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Technical Specification

Electromagnetic compatibility and Radio spectrum Matters (ERM); Expanded measurement uncertainty for the measurement of radiated electromagnetic fields

Reference

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Foreword

This Technical Specification (TS) has been produced by ETSI Technical Committee Electromagnetic compatibility and Radio spectrum Matters (ERM).

Introduction

The present document has been produced in response to the need for expanded measurement uncertainty information, and to determine practical maximum frequency of measurement which is also cost effective for manufacturers self declaration as well as for test laboratories offering certification testing.

In metrology the term "measurement uncertainty" is nearly always associated with the simple standard deviation (σ). In the case that a different confidence interval is used, the term "Expanded Measurement Uncertainty" is used, stating the associated expansion factor, see EA-4/02 [19].

Considerable work on radio test methods and expanded measurement uncertainty up to 1 GHz has previously been undertaken by ETSI to determine the contributions to the calculation of measurement uncertainty and these have been published in TR 100 028 [1] and [2] and TR 102 273 [3] to [10]. However, more and more ETSI standards and norms are generated for radio devices operating at higher frequencies as far as 100 GHz or even higher.

The expanded measurement uncertainty values have been included based on new information on state-of-the-art measurements for expanded measurement uncertainty for measurements at higher frequencies, also taking into account new work in ERM for radio applications at EHF frequencies.

The changing role of regulation due to the implementation of the Radio and Telecommunications Terminal Equipment (R&TTE) Directive [11] within the European Union has meant that there is a need to review and if necessary revise the previously agreed methods for the comparison of measurement values with limits to determine conformance with standards and specifications.

As a result of discussions with manufacturers, test laboratories, and regulators it is clear that some test methods need to be reviewed and more clearly defined as the frequency of measurement increases above 1 GHz. The re-defining of test methods is not within the scope of the present document, but may result in a more extensive evaluation of the test methods, bearing in mind the globalization of radio products, and the implementation of Mutual Recognition Agreements (MRA) for this purpose.

The present document contains the results of many discussions held with test equipment manufacturers, test laboratories, administrations, trade associations, societies, and members of the GRSC, all who have an interest in expanded measurement uncertainty above 1 GHz.

From an international perspective, measurements for radio testing, both radio parameters and EMC are already required above 1 GHz, notably in US FCC regulations (40 GHz), ITU-R spurious emissions (300 GHz), and CISPR EMC testing (6 GHz). These extensions to the measurement frequency range necessitate a review and some level of co-ordination to ensure that a common approach to test methods and the associated measurement uncertainty calculations are agreed.

Contrary to the requirement of performing measurements at higher frequencies up to 100 GHz or even more, the descriptions on traceable validation or calibration of test sites lacks considerable information leading to another source of uncertainties in the measurement results. The source descriptions for open area test sites, semi-anechoic rooms and anechoic test chambers at/in which radiated measurements can be performed are lacking information regarding frequencies above 40 GHz.

Measurement receivers are also limited regarding their capabilities in terms of fundamental frequency measurements and measurement bandwidth. At the time of writing, an investigation has shown that spectrum analyzers were only available for frequency measurements up to 63 MHz. Non-continuous, impulsive radio technologies could also be measured with a measurement bandwidth of up to 25 MHz. In the case of EHF frequency measurements above 60 GHz, it has therefore been considered to make use of external mixers (either ground wave or harmonic wave) to measure emissions. However, this comes at the expense of great additional measurement uncertainty contributions. The present document does not attempt to repeat the detailed statistical methods to calculate the expanded measurement uncertainty that has already been extensively prepared in other ETSI deliverables. However, to assist test engineers to calculate their own expanded measurement uncertainties associated with their particular test equipment configurations, a series of spread sheets are identified in the present document (see annex B).

The present document captures the state of the art regarding measurement techniques, their capabilities and associated expanded measurement uncertainties. It is offered as an assistive document to ETSI standard makers. Whilst it remains the responsibility of the individual Technical Bodies to define their own test methodologies, the present document should be considered as a source of what is possible, practical and therefore recommended.

1 Scope

The present document presents an evaluation of maximum acceptable measurement uncertainty for Radio Frequency (RF) electromagnetic field (emf) measurements for the frequency range from 30 MHz to 100 GHz for inclusion within ETSI documents on radio products used for compliance testing.

The maximum acceptable expanded measurement uncertainty is given for the following measurement parameters:

- radiated RF power;
- radiated unwanted emissions in the spurious domain; and
- EMC radiated emissions.

The maximum frequency specifications are based upon current capabilities of measurement equipment at April 2011 and the ability to calculate expanded measurement uncertainty from traceable calibration certificates. Frequencies above the specified maximum frequency for each method of measurement are for further study.

A specification is given on how to apply the laboratory calculated expanded measurement uncertainty to a measured parameter and to assess the quality of the measurement against a defined limit given in a standard.

In determining the maximum acceptable expanded measurement uncertainty, particular account has been taken of current methods of measurement already identified in ETSI standards. However where there is an inconsistency, or uncertainties that have not previously been taken into account in the uncertainty budgets, these are clearly identified in the relevant clauses.

Fixed link microwave methods of measurement do not use radiated measurements except for EMC and antennae characteristics testing. All other measurements are performed using conducted measurements. Therefore they are considered not to be covered by the present document. However, as new technologies with integral antennas are being developed, this may be reviewed in a future edition.

Satellite equipment is not covered by the present document; however, this may be reviewed in a future edition.

The expanded measurement uncertainty for conducted measurements is not covered by the present document.

The use of a test jig for radiated RF measurements of integral antenna radio equipment is not covered by the present document.

2 References

References are either specific (identified by date of publication and/or edition number or version number) or non-specific. For specific references, only the cited version applies. For non-specific references, the latest version of the reference document (including any amendments) applies.

Referenced documents which are not found to be publicly available in the expected location might be found at http://docbox.etsi.org/Reference.

NOTE: While any hyperlinks included in this clause were valid at the time of publication, ETSI cannot guarantee their long term validity.

2.1 Normative references

The following referenced documents are necessary for the application of the present document.

NOTE: Specifications to provide policy on the evaluation and reporting of expanded measurement uncertainty for testing and calibration laboratories are laid down in several reference documents, some examples of them being listed in annex H of the present document.

[1] ETSI TR 100 028-1: "Electromagnetic compatibility and Radio spectrum Matters (ERM); Uncertainties in the measurement of mobile radio equipment characteristics; Part 1".

[2] ETSI TR 100 028-2: "Electromagnetic compatibility and Radio spectrum Matters (ERM); Uncertainties in the measurement of mobile radio equipment characteristics; Part 2".

[3] ETSI TR 102 273-1-1 (V1.2.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Improvement on Radiated Methods of Measurement (using test site) and evaluation of the corresponding measurement uncertainties Part 1: Uncertainties in the measurement of mobile radio equipment characteristics; Sub-part 1: Introduction".

[4] ETSI TR 102 273-1-2 (V1.2.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Improvement on Radiated Methods of Measurement (using test site) and evaluation of the corresponding measurement uncertainties; Part 1: Uncertainties in the measurement of mobile radio equipment characteristics; Sub-part 2: Examples and annexes".

[5] ETSI TR 102 273-2 (V1.2.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Improvement on Radiated Methods of Measurement (using test site) and evaluation of the corresponding measurement uncertainties; Part 2: Anechoic chamber".

[6] ETSI TR 102 273-3 (V1.2.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Improvement on Radiated Methods of Measurement (using test site) and evaluation of the corresponding measurement uncertainties; Part 3: Anechoic chamber with a ground plane".

[7] ETSI TR 102 273-4 (V1.2.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Improvement on Radiated Methods of Measurement (using test site) and evaluation of the corresponding measurement uncertainties; Part 4: Open area test site".

[8] ETSI TR 102 273-5 (V1.2.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Improvement on Radiated Methods of Measurement (using test site) and evaluation of the corresponding measurement uncertainties; Part 5: Striplines".

[9] ETSI TR 102 273-6 (V1.2.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Improvement on Radiated Methods of Measurement (using test site) and evaluation of the corresponding measurement uncertainties; Part 6: Test fixtures".

[10] ETSI TR 102 273-7 (V1.2.1): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Improvement on Radiated Methods of Measurement (using test site) and evaluation of the corresponding measurement uncertainties; Part 7: Artificial human beings".

[11] Directive 1999/5/EC of the European Parliament and of the Council of 9 March 1999 on radio equipment and telecommunications terminal equipment and the mutual recognition of their conformity (R&TTE Directive).

[12] United Kingdom Accreditation Service LAB34 Edition 1 (2002): "The Expression of Uncertainty in EMC Testing".

[13] CISPR 16-4: "Specification for radio disturbance and immunity measuring apparatus and methods - Part 4: Uncertainties, statistics and limit modelling".

[14] CISPR 16-1: "Specification for radio disturbance and immunity measuring apparatus and methods - Part 1: Radio disturbance and immunity measuring apparatus".

[15] ISO/IEC 17025:2005: "General requirements for the competence of testing and calibration laboratories".

[16] CENELEC EN 62311:2008: "Assessment of electronic and electrical equipment related to human exposure restrictions for electromagnetic fields (0 Hz - 300 GHz)".

[17] ETSI TS 102 321: "Electromagnetic compatibility and Radio spectrum Matters (ERM); Normalized Site Attenuation (NSA) and validation of a fully lined anechoic chamber up to 40 GHz".

[18] ETSI EN 301 489-1: "Electromagnetic compatibility and Radio spectrum Matters (ERM); ElectroMagnetic Compatibility (EMC) standard for radio equipment and services; Part 1: Common technical requirements".

[19] EA-4/02: "Expression of the Uncertainty of Measurement in Calibration", European co-operation for Accreditation, December 1999 (previously EAL-R2).

[20] ETSI TS 103 052: "Electromagnetic compatibility and Radio spectrum Matters (ERM); Radiated measurement methods and general arrangements for test sites up to 100 GHz".

[21] JCGM 100:2008: "Evaluation of measurement data - Guide to the expression of uncertainty in measurement".

[22] Draft Technical Report - IEC/TR 61000-1-6 Ed. 1.0: "Electromagnetic Compatibility (EMC) - Part 1-6: General - Guide to the assessment of measurement uncertainty".

[23] "Measurement Instrumentation Uncertainty of Radiated Disturbances Due to Antenna - Receiver Transmission" elaborated by the test engineer Jan Sroka of EMC-Testcenter Zürich AG, Switzerland for the 19th International Wroclaw Symposium and Exhibition on Electromagnetic Compatibility, Wroclaw, 11 - 13 June, 2008.

[24] EA-4/16: "EA guidelines on the expression of uncertainty in quantitative testing", European co-operation for Accreditation, December 2003.

[25] ETSI EN 301 091 (Parts 1 and 2): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices; Road Transport and Traffic Telematics (RTTT); Radar equipment operating in the 76 GHz to 77 GHz range".

[26] ETSI EN 302 264 (Parts 1 and 2): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices; Road Transport and Traffic Telematics (RTTT); Short Range Radar equipment operating in the 77 GHz to 81 GHz band".

[27] ETSI EN 305 550 (Parts 1 and 2): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Radio equipment to be used in the 40 GHz to 246 GHz frequency range".

[28] ETSI EN 302 372 (Parts 1 and 2): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Equipment for Detection and Movement; Tanks Level Probing Radar (TLPR) operating in the frequency bands 5,8 GHz, 10 GHz, 25 GHz, 61 GHz and 77 GHz".

[29] ETSI EN 302 729 (Parts 1 and 2): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Short Range Devices (SRD); Level Probing Radar (LPR) equipment operating in the frequency ranges 6 GHz to 8,5 GHz, 24,05 GHz to 26,5 GHz, 57 GHz to 64 GHz, 75 GHz to 85 GHz".

[30] ETSI EN 302 686: "Intelligent Transport Systems (ITS); Radiocommunications equipment operating in the 63 GHz to 64 GHz frequency band; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive".

[31] ETSI EN 302 567: "Broadband Radio Access Networks (BRAN); 60 GHz Multiple-Gigabit WAS/RLAN Systems; Harmonized EN covering the essential requirements of article 3.2 of the R&TTE Directive".

2.2 Informative references

The following referenced documents are not necessary for the application of the present document but they assist the user with regard to a particular subject area.

Not applicable.

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purposes of the present document, the following terms and definitions apply:

antenna: part of a transmitting or receiving system that is designed to radiate or to receive electromagnetic waves

antenna factor: quantity relating the strength of the field in which the antenna is immersed to the output voltage across the load connected to the antenna

NOTE: When properly applied to the meter reading of the measuring instrument, yields the electric field strength in V/m or the magnetic field strength in A/m.

antenna gain: ratio of the maximum radiation intensity from an (assumed lossless) antenna to the radiation intensity that would be obtained if the same power were radiated isotropically by a similarly lossless antenna

confidence level: probability of the accumulated error of a measurement being within the stated range of uncertainty of measurement

NOTE: The confidence level is usually not below 95 %.

correction factor: numerical factor by which the uncorrected result of a measurement is multiplied to compensate for an assumed systematic error

directivity: ratio of the maximum radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions (i.e. antenna gain = directivity - losses)

error (of a measuring instrument): indication of a measuring instrument minus the true value

NOTE: See clause 4.2.

error of measurement (absolute): result of a measurement minus the true value of the measurand

NOTE: See clause 4.2.

error (relative): ratio of an error to the true value

estimated standard deviation: from a sample of n results of a measurement the estimated standard deviation is given by the formula:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n}}$$

x_i being the i^{th} result of measurement (i = 1, 2, 3, ..., n) and x the arithmetic mean of the n results considered.

A practical form of this formula is:

$$\sigma = \sqrt{\frac{Y - \frac{X^2}{n}}{n}}$$

where X is the sum of the measured values and Y is the sum of the squares of the measured values.

NOTE: The term **standard deviation** has also been used in the present document to characterize a particular probability density. Under such conditions, the term **standard deviation** may relate to situations where there is only one result for a measurement.

expansion factor: multiplicative factor used to change the confidence level associated with a particular value of a measurement uncertainty

free field: field (wave or potential) that has a constant ratio between the electric and magnetic field intensities, i.e. a plane wave outside of the Fresnel zone)

free space: region free of obstructions and characterized by the constitutive parameters of a vacuum

impedance: measure of the complex resistive and reactive attributes of a component in an alternating current circuit

impedance (wave): complex factor relating the transverse component of the electric field to the transverse component of the magnetic field at every point in any specified plane, for a given mode

influence quantity: quantity which is not the subject of the measurement but which influences the value of the quantity to be measured or the indications of the measuring instrument

isotropic radiator: hypothetical, lossless antenna having equal radiation intensity in all directions

measurand: quantity subjected to measurement

measurement repeatability: closeness of the agreement between the results of successive measurements of the same measurand carried out subject to all the following conditions:

- the same method of measurement;
- the same observer;
- the same measuring instrument;
- the same location;
- the same conditions of use;
- repetition over a short period of time.

measurement reproducibility: closeness of agreement between the results of measurements of the same measurand, where the individual measurements are carried out changing conditions such as:

- method of measurement;
- observer;
- measuring instrument;
- location;
- conditions of use;
- time.

measurement uncertainty: describes a region about an observed value of a physical quantity which is likely to enclose the true value

measuring system: complete set of measuring instruments and other equipment assembled to carry out a specified measurement task

polarization (for an electromagnetic wave): figure traced as a function of time by the extremity of the electric vector at a fixed point in space

probability density function (PDF): derivative, when it exists, of the distribution function

quantity (measurable): attribute of a phenomenon or a body that may be distinguished qualitatively and determined quantitatively

quiet zone: region within an anechoic chamber that complies with the Normalized Site Attenuation (NSA) requirements of being reflection free

NOTE: The term "quiet zone" does not imply that the physical dimensions of equipment under test can equal the same dimensions. The maximum size of the equipment is determined in accordance with TR 102 273-1-1 [3], clause 8.3.4 when related to range length and frequency of measurement.

shielded enclosure: structure that protects its interior from the effects of an exterior electric or magnetic field, or conversely, protects the surrounding environment from the effect of an interior electric or magnetic field

stochastic (random) variable: variable whose value is not exactly known, but is characterized by a distribution or probability function, or a mean value and a standard deviation (e.g. a measured value and the related measurement uncertainty)

uncertainty (combined standard): uncertainty characterizing the complete measurement or part thereof

NOTE: It is calculated by combining appropriately the standard uncertainties for each of the individual contributions identified in the measurement considered or in the part of it that has been considered. In the case of additive components (linearly combined components where all the corresponding coefficients **are equal to one**) and when all these contributions are independent of each other (stochastic), this combination is calculated by using the Root of the Sum of the Squares (the RSS method). A more complete methodology for the calculation of the combined standard uncertainty is given in TR 100 028-2 [2], clause D.3.12.

uncertainty (expanded): uncertainty value corresponding to a specific confidence level different from that inherent to the calculations made in order to find the combined standard uncertainty

NOTE: The combined standard uncertainty is multiplied by a constant to obtain the expanded uncertainty limits (see TR 100 028-2 [2], clause D.5.6.2).

uncertainty (limits of uncertainty of a measuring instrument): extreme values of uncertainty permitted by specifications, regulations etc. for a given measuring instrument

uncertainty (random): component of the uncertainty of measurement, which, in the course of a number of measurements of the same measurand, varies in an unpredictable way (and has not being considered otherwise)

uncertainty (standard): expression characterizing the uncertainty of each individual uncertainty component

NOTE: It is the standard deviation of the corresponding distribution.

uncertainty (systematic): component of the uncertainty of measurement, which, in the course of a number of measurements of the same measurand remains constant or varies in a predictable way

uncertainty (type A): uncertainties evaluated using the statistical analysis of a series of observations

uncertainty (type B): uncertainties evaluated using other means than the statistical analysis of a series of observations

3.2 Symbols

For the purposes of the present document, the following symbols apply:

a^+	Upper bound of quantity *X*
a^-	Lower bound of quantity *X*
°C	degrees Centigrade
cm	centimetres
dB	deciBel
GHz	GigaHertz
MHz	MegaHertz
mV	milliVolt
u(xi)	Standard uncertainty of the best estimate of the influence quantity X_i
X	Generic quantity
X_i	Influence quantity to a mathematical measurement model
x_i	Best estimate of the influence quantity to a mathematical measurement model

3.3 Abbreviations

For the purposes of the present document, the following abbreviations apply:

AFC	Automatic Frequency Control
ANSI	American National Standards Institute
EHF	Extremely High Frequency
e.i.r.p.	equivalent isotropically radiated power
EMC	ElectroMagnetic Compatibility
emf	electromagnetic fields
EMU	Expanded Measurement Uncertainty
e.r.p.	effective radiated power
EUT	Equipment Under Test
FCC	Federal Communications Commission
FH	Frequency Hopping
FMCW	Frequency Modulated Continuous Wave
FSL	Free Space Loss
GRSC	Global Radiocommunication Standardization Collaboration
IF	Intermediate Frequency
LNA	Low Noise Amplifier
LPDA	Log Periodic Dipole Antenna
MRA	Mutual Recognition Agreement
NRA	National Regulatory Authority
NSA	Normalized Site Attenuation
OATS	Open Area Test Site
PDF	Probability Density Function
R&TTE	Radio and Telecommunications Terminal Equipment (Directive)
RBW	Resolution BandWidth
RF	Radio Frequency
RSS	Root of the Sum of the Squares
TCXO	Temperature Compensated Crystal Oscillators
UKAS	United Kingdom Accreditation Service
VBW	Video BandWidth
VSWR	Voltage Standing Wave Radio
WGSE	Working Group on Spectrum Engineering

4 Measurement uncertainty

4.1 Introduction

The terms "accuracy" and "uncertainty" are frequently misused and interchanged when applied to measurement equipment and to a measured value. The following clauses define the meaning of each of the phrases and how they are used in measurement equipment literature. The difference in their meanings can be significant and in many measurement applications it is **vital** to understand the difference.

The use of the term "accuracy" plays a significant role in measurement equipment sales literature often to compete against similar equipment from other manufacturers and this should be regarded with caution. It has been known for competing manufacturers to quote performance values that exceed the finest metrology laboratory values for calibration and this of course is impossible. Realistic values are derived from traceable standards where the term "accuracy" is never used; only the term "uncertainty" is used. The true value of a measurand is never known, as it is impossible to define or make perfect measurements.

When a measured value with its measurement uncertainty bounds is compared with a specification (standard) limit interpretation of the result is not always clear. Clause 5 gives guidance on how to make this assessment, which is dependant upon the testing regime that is being followed.

Consequently, the present document only uses the term "uncertainty" and avoids completely the usage of the term "accuracy".

4.2 Measurement uncertainty

The definition of measurement uncertainty as described in clause 3.1 makes no attempt to define the true value, nor does it rely upon it. It is a statistical approach and is used to give a level of confidence that the measured value lays between a range of values.

The general requirements that testing and calibration laboratories have to meet if they wish to demonstrate that they operate to a quality system, are technically competent and are able to generate technically valid results are contained within ISO/IEC 17025:2005 [15]. This international standard forms the basis for international laboratory accreditation. For those manufacturers and test engineers wanting further information on the subject, it is suggested that EA-4/02 [19] (European co-operation for Accreditation): Expression of the Uncertainty of Measurement in Calibration is a starting document with further information available in the document listed in the bibliography of the present document.

ETSI has produced substantial reports on the subject in TR 102 273 [3] to [10] and it is not intended to reproduce the information here.

5 Application of expanded measurement uncertainty to specification limits

5.1 Introduction

ETSI developed an interpretation for the application of expanded measurement uncertainty when assessing compliance to specification limits from the outset of producing standards for radio products in 1991 (see annex A). This interpretation only related to the measured value. If the measured value complies with the limit, the equipment is deemed to meet the requirement of the relevant standard. However, the test laboratory did not make the decision. The testing was subject to third party mandatory testing (which still exists in many countries around the world) and the National Regulatory Authorities (NRA) made the decision as to compliance to the standard. The test laboratory was required to declare their expanded measurement uncertainty as part of the Accreditation process to carry out the testing on behalf of the NRA.

This assessment was declared as "shared risk" between the manufacturer and the NRA. The manufacturer accepted the risk that the product may exceed the limit specified in the standard, and the NRA accepted the risk that the product equalled or was below the limit specified in the relevant conformance standard.

The name "shared risk" originates in the fact that for test results near the limit the risk of making the wrong decision is shared equally between the consumer and the manufacturer. On one end it is possible that a perfectly conforming product is rejected. On the other hand it is possible that a totally not-conforming product passes. Shared risk could be seen as opposed to Worst Case.

This situation was acceptable to all parties, particularly to the test laboratories who had to declare their expanded measurement uncertainty but did not have to judge whether a product conformed to the limits set in the standard; the NRA carried out this function.

5.2 Development of the "shared risk" concept

As a consequence of deregulation under the R&TTE Directive [11] mandatory type testing is no longer required. The method for compliance is normally by self-certification provided the standard used is a harmonized standard published under the requirements of the Directive. This implies that the manufacturer now declares his compliance to the harmonized standard, and not the NRA as before. Therefore the contract between external laboratories (when they are used) and manufacturers is now different. The manufacturer shall state with confidence that his product meets the specification, whilst the test laboratory only states his measurement with an expanded measurement uncertainty in a report.

ETSI harmonized standards contain essential test suites, limit values and required expanded measurement uncertainty values. The "shared risk" approach is used to interpret the test results.

The required expanded measurement uncertainty value is part of the "shared risk" concept. It is needed to avoid too large extremes in these "wrong conclusions". In ETSI the required expanded measurement uncertainty is defined for a 95 % confidence interval.

A number of expert bodies have therefore developed refinements on the original "shared risk" concept to assist manufacturers and test laboratories in reaching a compliance/non compliance assessment against limits given in product standards. The new "shared risk" concept has developed somewhat differently in differing organizations. In the UK the LAB34 [12] document from the United Kingdom Accreditation Service (UKAS), detailing "The Expression of Uncertainty in EMC Testing" provides a modified test approach when assessing against a specification limit. CISPR 16-4 [13] gives insight into what to do if the test laboratory expanded measurement uncertainty exceeds the maximum acceptable expanded measurement uncertainty given in the relevant product standard.

ETSI, in the meantime, is reviewing the "shared risk" issues within the present document. To have "shared risk" implies that the risks are shared by a minimum of two parties. In the old regime of mandatory type testing the two parties were the NRAs and the manufacturer. Today there are no NRAs involved in the compliance assessment under the R&TTE Directive [11]. It is assumed that the manufacturers who self certify compliance would therefore wish to share the risk of compliance/non-compliance with the test laboratory when measurements are close to the limit and within the limits of expanded measurement uncertainty declared by the test laboratory.

Where a manufacturer carries out testing for compliance within their own test facility there is no second party to share the risk of compliance/non-compliance with - they themselves have to share the risk between their own test facility and the quality organization making the declaration of compliance.

In the absence of harmonized standards, or the use of other means allowed under the R&TTE directive to prove compliance, there are now two parties involved, the manufacturer and a Notified Body. Under this regime the notified bodies decide if a product meets or does not meet the essential requirements of the Directive [11]. It is therefore possible to use the "shared risk" approach in this assessment.

When a product has a complaint made against it that it is causing interference to radio services, the "shared risk" approach can still be used providing of course that the National Authorities accept the concept.

In those countries where third party testing is still the normal assessment of products then the old methods of "shared risk" are still valid.

5.3 Shared risk, the new approach

Taking all the current documentation on the issue into account, it is reasonable to redefine the shared risk approach to cover the new situations of deregulation as follows:

1) all standards where measurements are made for compliance testing shall include maximum acceptable expanded measurement uncertainty values for each test;

2) guidance shall be given on assessing the measurements against defined limits in the standard when the measured value is close to the limit;

3) in the case where laboratory expanded measurement uncertainty is greater than the maximum acceptable expanded measurement uncertainty stated in the standard, guidance shall be given on assessing compliance to standard limits.

This approach combines the current documented solutions in CISPR [13] and [14], ETSI [1] and [2], ISO/IEC, UKAS, NIST, and others (latter ones, see bibliography).

5.3.1 Maximum acceptable expanded measurement uncertainty

In most ETSI radio equipment standards a table of maximum acceptable expanded measurement uncertainty is included as a normative requirement. The table generally contains a list of the required measurement methods and their associated expanded measurement uncertainty.

The purpose of the table is to ensure that the expanded measurement uncertainty is controlled and that a wide variation of measured results between test laboratories is minimized. This approach also assists the process of laboratory accreditation for testing to the standard.

In discussion with test laboratories, they indicated that it would be extremely useful to associate directly the specification limit given in the standard with the required maximum allowable expanded measurement uncertainty for the measured value.

As frequency ranges increase it may be difficult to conclude a maximum allowable value for the expanded measurement uncertainty due to lack of knowledge of the new methods of test and determining the uncertainty components:

- The commercially available calibration capability is limited to around 66 GHz. Thus no such possibility is freely available on the market above that limit. As a consequence measurement results above 66 GHz of different labs are not fully comparable since the equipment will not be calibrated for the needed operational range and also for radiated unwanted emission measurements above the operational range.
- The expanded measurement uncertainty of measurements in the range between 66 GHz and 100 GHz will be clearly above the values valid for below 66 GHz. Precise values of expanded measurement uncertainty require calibration, and there are limitations as mentioned above.
- In general it has to be mentioned that these values become the higher the frequency will become the more a guideline.
- Starting from around 66 GHz the limits of coaxial systems are reached and the frontend has to switch to wave guide based technologies adding an additional attenuation and also decreasing the sensitivity. Commercially available analyzers can only measure up to around 66 GHz, thus making the use of external mixers unavoidable.

5.3.2 Guidance on compliance assessment when expanded measurement uncertainty is equal to or less than maximum acceptable expanded uncertainty

The interpretation of the results when comparing expanded measurement values with specification limits should be as follows:

a) When the measured value does not exceed the limit value the equipment under test meets the requirements of the standard.

b) When the measured value exceeds the limit value the equipment under test does not meet the requirements of the standard.

c) The expanded measurement uncertainty calculated by the test technician carrying out the measurement shall be recorded in the test report.

d) The expanded measurement uncertainty calculated by the test technician may be an expanded maximum value for a range of values of measurement, or may be the expanded measurement uncertainty for the specific measurement untaken. The method used shall always be recorded in the test report.

The method is not suitable for compliance tests on mass production devices. Testing only one device gives normally no clue whatsoever on the actual probability distribution of the mass production. However, this could be solved by testing more than one sample in the case of mass production devices and defining a pass/fail criterion that corresponds with that type of assessment. The advantage for the manufacturer of such products could be that - by proving the standard deviation of his production process is low - his products could be allowed a higher mean value. This can be easily motivated by comparing the number of devices that supersedes the limit with the amount that supersedes the limit in the "shared risk".

5.3.3 Strength and weaknesses of the "shared risk" approach

The strength of the concept is its simplicity. Apart from the measurement uncertainty calculations no statistical calculations have to be performed after the test.

However, there are a couple of weaknesses:

- The shared risk approach allows a substantial percentage of the products that go over the limit in reality, to pass the test. This statistical effect is not accounted for in the compatibility studies and associated SEAMCAT simulations performed by the CEPT (ECC Working Group on Spectrum Engineering - WGSE). It is therefore essential to inherently apply a high enough confidence level to minimize the potential impact on spectrum compatibility considerations.

- The required expanded measurement uncertainty value shall represent the state of the art - with some allowance to achieve a fair balance between cost and quality - and should be revised from time to time. When new measurement techniques or new frequency ranges come into use, this review has to take place. In practice this review is not done or not done often enough.

5.4 Assessment for market surveillance and enforcement

5.4.1 Market surveillance

For the purposes of market surveillance it is suggested that the interpretation of results should follow that given in clauses 5.3.2 and 5.3.3 using the test methods given in the relevant standard. The testing laboratory shall be competent in accordance with ISO/IEC 17025:2005 [15] and be formally accredited to carry out the relevant tests given in the appropriate standard.

5.4.2 Enforcement

Enforcement of the limits given in the relevant standard, when market surveillance indicates that a product exceeds the relevant limit, is the responsibility of the individual National Regulatory Authority as provided for in EU Directives.

5.5 Interpretation of EMF test results in CENELEC standards

The following approach has been accepted by CENELEC voting procedures and published in EN 62311:2008 [16], clause 6.

"The equipment is deemed to fulfil the requirements of the present document if the measured values are less than or equal to the limit and the assessment uncertainty is less than the measurement uncertainty of the applied assessment method(s)."

This statement implies that for the case of EMF testing the guidance given in clause 5.3.2 is valid.

6 Void

7 The role of calibration in measurement uncertainty

7.1 Introduction to calibration

To determine the "quality" of any part of a test system it is necessary to place a tolerance on the extreme measurement uncertainty applicable to the test equipment measurement capability. This is achieved via traceable reference standards that are of a higher quality than that of the test equipment being examined.

Traceability is achieved by using primary reference standards held by National Metrology Laboratories to calibrate secondary reference standards that are then used to calibrate general-purpose test equipment. Primary reference standards are manufactured to the highest quality, are never used to make measurements, and comparisons are made on a regular basis between the metrology laboratories to further refine the measurement uncertainty when comparing secondary standards to the primary reference standards.

Test equipment used for EMC and radio testing is considered as general-purpose test equipment that has been calibrated to secondary reference standards. From this calibration, systematic errors can be determined (providing correction factors to be applied to a measurand) and the contribution to overall expanded measurement uncertainty (from the measurement uncertainty declarations made by the calibration laboratory).

The following clauses address the calibration requirements for the various components of the overall test systems used to measure radiated RF fields.

Calibration of test equipment is normally carried out at a specific temperature e.g. 20°C, and therefore care should be taken to maintain the actual temperature when used to make formal measurements. Equipment used for calibration purposes is normally maintained in a controlled environment. When calculating measurement uncertainty the variation of temperature shall be taken into account.

7.2 Test site calibration

RF field strength measurements both for EMC and radio parameters are normally performed on an Open Area Test Site (OATS) that have a clear and level terrain. Such sites are clear of buildings, electric cables, fences, trees and underground pipes and are only supplied with the necessary cabling to support the operation of the equipment under test, and the connections for making the necessary measurements. Specific instructions for the construction of an OATS can be found in CISPR 16-1 [14] for sites operating over the frequency range 30 MHz to 1 GHz. It shall be noted that for both EMC and radio parameter testing a ground plane is required.

For testing above 1 GHz the OATS can be used subject to suitable calibration performance, and alternative test sites may be used. Current documentation only provides information to 18 GHz and does not cover the necessary performance of such a site above 1 GHz.

Research by a number of alternative site manufacturers has shown that testing can be carried out to 40 GHz with improved performance over the OATS. These alternative sites rely on semi-anechoic rooms, i.e. shielded rooms that have anechoic materials on the walls and ceiling whilst maintaining the ground plane.

The basis for the 4 dB acceptance criteria for site attenuation is given in CISPR 16-1 [14], annex L.

7.2.1 Calibration of OATS

The calibration of an OATS is given in CISPR 16-1 [14], clause 5.6. These procedures and acceptance criteria are currently only valid up to 1 GHz, but have been shown to also work up to 18 GHz with suitable modifications. For the purposes of the ETSI requirements it is specified to use the same test site validation procedures with the same 4 dB acceptance criteria until such time as an enhanced formal procedure is available from CISPR.

7.2.2 Calibration of semi-anechoic rooms

The calibration of semi-anechoic rooms (an alternative test site) is given in CISPR 16-1 [14], clause 5.6.7 up to 1 GHz. This method has been used by the room manufacturers up to 40 GHz and the results have shown that above 3 GHz to 18 GHz the deviation of the site attenuation against the calculated theoretical value is less than 2 dB.

The method given in the reference above determines a volume of measurement area and the research shows that a quiet zone of 2,5 metres can be determined within the site attenuation limit of 4 dB.

Actual calibrations of semi-anechoic rooms show that the deviation from calculated theoretical values of site attenuation from 20 GHz to 40 GHz is 2,5 dB.

7.2.3 Calibration of fully lined anechoic rooms

The calibration of fully lined anechoic rooms has not been formally defined in standards. It is well known that there is a difference of a few dBs when comparing this form of test site with test sites having a ground plane. The difference varies between 3 dB and 6 dB. In the absence of formal international measurement methods for the calibration of fully lined anechoic rooms. TS 102 321 [17] provides the methods for validating an anechoic chamber up to 40 GHz to support the needs of radio testing.

7.2.4 Calibration and minimum requirements for test sites for measurements above 18 GHz

Generally the test site shall be adequate to allow for testing in the far field of the EUT. The test site should therefore consist of an electromagnetic anechoic room where either at least the ground surface is covered with radio absorbing material or up to six surrounding surfaces are covered with radio absorbing material. The absorbing material shall have a minimum attenuation of 30 dB. It shall be verified that reflections are sufficiently reduced. The test site minimum requirements are described in TS 103 052 [20].

Highly directional receiving antennas help in reducing reflections. The use of standard gain horn antennas is recommended. It shall be noted that if the antenna aperture is smaller than the EUT, sufficient measurements in both azimuth and elevation shall be conducted in order to ensure that the maximum radiation is determined.

Due to high loss of coaxial cables at higher frequencies, the connection from the receiving antenna to the measuring receiver should not exceed 1 m, thus making it necessary to place the measuring receiver very close. This is especially the case when using external harmonic mixers with very short connections to the measuring receiver. Therefore the measuring receiver should somehow be covered with radio absorbing material in direction to the measuring field in order to reduce reflections. Figure 1 shows an example of a test site above 18 GHz with one reflecting surface.

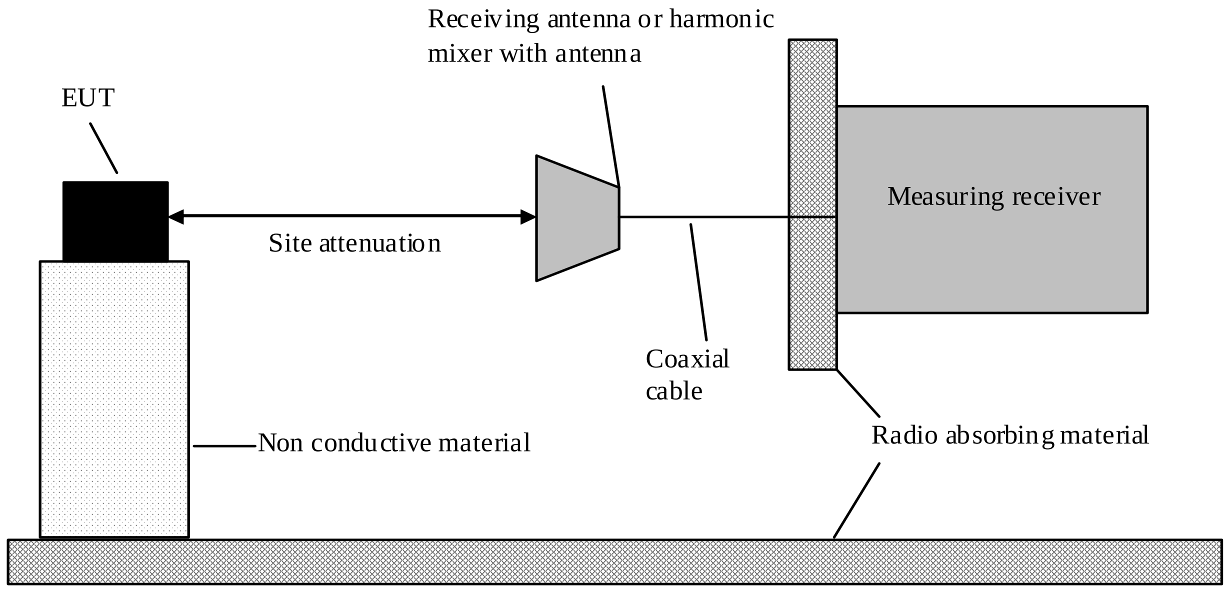


Figure 1: Example of a test site above 18 GHz with one reflecting surface

For calibration purposes, the site attenuation of the test site can be determined. Should the test site in its characteristics be nearly ideal, it may be possible to use the theoretical Free Space Loss (FSL) as site attenuation.

Table 1: Example of Free Space Loss at 1 m distance

Measuring distance/m	f/GHz	λ/1 m	[FSL]/dB
1	24,2	0,012397	60,12
	48,4	0,006198	66,14
	72,6	0,004132	69,66
	96,8	0,003099	72,16

Table 2: Example of Free Space Loss at 0,5 m distance

Measuring distance/m	f/GHz	λ/1 m	[FSL]/dB
0,5	24,2	0,012397	54,1
	48,4	0,006198	60,12
	72,6	0,004132	63,64
	96,8	0,003099	66,14

Table 3: Example of Free Space Loss at 0,25 m distance

Measuring distance/m	f/GHz	λ/1 m	[FSL]/dB
0,25	72,6	0,004132	57,62
	96,8	0,003099	60,12

Whereas:

$$\lambda = c/f$$

$$[FSL] = 10 \log (4\pi r/\lambda)^2$$

7.3 Antenna calibration

Antenna calibration is used to determine the antenna factors applied as correction factors to measurements. A calibration test site can be constructed similar to the OATS.

For antennae used above 1 GHz it is usual to have these calibrated by an independent calibration laboratory. Traceable calibration of antenna factors or antenna gain is available up to 100 GHz, for horizontal and vertical polarization, and at various measurement heights.

For antennae that have been calibrated for positive gain, i.e. directional antennae, it is important to also have the 3 dB beamwidth information to ensure that the antennae are correctly bore sight aligned when making measurements.

7.4 Test equipment calibration

In the introduction given in clause 7.1 the traceability route for calibration purposes is described. Calibration laboratories follow very strict rules for each measurement parameter they declare in their published capability documents. This allows clients seeking calibration services to evaluate the laboratories' capability and select the level of measurement uncertainty that they may require which is fit for the purpose of the test equipment calibration. *Smaller* measurement uncertainty value given by the calibration laboratory generally implies greater cost.

The calibration laboratory selected will provide a calibration certificate which gives the measured value of the parameter tested with a statement of measurement uncertainty. From this certificate it is possible to determine any systematic errors to be used as a correction factor for measurements made with the test instrument. The declared measurement uncertainty on the certificate can be used as a contribution to the overall measurement uncertainty calculations declared by the test engineer in his test report.

Calibration of this nature is normally carried out at regular intervals e.g. yearly, six monthly, quarterly.

Some test equipment also has inbuilt calibration procedures defined by the manufacturer. These are normally carried out at power on and thereafter on a daily basis and this internal calibration is used to maintain the short-term quality of the calibration carried out by calibration laboratories.

In the same way as test laboratories have to maintain and declare their measurement uncertainties so calibration laboratories are required to do the same.

In researching the capabilities of independent calibration laboratories, providing calibration to industry, the upper limit of frequency capability is currently set at 100 GHz. Above this frequency calibration may be provided by test equipment manufacturers.

For the purposes of the present document the upper limit of frequency has been set at 100 GHz.

7.5 Automated test system calibration

Automated test systems, inclusive of computer controllers, can be very complex particularly when used to carry out protocol testing that relies on the use of a radio channel via integral antennae. The providers of such test systems have the responsibility to define the necessary calibration requirements. The present document does not evaluate such systems for calibration nor for their measurement uncertainty contributions. This subject area is for further study.

8 Recommended maximum expanded measurement uncertainties for RF electromagnetic field measurements

8.1 Introduction

The following radio radiated measurement methods have been evaluated and the following clauses indicate the specified values of maximum frequency and maximum allowable expanded measurement uncertainty.

8.2 Substitution measurement methods

8.2.1 Frequency Error and Frequency Drift

For equipment with analogue modulation it is easy the switch-off the modulation and measure the frequency directly with a frequency counter/meter. Therefore, if the modulation can be switched-off, this is the normal method used to measure the frequency error while the equipment is under normal and extreme conditions (extreme voltages and temperatures). This has been implemented in a number of Harmonized Standards. It can be expected that the expanded measurement uncertainties relating to such measurement are very low.

In the case of digital modulated equipment it is not necessarily possible to switch-off the modulation. An example is a wideband direct sequence modulation or similar. In this case the frequency error is measured indirectly by measuring the drift of the transmitter spectrum mask, e.g. determining the drift of a certain attenuated point on the slope of the transmitter sideband (spectrum mask) or simply to determine if the spectrum mask attenuation is within the limit boundaries. It can be expected that the expanded measurement uncertainties relating to such measurement are by far, worse than those associated with approach before measuring the frequency error, for the simple reason that the modulation will generally have an effect on the spectrum mask.

Equipment may be using a high stability temperature compensated crystal oscillators (TCXO) and therefore the requirements are easily met. There are also techniques where the receiver is locked to the transmitter to minimize the error between the transmitter and the receiver (Automatic Frequency Control, AFC).

There is special equipment where the equipment is phase locked to an external frequency source e.g. a high power transmitter with a very stable frequency controlled by an atomic clock. This technique is often used for high power broadcast transmitters. In this case, if the requirements relating to frequency are felt necessary, they may relate to the locking mechanism, i.e. the time necessary to lock, and/or to more general precautions, such as impossibility of transmission unless the system is locked.

There is always a need for a frequency error requirement in standards. The limit and the principle of the related expanded measurement necessary to meet the essential requirement in relation to frequency error are depending on the actual system and the technical solution. The value in the present document however is stated for a frequency error that is measured with an unmodulated carrier. If the equipment is not capable of producing an unmodulated carrier, then it is recommended to measure instead the adjacent channel power (i.e. an e.r.p. or e.i.r.p. measurement) under extreme test conditions to ensure the equipment is operating inside the assigned frequency band.

Table 4: Frequency Error - Maximum expanded measurement uncertainty

	Maximum expanded measurement uncertainty
Operating radio Frequency	1×10^{-7}

8.2.2 Effective radiated power (e.r.p.) and equivalent isotropically radiated power (e.i.r.p.)

Table 5 gives recommended values of the maximum acceptable expanded measurement uncertainty for measurement of e.r.p. and e.i.r.p.

Table 5: Recommended maximum acceptable expanded measurement uncertainty

Parameter	Frequency range	Recommended maximum acceptable expanded uncertainty
e.r.p.	25 MHz to 1 GHz	4 dB
e.i.r.p.	1 GHz to 2,5 GHz	6 dB
	2,5 GHz to 3,5 GHz	6 dB
	3,5 GHz to 6 GHz	6 dB
	6 GHz to 10,5 GHz	6 dB
	10,5 GHz to 40 GHz	6 dB
	40 GHz to 66 GHz	8 dB
NOTE: These values are typical and are subject to periodic review.		

If an emission from an application covers more than one frequency range, the uncertainty from the highest frequency segment may be used.

8.2.2.1 Measurements in the frequency range above 66 GHz (e.i.r.p.)

The maximum expanded measurement uncertainty depends very much on the measurement capability of "standard" testing equipment.

"Standard" measurement equipment is only available up to a frequency range of around 66 GHz with a sensitivity of -72 dBm at 18 GHz down to around -64 dBm at 40 GHz (1 MHz RBW, 3 MHz VBW, 100 MHz span). For higher frequencies the sensitivity will further decrease.

However, thanks to the use of a low noise amplifier this value could be improved by up to 25 dB, having in mind the added general performance reduction.

The commercially available calibration capability is limited to around 66 GHz. Thus no such possibility is freely available on the market above that limit. As a consequence measurement results above 66 GHz of different labs are not fully comparable since the equipment will not be calibrated for the needed operational range.

The maximum expanded measurement uncertainty of measurements in the range above 66 GHz (millimetre domain) will be clearly above the initially assumed 6 dB for radiated measurements below 66 GHz. A value of 10 dB or even larger seems to be more adequate. Precise values of measurement uncertainty require calibration, and there are limitations as mentioned on above.

Setting a much higher value for the required expanded measurement uncertainty above 66 GHz seems reasonable today, but the same value may be considered far too wide 5 years to 10 years in the future.

In particular the ability of measuring the unwanted emissions in the spurious domain is limited. Measurements above 66 GHz need also to take into account for radiated measurements that reference to limits is normally given to equipment with 0 dBi antenna gain.

Achieved sensitivity and maximum expanded measurement uncertainty are a direct result of the chosen test suites, test-jigs, and the choice between radiated and conducted measurements. The values mentioned together with the concerns should therefore be considered illustrational rather than absolute, given the absence of the relevant information.

In general it has to be mentioned that the higher the frequency becomes, the more the ETSI standard(s) become(s) some kind of a guideline.

Further investigations and discussions within ETSI with interested parties during the development of standards for equipment operating above 40 GHz may lead to more consolidated findings.

Standard measurement equipment such as spectrum analyzers also show some other effects regarding measurements in the EHF frequency range compared to measurements performed with oscilloscopes or other real-time measurement analyzers:

- The displayed measurement value is normally under-evaluated by the device. This effect can be minimized by choosing the maximum possible resolution bandwidth that is available for a particular modulation technique. For impulsed techniques, current analyzers can perform measurements with a resolution bandwidth of up to 25 MHz.

- For more complex modulation schemes, it is important to exactly know the details of the modulation since the exact measurement equipment settings greatly affect the measurement value and related maximum expanded measurement uncertainty. Examples are the exact pulse bandwidth, exact FH or FMCW parameters to ensure measurement at the right frequency at the right time (this is important for averaging). Otherwise, measurements performed at different labs will not really be comparable. More information about the parameters which need exact description can be found in annex E.

If the Measuring Receiver is capable of measuring the signals directly without any down mixing, a fundamental or harmonic Mixer adding additional measurement uncertainty can be omitted. Currently, it is unavoidable to perform measurements above 66 GHz with mixers. The measuring receiver may be a spectrum analyser, oscilloscope, selective power meter or any measuring receiver which is appropriate to perform the intended measurement.

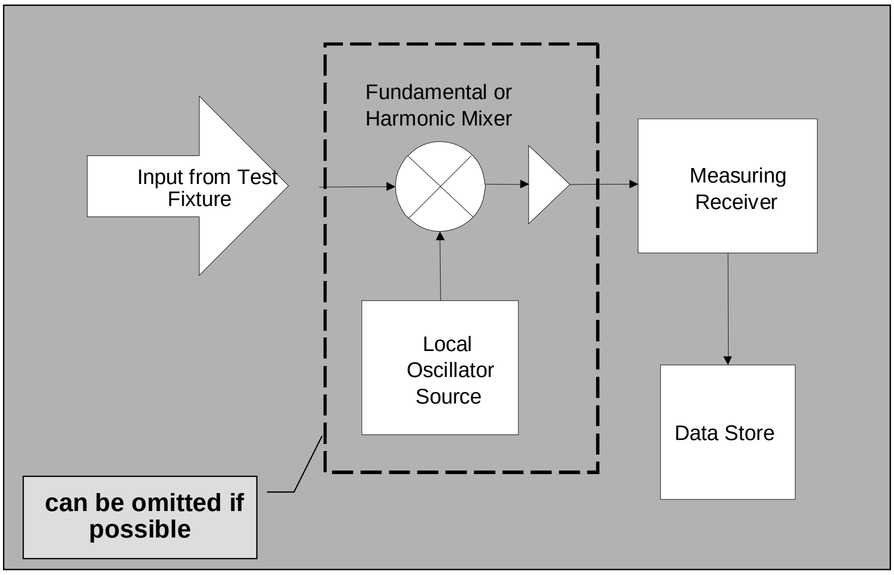


Figure 2: Test equipment using a mixer for measuring emissions in the EHF frequency range

The use of special test fixtures may also be an option at higher frequencies. The calibration of the test fixture establishes the relationship between the detected output from the test fixture, and the transmitted power of the equipment under testing. This can be achieved by using a calibrated horn with a gain of equal to or less than 20 dB, fed from an external signal source, in place of the EUT to determine the variations in detected power with temperature and over frequency.

The calibration of the test fixture is normally carried out by either the provider of the EUT or the accredited test laboratory. The results are to be approved by the accredited test laboratory.

The calibration should be carried out over the operating frequency band, at least three frequencies, for the declared polarization of the EUT.

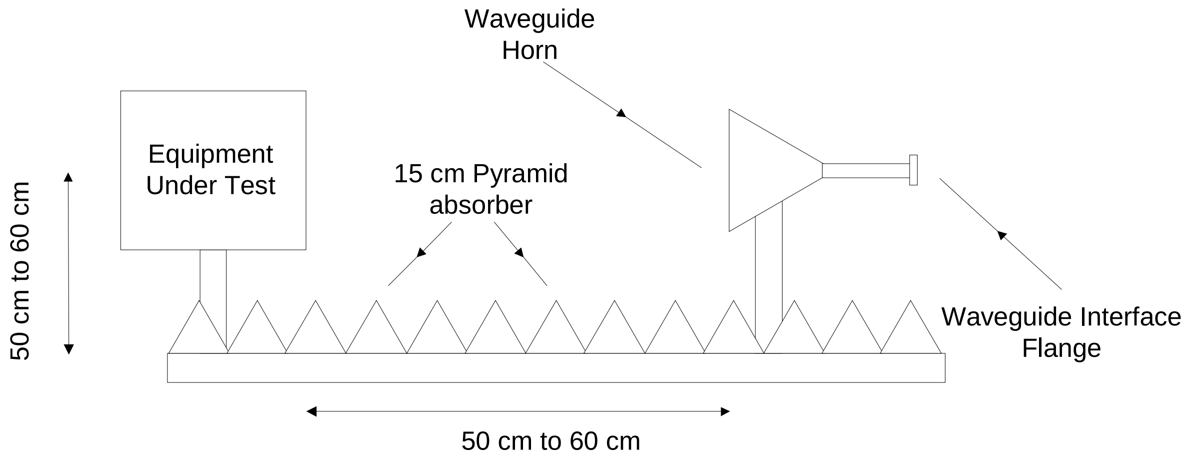


Figure 3: Example of a test fixture

The measuring distance shall be selected in such way that antenna coupling effects are avoided. A distance of at least 0,5 m is therefore recommended. The EUT may be positioned at any height that minimizes reflections from the floor.

All RF cables or waveguide interconnects, including their connectors at both ends, used within the measurement arrangements and set-ups shall adhere to the following minimum characteristics for EHF measurements:

- a VSWR of less than 1,5 at either end;
- a shielding loss in excess of 60 dB.

All RF cables and waveguide interconnects shall be routed suitably in order to reduce impacts on antenna radiation pattern, antenna gain, antenna impedance.

Maximum frequency = 100 GHz.

Maximum expanded measurement uncertainty = 10 dB (with mixer).

A list of standard for radio equipment operating at EHF frequencies being developed in ETSI or under development is given in annex F.

8.2.2.2 Conversion loss data and expanded measurement uncertainty for measurements above 66 GHz (e.i.r.p.)

Measurement system for use above 66 GHz is usually based on external harmonic mixers with some typical measurement uncertainty issues. The systems are described in TS 103 052 [20].

As frequency ranges increase it may be difficult to conclude a maximum allowable value for the expanded measurement uncertainty due to lack of knowledge of the new methods of test and determining the uncertainty components:

- The commercially available calibration capability is limited to around 66 GHz. Thus no such possibility is freely available on the market above that limit. As a consequence measurement results above 66 GHz of different labs are not fully comparable since the equipment will not be calibrated for the needed operational range and also for radiated unwanted emission measurements above the operational range.
- The expanded measurement uncertainty of measurements in the range between 66 GHz and 100 GHz will be clearly above the values valid for below 66 GHz. Precise values of expanded measurement uncertainty require calibration, and there are limitations as mentioned above.

- Starting from around 66 GHz the limits of coaxial systems are reached and the frontend has to switch to wave guide based technologies adding an additional attenuation and also decreasing the sensitivity. Commercially available analyzers can only measure up to around 67 GHz, thus making the use of external mixers unavoidable.

8.2.3 Radiated unwanted emissions in the spurious domain

8.2.3.1 Measurements in the frequency range between 30 MHz and 1 GHz (radiated)

Measurements shall be performed in the following frequency ranges.

Table 6: Measurement frequency ranges for spurious measurements below 1 GHz

Operating fundamental frequency range	Frequency range for measurements	
	Lower frequency	Upper frequency (The test should include the entire harmonic band and not be truncated at the precise upper frequency limit stated)
9 kHz to 100 MHz	30 MHz	up to 1 GHz
100 MHz to 300 MHz	30 MHz	10^{th} harmonic
300 MHz to 600 MHz	30 MHz	3 GHz
600 MHz to 1 000 MHz	30 MHz	5^{th} harmonic

- Maximum frequency = 1 GHz.
- Maximum expanded measurement uncertainty = 4 dB.

For the calculation of this value see annexes B and C.

This value is dependent upon the maximum dimension of the equipment under test upon the test site.

8.2.3.2 Measurements in the frequency range between 1 GHz and 66 GHz (radiated)

Measurements shall be performed in the following frequency ranges:

Table 7: Measurement frequency ranges for spurious measurements from 1 GHz to 66 GHz

Operating fundamental frequency range	Frequency range for measurements	
	Lower frequency	Upper frequency (The test should include the entire harmonic band and not be truncated at the precise upper frequency limit stated)
1 GHz to 5,2 GHz	30 MHz	5^{th} harmonic
5,2 GHz to 13 GHz	30 MHz	26 GHz
13 GHz to 66 GHz	30 MHz	2^{nd} harmonic or up to 100 GHz

- Maximum frequency = 66 GHz.
- Maximum expanded measurement uncertainty = 6 dB (up to 40 GHz).
- Maximum expanded measurement uncertainty = 8 dB (40 GHz up to 66 GHz).

For the calculation of this value see annexes B and C.

This value is dependent upon the maximum dimension of the equipment under test upon the test site.

For frequencies above 40 GHz a down converter may be used. The local oscillator used to down convert the received signals should be stable and with a phase noise of better than -80 dBc/Hz at 100 kHz offset. The local oscillator frequency should be selected such that the down converted signal is within the accepted band of the spectrum analyser, and maintaining an adequate Intermediate Frequency (IF) bandwidth to capture the full spectrum of the signal. For these measurements it is strongly recommended to use a Low Noise Amplifier (LNA) before the SA input to achieve the required sensitivity.

8.2.3.3 Measurements in the frequency range above 66 GHz (radiated)

Measurements shall be performed in the following frequency ranges:

Table 8: Measurement frequency ranges for spurious measurements above 40 GHz up to 100 GHz

Fundamental frequency range	Frequency range for measurements	
	Lower frequency	**Upper frequency** (The test should include the entire harmonic band and not be truncated at the precise upper frequency limit stated)
40 GHz to 100 GHz	30 MHz	2nd harmonic
above 100 GHz	30 MHz	no measurements are recommended

It should be noted that the level of unwanted emissions for systems is not yet fully defined and to be used in bands above 60 GHz should take into account systems already using these bands. The level of spurious emissions of systems being defined should therefore be compatible with the sensitivity of existing systems and their protection criteria (and the effects, for example on their availability over time) should also be addressed. It is further noted that WRC 2011 Agenda item 1.8 (technical and regulatory issues relative to the fixed service in the bands between 71 GHz and 238 GHz) should be taken into account when considering the limits of spurious emission falling in those bands.

The conformance to the spurious emissions requirement may also be shown in a different way, on a case-by-case basis (e.g. with partial tests and/or technical descriptions based on the specific implementation).

A list of standard for radio equipment operating at EHF frequencies being developed or under development is given in annex G.

- Maximum frequency = 100 GHz.
- Maximum expanded measurement uncertainty = 10 dB (with mixer).

NOTE: No maximum expanded measurement uncertainty level is provided in the present document for measurements above 100 GHz.

Currently, it is unavoidable to perform measurements above 66 GHz with mixers.

For the calculation of this value see annexes B and C.

This value is dependent upon the maximum dimension of the equipment under test upon the test site. Measurements above 66 GHz need also to take into account for radiated measurements that reference to limits is normally given to equipment with 0 dBi antenna gain.

For frequencies above 40 GHz a down converter may be used. The local oscillator used to down convert the received signals should be stable and with a phase noise of better than -80 dBc/Hz at 100 kHz offset. The local oscillator frequency should be selected such that the down converted signal is within the accepted band of the spectrum analyser, and maintaining an adequate Intermediate Frequency (IF) bandwidth to capture the full spectrum of the signal. For these measurements it is strongly recommended to use a Low Noise Amplifier (LNA) before the SA input to achieve the required sensitivity.

8.2.4 Low power radio wanted emission measurements (radiated)

There are practical limitations on measurements of RF radiated emissions. The minimum radiated levels that can be practically measured in the lower GHz frequency range by using a radiated measurement setup with a horn antenna and pre-amplifier are typically in the range of about -70 dBm/MHz to -75 dBm/MHz (e.i.r.p) to have sufficient confidence in the measured result (i.e. low emission signal level should be at least 6 dB above the noise floor of the spectrum analyser and the measurement is performed under far-field conditions).

Low power radio signals can be comparable with the power of spurious emissions from digital and analogue circuitry. If it can be clearly demonstrated that an emission from the low power device is not the wanted emission identified when using the appropriate test procedure (e.g. by disabling the device's low power transmitter) or it can clearly be demonstrated that it is impossible to differentiate between unwanted emission in the spurious domain and the low power wanted transmitter emissions , that emission or aggregated emissions should considered against the receiver spurious emissions limits (i.e. radiated power maximum expanded measurements uncertainty applies).

8.2.5 Radiated transient power

Transient power is the power falling into adjacent spectrum due to switching the transmitter on and off during normal operation (e.g. cyclic keying during data transmission). In general, one should observe that the limit values for the modulation bandwidth are fulfilled irrespective of the transient power limit values.

The modulation test signal (see clause 6.1) is applied at the transmitter. For constant envelope modulation schemes it is not required to apply modulation. The modulation used, if any, is recorded in the test report.

The radiated measurements of the transient powers are normally carried out using the method that is also used in CISPR 16-1 [14]. Alternatively to a measurement receiver a spectrum analyser can be employed. It provides a quasi-peak detector and is operated in time domain mode (Zero Span).

The exact measurement settings depend very much on the specific case such as the RBW, the center frequency of the measuring receiver is set at a certain offset frequency above the beginning of the upper adjacent channel and below the beginning of the lower adjacent channel.

The measurement procedure normally incorporates two measurement steps and is as follows:

STEP 1:

The transmitter is operated with powering on and off (e.g. by switching between active and standby state) at least n times within a specified period.

If the resulting maximum radiated power level in this step is above the spurious domain limit, the second measurement step is then performed.

STEP 2:

In the second measurement, the procedure is repeated with the same settings of the measuring receiver, whereas the transmitter is set on continuous transmission.

The measured radiated power level is also recorded for the same time period as in step 1 with the measurement receiver setting above and below the wanted channel as in step 1.

Measurement step 1 is also repeated within the spectrum mask every specified RBW step from the primarily adjusted point to both sides of the wanted frequencies, until either it is clearly ascertained that no power increases or limit exceeding appear, or until a maximum frequency offset is reached.

Table 9: Radiated transient power measurements - maximum expanded measurements uncertainty

Measurement frequencies	Transient power maximum expanded measurement uncertainty
30 MHz to 1 GHz	4 dB
1 GHz to 40 GHz	6 dB
40 GHz to 66 GHz	8 dB
66 GHz to 100 GHz	10 dB (with mixer)

8.2.6 Receiver sensitivity (radio)

The average usable sensitivity of a receiver is the average field strength at the antenna, expressed in dBμV/m, produced by a carrier at the nominal frequency of the receiver, modulated with the normal test signal which produces:

- a specified SND/ND ratio (analogue), or
- after demodulation, a data signal with a specified error ratio; or
- after demodulation, a specified message acceptance ratio.

The average, E_{mean}, is calculated from n measurements of field strength, where the receiver is rotated in increments, starting at an arbitrary orientation.

$$E_{mean} = 20\log_{10}\sqrt{\frac{n}{\sum_{i=1}^{i=n}\frac{1}{x_i^2}}}$$

Where x_i represents the eight field strengths in μV/m.

- A value of 8 (i.e. 45° increments) is specified for n.
- Maximum frequency = 100 GHz.
- Maximum expanded measurement uncertainty = 6 dB.

For the calculation of this value see annex B.

The values above are independent from the fundamental frequency range of operation although the physical size of the antenna may have a significant impact on measurement uncertainty.

8.2.7 Receiver 2-signal or multiple signal measurements (radiated)

Radiated 2-signal or multiple signal measurements on the receiving side of radio equipment are performed on equipment not having a connector for performing conducted measurements.

The relevant receiver parameters are:

- The adjacent channel selectivity which is a measure of the capability of the receiver to operate satisfactorily in the presence of an unwanted signal, which differs in frequency from the wanted signal by an amount equal to the adjacent channel separation for which the equipment is intended. This can even be extended to measure the receiver saturation which is a measure of the capability of the receiver to operate as intended in the presence of a strong signal in the wanted channel together with a strong signal in the adjacent channel, which differs in frequency from the wanted signal by an amount equal to the adjacent channel separation for which the equipment is declared.
- The blocking (or desensitization) capability of a receiver which is a measure of the capability of the receiver to receive a wanted modulated signal without exceeding a given degradation due to the presence of an unwanted input signal at any frequencies other than those of the spurious responses or the adjacent channels or bands.
- The receiver spurious response rejection which is a measure of the capability of the receiver to receive a wanted modulated signal without exceeding a given degradation due to the presence of an unwanted modulated signal at any other frequency, at which a response is obtained.

The signal generator A (wanted signal) and B (unwanted signal) together with a combiner and a TX test antenna are placed in the location of the turntable in correspondence with the EUT's antenna polarisation. The EUT is placed in location of the receiver test antenna at the orientation of the most sensitive position and the equipment under test is set to the specified sensitivity limit plus an additional defined level in dB above.

NOTE: Signal generator B can be further split to 2 unwanted signals to represent specific spectrum requirements from certain frequency or application environments as well as reducing the maximum expanded measurement uncertainty.

Table 10: Receiver 2-signal or 3-signal measurements - maximum expanded measurement uncertainty

Measurement frequencies	2-signal maximum expanded measurement uncertainty	3-signal maximum expanded measurement uncertainty
30 MHz to 1 GHz	4 dB	3 dB
1 GHz to 40 GHz	6 dB	4,5 dB
40 GHz to 66 GHz	8 dB (without mixer) 10 dB (with mixer)	6 dB (without mixer) 10 dB (with mixer)
66 GHz to 100 GHz	10 dB (with mixer)	10 dB (with mixer)

For the calculation of this value see annex B.

The physical size of antennae has a significant impact on measurement uncertainty.

8.3 Single measurement methods

8.3.1 Radiated emissions (EMC)

- Maximum frequency 18 GHz.
- Maximum expanded measurement uncertainty = 4 dB, valid up to 1 GHz.
- Maximum expanded measurement uncertainty = 6 dB, valid up to 18 GHz.

NOTE: EN 301 489-1 [18] only specifies EMC requirements up to 6 GHz.

The measurement distance is defined within the test method.

8.3.2 Radiated immunity (EMC)

- Maximum frequency 18 GHz.
- Maximum expanded measurement uncertainty = 4 dB , valid up to 1 GHz.
- Maximum expanded measurement uncertainty = 6 dB, valid up to 18 GHz.

The measurement distance is defined for a given radiated immunity field strength. As frequency increases different antennae may be used but shall be in the far field region.

9 Controlling measurement uncertainty

9.1 Introduction

This clause presents the specified processes and procedures to minimize the maximum expanded measurement uncertainty. The following subjects are covered:

- design and validation of appropriate test sites;
- quality of test methods given in standards;
- validation of test methods;
- test instrumentation; and
- documentation.

9.2 Void

9.3 Void

9.4 Void

9.5 Design and validation of appropriate test sites

Th reason for validation of a test site is to translate its physical properties and environmental conditions (e.g. potential interference) in an uncertainty associated with it.

The current ETSI radio testing standards usually define an Open Area Test Site (OATS) as being the accepted test facility and this type of site is also defined for EMC measurements. The ETSI radio standards generally provide the option of using alternative test sites including semi and fully anechoic chambers.

EMC testing standards are generally limited to a maximum test frequency of between 1 GHz and 3 GHz at defined test distances (3 metres or 10 metres). An OATS is perfectly acceptable to meet EMC objectives and thus ensuring interference capability when co-located with any other equipment in the same environment.

However the same cannot be said when considering the testing of radiated radio RF parameters. These parameters are tested to restrict the interference capability to other radio services. It has become common practice in recent years to specify the use of fully lined anechoic chambers within ETSI radio standards when test measurements are required above 1 GHz, thus providing a quiet RF environment for the testing.

When reviewing the ETSI test methods, and relating them to the appropriate regulatory requirements, radiated RF parameters are required to be made in the far field of the frequency under investigation. However the definition of "far field" is dependent upon the size of the equipment, the size of the receiving antenna and the frequency of the RF emission.

It is therefore recommended that standards should clearly state the type of test facilities that is to be used in relation to the frequency of measurement and the type of equipment under test. This also implies that the capability of test equipment to measure microwave frequencies in the far field has to be clearly understood by the standards developers.

Having clearly identified the type of test site within the appropriate standards the validation of the site is important to ensure that the maximum expanded measurement uncertainty of any measurements that are made on the site are under control (see clause 7).

9.6 Void

9.7 Validation of test methods

It is the responsibility of the test laboratory to validate non-standard methods, laboratory-designed/developed methods, standard methods used outside the intended scope, amplifications and modifications of standard methods to confirm that the methods are fit for the intended use and hence determine the measurement uncertainties associated with the test methods.

This validation is normally carried out using a number of different approaches:

1) comparison of repeated results;

2) comparison of results carried out using different test methods;

3) inter-comparisons with other test laboratories using standard test samples;

4) assessment of factors that can influence the result of the measurement; and

5) the assessment of the measurement uncertainty of the results using a scientific understanding of the test method and practical experience.

Item 1) is generally referred to as "measurement repeatability" and is used to judge the stability of a test set-up.

Item 2) is generally referred to as "measurement reproducibility" and is used to assess the quality of test methods by changing the method of measurement, the test engineer, the measurement equipment, test site, and time separation between tests.

Item 3) has been used successfully in the EMC environment but has been rarely used, if ever, within the radio parameter testing environment.

Items 4) and 5) are normal activities in determining the maximum expanded measurement uncertainty of a measurement, or series of measurements, as part of the general accreditation procedures of the test laboratory.

9.8 Test instrumentation

As the frequency range of radio testing develops into the higher microwave regions test methods become more complex and test equipment considerably more expensive to purchase as the number of equipment manufacturers is reduced. Test equipment capability can also exceed the ability to have traceability of calibration techniques. At the same time novel technologies are under development for which at the time of preparing standards test equipment is not yet available on the open market.

Standards makers should take great care that in specifying test methods for specific parameters that they do not define specific manufacturers' test equipment within the standards under their control. Advancing technologies often leaves the problem of testing to the test laboratories to solve and does nothing to assist the manufacturers' responsibility to regulators of the market. As a consequence, standards makers often stay with test methods they already know of from previous technologies and these test methods are often not applicable to the new technologies.

Test instrumentation in radio testing has been clearly defined by agreement between the manufacturers, the testing organizations, and the accreditation authorities by common practice. This arrangement has been suitable for test methods up to about 18 GHz, but as specific requirements advances towards 100 GHz to 200 GHz this situation changes dramatically.

The stability of test instrumentation has largely been driven by the development of test cables and connectors that provides the flexibility in carrying out the specific test procedures. In the 1980s this imposed a limitation of flexible testing to a frequency of 18 GHz above which it was necessary to change to waveguide techniques. Today cables and connectors are available to approximately 50 GHz, but traceable calibration at such frequencies is still limited to 40 GHz.

Equipment continues to evolve and standards writers may well be able to make use of improvements in equipment measurement uncertainty as time goes on.

9.9 Documentation

Test laboratories are required to maintain a considerable amount of documentation not limited to just the required test procedures.

To minimize the maximum expanded measurement uncertainty historical and current calibration data for all test equipment used for making the measurements is required to be maintained.

The control of technical reports and approval certificates is required to assist in any future evaluation that may be required by regulatory authorities. As deregulation has developed from a strict regulatory regime some demanded records are no longer being maintained due to the distinct lack of guidance on such issues within regulatory standards.

Testing standards are required to be maintained from a historical point of view and the latest edition of the testing standards has been easily available to all test personnel. This task is particularly onerous on the test laboratory as they are not always aware of new editions reaching the market from the standards organizations particularly when open public standards approval procedures are not used.

Further requirements can be found in ISO/IEC 17025:2005 [15].

Annex A (informative): History of the "shared risk" concept

The following clauses have been extracted from a sample of ETSI standards to show the current statements on interpretation of results. It can be seen that these statements vary between the documents and therefore should be aligned to avoid any confusion in their application.

A.1 Reporting and interpretation of the measurement results

When reporting the result of a measurement the following should be stated in the test report:

1) give full description of the measurement including the units of y and EMU where y is the measured value and EMU the value of the expanded measurement uncertainty;

2) give the value of the expansion factor k;

3) give the approximate level of confidence.

Interpretation of the results recorded in the test report for the measurements described in the present document should be as follows:

- the measured value y related to the corresponding limit shall be used to decide whether an equipment meets the requirements of the present document;

- the value of the expanded measurement uncertainty EMU for the measurement of each parameter shall be separately included in the test report;

- the value of the expanded measurement uncertainty EMU (for a 95 % confidence level), for each measurement, shall comply with the figures for maximum acceptable uncertainty in the relevant standard.

Table A.1: Examples for maximum acceptable expanded measurement uncertainty

Parameter	Maximum acceptable expanded uncertainty
RF frequency	1×10^{-7}
RF power, radiated, valid up to 1 GHz	4 dB
RF power, radiated, valid between 1 GHz and 40 GHz	6 dB
RF power, radiated, valid between 40 GHz and 66 GHz	8 dB
RF power, radiated, valid between 66 GHz and 100 GHz	10 dB
RF transient power, radiated, valid up to 1 GHz	4 dB
RF transient power, radiated, valid between 1 GHz and 40 GHz	6 dB
RF transient power, radiated, valid between 40 GHz and 66 GHz	8 dB
RF transient power, radiated, valid between 66 GHz and 100 GHz	10 dB
Two-signal measurements, radiated, valid up to 1 GHz	4 dB
Two-signal measurements, radiated, valid between 1 GHz and 40 GHz	6 dB
Two-signal measurements, radiated, valid between 40 GHz and 66 GHz	8 dB
Two-signal measurements, radiated, valid between 66 GHz and 100 GHz	10 dB
Time	2 %
Temperature	1 K
Humidity	5 %
Achieved sensitivity and measurement uncertainty are a direct result of the chosen test suites. The values mentioned together with the concerns should therefore be considered illustrational rather than absolute for measurements above 66 GHz, given the absence of some relevant information. For radiated emissions above 66 GHz the given measurement uncertainties are based on the assumption of the deployment of a cable based measurement set-up. In the cases of other measurement set-up (e.g. wave guides) it may not be possible to reduce measurement uncertainty to the levels specified in table A.1. For measurements above 100 GHz, the expanded measurement uncertainty shall also be recorded in the test report and a detailed calculation be added. A future revision of the present document may include a value for frequencies for expanded measurement uncertainty that is still under development.	

For the test methods, according to the present document the expanded measurement uncertainty figures should be calculated according to the methods described in TR 100 028 [1] and [2] and should include an expansion factor (coverage factor) k = 1,96 which provide a confidence level of respectively 95 % in cases where the distributions characterising the actual measurement uncertainties are normal (Gaussian)). Table A.1 is based on such expansion factors.

A confidence interval of 95 % is sought. An expansion factor of 1,96 is recommended.

The standard uncertainty of measurement has been determined in accordance with EAL Publication EA-4/02 [19].

NOTE: This procedure for using Maximum Acceptable Expanded Measurement Uncertainty values is valid until superseded by other appropriate publications of ETSI covering this subject.

The use of the measured value has been chosen because there is no other ETSI standard covering the subject at the time of publication of the present document. Therefore the expanded measurement uncertainty should be used as a quality of the actual measurement. Accreditation Authorities can also use the Expanded Measurement Uncertainty values during their accreditation procedures to ensure compliance/conformity with the requirements of type testing to ETSI standards. Figures A.1 and A.2 illustrate on how the interpretation takes place of the measurement result and also of the maximum expanded measurement uncertainty.

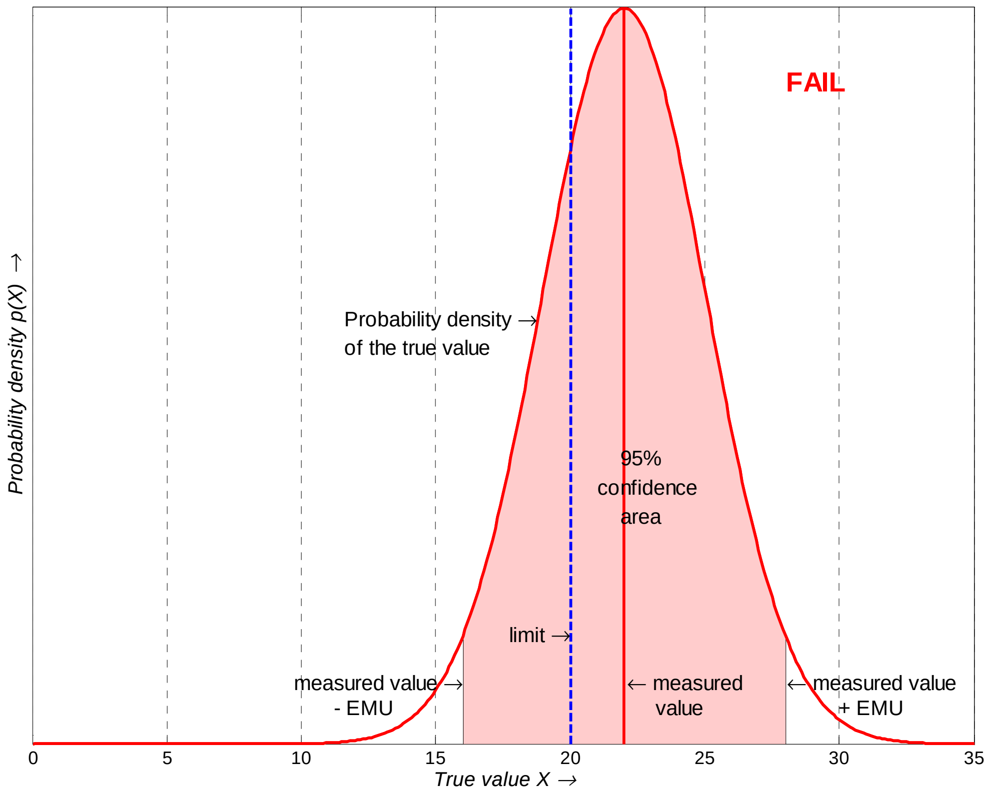


Figure A.1: Equipment does not meet the requirement

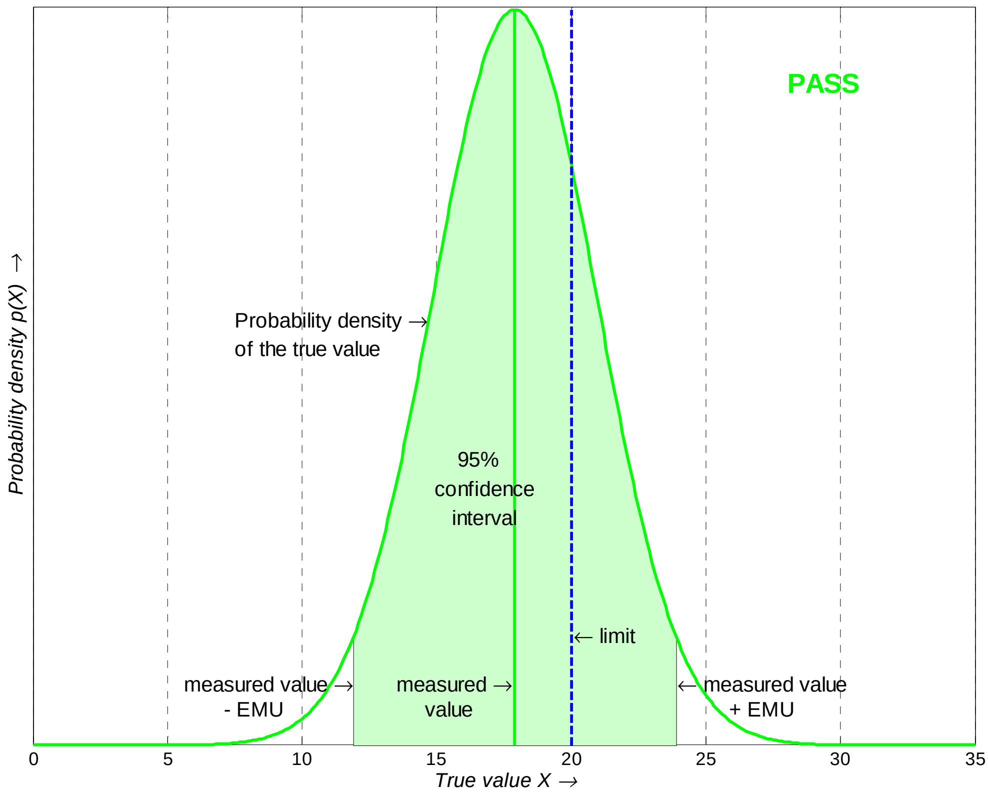


Figure A.2: Equipment meets the requirement

Annex B (informative): Examples of measurement uncertainty calculations

The examples in this annex are based on the substitution method and pre-substitution method as described in TS 103 052 [20]. The figures are not meant to be compulsory.

Measurement uncertainty can be determined according to TR 100 028 [1] and [2], TR 102 273 [3] to [10] and to the Guide to the expression of uncertainty in measurement [21] either using the type A evaluation as per clause 2.3.2 or using the type B evaluation as per clause 2.3.3. The full calculation method is not shown in the following tables for simplicity.

Unless otherwise stated, the values given for overall measurement uncertainty are calculated for a confidence level of 95 % in each example, considering the following expressions used to obtain standard uncertainty as described in IEC/TR 61000-1-6 Ed. 1.0 [22].

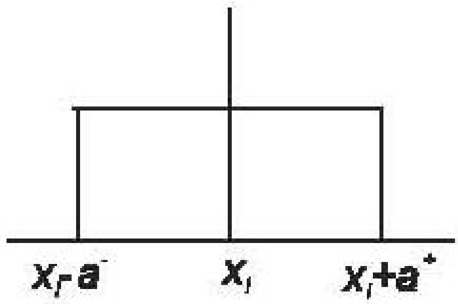


Figure B.1: Example for a rectangular PDF

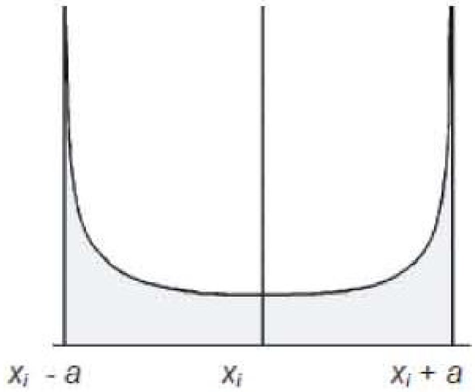


Figure B.2: Example for a u-shaped PDF

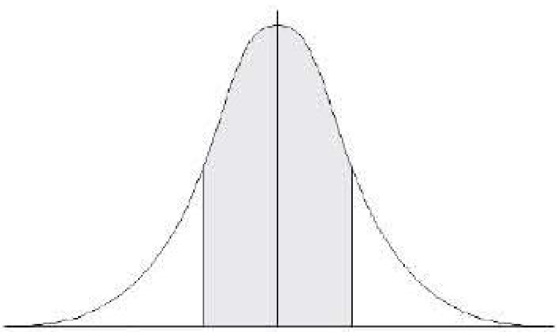


Figure B.3: Example for a normal PDF

B.1 Equivalent isotropically radiated power (e.i.r.p.) (Substitution method) anechoic room

Table B.1: Typical e.i.r.p. measurement uncertainty calculation with regard to the substitution method

Source of uncertainty	Value	Standard uncertainty (dB)	Comments
Stage 1: Site Factors			
Ambient effect	0,10 dB		With EUT switched off, receiver noise floor > 10 dB below the measured value.
Mutual coupling: test antenna to its images in the absorbing material	0,00	0,00	Substitution method.
Mutual coupling: test antenna to its images in the ground plane	0,00	0,00	Substitution method.
Test antenna			
Correction: measurement distance	0,00	0,00	Substitution method.
Correction: of bore sight angle in elevation plane	0,00	0,00	Substitution method.
Antenna: gain of the test antenna	0,00	0,00	Substitution method.
Antenna: tuning of the test antenna	0,00	0,00	Fixed broadband ridged guide antenna. Substitution method.
Position of the phase centre: test antenna	0,00	0,00	Substitution method.
Insertion loss: test antenna attenuator	0,00	0,00	Substitution method.
Insertion loss: test antenna cable	0,00	0,00	Substitution method.
Cable factor: test antenna cable	0,00	0,00	Substitution method.
Receiving device			
Receiving device: absolute level	0,00	0,00	Substitution method.
Receiving device: linearity	0,00	0,00	Substitution method.
Random uncertainty	0,00	0,00	This uncertainty is derived from repeated measurements of the equipment under test and is only important when the measured value is close to the specification limit.
Combined measurement uncertainty - Stage 1	$(0,47)^{0,5}$	0,69	
Stage two: Substitution measurement			
Mismatch uncertainty: transmitting parts and receiving parts		0,80	Signal generator to cable to antenna.
Signal generator: absolute output level		0,52	This value should be calculated dependant upon the measurement equipment used.
Signal generator: output level stability	0,00	0,00	Assumed to be included in the absolute out level uncertainty.
Insertion loss: substitution antenna cable	0,3	0,17	
Cable factor: substitution antenna cable		0,50	
Insertion loss: substitution antenna attenuator		0,17	
Antenna: gain of the substitution antenna		0,80	
Antenna: tuning of the substitution antenna		0,00	Fixed broadband ridged guide antenna.
Position of the substitution antenna: Phase centre		0,02	

Source of uncertainty	Value	Standard uncertainty (dB)	Comments
Site Factors			
Ambient effect		0,00	Assumes the use of an anechoic room.
Mutual coupling: substitution antenna to its images in the absorbing material		0,50	
Mutual coupling: substitution antenna to the test antenna		0,00	
Range length		0,00	
Reflectivity of absorbing material: substitution antenna to the test antenna		0,50	Little is known of the performance of anechoic materials up to 40 GHz, therefore the nominal value has been used.
Mutual coupling: test antenna to its images in the absorbing material		0,50	Little is known of the performance of anechoic materials up to 40 GHz, therefore the nominal value has been used.
Mutual coupling: test antenna to its image in the ground plane	0,00	0,00	Assumes a fully lined anechoic room.
Correction measurement distance		0,10	
Correction off bore sight angle in elevation plane		0,10	
Antenna: gain of the test antenna	0,00	0,00	Substitution method.
Antenna: tuning of the test antenna	0,00	0,00	Fixed broadband ridged guide antenna. Substitution method.
Position of the phase centre: test antenna	0,00	0,00	Substitution method.
Insertion loss: test antenna attenuator	0,00	0,00	Substitution method.
Insertion loss: test antenna cable	0,00	0,00	Substitution method.
Cable factor: test antenna cable	0,00	0,00	Substitution method.
Receiving device: absolute level	0,00	0,00	Substitution method.
Receiving device: linearity	0,00	0,00	Substitution method.
Stage 1combined contribution to uncertainty		0,69	
Stage 2 combined contribution to uncertainty		1,62	
Combined contribution to uncertainty Stage 1 and Stage 2		1,76	
Expanded uncertainty (k = 2, for 95 % confidence)		3,52	

It can be shown that the major contributions on the overall measurement uncertainty are:

- Stage 1: signal to noise at low levels of signal;
- Stage 2: Mismatch uncertainty; and
- Stage 2: Signal generator absolute power level.

B.2 Equivalent isotropically radiated power (e.i.r.p.) (Substitution method) OATS

Table B.2: Typical e.i.r.p. measurement uncertainty calculation with regard to the substitution method

Source of uncertainty	Value	Standard uncertainty (dB)	Comments
Stage 1: Site Factors			
Ambient effect	0,10 dB		With EUT switched off, receiver noise floor > 10 dB below the measured value.
Mutual coupling: test antenna to its images in the ground plane	0,00	0,00	Substitution method.
Test antenna			
Correction: measurement distance	0,00	0,00	Substitution method.
Correction: of bore sight angle in elevation plane	0,00	0,00	Substitution method.
Antenna: gain of the test antenna	0,00	0,00	Substitution method.
Antenna: tuning of the test antenna	0,00	0,00	Fixed broadband ridged guide antenna. Substitution method.
Position of the phase centre: test antenna	0,00	0,00	Substitution method.
Insertion loss: test antenna attenuator	0,00	0,00	Substitution method.
Insertion loss: test antenna cable	0,00	0,00	Substitution method.
Cable factor: test antenna cable	0,00	0,00	Substitution method.
Receiving device			
Receiving device: absolute level	0,00	0,00	Substitution method.
Receiving device: linearity	0,00	0,00	Substitution method.
Random uncertainty	0,00	0,00	This uncertainty is derived from repeated measurements of the equipment under test and is only important when the measured value is close to the specification limit.
Combined measurement uncertainty - Stage 1	$(0,1)^{0,5}$	0,31	
Stage two: Substitution measurement			
Mismatch uncertainty: transmitting parts and receiving parts		0,80	Signal generator to cable to antenna.
Signal generator: absolute output level		0,52	This value should be calculated dependant upon the measurement equipment used.
Signal generator: output level stability	0,00	0,00	Assumed to be included in the absolute out level uncertainty.
Insertion loss: substitution antenna cable	0,3	0,17	
Cable factor: substitution antenna cable		0,50	
Insertion loss: substitution antenna attenuator		0,17	
Antenna: gain of the substitution antenna		0,80	
Antenna: tuning of the substitution antenna		0,00	Fixed broadband ridged guide antenna.
Position of the substitution antenna: Phase centre		0,02	

Source of uncertainty	Value	Standard uncertainty (dB)	Comments
Site Factors			
Ambient effect		0,00	Assumes the use of an anechoic room.
Mutual coupling: substitution antenna to the test antenna		0,00	
Range length		0,00	
Mutual coupling: test antenna to its image in the ground plane	0,00	0,00	Assumes a fully lined anechoic room.
Correction measurement distance		0,10	
Correction off bore sight angle in elevation plane		0,10	
Antenna: gain of the test antenna	0,00	0,00	Substitution method.
Antenna: tuning of the test antenna	0,00	0,00	Fixed broadband ridged guide antenna. Substitution method.
Position of the phase centre: test antenna	0,00	0,00	Substitution method.
Insertion loss: test antenna attenuator	0,00	0,00	Substitution method.
Insertion loss: test antenna cable	0,00	0,00	Substitution method.
Cable factor: test antenna cable	0,00	0,00	Substitution method.
Receiving device: absolute level	0,00	0,00	Substitution method.
Receiving device: linearity	0,00	0,00	Substitution method.
Stage 1combined contribution to uncertainty		0,31	
Stage 2 combined contribution to uncertainty		0,35	
Combined contribution to uncertainty Stage 1 and Stage 2		0,45	
Expanded uncertainty (k = 2, for 95 % confidence)		0,90	

It can be shown that the major contributions on the overall measurement uncertainty are:

- Stage 1: signal to noise at low levels of signal;
- Stage 2: Mismatch uncertainty; and
- Stage 2: Signal generator absolute power level.

B.3 Equivalent isotropically radiated power (e.i.r.p.) (Pre-Substitution method above 1 GHz), effective radiated power (e.r.p.) (Pre-Substitution method below 1 GHz) anechoic room

Table B.3: Typical e.i.r.p. or e.r.p. measurement uncertainty calculation with regard to the pre-substitution method

Source of uncertainty	Value	Standard uncertainty (dB)	Comments
Stage 1: Site Factors			
Ambient effect	0,10 dB		With EUT switched off, receiver noise floor > 10 dB below the measured value.
Mutual coupling: EUT to its images in the absorbing material		0,50	
Mutual coupling: EUT to its images in the ground plane		0,15	This value is zero when a fully anechoic room is used.
Reflectivity of absorbing material: EUT to the test antenna		0,74	Pre-Substitution method.
Mutual coupling: test antenna to its images in the absorbing material		0,50	Pre-Substitution method.
Mutual coupling: test antenna to its images in the ground plane		0,15	Pre-Substitution method.
Test antenna			
Correction: measurement distance		0,10	Pre-Substitution method.
Correction: of bore sight angle in elevation plane		0,50	Pre-Substitution method.
Antenna: gain of the test antenna		0,60	Pre-Substitution method.
Antenna: tuning of the test antenna		0,06	Fixed broadband ridged guide antenna. Substitution method.
Position of the phase centre: test antenna		0,50	Pre-Substitution method.
Insertion loss: test antenna attenuator		0,17	Pre-Substitution method.
Insertion loss: test antenna cable		0,50	Pre-Substitution method.
Cable factor: test antenna cable		0,50	Pre-Substitution method.
Interpolation between two measurement values		0,60	Pre-Substitution method.
Receiving device			
Receiving device: absolute level		0,15	
Receiving device: linearity		0,10	
Combined measurement uncertainty - Stage 1		1,75	
Stage two: Pre-Substitution measurement			
Mismatch uncertainty: transmitting parts and receiving parts		0,80	Signal generator to cable to antenna.
Signal generator: absolute output level		0,52	This value should be calculated dependant upon the measurement equipment used.
Signal generator: output level stability	0,00	0,00	Assumed to be included in the absolute out level uncertainty.
Insertion loss: Pre-Substitution antenna cable	0,3	0,17	
Cable factor: Pre-Substitution antenna cable		0,50	

Source of uncertainty	Value	Standard uncertainty (dB)	Comments
Insertion loss: Pre-Substitution antenna attenuator		0,17	
Antenna: gain of the Pre-Substitution antenna		0,80	
Antenna: tuning of the Pre-Substitution antenna		0,00	Fixed broadband ridged guide antenna.
Position of the Pre-Substitution antenna: Phase centre		0,02	
Site Factors			
Ambient effect		0,30	Receiving device noise floor is within 6 dB to 10 dB of measurement.
Mutual coupling: substitution antenna to its images in the absorbing material		0,50	
Mutual coupling: substitution antenna to the test antenna		0,00	
Range length		0,00	
Reflectivity of absorbing material: substitution antenna to the test antenna		0,50	Little is known of the performance of anechoic materials up to 40 GHz, therefore the nominal value has been used.
Mutual coupling: test antenna to its images in the absorbing material		0,50	Little is known of the performance of anechoic materials up to 40 GHz, therefore the nominal value has been used.
Mutual coupling: test antenna to its image in the ground plane	0,00	0,00	Assumes a fully lined anechoic room.
Correction measurement distance		0,10	
Correction off bore sight angle in elevation plane		0,10	
Stage 1combined contribution to uncertainty		1,75	
Stage 2 combined contribution to uncertainty		1,62	
Combined contribution to uncertainty Stage 1 and Stage 2		2,38	
Expanded uncertainty (k = 2, for 95 % confidence)		4,76	

It can be shown that the major influences on the overall measurement uncertainty are:

- Stage 1: signal to noise at low levels of signal;
- Stage 2: Mismatch uncertainty; and
- Stage 2: Signal generator absolute power level.

B.4 Equivalent isotropically radiated power (e.i.r.p.) (Pre-Substitution method above 1 GHz), effective radiated power (e.r.p.) (Pre-Substitution method below 1 GHz) OATS

Table B.4: Typical e.i.r.p. or e.r.p. measurement uncertainty calculation with regard to the pre-substitution method

Source of uncertainty	Value	Standard uncertainty (dB)	Comments
Stage 1: Site Factors			
Ambient effect	0,10 dB		With EUT switched off, receiver noise floor > 10 dB below the measured value.
Mutual coupling: test antenna to its images in the ground plane		0,15	Pre-Substitution method.
Test antenna			
Correction: measurement distance		0,10	Pre-Substitution method.
Correction: of bore sight angle in elevation plane		0,50	Pre-Substitution method.
Antenna: gain of the test antenna		0,60	Pre-Substitution method.
Antenna: tuning of the test antenna		0,06	Fixed broadband ridged guide antenna. Substitution method.
Position of the phase centre: test antenna		0,50	Pre-Substitution method.
Insertion loss: test antenna attenuator		0,17	Pre-Substitution method.
Insertion loss: test antenna cable		0,50	Pre-Substitution method.
Cable factor: test antenna cable		0,50	Pre-Substitution method.
Interpolation between two measurement values		0,60	Pre-Substitution method.
Receiving device			
Receiving device: absolute level		0,15	
Receiving device: linearity		0,10	
Combined measurement uncertainty - Stage 1		1,29	
Stage two: Pre-Substitution measurement			
Mismatch uncertainty: transmitting parts and receiving parts		0,80	Signal generator to cable to antenna.
Signal generator: absolute output level		0,52	This value should be calculated dependant upon the measurement equipment used.
Signal generator: output level stability	0,00	0,00	Assumed to be included in the absolute out level uncertainty.
Insertion loss: Pre-Substitution antenna cable	0,3	0,17	
Cable factor: Pre-Substitution antenna cable		0,50	
Insertion loss: Pre-Substitution antenna attenuator		0,17	
Antenna: gain of the Pre-Substitution antenna		0,80	
Antenna: tuning of the Pre-Substitution antenna		0,00	Fixed broadband ridged guide antenna.
Position of the Pre-Substitution antenna: Phase centre		0,02	

Source of uncertainty	Value	Standard uncertainty (dB)	Comments
Site Factors			
Ambient effect		0,30	Receiving device noise floor is within 6 dB to 10 dB of measurement.
Mutual coupling: substitution antenna to the test antenna		0,00	
Range length		0,00	
Mutual coupling: test antenna to its image in the ground plane	0,00	0,00	Assumes a fully lined anechoic room.
Correction measurement distance		0,10	
Correction off bore sight angle in elevation plane		0,10	
Stage 1combined contribution to uncertainty		1,29	
Stage 2 combined contribution to uncertainty		1,35	
Combined contribution to uncertainty Stage 1 and Stage 2		1,81	
Expanded uncertainty (k = 2, for 95 % confidence)		3,62	

It can be shown that the major influences on the overall measurement uncertainty are:

- Stage 1: signal to noise at low levels of signal;
- Stage 2: Mismatch uncertainty; and
- Stage 2: Signal generator absolute power level.

B.5 Radiated field strength (EMC)

Table B.5: Typical radiated field strength measurement uncertainty calculation (at 3 m)

Source of uncertainty	Value	Standard uncertainty (dB)	Comments
Receiver Indication	0,05	0,03	This uncertainty is a function of the least significant digit of the receiver display readout, or the meter indication, or the marker function on an analyser.
Receiver sine wave	1,00	0,50	Receiver error due to sine wave voltage.
Receiver pulse amplitude	1,50	0,87	Receiver error due to pulse amplitude response.
Receiver pulse repetition	1,50	0,87	Receiver error due to pulse repetition response.
Noise floor proximity	0,50	0,25	Error only applicable when measuring within 10 dBs of the noise floor of the receiver.
Antenna factor calibration	1,00	0,50	The uncertainty of antenna factor is obtained from the calibration certificate.
Cable loss	0,50	0,25	The uncertainty of cable loss is obtained from the calibration certificate.
Antenna Directivity	3,00	1,73	This uncertainty varies with antenna type and measurement distance.
Antenna factor - height dependence	0,50	0,29	This uncertainty is based on experience of antenna calibration. The value given is typical for vertical polarization. With horizontal polarization can be as much as 2 dB. Above 1 GHz the uncertainty is much reduced when using horn type antennas.
Antenna phase centre variation	1,00	0,58	This uncertainty is based on experience of antenna calibration. Above 1 GHz the uncertainty is much reduced when using horn antennas.
Antenna factor frequency interpolation	0,25	0,14	This uncertainty depends on the frequency interval of calibration points and the rate of change of the antenna factor with frequency.
Site imperfections	4,00	1,63	This uncertainty can be assessed from the site normalized site attenuation.
Measurement distance variation	0,60	0,35	This is an estimate of the uncertainty of received signal strength when related to the uncertainty of the measurement distance.
Antenna balance	0,00	0,00	Above 1 GHz this uncertainty is assumed to be zero.
Cross polarization	0,90	0,52	This uncertainty is dependant on the type of antenna used to make the measurement. Can be considered as zero when using horn antennas.
Frequency step error	0,00	0,00	This uncertainty is assumed to be zero. However can be significant if the frequency step size is not set correctly in relation to the receiver bandwidth. Recommended step size is half the receiver bandwidth for minimum uncertainty.
Mismatch receiver and cables	-0,54	0,38	This uncertainty is derived from the combination of the reflection coefficient magnitudes of the antenna/cable/receiver combination. Additional uncertainty can be introduced when using cable connector adaptors.
Measurement system repeatability	0,50	0,50	This uncertainty is derived from a number of repeated measurements using a stable equipment under test (e.g. a reference noise source).

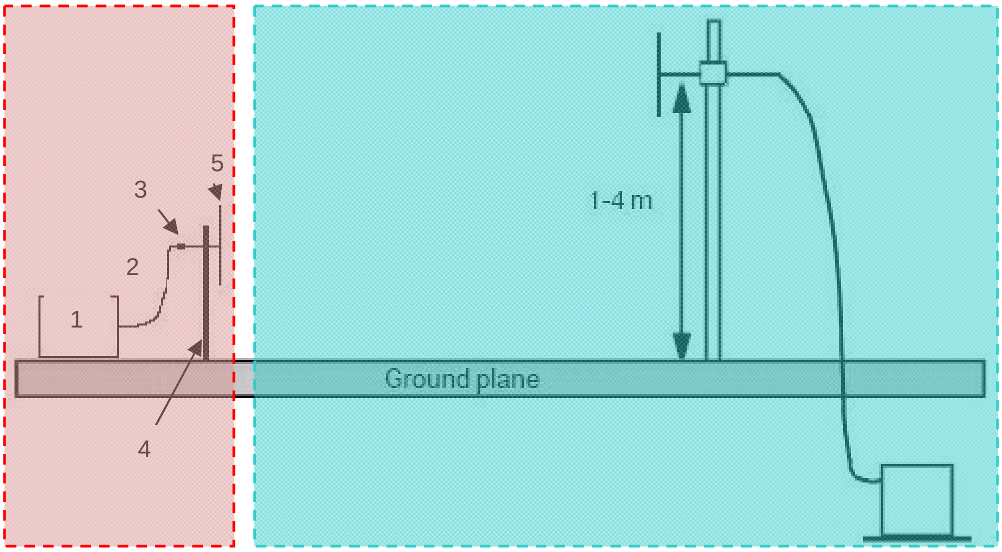
Source of uncertainty	Value	Standard uncertainty (dB)	Comments
Repeatability of the EUT	0,00	0,00	This uncertainty is derived from repeated measurements of the equipment under test, and is only important when the measured value is close to the specification limit.
Combined standard uncertainty		3,00	
Expanded uncertainty (k = 2, for 95 % confidence)		6,0	
NOTE 1: The uncertainties given in this table assumes that all measurement equipment, cables and antennas have been calibrated to traceable calibration standards, and that the result of the measurement is corrected for systematic errors given on the calibration certificate. Where receivers have a built in self-calibration function it is assumed that this has been carried out as required by the manufacturer's instructions. NOTE 2: The standard uncertainty has been derived by calculation, taking into account the probability distribution of each source of uncertainty. NOTE 3: For calculation of actual expanded measurement uncertainty, see annex C.			

The exemplary calculations shown above describe the possibility of a mathematical derivation of measurement uncertainty in an inaccurate overestimation, as the compensation of errors is not taken into account. For this reason, the measurement setup consisting of several different components should preferably be regarded as a complex structure with a definite measurement uncertainty (regardless of the different PDF) that can be verified using statistical means like the type A evaluation as per clause 2.3.2 of the Guide to the expression of uncertainty in measurement [21].

Further proof for the overestimation is described in the document "Measurement Instrumentation Uncertainty of Radiated Disturbances Due to Antenna - Receiver Transmission" [23] elaborated by the test engineer Jan Sroka of EMC-Testcenter Zürich AG, Switzerland.

The simplification can be illustrated with the help of the substitution test site as described in TS 103 052 [20].

The substitution test site (left box in figure B.4) consists of an unmodulated generator, variable in frequency and power, with a power that is traceable due to calibration or alternatively a calibrated power meter (1), a suitable 50 Ω cable with indication of the cable loss (2), a suitable, calibrated attenuator (3) for coercive adaption to the antenna, consisting of real active resistances, an antenna support without influence on the test result (4) as well as a standard dipole up to 1 GHz or respectively an antenna with indication of the calibrated, isotropic gain (5).



NOTE: Right box of figure B.4: Statistical evaluation/Repetition measurement uncertainty (Type A evaluation). Left box of figure B.4: Measurement uncertainty of the measurement chain consisting of a generator, conductors and the K-factor of the reference antenna (as well as attenuators used for coercive adaptation if necessary) can be summed up by determination of the substitution power with a reference power meter.

Figure B.4: Illustration of the simplification

In addition to that, EA-4/16 [24], clause 6.6.2 describes that certain measurement uncertainty components can be neglected, whereas in deciding whether an uncertainty contribution can be neglected, the following has to be considered:

- The relative sizes of the largest and the smaller contributions. For example, a contribution that is one fifth of the largest contribution will contribute at most 2 % of the combined standard uncertainty.
- The effect on the reported uncertainty. It is imprudent to make approximations that materially affect the reported uncertainty or the interpretation of the result.
- The degree of rigour justified for the uncertainty evaluation, taking into account the client and regulatory and other external requirements identified, for example, during contract review.

Annex C (informative): Void

Annex D (informative): Measurement Uncertainty contributions

This annex contains a list of the uncertainties identified in TR 102 273 [3] to [10] for usage until 1 GHz as being involved in radiated tests and gives details on how their magnitudes should be derived. Numerical and alphabetical lists of the uncertainties are given in tables D.18 and D.19. The principles given in TR 102 273 [3] to [10] can also be used for frequencies up to 100 GHz with appropriate adaptations.

A radiated test, whether a verification procedure or the measurement of a particular parameter, consists of two stages. For verification procedure the first stage is to set a reference level followed by the second stage that involves a measurement of the path loss between two antennas. For EUT testing, the first stage is to measure the EUT followed by the second stage that involves comparing the result to a known standard or reference. As a result of this methodology there are measurement uncertainty contributions that are common to both stages of any test, some of which cancel themselves out, others are included once whilst yet others have to be included twice.

NOTE: For the measurement of some EUT receiver parameters the stages are reversed.

Converting data: In the evaluation of any particular contribution it may be necessary to convert given data (e.g. from a manufacturer's information) into standard uncertainty. The following will aid any conversions that may be necessary.

Mismatch uncertainties have "U" shaped distributions. The standard uncertainty is: $a/\sqrt{2}$.

Systematic uncertainties e.g. the uncertainty associated with cable loss are, unless the actual distribution is known, assumed to have rectangular distributions. The standard uncertainty is: $a/\sqrt{3}$.

The rectangular distribution is a reasonable default model to choose in the absence of any other information.

For conversion of % to dB, table D1 can be used (for more information on the derivation of the table see TR 102 273-1-2 [4], annex C).

Table D.1: Standard uncertainty conversion factors

Converting from standard uncertainties in:	Conversion factor multiply by:	To standard uncertainties in:
dB	11,5	voltage %
dB	23,0	power %
power %	0,043 5	dB
power %	0,5	voltage %
voltage %	2,0	power %
voltage %	0,086 9	dB

Terminology: In this annex the following phases should be interpreted as follows:

- "Free field test sites": are anechoic chambers, anechoic chambers with ground planes and open area test sites.
- "Verification": refers to the measurement in which the test site is compared to its theoretical model.
- "Test methods": refers to all radiated tests apart from the verification procedure.
- "Transmitting" and "receiving" antennas: are used in the verification procedure only; all other references to antennas (i.e. substitution, measuring and test) are for test methods.

D.1 Reflectivity

Background: The absorber panels in Anechoic Chambers (both with and without ground planes) reflect signal levels that can interfere with the required field distribution.

u_{j01} *Reflectivity of absorbing material: EUT to the test antenna*

This uncertainty only contributes to test methods on free field test sites that incorporate anechoic materials. It is the estimated uncertainty due to reflections from the absorbing material.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: If the test is part of a substitution measurement the standard uncertainty is 0,00 dB, otherwise the value from table D.2 should be used.

Table D.2: Uncertainty contribution: reflectivity of absorbing material: EUT to the test antenna

Reflectivity of the absorbing material	Standard uncertainty of the contribution
reflectivity <10 dB	4,76 dB
10 dB ≤ reflectivity < 15 dB	3,92 dB
15 dB ≤ reflectivity < 20 dB	2,56 dB
20 dB ≤ reflectivity < 30 dB	1,24 dB
reflectivity ≥ 30 dB	0,74 dB

u_{j02} *Reflectivity of absorbing material: substitution or measuring antenna to the test antenna*

This uncertainty only contributes to test methods on free field test sites that incorporate anechoic materials. It is the estimated uncertainty due to reflections from the absorbing material.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: In a substitution type measurement the reflectivity of the absorber material tends to be nullified by the substitution methodology. However, there will always be some differences in the radiation patterns of the EUT and the substitution or measuring antenna and hence the standard uncertainty to allow for this should be taken as 0,5 dB.

u_{j03} *Reflectivity of absorbing material: transmitting antenna to the receiving antenna*

This uncertainty only contributes to the verification procedures on free field test sites that incorporate anechoic materials. It is the estimated uncertainty due to reflections from the absorbing material.

How to evaluate for free field test sites

Verification: The relevant value for this contribution should be taken from table D.3.

Test methods: Not applicable.

Table D.3: Uncertainty contribution: reflectivity of absorbing material: transmitting antenna to the receiving antenna

Reflectivity of the absorbing material	Standard uncertainty of the contribution
reflectivity <10 dB	4,76 dB
10 dB ≤ reflectivity < 15 dB	3,92 dB
15 dB ≤ reflectivity < 20 dB	2,56 dB
20 dB ≤ reflectivity < 30 dB	1,24 dB
reflectivity ≥ 30 dB	0,74 dB

D.2 Mutual coupling

Background: Mutual coupling is the mechanism which produces changes in the electrical behaviour of an EUT or antenna when placed close to a conducting surface, another antenna, etc. These mechanisms are illustrated in figure D.1. The effects can include de-tuning, gain variations, changes to the radiation pattern and input impedance, etc.

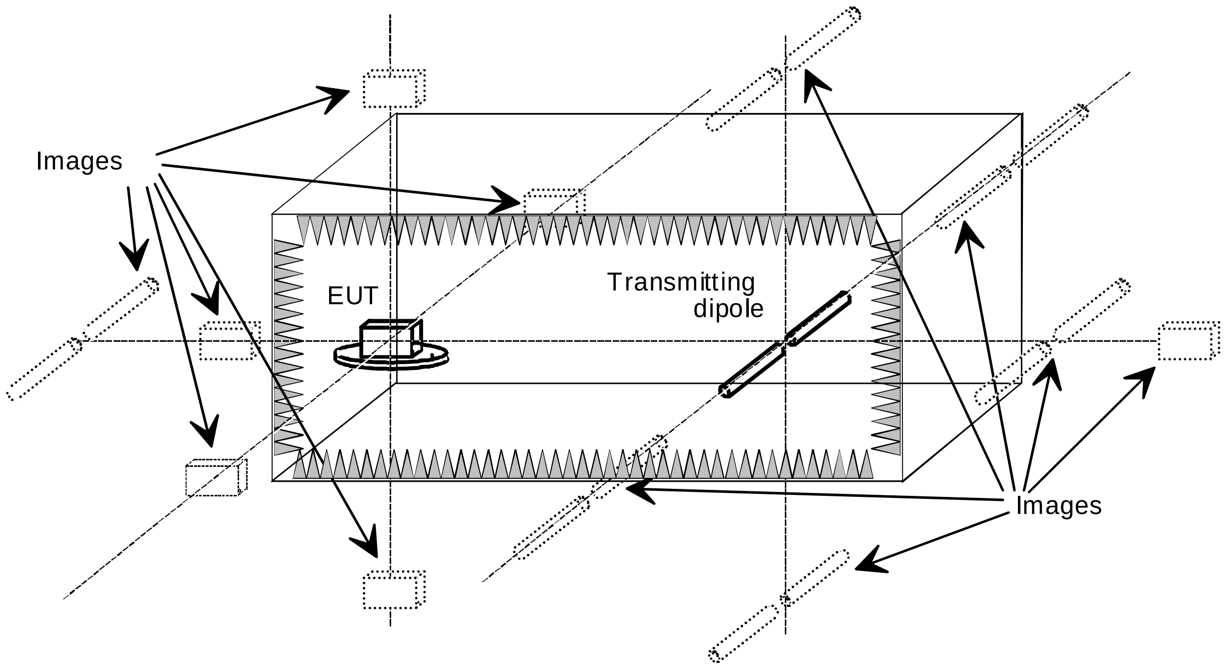


Figure D.1: Mutual coupling (Anechoic Chamber illustrated)

u_{j04} *Mutual coupling: EUT to its images in the absorbing material*

This uncertainty contributes to test methods and verification procedures on free field test sites that incorporate anechoic material. It is the uncertainty that results from the degree of imaging in the absorber/shield of the chamber and the resulting effect on the input impedance and/or gain of the integral antenna.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: The standard uncertainty is 0,50 dB.

u_{j05} *Mutual coupling: de-tuning effect of the absorbing material on the EUT*

This uncertainty only contributes to the test methods on free field test sites that incorporate anechoic materials. It is the uncertainty of any de-tuning effect due to the return loss of the absorbers.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: This value will be 0,00 Hz provided the absorbing panels are more than 1 m away from the EUT and the return loss of the panels is above 6 dB (testing should not take place for spacing of less than 1 m). For return losses below 6 dB, the value should be taken as 5 Hz standard uncertainty.

u_{j06} *Mutual coupling: substitution, measuring or test antenna to its images in the absorbing material*

This uncertainty only contributes to test methods on free field test sites that incorporate anechoic material. It is the uncertainty that results from the degree of imaging in the absorber/shield of the chamber and the resulting effect on the antenna's input impedance and/or gain.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods:

- for the test antenna only, if it is at the same height for both stages one and two of the test method, then for any absorber depth the uncertainty is 0,00 dB, otherwise the standard uncertainty is 0,50 dB;
- for substitution or measuring antennas the standard uncertainty is 0,50 dB.

u_{j07} *Mutual coupling: transmitting or receiving antenna to its images in the absorbing material*

This uncertainty only contributes to verification procedures on free field test sites that incorporate anechoic material. It is the uncertainty that results from the degree of imaging in the absorber/shield of the chamber and the resulting effect on the antenna's input impedance and/or gain.

How to evaluate for free field test sites

Verification:

- for the transmitting antenna the standard uncertainty is 0,50 dB;
- for the receiving antenna the standard uncertainty is 0,50 dB.

Test methods: Not applicable.

u_{j08} *Mutual coupling: amplitude effect of the test antenna on the EUT*

This uncertainty only contributes to test methods on free field test sites. It is the uncertainty that results from the interaction (impedance changes, etc.) between the EUT and the test antenna when placed close together.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: This is the uncertainty that results from the interaction (impedance changes, etc.) between the EUT and the test antenna when placed close together. The standard uncertainty can be taken from table D.4.

Table D.4: Uncertainty contribution: mutual coupling: amplitude effect of the test antenna on the EUT

Range length	Standard uncertainty of the contribution
$0{,}62\sqrt{((d_1 + d_2)^3/\lambda)} \leq$ range length $< 2(d_1 + d_2)^2/\lambda$	0,50 dB
range length $\geq 2(d_1 + d_2)^2/\lambda$	0,00 dB
NOTE: d_1 and d_2 are the maximum dimensions of the EUT and the test antenna.	

u_{j09} *Mutual coupling: de-tuning effect of the test antenna on the EUT*

This uncertainty only contributes to test methods on free field test sites that incorporate anechoic materials. It is the uncertainty of any de-tuning effect due to mutual coupling between the EUT and the test antenna.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: This value will be 0,00 Hz provided the spacing between the test antenna and EUT is greater than $(d_1 + d_2)^2/4\lambda$. For lesser spacing, the value should be taken as 5 Hz standard uncertainty.

NOTE: d_1 and d_2 are the maximum dimensions of the EUT and the test antenna.

u_{j10} *Mutual coupling: transmitting antenna to receiving antenna*

This uncertainty only contributes to verification procedures on free field test sites. It is the uncertainty which results from the change in coupled signal level between the transmitting and receiving antenna when placed close together.

How to evaluate for free field test sites

Verification: For ANSI dipoles the value of this uncertainty is 0,00 dB since it is included, where significant, in the mutual coupling and mismatch loss correction factors. For non-ANSI dipoles the standard uncertainty can be taken from table D.5.

Test methods: Not applicable.

Table D.5: Uncertainty contribution: mutual coupling: transmitting antenna to receiving antenna

Frequency	Standard uncertainty of the contribution (3 m range)	Standard uncertainty of the contribution (10 m range)
30 MHz ≤ frequency < 80 MHz	1,73 dB	0,60 dB
80 MHz ≤ frequency < 180 MHz	0,6 dB	0,00 dB
frequency ≥ 180 MHz	0,00 dB	0,00 dB

u_{j11} *Mutual coupling: substitution or measuring antenna to the test antenna*

This uncertainty only contributes to test methods on free field test sites. It is the uncertainty which results from the change in coupled signal level between the substitution or measuring and test antenna when placed close together.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: For ANSI dipoles the value of this uncertainty is 0,00 dB since it is included, where significant, in the mutual coupling and mismatch loss correction factors. For non-ANSI dipoles the standard uncertainty can be taken from table D.6.

Table D.6: Uncertainty contribution: mutual coupling: substitution or measuring antenna to the test antenna

Frequency	Standard uncertainty of the contribution (3 m range)	Standard uncertainty of the contribution (10 m range)
30 MHz ≤ frequency < 80 MHz	1,73 dB	0,60 dB
80 MHz ≤ frequency < 180 MHz	0,6 dB	0,00 dB
frequency ≥ 180 MHz	0,00 dB	0,00 dB

u_{j12} *Mutual coupling: interpolation of mutual coupling and mismatch loss correction factors*

This uncertainty contributes to test methods and verification procedures on free field test sites. It is the uncertainty that results from the interpolation between two values in the mutual coupling and mismatch loss correction factor table (given in the relevant test methods and verification procedures).

How to evaluate for free field test sites

Verification: The standard uncertainty can be obtained from table D.7.

Test methods: The standard uncertainty can be obtained from table D.7.

Table D.7: Uncertainty contribution: mutual coupling: interpolation of mutual coupling and mismatch loss correction factors

Frequency (MHz)	Standard uncertainty of the contribution
for a spot frequency given in the table	0,00 dB
30 MHz ≤ frequency < 80 MHz	0,58 dB
80 MHz ≤ frequency < 180 MHz	0,17 dB
frequency ≥ 180 MHz	0,00 dB

u_{j13} *Mutual coupling: EUT to its image in the ground plane*

This uncertainty contributes to test methods on free field test sites that incorporate a ground plane. It is the uncertainty that results from the change in gain and/or sensitivity of an EUT when placed close to a ground plane.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: The standard uncertainty can be obtained from table D.8.

Table D.8: Uncertainty contribution: mutual coupling: EUT to its image in the ground plane

Spacing between the EUT and the ground plane	Standard uncertainty of the contribution
For a vertically polarized EUT	
spacing ≤ 1,25 λ	0,15 dB
spacing > 1,25 λ	0,06 dB
For a horizontally polarized EUT	
spacing < $\lambda/2$	1,15 dB
$\lambda/2$ ≤ spacing < $3\lambda/2$	0,58 dB
$3\lambda/2$ ≤ spacing < 3λ	0,29 dB
spacing ≥ 3λ	0,15 dB

u_{j14} *Mutual coupling: substitution, measuring or test antenna to its image in the ground plane*

This uncertainty only contributes to test methods on free field test sites that incorporate a ground plane. It is the uncertainty that results from the change in input impedance and/or gain of the substitution, measuring or test antenna when placed close to a ground plane.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: The standard uncertainty can be obtained from table D.9.

Table D.9: Uncertainty contribution: mutual coupling: substitution, measuring or test antenna to its image in the ground plane

Spacing between the antenna and the ground plane	Standard uncertainty of the contribution
For a vertically polarized antenna	
Spacing ≤ 1,25 λ	0,15 dB
Spacing > 1,25 λ	0,06 dB
For a horizontally polarized antenna	
spacing < $\lambda/2$	1,15 dB
$\lambda/2$ ≤ spacing < $3\lambda/2$	0,58 dB
$3\lambda/2$ ≤ spacing < 3λ	0,29 dB
spacing ≥ 3λ	0,15 dB

u_{j15} ***Mutual coupling: transmitting or receiving antenna to its image in the ground plane***

This uncertainty only contributes to verification procedures on free field test sites that incorporate a ground plane. It is the uncertainty that results from the change in gain of the transmitting or receiving antenna when placed close to a ground plane.

How to evaluate for free field test sites

Verification: For ANSI dipoles the value of this uncertainty is 0,00 dB as it is included, where significant, in the mutual coupling and mismatch loss correction factors. For other dipoles the value can be obtained from table D.10.

Test methods: Not applicable.

Table D.10: Uncertainty contribution: mutual coupling: transmitting or receiving antenna to its image in the ground plane

Spacing between the antenna and the ground plane	Standard uncertainty of the contribution
For a vertically polarized antenna	
spacing ≤ 1,25 λ	0,15 dB
spacing > 1,25 λ	0,06 dB
For a horizontally polarized antenna	
spacing < $\lambda/2$	1,15 dB
$\lambda/2$ ≤ spacing < $3\lambda/2$	0,58 dB
$3\lambda/2$ ≤ spacing < 3λ	0,29 dB
spacing ≥ 3λ	0,15 dB

D.3 Range length

Background: The range length over which any radiated test is carried out always has to be adequate to enable far field-testing. It may also be specified in the relevant testing standard.

NOTE 1: Range length is defined as the horizontal distance between the phase centres of the EUT and the test antenna.

Over a reflective ground plane where a height scan is involved to peak the received signal the distance over which a measurement is performed is not always equal to the range length. Figure D.2 illustrates the difference between range length and measurement distance.

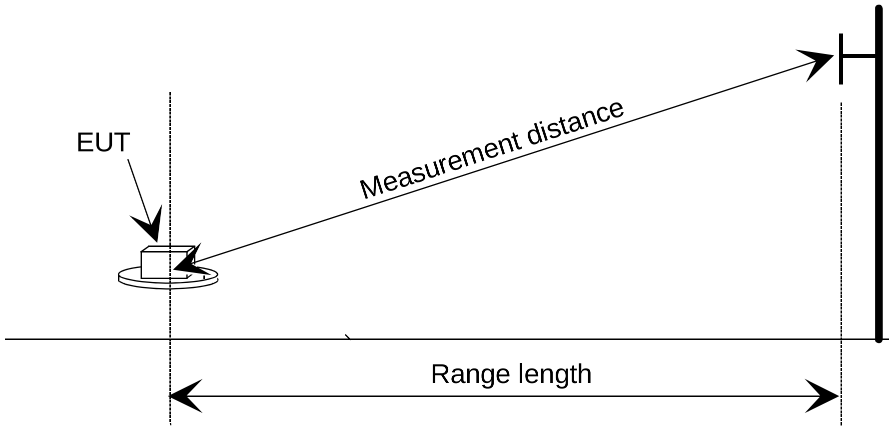


Figure D.2: Range length and measurement distance

It is important to distinguish clearly between these two terms.

u_{j16} *Range length*

This uncertainty contributes to test methods and verification procedures on free field test sites. It is the uncertainty associated with the curvature of the phase front resulting from inadequate range length between an EUT and antenna or, alternatively, between two antennas i.e. it should always be equal to or greater than $2\,(d_1 + d_2)^2/\lambda$.

NOTE 2: d_1 and d_2 are the maximum dimensions of the antennas.

How to evaluate for free field test sites

Verification: If ANSI dipoles are used the value is 0,00 dB, since it is included in the mutual coupling and mismatch loss correction factors, otherwise the value can be taken from table D.11.

Test methods: For the EUT to test antenna stage the value can be taken from table D.12. For the substitution or measuring antenna to the test antenna stage: if ANSI dipoles are used the value is 0,00 dB, since it is included in the mutual coupling and mismatch loss correction factors, otherwise the value can be taken from table D.12.

Table D.11: Uncertainty contribution: range length (verification)

Range length (i.e. the horizontal distance between phase centres)	Standard uncertainty of the contribution
$(d_1 + d_2)^2/4\lambda \le$ range length $< (d_1 + d_2)^2/2\lambda$	1,26 dB
$(d_1 + d_2)^2/2\lambda \le$ range length $< (d_1 + d_2)^2/\lambda$	0,30 dB
$(d_1 + d_2)^2/\lambda \le$ range length $< 2(d_1 + d_2)^2/\lambda$	0,10 dB
range length $\ge 2(d_1 + d_2)^2/\lambda$	0,00 dB
NOTE: d_1 and d_2 are the maximum dimensions of the antennas.	

Table D.12: uncertainty contribution: range length (test methods)

Range length (i.e. the horizontal distance between phase centres)	Standard uncertainty of the contribution
$(d_1 + d_2)^2/4\lambda \leq$ range length $< (d_1 + d_2)^2/2\lambda$	1,26 dB
$(d_1 + d_2)^2/2\lambda \leq$ range length $< (d_1 + d_2)^2/\lambda$	0,30 dB
$(d_1 + d_2)^2/\lambda \leq$ range length $< 2(d_1 + d_2)^2/\lambda$	0,10 dB
range length $\geq 2(d_1 + d_2)^2/\lambda$	0,00 dB
NOTE: d_1 and d_2 are the maximum dimensions of the EUT and the test antenna used in one stage and are the maximum dimensions of the two antennas in the other stage.	

D.4 Corrections

Background: In radiated tests the height of the test antenna is optimized in each stage of the test, often the heights for the two stages are different. This leads to different measuring distances and elevation angles and corrections should be applied to take account of these effects.

u_{j17} *Correction: off bore sight angle in elevation plane*

This uncertainty only contributes to test methods on free field test sites that incorporate a ground plane. Where the height of the antenna on the mast differs between the two stages of a particular measurement, two different elevation angles are subtended between the turntable and the test antenna. A correction factor should be applied to compensate. Its magnitude should be calculated using figure D.7 according to the guidance given in the test method. This uncertainty contribution is the estimate of the accuracy of the calculated correction factor and it only applies when the test antenna has a directional radiation pattern in the elevation plane see figure D.3.

NOTE: Figure D.7 applies to vertically polarized dipoles and bicones and to both polarizations of LPDAs. For horns, or any other type of antenna, figure D.7 is inappropriate and the test engineer should provide specific corrections.

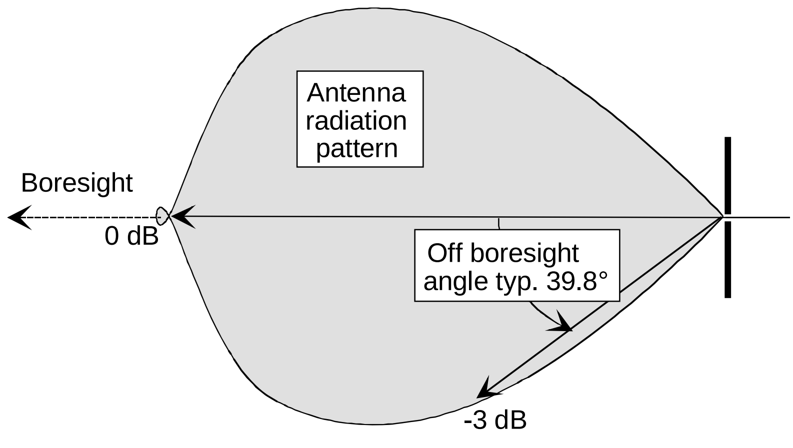


Figure D.3: Off bore sight correction

How to evaluate for free field test sites

Verification: Not applicable.

Test methods:

For any antenna:

- Where the optimized height of the antenna on the mast is the same in the two stages of the test, this value is 0,00 dB.
- For vertically polarized dipoles and bicones where the optimized height of the antenna on the mast is different in the two stages of the test, the standard uncertainty of the value is 0,10 dB.
- For horizontally or vertically polarized LPDAs where the optimized height of the antenna on the mast is different in the two stages of the test, the standard uncertainty of the value is 0,50 dB.
- For any other antenna, **after application of a correction specific to that antenna**, where the optimized height of the antenna on the mast is different in the two stages of the test, the standard uncertainty of the value is 0,50 dB.

u_{j18} ***Correction: measurement distance***

This uncertainty only contributes to test methods on free field test sites that incorporate a ground plane. Where the height of the antenna on the mast differs between the two stages of a particular measurement, two different path losses result from the different measurement distances involved. A correction factor should be applied to compensate. Its magnitude should be calculated according to the guidance given in the test method. This uncertainty contribution is the estimate of the accuracy of the calculated correction factor.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods:

- Where the optimized height of the antenna on the mast is the same in the two stages of the test, this value is 0,00 dB.
- Where the optimized height of the antenna on the mast is different in the two stages of the test, the standard uncertainty of the value is 0,10 dB.

D.5 Radio frequency cables

Background: There are radiating mechanisms by which RF cables can introduce uncertainties into radiated measurements:

- leakage;
- acting as a parasitic element to an antenna;
- introducing common mode current.

Leakage allows electromagnetic coupling into the cables. Because the electromagnetic wave contains both electric and magnetic fields, mixed coupling occurs and the voltage induced is very dependant on the orientation, with respect to the cable, of the electric and magnetic fields. This coupling can have different effects depending on the length of the cable and where it is in the system. Cables are usually the longest part of the test equipment configuration and as such, leakage can make them act as efficient receiving or transmitting antennas that, as a result, will contribute significantly to the uncertainty of the measurement.

The parasitic effect of the cable can potentially be the most significant of the three effects and can cause major changes to the antenna's radiation pattern, gain and input impedance. The common mode current problem has similar effects on an antenna's performance.

Routing and loading the cables with ferrite beads as detailed in the test methods can largely eliminate all three effects. An RF cable for which no precautions have been taken to prevent these effects can, simply by being repositioned, cause different results to be obtained.

u_{j19} *Cable factor*

This uncertainty contributes to test methods and verification procedures. Cable factor is defined as the total effect of the RF cable's influence on the measuring system.

How to evaluate for free field test sites

Verification: In the direct attenuation stage of the procedure (a conducted measurement) all fields are enclosed and hence the contribution is assumed to be zero. However in the radiated attenuation stage, the standard uncertainty for each cable is 0,5 dB provided the precautions detailed in the procedure have been observed. If the precautions have not been observed the contributions have a standard uncertainty of 4,0 dB.

Test methods: The standard uncertainty for each cable is 0,5 dB provided the precautions detailed in the method have been observed. If the precautions have not been observed the contributions have a standard uncertainty of 4,0 dB.

Exceptionally, where a cable and antenna combination has not been repositioned between the two stages (as in the case of the test antenna in an Anechoic Chamber) and the precautions detailed in the procedure have been observed, the contribution is assumed to be 0,00 dB. If the combination has not been repositioned but the precautions have not been observed the contribution is 0,5 dB.

NOTE: Repositioning means any change in the positions of either the cable or the antenna in stage two of the measurement relative to stage one e.g. height optimization over a ground plane.

D.6 Phase centre positioning

Background: The phase centre of an EUT or antenna is the point from which the device is considered to radiate. If the device is rotated about this point the phase of the signal, as seen by a fixed antenna, does not change. It is therefore critical:

a) to identify the phase centre of an EUT or antenna; and

b) to position it correctly on the test site.

u_{j20} *Position of the phase centre: within the EUT volume*

This uncertainty only contributes to test methods. It is the accuracy with which the phase centre is identified within the EUT.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: Only applicable in the stage in which the EUT is measured. If the precise phase centre is unknown, the uncertainty contribution should be calculated from:

$$\frac{\pm \text{ the maximum dimension of the device}}{\text{twice the range length}} \times 100\,\%$$

As the phase centre can be anywhere inside the EUT this uncertainty is assumed to be rectangularly distributed (see TR 102 273-1-1 [3], clause 5.1.2). The standard uncertainty can therefore be calculated and converted to the logarithmic form (see TR 102 273-1-2 [4], annex C).

u_{j21} *Positioning of the phase centre: within the EUT over the axis of rotation of the turntable*

This uncertainty only contributes to test methods. It is the accuracy with which the identified phase centre of the EUT is aligned with the axis of rotation of the turntable.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: Only applicable in the stage in which the EUT is measured. The maximum value should be calculated from:

$$\frac{\pm \textit{ the estimated offset from the axis of rotation}}{\textit{range length}} \times 100\,\%$$

As this error source can be anywhere between these limits this uncertainty is assumed to be rectangularly distributed (see TR 102 273-1-1 [3], clause 5.1.2). The standard uncertainty can therefore be calculated and converted to the logarithmic form (see TR 102 273-1-2 [4], annex C).

u_{j22} *Position of the phase centre: measuring, substitution, receiving, transmitting or test antenna*

This uncertainty contributes to test methods and verification procedures on free field test sites. It is the uncertainty with which the phase centre can be positioned.

How to evaluate for free field test sites

Verification:

For the transmitting antenna the maximum value should be calculated from:

$$\frac{\pm \textit{ the estimated offset from the axis of rotation}}{\textit{range length}} \times 100\,\%$$

For the receiving antenna in an Anechoic Chamber the maximum value should be calculated from:

$$\frac{\pm \textit{ the uncertainty with which the range length can be set}}{\textit{range length}} \times 100\,\%$$

For the receiving antenna over a ground plane the maximum value should be calculated from:

$$\frac{\pm \textit{ the maximum estimated deflection from vertical of the top of the mast}}{\textit{range length}} \times 100\,\%$$

As this error source can be anywhere between these limits this uncertainty is assumed to be rectangularly distributed (see TR 102 273-1-1 [3], clause 5.1.2). The standard uncertainty can therefore be calculated and converted to the logarithmic form (see TR 102 273-1-2 [4], annex C).

Test methods:

For the measuring and substitution antennas the maximum value should be calculated from:

$$\frac{\pm \textit{ the estimated offset from the axis of rotation}}{\textit{range length}} \times 100\,\%$$

For the test antenna in an Anechoic Chamber the maximum value should be calculated from:

$$\frac{\pm \textit{ the uncertainty with which the range length can be set}}{\textit{range length}} \times 100\,\%$$

For the test antenna over a ground plane the maximum value should be calculated from:

$$\frac{\pm \text{ the maximum estimated deflection from vertical of the top of the mast}}{\text{range length}} \times 100\,\%$$

As this error source can be anywhere between these limits this uncertainty is assumed to be rectangularly distributed (see TR 102 273-1-1 [3], clause 5.1.2). The standard uncertainty can therefore be calculated and converted to the logarithmic form (see TR 102 273-1-2 [4], annex C).

u_{j23} *Position of the phase centre: LPDA*

This uncertainty contributes to test methods and verification procedures on free field test sites. It is the uncertainty associated with the changing position of the phase centre with frequency of the LPDA.

How to evaluate for free field test sites

Verification: The maximum value should be calculated from:

$$\frac{\pm \text{ the maximum dimension of the device}}{\text{twice the range length}} \times 100\,\%$$

As this error source can be anywhere between these limits this uncertainty is assumed to be rectangularly distributed (see TR 102 273-1-1 [3], clause 5.1.2). The standard uncertainty can therefore be calculated and converted to the logarithmic form (see TR 102 273-1-2 [4], annex C).

Test methods: For the test antenna the contribution is 0,00 dB. For the substitution or measuring LPDA the maximum value should be calculated from:

$$\frac{\pm \text{ the length of the LPDA}}{\text{twice the range length}} \times 100\,\%$$

As this error source can be anywhere between these limits this uncertainty is assumed to be rectangularly distributed (see TR 102 273-1-1 [3], clause 5.1.2). The standard uncertainty can therefore be calculated and converted to the logarithmic form (see TR 102 273-1-2 [4], annex C).

D.7 Ambient signals

Background: Ambient signals are localized sources of radiated transmissions that can introduce uncertainty into the results of a test made on an Open Area Test Site and in unshielded Anechoic Chambers.

u_{j34} *Ambient effect*

This uncertainty contributes to test methods and verification procedures on free field test sites. It is the uncertainty caused by local ambient signals raising the noise floor of the receiver at the frequency of test.

How to evaluate for free field test sites

Verification: The values of the standard uncertainties should be taken from table D.13.

Test methods: The values of the standard uncertainties should be taken from table D.13.

Table D.13: Uncertainty contribution: ambient effect

Receiving device noise floor (with signal generator OFF) is within:	Standard uncertainty of the contribution
3 dB of measurement	1,57 dB
3 dB to 6 dB of measurement	0,80 dB
6 dB to 10 dB of measurement	0,30 dB
10 dB to 20 dB of measurement	0,10 dB
20 dB or more of the measurement	0,00 dB

D.8 Mismatch

Background: When two or more items of RF test equipment are connected together a degree of mismatch occurs. Associated with this mismatch there is an uncertainty component as the precise interactions are unknown. Mismatch uncertainties are calculated in the present document using *S*-parameters and full details of the method are given in TR 102 273-1-2 [4], annex D. For our purposes the measurement set-up consists of components connected in series, i.e. cables, attenuators, antennas, etc. and for each individual component in this chain, the attenuation and VSWRs needs to be known or assumed. The exact values of the VSWRs (which in RF circuits are complex values) are usually unknown at the precise frequency of test although worst-case values over an extended frequency band will be known. It is these worst-case values that should be used in the calculations. This approach will generally cause the calculated mismatch uncertainties to be worse than they actually are.

u_{j35} *Mismatch: direct attenuation measurement*

This uncertainty only contributes to verification procedures. It results from the interaction of the VSWRs of the components in the direct attenuation measurement. The direct attenuation measurement refers to the arrangement in which the signal generator is directly connected to the receiving device (via cables, attenuators and an adapter) to obtain a reference signal level (see figure D.4). Due to load variations (antennas replacing the adapter in the second stage of the procedure) contributions are not identical in the two stages of the verification procedure.

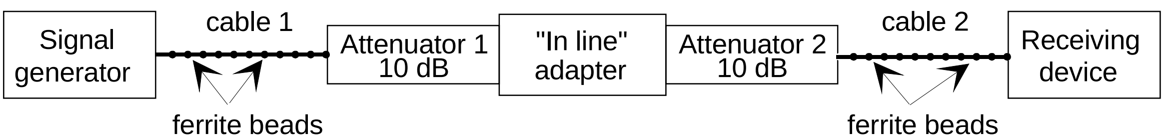


Figure D.4: Equipment set-up for the direct attenuation measurement

How to evaluate for free field test sites

Verification: The magnitude of the uncertainty contribution due to the mismatch in the direct attenuation measurement, is calculated from the approach described in TR 102 273-1-2 [4], annex D.

Test methods: Not applicable.

u_{j36} *Mismatch: transmitting part*

This uncertainty contributes to test methods and verification procedures. The transmitting part refers to the signal generator, cable, attenuator and antenna set-up shown in figure D.5. This equipment configuration is used for:

- the transmitting part of a free field test site verification procedure;
- the transmitting part of the substitution measurement in a transmitter test method;
- the transmitting part when generating a field in a receiver test method.

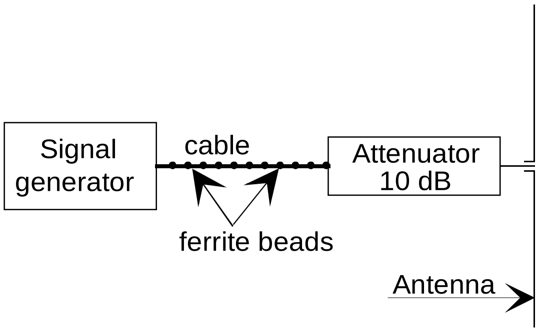


Figure D.5: Equipment set-up for the transmitting part

How to evaluate for free field test sites

Verification: The uncertainty contribution due to the mismatch in the transmitting part is calculated from the approach described in TR 102 273-1-2 [4], annex D.

Test methods: As for the verification.

u_{j37} *Mismatch: receiving part*

This uncertainty contributes to test methods and verification procedures. The receiving part refers to the antenna, attenuator, cable and receiving device set-up shown in figure D.6. This equipment configuration is used for:

- the receiving part of a free field test site verification procedure;
- the receiving part of the substitution measurement in a transmitter test method;
- the receiving part when measuring the field in a receiver test method.

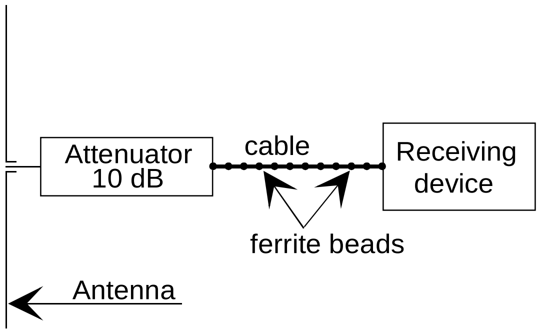


Figure D.6: Equipment set-up for the receiving part

How to evaluate for free field test sites

Verification: The uncertainty contribution due to the mismatch in the receiving part is calculated from the approach described in TR 102 273-1-2 [4], annex D.

Test methods: As for the verification.

D.9 Signal generator

Background: The signal generator is used as the transmitting source. There are two signal generator characteristics that contribute to the expanded uncertainty of a measurement: absolute level and level stability.

u_{j38} *Signal generator: absolute output level*

This uncertainty only contributes to test methods. It concerns the accuracy with which an absolute signal generator level can be set.

How to evaluate for free field test sites

Verification: The standard uncertainty is 0,00 dB.

Test methods: The uncertainty contribution should be taken from the manufacturer's data sheet and converted into standard uncertainty if necessary.

u_{j39} *Signal generator: output level stability*

This uncertainty contributes to test methods and verification procedures. It concerns the stability of the output level. In any test in which the contribution of the absolute level uncertainty of the signal generator contributes to the combined standard uncertainty of the test i.e. it does not cancel due to the methodology, the contribution from the output level stability is considered to have been included in the signal generator absolute output level, u_{j38}. Conversely, for any level in which the absolute level uncertainty of the signal generator does not contribute to the combined standard uncertainty, the output level stability of the signal generator should be included. The standard uncertainty of the contribution due to the signal generator output level stability is designated throughout all parts of the present document as u_{j39}. Its value can be derived from manufacturer's data sheet.

How to evaluate for free field test sites

Verification: The uncertainty contribution should be taken from the manufacturer's data sheet and converted into standard uncertainty if necessary.

Test methods: The standard uncertainty of the contribution due to the signal generator output level stability is taken as 0,00 dB as it is covered by the absolute level uncertainty.

D.10 Insertion losses

Test equipment components such as attenuators, cables, adapters, etc. have insertion losses at a given frequency that act as systematic offsets. Knowing the value of the insertion losses allows the results to be corrected by the offsets. However, there are uncertainties associated with these insertion losses that are equivalent to the uncertainty of the loss measurements.

u_{j40} *insertion loss: attenuator*

This uncertainty only contributes to test methods.

How to evaluate for free field test sites

Verification: This value is 0,00 dB.

Test methods:

- for the attenuator associated with the test antenna this uncertainty contribution is common to both stage one and stage two of the measurement. Consequently, this uncertainty contribution is assumed to be 0,00 dB due to the methodology;

- for the attenuator associated with the substitution or measuring antenna this uncertainty contribution is taken either from the manufacturer's data sheet or from the combined standard uncertainty figure of its measurement.

u_{j41} *Insertion loss: cable*

This uncertainty only contributes to the test methods.

How to evaluate for free field test sites

Verification: This value is 0,00 dB.

Test methods:

- for the cable associated with the test antenna, this uncertainty contribution is common to both stage one and stage two of the measurement. Consequently, it is assumed to be 0,00 dB due to the methodology.
- for the cable associated with the substitution or measuring antenna, this uncertainty contribution is taken either from the manufacturer's data sheet or from the combined standard uncertainty figure of its measurement.

u_{j42} *Insertion loss: adapter*

This uncertainty only contributes to the verification procedures.

How to evaluate for free field test sites

Verification: This uncertainty contribution is taken either from the manufacturer's data sheet or from the combined standard uncertainty figure of the loss measurement.

Test methods: Not applicable.

u_{j43} *Insertion loss: antenna balun*

This uncertainty contributes to test methods and verification procedures on free field test sites.

How to evaluate for free field test sites

Verification: The standard uncertainty of the contribution is 0,17 dB.

Test methods: The standard uncertainty of the contribution is 0,17 dB.

D.11 Antennas

Background: Antennas are used to launch or receive radiated fields on free field test sites. They can contribute to measurement uncertainty in several ways. For example, the uncertainty of the gain and/or antenna factor, the tuning, etc.

u_{j44} *Antenna: antenna factor of the transmitting, receiving or measuring antenna*

This uncertainty contributes to test methods and verification procedures on free field test sites. It is the uncertainty with which the antenna factor is known at the frequency of test.

How to evaluate for free field test sites

Verification: The antenna factor contributes only to the radiated part of this procedure. For ANSI dipoles the value should be obtained from table D.14. For other antenna types the figures should be taken from manufacturer's data sheets. If a figure is not given the standard uncertainty is 1,0 dB.

Table D.14: Uncertainty contribution: antenna: antenna factor of the transmitting, receiving or measuring antenna

Frequency	Standard uncertainty of the contribution
30 MHz ≤ frequency < 80 MHz	1,73 dB
80 MHz ≤ frequency < 180 MHz	0,60 dB
frequency ≥ 180 MHz	0,30 dB

Test methods: The uncertainty contribution should be taken from the manufacturer's data sheet and converted into standard uncertainty if necessary. If no value is given the standard uncertainty is assumed to be 1,0 dB.

u_{j45} ***Antenna: gain of the test or substitution antenna***

This uncertainty only contributes to test methods on free field test sites. It is the uncertainty with which the gain of the antenna is known at the frequency of test.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: For ANSI dipoles the value should be obtained from table D.15. For other antenna types the figures should be taken from manufacturer's data sheets. If a figure is not given the standard uncertainty is 1,0 dB.

Table D.15: Uncertainty contribution: antenna: gain of the test or substitution antenna

Frequency	Standard uncertainty of the contribution
30 MHz ≤ frequency < 80 MHz	1,73 dB
80 MHz ≤ frequency < 180 MHz	0,60 dB
frequency ≥ 180 MHz	0,30 dB

u_{j46} ***Antenna: tuning***

This uncertainty contributes to test methods and verification procedures on free field test sites. It is the uncertainty with which the lengths of the dipoles arms can be set for any test frequency.

How to evaluate for free field test sites

Verification: The standard uncertainty is 0,06 dB.

Test methods:

- In the test antenna case the uncertainty is equal in both stages of the test method so its contribution to the uncertainty is assumed to be 0,00 dB.

- In the substitution/measuring antenna case, the standard uncertainty is 0,06 dB.

D.12 Receiving device

Background: The receiving device (a measuring receiver or spectrum analyser) is used to measure the received signal level either as an absolute level or as a reference level. It can contribute uncertainty components in two ways: absolute level accuracy and non-linearity. An alternative receiving device (a power measuring receiver) is used for the adjacent channel power test method.

u_{j47} *Receiving device: absolute level*

This uncertainty contributes to test methods where the measurement of field strength is involved and the verification procedures where a range change to the receiving device's input attenuator occurs between the two stages of the procedure.

How to evaluate for free field test sites

Verification: The absolute level uncertainty is not applicable in stage one but should be included in stage two if the receiving device's input attenuator has been changed. This uncertainty contribution should be taken from the manufacturer's data sheet and converted if necessary.

Test methods: Only applicable in the electric field strength measurement stage for a receiving equipment. This uncertainty contribution should be taken from the manufacturer's data sheet and converted if necessary.

u_{j48} *Receiving device: linearity*

This uncertainty only contributes to the verification procedures.

How to evaluate for free field test sites

Verification: If the receiving devices input attenuator has been changed the value is 0,00 dB. If not, the value should be calculated from the manufacturer's data sheet e.g. a level variation of 62 dB gives an uncertainty of 0,62 dB at a linearity of 0,1 dB/10 dB. The uncertainty should be converted into standard uncertainty, assuming a rectangular distribution in logs.

Test methods: Not applicable.

u_{j49} *Receiving device: power measuring receiver*

This uncertainty only contributes to the transmitter adjacent channel power test method. There are three types of power measuring receiver, they are:

- an adjacent channel power meter;
- a spectrum analyser;
- a measuring receiver with digital filters.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: Contributions are the same as for the conducted case, see TR 100 028 [1] and [2].

D.13 Random uncertainty

u_{i01} *Random uncertainty*

This uncertainty contributes to all radiated tests. It is the estimated effect that randomness has on the measurement.

NOTE: It is important to identify whether this value (the random uncertainty) corresponds to the effect of other uncertainties already taken into account in the calculations (e.g. uncertainties due to the instrumentation) or whether this is a genuine contribution of randomness. Obviously there are uncertainties in all measurements, so it has to be expected that performing the same measurement a number of times may provide a set of different results. When a contribution due to randomness has to be taken into account, care should be taken to ensure the measurement conditions are kept constant, as far as possible, throughout the repetition of the measurements.

How to evaluate for free field test sites

Verification: Random uncertainty should be assessed by multiple measurements of the same measurand and treating the results statistically to derive the standard uncertainty of its contribution.

Test methods: Random uncertainty should be assessed by multiple measurements of the same measurand and treating the results statistically to derive the standard uncertainty of its contribution.

D.14 Summary, tables and figures

Table D.16: Mutual coupling and mismatch loss correction factors (Anechoic Chamber)

Frequency (MHz)	Range length 3 m		Frequency (MHz)	Range length 10 m
30	27,1		30	25,8
35	24,3		35	23,3
40	21,7		40	20,8
45	19,0		45	18,2
50	16,1		50	15,4
60	9,7		60	9,1
70	2,2		70	1,7
80	0,7		80	0,2
90	0,6		90	0,1
100	0,6		100	0,1
120	0,3		120	0,1
140	0,4		140	0,1
160	0,3		160	0,2
180	0,2		180	0,1

Table D.17: Mutual coupling and mismatch loss correction factors (over a ground plane)

	Horizontal polarization				Vertical polarization	
Freq. (MHz)	**3 m**	**10 m**		**Freq. (MHz)**	**3 m**	**10 m**
30	27,6	26,0		30	25,2	25,4
35	24,6	23,3		35	22,4	22,9
40	21,8	20,7		40	19,8	20,4
45	19,0	18,1		45	17,2	17,9
50	16,0	15,1		50	14,4	15,1
60	9,5	8,9		60	8,5	9,2
70	2,4	2,8		70	1,6	2,5
80	0,6	0,8		80	0,0	0,4
90	0,2	0,4		90	-0,2	0,1
100	-0,3	0,0		100	-0,6	0,0
120	-2,3	-1,2		120	-0,6	0,0
140	-1,0	-0,7		140	1,1	-0,1
160	-0,3	0,3		160	0,7	0,0
180	-0,3	0,3		180	0,3	0,0

Table D.18: Summary table of all contributions (numerical sort)

	Description
u_{j01}	*reflectivity of absorbing material: EUT to the test antenna*
u_{j02}	*reflectivity of absorbing material: substitution or measuring antenna to the test antenna*
u_{j03}	*reflectivity of absorbing material: transmitting antenna to the receiving antenna*
u_{j04}	*mutual coupling: EUT to its images in the absorbing material*
u_{j05}	*mutual coupling: de-tuning effect of the absorbing material on the EUT*
u_{j06}	*mutual coupling: substitution, measuring or test antenna to its image in the absorbing material*
u_{j07}	*mutual coupling: transmitting or receiving antenna to its image in the absorbing material*
u_{j08}	*mutual coupling: amplitude effect of the test antenna on the EUT*
u_{j09}	*mutual coupling: de-tuning effect of the test antenna on the EUT*
u_{j10}	*mutual coupling: transmitting antenna to the receiving antenna*
u_{j11}	*mutual coupling: substitution or measuring antenna to the test antenna*
u_{j12}	*mutual coupling: interpolation of mutual coupling and mismatch loss correction factors*
u_{j13}	*mutual coupling: EUT to its image in the ground plane*
u_{j14}	*mutual coupling: substitution, measuring or test antenna to its image in the ground plane*
u_{j15}	*mutual coupling: transmitting or receiving antenna to its image in the ground plane*
u_{j16}	*range length*
u_{j17}	*correction: off bore sight angle in the elevation plane*
u_{j18}	*correction: measurement distance*
u_{j19}	*cable factor*
u_{j20}	*position of the phase centre: within the EUT volume*
u_{j21}	*positioning of the phase centre: within the EUT over the axis of rotation of the turntable*
u_{j22}	*position of the phase centre: measuring, substitution, receiving, transmitting or test antenna*
u_{j23}	*position of the phase centre: LPDA*
u_{j34}	*ambient effect*
u_{j35}	*mismatch: direct attenuation measurement*
u_{j36}	*mismatch: transmitting part*
u_{j37}	*mismatch: receiving part*
u_{j38}	*signal generator: absolute output level*
u_{j39}	*signal generator: output level stability*
u_{j40}	*insertion loss: attenuator*
u_{j41}	*insertion loss: cable*
u_{j42}	*insertion loss: adapter*
u_{j43}	*insertion loss: antenna balun*
u_{j44}	*antenna: antenna factor of the transmitting, receiving or measuring antenna*
u_{j45}	*antenna: gain of the test or substitution antenna*
u_{j46}	*antenna: tuning*
u_{j47}	*receiving device: absolute level*
u_{j48}	*receiving device: linearity*
u_{j49}	*receiving device: power measuring receiver*
u_{j50}	*EUT: influence of the ambient temperature on the e.r.p. of the carrier*
uj_{51}	*EUT: influence of the ambient temperature on the spurious emission level*
u_{j52}	*EUT: degradation measurement*
u_{j53}	*EUT: influence of setting the power supply on the e.r.p. of the carrier*
u_{j54}	*EUT: influence of setting the power supply on the spurious emission level*
u_{j55}	*EUT: mutual coupling to the power leads*
u_{i01}	*Random (see note in clause D.18 of the present document and note in clause 6.4.7 of TR 102 273-1-1 [3])*

Table D.19: Summary table of all contributions (alphabetical sort)

	Description
u_{j34}	*ambient effect*
u_{j44}	*antenna: antenna factor of the transmitting, receiving or measuring antenna*
u_{j45}	*antenna: gain of the test or substitution antenna*
u_{j46}	*antenna: tuning*
u_{j19}	*cable factor*
u_{j18}	*correction: measurement distance*
u_{j17}	*correction: off bore sight angle in the elevation plane*
u_{j53}	*EUT: influence of setting the power supply on the e.r.p. of the carrier*
u_{j54}	*EUT: influence of setting the power supply on the spurious emission level*
u_{j50}	*EUT: influence of the ambient temperature on the e.r.p. of the carrier*
u_{j51}	*EUT: influence of the ambient temperature on the spurious emission level*
u_{j52}	*EUT: degradation measurement*
u_{j55}	*EUT: mutual coupling to the power leads*
u_{j42}	*insertion loss: adapter*
$u_{j}43$	*insertion loss: antenna balun*
u_{j40}	*insertion loss: attenuator*
u_{j41}	*insertion loss: cable*
u_{j35}	*mismatch: direct attenuation measurement*
u_{j37}	*mismatch: receiving part*
u_{j36}	*mismatch: transmitting part*
u_{j04}	*mutual coupling: EUT to its images in the absorbing material*
u_{j08}	*mutual coupling: amplitude effect of the test antenna on the EUT*
u_{j05}	*mutual coupling: de-tuning effect of the absorbing material on the EUT*
u_{j09}	*mutual coupling: de-tuning effect of the test antenna on the EUT*
u_{j13}	*mutual coupling: EUT to its image in the ground plane*
u_{j12}	*mutual coupling: interpolation of mutual coupling and mismatch loss correction factors*
u_{j11}	*mutual coupling: substitution or measuring antenna to the test antenna*
u_{j06}	*mutual coupling: substitution, measuring or test antenna to its image in the absorbing material*
u_{j14}	*mutual coupling: substitution, measuring or test antenna to its image in the ground plane*
u_{j10}	*mutual coupling: transmitting antenna to the receiving antenna*
u_{j07}	*mutual coupling: transmitting or receiving antenna to its image in the absorbing material*
u_{j15}	*mutual coupling: transmitting or receiving antenna to its image in the ground plane*
u_{j23}	*position of the phase centre: LPDA*
u_{j22}	*position of the phase centre: measuring, substitution, receiving, transmitting or test antenna*
u_{j20}	*position of the phase centre: within the EUT volume*
u_{j21}	*positioning of the phase centre: within the EUT over the axis of rotation of the turntable*
u_{i01}	*Random (see note in clause A.18 of the present document and note in clause 6.4.7 of TR 102 273-1-1 [3])*
u_{j16}	*range length*
u_{j47}	*receiving device: absolute level*
u_{j48}	*receiving device: linearity*
u_{j49}	*receiving device: power measuring receiver*
$u_{j}01$	*reflectivity of absorbing material: EUT to the test antenna*
u_{j02}	*reflectivity of absorbing material: substitution or measuring antenna to the test antenna*
u_{j03}	*reflectivity of absorbing material: transmitting antenna to the receiving antenna*
$u_{j}38$	*signal generator: absolute output level*
u_{j39}	*signal generator: output level stability*

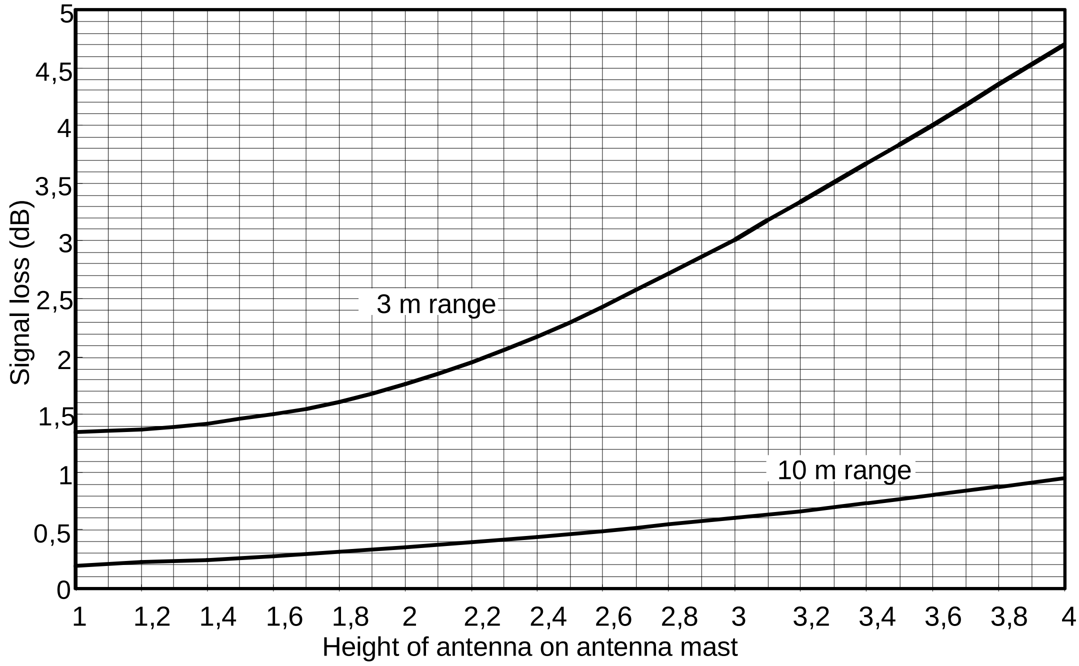


Figure D.7: Signal attenuation with increasing elevation offset angle

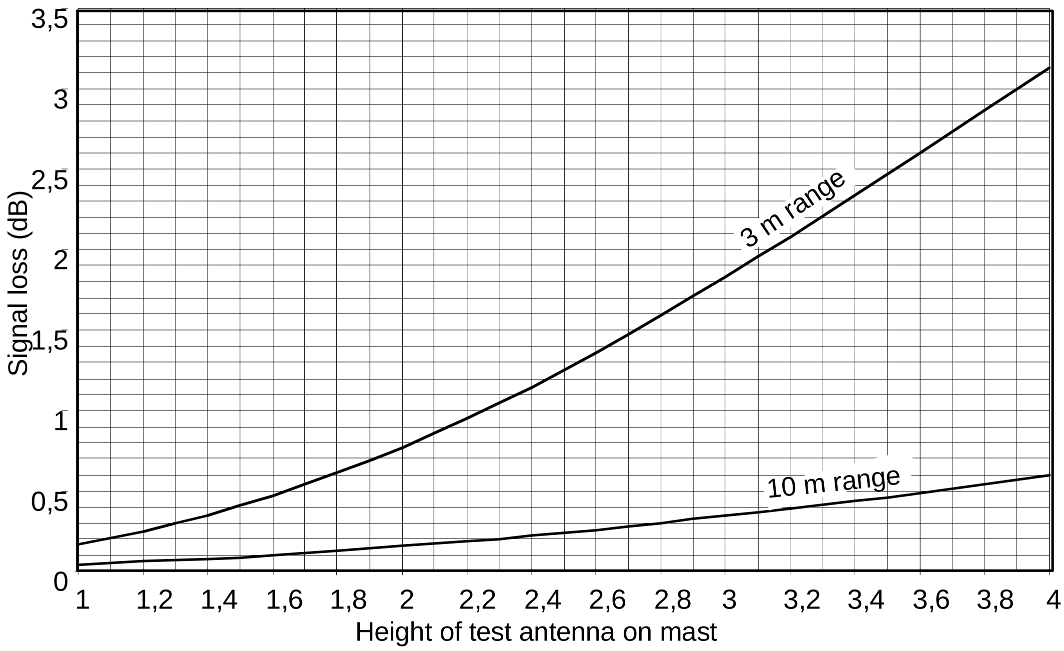


Figure D.8: Signal attenuation for antenna height on mast

Annex E (informative): Broadband Systems (BW > 10 MHz)

It is important to exactly know the details of the broadband modulation since the exact measurement equipment settings greatly affect the measurement value and related maximum expanded measurement uncertainty. Examples are the exact pulse bandwidth, exact FH FMCW, or multiple subcarrier parameters to ensure measurement at the right frequency at the right time (this is important for averaging). Otherwise, measurements performed at different labs will not really be comparable.

If the Measuring Receiver is capable of measuring the signals directly without any down mixing, a fundamental or harmonic Mixer adding additional measurement uncertainty can be omitted. Currently, it is unavoidable to perform measurements above 66 GHz with mixers. The measuring receiver may be a spectrum analyser, oscilloscope, selective power meter or any measuring receiver which is appropriate to perform the intended measurement.

The list below includes possible categories of parameters. Medium access mechanisms, generation of the emissions or the way the information is conveyed over the modulation is outside of this perspective: The applicable parameters have to be described accurately since it is otherwise not possible to make accurate calculations and comparisons regarding the maximum expanded measurement uncertainty.

- Time modulated/Impulse (carrier-less):
  - -simple short pulses whereby one can modify/modulate;
  - pulseform/pulseshape;
  - pulse duration;
  - pulse trains (i.e. number of pulses per burst);
  - pulse amplitude;
  - pulse position/spacing, time/pulse hopping, random pseudo-noise generation, dithering (intentional jitter);
  - direct sequence (generates UWB when performed quickly, typically pre-programmed);
  - or combinations of the above.
- Frequency modulated (carrier-based):
  - phase shift keying;
  - frequency hopping/stepping;
  - FMCW, can also be intermittent, i.e. pulsed or gated;
  - OFDM and similar (i.e. having multiple carriers/sub-carriers);
  - Random pseudo-noise generation, dithering or intentional pre-programmed direct sequencing can apply on all these carrier-based modulation schemes;
  - or combinations of the above, including complex time- and frequency modulated combinations.

Because of these possible combinations, the above categories are not exhaustive.

Annex F (informative): Overview of new standards at EHF frequencies using radiated measurements

Table F.1: Overview of new standards at EHF frequencies

	Operating frequency range	**ETSI standard**	**Spurious Emissions**
Long Range Radar 77 GHz	76 GHz to 77 GHz	EN 301 091 [25]	includes limit and measurement uncertainty up to 100 GHz
Short Range Radar 79 GHz	77 GHz to 81 GHz	EN 302 264 [26]	includes limit and measurement uncertainty up to 100 GHz
Non- specific Short Range Devices	up to 246 GHz	EN 305 550 [27]	limits up to 2nd harmonic, however measurement uncertainty only up to 100 GHz identified.
Tank Level Probing Radar (TLPR)	inter-alia 57 GHz to 64 GHz 75 GHz to 85 GHz	EN 302 372 [28]	limits up to 2nd harmonic, however measurement uncertainty only up to 100 GHz identified.
Level Probing Radars (LPR)	inter-alia 57 GHz to 64 GHz 75 GHz to 85 GHz	EN 302 729 [29]	limits up to 2nd harmonic, however measurement uncertainty only up to 100 GHz identified.
Intelligent Transport Systems (ITS)	63-64 GHz	EN 302 686 [30]	limits up to 2nd harmonic, however measurement uncertainty only up to 100 GHz identified.
MWGS	57-64 GHz	EN 302 567 [31]	up to 2nd harmonics (spurious limit in field strength and uncertainty limit); referring to 0 dBi antenna.

Annex G (informative): Bibliography

Guidelines to provide policy on the evaluation and reporting of measurement uncertainty for testing and calibration laboratories are laid down in several reference documents, some examples of them being listed below:

Directive 98/34/EC of the European Parliament and of the Council of 22 June 1998 laying down a procedure for the provision of information in the field of technical standards and regulations/as amended.

ETSI ETS 300 086 (1991): "Radio Equipment and Systems (RES); Land mobile group; Technical characteristics and test conditions for radio equipment with an internal or external RF connector intended primarily for analogue speech".

ETSI EN 300 086-1 (V1.2.1): "ElectroMagnetic Compatibility and Radio Spectrum Matters (ERM); Land Mobile Service; Radio equipment with an internal or external RF connector intended primarily for analogue speech; Part 1: Technical characteristics and methods of measurement".

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History

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