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Specification for radio disturbance and immunity measuring apparatus and methods

Part 4-1: Uncertainties, statistics and limit modelling — Uncertainties in standardized EMC tests

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National foreword

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TECHNICAL REPORT

INTERNATIONAL SPECIAL COMMITTEE ON RADIO INTERFERENCE

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

INTERNATIONAL
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CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

SPECIFICATION FOR RADIO DISTURBANCE AND IMMUNITY MEASURING APPARATUS AND METHODS –

Part 4-1: Uncertainties, statistics and limit modelling – Uncertainties in standardized EMC tests

FOREWORD

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CISPR 16-4-1, which is a technical report, has been prepared by CISPR subcommittee A: Radio-interference measurements and statistical methods, of IEC technical committee CISPR: International special committee on radio interference.

This second edition of CISPR 16-4-1 cancels and replaces the first edition published in 2003, and its Amendments 1 (2004) and 2 (2007). It constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition. The provisions available for application of uncertainties in the determination of the compliance criterion are explained more generally and a procedure is added for re-testing an approved EUT by another test house.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
CISPR/A/818/DTR	CISPR/A/831/RVC

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

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

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

The committee has decided that the contents of this publication will remain unchanged until the maintenance result 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.

A bilingual version of this publication may be issued at a later date.

INTRODUCTION

The result of the application of basic considerations (Clauses 4 and 5) in this part to existing or new CISPR standards will lead to proposals to improve and harmonise the uncertainty aspects of those CISPR standards. Such proposals will also be published as reports within this part and will give the background and rationale for improvement of certain CISPR standards. Clause 6 is an example of such a report.

The structure of clauses related to the CISPR standards compliance uncertainty work is depicted in Table 1. Clause 4 deals with the basic considerations of standards compliance uncertainties in emission measurements. Clauses 6, 7 and 8 contain uncertainty considerations related to voltage, absorbing clamp and radiated emission measurements, respectively.

Uncertainty work will also be considered for immunity compliance tests in the future. Clauses 5, 9 and 10 are reserved for this material. SCU (see 3.1.16) considerations of immunity tests differ from the emission SCU considerations in particular points. For instance, in an immunity test, the measurand is often a functional attribute of the EUT and not a specific quantity. This may cause additional specific SCU considerations. Priority has been given to the uncertainty evaluations for emission measurements at this stage of the work.

Table 1 – Structure of clauses related to the subject of standards compliance uncertainty

STANDARDS COMPLIANCE UNCERTAINTY			
Clause 1, 2, and 3: General			
EMISSION		**IMMUNITY**	
Clause 4	Basic considerations	Clause 5	Basic considerations
Clause 6	Voltage measurements	Clause 9	Conducted immunity tests
Clause 7	Absorbing clamp measurements	Clause 10	Radiated immunity tests
Clause 8	Radiated emission measurements		

SPECIFICATION FOR RADIO DISTURBANCE AND IMMUNITY MEASURING APPARATUS AND METHODS –

Part 4-1: Uncertainties, statistics and limit modelling – Uncertainties in standardized EMC tests

1 Scope

This part of CISPR 16-4 gives guidance on the treatment of uncertainties to those who are involved in the development or modification of CISPR electromagnetic compatibility (EMC) standards. In addition, this part provides useful background information for those who apply the standards and the uncertainty aspects in practice.

The objectives of this part are to:

a) identify the parameters or sources governing the uncertainty associated with the statement that a given product complies with the requirement specified in a CISPR recommendation. This uncertainty will be called "standards compliance uncertainty" (SCU, see 3.1.16);

b) give guidance on the estimation of the magnitude of the standards compliance uncertainty;

c) give guidance for the implementation of the standards compliance uncertainty into the compliance criterion of a CISPR standardised compliance test.

As such, this part can be considered as a handbook that can be used by standards writers to incorporate and harmonise uncertainty considerations in existing and future CISPR standards. This part also gives guidance to regulatory authorities, accreditation bodies and test engineers to judge the performance quality of an EMC test-laboratory carrying out CISPR standardised compliance tests. The uncertainty considerations given in this part can also be used as guidance when comparing test results (and their uncertainties) obtained by using different alternative test methods.

The uncertainty of a compliance test also relates to the probability of occurrence of an electromagnetic interference (EMI) problem in practice. This aspect is recognized and introduced briefly in this part. However, the problem of relating uncertainties of a compliance test to the occurrence of EMI in practice is not considered within the scope of this part.

The scope of this part is limited to all the relevant uncertainty considerations of a standardized EMC compliance test.

2 Normative references

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

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

IEC 60050-300:2001, *International Electrotechnical Vocabulary (IEV) – Electrical and electronic measurements and measuring instruments – Part 311: General terms relating to measurements – Part 312: General terms relating to electrical measurements – Part 313: Types of electrical measuring instruments – Part 314: Specific terms according to the type of instrument*

IEC 60359:2001, *Electrical and electronic measurement equipment – Expression of performance*

CISPR 16-1-2:2003, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-2: Radio disturbance and immunity measuring apparatus – Conducted disturbances*

CISPR 16-1-3:2004, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-3: Radio disturbance and immunity measuring apparatus – Ancillary equipment – Disturbance power*

CISPR 16-1-4:2007, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-4: Radio disturbance and immunity measuring apparatus – Ancillary equipment – Radiated disturbances*

CISPR 16-1-5:2003, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 1-5: Radio disturbance and immunity measuring apparatus – Antenna calibration test sites for 30 MHz to 1 000 MHz*

CISPR 16-2-2:2003, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 2-2: Methods of measurement of disturbances and immunity – Measurement of disturbance power*
Amendment 1 (2004)
Amendment 2 (2005)

CISPR 16-2-3:2006, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 2-3: Methods of measurement of disturbances and immunity – Radiated disturbance measurements*

CISPR 16-4-2:2003, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 4-2: Uncertainties, statistics and limit modelling – Uncertainty in EMC measurements*

CISPR/TR 16-4-3:2004, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 4-3: Uncertainties, statistics and limit modelling – Statistical considerations in the determination of EMC compliance of mass-produced products*

CISPR 22:2008, *Information technology equipment – Radio disturbance characteristics – Limits and methods of measurement*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement* (GUM:1995)

ISO/IEC Guide 99:2007, *International vocabulary of metrology – Basic and general concepts and associated terms (VIM)*

3 Terms, definitions, and abbreviations

For the purposes of this document, the following terms, definitions and abbreviations apply.

NOTE 1 Wherever possible, existing terminology, from the normative standards of Clause 2 is used. Additional terms and definitions not included in those standards are listed below.

NOTE 2 Terms shown in **bold** are defined in this clause.

3.1 Terms and definitions

3.1.1
electromagnetic (EM) disturbance
any electromagnetic phenomenon which may degrade the performance of a device, equipment or system, or adversely affect living or inert matter

[IEV 161-01-05]

3.1.2
emission level
the level of a given electromagnetic disturbance emitted from a particular device, equipment or system measured in a specified way

[IEV 161-03-11, modified]

3.1.3
emission limit
the specified maximum emission level of a source of electromagnetic disturbance

NOTE In IEC this limit has been defined as “the maximum permissible emission level”.

[IEV 161-03-12, modified]

3.1.4
influence quantity
quantity that is not the **measurand** but that affects the result of the measurement

[ISO/IEC Guide 98-3, B.2.10]

NOTE 1 In a standardised compliance test an influence quantity may be specified or non-specified. Specified influence quantities preferably include **tolerance** data.

NOTE 2 An example of a specified influence quantity is the measurement impedance of an artificial mains network. An example of a non-specified influence quantity is the internal impedance of an EM disturbance source.

3.1.5
interference probability
probability that a product complying with the EMC requirements will function satisfactorily (from an EMC point of view) in its normal use in an electromagnetic environment

3.1.6
intrinsic uncertainty of the measurand
minimum uncertainty that can be assigned in the description of a measured quantity. In theory, the intrinsic uncertainty of the measurand is obtained if the measurand is measured using a measurement system having a negligible **measurement instrumentation uncertainty**

NOTE 1 No quantity can be measured with continually lower uncertainty, inasmuch as any given quantity is defined or identified at a given level of detail. If one tries to measure a given quantity at an uncertainty lower than its own intrinsic uncertainty one is compelled to redefine it with higher detail, so that one is actually measuring another quantity. See also ISO/IEC Guide 98-3, D.1.1.

NOTE 2 The result of a measurement carried out with the intrinsic uncertainty of the measurand may be called the best measurement of the quantity in question.

[IEC 60359:2001, definition 3.1.11, modified]

3.1.7
intrinsic uncertainty of the measurement instrumentation
uncertainty of a measurement instrumentation when used under **reference conditions**. In theory, the intrinsic uncertainty of the measurement instrumentation is obtained if the **intrinsic uncertainty of the measurand** is negligible

NOTE Application of a reference EUT is a means to create reference conditions in order to obtain the intrinsic uncertainty of the measurement instrumentation (4.5.5).

[IEC 60359:2001, definition 3.2.10, modified]

3.1.8
level
value of a quantity, such as a power or a field quantity, measured and/or evaluated in a specified manner during a specified time interval

NOTE The level may be expressed in logarithmic units, for example in decibels with respect to a reference value.

[IEV 161-03-01, modified]

3.1.9
measurand
particular quantity subject to measurement

[IEV 311-01-03]

EXAMPLE Electric field, measured at a distance of 3 m, of a given sample.

NOTE The specification of a measurand may require statements about influence quantities (see ISO/IEC Guide 98-3, B.2.9).

3.1.10
measurement instrumentation uncertainty
MIU
parameter, associated with the result of a measurement that characterises the dispersion of the values that can reasonably be attributed to the **measurand**, induced by all relevant influence quantities that are related to the measurement instrumentation

[ISO/IEC Guide 99, 4.24, and IEC 60359:2001, 3.1.4, modified]

3.1.11
measuring chain
series of elements of a measuring instrument or system that constitutes the path of the measuring signal from input to the output

[IEV 311-03-07, modified]

3.1.12
(measurement) compatibility
property satisfied by all the results of measurement of the same **measurand**, characterized by an adequate overlap of their intervals

[IEV 311-01-14]

3.1.13
reference conditions
set of specified values and/or ranges of values of influence quantities under which the uncertainties, or limits of error, admissible for the measurement system are smallest

[IEV 311-06-02, modified]

3.1.14
reproducibility (of results of measurements)
closeness of the agreement between the results of successive measurements of the same **measurand** carried out under changed conditions as determined by one or more specified **influence quantities**

NOTE In general, this reproducibility is also determined by non-specified influence quantities, hence the closeness of the agreement can only be stated in terms of probability.

[ISO/IEC Guide 98-3, B.2.16, modified]

3.1.15
sensitivity coefficient
coefficient used to relate the change of a physical quantity due to a variation of one of the specified or non-specified **influence quantities**

NOTE 1 In mathematical form, the sensitivity coefficient is, in general, the partial derivative of the physical quantity with respect to the varying influence quantity.

NOTE 2 This term and definition is based on the definitions of sensitivity coefficient given in the ISO/IEC Guide 98-3 and the description given in [33][1].

3.1.16
standards compliance uncertainty
SCU
parameter, associated with the result of a compliance measurement as described in a standard, that characterises the dispersion of the values that could reasonably be attributed to the **measurand**

[adapted from ISO/IEC Guide 98-3, B.2.18 and IEV 311-01-02]

3.1.17
tolerance
maximum variation of a value permitted by specifications, regulations, etc. for a given specified **influence quantity**

3.1.18
true value (of a quantity)
value consistent with the definition of a particular quantity

[adapted from ISO/IEC Guide 98-3, B.2.3, IEV 311-01-04]

3.1.19
uncertainty source
source (descriptive, not quantitative) that contributes to the uncertainty of the value of a measurand, and that shall be divided into one or more relevant **influence quantities**

NOTE An uncertainty source can be defined also as a qualitative description of a source of uncertainty. In practice the uncertainty of a result may arise from many possible categories of sources, including examples such as test personnel, sampling, environmental conditions, measurement instrumentation, measurement standard, approximations and assumptions incorporated in the measurement method and procedure. Relevant uncertainty sources are ‘translated’ into one or more **influence quantities** (see 4.2.3 and K.3 of [39]).

3.1.20
variability (of results of measurements)
closeness of the agreement between the results of successive measurements of the same **measurand** carried out under changed conditions as determined by one or more non-specified **influence quantities**

NOTE 1 This term and definition are based on IEV 311-06-07 (see also IEV 311-07-03).

NOTE 2 The closeness of the agreement can only be stated in terms of probability.

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[1] Figures in brackets refer to the bibliography.

3.2 Abbreviations

ACTM	absorbing clamp test method
AMN	artificial mains network
CDN	coupling/decoupling network
CISPR	International special committee on radio interference
CMAD	common-mode absorbing device
CRP	clamp reference point
EMC	electromagnetic compatibility
EUT	equipment under test
ILC	interlaboratory comparison
LISN	line impedance stabilization network
LPDA	log-periodic dipole array
LUT	lead under test
MIU	measurement instrumentation uncertainty
NSA	normalised site attenuation
OATS	open-area test site
RRT	round-robin test
SAC	semi-anechoic chamber
SAD	secondary absorbing device
SCU	standards compliance uncertainty
SRP	slide reference point
V-AMN	V-terminal artificial network

4 Basic considerations on uncertainties in emission measurements

4.1 Introductory remarks

In a standardised emissions compliance measurement, the emission level of an electrical or electronic product is measured, after which compliance with the associated limit is determined. The measured emission level is an approximation of the true emission level due to uncertainties induced by the 'influence quantities' (3.1.4). In classical metrology, all relevant influence quantities are known and the 'intrinsic uncertainty of the measurand' (3.1.6) is generally very small. Hence for classical metrology problems, it is generally sufficient to consider only the 'measurement instrumentation uncertainty', or MIU (3.1.10).

In emissions compliance testing however, major relevant influence quantities related to the EUT happen to be unspecified [31] and no quantitative information is available about their values. Hence, for emissions measurements, the intrinsic uncertainty related to the measurand may be significant compared to the uncertainty due to the measurement instrumentation. Therefore, the term 'standards compliance uncertainty', or SCU (3.1.16), has been introduced to distinguish all uncertainties encountered during an actual emissions compliance test from the MIU, which is a subpart of the SCU. Terms and definitions of standards compliance uncertainty and other related EMC and uncertainty specific terms are given in Clause 3.

In Figure 1, a) illustrates how the intrinsic uncertainty of the measurand and the MIU combine to form the SCU in a typical emissions measurement. Subfigure b) is representative of classical metrology measurement, for which the intrinsic uncertainty of the measurand is small compared with the MIU, and c) shows the rare case of a negligible MIU. It should be noted that the sigma symbol, $\sum$, in Figure 1 is a mathematical operator representing summation. The method to 'sum' these uncertainties depends on the probability distributions and on the correlation of the two uncertainty sources involved.

NOTE It is possible that in the future, classical metrology and EMC disciplines will merge to such an extent that different terminology and approaches will no longer be needed. For example, the results of the CISPR studies on measurement instrumentation uncertainty [29] and standards compliance uncertainty should merge directly, wherever possible.

The various categories of uncertainties that can be encountered during emissions compliance testing and the distinction between 'standards compliance uncertainty', 'intrinsic uncertainty of the measurand' and 'measurement instrumentation uncertainty' is addressed in more detail in 4.2. Subclause 4.3 briefly discusses the relation between uncertainties of a compliance test and the risk of interference in practice. Subclause 4.4 describes the steps to be taken to perform an uncertainty analysis for a standardised emission measurement. Subclause 4.5 gives methods to verify the validity of the uncertainty budget. Subclause 4.6 gives information on how to report uncertainty estimates and on how to express the result of a measurement and its uncertainty. Subclause 4.7 provides some general guidance on the application of the uncertainties in the compliance criterion. More specific guidance on the application of uncertainties in pass/fail criteria is under consideration.

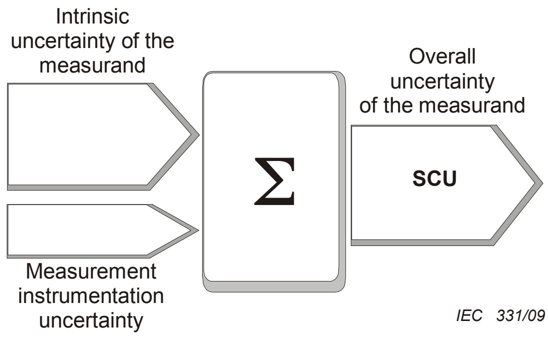


Figure 1a) – Typical emission measurement

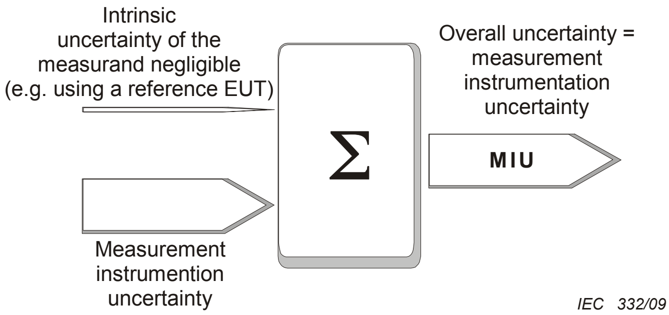


Figure 1b) – An emission measurement with a negligible intrinsic uncertainty of the measurand

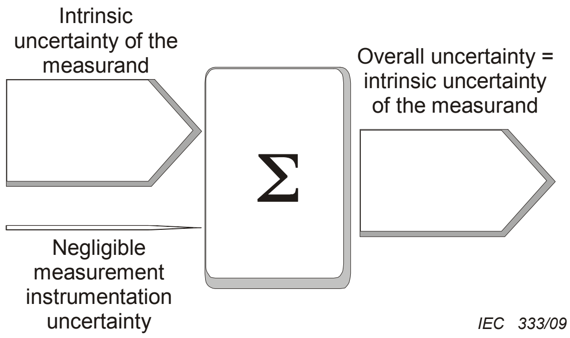


Figure 1c) An emission measurement with a negligible measurement instrumentation uncertainty

Figure 1 – Illustration of the relation between the overall uncertainty of a measurand due to contributions from the measurement instrumentation uncertainty and the intrinsic uncertainty of the measurand

4.2 Types of uncertainties in emission measurements

4.2.1 General

At first, this subclause discusses the different purposes of uncertainty considerations in emission measurements. Depending on the purpose, a different type of uncertainty analysis is required, and the compliance criterion may be incorporated in different ways. In addition, the uncertainty sources associated with an emission measurement, as well as their corresponding influence quantities are introduced. Finally, different categories of uncertainties in emission measurements are defined and discussed in more detail.

4.2.2 Purpose of uncertainty considerations

The result of an emission measurement is subject to uncertainties, and there may be different reasons to consider the uncertainties in a quantitative way. The following cases can be considered:

a) qualification of the technical measurement capabilities of a test laboratory;

b) judgement of compliance of a measurement result with respect to the limit;

c) comparison of the measurement results obtained from different test laboratories;

d) comparison of different emission measurement methods;

e) sampled testing of the emission performance of mass-produced products.

The type of uncertainties to be considered differ in each of these cases, as discussed in the following.

In case a), it may be sufficient to consider the uncertainties of the measuring chain (3.1.11) and the uncertainties due to the implementation of the measurement procedures. For instance, one can consider the technical performance of the measurement equipment, such as the test site, the measurement receiver and receive antenna. The measurement procedures as carried out by the personnel and/or by the software can also be evaluated. Application of a calculable EUT or a reference EUT is a means to evaluate the uncertainty due to the measurement instrumentation [see Figure 1 b)].

In case b), the result of an emission compliance test is judged against a given limit. The resulting uncertainty will include the uncertainties due to the measuring chain and the measurement procedure, but also the intrinsic uncertainties due to the set up of the EUT or the operation of the EUT. Compared to a classical metrology measurement, the intrinsic uncertainty of an emission measurement may have relatively large values. It is a matter of EMI risk assessment how this overall uncertainty is incorporated in the pass/fail criterion. One property of the intrinsic uncertainty is that this uncertainty contribution depends not only on the specification of the measurand, and the class of products, but also on the specification of the EUT set-up, including the layout and termination of the cables. In first order approximation, the intrinsic uncertainty is independent of the measurement instrumentation uncertainty. It is the responsibility of the authors of standards to reduce the intrinsic uncertainty to an acceptable low level. The magnitude of the intrinsic uncertainty is beyond the control of the test laboratory and also beyond control of the manufacturer of the product. Consequently, a manufacturer of a product should not be punished by requiring that the value of the intrinsic uncertainty shall be taken into account in the pass/fail criterion, i.e. subtracted from the limit.

NOTE 1 The first edition of CISPR 16-4-2 specifies only MIU for the determination of compliance. However, it was noted during the development of CISPR 16-4-2 that other uncertainty categories besides MIU affect compliance determination to some extent. That was the reason to use the more specific title ‘measurement instrumentation uncertainty’ in CISPR 16-4-2. Because CISPR 16-4-2 includes CISPR/TR 16-4-1, per reference, this discrepancy must be resolved (although CISPR 16-4-2 is a normative document, CISPR/TR 16-4-1 is an informative document). Therefore, for reasons of consistency, a future amendment of CISPR 16-4-2 may be considered.

An example of case c) is market control by an authority of a certain product. In this case both test laboratories (manufacturer and authority) judge compliance of the measurement result against the applicable limit. Also, the two results can be compared with each other directly. Different samples of the same product may be used by the auditing authority and by the manufacturer of the product. In this case, the emission performance of the same type of product may be subject to spread due to tolerances in production and performance of components. This means that the product itself is a source of uncertainty. Again in this case an intrinsic uncertainty is present, i.e. differences in set up of the EUT and layout and termination of the EUT cables may cause significant differences in the outcome of a measurement. The EUT operational states and internal measurement procedures may be different for the two test laboratories. Different procedures (e.g. an operator-controlled versus a software-controlled measurement procedure) may lead to different results as well.

NOTE 2 CISPR emission measurements require measurement of an emission level, defined as the level of a given EM disturbance emitted from a particular device, equipment or system, 'measured in a specified way'. As a consequence, the value of the measurand is influenced by this 'in a specified way', e.g. the influence of the layout of the measurement set-up during the actual measurement. The uncertainty considerations shall reflect this for purposes of compliance measurements. For instance, in CISPR 16-4-2 and in LAB 34 [46], the uncertainty considerations are limited only to the measurement instrumentation uncertainties; uncertainties arising from the EUT variations are not included.

Case d) may be, for instance, a comparison of the results obtained from measurements using a classical radiated emission measurement on a 10 m OATS or in a 3 m SAC. To compare these 3 m and 10 m measurement results, additional uncertainties need to be considered due to the differences of the measurement methods. In general, 10 m measurement results cannot be easily converted into 3 m results. The conversion depends on the type of EUT (small, large, table top, floor standing) and the associated uncertainties.

In case e), manufacturing tolerances are an uncertainty source that may be taken into account in the compliance criterion. This has already been included in Clause 4 of CISPR/TR 16-4-3:2004 as the so-called 80 %/80 % rule. The emission performance results of mass-produced products have a spread due to manufacturing tolerances. For type testing of such mass-produced goods, from an uncertainty point of view this spread can be covered by the following two CISPR methods (see CISPR/TR 16-4-3):

1) testing of one representative sample of the product, then subsequent periodic quality assurance tests, or
2) testing of a representative and finite number of samples, then applying statistical evaluation of the measurement results in accordance with the 80 %/80 % rule.

The compliance criterion for these two cases is different. In the first method (periodic testing of one sample), the product complies as long as the limit is not exceeded. In the second method, a penalty margin is incorporated in the compliance criterion which depends on the number of samples (student's-t distribution) or the results are compared directly with the limit and a number of samples may be rejected depending on the total number of samples (binominal distribution).

NOTE 3 The compliance determination for production should be determined by applying the 80 %/80 % rule as described in Clause 4 of CISPR/TR 16-4-3:2004. Because of the publication of CISPR 16-4-2, the MIU compliance criterion (Clause 4 of CISPR 16-4-2:2003) shall be applied as well. It has yet to be determined how the 80 %/80 % rule compliance criterion, given in CISPR/TR 16-4-3), and the MIU compliance criterion of CISPR 16-4-2 are to be combined (order of precedence) in case both criteria are applicable. The combination of these two compliance criteria is subject of further studies in CISPR/A.

NOTE 4 It should be noted that sampling and production uncertainties do not contribute to the uncertainty of a single EUT measurement. However, in a type approval scenario (as described in Clause 4 of CISPR/TR 16-4-3:2004), where compliance determination of a whole series of products is based on the measurement of one or more samples, these factors do indeed contribute to the compliance uncertainty. The additional uncertainty is due to variations in the manufacturing process and also due to the fact that the number of samples is limited. In ISO/IEC Guide 98-3 (E.4.3) it is also recognized that an additional uncertainty occurs due to limited sampling of an ensemble of products. E.4.3 of ISO/IEC Guide 98-3 states: *This 'uncertainty of the uncertainty', which arises from the purely statistical reason of limited sampling, can be surprisingly large*. Examples are given in Table E.1 of ISO/IEC Guide 98-3.

EXAMPLE The compliance decision may be different for a group of samples, selected from an early batch in the production process, compared to a group of samples selected from a batch produced in a more mature manufacturing process having improved tolerances and therefore yielding a reduced standard deviation of the product properties under consideration.

From the discussion of the cases a) through e) explained above, it is clear that the categories of uncertainties to be considered depend very much on the specific application purpose. The uncertainty and its inclusion in the compliance criterion usually depend strongly on these purposes. In the following paragraphs, the various categories and types of uncertainties will be distinguished in a more systematic way.

4.2.3 Categories of uncertainty sources

Figure 2 shows the flow of the general process of emission compliance measurements. First, one or more EUTs are sampled from the total population of a specific product. As discussed in the previous clause, due to the production spread and due to the sampling, an uncertainty in the measured result can be expected (production and sampling induced uncertainties). Further, the standard specifies the measurand and the method, means and conditions under which to measure the measurand. In this process of standardized measurements additional uncertainties can arise, due to different uncertainty sources. In general, an uncertainty source is a factor that contributes to the uncertainty of a measurement result (see 3.1.19). An uncertainty source can be defined also as a qualitative description of a source of uncertainty. Table 2 lists possible categories of uncertainty sources that can be distinguished in the general emission compliance measurement process given in Figure 2.

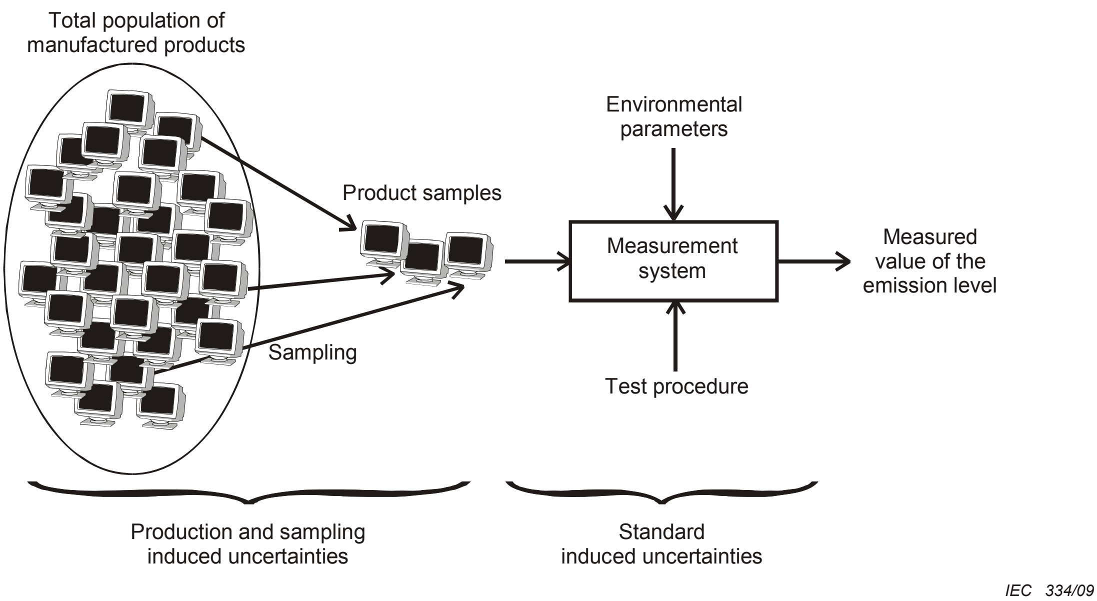


Figure 2 – The process of emission compliance measurements and the associated (categories of) uncertainty sources (see also Table 2)

Table 2 – Categories of uncertainty sources in standardised emission measurements

Test laboratory induced	Standard induced	Production and sampling induced
▪ Operator skills ▪ Analysis and calculations ▪ Reporting ▪ Implementation of the standard in measurement procedure and software ▪ Quality system	▪ Specification of the measurand ▪ Measurement instrumentation including calibrations and verifications ▪ Measurement procedure description ▪ Environmental conditions ▪ Set up of the EUT ▪ Operation of the EUT ▪ Type of EUT	▪ Production tolerance ▪ Sampling ▪ Non-representative sampling

As explained in the previously, there may be differing reasons for the consideration of the uncertainty of measurement results. Depending on the purpose of the uncertainty evaluation, the various categories of uncertainty sources shall be taken into account. For a *compliance* measurement of an arbitrary EUT in accordance with the *standard*, all the categories of uncertainty sources given in Table 2 are of importance. The resulting uncertainty associated with this situation is called the '*standards compliance uncertainty'*. In practice, the *test laboratory induced uncertainties* should be minor, and are controlled and sustained by the quality system of a test laboratory. It should be noted that the test laboratory has to use the available standard and has to interpret it in some way to actually implement it in a measurement process. The quality system only ensures that the established process is evaluated in some form and applied consistently. The quality system however does not minimize the kind of error, due to incomplete or ambiguous standards. In the remainder of this clause it will be assumed that the (additional) test laboratory induced uncertainties are negligible and need not be incorporated in the compliance criterion. The *production and sampling induced uncertainty sources* are presently taken into account by the CISPR 80 %/80 % rule that is described in Clause 4 of CISPR/TR 16-4-3:2004. Therefore, this category of uncertainties will not be treated further in this subclause. However, this source of uncertainty is listed in Table 2 to present the full picture of all candidate uncertainty sources that may be involved in a CISPR disturbance compliance measurement.

The standard induced uncertainty sources are of importance, when different test laboratories measure the same physical EUT. If the same physical EUT is measured at different test sites using different measurement equipment, but the same operator and the same procedures and exactly the same set up are used, then the uncertainty is governed mainly by the measurement instrumentation including the test site. This case shows that consideration of ‘measurement instrumentation uncertainties’ alone (as in CISPR 16-4-2 or in LAB 34 [46]), is valid only for specific cases. The latter situation may be appropriate if only the technical capabilities (the measuring chain) of a specific emission measurement facility are being assessed.

The category of ‘standard induced uncertainty sources’ in Table 2 can be further split into sub-categories. Example uncertainty sources sub-categories are detailed again in Table 3. Table 3 lists the typical qualitative uncertainty sources that may contribute to the overall uncertainty of the radiated emission measurement result.

In general, the starting point for an uncertainty assessment of any new measurement method is to assemble all possible uncertainty sources. It may be convenient to cluster these uncertainty sources into sub-categories. Further guidance on how uncertainty sources can be found is given in 4.4.3. These uncertainty sources will be called the ‘identified uncertainty sources’. After experimental verification of the final uncertainty budget, a discrepancy may appear between the actual and estimated uncertainty. One of the reasons may be that one or more relevant uncertainty sources were initially overlooked. Such an uncertainty source is called an ‘unidentified uncertainty source’. Of course, when an uncertainty assessment is done for a new standardized measurement method, the aim is to assemble all relevant uncertainty sources.

EXAMPLE Examples of uncertainty sources that have been previously overlooked are the common-mode termination of EUT cables and the mast structure of the receive antenna. The impact of the material and construction of an EUT positioning table was an identified uncertainty source. However, recently it became apparent that this uncertainty source is not adequately implemented in the CISPR standards by just specifying that the table shall be non-conductive and non-reflective e.g. like wood.

Table 3 – Example of detailed standard induced uncertainty sources for a radiated emission measurement

Measurement instrumentation	Measurement procedure	Environmental conditions	EUT set-up and operation	Type of EUT
▪ Site performance ▪ Receive antenna performance ▪ Receiver performance ▪ Cable performance	▪ Height scanning ▪ EUT table rotation ▪ Receiver settings (proper signal interception)	▪ Radiated ambient ▪ Conducted ambient ▪ Temperature, humidity	▪ Tolerances measurement distance and height ▪ Set-up units ▪ Routing cables ▪ Termination cables ▪ Modes of operation	▪ Table top or floor standing ▪ Dimension

4.2.4 Summary of types of uncertainties

Previously, different types of uncertainties have been defined and used within CISPR. These different types are summarised in Table 4.

Table 4 – Different types of uncertainties used within CISPR at present

Type of uncertainty	Associated (categories of) uncertainty sources	Application
Measurement instrumentation uncertainty (MIU)	Measurement instrumentation	Quality assessment of a measurement facility (like U_{cispr} given CISPR 16-4-2)
Standards compliance uncertainty (SCU)	▪ Standard induced (including the measurement instrumentation; see Table 2) ▪ Production and sampling induced	Compliance measurements
Measurement method correlation uncertainty [i.e. case d), 4.2.2]	▪ Standard induced (including the measurement instrumentation; see Table 2)	Comparison of alternative measurement methods
Emission performance uncertainty of a mass-produced product	Production and sampling induced	Compliance measurements of mass produced products (quality assurance, 80 %/80 % rule in CISPR/TR 16-4-3)

4.2.5 Influence quantities

In practice the uncertainty in the result of a standardized measurement may arise from many possible ‘uncertainty sources’. In a measurement standard each uncertainty source should be specified in a quantitative way by using one or more influence quantities. An ‘influence quantity’ can be specified in different ways. For instance, the ‘electromagnetic ambient’ is one uncertainty source. This uncertainty source can be quantified for example by bounding the absolute value of ambient signals in terms of electric field strength as a function of the frequency, as measured by the measurement system. Another more indirect ‘influence quantity’ is the specification of the shielding performance of a test site.

It may not always be easy to translate a qualitative uncertainty source into one or more quantitative influence quantities. In practice it may not be possible to fully quantify an uncertainty source. The portion of the uncertainty source that is specified by an influence quantity will be called a specified influence quantity. Influence quantities that are difficult to quantify, but that are identified as relevant, will be called ‘non-specified influence quantities’.

EXAMPLE 1 The ‘height scanning of the receive antenna’ is an uncertainty source (part of the category ‘measurement procedure’ in Table 3). This uncertainty source can be made quantitative by two influence quantities, the ‘scan window’ and the ‘maximum scan step size’. In 7.2.4 of CISPR 16-2-3:2006, only the scan window (upper and lower bound as a function of the measurement distance is given. The ‘scan window’ is a ‘specified influence quantity’. However, in CISPR 16-2-3, the step size of the height scan is not explicitly given although it should be clear that the maximum step size (in relation to the scanning speed of the mast) influences the field maximisation. The influence quantity ‘maximum step size of height scan’ is in this case a ‘non-specified influence quantity’. This uncertainty source only applies when a height scan in certain steps is performed. A continuous scan will eliminate this uncertainty source altogether.

EXAMPLE 2 In CISPR 16-2 series the uncertainty source ‘environmental conditions’ is an identified uncertainty source (see the ‘measurement environment’ 7.2.5.1 of CISPR 16-2-3:2006 and 4.3.1 of CISPR 16-2-4:2003). This uncertainty source can easily be translated into influence quantities like ‘temperature range’, ‘humidity range’, and ‘atmospheric pressure range’. In the CISPR 16-2 clauses mentioned, the ‘temperature’ and ‘humidity’ are identified as relevant influence quantities for the product under test. The ‘atmospheric pressure’ is not considered a relevant uncertainty source. However, the above-mentioned environmental conditions are not specified and even not mentioned in relation to proper operation of the measurement equipment, such as the measurement receiver. Consequently, the ‘temperature range’ and ‘humidity range’ are ‘non-specified influence quantities’. In general it is expected that these environmental influence quantities will have a minor effect on the result of a disturbance measurement. The impact is incorporated in the uncertainty contribution resulting from repeated measurements (repeatability contribution).

EXAMPLE 3 'Routing of cables' is a well known and identified 'uncertainty source' (part of 'EUT set up and operation' category in Table 3). In 7.2.5.2 of CISPR 16-2-3:2006 some requirements are given about the routing of the cables. Specified influence quantities are 'the position of the cable' and 'length of the cable'. However, it is questionable whether the present description of these cable routing influence quantities is sufficiently strict to reduce the resulting 'reproducibility' uncertainty to a certain value.

More examples showing the translation of 'uncertainty sources' into 'influence quantities' in a radiated emission measurement are listed in Table 5. These examples show that it is sometimes difficult to determine an influence quantity to adequately cover a certain uncertainty source. We also see that some influence quantities are not specified or not sufficiently specified. For example, the normalised site attenuation (NSA) is a figure-of-merit for performance of a site for radiated emission measurements. The NSA characteristic is often evaluated using a broadband transmit antenna and a typical receive antenna (often the same type of broadband antenna as used for transmit) that may not be the same as the receive antenna used in the actual emission measurement. Therefore the evaluated NSA may not be a representative figure-of-merit that applies to all types of EUTs (size, table top, floor standing) and for all types of receive antennas used in the actual emission test.

Table 5 – Examples (not exhaustive) of the translation of 'uncertainty sources' into 'influence quantities' for an emission measurement on an OATS per CISPR 22

Uncertainty source	Influence quantity	Specified in CISPR 22?	Tolerance given
Site performance	▪ Normalised site attenuation	▪ Yes	▪ Yes
Radiated ambient	▪ Ambient noise level	▪ No	▪ No
Conducted ambient	▪ Filter performance of a LISN	▪ Yes	▪ No
Receive antenna performance	▪ Antenna factor ▪ Unbalance ▪ Cross polarisation	▪ Indirectly, through 4.4.1 of CISPR 16-1-4:2007 ▪ Yes ▪ Yes	▪ Yes ▪ Yes ▪ Yes
Set up EUT units and routing of cables	▪ Position and orientation of units and geometrical position of cables	▪ Yes, partially	▪ No
Termination of EUT cables	▪ CM impedance	▪ No	▪ No
Modes of operation EUT	▪ Modes of operation EUT	▪ Partially (qualitative)	▪ No

For each respective identified uncertainty source, one or more adequate influence quantities shall be determined. From Table 5 and previous examples it can be observed that the uncertainty sources listed are not always covered by adequate 'influence quantities' and the influence quantities are not always specified by a quantity including a tolerance. This may lead to discrepancies between the *actual* uncertainty and the *estimated* expanded uncertainty based on the uncertainty contributions from the list of specified influence quantities.

4.2.6 The measurand and the intrinsic uncertainty

Previous paragraphs have discussed that the uncertainty in the measurand is determined by various uncertainty sources that may be described quantitatively by influence quantities. During the development of a measurement standard, it is generally the goal to define the specifications in the standard such that the resulting uncertainty budget complies with the actual uncertainty. For a new proposed standard, the actual uncertainty is usually not yet known. The actual uncertainty in a compliance measurement can be verified for instance by a round-robin test or interlaboratory comparison. If a discrepancy appears between the uncertainty actually achieved and the budgeted uncertainty, this demonstrates that one or more relevant uncertainty sources are not identified, or that the influence quantities do not describe the associated uncertainty source sufficiently, provided that the EUT-induced uncertainties are eliminated. However, there is also a fundamental limitation due to the principle that a measurand cannot be completely described without an infinite amount of information (see ISO/IEC Guide 98-3, D.1.1). In other words, if the uncertainty of the measurement system were negligible, then the measured quantity would still be affected by a minimum uncertainty that can be assigned to an incomplete description of the measurand. This minimum uncertainty was defined as the 'intrinsic uncertainty' of the measurand (see 3.1.6).

As discussed previously, the intrinsic uncertainty may be quite significant in emission measurements. This is due for example to the fact that for an arbitrary EUT there are practical limitations on the precise description of the component set-up, its cable layouts, and operation modes. Conversely, if the intrinsic uncertainty of the measurand was negligible, the uncertainty that is obtained for a standardised measurement can be attributed completely to the specified influence quantities such as the measurement system specifications, the environmental specifications, and the measurement procedure specifications. This subset of uncertainties is considered in CISPR 16-4-2, and is briefly denoted as the 'measurement instrumentation uncertainty'. It must be noted that the lack of specification of EUT-related influence quantities in emission standards is an important reason that the intrinsic uncertainty of the measurand is significant.

EXAMPLE 1 The following two different ways of specifying a measurand may cause significant differences in the result of the measurements:

1) The maximum electric field strength emitted by the EUT located at 0,8 m above a conducting ground plane and measured at 3 m distance from the receive antenna, while the measuring antenna is scanned in height between 1 m and 4 m.

2) The maximum electric field strength of the EUT located at 0,8 m above a conducting ground plane and measured at 3 m distance from the receive antenna, while

   a. the antenna is scanned in height between 1 m and 4 m with minimum step of 0,1 m height;

   b. the antenna is positioned in horizontal and vertical polarisation;

   c. the EUT is positioned on a table that does not disturb the result of the measurement;

   d. the EUT is rotated in azimuth with angular steps of at least 15 °C;

   e. the receive antenna is a tuned dipole at each frequency.

Although a measurand should be defined with sufficient detail such that any uncertainty caused by its incomplete definition is negligible in comparison with the required accuracy of the measurement, it must be recognized that this may not always be practical. The definition may have been assumed, unjustifiably, to have negligible effects, or it may imply conditions that can never be fully met and whose imperfect realization is difficult to take into account. Inadequate specification of the measurand can lead to discrepancies between results of measurements of ostensibly the same quantity carried out by different test laboratories (see ISO/IEC Guide 98-3, Annex D).

EXAMPLE 2 For instance, in general it is difficult in a standard to specify the required operational states of the EUT. Specifying that the highest emission shall be found as a function of frequency, all operational states of the EUT, and all possible cable routings give rise to impractical long measurement times, but also give rise to a significant intrinsic uncertainty.

Figure 3 illustrates the relationship between the uncertainty sources, the corresponding influence quantities and the resulting uncertainties. This figure emphasises that the intrinsic uncertainty of an emission measurement is the absolute minimum uncertainty with which a measurand can be determined, due to the fact some influence quantities are not identified and due to the fact there are limitations in the specification of influence quantities.

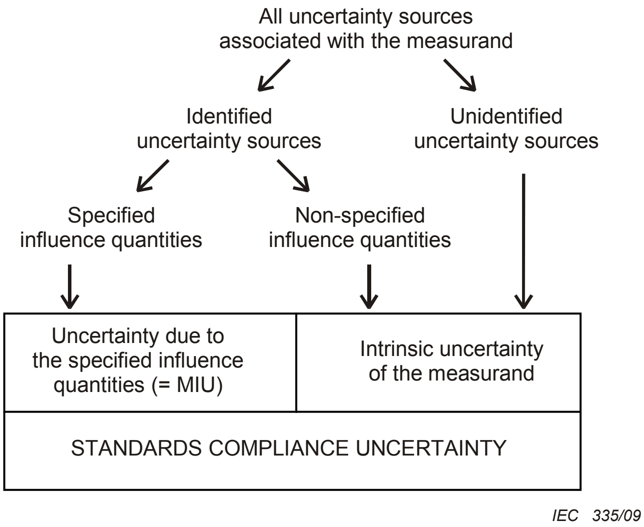


Figure 3 – Relationship between uncertainty sources, influence quantities and uncertainty categories

4.3 Relation between standards compliance uncertainty and interference probability

4.3.1 General

CISPR emission measurement methods are prepared to ensure that the probability of occurrence of a particular interference problem, caused by a given product or class of products, is reasonably low. In a probabilistic sense, the measured level only represents a figure-of-merit of the interference potential. Therefore, the term ‘interference probability’ is introduced and is defined as the probability that a product complying with the EMC requirements will function satisfactorily (from an EMC point of view) in its normal use electromagnetic environment. In general, determination of the interference probability is quite complicated. This subclause describes how the interference probability is affected by the choice of the emission quantity to be measured, its limit level and the standards compliance uncertainty of this measured quantity.

4.3.2 The measurand and the associated limit

In contrast to classical metrology problems, in the field of EMC there has always been great emphasis on performing measurements using a specified and standardized method, rather than ensuring traceability to a defined standard or SI unit. This has led to the use of standardized measurement methods, like the CISPR standards, to meet legislative and trade requirements. Consequently, results of EMC tests depend very much on the methods used. Such methods are often referred to as *empirical methods* (see [27]). Furthermore, the measurand is defined by the measurement method used.

EXAMPLE The disturbance power measurement method is described in Clause 7 of CISPR 16-2-2:2003. The result of this measurement (in fact a voltage measurement) depends amongst others, on the set-up of the EUT, the scanning method of the absorbing clamp and on the settings of the measurement receiver. The measurement result is not traceable to a defined disturbance power reference standard.

In EMC compliance tests, it is not the goal to measure physical quantities like voltages, currents, field strengths, etc. as direct quantities of interest. Instead, the measurand is a derived or indirect quantity, i.e. a quantity that is assumed to provide a figure-of-merit for the degree of a product’s EMC at the intended locations.

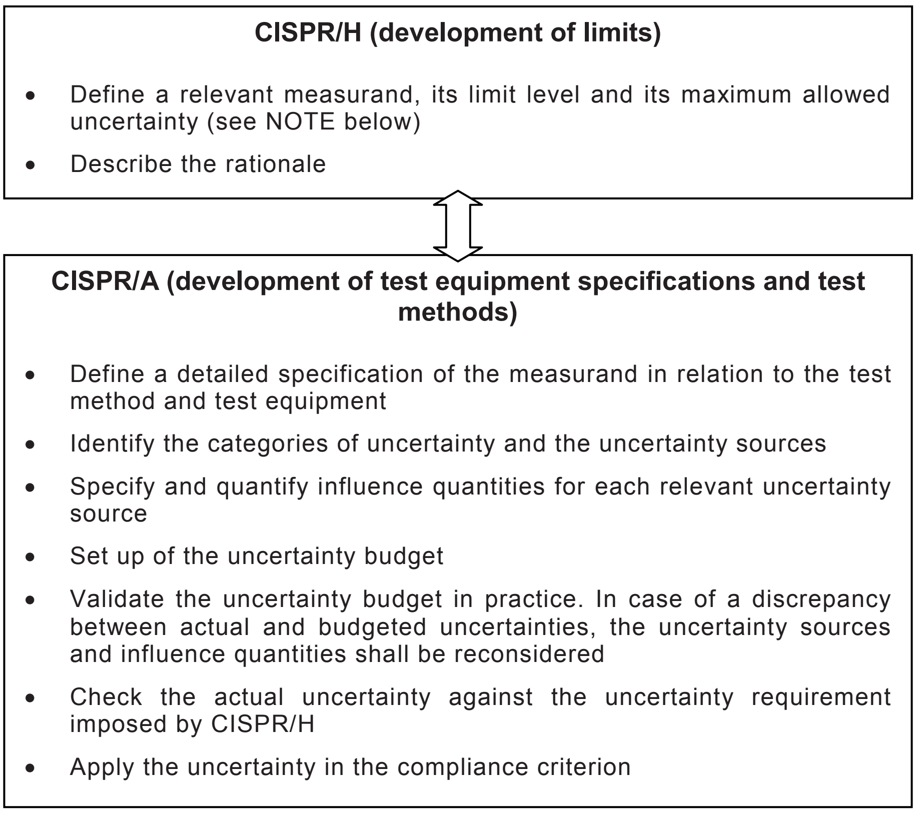
The measurand, its uncertainty and the level of the associated limit are related to the interference probability. In Annex A, the relationship between standards compliance uncertainty and interference probability is addressed in more detail. Because actual quantitative data is available, the annex is descriptive and qualitative in nature. Apart from the description in Annex A, the subject of relating SCU and ‘interference probability’ will not be described further because CISPR/H is responsible for this subject. This subcommittee is tasked with the derivation of adequate measurands, limit levels and uncertainty constraints for the limit levels.

The selected measurand shall be a relevant figure-of-merit from a practical EMC point of view. The same is true for the allowed emission level (the limit level). A low emission limit will result in low interference probability and vice versa. Also the uncertainty of a measurand may affect the interference probability. Consequently, for a certain measurand, its uncertainty and the associated limit regarding an ‘interference probability’ assessment shall be performed by CISPR/H.

To indicate the relevance of a selected measurand in relationship to the interference probability, a CISPR compliance test should include (for example in an annex) a rationale for the defined measurand and for the associated limit, or should make reference to international reports and available publications. Annex A provides an example on how the measurand, its uncertainty and the corresponding limit level may affect the ‘interference probability’.

4.3.3 Process of determination and application of uncertainties

A summary of the major steps in the determination and application of uncertainties and the involvement of both CISPR/A and CISPR/H in this process are depicted in Figure 4.



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NOTE Ideally, the establishment of a limit should be accompanied by specifying a maximum allowable uncertainty. At present, this may be an academic approach but in the future, CISPR/H should be responsible for determining the limits and related maximum permissible uncertainties.

Figure 4 – Involvement of the subcommittees CISPR/H and CISPR/A in the determination of the measurands and application of uncertainties

In summary, it is important to recognise that:

a) the uncertainty of a measurand affects the interference probability;

b) all categories of uncertainties contributing to the SCU shall be considered when performing an 'interference probability assessment';

c) it is considered the task of CISPR/H to provide CISPR/A with requirements on measurands, limit levels and maximum uncertainties;

d) it is considered the task of CISPR/A to develop adequate measurement methods and measurement equipment specifications for a certain measurand, such that the limit levels can be determined in a reproducible way and actual uncertainties comply with the uncertainty tolerance set forth by CISPR/H.

4.4 Assessment of uncertainties in a standardised emission measurement

4.4.1 The process of uncertainty estimation

In principle, uncertainty estimation is simple. The following subclauses summarise the tasks that need to be performed in order to obtain an estimate of the uncertainty associated with a measurement result. The steps to be considered are as follows (see Figure 5).

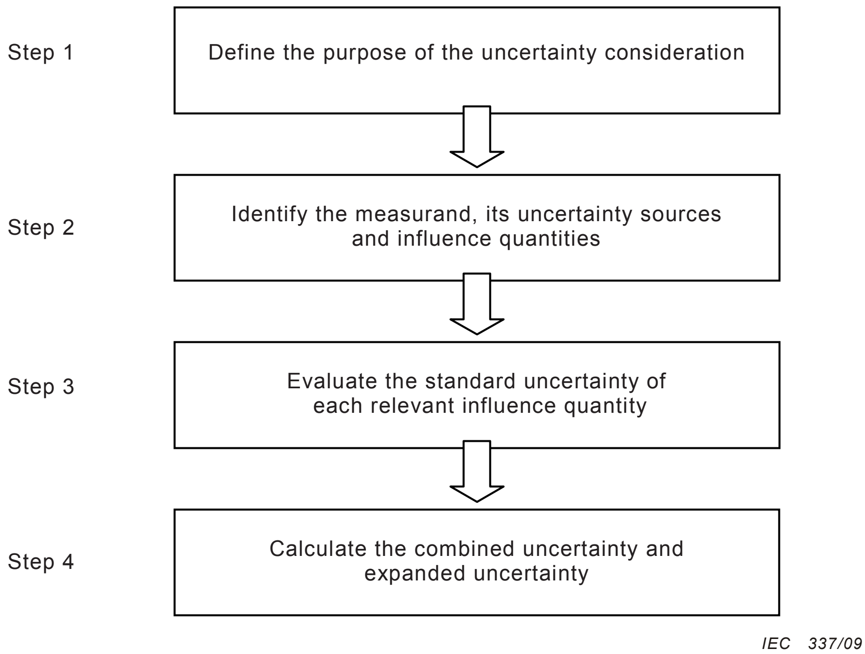


Figure 5 – The uncertainty estimation process

4.4.2 Step 1: Definition of the purpose of the uncertainty consideration

As explained in 4.2.2, there may be different reasons for performing an uncertainty analysis. Some examples of different types of uncertainties are given in Table 4. In the remainder of this subclause it is assumed that the uncertainty analysis is performed in order to determine the 'standards compliance uncertainty'. In principle, however, steps 1 through 4 of Figure 5 are also applicable if the 'measurement instrumentation uncertainty' is to be determined. In this case the 'uncertainty sources' and the 'influence quantities' to be considered will be a subset of the 'uncertainty sources' and the 'influence quantities' that are applicable for 'standards compliance uncertainty' considerations.

4.4.3 Step 2: Identifying the measurand, its uncertainty sources and influence quantities

The definition of the measurand requires both a clear and unambiguous statement of the quantity to be measured and a quantitative expression relating the value of the measurand to the parameters on which it depends (influence quantities). These parameters may be other measurands, quantities that are not directly measured, or constants.

EXAMPLE 1 Suppose the measurand for a radiated emissions measurement is specified as follows:

'The maximum electric field emitted by the EUT located at 0,8 m above a conducting ground plane and measured at 3 m distance from the receive antenna, while the measuring antenna is scanned in height between 1 m and 4 m'.

This definition is still ambiguous, because several relevant parameters like scanning step size of the receive antenna, polarization of the receive antenna, set-up of the EUT and cables, type of receive antenna, environmental conditions, test site requirements, etc, are not provided.

It must be clearly stated whether sampling is included in the process. If this is the case, an estimation of uncertainties associated with the sampling procedure is to be considered (application of the 80 %/80 % rule, see CISPR/TR 16-4-3).

A comprehensive list of relevant sources of uncertainty should be compiled. At this stage, it is not necessary to be concerned with quantifying individual components.

In order to identify uncertainty sources and influence quantities, it may be helpful to consider each specification and statement of a (concept) standard as a possible uncertainty source or influence quantity. Also, each step in the measurement procedure represents, in principle, a possible source of uncertainty.

A cause and effect diagram (sometimes known as a 'fishbone' diagram [27]) can be used to list the uncertainty sources, indicating their relationship and influence on the uncertainty of the measurement result. This way of documenting also helps to avoid double counting of sources. Although the list of uncertainty sources can be prepared in other ways, the cause and effect diagram is preferred. An example of a fishbone diagram is given in Figure 6. This figure shows the various uncertainty sources associated with the absorbing clamp measurement method. The uncertainty sources are grouped into categories, similar to the categories given in Table 3.

Other examples of categories of uncertainty sources that are typical for emissions measurements are shown in the Tables 2 and 3 of 4.2.3.

The next step is to convert each uncertainty source into one or more influence quantities. In 4.2.5, a method is provided to relate uncertainty sources to influence quantities. In 4.2.5 and in Table 5 some examples are given – a further example is given below.

EXAMPLE 2 An EUT support and positioning table is an 'uncertainty source' for the results of a radiated emissions measurement. This uncertainty source can be related to one or more influence quantities, in different ways:

1. precise specification of the type of material and construction, e.g. the table material shall be dry oak plywood, the maximum thickness of the table top shall be 10 mm and no metallic construction components shall be used.

2. precise specification of the electrical properties of the table material, e.g. by specifying the maximum values for relative dielectric permittivity and the loss tangent.

3. requiring that the positioning table shall be integral part of the site validation process for the radiated emission measurement facility, i.e. the table shall be put in its normal position during the site attenuation measurements.

The first approach is limited. Dry oak plywood may not be the same in each part of the world and 'dry' needs to be specified. The moisture content could be an 'influence quantity' for this source of uncertainty. The second translation into influence quantities has limitations because construction constraints need to be provided as well and it is difficult to directly relate the electrical properties into a specific effect on radiated emissions measurement results. The third specification allows many possible implementations for a positioning table. The influence quantity is specified in terms of a contribution to the NSA degradation of the test site. Compared to the first two approaches, this way of specification is integral and the resulting figure is more closely related to the uncertainty of an actual measurement.

Influence quantities that are difficult to specify or which cannot be specified at all (non-specified influence quantities) shall be included in the uncertainty budget as well, despite this difficulty. This can be done by assuming a range of values for the influence quantity under consideration or by considering a range of possibilities for the uncertainty source. For instance, the uncertainty source ‘routing of cables’ (fourth column of Table 3) may be difficult to specify. Experimental statistical variation studies can be performed using different classes of EUTs in order to derive the uncertainty associated with this uncertainty source.

After the identification of specified and non-specified influence quantities and the associated tolerances, the uncertainty of the measurement result must be determined. This can be done by modelling of the standardised measurement method or by experiments.

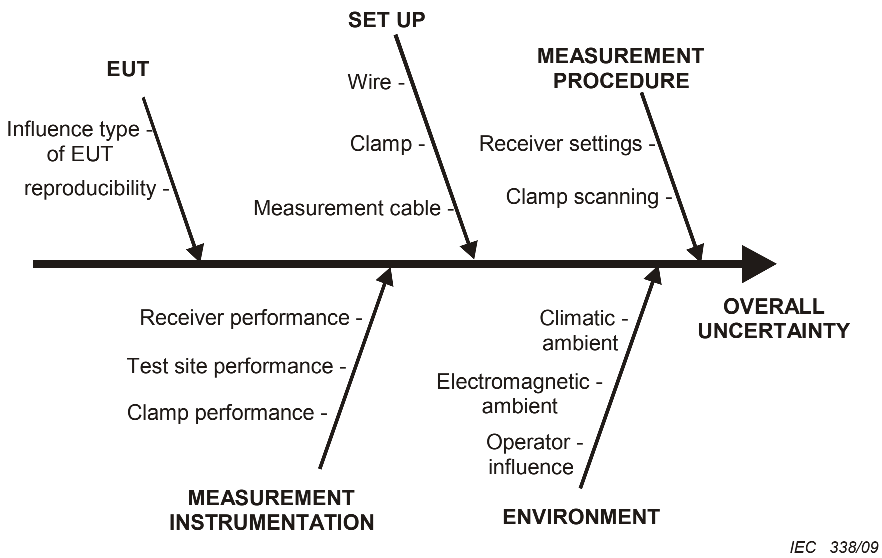


Figure 6 – Example of a fishbone diagram indicating the various uncertainty sources for an absorbing clamp compliance measurement in accordance with CISPR 16-2-2

4.4.4 Step 3: Evaluate the standard uncertainty of each relevant influence quantity

The methods to derive the uncertainties associated with influence quantities are described in detail in ISO/IEC Guide 98-3 and in [39] and [46]. For convenience, the major aspects of these methods are repeated below.

The effects of uncertainty sources and influence quantities on the measurand should, in principle be represented by a formal measurement model. This model will include each effect as a parameter or variable. Such an equation represents a complete model of the measurement process in terms of the individual factors affecting the measurement result. For EMC measurements this function can be very complicated and it may not be possible to formulate it explicitly at all. Where possible, this should be done, as the form of the expression will generally determine the method of combining individual uncertainty contributions.

In general, the measured emission level L_{m} (the output quantity) will depend on a number of specified influence quantities $x_{\mathrm{s},i}$ (i = 1,2,...,n) and a number of non-specified influence quantities $x_{\mathrm{u},j}$ (j = 1,2,...,k).

$$L_{\mathrm{m}} = f(x_{\mathrm{s},i}, x_{\mathrm{u},j}) \tag{1}$$

For each influence quantity x the standard uncertainty $U(x)$ shall be determined. All standard uncertainties can then be combined into the ‘combined uncertainty’ (see Step 4 in 4.4.5).

As a consequence, the overall uncertainty $U(L_{\mathrm{m}})$ of the measured level L_{m} is a combined uncertainty that can formally be written as a total differential

$$U(L_{\mathrm{m}}) = \sum_{i=1}^{n} \frac{\partial L_{\mathrm{m}}}{\partial x_{\mathrm{s},i}} U(x_{\mathrm{s},i}) + \sum_{j=1}^{k} \frac{\partial L_{\mathrm{m}}}{\partial x_{\mathrm{u},j}} U(x_{\mathrm{u},j}) = \sum_{i=1}^{n} c_{\mathrm{s},i} U(x_{\mathrm{s},i}) + \sum_{j=1}^{k} c_{\mathrm{u},j} U(x_{\mathrm{u},j}) \tag{2}$$

In Equation (2), $c_{\mathrm{s},i}$ and $c_{\mathrm{u},j}$ are the sensitivity coefficients, given by the partial derivatives of the level with respect to the influence quantity x, while $U(x)$ represents the uncertainty associated with that influence quantity.

Sensitivity coefficients are usually unknown because the coefficients depend on specified as well as non-specified (unknown) influence quantities. A model describing the relationship between the measurand and *all* influence quantities is required in order to estimate the magnitude of the sensitivity coefficient (see also ISO/IEC Guide 98-3).

The influence quantities can be categorised in type A and type B categories. The type A and type B distinction is widely used and is for convenience of the discussion only. Both types of evaluation of standard uncertainties of influence quantities are based on knowledge of the probability distribution associated with the influence quantity.

Type A standard uncertainties are calculated from a series of repeated measurements using statistical methods. The type A standard uncertainty applies the standard deviation of the mean of the repeated measurements. The standard uncertainties of type B influence quantities are evaluated using available knowledge. For example, data from calibration certificates, previous measurement data, manufacturers specifications or other relevant data.

In compliance emission measurements, the uncertainty in the result of a measurement can be formally expressed by an interval centred on the actual measured value of the measurand. Uncertainty estimates can only be determined based on a model that describes the relationship between the measurand and all relevant specified and non-specified influence quantities. Only when a model is available, the propagation of an uncertainty $U(x_i)$, associated with the i-th influence quantity x_i into the overall uncertainty contribution $U(L_{\mathrm{m}})$ to the measurand L_{m} is known. Mathematically, $U_i(L_{\mathrm{m}}) = c_i \times U(x_i)$ must be known. The quantity c_i is called ‘sensitivity coefficient’. Among other parameters, c_i may be frequency dependent. See also 4.4.5. The model required may be an analytical or a numerical model. It should be noted however, that for EMC measurements in general accurate models are not available. Therefore it is more convenient to apply repeated measurements and statistical methods in order to estimate the magnitude of the standard uncertainty associated with the type A influence quantities. The existing uncertainty guides like LAB34 [46], M3003 [39] and ISO/IEC Guide 98-3 give detailed guidance on this matter. Note that for statistical experimental uncertainty investigations, it is also a good practice to use specific EUTs, such as reference EUTs, or EUTs that can be numerically modelled, i.e. ‘calculable EUTs’ (see also 4.5.4).

4.4.5 Step 4: Calculation of the combined and expanded uncertainty

The steps to be taken to derive the combined and expanded uncertainty of the measurand are described in detail in ISO/IEC Guide 98-3 and in [39] and [46]. For convenience, these steps are repeated below.

If $U(L_m)$ can be written as a linear sum of uncertainty contributions $\pm c_p U(x_p)$, as assumed in Equation (2), and the sign of each contribution is generally unknown (only the interval around a quantity x_p is known), then the 'combined standard uncertainty' $U_c(L_m)$ can be written as:

$$U_c[L_m(f)] = \sqrt{\sum_{p=1}^{m} \{c_p(f) \times U[x_p(f)]\}^2} \qquad (3)$$

where $m = n+k$. To emphasise that $U_c(L_m)$ is actually a function of the frequency f, the frequency dependence has explicitly been indicated in Equation (3).

NOTE In CISPR 16-4-2 it has been assumed that $U_c(L_m)$ is frequency independent without stating a rationale for this assumption. In addition, in CISPR 16-4-2 it has been assumed that Equation (3) is always applicable. This is generally not the case as is demonstrated, for example, in 6.4.4.

The expanded uncertainty $U(L_m)$ shall be determined from the combined uncertainty using Equation (3) and the Equation (4) below:

$$U(L_m) = k \times U_c(L_m) \qquad (4)$$

where k is the coverage factor. For EMC measurements, it is general practice to apply a coverage factor $k = 2$ that corresponds with a 95 % level of confidence when the number of degrees of freedom is large. This expanded uncertainty, with a 95 % level of confidence, will be used for all further discussions of uncertainties. This means that if the term 'measurement instrumentation uncertainty' is used for example, the 'expanded uncertainty', due to the measurement instrumentation uncertainty sources, is referred to.

As discussed in 4.3, the maximum allowable magnitude of the combined uncertainty $U(L_m)$ may be found after considering the interference probability. This consideration should result in the specification of the limit level L_{lim} for compliance determination, reflecting the agreed level of interference probability. Then $U(L_m)$ shall be defined in a way that makes its influence on the interference probability low. If this is not possible, L_{lim} has to be adjusted to a level that will provide the same interference probability.

4.5 Verification of the uncertainty budget

4.5.1 Introductory remarks

The validity of the uncertainty estimates, obtained through the steps given in 4.4, shall be verified when a new standard or an amendment is developed. A verification of the 'measurement compatibility' (see 3.1.12) can be done by the following experimental means:

a) comparison of measurement results and uncertainty budget obtained from two different test laboratories, or by

b) execution of an interlaboratory comparison and statistical evaluation of the results.

Also the application of a 'calculable EUT' or a 'reference EUT' is useful to evaluate certain aspects of the uncertainty budget. These verification methods, their purposes and application are described in more detail in the next subclauses. Other information about comparison of results is given in [51].

4.5.2 Test laboratory comparison and the measurement compatibility requirement

4.5.2.1 Results from two laboratories

The uncertainty of a measurement result can be expressed by an interval ΔL_{m}, containing the true value of the emission level L_{t}. In the metrology field, this interval is normally stated together with its confidence level. If L_{u} is the upper boundary of the interval and L_{l} the lower boundary, with $L_{\text{u}} - L_{\text{l}} = \Delta L_{\text{m}}$, the interval ΔL_{m} only has a relevant meaning if the following simple relation is satisfied:

$$L_{\text{l}} \leq L_{\text{t}} \leq L_{\text{u}} \quad (5)$$

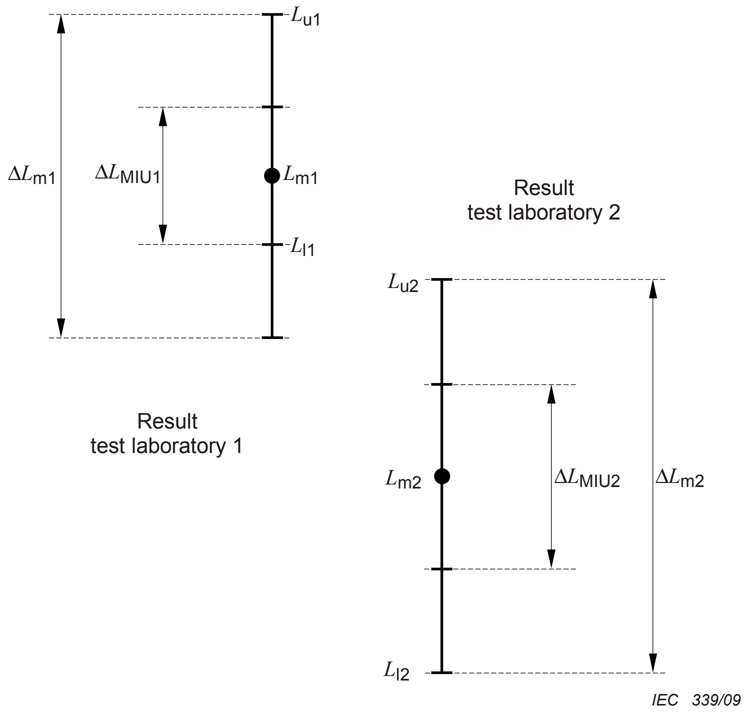
with a certain level of confidence. Similarly, if L_{m} is the measured emission level, the relationship $L_{\text{l}} \leq L_{\text{m}} \leq L_{\text{u}}$ has to be satisfied with a certain level of confidence. The interval ΔL_{m} includes the (weighted) contributions of the uncertainties associated with the specified and the non-specified influence quantities. This interval can be expressed in terms of the expanded uncertainty:

$$\Delta L_{\text{m}} = 2 \times U(L_{\text{m}}) \quad (6)$$

The level of the measurand L_{m} and the associated uncertainty interval ΔL_{m} can be used to verify the validity of the uncertainty estimate by checking the measurement compatibility: when two independent measurements, carried out on the same product and both measurements being completely in accordance with the standard, yield measurand levels $L_{\text{l1}} \leq L_{\text{m1}} \leq L_{\text{1u}}$, with $\Delta L_{\text{m1}} = L_{\text{u1}} - L_{\text{l1}}$ and $L_{\text{l2}} \leq L_{\text{m2}} \leq L_{\text{u2}}$, with $\Delta L_{\text{m2}} = L_{\text{u2}} - L_{\text{l2}}$, while ΔL_{m1} and ΔL_{m2} both have the same confidence level, then the following relationships must be satisfied:

$$L_{\text{l1}} \leq L_{\text{u2}} \quad \text{and} \quad L_{\text{l2}} \leq L_{\text{u1}} \quad (7)$$

As an illustration, Figure 7 shows a situation in which these two relationships are satisfied, when using (L_{l1}, L_{u1}) and (L_{l2}, L_{u2}). Since there is an overlap of the intervals ΔL_{m1} and ΔL_{m2}, the intervals associated with the assumed measurements have a realistic meaning as, with the associated confidence level, the true value of the emission level is within both intervals at the same time. Also shown in Figure 7 are intervals ΔL_{MIU1} and ΔL_{MIU2} (see also NOTE 2), determined by the measurement instrumentation uncertainty U_{MIU}, as derived in [29], including only measurement instrumentation uncertainty. Since the latter uncertainties form a subset of the total set of relevant uncertainties in a compliance test, it is to be expected that the interval ΔL_{MIU} is smaller than an interval ΔL_{m} associated with the standards compliance uncertainty. In the example of Figure 7 there is no overlap of the intervals determined by ΔL_{MIU}. Hence, the true value of the emission level cannot be in both intervals ΔL_{MIU} at the same time. In other words, these ΔL_{MIU} intervals do not satisfy the minimum requirement to be set to a realistic uncertainty interval.



NOTE Equation (7) is satisfied when using the standards compliance uncertainty intervals ΔL_{m1} and ΔL_{m2}, but it is not satisfied when using the measurement instrumentation intervals determined by ΔL_{MIU1} and ΔL_{MIU2}.

Figure 7 – Illustration of the minimum requirement (interval compatibility requirement) for the standards compliance uncertainty

In regard to the non-specified influence quantities, it is the task of the standards authors to provide the procedure for the quantitative determination of ΔL_m in each standard that requires the inclusion of uncertainty considerations.

NOTE 1 This procedure does not need to be published if the standard specifies a fixed value for the uncertainty interval which allows the test laboratory to demonstrate compliance with the CISPR specified tolerances of the specified influence quantities, e.g. as in 4.5.2.3 of CISPR 16-1-5:2003.

NOTE 2 The relationship between ΔL_{MIU} and measurement instrumentation uncertainty U_{CISPR} published in [29] is given by Equation (6), i.e. $\Delta L_{MIU} = 2U_{CISPR}$.

4.5.2.2 Correlation of results

The uncertainty of a valid measurement result shall be such that compatibility with all other valid measurements of the same measurand and the same EUT is ensured. The compatibility is indicated by the overlap of the intervals. This compatibility criterion results from application of the criteria for the combination of uncertainties to the uncertainty of the difference between two results. Two results of measurements are deemed to be compatible with each other when they are expressed by intervals such that

$$U_{12} = \sqrt{(U_{m1}^2 + U_{m2}^2 - 2rU_{m1}U_{m2})} \quad (8)$$

where U_{12} is the uncertainty of the difference of the two measurements and r is the correlation coefficient of the two measurements. If the two measurements are completely uncorrelated, then $r = 0$ and the two intervals must be partially overlapping for compatibility. If they are totally positively correlated, then $r = 1$ and $U_{12} = U_1 - U_2$, and compatibility requires complete overlapping. If they are anti-correlated with $r = -1$, then $U_{12} = U_1 + U_2$ and the overlapping of the two intervals may be reduced to one common element for compatibility. The assessment of compatibility is therefore related to a determination of the correlation between the several measurements, which may be difficult and will require much care in the statistical analysis of the data.

The minimum requirement for the uncertainty interval derived by two different test laboratories and applied to the measurement result of these test laboratories, is their overlap. If no overlap exists, it may be concluded that not all uncertainty sources and influence quantities are taken into account, which means that the specifications of the influence quantities are not adequate. In this case, the standard must be revised to avoid these reproducibility problems.

4.5.3 Interlaboratory comparison and statistical evaluation

From a statistics standpoint, it is advantageous to perform verification measurements at several sites, and analyse the results using statistical methods instead of comparing results from two test laboratories (as described in 4.5.2). Such a series of measurements is often referred to as interlaboratory comparison, site reproducibility program or round-robin test. The expression ‘round-robin test (RRT)’ will be used in the remainder of this subclause. A RRT is a statistical and experimental means to verify the uncertainty budget of a standardised emission measurement. This subclause provides guidance on the organization of an RRT to be used as a verification procedure.

General information on the organisation of a RRT can be found in e.g. EAL-P7 [26]. This document provides information on basic principles, the planning, preparation, execution and reporting of a RRT. A specific example of a RRT is included in [29]: the document provides results of a RRT and the set up to investigate the uncertainty sources of the radiated emission measurements as specified in CISPR 22 in the frequency range of 30 MHz to 300 MHz.

For the purposes of emission measurement uncertainty budget verification it is important to carefully define the goals of the RRT and the EUTs to be used. Basically, there are two options for the EUTs involved:

1) a reference EUT: an EUT that is very stable and that has the lowest possible intrinsic uncertainty. Optically or battery fed reference radiators that consist of a very stable generator portion and a rigid and reproducible radiating portion are frequently used for this purpose. Use of a reference EUT basically allows information to be gained about the measurement instrumentation uncertainty of the (draft) standard under consideration.
2) a real EUT: an EUT that is very stable, but that is real in a sense that it resembles, for example, typical floor standing equipment or typical table top equipment. When using a real EUT, information is collected about the standards compliance uncertainty for the class of products covered by the type of the EUT that is selected (large, small, floor standing, table top, single unit, multiple units, battery fed etc.).

The test plan circulated with the EUT shall be the same as the (draft or amended) standard that is subject to verification.

To ensure proper analysis of the results, it is important to establish a standard data format for the participants to use when reporting the results. Furthermore, additional information is to be requested (e.g. about equipment and automation software), in order to verify the validity of the submitted results.

In addition to the measurement data, it is also important to request the uncertainty budget from the participants. Annex D provides an example showing how the RRT data can be analysed and compared to the result of the uncertainty assessment (which was derived following the steps given in 4.4).

4.5.4 Application of a 'calculable EUT'

This subclause provides some guidance on the use of a calculable EUT for the verification of an uncertainty estimate. All relevant influence quantities of a 'calculable EUT' should be specified and the associated uncertainties can be determined following the classical metrology approach as given in ISO/IEC Guide 98-3. For that reason, a calculable EUT can be used to verify an uncertainty budget.

The approach using calculable devices is applied successfully to the validation of the antenna calibration site (described in Clause 4 of CISPR 16-1-5:2003). In this case, so-called calculable dipole antennas are used to validate a calibration test site (CALTS).

Similarly, the application of a calculable EUT also would allow a quantitative assessment of a test laboratory's ability to carry out CISPR-standardised compliance measurements. This method is also applied in a part of the CISPR/A radiated emission round-robin test reported in [29].

An important condition for the use of a calculable EUT is the availability of a validated simulation model for the measurements to be performed.

The lack of a validated model presents a problem for several practical EMC emission measurements. If a validated simulation model is available, several aspects of the influence quantities could be analysed by performing a parameter study, using this model. Modelling of the measurement set up and using a calculable EUT may provide information about intrinsic uncertainties associated with the physical aspects of the standardized measurement. It should be noted that such modelling generally does not provide information about uncertainties in certain parts of the measuring chain such as the measuring receiver.

4.5.5 Application of a 'reference EUT'

A 'reference EUT' is an emission source with specified and stable emission properties. Reference EUTs are often used as EUTs for interlaboratory comparisons (see 4.5.3). It can also be used for a quick integral verification of test facility characteristics. Integral verification means that the characteristics of individual parts of the measurement chain (cables, antenna, test site, etc.) are evaluated together. For example, in a radiated emission measurement facility, the measuring chain consists of the site, the receive antenna, the antenna cable and the receiver/analyser. Various CISPR specifications apply for these parts of the measuring chain and much effort is required for periodic verification of these specifications. Therefore, a reference EUT can be used as a transfer standard to verify complete sections of the measurement chain. The measurement results can be used to establish an internal reference for a specific measurement. The validity of this approach depends on the stability of the source within the reference EUT and on the reproducibility of the reference set-up and configuration in the measurement facility.

The reference result obtained from a careful reference EUT measurement shall be recorded. The measurement with the reference EUT can be repeated from time to time. The periodically obtained data can be compared with the reference results; and, since the intrinsic uncertainty related to these measurements is low, it can provide information about the measurement instrumentation uncertainty [see Figure 1 b)]. Therefore, a pass/fail criterion shall be applied, that is related to the magnitude of the measurement instrumentation uncertainty of the measurand (see 4.7.4).

4.6 Reporting of the uncertainty

4.6.1 General

This clause provides guidance for the reporting of uncertainty considering the following two cases:

1) reporting of results of uncertainty assessments as part of the development process of a new standard or in case a test laboratory has to determine its own uncertainty budget, for example to meet the requirements for accreditation in accordance with ISO/IEC 17025;
2) reporting of uncertainties related to routine emissions compliance measurements, performed by a test laboratory.

4.6.2 Reporting results of uncertainty assessments

The information necessary to report the result of an uncertainty analysis is dependent on its intended use. The guiding principle is to present sufficient information to allow the result to be re-evaluated if new information or data becomes available.

When details of the uncertainty analysis, including the method of determination, depend on published documentation, it is imperative that this documentation is clearly referenced.

A complete report on the determination of the uncertainty should include information related to the steps described in 4.4 and 4.5 and address the following:

1) statement, declaration of the purpose of the uncertainty analysis;
2) identification of the measurand, its uncertainty sources and influence quantities;
3) determination of the uncertainty magnitude of each relevant influence quantity, either by modelling or experimentation, as a function of certain parameters such as frequency, types of EUTs, etc.;
4) calculation of the combined uncertainty and expanded uncertainty;
5) verification of the uncertainty budget;
6) listing of reference documents (if applicable).

The estimate of the magnitude [item 3)] shall include:

- a description of the methods used to calculate the measurement result and its uncertainty from the experimental observations and input data;
- the values and sources of all corrections and constants used in both the calculation and the uncertainty analysis;
- a list of all uncertainty components, along with a detailed description of their evaluation.

The data and analysis should be presented in a way that the major steps in the process can be easily identified and the calculation repeated if necessary.

4.6.3 Uncertainty statements in routine compliance measurement results

When a test laboratory is to report the results of emissions measurements, it may be sufficient to only state the value of the expanded uncertainty and the value of k, along with a reference to the applicable internal uncertainty assessment report.

4.6.4 Reporting of the expanded uncertainty

Unless otherwise required, the result L_{m} of an emissions measurement should be stated together with the expanded uncertainty $U(L_{\mathrm{m}})$, calculated using a coverage factor k = 2 [as described in Equation (4) of 4.4.5]. The following form of reporting is recommended:

<Result>: $< L_{\mathrm{m}} \pm U(L_{\mathrm{m}}) >$ <unit>

where the reported uncertainty is an expanded uncertainty, as defined in ISO/IEC Guide 98-3 and calculated using a coverage factor of 2 which gives a level of confidence of approximately 95 %.

The coverage factor should, of course, be adjusted to show the value actually used. However, for EMC testing, it is a general practice to apply a coverage factor $k = 2$ that corresponds to a level of confidence of approximately 95 %.

EXAMPLE Maximum disturbance power: [(39,5 ± 4,3) dB(pW)]. *

*The reported uncertainty is an expanded uncertainty calculated using a coverage factor of 2, which gives a level of confidence of approximately 95 %.

The numerical values of the result and its uncertainty should be stated with appropriate resolution; a large number of digits should be avoided. For the expanded uncertainty of emissions measurements, it is not necessary to provide more than one significant digit for the uncertainty expressed in dB. Results should be rounded to be consistent with the uncertainty given.

4.7 Application of uncertainties in the compliance criterion

4.7.1 Introductory remarks

4.7.1.1 Compliance determination scenarios

4.7.1.1.1 General

Compliance of an EUT to emission requirements requires that the disturbance level be below a particular limit. The uncertainty of an emission measurement result has an impact on the pass/fail determination. The following two scenarios should be considered:

1) The limit was established without consideration of an uncertainty applicable to the measurement method; or
2) The limit was established with consideration of an uncertainty applicable to the measurement method.

4.7.1.1.2 Judging compliance with uncertainty being considered

Considering scenario 1) of 4.7.1.1.1, it is necessary to take into account the uncertainty of the measurement method when determining compliance with an emission limit. This leads to the following four cases (see Figure 8):

a) the measurement result exceeds the limit level, by a margin greater than the expanded uncertainty value applicable to the measurement;
b) the measurement result exceeds the limit level, by a margin less than the expanded uncertainty value applicable to the measurement;
c) the measurement result is below the limit level, by a margin less than the expanded uncertainty value applicable to the measurement;
d) the measurement result is below the limit level, by a margin greater than the expanded uncertainty value applicable to the measurement.

Case a) may be interpreted as a situation of non-compliance with a confidence level of 95 %. This is because the lower limit of the expanded uncertainty range of the results at 95 % confidence level is above the limit level.

Case b) may be interpreted as a situation of non-compliance with a confidence level of less than 95 %. This is because the lower limit of the expanded uncertainty range of the results at 95 % confidence level is below the limit level.

Case c) may be interpreted as a situation of compliance with a confidence level of less than 95 %. This is because the upper limit of the expanded uncertainty range of the results at 95 % confidence level is above the limit level.

Case d) may be interpreted as a situation of compliance with a confidence level of 95 %. This is because the upper limit of the expanded uncertainty range of the results at 95 % confidence level is below the limit level.

Cases b) and c) will require individual consideration, for example based on any agreements between the user of the data, the manufacturer of the EUT or the re-testing party. Both parties may apply different compliance criteria, depending on the purpose of the conformity assessment and the risks involved. Similar compliance considerations for emission measurements are given in LAB 34 [46].

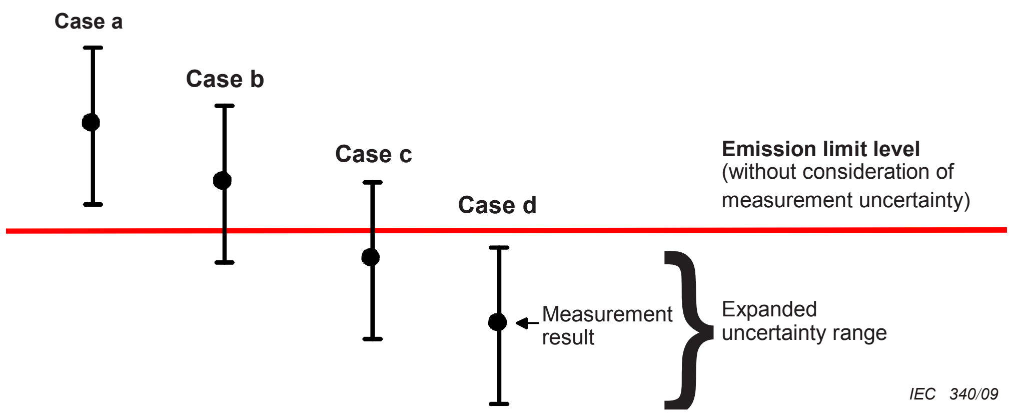


Figure 8 – Graphical representation of four cases in the compliance determination process without consideration of measurement uncertainty during limits setting

4.7.1.1.3 Judging compliance when uncertainties were considered during limits setting

Considering scenario 2) of 4.7.1.1.1, a judgement of compliance depends upon:

a) the amount of uncertainty determined by the test laboratory to be applicable to the measurement;

b) the amount of uncertainty that was considered when the limit level was established.

As discussed in 4.3, CISPR/H should determine and document the uncertainty allowance that was used to establish the limit level.

If the value from a) exceeds that from b), then the value from a) minus the value from b) shall be used as the uncertainty, and product compliance shall be determined as above for scenario 1).

If the value from a) is less than or equal to that from b), no consideration of measurement uncertainty is required in the determination of compliance, which leads to the four cases a) through d) shown in Figure 9. This situation is covered in CISPR 16-4-2, where a clear approach for the pass/fail determination of a device that takes the MIU into consideration is provided.

For this situation, cases a) and b) fail, while cases c) and d) pass.

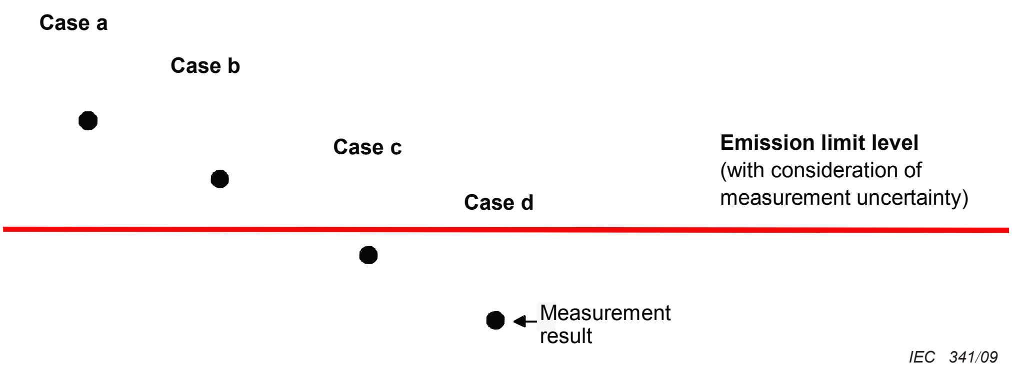


Figure 9 – Graphical representation of four cases in the compliance determination process with consideration of measurement uncertainty during limits setting.

4.7.1.2 Consideration of uncertainty categories

In the preceding subclauses, two different scenarios are described for the compliance assessment process. In the following, effects of different categories of uncertainties are taken into account. These different categories of uncertainty are used in various test applications (see also 4.2.2, 4.2.3 and Table 4). It can be assumed that the different categories of uncertainties result in an overall uncertainty $U(L_m)$ as shown in Figure 10.

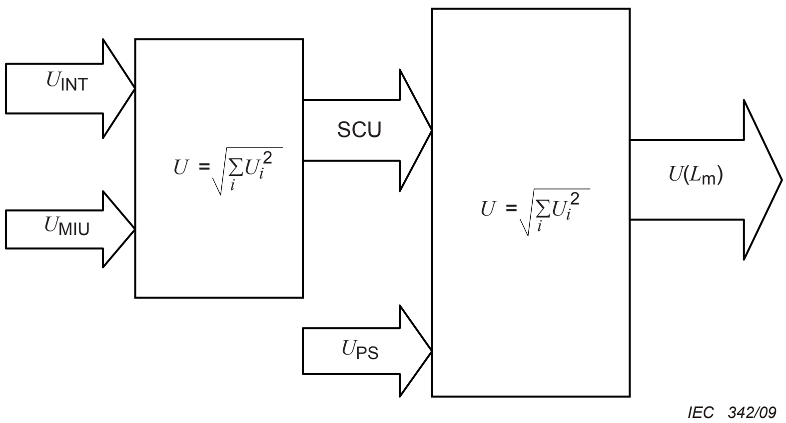


Figure 10 – Generic relation between overall uncertainty of measurand and some major categories of uncertainties

Figure 10 illustrates that generally a certain number of independent uncertainties contribute to the overall uncertainty of an emission measurement; the concept is formulated in Equation (1) as well. This concept can be explained by assuming that the overall uncertainty is equal to the root of the sum of the squares of a number of uncorrelated uncertainty contributions that are expressed as standard uncertainties:

$$U(L_m) = \sqrt{U_{MIU}^2 + U_{INT}^2 + U_{PS}^2} \quad (9)$$

where

$U(L_m)$ is the overall uncertainty of the measured level L_m involved for a particular application,

U_{MIU} is the measurement instrumentation uncertainty that was determined for a specific test set-up in accordance with CISPR 16-4-2,

U_{INT} is the intrinsic uncertainty of the measurand, and

U_{PS} is the uncertainty due to the spread of emission performance of the total population of manufactured products.

Figure 10 helps to identify the relevant uncertainty contributions for different applications. Furthermore, different parties involved may be able to influence or limit only some uncertainty categories, but not all of them, i.e.:

- A test laboratory may only have direct impact on the MIU through the use of adequate test equipment and test sites and by performing calibrations and validations. Typical state-of-the-art test equipment and test sites have a lower bound of uncertainty. Therefore, the MIU cannot be reduced to an infinitely small value, due to practical and economical considerations.
- The intrinsic uncertainty of the measurand is an intrinsic property of the EUT associated with certain types of EUTs in combination with the measurement method and measurement procedure. This intrinsic uncertainty is beyond the control of a test laboratory. It is an intrinsic property of a certain type of EUT in combination with the standardized measurement method. Standardization bodies are responsible for reducing the intrinsic uncertainty of a measurand as much as possible.
- The unintended emission properties of a product depend on tolerances of functional electrical properties of the product. Also manufacturing tolerances and parasitic (non-functional) electromagnetic properties of components, wiring and modules determine the emission performance of a product. Consequently the emission performance of the total population of manufactured products is a variable with a certain probability distribution. The spread of the emission performance of the total population of manufactured products can be considered as an uncertainty if compliance tests are done with a limited sample size. The spread of the emission performance is determined by the design and manufacturing. The uncertainty is determined by the statistical property of the involved product (spread of emission performance) and by the sample size. Therefore the associated uncertainty and the manner in which this uncertainty is considered in the pass/fail criterion is the responsibility of the manufacturer (i.e. 80 %/80 % rule; see also 4.7.3).

The possibility to control or minimize certain categories of uncertainties should be considered when compliance criteria are developed. Rationales and options to limit certain categories of uncertainties will vary depending on the parties involved, e.g. manufacturer, test laboratory, standards body, or authorities. The burden of the different uncertainty categories should be ‘allocated’ to the parties involved in the conformity assessment process who are able to control a specific uncertainty category in question. If such allocation is not possible, or if several parties are responsible, then ‘shared-risk’ concepts should be used. In the “shared risk” concept the measurement results of the test laboratories are accepted by all parties involved without consideration of measurement uncertainty. Each party accepts that there is a risk for over- or under-testing of the EUT.

Because different categories of uncertainties apply for different applications, different uncertainty budgets and different acceptance criteria may also apply for different applications. Table 4 shows some examples of different applications and the associated categories of uncertainties. In the following subclauses, the compliance (pass/fail) criteria are considered for a number of applications in more detail, i.e.:

a) manufacturers' compliance criterion for compliance measurements (4.7.2);
b) compliance criterion for mass-produced products (4.7.3);
c) compliance criterion for quality assurance tests (4.7.4);
d) application of uncertainties in re-testing (4.7.5).

4.7.2 Manufacturers' compliance criterion for compliance measurements

In CISPR 16-4-2 the following compliance criterion is used: the measured level is in compliance with the limit if

$$L_m \le L_{lim} \quad \text{and} \quad L_m + U(L_m) \le L_{lim} + U_{cispr} = L_{eff} \qquad (10)$$

This criterion is shown in a graphical form in Figure 11, where U_{cispr} is an agreed (default) quantity, specified in Table 1 of CISPR 16-4-2:2003, for different types of disturbance measurements.

This compliance criterion means that if the uncertainty of a test laboratory exceeds an agreed value U_{cispr}, the excess $U(L_m) - U_{cispr}$ shall be taken into account when determining pass/fail against the limit L_{lim}.

The magnitude of the agreed value U_{cispr} quantity shall reflect that a test laboratory, using state of the art equipment, facilities and procedures, may typically comply without having to take into account the 'penalty factor' $U(L_m) - U_{cispr}$. It should be noted that the value of U_{cispr} is based on measurement instrumentation influence quantities only.

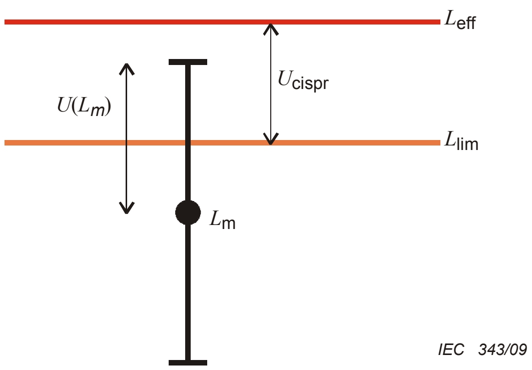


Figure 11 – Graphical representation MIU compliance criterion for compliance measurements, per CISPR 16-4-2

4.7.3 Compliance criteria for mass-produced products (80 %/80 % rule)

For type testing of mass-produced articles, the spread in results of emission measurements is addressed, for the uncertainty point of view, by the following two methods (see CISPR/TR 16-4-3):

1) testing of one representative sample of the product, and with subsequent periodic quality assurance tests, or;
2) testing of a representative and finite number of samples, with statistical evaluation of the measurement results in accordance with the 80 %/80 % rule.

The compliance criterion for these two cases is different. In the first case (i.e. periodically testing one sample), the product passes as long as the limit is not exceeded. In the second case, a penalty margin is incorporated in the compliance criterion that depends on the number of samples (student's-*t* distribution), or the results are compared directly with the limit and a number of samples may be rejected depending on the total number of samples (binominal distribution).

Both of these 80 %/80 % compliance criteria are based on a direct comparison of the measured value of the measurand against the limit, and the MIU is not taken into account.

NOTE It has not yet been established by CISPR/A how the 80 %/80 % rule compliance criterion, specified in CISPR/TR 16-4-3, and the MIU compliance criterion of CISPR 16-4-2, are to be combined in situations were both criteria are applicable. The combination of the two compliance criteria remains a subject of further investigations within CISPR/A.

4.7.4 Compliance criteria for quality assurance tests using a reference EUT

Data obtained from periodic quality assurance tests or ad-hoc checks can be compared directly with reference results (see 4.5.5). Pass/fail criteria shall be applied, that are related to the magnitude of the measurement instrumentation uncertainty of the measurand, because when using a reference EUT, the intrinsic uncertainty is generally small and therefore not incorporated in the quality assurance test. A maximum deviation of 20 %, with respect to the MIU, is considered an acceptable pass/fail criterion.

4.7.5 Application of uncertainties in re-testing

Re-testing takes place if a sample of products that was tested as compliant with a relevant standard by a test laboratory is tested a second time by another test laboratory.

The sample of products may be as follows:

a) several samples of a specific product (i.e. specific model number) from a single manufacturer;

b) single samples from the product line offered by a single manufacturer;

c) single samples of comparable models from different manufacturers (i.e. the group being considered as a product type).

This subclause provides guidance for situations of disagreement between the results obtained from two laboratories (i.e. when the test results lead the laboratories to come to different conclusions regarding the compliance status of the sample of products).

During compliance measurements by the re-testing laboratory (or the laboratory of a relevant authority), the SCU indirectly plays a role. The test laboratory compares the measured result with the limit of the product standard and subsequently decides, following the rules of CISPR 16-4-2 (i.e. using the MIU), whether the product complies with the provisions of the relevant standard. It is up to the manufacturer to estimate the risk of non-compliance in a re-testing situation, considering that the SCU of a particular test may be much larger than the MIU. For this reason, the order of magnitude of the SCU for each test method and for certain categories of EUTs should be known.

d) In cases of product non-compliance found during re-testing, the measurement results obtained will be compared with relevant measurement results from a type test for the same type of product as obtained by another test laboratory performing testing on behalf of the manufacturer.

Subsequently, the disagreeing parties are tasked to determine the reasons for the differences in the conformity assessment results. This process may be accomplished by comparing the specific technical conditions encountered and used during the respective compliance measurements. Eventually the disagreeing parties may come to a unique approach and decision as to whether or not the type of product in question complies with the limits (and provisions/intent) of the standard. In this context, the effort of determining the SCU is resolved on an individual (case-by-case) basis.

If the SCU evaluations between the manufacturer’s test laboratories and the re-testing laboratory indicate that the technical content of the relevant standards can be interpreted in different ways, then such findings should be reported to the responsible standards developing organization, including a request for amendment or corrigendum to the standard so as to address the ambiguities found.

The re-testing laboratory should take particular care to minimise the SCU involved in a particular measurement. In accordance with the provisions of the applied standard, a careful maximization of the EUT emissions is to be performed. In general, all possible modes of operation and test arrangements of the EUT should be considered to assure that the maximum disturbance level is measured. In other words, the EUT should be:

1) in a test arrangement that reflects the typical and intended use of the product and generates the maximum disturbance levels, and
2) in the operating mode which generates the maximum disturbance levels.

Therefore the test laboratory has to determine the worst-case arrangement and mode of operation to be able to determine the maximum disturbance levels before making a final decision about the compliance of the product. Nevertheless this Technical Report does not call out further requirements for the identification and determination of the maximum emission levels generated by an EUT.

Due to the general statements in the product standards, it cannot be ensured that a test laboratory will identify and record the maximum emission levels of an EUT. This increases the risk of not capturing the worst-case (i.e. maximum) emission levels and therefore increases the SCU as well.

In a re-test scenario, it is impossible for both the re-testing laboratory and the manufacturer’s laboratory to fully take the SCU into account, since the SCU-values may be quite large for certain test methods or even more important, since the SCU-values of test methods are unknown. Therefore the following procedure can be considered as a practical approach:

- The re-testing laboratory measures and assessments of a product in accordance with the specific product standard. If the product is determined to be non-compliant, the manufacturer, who is confronted with this non-compliance, has to explain the applied procedure and measurement results that lead to the declaration of conformity. This will require the review of the final test report of the compliance test.
- If the manufacturer’s laboratory used a mode of operation or test arrangement that differs from the one the re-testing laboratory used but is in accordance with the applied standard, then the re-testing laboratory will replicate the test of the product in accordance with the description of the manufacturer’s test report.
  – If the replicated measurement reveals that the difference in measurement results of the manufacturer’s test laboratory and the re-testing laboratory is caused mainly by differences in the set-up and/or operating mode (due to ambiguities in the relevant standard), then the re-testing laboratory will acknowledge the manufacturer's test report and revise its own decision. As a consequence it is up to the re-testing laboratory to bring the discovered ambiguity in the standard to the attention of responsible standard committee.
  – If this replicated measurement indicates that, in accordance with the provisions of the applied standard, the manufacturer’s test laboratory has failed to identify and record the maximum emission of the EUT during the compliance measurement, then the conformity decision of the re-testing authority prevails.

The decision-making process of the re-testing laboratory in regard to non-compliance of the product should take the uncertainty of the reproducibility (i.e. SCU) into account. For this reason, the orders of magnitude[2] of SCU values for each test method and for certain categories of EUTs should be available as general guidance for consideration by the decision making parties, the manufacturer, the authority, or other parties if needed.

In this technical report it is not possible to provide more specific guidelines on application of compliance criteria for re-testing laboratories.

The approach described in this subclause is applicable for market-surveillance reasons by the authority and also for re-testing or reproducibility disputes in case a manufacturer subcontracts different laboratories for compliance testing of products.

5 Basic considerations on uncertainties in immunity testing

Under consideration.

The SCU considerations of immunity tests differ from the emission SCU considerations in terms of particular parameters, for example, the measurand is often a functional attribute of the EUT rather than a quantity.

6 Voltage measurements

6.1 Introductory remarks

This report deals with modelling of CISPR standardized voltage measurements in order to identify the possible contributions to the standards compliance uncertainty, with the exception of:

a) product variability that is covered by the CISPR 80 %/80 % sampling procedure, and;

b) test-house induced uncertainties (see Clause 4).

After a discussion of the voltage measurement basics in 6.2.2, voltage measurements using a voltage probe are discussed in 6.3. Voltage measurements using a V-terminal artificial mains network applied to Class II appliances with only a mains cable are discussed in 6.4. Additional voltage measurements, for example, on appliances equipped with a protective earth, appliances with more than one connected cable, and appliances connected to ancillary equipment, are under consideration.

6.2 Voltage measurements (general)

6.2.1 Introductory remarks

Subclause 6.2.2 presents a consideration of the voltage measurements basics, followed by some remarks about voltage measurements using a voltage probe (see 6.3). After that, the most commonly used conducted emission measurement is discussed, i.e. the emission measurement using a V-type artificial mains network (see 6.4). Throughout the discussion, it is assumed that the EUT is a two-terminal device: only one two-wire mains cable is connected to the EUT. N-terminal devices (N > 2) with or without connections to ancillary equipment are under consideration.

6.2.2 Voltage measurements basics

6.2.2.1 Specification of the measurement loop

A voltage is always measured between two specified terminals. Figure 12 illustrates such a measurement. U_{12} is the voltage of interest. The measurement leads transport the signal to

2 “Orders of magnitude” means that values such as 1 dB, 3 dB, 6 dB, 10 dB or 20 dB can be selected for SCU.

the terminals 3 and 4 of the load impedance Z_L formed by the input impedance of the voltmeter, and U_{34} is the actual measured voltage. The EUT, leads and voltmeter load impedance form a loop of which the contour is denoted by C, and the loop area by S.

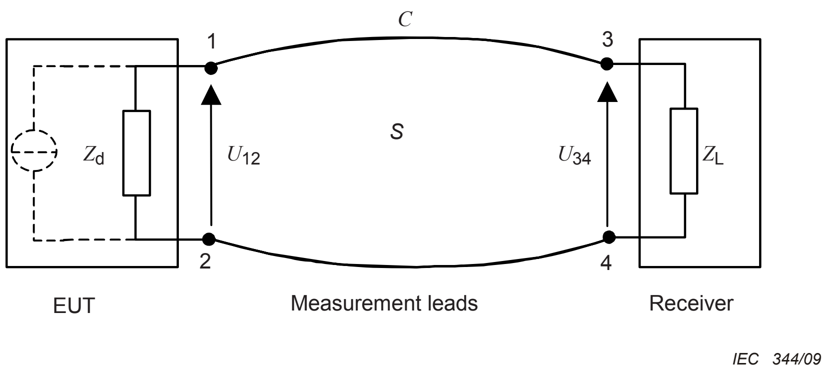


Figure 12 – Basic circuit of a voltage measurement

In particular when the internal impedance of the disturbance source is unknown (as is usually the case in compliance testing) care shall be taken that $Z_L >> Z_d$ otherwise the measured voltage depends on Z_L in an unknown way, creating large contributions to the standards compliance uncertainty. Consequently, Z_L has to be specified starting from estimated or measured values of Z_d for the class of subject EUTs.

NOTE 1 Specifying only one terminal, the 'hot' terminal, and assuming that the other terminal can be any point that is 'grounded', is allowed only in electrostatics, i.e. at d.c. (zero frequency) (see 6.3).

NOTE 2 Stray capacitances may limit the maximum value of Z_L (see 6.3).

6.2.2.2 Measurement loop constraint

The result of the voltage measurement has a physical meaning if, and only if, the circumference of the measurement loop (the contour C) is electrically small, i.e. if the circumference of the loop is small compared to the wavelength of the signal, or compared to the signal component to be measured.

If this condition is not satisfied, resonance effects will occur, creating large and undefined uncertainty contributions. These uncertainties may be reduced to an acceptable level by placing the load impedance close to the terminals where the voltage has to be measured, and to transport the measurement signal to the receiver via a transmission line, such as a coaxial cable. The characteristic impedance of that line should match the input impedance of the receiver. The possible mismatch is often expressed as a voltage standing wave ratio (VSWR). See also 6.4.6.2.

If the condition 'C electrically small' is satisfied, the use of a lumped element equivalent circuit to describe a voltage measurement is allowed. Unless indicated otherwise, it is assumed that this condition has been satisfied.

6.2.2.3 The measured voltage

Faraday's law is always applicable to a voltage measurement loop. For the loop given in Figure 12 this means that

$$\oint_c \vec{E} \times \mathrm{d}\vec{l} = -\frac{\partial}{\partial t} \oiint_S \vec{B} \times \mathrm{d}\vec{s} \tag{11}$$

where the electric field $\vec{E}$ and the magnetic flux density $\vec{B}$ are generated by the disturbance source inside the EUT, or by some ambient disturbance source. Unless specified otherwise, the latter source is assumed to be negligibly small; for example, the measurement set-up is sufficiently screened.

From Equation (11) it follows that the voltage U_{34} is given by

$$U_{34} = \int_3^4 \vec{E} \times d\vec{l} = U_{12} - \int_1^3 \vec{E} \times d\vec{l} - \int_4^2 \vec{E} \times d\vec{l} - \frac{\partial}{\partial t} \oiint_S \vec{B} \times d\vec{s} \qquad (12)$$

where U_{12} is the voltage to be measured. In this equation, the contribution of the magnetic field term to U_{34} often dominates. Therefore, the voltage measuring method shall include a sufficiently accurate description of the layout of the measuring leads.

A numerical example illustrating the importance of the influence of the physics described by Faraday's law on the measurand is given in Annex B.

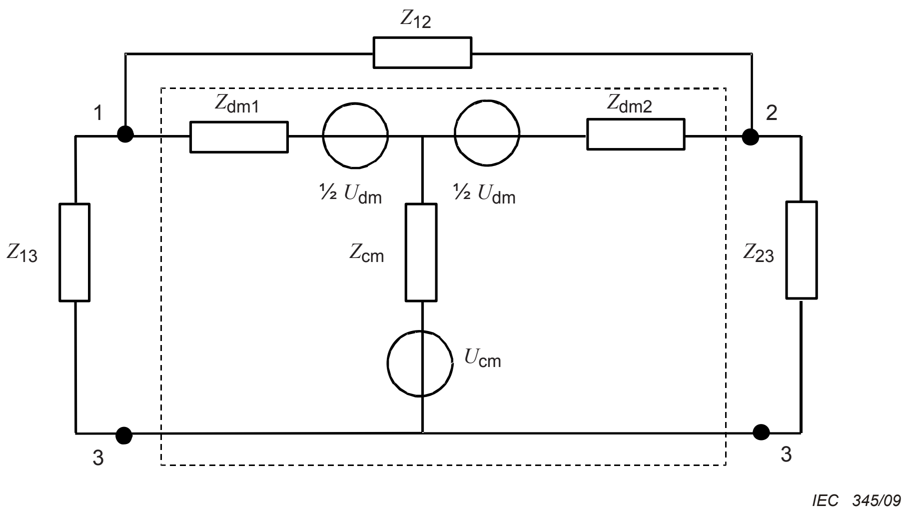


Figure 13 – Basic circuit of a loaded disturbance source (N = 2)

6.2.3 The disturbance source and types of voltage

6.2.3.1 General

At the interface, the disturbance voltage is measured while the measurement loop constraints are satisfied. The source creating that voltage can be described by a lumped element N-port. Since differential-mode (DM) and common-mode (CM) phenomena are of importance, the number of terminals of the N-port equals N + 1, where N is the actual number of terminals. The additional terminal represents the surroundings of the source to which coupling via electric and magnetic fields is possible and to which the source may have a galvanic connection. It is the task of the standards author to define the surroundings in such a way that this additional terminal is a relevant reference point in the voltage measurement.

In this subclause N = 2 is assumed, so that a three-terminal network results and the equivalent circuit of Figure 13 applies. An example of an EUT presenting an N = 2 disturbance source is

a) an appliance with only a two-wire mains lead, and

b) the voltage is to be measured at the mains connector terminals.

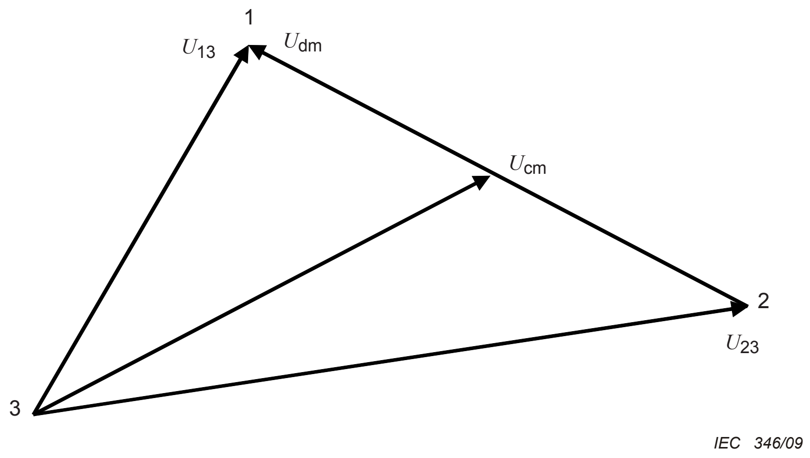


Figure 14 – Relation between the voltages

In Figure 13, all elements are – in principle – frequency-dependent. Z_{dm1} and Z_{dm2} represent the internal impedance of the equivalent DM source with open-circuit voltage U_{dm}. In general, $Z_{dm1} \neq Z_{dm2}$ as at the frequencies of interest the circuit will seldom be symmetrical. Z_{cm} is the internal impedance of the equivalent CM source with open-circuit voltage U_{cm}. The load is represented by the impedances Z_{13} and Z_{23} between the actual terminals 1 and 2 and the reference 3, and the impedance Z_{12} between the actual terminals. Denoting the voltages across Z_{13} and Z_{23} by U_{13} and U_{23}, the relation between these voltages and U_{dm} and U_{cm}, is given in Figure 14.

6.2.3.2 Interference probability

The DM- and the CM-conducted emission voltage level are, in general, a figure-of-merit for the interference potential of an appliance when the main coupling mechanism to the victim is crosstalk. In addition, the CM-conducted emission voltage level is generally also a figure-of-merit when the main coupling mechanism is (far-field) radiation. However, in the latter case, the CM current is generally a more direct figure-of-merit (see C.5). The so-called unsymmetrical conducted emission levels U_{13} or U_{23} give, in general, no information about the interference potential of an appliance. Additional information about the phase angle between U_{13} and U_{23} is needed to convert these voltages into the relevant voltages U_{dm} and U_{cm}. So in compliance probability studies, both the DM and CM properties of the disturbance signal have to be considered.

6.2.3.3 CM/DM and DM/CM conversion

The parasitic properties, for example, parasitic capacitance and stray inductance, of a voltage measuring device may cause an unwanted conversion of DM disturbances into CM disturbances, and vice versa. Therefore, the DM/CM or CM/DM conversion properties of a voltage-measuring device may play a part in uncertainty studies, in particular those of artificial or impedance simulation networks. The conversion properties may also be desired in the case where these properties dominate the compliance probability in actual situations. To give some examples:

a) if the device is used to simulate a telephone-subscriber line, the conversion properties should be related to the actual conversion properties of those lines;

b) if the device is used to investigate the conversion properties of telephone-subscriber lines, the conversion properties of the device shall not influence the results of that investigation;

c) if the device is used to characterize the CM-disturbance signal emitted by a given EUT via the telephone-subscriber line port, the DM/CM conversion properties of the device shall not influence the measurement results. In addition, the DM/CM conversion properties of the ancillary equipment, connected to that port during the emission test, shall not influence the measurement results.

6.3 Voltage measurements using a voltage probe

When using a voltage probe it is very important to specify the two terminals between which the voltage is to be measured. As already mentioned in Note 1 of 6.2.2.1, specifying only one terminal, the 'hot' terminal, and assuming that the other terminal can be any point that is 'grounded' is only allowed in electrostatics, i.e. at d.c. (zero frequency). In the case of a two-terminal disturbance source, the circuit of Figure 13 applies, where Z_{13}, Z_{12} and Z_{23} represent the generally unknown and unequal load impedances of the source, for example, those formed by the mains network. If, for example, the voltage between terminals 1 and 3 is measured, the input impedance of the voltage probe is in parallel with Z_{13} and in parallel with (Z_{12} + Z_{23}).

In addition, the layout of the measurement loop has to be specified to assure that the measurement loop constraint is met (6.2.2.2), as resonance effects contribute to the uncertainty in the voltage to be measured. That layout specification should be such that it minimizes the voltage that may be induced by the magnetic field emitted by the EUT itself. The latter voltage contributes to the uncertainty of the voltage to be measured. A numerical example is given in Annex B.

As specified in CISPR 16-1-2, the voltage probe is a device having a large input impedance (for example, 1 500 Ω). As a consequence, attention has to be paid to the possible effect of the stray capacitance between the 'hot' input terminal of the probe and its surroundings. That capacitance reduces the effective input impedance of the probe (Z_{13}), thus creating an uncertainty contribution. In addition, if the input impedance is not very much larger than the source impedance (*a priori* unknown in a compliance test), an additional uncertainty may be introduced as a result of the uncertainty in the voltage division factor. Moreover, the loading by the voltage probe having an insufficiently large input impedance may cause an unbalanced loading of the disturbance source, and since generally $Z_{dm1} \neq Z_{dm2}$, this unbalance may differ when measuring the voltage between the terminals 2 and 3, compared to that between 1 and 3.

Finally, the unsymmetrical voltage measured by the probe is not a direct figure-of-merit for the interference potential of the EUT. Hence, it gives no information about the interference probability so the standardized use of the probe should be kept to an absolute minimum.

In summary, in a well-written standard both EUT terminals in the voltage-probe measurement shall be carefully specified, as well as the layout of the leads between these two terminals and the two terminals of the probe. Moreover, attention should be paid to the magnitude of the input impedance of the probe relative to the actual load impedance of the EUT disturbance source. In Annex C, attention is paid to possible improvements of CISPR standards.

6.4 Voltage measurement using a V-terminal artificial mains network

6.4.1 Introductory remarks

The V-terminal artificial network (V-AMN) essentially forms a T-network or π-network loading of the disturbance source. Throughout 6.4, it is assumed that the EUT is a two-terminal device: only one two-wire mains cable is connected to the EUT. Assuming a π-network loading, the basic circuit with the impedances Z_{13}, Z_{23} and Z_{12} as given in Figure 13 applies at the interface of the measurement impedances. Clause 4 of CISPR 16-1-2 specifies the two unsymmetrical impedances Z_{13} and Z_{23}, including the tolerance of the absolute value of these impedances. In Clause 4 of CISPR 16-1-2, the shunt-impedance Z_{12} is a non-specified influence quantity; it seems that CISPR assumes that Z_{12} is always 'infinitely' large.

NOTE Subsequent to when Subclause 6.4 was originally written, Clause 4 of CISPR 16-1-2 was amended to include specification of the magnitude and phase angle for the AMN impedance, as well as tolerances for both.

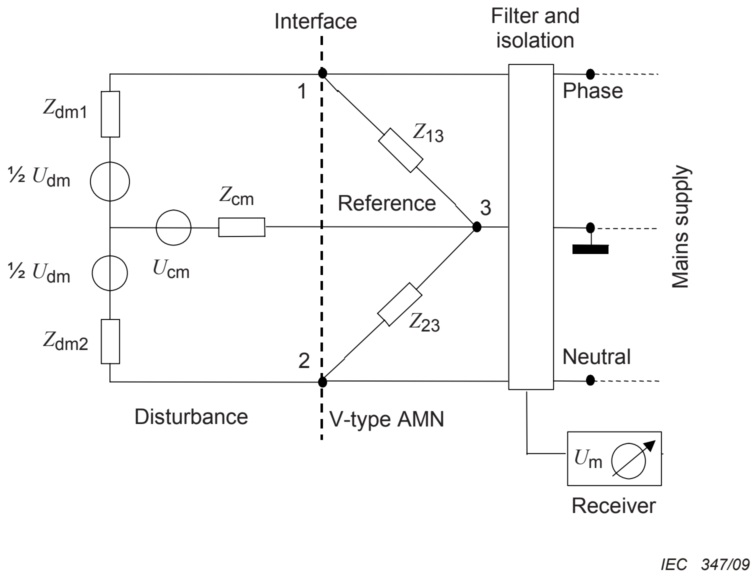


Figure 15 – Basic circuit of the V-AMN voltage measurement (N = 2)

The basic circuit can be described as in Figure 15. The filter and isolation between the measurement circuit and the mains terminals is, to some extent, also specified in Clause 4 of CISPR 16-1-2. The unsymmetrical voltages across Z_{13} and Z_{23} have to be measured (see Annex C of this technical report for comments in regards to interference probability).

Valuable information about uncertainties associated with this type of measurement, that also may influence the calibration of the V-AMN, can be found in [49] and [44].

6.4.2 Basic circuit diagram of the voltage measurement

When reading the level U_m at the CISPR receiver, the circuit of Figure 15 'reduces' to that of Figure 16. In Figure 16 U_d and Z_d, being non-specified influence quantities, represent the effective disturbance source at the interface formed by the subject unsymmetrical input terminal of the V-AMN and the reference of the voltage measurement set-up. The latter is normally the metal enclosure of the V-AMN. Z_{in} is the input impedance of the measurement set-up as experienced by the disturbance source. Z_{in} is a specified influence quantity that can be influenced by non-specified or by not sufficiently specified quantities (see 6.4.6). The factor $\alpha = \frac{U_m}{U_{in}}$, where U_{in} is the voltage across Z_{in}. This factor is, to a large extent, deterministic. In the absence of uncertainties, that is in the ideal situation, Z_{in} = Z_{13} = Z_{23}, for example, equal to 50 Ω in parallel with 50 µH, and α = 1.

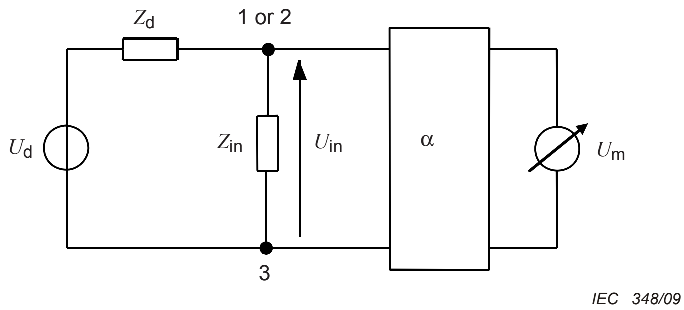


Figure 16 – Basic circuit of the V-AN measurement during the reading of the received voltage U_m (the numbers refer to Figure 15)

6.4.3 Voltage measurement and standards compliance uncertainty

If U_{mt} is the true level of the voltage reading at the CISPR receiver in the ideal situation, U_{mt} is given by

$$U_{mt} = \frac{\alpha_0 Z_{13}}{Z_{d0} + Z_{13}} U_{d0} \tag{13}$$

where α_0 is the true value of α. Z_{d0} and U_{d0} are the true values of the disturbance source parameters when the source is loaded with the ideal impedance Z_{13}. However, in the actual set-up, the parameters are α, Z_{in}, Z_d and U_d, so the voltage reading U_m is given by

$$U_m = \alpha \frac{Z_{in}}{Z_d + Z_{in}} U_d \tag{14}$$

After substitutions of $U_m = U_{mt} + \Delta U_m$, $\alpha = \alpha_0 + \Delta\alpha$, $Z_{in} = Z_{13} + \Delta Z_{in}$, $Z_d = Z_{d0} + \Delta Z_d$ and $U_d = U_{d0} + \Delta U_d$ it follows from Equation (13) and Equation (14) that

$$\frac{\Delta U_m}{U_{mt}} = \frac{Z_{d0} + Z_{13}}{Z_d + Z_{in}} \left(\frac{\Delta\alpha}{\alpha_0} + \frac{\Delta U_d}{U_{d0}} \right) + \frac{Z_{d0}}{Z_d + Z_{in}} \left(\frac{\Delta Z_{in}}{Z_{13}} - \frac{\Delta Z_d}{Z_{d0}} \right) \tag{15}$$

if higher order terms in Δ are neglected. If knowledge is available about the actual value and deviations it may be possible to apply corrections [1]. For example, if from independent measurements it can be concluded that the actual value of Z_{13} shows a systematic difference with its ideal value and the difference is within the allowed tolerance of Z_{13}, the actual value may be inserted in Equation (15).

In Equation (15), ΔU_m can be identified as the compliance uncertainty margin, which depends on the non-specified influence quantities Z_d and U_d, and the specified influence quantities α and Z_{in} (i.e. the influence quantities that can be determined from independent measurements and do not depend on the EUT properties). Moreover, two sensitivity coefficients can be identified:

$$c_1 = \frac{Z_{d0} + Z_{13}}{Z_d + Z_{in}} \approx \frac{Z_{d0} + Z_{13}}{Z_{d0} + Z_{13}} = 1 \tag{16}$$

$$c_2 = \frac{Z_{d0}}{Z_d + Z_{in}} \approx \frac{Z_{d0}}{Z_{d0} + Z_{13}} = \frac{1}{1 + \rho e^{j\varphi}} \tag{17}$$

The latter coefficient clearly depends on the non-specified influence quantity Z_d.

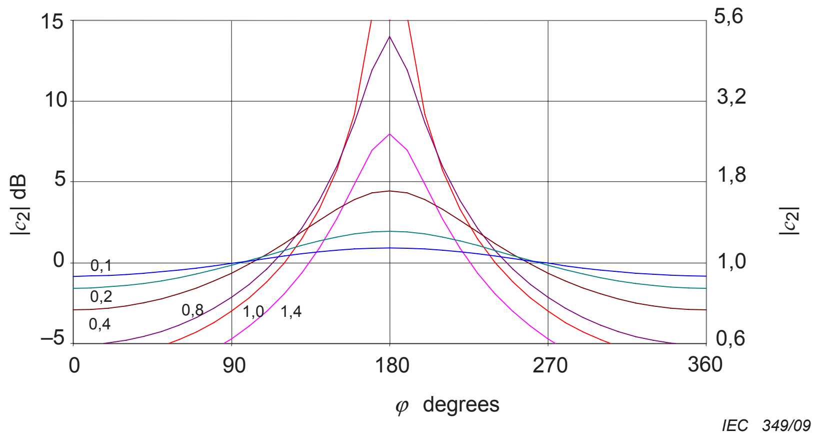


Figure 17 – The absolute value of the sensitivity coefficient c_2 as a function of the phase angle difference φ of the impedances Z_{13} and Z_{d0} for several values of the ratio $|Z_{13}/Z_{d0}|$

In Equation (17) $\rho = \rho_{13}/\rho_{d0}$ and $\varphi = \varphi_{13} - \varphi_{d0}$, which follow after writing $Z_{13} = \rho_{13}\exp(j\varphi_{13})$ and $Z_{d0} = \rho_{d0}\exp(j\varphi_{d0})$. Figure 17 shows the absolute value of c_2 for several values of ρ as a function of φ. It will be clear that additional information about Z_{d0} is needed to estimate c_2. However, that information is normally not available in a standardized compliance test. Hence, the standards authors have to make an estimate when drafting a standard for a certain class of equipment, for example, by carrying out a statistical investigation during the development of a standard.

6.4.4 Combined uncertainty

It should be noted that in Equation (15) all quantities are in linear units. Therefore, the combined uncertainty can be written as the root of the sum of the partial uncertainties squared (RSS). In standardized EMC compliance testing, logarithmic units are commonly used for the quantities and their uncertainty margin. Converting to logarithmic units, it follows from Equations (13) and (14) that

$$\frac{U_m}{U_{mt}}(\text{dB}) = \frac{\alpha}{\alpha_0}(\text{dB}) + \frac{Z_{in}}{Z_{13}}(\text{dB}) + \frac{U_d}{U_{d0}}(\text{dB}) - \frac{Z_d + Z_{in}}{Z_{d0} + Z_{13}}(\text{dB}) \tag{18}$$

so that

$$\Delta U_m(\text{dB}) = \Delta\alpha(\text{dB}) + \Delta Z_{in}(\text{dB}) + \Delta U_d(\text{dB}) - \Delta(Z_d + Z_{in})(\text{dB}) \tag{19}$$

The problem is the last term on the right-hand side of these two equations, since it is not possible to split up this term in one for Z_d and one for Z_{in}. So, in this case, there is no linear relationship between the various Δ terms and it is not correct to use the RSS as done in Equation (15). Additional information about Z_{d0} in relation to Z_{13} is needed to circumvent this problem. However, that information is normally not available in a standardized compliance test. Hence, the standards authors have to give a procedure for solving this problem for a certain class of equipment.

6.4.5 The compliance criterion

The compliance criterion is normally not formulated for U_m but for U_{in}, the voltage across Z_{in}. The true value U_{int} is then given by $U_{int} = \frac{U_{mt}}{\alpha_0}$. If the compliance uncertainty margin is indicated by ΔU_{in}, the ratio $\frac{\Delta U_{in}}{U_{int}}$ can be calculated from $U_{int} + \Delta U_{in} = \frac{U_{mt} + \Delta U_m}{\alpha_0 + \Delta\alpha}$.

6.4.6 Influence quantities

6.4.6.1 Introductory remarks

In this subclause, the influence quantities playing a part in the CISPR V-terminal voltage measurement discussed in 6.4.3 to 6.4.5 will be considered in some detail, particularly in view of a possible improvement of CISPR standards dealing with this type of measurement. Note that the influence quantities may not be independent [see, for example, 6.4.6.4 d) and e)], so not all phenomena are discussed in connection with each of the influence quantities.

The final standards compliance uncertainty study for voltage measurements on a two-terminal EUT using a V-terminal artificial mains network, shall start from the final model (the circuit description) depicted in Figure 19.

6.4.6.2 The input impedance Z_{in}

In the ideal case, the input impedance Z_{in} = Z_{13} (or Z_{23}), where Z_{13} is the specified input impedance of the V-AMN (see 4 of CISPR 16-1-2), a resistor R_{13} = 50 Ω in parallel with an inductor L_{13} = 50 µH. In the practical realization of the V-AMN, however, the actual input impedance may be influenced by

a) The actual value of the input impedance of the measuring receiver which in practice is assumed to represent R_{13}, plus the influence of the length of the transmission line between the V-AMN and the receiver. This effect can be characterized as a VSWR (see 6.2.2.2) and is discussed in detail in [15]. A procedure on how to characterize the VSWR is needed and a tolerance for this VSWR (in particular, *in situ*) has to be specified.
b) The influence of the unknown impedance of the mains network, which is in parallel with the specified input impedance (see Figure 14). The isolation needed to avoid this influence is to be specified.
c) The influence of the circuit parallel to Z_{13} as formed by Z_{23} in series with the non-specified impedance Z_{12} (see Figure 13). The latter impedance should be ‘infinitely’ large but will have a finite value in practice, so a specification is needed.

From this list of examples it will be clear that Z_{in} is not a completely specified influence quantity. [See also 6.4.6.4 d)].

In Clause 4 of CISPR 16-1-2 it is stated that for Z_{13} and Z_{23} a tolerance of 20 % is permitted around the absolute value of those impedances. In view of uncertainty contribution estimates, it is necessary to specify that tolerance in more detail, for example, as a tolerance of the absolute value of the impedance and a tolerance of the phase angle of that impedance (or that of its real and imaginary part).

NOTE A tolerance for the phase angle has been added for the V-AMN in CISPR 16-1-2:2003.

6.4.6.3 The attenuation factor α

The attenuation factor α is a non-specified influence quantity. However, in general it is a deterministic quantity that can be derived from independent measurements. Therefore, for a given and fixed V-terminal voltage measurement set-up in which α has been determined, it can be considered as a specified influence quantity.

Contributions to $\Delta\alpha$ may stem from losses in the V-AMN (also determined by some of the aspects mentioned in 6.4.6.2) and in the signal cable between V-AMN and receiver. Consequently, a specified procedure to determine α (in particular, *in situ*) is needed.

6.4.6.4 The effective disturbance source impedance Z_d

A marked difference between metrology measurements and EMC compliance measurements is that in the latter measurements the source impedance, Z_d, is a non-specified influence quantity.

From a comparison between the circuits of Figures 15 and 16 it follows that if U_{13} is measured, Z_d is given by

$$Z_d = Z_{dm1} + \frac{Z_{cm}(Z_{23} + Z_{dm2})}{Z_{cm} + Z_{23} + Z_{dm2}} \quad (20)$$

as easily follows when applying Thevenin's theorem. In this relation, Z_{dm1}, Z_{dm2} and Z_{cm} are non-specified influence quantities. An important observation is that Z_d depends also on the CM-impedance Z_{cm}. Hence, the coupling to the surroundings of the EUT plays a part in the measurement result. In Figure 18, this coupling is indicated by the parasitic capacitance C_{p1} between the relevant (electronic) parts of the EUT (so, as an example, not the plastic housing of that EUT) and the prescribed reference plane. In Figure 19 also magnetic field coupling is included, where a mutual inductance, M, plays a part. Depending on the EUT properties (for example, the dimensions of conducting parts of that EUT) it may be needed to include other parasitic effects. The two examples given here (electric field coupling characterized by C_{p1} and magnetic field coupling characterized by M) are assumed to be relevant in all cases.

Five possible uncertainty contributions will be considered:

a) Parasitic capacitance variations:

The emission standard specifies a distance, for example, 40 cm, between the housing of the EUT and the reference plane. However, the standard does not specify which side of the EUT housing has to face that plane. In Figure 18 the dashed line represents another allowed position of the reference plane at the correct distance from the EUT housing. However, the resulting parasitic capacitance is now $C_{p2} \neq C_{p1}$. Hence, the (allowed) variation of the parasitic capacitance contributes to the standards compliance uncertainty.

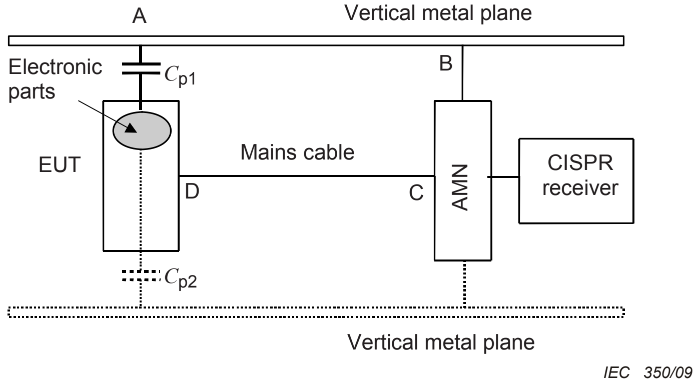


Figure 18 – Variation of the parasitic capacitance, and hence of the CM-impedance, by changing the position of the reference plane (non-conducting EUT housing)

The C_p variation can be reduced by replacing the vertical reference plane at the specified distance by a horizontal reference plane at that distance below the set-up and requiring that the EUT is always positioned at its normal feet.

b) Measurement loop constraint:

Figure 15 is applicable at the interface of the specified measurement impedances. To identify relevant uncertainty contributions, the complete set-up has to be considered where a mains cable is present and the distance between EUT and AMN is specified, for example, 80 cm. So in practice a CM-loop exists, in Figure 18 the loop ABCDA. At sufficiently high frequencies and sufficiently extended EUTs, for example, a fluorescent tube in its luminaire may be starting to violate the measurement loop constraint (6.2.2.2), thus creating resonant-like phenomena and the associated uncertainty contributions.

c) LC series circuit:

In Figure 18, the loop ABCDA can also be seen as an LC series circuit. Major contributions to the inductance stem from the mains cable and the specified grounding strap between V-AMN and the reference plane. In Figure 18 the capacitance is represented by C_{p1}, and, more generally, by C_p in Figure 19. This circuit plays a part in the CM impedance [see Equation (20)]. As a consequence, Z_d is sensitive to the total loop inductance as well, hence it is sensitive to the actual layout of the mains cable between the EUT and V-AMN. In particular, when meandering of the mains cable is needed, variations in the electrical loop may be large. Experimental results [48] show a variation of several dBs when the method of meandering is varied. Hence, meandering is another source of uncertainties and a detailed specification of the method of meandering is needed. See also 6.4.6.5 b) and c).

d) LC parallel circuit:

In practice, also the parasitic capacitance between the V-AMN and the reference plane (see C_{AMN} in Figure 19) may play a part. Then the parallel resonance of the inductance of the ground bonding strap and this parasitic capacitance may be resonant within the measurement frequency range, thus influencing in an unknown way the CM impedance. In other words, a contribution may be made to the variation of the results that can amount up to several dB [49]. In addition, the voltage difference between the reference point of the voltage measurements and the point on the reference plane where the strap is connected, is no longer zero, as has been tacitly assumed in the CISPR standards. So the afore-mentioned variation may also be interpreted as a variation in Z_{in} (6.4.6.2). The latter is an example of the statement made in 6.4.6.1 that the influence quantities are not always independent.

The contribution of the variation to the standards compliance uncertainty can be avoided by specifying an *in situ* measuring method, for example, one based on [49] to improve the set-up in such a way that a possible resonance is outside the frequency band considered in the compliance test.

e) Magnetic field coupling of parallel current loops:

Another example of the statement made in 6.4.6.1 that the influence quantities are not always independent is the magnetic field coupling of loop-1 and loop-2 (see Figure 19). This coupling that also influences the effective CM impedance, will be discussed in connection with U_d in 6.4.6.5.

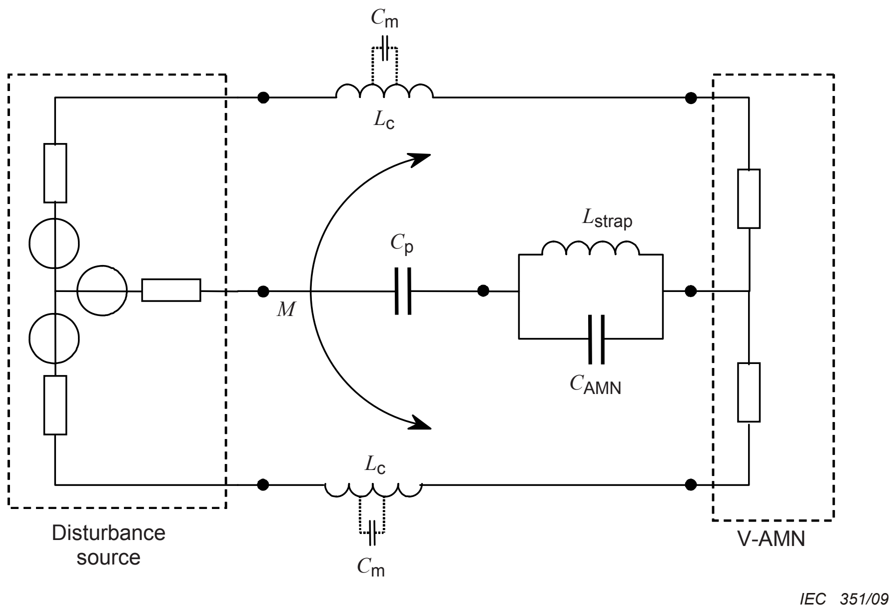


Figure 19 – Influence quantities in between the EUT (disturbance source) and the V-AMN

6.4.6.5 The effective open-circuit voltage source U_d

A marked difference between metrology measurements and EMC compliance measurements is that in the latter measurements the open-circuit voltage of the source is a non-specified influence quantity.

The open circuit voltage U_d depends on

1) the non-specified open-circuit voltages U_{dm} and U_{cm} (see Figure 15);
2) a contribution U_{ind} which may arise from an induction by the fields emitted by the product under test and is described by Faraday's law (see 6.2.2.3 and Annex B);
3) a contribution U_{Zt} which may arise via the transfer-impedance Z_t of the cable between the product under test and the V-AMN and that of the circuitry inside the V-AMN, i.e. contributions related to CM/DM and DM/CM conversion.

Additional considerations for these parameters are as follows:

a) U_{dm} and U_{cm}:

Since U_{dm} and U_{cm} are non-specified influence quantities their long-term stability may be very poor. In this case ‘long-term’ has to be compared with the measuring time of the emission measurement. Effects like warming-up time and in-rush period may influence that stability in an unknown way, thus giving rise to uncertainty contributions. On the other hand, this long-term stability may be sufficient, but the measurement time may be short compared to the possible variations of U_{dm} and U_{cm} due to the various modes of operation of the EUT resulting in mode-related values of U_{dm} and U_{cm}. Again, uncertainty contributions may result.

When a source is loaded, a feedback mechanism may cause a change of the source properties. This phenomenon is, for example, very well known in transistor circuits and, in the h-parameter description of a transistor, is quantified by the reverse parameter h_r. In resonant circuits, this effect is normally called 'pulling'. The effect may cause a change in the amplitude and/or the frequency characteristic of the disturbance signal. There are no physical reasons to assume that this kind of feedback mechanism is not present for the DM and CM components of the disturbance source. Hence, the feedback effect gives rise to the uncertainty contributions ΔU_{dm} and ΔU_{cm}. The effect can only be quantified when performing dedicated measurements. In metrology, where the open-circuit voltage, the source impedance and the load impedance are specified influence quantities, this effect is normally negligible as long as the loading of the source is within the specified values.

b) U_{ind}:

In particular since the CM-loop illustrated by the ABCDA in Figure 18 plays a part in the voltage measurement, it is important to consider contributions of the unwanted induced voltage (6.2.2.3) as the loop has a relatively large area. That area, and hence the induced voltage, depends on the layout of the set-up, and thus on the layout of the mains cable and its possible meandering. See also Annex B.

c) U_{Zt}:

The contribution U_{Zt} stems from the conversion of a DM disturbance into a CM disturbance and is determined by the properties of the mains cable between the product and the V-AMN and by the circuitry inside the V-AMN. The latter contribution can be made negligibly small by setting proper DM/CM and CM/DM conversion limits for the V-AMN in CISPR 16-1 series.

The mains cable influence can be expressed in terms of the cable transfer impedance that in the case of a two-wire mains cable can be written as [30]

$$Z_{\text{t}} = R_{\text{c}} + j\omega(L_{\text{c}} - M) = R_{\text{c}} + j\omega(1-k)L_{\text{c}} \tag{21}$$

where R_{c} is the resistive part of Z_{t} (about 10 mΩ per metre of cable), L_{c} the inductive part of Z_{t} (about 1 μH per metre cable). The constant $k = M/L_{\text{c}}$, where M is the mutual inductance between the two loops formed by one of the wires, part of the disturbance source, the ground plane and part of the V-AMN (see Figure 19). This constant ranges from about 0,6 (relatively wide separation) to 0,8 (relatively small separation). Since the transfer impedance of the cable between the product under test and the V-AMN is normally a non-specified influence quantity, the contribution to ΔU_{Zt} is generally unknown, so uncertainty contributions result. By considering the Kirchhoff equations for the circuit of Figure 19, it will be clear that the magnetic coupling between the two loops also influences the effective CM impedance.

NOTE The cable transfer impedance effect hardly plays a part in normal metrology measurements as the leakage of the wanted signal to the surroundings is normally so small that it will be difficult to measure. On the other hand, very small leakage may easily be large enough to cause the product not to comply with the emission limit.

When the layout of the cable between EUT and V-AMN contains meanders, the way these meanders are put influence L_{c} and M. Moreover, at the higher frequencies, a capacitive cross-talk over the meander part of the mains cable (in Figure 19 schematically represented by C_{m}) may play a part. As already mentioned, a non-specified meander layout may create relevant uncertainty contributions [48].

7 Absorbing clamp measurements

7.1 General

7.1.1 Objective

The primary goal of this clause is to provide information and guidance for the determination of uncertainties associated with the absorbing clamp measurement and calibration methods. This clause gives rationale for the various uncertainty aspects described in several parts of CISPR 16 related to the absorbing clamp, i.e.:

- the absorbing clamp calibration method (see Clause 4 of CISPR 16-1-3:2004);
- the absorbing clamp measurement method (see Clause 7 of CISPR 16-2-2:2003).

The rationale given in this clause is background information for the above-mentioned parts of CISPR 16 related to the absorbing clamp and it may be useful in the future when modifying these parts. In addition, this clause provides useful information for those who apply the absorbing clamp measurement and calibration method and who have to establish their own uncertainty estimates.

7.1.2 Introductory remarks

This subclause provides information on the uncertainties associated with the absorbing clamp test method (ACTM) described in CISPR 16-2-2, and with the absorbing clamp calibration methods described in CISPR 16-1-3. The uncertainty budgets on the ACTM as described in CISPR 16-4-2 or in LAB 34 [46] are not suitable for actual compliance tests in accordance with the CISPR specification given in CISPR 16-2-2. The reason is that this uncertainty budget is limited to the measurement instrumentation uncertainties (MIUs). Uncertainties due to the set up of the equipment under test (EUT) including the lead under test (LUT), and due to the measurement procedure are not taken into account. In this subclause, however, as far as the uncertainty considerations of the absorbing clamp measurement method is concerned, all the uncertainty sources that are relevant for the compliance test in accordance with the standard [the standards compliance uncertainty (SCU)] are considered. As far as these uncertainty calculations are concerned, it is assumed that the EUT is the same. In other words, we consider the uncertainty of an ACTM using the same EUT that is measured by different test laboratories, using different measurement instrumentation, a different test site, different measurement procedures and different operators. Consequently, the reproducibility of this 'same' EUT may become a significant uncertainty source. Also the length of the LUT and the type of the cable can be slightly different if a test laboratory has to extend the lead by a cable of the 'same' type.

The uncertainty assessment described in this subclause is performed in accordance with the basic considerations on uncertainties in emission measurements given in Clause 4.

Subclause 7.2 gives the uncertainty considerations related to the calibration of the absorbing clamp, while 7.3 gives the uncertainty considerations related to the absorbing clamp measurement method.

7.2 Uncertainties related to the calibration of the absorbing clamp

7.2.1 General

CISPR 16-1-3 specifies three different calibration methods for the absorbing clamp, i.e. the original method, the jig method and the reference device method.

This subclause describes the determination of the uncertainty budgets for the original clamp calibration method. The budgets for the jig and reference calibration methods will be included at a later stage.

For convenience a schematic overview of the original clamp calibration method is given in Figure 20.

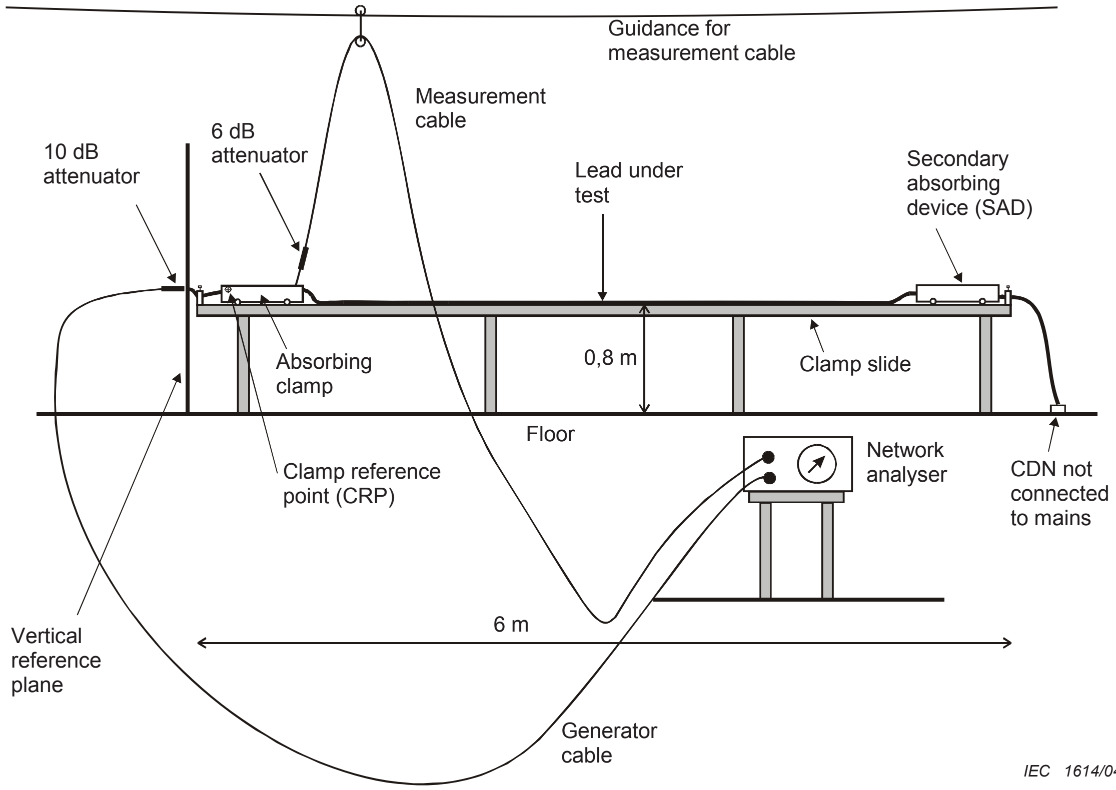


Figure 20 – Schematic overview of the original clamp calibration method

7.2.2 The measurand

For a clamp calibration using the original method (subscript 'org'), the measurand is the clamp factor $F_{\mathrm{c\,org}}$ in dB(pW/μV).

The original clamp calibration method is in fact an insertion loss measurement (see Clause 4 of CISPR 16-1-3:2004):

$$F_{\mathrm{c\,org}} = A_{\mathrm{org}} - 17 \ \text{in dB(pW/}\mu\text{V)} \qquad (22)$$

where A_{org} is the measured insertion loss in dB.

7.2.3 Uncertainty sources

This subclause gives the uncertainty sources associated with the clamp factor measurement.

The uncertainty of the clamp factor is equal to the uncertainty of the measured insertion loss [see Equation (22)].

The uncertainty sources for the insertion loss are given by the uncertainty sources of the measurement chain. The measurement chain-related uncertainty sources are the EUT (EUT is clamp under test in this case), the measurement instrumentation, the set-up, the measurement procedure and the environmental conditions. Figure 21 gives a schematic overview of all relevant uncertainty sources using a fishbone diagram. The fishbone diagram indicates the categories of uncertainty sources that contribute to the overall uncertainty of the clamp factor.

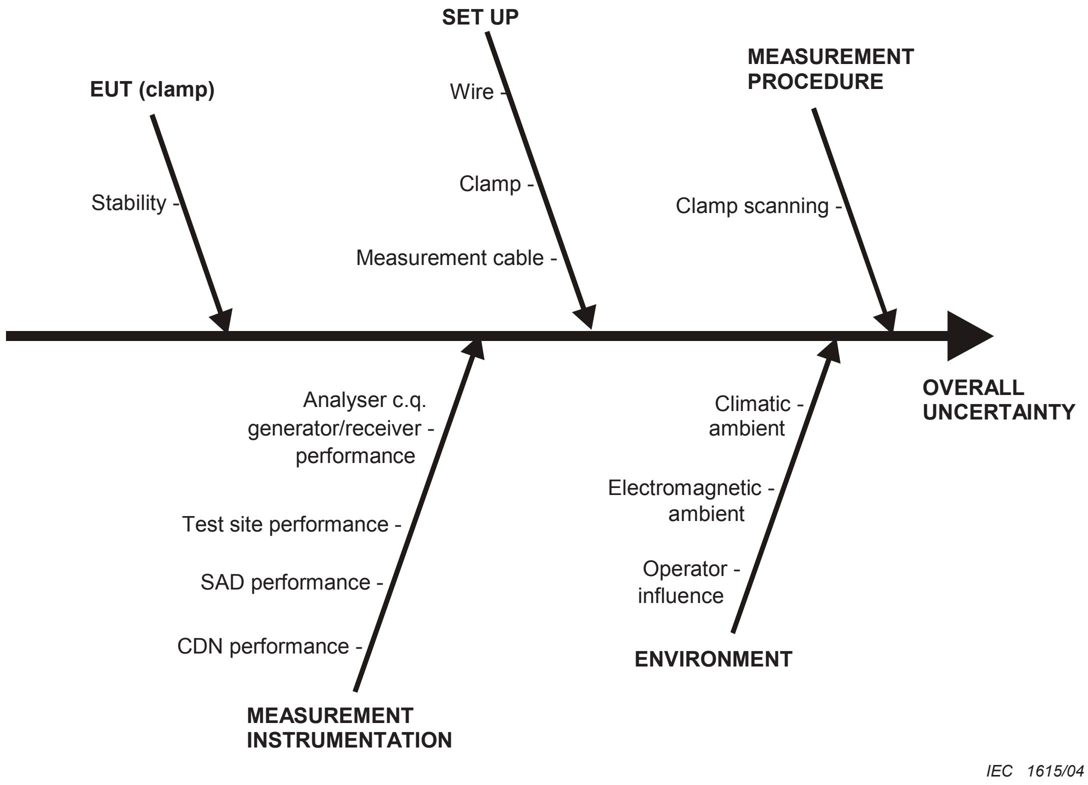


Figure 21 – Diagram that illustrates the uncertainty sources associated with the original clamp calibration method

7.2.4 Influence quantities

7.2.4.1 General

For most of the qualitative uncertainty sources given in Figure 21, one or more influence quantities can be used ‘to translate’ the uncertainty source in question. Table 6 gives the relation between the uncertainty source and the influence quantity. If no influence quantity can be given, then in the uncertainty budget, the original uncertainty source will be used.

For each of the uncertainty sources/influence quantities, some explanation is now given in the following subclauses.

Table 6 – Influence quantities associated with the uncertainty sources given in Figure 21 for the original clamp calibration method

UNCERTAINTY SOURCE	INFLUENCE QUANTITY
EUT-RELATED	
Stability clamp	Stability clamp
SET-UP-RELATED	
Lead under test (LUT) set up	Cross section
	Length
	Displacement tolerance in clamp at the CRP
	Height above reference plane
Clamp set up	Start and stop position tolerance
Measurement cable set up	Guidance and routing of the measurement cable
MEASUREMENT PROCEDURE-RELATED	
Clamp scanning	Clamp scanning step size
ENVIRONMENT-RELATED	
Climatic ambient	Temperature and humidity tolerances
Electromagnetic ambient	Signal to ambient ratio
Operator influence	Distance between operator and set up
MEASUREMENT INSTRUMENTATION-RELATED	
Analyzer or generator/receiver performance	Stability generator
	Linearity receiver/analyzer
	Mismatch at the input
	Mismatch at the output
	Measuring system reading
	Signal to noise ratio
Test site performance	Absorbing clamp test site deviation
	Clamp slide material
SAD performance	SAD decoupling factor
CDN performance	CDN impedance tolerance

7.2.4.2 EUT-related

The stability of clamp influence quantity is addresses as follows.

The absorbing clamp is a mechanically rigid device that is typically quite stable over time. Nonetheless, aging effects may lead to poor contact between the ferrite cores which degrades the functions of the current probe and the decoupling. This may result in a ‘degradation’ of the clamp factor and may also cause a degradation of the decoupling factor. This is especially important if the test laboratory for quality assurance reasons repeats the clamp calibration. If the manufacturer calibrates new clamps, aging is not an issue. If the manufacturer performs a type test, then the manufacturer may repeat the calibration using different samples of the same type of clamp. Depending on the number of samples used, this type A uncertainty must be entered in the uncertainty budget. If the manufacturer performs a unit-specific calibration, then the calibration result is valid for that specific unit only, and consequently no uncertainty due to type testing shall be incorporated.

7.2.4.3 Set-up related

a) Cross section of lead under test:

For calibration of the clamp, a 4 mm diameter wire shall be used. The tolerance of the wire diameter is not specified. The resulting uncertainty is however considered negligible.

b) Length of lead under test:

The length of the lead under test shall be 7 m, of which 6 m runs over the clamp slide and 1 m is routed downwards to the CDN on the reference plane. Due to the application of the secondary absorbing device, the uncertainty due to variation in length and routing of the lead under test is considered to be low.

c) Height of lead under test above reference plane:

The LUT is running at a height of 0,8 m above the reference on top of the clamp slide with a tolerance of 5 cm. At the end of the clamp slide, the LUT is routed to the CDN. The uncertainty due to residual routing variations is considered to be minor.

d) Displacement tolerance of lead under test in clamp:

For the calibration procedure, a centering guide shall be used to control the position of the LUT within ± 1 mm of the centre position at the location of the clamp reference point (CRP). The uncertainty figures reported in [49] are used.

e) Start and stop position tolerance:

The start position of the CRP is 100 mm from the vertical reference plane (i.e. the SRP). The stop position of the CRP is 5,1 m from the vertical reference plane (SRP). The tolerance of the start position determines the uncertainty. A tolerance of ± 5 mm is assumed. The resulting uncertainty is considered to be minor.

f) Guidance and routing of the measurement cable:

The guidance and routing of the measurement cable to the receiver is specified. Still some degree of freedom remains, which contributes to uncertainty.

7.2.4.4 Measurement procedure related

For the influence quantity of clamp scanning step size, the scanning speed and the frequency step size is specified. Still a residual uncertainty is expected due to the limited scanning step size.

7.2.4.5 Environment related

a) Temperature and humidity tolerances:

These environmental influence quantities are considered to have a negligible impact on the result of the measurement if the calibration is performed using an indoor test site. For outdoor test sites, the influence of temperature and humidity on the uncertainty shall be incorporated.

b) Signal to ambient ratio:

For calibration, the measured signal levels shall be 40 dB above ambient levels. In this situation, the resulting uncertainty may be neglected. An additional uncertainty shall be taken into account for lower signal to noise ratios.

c) Distance between operator and set-up:

It is assumed that the scanning of the clamp is automated by some means (e.g. by a rope and pulley arrangement), and that the operator is not in the vicinity of the set-up. However, if an operator is needed to scan the clamp by hand, then the consequent uncertainty may be significant, especially below 100 MHz [49]. Such an operator-induced uncertainty can be investigated experimentally by measuring the clamp output signal at certain fixed position of the clamp, while the operator is approaching and touching the clamp from different sides (e.g. from the left and right side of the clamp slide). This can be repeated for a number of positions of the clamp. The maximum variation due to presence of the operator and touching the clamp can be determined for instance by using the maximum-hold and minimum-hold functions of a spectrum analyzer. This maximum variation can be used as a type B input for the uncertainty budget.

7.2.4.6 Measurement instrumentation related

a) Generator stability:

The stability of the generator of the spectrum or network analyzer system is of importance for the uncertainty of the measured site attenuation.

b) Receiver/analyzer linearity:

This uncertainty is obtained from information on the calibration of the measuring system. The uncertainty depends on the sweep mode or stepped mode of the analyzer.

c) Mismatch at the input:

The attenuator in the input cable shall be at least 10 dB. Resulting mismatch uncertainties are taken from [49].

d) Mismatch at the output:

The attenuator in the measuring cable shall be at least 6 dB. Resulting mismatch uncertainties are taken from [49].

e) Attenuator (optional):

If a separate generator is used for the clamp factor measurement, then during the direct measurement of the generator output, an additional attenuator may be used to avoid overload and consequent non-linear effects in the receiver. In this case, the absolute value of the attenuator and its uncertainty shall be taken into account in Equation (22) and in the uncertainty budget respectively.

f) Measuring system reading:

Receiver reading uncertainties depend on receiver noise, meter scale interpolation errors. The latter should be a relatively insignificant contribution to the uncertainty for measuring systems with electronic displays (least significant digit fluctuation). For classical analogue meter displays, this uncertainty contribution needs to be considered.

g) Signal to noise ratio:

For clamp calibrations, the noise floor is usually sufficiently below the measured signal levels for calibration. The impact of the noise depends on the type of measuring system used (network analyzer versus spectrum analyzer).

h) Absorbing clamp test site deviation:

The clamp calibration result is sensitive to the surrounding environment. The test site performance depends on the floor material and nearby obstacles.

The test site that is used for the calibration shall be validated in accordance with the specified validation procedure. Consequently, the pass/fail criterion for the deviation between the test site attenuation and the reference site attenuation given in CISPR 16-1-3 can be used in the uncertainty budget.

i) Clamp slide material:

Typically the same clamp slide is used for clamp site validation and for clamp calibration procedure. If the clamp slide material is not RF-transparent, then the possible perturbing effects of the clamp slide material shall be taken into account.

j) SAD decoupling factor:

The decoupling performance of the SAD specifies the decoupling of the far end of the LUT from the near end of the LUT. A minimum requirement for the SAD decoupling factor is given.

k) CDN impedance tolerance:

For the clamp calibration, a CDN is specified to terminate the LUT near the reference plane. In the lower frequency range (30 MHz to 230 MHz) this gives a common-mode termination impedance of approximately 150 Ω. Beyond 230 MHz, the common-mode termination impedance of CDNs is not specified. The tolerance of the common-mode impedance of the CDN will affect the common-mode current in the LUT. However this effect will also depend on the common-mode impedance contributions from the EUT, LUT and the SAD. Quantitative information on the resulting uncertainty is not available. It is estimated that the effect due to the CDN common-mode impedance tolerance is minor.

7.2.4.7 Repeatability of measurement

‘Measurement system repeatability’ is an influence quantity that is often a generic part of uncertainty budgets.

The repeatability of the calibration is determined by deriving the standard deviation of a series of repeated calibration measurements using the same set up and measurement equipment. In this way, statistical information is gained about a number of influence quantities together, i.e. stability of the clamp, stability of the analyzer generator, measuring system reading, start/stop position tolerance, clamp scanning. Consequently, if ‘repeatability of measurement’ is included as a generic item of the uncertainty budget, then it is important to be sure that certain influence quantities that are part of this ‘repeatability of measurement’ category, are not included twice.

7.2.5 Application of the uncertainty budget

In general, the expanded uncertainty figure of the clamp factor is used by a test laboratory as an input to derive the expanded uncertainty of its clamp measurement method. Note that for this purpose, the standard uncertainty has to be derived from the expanded uncertainty. If we assume that the uncertainty of the clamp factor has a normal distribution, then the expanded uncertainty value of the clamp factor has to be divided by a factor $k = 2$. Consequently, the clamp manufacturer may also directly provide the standard uncertainty instead of the expanded uncertainty.

As already discussed in the previous subclause, the uncertainty figure of the clamp factor may be a unit-specific figure or it may be a figure that is applicable to that type of clamp. The uncertainty that is related to a type calibration is generally larger than the unit specific uncertainty. The reason is that for type testing, a limited number of samples of the same type of clamp is used and the average of the individual clamp sources is taken as clamp factor of that particular type. Consequently the uncertainty due to the spread of this average clamp factor will result in an increased uncertainty.

7.2.6 Typical examples of an uncertainty budget

Tables E.1 and E.2 of Annex E give a typical uncertainty budget for the original clamp calibration method in the two frequency bands 30 MHz to 300 MHz and 300 MHz to 1 000 MHz respectively. The uncertainty budgets for the jig calibration method and the reference device calibration method are still under consideration.

The uncertainty budgets are calculated in accordance with the procedure given in Clause 4. Each budget contribution can be determined by using the type A and type B methods of evaluation. type A evaluations of uncertainty are done by using statistical analysis of repeated measurement, and type B evaluations of uncertainty are done by other than statistical analysis.

In practice, EMC compliance measurements are typically executed once for a certain type of EUT. Repeated measurements using the same EUT are not common practice. Therefore, the uncertainty budget contributions are mostly determined using the type B method of evaluation.

This is also the case for the budgets presented in Annex F, i.e. most of the budget contributions are type B evaluations and use data from calibration certificates, instrumentation manuals, manufacturers’ specifications, previous measurements or from models or generic understanding of the measurement method. The probability distributions and uncertainty values for the various uncertainty sources/influence quantities that are given in Annex E are derived from various sources of information [49], [22], [41].

Unfortunately no model is available for the relation between the measurand and the various influence quantities. All that can be said is that the measurand is a function of the influence quantities given in Table 6. Most standard uncertainty values of each influence quantity must be derived from specifications or from experimental data. Further, it is assumed that all sensitivity coefficients are equal to one. However, due to the absence of a realistic model, the true value of the sensitivity coefficients is unknown.

From the clamp calibration uncertainty budgets given in Annex E, it can be concluded that the expanded uncertainty is approximately 3 dB for the frequency band of 30 MHz to 1 000 MHz. The latter value is also applied in the tables of Annex F. Note that this value is also used in the disturbance power uncertainty budget given in Table A.3 of CISPR 16-4-2:2003.

7.2.7 Verification of the uncertainty budget

Two round robin tests (RRTs) have been carried out as part of the CISPR work on modifying the clamp calibration method. The results of the last RRT are reported in [21]. Six test laboratories contributed to this RRT. The standard deviation was less than approximately 1 dB over the frequency band of 30 MHz to 1 000 MHz, resulting in an expanded uncertainty of approximately 2 dB.

7.3 Uncertainties related to the absorbing clamp measurement method

7.3.1 General

This subclause describes the determination of the uncertainty budgets for the absorbing clamp test method (ACTM) described in Clause 7 of CISPR 16-2-2:2003.

For convenience a schematic overview of the clamp measurement method is given in Figure 22.

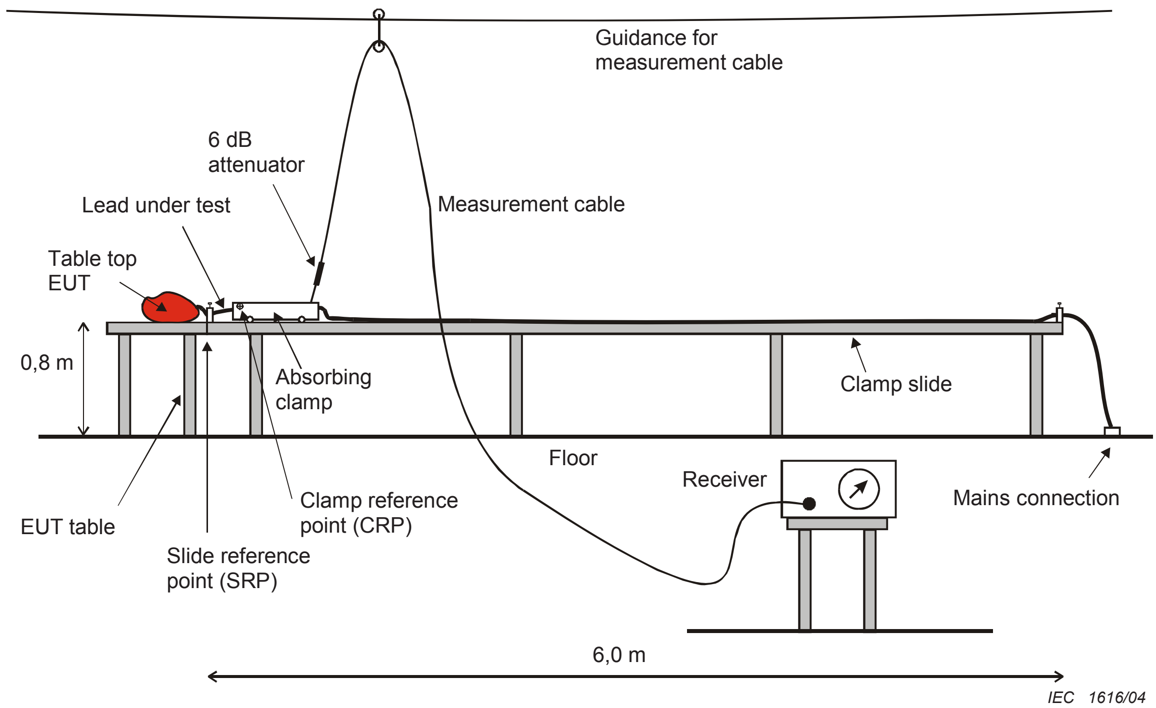


Figure 22 – Schematic overview of the clamp measurement method

7.3.2 The measurand

For a clamp measurement, the measurand is the disturbance power. The disturbance power P corresponding to the measured voltage V at each measurement frequency is calculated by using the clamp factor F_c obtained from the absorbing clamp calibration procedure described in CISPR 16-1-3.

$$P = V + F_c \tag{23}$$

where

P the disturbance power in dB(pW);

V the measured voltage in dB(μV);

F_c the clamp factor in dB(pW/μV).

7.3.3 Uncertainty sources

This subclause gives the uncertainty sources associated with the clamp measurement. From Equation (23) we see that the uncertainty is determined by the uncertainty of the voltage measurement and the uncertainty of the clamp factor.

The uncertainty of the voltage measurement is determined by the uncertainties induced by the EUT, the set-up, the measurement procedure, the measurement instrumentation and the environment.

Figure 23 gives a schematic overview of all the relevant uncertainty sources. This fishbone diagram indicates the categories of uncertainty sources that contribute to the overall uncertainty of the disturbance power. From this diagram, we see that most set-up related uncertainty sources are the same as the sources that were applicable for the clamp calibration. An important set-up uncertainty source that has been added is the reproducibility of the set up of the EUT. For the measurement instrumentation uncertainty, now the absolute uncertainty of the receiver and the uncertainty of the clamp factor are important uncertainty sources that were not relevant for the clamp calibration.

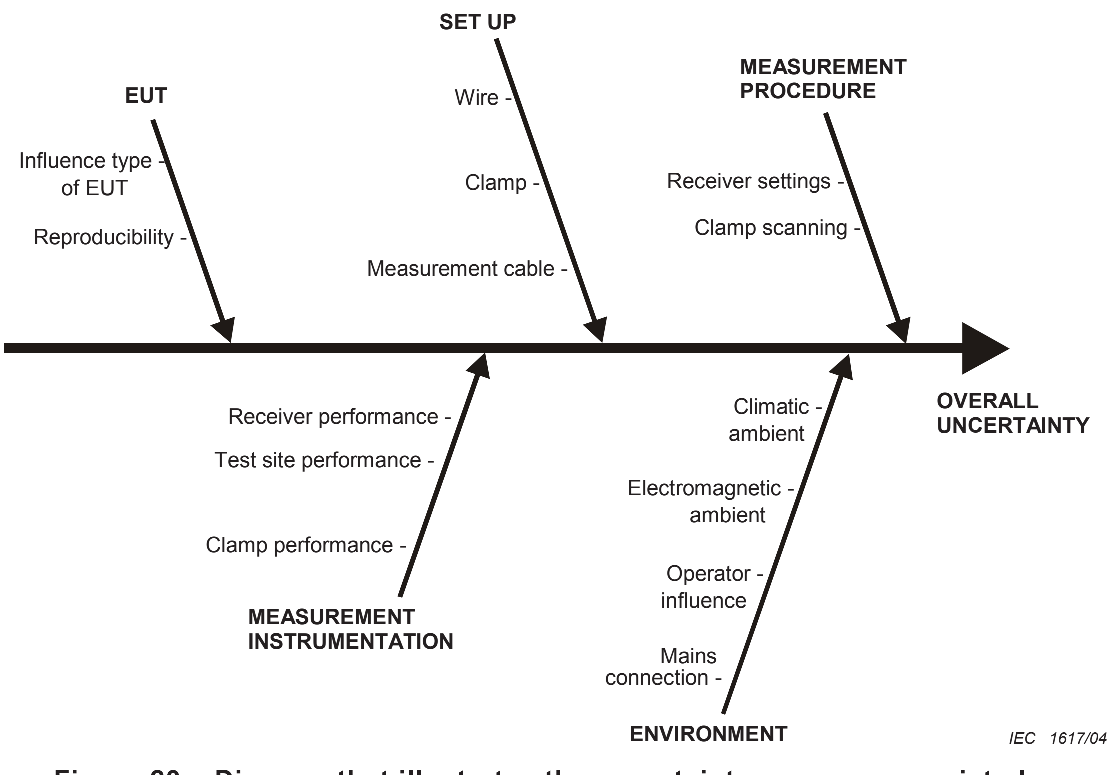


Figure 23 – Diagram that illustrates the uncertainty sources associated with the clamp measurement method

7.3.4 Influence quantities

7.3.4.1 General

For most of the uncertainty sources given in Figure 23, no real influence quantities can be defined to translate the qualitative uncertainty source in question. Table 7 gives the relation between the uncertainty source and the influence quantity. If no influence quantity can be given, then in the uncertainty budget, the original uncertainty source will be used.

For each of the uncertainty sources or influence quantities that are new or that deviate from the calibration situation (see 7.2.4), some explanation is given in the following subclauses.

Table 7 – Influence quantities associated with the uncertainty sources given in Figure 23 for the clamp measurement method

UNCERTAINTY SOURCE	INFLUENCE QUANTITY
EUT-RELATED	
Influence type EUT on other uncertainty sources	Size of EUT
	Signature disturbance
Reproducibility EUT	Set up of unit(s) and cables
	Modes of operation
SET-UP-RELATED	
Lead under test (LUT) set up	Cross section
	Length
	Displacement tolerance in clamp at the CRP
	Height above reference plane
Clamp set-up	Start and stop position tolerance
Measurement cable set-up	Guidance and routing of the measurement cable
MEASUREMENT PROCEDURE-RELATED	
Receiver settings	Receiver settings
Clamp scanning	Clamp scanning step size
ENVIRONMENT-RELATED	
Climatic ambient	Temperature and humidity tolerances
Electromagnetic ambient	Signal to ambient ratio
Operator influence	Distance between operator and set up
Mains connection	Mains voltage variation
	Application of mains decoupling devices
MEASUREMENT INSTRUMENTATION-RELATED	
Receiver performance	Accuracy
	Mismatch at the output
	Measuring system reading
	Signal to noise ratio
Test site performance	Absorbing clamp test site deviation
	Clamp slide material
Clamp performance	Clamp factor uncertainty
	Decoupling factor clamp
	Decoupling to receiver

7.3.4.2 EUT-related

a) Size of EUT:

Various influence quantities depend on the type of the EUT, i.e. large EUTs, small EUTs, EUTs with just one, or with many cables. The electromagnetic behavior of these different types may cause different magnitudes of uncertainty.

b) Signature of disturbance:

The signature of the disturbance (wide band, narrow band) may affect the magnitude of uncertainties induced by the receiver.

c) Product sampling (optional):

This is especially important if the measurement is repeated by the manufacturer for quality assurance reasons or if the 80 %/80 % rule is to be applied. If the manufacturer performs a type test, then the manufacturer may repeat the measurement using different samples of the same type of EUT. In case of market control by an authority using different samples of the same type of EUT, then also the 80 %/80 % rule may be applied.

d) Set-up of unit(s) and cables:

Despite the specification of the EUT set-up in product standards, this influence quantity may give rise to significant uncertainties if the same EUT is prepared and set up by different operators and test laboratories. Especially if the EUT consists of different units and several interconnecting cables, the uncertainty due to the many degrees of freedom of setting up the EUT may be significant. Also EUT cables have to be extended using representative cables, to make clamp measurements possible. Different types (diameter/shield performance, etc) of extension cables may introduce also differences in results.

e) Modes of operation of EUT:

During the measurement, meaningful modes of operation shall be selected. If the test mode of operation is not specified, then different operators/test laboratories may select different modes in conjunction with different receiver settings and scan speeds.

7.3.4.3 Measurement procedure-related

Receiver settings are discussed in this subclause. Still some degrees of freedom are left for settings of the receiver (by hand or software controlled). This may lead to uncertainties that depend on the type of disturbance (broadband/ narrowband) of the EUT in question.

7.3.4.4 Environment-related

a) Signal to ambient ratio:

Due to the fact that the EUT is connected to the mains, an increased conducted ambient disturbance signal shall be considered as an influence quantity.

b) Mains voltage variations:

Mains voltage deviations from the nominal mains voltage may give rise to uncertainties, as the level of disturbance power depends on the mains voltage level.

c) Application of mains decoupling devices:

Different test laboratories may apply different mains decoupling devices like CDNs, decoupling transformers, variacs, LISNs or combinations thereof. These different decoupling devices may give rise to different disturbance levels, also depending on the category of EUTs (mains connection with or without protective earth).

7.3.4.5 Measurement instrumentation-related

a) Accuracy of receiver:

The accuracy can be taken from the specification and calibration certificate of the receiver. If necessary, the uncertainty for different types of signals/responses may be considered, i.e. CW accuracy, pulse amplitude response accuracy, pulse repetition response accuracy.

b) Clamp factor uncertainty:

The clamp factor uncertainty shall be taken from the clamp calibration uncertainty budget provided by the clamp supplier or derived by the test laboratory itself (see 7.2.5 and Annex C).

c) Decoupling factor clamp:

A minimum requirement is specified for the decoupling factor of the absorbing clamp. The decoupling factor specifies the amount of decoupling of the far end of the LUT from the near end of the LUT. Although different clamps will comply with the minimum requirement, the decoupling performance may be different and may give rise to different measurement results.

d) Decoupling to receiver:

Also a minimum requirement for the common mode decoupling of the LUT to the measuring system is given. It is expected that the residual uncertainty is small.

7.3.5 Application of the uncertainty budget

7.3.5.1 General

In general, the knowledge of the expanded uncertainty of the clamp measurement method serves two purposes, i.e. determination of the measurement instrumentation uncertainty and/or the standards compliance uncertainty.

7.3.5.2 Measurement instrumentation uncertainty (MIU) considerations

First, the MIU can be calculated for accreditation purposes of the test laboratory. For this purpose it is sufficient to consider the uncertainties induced by the test laboratory only, i.e. the uncertainties related to the measurement instrumentation, the environment and the measurement procedure. The resulting MIU can be used to compare with the minimum MIU values stated in CISPR 16-4-2.

7.3.5.3 Standards compliance uncertainty (SCU) considerations

Secondly, the SCU can be calculated for the measurement method in combination with a typical type of product. This value of the SCU can be used for risk assessment of non-compliance against a certain limit. For measurement correlation discussions between two test laboratories where the ‘same’ measurement was performed using the ‘same’ EUT, also the uncertainties induced by the EUT has to be included in the budget. Also for market surveillance, the SCU of both test laboratories involved shall be considered.

7.3.6 Typical examples of the uncertainty budget

Tables F.1 and F.2 of Annex F give a typical uncertainty budget for the clamp measurement method. The two tables are for the two frequency ranges of 30 MHz to 300 MHz and 300 MHz to 1 000 MHz respectively.

The uncertainty budgets are calculated in accordance with the procedure given in Clause 4.

For the budgets presented in Annex F, most of the budget contributions are type B evaluations, and use data from calibration certificates, instrumentation manuals, manufacturer’s specifications, previous measurements or from models or generic understanding of the measurement method. The probability distributions and uncertainty values for the various uncertainty sources/influence quantities that are given in Annex F are derived from various sources of information, i.e. [49], [22], [41].

Unfortunately no model is available for the relation between the measurand (disturbance power) and the various influence quantities. All that can be said is that the measurand is a function of the influence quantities given in Table 7. Most standard uncertainty values of each influence quantity must be derived using type B methods of evaluations. Further, it is assumed that all sensitivity coefficients are equal to one. However, due to the absence of a realistic model, the true value of the sensitivity coefficients is unknown.

Each table also provides the result of both the MIU and SCU calculations. The typical values of the MIU and SCU from these tables are summarized in Table 9. The MIU is typically 5 dB to 6 dB whereas the SCU may amount to approximately 8 dB.

7.3.7 Verification of the uncertainty budget

Four round robin tests (RRTs) have been carried out as part of the CISPR work on amending the clamp calibration and clamp measurement method.

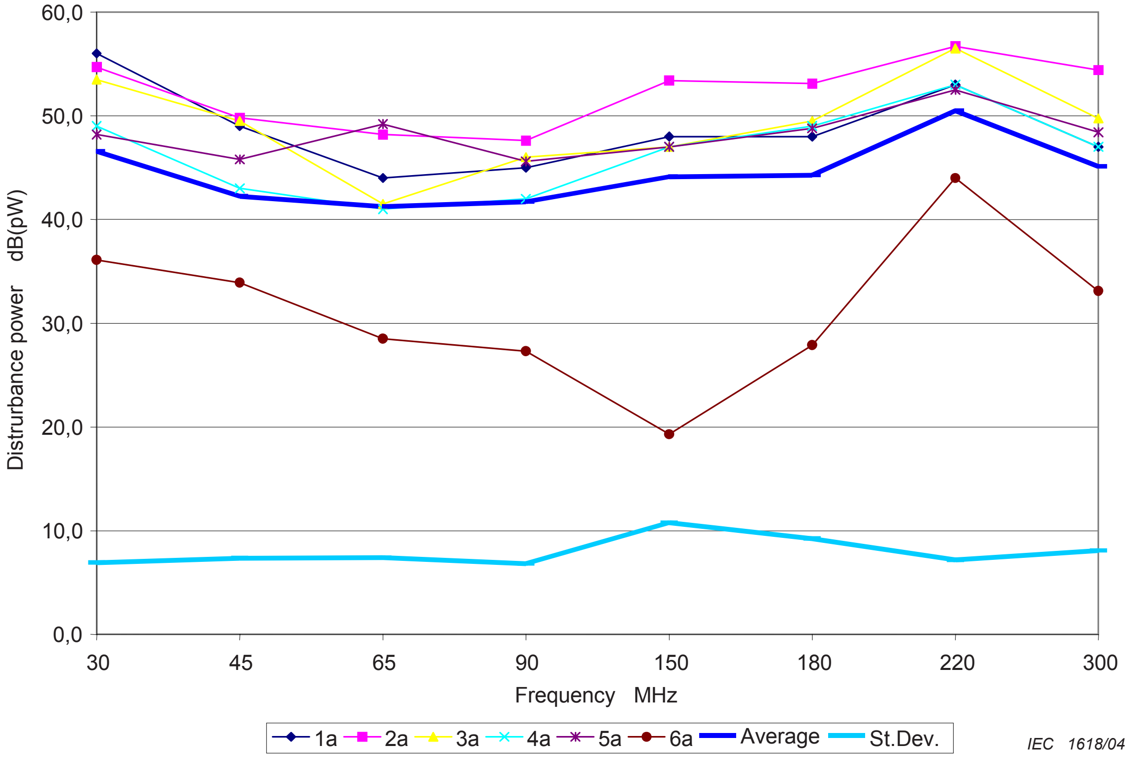
The results of the second RRT are reported in [21]. In this RRT, four test laboratories participated and a reference radiator (comb generator based) was used as EUT. Also each test laboratory used the same absorbing clamp. Consequently, the uncertainties resulting from this RRT represent just a part of the MIU. The measurement results of this RRT show a standard deviation of approximately 1 dB up to 300 MHz and 2 dB up to 1 GHz. This corresponds to expanded uncertainties of approximately 2 dB and 4 dB respectively.

The results of the third RRT are reported in [23]. Six accredited laboratories contributed to this RRT using two different types of real EUTs, i.e. a drill and a hairdryer. For the two EUTs used in this RRT, the expanded SCU was 16 dB and 8,1 dB respectively. The measurement results of the drill are given in Figure 24 as an example. The large value of the SCU for the drill was due to repeatability problems of the drill. But also the measurement results of one of the laboratories were the main contributor to this large uncertainty (see curve 6a in Figure 24). When the results of this laboratory are skipped from the database, then the expanded SCU values reduce to 6,3 dB and 5,3 dB respectively.

In 1998, a disturbance power RRT was also carried out in Germany. Six laboratories participated in this RRT where a universal motor of a vacuum cleaner was used as the EUT. The results are depicted in Table 8. The expanded uncertainty of 4 dB (see Table 8) is estimated from the maximum value of the standard deviation.

From the results of the various RRTs, it is concluded that the SCU depends very much on the type of EUT and its intrinsic uncertainty.

Finally, for comparison reasons also the typical MIU (4,45 dB) given in Table A.3 of CISPR 16-4-2:2003 is included in Table 9.



The thick curves represent the average and standard deviation.

Figure 24 – Measurement results of an absorbing clamp RRT performed by six test laboratories in the Netherlands using a drill as EUT

Table 8 – Measurement results of an absorbing clamp RRT performed by six test laboratories in Germany using a vacuum cleaner motor as EUT

Laboratory	**Frequency range**							
	30 MHz -50 MHz		50 MHz -100 MHz		100 MHz - 200 MHz		200 MHz - 300 MHz	
	Max. value dB(pW)	Freq. MHz	Max. value dB(pW)	Freq. MHz	Max. value dB(pW)	Freq. MHz	Max. value dB(pW)	Freq. MHz
Lab 1 (outside)	34	35,3	29	52,3	31	189,3	30	243,9
Lab 2 (screened room)	37,9	31,6	30,1	70,5	30,4	187	27,9	264,6
Lab 3 (screened room)	38,4	31,8	29,9	54,2	29,8	189,5	26,4	237,5
Lab 4 (screened room)	34,1	32,1	27,1	73,0	30,5	123,1	26,2	260,5
Lab 5 (outside)	35	31,7	28	70,5	32	191,3	29	257,7
Lab 6 (screened room)	34	30,5	30	70,1	30	150	28	250
Average	35,6		29,0		30,6		27,9	
Standard deviation	2,0		1,2		0,8		1,5	
Max. deviation from the average	+2,8		-1,9		+1,4		+2,1	
Max. difference between max. and min.	4,4		3,0		2,2		3,8	

Table 9 – Summary of various MIU and SCU values (expanded uncertainties) for the clamp measurement method derived from different sources of information

Reference	Uncertainty category	Expanded uncertainty value (dB)	
		30 MHz – 300 MHz	300 MHz – 1 000 MHz
Tables F.1 and F.2 of Annex F	MIU	6,2	5,1
CISPR 16-4-1	MIU	4,45	Not applicable
Tables F.1 and F.2 of Annex F	SCU	7,9	8,4
RRT result: drill [23] and Figure 24 (all laboratories included)	SCU	16,0	Not applicable
RRT result hairdryer [23] (all laboratories included)	SCU	8,1	Not applicable
RRT result: drill [23] (one laboratory excluded)	SCU	6,3	Not applicable
RRT result hairdryer [23] (one laboratory excluded)	SCU	5,3	Not applicable
RRT result vacuum cleaner motor [19]	SCU	4,0	Not applicable

8 Radiated emission measurements using a SAC or an OATS in the frequency range of 30 MHz to 1 000 MHz

8.1 General

8.1.1 Objective

This subclause provides information and guidance for the determination of uncertainties associated with measurement equipment and the measurement method used for radiated emission measurements in the frequency range of 30 MHz to 1 000 MHz in a SAC or on an OATS. Furthermore, a rationale is provided for the various uncertainty aspects described in several parts of CISPR 16 that are related to the radiated emission measurement method (see Clause 7 of CISPR 16-2-3:2006).

In CISPR 16-4-2, the uncertainty considerations for SAC/OATS-based radiated emission measurements are limited to measurement instrumentation uncertainties (MIU). This part addresses all uncertainties that are relevant for compliance testing, i.e. the standards compliance uncertainty (SCU), which also includes the MIU.

The rationale for the methods of uncertainty estimation provided in this clause is intended to serve as background information for the parts of CISPR 16 that are related to the SAC/OATS-based emission measurement method. This background information may be used by CISPR subcommittees to improve existing standards as far as uncertainties are concerned. In addition, this subclause provides information for those who apply the radiated emission measurement method and who have to establish their own uncertainty estimates.

8.1.2 Introductory remarks

This subclause provides information on the uncertainties associated with the SAC/OATS-based radiated emission measurement method as described in CISPR 16-2-3. The uncertainty estimates for the SAC/OATS radiated emission measurement method described in CISPR 16-4-2, or for example in LAB 34 [46], address only some of the uncertainty components present in actual compliance tests performed in accordance with CISPR 16-2-3. Uncertainty estimates in the aforementioned documents account only for the measurement instrumentation uncertainties (MIUs), whereas uncertainties due to the set-up of the EUT including its cables, and due to the measurement procedure itself, are not taken into account. In this subclause, all uncertainty sources that are relevant for the measurement uncertainty of the compliance test, termed as the standards compliance uncertainty (SCU), are considered. One basic assumption for these SCU estimations is that the EUT does not change. In other words, the uncertainty of the SAC/OATS radiated emission measurement method is considered based on using the same EUT as measured by different test laboratories. The laboratories will use different measurement instrumentation, a different test site, different measurement procedures, and different operators. Often the laboratories may also apply different measurement set-ups or different EUT operating modes. The latter EUT-related sources of uncertainty may become significant, and can contribute to poor reproducibility.

The uncertainty estimation described in this clause is done in accordance with the basic considerations on uncertainties in emission measurements given in Clause 4.

8.2 Uncertainties related to the SAC/OATS radiated emission measurement method

8.2.1 General

This subclause describes the preparation of the uncertainty estimates for the SAC/OATS-based radiated emission measurement method described in Clause 7 of CISPR 16-2-3:2006. For reference, a schematic overview of the radiated emission measurement method is given in Figure 25. This figure shows an EUT set up on a positioning table in a SAC. The receive antenna measures the sum of the direct and reflected emission from the EUT.

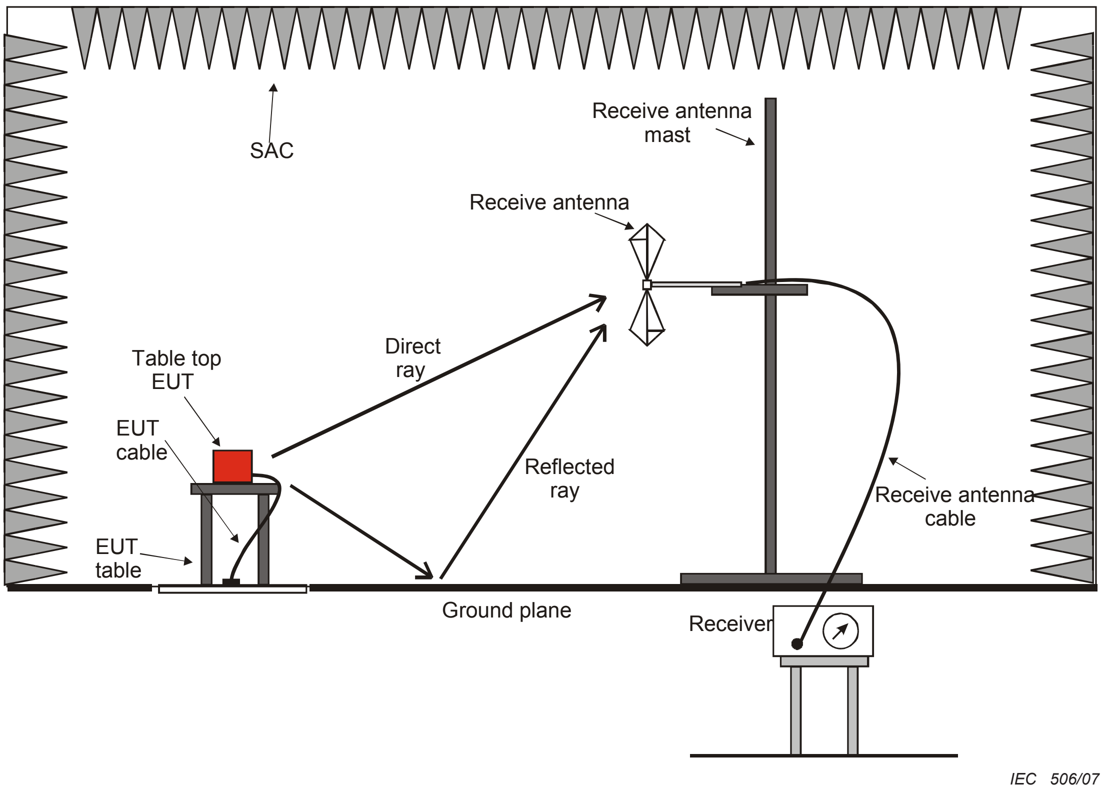


Figure 25 – Schematic of a radiated emission measurement set-up in a SAC

8.2.2 The measurand

Previously, the measurand for the SAC/OATS-based radiated emission measurement method in CISPR 16-2-3 was only incompletely defined. In Clause 4 of CISPR 16-1-4:2007, which covers the frequency range 9 kHz to 18 GHz, a reference antenna (balanced dipole) was specified in the range 30 MHz to 300 MHz. For convenience, the measurand was called the reference electric field strength (E-field), i.e. the E-field measured by the CISPR reference antenna. In the frequency range 300 MHz to 1 000 MHz, a reference antenna was not defined, and the measurand is the electric field strength. Recently work was done in CISPR/A to implement E-field as the quantity to be measured over the frequency range of 30 MHz to 1 000 MHz, as published in CISPR 16-1-4 (2007).

In this subclause, it is assumed that the quantity to be measured is the E-field. However, this is not a complete description of the measurand, because as described in the ISO/IEC Guide 98-3, the measurand definition also requires statements about the influence quantities.

From a metrological viewpoint, a more appropriate description of the measurand associated with the SAC/OATS-based radiated emission measurement, is as follows:

The quantity to be measured is the maximum field strength emitted by the EUT as a function of horizontal and vertical polarisation and at heights between 1 m and 4 m, and at a horizontal distance of 10 m from the EUT, over all angles in the azimuth plane.

This quantity shall be determined with the following provisions:

a) the frequency range of interest is 30 MHz to 1 000 MHz;
b) the quantity shall be expressed in terms of field strength units that correspond with the units used to express the limit levels for this quantity;
c) a SAC/OATS measurement site and positioning table shall be used that complies with the applicable CISPR validation requirements;
d) a CISPR-compliant EMI receiver shall be used;
e) the application of alternative measurement distances, such as 3 m or 30 m rather than the nominal distance of 10 m [see 8.2.4.4 a)], is considered to be an alternative measurement method; correlation factors shall be used to translate results obtained at these measurement distances to 10 m results [see 8.2.4.4 a) for the consequences in terms of uncertainties];
f) the measurement distance is the horizontal projection onto the ground plane of the distance between the boundary of the EUT and the antenna reference point;
g) the EUT is configured and operated in accordance with the CISPR specifications;
h) free-space antenna factors shall be used.

The measurand E is derived from the maximum voltage reading V_{r} by using the free-space antenna factor F_{A}:

$$E = V_{\mathrm{r}} + L_{\mathrm{c}} + F_{\mathrm{A}} + \sum_{i} C_i^{\mathrm{IQ}} \qquad (24)$$

where

E is the field strength in dB(μV/m) as described in the measurand description;

V_{r} is the maximum voltage reading in dB(μV) using the procedure as described in the measurand description;

L_{c} is the loss in dB of the measuring cable between antenna and receiver;

F_A	is the free-space antenna factor [3] of the receive antenna in dB(m^{-1}); and
$\sum_i C_i^{IQ}$	is the sum of the correction factors C_i^{IQ} that may be applicable for the various influence quantities as described in 8.2.4.

8.2.3 Uncertainty sources

This subclause summarises the sources of uncertainty associated with the SAC/OATS-based measurement method. From Equation (24), it can be seen that the uncertainty is determined by the uncertainty of the measured voltage, the uncertainty of the cable loss, and the uncertainty of the antenna factor.

The uncertainty of the measured voltage is determined by the uncertainties induced by the EUT, the set-up, the measurement procedure, the measurement instrumentation and the environment. Figure 26 gives a schematic overview of all the relevant uncertainty sources. This fishbone diagram indicates the categories of uncertainty sources that contribute to the overall uncertainty of the measurand. An important set-up uncertainty source is the reproducibility of the set-up of the EUT.

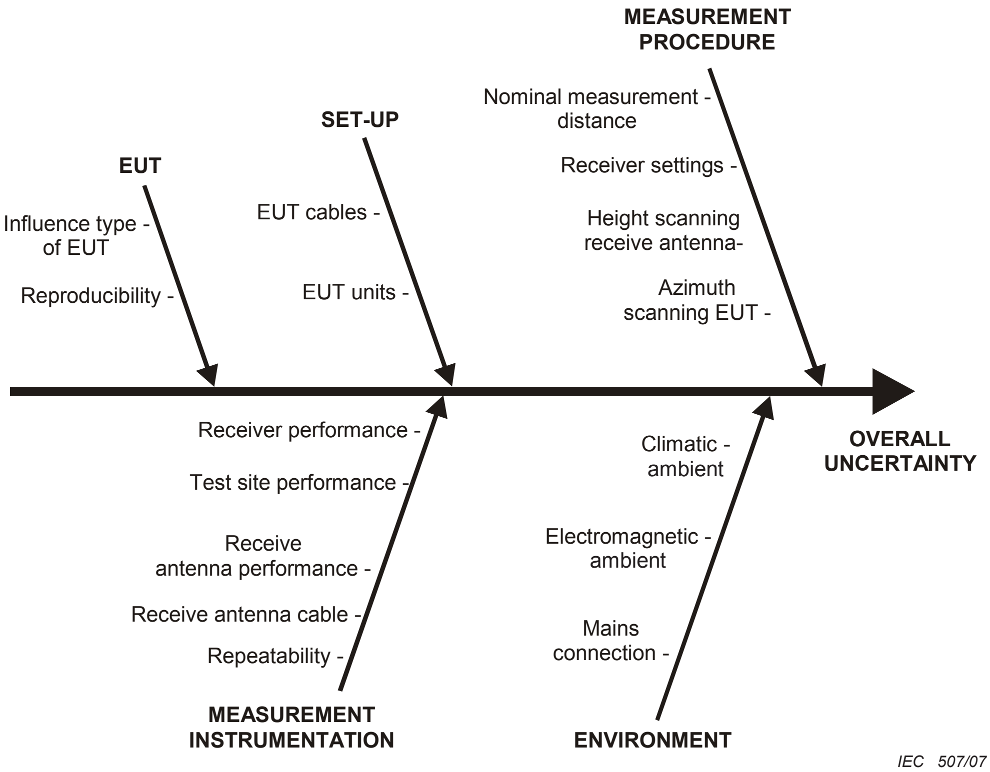


Figure 26 – Uncertainty sources associated with the SAC/OATS radiated emission measurement method

3 Free-space antenna factors are used as a figure-of-merit for the antenna. It should be noted the field strength is not measured in a free-space environment but over a ground plane. See 8.2.4.6 h) for further information.

8.2.4 Influence quantities

8.2.4.1 General

For most of the qualitative uncertainty sources given in Figure 26, one or more influence quantities can be used to “translate” the uncertainty source in question. Table 10 shows the relationship between the uncertainty sources and the influence quantities. If an influence quantity cannot be identified, the original uncertainty source will be used in the uncertainty estimate. For each of the uncertainty sources and influence quantities, details are provided below.

NOTE The uncertainty sources and influence quantities terms used in this subclause and in the remainder of Clause 8 may deviate from similar terms used in CISPR 16-4-2. This is justified for the following reasons: a) some of the influence quantities are specifically applicable for SCU, and are not applicable for the MIU-only estimates of CISPR 16-4-2; b) some of the influence-quantity terms used in CISPR 16-4-2 are not quantified or are not clearly identified. For instance, the term “site imperfection” is a qualitative term used in CISPR 16-4-2. The term “NSA deviation” used in Table 10 is more appropriate because it reflects a specific and well-known quantity. Furthermore, the term ”noise floor proximity” is not clearly defined, while the term “signal-to-noise ratio” is a well-known and quantifiable term.

Therefore it is intended to harmonise with the terms used in this document in future maintenance of CISPR 16-4-2.

Table 10 – Influence quantities for the SAC/OATS radiated emission measurement method associated with the uncertainty sources of Figure 26

Subclause	Uncertainty source	Influence quantity
8.2.4.2	**EUT-RELATED**	
a)	Influence of type EUT on other uncertainty sources	Size of EUT
b)		Type of disturbance
c)	Reproducibility of EUT	Product sampling
d)		Modes of operation
8.2.4.3	**SET-UP-RELATED**	
a)	EUT set-up	Layout of EUT unit(s) and cable(s)
b)		Termination of cable(s)
c)		Measurement distance tolerance
d)		EUT height above ground plane tolerance
8.2.4.4	**MEASUREMENT-PROCEDURE-RELATED**	
a)	Nominal measurement distance	Nominal measurement distance
b)	Receiver settings	Receiver settings
c)	Height-scanning of receive antenna	Height-scanning step size
d)		Start and stop position tolerance
e)	Azimuth-scanning of EUT	Azimuth step size
8.2.4.5	**ENVIRONMENT-RELATED**	
a)	Climatic, ambient	Temperature and humidity tolerances
b)	Electromagnetic ambient signals	Signal-to-ambient-signal ratio
c)	Mains connection	Mains voltage variation
d)		Application of mains coupling devices
8.2.4.6	**MEASUREMENT-INSTRUMENTATION-RELATED**	
a)	Receiver performance	Receiver accuracy
b)		Mismatch at the receiver input
c)		Measuring system reading
d)		Signal–to-noise ratio
e)	Test-site performance	NSA deviation
f)		EUT positioning table
g)		Influence receive-antenna mast
h)	Receive-antenna performance	Free-space antenna factor uncertainty
i)		Type of receive antenna (directivity)
j)		Antenna-factor height dependence
k)		Antenna-factor frequency interpolation
l)		Antenna phase-centre variation
m)		Antenna unbalance
n)		Cross-polarisation performance
o)	Receive antenna cable	Cable loss uncertainty
p)		Mismatch [a]
q)	Measurement system repeatability	Measurement system repeatability

[a] When a single cable is used, there are two sources of mismatch between the antenna and the receiver:

– between the antenna and the cable;

– between the cable and the receiver (=mismatch at receiver input).

If a test lab uses several cables to interconnect the antenna and the receiver, additional mismatches may be present. In the estimation of MIU, typically only a single mismatch influence quantity is included.

8.2.4.2 EUT-related influence quantities

a) Size of EUT:

Various influence quantities depend on the type of the EUT, i.e. large EUTs, small EUTs, EUTs with single or multiple attached cables. The electromagnetic behaviour of these different EUT types may cause different contributions to uncertainty. Influence quantities that are affected by the size of the EUT are included as part of the EUT set-up-related influence quantities in 8.2.4.3. For the EUT-related uncertainty source, no specific uncertainty value will be assigned to the size of the EUT, to avoid double counting of uncertainties. Instead, the size of the EUT shall be considered as an influence quantity for the uncertainties of the set-up-related uncertainty sources discussed in 8.2.4.3.

b) Type of disturbance:

The type of the disturbance (broadband, narrowband or intermittent) radiated by the EUT may affect the magnitudes of the uncertainties induced by the receiver and by the measurement method applied (e.g. probability of intercept of broadband signals).

c) Product sampling (if applicable):

This influence quantity is especially important if the measurement is repeated by the manufacturer for quality assurance reasons, or if the 80 %/80 % rule is to be applied. If the manufacturer performs a type test, the manufacturer may repeat the measurement using different samples of the same type of EUT. In case of market surveillance that involves measurements on different samples by another test laboratory, the 80 %/80 % rule may also be applied.

d) Modes of operation of the EUT:

During the measurement, meaningful modes of operation shall be selected such that representative and worst case radiated emissions are obtained. In cases that the modes of operation are not specified, different operators and/or test laboratories could select different modes in conjunction with different receiver settings and scan speeds, which may induce significant reproducibility uncertainties, and therefore affecting SCU.

8.2.4.3 Set-up-related influence quantities

a) Layout of EUT unit(s) and cable(s):

Despite the specification of the EUT set-up in product standards, this influence quantity may cause significant uncertainties when different operators and different test laboratories configure a given EUT. Especially for an EUT that consists of several enclosures and interconnecting cables, the uncertainty due to the many degrees of freedom allowed for setting up the EUT may be significant. This influence quantity contributes to the SCU. Results of the CISPR/A RRT in the frequency range 30 MHz to 300 MHz [32] revealed that the uncertainty induced by the set-up for the specific EUT was approximately 7 dB. The uncertainty associated with the set-up of an EUT depends largely on the type of the EUT. Table 11 provides qualitative guidance for the set-up uncertainty as a function of EUT type. Above 200 MHz, the effect of different cable layouts is reduced.

Table 11 – Relation between/and type of EUT and set-up-related uncertainties

Type of EUT	Set-up uncertainty
Table-top battery fed	Very low
Table-top: single unit, single cable to mains	Low
Table-top: multiple units, multiple cables to mains and auxiliary equipment	High
Floor-standing equipment, single cable to mains	Low
Floor standing equipment, multiple cables to mains and auxiliary equipment	High

b) Termination of cable(s):

Different test laboratories may use different cable decoupling devices, such as CDNs, decoupling transformers, absorbing clamps, LISNs, or some combination thereof, or none. These different decoupling devices affect the common-mode impedance, as seen from the EUT, and may produce different disturbance levels. Disturbance levels also depend on the category of the EUT (mains connection with or without protective earth) and on the type (dimension) of EUT (see references [34] and [24] for further details). A summary of the expanded uncertainty results for the EUTs of [24] is given in Figure H.1 of Annex H. Between 30 MHz and 200 MHz, application of different termination devices, such as common-mode absorbing device (CMADs), CDNs or LISNs, may cause a significant variation of results, i.e. 10 dB to 20 dB expanded uncertainty below 100 MHz. This influence quantity may be significant when estimating the SCU, especially below 200 MHz.

c) Measurement distance tolerance:

The uncertainty in measurement distance arises from uncertainties due to determination of the perimeter of the EUT, distance measurement, and antenna mast rigidity. No correction is made for errors in the measurement distance between the perimeter of the EUT and the reference point of the receive antenna. Typically a measurement distance tolerance of ± 10 cm can be expected, the effect of which is largest at small measurement distances. The maximum uncertainty varies as a function of nominal measurement distance and as a function of EUT height [12]. For table-top EUTs at 3 m measurement distance, the resulting uncertainty is approximately ± 0,4 dB (rectangular distribution). In practice, this maximum uncertainty is often estimated from the field variation of a source in free space at a certain nominal distance. It should be noted that oftentimes for larger measurement distances, the free-space estimate does not provide a conservative value [12]. See Table G.3 and Table G.4 in Annex G for uncertainty values as a function of measurement distance.

d) EUT height above ground plane tolerance:

The uncertainty of the standard EUT height above the ground plane, i.e. 0,8 m for table-top EUTs, is typically ± 1 cm. The resulting effect is a change in the interference (radiation) pattern at the measurement location. Depending on the step size of the height scanning of the receive antenna, this influence will induce an uncertainty of the measured maximum electric field strength, the effect of which is largest at small measurement distances. This uncertainty has an effect mostly at frequencies where the maximum field strength is measured at either the lower or upper limits of the antenna scan height (typically at the lower limit, near 1 m), provided that the height-scan step size is sufficiently small. The uncertainty varies as a function of measurement distance, polarisation, and frequency range, and as a function of nominal height of the EUT [12]. It is shown in [12] that the effect of a 1 cm height tolerance is quite significant (± 0,5 dB) for a nominal EUT-height of 0,4 m. For a table-top EUT (nominal EUT-height of 0,8 m) and 3 m measurement distance, the height uncertainty of ± 1 cm causes an uncertainty of approximately ± 0,3 dB (rectangular distribution). See Table G.3 and Table G.4 in Annex G for uncertainty values as a function of measurement distance.

8.2.4.4 Measurement procedure-related influence quantities

a) Nominal measurement distance:

For SAC/OATS-based radiated emission measurements, the nominal measurement distance is 10 m (see definition of measurand in 8.2.2). If an alternative measurement distance is applied, for example 3 m, then a conversion of the 3 m results into emission results expected at the nominal measurement distance of 10 m shall be applied.

NOTE 1 The application of an alternative measurement distance, such as 3 m or 30 m rather than 10 m, is considered to comprise an alternative measurement method. Conditions for the use of alternative measurement methods, including uncertainty considerations, are described in CISPR/TR 16-4-5:2006.

In practice, such conversions are often done assuming that the emission from an EUT at a certain measurement distance may be converted to another distance by applying the free-space field-strength attenuation formula, i.e. 20 dB/decade or $1/r$ behaviour.

NOTE 2 In CISPR 22 (2008) the NOTE in 10.3.1 states that an inverse proportionality factor of 20 dB per decade should be used to normalize the measured data to the specified distance, for conformity assessment.

However, the exact conversion very much depends on the type of EUT, the actual measurement distances involved, and frequency. Different RRT results (see 8.2.7) confirm that the correlations for a specific EUT do not follow the simplified free-space conversion rule of 20 dB/decade. As an example, Figure H.5 of Annex H shows the actual and free-space converted results from 3 m to 10 m distances for a small table-top EUT, based on results from an RRT [13], [25].

The correlation of results obtained from a SAC/OATS 3 m measurement distance to a 10 m measurement distance is done by subtracting 10,5 dB from the results at each frequency. For the example of Figure H.5, the actual correlation factor varies with frequency between 5 dB and 9 dB, and the average correlation factor is 7,6 dB. This correlation factor shall be used as a correction of the results [Equation (24)]. Generic correlation factors applicable to any EUT are generally not available. Use of a single correction factor value for the entire frequency range causes an uncertainty that becomes relevant when 3 m and 10 m emission measurement results for the same EUT are compared. Such a comparison can occur in market surveillance situations, for example. Consequently the resulting uncertainty contributes to the SCU. Note also that this influence quantity does not contribute to the MIU, because uncertainty contribution is present even if measurement instrumentation and site effect uncertainties are negligible. The results of Figure H.5 show that use of a correlation factor of 10,5 dB yields overly compensated results at 10 m. From a compliance determination point of view it may be more appropriate to apply a smaller correlation factor. The selection of the correlation factor determines the resulting uncertainty, as far as the difference in results obtained at different measurement distances is concerned. From the aspect of market surveillance, the difference in results may have less of an impact because it is more important that the measurement data is below the applicable limit in both cases. In this case it might be prudent to apply a conservative correlation factor, e.g. 5 dB.

b) Receiver settings:

Some flexibility is provided in the measurement method standards for receiver settings, as performed either manually or under software control. This may lead to uncertainties that are dependent on the type of disturbance (broadband/narrowband or intermittent) emitted by the EUT (see CISPR 16-2-3). Some examples are the sweep time setting, setting of input attenuation, and reference level setting.

c) Height-scanning step size:

The height of the receive antenna is varied between 1 m and 4 m. The operator or the measurement automation software establishes the step size for the height variation. The height step size influences the probability of missing the maximum electric field strength at the measurement position. The associated uncertainty also depends on the type of EUT (height above ground plane, polarisation of the disturbance) and on the measurement distance and frequency. The lobe height of the interference pattern is smallest for table-top EUTs at the highest frequency and at the shortest measurement distance of 3 m. Under these conditions, the step-size induced uncertainty will become highest. Below 200 MHz, the associated uncertainty is negligible provided that the step size is less than 25 cm. At higher frequencies (> 200 MHz) the uncertainty may be significant [12]. For example, at a 3 m measurement distance and for a step size of 25 cm, the measured field may be 1 dB lower than the value measured using a near-continuous scan (height step size of 0,01 m). A reduced step size of 10 cm will reduce this deviation to 0,2 dB. The latter figure is what is included in the example uncertainty estimates listed in Annex G (0 dB to -0,2 dB, rectangular distribution, and a correction factor of +0,1 dB). At 10 m and 30 m measurement distances, the step size may be reduced considerably to maintain the same step-size induced uncertainty of +0 dB to -0,2 dB. For EUT heights of 0,4 m above the ground plane, the step-size induced uncertainty is negligible. In general, a continuous height scan minimizes this error contribution. However, with smaller height step sizes, measurement time may increase drastically, because sufficient dwell time at each incremental height is used to accommodate EUT operations.

d) Start and stop position tolerance (height scan):

The uncertainty in height of the start and stop position is typically a few centimetres. Depending on the receive antenna height step size, measurement distance and frequency, this will affect the probability of measuring the maximum electric field strength. This uncertainty is related and similar in nature to the uncertainty-related to EUT height tolerance. This uncertainty is significant at those frequencies where the maximum field strength is measured at either the lowest or the highest positions of the antenna height scan (generally at the lower limit near 1 m). There is an additional uncertainty if the height-scan step size is too large. The uncertainty is largest at the measurement distance of 3 m and in the case of predominantly vertical polarisation of the disturbance source [12]. For a table-top EUT at 3 m measurement distance, and with a receive antenna start-position tolerance of ± 3 cm, the resulting uncertainty is ± 0,6 dB (rectangular distribution). For EUTs at a height of 0,4 m, the resulting uncertainty is ± 0,2 dB. See Table G.3 and Table G.4 in Annex G for uncertainty values as a function of measurement distance.

e) Azimuth step size:

The azimuth radiation pattern of an EUT radiating in free space becomes more directive at higher frequencies. However, the ground reflection tends to make the overall azimuth pattern omni-directional again, whereas grating lobes appear in the elevation pattern. The EUT must be rotated in azimuth in order to capture the maximum emission, and thus the azimuth step size and the azimuth start position determine the probability of intercept of the maximum electric field strength within a certain tolerance. The associated uncertainty does not depend on measurement distance. A continuous rotation will minimize this effect.

8.2.4.5 Environment-related influence quantities

a) Temperature and humidity tolerances:

These environmental influence quantities are considered to have a negligible impact on the result of the measurement for measurements done in a SAC. If an OATS is used, then depending on the dimensions and shape of the conducting ground plane, the influence of water on the ground plane, the ground properties beyond the ground plane, and wet or dry nearby vegetation may have an impact on site performance. So this influence quantity should be taken into account in the test site performance [see 8.2.4.6 e)]. In addition, sensitivity of the measuring equipment (antenna, receiver) to environmental parameters is generally negligible.

The insertion loss of the cable between antenna and receiver varies with temperature. This may cause repeatability problems for OATS measurements. The cable loss should be measured at a temperature close to the temperature at which the emission measurements will be made. The use of white-sheathed cable can reduce short-term variations caused by intervals of direct sunlight and cloud cover.

Similarly, for measurements done at an OATS, direct exposure to sunlight may cause temperature variations within the EUT and consequently variation of the level of radiated emission. This influence quantity will contribute to the SCU. The use of an electromagnetically-transparent shelter (radome) may reduce the impact on the EUT from sunlight irradiation and humidity.

b) Signal-to-ambient-signal ratio:

When using an OATS, the ambient levels of radiated emissions from radio transmitters may negatively impact the measurement of radiated emissions at specific frequencies, or even render emissions measurements impossible. The associated uncertainty of the measured disturbances that coincide with the ambient radio frequencies may therefore be significant. In general these ambient signals are not coherent with the measured disturbance, and therefore can be treated as a noise signal. The resulting errors depend on the ratio of the disturbance signal and the ambient signal, and the level of the internal receiver noise [42], [50]. For measurements done in a SAC, the uncertainty due the ambient radiated signals is negligible.

c) Mains voltage variations:

The EUT shall be operated using a supply that has the rated voltage of the EUT (see 6.3.4 of CISPR 16-2-3:2006). If the level of disturbance varies considerably with the supply voltage, the measurements shall be repeated for supply voltages over the range of 0,9 to 1,1 times the rated voltage. EUTs with more than one rated voltage shall be tested at the rated voltage that causes the maximum disturbance. Deviations of the mains voltage deviations from the nominal may introduce uncertainties if the level of disturbance power depends on the mains voltage level. The magnitude of this variation will be highly dependent on the type of EUT, and therefore should be evaluated for each EUT. Consequently, this influence quantity will contribute to SCU. However, no specific uncertainty figure can be estimated for this influence quantity.

d) Application of mains decoupling devices:

The different mains filters and mains decoupling devices, such as CDNs, decoupling transformers, variacs, LISNs or combinations thereof, used in various laboratories may give rise to different disturbance levels, also depending on the category of EUTs (mains connection with or without protective earth). See also 8.2.4.3 b) about mains connections.

8.2.4.6 Measurement instrumentation-related influence quantities

a) Receiver accuracy:

The accuracy can be obtained from the specifications sheet or the calibration certificate of the receiver. If calibration data is not available, or if only verification was performed, i.e. verification that the parameters are within specifications, then the specification values should be used and treated as rectangular-distributed values to calculate the uncertainty. If calibration data is available (i.e. a specific value for each parameter and an associated uncertainty, probability distribution, and confidence level), then this information can be used to calculate the uncertainty contribution. If necessary, the uncertainty for different types of signals/responses may be considered, i.e. CW accuracy, pulse-amplitude response accuracy, and pulse-repetition response accuracy. See also Annex A of CISPR 16-4-2:2003 for detailed considerations about the accuracy of the receiver.

b) Mismatch at the receiver input:

Mismatch uncertainties will occur due to the mismatch of the measuring cable connected to the receiver. This mismatch uncertainty depends on the receiver input impedance, the input attenuation setting of the receiver, the antenna impedance, and the impedance and attenuation properties of the measuring cable, which are functions of frequency. See also Annex A of CISPR 16-4-2:2003 and [34]. The return loss of biconical and hybrid antennas generally gets worse at low frequencies, such that an attenuator is typically used between the antenna and the cable to reduce VSWR to less than 2,0 to 1 [CISPR 16-1-4:2007, 4.4.2 d)]. The VSWR of the receiver input has a maximum value of 2,0 to 1 (for zero dB input attenuation – which should be avoided, however), and VSWR of biconical and log-periodic dipole array (LPDA) antennas are 4,6 to 1 (maximum 10 to 1 or more) and 2,0 to 1, respectively. The mismatch uncertainty has a U-shaped distribution [16]. Typical values for mismatch uncertainties are +0,9/-1,0 dB below 200 MHz, and ± 0,3 dB between 200 MHz and 1 000 MHz (data taken from [34], [1]).

c) Measuring system reading:

Receiver reading uncertainties depend on receiver noise, display fidelity, and meter scale interpolation errors. The latter should be a relatively insignificant contribution to the uncertainty for measuring systems with electronic displays (least-significant digit fluctuation). However, for analogue meter displays, this latter uncertainty contribution shall be considered.

d) Signal-to-noise ratio:

For radiated emission measurements, the receiver noise floor will influence measurement results, especially at the larger measurement distances of 10 m and 30 m. In general, the impact of the noise also depends on the type of noise. Boltzmann (random) noise has far less effect on a signal than does a coherent noise signal. The internal receiver noise is random noise, and the resulting error when measuring a disturbance will depend on the disturbance-to-noise-level ratio [42], [50]. For example, a random noise level of 10 dB below a CW signal causes an error of +0,7 dB on the CW signal, but an unwanted random noise level of 3 dB down causes an error of +1,4 dB. In general, a larger measurement distance will reduce the disturbance-level-to-internal-noise ratio [42]. Also, the use of pre-amplifiers near the antenna will influence the noise floor level. Therefore, it is difficult to give uncertainty estimates as a function of measurement distance due to the internal noise floor level of the receiver. Table G.3 and Table G.4 in Annex G give some typical uncertainty estimates as a function of measurement distance. The proximity of the actual internal noise floor to the applicable emission limit can be used to estimate the resulting error.

e) NSA deviation:

Imperfections of a SAC or OATS test site, for example caused by non-ideal absorbing walls or a finite and irregular ground plane, directly affect the result of a radiated emission measurement. The test site imperfections depend on the type of EUT (large, small) and on frequency. The test site performance is quantified by the normalized site attenuation (NSA), wherein the EUT is represented by a transmit antenna of similar type as the receive antenna, and the NSA is evaluated for several positions of the transmit antenna in the test volume. The test site pass/fail criterion for the NSA-deviation is ± 4,0 dB. Note that an NSA measurement includes uncertainty components such as linearity of the receiver, stability of the generator, and uncertainties of the two antenna factors. See also 5.6.3 and Annex E of CISPR 16-1-4:2007. For purposes of this subclause, the intrinsic NSA performance should be used, i.e. the uncertainty of the NSA measurement is subtracted from the NSA results. An example of the uncertainty estimate associated with the NSA measurement method, including uncertainty contributions from instrumentation, is given in Table 12. The resulting expanded uncertainty is ± 2,0 dB. Table 13 shows how this uncertainty affects a NSA measurement of a site with an intrinsic (actual) site attenuation deviation performance of ± 3,0 dB (rectangular distribution).

Table 12 – Example of uncertainty estimate associated with the NSA measurement method, 30 MHz to 1 000 MHz

UNCERTAINTY SOURCES **Influence quantities**	**Uncertainty** **value (+/-dB)**	**Probability distribution**	**Divisor**	**Standard uncertainty**
ANTENNA-RELATED				
Transmit antenna factor uncertainty	1,0	Rectangular	1,73	0,58
Receive antenna factor uncertainty	1,0	Rectangular	1,73	0,58
SET-UP-RELATED				
Tolerance measurement distance	0,1	Rectangular	1,73	0,06
Tolerance transmit antenna height	0,1	Rectangular	1,73	0,06
Tolerance start and stop position receive antenna	0,1	Rectangular	1,73	0,06
TEST PROCEDURE-RELATED				
Repeatability	0,5	Rectangular	1,73	0,29
MEASUREMENT INSTRUMENTATION-RELATED				
Stability generator	0,1	Normal	2,00	0,05
Linearity receiver/analyser	0,5	Rectangular	1,73	0,29
Mismatch at the input	0,4	U-shaped	1,41	0,28
Mismatch at the output	0,4	U-shaped	1,41	0,28
Measuring system reading	0,1	Rectangular	1,73	0,06
Signal to noise ratio	0,1	Rectangular	1,73	0,06
Combined standard uncertainty				1,01
Expanded uncertainty		Normal	2,00	2,01

Table 13 – Relationship between intrinsic and apparent NSA

	Value (+/-dB)	Probability distribution	Divisor	Standard uncertainty
Uncertainty NSA measurement	2,0	Normal	2,00	1,00
Test site deviation (=intrinsic NSA specification)	3,0	Rectangular	1,73	1,73
Combined standard uncertainty				2,00
Expanded uncertainty (= apparent NSA specification)		Normal	2,00	4,00

Calculation of the overall or apparent NSA (NSA including measurement uncertainty) obeys the rules of the uncertainty calculations, because the NSA is also a statistical quantity that varies independently from the NSA uncertainty. In conclusion, a site that complies with the NSA specification ± 4,0 dB has an intrinsic test site deviation of ± 3,0 dB (rectangular distribution). See also 8.2.4.5 a) for the impact of weather on OATS performance. If the measured NSA is less than the ± 4 dB specification level, then the actual measured (intrinsic) values can be used in the uncertainty estimates thereby to reduce the overall MIU.

f) EUT positioning table:

Support tables for EUTs are constructed of wood or other types of non-conducting materials. The dielectric properties of these materials or absorbed moisture may affect the emission results, especially above 200 MHz (see 5.9 of CISPR 16-1-4:2007) for table-top equipment. An estimate of the deviation can be obtained using the measurement method described in 5.9 of CISPR 16-1-4:2007 (rectangular distribution). The impact of low-height support tables used for floor-standing equipment are considered to have a negligible impact, provided that the perimeter of the support table is less than or equal to the EUT perimeter at the base (footprint).

g) Influence of the receive antenna mast:

The antenna mast assembly used for the positioning of the receive antenna may also affect the measurement results. If the same antenna mast is in place during the site validation testing, the uncertainty due to the receive antenna mast does not need to be considered separately. However, if a different antenna mast is used during NSA measurements, the effects of the antenna mast used for emission measurements shall be evaluated separately. The resulting deviation shall be included in the uncertainty estimate (see also 5.9 of CISPR 16-1-4:2007).

h) Free-space antenna factor uncertainty:

The uncertainty of the antenna factor directly affects the uncertainty of the measurement result [see Equation (24)]. In principle, the antenna factor to be used depends on the EUT to be measured and on the test site configuration. This is because the incident field is not a uniform plane wave, incident from a single direction, and in addition the height of the antenna above the ground plane is varied during the measurement. However, it has been demonstrated that on average, the application of free-space antenna factors instead of geometry-specific antenna factors yields results with the lowest uncertainties (see [11]). For this reason, CISPR/A recommends the application of free-space antenna factors as a practical single frequency-dependent figure-of-merit (ongoing work in CISPR/A). The uncertainty of the free-space antenna factor is listed in antenna calibration reports. Typical expanded uncertainty values for the calibration of free-space antenna factor are ± 1,5 dB (normal distribution, coverage factor k = 2).

Apart from the calibration uncertainty, uncertainties associated with the practical simplification that comes from application of the free-space antenna factor shall also be considered. The influence quantities associated with this antenna factor simplification are the type of receive antenna (directivity), and the antenna height dependence. These influence quantities are discussed in the following two list items.

i) Type of receive antenna (directivity):

The free-space antenna factor used as a simplified single figure-of-merit is not sufficient to give an accurate conversion of the measured voltage to electric field strength at the position of the antenna phase centre. In practice, various types of antennas may be used, ranging from tuned dipole antennas to broadband antennas. Different types of antennas will average the incident field strength differently. Instead of this “spatial” viewpoint (averaging of incident field strength), a “radiation pattern” viewpoint (plane-wave spectral approach) can be used to represent the effects of different types of antennas. For instance, electrically-small antennas generally have a wide beamwidth, while large antennas are more directional and have a smaller beamwidth. This will influence the weighting of the direct and reflected field rays from the EUT. The uncertainty associated with different types of antennas may be expressed by considering the radiation pattern (directivity) of the antenna. Large uncertainties may result in case the radiation pattern collapses, meaning the gain in the direction of the direct field ray from the EUT is much smaller than the gain in the direction of the reflected field ray contribution. A quantitative analysis of this “directivity” influence quantity is given in [47], where the CISPR tuned dipole (see Clause 4 of CISPR 16-1-4:2007) is used as the reference for judging the differences due to application of different types of receive antennas. The impact of the type of receive antenna depends on the following parameters:

– type of EUT (vertical polarisation, due to directivity of receive antenna);
– frequency (higher frequencies yield higher directivity of receive antenna patterns);
– measurement distance (smaller incidence angle of the reflected field at larger measurement distances).

See Table G.3 and Table G.4 in Annex G for uncertainty values as a function of measurement distance.

j) Antenna factor height dependence:

The actual antenna factor will vary as a function of height above the ground plane, due to the coupling of the antenna with its image. On average, the free-space antenna factor is the best choice to replace the height-dependent antenna factor. The antenna factor height variation depends on:

– polarisation (substantial effect for horizontal polarisation, mostly negligible for vertical polarisation);
– antenna type (LPDA, biconical, etc);
– frequency (less coupling of the antenna with its image at higher frequencies due to larger distance in terms of wavelengths).

In reference [28], background information and quantitative information is available about antenna factor variations (with respect to the free-space antenna factor) for different types of antennas and as a function of frequency.

k) Antenna factor frequency interpolation:

An antenna calibration report generally provides antenna factor data at a number of discrete frequencies. Antenna factors at intermediate frequencies are then often derived by linear interpolation. The uncertainty associated with antenna factor interpolations depends on the initial number of frequency points provided in the calibration report. Commercially available receive antennas generally have a smooth variation of the antenna factor as a function of the frequency, and therefore the uncertainty due to antenna factor interpolation is small. The maximum of half of the differences between two successive values of the antenna factor can be used to estimate the antenna factor interpolation uncertainty, using a rectangular distribution. Many antennas, particularly hybrid ones, have sharp changes of antenna factor with frequency, where the uncertainty will be larger; use of smaller frequency steps in the antenna calibration will minimize this uncertainty.

l) Antenna phase centre variation:

It is advantageous to use the phase centre of the receive antenna as the reference point to establish the measurement distance between the EUT and the receive antenna, because the phase centre is the point on the antenna where the free-space antenna factor is applicable.

NOTE In the transmit mode, the phase centre can be considered as the apparent point source from which radiation originates. In general, the phase centre of an antenna may vary as a function of the angle of incidence, but this effect is small for EMC measurements.

For dipole-type antennas, the phase centre of the antenna is located between the two elements at the feed point (or balun). The position of the phase centre of an LPDA antenna varies with frequency, and it is located near the dipole element that is active at a certain frequency. Consequently, the position of the phase centre varies with respect to the fixed reference point of the LPDA antenna, which is usually taken to be midway between the elements that are resonant at the ends of the operating frequency range. As the antenna reference point is at a fixed measurement distance from the EUT, the actual measurement distance may vary as a function of frequency. This distance variation effect (uncertainty) is largest at the ends of the operating frequency range, and is larger for shorter measurement distances. The uncertainty can be neglected for antennas, where the phase centre coincides with the reference point, e.g. tuned dipoles and biconical antennas.

Table G.3 and Table G.4 in Annex G include phase centre variation uncertainty values as a function of measurement distance. See also references [17], [11] for other information about phase centre considerations of LPDA antennas.

m) Antenna unbalance:

The effect of an unbalanced antenna, i.e. when the balun has poor differential-to-common-mode conversion properties, is most evident in the low frequency range (<200 MHz) and when the measurement cable is oriented in parallel with the antenna elements. The pass/fail criterion for the unbalance of an antenna, i.e. response < 1 dB (see 4.4.3 of CISPR 16-1-4:2007), provides an estimate for the resulting uncertainty (rectangular probability distribution).

n) Cross-polarisation performance:

The cross-polarisation performance of an antenna indicates how the antenna responds to a cross-polarised incident plane wave, relative to a co-polarised incident plane wave. When an antenna is placed in a plane-polarized electromagnetic field, the terminal voltage when the antenna and field are cross-polarized shall be at least 20 dB below the terminal voltage when they are co-polarized (see CISPR 16-1-4:2007, 4.4.4). The cross-polarisation performance of dipole-type antennas (including biconical antennas) is generally negligible. LPDA antennas generally have a non-negligible cross-polar response. An LPDA illuminated by equal field strengths in horizontal and vertical polarisation (i.e. a field at 45°) will be measuring the co-polar field strength with an error of 0,9 dB if the cross-polar rejection of the LPDA is 20 dB [11]. The latter value may be used as an uncertainty estimate (rectangular probability distribution) in the frequency range where LPDAs are used (200 MHz to 1 000 MHz). The cross-polarisation induced uncertainty is relatively independent of measurement distance. In addition, at an OATS/SAC, the receive antenna may respond to longitudinal-polarised fields emitted by an EUT (see [45], [37], [35]); the contribution from this longitudinal component depends also on the measurement distance and the site performance. If the longitudinal cross-polarisation rejection for a given combination of receive antenna and test site is poor (susceptible to receive longitudinal field components), then the effect shall be accounted for in the uncertainty estimates. References [45], [37], [35] do not provide quantitative information on the uncertainties involved in responses to longitudinal-polarised field components. Future enhancements of the SAC/OATS measurement method should take this influence quantity into account.

o) Cable loss uncertainty:

The uncertainty of the cable loss directly affects the uncertainty of the measurement result [see Equation (24)]. An estimate for the uncertainty of the loss of the measuring cable between antenna and receiver can be obtained from the cable calibration report (expanded uncertainty and normal distribution) or from manufacturer's data (specified tolerance and rectangular distribution). The level of cable-loss uncertainty is generally low, except when long cables are used on an OATS with large temperature variations (see also temperature effects discussion in 8.2.4.5).

p) Mismatch:

This influence quantity is covered in 8.2.4.6 b); see also [16].

q) Measurement system repeatability:

The measurement system repeatability can be evaluated from the standard deviation of a series of repeated measurements using a stable reference radiator. The measurement conditions for determining the measurement system repeatability should be considered carefully to avoid double counting of uncertainties in the uncertainty estimate. It should include typical variations caused by the measurement system that will occur in normal testing. The purpose of the measurement-system repeatability is to account for unpredictable (random) variations of influence quantities that have not been identified. Therefore repeatability measurements should not include rotation of the EUT (reference radiator in this case) and the receive antenna should be fixed in height because those influence quantities have been addressed separately. Environment-related uncertainties may be identified as well by performing a measurement system repeatability check. However, these uncertainties may have already been included in the uncertainty estimate (see 8.2.4.5). Note that the uncertainty contribution from the reference radiator shall be very small. This may be verified from specifications or from direct measurement of the RF-output of the reference radiator.

8.2.5 Application of the uncertainty estimate

8.2.5.1 General

In general, knowledge of the expanded uncertainty of the SAC/OATS-based radiated emission measurement method serves two purposes: estimation of the measurement instrumentation uncertainty, and/or the standards compliance uncertainty.

8.2.5.2 Measurement instrumentation uncertainty (MIU) considerations

The MIU can be calculated for accreditation purposes of a test laboratory. For this purpose, it is sufficient to consider the uncertainties induced by the test laboratory only, i.e. the uncertainties related to the measurement instrumentation, the environment, and the measurement procedure. The resulting MIU can be used to compare with the specified MIU value stated in CISPR 16-4-2:2003, i.e. U_{CISPR} = 5,2 dB. If the MIU exceeds this U_{CISPR} value, the exceeding amount shall be accounted for in the pass/fail decision, as described in 4.1 of CISPR 16-4-2:2003.

8.2.5.3 Standards compliance uncertainty (SCU) considerations

The SCU can be estimated for the measurement method in combination with a typical type of product. This value of the SCU can be used for assessment of risk of non-compliance against a certain radiated emissions limit. In cases of measurement correlation discussions between two test laboratories where the “same” measurement was performed using the “same” EUT, the uncertainties induced by the EUT must be included as well in the uncertainty estimate. In market surveillance situations, in principle the SCU should be considered by all of the involved parties (manufacturer and the authority), because the SCU is a relevant figure-of-merit for the reproducibility of the measurement method. However, an estimation of the SCU applicable for any type of EUT may be difficult in practice. Therefore, some other approach should be used for market surveillance applications. See 4.7.5.

8.2.6 Typical examples of the uncertainty estimate

Table G.1 and Table G.2 in Annex G provide a typical uncertainty estimate for a SAC-based radiated emission measurement of a table-top EUT at a measurement distance of 3 m. Two tables are provided corresponding to the 30 MHz to 200 MHz and 200 MHz to 1 000 MHz frequency ranges. Two additional tables, Table G.3 and Table G.4, are provided which include uncertainty data for some influence quantities for the radiated emission measurement method at measurement distances of 3 m, 10 m, or 30 m. The uncertainty estimates are calculated in accordance with the procedure defined in Clause 4.

For the estimates presented in Annex G, most of the contributions are type B evaluations, and use data from calibration certificates, instrumentation manuals, manufacturer's specifications, previous measurements, or from models or generic knowledge about the measurement method. The probability distributions and uncertainty values for the various uncertainty sources/influence quantities that are given in Annex G are derived from various sources of information, as discussed in 8.2.4.

Unfortunately, a model is not always available for the relationship between the measurand and the various influence quantities. In this case, only an assumption can be made that the measurand is a function of the influence quantities summarized in Table 10. Most standard uncertainty values for each influence quantity must be derived using type B evaluation methods. Furthermore, it is assumed that all sensitivity coefficients are equal to one. However, in absence of a realistic model, actual values for the sensitivity coefficients are usually unknown.

For example, for measurements done at other than 10 m, the assumption used for the effects of the measurement distance on the field strength level is not correct. The maximum field strength at an alternative measurement distance does not vary linearly with distance, due to the presence of the ground plane and the field maximisation process. At close measurement distances and low frequencies, additional “non-linear” effects occur in the near-field region.

Table G.1 and Table G.2 each also provides results for both MIU and SCU calculations. For a 3 m measurement distance, the MIU is nearly 5,5 dB, whereas the SCU may be as large as approximately 15,5 dB.

8.2.7 Verification of the uncertainty estimate

Various round robin tests (RRTs), sometimes called interlaboratory comparison (ILC) measurements or site reproducibility programs, have been performed previously for SAC/OATS-based radiated emission measurements, with results reported in various papers. The results of these RRTs are usful because they can provide insight into the actual uncertainties associated with SAC/OATS-based radiated emission measurements. Accordingly, RRT results can be used to support the validity of the uncertainty estimates shown in Annex G.

Table H.1 in Annex H summarizes relevant parameters and results from a number of RRTs. Figure H.1, Figure H.2, Figure H.3, and Figure H.4 in Annex H show sample results from some RRTs. The following conclusions can be drawn from these results.

a) Results of RRTs using a reference radiator show uncertainties (expanded, or 2σ) ranging from 3 dB to 6 dB. Reference radiators are generally stable and reproducible. RRTs using these simple types of EUTs fundamentally provide information about the MIU. This assumes a very simple EUT and a very detailed measurement procedure for the RRT. The range of uncertainty found is consistent with the results of the MIU estimates shown in Annex G.

b) Results of RRTs using a more complex and realistic EUT exhibit much larger uncertainties, i.e. up to 11 dB. This uncertainty estimate has also been confirmed by numerical modelling. The larger uncertainty is due to the intrinsic uncertainty of the EUT, i.e. a poor reproducibility of the set-up, combined with variable methods of terminating cables. RRTs using such realistic EUTs fundamentally provide information about the SCU. The range of uncertainty found is consistent with the results of the SCU values shown in Annex G.

9 Conducted immunity measurements

Under consideration.

10 Radiated immunity measurements

Under consideration.

Annex A
(informative)

Compliance uncertainty and interference probability

A.1 General

Clause 4 of this document discussed use of 'standards compliance uncertainty' in connection with the compliance criterion in a standardised test and 'interference probability' in connection with the probability of occurrence of an interference problem to be prevented by that test. Moreover, in 4.3, it was explained that the level measured in a test is a figure-of-merit of the interference potential of the measured product. Hence, to judge the possible effect of uncertainties, the complete EM interference problem has to be considered and measured data have to be converted into interference probability data.

An example of a basic study needed in the determination of the interference probability is given in [1]. The interference probability shall set a maximum for the allowable SCU associated with that test. If that maximum is exceeded, the test shall be improved. Another example study is given in A.2. Finally, A.3 addresses the problem that a reduction of the compliance uncertainty does not need to lead to a reduction of the interference probability.

Because no actual quantitative data are available, A.2 and A.3 are of a descriptive and qualitative nature. The purpose of this annex is to illustrate that the uncertainty of a compliance test will affect in some way the 'interference probability'. Apart from the description in this annex, the subject of relating SCU and 'interference probability' will not be treated further in this part of CISPR 16, because it is the responsibility of CISPR/H.

A.2 Application to radiated emissions, an example

In Figure A.1, distribution X1 is assumed to represent the results from radiated emission measurements performed using a very large number of various appliances subject to compliance with a radiated emission limit of 30 dB(μV/m) at 10 m in accordance with, for example, CISPR 11 [1] (ISM equipment) or CISPR 22 (IT equipment). The problem to be prevented is defined as interference in TV reception caused by the field emitted by those appliances. Degradation will occur when the disturbing field arrives with the correct frequency and polarisation at the TV antenna with a level of 6 dB(μV/m). Note that in this case the level to be protected is 24 dB below the emission limit. Assume that for a given TV-reception frequency, the field strength distribution X1 follows from the measurement results. The relatively large width of distribution X1 can be explained by several factors, such as the following:

a) not all appliances need to emit at the chosen TV-reception frequency;
b) the non-specified influence quantities governed by the layout of the cables attached to the appliances;
c) the uncertainties associated with the receive antenna properties, such as antenna factor, balance, and cross-polarisation;
d) the tolerances of the CISPR receiver and test site, as specified in CISPR 16-1-1 and CISPR 16-1-4.

Note that distribution X1 exceeds the limit. This is due to the fact that the uncertainties include the intrinsic uncertainty and, in this case of mass-produced appliances, the consequences of the CISPR 80 % /80 % sampling criterion.

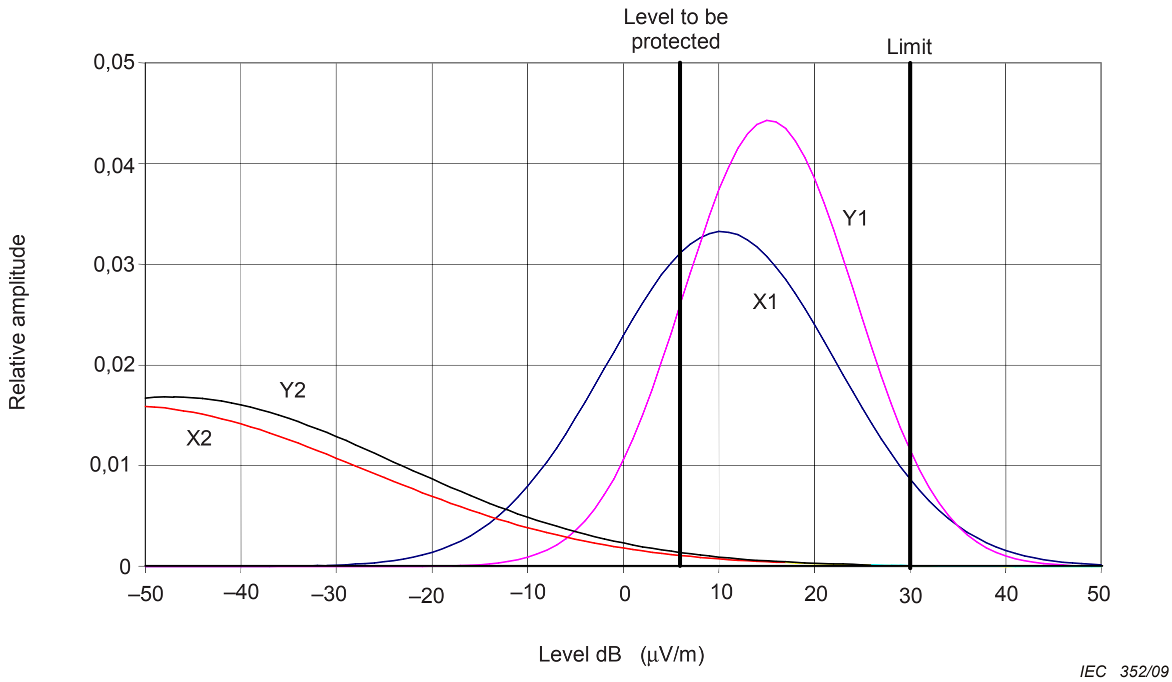


Figure A.1 – Measured field strength distributions X1 and Y1, emission limit and level to be protected of relevance in the determination of the corresponding interference probability determined by distributions X2 and Y2

The associated interference probability is represented by distribution X2. This distribution is even wider than distribution X1 as a result of many influence quantities, such as

a) the maximum of the field strength (required in the radiated emission measurement) does not need to point in the direction of the victim antenna;
b) mismatch of polarisation of the field at the victim antenna and, in general, no constructive addition of the direct and indirect field at that antenna;
c) field scattering and building attenuation;
d) the probability distribution of the actual distance between the source and the victim, compared to the fixed measurement distance of 10 m.

A conclusion is that the actual coupling parameters between the disturbance source and the victim antenna differ significantly from the coupling parameters between that source and the receive antenna in the radiated emission measurement. The spread in the actual coupling parameters causes the large width of distribution X2. From practice over several years and decades, it is known that the number of interference complaints is acceptably low, so that distribution X2 can only slightly exceed the level to be protected. From the foregoing it should be clear that from an interference probability point of view, the standards compliance uncertainty should be sufficiently small, to ensure that its influence on the transition from distribution X1 to distribution X2 is negligible.

A.3 Reducing the compliance uncertainty

If the combined uncertainty margin is reduced, it is possible to design appliances such that the distribution X1 in Figure A.1 shifts in the direction of the limit level so that distribution Y1 is produced. Using the same conversion data as in the case X1⇒X2, produces distribution Y2. It should be clear from Figure A.1 that in this case a larger number of complaints may result. So a reduction of the uncertainty does not automatically leads to an improvement of the interference probability. In other words, when reducing the uncertainty, it may be necessary to choose a stricter limit to arrive at the same interference probability. At present, the limit has been chosen such that the interference probability is sufficiently large with the present uncertainties associated with the CISPR radiated emission measurement.

Annex B
(informative)

Numerical example of the consequences of Faraday's law

To demonstrate the importance of the physics described by Faraday's law, discussed in 6.2.2.3 and in particular when a voltage probe is used, it is assumed that the EUT has to comply simultaneously with:

a) the voltage limits at load and control terminals as given in Table 2b of CISPR 15:2005 [3], to be verified by means of a voltage probe measurement, and

b) the radiated EM-disturbance limits as given in Table 3 of CISPR 15:2005 [3], to be verified by means of the large-loop antenna (LLA) system.

To keep the calculations very simple, it is assumed that the loop formed by the 'hot' EUT terminal, the voltage-probe tip, the probe input circuit, the ground lead of the probe to the second EUT terminal, and the EUT circuit between its two terminals, can be described by a segment of a circular area.

It is assumed that the ambient field is negligibly low and that the non-negligible magnetic field emitted by the EUT itself, which may influence the measurement result [see Equation (12)], stems from the near field of a small magnetic dipole. That dipole is assumed to be located at the centre of the EUT and at the centre of the mentioned circular area, while the vector of the dipole moment is perpendicular to that area. In the LLA system this dipole moment, m_H, is indirectly measured if the EUT is at the centre of the loop antenna in which the current I_m is measured. The relation between m_H and I_m is well approximated by

$$I_m = \frac{\mu_0 \ m_H}{D_a L_a} \qquad \text{or} \qquad m_H = \frac{D_a L_a I_m}{\mu_0} \tag{B.1}$$

where D_a is the diameter of the large loop antenna and L_a the inductance of that loop [14].

The magnitude of the voltage induced in the segment $U_i = \omega \, \Phi$, where Φ is the magnetic flux through the segment. If the segment is defined by $\{\phi_0, R_1, R_2\}$, where ϕ_0 is the arc-angle, R_1 the inner radius of the segment and R_2 its outer radius, and the magnetic near-field component is given by

$$H_\theta = \frac{m_H}{4 \, \pi \, r^3} e^{j\omega t} \tag{B.2}$$

U_i can be written as

$$U_i = \frac{\mu_0 \ \omega \ m_H}{4\pi} \int_0^{\phi_0} \int_{R_1}^{R_2} \frac{r}{r^3} \mathrm{d}\phi \, \mathrm{d}r = \frac{\omega \ D_a L_a \ I_m \ \phi_0}{4\pi} \left(\frac{1}{R_1} - \frac{1}{R_2} \right) \tag{B.3}$$

Note that due to the assumed orientation of the dipole moment with respect to the segment area, only H_θ contributes to U_i.

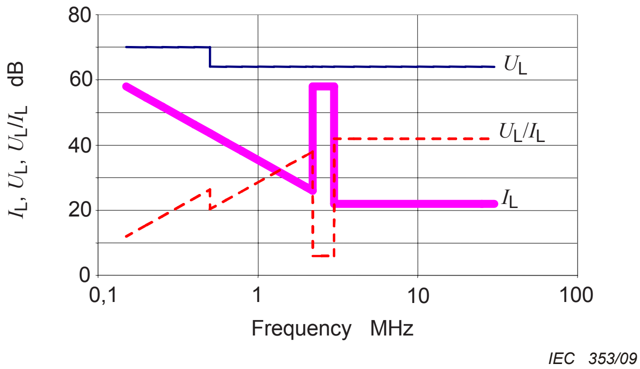


Figure B.1 – Voltage and current limits as given in CISPR 15:2005, Tables 2b and 3, and the ratio U_L/I_L

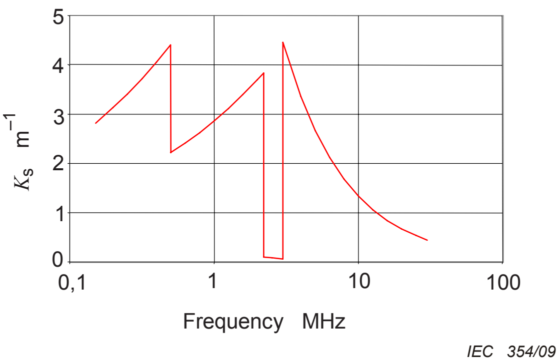


Figure B.2 – Factor K_s derived from the data in Figure B.1 and Equation (B.4)

Assume that I_m has the limit value I_L as given in Table 3 of [3] (see Figure B.1) and that U_i just equals the limit value U_L as given in Table 2b of [3] (see Figure B.1). Then the factor K_s representing the segment parameters $\{\phi_0, R_1, R_2\}$ that make $U_i = U_L$, is given by

$$K_s = \phi_0 \left(\frac{1}{R_1} - \frac{1}{R_2} \right) = \frac{2}{D_a L_a f} \frac{U_L}{I_L} \approx \frac{1{,}06 \times 10^5}{f} \frac{U_L}{I_L} \qquad \text{(B.4)}$$

where $f = \omega / 2\pi$. The numerical value follows when taking D_a = 2 m and the approximate value $L_a = 1{,}5\pi D_a$. Figure B.2 gives the results for K_s as a function of frequency.

From Equation (B.2) or Figure B.2 it follows that at 10 MHz, for example, K_s = 1,34. Assuming $\phi_0 = 30° \equiv \pi/6$ rad and R_1= 10 cm, it follows that R_2 = 13 cm. Then the resulting segment area, giving rise to an unwanted induced voltage equal to the voltage limit, amounts to only 21 cm^2. This clearly illustrates the need to specify the measurement loop in detail.

Annex C
(informative)

Possible amendments to CISPR publications with regards to voltage measurements

C.1 Introductory remarks

Compliance uncertainty studies form an excellent tool to discover ambiguities and weak specifications in the existing CISPR standards. In addition, these studies can be of great assistance when drafting standards. Without going into detail, this annex give some examples indicating where some of the standards existing in 2001 may be amended as a first step in reducing uncertainty contributions, without limiting the application of that standard. In some cases, it will be indicated that it might be relevant to choose a more rigorous amendment.

C.2 Voltage measurement basics

It seems to be relevant to include in CISPR 16-2-1 a subclause on voltage measurement basics (discussed in 6.2.2) and to refer to this clause whenever basics are addressed, for example, in Clauses 6 and 7 of CISPR 16-2-1. Such an inclusion allows a more to-the-point description of existing clauses and may lead to relevant additional clauses. For example:

a) in view of the interference probability (6.2.3.2) an improvement of Clause 7 in CISPR 16-2-1 is needed, stating that without additional information or assumptions the unsymmetrical mode voltage is not a figure-of-merit for the interference potential of an emitting device. A rigorous approach to improve the relation of measurement results and interference probability is given in C.5;
b) the addition in CISPR 16-2-1 of a clause on the measurement loop constraint [6.2.2.2 and the example of the fluorescent tube in its luminaire mentioned in 6.4.6.4 b)];
c) the addition in CISPR 16-1-2, CISPR 16-2-1 of a clause dealing with the importance of the magnetic field-induced voltages (6.2.2.3), in particular in the case of measurements using a voltage probe (6.3 and Annex B).

C.3 Voltage measurements using a voltage probe

In general, at present the voltage-probe measurements are ill defined, in particular the specification of the ‘ground terminal’ in the voltage measurement. With regard to the interference probability, it should be mentioned, at least in CISPR 16-2-1, that it is better to give up voltage-probe measurements.

The discussion of 6.3 should lead to improved formulation of 6.2.2 that should also lead to an improved Figure 12. In particular, this figure should be updated to indicate the area in which the magnetic field may induce too large a voltage. Also, the relevant aspects of the layout of the set-up should be addressed.

Subclause 5.2.1 in CISPR 16-1-2 should also reconsider the statement ‘...such that the total resistance between line and earth is 1 500 Ω.’ This value may not be sufficiently large in the case of devices like a.c.-to-d.c. converters. So at least a warning should be given. Requiring a higher value than 1 500 Ω may lead to unwanted effects of parasitic capacitances (6.3). Moreover, the asymmetric loading of the source should be mentioned.

In addition to the CISPR 16 standards, there is a similar need to improve, for example:

a) CISPR 11:2003 [1], 6.2.3 and Figure 4;
b) CISPR 14-1:2005 [2], 5.2.4 and Figures 5a and 5b;
c) CISPR 15:2005 [3], 8.1.2 and Figure 5.

C.4 Voltage measurements using a V-terminal artificial mains network

Subclause 6.4.6, in particular, which is about the influence quantities may lead to improved formulations in CISPR 16-1-2 and CISPR 16-2-1.

To give some examples:

a) The uncertainties in Z_{in} as a result of a possible mismatch of the receiver plus its signal cable [6.4.6.2 a)] can be reduced by requiring a 10 dB attenuator at the output of the V-AMN [15].
b) The uncertainties in Z_{in} as a result of the unknown impedance of the mains network [6.4.6.4 b)] to which the V-AMN is connected can be reduced by quantitatively specifying an isolation between the measurement impedance and the unknown mains network impedance. The verification of that isolation shall then be incorporated in CISPR 16-1-2.
c) As mentioned at the end of 6.4.6.2, a better specification of measurement impedances Z_{13} (Z_{23}) is needed, i.e. not only the tolerance of the absolute value is needed, but also that of the phase angle of that impedance.
d) The verification procedure CISPR 16-1-2 for α (proposed in 6.4.6.3) has to pay attention to the determination of α *in situ*, i.e. in an actual measurement set-up, so no separate measurement of the V-AMN, the signal cables and the receiver. That procedure should also indicate under which conditions α becomes a specified influence quantity. In addition, a procedure should be given for the determination of $\Delta\alpha$.
e) As mentioned in 6.4.6.4 a), the problem of the uncertainty in Z_d as a result of the parasitic capacitance between the EUT and the reference plane may be solved by requiring in CISPR 16-2-1 that the reference plane is always horizontal and that the EUT is always positioned on its normal feet. In this way, the problem with C_{p1} and C_{p2} is eliminated.
f) In the foregoing, the uncertainties in Z_d as a result of the measurement loop constraint [6.4.6.4 b)] have already been discussed. The measurement loop constraint becomes increasingly important when not a single EUT is considered, but an EUT having auxiliary apparatus, dealt with in 7.4.2.6 of CISPR 16-2-1.
g) The uncertainties in Z_d as a result of the LC parallel circuit. As mentioned in 6.4.6.4 d), these uncertainties can be avoided by drafting a procedure, for example, in CISPR 16-1-2, for the verification of all V-AMN properties *in situ*. This procedure could be combined with that mentioned in the previous example d). It might be necessary to specify a special disturbance source (for example, a comb generator with special properties [49]) for this purpose.
h) The uncertainties as a result of the DM/CM and CM/DM conversion [6.4.6.5]. The contributions stemming from the V-AMN can be made negligibly small by specifying maximum values for these types of conversion. See also the last paragraph of this subclause.
i) The uncertainties as a result of meandering part of the mains cable [6.4.6.5]. Existing studies [48] form a good basis for an improved formulation of the layout of meanders.

C.5 Replacing voltage measurements by current measurements

As in the case of voltage measurements using a voltage probe, CISPR 16-2-1 should indicate that in view of the interference probability, the V-terminal voltages (the unsymmetrical mode voltages) are not a figure-of-merit for the interference potential of an emitting device without additional information or assumptions.

An improved figure-of-merit can be obtained in a rather easy way. Instead of measuring two unsymmetrical voltages now two currents are measured, without changing the measurement impedance specifications. This is schematically shown in Figure C.1 where, in one position of the switch, the receiver measures twice the DM current and, in the other position, it measures the CM current. See also 6.2.3 and 6.2.3.2.

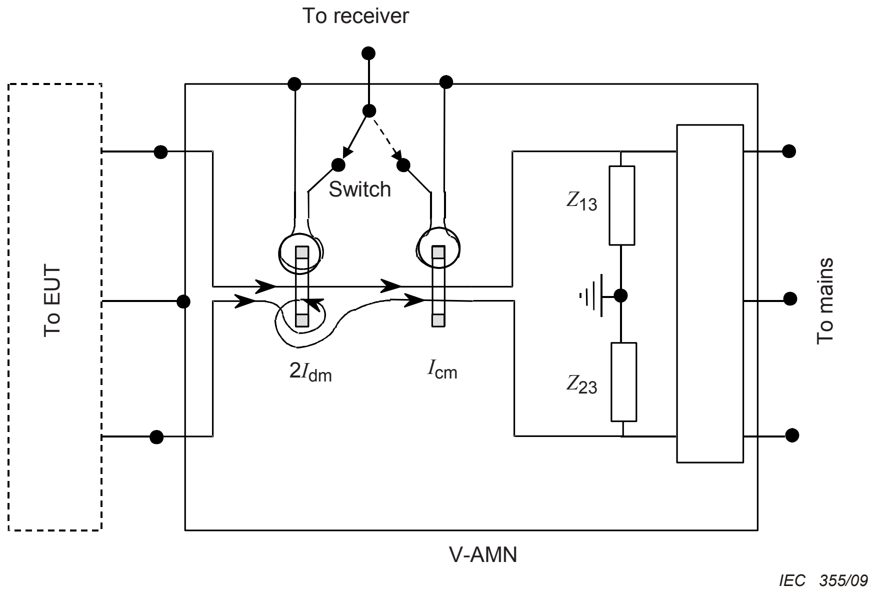


Figure C.1 – Schematic diagram of a V-AMN yielding an improved figure-of-merit about the actual compliance probability via two current probes

The approach sketched in Figure C.1 may also be interesting when conducted emissions are to be measured up to higher frequencies, for example, 80 MHz instead of 30 MHz as in conducted voltage emission measurements. Then the measurement impedances can be realized with less uncertainty than in the case of voltage measurements, where the VSWR of the receiver plus its cable play a more dominant part. Conducted emission measurements up to 80 MHz and radiated emission measurements starting at 80 MHz would also solve some of the uncertainty problems in radiated emission and in absorbing clamp measurements. Moreover, the choice of 80 MHz would bring in line the 'crossover-frequency' for conducted and radiated measurements in emission and immunity testing (IEC/SC77B).

Annex D
(informative)

Analysis method of results of an interlaboratory test

This Annex gives guidance on the statistical evaluation of the results of an interlaboratory comparison test, or round robin test (RRT). Suppose a RRT is set up using one EUT and suppose that the value of a certain measurand is measured by n participating laboratories.

Suppose that the measurement result $E_i(f)$ of each participating laboratory is a function of the frequency f. The average of the measurement result $\overline{E}(f)$ and the estimate for the deviation $\delta E_i(f)$ of each individual result from this average can be determined as follows:

$$\overline{E}(f) = \frac{1}{n}\sum_{i=1}^{n} E_i(f) \qquad \text{(D.1)}$$
$$\delta E_i(f) = E_i(f) - \overline{E}(f)$$

An estimate for the variance $s_i^2(f)$ is given by

$$s_i^2(f) = \frac{1}{n-1}\sum_{i=1}^{n} \delta E_i^2(f) \qquad \text{(D.2)}$$

An estimate for the expanded uncertainty with a 95 % level of confidence may be written as:

$$U_i^{\text{RRT}} = \sqrt{t_{95}^2(n) \times s_i^2(f)} \qquad \text{(D.3)}$$

Here $t_{95}(n)$ is taken from the t-distribution for n degrees of freedom and 95 %. For large n, the value of $t_{95}(n)$ is nearly 2. Exact values as a function of n can be found in Table G.2 of the ISO/IEC Guide 98-3. Note that the equations given above assume that the data obeys a uniform distribution. From these frequency dependent estimates of the expanded uncertainty, an overall expanded uncertainty figure can also be derived, for instance by taking the maximum expanded uncertainty over the frequency interval of interest. This value, obtained from the RRT, can then be compared with the value obtained from the uncertainty budget.

Annex E
(informative)

Uncertainty budgets for the clamp calibration methods

This annex gives examples of typical uncertainty budgets for the original clamp calibration method. Table E.1 applies to the frequency range 30 MHz to 300 MHz and Table E.2 to the frequency range 300 MHz to 1 000 MHz.

The uncertainty budgets for the jig calibration method and the reference device calibration method are still under consideration.

Table E.1 – Uncertainty budget for the original absorbing clamp calibration method in the frequency range 30 MHz to 300 MHz

Source of uncertainty (Uncertainty factors/influence quantities)	Uncertainty value (+/- dB)	Probability distribution	Divisor	Standard uncertainty
EUT-RELATED				
Stability	0,1	Normal	2,00	0,05
SET-UP-RELATED				
Wire cross section	0,1	Rectangular	1,73	0,06
Length of wire	0,2	Rectangular	1,73	0,12
Wire displacement in clamp	0,2	Rectangular	1,73	0,12
Height wire above reference plane	0,1	Rectangular	1,73	0,06
Start and stop position tolerance	0,5	Rectangular	1,73	0,29
Guidance and routing of the measurement cable	1,0	Rectangular	1,73	0,58
TEST PROCEDURE-RELATED				
Clamp scanning repeatability	0,1	Rectangular	1,73	0,06
ENVIRONMENT-RELATED				
Temperature and humidity	0,1	Rectangular	1,73	0,06
Signal to ambient ratio	0,1	Normal	2,00	0,05
Presence of operator	1,0	Rectangular	1,73	0,58
MEASUREMENT INSTRUMENTATION-RELATED				
Stability generator	0,1	Normal	2,00	0,05
Linearity receiver/analyser	0,5	Rectangular	1,73	0,29
Mismatch at the input	0,4	U-shaped	1,41	0,28
Mismatch at the output	0,4	U-shaped	1,41	0,28
Measuring system reading	0,1	Rectangular	1,73	0,06
Signal to noise ratio	0,1	Rectangular	1,73	0,06
Absorbing clamp test site deviation	2,5	Normal	2,00	1,25
Clamp slide material	0,2	Rectangular	1,73	0,12
Decoupling factor SAD	0,1	Rectangular	1,73	0,06
CDN performance	0,1	Rectangular	1,73	0,06
Combined standard uncertainty				1,62
Expanded uncertainty		Normal	2,00	3,24

Table E.2 – Uncertainty budget for the original absorbing clamp calibration method in the frequency range 300 MHz to 1 000 MHz

Source of uncertainty (Uncertainty factors/influence quantities)	Uncertainty value (+/- dB)	Probability distribution	Divisor	Standard uncertainty
EUT-RELATED				
Stability	0,2	Normal	2,00	0,10
SET-UP-RELATED				
Wire cross section	0,1	Rectangular	1,73	0,06
Length of wire	0,2	Rectangular	1,73	0,12
Wire displacement in clamp	1,0	Rectangular	1,73	0,58
Height wire above reference plane	0,2	Rectangular	1,73	0,12
Start and stop position tolerance	1,0	Rectangular	1,73	0,58
Guidance and routing of the measurement cable	0,5	Rectangular	1,73	0,29
TEST PROCEDURE-RELATED				
Clamp scanning repeatability	0,5	Rectangular	1,73	0,29
ENVIRONMENT-RELATED				
Temperature and humidity	0,1	Rectangular	1,73	0,06
Signal to ambient ratio	0,1	Normal	2,00	0,05
Presence of operator	0,3	Rectangular	1,73	0,17
MEASUREMENT INSTRUMENTATION-RELATED				
Stability generator	0,1	Normal	2,00	0,05
Linearity receiver/analyser	0,5	Rectangular	1,73	0,29
Mismatch at the input	0,4	U-shaped	1,41	0,28
Mismatch at the output	0,4	U-shaped	1,41	0,28
Measuring system reading	0,1	Rectangular	1,73	0,06
Signal to noise ratio	0,3	Rectangular	1,73	0,17
Absorbing clamp test site deviation	2,0	Normal	2,00	1,00
Clamp slide material	0,5	Rectangular	1,73	0,29
Decoupling factor SAD	0,1	Rectangular	1,73	0,06
CDN performance	0,1	Rectangular	1,73	0,06
Combined standard uncertainty				1,51
Expanded uncertainty		Normal	2,00	3,02

Annex F
(informative)

Uncertainty budget for the clamp measurement method

This annex gives a typical uncertainty budget for the clamp measurement method. Table F.1 applies to the frequency range 30 MHz to 300 MHz and Table F.2 to the frequency range 300 MHz to 1 000 MHz.

Table F.1 – Uncertainty budget for the absorbing clamp measurement method in the frequency range 30 MHz to 300 MHz

Source of uncertainty (Uncertainty factors/ influence quantities)	Uncertainty value (+/- dB)	Probability distribution	Divisor	Standard uncertainty	Reference
EUT-RELATED					
Size of EUT	0,0	Rectangular	1,73	0,0	NOTE 1
Signature disturbance	0,0	Rectangular	1,73	0,0	NOTE 1
Set up of unit(s) and cables	3,0	Rectangular	1,73	1,7	
Modes of operation	3,0	Rectangular	1,73	1,7	NOTE 2
SET-UP-RELATED					
Wire cross section	0,1	Rectangular	1,73	0,1	
Length of wire	0,2	Rectangular	1,73	0,1	
Wire displacement in clamp	0,2	Rectangular	1,73	0,1	
Height wire above reference plane	0,1	Rectangular	1,73	0,1	
Start and stop position tolerance	0,5	Rectangular	1,73	0,3	
Guidance and routing of the measurement cable	1,0	Rectangular	1,73	0,6	
TEST PROCEDURE-RELATED					
Receiver settings	1,0	Rectangular	1,73	0,6	
Clamp scanning step size	0,1	Rectangular	1,73	0,1	
ENVIRONMENT-RELATED					
Temperature and humidity	0,1	Rectangular	1,73	0,1	
Signal to ambient ratio	0,1	Normal	2,00	0,1	
Presence of operator	1,0	Rectangular	1,73	0,6	
Mains voltage variation	0,2	Rectangular	1,73	0,1	
Application of mains decoupling devices	3,0	Rectangular	1,73	1,7	
MEASUREMENT INSTRUMENTATION-RELATED					
Accuracy	2,0	Rectangular	1,73	1,2	
Mismatch at the output	0,6	U-shaped	1,41	0,4	
Measuring system reading	0,1	Rectangular	1,73	0,1	
Signal to noise ratio	0,1	Rectangular	1,73	0,1	
Absorbing clamp test site deviation	2,5	Normal	2,00	1,3	
Clamp slide material	0,2	Rectangular	1,73	0,1	
Clamp factor uncertainty	3,0	Normal	2,00	1,5	
Decoupling factor clamp	0,1	Rectangular	1,73	0,1	
Decoupling to receiver	0,1	Rectangular	1,73	0,1	
Combined standard uncertainty (SCU)				3,9	NOTE 3
Expanded uncertainty (SCU)		Normal	2,00	7,9	
Combined standard uncertainty (MIU)				3,1	NOTE 4
Expanded uncertainty (MIU)		Normal	2,00	6,2	

NOTE 1 These influence quantities indirectly influence the uncertainty due to the set up of the EUT.

NOTE 2 For complex EUTs a significant uncertainty may be due to the various modes of operations.

NOTE 3 This standard compliance uncertainty (SCU) includes all influence quantities.

NOTE 4 This measurement instrumentation uncertainty (MIU) includes all the influence quantities with the exception of the EUT-related.

Table F.2 – Uncertainty budget for the absorbing clamp measurement method in the frequency range 300 MHz to 1 000 MHz

Source of uncertainty (Uncertainty factors/ influence quantities)	Uncertainty value (+/- dB)	Probability distribution	Divisor	Standard uncertainty	Reference
EUT-RELATED					
Size of EUT	0,0	Rectangular	1,73	0,0	NOTE 1
Signature disturbance	0,0	Rectangular	1,73	0,0	NOTE 1
Set up of unit(s) and cables	5,0	Rectangular	1,73	2,9	
Modes of operation	3,0	Rectangular	1,73	1,7	NOTE 2
SET-UP-RELATED					
Wire cross section	0,1	Rectangular	1,73	0,1	
Length of wire	0,2	Rectangular	1,73	0,1	
Wire displacement in clamp	1,0	Rectangular	1,73	0,6	
Height wire above reference plane	0,2	Rectangular	1,73	0,1	
Start and stop position tolerance	1,0	Rectangular	1,73	0,6	
Guidance and routing of the measurement cable	0,5	Rectangular	1,73	0,3	
TEST PROCEDURE-RELATED					
Receiver settings	1,0	Rectangular	1,73	0,6	
Clamp scanning step size	0,1	Rectangular	1,73	0,1	
ENVIRONMENT-RELATED					
Temperature and humidity	0,1	Rectangular	1,73	0,1	
Signal to ambient ratio	0,1	Normal	2,00	0,1	
Presence of operator	0,3	Rectangular	1,73	0,2	
Mains voltage variation	0,2	Rectangular	1,73	0,1	
Application of mains decoupling devices	0,5	Rectangular	1,73	0,3	
MEASUREMENT INSTRUMENTATION-RELATED					
Accuracy receiver	2,0	Rectangular	1,73	1,2	
Mismatch at the output	0,6	U-shaped	1,41	0,4	
Measuring system reading	0,1	Rectangular	1,73	0,1	
Signal to noise ratio	0,3	Rectangular	1,73	0,2	
Absorbing clamp test site deviation	2,0	Rectangular	1,73	1,2	
Clamp slide material	0,5	Normal	2,00	0,3	
Clamp factor uncertainty	3,0	Normal	2,00	1,5	
Decoupling factor clamp	0,1	Rectangular	1,73	0,1	
Decoupling to receiver	0,1	Rectangular	1,73	0,1	
Combined standard uncertainty (SCU)				4,2	NOTE 3
Expanded uncertainty (SCU)		Normal	2,00	8,4	
Combined standard uncertainty (MIU)				2,5	NOTE 4
Expanded uncertainty (MIU)		Normal	2,00	5,1	

NOTE 1 These influence quantities indirectly influence the uncertainty due to the set up of the EUT.

NOTE 2 For complex EUTs a significant uncertainty may be due to the various modes of operations.

NOTE 3 This standard compliance uncertainty (SCU) includes all influence quantities.

NOTE 4 This measurement instrumentation uncertainty (MIU) includes all the influence quantities with the exception of the EUT related.

Annex G
(informative)

Uncertainty estimates for the radiated emission measurement methods

This annex provides examples of typical uncertainty estimates for a radiated emission measurement method using a SAC at 3 m measurement distance and assuming a tabletop EUT. Tables G.1 and G.3 are for the frequency range 30 MHz to 200 MHz, and Tables G.2 and G.4 are for the frequency range 200 MHz to 1 000 MHz. Note that separate uncertainty estimates are not provided for horizontal and vertical polarisations, because actual radiated emission measurement results report a single figure for the maximum value of both horizontal and vertical polarisation at each frequency. Separate uncertainty figures for horizontal and vertical polarisations may provide further insights on the impact of specific uncertainty components, but are unnecessary for compliance test results.

Table G.1 – Uncertainty estimate for the radiated emission measurement method in the frequency range 30 MHz to 200 MHz at a measurement distance of 3 m

UNCERTAINTY SOURCES Influence quantities	Correction factor (dB)	Uncertainty value (+/- dB)	Probability distribution	Divisor	Standard uncertainty	Reference
EUT-RELATED						
Size of EUT		0,0	Rectangular	1,73	0,00	NOTE 1, SCU only
Type of disturbance		0,0	Rectangular	1,73	0,00	
Modes of operation		3,0	Rectangular	1,73	1,73	SCU only
SET-UP RELATED						
Layout of units and cables		6,0	Rectangular	1,73	3,46	SCU only
Termination of cables		10,0	Rectangular	1,73	5,77	SCU only
Measurement distance tolerance		0,4	Rectangular	1,73	0,23	
EUT height above groundplane tolerance		0,2	Rectangular	1,73	0,12	
MEASUREMENT PROCEDURE RELATED						
Nominal measurement distance	-10,5	4,0	Rectangular	1,73	2,31	SCU only
Receiver settings		1,0	Rectangular	1,73	0,58	
Height scanning step size		0,0	Rectangular	1,73	0,00	
Start and stop position tolerance		0,0	Rectangular	1,73	0,00	
Azimuth step size		0,1	Rectangular	1,73	0,06	
ENVIRONMENT RELATED						
Temperature and humidity		0,1	Rectangular	1,73	0,06	
Signal to ambient signal ratio		0,0	Normal	2,00	0,00	
Mains voltage variation		0,2	Rectangular	1,73	0,12	SCU only
MEASUREMENT INSTRUMENTATION RELATED						
Receiver accuracy		2,0	Rectangular	1,73	1,16	
Mismatch at receiver input		+0,9/-1,0	U-shaped	1,41	0,64	
Measuring system reading		0,1	Rectangular	1,73	0,06	
Signal to noise ratio		0,5	Normal	2,00	0,25	
NSA deviation		3,0	Rectangular	1,73	1,73	
EUT positioning table		0,0	Rectangular	1,73	0,00	
Free-space antenna factor uncertainty		1,5	Normal	2,00	0,75	
Type of receive antenna (directivity)		0,0	Rectangular	1,73	0,00	
Antenna factor height dependence		1,0	Rectangular	1,73	0,58	
Antenna factor frequency interpolation		0,2	Rectangular	1,73	0,12	
Antenna phase centre variation		0,0	Rectangular	1,73	0,00	
Antenna unbalance		0,9	Rectangular	1,73	0,52	
Cross polarization performance		0,0	Rectangular	1,73	0,00	
Cable loss uncertainty		0,1	Rectangular	1,73	0,06	
Measurement system repeatability		0,5	Rectangular	1,73	0,29	
Combined standard uncertainty (SCU)					7,8	NOTE 2
Expanded uncertainty (SCU)			Normal	2,00	15,5	
Combined standard uncertainty (MIU)					2,5	NOTE 3
Expanded uncertainty (MIU)			Normal	2,00	5,1	

NOTE 1 These influence quantities indirectly influence the uncertainty due to the set up of the EUT.

NOTE 2 This standard compliance uncertainty (SCU) includes all influence quantities.

NOTE 3 This measurement instrumentation uncertainty (MIU) includes all influence quantities with the exception of those indicated in the right column with “SCU only”.

Table G.2 – Uncertainty estimate for the radiated emission measurement method in the frequency range 200 MHz to 1 000 MHz at a measurement distance of 3 m

UNCERTAINTY SOURCES Influence quantities	Correction factor (dB)	Uncertainty value (+/- dB)	Probability distribution	Divisor	Standard uncertainty	Reference
EUT-RELATED						
Size of EUT		0,0	Rectangular	1,73	0,00	NOTE 1, SCU only
Type of disturbance		0,0	Rectangular	1,73	0,00	
Modes of operation		3,0	Rectangular	1,73	1,73	SCU only
SET-UP RELATED						
Layout of units and cables		3,0	Rectangular	1,73	3,46	SCU only
Termination of cables		3,0	Rectangular	1,73	5,77	SCU only
Measurement distance tolerance		0,4	Rectangular	1,73	0,23	
EUT height above groundplane tolerance		0,3	Rectangular	1,73	0,12	
MEASUREMENT PROCEDURE RELATED						
Nominal measurement distance	-10,5	3,0	Rectangular	1,73	2,31	SCU only
Receiver settings		1,0	Rectangular	1,73	0,58	
Height scanning step size	0,1	0,0/-0,2	Rectangular	1,73	0,00	
Start and stop position tolerance		0,5	Rectangular	1,73	0,00	
Azimuth step size		0,3	Rectangular	1,73	0,06	
ENVIRONMENT RELATED						
Temperature and humidity		0,1	Rectangular	1,73	0,06	
Signal to ambient signal ratio		0,0	Normal	2,00	0,00	
Mains voltage variation		0,2	Rectangular	1,73	0,12	SCU only
MEASUREMENT INSTRUMENTATION RELATED						
Receiver accuracy		2,0	Rectangular	1,73	1,16	
Mismatch at receiver input		0,3	U-shaped	1,41	0,64	
Measuring system reading		0,1	Rectangular	1,73	0,06	
Signal to noise ratio		0,5	Normal	2,00	0,25	
NSA deviation		3,0	Rectangular	1,73	1,73	
EUT positioning table		0,5	Rectangular	1,73	0,00	
Free-space antenna factor uncertainty		1,5	Normal	2,00	0,75	
Type of receive antenna (directivity)		1,5	Rectangular	1,73	0,00	
Antenna factor height dependence		0,5	Rectangular	1,73	0,58	
Antenna factor frequency interpolation		0,2	Rectangular	1,73	0,12	
Antenna phase centre variation		1,0	Rectangular	1,73	0,00	
Antenna unbalance		0,3	Rectangular	1,73	0,52	
Cross polarization performance		0,9	Rectangular	1,73	0,00	
Cable loss uncertainty		0,1	Rectangular	1,73	0,06	
Measurement system repeatability		0,5	Rectangular	1,73	0,29	
Combined standard uncertainty (SCU)					7,8	NOTE 2
Expanded uncertainty (SCU)			Normal	2,00	15,5	
Combined standard uncertainty (MIU)					2,5	NOTE 3
Expanded uncertainty (MIU)			Normal	2,00	5,1	

NOTE 1 These influence quantities indirectly influence the uncertainty due to the set up of the EUT.

NOTE 2 This standard compliance uncertainty (SCU) includes all influence quantities.

NOTE 3 This measurement instrumentation uncertainty (MIU) includes all influence quantities with the exception of those indicated in the right column with “SCU only”.

Table G.3 – Uncertainty data of some influence quantities for the radiated emission measurement method in the frequency range 30 MHz to 200 MHz at measurement distances of 3 m, 10 m, or 30 m

UNCERTAINTY SOURCES Influence quantities	Measurement distance (m)	Correction factor (dB)	Uncertainty value (+/- dB)	Probability distribution	Divisor	Standard uncertainty
Measurement distance tolerance	3		0,4	Rectangular	1,73	0,23
	10		0,2	Rectangular	1,73	0,10
	30		0,1	Rectangular	1,73	0,05
EUT height above groundplane tolerance	3		0,2	Rectangular	1,73	0,12
	10		0,1	Rectangular	1,73	0,06
	30		0,1	Rectangular	1,73	0,06
Nominal measurement distance	3	-10,5	4,0	Rectangular	1,73	2,31
	10	0	not applicable			0,00
	30	10,5	4,0	Rectangular	1,73	2,31
Height scanning step size	3		0,0	Rectangular	1,73	0,00
	10		0,0	Rectangular	1,73	0,00
	30		0,0	Rectangular	1,73	0,00
Start and stop position tolerance	3		0,4	Rectangular	1,73	0,23
	10		0,1	Rectangular	1,73	0,06
	30		0,1	Rectangular	1,73	0,06
Signal to ambient signal ratio	3		0,0	Normal	2,00	0,00
	10		1,0	Normal	2,00	0,50
	30		2,0	Normal	2,00	1,00
Signal to noise ratio	3		0,5	Normal	2,00	0,25
	10		1,0	Normal	2,00	0,50
	30		2,0	Normal	2,00	1,00
Type of receive antenna (directivity)	3		0,0	Rectangular	1,73	0,00
	10		0,0	Rectangular	1,73	0,00
	30		0,0	Rectangular	1,73	0,00
Antenna phase centre variation	3		0,0	Rectangular	1,73	0,00
	10		0,0	Rectangular	1,73	0,00
	30		0,0	Rectangular	1,73	0,00
Cross polarization performance	3		0,0	Rectangular	1,73	0,00
	10		0,0	Rectangular	1,73	0,00
	30		0,0	Rectangular	1,73	0,00

Table G.4 – Uncertainty data of some influence quantities for the radiated emission measurement method in the frequency range 200 MHz to 1 000 MHz at measurement distances of 3 m, 10 m, or 30 m

UNCERTAINTY SOURCES Influence quantities	Measurement distance (m)	Correction factor (dB)	Uncertainty value (+/- dB)	Probability distribution	Divisor	Standard uncertainty
Measurement distance tolerance	3		0,4	Rectangular	1,73	0,23
	10		0,2	Rectangular	1,73	0,09
	30		0,1	Rectangular	1,73	0,03
EUT height above groundplane tolerance	3		0,3	Rectangular	1,73	0,17
	10		0,1	Rectangular	1,73	0,06
	30		0,1	Rectangular	1,73	0,06
Nominal measurement distance	3	-10,5	3,0	Rectangular	1,73	1,73
	10		not applicable			0,00
	30	10,5	3,0	Rectangular	1,73	1,73
Height scanning step size	3	0,1	0,0/-0,2	Rectangular	1,73	0,06
	10		0,0	Rectangular	1,73	0,00
	30		0,0	Rectangular	1,73	0,00
Start and stop position tolerance	3		0,6	Rectangular	1,73	0,35
	10		0,2	Rectangular	1,73	0,09
	30		0,1	Rectangular	1,73	0,06
Signal to ambient signal ratio	3		0,0	Normal	2,00	0,00
	10		1,0	Normal	2,00	0,50
	30		2,0	Normal	2,00	1,00
Signal to noise ratio	3		0,5	Normal	2,00	0,25
	10		1,0	Normal	2,00	0,50
	30		2,0	Normal	2,00	1,00
Type of receive antenna (directivity)	3		1,5	Rectangular	1,73	0,87
	10		1,0	Rectangular	1,73	0,58
	30		0,5	Rectangular	1,73	0,29
Antenna phase centre variation	3		1,0	Rectangular	1,73	0,58
	10		0,3	Rectangular	1,73	0,17
	30		0,1	Rectangular	1,73	0,06
Cross polarization performance	3		0,9	Rectangular	1,73	0,52
	10		0,9	Rectangular	1,73	0,52
	30		0,9	Rectangular	1,73	0,52

Annex H
(informative)

Results of various round robin tests for SAC/OATS-based radiated emission measurements

Various round robin tests (RRTs), also sometimes called interlaboratory comparison (ILC) measurements or site reproducibility programs, have been performed previously for SAC/OATS-based radiated emission measurements, with results reported in various documents. Accomplishment of RRTs is a useful means to verify uncertainty estimates (see 4.5). Table H.1 summarizes relevant parameters and results from a number of RRTs. Figure H.1, Figure H.2, Figure H.3, Figure H.4, and Figure H.5 show some sample results from some of these RRTs. Figure H.1 shows the expanded uncertainties of emission measurement results for five different emulated EUTs, each with five different cable termination conditions [24]. The results show that between 30 MHz and 200 MHz, application of different termination devices, such as common-mode absorbing device (CMADs), CDNs or LISNs, may cause a significant variation of results, i.e. 10 dB to 20 dB expanded uncertainty below 100 MHz. Figure H.2 shows interlaboratory comparison measurement results of twelve 10 m SACs. Figure H.3 gives ILC measurement results of radiated emission measurements of an emulated computer at eleven SAC/OATS sites at 3 m measurement distance [32]. The EUT consist of 3 units and interfaces between the units and a power connection. An expanded uncertainty up to 11 dB can be observed which is mainly due to differences in set-up. Figure H.4 shows ILC measurement results of a reference radiator measured at 14 different SAC/OATS at 3 m measurement distance [13], [25]. In this case an overall expanded uncertainty of 3,3 dB is visible due to the good reproducibility of the EUT. Figure H.5 shows the conversion factor between 3 m and 10 m SAC/OATS-emission measurement results of a battery-fed table-top type of EUT as a function of frequency. In this figure the conversion factor is also compared with the free-space rule-of-thumb ratio of 10,5 dB [13], [25]. See also 8.2.7 for a discussion of the results.

Table H.1 – Summary of various MIU and SCU uncertainty values for the SAC/OATS-based radiated emission measurement method, assembled from various sources

Name organization (year) [reference]	Type of EUT	Frequency range (MHz)	Measurement distance (m)	Number of sites	Type of uncertainty	Uncertainty values [a]
HP (1994) [36]	Reference standard source (ET23374)	30 - 1 000	10	13	MIU	3,8 dB, vertical, 2σ
METAS (1996) [24]	Five different EUTs with different coupling to power supply cable (2 small and 3 medium sized)	30 - 200	3	5, different cable terminations for each EUT	SCU (effect cable termination)	Expanded uncertainty 5 dB to 20 dB [c]
HP (2000)	Site reference source (monopole on pillbox)	30 – 1 000 [b]	10	12, SAC chambers	MIU	4,8 dB vertical, 2σ
			10	16, OATS	MIU	5,7 dB vertical, 2σ
			3	9, SAC chambers	MIU	4,4 dB vertical, 2σ
CISPR/A RRT (2000-2001) [32]	Reference radiator (2 m monopole above a square ground plane)	30 - 300	3	11,SAC/OATS	MIU	Expanded uncertainty 3,1 dB vertical
			10	8,SAC/OATS	MIU	Expanded uncertainty 2,8 dB vertical
	Emulated computer (3 units + cables)		3	11, SAC/OATS	SCU	Expanded uncertainty 11,1 dB (V and H)
			10	8,SAC/OATS	SCU	Expanded uncertainty 10,4 dB, V and H
KRISS [34]	Reference radiator (spherical dipole)	30 – 1 000	10	12, OATS	MIU	5,1 dB vertical 6,0 dB horizontal 2σ
DATech – PTB [43]	Emulated computer (single unit; battery and mains fed)	30 – 1 000 (battery fed EUT), 30 –200 (mains fed EUT)	Mixed 3 and 10	Best 42SAC/OATS sites	MIU	4,2 dB (battery fed EUT)2σ
					SCU	7,6 dB (mains fed EUT) 2σ
Matsushita (2000) [40]	PC with a power cord	30 - 200	3	2 OATS + 12 SAC	SCU	11 dB vertical 2σ
Philips ILC (2003-2005) [13], [25]	Reference radiator (45° rotated biconical antenna fed by reference generator)	30 - 1 000	3	14	MIU	Expanded uncertainty 3,3 dB, vertical and horizontal
			10	9	MIU	2,8 dB vertical and horizontal

a 2σ is 2 times the standard deviation as a function of frequency.

b This site reproducibility program was executed up to 4 000 MHz; however uncertainty results shown are applicable for the frequency range from 30 MHz to 1 000 MHz.

c Uncertainty depends on EUT size, number of cables and frequency range. For medium size EUTs with one cable and for small EUTs with more than one cable, the expanded uncertainty is in the order of 10 dB.

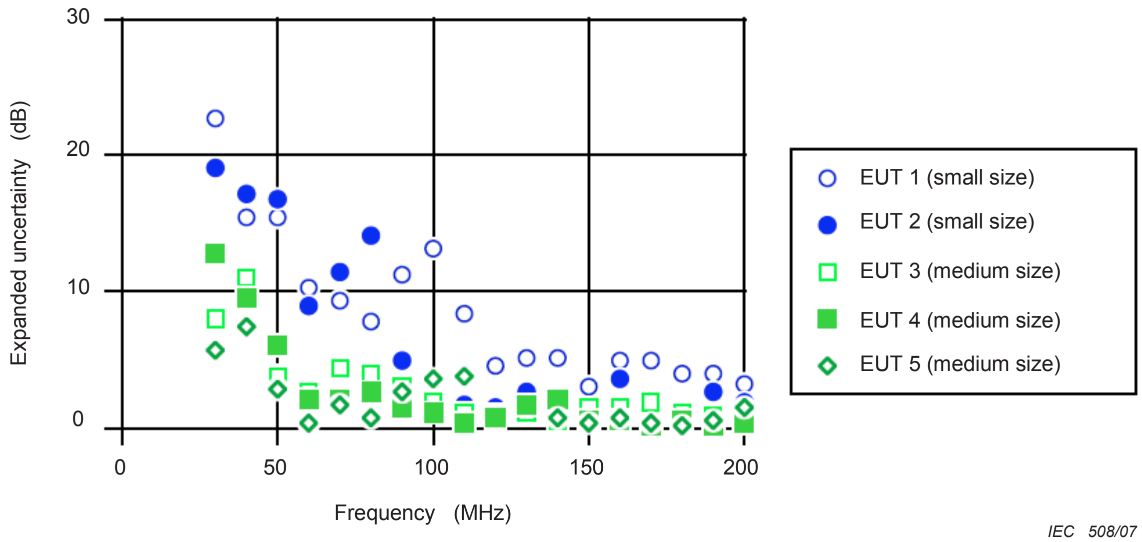
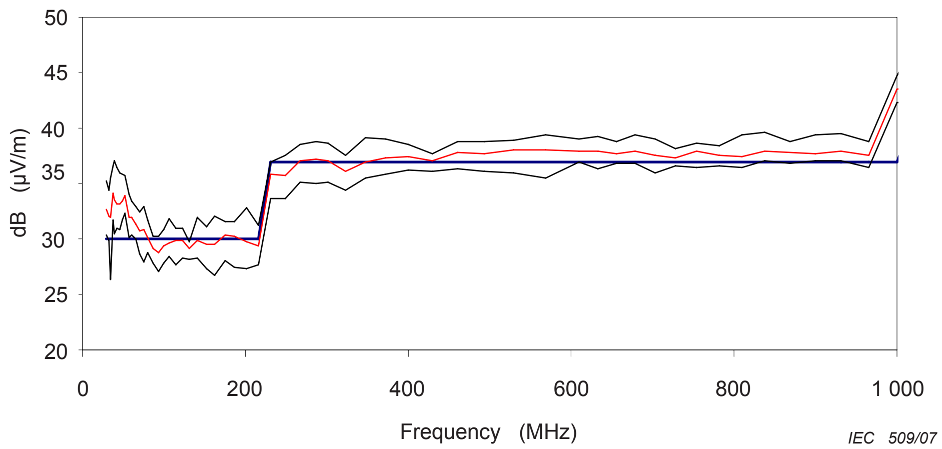
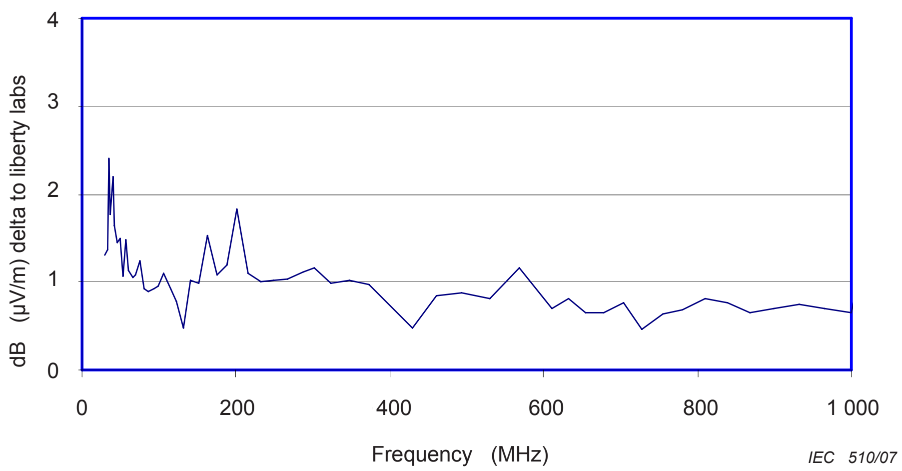


Figure H.1 – Expanded uncertainties of emission measurement results for five different emulated EUTs each with five different cable termination conditions [24]

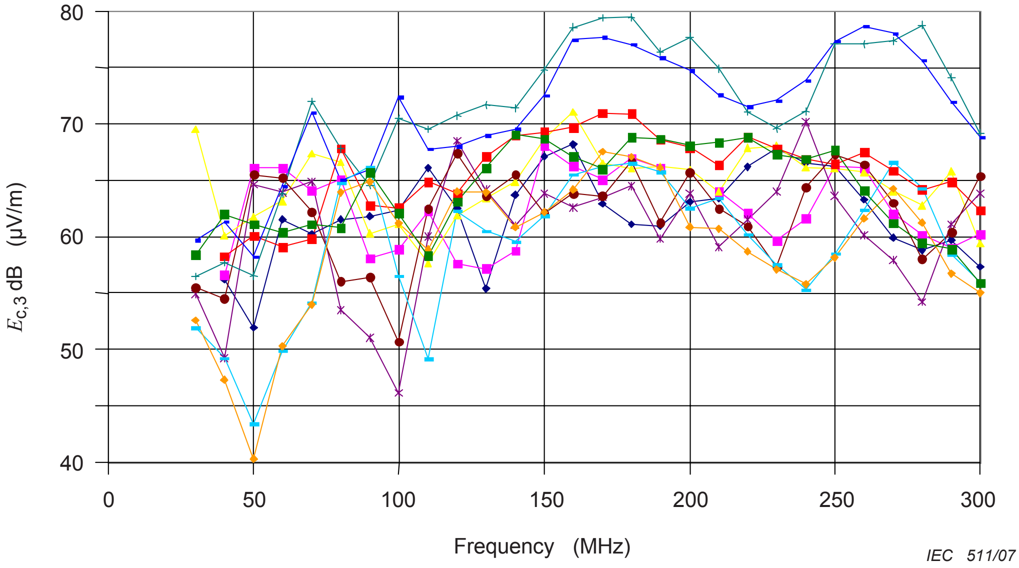


a) Maximum, minimum, average results and limit line

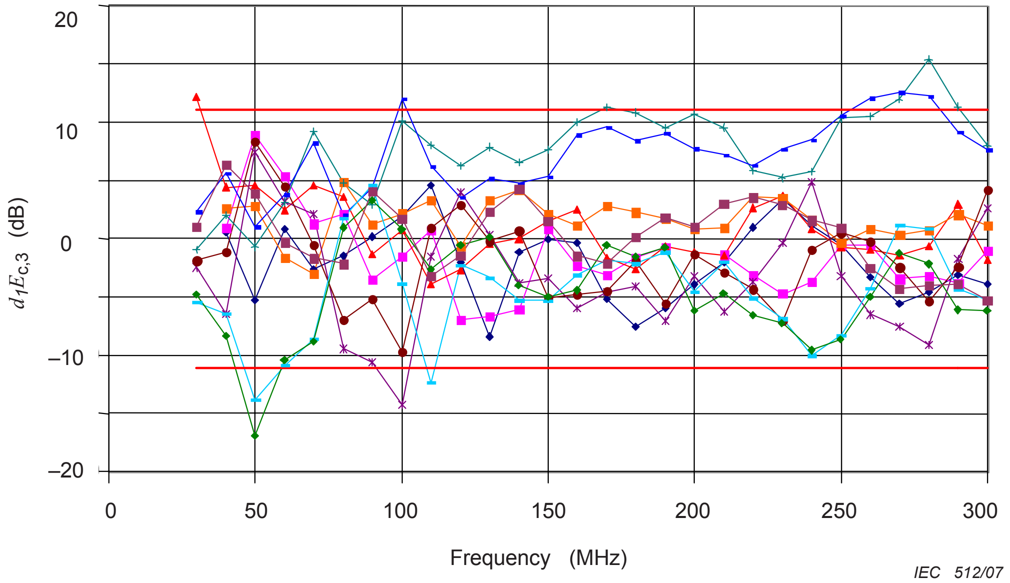


b) Standard deviation as function of frequency

Figure H.2 – Interlaboratory comparison measurement results of twelve 10 m SACs [see "HP (2000)" in Table H.1]



a) Raw results



b) Differences from average and expanded uncertainty bounds (red horizontal lines)

Figure H.3 – ILC measurement results radiated emission SAC/OATS 3 m (11 sites) [32]

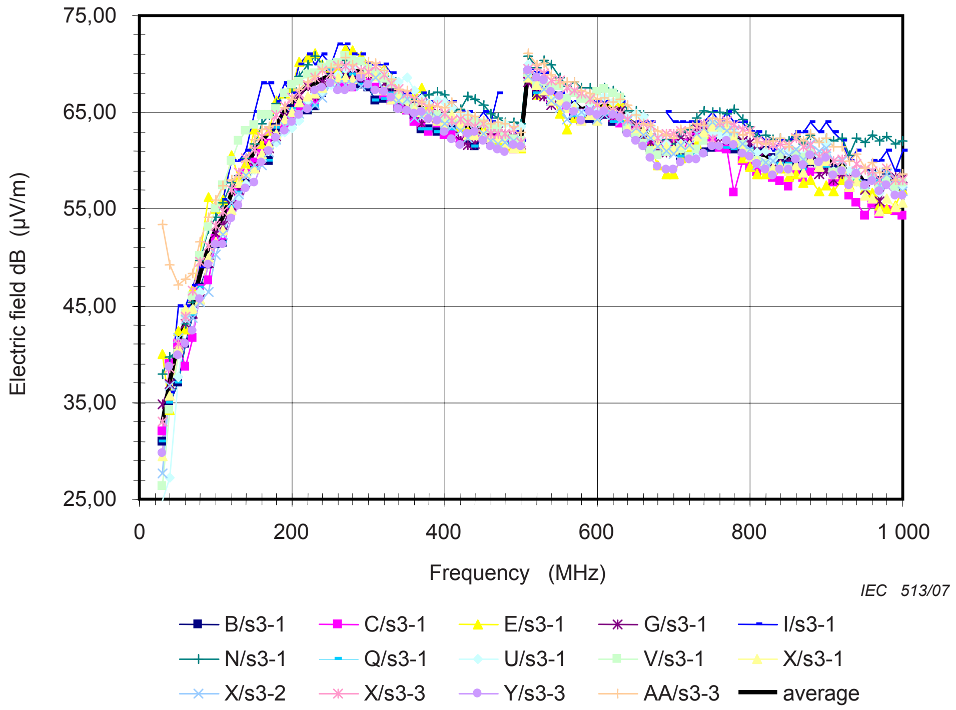


Figure H.4a) – Raw results

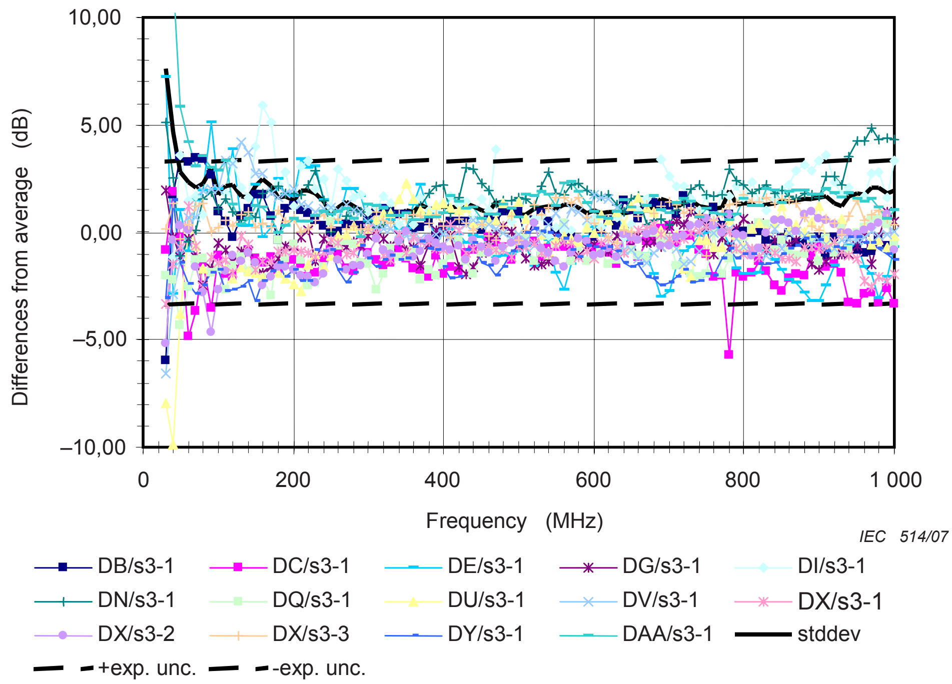


Figure H.4b) – Differences from average and expanded uncertainty bounds (dashed horizontal black lines)

Figure H.4 – ILC measurement results radiated emission SAC/OATS 3 m (14 sites) [13], [25]

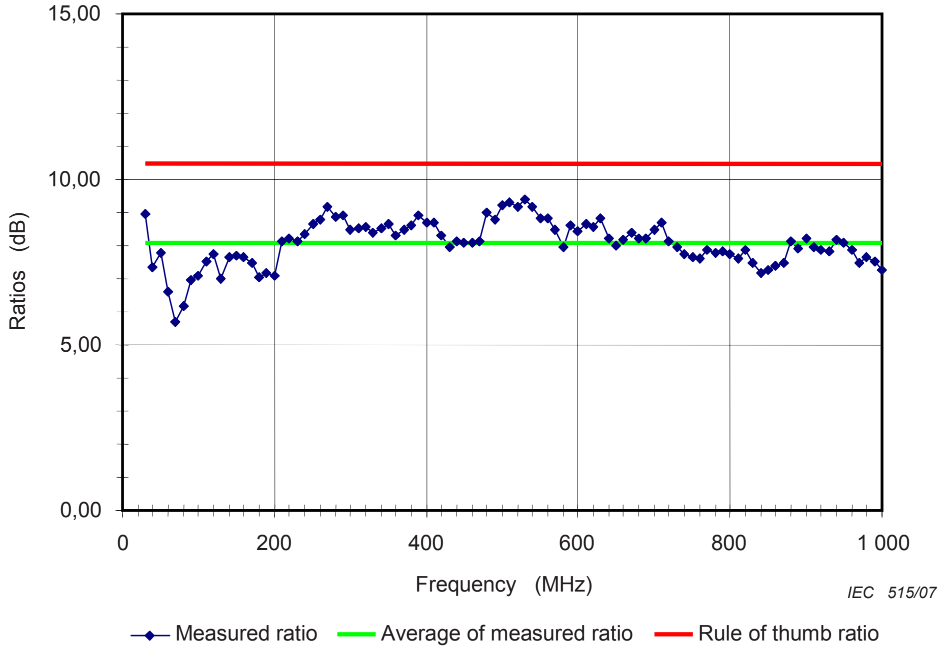


Figure H.5 – Measured correlation curve of 3 m and 10 m SAC/OATS-emission measurement of a battery-fed table-top type of EUT, compared with the free-space rule-of-thumb ratio [13], [25]

Annex I
(informative)

Additional information about distinctions between the terms measurement uncertainty and standards compliance uncertainty

I.1 Intrinsic uncertainty

Intrinsic uncertainty (of the measurand) as defined in 3.1.6 corresponds to definition 2.27 of ISO/IEC Guide 99, i.e.:

definitional uncertainty
component of measurement uncertainty resulting from the finite amount of detail in the definition of a measurand

NOTE 1 Definitional uncertainty is the practical minimum measurement uncertainty achievable in any measurement of a given measurand.

NOTE 2 Any change in the descriptive detail leads to another definitional uncertainty.

NOTE 3 In ISO/IEC Guide 98-3:2008, D.3.4, and in IEC 60359:2001, the concept 'definitional uncertainty' is termed "intrinsic uncertainty".

I.2 Measurement instrumentation uncertainty

Measurement instrumentation uncertainty as defined in 3.1.10 corresponds to definition 4.24 of ISO/IEC Guide 99, i.e.:

instrumental measurement uncertainty
component of measurement uncertainty arising from a measuring instrument or measuring system in use

NOTE 1 Instrumental measurement uncertainty is obtained through calibration of a measuring instrument or measuring system, except for a primary measurement standard for which other means are used.

NOTE 2 Instrumental uncertainty is used in a Type B evaluation of measurement uncertainty.

NOTE 3 Information relevant to instrumental measurement uncertainty may be given in the instrument specifications.

I.3 Measurement uncertainty

Definition 2.26 of ISO/IEC Guide 99 is:

measurement uncertainty
uncertainty of measurement
uncertainty
non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used

NOTE 1 Measurement uncertainty includes components arising from systematic effects, such as components associated with corrections and the assigned quantity values of measurement standards, as well as the definitional uncertainty. Sometimes estimated systematic effects are not corrected for but, instead, associated measurement uncertainty components are incorporated.

NOTE 2 The parameter may be, for example, a standard deviation called standard measurement uncertainty (or a specified multiple of it), or the half-width of an interval, having a stated coverage probability.

NOTE 3 Measurement uncertainty comprises, in general, many components. Some of these may be evaluated by Type A evaluation of measurement uncertainty from the statistical distribution of the quantity values from series of measurements and can be characterized by standard deviations. The other components, which may be evaluated by Type B evaluation of measurement uncertainty, can also be characterized by standard deviations, evaluated from probability density functions based on experience or other information.

NOTE 4 In general, for a given set of information, it is understood that the measurement uncertainty is associated with a stated quantity value attributed to the measurand. A modification of this value results in a modification of the associated uncertainty.

Based on the preceding considerations, “measurement uncertainty” overall is generally comprised of instrumental (MIU) and definitional (intrinsic) uncertainty components.

I.4 Standards compliance uncertainty

In cases where sampling issues are not considered, standards compliance uncertainty as defined in 3.1.16 corresponds to the ISO/IEC Guide 99 definition of measurement uncertainty.

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