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Technical Report

Electromagnetic compatibility and Radio spectrum Matters (ERM); Recommended approach, and possible limits for measurement uncertainty for the measurement of radiated electromagnetic fields between 1 GHz and 300 GHz

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Foreword

This Technical Report (TR) 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 measurement uncertainty information above 1 GHz, and to determine practical maximum frequency of measurement which is also cost effective for manufacturers self declaration, and for test laboratories offering certification testing.

Considerable work on radio test methods and 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] to [2] and TR 102 273 [3] to [10].

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 method 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.

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 (under discussion to 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.

The present document does not attempt to repeat the detailed statistical methods to calculate measurement uncertainty that has already been extensively prepared in other ETSI deliverables. However, to assist test engineers to calculate their own measurement uncertainties associated with their particular test equipment configurations, a series of spread sheets are attached to the present document (see annex C).

1 Scope

The present document presents an evaluation of maximum acceptable measurement uncertainty for Radio Frequency (RF) electromagnetic field (emf) measurements above the frequency one gigahertz (1 GHz) for inclusion within ETSI harmonized standards and radio product standards used for compliance testing.

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

- radiated RF power;
- radiated spurious emissions; and
- EMC radiated emissions.

The maximum frequency recommendations are based upon current capabilities of measurement equipment *at May 2003* and the ability to calculate measurement uncertainty from traceable calibration certificates. Frequencies above the recommended maximum frequency for each method of measurement is for further study.

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

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 measurement uncertainty above 1 GHz.

In determining the maximum acceptable 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.

Whilst an analysis has been carried out on safety related measurements by ETSI, the responsibility for standards rests with CENELEC. The present document will include any recommendations from CENELEC TC 106X related to radiated measurements in a future edition.

Fixed link microwave methods of measurement do not use radiated measurements only conducted measurements (excepting EMC testing). Therefore they are considered outside the scope of the present document . However, as new technologies with integral antennas are being developed, this may be reviewed in a future edition.

Satellite equipment is outside the scope of the present document, however, this may be reviewed in a future edition.

The measurement uncertainty for conducted measurements is outside the scope of the present document.

The use of a test jig for radiated RF measurements of integral antenna radio equipment is outside the scope of the present document.

2 References

For the purposes of this Technical Report (TR), the following references apply:

[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.

[12] LAB34: "Measurement Traceability and Calibration in the Mechanical Testing of Metallic Materials".

[13] CISPR 16-4: "Specification for radio disturbance and immunity measuring apparatus and methods - Part 4: Uncertainty in EMC Measurements".

[14] Council Directive 83/189/EEC of 28 March 1983 laying down a procedure for the provision of information in the field of technical standards and regulations/as amended.

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

[16] 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".

[17] 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".

[18] ETSI EN 301 681 (V1.3.2): "Satellite Earth Stations and Systems (SES); Harmonized EN for Mobile Earth Stations (MESs) of Geostationary mobile satellite systems, including handheld earth stations, for Satellite Personal Communications Networks (S-PCN) in the 1,5/1,6 GHz bands under the Mobile Satellite Service (MSS) covering essential requirements under article 3.2 of the R&TTE Directive".

3 Definitions, symbols and abbreviations

3.1 Definitions

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

accuracy: in relation to the measured value, in clause 4.2; it has also been used in the rest of the document in relation to test instrumentation

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

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

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

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

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

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

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:

$$\sigma = \sqrt{\frac{Y - \frac{X^2}{n}}{n-1}}$$

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

error (of a measuring instrument): indication of a measuring instrument minus the (conventional) true value (see clause 4.2)

free field: field (wave or potential) which has a constant ratio between the electric and magnetic field intensities

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

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

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.

measurand: quantity subjected to measurement

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

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

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 measurand and the related measurement uncertainty)

uncertainty: parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to that measurement

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 (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

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

NOTE: This term is also known as "tolerance".

uncertainty (standard): for each individual uncertainty component, an expression characterizing the uncertainty for that component

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

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 which 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): expanded uncertainty is the 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).

3.2 Symbols

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

°C	degrees Centigrade
cms	centimetres
dB	deciBel
GHz	GigaHertz
MHz	MegaHertz
mV	milliVolt

3.3 Abbreviations

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

EIRP	Effective Isotropic Radiated Power
EMC	ElectroMagnetic Compatibility
emf	electromagnetic fields
EUT	Equipment Under Test
FCC	Federal Communications Commission
NRA	National Regulatory Authority
OATS	Open Area Test Site
R&TTE	Radio and Telecommunications Terminal Equipment (Directive)
RF	Radio Frequency
SDO	Standard Development Organization
UKAS	United Kingdom Accreditation Service

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

4.2 Accuracy of measurement

The term "accuracy of measurement" is defined by international agreement as:

- the closeness of the agreement between the result of a measurement and a true value of the measurand.

The full definition also states that accuracy is a qualitative concept and it can be attributed to be "high accuracy" or "low accuracy". In linguistic terms "accuracy" has a positive feeling and is easily accepted by engineers.

In practice, therefore, the definition is often redefined into a quantitative expression given as follows:

- the difference between a measurand and the true value expressed as "accurate to ±X".

This interpretation of the meaning immediately falls down for the reason given in clause 4.1, i.e. the true value is never known.

The use of the term "accurate to ±X" can also lead to confusion within the manufacturers organization, particularly in financial terms. Given that the reference standard states that the maximum acceptable measurement uncertainty is, lets say, ±6 dB, and an investment request is made for a measurement receiver. Manufacturers specifications for differently priced measurement receivers states accuracy for three instruments as ±2 dB, ±3 dB and ±4 dB at a price of 20 k Euros, 15 k Euros and 10 k Euros it is easy to see the equipment that the financial controller is prepared to pay for. However, the manufacturers specification only relates to the actual value measured at the cable entry point to his receiver and does not take into account all the other additional components which make up the total measurement uncertainty of the overall test set-up.

4.3 Measurement uncertainty

The term "measurement uncertainty" is defined by international agreement as:

- a parameter, associated with the result of a measurement, that characterizes the dispersion of values that could reasonably be attributed to the measurand.

This definition 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 lies between a range of values. In linguistic terms "uncertainty" has a negative feeling and is not easily accepted by engineers.

The calculation of uncertainty is, to say the least, complex, and the test engineer has to have extensive knowledge of the test system that is making the measurement, and, at the same time, have some reasonable knowledge of how the equipment under test should perform.

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.

The present document will use the previous work as reference to determine maximum acceptable measurement uncertainty to be used when measuring RF electromagnetic fields above 1 GHz.

Having surveyed a number of existing ETSI specifications where measurement uncertainty and accuracy are confused the following clauses attempt to clarify this situation.

5 Application of measurement uncertainty to specification limits

5.1 Introduction

ETSI developed an interpretation for the application of 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 (the measurand). If the measurand was equal to or below the limit the equipment was deemed to meet the requirement of the present document. However, the decision was not made by the test laboratory. The testing was subject to third party mandatory testing (which still exists in many countries around the world) and the decision as to compliance to the standard was made by the National Regulatory Authorities (NRA). The test laboratory was required to declare their 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 NRA accepted the risk that the product may exceed the limit specified in the standard, and the manufacturer accepted the risk that the product equalled or was below the limit specified in the present document.

This situation was acceptable to all parties, particularly to the test laboratories who had to declare their 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

Today (year 2003) there is no longer mandatory testing within the European Union. As a consequence of deregulation under the Radio and Telecommunications Terminal 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 has to state with confidence that his product meets the specification, whilst the test laboratory only states his measurement with an measurement uncertainty in a report.

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 measurement uncertainty exceeds the maximum acceptable 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 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 decides if a product meets or does not meet the essential requirements of the Directive. 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 should include maximum acceptable measurement uncertainty values for each test;

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

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

This approach combines the current documented solutions in CISPR, ETSI, and UKAS.

5.3.1 Maximum acceptable measurement uncertainty

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

The purpose of the table is to ensure that 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 measurement uncertainty for the measured value.

As frequency ranges increase it may be difficult to conclude a maximum allowable value for the measurement uncertainty due to lack of knowledge of the new methods of test and determining the uncertainty components. Therefore some flexibility should be allowed to deviate from the initially determined maximum allowable values and this is dealt with in clause 5.3.3.

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

The interpretation of the results when comparing 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 measurement uncertainty calculated by the test technician carrying out the measurement should be recorded in the test report;

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

5.3.3 Guidance on compliance assessment when measurement uncertainty is greater than maximum acceptable uncertainty

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

a) when the measured value plus the difference between the maximum allowable measurement uncertainty and the measurement uncertainty calculated by the test technician does not exceed the limit value the equipment under test meets the requirements of the standard;

b) when the measured value plus the difference between the maximum allowable measurement uncertainty and the measurement uncertainty calculated by the test technician exceeds the limit value the equipment under test does not meet the requirements of the standard;

c) the measurement uncertainty calculated by the test technician carrying out the measurement should be recorded in the test report;

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

6 The role of standards (or specifications)

6.1 Introduction

Continuing confusion exists due to the fact that the term "standard" has been misused within the telecommunications industry for many years by referring to such documents as "de facto" or "proprietary" standards, whilst the more formal definitions have been avoided. This clause outlines the principal definitions required to identify what is a "standard", and gives the priority by which standards are applied:

technical specification: A specification contained in a document which lays down the characteristics required of a product such as levels of quality, performance, safety or dimensions, including requirements applicable to the product as regards terminology, symbols, testing and test methods, packaging, marking or labelling.

standard: A technical specification approved by a recognized standardizing body *(e.g. European Telecommunications Standards Institute (ETSI))* for repeated or continuous application, with which compliance is not compulsory.

European standards: A standard which has been approved pursuant to the statutes of the standards bodies with which the Community has concluded agreements.

technical regulation: Technical specifications, including the relevant administrative provisions, the observance of which is compulsory, de jure or de facto, in the case of marking or use in Member States or a major part thereof, except those laid down by local authorities.

harmonized standard: Technical specifications (ENs or HDs) adopted by CEN/CENELEC or ETSI on a basis of a remit from the Commission in accordance with the provisions of Council Directives and in accordance with the General Guidelines.

The above definitions have been extracted from a number of European Directives related to the application of standards within the Community.

6.2 The players

In the field of telecommunications in Europe, and in a wider world-wide area, a number of players have an interest.

On an International scale the interests rest with ITU-T for general telecoms, and ITU-R for radio issues. ISO/IEC also have an interest in some areas.

Within Europe the interests rests with CEN/CENELEC and ETSI, being recognized as being competent to prepare European Standards. This recognition in the European Union is provided by the application of European Commission Directive 83/189/EEC [14].

For regulatory issues within the European Union a number of Directives are used, specifically related to telecommunications terminals. For the whole of Europe radio equipment interests are further represented by CEPT/ERC who have the responsibility for efficient use of the frequency spectrum and the allocation of specific frequency bands to be used for specific services and in some cases for specific equipment.

6.3 The drafting of standards

For any new radio technology, the drafting of standards for the EU is a joint effort between the Standard Development Organization (SDO) and the relevant CEPT Committee. The CEPT organization is responsible for the spectrum allocation, the controlled parameters, and efficient use of the frequency spectrum, whereas the SDO is responsible for the application of the CEPT recommendations within a standard. Outside the EU the relevant European National Administration works with CEPT and a National standards body or an SDO.

Compliance to the overall requirements given in a standard is demonstrated in a number of ways as defined in Community Directives for radio terminals, marine equipment, aeronautical equipment and automobile equipment.

Standards developed in the SDO committees are approved by consensus within the relevant Member States or directly by the SDO membership.

Outside the EU the National administration may chose to use a "Type Approval" regimen or adopt the EU compliance critia.

6.4 The content of standards

For compliance testing the standards contain specification limits, test methods, and compliance interpretation for the parameters considered to be required to manufacture a radio product and place it on the market. Recent changes to compliance testing requirements have already been alluded to, and as a consequence the content of a standard has to be clear and precise. Lack of precision in test methods can have serious consequences, leading to confusion within testing organizations and the inability to define associated measurement uncertainty of measurements made by the test laboratory.

Clause 9 of the present document further elaborates on the needs of test methods when related to measurement uncertainty.

6.5 Specification limits

The specification limits provided within standards are used to determine compliance with the requirements within the standard. These limits are derived in a number of ways; they are the result of spectrum studies undertaken by CEPT, recommendations from ITU-R that have been implemented by CEPT, decisions made in international standards produced by CISPR to name a few.

The limits derived for radio equipment parameters are different to those derived for EMC due to the different application of the measurement test methods. Radio parameters are defined as a radiated field strength value directly at the source and this is used to assess the protection to and from other radio services. EMC parameters are defined as a radiated field strength value at a distance from the source normally at a three metre or ten metre boundary.

The derivation of the specification limit has a direct impact on the measurement method, radio parameters are normally measured using substitution techniques whereas EMC test methods use a single measurement techniques. The consequence is that measurement uncertainty calculations contain different uncertainty contributions. This is reflected in the typical measurement uncertainty calculations given in annex B for what appears at first site as the same measurement.

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 which 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 which 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 which 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 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.

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 [15] for sites operating over the frequency range 30 MHz to 1 GHz. It should 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 sites 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 relies 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 [15], annex L.

7.2.1 Calibration of OATS

The calibration of an OATS is given in CISPR 16-1 [15], clause 5.6.6 as well as annex G. 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 recommended 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 [15], 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 measurement methods for the calibration of fully lined anechoic rooms, this has been left for further investigation and determination in a future version of the present document.

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. A procedure for the calibration of antennas is given in CISPR 16-1 [15], clause 5.13.

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 40 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 boresight 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 measurand 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 measurands 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 40 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 40 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 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 recommended values of maximum frequency and maximum allowable measurement uncertainty.

8.2 Substitution measurement methods

8.2.1 Effective Isotropic Radiated Power (EIRP) (radio)

- Maximum frequency = 40 GHz
- Maximum uncertainty = ±6 dB

For the calculation of this value see annex B.

8.2.2 Radiated spurious emissions (radio)

- Maximum frequency = 40 GHz
- Maximum uncertainty = ±6 dB

For the calculation of this value see annex B.

8.2.3 Receiver sensitivity (radio)

- Maximum frequency = 40 GHz
- Maximum uncertainty = ±6 dB

For the calculation of this value see annex B.

8.3 Single measurement methods

8.3.1 Radiated emissions (EMC)

- Maximum frequency 6 GHz
- Maximum uncertainty = ±6 dB

For the calculation of this value see annex B.

8.3.2 Radiated immunity (EMC)

- Maximum frequency 18 GHz
- Maximum uncertainty = ±6 dB

For the calculation of this value see annex B.

8.3.3 Radiated receiver blocking (radio)

- Maximum frequency 40 GHz
- Maximum uncertainty = ±6 dB

For the calculation of this value see annex B.

9 Controlling measurement uncertainty

This clause is reserved for further development in the next edition of the present document.

Annex A: 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 Interpretation of the measurement results (ETS 300 086 Edition 1)

The interpretation of the results recorded in a report for the measurements described in this standard shall be as follows.

The measured value related to the corresponding limit will be used to decide whether equipment meets the requirements of the standard.

The measurement uncertainty value for the measurement of each parameter shall be included in the report.

The recorded value of the measurement uncertainty shall be, for each measurement, equal to or lower than the figures in clause 10 (table of measurement uncertainty).

NOTE: This procedure for using Maximum Acceptable 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 this standard. Therefore the measurement uncertainty shall be used as a quality of the actual measurement. Accreditation Authorities can also use the Measurement Uncertainty values during their accreditation procedures to ensure compliance/conformity with the requirements of type testing to ETSI Standards.

A.2 Interpretation of the measurement results (EN 300 086-1 V1.2.1)

The following text is the interpretation given in EN 300 086-1 [17], clause 4.3.

The interpretation of the results (e.g. results recorded in a report) for the measurements described in the present document shall be as follows:

a) the measured value related to the corresponding limit shall be used to decide whether equipment meets the requirements for that parameter of the present document;

b1) the values of the actual measurement uncertainty shall be, for each measurement, equal to or lower than the figures given in clause 11 (maximum acceptable values of the measurement uncertainties);

b2) the actual measurement uncertainty of the laboratory carrying out the measurements, for each particular measurement, shall be included in the corresponding report (if any).

For the methods of measurement, according to the present document, the measurement uncertainty figures shall be calculated in accordance with TR 100 028 [1] to [2] and shall correspond to an expansion factor (coverage factor) k = 1,96 or k = 2 (which provide confidence levels of respectively 95 % and 95,45 % in the case where the distributions characterizing the actual measurement uncertainties are normal (Gaussian)).

The particular expansion factor used for the evaluation of the measurement uncertainty shall be stated.

A.3 Interpretation of the measurement results (EN 301 681 V1.3.2)

The following text is the interpretation given in EN 301 681 [18], clause 5.2.1.4.7.

The interpretation of the results for the measurements described in the present document shall be as follows:

a) the measured value related to the corresponding limit shall be used to decide whether an equipment meets the minimum requirements of the standard;

b) the actual measurement uncertainty of the test laboratory carrying out the measurement, for each particular measurement, shall be included in the report;

c) the values of the actual measurement uncertainty shall be, for each measurement, equal to or lower than the figures in clause 5.2.1.4.3.

Annex B: Examples of measurement uncertainty calculations

The examples in this annex reflect uncertainties gathered from test laboratory input, calibration uncertainties, examination of manufacturers specifications and the fixed values given in TR 102 273-1-2 [4].

The full calculation method is not shown in the following tables for simplicity. However, see annex C for the full calculation method.

The values given for overall measurement uncertainty are calculated for a confidence level of 95 % in each example unless otherwise stated.

Random uncertainty due to EUT performance has been excluded from the calculations on the basis that normally only one measurement is made. However, for measurements made close to the limit that invokes the need for a decision on compliance/non-compliance of the measured result, the random uncertainty should be included with a minimum of 10 measurements of the parameter. These results should be then used to calculate the new overall measurement uncertainty.

Not all the tables are yet complete, as the measurement methods are not yet stable. The next edition of the presently document will address these issues.

B.1 Effective Isotropic Radiated Power (EIRP) (radio)

Table B.1: Typical EIRP measurement uncertainty calculation

Source of uncertainty	Value	Standard uncertainty	Comments
Stage 1: EUT Measurement			
Influence of setting power supply	±100 mV	0,03	
Influence of the ambient temperature	±1 °C	0,20	
Mutual coupling to the power leads	0,00	0,00	Above 1 GHz no influence.
Position of the phase centre within the EUT volume	±5 %	0,25	For EUT dimensions < 30 cms.
Positioning of the phase centre within the EUT over the axis of rotation of the turntable	±3 cms	0,05	
Range length	±3 cms	0.05	
Curvature of the phase front EUT to test antenna		0,30	
Site Factors			
Ambient effect	0,10 dB		With EUT off , the noise receiver floor > 10 dB below the measured value.
Mutual coupling: amplitude effect of the test antenna on the EUT	0,00	0,00	Range length ≥ $2(d1+d2)^2/\lambda$.
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	0,00	0,00	Substitution method.
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.

Source of uncertainty	Value	Standard uncertainty	Comments
Test antenna			
Correction: measurement distance	0,00	0,00	Substitution method.
Correction: of boresight 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	
Site Factors			
Ambient effect		0,00	Assumes the use of 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	

Source of uncertainty	Value	Standard uncertainty	Comments
Correction off boresight 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.
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.
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, 95 % confidence)		3,52	

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 1: random uncertainty of the EUT;
- Stage 2: Mismatch uncertainty;
- Stage 2: Signal generator absolute power level; and
- Stage 2: Random uncertainty of the measurement system.

B.2 Radiated spurious emissions (radio)

Table B.2: Typical radiated spurious emissions measurement uncertainty calculation (under consideration)

Source of uncertainty	Value	Standard uncertainty	Comments

B.3 Receiver sensitivity (radio)

Table B.3: Typical receiver sensitivity measurement uncertainty calculation (under consideration)

Source of Uncertainty	Value	Standard uncertainty	Comments

B.4 Radiated field strength (EMC)

Table B.4: Typical radiated field strength measurement uncertainty calculation (at 3 m)

Source of uncertainty	Value	Standard uncertainty	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.

Source of uncertainty	Value	Standard uncertainty	Comments
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).
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, 95 %)		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 manufacturers 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 measurement uncertainty, see annex C.			

B.5 Radiated immunity (EMC)

Table B.5: Typical radiated immunity measurement uncertainty calculation (under consideration)

Source of uncertainty	Value	Standard uncertainty	Comments

B.6 Radiated receiver blocking (radio)

Table B.6: (under consideration)

Source of uncertainty	Value	Standard uncertainty	Comments

Annex C: Example EXCEL™ spreadsheets for calculation of measurement uncertainty

Spreadsheets are under preparation to assist the test engineer to calculate the measurement uncertainties of the different measure methods indicated in the present document. The spreadsheets will be attached to the present document in separate electronic files in the next edition.

History

Document history		
V1.1.1	August 2003	Publication