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Radio Equipment and Systems (RES); Uncertainties in the measurement of mobile radio equipment characteristics

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Contents

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Foreword

This ETSI Technical Report (ETR) has been prepared by the Radio Equipment and Systems (RES) Technical Committee of the European Telecommunications Standards Institute (ETSI).

In this second edition the area of data communication measurement uncertainties has been addressed and added to the analogue measurement uncertainties in the first edition of this ETR, in addition the diagrams have been standardised and minor editorial corrections have been carried out.

Introduction

This ETR has been written to clarify the many problems associated with the interpretation, calculation and application of measurement uncertainty.

This ETR is intended to provide, for relevant standards, the method of calculating the measurement uncertainty relating to type testing. This ETR is not intended to replace any test methods in the relevant standards although Clauses 6, 7 and 8 contain brief descriptions of each measurement.

This ETR is intended for use, in particular, by accredited test laboratories performing type testing.

The basic purpose of this ETR is to:

- provide the method of calculating the total measurement uncertainty;

- provide the maximum acceptable "window" of measurement uncertainty (see Annex A, table A.1), when calculated using the methods described in this ETR;

- provide the Equipment Under Test (EUT) dependency functions (see Annex C, table C.1) which should be used in the calculations unless these functions are evaluated by the individual laboratories;

- provide a recommended method of applying the uncertainties in the interpretation of the results (see Annex B).

Exact measurement of a quantity which can vary infinitesimally is an ideal which cannot be attained in practical work. Both science and industry assesses measurements which are always in error by an amount that may or may not be significant for the particular purpose in hand. Examples of such errors are:

a) that the measured value will be influenced by the operators, perhaps in a scale being misread;

b) the test configuration or test method, which may result in the measured value being biased in some way;

c) the test equipment used, which may be subject to several sources of error and may alter the value being measured simply by making the measurement (e.g. loading);

d) the environment, for example the humidity and the temperature;

e) the equipment under tests input and output impedances, transfer characteristics, stability etc.

A method is required to calculate the error of the measured value which takes into account:

- systematic errors, which are those errors inherent in the construction and calibration of the equipment used and in the method employed;

- random errors, which are errors due to chance events which, on average, are as likely to occur as not to occur and are outside the engineers control; and

- influence quantity errors, whose magnitude is dependant on a particular parameter or function of the EUT.

Error is usually taken to mean the difference between the measured value of a quantity and the true value. The error is something that can never be known exactly, generally the measurement would not be made if the true value was known.

The definition of absolute error is:

Absolute error = the measured value - the true value.

The true value (which is the ideal result) is not known, only the measured value, therefore the magnitude of the absolute error can never be known, and it is only possible to approximate the true value.

To estimate the amount of error in the approximation, a set of rules is needed to determine the value of the error.

In practice there usually is some idea of the size of the error inherent in the components of a system. No measuring equipment is perfect, so skill should be exercised in measurement and in the use of statistics to assess the probable limits of error, or the uncertainty. One method is by arithmetic summation, this method can be used to arrive at a range of values within which the result lies.

When, in a particular measurement system, the measured result is biased away from the true value, the mean value towards which several readings tend, is in error by a specific offset value. For example, when measuring RF power, the radio frequency attenuation of a connecting cable will consistently produce readings that are lower than the true value. The results are in error by the value of the RF attenuation of the cable.

This offset is a systematic error and if the attenuation is known the results can be corrected to eliminate this error.

Systematic errors are inherent in the construction and calibration of the equipment used and in the method employed. They cannot be measured by repeating the measurement under standard conditions.

The assessment of systematic uncertainty requires changes to be made to the measurement system. If, at the same laboratory using the same test configuration and the same test equipment, including the set up and breakdown of the test equipment, a measurement is repeated a number of times, assuming there is a sufficient resolution in the measurement system, the measured value will differ from one measurement to the next. This is known as repeatability and corresponds to random uncertainty. The mean value of the measurements will however converge to a particular value.

Random uncertainty can only be assessed if the measurement system is sufficiently sensitive and in a state of statistical control.

If unknown variations are occurring, the mean value of the measurement will drift and will not converge to any particular value making the exercise pointless.

The assessment of random errors requires that no changes will be made to the measurement system.

The measured value that differs from one measurement to another (assuming there is sufficient resolution) by using a different test equipment configuration, or different test equipment, or by comparison with another laboratory is known as reproducibility and should not be confused with repeatability.

A further uncertainty in the measurement process is the influence from quantities which are not directly related to the function or parameter being measured. These are known as influence quantities.

Influence quantities create errors whose magnitude is dependant on a specific parameter or function of the particular equipment under test and will vary between identically built standard equipments.

The influence functions have no connection with the test equipment, they do not change the random or systematic error of the measurement system but they do interact with the measurement system to produce influence uncertainties.

For example, consider the measurement of receiver sensitivity, where a SINAD meter, connected to the audio output is used to evaluate an RF sensitivity expressed in µV. The uncertainty in the measurement of the SINAD on the audio side of the receiver has at some point in time to be converted into an uncertainty in terms of µV at the RF input of the receiver. This conversion depends clearly on the characteristics of the receiver being measured, more specifically, of the slope Signal/Noise (S/N) as a function of Carrier/Noise (C/N) (see subclause 5.3).

The measurement conditions can also have an influence on the results. Consider, for example the heating effect of a continuous carrier on the output stage of a power amplifier in a transmitter. Assume the measurement system would measure carrier power to within 0,5 dB, but that the transmitter output power fell at the rate of 1,0 dB per minute. If the carrier power was measured at the instant of stabilising at full power (say less than one second after switching on) a particular value for the carrier power would be recorded. If however the measurement was performed two minutes after the switching on, then the carrier power would have been 2 dB lower than that found during the first case. Both have been measured with an accuracy of 0,5 dB but the results are in fact separated by 2 dB, and have an apparent conflict as the uncertainties of both measurements do not overlap.

As the time between turning on the transmitter and the measurement is not known exactly, this is an example of an influence uncertainty and, taken to its logical conclusion, does not satisfy the requirements of estimating for a random uncertainty as it is obvious that the mean of a series of measurements will not converge but will drift to zero or until the transmitter is destroyed.

The characteristics of the equipment can also change in time, due, for example, to the ageing of components e.g. crystals. The aim of the evaluation of measurement uncertainty is to ensure that at the time when a measurement is performed the measurement is within the an expected range of values. This does not imply, in all cases necessarily, that if the measurement was to be performed at another moment or by another laboratory the true value of the measurement would be the same, or lie within the measurement uncertainty of the first measurement.

Influence uncertainty is related to the parameters of the EUT, e.g. the input and output impedances, transfer characteristics, stability, sensitivity to changes in the environment etc. The dependencies can be evaluated for each equipment by the laboratories, or can be taken from table C.1 of this ETR. However arrived at, the magnitudes of the influence uncertainties should be included in the calculation of the total uncertainty for each measurement.

When estimating the measurement uncertainty by arithmetic summation, a pessimistic range of uncertainty limits are calculated. This is because the principle of summation corresponds to the case when all the error components act in the same direction at the same time. This approach gives the maximum and minimum error bounds with 100 % confidence.

To overcome this very pessimistic view of the uncertainty of measurement, the guidelines given in the reference documents (see Clause 2), have been adopted in this ETR.

These guidelines apply statistical analysis to the calculation of the overall probable error but relies on the knowledge of the magnitude and the distribution of the individual error components.

As a first principle, the following guidelines for reducing and estimating uncertainties in measurement should be used:

a) list the sources of error that could exist in the system;

b) separate the list into three parts: errors that are systematic errors, random (repeatability) errors, and human errors;

NOTE: Some of the sources may appear in more than one list.

c) examine carefully the procedure for reducing the probability of human errors (a typical one might be wrongly interpreting the manufacturers data); good documentation of results is essential;

d) make a first estimate of the uncertainties of the systematic errors; determine the distribution factors used in the combination and arrange the lists of systematic and random errors in order of importance;

e) consider the benefits of making a correction to a systematic error in order to reduce the systematic uncertainty, in some cases a systematic error correction may not be feasible;

f) where corrections have been made, revise the list for systematic uncertainties;

g) investigate repeatability; use previous experience to decide on how many samples should be made; the decision will depend, in part, on the relative size of the random errors and their distribution factors;

h) consider tightening the control of influence quantities; you should first make an assessment of the effect of each influence quantity; there is no point in making a negligible uncertainty even smaller, or in controlling an influence quantity which has very little, if any, effect on the measured quantity;

j) state clearly and explicitly all the assumptions in your calculations of uncertainty.

For further reading see the bibliography in Annex D.

The main advantage of this ETR is in the flexible approach that has been adopted; it is based on an "error budget" for each test. The budget is used to calculate the measurement uncertainty, which should be compared to the relevant figure in table A.1. The values in table A.1 have been set and should not be exceeded, but it is left to the individual as to how this is actually accomplished. More accurate test equipment will enable a more flexible approach whilst still remaining within the appropriate value, but it does not automatically exclude "less accurate" test equipment.

For this reason individual test equipment parameters are not specified. However, a test equipment performance for a specific parameter should be known, and including this value in the specific example will allow rapid assessment of the suitability for that particular task in relation to the other parameters. When selecting equipment that is suitable for making a particular measurement some points that should be taken into account are:

a) the test equipment measurement uncertainty is appropriate to the required uncertainty;

b) equipment resolution is appropriate to its uncertainty;

c) the overall measurement uncertainty is equal to, or better than that required by the appropriate standard;

d) equipment resolution is at least an order of magnitude better than the limits of measurement variation;

e) the number of measurements (n) should ideally be large enough so that the measurement (n+1) varies the mean value by less than the equipment resolution or one tenth of the maximum acceptable uncertainty stated by the specification.

Caution should be exercised when:

a) the measured parameter varies significantly from one measurement to the next;

b) the measurement system contains loose connections, poor loads, VSWR's or conditions which vary during the measurement.

Summarising, if the uncertainty (or error bound) of a particular parameter of an item of test equipment is known, and if its interaction within a test configuration is understood, the overall measurement error can be predicted by calculation and hence controlled.

Caution should be exercised in using calibration curves or figures. For example a particular manufacturer states an insertion loss of 6,0 ± 2 dB. The calibration curve states 6,5 dB ± 0,5 dB and the calibration curve figures are used in the calculation.

Subsequently, the previous three calibration reports (6 months interval) should be viewed which gives insertion losses as 6,5 dB ± 0,25 dB, 4,9 dB ± 0,25 dB and 7,2 dB ± 0,25 dB respectively. Obviously this equipment has insufficient stability to allow the uncertainty of ± 0,25 dB to be used.

As a conclusion, calibration curves should not be used unless they can be supported by historical evidence of the stability of the device.

This ETR has been produced, (and is to be used in conjunction with the appropriate standard, that references this ETR), to reconcile not only the foregoing but also the interpretation of the various elements that are required in assessing measurement uncertainty. This will ensure that there is a clear and harmonised approach to the assessment of measurement uncertainty.

On a final note it should be remembered that no matter how carefully a measurement is made, if the EUT is unrepresentative, the result will also be unrepresentative. Generally the EUT is a sample of one from an undefined population size and is subject to unknown statistical fluctuations.

The definitions, symbols and abbreviations used in this report are described in Clause 3. This was included to ensure that there shall be no other interpretation of their meaning. Measurement equipment requirements are detailed in Clause 4.

Clause 5 covers the calculations of measurement uncertainty, particular attention is drawn to subclause 5.1 which provides a general introduction to the calculation of measurement uncertainty, and includes details of some of the assumptions made and expansion of some of the definitions. Subclause 5.2 details specific examples, subclause 5.3 discusses noise behaviour in receivers, subclause 5.4 examines uncertainties in third order intermodulation rejection, subclause 5.5 discusses uncertainties in measuring continuous bit streams, subclause 5.6 discusses uncertainties in measuring messages. Subclause 5.7 is a detailed example of the calculation of the measurement uncertainty of a transmitter carrier power measurement.

Clause 6 contains worked examples of transmitter measurement uncertainty calculations. Clause 7 contains worked examples of receiver measurement uncertainty calculations. Clause 8 contains worked examples of duplex operation measurement uncertainty calculations.

Finally there are four annexes:

- Annex A, contains a table of maximum accumulated measurement uncertainty values;
- Annex B, describes how to interpret the measurement result;
- Annex C, contains a table of values of influence quantities;
- Annex D, contains the bibliography.

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1 Scope

This ETSI Technical Report (ETR) provides a method to be applied to all applicable European Telecommunication Standards (ETSs) and ETRs, and supports ETR 027 [1]. The following aspects relate to the measurements:

- the calculation of the total uncertainty for each of the measured parameters;
- recommended maximum acceptable uncertainties for each of the measured parameters;
- a method of applying the uncertainties in the interpretation of the results.

This ETR provides the methods of evaluating and calculating the measurement uncertainties and the required corrections on measurement conditions and results. These corrections are necessary in order to remove the errors caused by certain deviations of the test system due to its known characteristics (e.g. the RF signal path attenuation and mismatch loss, etc.).

2 References

Within this ETR the following references apply:

[1] ETR 027: "Methods of measurement for private mobile radio equipment".

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

[3] I-ETS 300 113: "Radio Equipment and Systems (RES); Land mobile service Technical characteristics and test conditions for non-speech and combined analogue speech/non-speech equipment with an internal or external antenna connector intended for the transmission of data".

[4] CEPT Recommendation T/R 24-01: "Specifications for equipments for use in the Land Mobile Service".

3 Definitions, symbols and abbreviations

3.1 Definitions

For the purpose of this ETR the following definitions apply.

Measurand: a quantity subjected to measurement.

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

Repeatability of measurements: the 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.