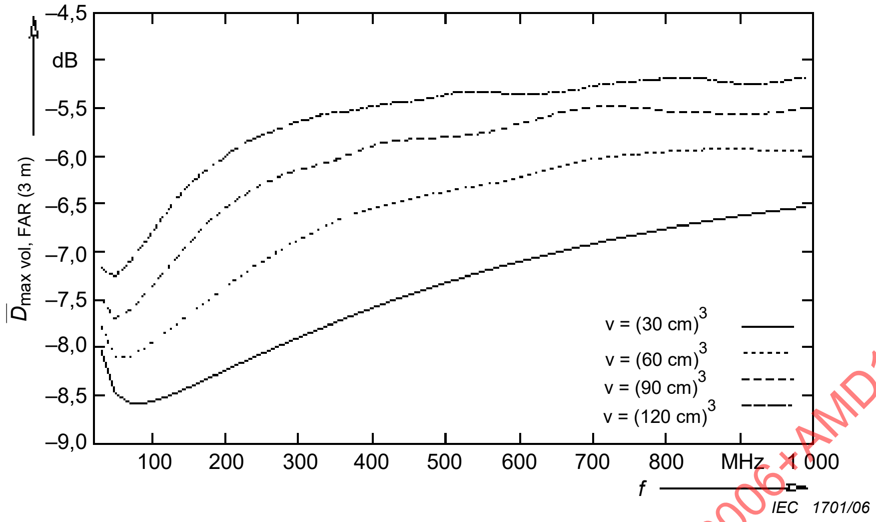
$\overline{D}_{\text{set, FAR(3m)}}$ is the same as in Equation (B.3);

$\overline{D}_{\text{set, OATS(10m)}}$ is the same as in Equation (B.4);

$\overline{D}_{\text{max vol, FAR(3m)}}$ is the maximum average deviation of the 3 m FAR test method for one assumed EUT volume;

$\overline{D}_{\text{max vol, OATS(10m)}}$ is the maximum average deviation of the 10 m OATS test method for one assumed EUT volume.

The example maximum deviations are displayed in Figure B.5.



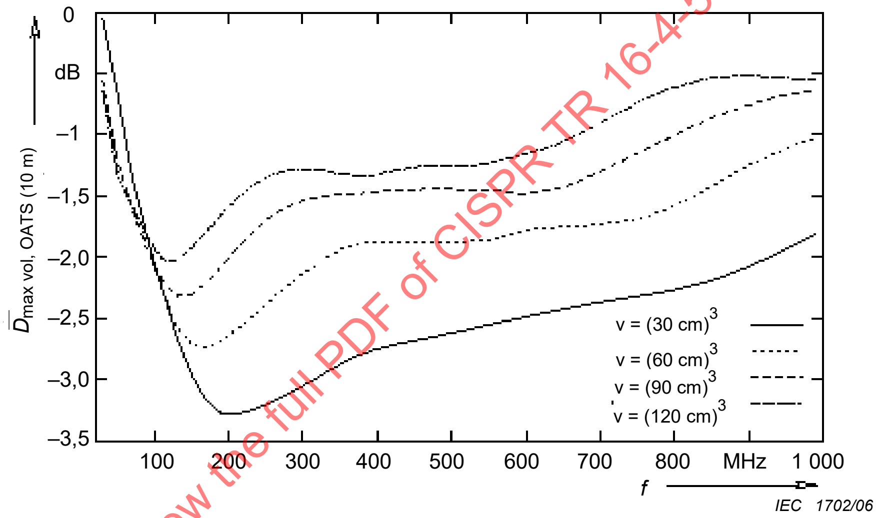


Figure B.5 – Maximum average deviations for 3 m FAR (top) and 10 m OATS (bottom)

B.1.1.5 Estimate the standard uncertainties of the test methods (see 6.6)

Instrumentation uncertainty: At the time of drafting of this Annex, for the alternative test method (3 m FAR), the instrumentation uncertainty ~~has~~ had not yet been given in CISPR standards. For the antenna and site contributions, numeric values from the final technical report of the EU FAR project ~~can be~~ have been used [4]. The other numeric values ~~are~~ were taken from CISPR 16-4-2:2003 [24], because these ~~are~~ were expected to be the same for OATS and FAR. These instrumentation measurement uncertainties are given in Table B.1. For the established test method, the measurement instrumentation uncertainty is as shown in the basic standard CISPR 16-4-2:~~2003~~2011.

Table B.1 – Instrumentation uncertainty of the 3 m fully anechoic chamber test method

Input quantity	X_i	Uncertainty of x_i dB	Probability distribution function	$u(x_i)$ dB	c_i	$c_i \cdot u(x_i)$ dB
Receiver reading	V_r	±0,1	k = 1	0,10	1	0,10
Attenuation: antenna-receiver	L_c	±0,1	k = 2	0,05	1	0,05
Biconical antenna factor	AF	±2,0	k = 2	1,0	1	1,0
Receiver corrections:						
Sine wave voltage	δVsw	±1,0	k = 2	0,50	1	0,50
Pulse amplitude response	δVpa	±1,5	Rectangular	0,87	1	0,87
Pulse repetition rate response	δVpr	±1,5	Rectangular	0,87	1	0,87
Noise floor proximity	δVnf	±0,5	k = 2	0,25	1	0,25
Mismatch: antenna-receiver	δM	+0,9 / -1,0	U-shaped	0,67	1	0,67
Biconical antenna corrections:						
AF frequency interpolation	δAF_f	±0,3	Rectangular	0,17	1	0,17
AF height deviations	δAF_h	±0,0		0,00	1	0,00
Directivity difference	$\delta A_{dir,h}$	±0,0		0,00	1	0,00
Phase center location	δAph	±0,0		0,00	1	0,0
Cross-polarisation	δAcp	±0,0		0,00	1	0,0
Balance (hor.)	$\delta Abal$	±0,3	Rectangular	0,17	1	0,17
Balance (ver.)	$\delta A_{bal,v}$	±0,9	Rectangular	0,52	1	0,52
Log-periodic antenna corrections:						
AF frequency interpolation	δAF_f	±0,3	Rectangular	0,17	1	0,17
AF height deviations	δAF_h	±0,0		0,00	1	0,00
Directivity difference	$\delta A_{dir,h}$	+0,2 / -0,0	Rectangular	0,05	1	0,05
Phase center location	δAph	±0,5	Rectangular	0,29	1	0,29
Cross-polarisation	δAcp	±0,9	Rectangular	0,52	1	0,52
Balance	$\delta Abal$	±0,0		0,00	1	0,00
Site corrections:						
Site imperfections	δSA	±4,0	Triangular	1,63	1	1,63
Separation distance at 3 m	δd	±0,3	Rectangular	0,17	1	0,17
Table height at 3 m	δh	±0,1	k = 2	0,05	1	0,05

Intrinsic uncertainty: Numeric values for intrinsic uncertainties are still under consideration in CISPR 16-4-1~~:2003~~; therefore this uncertainty contribution is not included in this example.

Uncertainty due to unknown EUT characteristics: The standard inherent uncertainty u_{inherent} can be calculated for alternative and established test methods using Equation (5) and Equation (6) from 6.6, respectively. Because the cumulative distribution functions of the deviations have strong asymmetric shapes, the straightforward application of the equations would yield a estimate of the uncertainty that is too low. The sample cumulative distribution function (CDF) in Figure B.6 illustrates this underestimation. If the CDF were symmetric, the interval $\left[\overline{D}_{\text{ETM}};\, k_{\text{ETM}} \cdot s(D_{\text{ETM}})\right]$ would cover the upper half of the 95 % interval.

As can be seen from the figure, this is not true – actually $k_{\mathrm{ETM}} \cdot s(D_{\mathrm{ETM}})$ underestimates the upper bound of the 95% interval. To avoid this, the standard deviation, s_+, is introduced, which is calculated using only values larger than the average.

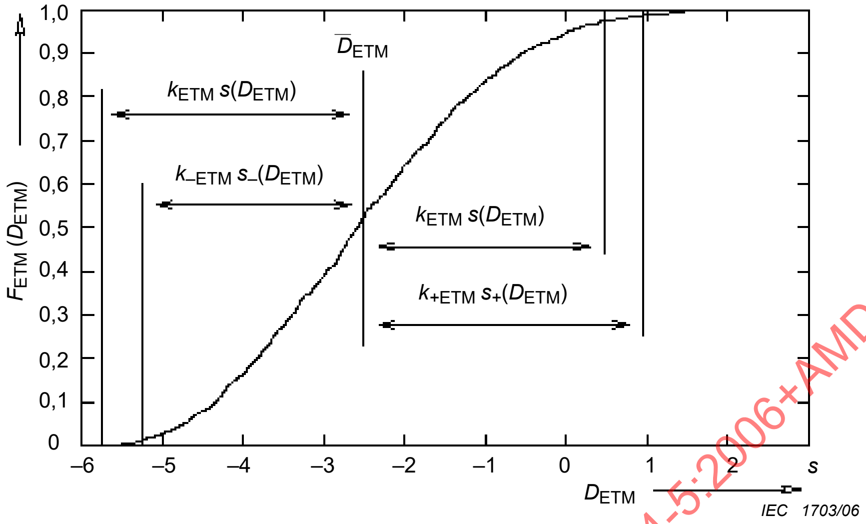


Figure B.6 – Sample cumulative distribution function

The number of these values is denoted N_+, and the approximated standard deviation is denoted s_+. The index of a given EUT i = 1...N is mapped to a new index $j = 1...N_+$. The standard deviation is calculated for every set of EUTs using

$$s_{+\mathrm{set}}(D_{\mathrm{FAR(3m)}}) = \sqrt{\frac{\sum_{i=1}^{N_+}(D_{\mathrm{FAR(3m)}j} - \overline{D}_{\mathrm{set,FAR(3m)}})^2}{N_+ - 1}} \tag{B.6}$$

where

$D_{\mathrm{FAR(3m)}i}$, $\overline{D}_{\mathrm{set,FAR(3m)}}$ are the same as in Equation (B.3);

N_+ is the number of values larger than the average value;

$s_{+\mathrm{set}}(D_{\mathrm{FAR(3m)}})$ is the one-side standard deviation of the deviations for one set of 1 000 EUTs of the 3 m FAR test method,

and

$$s_{+\mathrm{set}}(D_{\mathrm{OATS(10m)}}) = \sqrt{\frac{\sum_{i=1}^{N_+}(D_{\mathrm{OATS(10m)}j} - \overline{D}_{\mathrm{set,OATS(10m)}})^2}{N_+ - 1}} \tag{B.7}$$

where

$D_{\mathrm{OATS(10m)}i}$, $\overline{D}_{\mathrm{set,OATS(10m)}}$ are the same as in Equation (B.4);

N_+ is the number of values larger than the average value;

$s_{+\mathrm{set}}(D_{\mathrm{OATS(10m)}})$ is the one-side standard deviation of the deviations for one set of 1 000 EUTs of the 10 m OATS test method.

This approach gives a worst-case estimation; more precise results can be obtained by considering the skew of the CDF.

As done for the average deviations, from the approximated standard deviations of the deviations for each volume, the maximum value is determined. This maximum is taken as a safe approximation of the uncertainty.

$$u_{\mathrm{ATM,inherent}} = u_{\mathrm{FAR(3m),inherent}} \approx s_{+\mathrm{max,vol}}\left(D_{\mathrm{FAR(3m)}}\right) = \max_{\text{number of radiators}} s_{+\mathrm{set}}\left(D_{\mathrm{FAR(3m)}}\right) \quad (B.8)$$

$$u_{\mathrm{ETM,inherent}} = u_{\mathrm{OATS(10m),inherent}} \approx s_{+\mathrm{max,vol}}\left(D_{\mathrm{OATS(10m)}}\right) = \max_{\text{number of radiators}} s_{+\mathrm{set}}\left(D_{\mathrm{OATS(10m)}}\right) \quad (B.9)$$

where

$s_{+\mathrm{set}}\left(D_{\mathrm{FAR(3m)}}\right)$ is the same as in Equation (B.6);

$s_{+\mathrm{set}}\left(D_{\mathrm{OATS(10m)}}\right)$ is the same as in Equation (B.7);

$s_{+\mathrm{max,vol}}\left(D_{\mathrm{FAR(3m)}}\right)$ is the maximum approximated standard deviation of the deviations of the 3 m FAR test method for one assumed EUT volume;

$s_{+\mathrm{max,vol}}\left(D_{\mathrm{OATS(10m)}}\right)$ is the maximum approximated standard deviation of the deviations of the 10 m OATS test method for one assumed EUT volume;

$u_{\mathrm{FAR(3m),inherent}}$ is the inherent uncertainty of the 3 m FAR test method;

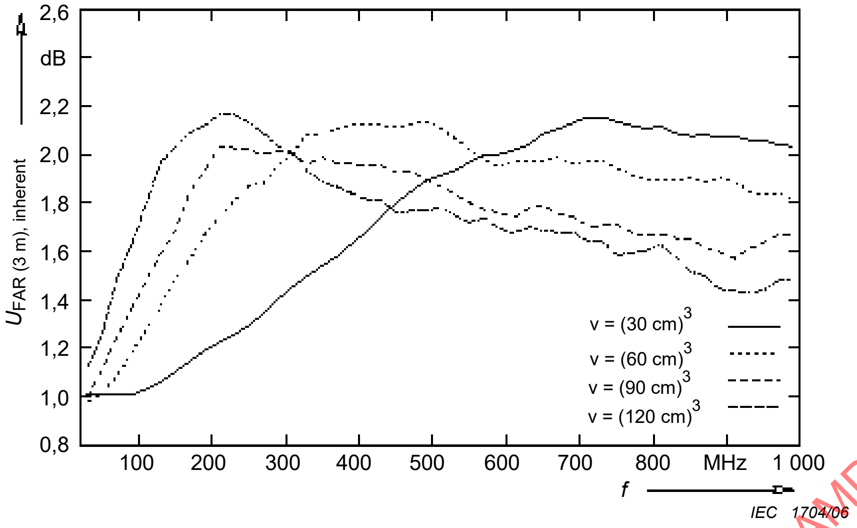
$u_{\mathrm{ATM,inherent}}$ is given in Table 2;

$u_{\mathrm{OATS(10m),inherent}}$ is the inherent uncertainty of the 10 m OATS test method;

$u_{\mathrm{ETM,inherent}}$ is given in Table 2.

The values are displayed in Figure B.7 and are given numerically in Tables B.2 and B.3.

NOTE It should be noted, that the large uncertainty of the OATS test method results from the fact, that the values include both horizontal and vertical polarisation. Smaller uncertainties could be obtained if the polarisations are considered separately. Such a consideration needs a sophisticated rule, in which case conversion factors for horizontal, vertical or both polarisations can be applied.



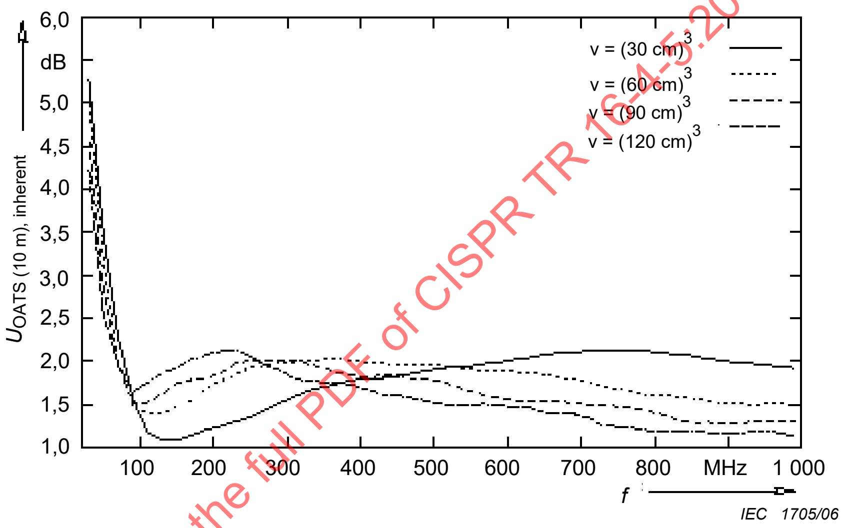


Figure B.7 – Uncertainties due to the unknown EUT characteristic for 3 m FAR (top) and 10 m OATS (bottom)

From the set of calculated deviations, and from the standard deviations, a 95 % tolerance interval for both test methods can be determined. Using their widths and the standard deviations, the coverage factor *k* can be approximated. For the alternative test method the factor is

$$k_{\mathrm{ATM}} = k_{+\mathrm{FAR(3m)}} \approx 2{,}2 \tag{B.10}$$

where

k_{ATM} is the coverage factor for the alternative test method;

$k_{+\mathrm{FAR(3m)}}$ is the coverage factor for the 3 m FAR test method derived from the values larger than the average;

and for the established test method it is

$$k_{\mathrm{ETM}} = k_{+\mathrm{OATS(10m)}} \approx 2{,}2 \tag{B.11}$$

where

k_{ETM} is the coverage factor for the established test method;

$k_{+OATS(10m)}$ is the coverage factor for the 10 m OATS test method derived from the values larger than the average.

Again only the values larger than the average are used.

Table B.2 – Uncertainties in dB due to the unknown EUT characteristic for 3 m FAR

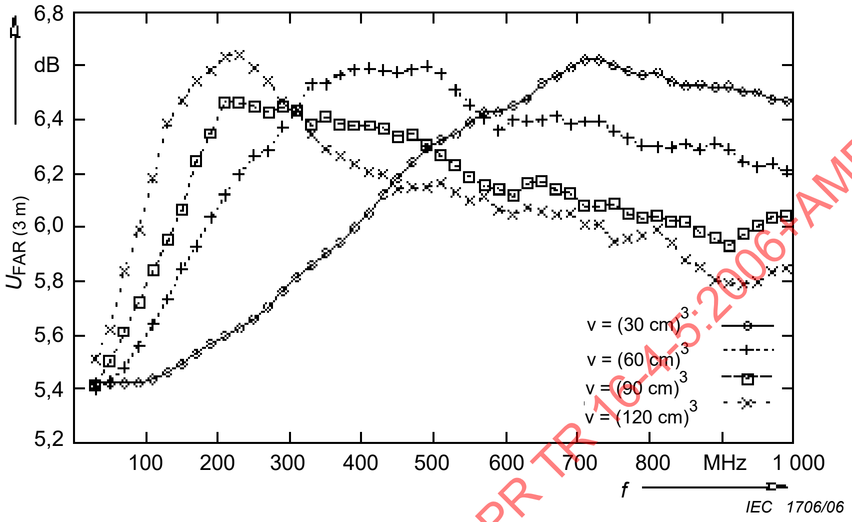
Frequency MHz	*v* = (30 cm)^3	*v* = (60 cm)^3	*v* = (90 cm)^3	*v* = (120 cm)^3
30	1,00	0,97	0,99	1,12
50	1,00	1,01	1,11	1,25
70	1,00	1,08	1,24	1,48
90	1,00	1,17	1,36	1,62
110	1,02	1,27	1,47	1,79
130	1,06	1,37	1,58	1,96
150	1,10	1,48	1,69	2,03
170	1,14	1,56	1,84	2,08
190	1,19	1,66	1,93	2,12
210	1,22	1,74	2,03	2,16
230	1,25	1,80	2,02	2,16
250	1,29	1,86	2,01	2,12
270	1,34	1,88	2,00	2,08
290	1,40	1,95	2,01	2,03
310	1,45	2,00	2,00	2,00
330	1,49	2,08	1,96	1,93
350	1,54	2,08	1,98	1,88
370	1,57	2,10	1,96	1,86
390	1,63	2,12	1,95	1,83
410	1,68	2,12	1,95	1,81
430	1,74	2,11	1,95	1,80
450	1,79	2,11	1,92	1,76
470	1,84	2,12	1,93	1,76
490	1,88	2,13	1,89	1,76
510	1,91	2,11	1,86	1,77
530	1,93	2,06	1,83	1,74
550	1,96	2,02	1,79	1,71
570	1,99	1,98	1,77	1,73
590	1,99	1,94	1,76	1,69
610	2,01	1,97	1,73	1,67
630	2,03	1,97	1,77	1,69
650	2,08	1,97	1,78	1,68
670	2,10	1,98	1,75	1,67
690	2,12	1,96	1,74	1,68
710	2,15	1,97	1,70	1,64
730	2,15	1,97	1,70	1,64
750	2,13	1,94	1,71	1,58
770	2,11	1,91	1,67	1,59
790	2,10	1,89	1,66	1,60
810	2,11	1,89	1,67	1,62
830	2,08	1,89	1,65	1,57
850	2,07	1,90	1,65	1,52
870	2,07	1,88	1,61	1,49
890	2,07	1,90	1,59	1,44
910	2,07	1,88	1,56	1,43
930	2,05	1,84	1,60	1,42
950	2,05	1,83	1,63	1,43
970	2,03	1,84	1,66	1,47
990	2,03	1,81	1,67	1,48

Table B.3 – Uncertainties in dB due to the unknown EUT characteristic for 10 m OATS

Frequency MHz	v = (30 cm)³	v = (60 cm)³	v = (90 cm)³	v = (120 cm)³
30	5,27	4,55	4,55	4,20
50	3,48	2,84	2,84	2,54
70	2,28	1,96	1,96	1,95
90	1,55	1,49	1,49	1,64
110	1,17	1,52	1,52	1,74
130	1,08	1,62	1,62	1,86
150	1,07	1,74	1,74	1,92
170	1,13	1,78	1,78	2,01
190	1,20	1,80	1,80	2,06
210	1,24	1,86	1,86	2,11
230	1,29	1,97	1,97	2,11
250	1,35	2,00	2,00	2,05
270	1,43	2,00	2,00	1,95
290	1,51	2,01	2,01	1,89
310	1,58	2,01	2,01	1,79
330	1,65	1,96	1,96	1,76
350	1,69	1,91	1,91	1,75
370	1,73	1,85	1,85	1,74
390	1,77	1,83	1,83	1,71
410	1,79	1,81	1,81	1,67
430	1,80	1,84	1,84	1,61
450	1,81	1,83	1,83	1,60
470	1,85	1,79	1,79	1,57
490	1,88	1,79	1,79	1,53
510	1,91	1,75	1,75	1,50
530	1,93	1,70	1,70	1,48
550	1,94	1,64	1,64	1,49
570	1,97	1,60	1,60	1,50
590	1,98	1,56	1,56	1,48
610	2,01	1,53	1,53	1,46
630	2,04	1,53	1,53	1,45
650	2,07	1,52	1,52	1,40
670	2,09	1,53	1,53	1,38
690	2,10	1,50	1,50	1,38
710	2,11	1,49	1,49	1,33
730	2,12	1,48	1,48	1,25
750	2,12	1,47	1,47	1,23
770	2,12	1,45	1,45	1,22
790	2,11	1,41	1,41	1,19
810	2,09	1,37	1,37	1,17
830	2,07	1,31	1,31	1,18
850	2,06	1,28	1,28	1,18
870	2,02	1,29	1,29	1,17
890	2,01	1,27	1,27	1,15
910	1,97	1,27	1,27	1,15
930	1,97	1,29	1,29	1,17
950	1,95	1,30	1,30	1,19
970	1,93	1,30	1,30	1,15
990	1,91	1,29	1,29	1,13

B.1.1.6 Estimate the expanded uncertainties of the test methods (see 6.7)

The instrumentation uncertainties and the uncertainties due to the EUT characteristics are combined into one standard uncertainty using Equations (7) and (9) from 6.7. The differences of the instrumentation uncertainty for different frequency ranges and polarisations are negligible, so that one uncertainty for all cases is sufficient. The combined and the expanded uncertainties are not given here numerically, because the EUT-dependent uncertainty is frequency-dependent. Figure B.14 displays the expanded uncertainties for the alternative and established test methods for a coverage factor of k = 2.



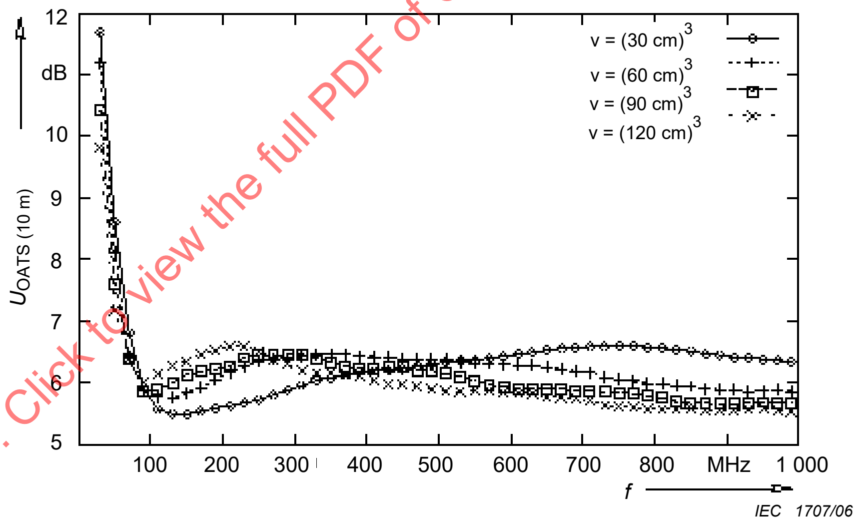


Figure B.8 – Expanded uncertainties (k = 2) of alternative (3 m FAR, top) and established (10 m OATS, bottom) test methods

B.1.1.7 Calculate the average conversion factor (see 6.8)

Using 6.8 Equation (14), the average conversion factor can be calculated from the measurement results of the EUTs. For each set of EUTs the average conversion factors are given by

$$\overline{K}_{\text{set}} = \frac{1}{N}\sum_{i=1}^{N}\left(E_{\text{OATS(10m)}i} - E_{\text{FAR(3m)}i}\right) \tag{B.12}$$

where

N, i	are given in Table 2;
$E_{\text{FAR(3m)}i}$	is the same as in Equation (B.1);
$E_{\text{OATS(10m)}i}$	is the same as in Equation (B.2);
$\overline{K}_{\text{set}}$	is the average conversion factor for a set of EUTs.

From this the maximum values for each volume are searched,

$$\overline{K}_{\text{max, vol}} = \max_{\text{numbers of radiators}} \overline{K}_{\text{set}} \tag{B.13}$$

where

$\overline{K}_{\text{set}}$	is the same as in Equation (B.12);
$\overline{K}_{\text{max, vol}}$	is the maximum average conversion factor for one assumed EUT volume.

These values are displayed in Figure B.9, and numerical values are given in Table B.4.

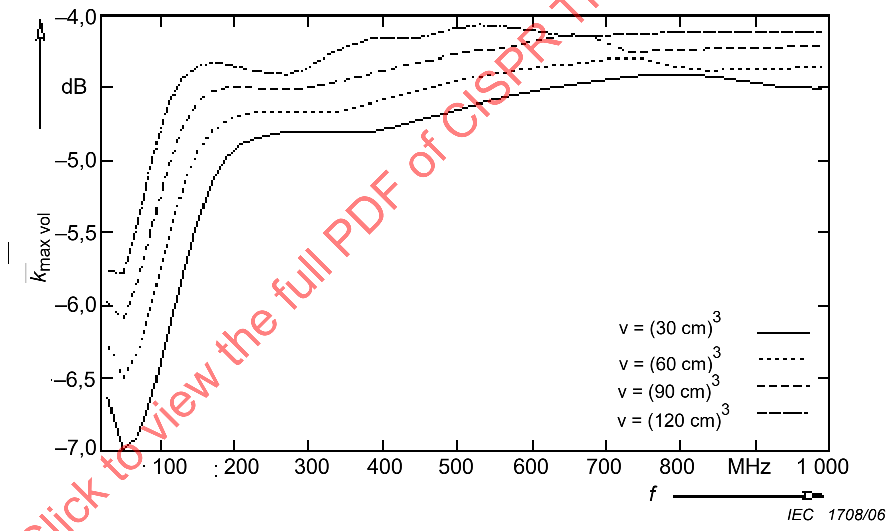


Figure B.9 – Maximum average conversion factors for different volumes

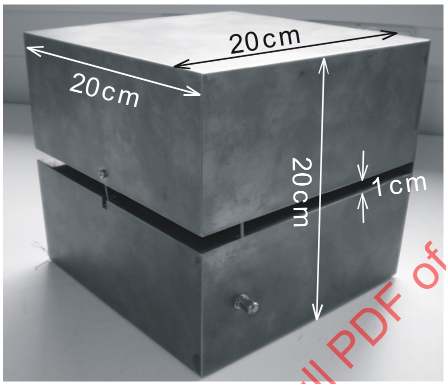
Table B.4 – Maximum average conversion factors in dB between 10 m OATS and 3 m FAR

Frequency in MHz	v = (30 cm)^3	v = (60 cm)^3	v = (90 cm)^3	v = (120 cm)^3
30	–6,63	–6,26	–5,97	–5,76
50	–6,99	–6,48	–6,10	–5,78
70	–6,90	–6,31	–5,83	–5,43
90	–6,59	–5,96	–5,44	–4,98
110	–6,20	–5,56	–5,05	–4,62
130	–5,80	–5,20	–4,77	–4,43
150	–5,43	–4,94	–4,61	–4,35
170	–5,14	–4,80	–4,52	–4,32
190	–4,97	–4,73	–4,50	–4,34
210	–4,88	–4,68	–4,49	–4,36
230	–4,85	–4,67	–4,51	–4,38
250	–4,82	–4,66	–4,51	–4,40
270	–4,80	–4,66	–4,51	–4,41
290	–4,80	–4,67	–4,50	–4,38
310	–4,80	–4,67	–4,49	–4,32
330	–4,81	–4,67	–4,47	–4,26
350	–4,81	–4,65	–4,44	–4,22
370	–4,81	–4,63	–4,42	–4,19
390	–4,80	–4,60	–4,39	–4,15
410	–4,77	–4,57	–4,36	–4,16
430	–4,75	–4,54	–4,34	–4,15
450	–4,72	–4,51	–4,33	–4,15
470	–4,69	–4,49	–4,30	–4,12
490	–4,67	–4,46	–4,28	–4,10
510	–4,63	–4,44	–4,25	–4,08
530	–4,61	–4,42	–4,24	–4,06
550	–4,58	–4,40	–4,24	–4,07
570	–4,56	–4,39	–4,22	–4,08
590	–4,54	–4,37	–4,19	–4,09
610	–4,52	–4,36	–4,17	–4,11
630	–4,50	–4,34	–4,15	–4,13
650	–4,48	–4,33	–4,13	–4,15
670	–4,47	–4,33	–4,14	–4,14
690	–4,45	–4,31	–4,17	–4,14
710	–4,44	–4,30	–4,21	–4,13
730	–4,42	–4,29	–4,25	–4,13
750	–4,41	–4,30	–4,25	–4,13
770	–4,41	–4,32	–4,25	–4,12
790	–4,40	–4,35	–4,24	–4,12
810	–4,41	–4,36	–4,24	–4,11
830	–4,41	–4,38	–4,23	–4,11
850	–4,43	–4,38	–4,23	–4,11
870	–4,44	–4,37	–4,23	–4,11
890	–4,46	–4,37	–4,23	–4,11
910	–4,47	–4,37	–4,23	–4,11
930	–4,49	–4,36	–4,22	–4,11
950	–4,50	–4,36	–4,22	–4,12
970	–4,50	–4,36	–4,22	–4,12
990	–4,50	–4,36	–4,22	–4,12

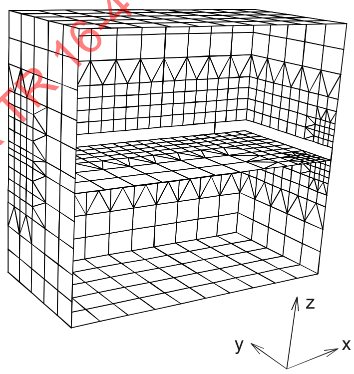
B.1.1.8 Verify the calculated values (see 6.9)

The numerical values presented above are from simulations with the statistical EUT model; thus a verification of these theoretical values is necessary. Since it is impossible in a reasonable time to produce the same large number of measurement results as was used for the statistical simulations, at least a certain number of measurements should be done to support the calculated results.

The results are derived in terms of deviations from the reference quantity. For even a single EUT only, it is almost impossible to measure this selected reference quantity over the full surrounding sphere. Due to these limitations, a special-purpose generic EUT is used for measurements to verify the theoretical results. The radiation characteristics for this EUT, and hence the reference quantity as well as the measurement results, can be calculated. The latter is important for the identification and evaluation of any possible unexpected measurement results. The EUT is constructed as a cube with a 0,2 m side length. To represent real-world EUT radiation effects, the cube has a slot, which is excited by a comb generator with an emissions frequency spacing of 10 MHz. Figure B.10 shows a picture and the simulation model (cut-view) of the specimen EUT.



IEC 1709/06



IEC 1710/06

Figure B.10 – Photo (left) and cut-view of simulation model (right) of the specimen EUT

The measurements were performed for two different orientations of the specimen EUT: one measurement series with the orientation shown in Figure B.10, and the other measurement series with the EUT rotated by 90° around the *x*-axis.

Figure B.11 shows the deviations from the reference quantity for the results of alternative and established test method. The statistical EUT model with $v = (30\ \text{cm})^3$ is chosen for comparison with the values of the specimen EUT. For each number of radiators, a 95% tolerance interval is shown (dotted lines). For the specimen EUT, the measured as well as the calculated deviations from the calculated reference quantity are shown, for both orientations of the EUT. Except for one data point, the measured values deviate from the tolerance interval by up to 3,5 dB. This deviation is smaller than the instrumentation measurement uncertainty given in CISPR 16-4-2. One measured value (OATS measurement with rotated EUT at 120 MHz) deviates by 8,5 dB from the tolerance interval. These deviations were not seen in the results from the simulations with the specimen EUT. Consequently, these deviations are expected to be due to measurement problems. Then it can be said that the measured results for the specimen EUT support the statistically-derived deviations from the reference quantity, and hence the derived conversion factors and the uncertainties.

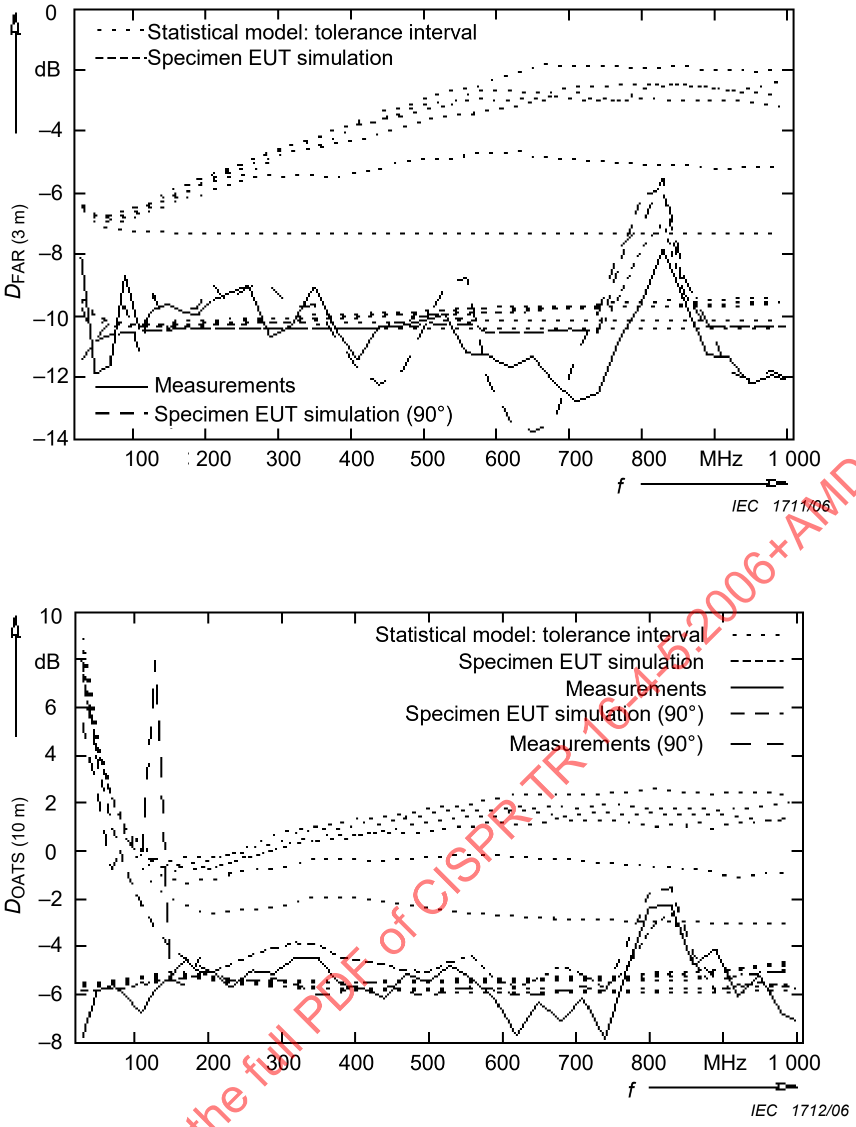


Figure B.11 – Deviations of the specimen EUT: 3 m fully anechoic room (top) and 10 m open area test site (bottom)

B.1.1.9 Apply the conversion (see 6.10)

Figure B.12 shows a sample of measured values with their expanded uncertainties from a FAR emission measurement, for an EUT with maximum cube-edge dimension of 0,3 m. The converted limits according to 6.10 Equation (15) are shown in Figure B.13. Based on the largest dimension of the EUT, the average conversion factors for (30 cm)^3 are applied (see Figure B.9). The comparison of the measured values with the converted limits must consider the differences between the uncertainties of the alternative and established test methods. Figure B.14 displays the expanded uncertainties of 10 m OATS and 3 m FAR for the (30 cm)^3 EUT volume. As can be seen, the uncertainty of the FAR is at some frequencies about 0,1 dB larger than the uncertainty of the OATS. At these frequencies the converted limit has to be corrected with the amount of the difference according to 6.10 Equation (17). The measured values then can be compared with the corrected and converted limit line, as shown in Figure B.15. The EUT fails due to the emission values at 150 MHz and 550 MHz.

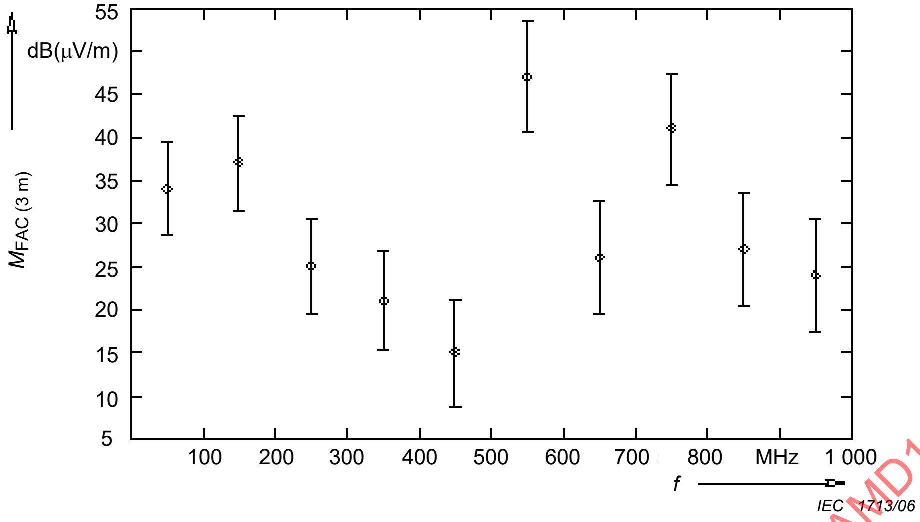


Figure B.12 – Sample FAR measurement

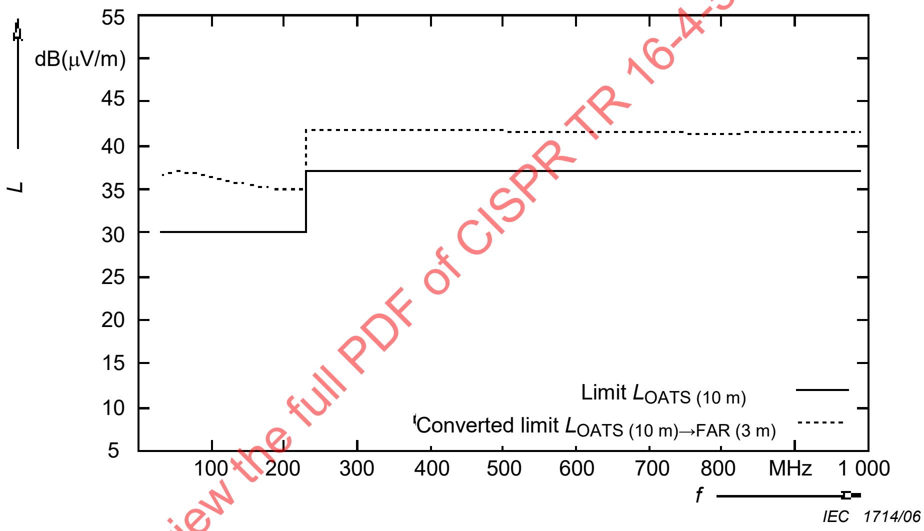


Figure B.13 – OATS 10 m limit line converted to FAR 3 m conditions

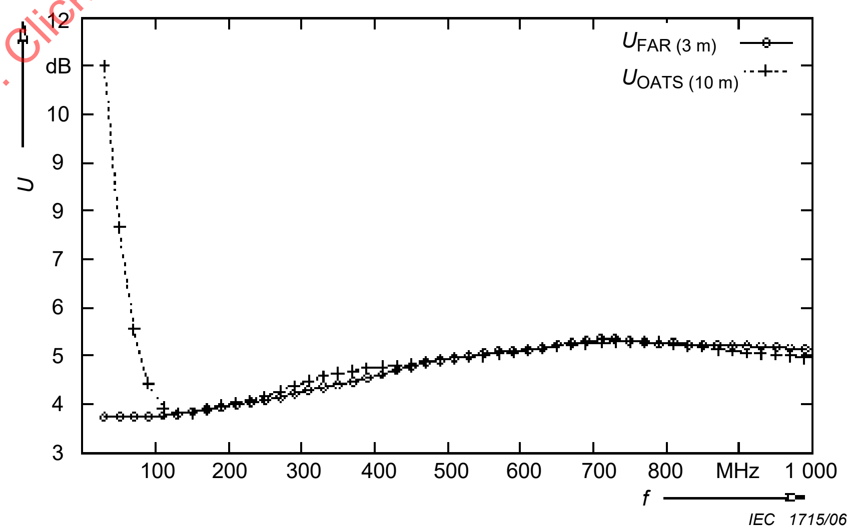


Figure B.14 – Expanded uncertainties

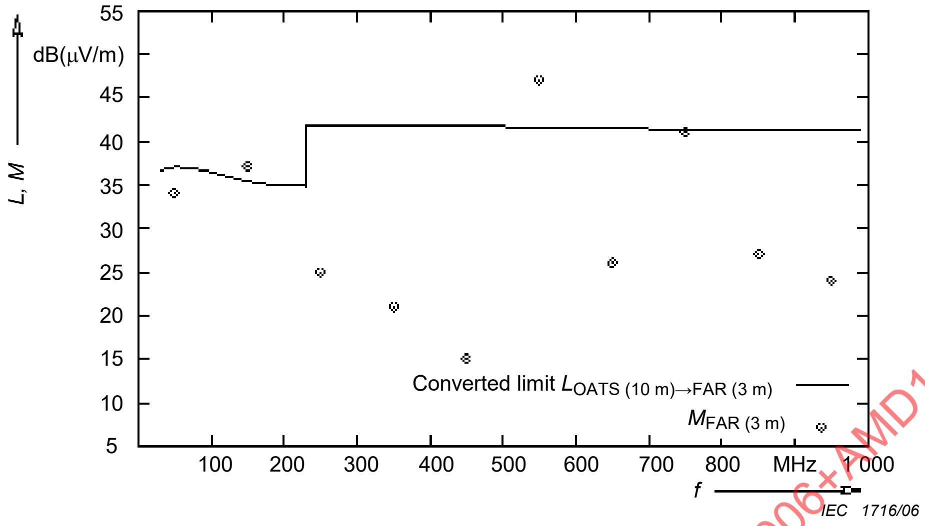


Figure B.15 – Comparison of the measured values with the corrected converted limit

B.1.2 Small EUTs with cables

Results different from those shown in B.1.1 are expected, but are under investigation.

B.2 Example 2 – 3 m open-area test site measurements compared to 10 m open-area test site measurements

B.2.1 Small EUTs without cables

B.2.1.1 Select the reference quantity *X* (see 6.2)

As above, the reference quantity is selected as free-space electric field – see B.1.1.1.

B.2.1.2 Describe the test methods and measurands (see 6.3)

Alternative test method: 3 m open-area test site, OATS (3 m). Figure B.16 displays the measurement set-up of an OATS with 3 m distance for measurements in the frequency range from 30 MHz to 1 GHz. The receiving antenna is located at a distance of $d_{OATS(3m)}$ = 3 m to the EUT. To detect the maximum field strength, the EUT is rotated in azimuth and the antenna height is varied between 1 and 4 meters. The set-up is placed on a conducting ground plane. The perimeter and surroundings of the OATS and set-up is free of any reflecting objects, therefore ideally the antenna receives only the direct radiation and the ground reflected signal.

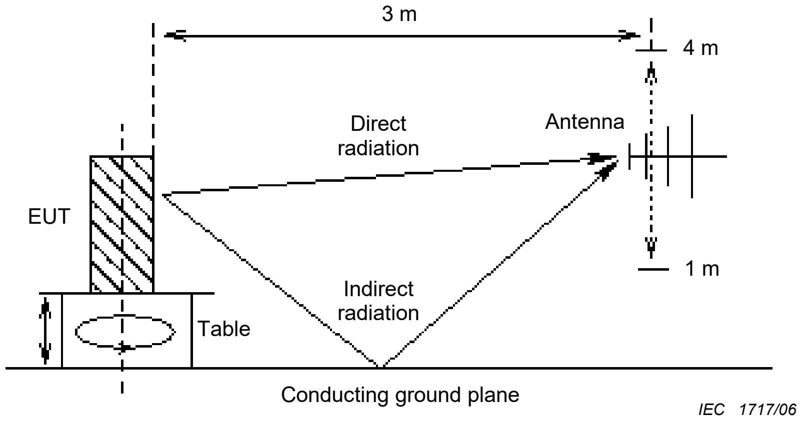


Figure B.16 – EUT and antenna set-up of 3 m open area test site measurement

Established test method: 10 m open-area test site, OATS (10 m). See B.1.1.2

B.2.1.3 Determine the deviations of the measured quantities from the reference quantity (see 6.4)

A description of the statistical model used for the small EUT is given in B.1.1.3. From the simulation results, the deviations between the alternative test method results and the reference quantity values are obtained using

$$D_{\mathrm{ATM}i} = D_{\mathrm{OATS(3m)}i} = X_i - E_{\mathrm{OATS(3m)}i} \qquad \text{(B.14)}$$

where

$E_{\mathrm{OATS(3m)}i}$ is the field-strength for 3 m OATS test method for EUT i;

X_i, $D_{\mathrm{ATM}i}$, i are the same as in 6.4 Equation (1);

$D_{\mathrm{OATS(3m)}i}$ is the deviation from the reference quantity X of the 3 m FAR test method result for EUT i,

and for the established test method using Equation (B.2) from B.1.1.3.

B.2.1.4 Determine the average values of the deviations (see 6.5)

Calculations for the established test method are done in the way as in B.1.1.4. For the alternative test method the average deviations can be calculated using Equation (3) from 6.5. This is done for every set of 1 000 EUTs using:

$$\overline{D}_{\mathrm{set,\,ATM}} = \overline{D}_{\mathrm{set,\,OATS(3m)}} = \frac{1}{1000}\sum_{i=1}^{1000} D_{\mathrm{OATS(3m)}i} \qquad \text{(B.15)}$$

where

$\overline{D}_{\mathrm{set,\,ATM}}$ is the average deviation of the alternative test method for the set of 1 000 EUTs;

$\overline{D}_{\mathrm{set,\,OATS(3m)}}$ is the average deviation of the 3 m OATS test method for the set of 1 000 EUTs;

$D_{\mathrm{OATS(3m)i}}$, i are the same as in Equation (B.14).

In order to estimate the worst-case results for each volume the maximum average deviation is determined using

$$\overline{D}_{\text{max vol, OATS(3m)}} = \max_{\text{number of radiators}} \overline{D}_{\text{set, OATS(3m)}} \qquad \text{(B.16)}$$

where

$\overline{D}_{\text{set, OATS(3m)}}$ is the same as in Equation (B.15);

$\overline{D}_{\text{max vol,OATS(3m)}}$ is the maximum average deviation of the established test method 3 m OATS for one assumed EUT volume.

The maximum deviations for the alternative test method are shown in Figure B.17, and the deviations for the established test method are shown in Figure B.5 (bottom).

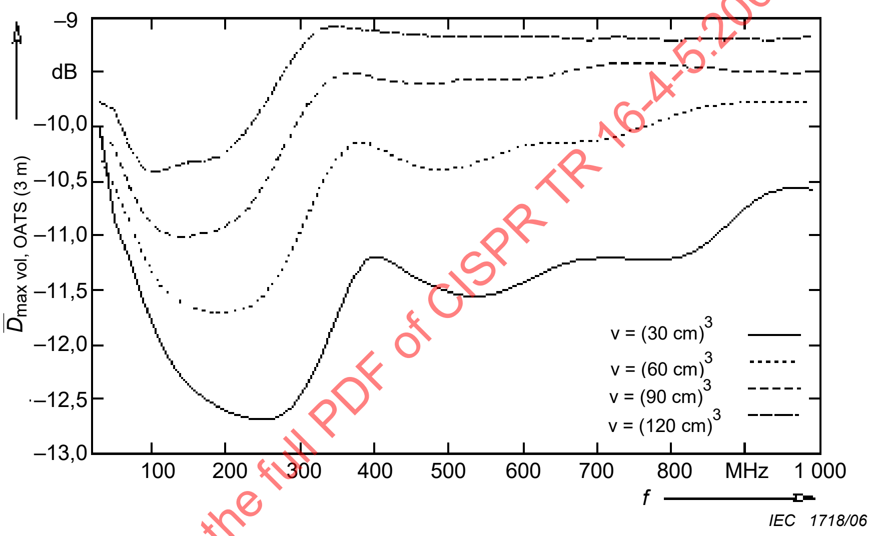


Figure B.17 – Maximum average deviations for 3 m OATS

B.2.1.5 Estimate the standard uncertainties of the test methods (see 6.6)

Instrumentation uncertainty: For both the alternative and established test methods, the measurement instrumentation uncertainty is as given in the basic standard CISPR 16-4-2:~~2003~~2011.

Intrinsic uncertainty: In CISPR 16-4-1~~ ed. 1.1~~, values for intrinsic uncertainties are still under consideration; therefore this uncertainty is not considered here.

Uncertainty due to unknown EUT characteristics: The standard inherent uncertainty, u_{inherent}, for the standard measurement procedure is given in B.1.1.5. For the alternative test method, u_{inherent} can be calculated using Equation (5) from 6.6. For the same reasons as given in B.1.1.5, the standard deviation is calculated using only values larger than the average value. The number of these values is denoted N_+, and the standard deviation is denoted s_+. The index of a given EUT i = 1...N is mapped to a new index $j = 1...N_+$. The standard deviation is calculated for every set of EUTs.

$$s_{+\text{set}}(D_{\text{OATS(3m)}}) = \sqrt{\frac{\sum_{j=1}^{N_+}(D_{\text{OATS(3m)}j} - \overline{D}_{\text{set, OATS(3m)}})^2}{N_+ - 1}} \qquad \text{(B.17)}$$

where

$D_{\text{OATS(3m)}i}$, $\overline{D}_{\text{set, OATS(3m)}}$ are the same as in Equation (B.15);

N_+ is the number of values larger than the average value;

$s_{+\text{set}}(D_{\text{OATS(3m)}})$ is the one-side standard deviation of the deviations for one set of 1 000 EUTs of the 3 m OATS test method.

This approach gives a worst-case estimation. A more precise result can be obtained by considering the skew of the CDF.

From the standard deviations of the deviations for each EUT volume size, next the maximum value is determined. This maximum is taken as a safe approximation of the uncertainty.

$$u_{\text{ATM,inherent}} = u_{\text{OATS(3m),inherent}} \approx s_{+\text{max,vol}}(D_{\text{OATS(3m)}}) = \max_{\text{number of radiators}} s_{+\text{set}}(D_{\text{OATS(3m)}}) \qquad \text{(B.18)}$$

The uncertainty values are given in Figure B.18 and given numerically in Table B.5.

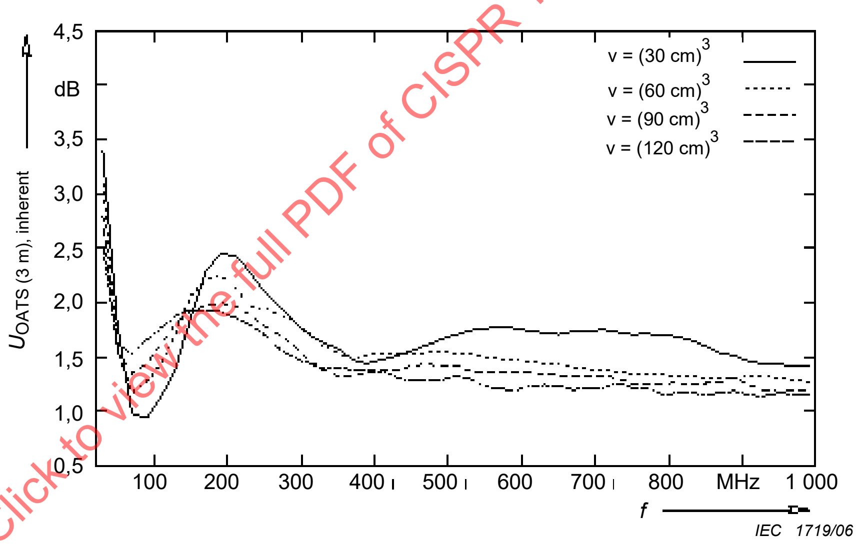


Figure B.18 – Uncertainties due to the unknown EUT characteristic for 3 m OATS

Table B.5 – Uncertainties in dB due to the unknown EUT characteristic for 3 m OATS

Frequency in MHz	*v* = (30 cm)³	*v* = (60 cm)³	*v* = (90 cm)³	*v* = (120 cm)³
30	3,38	3,09	2,78	2,50
50	1,80	1,57	1,53	1,61
70	0,97	1,17	1,34	1,53
90	0,93	1,27	1,43	1,65
110	1,13	1,44	1,62	1,76
130	1,40	1,72	1,80	1,87
150	1,87	2,06	1,92	1,92
170	2,28	2,20	1,96	1,92
190	2,43	2,25	1,99	1,91
210	2,43	2,13	1,96	1,85
230	2,27	1,96	1,88	1,79
250	2,09	1,94	1,78	1,70
270	1,96	1,89	1,70	1,57
290	1,81	1,82	1,59	1,49
310	1,70	1,72	1,47	1,43
330	1,62	1,60	1,39	1,38
350	1,57	1,53	1,32	1,40
370	1,47	1,47	1,31	1,37
390	1,43	1,51	1,35	1,37
410	1,47	1,52	1,38	1,36
430	1,50	1,53	1,38	1,31
450	1,55	1,52	1,41	1,27
470	1,60	1,53	1,43	1,28
490	1,66	1,54	1,40	1,28
510	1,70	1,53	1,41	1,32
530	1,74	1,52	1,37	1,30
550	1,75	1,49	1,36	1,22
570	1,77	1,48	1,35	1,20
590	1,75	1,46	1,35	1,18
610	1,73	1,45	1,36	1,22
630	1,72	1,44	1,33	1,23
650	1,70	1,42	1,33	1,23
670	1,73	1,40	1,31	1,19
690	1,73	1,38	1,32	1,21
710	1,74	1,38	1,33	1,21
730	1,72	1,36	1,29	1,25
750	1,70	1,34	1,25	1,21
770	1,70	1,33	1,24	1,20
790	1,69	1,33	1,25	1,15
810	1,68	1,31	1,25	1,16
830	1,65	1,31	1,25	1,16
850	1,59	1,30	1,25	1,15
870	1,53	1,30	1,26	1,16
890	1,50	1,30	1,30	1,18
910	1,45	1,31	1,23	1,14
930	1,43	1,31	1,19	1,13
950	1,42	1,29	1,17	1,16
970	1,41	1,28	1,18	1,16
990	1,41	1,27	1,19	1,15

From the set of calculated deviations, a 95% tolerance interval can be determined. Using the width and standard deviation of the tolerance interval, the coverage factor k can be approximated. For the alternative test method, the coverage factor is

$$k_{\mathrm{ATM}} = k_{+\mathrm{OATS(3m)}} \approx 2{,}3 \qquad \text{(B.19)}$$

where

k_{ATM} is the coverage factor for the alternative test method

$k_{+\mathrm{OATS(3m)}}$ is the coverage factor for the 3 m OATS test method derived from the values larger than the average

The coverage factor of the established test method is as given in B.1.1.5, Equation (B.11)

B.2.1.6 Estimate the expanded uncertainties of the test methods (see 6.7)

The instrumentation uncertainties and the uncertainties due to the EUT characteristics must be combined into one standard uncertainty using Equation (7) from 6.7. The differences in the instrumentation uncertainty for different frequency range and polarisation are negligible, such that one uncertainty for all cases is sufficient. The combined and the expanded uncertainties are not given here numerically, because the EUT-dependent uncertainty depends on frequency. Figure B.19 displays the expanded uncertainties of the alternative test method for a coverage factor of k = 2.

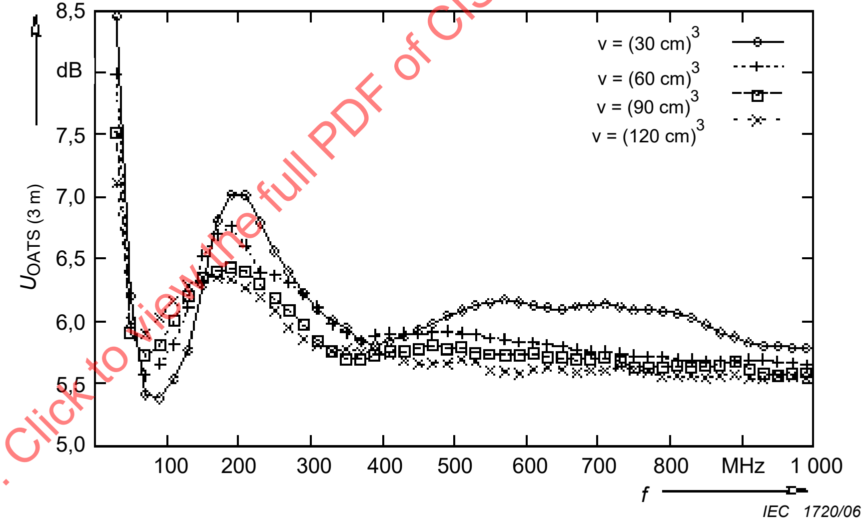


Figure B.19 – Expanded uncertainties (k = 2) of alternative test method [OATS (3 m)]

B.2.1.7 Calculate the average conversion factor (see 6.8)

According to 6.8 Equation (14) the average conversion factor can be calculated from the measurement results of the EUTs. For each set of EUTs the average conversion factors are given by

$$\overline{K}_{\text{set}} = \frac{1}{N}\sum_{i=1}^{N}\left(E_{\text{OATS(10m)}i} - E_{\text{OATS(3m)}i}\right) \quad \text{(B.20)}$$

where

N, i	are given in Table 2;
$E_{\text{OATS(3m)}i}$	is the same as in Equation (B.14);
$E_{\text{OATS(10m)}i}$	is the same as in Equation (B.2);
$\overline{K}_{\text{set}}$	is the average conversion factor for a set of EUTs.

From this, the maximum values for each EUT volume size are searched to find the maximum,

$$\overline{K}_{\text{max, vol}} = \max_{\text{numbers of radiators}} \overline{K}_{\text{set}} \quad \text{(B.21)}$$

where

$\overline{K}_{\text{set}}$	is the same as in Equation (B.12);
$\overline{K}_{\text{max, vol}}$	is the maximum average conversion factor for one assumed EUT volume.

These maximum values are displayed in Figure B.20 and are given numerically in Table B.6.

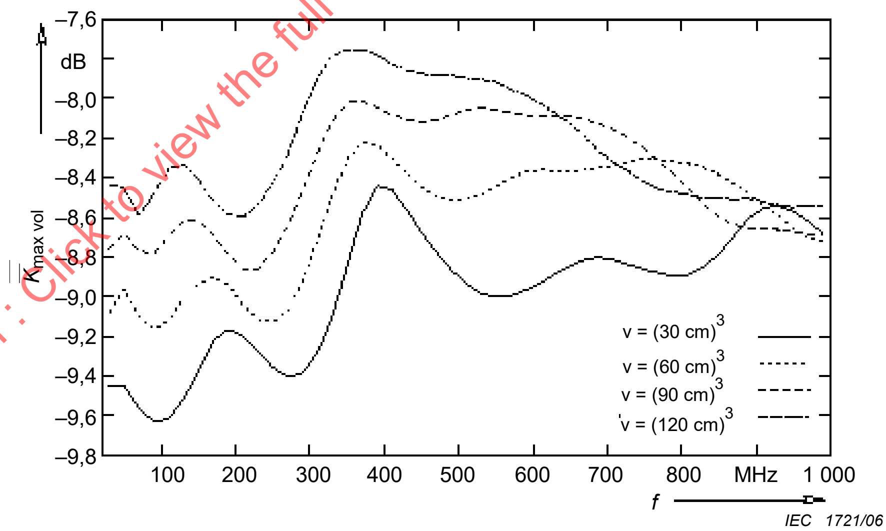


Figure B.20 – Maximum average conversion factors

Table B.6 – Maximum average conversion factors in dB between 10 m and 3 m OATS

Frequency in MHz	*v* = (30 cm)^3	*v* = (60 cm)^3	*v* = (90 cm)^3	*v* = (120 cm)^3
30	–9,45	–9,08	–8,76	–8,43
50	–9,45	–8,96	–8,68	–8,45
70	–9,56	–9,10	–8,76	–8,59
90	–9,63	–9,16	–8,78	–8,47
110	–9,61	–9,12	–8,69	–8,35
130	–9,51	–9,01	–8,61	–8,33
150	–9,37	–8,93	–8,61	–8,41
170	–9,22	–8,90	–8,69	–8,51
190	–9,16	–8,94	–8,78	–8,58
210	–9,19	–9,03	–8,85	–8,59
230	–9,27	–9,11	–8,85	–8,53
250	–9,35	–9,12	–8,77	–8,42
270	–9,40	–9,07	–8,64	–8,28
290	–9,38	–8,92	–8,46	–8,07
310	–9,28	–8,71	–8,27	–7,89
330	–9,10	–8,48	–8,11	–7,78
350	–8,84	–8,31	–8,02	–7,75
370	–8,58	–8,22	–8,01	–7,75
390	–8,44	–8,23	–8,04	–7,78
410	–8,46	–8,30	–8,08	–7,82
430	–8,56	–8,38	–8,10	–7,85
450	–8,67	–8,44	–8,12	–7,87
470	–8,77	–8,49	–8,10	–7,88
490	–8,86	–8,51	–8,08	–7,88
510	–8,93	–8,50	–8,05	–7,89
530	–8,98	–8,48	–8,04	–7,90
550	–9,00	–8,44	–8,06	–7,91
570	–8,99	–8,40	–8,07	–7,95
590	–8,96	–8,37	–8,08	–7,98
610	–8,93	–8,36	–8,08	–8,02
630	–8,88	–8,36	–8,08	–8,07
650	–8,84	–8,36	–8,08	–8,12
670	–8,81	–8,36	–8,10	–8,19
690	–8,80	–8,35	–8,13	–8,27
710	–8,81	–8,33	–8,15	–8,32
730	–8,84	–8,31	–8,20	–8,37
750	–8,86	–8,30	–8,25	–8,42
770	–8,88	–8,31	–8,31	–8,46
790	–8,89	–8,31	–8,38	–8,47
810	–8,88	–8,33	–8,46	–8,48
830	–8,85	–8,34	–8,53	–8,50
850	–8,78	–8,38	–8,59	–8,50
870	–8,69	–8,42	–8,63	–8,50
890	–8,60	–8,48	–8,65	–8,50
910	–8,55	–8,53	–8,65	–8,52
930	–8,54	–8,59	–8,66	–8,53
950	–8,56	–8,65	–8,67	–8,54
970	–8,61	–8,70	–8,68	–8,54
990	–8,68	–8,72	–8,69	–8,54

B.2.1.8 Verify the calculated values (see 6.9)

For verification of the values of the 3 m OATS test method the same considerations as in B.1.1.8 are applicable. Consequently, the same specimen EUT is used for verification measurements.

The measurements are performed using two different orientations of the specimen EUT: one measurement series with the orientation shown in Figure B.10, and the other with the EUT rotated by 90° around the *x*-axis.

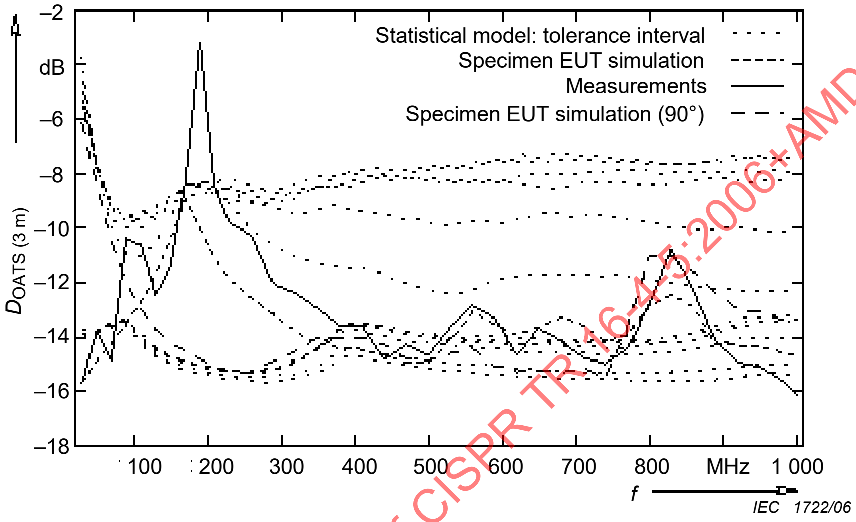


Figure B.21 – Deviations of the specimen EUT: Open area test site (3 m)

Figure B.21 shows the deviations of the specimen EUT from the reference quantity. The statistical EUT model with $v = (30\ \text{cm})^3$ is chosen for comparison with the values of the specimen EUT. For each number of radiators one 95% tolerance interval is shown (dotted lines). For the specimen EUT the measured as well as the calculated deviations from the calculated reference quantity are shown for both orientations of the EUT.

Except for one data point, the measured values deviate from the tolerance interval in a range of up to 1 dB. This deviation is smaller than the instrumentation measurement uncertainty given in CISPR 16-4-2:~~2002~~2011. One measured value (210 MHz with EUT in normal orientation) deviates about 6 dB from the tolerance interval. These deviations are not seen in the specimen-EUT simulation results; therefore, these deviations can be considered to be due to measurement uncertainties. In that case the results of the specimen EUT support the statistically-derived deviations from the reference quantity, and also the derived conversion parameters.

B.2.1.9 Apply the conversion (see 6.10)

Figure B.22 shows a sample of measured values with their expanded uncertainties from an OATS (3 m) emission measurement. The measured EUT has a maximum dimension of 0,3 m. The converted limits according to 6.10 Equation (15) are shown in Figure B.23. Based on the largest dimension of the EUT, the average conversion factors for the (30 m^3) volume are applied (see Figure B.20). The comparison of measured values with the converted limits must consider the difference between the uncertainties of the alternative and established test method. Figure B.24 displays the expanded uncertainties of OATS (10 m) and OATS (3 m) for the EUT volume of (30 m^3). As can be seen in that figure, the uncertainty for the 3 m open-area test site test method in the frequency range from 110 MHz to 310 MHz is larger than the uncertainty of the 10 m open area test site test method. The maximum difference occurs around 200 MHz, with a value of about 2 dB.

NOTE The increase of the uncertainty of the 3 m OATS procedure in this frequency range is due to the measurements with vertical polarisation. Considering horizontal and vertical polarisation separately leads to different uncertainties. To use these different uncertainties, a rule has to be established, which describes under which conditions the conversions for horizontal, vertical or both polarisations shall be used.

At these frequencies, the converted limit has to be corrected using the magnitude of the uncertainty difference, according to 6.10 Equation (17). The measured values can then be compared with the corrected and converted limit line, as shown in Figure B.25. In this case, the EUT fails due to the emission values at 190 MHz, 690 MHz, and 890 MHz.

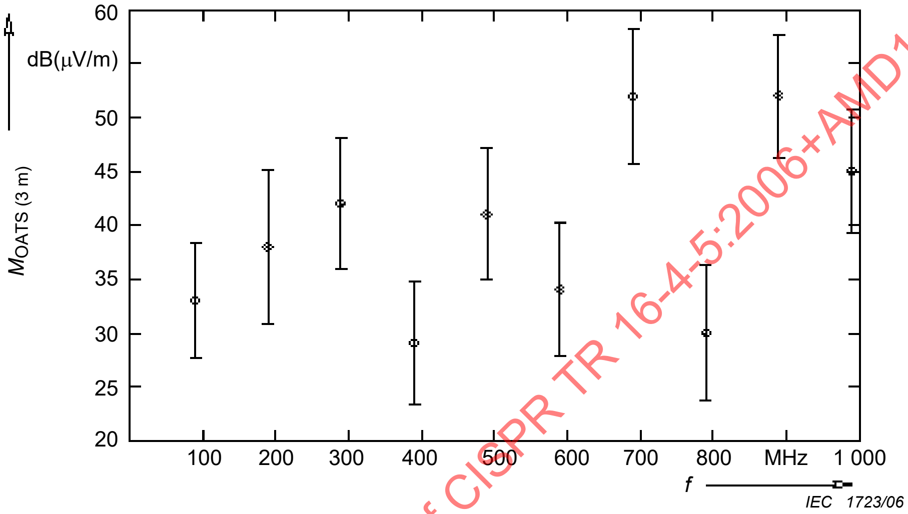


Figure B.22 – Sample OATS (3 m) measurement

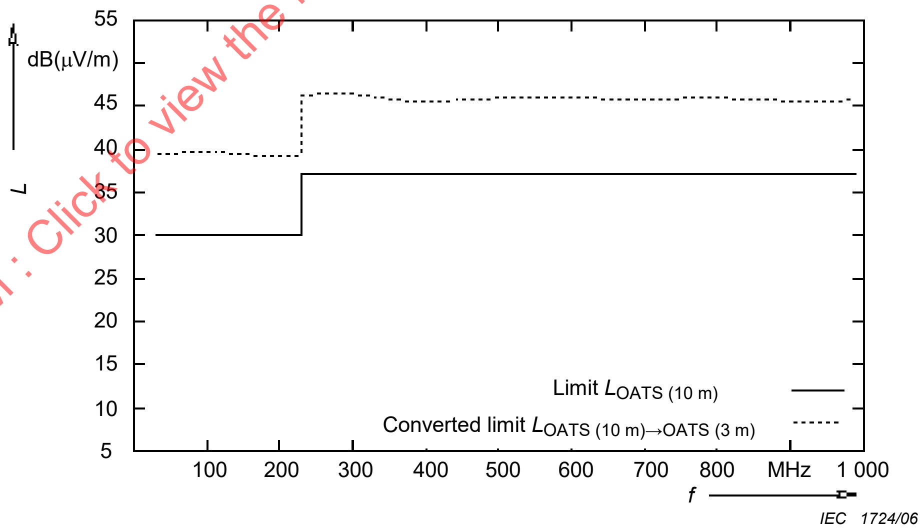


Figure B.23 – OATS (10 m) limit line converted to OATS (3 m) conditions

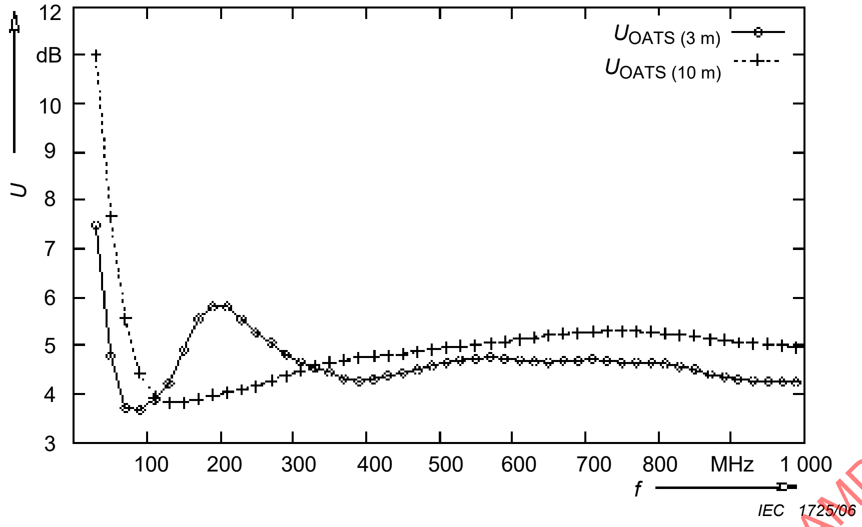


Figure B.24 – Expanded uncertainties

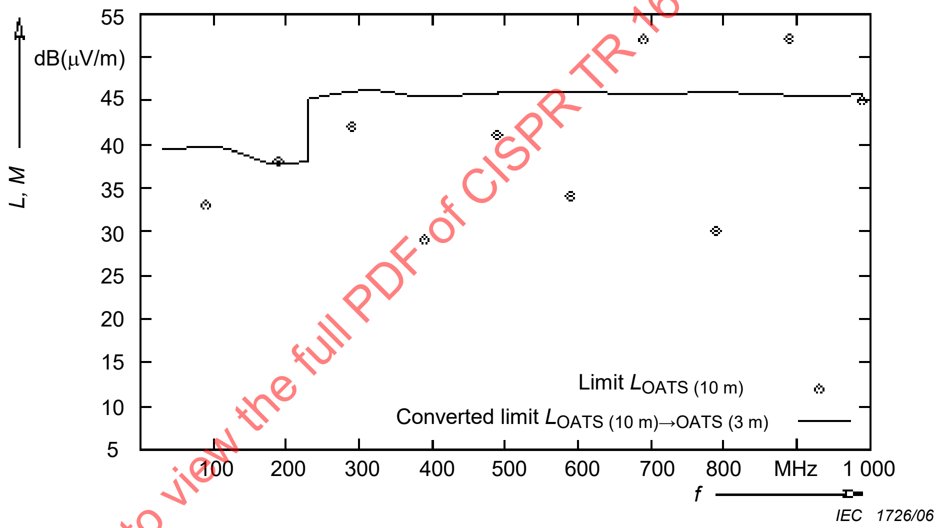


Figure B.25 – Comparison of the corrected values with the converted limit

B.2.2 Small EUTs with cables

Results different from those shown in Clause B.2 are expected, but are presently under investigation.

B.3 Example 3 – reverberation chamber measurement results compared to 10 m open-area test site results

Under consideration.

Annex C
(informative)

Example of the application of the test method comparison procedure based on measurement results

NOTE 1 The example described in this annex uses the results of a RRT with a CDNE. The correction of measurement results and missing data sets are deemed acceptable for the purposes of this demonstration.

NOTE 2 A CDNE is defined in CISPR 16-1-2 as a coupling/decoupling network for emission measurement in the frequency range 30 MHz to 300 MHz.

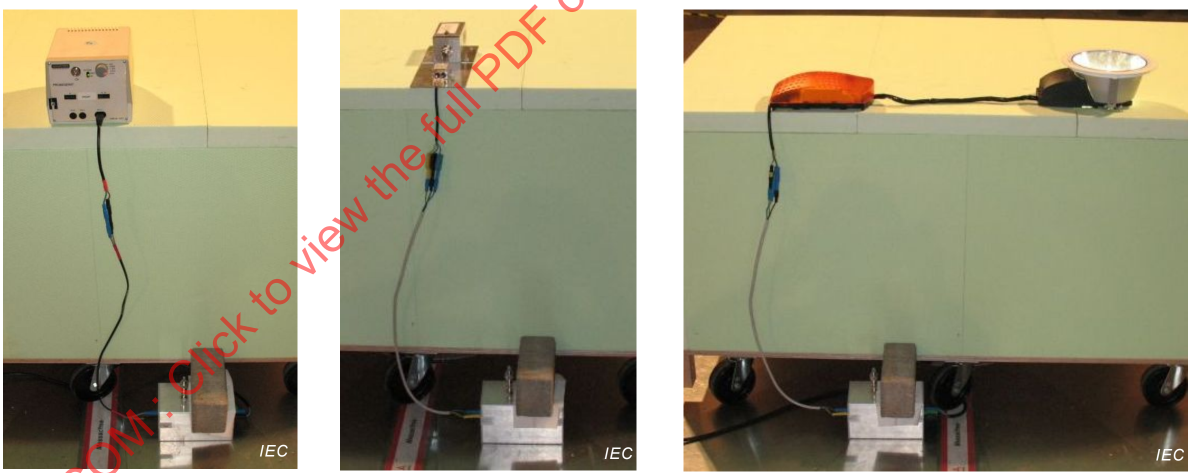
C.1 General

A RRT was carried out by CISPR/A participants for estimating the conversion factor for the ATM "measurement of the disturbance voltage in the frequency range 30 MHz to 300 MHz with a CDNE." Six international test labs participated.

Three different representative EUTs were used. Figure C.1 a) shows comb generator 1 radiating via the connected cable as well as via its case. Figure C.1 b) shows comb generator 2 radiating via the connected cable that was fed via a typical EMI-mitigation filter. Figure C.1 c) shows a luminaire downlight.

The field strength measurement (i.e. ETM) was carried out using a CDNE as a CMAD. Where available for a given test lab, two different CDNEs from different manufacturers were utilized.

NOTE A CMAD is defined in CISPR 16-1-4 as a common mode absorption device that can be applied on cables leaving the test volume in radiated emission measurements to reduce the compliance uncertainty.



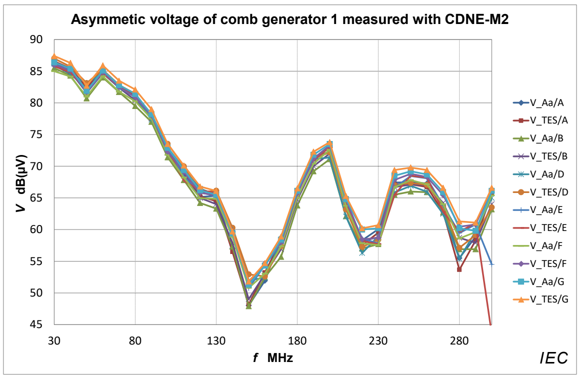
a) Comb generator 1 b) Comb generator 2 c) Luminaire downlight

Figure C.1 – EUTs used during RRT

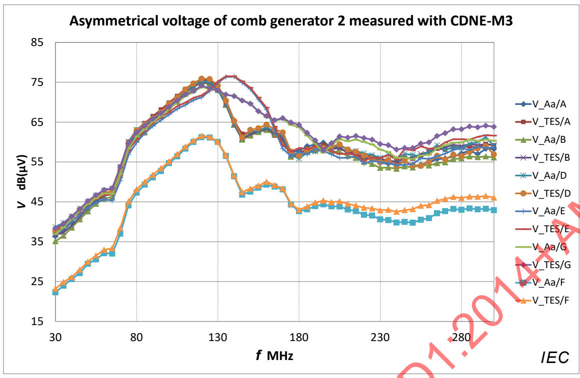
C.2 Measurement of conducted disturbance using CDNEs

Figure C.2 shows the results of measurements of the asymmetric voltage using both CDNEs. An approximately constant deviation of 10 dB for lab "F" in Figure C.2 b) can be seen. This measurement is not taken into account for further consideration of the standards compliance uncertainty.

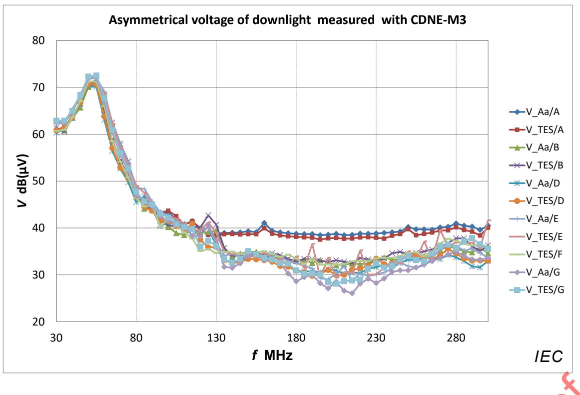
For the downlight results, one test lab used a measurement bandwidth of 10 kHz. A correction of 10,8 dB is made, which allows inclusion of the measurement results. Further it should be noted that above about 130 MHz there are no EUT emissions. Therefore only measurement results up to 130 MHz are considered.



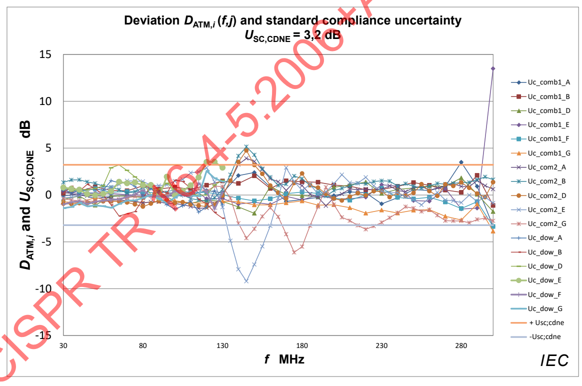
a) Comb generator 1



b) Comb generator 2



c) Downlight



d) Deviations and SCU

Figure C.2 – Measurement results of the asymmetrical voltage using both CDNEs

For estimating the SCU, the average of all T = 6 test labs for EUT i is calculated using Equation (23).

For each frequency f and for each EUT i, the deviation $D_{ATM,i}(f,j)$ between the measured values' average $\overline{M}_{XTM,i}(f)$ and each measured value $M_{ATM,i}(f,j)$ is calculated using Equation (24).

The experimental standard deviation of all these deviations $D_{ATM,i}(f,j)$ is calculated to be 1,6 dB, using Equation (25).

The uncertainty that causes this deviation depends on the measurement equipment and the measurement procedure. This uncertainty is the SCU, which is estimated by Equation (26).

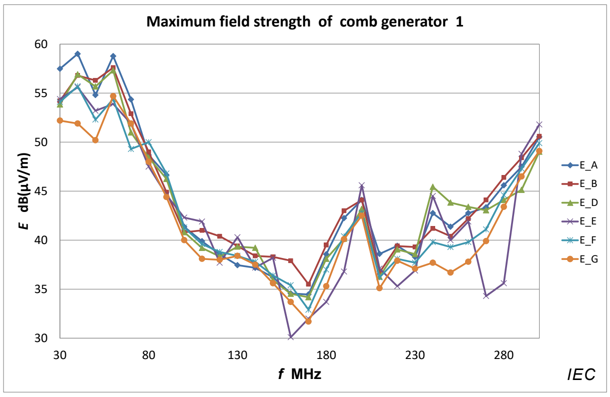
The calculated deviations $D_{ATM,i}(f,j)$, and the SCU of 3,2 dB, are shown in Figure C.2 d).

C.3 Measured disturbance field strength

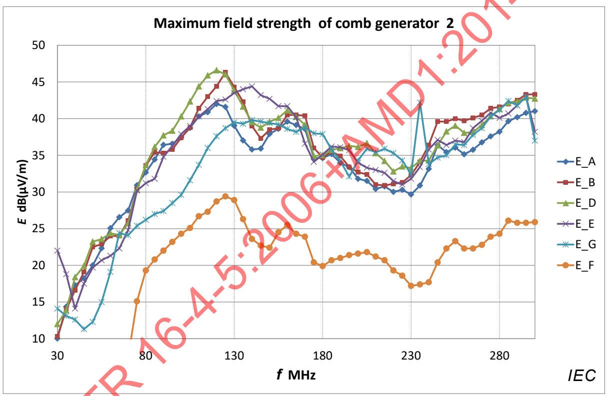
The disturbance field strength of the EUTs was measured in a 10 m SAC or on a 10 m OATS. This measurement procedure is the established measurement procedure (ETM), with the exception that then CDNE was used as a CMAD.

Figure C.3 shows the measured disturbance field strength. It can be seen in Figure C.3 b) that lab "F" again has a systematic deviation of 10 dB. This measurement result of lab "F" is not taken into account for the SCU calculation. The measurement result of the downlight [Figure C.3 c)] for lab “F” again contains a correction for a systematic deviation of 10 dB. This measurement result was corrected to enable calculating the correction factor. The correction was taken because half of all measurement results from this lab show the systematic deviation of 10 dB from the average. Figure C.3 c) also shows a large deviation for lab “E.” This measurement result is not considered.

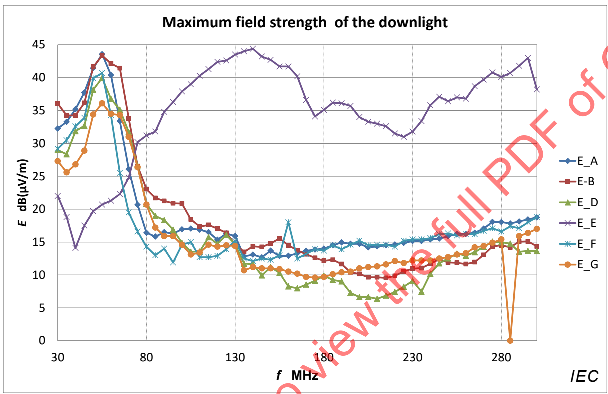
Equations (23) to (26) were used to calculate the SCU of the field strength measurement. The calculated SCU of 5,5 dB is very low for the field strength measurement with a connected cable. This low value is the result of the exact termination of the cables with a CDNE, and it shows that a CDNE can be used as a CMAD for field strength measurements.



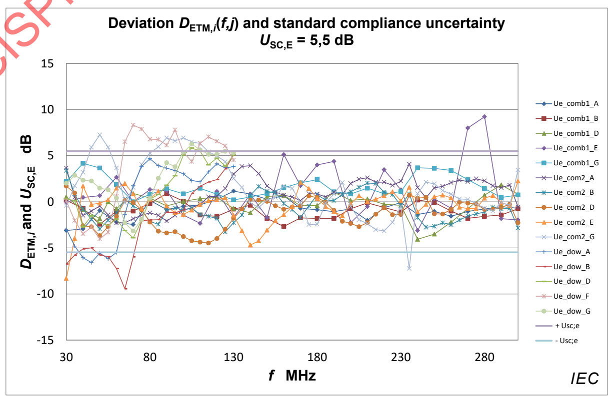
a) Comb generator 1



b) Comb generator 2



c) Downlight



d) Deviation and SCU

Figure C.3 – Measured disturbance field strength

C.4 Conversion factor for the measurement with a CDNE

C.4.1 The conversion factor

For each of the measured frequencies, for each of the *N* EUTs, and for each of the *T* labs, the conversion factor $K_i(f,j)$ can be calculated using Equation (18).

Figure C.4 shows the frequency dependent results of $K_i(f,j)$. Figure C.5 shows the mean value of the conversion factor for each i^{th} EUT, as well as the mean value of the frequency dependent conversion factors $\overline{K}(f)$ and its correlation function trend line, which uses a polynomial of 2^{nd} order. A commonly used electronic spreadsheet program indicates this trend line as “poly(mean value *K*(*f*))”, as seen in Figure C.5. This choice of a polynomial of 2^{nd} order avoids a strong gradient in the lower frequency range. The conversion factor $\overline{K}(f)$ is calculated using Equation (19).

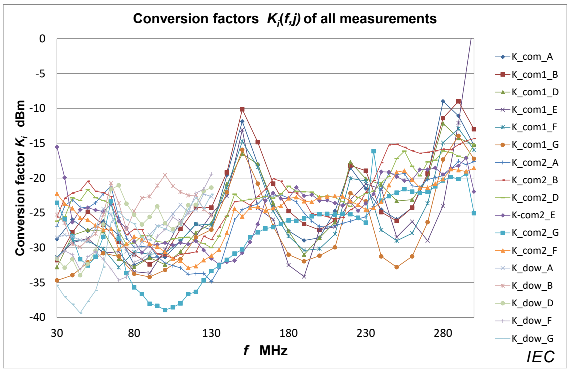


Figure C.4 – Conversion factors of all measurements

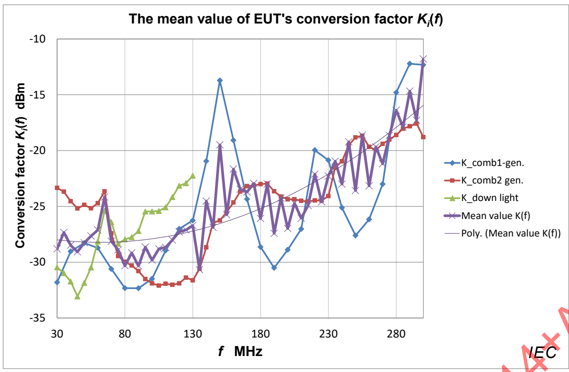


Figure C.5 – Mean conversion factors for each EUT

The conversion factor $\overline{K}(f)$ differs from that used in CISPR 15:2013 [12]; the conversion factor from CISPR 15:2013 is -24 dB at 300 MHz (see Figure C.7). The lower calculated value of about -17 dB may be caused by the radiation characteristics of the EUTs. The precondition for the ATM is that the main radiation from the EUT is via the connected cable, and therefore a vertical polarization should be expected with the arrangement according to Figure C.1. A check of the polarization of the measured maximum field strength shows that the vertical as well as the horizontal polarization show the maximum reading.

Figure C.6 shows the polarization's mean value of the measured maximum field strength of all labs for each EUT. The mean value indicates the changes from vertical to horizontal polarization and vice versa for the measurement in n test houses. When all labs measured the maximum field strength for the EUT with the vertical polarization, the indication in Figure C.6 is on the level "vertical". If one lab measured the maximum field strength with horizontal polarization, the indication goes down one step. If all labs measured the maximum field strength with horizontal polarization, the indication is on the level "horizontal." Figure C.6 illustrates that a larger EUT radiates at lower frequencies with horizontal polarization, and the precondition for the ATM may be questionable.

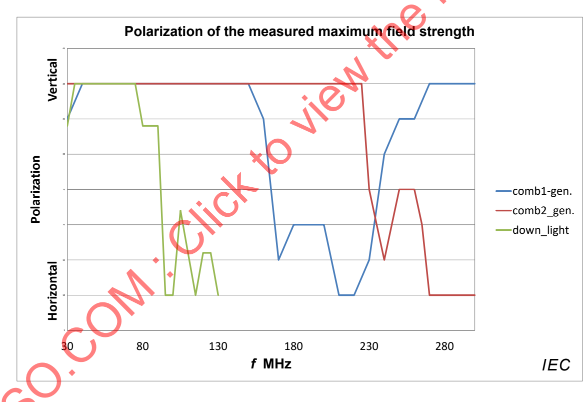


Figure C.6 – Measured polarization

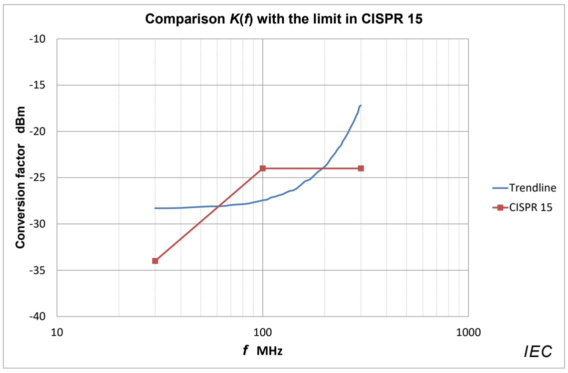


Figure C.7 – Comparison with CISPR 15:2013

C.4.2 Uncertainty of the conversion factor

The uncertainty of the average conversion factor $\overline{K}(f)$ can be estimated by the deviations $D_{K,i}(f,j)$ of each calculated conversion factor $K_i(f,j)$ from the average conversion factor $\overline{K}(f)$, and the standard deviation s_K of $D_{K,i}(f,j)$.

The experimental standard deviation has been calculated to be 2,65 dB using Equation (21).

The resulting expanded uncertainty U_K of the conversion factor is calculated by Equation (22).

Figure C.8 shows the deviations $D_{K,i}(f,j)$ of each conversion factor from the mean value of the EUT. That means in Equation (19) $\overline{K}(f)$ is replaced by $\overline{K}_i(f)$, i.e. the conversion factor for each EUT. The uncertainty of the conversion factor due to the SCU is 5,3 dB.

Because the conversion factor of each EUT is different, the limit for the ATM should be in line with the average of all $K_i(f,j)$, or the correlation function poly (mean value) shown in Figure C.5. Figure C.9 shows that the distribution of the deviation $D_{K,i}(f,j)$ of each individual EUT increases if the trend line [poly (mean value $K(f)$)] is used as the reference for the calculation of $D_{K,i}(f,j)$. Therefore the uncertainty of the conversion factor U_K increases to 8,4 dB.

The results of the RRT are in line with the presentation [11] that has shown that the conversion factor of different modelled large EUTs deviates mostly less than 10 dB from the selected conversion factor.

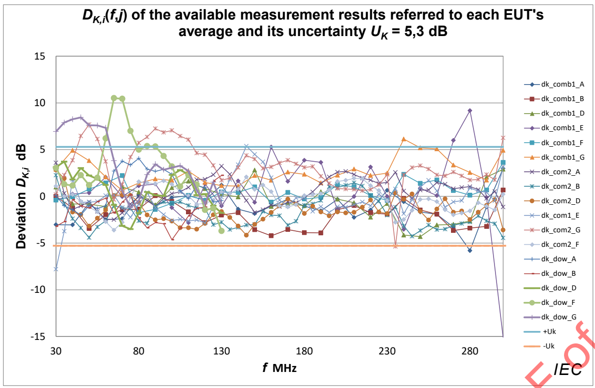


Figure C.8 – Deviation of the conversion factors from the average conversion factor of each EUT

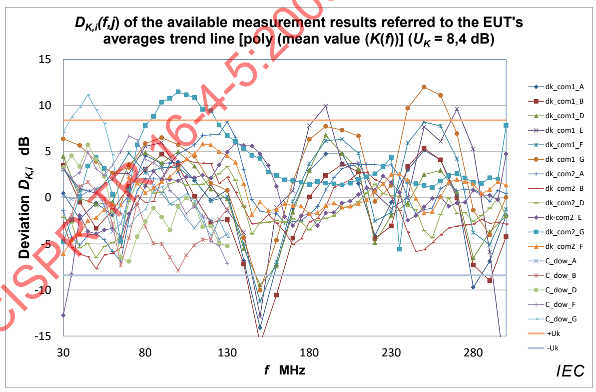


Figure C.9 – Deviation of the conversion factors from the trend line [poly (mean value *K*(*f*))]

C.4.3 Applying the conversion factor

The limit of an established test method can be converted into limit conditions for an alternative test method using the average conversion factor and consideration of Δ_{meas}, i.e. the difference of U_{ATM} and $U_{SC,ETM}$ according to Equation (27).

U_{ATM} is determined according to Equation (32). The uncertainty U_{EUT} is calculated by Equations (29), (30), and (31) to be 5,6 dB. Consequently U_{ATM} becomes

$$U_{ATM} = \sqrt{5{,}6^2 + 3{,}2^2} = 6{,}4 \text{ in dB.}$$

Therefore Δ_{meas} is

$$\Delta_{meas} = 6{,}4 - U_{SC,ETM} \text{ in dB.}$$

U_{ATM} is less than the estimated $U_{SC,ETM}$, and hence $\Delta_{meas} \leq 0$. Therefore for the measurement procedure with a CDNE, the applicable limit can be calculated using Equations (32) and (15), which gives Equation (C.1):

$$L_{ATM,U} = L_{ETM} - \overline{K}(f) . \qquad (C.1)$$

Annex D
(informative)

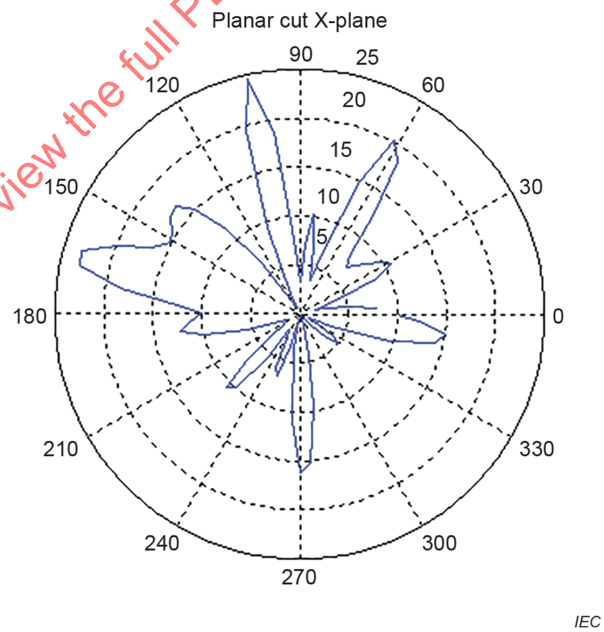
Statistical method for conversion of disturbance limits from radiated disturbance established test methods to the RC test method

D.1 General

Radiated disturbance established test methods (ETMs) measure field strength at a specified distance from an EUT, whereas the RC test method (alternative test method, ATM) measures the radiated power from an EUT. Because the EUT directivity varies from type to type, statistical techniques are used to derive conversion factors from ETM results to ATM results. With increasing electrical size of an EUT, the complexity of an EUT's radiation pattern increases
(see Wilson [17]).

Wilson [17] explains how the electrical size of an EUT is established by the quantity ka, where $k = 2\pi/\lambda$ is the wave number, and a is the radius of the minimum sphere that encloses the EUT. The preceding concept applies for this entire annex. An EUT is considered electrically large, if $ka > 1$, and it is electrically small, if $ka \leq 1$. Figure D.1 shows an example radiation pattern for a simulated electrically-large emitter. Table D.1 provides the EUT dimensions for the transition from electrically small to electrically large as a function of frequency.

Wilson [17] also provides a statistical estimate of 3 dB for the probability of finding the maximum radiation between a planar-cut scan (e.g. an EUT rotation without an antenna height scan) and a full-sphere scan valid for very large EUTs. Thus, the planar-cut scan is regarded as a reduced sampling procedure for finding the maximum field strength of an EUT. This also means that the radiation limit for a full-sphere scan of a large EUT can be reduced by a conservative amount of 3 dB if the full-sphere scan is replaced by a planar-cut scan.



NOTE The Y-plane and Z-plane patterns have similar characteristics, but normally only a single lobe in one plane reaches the maximum (i.e. amplitude of 25 in this example).

Figure D.1 – Simulated radiation pattern of an electrically large emitter (50 cm radius, ka = 10,5 at 1 GHz) in a single plane (X-plane) (Wilson [17])

Table D.1 – Overview of EUT diameters (= 2*a*) at the transition from electrically small to electrically large (from [17])

Frequency MHz	*k* 1/m	*ka*	radius *a* cm	diameter cm
30	0,6	1,0	159,2	318,3
100	2,1	1,0	47,8	95,5
200	4,2	1,0	23,9	47,7
500	10,5	1,0	9,6	19,1
1 000	20,9	1,0	4,8	9,6
2 000	41,9	1,0	2,4	4,8
5 000	104,7	1,0	0,9	1,9
10 000	209,4	1,0	0,5	1,0
20 000	418,9	1,0	0,2	0,5
40 000	837,8	1,0	0,1	0,2

D.2 Models for EUT directivity

For a starting point Annex H of IEC 61000-4-20:20— [18] uses a Hertzian, i.e. short, dipole (D_{max} = 3/2, and D is directivity) as a model for an EUT. For the Hertzian dipole in free space (at an FSOATS/FAR) the linear conversion factor *k* can be calculated using Equation (D.1):

$$E_{max}^2 = \frac{3}{2}\frac{\eta_0}{4\pi d^2}P_T$$

$$k = \frac{E_{max}^2}{P_T} = \frac{3}{2}\frac{\eta_0}{4\pi d^2} \qquad \text{(D.1)}$$

where

η_0 is the free space wave impedance (approximately 120π Ω);

d is the measurement distance.

For d = 3 m, k = 5 V²/(m²W).

For a Hertzian dipole in half space (at an OATS/SAC) a geometry factor g_{max} is included, taking into account the reflection from the ground plane, per Equation (D.2):

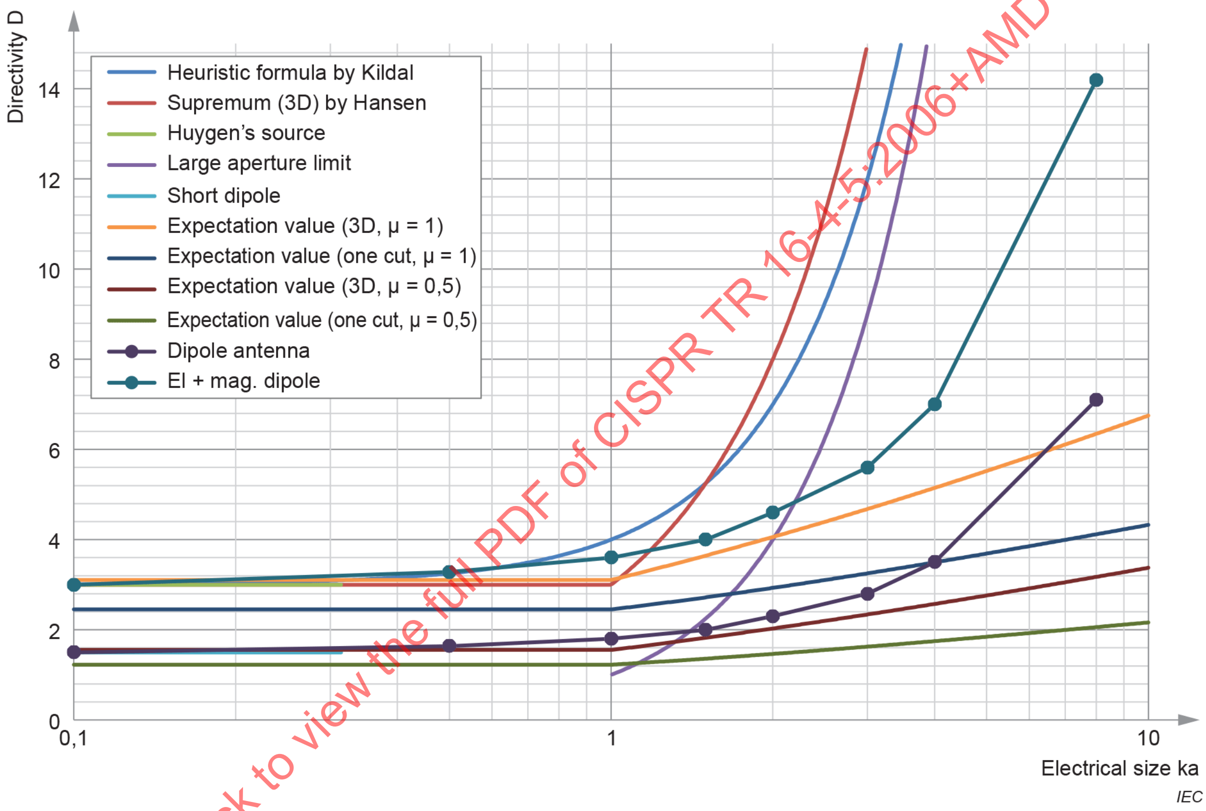
$$E_{max}^2 = \frac{3}{2}\frac{\eta_0}{4\pi d^2}g_{max}^2 P_T$$

$$k = \frac{E_{max}^2}{P_T} = \frac{3}{2}\frac{\eta_0}{4\pi d^2}g_{max}^2 \qquad \text{(D.2)}$$

For d = 10 m and $g_{max} \approx 2$, k = 1,8 $V^2/(m^2W)$.

For the Hertzian dipole model, the conversion factor is independent of frequency. Using Equation (36) (see 8.1) the logarithmic conversion factor is K = 2,6 dB for the OATS/SAC to RC conversion in the frequency range 80 MHz to 1 000 MHz, and K = 7,0 dB for the FSOATS/FAR to RC conversion in the frequency range 1 GHz to 40 GHz. These conversion factors are useful for comparison with the values in D.3.

As frequency increases, the directivity increases. Krauthäuser [19] shows and compares different expressions; see Figure D.2. For modelling the directivity of unintentional radiators, Krauthäuser [19] applies two different simulations: 1) the spherical wave expansion, and 2) the Monte-Carlo method of isotropic point sources. Reference [19] establishes a link between the two methods – the two models are statistically equivalent for certain values of *ka*. A relationship for the number of sources as a function of *ka* necessary to achieve equivalent distribution functions is given. The number of angle steps to calculate the directivities of large EUTs is also described.



NOTE The two lines for "Huygen's Source" and "Short Dipole" are defined for ka = 0,1π only, and therefore are only visible in the lower left corner.

Figure D.2 – Comparison of different expressions for maximum directivity of antennas and unintentional emitters as a function of electrical size ka. μ is the polarization mismatch factor

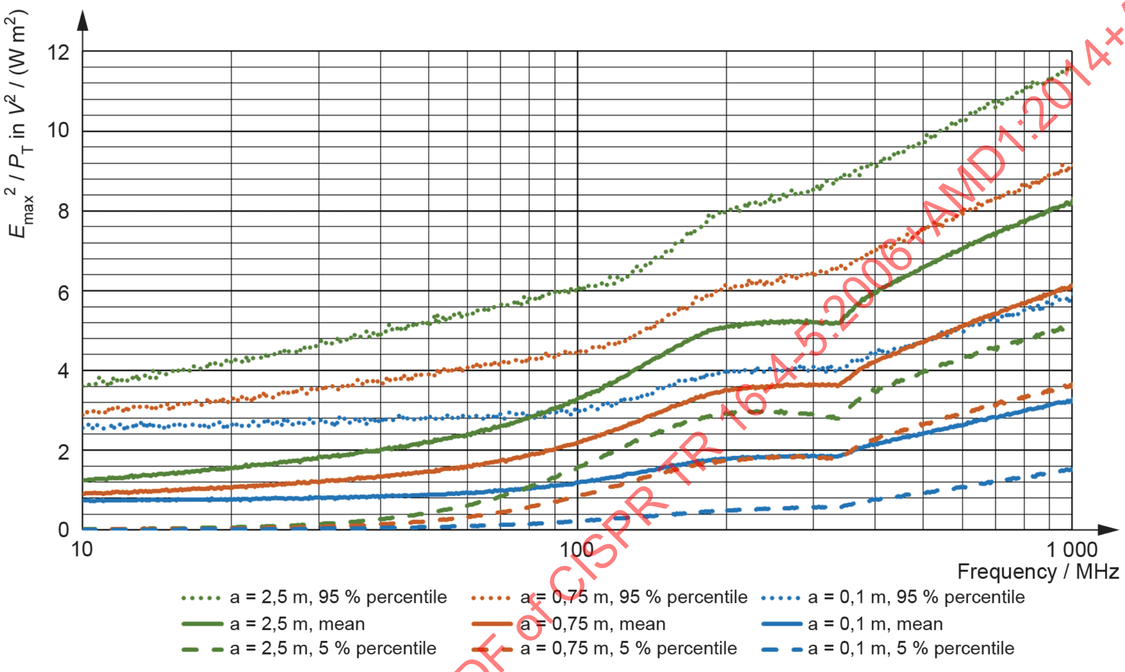
D.3 Results of modelling

Krauthäuser [19] provides conversion factors as a function of frequency and EUT size from OATS/SAC to RC, as shown in Figure D.3.

Conversion factors $k(f)$ of Table D.2, Table D.3 and Table D.4 are taken from the 'mean' curves. To convert field-strength limits to limits of the transmitted power, values in dB are more practical [$K(f)$ = 10lg$k(f)$]. Consequently, $P_{\text{limit}} = E_{\text{limit}} - K(f)$ [see Equation (15) in 6.10, and Equation (35) and Equation (38) in 8.1]. If conversion factors for other EUT radii are to be determined, interpolation should be done between the mean-value curves of Figure D.3.

Table D.5 shows an example of limits for *E* and *P* for *a* = 0,75 m for the residential environment.

The values for the standard deviations σ in the tables are obtained by dividing the difference between the mean and the quantile values of $K(f)$ by 1,645, assuming a normal distribution (the factor applies for 5 %, 95 %); e.g. $\sigma = (K(230)_{95\ \%} - K(230)_{mean})/1{,}645 = 1{,}34$ dB for a = 0,75 m at 230 MHz. The variable σ is the standard uncertainty of the conversion factor. In the diagrams of [19], σ increases when $k(f)$ approaches 0.



NOTE Data for *a* = 0,1 m, 0,75 m and 2,5 m directivities (instead of 100 as in [19]) were provided by Dr. Magdowski using Krauthäuser's material.

Figure D.3 – Conversion factors (mean and quantile values) from OATS/SAC (measurement distance of 10 m) results to RC results and different radii *a* of the surrounding sphere as a function of frequency

Table D.2 – Conversion factors (mean, quantile values, and standard deviation σ) for *a* = 0,1 m

f MHz	80			230			1 000		
Quantile	$k(f)$ Ω/m²	$K(f)$ dB(Ω/m²)	σ dB	$k(f)$ Ω/m²	$K(f)$ dB(Ω/m²)	σ dB	$k(f)$ Ω/m²	$K(f)$ dB(Ω/m²)	σ dB
95 %	2,81	4,49	2,71	4,31	6,34	2,23	5,78	7,62	1,55
Mean	1,05	**0,21**		1,82	**2,60**		3,23	**5,09**	
5 %	0,158	−8,0	4,89	0,532	−2,74	3,29	1,47	1,67	2,07

Table D.3 – Conversion factors (mean, quantile values, and standard deviation σ) for *a* = 0,75 m

f MHz	80			230			1 000		
Quantile	*k*(*f*) Ω/m²	*K*(*f*) dB(Ω/m²)	σ dB	*k*(*f*) Ω/m²	*K*(*f*) dB(Ω/m²)	σ dB	*k*(*f*) Ω/m²	*K*(*f*) dB(Ω/m²)	σ dB
95 %	4,31	6,34	2,1	5,86	7,68	1,34	8,93	9,51	1,03
Mean	1,88	**2,74**		3,57	**5,53**		6,12	**7,87**	
5 %	0,62	−2,1	3,03	1,87	2,72	1,67	3,64	5,61	1,34

Table D.4 – Conversion factors (mean, quantile values, and standard deviation σ) for *a* = 2,5 m

f MHz	80			230			1 000		
Quantile	*k*(*f*) Ω/m²	*K*(*f*) dB(Ω/m²)	σ dB	*k*(*f*) Ω/m²	*K*(*f*) dB(Ω/m²)	σ dB	*k*(*f*) Ω/m²	*K*(*f*) dB(Ω/m²)	σ dB
95 %	5,84	7,66	1,92	8,39	9,23	1,24	11,43	10,58	1,3
mean	2,82	**4,50**		5,18	**7,14**		8,22	**9,15**	
5 %	1,10	0,41	2,48	3,0	4,77	1,47	5,00	6,99	0,88

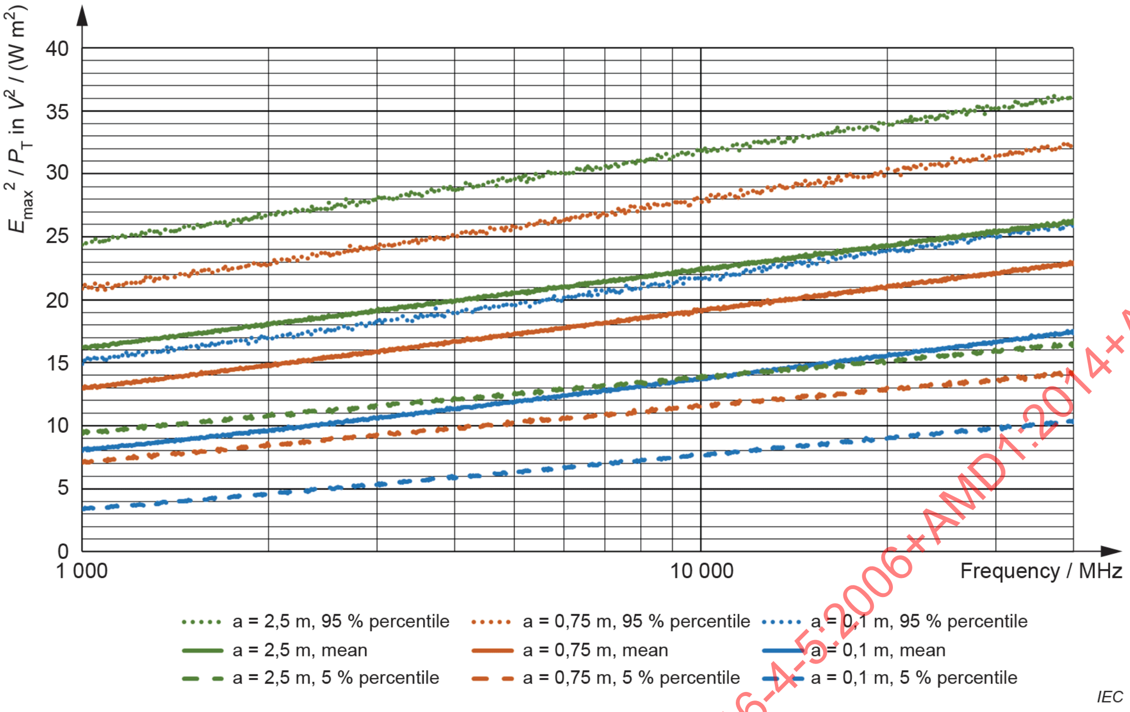
Table D.5 – Example of disturbance limits for *a* = 0,75 m (EUT diameter 1,5 m) for the residential environment

f MHz	80	230	230	1 000
E_{limit} dB(µV/m)	30	30	37	37
K(*f*) dB(Ω/m²)	2,74	5,53	5,53	7,87
P_{limit} dB(pW)	27	24	31	29
P_{limit} dBm	−63	−66	−59	−61

Above 1 GHz, the ETM is measurement at an FSOATS/FAR with d = 3 m. Figure D.4 shows the results of modelling.

The conversion factors of Table D.6, Table D.7, and Table D.8 for frequencies of 1 GHz, 3 GHz, and 6 GHz are taken from the mean values in Figure D.4 with a = 0,75 m.

Table D.9 shows an example of limits for E and P for a = 0,75 m for the residential environment.



NOTE Data for a = 0,75 m and 2,5 m, and 1 000 directivities (instead of 100 as in [19]) were provided by Dr. Magdowski using Krauthäuser's material.

Figure D.4 – Conversion factors (mean and quantile values) from FSOATS/FAR (d = 3 m measurement distance) results to RC results and different radii a of the surrounding sphere as a function of frequency

Table D.6 – Conversion factors (mean, quantile values, and standard deviation σ) for a = 0,1 m

f GHz	1			3			6		
Quantile	$k(f)$ Ω/m²	$K(f)$ dB(Ω/m²)	σ dB	$k(f)$ Ω/m²	$K(f)$ dB(Ω/m²)	σ dB	$k(f)$ Ω/m²	$K(f)$ dB(Ω/m²)	σ dB
95 %	14,80	11,70	1,59	18,54	12,68	1,43	20,02	13,01	1,28
mean	7,97	**9,01**		10,70	**10,29**		12,8	**11,07**	
5 %	3,22	5,08	2,43	5,29	7,23	1,88	6,74	8,29	1,59

Table D.7 – Conversion factors (mean, quantile values, and standard deviation σ) for a = 0,75 m

f GHz	1			3			6		
Quantile	$k(f)$ Ω/m²	$K(f)$ dB(Ω/m²)	σ dB	$k(f)$ Ω/m²	$K(f)$ dB(Ω/m²)	σ dB	$k(f)$ Ω/m²	$K(f)$ dB(Ω/m²)	σ dB
95 %	21,0	13,22	1,25	24,65	13,92	1,19	26,52	14,24	1,06
Mean	13,0	**11,14**		15,8	**11,98**		17,8	**12,50**	
5 %	7,33	8,65	1,53	9,13	9,6	1,43	10,23	10,1	1,45

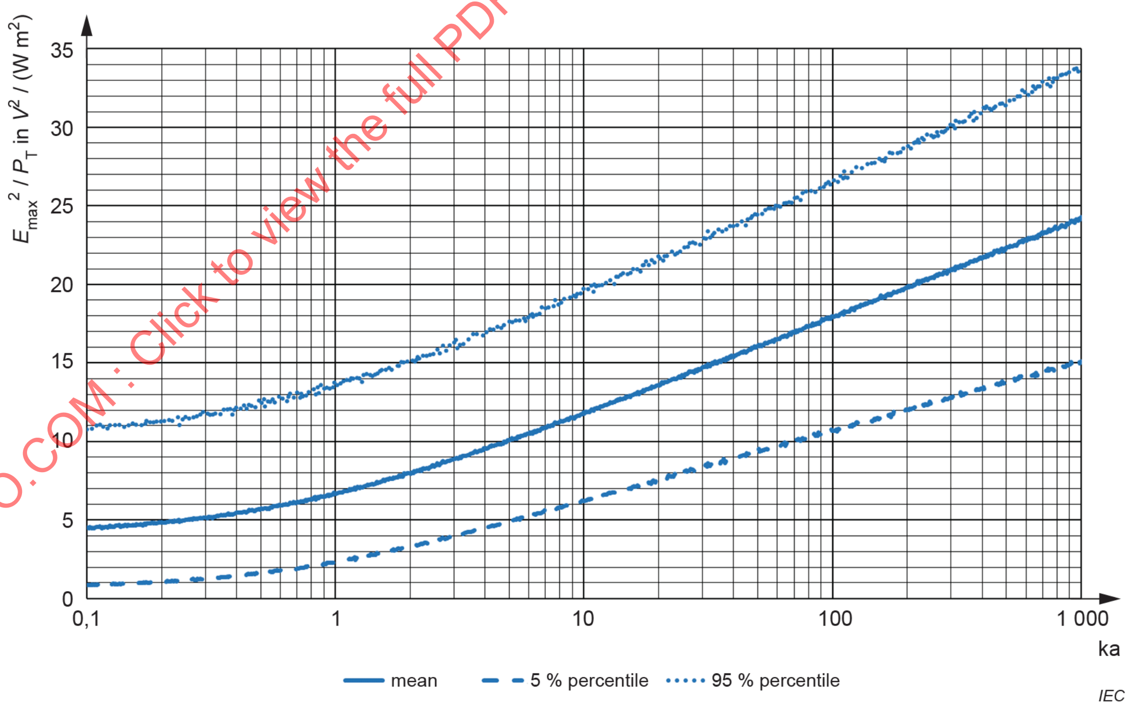
Table D.8 – Conversion factors (mean, quantile values, and standard deviation σ) for a = 2,5 m

f GHz	1			3			6		
Quantile	$k(f)$ Ω/m^2	$K(f)$ dB(Ω/m^2)	σ dB	$k(f)$ Ω/m^2	$K(f)$ dB(Ω/m^2)	σ dB	$k(f)$ Ω/m^2	$K(f)$ dB(Ω/m^2)	σ dB
95 %	24,65	13,92	1,11	27,8	14,44	0,997	29,97	14,77	0,93
mean	16,20	**12,10**		19,2	**12,83**		21,0	**13,22**	
5 %	9,70	9,87	1,35	11,66	10,67	1,29	13,1	11,17	1,26

Table D.9 – Example of disturbance limits for *a* = 0,75 m (EUT diameter 1,5 m) for the residential environment

f GHz	1	3	3	6
E_{limit} dB(µV/m)	50	50	54	54
$K(f)$ dB(Ω/m^2)	11,14	11,98	11,98	12,50
P_{limit} dB(pW)	39	38	42	41
P_{limit} dBm	−51	−52	−48	−49

Figure D.5 (mean values) can be used for interpolation purposes if conversion factors for other EUT radii are to be determined.



NOTE Data for a = 0,75 m and 2,5 m, and 1 000 directivities (instead of 100 as in [19]) were provided by Dr. Magdowski using Krauthäuser's material.

Figure D.5 – Conversion factor (mean and quantile values) from FSOATS/FAR results to RC results for *d* = 3 m measurement distance as a function of electrical EUT size *ka*

The measurement results $M(f)$ and the deviations $D(f)$ in Equation (1) (see 6.4) and Equation (18) (see 7.2.1) are logarithmic quantities, and the conversion factors $\overline{K}(f)$ in Equation (12) (see 6.8) and Equation (19) (see 7.2.1) are mean values of logarithmic quantities; however, the conversion factor $K(f)$ in Equation (37) (see 8.1) and in this annex is the logarithm of the conversion factor $k(f)$, which is the mean value $\overline{K}(f)$ of individual linear conversion factors $k_i(f)$. Because the logarithm is a non-linear transformation, the difference between the logarithm of the mean of individual linear conversion factors $K_{\text{lin mean}}(f) = 10\lg \overline{k}(f) = 10\lg[1/N\sum_1^N k_i(f)]$ and the mean of individual logarithmic conversion factors $K_{\text{log mean}}(f) = \overline{K}(f) = 1/N\sum_1^N K_i(f) = 1/N\sum_1^N 10\lg k_i(f)$ is of interest. This difference was investigated by Dr. Magdowski using Krauthäuser's material with the results listed in Table D.10 and Table D.11, showing that the dispersion of conversion factors decreases with increasing frequency.

Table D.10 – Comparison of $K_{\text{lin mean}}(f)$ and $K_{\text{log mean}}(f)$ for the conversion of OATS/SAC (*d* = 10 m) results to RC results for *a* = 0,75 m

f/MHz	30	80	230	1 000
$K_{\text{lin mean}}(f)$/dB	0,84	2,73	5,52	7,86
$K_{\text{log mean}}(f)$/dB	−1,59	1,90	5,22	7,70

Table D.11 – Comparison of $K_{\text{lin mean}}(f)$ and $K_{\text{log mean}}(f)$ for the conversion of FOATS/FAR (*d* = 3 m) results to RC results for *a* = 0,75 m

f/GHz	1	3	6	10	40
$K_{\text{lin mean}}(f)$/dB	11,13	12,01	12,50	12,82	13,60
$K_{\text{log mean}}(f)$/dB	10,90	11,83	12,33	12,67	13,47

D.4 Instrumentation uncertainty for radiated disturbance measurement results in an RC

D.4.1 Measurand for radiated disturbance measurements using an RC

P Radiated power, in dB(pW),
against power limits converted from 10 m OATS/SAC results for 80 MHz to 1 000 MHz
against power limits converted from 3 m FSOATS/FAR results for 1 GHz to 18 GHz

NOTE Measurement results taken in a reverberation chamber are compared to the limit of radiated power defined in a product standard between 80 MHz and 1 GHz, and between 1 GHz and 6 GHz. 0 dB(µV) = −17 dB(pW) in a 50 Ω system.

D.4.2 Symbols of input quantities common to all disturbance measurements

a_{ca} attenuation of the connection between the receiver and the RC, in dB

δM correction for the error caused by mismatch, in dB

V_{r} receiver voltage reading, in dB(µV)

δV_{sw} correction for the receiver sine wave voltage inaccuracy, in dB

δV_{pa} correction for the imperfect receiver pulse amplitude response, in dB

δV_{pr} correction for the imperfect receiver pulse repetition rate response, in dB

δV_{nf} correction for the effect of the receiver noise floor, in dB

D.4.3 Symbols of input quantities specific to RC measurements

F_{cv} chamber validation factor, in dB

$\delta P_{\text{nonunif}}$ correction factor for the field non-uniformity in the EUT volume, in dB

$\delta P_{\text{EUT size}}$ correction factor for the deviation from the reference EUT size, in dB

D.4.4 Input quantities to be considered for radiated disturbance measurements using an RC

a) Receiver reading
b) Cable attenuation between RC and measuring receiver
c) Receiver related input quantities
   1) Sine wave voltage accuracy
   2) Pulse amplitude response
   3) Pulse repetition rate response
   4) Noise floor proximity
d) Mismatch effects between RC receiver port and measuring receiver
e) Chamber validation factor
f) Effect of field non-uniformity in EUT volume (see Annex B of IEC 61000-4-21:2011[22])
g) Effect of deviating directivity due to EUT size deviating from the assumed reference EUT size

D.4.5 Uncertainty budget for radiated disturbance measurement results using an RC

The measurand P is calculated using model Equation (D.3):

$$P = V_{\text{r}} + a_{\text{c}} + F_{\text{cv}} + \delta V_{\text{sw}} + \delta V_{\text{pa}} + \delta V_{\text{pr}} + \delta V_{\text{nf}} + \delta M + \delta P_{\text{nonunif}} + \delta P_{\text{EUT size}} - 17 \text{ dB}\Omega \qquad \text{(D.3)}$$

Table D.12 (80 MHz to 1 000 MHz) and Table D.13 (1 GHz to 6 GHz) show example uncertainty budgets for radiated disturbance measurement results using an RC.

Table D.12 – Uncertainty budget for radiated disturbance measurement results using an RC from 80 MHz to 1 000 MHz (example)

Input quantity[a]	X_i	Uncertainty of x_i dB	Probability distribution function	$c_i\ u(x_i)$[b] dB
Receiver reading[D1)]	V_r	±0,1	k = 1	0,10
Attenuation: RC-receiver[D2)]	a_c	±0,2	k = 2	0,10
Receiver corrections:				
Sine wave voltage[D3)]	δV_{sw}	±1,0	k = 2	0,50
Pulse amplitude response[D4)]	δV_{pa}	±1,5	Rectangular	0,87
Pulse repetition rate response[D4)]	δV_{pr}	±1,5	Rectangular	0,87
Noise floor proximity[D5)]	δV_{nf}	±0,3	Rectangular	0,17
Mismatch: RC-receiver[D6)]	δM	+0,79/–0,87	U-shaped	0,58
Chamber validation factor[D7)]	F_{cv}	±1,5	k = 2	0,75
Field non-uniformity[D8)]	$\delta P_{nonunif}$	±3,5	k = 1	3,5
Deviation from reference EUT size[D9)]	$\delta P_{EUT\ size}$	±1,0	Rectangular	0,58

[a] Superscripts (e.g. [D1)]) correspond to the comments in D.4.6.

[b] All c_i = 1.

NOTE The distribution function is normal, unless otherwise expressed in the table.

Hence, the expanded uncertainty is $U(P) = 2u_c(P)$ = 7,82 dB.

Table D.13 – Uncertainty budget for radiated disturbance measurement results using an RC from 1 GHz to 6 GHz (example)

Input quantity[a]	X_i	Uncertainty of x_i dB	Probability distribution function	$c_i\ u(x_i)$[b] dB
Receiver reading[D1)]	V_r	±0,1	k = 1	0,10
Attenuation: RC-receiver[D2)]	a_c	±0,4	k = 2	0,20
Receiver corrections:				
Sine wave voltage[D3)]	δV_{sw}	±1,5	k = 2	0,75
Noise floor proximity[D5)]	δV_{nf}	+ 0,1/0,0	Rectangular	0,06
Mismatch: RC-receiver[D6)]	δM	+0,79/–0,87	U-shaped	0,58
Chamber validation factor[D7)]	F_{cv}	±1,5	k = 2	0,75
Field non-uniformity[D8)]	$\delta P_{nonunif}$	±2,0	k = 1	2,0
Deviation from reference EUT size[D9)]	$\delta P_{EUT\ size}$	±1,0	Rectangular	0,58

[a] Superscripts (e.g. [D1)]) correspond to the comments in D.4.6.

[b] All c_i = 1.

The distribution function is normal, unless otherwise expressed in the table.

Hence, the expanded uncertainty is $U(P) = 2u_c(P)$ = 4,84 dB.

NOTE The expanded uncertainties per Table D.12 and Table D.13 are typical values only and are not intended to become values for U_{CISPR}.

D.4.6 Rationale for the estimates of input quantities for radiated disturbance measurement results using an RC

NOTE 1 Comments in D1) through D6) are adapted from CISPR 16-4-2 [24].

D1) Receiver readings will vary for reasons that include measuring system instability and meter scale interpolation errors. The estimate of V_r is the mean of many readings (sample size larger than 10) of a stable signal, with a standard uncertainty given by the experimental standard deviation of the mean (k = 1).

D2) An estimate of the attenuation a_c of the connection between the receiver and the RC is assumed to be available from a calibration report, along with an expanded uncertainty and a coverage factor.

NOTE 2 If the estimate of attenuation a_c is obtained from manufacturer's data for a cable or attenuator, a rectangular probability distribution having a half-width equal to the manufacturer's specified tolerance on the attenuation can be assumed. If the connection is a cable and attenuator in tandem, with manufacturer's data available on each, a_c has two components, each with its own rectangular probability distribution.

NOTE 3 In the frequency range below 30 MHz, the estimate of the expanded uncertainty is 0,1 dB, from 30 MHz to 1 000 MHz it is 0,2 dB, from 1 GHz to 6 GHz it is 0,3 dB, and from 6 GHz to 18 GHz it is 0,6 dB, with a coverage factor of 2. A lower estimate for this uncertainty contribution can be achieved using a vector network analyzer for the cable calibration.

D3) An estimate of the correction δV_{sw} for receiver sine-wave voltage inaccuracy is assumed to be available from a calibration report, along with an expanded uncertainty and a coverage factor.

NOTE 4 If a calibration report states only that the receiver sine-wave voltage accuracy is within the CISPR 16-1-1 tolerance (±2 dB), then the estimate of the correction δV_{sw} is taken as zero with a rectangular probability distribution having a half-width of 2 dB. If the calibration report states a value less than the CISPR 16-1-1 tolerance (e.g. ±1 dB), then the stated value is used in the uncertainty calculation, not the stated uncertainty value of the calibration process. If the calibration report provides detailed deviations from reference values, then the reported deviations and the uncertainties of the calibration laboratory can be used to determine the uncertainties of the measuring receiver.

D4) In general, it is impractical to correct for imperfect receiver pulse response characteristics.

The requirements in CISPR 16-1-1 shall be used as the reference for uncertainty estimation. A verification report stating that the receiver pulse amplitude response complies with the CISPR 16-1-1 tolerance of ±1,5 dB for peak, quasi-peak, average or RMS-average detection is assumed to be available. The correction δV_{pa} is estimated to be zero with a rectangular probability distribution having a half-width of 1,5 dB.

The CISPR 16-1-1 tolerance for pulse repetition rate response varies with repetition rate and detector type. A verification report stating that the receiver pulse repetition rate responses comply with the CISPR 16-1-1 tolerances is assumed to be available. The correction δV_{pr} is estimated to be zero with a rectangular probability distribution having a half-width of 1,5 dB, a value considered to be representative of the various CISPR 16-1-1 tolerances.

NOTE 5 If the pulse amplitude response or the pulse repetition rate response is verified to be within ±α dB of the CISPR specification ($\alpha \leq 1,5$), the correction for that response can be estimated to be zero with a rectangular probability distribution having a half-width of α dB.

NOTE 6 If a disturbance produces a continuous wave signal at the detector, pulse response corrections are not considered.

D5) The noise floor of a CISPR receiver is compared with the RC output voltage level V_{lim} corresponding to the power limit P_{lim} in order to determine the signal-to-noise ratio.

Mean values for a = 0,75 m from Figure D.3 using Equation (35) (see 8.1) enable the calculation of P_{lim} in Table D.14.

For radiated disturbance measurement using an RC below 1 GHz, the deviation δV_{nf} is estimated to be between zero and +0,6 dB. The correction is estimated to be zero as if the deviation would be symmetric around the value to be measured with a rectangular probability distribution having a half-width of 0,6 dB. Any correction for the effect of the noise floor would depend on the signal type (e.g. impulsive or unmodulated sinewave) and the signal-to-noise ratio and would change the noise level indication. The value of 0,6 dB is taken from Figure D.6 for a *S/N* = 22 dB. The *S/N* has been obtained for a noise figure of 6 dB, using Equation (D.4)

$$
\begin{aligned}
P_{\text{NQP}} &= V_{\text{NQP}} + a_{\text{IL RC}} + a_{\text{c}} - 17 \\
&= -67 + 10\lg F_{\text{N}} + 10\lg B_{\text{N}} + w_{\text{NQP}} + a_{\text{IL RC}} + a_{\text{c}} - 17
\end{aligned}
\tag{D.4}
$$

where

P_{NQP} is the equivalent power of the quasi-peak noise floor, in dB(pW);
V_{NQP} is the receiver quasi-peak noise floor, in dB(µV);
$a_{\text{IL RC}}$ is the RC insertion loss at the receive frequency, in dB;
a_{c} is the attenuation of the receiver connecting cable, in dB;
F_{N} is the noise factor of the measuring receiver, i.e. a number;
$10\lg F_{\text{N}}$ is the noise figure of the measuring receiver, in dB;
B_{N} is the noise bandwidth of the measuring receiver, in Hz;
w_{NQP} is the quasi-peak weighting factor of noise, in dB;
−67 is $10\lg(kT_0 \times 1\text{ Hz} / P_{1\mu\text{V}})$, the absolute noise level in dB(µV) in 1 Hz bandwidth, with k = Boltzmann's constant, T_0 = 293,15 K, and $P_{1\mu\text{V}}$ is the power generated by 1 µV across 50 Ω;
−17 is the conversion from dB(µV) to dB(pW) in a 50 Ω system (0 dB(µV) = −17 dB(pW)).

The worst-case *S/N* is obtained near 1 000 MHz. With $10\lg F_{\text{N}}$ = 6, $10\lg B_{\text{N}}$ = 50,8 (for 120 kHz), the weighting factor w_{NQP} being 7 dB, the RC insertion loss of $a_{\text{IL RC}}$ = 15 dB for 1 000 MHz (extrapolated from reference [21]), and the cable attenuation a_{c} = 2 dB, the quasi-peak noise indication in terms of power is P_{NQP} = −3 dB(pW). This is compared to a disturbance power at the disturbance limit of 29 dB(pW) to give a signal-to-noise ratio *S/N* of 32 dB. In the frequency range below 1 000 MHz, the *S/N* is higher, hence an *S/N* > 30 dB may be assumed.

For the FSOATS-based power limits (above 1 GHz), Figure D.4 is used, where *d* = 3 m to calculate P_{lim} using a = 0,75 m in Table D.15.

For radiated disturbance measurements above 1 GHz the limits apply for average and peak detectors; similar considerations for the noise floor as below 1 GHz apply. The stronger influence of noise and higher uncertainty caused by noise is with the peak detector.

Figure D.7 provides plots of the deviation from signal level as a function of *S/N*.

The worst-case *S/N* is obtained near 6 GHz. With $10\lg F_{\text{N}}$ = 6, $10\lg B_{\text{N}}$ = 58,2 (corresponding to 0,66 MHz), the weighting factor w_{NPk} being 11 dB, the RC insertion loss of $a_{\text{IL RC}}$ = 31 dB for 6 GHz, and the cable attenuation a_{c} = 2 dB, the peak noise indication in terms of power is P_{NQP} = 24 dB(pW). This is compared to a disturbance power level of 62 dB(pW) at the disturbance limit (corresponding to 74 dB(µV/m) at 3 m distance) to give a signal-to-noise ratio *S/N* of 38 dB. In the frequency range below 6 GHz, the *S/N* is higher, hence an *S/N* > 38 dB may be assumed. From Figure D.7 a maximum deviation for sine waves of 0,1 dB can be read.

Table D.14 – Values of P_{lim} for 30 MHz to 1 000 MHz (E_{lim} from [20])

Frequency MHz	E_{lim} dB(μV/m)	P_{lim} dB(pW)
80	30	27,0
230	30	25,0
230	37	32,0
1 000	37	29,0

Table D.15 – Values of P_{lim} for 1 GHz to 6 GHz (E_{lim} from [20])

Frequency MHz	E_{lim} dB(μV/m)	P_{lim} dB(pW)
1	50	39
3	50	38
3	54	42
6	54	42

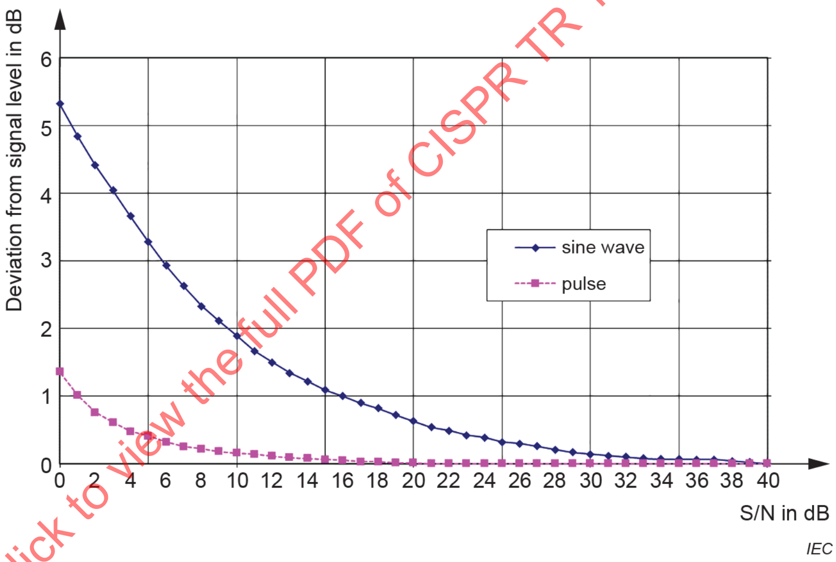


Figure D.6 – Deviation of the QP detector level indication from the signal level at receiver input for two cases: sine-wave signal, and impulsive signal (PRF 100 Hz)

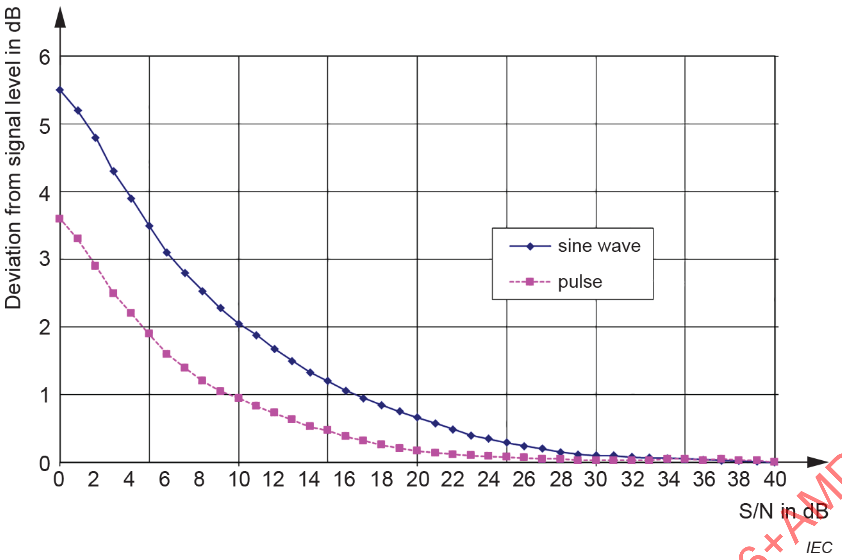


Figure D.7 – Deviation of the peak detector level indication from the signal level at receiver input for two cases: sine-wave signal, and impulsive signal (PRF 100 Hz)

D6) Mismatch uncertainty

a) General

In general, the receiver port of an RC will be connected to port 1 of a two-port network whose port 2 is terminated by a receiver of reflection coefficient Γ_r. The two-port network (which might be a cable, attenuator, attenuator and cable in tandem, or some other combination of components) can be represented by its S-parameters. The mismatch correction is then per Equation (D.5):

$$\delta M = 20\lg\left[(1-\Gamma_e S_{11})(1-\Gamma_r S_{22}) - S_{21}^2 \Gamma_e \Gamma_r\right] \quad \text{(D.5)}$$

where Γ_e is the reflection coefficient looking into the receiver port of the RC with the EUT inserted when it is set up for disturbance measurement. All parameters are referenced to 50 Ω.

When only the magnitudes or extremes of magnitudes of the parameters are known, it is not possible to calculate δM, but its extreme values $\delta M^{\pm}$ are not greater than per Equation (D.6)

$$\delta M^{\pm} = 20\lg\left[1 \pm \left(|\Gamma_e||S_{11}| + |\Gamma_r||S_{22}| + |\Gamma_e||\Gamma_r||S_{11}||S_{22}| + |\Gamma_e||\Gamma_r||S_{21}|^2\right)\right] \quad \text{(D.6)}$$

The probability distribution of δM is approximately U-shaped, with a width not greater than ($\delta M^{+} - \delta M^{-}$) and a standard deviation not greater than the half-width divided by $\sqrt{2}$.

b) Radiated disturbance measurement using an RC

For radiated disturbance measurements below 1 GHz, a VSWR specification of the receiving antenna of the RC of $s_{wr} \leq 1{,}8{:}1$ is assumed, implying $|\Gamma_e| \leq 0{,}29$. It is also assumed that the connection to the receiver is made using a well-matched cable ($|S_{11}| \ll 1$, $|S_{22}| \ll 1$) of negligible attenuation ($|S_{21}| \approx 1$) and that the receiver RF attenuation is 0 dB, for which the CISPR 16-1-1 tolerance of $s_{wr} \leq 2{,}0{:}1$ implies $|\Gamma_r| \leq 0{,}33$.

The estimate of the correction δM is zero with a U-shaped probability distribution having a width equal to the difference ($\delta M^+ - \delta M^-$).

The influence of the stirrer position on the VSWR of the receiving antenna shall be taken into account.

NOTE 7 The expressions for δM and $\delta M^\pm$ show that mismatch error can be reduced by increasing the attenuation of the well-matched two-port network preceding the receiver. The penalty is a reduction in measurement sensitivity.

NOTE 8 Additional considerations related to Equation (D.5): a) Due to non-existing or only weak correlation of the addends (summands, or terms in the sum), the linear addition can be replaced by the root-sum-square rule; b) Due to the usually small magnitude of the addends, a further approximation (where $\delta M^\pm$ is the half width of a U-shaped distribution) is applicable, yielding finally:

$$\delta M^{\pm} = 8{,}7\sqrt{\left(|\Gamma_e||S_{11}|\right)^2 + \left(|\Gamma_r||S_{22}|\right)^2 + \left(|\Gamma_e||\Gamma_r||S_{21}|^2\right)^2}\ \text{dB}$$

D7) The chamber validation is done by a substitution method described with Equation (E.1) and Equation (E.2) from IEC 61000-4-21:2011 [22]. The estimate of 1,5 dB takes into account the uncertainties of the transmit power, the transmit antenna efficiency and the chamber validation factor, chamber loading factor, and insertion loss.

D8) Field non-uniformity: For the useable test volume, the requirements in Table B.2 of IEC 61000-4-21:2011 [22] apply. A normal distribution is assumed with a coverage factor of k = 1. Smaller values are typical (3,5 dB up to 100 MHz, 2,0 dB above 400 MHz).

D9) It was assumed that a product committee follows the recommendation in this annex and has chosen a reference EUT size of a = 0,75 m for the conversion factor (see Figure D.3 and Figure D.4). The deviation of the actual EUT size from the reference EUT size causes an uncertainty. However, it was assumed the product committee also decides that the disturbance limit applies for EUT sizes of a = 0,25 m, …, 1,5 m. For a frequency of 1 GHz, this results in values of ka = 5,23, …, 15,7, …, 31,4, where 15,7 applies for the reference EUT size of a = 0,75 m. For these values the corresponding conversion factor can be read from Figure D.5 as 10,3, …, 13, …, 15 (linear), respectively, 10,1, …, 11,14, …, 11,75 (logarithmic in dB). This results in a difference of 1 dB between the reference EUT size and the smallest EUT, which is included in Table D.12 and Table D.13. The product committee could also apply a correction of the disturbance limit for smaller EUTs and take into account an uncertainty of the correction factor.

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3 This publication was withdrawn.

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Specification for radio disturbance and immunity measuring apparatus and methods –
Part 4-5: Uncertainties, statistics and limit modelling – Conditions for the use of alternative test methods

CISPR TR 16-4-5:2006-10+AMD1:2014-07+AMD2:2021-10 CSV(en)

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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SPECIFICATION FOR RADIO DISTURBANCE AND IMMUNITY MEASURING APPARATUS AND METHODS –

Part 4-5: Uncertainties, statistics and limit modelling – Conditions for the use of alternative test methods

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CISPR TR 16-4-5 edition 1.2 contains the first edition (2006-10) [documents CISPR/A/665/DTR and CISPR/A/685/RVC], its amendment 1 (2014-07) [documents CISPR/A/1050/DTR and CISPR/A/1069/RVC] and its amendment 2 (2021-10) [documents CIS/A/1321/DTR and CIS/A/1324/RVDTR].

This Final version does not show where the technical content is modified by amendments 1 and 2. A separate Redline version with all changes highlighted is available in this publication.

The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

CISPR 16-4-5, which is a technical report, has been prepared by CISPR subcommittee A: Radio-interference measurements and statistical methods.

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

A list of all parts of the CISPR 16-4 series, published under the general title *Specification for radio disturbance and immunity measuring apparatus and methods – Part 4: Uncertainties, statistics and limit modelling*, can be found on the IEC website.

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

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

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SPECIFICATION FOR RADIO DISTURBANCE AND IMMUNITY MEASURING APPARATUS AND METHODS –

Part 4-5: Uncertainties, statistics and limit modelling – Conditions for the use of alternative test methods

1 Scope

This part of CISPR 16-4 specifies a method to enable product committees to develop limits for alternative test methods, using conversions from established limits. This method is generally applicable for all kinds of disturbance measurements, but focuses on radiated disturbance measurements (i.e. field strength and total radiated power), for which several alternative methods are presently specified. These limits development methods are intended for use by product committees and other groups responsible for defining emissions limits in situations where it is decided to use alternative test methods and the associated limits in product standards.

2 Normative references

IEC 60050-161:1990, *International Electrotechnical Vocabulary (IEV) – Chapter 161: Electromagnetic compatibility*

CISPR 16-1-1:2019, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-1: Radio disturbance and immunity measuring apparatus – Measuring apparatus*

CISPR 16-4-2:2011, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 4-2: Uncertainties, statistics and limit modelling – Measurement instrumentation uncertainty*
CISPR 16-4-2:2011/AMD1:2014
CISPR 16-4-2:2011/AMD2:2018

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60050-161 and the following apply.

3.1
established test method
test method described in a basic standard with established emissions limits defined in corresponding product or generic standards. An established test method consists of a specific test procedure, a specific test set-up, a specific test facility or site, and an established emissions limit

NOTE The following test methods have been considered to be established test methods in CISPR:

– conducted disturbance measurements at mains ports using an AMN in the frequency range 9 kHz to 30 MHz; this method is defined in CISPR 16-2-1;
– radiated disturbance measurements in the frequency range 30 MHz to 1 GHz at 10 m distance on an OATS or in a SAC; this method is defined in CISPR 16-2-3;
– radiated disturbance measurements in the frequency range 1 GHz to 18 GHz at 3 m distance on an FSOATS; this method is defined in CISPR 16-2-3.

3.2
alternative test method
test method described in a basic standard without established emissions limits. The alternative test method is designed for the same purpose as the established test method. An alternative test method consists of a specific test procedure, a specific test set-up, a specific test facility or site, and a derived emissions limit that was determined by the application of the proposed method stated in this document

3.3
established limit
limit having "many years" of good protection of radio services.

NOTE An example is radiated field strength measured on OATS, developed to protect radio services as described in CISPR 16-3.

3.4
derived limit
limit applicable for the alternative test method, derived by appropriate conversion from the established limit and expressed in terms of the misbrands

3.5
conversion factor *K*
for a given EUT or type of EUT, the relation of the measured value of the established test method to the measured value of the alternative test method

NOTE The terms measured and calculated are used interchangeably at various places in this document to describe actual laboratory tests and computer simulations.

3.6
reference quantity *X*
the basic parameter which determines the interference potential to radio reception. It may be independent of the parameters presently used in established standards

NOTE The goal for both the established and alternative test methods is to determine the reference quantity (*X*) for all frequencies of interest. For both established and alternative test methods, the test results may deviate from the reference quantity values. The specification of the reference quantity when applying methods of this document should include applicable procedures and conditions to calculate (or measure) this quantity

3.7
inherent uncertainty
u_{inherent}
uncertainty caused solely by the difference in EUT characteristics and the ability of the measurement procedure to cope with them. It is specific to each test method and remains, even if the measurement is performed perfectly, i.e., the standards compliance uncertainty is zero and the measurement instrumentations uncertainty is zero

3.8
intrinsic uncertainty of the measurand
$u_{\mathrm{intrinsic}}$
minimum uncertainty that can be assigned in the description of a measured quantity. In theory, the intrinsic uncertainty of the measurand would be obtained if the measurand was measured using a measurement system having negligible measurement instrumentation uncertainty.

[CISPR 16-4-1:2009, 3.1.6, modified – Deletion of notes]

3.9
EUT type
grouping of products with sufficient similarity in electromagnetic characteristics to allow testing with the same test installation and the same test protocol.

3.10
standards compliance uncertainty
SCU
parameter, associated with the result of a compliance measurement as described in a standard, that characterizes the dispersion of the values that could reasonably be attributed to the measurand

[IEC 60050-161:1990, 311-01-02, modified, deletion of the notes]

3.11
EUT volume
cylinder defined by EUT boundary diameter and height that fully encompasses all portions of the actual EUT, including cable racks and 1,6 m of cable length (for 30 MHz to 1 GHz), or 0,3 m of cable length (for 1 GHz and above)

NOTE 1 The test volume is one of several criteria limiting the EUT volume.

NOTE 2 The EUT volume has a diameter D (boundary diameter) and a height h.

4 Symbols and abbreviated terms

The following abbreviations are used in this technical report. Note that the symbol k is used for four different quantities.

ATM	alternative test method (e.g. subscript in D_{ATM})
D	deviation
ETM	established test method (e.g. subscript in D_{ETM})
f	index number of an individual measured frequency
F	number of measured frequencies in the considered frequency range
FAR	fully anechoic room
i	index number of an individual EUT
j	index number of an individual test lab
k	$= 2\pi/\lambda$, wave number (in this document, k is used in the electrical size ka, where a is the EUT radius)
$k(f)$	linear conversion factor
$K(f)$	logarithmic conversion factor
k	coverage factor
k	Boltzmann's constant
L	limit
M	measurement (or calculation) result
N	number of EUTs
OATS	open-area test site
RC	reverberation chamber
RRT	round robin test
s	standard deviation
SAC	semi-anechoic chamber
SCU	standards compliance uncertainty
T	number of test labs
U	expanded uncertainty
u	standard uncertainty

v volume

X reference quantity

Δ difference of two values or quantities

$\overline{x}$ mean value of a set of values x (e.g., $\overline{D}$)

5 Introduction

Over the years, several test methods and test set-ups for radiated disturbance measurement have been described in basic standards. One particular combination of test method and test set-up also having defined disturbance limits is the open area test site (OATS) method, which has proven to be successful for the protection of radio services. Since the first edition of this document, limits have been defined for other – alternative – test methods, e.g., fully anechoic rooms and TEM waveguides, but not for reverberation chambers.

Each alternative method can be used to get measurement results related to disturbance from an EUT. Although each method gives a disturbance level from an EUT, the different methods might capture the EUT disturbance differently. For example, considering radiated disturbance measurements, different methods may capture different EUT radiation pattern lobes, a different number of lobes, or the test facility might alter the EUT radiation pattern producing a different apparent disturbance level. Therefore the limits defined for the established test method cannot be applied directly to the alternative test methods. Consequently, procedures are needed to derive limits to be used for the results of alternative test methods.

The specification of such procedures considers the general goal of disturbance measurements, which is to verify whether an EUT satisfies or violates certain compliance criteria. Past experience has shown that using the present system of established test methods and associated limits yields a situation without many cases of interference due to conducted disturbance or radiated disturbance. Applying an established test method with its associated limits will fulfill the protection requirement with a high probability. To preserve this situation, the most important requirement for the use of alternative test methods is the following:

– Use of an alternative test method in a normative standard shall provide the same protection of radio services as the established test method.

This requirement can be met by developing procedures to derive disturbance limits for alternative test methods from the existing limits of the established test methods. Such procedures shall relate the results from an alternative test method to those from an established test method. Using the relations derived in this document, the limits of the relevant established test method can be converted into limits for the alternative test method. The measured values of the alternative test method can then easily be evaluated against the converted limits. Such procedures will provide a similar amount of protection, even though an alternative test method is used.

The limit conversion procedures consider the preceding goal of disturbance measurements. The results of standard disturbance measurements can be considered as an approximation of the interference potential of an EUT. Depending on the characteristics of an EUT (e.g., radiation pattern characteristics for radiated disturbance test methods), and the test set-up, the measured value deviates from the actual interference potential of the EUT. This deviation can be divided into two parts: 1) a systematic deviation, which can be interpreted as a bias of the test method; and 2) a random deviation depending on the characteristics of different EUTs, which can be interpreted as an uncertainty of the test method. Each disturbance test method contains both quantities, and consequently the established test method does too. In the following clauses, a procedure based on these two quantities for comparing an alternative test method with the established test method is described. To determine these quantities, the abstract term “interference potential” shall be expressed in terms of a physical quantity. For the purposes of this document, this physical quantity is called the “reference quantity” X.

Other details about comparison of test methods using a reference quantity can be found in [1][1].

The significance of a reference quantity is under discussion (see Magdowski [16]). It is not used in the derivation of limits for an alternative test method based on measurements (see Clause 7 of CISPR TR 16-4-5:2006/AMD1:2014), and in the derivation of limits for disturbance measurements using a reverberation chamber (i.e. in this document).

6 Procedure to derive limits for an alternative test method

6.1 Overview

A procedure to derive limits for an alternative test method based on the limits of an established test method is described in the following paragraphs. Figure 1 shows a summary of the estimated quantities needed for the correlation process. Figure 2 shows a flowchart for the correlation process using these quantities. The nine-step conversion process below can be accomplished using numerical simulations, measurements, or a combination of simulations and measurements. Calculable or reference EUTs are invaluable for this conversion procedure. In the following subclauses, as part of the conversion process the quantities shown in Figure 1 and Figure 2 are combined into several equations. A summary of the equations is given in Table 2. A summary of the steps in the conversion procedure is shown in Table 1.

Table 1 – Summary of steps in conversion procedure

1	Select the reference quantity
2	Describe the test methods and measurands
3	Determine the deviations of the measured quantities from the reference quantity
4	Determine the average values of the deviations
5	Determine the standard uncertainties of the test methods
6	Verify the calculated values
7	Apply the conversion

[1] Figures in square brackets refer to the Bibliography.

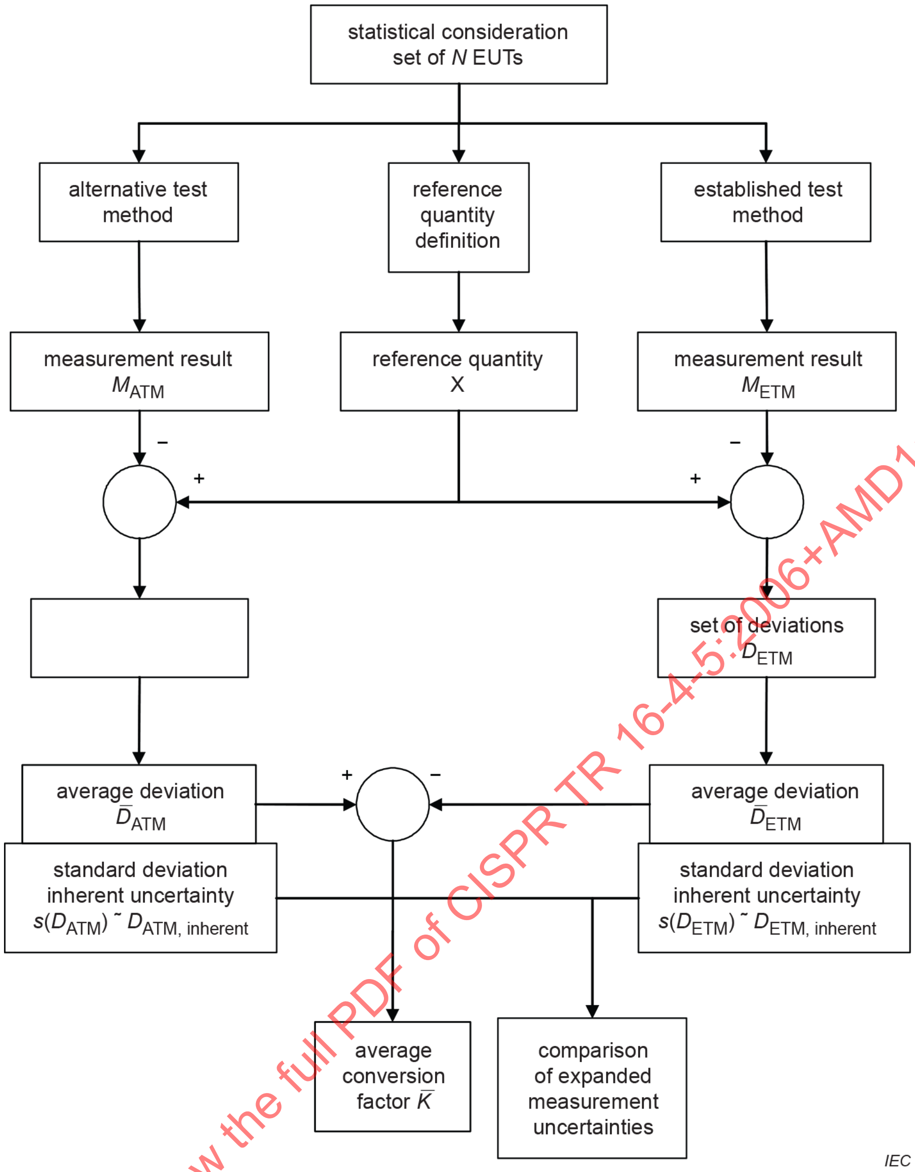


Figure 1 – Overview of quantities to estimate for use in conversion procedure

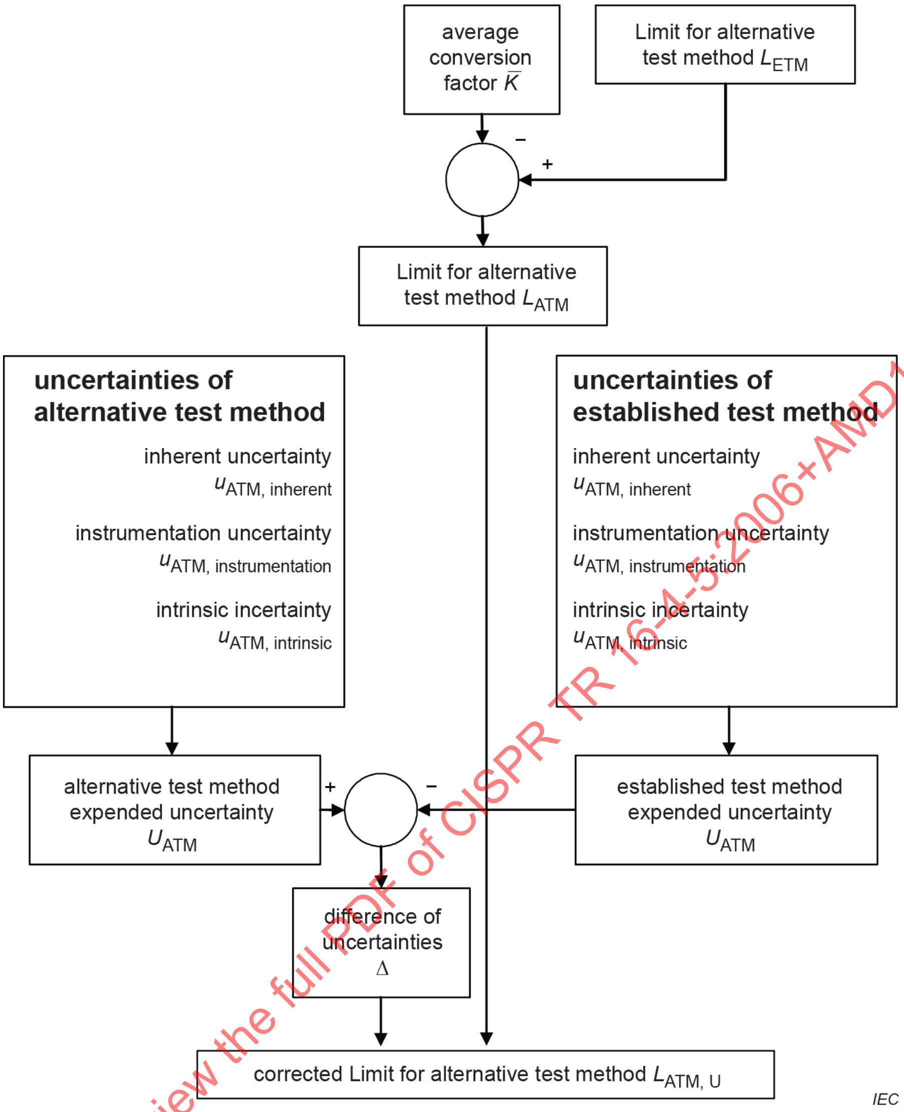


Figure 2 – Overview of limit conversion procedure using estimated quantities

Table 2 – Overview of quantities and defining equations for conversion process

Quantity	Meaning	Equation no.
$D_{ATMi}(f)$	the deviation from the reference quantity of the measurement result of EUT *i* as produced by the alternative test method	(1)
$D_{ETMi}(f)$	the deviation from the reference quantity of the measurement result of EUT *i* as produced by the established test method	(2)
$\overline{D}_{ATM}$	the average deviation of the alternative test method	(3)
$\overline{D}_{ETM}$	the average deviation of the established test method	(4)
$u_{ATM,inherent}$	the inherent uncertainty of the alternative test method	(5)
$u_{ETM,inherent}$	the inherent uncertainty of the established test method	(6)
u_{ATM}	combined standard uncertainty of the alternative test method	(7)
U_{ATM}	the expanded uncertainty of the alternative test method	(8)
u_{ETM}	combined standard uncertainty of the established test method	(9)
U_{ETM}	the expanded uncertainty of the established test method	(10)
$K_i(f)$	frequency dependent conversion factor for EUT *i*	(11)
$\overline{K}(f)$	the average of the conversion factors	(12), (13), (14)
$L_{ATM}(f)$	the limit line of the alternative test method equivalent to the limit of the established test method, without consideration of the uncertainties	(15)
Δ	difference of expanded uncertainties	(16)
$L_{ATM,U}$	the limit to be used for alternative measurements	(17)
USC,XTM	standards compliance uncertainty for the test method X, where X is either “E” for established test method or “A” for alternative test method	(26)
DK	deviation of the single calculated conversion factor $K_i(f,j)$ from the average conversion factor $\overline{K}(f)$	(20), (21)
DXTM	deviation of the single measured value $M_{XTM,i}(f,j)$ from the average for the measured values $\overline{M}_{XTM,i}$	(24), (25)
MXTM,i(f,j)	measured value depending on EUT, lab, and frequency	(18), (23)
Emax	Maximum field strength of an EUT in µV/m measured using the ETM, i.e. at d = 10 m at an OATS/SAC from 80 MHz to 1 000 MHz, and at d = 3 m at a FSOATS/FAR from 1 GHz to 18 GHz	(35)
PT	Power transmitted from an EUT in pW measured using the reverberation chamber test method (ATM), and virtual powera) producing the field-strength maximum Emax measured using the ETM	(35)
[a] The virtual power is the power generating E_{max} assuming the EUT directivity is estimated in this document.		

6.2 Select the reference quantity *X*

The first step is to select the reference quantity *X*. It should be selected on the basis of a quantity that can possibly cause interference to a radio service, and selection of a reference quantity also depends on the type of EUT.

For the types of EUTs investigated in Annex B, as an example the maximum electric field strength determined on a sphere of a certain radius around the EUT has been selected as the reference quantity for radiated emission measurements in the frequency range of 30 MHz to 1 GHz. In the frequency range below 30 MHz, depending on the frequency subrange and the coupling model, the reference quantity may be the vertical component of the electric field strength, the magnetic field strength, or the asymmetric voltage. In general, the reference quantity and the actual measurands will not necessarily have the same units.

6.3 Describe the test methods and measurands

The measurand shall be described for both the alternative and the established test methods. In addition, the test set-up geometry, the methods of measurement for EUT emissions, and any analysis methods producing the final measurement results shall be described. This description is necessary for an understanding about how the test method works and to give a basis for comparison of the two test methods. In most cases this description is explicit or implicit in the standards that specify the test methods.

6.4 Determine the deviations of the measured quantities from the reference quantity

Each test method provides results, each of which deviate from the reference quantity X. The deviation depends on the characteristics of the test set-up as well as on the characteristics of the EUT. Considering a certain EUT i, a frequency dependent deviation can be determined for both alternative and established test method.

For a given EUT i the deviation of the alternative test method, in a logarithmic scale, is given as

$$D_{\mathrm{ATM}i}(f) = X_i(f) - M_{\mathrm{ATM}i}(f) \quad (1)$$

where

i	is the index of the EUT;
f	is the frequency;
$D_{\mathrm{ATM}i}(f)$	is the deviation from the reference quantity of the measurement result of EUT i as produced by the alternative test method;
$X_i(f)$	is the reference quantity defined in 6.2 for the EUT i, and
$M_{\mathrm{ATM}i}(f)$	is the measurement result given by the alternative test method for the EUT i.

The results of the established test method will deviate from the reference quantity as well. The deviation of the established test method is analogously given by the equation

$$D_{\mathrm{ETM}i}(f) = X_i(f) - M_{\mathrm{ETM}i}(f) \quad (2)$$

where

$X_i(f)$, f, i	are the same as in Equation (1);
$D_{\mathrm{ETM}i}(f)$	is the deviation from the reference quantity of the measurement result of EUT i as produced by the established test method;
$M_{\mathrm{ETM}i}(f)$	is the measurement result given by the established test method for the EUT i.

6.5 Determine the average values of the deviations

The deviations given by Equations (1) and (2) will differ for different EUTs. In order to obtain more universal results, varying characteristics of EUTs shall be considered, for example as shown in Annex A. Considering a range of N EUTs leads to a set of N values for the deviation D for both alternative and established test methods. From this set of D the average can be easily determined. See Annex A for more details about EUT considerations and variations.

An estimate of the mean of the deviation of the alternative test method is given by

$$\overline{D}_{\mathrm{ATM}} = \frac{1}{N}\sum_{i=1}^{N} D_{\mathrm{ATM}i} \tag{3}$$

where

D_{ATM}	is the set of deviations of the alternative test method;
$\overline{D}_{\mathrm{ATM}}$	is the average deviation of the alternative test method;
N	is the number of EUTs considered, and shall be as large as possible for statistical reasons;
i	is the index of any one EUT;
$D_{\mathrm{ATM}i}$	is the deviation from the reference quantity of the measurement result of EUT i, as produced by the alternative test method [Equation (1)].

An estimate of the mean of the deviation of the established test method is given by

$$\overline{D}_{\mathrm{ETM}} = \frac{1}{N}\sum_{i=1}^{N} D_{\mathrm{ETM}i} \tag{4}$$

where

D_{ETM}	is the set of deviations of the established test method;
$\overline{D}_{\mathrm{ETM}}$	is the average deviation of the established test method;
N, i	are the same as in Equation (3);
$D_{\mathrm{ETM}i}$	is the deviation from the reference quantity of the measurement result of EUT i, as produced by the established test method [Equation (2)].

6.6 Estimate the standard uncertainties of the test methods

The methods comparison procedure must consider uncertainties, as are associated with every measurement result. Because the results from the established test method itself have uncertainties, care must be taken that these uncertainties are not transferred to results from the alternative test methods as part of the conversion procedure. Otherwise, the use of alternative test methods would be burdened with uncertainties that are characteristics of the established test method.

The uncertainty of emission measurements consists of several components. On one hand, the measurement equipment contributes several uncertainties, as documented in CISPR 16-4-2. On the other hand the test set-up combined with the radiation characteristics of the EUT causes an inherent uncertainty, u_{inherent}. For example, in radiated emissions measurements, for some types of EUT radiation patterns, an OATS test (established test method) may fail to capture the radiated emission peak lobe. Deviations between the results of a test method and the reference quantity depend on the radiation characteristics of the EUT, but the radiation characteristics of an arbitrary EUT are not known *a priori*. The resulting uncertainty u_{inherent} can be estimated only if the behaviour of EUTs with different characteristics is examined. Analogously to as in 6.4, the deviations from the reference quantity of a set of N EUTs can be used for estimating the standard deviation as a measure for the inherent uncertainties.

Using the formula for experimental standard deviation, the inherent uncertainty of the alternative test method is given by:

$$u_{\mathrm{ATM,inherent}} = s(D_{\mathrm{ATM}}) = \sqrt{\frac{\sum_{i=1}^{N}(D_{\mathrm{ATM}i} - \overline{D}_{\mathrm{ATM}})^2}{N-1}} \tag{5}$$

where

$u_{\text{ATM,inherent}}$	is the inherent uncertainty of the alternative test method;
$s(D_{\text{ATM}})$	is the experimental standard deviation of the set D_{ATM};
N, i, D_{ATM}, $D_{\text{ATM}i}$	are the same as in Equation (3).

Analogously, the inherent uncertainty of the established test method is given:

$$u_{\text{ETM,inherent}} = s(D_{\text{ETM}}) = \sqrt{\frac{\sum_{i=1}^{N}(D_{\text{ETM}i} - \overline{D}_{\text{ETM}})^2}{N-1}} \tag{6}$$

where

$u_{\text{ETM,inherent}}$	is the inherent uncertainty of the established test method;
$s(D_{\text{ETM}})$	is the experimental standard deviation of the set D_{ETM};
N, i, D_{ETM}, $D_{\text{ETM}i}$	are the same as in Equation (4).

6.7 Estimate the expanded uncertainties of the test methods

The expanded measurement uncertainty is obtained from the multiplication of the combined standard uncertainties by a coverage factor k. The combined standard uncertainty of the alternative test method u_{ATM} can be calculated from

$$u_{\text{ATM}} = \sqrt{u_{\text{ATM,m}}^2 + u_{\text{ATM,intrinsic}}^2 + u_{\text{ATM,inherent}}^2} \tag{7}$$

where

$u_{\text{ATM,m}}$	is the combined standard uncertainty of the alternative test method contributed by measurement instrumentation;
$u_{\text{ATM,inherent}}$	is the inherent uncertainty of the alternative test method, according to Equation (5);
$u_{\text{ATM,intrinsic}}$	is the intrinsic uncertainty of the alternative test method.

Using the coverage factor k, the expanded uncertainty of the alternative test method is estimated:

$$U_{\text{ATM}} = k \cdot u_{\text{ATM}} \tag{8}$$

where

U_{ATM}	is the expanded uncertainty of the alternative test method;
k	is the coverage factor;
u_{ATM}	is the combined standard uncertainty of the alternative test method according to Equation (7).

Analogously the combined standard uncertainty of the established test method u_{ETM} can be obtained,

$$u_{\text{ETM}} = \sqrt{u_{\text{ETM,m}}^2 + u_{\text{ETM,intrinsic}}^2 + u_{\text{ETM,inherent}}^2} \tag{9}$$

where

$u_{ETM,m}$ is the combined standard uncertainty of the established test method contributed by measurement instrumentation;

$u_{ETM,inherent}$ is the EUT-dependent uncertainty of the established test method, according to Equation (6);

$u_{ETM,intrinsic}$ is the intrinsic uncertainty of the established test method.

The expanded uncertainty of the established test method is given by

$$U_{ETM} = k \cdot u_{ETM} \tag{10}$$

where

U_{ETM} is the expanded uncertainty of the established test method;

k is the coverage factor;

u_{ETM} is the combined standard uncertainty of the established test method according to Equation (9).

6.8 Calculate the average conversion factor

For each EUT i a frequency dependent conversion factor $K_i(f)$ can be calculated using

$$K_i(f) = D_{ATMi}(f) - D_{ETMi}(f) \tag{11}$$

where

$D_{ATMi}(f)$ is the deviation from the reference quantity of the measurement result of EUT i, as produced by the alternative test method [Equation (1)];

$D_{ETMi}(f)$ is the deviation from the reference quantity of the measurement result of EUT i, as produced by the established test method [Equation (2)].

The average conversion factor can be calculated from the average deviations of the alternative and the established test methods:

$$\overline{K}(f) = \overline{D}_{ATM}(f) - \overline{D}_{ETM}(f) \tag{12}$$

where

$K(f)$ is the set of conversion factors;

$\overline{K}(f)$ is the average of the conversion factors;

$\overline{D}_{ATM}(f)$ is the average deviation of the alternative test method from the reference quantity, in dB;

$\overline{D}_{ETM}(f)$ is the average deviation of the established test method from the reference quantity, in dB.

Substituting the averages by Equations (3) and (4) gives:

$$\overline{K} = \overline{D}_{ATM} - \overline{D}_{ETM} = \frac{1}{N}\sum_{i=1}^{N} D_{ATMi} - \frac{1}{N}\sum_{i=1}^{N} D_{ETMi} \tag{13}$$

Using Equations (1) and (2), the average conversion factor can be expressed in terms of the measurement results of the set of EUTs:

$$\overline{K} = \frac{1}{N}\sum_{i=1}^{N}(X_i - M_{\text{ATM}i}) - \frac{1}{N}\sum_{i=1}^{N}(X_i - M_{\text{ETM}i}) = \frac{1}{N}\sum_{i=1}^{N}(M_{\text{ETM}i} - M_{\text{ATM}i}) \qquad (14)$$

where $\overline{K}$ is the same as in Equation (12) and $M_{\text{ETM}i}$ and $M_{\text{ATM}i}$ are the same as in Equation (1) and Equation (2).

6.9 Verify the calculated values

In many cases it is necessary to obtain both the deviations from the reference quantity, and their average and standard deviation values, from numerical simulations. It is strongly recommended to verify such calculations by measurements.

6.10 Apply the conversion

If the limit lines defined for the established test method are to be converted into limit lines for an alternative test method, the results from Equations (8), (10), and (12) or (14), respectively, are needed.

A limit line of an established test method can be converted into limit conditions for an alternative test method using the average conversion factor:

$$L_{\text{ATM}}(f) = L_{\text{ETM}}(f) - \overline{K}(f) \qquad (15)$$

where

$\overline{K}(f)$ is the frequency-dependent average conversion factor according to Equation (12);

$L_{\text{ETM}}(f)$ is the frequency-dependent limit of the established test method;

$L_{\text{ATM}}(f)$ is the limit line of the alternative test method equivalent to the limit of the established test method, without consideration of the uncertainties.

To complete the process, the uncertainties of both alternative and established test methods have to be taken into account. Defining a difference, Δ, between the uncertainty of the alternative test method, U_{ATM}, and the uncertainty of the established test method U_{ETM}, i.e.,

$$\Delta = U_{\text{ATM}}(f) - U_{\text{ETM}}(f) \qquad (16)$$

implies a rule for how to handle the measurement uncertainties. If the uncertainty of the alternative test method is larger than the uncertainty of the established test method, it shall be used to correct the limit of the alternative test method:

$$L_{\text{ATM},U} = \begin{cases} L_{\text{ATM}} - \Delta & \text{if } \Delta > 0 \\ L_{\text{ATM}} & \text{if } \Delta \le 0 \end{cases} \qquad (17)$$

where $L_{\text{ATM},U}$ is the limit to be used for alternative measurements.

7 Measurement-based procedure to derive limits for an alternative test method based on measurement results

7.1 General

As presented in Clause 6, the conversion factor $\overline{K}$ of alternative disturbance measurement methods is based on the concept of the availability of models of the measurement methods under consideration, the considered EUTs, and the application of an independent reference quantity X. In this way, the inherent uncertainties of the two methods under comparison are determined, and these uncertainties plus the intrinsic uncertainties of the measurand and the measurement instrumentation uncertainties (MIUs) are taken into account in determining the limit for the ATM [see Equations (7), (9) and (16)].

Because the independent reference quantity is not always available, the conversion factor $\overline{K}$ can be estimated by direct comparison of the measurement results [see Equation (14)]. The uncertainty of each measurement procedures is estimated by the standards compliance uncertainty (SCU). The uncertainty of the conversion factor is determined by the SCUs of the ETM and ATM, as well as by the different characteristics of the EUTs. The limit L_{ATM} is determined according to Equation (15) using the conversion factor $\overline{K}$. The limit $L_{ATM,U}$ takes into account the difference between the SCUs of the ATM and ETM, as well as the uncertainty caused by the different characteristics of the EUTs.

The condition for the estimation of the conversion factor by measurements is that at least five independent sets of data for each EUT are obtained through a round robin test (RRT), and N representative EUTs are used for the RRT. To assure statistical independence of the sets of data, the RRT involves at least five test houses. For simplicity, it is assumed here that each set of data is provided by a different test house. Outliers are identified and removed from the sets of data if no correction is possible.

7.2 Application of practical measurement results to determine the conversion factors

7.2.1 The conversion factor

The conversion factor K_i in the considered frequency range can be calculated for each of the F measured frequencies, for each of the N EUTs and for each of T labs.

$$K_i(f,j) = M_{ATM,i}(f,j) - M_{ETM,i}(f,j) \quad \text{in dB} \tag{18}$$

The average conversion factor $\overline{K}(f)$ is calculated using Equation (19).

$$\overline{K}(f) = \frac{1}{NT}\sum_{i=1}^{N}\sum_{j=1}^{T} K_i(f,j) \quad \text{in dB} \tag{19}$$

The uncertainty of the average conversion factor $\overline{K}(f)$ can be estimated by the deviation $D_{K,i}(f,j)$ of each calculated conversion factor $K_i(f,j)$ from the average conversion factor $\overline{K}(f)$ and the standard deviation s_K of $D_{K,i}(f,j)$.

$$D_{K,i}(f,j) = \overline{K}(f) - K_i(f,j) \quad \text{in dB} \tag{20}$$

The experimental standard deviation can be calculated by

$$s_K = \sqrt{\frac{1}{(NTF)-1}\sum_{i=1}^{N}\sum_{j=1}^{T}\sum_{f=1}^{F}[\overline{D}_K - D_{K,i}(f,j)]^2} \quad \text{in dB} \tag{21}$$

where $\overline{D}_K$ is the average of all $D_{K,i}(f,j)$.

The resulting expanded uncertainty U_K of the conversion factor is

$$U_K = 2s_K \quad \text{in dB} \tag{22}$$

7.2.2 Estimation of SCU by measurement

For the estimation of the SCU, the average for the measured values of all T test labs for each EUT i is calculated using Equation (23).

$$\overline{M}_{\text{XTM},i}(f) = \frac{1}{T}\sum_{j=1}^{T} M_{\text{XTM},i}(f,j) \quad \text{in dB} \tag{23}$$

where XTM is either ETM or ATM.

For each frequency f and for each EUT i, the deviation $D_{\text{XTM},i}(f,j)$ between the measured values' average $\overline{M}_{\text{XTM},i}(f)$ and each measured value $M_{\text{XTM},i}(f,j)$ is calculated using Equation (24).

$$D_{\text{XTM},i}(f,j) = \overline{M}_{\text{XTM},i}(f) - M_{\text{XTM},i}(f,j) \quad \text{in dB} \tag{24}$$

The experimental standard deviation of all these deviations $D_{\text{XTM},i}(f,j)$ can be calculated by

$$s = \sqrt{\frac{1}{(NTF)-1}\sum_{i=1}^{N}\sum_{j=1}^{T}\sum_{f=1}^{F}[\overline{D}_{\text{XTM}}(f) - D_{\text{XTM},i}(f,j)]^2} \quad \text{in dB} \tag{25}$$

where $\overline{D}_{\text{XTM}}(f)$ is the average of all $D_{\text{XTM},i}(f,j)$.

The uncertainty that causes this deviation depends on the measurement equipment and the measurement procedure. This uncertainty is the SCU, and it is estimated by

$$U_{\text{SC,XTM}} = 2s \quad \text{in dB} \tag{26}$$

7.2.3 Applying the conversion factor

The limit of an established test method can be converted into limit conditions for an alternative test method using the average conversion factor [see Equation (15)] and the measurement uncertainties of ETM and ATM [see Equations (16) and (17)].

Equations (16) and (17) take into account the instrumentation uncertainty. The inherent and intrinsic uncertainty of the measurand is considered by using a reference quantity X in estimating the conversion factor $\overline{K}(f)$. If $\overline{K}(f)$ is estimated by measuring the influence of all uncertainties, then the instrumentation uncertainty, the uncertainty of the measurement procedure, and the uncertainty caused by the different radiation characteristics of the EUTs are all taken into account. Therefore the difference Δ_{meas} of the uncertainties of the ATM and ETM is:

$$\Delta_{\text{meas}} = U_{\text{ATM}} - U_{\text{SC,ETM}} \quad \text{in dB} \tag{27}$$

For the estimation of the uncertainty U_{ATM} [see Equation (32)], the uncertainty of the conversion factor U_K is investigated. The amount of the uncertainty U_K of the conversion factor can be estimated by:

$$U_K^2 = U_{\mathrm{SC,ETM}}^2 + U_{\mathrm{SC,ATM}}^2 + U_{\mathrm{EUT}}^2 \quad (28)$$

where

$U_{\mathrm{SC,ETM}}$ is the SCU of the ETM,

$U_{\mathrm{SC,ATM}}$ is the SCU of the ATM, and

U_{EUT} is the uncertainty that is caused by the different radiation characteristics of the EUTs, which is estimated by Equations (29) to (31).

The different characteristics cause a unique conversion factor for each EUT. The difference between the conversion factors is estimated by the deviation $D_{K,\mathrm{EUT}}$ between the average conversion factor $\overline{K}(f)$ and the average conversion factor for each EUT $\overline{K}_i(f)$.

$$D_{K,\mathrm{EUT}}(f) = \overline{K}(f) - \overline{K}_i(f) \quad (29)$$

$D_{K,\mathrm{EUT}}$ has standard deviation

$$s_{\mathrm{EUT}} = \sqrt{\frac{1}{(NF)-1}\sum_{i=1}^{N}\sum_{f=1}^{F}[\overline{D}_{K,i} - D_{K,\mathrm{EUT}}(f)]^2} \quad (30)$$

where $\overline{D}_{K,i}$ is the average of all $D_{K,\mathrm{EUT}}(f)$.

The uncertainty U_{EUT} is estimated by

$$U_{\mathrm{EUT}} = 2s_{\mathrm{EUT}} \text{ in dB.} \quad (31)$$

The uncertainty U_{ATM} is determined by the uncertainty $U_{\mathrm{SC,ATM}}$ of the ATM and the uncertainty U_{EUT} caused by the EUTs. Therefore U_{ATM} can be estimated by

$$U_{\mathrm{ATM}} = \sqrt{U_{\mathrm{EUT}}^{\ 2} + U_{\mathrm{SC,ATM}}^{\ 2}}\ . \quad (32)$$

Therefore, using Equation (27) the application of Equation (17) becomes

$$L_{\mathrm{ATM},U} = L_{\mathrm{ATM}} - \Delta_{\mathrm{meas}} \text{ if } \Delta_{\mathrm{meas}} > 0\text{, and} \quad (33)$$

$$L_{\mathrm{ATM},U} = L_{\mathrm{ATM}} \text{ if } \Delta_{\mathrm{meas}} \leq 0 \quad (34)$$

It should be considered that $U_{\mathrm{SC,ETM}}$ in Equation (27) is estimated in accordance with CISPR 16-4-1, which estimates generally the U_{SC} for 3 m test site results in the frequency range 30 MHz to 300 MHz to be 15,5 dB; for the conditions of the RRT and the terminated cables, U_{SC} may be reduced to 11 dB. CISPR 16-4-1 gives no value for the $U_{\mathrm{SC,ETM}}$ of the 10 m test site results, but the value can be expected to be in the order of about 10 dB.

8 Derivation of limits for the use of reverberation chambers as ATM for radiated disturbance measurements based on a statistical analysis of all essential factors

8.1 Conversion factor

Measurement of radiated power from an EUT using the RC method is described in IEC 61000-4-21 [22]. This clause attempts to provide rules to derive disturbance limits for the radiated power measured using the RC test method based on existing limits for radiated field strength measured using the ETM. Radiated field strength and radiated power of an EUT are related via the EUT directivity, and EUT directivity depends on frequency and EUT volume. Because the type of an EUT and its directivity are typically unknown for generic and product standards, this clause uses a statistical estimate based on assumptions described by Krauthäuser [19]. For comparison and easier understanding, the conversion factors using a short dipole as a model are described in D.2.

With reference to Annex D, conversion factors

– from OATS/SAC to RC for 80 MHz to 1 000 MHz, and

– from FSOATS/FAR to RC for 1 GHz to 40 GHz.

are introduced.

NOTE The start frequency of 80 MHz is selected because IEC 61000-4-21:2011, Table B.2 [22] on field uniformity requirements starts at 80 MHz. Because there are RCs with lower or higher lowest useable frequencies (LUFs), 80 MHz can be replaced by "LUF." The highest frequency of 40 GHz is selected because that is under consideration to be the highest frequency for all CISPR documents pending agreement by NCs.

The linear conversion factor *k*(*f*) is defined as in Equation (35)

$$k(f) = E_{max}^2 / P_T \tag{35}$$

where

E_{max} is the maximum field strength of an EUT in μV/m measured using the ETM;

P_T is the power transmitted from an EUT in pW measured using the RC test method.

The unit of $k(f)$ is V²/m²W or Ω/m². To convert into logarithmic quantities, Equation (35) can be written as Equation (36):

$$\begin{aligned} \lg P_T &= \lg E_{max}^2 - \lg k(f), \text{ or} \\ 10 \lg P_T &= 20 \lg E_{max} - 10 \lg k(f) \end{aligned} \tag{36}$$

The logarithmic conversion factor *K*(*f*) is defined as in Equation (37):

$$K(f) = 10 \lg k(f) \tag{37}$$

The logarithmic conversion factor can be used to convert radiated disturbance limits L_{ETM} in dB(μV/m) into limits of the disturbance power L_{ATM} in dB(pW) measured in an RC as shown in Equation (38) (see also Equation (15) in 6.10).

$$L_{\text{ATM}}/\text{dB(pW)} = L_{\text{ETM}}/\text{dB}(\mu\text{V/m}) - K(f) \tag{38}$$

The logarithmic conversion factor $K(f)$ has the unit dB(Ω/m²).

8.2 Measurement uncertainty

Equation (7) and Equation (9) of 6.7 provide the combined standard uncertainties of ATM and ETM results with contributions designated in subscripts as: "m" for the instrumentation uncertainty, "intrinsic" for the intrinsic uncertainty of the measurand, and "inherent" for the inherent uncertainty of the method.

$$u_{\text{XTM}} = \sqrt{u_{\text{XTM,m}}^2 + u_{\text{XTM,intrinsic}}^2 + u_{\text{XTM,inherent}}^2}$$

where X in the subscript terms denotes either E or A (i.e. ETM or ATM).

For the effect of the measurement uncertainties of ETM and ATM on the disturbance limit, the expanded uncertainties are compared (see Equation (16) in 6.10). The expanded uncertainty of the conversion factor in Annex D (2σ in Table D.2, Table D.3,Table D.4,Table D.6, Table D.7 and Table D.8) takes into account the inherent uncertainties of the ETM ($U_{\text{inherent,ETM}}$) and ATM ($U_{\text{inherent,ATM}}$). The inherent uncertainty is an indicator of the ability of a measurement procedure to account for differences in EUT characteristics. A three-dimensional (3D) spatial scan would provide the lowest uncertainty for capturing the maximum field strength radiated by an EUT, but none of the ETMs are ideal in that respect. However, the RC ATM does capture the radiated power of an EUT across all directions. Consequently, the inherent uncertainty of the RC ATM is zero whereas the inherent uncertainties of the ETMs are non-zero.

In addition to the uncertainty of the conversion factor, the actual EUT size can deviate from the EUT size assumed for the conversion factor calculation in Annex D, which justifies a contribution U_{EUT}.

As can be seen from Table H.1 of CISPR TR 16-4-1:2009, the SCU $U_{\text{ETM,SC}}$ of the ETM (OATS/SAC with d = 10 m) is on the order of 10 dB, whereas $U_{\text{XTM,m}}$ is around 5 dB according to CISPR 16-4-2. Thus,

$$U_{\text{ETM,SC}} = \sqrt{U_{\text{ETM,intrinsic}}^2 + U_{\text{ETM,m}}^2}$$

and consequently

$$U_{\text{ETM,intrinsic}} = \sqrt{U_{\text{ETM,SC}}^2 - U_{\text{ETM,m}}^2} = 8{,}7\ \text{dB}$$

This means that the intrinsic uncertainty of the ETM is much larger than the uncertainty of the conversion factor K, so Equation (28) of 7.2.3 does not apply for Annex D. The intrinsic uncertainty is largely dependent on cable layout and cable termination, which is an important topic for the reproducibility of measurement set-ups. By future standardization of cable layout and cable termination, intrinsic uncertainty and standards compliance uncertainty can be minimized.

At present values of SCU (and intrinsic uncertainty) are not available for the ETM above 1 GHz, as well as for the RC ATM below and above 1 GHz. This does not mean that the RC method should be precluded for radiated disturbance measurements usage; there is no reason to assume that the SCU of the RC method results will be larger than the SCU of the ETM results. Product committees should provide appropriate investigations and measurements for establishing the SCU.

In addition to any deviation from the EUT size for the conversion factor, the EUT type can be different from that assumed for the conversion; e.g. with different cable arrangement and cable termination. This means that Equation (32), Equation (33), and Equation (34) of 7.2.3 also apply for the use of an RC disturbance measurement method as an ATM.

Details on instrumentation contributions to uncertainty for RC disturbance measurement results is given in D.4.

Annex A
(informative)

Remarks on EUT modelling

As discussed in 6.5 and 6.6, the characteristics of an EUT directly influence the measurement results, and thus influence the deviations from the reference quantity. Considering the example of radiated emission measurements, the radiation pattern of the EUT influences the probability of capture for a maximum emission using the peak search procedure of an open-area test site or a fully-anechoic room measurement. To obtain more universal results, it is necessary to consider multiple EUTs having different radiation characteristics for use in determining conversion parameters. This annex describes general considerations about EUT modelling for use in investigations about emission measurement methods.

A.1 Types of EUTs

Certain characteristics of EUTs typically have the most influence on the radiation behaviour. It is useful to categorize EUTs with equivalent primary characteristics into several EUT types, which can then be considered and investigated independently. One general classification is to group EUTs into the following three types, based on the test set-up:

a) tabletop equipment without cables;

b) tabletop equipment with cable(s);

c) floorstanding equipment.

A.2 Application of statistics

Each EUT category of Clause A.1 consists of many different devices and operating and performance characteristics. To best cover these widely-varying characteristics, applying statistical methods is helpful. With a statistical approach, universally valid values for average conversion parameters and the uncertainties can be obtained. The uncertainty resulting from the unknown radiation characteristics of an EUT, u_{inherent}, can only be determined by considering a range of different EUTs and analysing the resulting data statistically. An example of such a statistical approach is given in Annex B.

Annex B
(informative)

Examples of application of the test method comparison procedure

B.1 Example 1 – Measurements at 3 m-separation in fully anechoic room compared to 10 m-separation measurements on open-area test site

In the following subclause headings, numbers in parentheses refer to subclauses in the main body of this document.

B.1.1 Small EUTs without cables

B.1.1.1 Select the reference quantity *X* (see 6.2)

The protection requirement is to minimize the risk that the disturbance field strength radiated by an EUT interferes with radio services. A measure for this interference potential of the EUT is the electric field strength emitted by the EUT. Because the EUT final-use set-up in general is unknown or is variable, it is necessary to search for the maximum field strength in all directions from the EUT and for all polarisations. Therefore the reference quantity is selected to be the maximum far-field electric field-strength emitted under free space conditions, independent of direction or polarisation. At a distance from the EUT of d_{ref} = 10 m and for the frequency range and EUT sizes considered here, far-field conditions can be assumed. Figure B.1 displays this scheme for defining the reference quantity. It is noted that in reality it is difficult or nearly impossible to perform such measurements, but this set-up and reference quantity is very amenable to numerical simulations. This reference quantity definition is applicable in the frequency range of 30 MHz to 1 GHz.

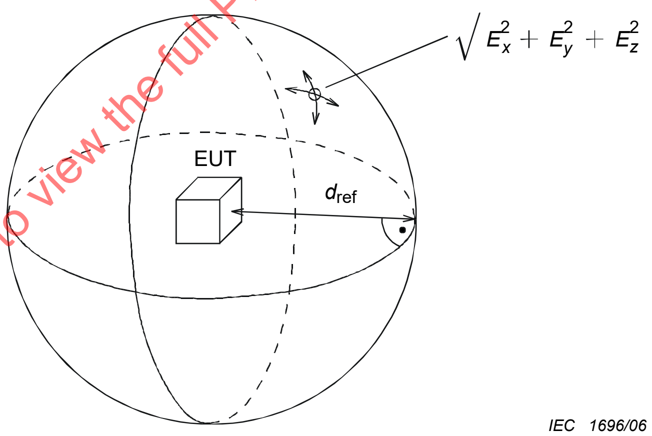


Figure B.1 – Example reference quantity

B.1.1.2 Describe the test methods and measurands (see 6.3)

Alternative test method – 3 m fully anechoic room (FAR): Figure B.2 shows the EUT and antenna set-up for a fully anechoic room measurement for frequencies of 30 MHz to 1 GHz. The receiving antenna is located at a distance d_{far} = 3 m from the EUT. The antenna is positioned at a fixed height corresponding to the vertical centre of the EUT. To detect the maximum field strength, the EUT is rotated in azimuth in the horizontal plane, and both horizontal and vertical polarisations of radiated field are measured. The FAR is a shielded enclosure with absorbing material on the walls, ceiling, and floor. Therefore, ideally the antenna receives only the direct emission radiated from the EUT.

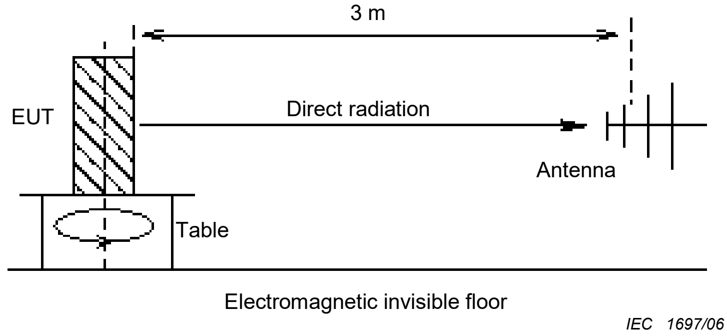


Figure B.2 – EUT and antenna set-up for fully anechoic room emission measurement

Established test method – 10 m open-area test site (OATS): Figure B.3 displays the measurement set-up for an open-area test site for the frequency range of 30 MHz to 1 GHz. The receiving antenna is located at a distance d_{oats} = 10 m to the EUT. To detect the maximum field strength, the EUT is rotated, and the antenna height is varied between 1 m and 4 m. The set-up is placed on a conducting ground plane. The perimeter and surroundings of the OATS and set-up is free of any reflecting objects, therefore ideally the antenna receives only the direct radiation and the ground reflected signal.

Semi-anechoic rooms that meet the CISPR normalized site attenuation (NSA) site-validation criteria can be used to perform compliance tests, and therefore semi-anechoic room could be selected as the established test method instead. The example results shown below remain applicable in this case, because the estimation of the inherent uncertainty assumes conditions of an ideal test site. Considered ideally, a semi-anechoic room and an open-area test site would both ideally provide free-field reflection-free (except ground) conditions.

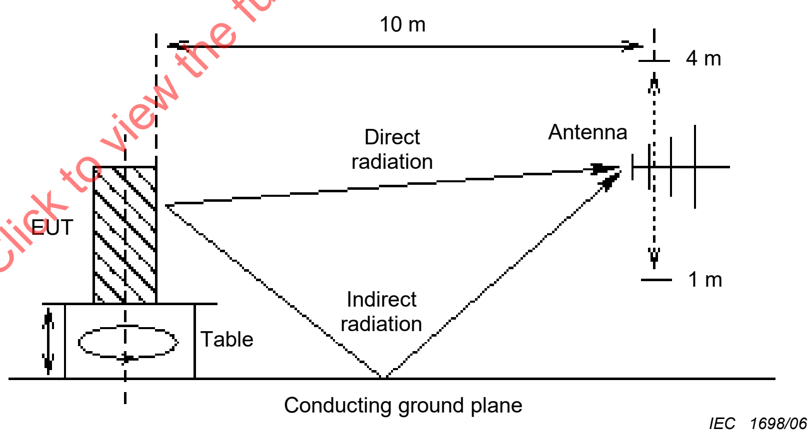


Figure B.3 – EUT and antenna set-up for open-area test site measurement

B.1.1.3 Determine the deviations of the measured quantities from the reference quantity (see 6.4)

The results of the measurement depend strongly on the radiation characteristics of the EUT. Therefore an investigation on the characteristics of the different measurement set-ups must include a wide range of differently radiating EUTs. In the following a statistical model for tabletop EUTs without external cables is used.

In general, any EUT radiation pattern can be approximated by superposing the radiated fields from elementary radiators, such as electrically-short dipoles. Therefore, a quantity of electrically-short dipoles with varying characteristics (direction of axis, amplitude, phase shift, position) will generate statistically different radiation patterns. An example arrangement is shown in Figure B.4. Specifically, the EUT model used here is based on the following concepts: a certain number of dipoles are located inside a certain volume, and their positions, directions and excitations are varied statistically to generate a statistical distribution of radiation characteristics. This statistical EUT model is one practical and reasonable approach among others to simulate tabletop equipment.

Four different virtual-EUT volumes [(30 cm)^3, (60 cm)^3, (90 cm)^3, (120 cm)^3] were simulated to investigate the effect of different EUT models on the resulting emissions. These volumes can be considered to represent the maximum volumes of typical tabletop EUTs. The number of elementary radiators applicable to represent real-world EUT characteristics is indeterminable, thus the ideal number of radiators to be located in the chosen volumes is unknown. Therefore, effects for varying numbers of elementary radiators is investigated. Effects expected from a variation of the numbers of radiators are as follows:

for one radiator, the behaviour of a dipole is modelled;

an increasing number of radiators leads to increasingly complex radiation patterns;

an infinite number of radiators will behave like one equivalent dipole.

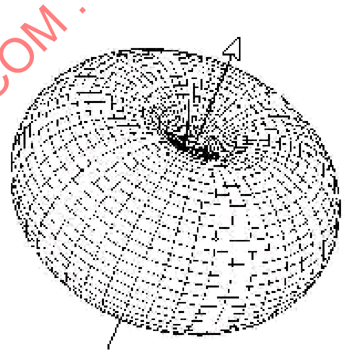
Simulations done for 1, 2, 5, 10, 30, and 50 radiators mainly show the following three characteristics:

the results for 1 or 2 radiators produces the worst-case results only for some frequencies;

the results for 10, 30, or 50 are the worst case for nearly the entire frequency range;

the differences between the results for 10, 30, and 50 radiators are very small, for example compared to the differences between the results for 10 and 2 radiators.

From these observations it can be concluded that simulations with more than 50 radiators probably will not give different results. Therefore the results of the carried out simulations are taken in order to get a safe approximation of the worst case.


IEC 1699/06

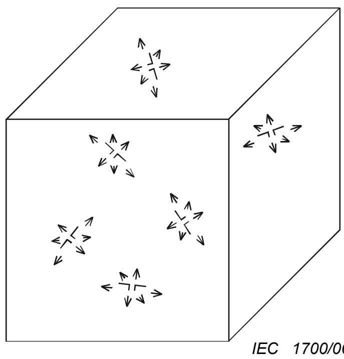

IEC 1700/06

Figure B.4 – Radiation characteristics of elementary radiator (left), and scheme of EUT-model (right)

For each pair of volume and number of radiators, a set of N = 1 000 individual EUTs are generated.

NOTE 1 In general, the number of individual EUTs should be as large as possible. On the other hand, the simulation time has to be finite. A number of 1 000 individual EUTs is deemed to be a reasonable compromise: Based on nonparametric statistics theory, a number of 1 000 individuals enables a confidence level of 99,9% for the estimations of the bounds of interval holding 95% of the simulated values. These bounds are important values to estimate the standard deviation and thus the inherent uncertainty. For more details, see [2] or Chapter 3 of [1].

For each EUT i of such a set, e.g. of the set belonging to a volume of (30 cm)^3 with 5 radiators, the reference quantity X_i and the field strengths $E_{\mathrm{FAR(3m)}i}$ for FAR and $E_{\mathrm{OATS(10m)}i}$ for OATS are calculated, which are equivalent to measured field strength values.

NOTE 2 Because the statistical EUT model yields individual EUTs with larger horizontal or larger vertical field components, the calculated field strengths are determined the same way as in real-world measurements: The maximum value is taken, independent from its polarisation. As a consequence, the polarisation of the field strength values varies statistically, and the derived conversion covers both horizontal and vertical polarisations.

From these results, the deviations for the alternative test method from 6.4, Equation (1),

$$D_{\mathrm{ATM}i} = D_{\mathrm{FAR(3m)}i} = X_i - E_{\mathrm{FAR(3m)}i} \tag{B.1}$$

where

$E_{\mathrm{FAR(3m)}i}$ is the field-strength for 3 m FAR test method for EUT i,

X_i, $D_{\mathrm{ATM}i}$, i are the same as in 6.4 Equation (1),

$D_{\mathrm{FAR(3m)}i}$ is the deviation from the reference quantity X of the 3 m FAR test method result for EUT i,

and for the established test method according to 6.4, Equation (2),

$$D_{\mathrm{ETM}i} = D_{\mathrm{OATS(10m)}i} = X_i - E_{\mathrm{OATS(10m)}i} \tag{B.2}$$

where

$E_{\mathrm{OATS(10m)}i}$ is the field-strength for 10 m OATS test method for EUT i,

X_i, $D_{\mathrm{ETM}i}$, i are the same as in 6.4 Equation (2),

$D_{\mathrm{OATS(10m)}i}$ is the deviation from the reference quantity X of the 10 m OATS test method result for EUT i,

are calculated.

B.1.1.4 Determine the average values of the deviations (see 6.5)

For both alternative and established test methods, the average deviations can be calculated using Equation (3) and Equation (4) from 6.5, respectively. This is done for every set of 1 000 EUTs:

$$\overline{D}_{\mathrm{ATM}} = \overline{D}_{\mathrm{set,\,FAR(3m)}} = \frac{1}{1000}\sum_{i=1}^{1000} D_{\mathrm{FAR(3m)}i} \tag{B.3}$$

$$\overline{D}_{\mathrm{ETM}} = \overline{D}_{\mathrm{set,\,OATS(10m)}} = \frac{1}{1000}\sum_{i=1}^{1000} D_{\mathrm{OATS(10m)}i} \tag{B.4}$$

where

$\overline{D}_{\text{set, ATM}}$ is the average deviation of the alternative test method for the set of 1 000 EUTs;

$\overline{D}_{\text{set, ETM}}$ is the average deviation of the established test method for the set of 1 000 EUTs;

$\overline{D}_{\text{set, FAR(3m)}}$ is the average deviation of the 3 m FAR test method for the set of 1 000 EUTs;

$\overline{D}_{\text{set, OATS(10m)}}$ is the average deviation of the 10 m OATS test method for the set of 1 000 EUTs;

$D_{\text{FAR(3m)}i}$, $D_{\text{OATS(10m)}i}$, i are the same as in Equations (B.1) and (B.2), respectively.

In order to estimate the worst-case emissions, for each volume the maximum average deviation for both test methods is determined using

$$\overline{D}_{\text{max vol, FAR(3m)}} = \max_{\text{number of radiators}} \overline{D}_{\text{set, FAR(3m)}};$$
$$\overline{D}_{\text{max vol, OATS(10m)}} = \max_{\text{number of radiators}} \overline{D}_{\text{set, OATS(10m)}} \qquad \text{(B.5)}$$

where

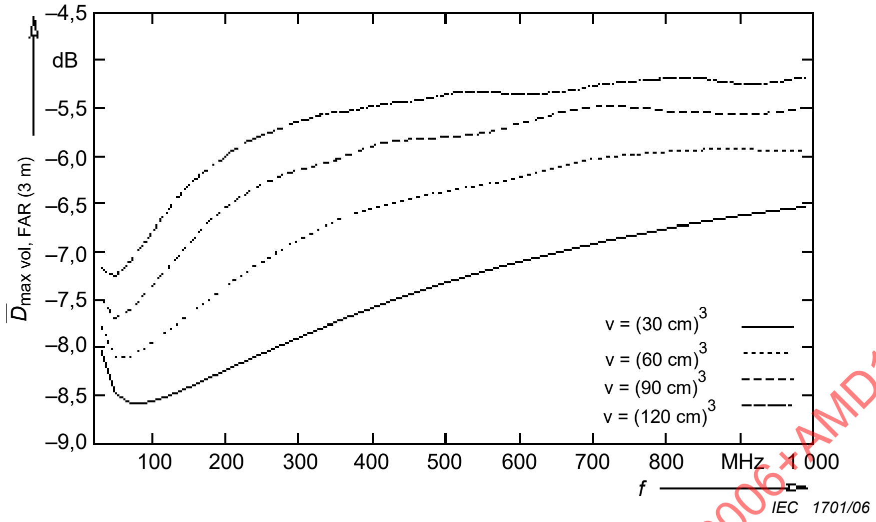
$\overline{D}_{\text{set, FAR(3m)}}$ is the same as in Equation (B.3);

$\overline{D}_{\text{set, OATS(10m)}}$ is the same as in Equation (B.4);

$\overline{D}_{\text{max vol, FAR(3m)}}$ is the maximum average deviation of the 3 m FAR test method for one assumed EUT volume;

$\overline{D}_{\text{max vol, OATS(10m)}}$ is the maximum average deviation of the 10 m OATS test method for one assumed EUT volume.

The example maximum deviations are displayed in Figure B.5.



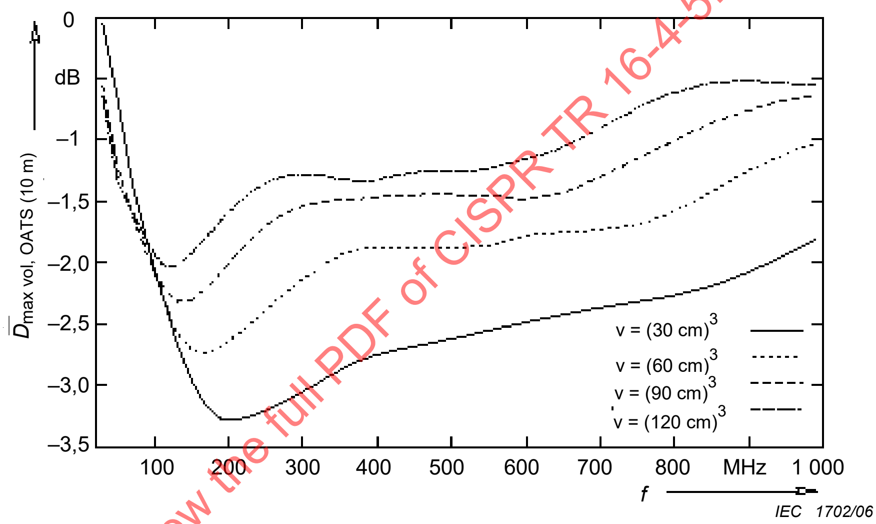


Figure B.5 – Maximum average deviations for 3 m FAR (top) and 10 m OATS (bottom)

B.1.1.5 Estimate the standard uncertainties of the test methods (see 6.6)

Instrumentation uncertainty: At the time of drafting of this Annex, for the alternative test method (3 m FAR), the instrumentation uncertainty had not yet been given in CISPR standards. For the antenna and site contributions, numeric values from the final technical report of the EU FAR project have been used [4]. The other numeric values were taken from CISPR 16-4-2:2003 [24], because these were expected to be the same for OATS and FAR. These instrumentation measurement uncertainties are given in Table B.1. For the established test method, the measurement instrumentation uncertainty is as shown in the basic standard CISPR 16-4-2:2011.

Table B.1 – Instrumentation uncertainty of the 3 m fully anechoic chamber test method

Input quantity	X_i	Uncertainty of x_i dB	Probability distribution function	$u(x_i)$ dB	c_i	$c_i \cdot u(x_i)$ dB
Receiver reading	V_r	±0,1	k = 1	0,10	1	0,10
Attenuation: antenna-receiver	L_c	±0,1	k = 2	0,05	1	0,05
Biconical antenna factor	AF	±2,0	k = 2	1,0	1	1,0
Receiver corrections:						
Sine wave voltage	δVsw	±1,0	k = 2	0,50	1	0,50
Pulse amplitude response	δVpa	±1,5	Rectangular	0,87	1	0,87
Pulse repetition rate response	δVpr	±1,5	Rectangular	0,87	1	0,87
Noise floor proximity	δVnf	±0,5	k = 2	0,25	1	0,25
Mismatch: antenna-receiver	δM	+0,9 / -1,0	U-shaped	0,67	1	0,67
Biconical antenna corrections:						
AF frequency interpolation	δAF_f	±0,3	Rectangular	0,17	1	0,17
AF height deviations	δAF_h	±0,0		0,00	1	0,00
Directivity difference	$\delta A_{dir,h}$	±0,0		0,00	1	0,00
Phase center location	δAph	±0,0		0,00	1	0,0
Cross-polarisation	δAcp	±0,0		0,00	1	0,0
Balance (hor.)	$\delta Abal$	±0,3	Rectangular	0,17	1	0,17
Balance (ver.)	$\delta A_{bal,v}$	±0,9	Rectangular	0,52	1	0,52
Log-periodic antenna corrections:						
AF frequency interpolation	δAF_f	±0,3	Rectangular	0,17	1	0,17
AF height deviations	δAF_h	±0,0		0,00	1	0,00
Directivity difference	$\delta A_{dir,h}$	+0,2 / -0,0	Rectangular	0,05	1	0,05
Phase center location	δAph	±0,5	Rectangular	0,29	1	0,29
Cross-polarisation	δAcp	±0,9	Rectangular	0,52	1	0,52
Balance	$\delta Abal$	±0,0		0,00	1	0,00
Site corrections:						
Site imperfections	δSA	±4,0	Triangular	1,63	1	1,63
Separation distance at 3 m	δd	±0,3	Rectangular	0,17	1	0,17
Table height at 3 m	δh	±0,1	k = 2	0,05	1	0,05

Intrinsic uncertainty: Numeric values for intrinsic uncertainties are still under consideration in CISPR 16-4-1; therefore this uncertainty contribution is not included in this example.

Uncertainty due to unknown EUT characteristics: The standard inherent uncertainty u_{inherent} can be calculated for alternative and established test methods using Equation (5) and Equation (6) from 6.6, respectively. Because the cumulative distribution functions of the deviations have strong asymmetric shapes, the straightforward application of the equations would yield a estimate of the uncertainty that is too low. The sample cumulative distribution function (CDF) in Figure B.6 illustrates this underestimation. If the CDF were symmetric, the interval $\left[\overline{D}_{\text{ETM}}; k_{\text{ETM}} \cdot s(D_{\text{ETM}})\right]$ would cover the upper half of the 95 % interval.

As can be seen from the figure, this is not true – actually $k_{\mathrm{ETM}} \cdot s(D_{\mathrm{ETM}})$ underestimates the upper bound of the 95% interval. To avoid this, the standard deviation, s_+, is introduced, which is calculated using only values larger than the average.

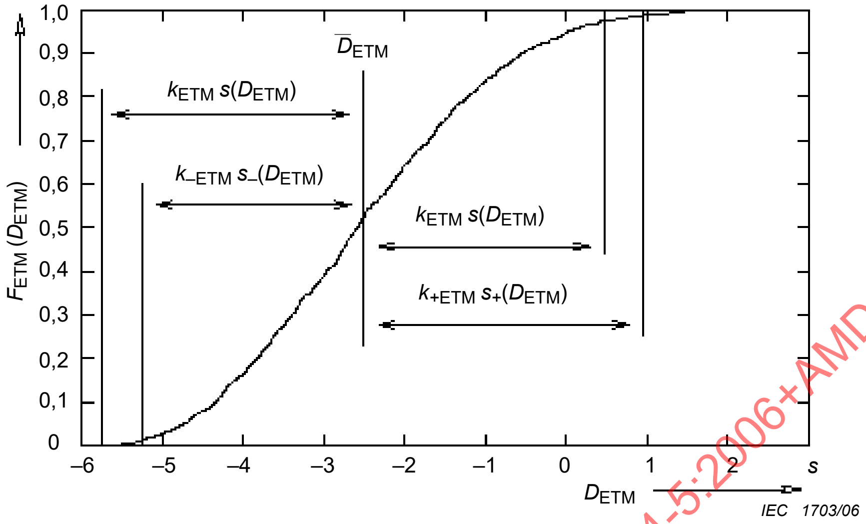


Figure B.6 – Sample cumulative distribution function

The number of these values is denoted N_+, and the approximated standard deviation is denoted s_+. The index of a given EUT i = 1...N is mapped to a new index $j = 1...N_+$. The standard deviation is calculated for every set of EUTs using

$$s_{+\mathrm{set}}(D_{\mathrm{FAR(3m)}}) = \sqrt{\frac{\sum_{i=1}^{N_+}(D_{\mathrm{FAR(3m)}j} - \overline{D}_{\mathrm{set,FAR(3m)}})^2}{N_+ - 1}} \qquad \text{(B.6)}$$

where

$D_{\mathrm{FAR(3m)}i}$, $\overline{D}_{\mathrm{set,FAR(3m)}}$ are the same as in Equation (B.3);

N_+ is the number of values larger than the average value;

$s_{+\mathrm{set}}(D_{\mathrm{FAR(3m)}})$ is the one-side standard deviation of the deviations for one set of 1 000 EUTs of the 3 m FAR test method,

and

$$s_{+\mathrm{set}}(D_{\mathrm{OATS(10m)}}) = \sqrt{\frac{\sum_{i=1}^{N_+}(D_{\mathrm{OATS(10m)}j} - \overline{D}_{\mathrm{set,OATS(10m)}})^2}{N_+ - 1}} \qquad \text{(B.7)}$$

where

$D_{\mathrm{OATS(10m)}i}$, $\overline{D}_{\mathrm{set,OATS(10m)}}$ are the same as in Equation (B.4);

N_+ is the number of values larger than the average value;

$s_{+\mathrm{set}}(D_{\mathrm{OATS(10m)}})$ is the one-side standard deviation of the deviations for one set of 1 000 EUTs of the 10 m OATS test method.

This approach gives a worst-case estimation; more precise results can be obtained by considering the skew of the CDF.

As done for the average deviations, from the approximated standard deviations of the deviations for each volume, the maximum value is determined. This maximum is taken as a safe approximation of the uncertainty.

$$u_{\text{ATM,inherent}} = u_{\text{FAR(3m),inherent}} \approx s_{+\text{max,vol}}(D_{\text{FAR(3m)}}) = \max_{\text{number of radiators}} s_{+\text{set}}(D_{\text{FAR(3m)}}) \quad \text{(B.8)}$$

$$u_{\text{ETM,inherent}} = u_{\text{OATS(10m),inherent}} \approx s_{+\text{max,vol}}(D_{\text{OATS(10m)}}) = \max_{\text{number of radiators}} s_{+\text{set}}(D_{\text{OATS(10m)}}) \quad \text{(B.9)}$$

where

$s_{+\text{set}}(D_{\text{FAR(3m)}})$	is the same as in Equation (B.6);
$s_{+\text{set}}(D_{\text{OATS(10m)}})$	is the same as in Equation (B.7);
$s_{+\text{max,vol}}(D_{\text{FAR(3m)}})$	is the maximum approximated standard deviation of the deviations of the 3 m FAR test method for one assumed EUT volume;
$s_{+\text{max,vol}}(D_{\text{OATS(10m)}})$	is the maximum approximated standard deviation of the deviations of the 10 m OATS test method for one assumed EUT volume;
$u_{\text{FAR(3m),inherent}}$	is the inherent uncertainty of the 3 m FAR test method;
$u_{\text{ATM,inherent}}$	is given in Table 2;
$u_{\text{OATS(10m),inherent}}$	is the inherent uncertainty of the 10 m OATS test method;
$u_{\text{ETM,inherent}}$	is given in Table 2.

The values are displayed in Figure B.7 and are given numerically in Tables B.2 and B.3.

NOTE It should be noted, that the large uncertainty of the OATS test method results from the fact, that the values include both horizontal and vertical polarisation. Smaller uncertainties could be obtained if the polarisations are considered separately. Such a consideration needs a sophisticated rule, in which case conversion factors for horizontal, vertical or both polarisations can be applied.

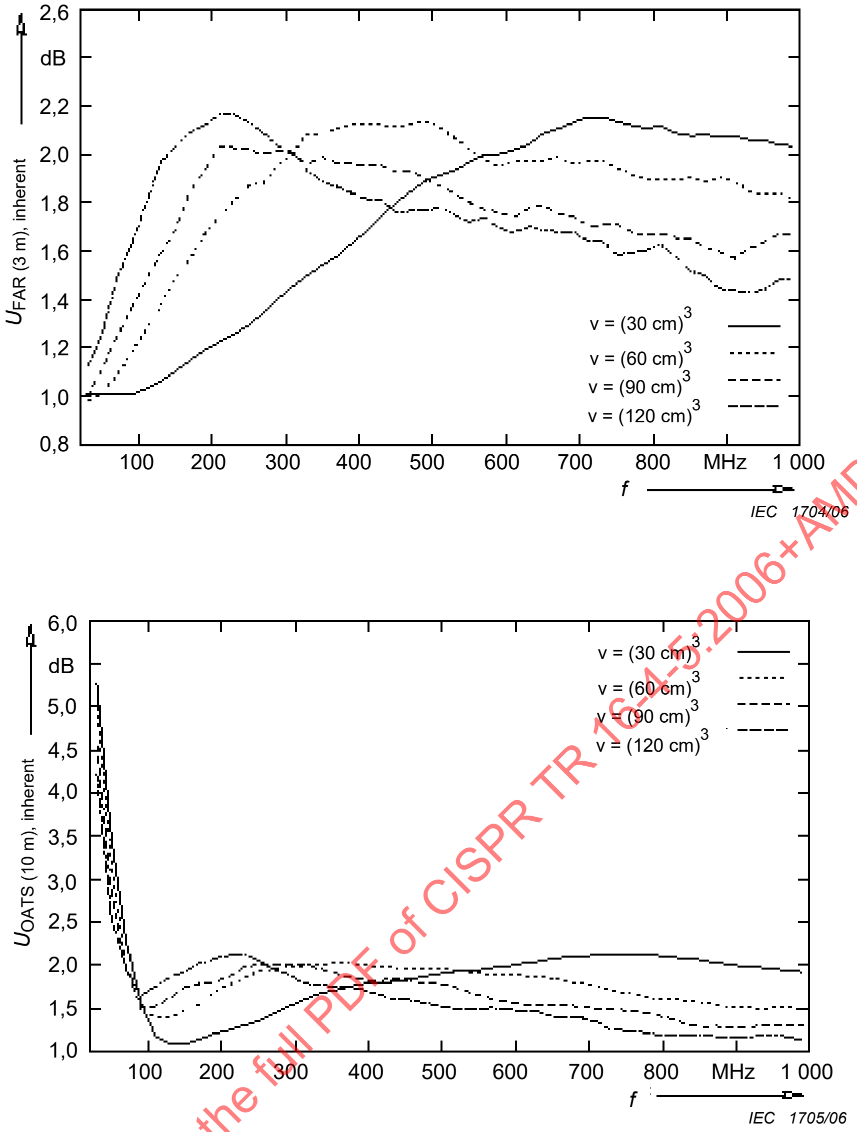


Figure B.7 – Uncertainties due to the unknown EUT characteristic for 3 m FAR (top) and 10 m OATS (bottom)

From the set of calculated deviations, and from the standard deviations, a 95 % tolerance interval for both test methods can be determined. Using their widths and the standard deviations, the coverage factor *k* can be approximated. For the alternative test method the factor is

$$k_{ATM} = k_{+FAR(3m)} \approx 2{,}2 \qquad (B.10)$$

where

k_{ATM} is the coverage factor for the alternative test method;

$k_{+FAR(3m)}$ is the coverage factor for the 3 m FAR test method derived from the values larger than the average;

and for the established test method it is

$$k_{ETM} = k_{+OATS(10m)} \approx 2{,}2 \qquad (B.11)$$

where

k_{ETM} is the coverage factor for the established test method;

$k_{+OATS(10m)}$ is the coverage factor for the 10 m OATS test method derived from the values larger than the average.

Again only the values larger than the average are used.

Table B.2 – Uncertainties in dB due to the unknown EUT characteristic for 3 m FAR

Frequency MHz	v = (30 cm)^3	v = (60 cm)^3	v = (90 cm)^3	v = (120 cm)^3
30	1,00	0,97	0,99	1,12
50	1,00	1,01	1,11	1,25
70	1,00	1,08	1,24	1,48
90	1,00	1,17	1,36	1,62
110	1,02	1,27	1,47	1,79
130	1,06	1,37	1,58	1,96
150	1,10	1,48	1,69	2,03
170	1,14	1,56	1,84	2,08
190	1,19	1,66	1,93	2,12
210	1,22	1,74	2,03	2,16
230	1,25	1,80	2,02	2,16
250	1,29	1,86	2,01	2,12
270	1,34	1,88	2,00	2,08
290	1,40	1,95	2,01	2,03
310	1,45	2,00	2,00	2,00
330	1,49	2,08	1,96	1,93
350	1,54	2,08	1,98	1,88
370	1,57	2,10	1,96	1,86
390	1,63	2,12	1,95	1,83
410	1,68	2,12	1,95	1,81
430	1,74	2,11	1,95	1,80
450	1,79	2,11	1,92	1,76
470	1,84	2,12	1,93	1,76
490	1,88	2,13	1,89	1,76
510	1,91	2,11	1,86	1,77
530	1,93	2,06	1,83	1,74
550	1,96	2,02	1,79	1,71
570	1,99	1,98	1,77	1,73
590	1,99	1,94	1,76	1,69
610	2,01	1,97	1,73	1,67
630	2,03	1,97	1,77	1,69
650	2,08	1,97	1,78	1,68
670	2,10	1,98	1,75	1,67
690	2,12	1,96	1,74	1,68
710	2,15	1,97	1,70	1,64
730	2,15	1,97	1,70	1,64
750	2,13	1,94	1,71	1,58
770	2,11	1,91	1,67	1,59
790	2,10	1,89	1,66	1,60
810	2,11	1,89	1,67	1,62
830	2,08	1,89	1,65	1,57
850	2,07	1,90	1,65	1,52
870	2,07	1,88	1,61	1,49
890	2,07	1,90	1,59	1,44
910	2,07	1,88	1,56	1,43
930	2,05	1,84	1,60	1,42
950	2,05	1,83	1,63	1,43
970	2,03	1,84	1,66	1,47
990	2,03	1,81	1,67	1,48

Table B.3 – Uncertainties in dB due to the unknown EUT characteristic for 10 m OATS

Frequency MHz	v = (30 cm)^3	v = (60 cm)^3	v = (90 cm)^3	v = (120 cm)^3
30	5,27	4,55	4,55	4,20
50	3,48	2,84	2,84	2,54
70	2,28	1,96	1,96	1,95
90	1,55	1,49	1,49	1,64
110	1,17	1,52	1,52	1,74
130	1,08	1,62	1,62	1,86
150	1,07	1,74	1,74	1,92
170	1,13	1,78	1,78	2,01
190	1,20	1,80	1,80	2,06
210	1,24	1,86	1,86	2,11
230	1,29	1,97	1,97	2,11
250	1,35	2,00	2,00	2,05
270	1,43	2,00	2,00	1,95
290	1,51	2,01	2,01	1,89
310	1,58	2,01	2,01	1,79
330	1,65	1,96	1,96	1,76
350	1,69	1,91	1,91	1,75
370	1,73	1,85	1,85	1,74
390	1,77	1,83	1,83	1,71
410	1,79	1,81	1,81	1,67
430	1,80	1,84	1,84	1,61
450	1,81	1,83	1,83	1,60
470	1,85	1,79	1,79	1,57
490	1,88	1,79	1,79	1,53
510	1,91	1,75	1,75	1,50
530	1,93	1,70	1,70	1,48
550	1,94	1,64	1,64	1,49
570	1,97	1,60	1,60	1,50
590	1,98	1,56	1,56	1,48
610	2,01	1,53	1,53	1,46
630	2,04	1,53	1,53	1,45
650	2,07	1,52	1,52	1,40
670	2,09	1,53	1,53	1,38
690	2,10	1,50	1,50	1,38
710	2,11	1,49	1,49	1,33
730	2,12	1,48	1,48	1,25
750	2,12	1,47	1,47	1,23
770	2,12	1,45	1,45	1,22
790	2,11	1,41	1,41	1,19
810	2,09	1,37	1,37	1,17
830	2,07	1,31	1,31	1,18
850	2,06	1,28	1,28	1,18
870	2,02	1,29	1,29	1,17
890	2,01	1,27	1,27	1,15
910	1,97	1,27	1,27	1,15
930	1,97	1,29	1,29	1,17
950	1,95	1,30	1,30	1,19
970	1,93	1,30	1,30	1,15
990	1,91	1,29	1,29	1,13

B.1.1.6 Estimate the expanded uncertainties of the test methods (see 6.7)

The instrumentation uncertainties and the uncertainties due to the EUT characteristics are combined into one standard uncertainty using Equations (7) and (9) from 6.7. The differences of the instrumentation uncertainty for different frequency ranges and polarisations are negligible, so that one uncertainty for all cases is sufficient. The combined and the expanded uncertainties are not given here numerically, because the EUT-dependent uncertainty is frequency-dependent. Figure B.14 displays the expanded uncertainties for the alternative and established test methods for a coverage factor of k = 2.

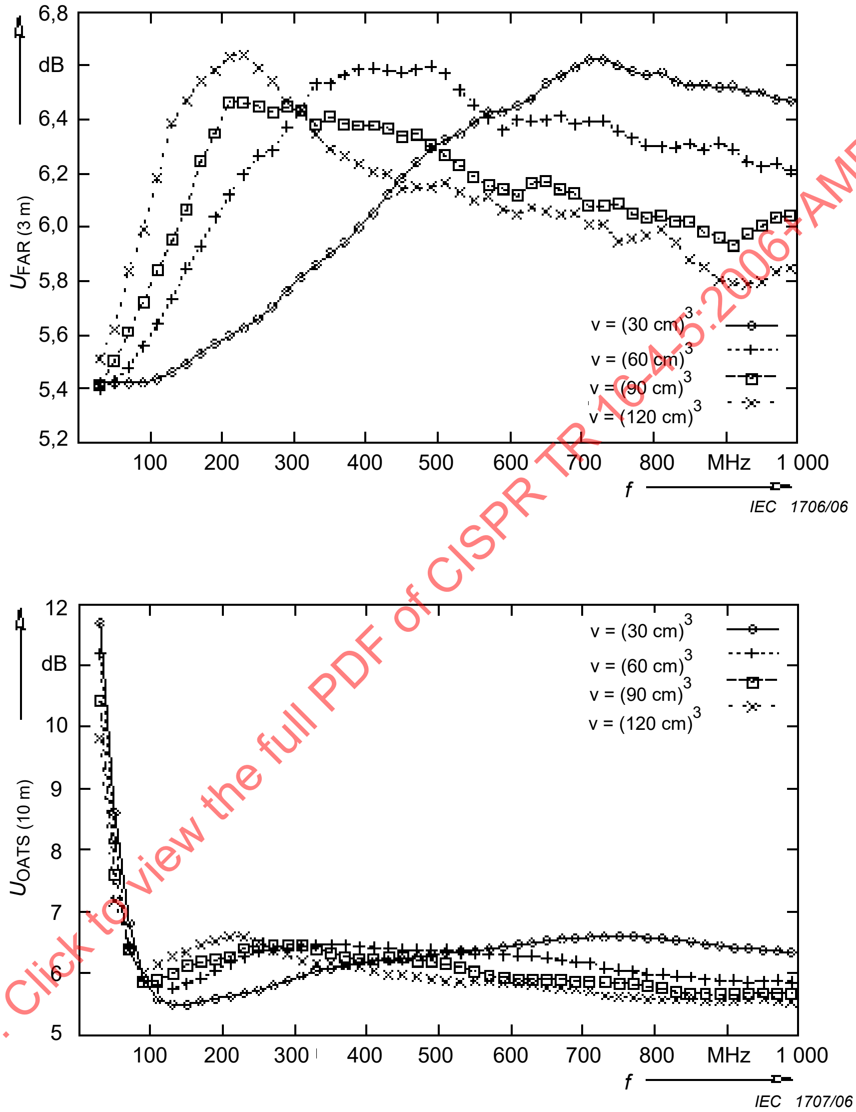


Figure B.8 – Expanded uncertainties (k = 2) of alternative (3 m FAR, top) and established (10 m OATS, bottom) test methods

B.1.1.7 Calculate the average conversion factor (see 6.8)

Using 6.8 Equation (14), the average conversion factor can be calculated from the measurement results of the EUTs. For each set of EUTs the average conversion factors are given by

$$\overline{K}_{set} = \frac{1}{N}\sum_{i=1}^{N}(E_{OATS(10m)i} - E_{FAR(3m)i}) \tag{B.12}$$

where

N, i are given in Table 2;

$E_{FAR(3m)i}$ is the same as in Equation (B.1);

$E_{OATS(10m)i}$ is the same as in Equation (B.2);

$\overline{K}_{set}$ is the average conversion factor for a set of EUTs.

From this the maximum values for each volume are searched,

$$\overline{K}_{max, vol} = \max_{\text{numbers of radiators}} \overline{K}_{set} \quad (B.13)$$

where

$\overline{K}_{set}$ is the same as in Equation (B.12);

$\overline{K}_{max, vol}$ is the maximum average conversion factor for one assumed EUT volume.

These values are displayed in Figure B.9, and numerical values are given in Table B.4.

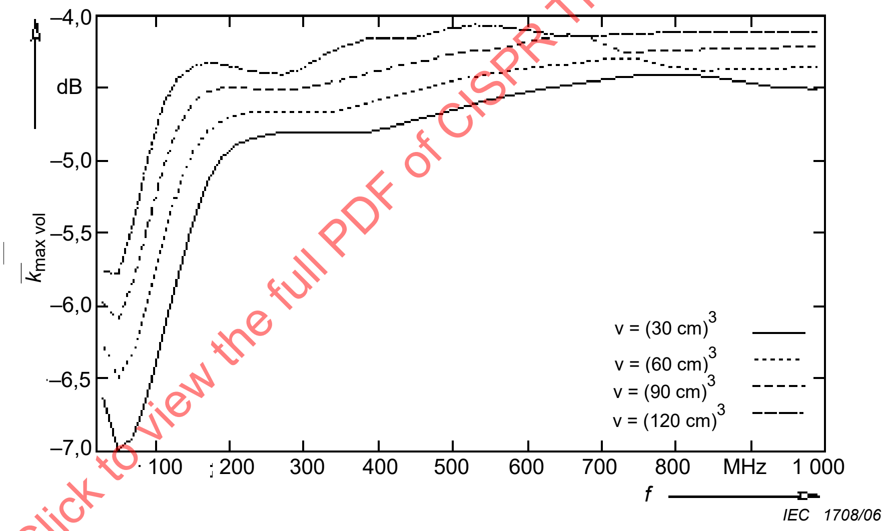


Figure B.9 – Maximum average conversion factors for different volumes

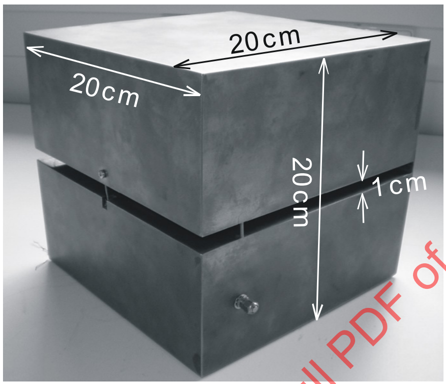
Table B.4 – Maximum average conversion factors in dB between 10 m OATS and 3 m FAR

Frequency in MHz	v = (30 cm)^3	v = (60 cm)^3	v = (90 cm)^3	v = (120 cm)^3
30	–6,63	–6,26	–5,97	–5,76
50	–6,99	–6,48	–6,10	–5,78
70	–6,90	–6,31	–5,83	–5,43
90	–6,59	–5,96	–5,44	–4,98
110	–6,20	–5,56	–5,05	–4,62
130	–5,80	–5,20	–4,77	–4,43
150	–5,43	–4,94	–4,61	–4,35
170	–5,14	–4,80	–4,52	–4,32
190	–4,97	–4,73	–4,50	–4,34
210	–4,88	–4,68	–4,49	–4,36
230	–4,85	–4,67	–4,51	–4,38
250	–4,82	–4,66	–4,51	–4,40
270	–4,80	–4,66	–4,51	–4,41
290	–4,80	–4,67	–4,50	–4,38
310	–4,80	–4,67	–4,49	–4,32
330	–4,81	–4,67	–4,47	–4,26
350	–4,81	–4,65	–4,44	–4,22
370	–4,81	–4,63	–4,42	–4,19
390	–4,80	–4,60	–4,39	–4,15
410	–4,77	–4,57	–4,36	–4,16
430	–4,75	–4,54	–4,34	–4,15
450	–4,72	–4,51	–4,33	–4,15
470	–4,69	–4,49	–4,30	–4,12
490	–4,67	–4,46	–4,28	–4,10
510	–4,63	–4,44	–4,25	–4,08
530	–4,61	–4,42	–4,24	–4,06
550	–4,58	–4,40	–4,24	–4,07
570	–4,56	–4,39	–4,22	–4,08
590	–4,54	–4,37	–4,19	–4,09
610	–4,52	–4,36	–4,17	–4,11
630	–4,50	–4,34	–4,15	–4,13
650	–4,48	–4,33	–4,13	–4,15
670	–4,47	–4,33	–4,14	–4,14
690	–4,45	–4,31	–4,17	–4,14
710	–4,44	–4,30	–4,21	–4,13
730	–4,42	–4,29	–4,25	–4,13
750	–4,41	–4,30	–4,25	–4,13
770	–4,41	–4,32	–4,25	–4,12
790	–4,40	–4,35	–4,24	–4,12
810	–4,41	–4,36	–4,24	–4,11
830	–4,41	–4,38	–4,23	–4,11
850	–4,43	–4,38	–4,23	–4,11
870	–4,44	–4,37	–4,23	–4,11
890	–4,46	–4,37	–4,23	–4,11
910	–4,47	–4,37	–4,23	–4,11
930	–4,49	–4,36	–4,22	–4,11
950	–4,50	–4,36	–4,22	–4,12
970	–4,50	–4,36	–4,22	–4,12
990	–4,50	–4,36	–4,22	–4,12

B.1.1.8 Verify the calculated values (see 6.9)

The numerical values presented above are from simulations with the statistical EUT model; thus a verification of these theoretical values is necessary. Since it is impossible in a reasonable time to produce the same large number of measurement results as was used for the statistical simulations, at least a certain number of measurements should be done to support the calculated results.

The results are derived in terms of deviations from the reference quantity. For even a single EUT only, it is almost impossible to measure this selected reference quantity over the full surrounding sphere. Due to these limitations, a special-purpose generic EUT is used for measurements to verify the theoretical results. The radiation characteristics for this EUT, and hence the reference quantity as well as the measurement results, can be calculated. The latter is important for the identification and evaluation of any possible unexpected measurement results. The EUT is constructed as a cube with a 0,2 m side length. To represent real-world EUT radiation effects, the cube has a slot, which is excited by a comb generator with an emissions frequency spacing of 10 MHz. Figure B.10 shows a picture and the simulation model (cut-view) of the specimen EUT.



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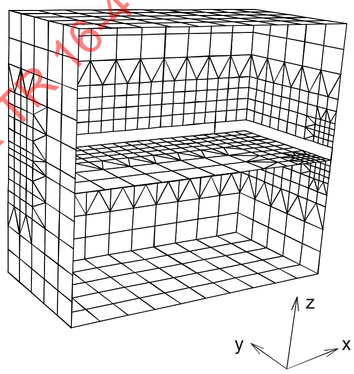

IEC 1710/06

Figure B.10 – Photo (left) and cut-view of simulation model (right) of the specimen EUT

The measurements were performed for two different orientations of the specimen EUT: one measurement series with the orientation shown in Figure B.10, and the other measurement series with the EUT rotated by 90° around the *x*-axis.

Figure B.11 shows the deviations from the reference quantity for the results of alternative and established test method. The statistical EUT model with $v = (30\ \text{cm})^3$ is chosen for comparison with the values of the specimen EUT. For each number of radiators, a 95% tolerance interval is shown (dotted lines). For the specimen EUT, the measured as well as the calculated deviations from the calculated reference quantity are shown, for both orientations of the EUT. Except for one data point, the measured values deviate from the tolerance interval by up to 3,5 dB. This deviation is smaller than the instrumentation measurement uncertainty given in CISPR 16-4-2. One measured value (OATS measurement with rotated EUT at 120 MHz) deviates by 8,5 dB from the tolerance interval. These deviations were not seen in the results from the simulations with the specimen EUT. Consequently, these deviations are expected to be due to measurement problems. Then it can be said that the measured results for the specimen EUT support the statistically-derived deviations from the reference quantity, and hence the derived conversion factors and the uncertainties.

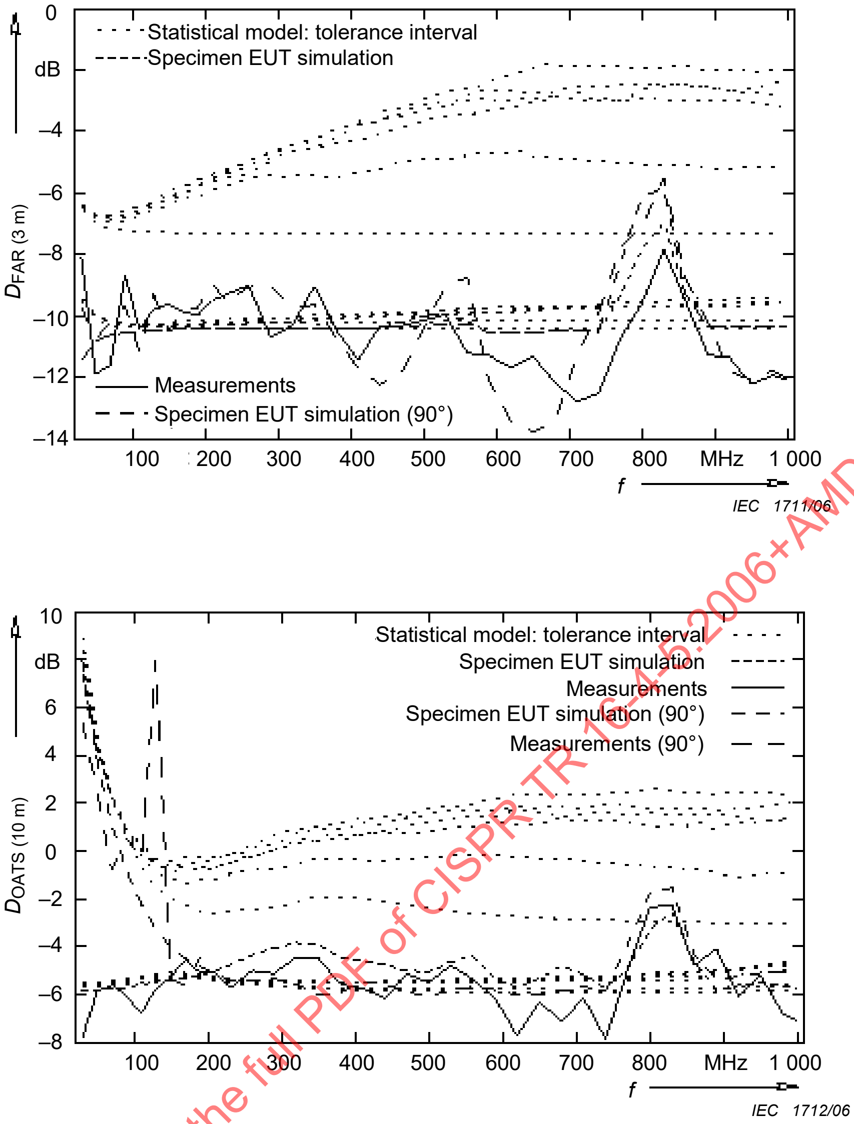

Figure B.11 – Deviations of the specimen EUT: 3 m fully anechoic room (top) and 10 m open area test site (bottom)

B.1.1.9 Apply the conversion (see 6.10)

Figure B.12 shows a sample of measured values with their expanded uncertainties from a FAR emission measurement, for an EUT with maximum cube-edge dimension of 0,3 m. The converted limits according to 6.10 Equation (15) are shown in Figure B.13. Based on the largest dimension of the EUT, the average conversion factors for (30 cm)^3 are applied (see Figure B.9). The comparison of the measured values with the converted limits must consider the differences between the uncertainties of the alternative and established test methods. Figure B.14 displays the expanded uncertainties of 10 m OATS and 3 m FAR for the (30 cm)^3 EUT volume. As can be seen, the uncertainty of the FAR is at some frequencies about 0,1 dB larger than the uncertainty of the OATS. At these frequencies the converted limit has to be corrected with the amount of the difference according to 6.10 Equation (17). The measured values then can be compared with the corrected and converted limit line, as shown in Figure B.15. The EUT fails due to the emission values at 150 MHz and 550 MHz.

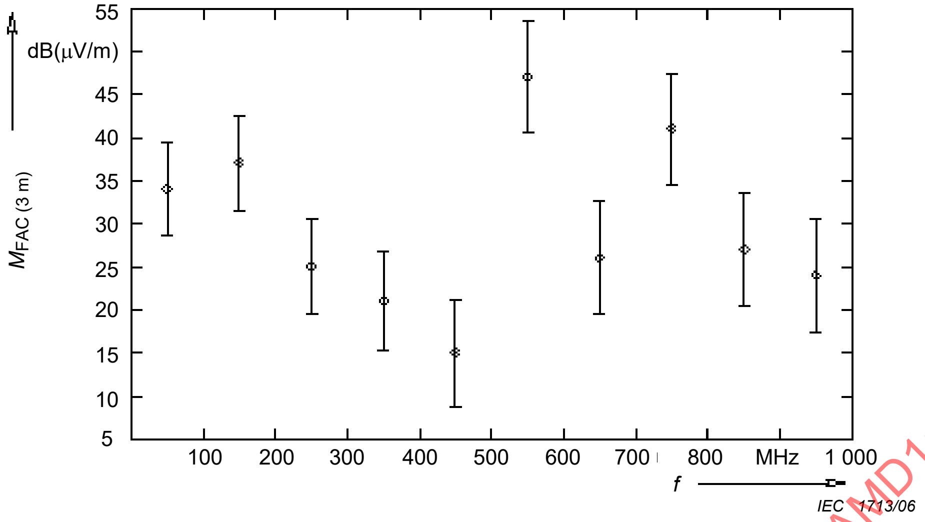

Figure B.12 – Sample FAR measurement

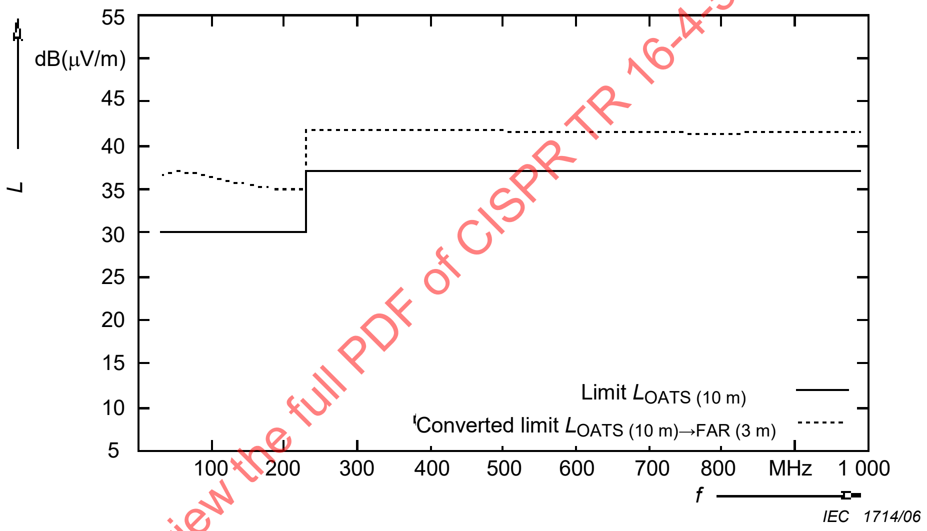

Figure B.13 – OATS 10 m limit line converted to FAR 3 m conditions

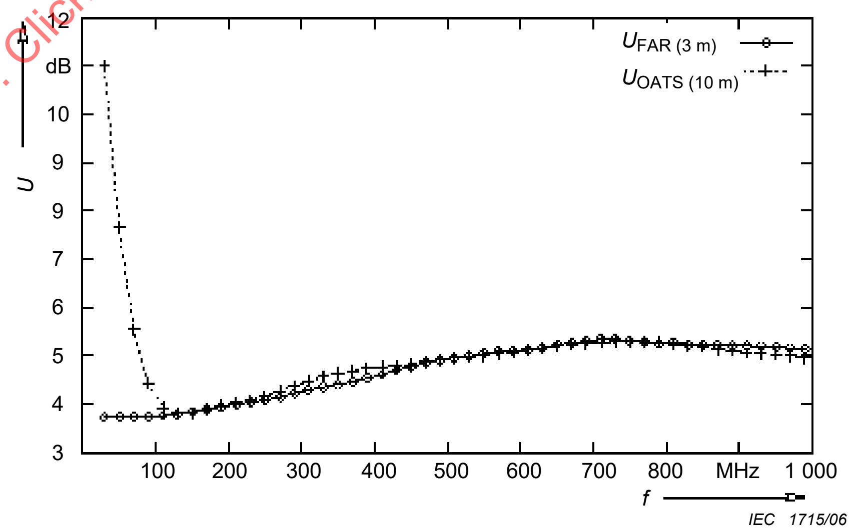

Figure B.14 – Expanded uncertainties

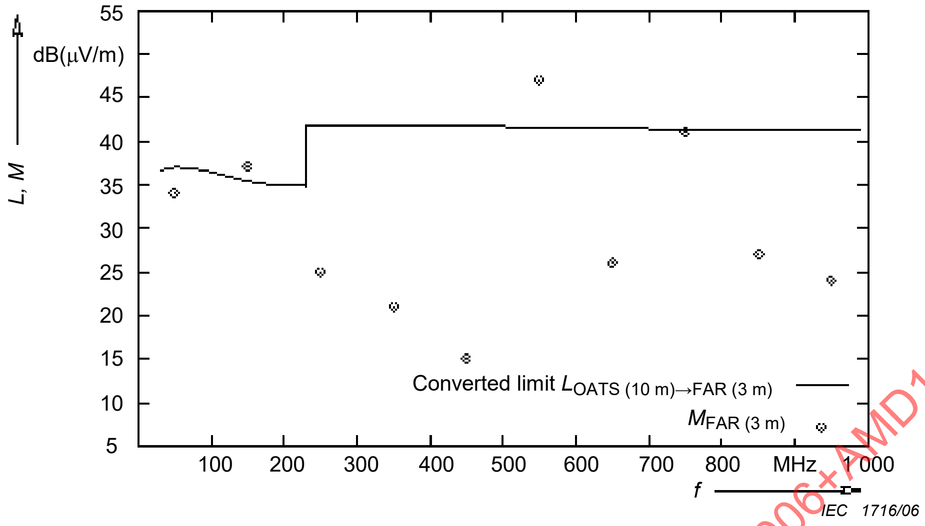

Figure B.15 – Comparison of the measured values with the corrected converted limit

B.1.2 Small EUTs with cables

Results different from those shown in B.1.1 are expected, but are under investigation.

B.2 Example 2 – 3 m open-area test site measurements compared to 10 m open-area test site measurements

B.2.1 Small EUTs without cables

B.2.1.1 Select the reference quantity *X* (see 6.2)

As above, the reference quantity is selected as free-space electric field – see B.1.1.1.

B.2.1.2 Describe the test methods and measurands (see 6.3)

Alternative test method: 3 m open-area test site, OATS (3 m). Figure B.16 displays the measurement set-up of an OATS with 3 m distance for measurements in the frequency range from 30 MHz to 1 GHz. The receiving antenna is located at a distance of $d_{OATS(3m)}$ = 3 m to the EUT. To detect the maximum field strength, the EUT is rotated in azimuth and the antenna height is varied between 1 and 4 meters. The set-up is placed on a conducting ground plane. The perimeter and surroundings of the OATS and set-up is free of any reflecting objects, therefore ideally the antenna receives only the direct radiation and the ground reflected signal.

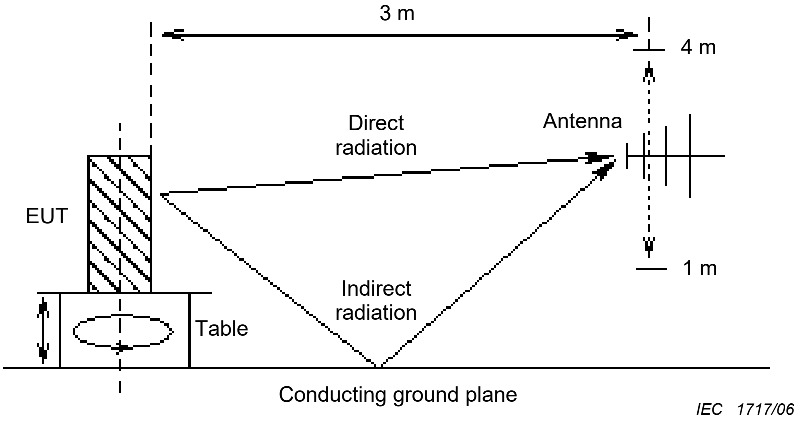

Figure B.16 – EUT and antenna set-up of 3 m open area test site measurement

Established test method: 10 m open-area test site, OATS (10 m). See B.1.1.2

B.2.1.3 Determine the deviations of the measured quantities from the reference quantity (see 6.4)

A description of the statistical model used for the small EUT is given in B.1.1.3. From the simulation results, the deviations between the alternative test method results and the reference quantity values are obtained using

$$D_{\text{ATM}i} = D_{\text{OATS(3m)}i} = X_i - E_{\text{OATS(3m)}i} \tag{B.14}$$

where

$E_{\text{OATS(3m)}i}$ is the field-strength for 3 m OATS test method for EUT i;

X_i, $D_{\text{ATM}i}$, i are the same as in 6.4 Equation (1);

$D_{\text{OATS(3m)}i}$ is the deviation from the reference quantity X of the 3 m FAR test method result for EUT i,

and for the established test method using Equation (B.2) from B.1.1.3.

B.2.1.4 Determine the average values of the deviations (see 6.5)

Calculations for the established test method are done in the way as in B.1.1.4. For the alternative test method the average deviations can be calculated using Equation (3) from 6.5. This is done for every set of 1 000 EUTs using:

$$\overline{D}_{\text{set, ATM}} = \overline{D}_{\text{set, OATS(3m)}} = \frac{1}{1000}\sum_{i=1}^{1000} D_{\text{OATS(3m)}i} \tag{B.15}$$

where

$\overline{D}_{\text{set, ATM}}$ is the average deviation of the alternative test method for the set of 1 000 EUTs;

$\overline{D}_{\text{set, OATS(3m)}}$ is the average deviation of the 3 m OATS test method for the set of 1 000 EUTs;

$D_{\text{OATS(3m)i}}$, i are the same as in Equation (B.14).