TECHNICAL REPORT

CISPR 16-4-1

First edition
2003-11

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

IEC

Reference number
CISPR 16-4-1/TR:2003(E)

Publication numbering

As from 1 January 1997 all IEC publications are issued with a designation in the 60000 series. For example, IEC 34-1 is now referred to as IEC 60034-1.

Consolidated editions

The IEC is now publishing consolidated versions of its publications. For example, edition numbers 1.0, 1.1 and 1.2 refer, respectively, to the base publication, the base publication incorporating amendment 1 and the base publication incorporating amendments 1 and 2.

Further information on IEC publications

The technical content of IEC publications is kept under constant review by the IEC, thus ensuring that the content reflects current technology. Information relating to this publication, including its validity, is available in the IEC Catalogue of publications (see below) in addition to new editions, amendments and corrigenda. Information on the subjects under consideration and work in progress undertaken by the technical committee which has prepared this publication, as well as the list of publications issued, is also available from the following:

- **IEC Web Site (www.iec.ch)**

- **Catalogue of IEC publications**

  The on-line catalogue on the IEC web site (www.iec.ch/searchpub) enables you to search by a variety of criteria including text searches, technical committees and date of publication. On-line information is also available on recently issued publications, withdrawn and replaced publications, as well as corrigenda.

- **IEC Just Published**

  This summary of recently issued publications (www.iec.ch/online_news/ justpub) is also available by email. Please contact the Customer Service Centre (see below) for further information.

- **Customer Service Centre**

  If you have any questions regarding this publication or need further assistance, please contact the Customer Service Centre:

  Email: custserv@iec.ch
  Tel: +41 22 919 02 11
  Fax: +41 22 919 03 00

TECHNICAL REPORT

CISPR 16-4-1

First edition
2003-11

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, 3, rue de Varembé, PO Box 131, CH-1211 Geneva 20, Switzerland
Telephone: +41 22 919 02 11 Telefax: +41 22 919 03 00 E-mail: inmail@iec.ch Web: www.iec.ch

Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

PRICE CODE XB

For price, see current catalogue

CONTENTS

FOREWORD 3
INTRODUCTION 5
TABLE RECAPITULATING CROSS-REFERENCES 8

1 General 9
1.1 Scope 9
1.2 Structure of clauses related to standards compliance uncertainties 9
2 Normative references 10
3 Terms and definitions 11
4 Basic considerations on uncertainties in emission measurements 14
4.1 Introduction 14
4.2 Types of uncertainties in emission measurements 15
4.3 Relation between standards compliance uncertainty and interference probability 23
4.4 Assessment of uncertainties in a standardized emission measurement 25
4.5 Verification of the uncertainty budget 29
4.6 Reporting of the uncertainty 33
4.7 Application of uncertainties in the compliance criterion 35
5 Basic considerations on uncertainties in immunity testing 38
6 Voltage measurements 38
6.1 Introduction 38
6.2 Voltage measurements (general) 38
6.3 Voltage measurements using a voltage probe 42
6.4 Voltage measurement using a V-terminal Artificial Mains Network 43
6.5 Bibliography 50
7 Absorbing clamp measurements 57
8 Radiated emission measurements 57
9 Conducted immunity measurements 57
10 Radiated immunity measurements 57

Annex A (informative) Compliance uncertainty and interference probability 58
A.1 Introduction 58
A.2 Application to radiated emissions, an example 58
A.3 Reducing the compliance uncertainty 59
Annex B (informative) Analysis method of results of an inter-laboratory test 60

Bibliography 61

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

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.

This first edition of CISPR 16-4-1, together with CISPR 16-4-3, CISPR 16-4-4 and the second edition of CISPR 16-3, cancels and replaces the first edition of CISPR 16-3, published in 2000, and its amendment 1 (2002). It contains the relevant clauses of CISPR 16-3 without technical changes.

The text of this technical report is based on the first edition of CISPR 16-3 and on the following documents:

Enquiry draft	Report on voting
CISPR/A/450/DTR	CISPR/A/466/RVC

Full information on the voting for the approval of this technical report 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 bilingual version of this publication may be issued at a later date.

The committee has decided that the contents of this publication will remain unchanged until 2004. At this date, the publication will be

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

INTRODUCTION

CISPR 16-1, CISPR 16-2, CISPR 16-3 and CISPR 16-4 have been reorganised into 14 parts, to accommodate growth and easier maintenance. The new parts have also been renumbered. See the list given below.

Old CISPR 16 publications

CISPR 16-1	Radio disturbance and immunity measuring apparatus
CISPR 16-2	Methods of measurement of disturbances and immunity
CISPR 16-3	Reports and recommendations of CISPR
CISPR 16-4	Uncertainty in EMC measurements

New CISPR 16 publications

CISPR 16-1-1	Measuring apparatus
CISPR 16-1-2	Ancillary equipment – Conducted disturbances
CISPR 16-1-3	Ancillary equipment – Disturbance power
CISPR 16-1-4	Ancillary equipment – Radiated disturbances
CISPR 16-1-5	Antenna calibration test sites for 30 MHz to 1 000 MHz
CISPR 16-2-1	Conducted disturbance measurements
CISPR 16-2-2	Measurement of disturbance power
CISPR 16-2-3	Radiated disturbance measurements
CISPR 16-2-4	Immunity measurements
CISPR 16-3	CISPR technical reports
CISPR 16-4-1	Uncertainties in standardised EMC tests
CISPR 16-4-2	Measurement instrumentation uncertainty
CISPR 16-4-3	Statistical considerations in the determination of EMC compliance of mass-produced products
CISPR 16-4-4	Statistics of complaints and a model for the calculation of limits

More specific information on the relation between the 'old' CISPR 16-3 and the present 'new' CISPR 16-4-1 is given in the table after this introduction (TABLE RECAPITULATING CROSS REFERENCES).

Measurement instrumentation specifications are given in five new parts of CISPR 16-1, while the methods of measurement are covered now in four new parts of CISPR 16-2. Various reports with further information and background on CISPR and radio disturbances in general are given in CISPR 16-3. CISPR 16-4 contains information related to uncertainties, statistics and limit modelling.

CISPR 16-4 consists of the following parts, under the general title *Specification for radio disturbance and immunity measuring apparatus and methods - Uncertainties, statistics and limit modelling:*

- Part 4-1: Uncertainties in standardised EMC tests,
- Part 4-2: Uncertainty in EMC measurements,
- Part 4-3: Statistical considerations in the determination of EMC compliance of mass-produced products,
- Part 4-4: Statistics of complaints and a model for the calculation of limits.

For practical reasons, standardised EMC tests are drastic simplifications of all possible EMI scenarios that a product may encounter in practice. Consequently, in an EMC standard the measurand, the limit, measurement instruments, set-up, measurement procedure and measurement conditions shall be simplified but still meaningful. Meaningful means that there is a statistical correlation between compliance of the product with a standardized EMC test and a high probability of actual EMC of the same product during its life cycle. Part 4-4 provides statistical based methods to derive meaningful disturbance limits to protect the radio services.

In general, a standardized EMC test must be developed such that reproducible results are obtained if different parties perform the same test with the same product. However, various uncertainty sources and influence quantities cause that the reproducibility of a standardized EMC test is limited. Part 4-1 consists of a collection of informative reports that deal with all relevant uncertainty sources that may be encountered during EMC compliance tests. Typical examples of uncertainty sources are the product itself, the measurement instrumentation, the set-up of the product, the test procedures and the environmental conditions.

Part 4-2, deals with a limited and specific category of uncertainties (i.e. the measurement instrumentation uncertainties). In Part 4-2, examples of measurement instrumentation uncertainty budgets are given for most of the CISPR test methods. In this part also requirements are given on how to incorporate the measurement instrumentation uncertainty in the compliance criterion.

If a compliance test is performed using different samples of the same product, then the spread of the EMC performance of the product samples shall be incorporated also in the compliance criterion. Part 4-3 deals with the statistical treatment of test results in case compliance test are performed using samples of mass-produced products. This treatment is well known as the 80 %-80 % rule.

Many important decisions are based on the results of EMC tests. The results are used, for example, to judge compliance against specifications or statutory requirements. Whenever decisions are based on EMC tests, it is important to have some indication of the quality of the results, that is, the extent to which they can be relied on for the purpose in hand. Confidence in test results obtained outside the user's own organisation is a prerequisite to meeting this objective. In the sector of EMC it is often times a formal (frequently legislative) requirement for test laboratories to introduce quality assurance measures to ensure that they are capable of and are providing results of the required quality. Such measures include: the valid use of standardized test methods; the use of defined internal quality control procedures; participation in proficiency testing schemes; accreditation to ISO 17025; and establishing traceability of the results of the tests.

As a consequence of these requirements, EMC test laboratories are, for their part, coming under increasing pressure to demonstrate the quality of their test results. This includes the degree to which a test result would be expected to agree with other test results (reproducibility using the same test method), normally irrespective of the methods used (reproducibility using alternative test methods). A useful means to demonstrate the quality of standardized EMC tests is the evaluation of the associated uncertainty.

Although the concept of measurement uncertainty has been recognised by EMC specialists for many years, it was the publication of the 'Guide to the Expression of Uncertainty in Measurement' (the GUM) by ISO in 1993, and the publication of the EMC specific NAMAS publication NIS 81 on 'The treatment of Uncertainty in EMC measurements' in 1994, which established general and EMC specific rules for evaluating and expressing uncertainty of EMC measurements.

In contrast to classical metrology problems, in EMC there has been great emphasis on precision of results obtained using a specified and standardized method, rather than on their traceability to a defined standard or SI unit. This has led to the use of standardized test methods, such as the CISPR standards, to fulfil legislative and trading requirements. Furthermore, in EMC tests the magnitude of the intrinsic uncertainty (mainly due to reproducibility problems of the set-up of products and their cabling) is large compared to the uncertainties induced by the measurement instrumentation and test procedure. These two important differences between EMC test methods and classical metrology tests, makes it necessary to give specific guidance for evaluating uncertainties of EMC tests, in addition to the generic uncertainty guides like the aforementioned ISO Guide (GUM) on measurement uncertainties.

CISPR 16-4-1 consists of a collection of informative reports that deal with all relevant uncertainty sources that may be encountered during EMC compliance tests. Typical examples of uncertainty sources are the product itself, the measurement instrumentation, the product set-up, the test procedures and the environmental conditions. This CISPR document shows how the concepts given in the ISO Guide may be applied in standardised EMC tests. The EMC-specific basic uncertainty aspects of both emission and immunity tests are outlined in Clauses 4 and 5 respectively. These basic concepts include the introduction of the different types of uncertainties relevant in EMC tests and also the various typical categories of uncertainty sources encountered. This is followed by a description of the steps involved in the evaluation and application of uncertainties in EMC tests.

TABLE RECAPITULATING CROSS-REFERENCES

First edition of CISPR 16-4-1 Clauses	First edition of CISPR 16-3 Clauses
1	1 (of document CISPR/A/450/DTR)
2	2 (of document CISPR/A/450/DTR)
3	3 (of document CISPR/A/450/DTR)
4	4 (of document CISPR/A/450/DTR)
5	Reserved
6	6.3
7	Reserved
8	Reserved
9	Reserved
10	Reserved
Annexes	Annexes
A	A (of document CISPR/A/450/DTR)
B	B (of document CISPR/A/450/DTR)

SPECIFICATION FOR RADIO DISTURBANCE AND IMMUNITY MEASURING APPARATUS AND METHODS –

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

1 General

1.1 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:

a) to 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' (abbreviated as SCU, see 3.16);

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

c) to 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 its 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.

1.2 Structure of clauses related to standards compliance uncertainties

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 a report 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 3 deals with the basic considerations of standards compliance uncertainties in emission measurements. Clause 6 contains the uncertainty considerations related to voltage measurements. Clauses 7 and 8 are reserved for SCU considerations of absorbing clamp and radiated emission measurements, respectively.

Uncertainty work is also considered for immunity compliance tests in the future. Clauses 5, 9 and 10 are reserved for this material. SCU 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 an isolated quantity. This may cause additional specific SCU considerations. Priority is 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		

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*
Amendment 1 (1997)
Amendment 2 (1998)

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 (all parts), *Specification for radio disturbance and immunity measuring apparatus and methods – Radio disturbance and immunity measuring apparatus*

CISPR 16-2 (all parts), *Specification for radio disturbance and immunity measuring apparatus and methods – Methods of measurement of disturbances and immunity*

CISPR 16-3:2003, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 3: CISPR technical reports*

CISPR 16-4-2:2003, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 4-2: Uncertainties, statistics and limit modelling – Measurement instrumentation uncertainties*

CISPR 16-4-3:2003, *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 16-4-4:2003, *Specification for radio disturbance and immunity measuring apparatus and methods – Part 4-4: Uncertainties, statistics and limit modelling – Statistics of complaints and a model for the calculation of limits*

ISO/IEC 17025:1999, *General requirements for the competence of testing and calibration laboratories*

ISO Guide:1995, *Guide to the expression of uncertainty in measurement* (GUM)

ISO:1993, *International vocabulary of basic and general terms in metrology*, 1993 (the VIM)

3 Terms and definitions

For the purposes of this document, the following terms and definitions 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
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]

3.2
emission level
the **level** of a given **EM disturbance** emitted from a particular device, equipment or system, measured in a specified way

[IEV 161-03-11]

3.3
emission limit
the specified maximum **emission level** of a source of **EM disturbance**

NOTE In IEC this limit has been defined as 'the maximum permissible emission level'

[IEV 161-03-12]

3.4
influence quantity
quantity that is not the **measurand** but that affects the result of the measurement

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.

[ISO GUM, B.2.10]

3.5
interference probability
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

3.6
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 would be obtained if the measurand was 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 GUM 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, definition 3.1.11]

3.7
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 would be obtained if the **intrinsic uncertainty of the measurand** would be 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, definition 3.2.10, modified]

3.8
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]

3.9
measurand
particular quantity subject to measurement

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 GUM, B.2.9)

[ISO VIM 2.6]

3.10
measurement instrumentation uncertainty
MIU
parameter, associated with the result of a measurement which characterises the dispersion of the values that could reasonably be attributed to the **measurand**, induced by all relevant influence quantities that are related to the measurement instrumentation

[ISO VIM 3.9 and IEC 60359, definition 3.1.4, modified]

3.11
measuring chain
series of elements of a measuring instrument or system that constitutes the path of the measuring signal from input to the output

[ISO VIM 4.4, IEV 311-03-07]

3.12
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]

3.13
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]

3.14
reproducibility of results of EMC 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 VIM 3.7, ISO GUM B.2.16]

3.15
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 GUM and the description given in [5] [1)].

3.16
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**

[based on the ISO GUM B.2.18 and ISO VIM 3.9]

3.17
tolerance
maximum variation of a value permitted by specifications, regulations, etc. for a given specified **influence quantity**

[this definition deviates from that given in ISO VIM 5.21]

3.18
true value (of a quantity)
value consistent with the definition of a particular quantity

[ISO GUM B.2.3, ISO VIM 1.19]

———————

1) Figures in brackets refer to the bibliography.

3.19
uncertainty source
a 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 4.2.2 and K3 of [9]]

3.20
variability of results of EMC 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 is based on ISO VIM 3.7.

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

4 Basic considerations on uncertainties in emission measurements

4.1 Introduction

In a standardised emission compliance measurement, the emission level of an electrical or electronic product is measured, after which compliance with the associated limit is determined. The measured level only approximates the true level to be measured, due to uncertainties induced by the 'influence quantities' (3.4). In classical metrology, all relevant influence quantities are known and the uncertainty arises mainly from the classical 'measurement instrumentation uncertainty' because the 'intrinsic uncertainty of the measurand' (3.6) is generally very small. In EMC compliance testing however, major relevant influence quantities related to the EUT happen to be non-specified [1] and no quantitative information is available about their values. Hence, for EMC measurements, the intrinsic uncertainty related to the quantity to be measured may be significant compared to the uncertainty due to the measurement instrumentation. Therefore, the term 'standards compliance uncertainty' (SCU) has been introduced to distinguish all uncertainties encountered during an actual EMC compliance test from the measurement instrumentation uncertainty (MIU), which is a subpart of the SCU. For classical metrology problems it is generally sufficient to consider only the MIU. Definition of standards compliance uncertainty (SCU) and other related EMC and uncertainty specific terms are given in Clause 3. Figure 1 illustrates the relation between overall uncertainty of the measurand and the measurement instrumentation uncertainty and the intrinsic uncertainty of the measurand for the different situations explained above. It should be noted that the summation operator in Figure 1 (Σ) is a symbolic operator. 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 [3] and standards compliance uncertainty shall merge directly, wherever possible.

The various categories of uncertainties that can be encountered during EMC 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 discusses briefly 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.

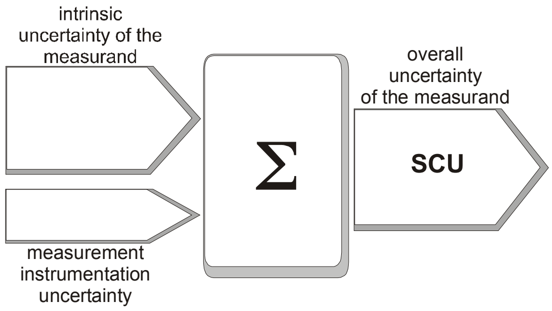


Figure 1a – Typical emission measurement

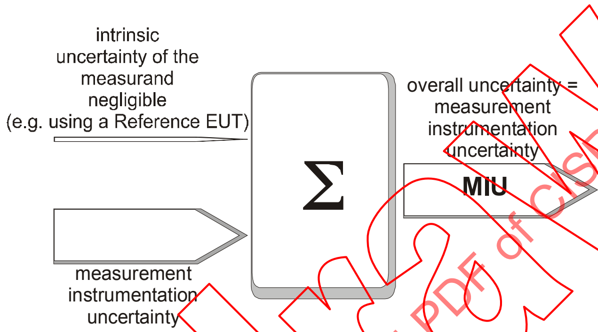


Figure 1b – An emission measurement with a negligible intrinsic uncertainty of the measurand

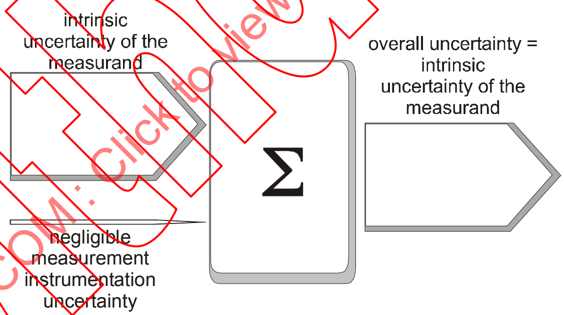


Figure 1c – An emission measurement with negligible measurement instrumentation uncertainty

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

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

4.2.1 Purpose of uncertainty considerations

The measurement result of an EMC 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 (3.11) 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 1b).

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 EMC 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 16-3, per reference, this discrepancy must be resolved (although CISPR 16-4-2 is a normative document, CISPR16-3 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 LAB34 [11], the uncertainty considerations are limited 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 SAR. 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 4 of CISPR 16-4-3 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 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 has to be determined by applying the 80 %/80 % rule as described in 4 of CISPR 16-4-3. Because of the publication of CISPR 16-4-2, the MIU compliance criterion (Clause 4 of CISPR 16-4-2) shall be applied as well. It has yet to be determined how the 80 %/80 % rule compliance criterion, given in CISPR 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 4 of CISPR 16-4-3), 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 the GUM (E.4.3) it is also recognized that an additional uncertainty occurs due to limited sampling of an ensemble of products. E4.3 of the GUM 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 the GUM.

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.

4.2.2 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 3.17). 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.

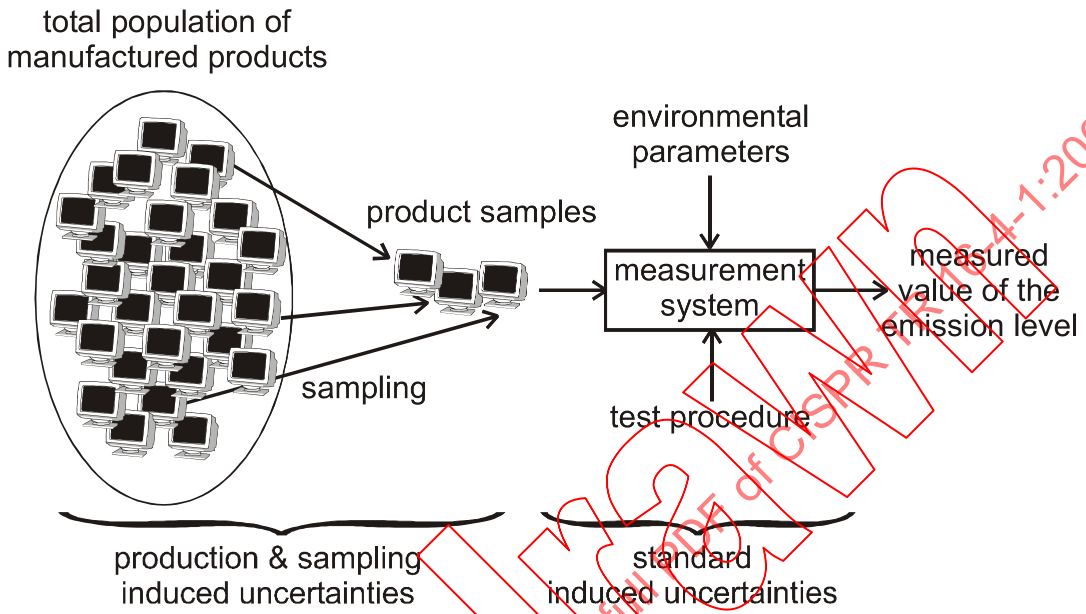


Figure 2 – The process of emission compliance measurements and the associated (categories of) uncertainty sources (see also Table 2)

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 previous clause, 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 <u>compliance</u> measurement of an arbitrary EUT in accordance with the <u>standard</u>, all the categories of uncertainty sources given in Table 2 are of importance. The resulting uncertainty associated with this situation is called the '<u>standards compliance uncertainty</u>'. 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 4 of CISPR 16-4-3. 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 LAB34 [11]), 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 'un-identified 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 & 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

4.2.3 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 (ref case d, 4.2.1)	▪ 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 16-4-3)

4.2.4 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.

EXAMPLES

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, 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.

2. In CISPR 16-2 the uncertainty source ‘environmental conditions’ is an identified uncertainty source (see the ‘measurement environment’ 7.2.5.1 of CISPR 16-2-3 and 4.3.1 of CISPR 16-2-4). 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).

3. ‘Routing of cables’ is a well known and identified ‘uncertainty source’ (part of ‘EUT set up & operation’ category in Table 3). In 7.2.5.2 of CISPR 16-2-3 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 5.5.1 of CISPR 16-1 ▪ 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 <u>actual</u> uncertainty and the <u>estimated</u> expanded uncertainty based on the uncertainty contributions from the list of specified influence quantities.

4.2.5 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 inter-laboratory 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 the GUM 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 definition 3.6).

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 – 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 receiving 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 degrees

   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 GUM Annex D).

EXAMPLE – 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 will give rise to impractical long measurement times, but also will 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.

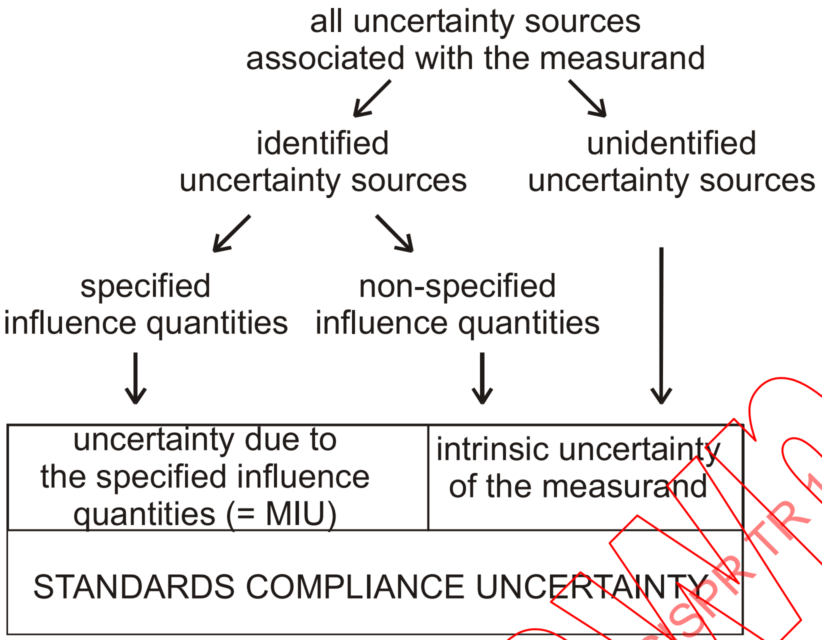


Figure 3 – Relationship between uncertainty sources, influence quantities and uncertainty categories

4.3 Relation between standards compliance uncertainty and interference probability

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.

4.3.1 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 [13]). Furthermore, the measurand is defined by the measurement method used.

EXAMPLE – The disturbance power measurement method is described in 7 of CISPR 16-2-2. 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 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'.

4.3.2 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.

CISPR H (development of limits)

- Define a relevant measurand, its limit level and its maximum allowed uncertainty (see NOTE below)
- Describe the rationale

⇕

CISPR A (development of test equipment specifications and test methods)

- Define a detailed specification of the measurand in relation to the test method and test equipment
- Identify the categories of uncertainty and the uncertainty sources
- Specify and quantify influence quantities for each relevant uncertainty source
- Set up of the uncertainty budget
- Validate the uncertainty budget in practice. In case of a discrepancy between actual and budgeted uncertainties, the uncertainty sources and influence quantities shall be reconsidered
- Check the actual uncertainty against the uncertainty requirement imposed by CISPR H
- Apply the uncertainty in the compliance criterion

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 CISPR subcommittees H and 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 standardized 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.

Step 1 Define the purpose of the uncertainty consideration.

Step 2. Identify the measurand, its uncertainty sources and influence quantities.

Step 3. Evaluate the standard uncertainty of each relevant influence quantity.

Step 4. Calculate the combined uncertainty and expanded uncertainty.

Figure 5 summarizes these steps.

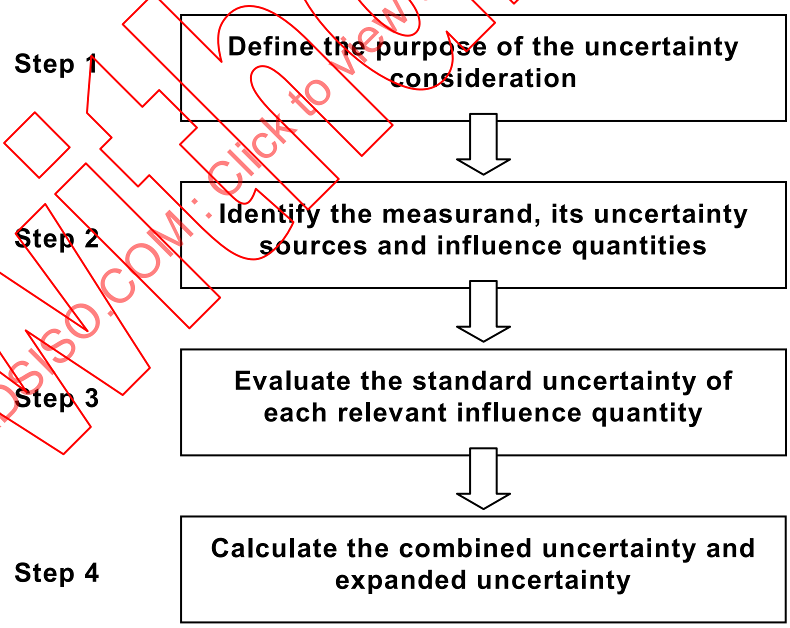


Figure 5 – The uncertainty estimation process

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

As explained in 4.2.1, 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 – 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 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 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 [13]) 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 4.2.2.

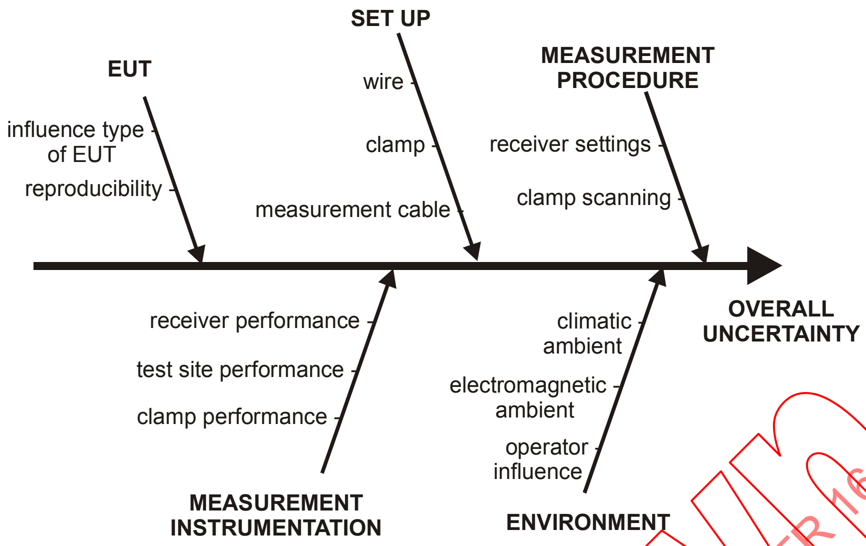


Figure 6 – Example of a fishbone diagram indicating the various uncertainty sources for an absorbing clamp compliance measurement in accordance with CISPR 16-2

The next step is to convert each uncertainty source into one or more influence quantities. In 4.2.4 a method is provided to relate uncertainty sources to influence quantities. In 4.2.4 and in Table 5 some examples were given, a further example is given below.

EXAMPLE – 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' (4^{th} 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.

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 the GUM and in [9] or in [11]. 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).

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

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 $u(L_m)$ of the measured level L_m is a combined uncertainty that can formally be written as a total differential

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

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 the GUM).

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 $u(L_m)$ to the measurand L_m is known. Mathematically, $u_i(L_m) = c_i.u(x_i)$ 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 LAB 34, M3003 and the GUM give detailed guidance on this matter [9][11]. 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 4.5.3).

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 the GUM and in [9] or in [11]. 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:

$$u_c(L_\mathrm{m}(f)) = \sqrt{\sum_{\mathrm{p}=1}^{\mathrm{m}} \{c_\mathrm{p}(f).u(x_\mathrm{p}(f))\}^2} \qquad (3)$$

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 1 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:

$$U(L_m) = k.u_c(L_\mathrm{m}) \qquad (4)$$

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 which will provide the same interference probability.

4.5 Verification of the uncertainty budget

4.5.1 Introduction

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 3.12) 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 Inter-Laboratory 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.

4.5.2 Test laboratory comparison & the measurement compatibility requirement

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

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

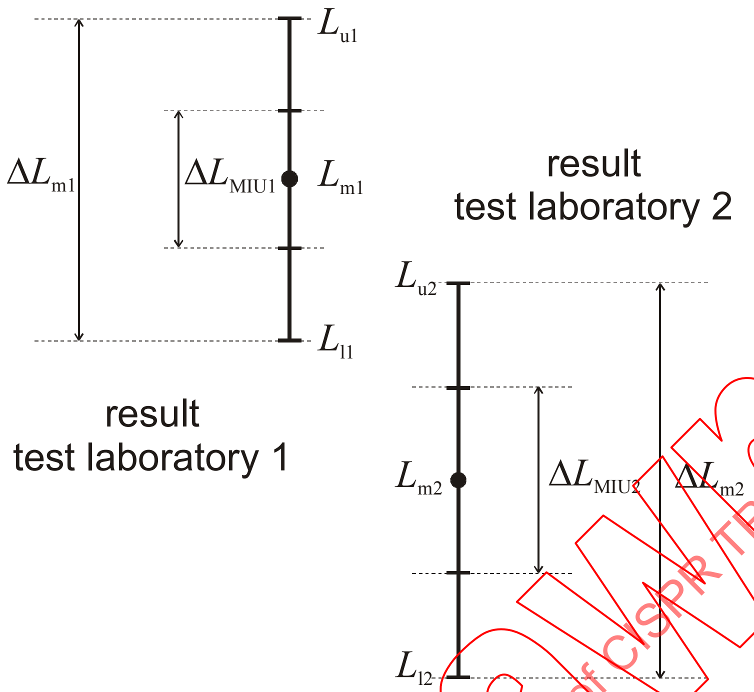
with a certain level of confidence. Similarly, if L_m is the measured emission level, the relationship $L_l \le L_m \le L_u$ has to be satisfied with a certain level of confidence. The interval ΔL_m includes the (weighted) contributions of the uncertainties associated with the specified and the non-specified influence quantities. This interval can be expressed in terms of the expanded uncertainty:

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

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 $L_{l1} \le L_{m1} \le L_{1u}$, with $\Delta L_{m1} = L_{u1} - L_{l1}$ and $L_{l2} \le L_{m2} \le L_{u2}$, 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:

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

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 [3], 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 which 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.

NOTE 2 The relationship between ΔL_{MIU} and measurement instrumentation uncertainty U_{CISPR} published in [3] is given by equation 6, i.e. $\Delta L_{MIU} = 2U_{CISPR}$.

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

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

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 Inter-laboratory comparison & 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 Inter-laboratory 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 EAL publication EAL-P7 (see [12]). 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 [3]: 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 – 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 B 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 the GUM. 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 4 of CISPR 16-1-5). 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 [3].

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 inter-laboratory 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 1b). 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

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.

4.6.1 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.

4.6.2 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.

4.6.3 Reporting of the expanded uncertainty

Unless otherwise required, the result L_m of an emissions measurement should be stated together with the expanded uncertainty $U(L_m)$, calculated using a coverage factor k = 2 (as described in equation (4) of 4.4.5). The following form of reporting is recommended:

<Result>: < $L_m \pm U(L_m)$ > <unit>

where the reported uncertainty is an expanded uncertainty, as defined in the GUM 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) dBpW). *

*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 Introduction

Regulatory compliance generally requires a measurand, such as the emission level of an EUT, to be below a particular limit. The uncertainty of an emissions measurement result has an impact on the pass/fail determination. The following two cases should be considered:

1) the uncertainty of the measured emission level may need to be taken into account when determining compliance, or
2) the limits may have been established to allow for some degree of uncertainty in the process of compliance determination.

Assuming that disturbance limits were established without consideration of uncertainties (case 1 above), then four scenarios can occur when determining compliance with an emission limit:

a) The result exceeds the limit value plus the expanded uncertainty.
b) The result exceeds the limiting value by less than the expanded uncertainty.
c) The result is below the limiting value by less than the expanded uncertainty.
d) The result is less than the limiting value minus the expanded uncertainty.

Case a) is usually interpreted as a situation of non-compliance. Case d) is interpreted as demonstrating clear compliance. Cases b) and c) will require individual consideration, for example based on any agreements with the user of the data, the manufacturer of the EUT or the auditing regulatory authority. Both parties may apply different compliance criteria, depending on the purpose of the assessment and the risks involved. Similar compliance considerations for emission measurements are given in LAB34 [11].

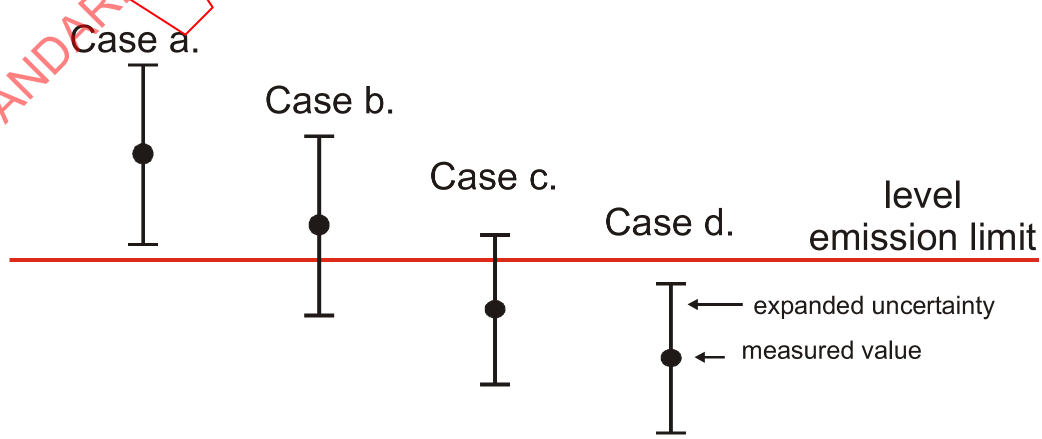


Figure 8 – Graphical representation of four cases in the compliance determination process.

Another compliance approach (case 2 above) can be used if it is known that the emissions limits have been defined to allow for some degree of uncertainty. Then a judgement of compliance can reasonably be made only with knowledge of the amount of uncertainty included in the limit level. As discussed earlier in 4.3, CISPR/H should determine such an uncertainty allowance. If the expanded uncertainty of the measurement, as determined by the laboratory, exceeds this allowance, then the excess shall be taken into account when determining product compliance.

More detailed considerations on compliance criteria with respect to emissions measurements are under development in CISPR/A. In this context, the different compliance approaches that a manufacturer and an auditing authority can apply are a subject of further work since this interpretation of manufacturers and market observers (e.g. regulatory authorities) is different. A further subject of investigation is the determination of different uncertainty categories that are to be incorporated into the compliance criterion. In 4.2 the different types of uncertainties and their relationship to different purposes are outlined. Consequently, these different purposes may also require the application of different compliance criteria.

The following applications of compliance (pass/fail) criteria should be considered:

a) compliance criterion for compliance measurements (CISPR 16-4-2);
b) compliance criterion for mass produced products (CISPR 16-4-3: the 80 %/80 % rule);
c) compliance criterion for quality assurance tests.

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

$$L_\mathrm{m} \le L_\mathrm{lim} \quad \text{and} \quad L_m + U(L_m) \le L_\mathrm{lim} + U_\mathrm{cispr} = L_\mathrm{eff} \tag{8}$$

This criterion is shown in a graphical form in Figure 9, where U_cispr is an agreed (default) quantity, specified in Table 1 of CISPR 16-4-2, 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.

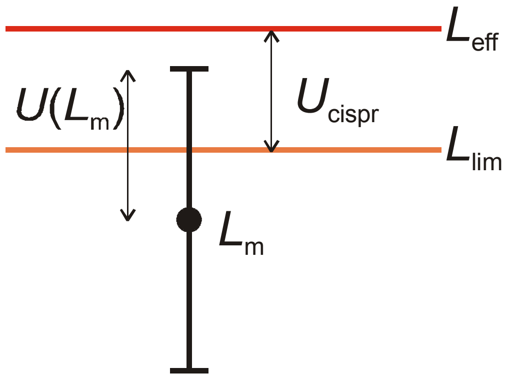


Figure 9 – Graphical representation MIU compliance criterion for compliance measurements, per CISPR 16-4-2

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, from an uncertainty point of view, by the following two methods (see CISPR 16-4-3):

1) testing of one representative sample of the product 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 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 been determined yet how the 80 %/80 % rule compliance criterion, called out in CISPR 16-4-3, and the MIU-compliance criterion of CISPR 16-4-2 are to be combined in cases were both criteria are applicable. This combination of the two compliance criteria is the subject of further investigations within CISPR/A.

4.7.4 Compliance criteria for quality assurance tests using a reference EUT

The data obtained from the periodic quality assurance tests or ad-hoc checks can be compared directly with the 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.

5 Basic considerations on uncertainties in immunity testing

Under consideration.

The SCU considerations of immunity tests differ from the emission SCU considerations at particular points, for example, the measurand is often a functional attribute of the EUT and not a quantity.

6 Voltage measurements

6.1 Introduction

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, those 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 Introduction

Subclause 6.2.2 presents a consideration of the voltage measurements basics, followed by some remarks about voltage measurements using a voltage probe (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 (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 6-1 illustrates such a measurement. U_{12} is the voltage of interest. The measurement leads transport the signal to 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.

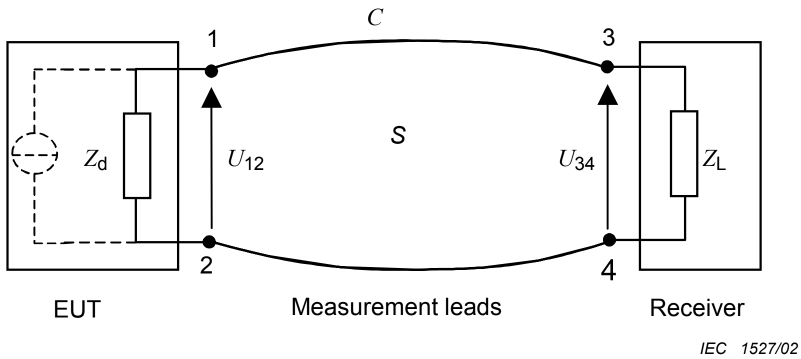


Figure 6-1 – Basic circuit of a voltage measurement

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 in an unknown way on Z_L, thus creating large contributions to the standards compliance uncertainty. Consequently, Z_L has to be specified starting from estimated or measured values of Z_d of 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 only allowed 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 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 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 6-1 this means that

$$\oint_c \vec{E} \cdot d\vec{l} = -\frac{\partial}{\partial t} \oiint_S \vec{B} \cdot d\vec{s} \tag{6-1}$$

where the electric field $\vec{E}$ and the magnetic flux $\vec{B}$ 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 (6-1) it follows that the voltage U_{34} is given by

$$U_{34} = \int_3^4 \vec{E} \cdot d\vec{l} = U_{12} - \int_1^3 \vec{E} \cdot d\vec{l} - \int_4^2 \vec{E} \cdot d\vec{l} - \frac{\partial}{\partial t} \oint\!\!\!\oint_S \vec{B} \cdot d\vec{s} \qquad (6\text{-}2)$$

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 6-A.

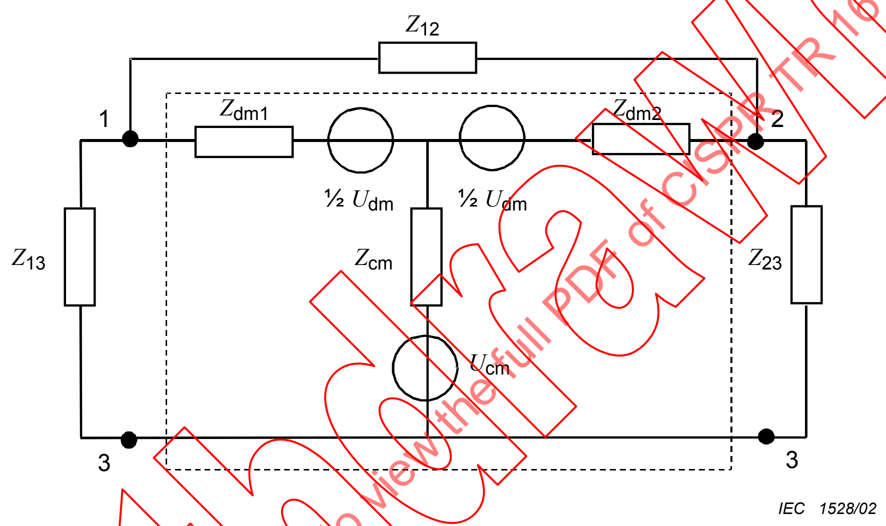


Figure 6-2 – Basic circuit of a loaded disturbance source (N = 2)

6.2.3 The disturbance source and types of voltage

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 standard drafter to define the surroundings in such a way that this additional terminal is a relevant reference point in the voltage measurement.

In this section N = 2 is assumed, so that a three-terminal network results and the equivalent circuit of figure 6-2 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.

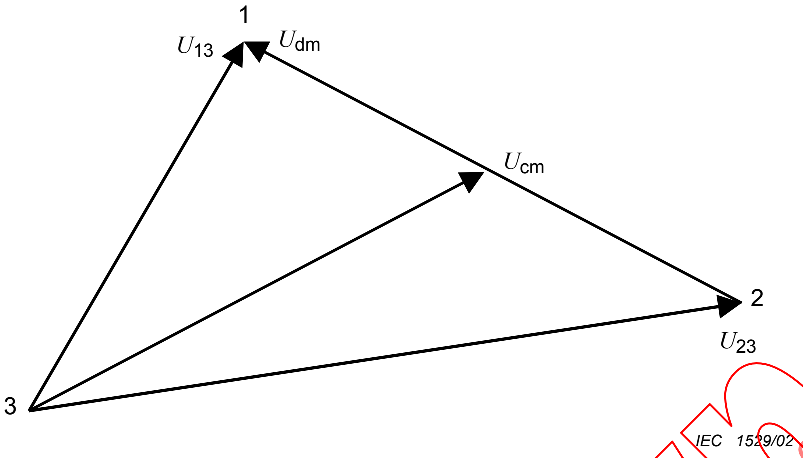


Figure 6-3 – Relation between the voltages

In figure 6-2, 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 6-3.

6.2.3.1 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 6-B5). 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.

6.2.3.2 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 6-2 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 6-A.

In the CISPR specifications [3] 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 6-B, attention is paid to possible improvements of CISPR standards.

6.4 Voltage measurement using a V-terminal Artificial Mains Network

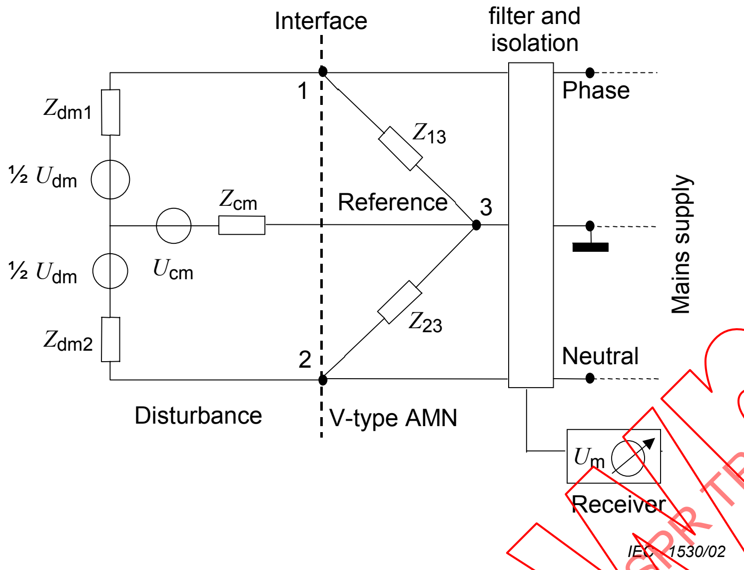


Figure 6-4 – Basic circuit of the V-AMN voltage measurement (N = 2)

6.4.1 Introduction

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 6-2 applies at the interface of the measurement impedances. Subclause 4.1 of CISPR 16-1-1 [3] specifies the two unsymmetrical impedances Z_{13} and Z_{23}, including the tolerance of the absolute value of these impedances. In 4.1 of CISPR 16-1-1 [3], the shunt-impedance Z_{12} is a non-specified influence quantity; it seems that CISPR assumes that Z_{12} is always 'infinitely' large.

The basic circuit can be described as in figure 6-4. The filter and isolation between the measurement circuit and the mains terminals is, to some extent, also specified in CISPR 16-1-1 [3]. The unsymmetrical voltages across Z_{13} and Z_{23} have to be measured (see 5.3.1 of CISPR 16-4-3 for comments with regard 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 [9] and [12].

6.4.2 Basic circuit diagram of the voltage measurement

When reading the level U_m at the CISPR receiver, the circuit of figure 6-4 'reduces' to that of figure 6-5. In figure 6-5 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 $\alpha = U_m/U_{in}$, 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.

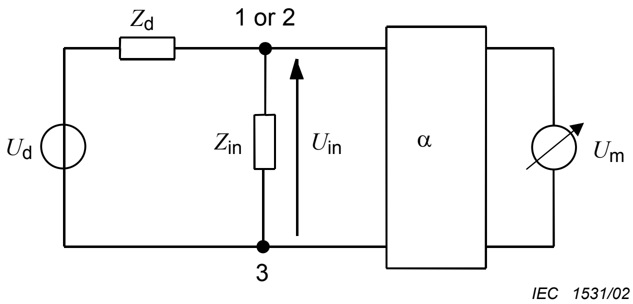


Figure 6-5 – Basic circuit of the V-AN measurement during the reading of the received voltage U_m (the numbers refer to figure 6-4)

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

$$U_{mt} = \frac{\alpha_0 Z_{13}}{Z_{d0} + Z_{13}} U_{d0} \qquad (6\text{-}3)$$

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 actual parameters are α, Z_{in}, Z_d and U_d, so the voltage reading U_m is given by

$$U_m = \alpha \frac{Z_{in}}{Z_d + Z_{in}} U_d \qquad (6\text{-}4)$$

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 (6-3) and equation (6-4) that

$$\frac{\Delta U_m}{U_{mt}} = \frac{Z_{d0} + Z_{13}}{Z_d + Z_{in}} \left(\frac{\Delta\alpha}{\alpha_0} + \frac{\Delta U_d}{U_{d0}} \right) + \frac{Z_{d0}}{Z_d + Z_{in}} \left(\frac{\Delta Z_{in}}{Z_{13}} - \frac{\Delta Z_d}{Z_{d0}} \right) \qquad (6\text{-}5)$$

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 [6]. 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 (6-5).

In equation (6-5), 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:

$$c_1 = \frac{Z_{d0} + Z_{13}}{Z_d + Z_{in}} \approx \frac{Z_{d0} + Z_{13}}{Z_{d0} + Z_{13}} = 1 \quad (6\text{-}6)$$

$$c_2 = \frac{Z_{d0}}{Z_d + Z_{in}} \approx \frac{Z_{d0}}{Z_{d0} + Z_{13}} = \frac{1}{1 + \rho e^{j\varphi}} \quad (6\text{-}7)$$

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

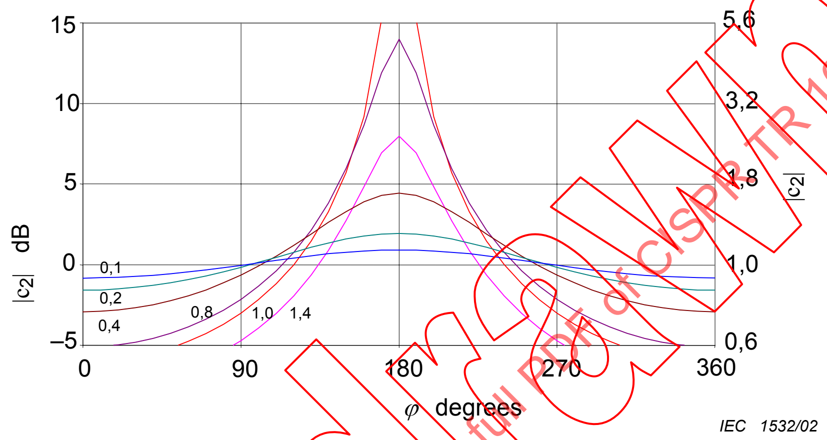


Figure 6-6 – The absolute value of the sensitivity coefficient c_2 as a function of the phase angle difference φ of the impedances Z_{13} and Z_{d0} for several values of the ratio $|Z_{13}/Z_{d0}|$.

In equation (6-7) $\rho = \rho_{13}/\rho_{d0}$ 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 6-6 presents 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 standard drafters 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 (6-5) 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 (6-3) and (6-4) that

$$\frac{U_m}{U_{mt}}(\mathrm{dB}) = \frac{\alpha}{\alpha_0}(\mathrm{dB}) + \frac{Z_{\mathrm{in}}}{Z_{13}}(\mathrm{dB}) + \frac{U_{\mathrm{d}}}{U_{\mathrm{d0}}}(\mathrm{dB}) - \frac{Z_{\mathrm{d}} + Z_{\mathrm{in}}}{Z_{\mathrm{d0}} + Z_{13}}(\mathrm{dB}) \quad (6\text{-}8)$$

so that

$$\Delta U_{\mathrm{m}}(\mathrm{dB}) = \Delta\alpha(\mathrm{dB}) + \Delta Z_{\mathrm{in}}(\mathrm{dB}) + \Delta U_{\mathrm{d}}(\mathrm{dB}) - \Delta(Z_{\mathrm{d}} + Z_{\mathrm{in}})(\mathrm{dB}) \quad (6\text{-}9)$$

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 Δs and it is not correct to use the RSS as with equation (6-5). 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 standard drafters 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 $U_{int} = U_{mt}/\alpha_0$. If the compliance uncertainty margin is indicated by ΔU_{in}, the ratio $\Delta U_{in}/U_{int}$ can be calculated from $U_{int} + \Delta U_{in} = (U_{mt} + \Delta U_m)/(\alpha_0 + \Delta\alpha)$.

6.4.6 Influence quantities

6.4.6.1 Introduction

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, 6.4.6.4d) 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 6-8.

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 [3], 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 [7]. 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 6-3). 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 6-2). 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 6.4.6.4d)).

In 5.1.3 of [3] 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), as was the case in CISPR 16 (1977) in the case of a V-AMN having 150 Ω input impedances.

6.4.6.3 The attenuation factor α

The attenuation factor α is a non-specified influence quantity. However, it is – in general – 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 Δα may stem from losses in the V-AMN (also determined by some of the aspects mentioned in section 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 6-4 and 6-5 it follows that if U_{13} is measured, Z_d is given by

$$Z_d = Z_{dm1} + \frac{Z_{cm}(Z_{23} + Z_{dm2})}{Z_{cm} + Z_{23} + Z_{dm2}} \qquad (6\text{-}10)$$

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 6-7, 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 6-8 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 6-7 the dashed line represents the anther 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.

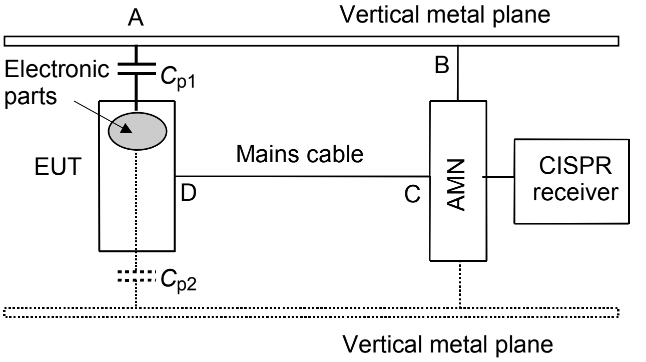


Figure 6-7 – Variation of the parasitic capacitance, and hence of the CM-impedance, by changing the position of the reference plane (non-conducting EUT housing)

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 6-4 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 6-7 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 6-7, 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 ground nding strap between V-AMN and the reference plane. In figure 6-7 the capacitance is represented by C_{p1}, and, more generally, by C_p in figure 6-8. This circuit plays a part in the CM impedance (see equation (6-10)). 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 EUT and V-AMN. In particular, when meandering of the mains cable is needed, variations in the electrical loop properties may be large. Experimental results [10] 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 6.4.6.5b) 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 6-8) 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 [9]. 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 aforementioned 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 [9] 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 6-8). This coupling that also influences the effective CM impedance, will be discussed in connection with U_d in 6.4.6.5.

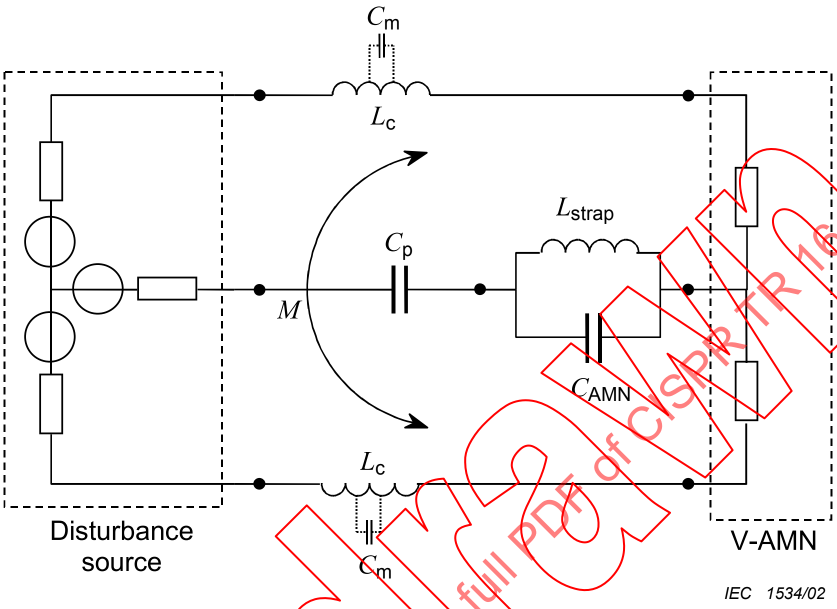


Figure 6-8 – Influence quantities in between the EUT (disturbance source) and the V-AMN

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

a) the non-specified open-circuit voltages U_{dm} and U_{cm} (see figure 6-4);

b) 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 6-A);

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.

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 a 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 6-7 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 6-A.

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.

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 [11]

$$Z_t = R_c + j\omega(L_c - M) = R_c + j\omega(1-k)L_c \tag{6-11}$$

where R_c is the resistive part of Z_t (about 10 mΩ per metre cable), L_c the inductive part of Z_t (about 1 µH per metre cable). The constant $k = M/L_c$, 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 6-8). 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 6-8, 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 6-8 schematically represented by C_m) may play a part. As already mentioned, a non-specified meander layout may create relevant uncertainty contributions [10].

6.5 Bibliography

[1] *Uncertainties in standardized EMC compliance testing*, J.J. Goedbloed, Proc. Intern. Symp. on EMC, Zurich, Switzerland, February 1999, Supplement pp. 161–178.

[2] *Characterization and classification of the asymmetrical disturbance source induced in telephone-subscriber lines by AM broadcasting transmitters in the LW, MW and SW bands*, Report CISPR/A(Secr)128, 1992, to be published in CISPR 16-3.

[3] *Specifications and validation procedures for a test site to be used to calibrate antennas in the frequency range of 30 MHz to 1000 MHz*, CISPR 16-1, Ed.2, 1999.