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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

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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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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.

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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~~;

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– 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
$u_{intrinsic}$
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.

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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

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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~~

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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.

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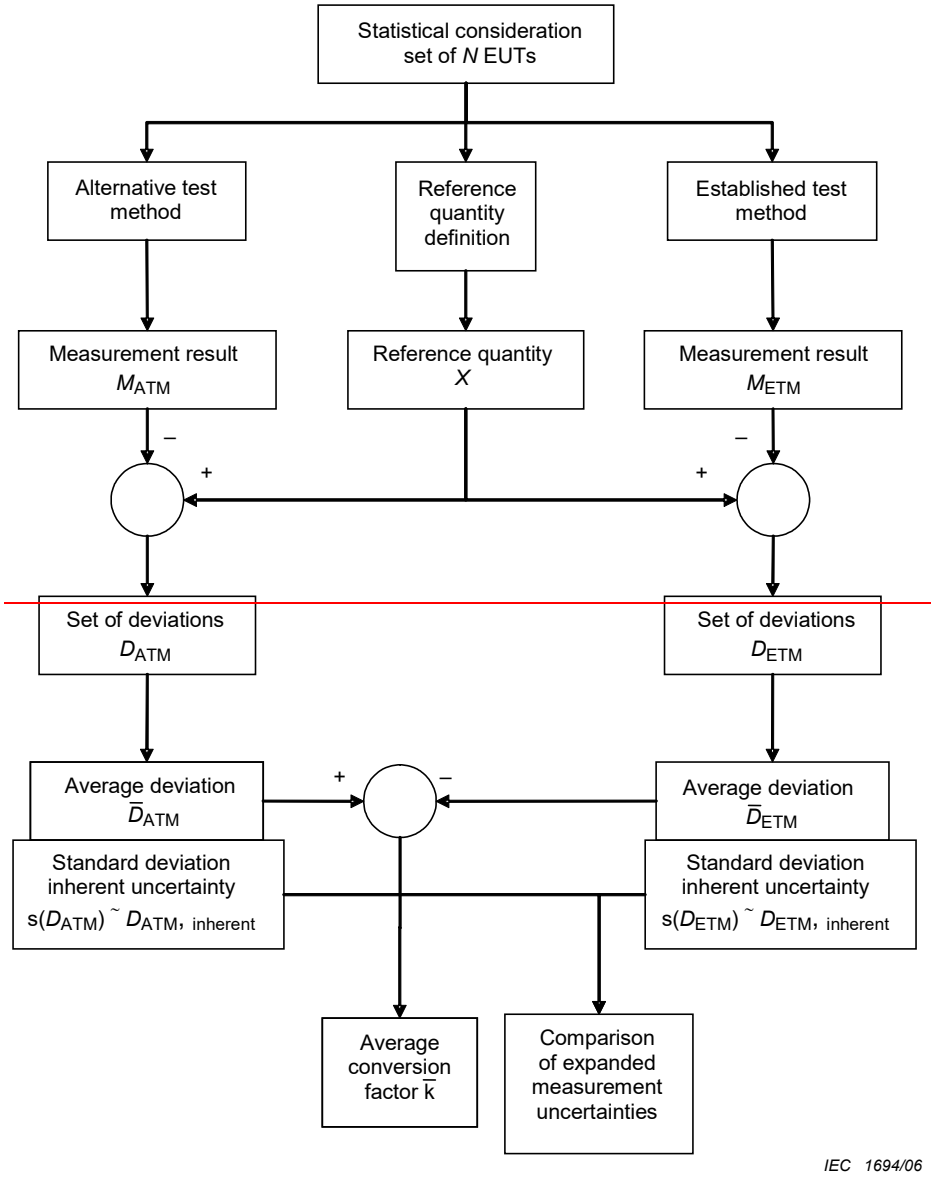

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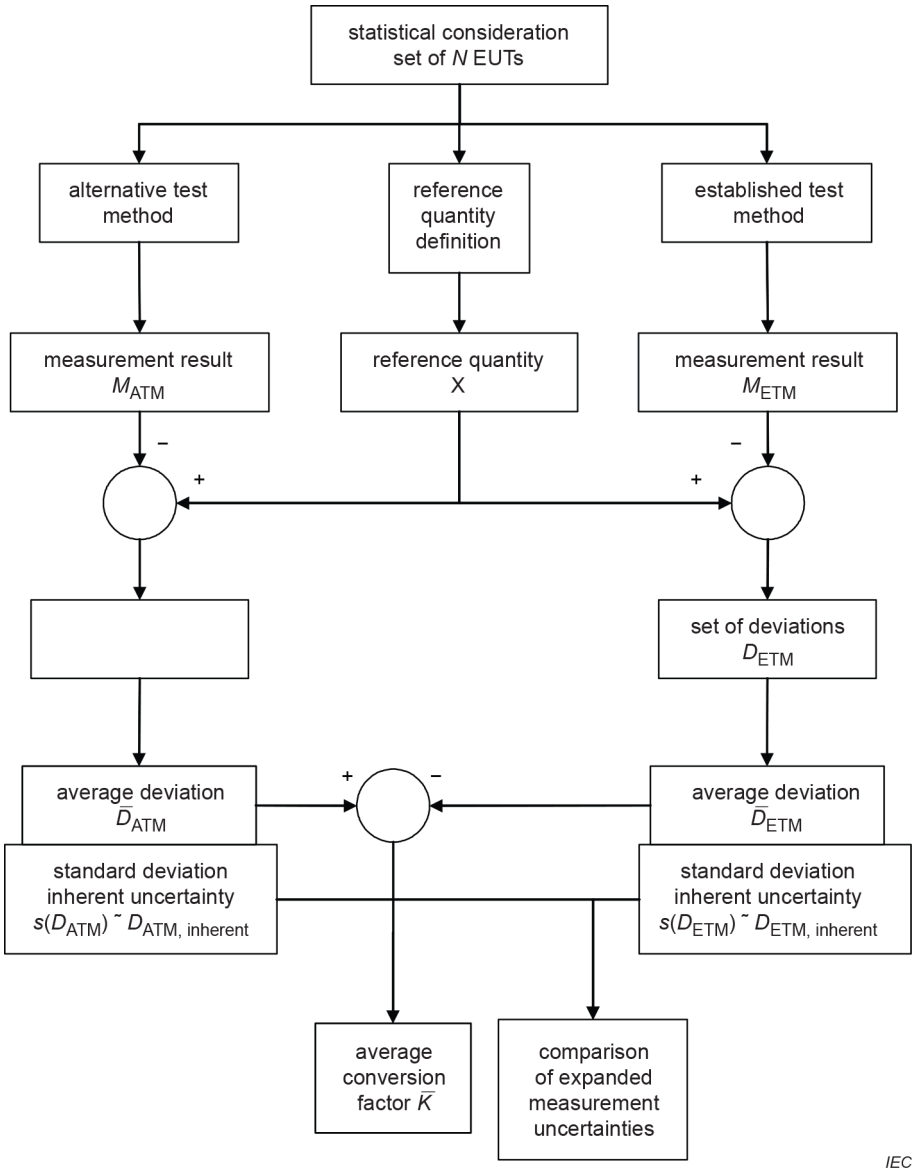

Figure 1 – Overview of quantities to estimate for use in conversion procedure

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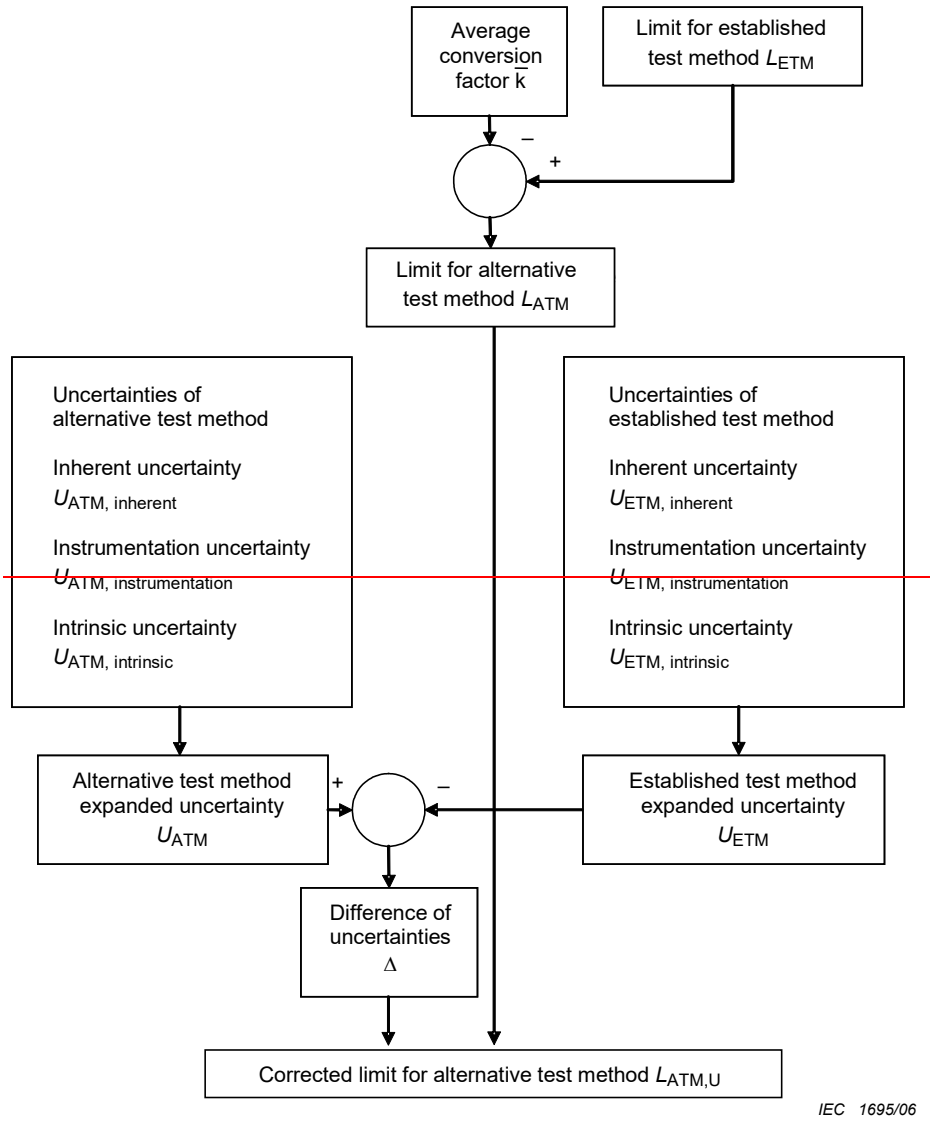

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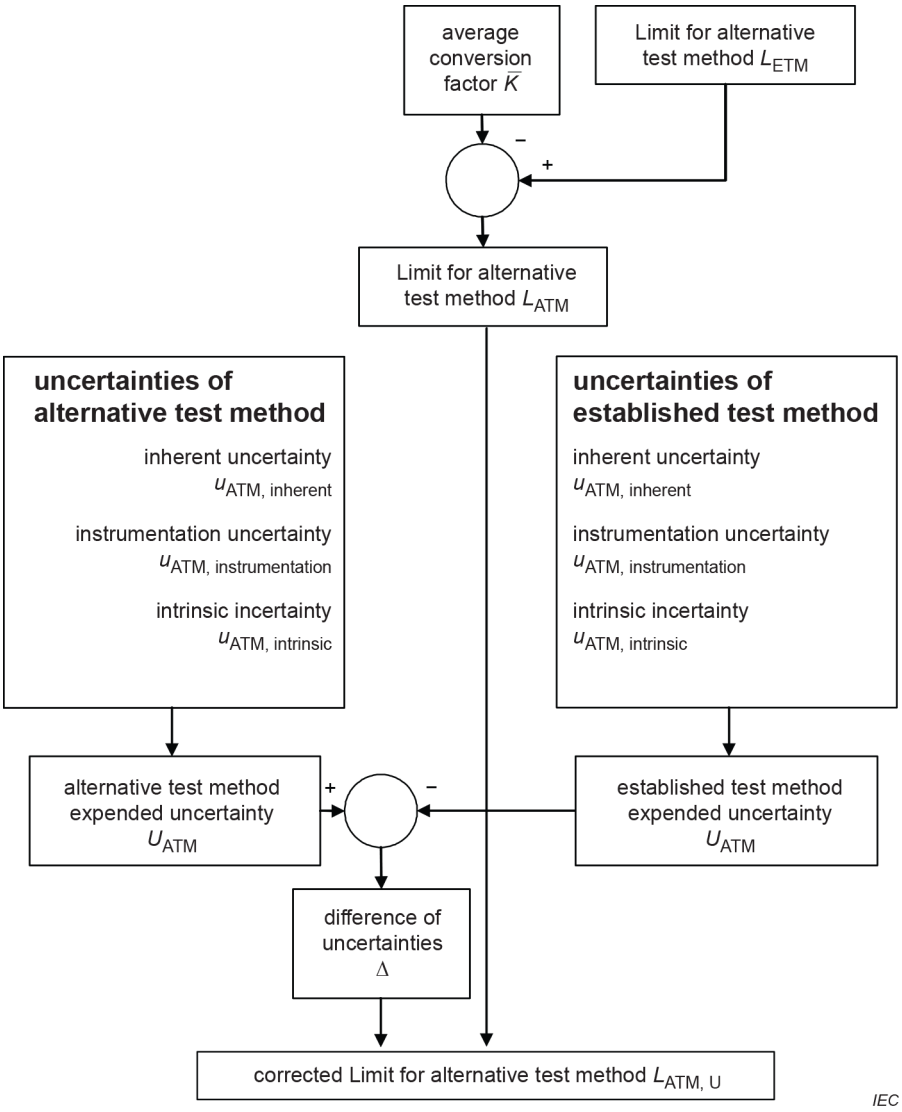

Figure 2 – Overview of limit conversion procedure using estimated quantities

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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.

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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.

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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:

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

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where

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

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

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

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

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

where

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

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

N, i, D_{ETM}, $D_{\mathrm{ETM}i}$ 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

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

where

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

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

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

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

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

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,

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

where

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$u_{ETM,m}$ 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:

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

where $\overline{K}$ is the same as in Equation (12) and $M_{\mathrm{ETM}i}$ and $M_{\mathrm{ATM}i}$ 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:

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

where

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

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

$L_{\mathrm{ATM}}(f)$ 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.,

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

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:

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

where $L_{\mathrm{ATM},U}$ 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.

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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 $L_{\mathrm{ATM,U}}$ 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.

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

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 $K(f,j)$ 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

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

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

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

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:

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

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:

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

where

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

$U_{SC,ATM}$ 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 $D_{K,EUT}$ between the average conversion factor $\overline{K}(f)$ and the average conversion factor for each EUT $\overline{K}_i(f)$.

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

$D_{K,EUT}$ has standard deviation

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

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

The uncertainty U_{EUT} is estimated by

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

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

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

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

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

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

It should be considered that $U_{SC,ETM}$ 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 $U_{SC,ETM}$ of the 10 m test site results, but the value can be expected to be in the order of about 10 dB.

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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 V^2/m^2W or Ω/m^2. To convert into logarithmic quantities, Equation (35) can be written as Equation (36):

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

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).

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

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.

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

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,

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

and consequently

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

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

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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.

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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.

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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.

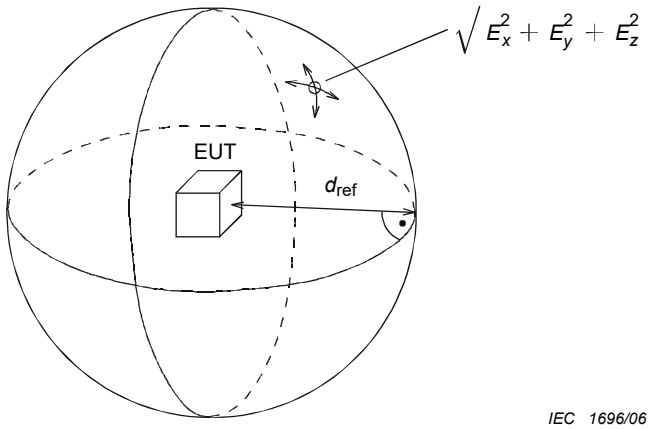

Figure B.1 – Example reference quantity

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.

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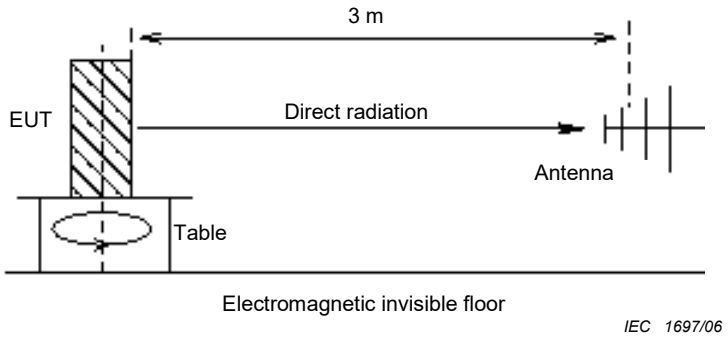

Figure B.2 – EUT and antenna set-up for fully anechoic room emission measurement

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.

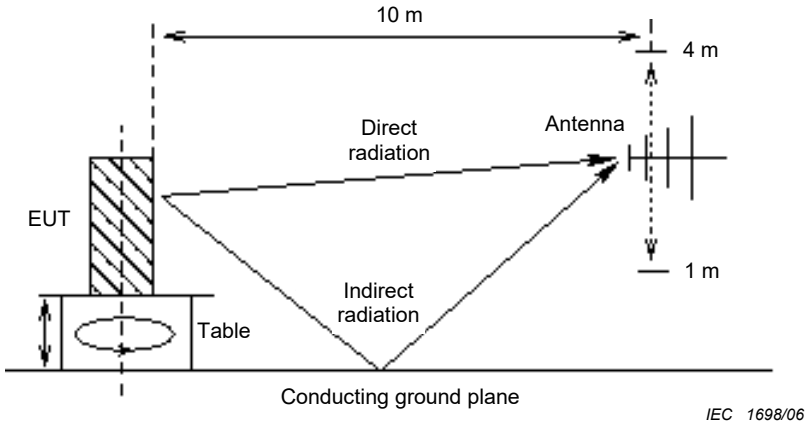

Figure B.3 – EUT and antenna set-up for open-area test site measurement

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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.

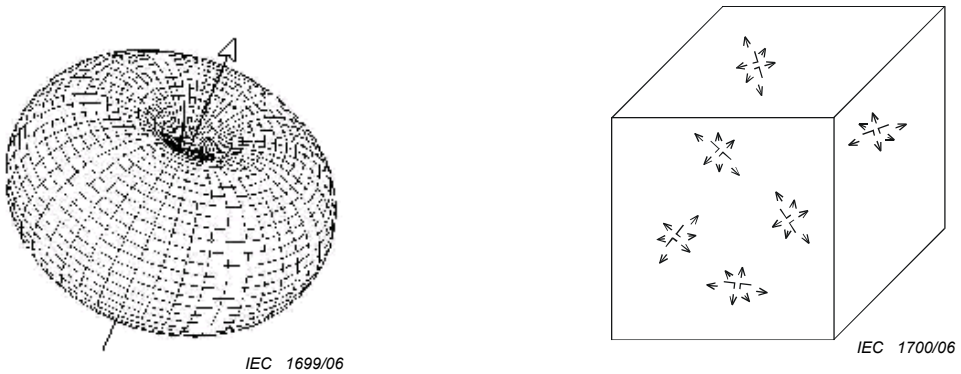

Figure B.4 – Radiation characteristics of elementary radiator (left), and scheme of EUT-model (right)

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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 $(30\ \text{cm})^3$ with 5 radiators, the reference quantity X_i and the field strengths $E_{\text{FAR(3m)}i}$ for FAR and $E_{\text{OATS(10m)}i}$ 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),

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

where

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

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

$D_{\text{FAR(3m)}i}$ 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),

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

where

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

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

$D_{\text{OATS(10m)}i}$ 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:

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

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

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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

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

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.

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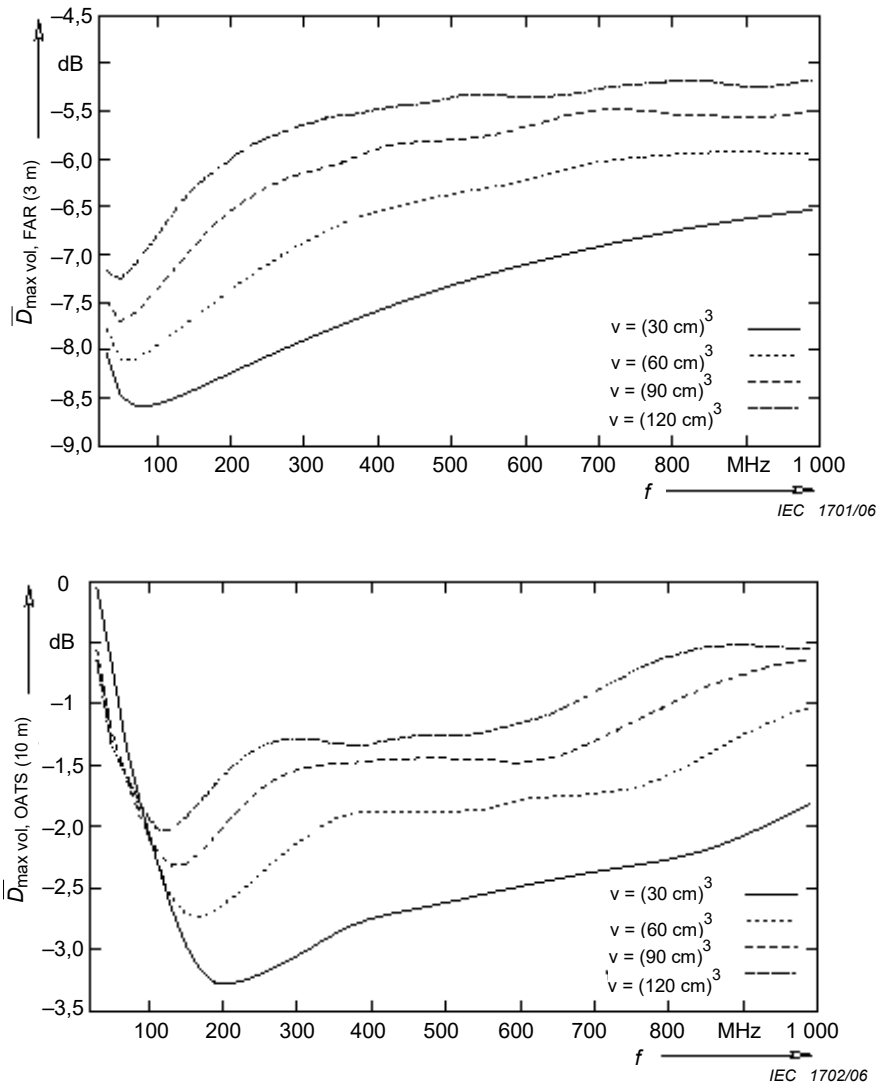

Figure B.5 – Maximum average deviations for 3 m FAR (top) and 10 m OATS (bottom)

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.

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

Input quantity	X_i	Uncertainty of x_i		$u(x_i)$	c_i	$c_i \cdot u(x_i)$
		dB	Probability distribution function	dB		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.

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As can be seen from the figure, this is not true – actually $k_{ETM} \cdot s(D_{ETM})$ 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.

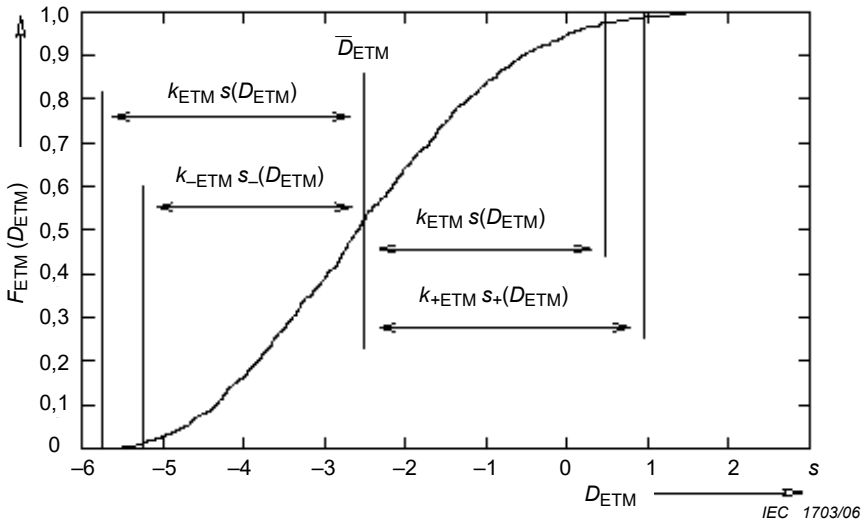

Figure B.6 – Sample cumulative distribution function

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

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

where

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

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

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

and

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

where

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

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

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

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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.

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

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

where

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

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

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

$s_{+\mathrm{max,vol}}(D_{\mathrm{OATS(10m)}})$ 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.

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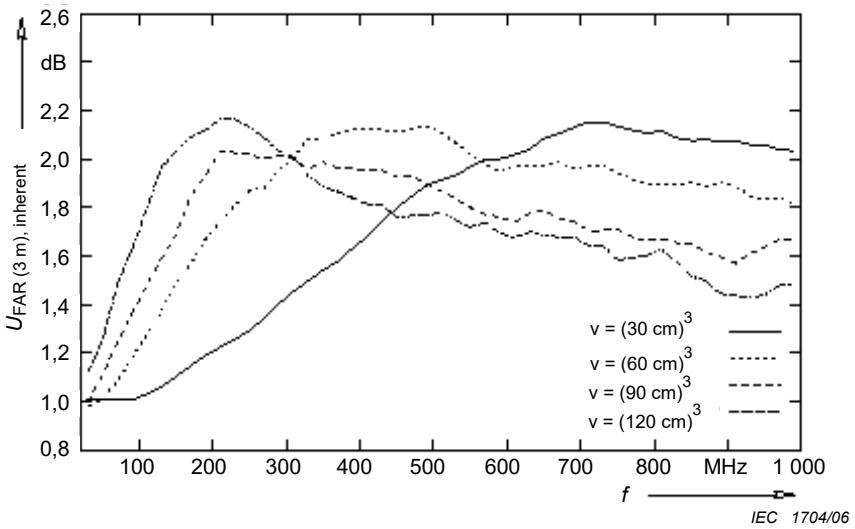

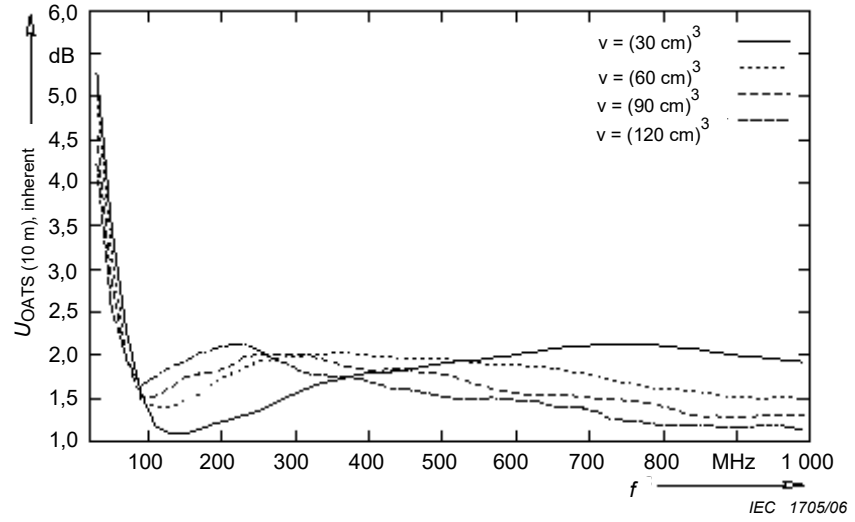

Figure B.7 – Uncertainties due to the unknown EUT characteristic for 3 m FAR (top) and 10 m OATS (bottom)

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

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

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

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

where

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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.

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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

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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

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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.

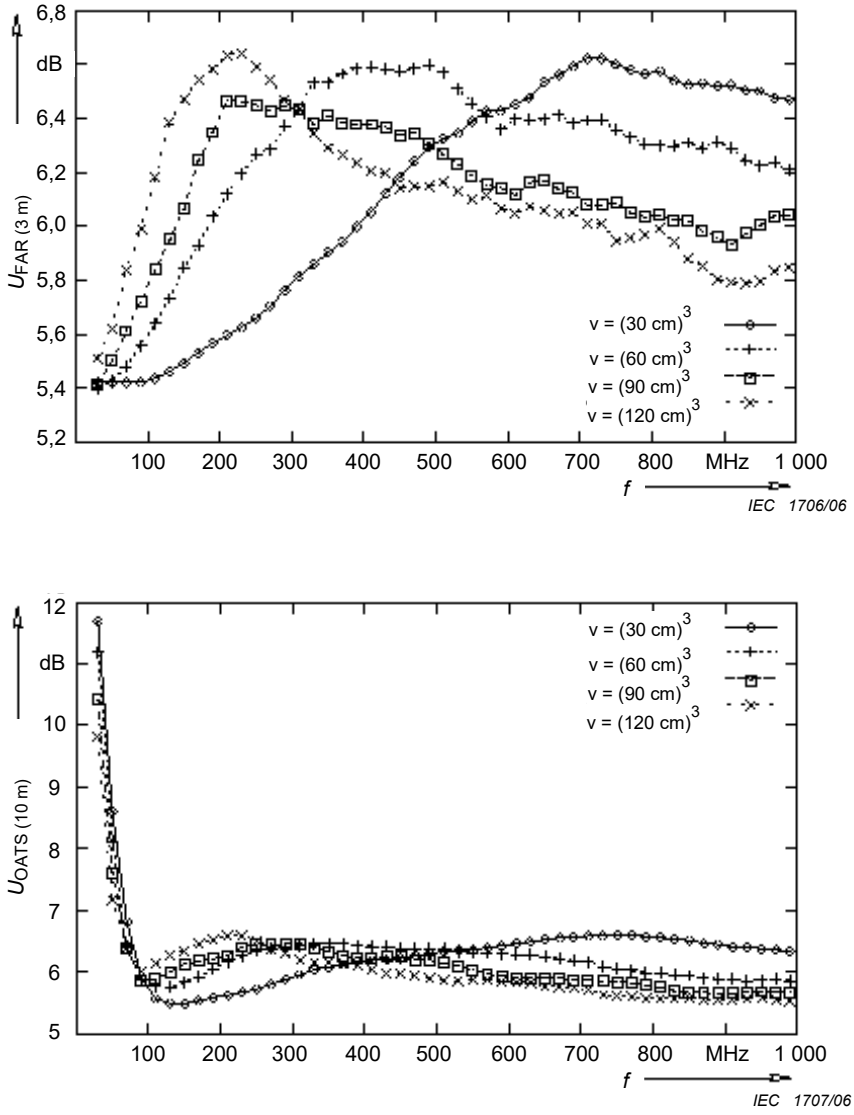

Figure B.8 – Expanded uncertainties (k = 2) of alternative (3 m FAR, top) and established (10 m OATS, bottom) test methods

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

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

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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,

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

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.

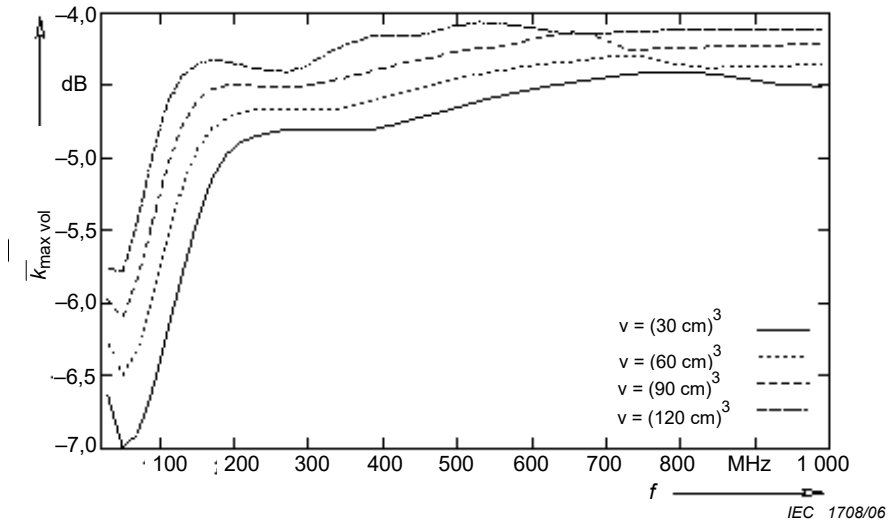

Figure B.9 – Maximum average conversion factors for different volumes

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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

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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.

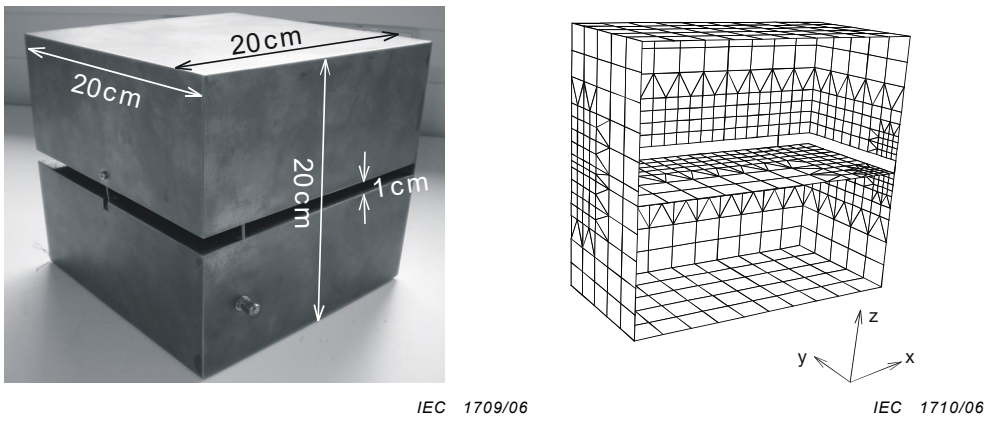

Figure B.10 – Photo (left) and cut-view of simulation model (right) of the specimen EUT

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.

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