PD CISPR/TR 16-4-1:2009

BSI Standards Publication

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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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
ELECTROTECHNICAL
COMMISSION

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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

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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The main task of IEC technical committees is to prepare International Standards. However, a technical committee may propose the publication of a technical report when it has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

CISPR 16-4-1, 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

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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.

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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			

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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

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*

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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.

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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

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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**

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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.

[1] Figures in brackets refer to the bibliography.

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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

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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.

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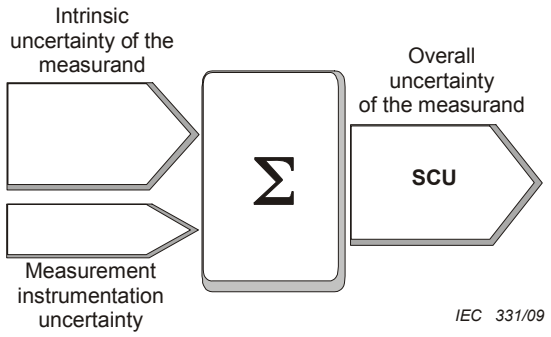

Figure 1a) – Typical emission measurement

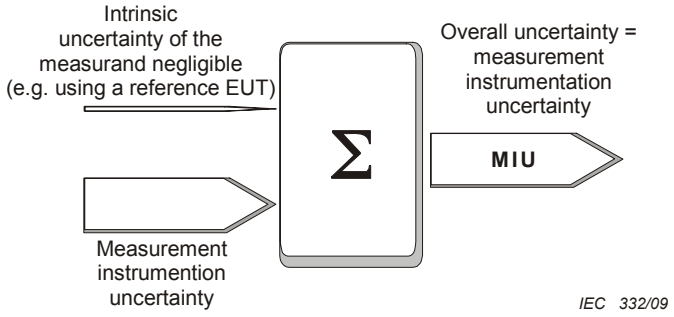

Figure 1b) – An emission measurement with a negligible intrinsic uncertainty of the measurand

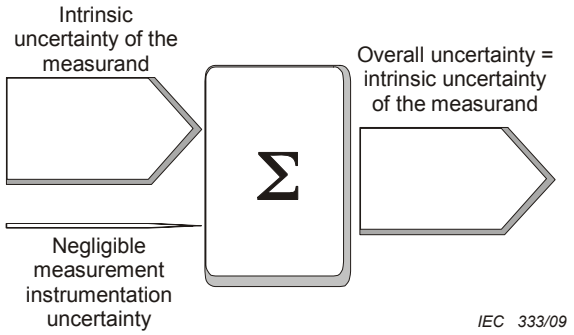

Figure 1c) An emission measurement with a negligible measurement instrumentation uncertainty

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.

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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.

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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

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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.

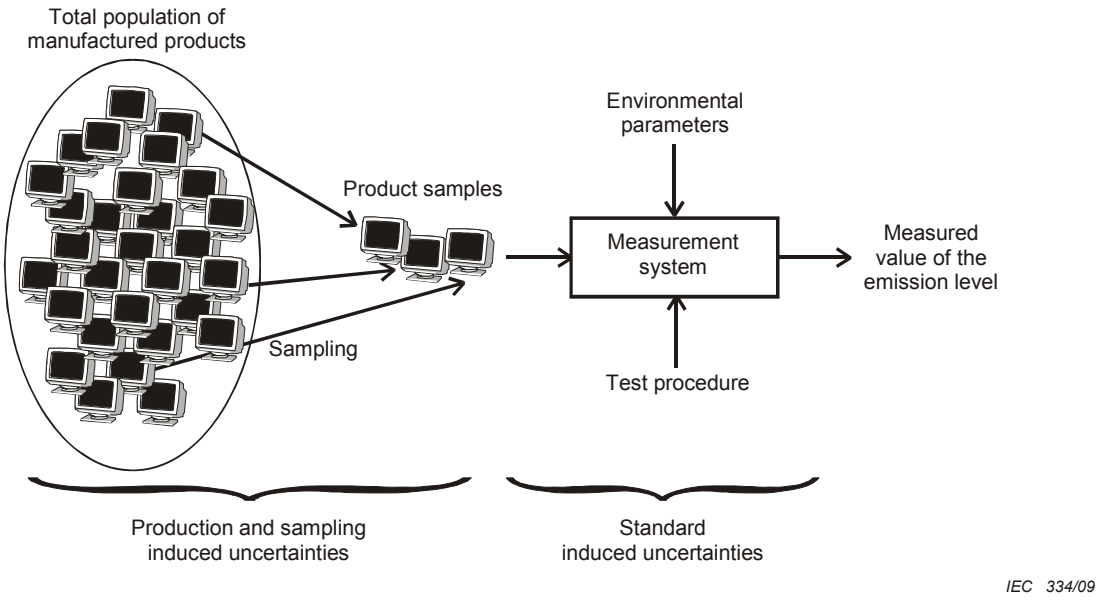

Figure 2 – The process of emission compliance measurements and the associated (categories of) uncertainty sources (see also Table 2)

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

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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

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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).

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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

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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.

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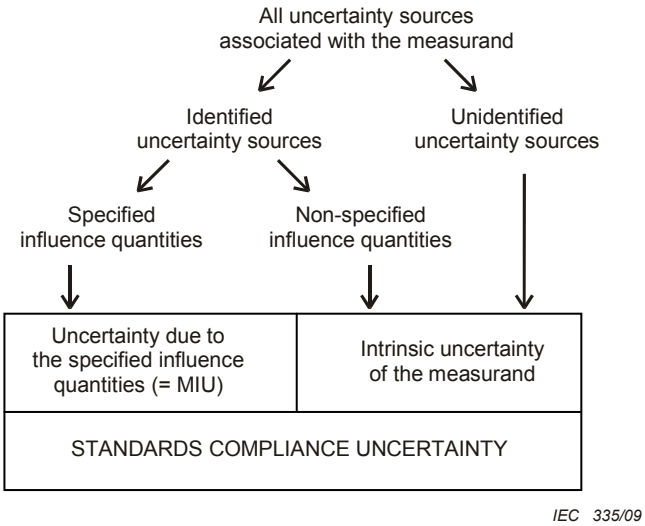

Figure 3 – Relationship between uncertainty sources, influence quantities and uncertainty categories

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

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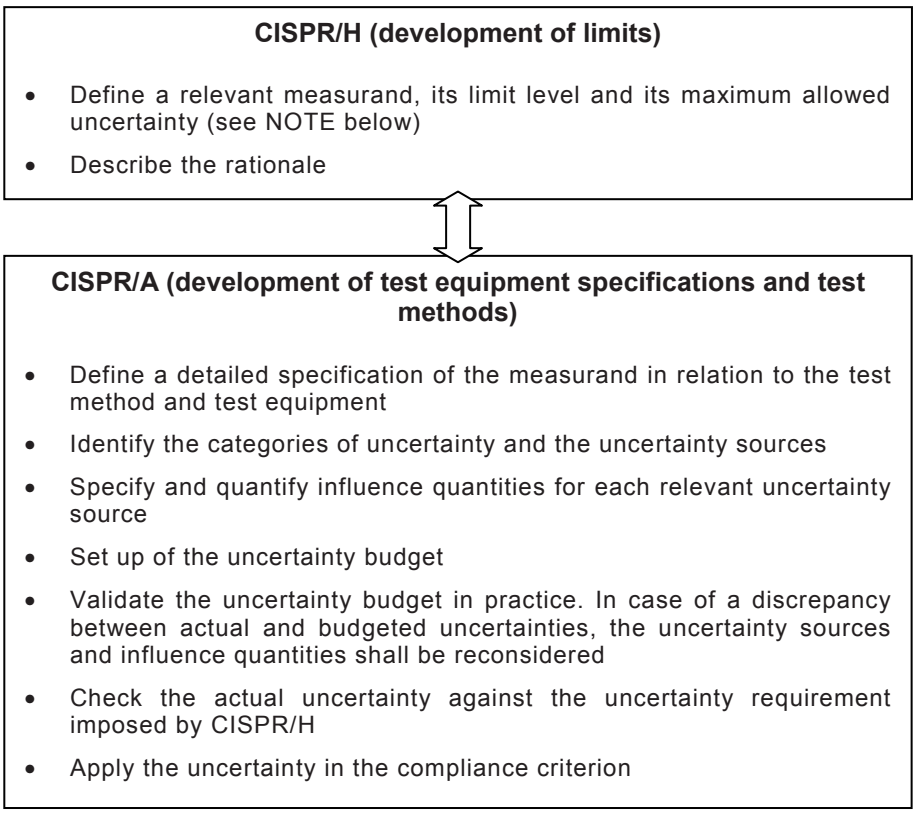
quantitative data is available, the annex is descriptive and qualitative in nature. Apart from the description in Annex A, the subject of relating SCU and 'interference probability' will not be described further because CISPR/H is responsible for this subject. This subcommittee is tasked with the derivation 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.



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

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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).

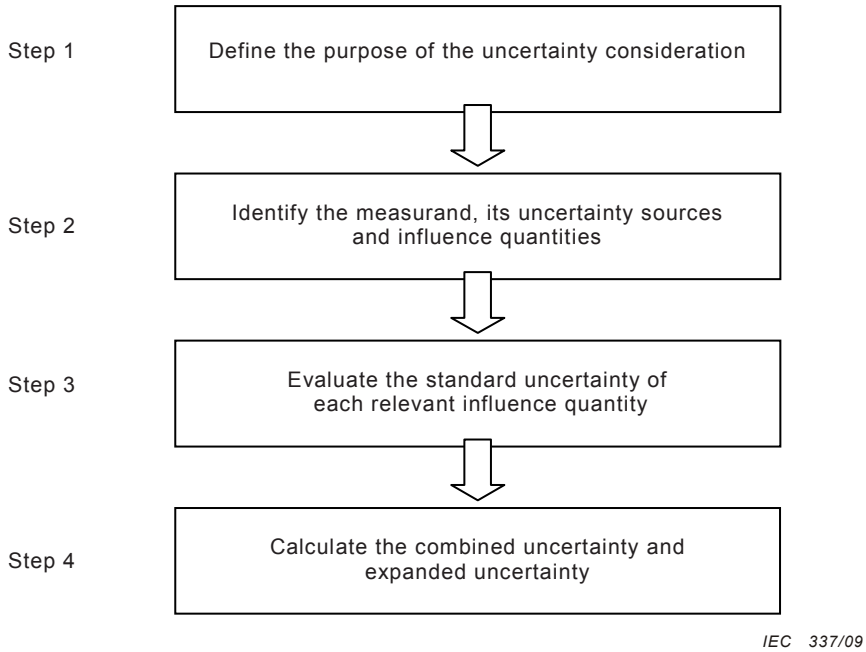

Figure 5 – The uncertainty estimation process

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.

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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

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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.

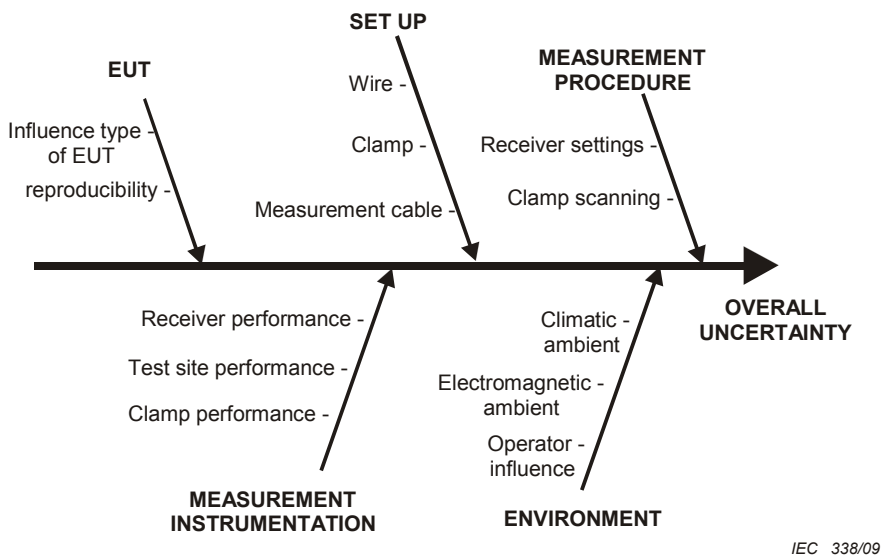

Figure 6 – Example of a fishbone diagram indicating the various uncertainty sources for an absorbing clamp compliance measurement in accordance with CISPR 16-2-2

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 $x_{s,i}$ (i = 1,2,…,n) and a number of non-specified influence quantities $x_{u,j}$ (j = 1,2,…,k).

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

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.

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If $U(L_{\mathrm{m}})$ 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' $U_{\mathrm{c}}(L_{\mathrm{m}})$ can be written as:

$$U_{\mathrm{c}}[L_{\mathrm{m}}(f)] = \sqrt{\sum_{p=1}^{m} \{c_p(f) \times U[x_p(f)]\}^2} \tag{3}$$

where $m = n+k$. To emphasise that $U_{\mathrm{c}}(L_{\mathrm{m}})$ 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 $U_{\mathrm{c}}(L_{\mathrm{m}})$ 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 $U(L_{\mathrm{m}})$ shall be determined from the combined uncertainty using Equation (3) and the Equation (4) below:

$$U(L_{\mathrm{m}}) = k \times U_{\mathrm{c}}(L_{\mathrm{m}}) \tag{4}$$

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 $U(L_{\mathrm{m}})$ 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 $U(L_{\mathrm{m}})$ 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].

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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 $\Delta L_{m,}$ 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 $L_u - L_l = \Delta L_m$, the interval ΔL_m only has a relevant meaning if the following simple relation is satisfied:

$$L_l \leq L_t \leq L_u \tag{5}$$

with a certain level of confidence. Similarly, if L_m is the measured emission level, the relationship $L_l \leq L_m \leq L_u$ 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:

$$\Delta L_m = 2 \times U(L_m) \tag{6}$$

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 $L_{l1} \leq L_{m1} \leq L_{1u}$, with $\Delta L_{m1} = L_{u1} - L_{l1}$ and $L_{l2} \leq L_{m2} \leq L_{u2}$, with $\Delta L_{m2} = L_{u2} - L_{l2}$, while ΔL_{m1} and ΔL_{m2} both have the same confidence level, then the following relationships must be satisfied:

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

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.

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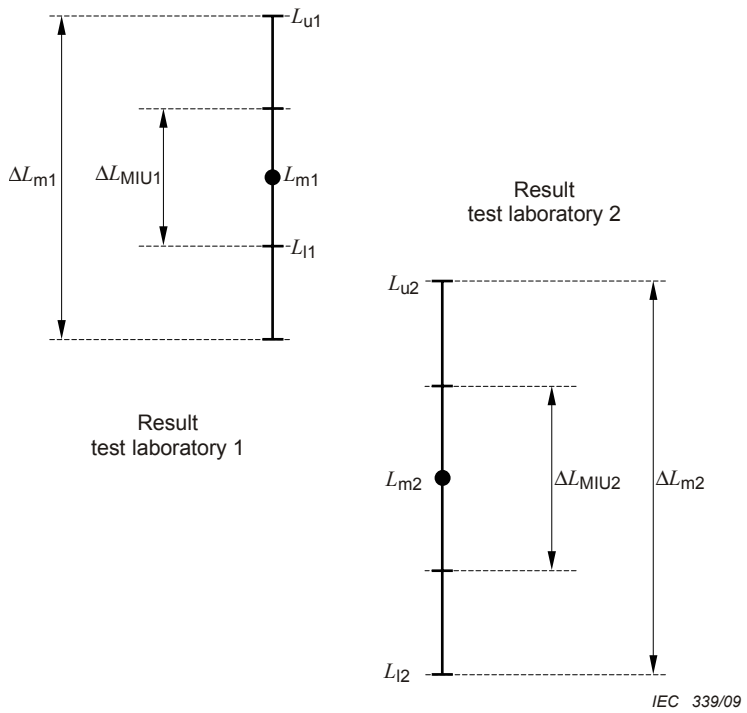

NOTE Equation (7) is satisfied when using the standards compliance uncertainty intervals ΔL_{m1} and ΔL_{m2}, but it is not satisfied when using the measurement instrumentation intervals determined by ΔL_{MIU1} and ΔL_{MIU2}.

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

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

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

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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).

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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:

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