

AS/NZS CISPR 16.4.5:2013
CISPR TR 16-4-5:2006
CISPR TR 16-4-5:2006/AMD 1:2014
CISPR TR 16-4-5:2006/AMD 2:2021
(Incorporating Amendments up to and including No. 2)



Australian/New Zealand Standard™

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



AS/NZS CISPR 16.4.5:2013

This Joint Australian/New Zealand Amendment was prepared by Joint Technical Committee TE-003, Electromagnetic Compatibility. It was approved on behalf of the Council of Standards Australia on 31 May 2013 and on behalf of the Council of Standards New Zealand on 23 April 2013.

This Standard was published on 20 June 2013.

The following are represented on Committee TE-003:

- Association of Accredited Certification Bodies
- Australian Broadcasting Corporation
- Australian Industry Group
- Consumer Electronics Suppliers Association
- Department of Defence (Australian Government)
- EMC Society of Australia
- Energy Networks Australia
- Engineers Australia
- Free TV Australia
- Lighting Council New Zealand
- NZ Ministry of Business, Innovation and Employment (MBIE)
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This Standard was issued in draft form for comment as DR AS/NZS CISPR 16.4.5.

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ISBN 978 1 74342 505

Australian/New Zealand Standard™

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Part 4.5: Uncertainties, statistics and limit modelling — Conditions for the use of alternative test methods

First published as AS/NZS CISPR 16.4.5:2013.
Reissued incorporating Amendment No 2 (2023).



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Preface

This Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee TE-003, Electromagnetic Interference.

Amendment No. 2 to this Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee TE-003, Electromagnetic Compatibility.

The objective of this Standard is to specify a method to enable product committees to develop limits for alternative test methods, using conversions from established limits.

This Standard is identical with, and has been reproduced from CISPR/TR 16-4-5, Ed. 1.0 (2006), *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*, and its Amendment No. 1 (2014) and Amendment No. 2 (2021), which are consolidated into the source text.

As this Standard is reproduced from an International Standard, the following applies:

- (a) In the source text “this part of CISPR 16-4” should read “this Australian/New Zealand Standard”.
- (b) A full point substitutes for a comma when referring to a decimal marker.

References to International Standards should be replaced by references to Australian or Australian/New Zealand Standards, as follows:

Reference to International Standard		Australian/New Zealand Standard	
CISPR		AS/NZS CISPR	
16	Specification for radio disturbance and immunity measuring apparatus and methods	16	Specification for radio disturbance and immunity measuring apparatus and methods
16-4-1 (2003)	Part 4-1: Uncertainties, statistics and limit modelling—Uncertainties in standardized EMC tests	16.4.1 (2004)	Part 4.1: Uncertainties, statistics and limit modelling—Uncertainties in standardized EMC tests
16-4-2 (2003)	Part 4-2: Uncertainties, statistics and limit modelling—Uncertainty in EMC measurements	16.4.2 (2004)	Part 4.2: Uncertainties, statistics and limit modelling—Uncertainty in EMC measurements

Only international references that have been adopted as Australian or Australian/New Zealand Standards have been listed.

The term “informative” has been used in this Standard to define the application of the annex to which it applies. An “informative” annex is only for information and guidance.

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

**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**

FOREWORD

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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.

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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.

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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

$U_{\text{intrinsic}}$

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

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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 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

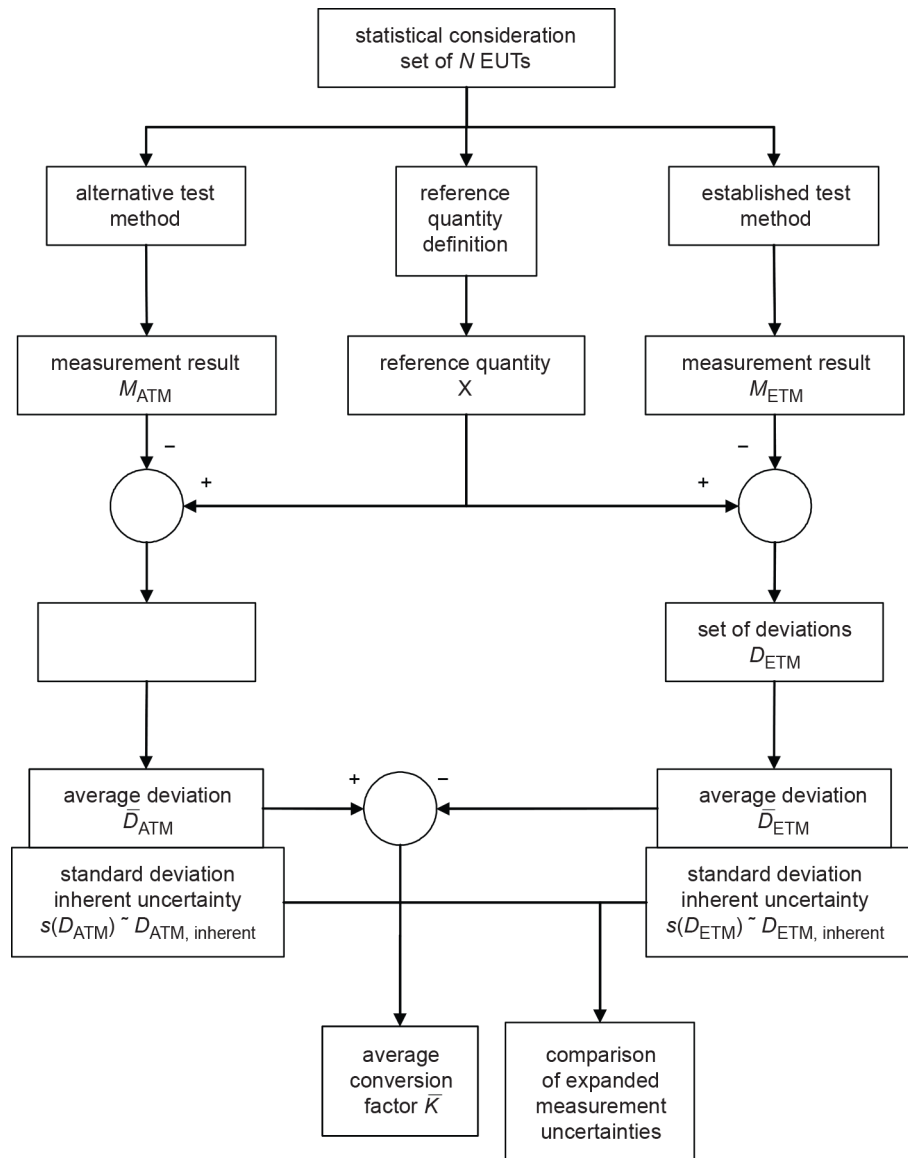
6.1 Overview

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

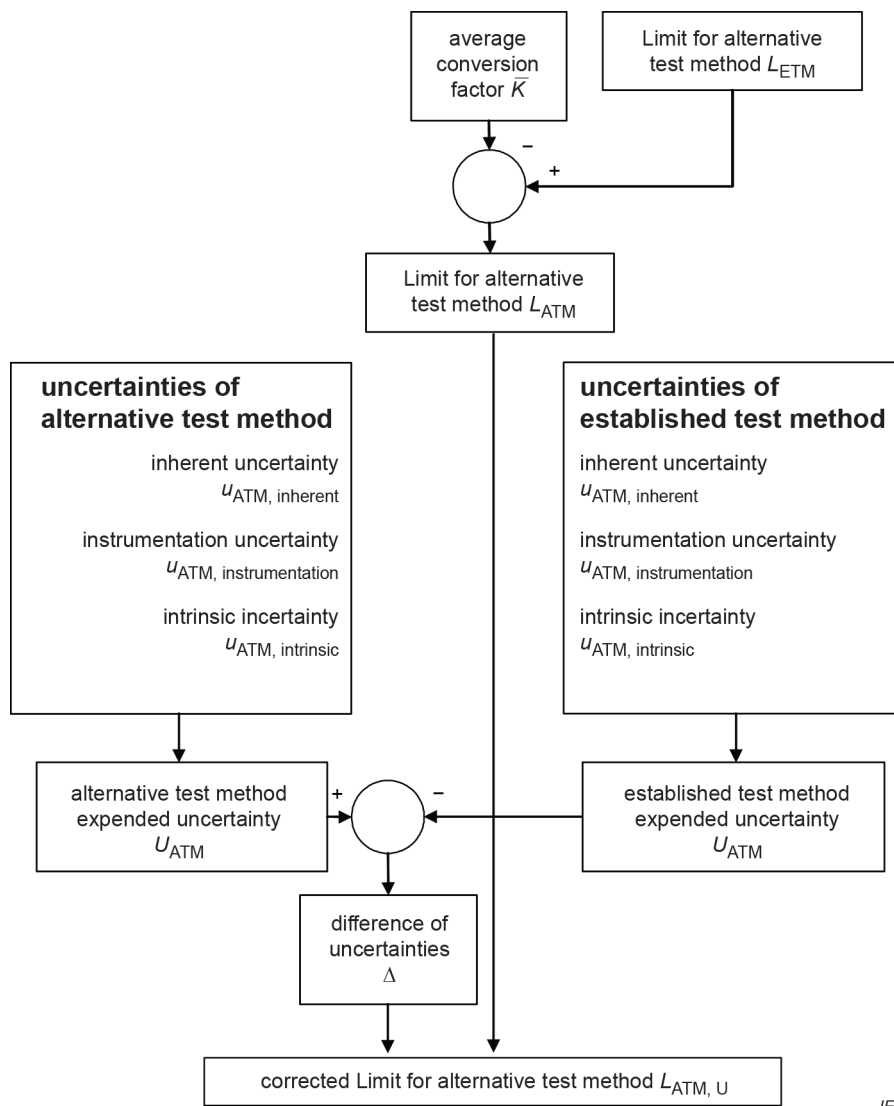
1	Select the reference quantity
2	Describe the test methods and measurands
3	Determine the deviations of the measured quantities from the reference quantity
4	Determine the average values of the deviations
5	Determine the standard uncertainties of the test methods
6	Verify the calculated values
7	Apply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

¹ Figures in square brackets refer to the Bibliography.



IEC

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



IEC

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.
$D_{ATM_i}(f)$	the deviation from the reference quantity of the measurement result of EUT i as produced by the alternative test method	(1)
$D_{ETM_i}(f)$	the deviation from the reference quantity of the measurement result of EUT i as produced by the established test method	(2)
$\bar{D}_{ATM}$	the average deviation of the alternative test method	(3)
$\bar{D}_{ETM}$	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)
$\bar{K}(f)$	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 $\bar{K}(f)$	(20), (21)
DXTM	deviation of the single measured value $M_{XTM,i}(f,j)$ from the average for the measured values $\bar{M}_{XTM,i}$	(24), (25)
MXTM,i(f,j)	measured value depending on EUT, lab, and frequency	(18), (23)
E _{max}	Maximum field strength of an EUT in $\mu V/m$ 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 power ^{a)} producing the field-strength maximum E _{max} 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

$$D_{ATMi}(f) = X_i(f) - M_{ATMi}(f) \quad (1)$$

where

i is the index of the EUT;

f is the frequency;

$D_{ATMi}(f)$ 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

$M_{ATMi}(f)$ 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

$$D_{ETMi}(f) = X_i(f) - M_{ETMi}(f) \quad (2)$$

where

$X_i(f)$, f , i are the same as in 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;

$M_{ETMi}(f)$ 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

$$\bar{D}_{\text{ATM}} = \frac{1}{N} \sum_{i=1}^N D_{\text{ATM}i} \quad (3)$$

where

- D_{ATM} is the set of deviations of the alternative test method;
- $\bar{D}_{\text{ATM}}$ 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;
- $D_{\text{ATM}i}$ 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

$$\bar{D}_{\text{ETM}} = \frac{1}{N} \sum_{i=1}^N D_{\text{ETM}i} \quad (4)$$

where

- D_{ETM} is the set of deviations of the established test method;
- $\bar{D}_{\text{ETM}}$ is the average deviation of the established test method;
- N, i are the same as in Equation (3);
- $D_{\text{ETM}i}$ 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:

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

where

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

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

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

where

$u_{\text{ETM},\text{inherent}}$ is the inherent uncertainty of the established test method;
 $s(D_{\text{ETM}})$ is the experimental standard deviation of the set D_{ETM} ;
 $N, i, D_{\text{ETM}}, D_{\text{ETM}i}$ 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

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

where

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

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

where

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- $u_{\text{ETM},m}$ is the combined standard uncertainty of the established test method contributed by measurement instrumentation;
- $u_{\text{ETM},\text{inherent}}$ is the EUT-dependent uncertainty of the established test method, according to Equation (6);
- $u_{\text{ETM},\text{intrinsic}}$ is the intrinsic uncertainty of the established test method.

The expanded uncertainty of the established test method is given by

$$U_{\text{ETM}} = k \cdot u_{\text{ETM}} \quad (10)$$

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

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

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:

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

where

- $K(f)$ is the set of conversion factors;
- $\bar{K}(f)$ is the average of the conversion factors;
- $\bar{D}_{\text{ATM}}(f)$ is the average deviation of the alternative test method from the reference quantity, in dB;
- $\bar{D}_{\text{ETM}}(f)$ is the average deviation of the established test method from the reference quantity, in dB.

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

$$\bar{K} = \bar{D}_{\text{ATM}} - \bar{D}_{\text{ETM}} = \frac{1}{N} \sum_{i=1}^N D_{\text{ATM}i} - \frac{1}{N} \sum_{i=1}^N D_{\text{ETM}i} \quad (13)$$

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

$$\bar{K} = \frac{1}{N} \sum_{i=1}^N (X_i - M_{ATMi}) - \frac{1}{N} \sum_{i=1}^N (X_i - M_{ETMi}) = \frac{1}{N} \sum_{i=1}^N (M_{ETMi} - M_{ATMi}) \quad (14)$$

where $\bar{K}$ is the same as in Equation (12) and M_{ETMi} and M_{ATMi} 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:

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

where

- $\bar{K}(f)$ is the frequency-dependent average conversion factor according to Equation (12);
- $L_{ETM}(f)$ is the frequency-dependent limit of the established test method;
- $L_{ATM}(f)$ 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.,

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

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:

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

where $L_{ATM,U}$ 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 $\bar{K}$ 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 $\bar{K}$ can be estimated by direct comparison of the measurement results [see Equation (14)]. The uncertainty of each measurement procedure 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 $\bar{K}$. The limit $L_{\text{ATM,U}}$ 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.

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

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

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

The uncertainty of the average conversion factor $\bar{K}(f)$ 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 $\bar{K}(f)$ and the standard deviation s_K of $D_{K,i}(f, j)$.

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

The experimental standard deviation can be calculated by

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

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

The resulting expanded uncertainty U_K of the conversion factor is

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

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).

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

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 $\bar{M}_{\text{XTM},i}(f)$ and each measured value $M_{\text{XTM},i}(f, j)$ is calculated using Equation (24).

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

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

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

where $\bar{D}_{\text{XTM}}(f)$ 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

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

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 $\bar{K}(f)$. If $\bar{K}(f)$ 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:

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

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:

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

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 $\bar{K}(f)$ and the average conversion factor for each EUT $\bar{K}_i(f)$.

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

$D_{K,EUT}$ has standard deviation

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

where $\bar{D}_{K,i}$ 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.