ETSI TECHNICAL REPORT

ETR 028

March 1994

Second Edition

Source: ETSI TC-RES

Reference: DTR/RES 02-10

ICS: 33.020

Key words: Mobile radio, testing, measurement uncertainty, analogue, data, conducted measurements

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

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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.

Reproducibility of measurements: the 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.

Uncertainty of measurement: an estimate characterising the range of values within which the true value of a measurand lies.

Part uncertainty: an estimate characterising one of the parts of a combination of individual uncertainties.

(Absolute) error of measurement: the result of a measurement minus the (conventional) true value of the measurand.

Random error: a component of the error of measurement which, in the course of a number of measurements of the same measurand, varies in an unpredictable way.

Systematic error: a component of the error of measurement which, in the course of a number of measurements of the same measurand remains constant or varies in a predictable way.

A systematic error is unchanged when a measurement is repeated under the same conditions, but it may become evident whenever the test configuration is changed. Thus, before a systematic error can be determined and afterwards corrected, it should be identified; that is, related to some part of the measurement apparatus or procedure. Then, a modification of the method or the apparatus may be made that will reveal the error, so that a correction can be applied. Often, it is not possible to determine a systematic error precisely. In these cases a systematic uncertainty is estimated.

An example of systematic error is the cable loss which may be measured at the relevant frequencies and allowed for in the measurements. Thus a signal generator output may be set 1 dB higher than the required level, if the connecting cable loss is known to be 1 dB.

However, the error in measuring the cable loss should be allowed for.

Correction: the value which, added algebraically to the uncorrected result of a measurement, compensates for assumed systematic error.

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

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

Accuracy of a measuring instrument: the ability of a measuring instrument to give indications approaching the true value of a measurand.

Limits of error of a measuring instrument: the extreme values of an error permitted by specifications, regulations etc. for a given measuring instrument.

NOTE 1: This term is also known as "tolerance".

Error of a measuring instrument: the indication of a measuring instrument minus the (conventional) true value.

Standard deviation of a single measurement in a series of measurements: the parameter characterising the dispersion of the result obtained in a series of n measurements of the same measured quantity, given by the formula:

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

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

Bit error ratio: the ratio of the number of bits in error to the total number of bits.

Standard deviation of the arithmetic mean of a series of measurements: the parameter characterising the dispersion of the arithmetic mean of a series of independent measurements of the same value of a measured quantity, given by the formula:

$$\sigma_r = \frac{\sigma}{\sqrt{n}}$$

where σ is an estimate of the standard deviation of a single measurement of the series and n the number of measurements in the series.

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

Range of uncertainty (confidence interval) of measurement: the value expressed by the formula 2kσ for a single measurement and by $2k\sigma_r$ for the arithmetic mean of a series of measurements. This corresponds to the statistical term "confidence interval".

NOTE 2: In this ETR the range of uncertainty is expressed as $\pm U_x$.

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

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

Influence quantity: a 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 or the value of the material measure reproducing the quantity.

Influence function: a function defining the influence of the "influence quantity" on the measurand.

Noise gradient of EUT: a function characterising the relationship between the RF input signal level and the performance of the EUT, e.g., the SINAD of the AF output signal.

3.2 Symbols

k	a factor from Student's t distribution
M_{iu}	Mismatch uncertainty
R_g	Reflection coefficient of the generator part of a connection
R_l	Reflection coefficient of the load part of the connection
σ	standard deviation
σ^n	the standard deviation of the n'th part uncertainty
σ_r	the standard deviation of the mean value of a series of measurements

σ_t	the standard deviation of the total accumulated error
σ_{n+}	if the standard deviation consists of two figures (one for the positive (or upper) part of the uncertainty and one for the negative (or lower) part the abbreviation has a sign, e.g. the standard deviation of the 5 part uncertainty is characterised by two figures: σ_{5+} and σ_{5-}
U_x	the uncertainty figure for the accumulated uncertainty corresponding to a confidence level of x %: $U_x = k \times \sigma_t$
SNR_b	Signal to Noise Ratio per bit
SNR_b*	SNR at a specific Bit Error Ratio
C_{cross}	cross correlation coefficient
$Pe_{(n)}$	Probability of error n
$Pp_{(n)}$	Probability of position n

3.3 Abbreviations

a	assumed
AF	Audio Frequency
BER	Bit Error Ratio
BIPM	the International Bureau of Weights and Measures (Bureau International des Poids et Mesures)
c	calculated on the basis of given and measured data
d	derived from a measuring equipment specification
EUT	Equipment Under Test
FSK	Frequency Shift Keying
GMSK	Gaussian Minimum Shift Keying
GSM	Global System for Mobile telecommunication (Pan European digital telecommunication system)
m	measured
p	power level value
r	indicates rectangular distribution
RF	Radio Frequency
RSS	Root-Sum-of-the-Squares
t	indicates triangular distribution
u	indicates U-distribution
VSWR	Voltage Standing Wave Ratio.

4 General requirements

4.1 Test environment

Measuring equipment should not be operated outside the manufacturer's stated temperature and humidity range.

4.2 Calibration

Measuring instruments and their associated components should be calibrated by an accredited calibration laboratory.

5 Calculation of measurement uncertainty

5.1 General

The method of calculating the total uncertainty of a measurement is to calculate the standard deviation for the distribution of the accumulated error. This method is known as the BIPM-method proposed by the International Bureau of Weight and Measures (IBWM).

It is assumed, that all errors are stochastic and the total error is Gaussian distributed. This is correct, when the total error is a combination of many individual errors, where the individual errors are not necessarily Gaussian distributed. Therefore it is possible to calculate the measurement uncertainty for a given confidence level. Calculating the standard deviation of the accumulated error is achieved by combining the standard deviations of the individual errors that contribute to the measurement uncertainty. Therefore the distribution functions of the individual errors should be known or assumed.

The standard deviation for the total accumulated error distribution corresponds to a confidence level of 68 %. It is then possible by means of Student's t function to calculate the measurement uncertainty for other confidence levels.

Both the standard deviation and Student's t factor and the confidence level should be stated in the test report to make it possible for the user of the measured results to calculate other uncertainty figures corresponding to other confidence levels.

5.1.1 Confidence level

Given that the distribution function of the accumulated error is a Gaussian function, the confidence level corresponding to the standard deviation is 68 %.

Calculating the measurement uncertainty corresponding to greater confidence levels is done by multiplying the standard deviation by Student's t factor, e.g. the factor corresponding to 95 % is 1,96, and the factor corresponding to 99 % is 2,58.

5.1.2 Error distributions and standard deviations

Systematic errors are, unless the actual distribution is known, assumed to have a rectangular distribution, which means, that the error can be anywhere between the error limits with equal probability. If the limits are ± a the standard deviation is $a/\sqrt{3}$ (r).

Random errors, e.g. noise, are normally Gaussian distributed. The Gaussian distribution is characterised by the standard deviation alone. This is known or calculated by means of repetitive measurements.

Mismatch errors and errors caused by temperature deviations around a mean temperature have a 'U' shaped distribution, which means that the error is more likely to be near the limits than to be small or zero. If the limits are ± a the standard deviation is $a/\sqrt{2}$ (u).

Some errors are triangularly distributed. If the limits are ± a the standard deviation is $a/\sqrt{6}$ (t).

All the measured results should be corrected for known errors so that the mean value of the error is zero.

5.1.3 Combining standard deviations

The calculation of the accumulated measurement uncertainty is achieved by combining the individual standard deviations by the Root-Sum-of-the-Squares (RSS) method. This is valid under the assumption that the measurement configuration (gains, attenuations, noise, non-linearities, calibration factors) are stochastic values, and that the final result of the measurement is the arithmetic summation of these values.

$$\sigma_t = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 +, \ldots\ldots\ldots, +\sigma_n^2} \quad (1)$$

NOTE: When a new formula is introduced in general terms it is marked with the appropriate number in brackets (n). Whenever there is a reference to this formula it is stated as formula (n).

If not all the distributions of the part uncertainties involved are symmetrical about zero, the calculation of s_t is divided in two parts, one for the positive part and one for the negative part:

$$\sigma_{t+} = \sqrt{\sigma_{1+}{}^2 + \sigma_{2+}{}^2 + \sigma_{3+}{}^2 +, \ldots\ldots\ldots, + \sigma_{n+}{}^2}$$

$$\sigma_{t-} = \sqrt{\sigma_{1-}{}^2 + \sigma_{2-}{}^2 + \sigma_{3-}{}^2 +, \ldots\ldots\ldots, + \sigma_{n-}{}^2}$$

where σ_t (σ_{t+}, σ_{t-}) is the standard deviation of the accumulated error and σ_1 (σ_{1+}, σ_{1-}) to σ_n (σ_{n+}, σ_{n-}) are the standard deviations for all the contributing errors.

The only exceptions to this formula are standard deviations which are closely correlated. Closely correlated standard deviations should be added before they are combined with the others. In measurements, where the result is found as a difference between two or more signals or two different levels of the same signal the uncertainty of the levels contributes separately unless there is a known correlation between the errors, e.g. two levels of the same signal generator at equal frequency in the same level range or with the same attenuator setting, in which case the contribution may be insignificant).

As the mathematics requires linear values (squaring of a term in dB is for example not defined) all figures shall be converted to linear voltage values before the formulas are applied.

If the upper and lower limits of an error contributing to the total uncertainty turns out to be different (which is the case if the limits of error are stated as ± a value in dB) the calculations should be carried out both for the upper and the lower limit of the total uncertainty.

For the purpose of the calculations it is assumed, that the distribution function is the same as before the conversion.

The standard deviation of the total uncertainty may then be converted from linear voltage values to dB or power terms if required.

Example 1: A part uncertainty is stated as ± 3 dB. This should be converted to percentage by means of the following formulas:

The upper limit = 100 x ($10^{3/20}$ - 1) % = + 41,25 % ; and

The lower limit = 100 x ($10^{-3/20}$ - 1) % = - 29,21 %.

Example 2: As uncertainty is stated as ± 3 % of the power measured by an instrument. The corresponding linear voltage values are:

the upper limit:

$$= 100 \times \left(\left(\sqrt{(1 + \frac{3}{100})} \right) - 1 \right) \% = +1{,}49\ \%$$

and,

the lower limit:

$$= 100 \times \left(\left(\sqrt{(1 - \frac{3}{100})} \right) - 1 \right) \% = -1{,}51\ \%$$

5.1.4 Combining uncertainties of different parameters, where their influence on each other is dependant on the device under test (influence quantities)

In many measurements the uncertainties of different measurement parameters influence the uncertainty of other parameters in an unknown manner that may depend either on the characteristics of the EUT or other instrumentation characteristics or both. All tests are carried out under specified standard conditions. Some standard signals may be applied to the EUT and some output parameters may be measured or the input signals may be varied in order to obtain a standard output.

It is not possible to fully characterise test conditions, signals and measurands. Uncertainties are related to each of them. These uncertainties may be well known, but their influence on the total accumulated measurement uncertainty depends on the EUT. Uncertainties related to general test conditions are:

- ambient temperature;
- the effect of cooling and heating;
- power supply voltage;
- power supply impedance;
- impedance of test equipment connectors (VSWR).

Uncertainties related to applied test signals and measured values are:

- level;
- frequency;
- modulation;
- distortion;
- noise.

Uncertainties that combine and influence the test results may vary from one EUT to another.

Examples of the characteristics that can affect the calculation of the uncertainties are as follows:

- receiver noise dependency of RF input signal levels;
- impedance of input and output connectors (VSWR);
- receiver noise distribution;
- performance dependency of changes of test conditions and test signals;
- modulator limiting function e.g. maximum deviation limiting;
- system random noise.

If the appropriate value for each characteristic has not been determined, the values listed in table C.1 should be used.

These figures are based on measurements from several equipments. They are stated as mean values associated with a standard deviation reflecting the spread from one EUT to another.

When the EUT dependent uncertainties add to the total uncertainty, the RSS method of combining the standard deviations is used, but in many calculations the EUT dependency is a function that converts uncertainty from one part of the measurement configuration to another. It is assumed that the function is linear, therefore the conversion is carried out by multiplication.

The standard deviation of the uncertainty is σ_1. The mean value of the factor is A and its standard deviation is σ_a.

The standard deviation σ of the converted uncertainty is:

$$\sigma = \sqrt{\sigma_1^2 \text{ x } \left(A^2 + \sigma_a^2\right)} \qquad (2)$$

The standard deviation is then looked upon as any other part uncertainty and is combined with the other uncertainties by means of the RSS method.

Example:

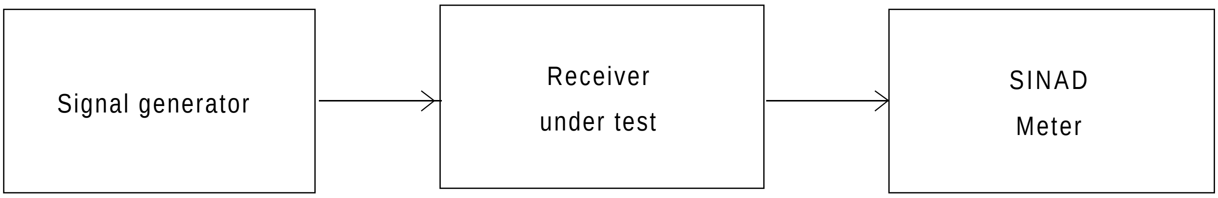


Figure 1: Receiver sensitivity measurement

A receiver sensitivity measurement is to be carried out. The RF level presented to the antenna connector of the receiver has an uncertainty which is rectangularily distributed between the limits ± 1 dB from the nominal. These limits are converted into linear voltage terms: +12,2 % and -10,9 % corresponding to the standard deviations σ_{1+} = 7,05 % and σ_{1-} = 6,28 %.

The SINAD measurement is carried out with an uncertainty of a standard deviation of σ_{2+} = 7,14 % and σ_{2-} = 6,40 %.

a) Sub carrier modulated above the knee point

See subclause 5.3.1 for the definition of knee point. The conversion factor (from table C.1) for sub carrier modulated above the knee point is characterised by the mean value 1,0 dB $_{\text{RF INPUT LEVEL}}$/dB$_{\text{SINAD}}$ and the standard deviation 0,2 dB$_{\text{RF INPUT LEVEL}}$/dB$_{\text{SINAD}}$. (Valid for both the positive and negative part of the uncertainty).

The SINAD uncertainty is then converted into RF level uncertainty (σ_3) thus:

$$\sigma_{3+} = \sqrt{(7{,}14\%)^2 \text{ x} \left(\left(1{,}0\ dB_{RF\ INPUT\ LEVEL} / dB_{SINAD}\right)^2 + \left(0{,}2\ dB_{RF\ INPUT\ LEVEL} / dB_{SINAD}\right)^2 \right)} = 7{,}28\ \% \qquad \text{formula (2)}$$

$$\sigma_{3-} = \sqrt{(6{,}40\%)^2 \text{ x} \left(\left(1{,}0\ dB_{RF\ INPUT\ LEVEL} / dB_{SINAD}\right)^2 + \left(0{,}2\ dB_{RF\ INPUT\ LEVEL} / dB_{SINAD}\right)^2 \right)} = 6{,}56\ \% \qquad \text{formula (2)}$$

The standard deviation σ_4 of the resulting level uncertainty is:

$$\sigma_4 = \sqrt{\sigma_1{}^2 + \sigma_3{}^2}$$

$$\sigma_{4+} = \sqrt{(7{,}05\ \%)^2 + (7{,}28\ \%)^2} = 10{,}13\ \% \qquad \text{formula (1)}$$

$$\sigma_{4-} = \sqrt{(6{,}28\ \%)^2 + (6{,}56\ \%)^2} = 9{,}08\ \% \qquad \text{formula (1)}$$

b) Sub carrier modulated below the knee point

See subclause 5.3.1 for the definition of knee point. The conversion factor (from table C.1) for sub carrier modulated below the knee point is characterised by the mean value 0,375 dB$_{\text{RF INPUT LEVEL}}$/dB$_{\text{SINAD}}$ and the standard deviation 0,075 dB$_{\text{RF INPUT LEVEL}}$/dB$_{\text{SINAD}}$. (Valid for both the positive and negative part of the uncertainty).

The SINAD uncertainty is then converted into RF level uncertainty (σ_3) thus:

$$\sigma_{3+} = \sqrt{(7{,}14\%)^2 \text{ x} \left(\left(0{,}375\ dB_{RF\ INPUT\ LEVEL} / dB_{SINAD}\right)^2 + \left(0{,}075\ dB_{RF\ INPUT\ LEVEL} / dB_{SINAD}\right)^2 \right)} = 2{,}73\% \qquad \text{formula (2)}$$

$$\sigma_{3-} = \sqrt{(6{,}40\%)^2 \text{ x} \left(\left(0{,}375\ dB_{RF\ INPUT\ LEVEL} / dB_{SINAD}\right)^2 + \left(0{,}075\ dB_{RF\ INPUT\ LEVEL} / dB_{SINAD}\right)^2 \right)} = 2{,}45\% \quad \text{formula (2)}$$

The standard deviation σ_4 of the resulting level uncertainty is:

$$\sigma_{4+} = \sqrt{(7{,}05\ \%)^2 + (2{,}73\ \%)^2} = 7{,}56\ \% \quad \text{formula (1)}$$

$$\sigma_{4-} = \sqrt{(6{,}28\ \%)^2 + (2{,}45\ \%)^2} = 6{,}74\ \% \quad \text{formula (1)}$$

5.1.5 Estimate of standard deviation of random errors

It is possible to estimate the standard deviation of a random error by repeating the measurement.

The first step should be to calculate the arithmetic mean or average of the result obtained.

The spread in the measured results, i.e. the range, reflects the merit of the measurement process and depends on the apparatus used, the method, and sometimes the person making the measurement. A more useful statistic, however, is the standard deviation of the sample s. This is the root mean square different from the arithmetic mean of the sample results. If there are n results for xm where m = 1,2,...,n and the sample mean x then standard deviation σ:

$$\sigma = \sqrt{\frac{1}{n} \text{ x} \sum_{m=1}^{n} \left(x_m - \overline{x}\right)^2} \quad (3)$$

If further measurements are made, then for each sample of results considered, different values for the arithmetic mean and standard deviation will be obtained. For large values of n these mean values approach a central limit value of a distribution of all possible values. This probability density can usually be assumed, for practical purposes, to have the Gaussian form.

From the results of a relatively small number of measurements an estimate can be made of the standard deviation of the whole population of possible values, of which the measured values are a sample, from the relation.

Estimate of the standard deviation σ':

$$\sigma' = \sqrt{\left(\frac{1}{n-1}\right) \text{ x} \sum_{m=1}^{n} \left(x_m - \overline{x}\right)^2} \quad (4)$$

A practical form of this formula is σ':

$$\sigma' = \sqrt{\frac{Y - \frac{X^2}{n}}{n-1}} \quad (5)$$

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

It will be noted that the only difference between σ' and σ is in the factor 1/(n-1) in place of 1/n, so that the difference becomes smaller as the number of measurements is increased.

When a measured results is obtained as the arithmetic mean of a series of n measurements the standard deviation is reduced by a factor √n thus:

$$\sigma_r = \frac{\sigma'}{\sqrt{n}} \quad (6)$$

This is an efficient method of reducing measurement uncertainty when making noisy or fluctuating measurements, and it applies both for random errors in the measurement configuration and the EUT.

As the uncertainty due to random errors is highly dependent on the measurement configuration and the test method used it is not possible to estimate a general value.

Each laboratory should by means of repetitive measurements, estimate their own standard deviations characterising the random uncertainties involved in each measurement.

Once having done this, the estimations may be used in future measurements and calculations.

5.2 Specific to radio equipment

5.2.1 Uncertainty in measuring attenuation

In many measurements the absolute level of the RF signal is part of the measured result. The RF signal path attenuation has to known in order to apply a systematic correction to the result.

The RF signal path may be characterised using manufacturers' information about the components involved, but this method normally causes unacceptable uncertainties.

An alternative method is to measure the attenuation directly, for example, by using a signal generator and a detector.

To measure the attenuation, connect the signal generator to the detector and read the reference level (A) and then insert the unknown attenuation, repeat the measurement and read the new level (B).

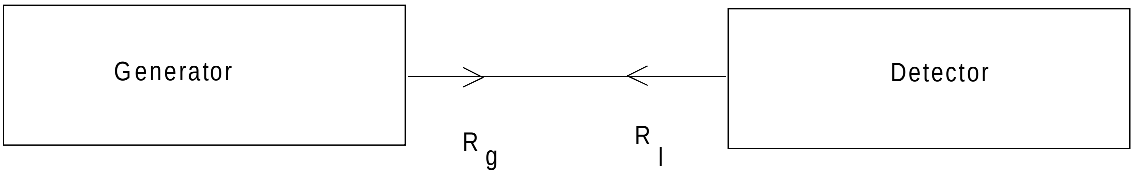


Figure 2: Measurement of level A

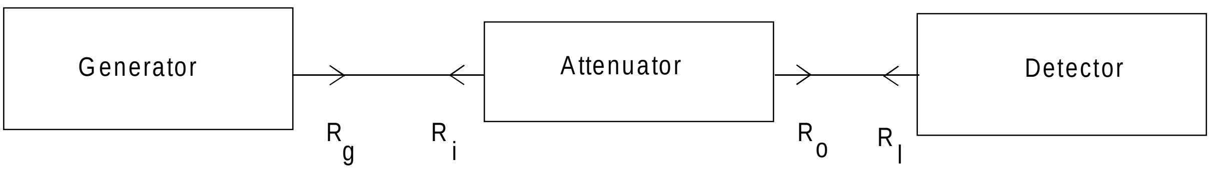


Figure 3: Measurement of level B

where:
- R_g is the complex reflection coefficient of the signal generator
- R_l is the complex reflection coefficient of the load
- R_i is the complex reflection coefficient of the attenuator input
- R_o is the complex reflection coefficient of the attenuator output

The attenuation is calculated as B/A if the readings are linear values or A-B if the readings are in dB.

Using this method two error sources occur. One is the linearity of the detector and the other is the mismatch uncertainties caused by reflections both at the terminals of the network under test and the instruments used.

The linearity may be obtained from the data sheets of the instruments, but the mismatch uncertainty should be estimated by calculation.

The mismatch error of the attenuation measurement may be evaluated by means of the following formula:

Error:

$$= \frac{1-\left(R_g \text{ x } R_1\right)}{1-\left(R_g \text{ x } R_i\right)-\left(R_I \text{ x } R_o\right)+\left(R_g \text{ x } \left(Att \text{ x } Att-\left(R_i \text{ x } R_o\right)\right)\right)} \qquad (7)$$

where Att is the linear value of the attenuation and R_g, R_l, R_i, R_o are the complex reflection coefficients at the signal generator output, the detector input and the input and output of the unknown network (as the attenuation is not exactly known, the measured linear value B/A must be used in the calculation).

If both the magnitude and the phase of each reflection coefficient were known the error could be calculated directly and the result corrected accordingly.

But normally only the magnitudes of the reflection coefficients are known from data or from measurements so the error limits must be found from formula (7).

When R_g and R_l are negative and R_i and R_o are positive the error is at its minimum value and when R_g and R_i are negative and R_l and R_o are positive the error is at the maximum value.

As the maximum value is slightly greater than the minimum value it is safe to consider the limits of error to be ± the maximum value. The error distribution (found by computer simulation) of the mismatch error is close to triangular.

The standard deviation is a/√6, where ± a are the limits.

The detector linearity and the mismatch uncertainty are then combined with the other errors by the normal RSS method.

Example:

An attenuator of nominal 20 dB is measured at 500 MHz by means of a signal generator and a measuring receiver. The reflection coefficient of the generator R_g is 0,2, the reflection coefficient of the measuring receiver R_l is 0,15 and the reflection coefficients of the attenuator R_i and R_o are 0,05.

The linearity uncertainty of the measuring receiver is ± 0,04 dB (d) corresponding to ± 0,46 %.

The signal generator is adjusted to 0 dBm and the reference level A is measured (as the receiver has a ratio function A = 0 dB).

The attenuator is then inserted and the level, B = - 20,2 dB, is measured.

The attenuation is then 20,2 dB. The linear value is 0,098. By means of formula (7) the error limits are found: (R_g = - 0,2, R_i = - 0,05, R_l = 0,15 and R_o = 0,05)

Max value:

$$\frac{1-\left(-0{,}2 \text{ x } 0{,}15\right)}{1-\left(-0{,}2 \text{ x } 0{,}05\right)-\left(0{,}5 \text{ x } 0{,}05\right)+\left(-0{,}2 \text{ x}\left(\left(0{,}098 \text{ x } 0{,}098\right)-\left(-0{,}05 \text{ x } 0{,}05\right)\right)\right)}$$

= 1,048 corresponding to limits of ± 4,8 %

The standard deviation of the total uncertainty:

$$\sigma_t = \sqrt{\frac{\left(0{,}46 \ \%\right)^2}{3}+\frac{\left(4{,}8 \ \%\right)^2}{6}} = 1{,}98 \ \%$$

This uncertainty may be reduced significantly by means of inserting attenuators with low reflection coefficients at the generator output and the receiver input.

If all reflection coefficients are 0,05 the corresponding uncertainty is reduced to σ_t = 0,42 %.

5.2.2 Mismatch uncertainty and mismatch loss

Mismatch uncertainty

Where two parts or elements in a measurement configuration are connected there will be a mismatch uncertainty of the level of the RF signal passing through the connection, because the matching is not ideal. The extent of the uncertainty depends on the VSWR of the two connectors connected together.

The error limits of the mismatch uncertainty, M_{iu} are calculated by means of the following formula:

$$M_{iu} = R_g \text{ x } R_I \text{ x } 100\ \% \qquad (8)$$

where R_g and R_l are the arguments of the reflection coefficients involved in the connection between the two components. (R_g is the generator part and R_l is the load part).

The distribution of the mismatch error is U-shaped, (see subclause 5.1.2). If M_{iu} is ± a, the standard deviation is $a/\sqrt{2}$.

For the calculation of mismatch uncertainty at the antenna connector of the EUT the reflection coefficient of the receiver or transmitter is required. Therefore the laboratory should either be able to measure it in advance or it should use the reflection coefficients given in table C.1.

As the reflection coefficients given in table C.1 each consist of a mean value and a standard deviation some additional calculation has to be done.

First the standard deviation from table C.1 should be normalised (divided) by the mean value. Then the uncertainty correction factor c (which is a function of the normalised standard deviation) is taken from the graph given in figure 4. (The graph of figure 4 is derived from computer simulations).

M_{iu} is then calculated by means of formula (8) (using the mean value from table C.1 and R_l).
Finally the standard deviation of the mismatch uncertainty is calculated:

$$\sigma = c \text{ x } \frac{M_{iu}}{\sqrt{2}} \qquad (9)$$

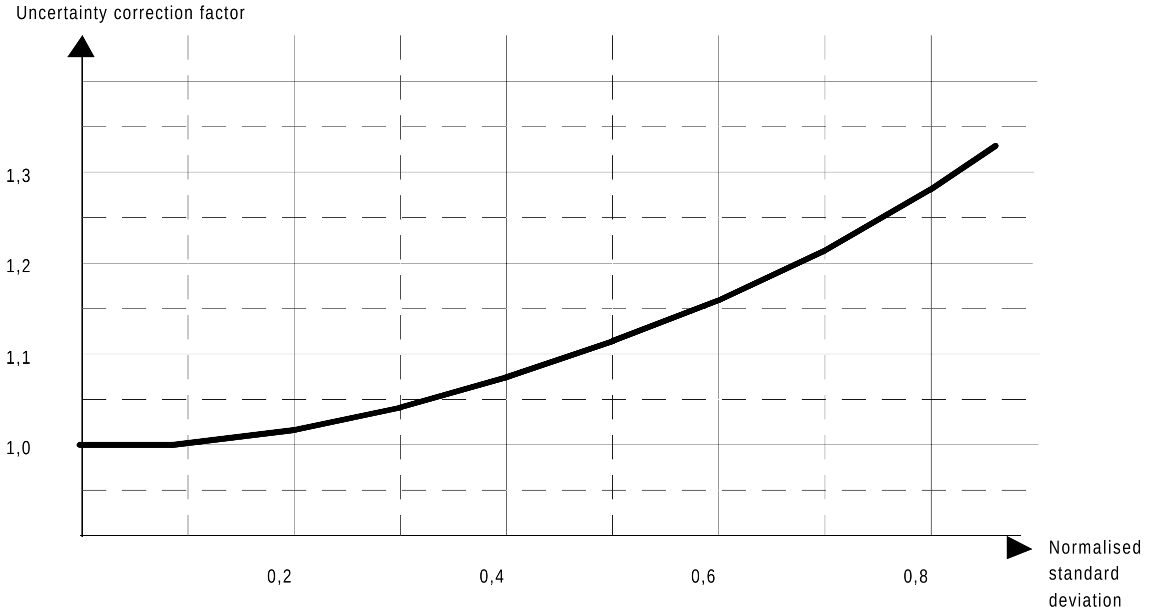


Figure 4: Correction factor against normalised standard deviation

Example:

The mismatch uncertainty at the antenna connector when measuring the carrier power is calculated as follows: The reflection coefficient of the input of the matching network is measured to be 0,1. The reflection coefficient of the EUT is characterised from table C.1 as mean value = 0,5 and standard deviation σ = 0,2.

M_{iu} = 0,1 x 0,5 x 100 % = 5,0 % formula (8)

$$\sigma = \frac{M_{iu}}{\sqrt{2}} \% \quad = \frac{5,0}{\sqrt{2}} \% = 3,54 \%$$

$$\sigma' = \frac{\sigma_{table\,c.1}}{m_{table\,c.1}} = \frac{0,2}{0,5} = 0,4$$

The uncertainty correction factor is found to be 1,075 by means of the graph given in figure 4. The standard deviation of the mismatch uncertainty:

$$\sigma_{miu} = 1,075 \text{ x } \frac{3,54 \%}{\sqrt{2}}$$ formula (9) 2,69 %

Mismatch loss

Where a 50 Ω source is connected to a not ideal termination, part of the power is reflected back into the source. The amount of reflected power (the mismatch loss) depends on the reflection coefficient of the termination or load.
Mismatch loss = 10 x log(1 - R_l^2) (10)
where R_l is the argument of the reflection coefficient of load.

In measurements where the level of the RF signal is part of the measured result the RF level should be corrected for mismatch loss. The only exception is the mismatch loss at the antenna connector of the EUT related to RF signals supplied to the EUT.

5.3 Noise behaviour in receivers

5.3.1 Possible front ends of receivers

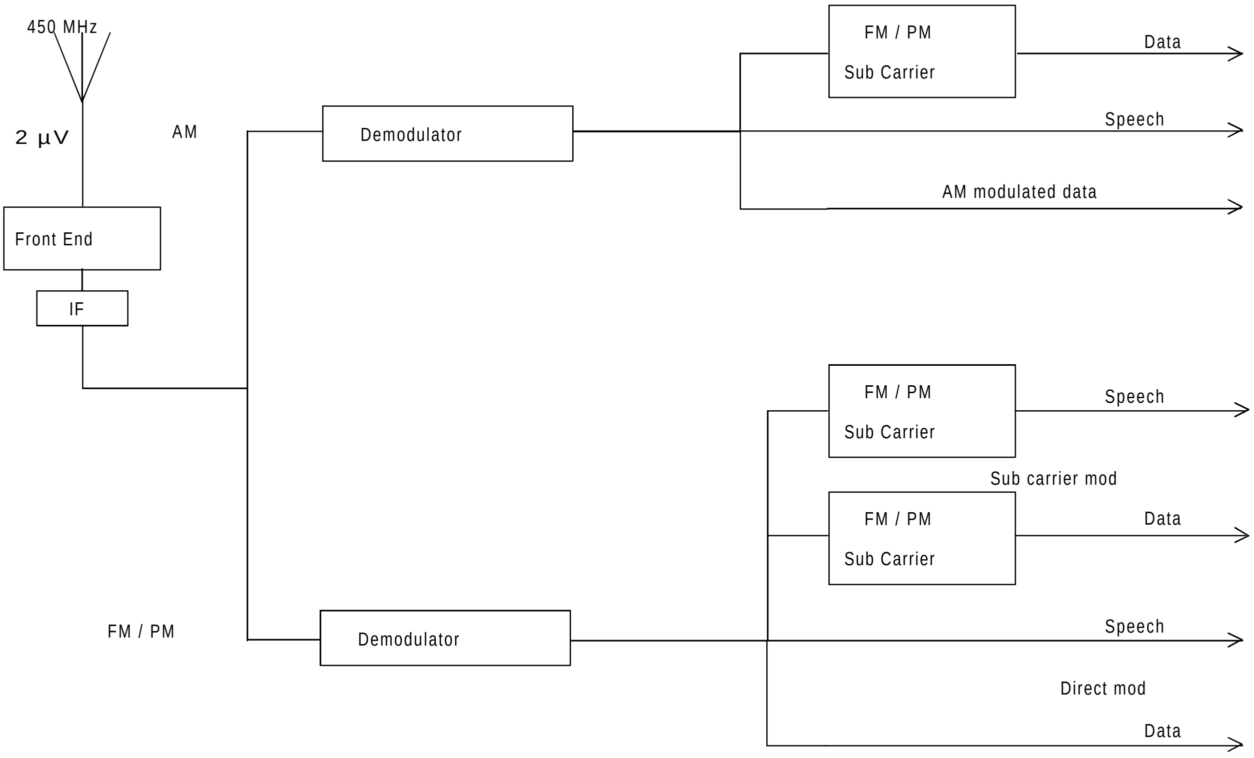


Figure 5: Possible front ends of receivers

The effect of noise on radio receivers is very dependant on the actual design. A radio receiver has (generally) a front end and demodulation stages according to one of the possibilities presented in figure 5. This simplified diagram (for AM and FM/PM systems) illustrates several possible routes from the front end to the "usable output".

The route involves a 1:1 conversion after the front end and the amplitude demodulation information is available immediately (analogue) or undergoes data demodulation.

The FM/PM route introduces an enhancement to the noise behaviour in non-linear (e.g. FM/PM) systems compared to linear (e.g. AM) systems, (see figure 6), until a certain threshold or lower limit is reached. Below this knee-point the signal to noise ratio degrades more rapidly for non-linear systems than the linear system for an equivalent degradation of the Carrier to Noise ratio (C/N), and this gives rise to two values for the slope, one value for C/N ratios above the knee and one value for C/N ratios below the knee.

A similar difference will occur in data reception between systems which utilise AM and FM/PM data. Therefore "Noise Gradient" corresponds to several entries in table C.1.

5.3.2 Uncertainties in measuring sensitivity in a receiver

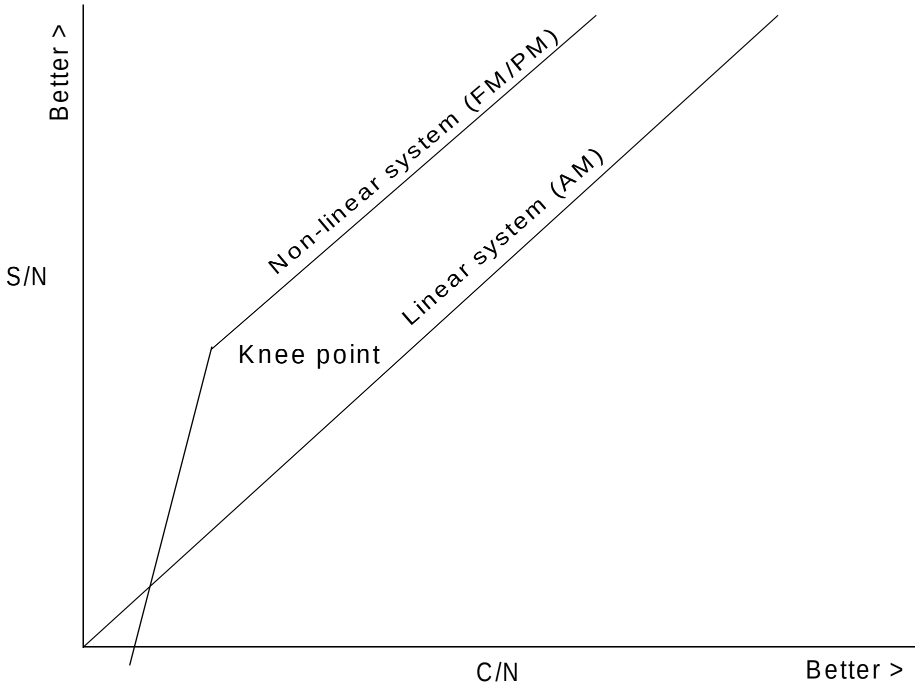


Figure 6: Noise behaviour in receivers

Sensitivity is normally stated as an RF input level.

For analogue systems this is stated as at a specified SINAD value, for continuous bit streams, at a specified bit error ratio, and, for messages at a specified message acceptance ratio.

For an analogue receiver, the dependency function to transform the SINAD uncertainty to the RF input level uncertainty is the slope of the noise function described above in subclause 5.3.2 and depends on the type of carrier modulation.

The dependency function involved when measuring the sensitivity of an FM/PM receiver is the noise behaviour usually below the knee-point for a non-linear system, in particular in the case of data equipment. This function also affects the uncertainty when measuring sensitivity of an FM/PM based data equipment.

This dependency function has been empirically derived at 0,375 $dB_{RF\ INPUT\ LEVEL}/dB_{SINAD}$ associated with a standard deviation of 0,075 $dB_{RF\ INPUT\ LEVEL}/dB_{SINAD}$ and is one of the values stated in table C.1

5.4 Uncertainty in measuring third order intermodulation rejection

5.4.1 Third order intermodulation mechanisms

When two unwanted signals X and Y occur at frequency distance d(X) and 2d(Y) from the receiving channel a disturbing signal Z is generated in the receiving channel due to non linearities in filters, amplifiers and mixers.

The predominant function is a third order function:

$$l_z = l_c + 2 \times l_\chi + l_y \qquad (11)$$

where l_z is the level of the intermodulation product Z, l_c is a constant, 1_x and l_y are the levels of X and Y. All terms are logarithmic.

5.4.2 Measurement of third order intermodulation rejection

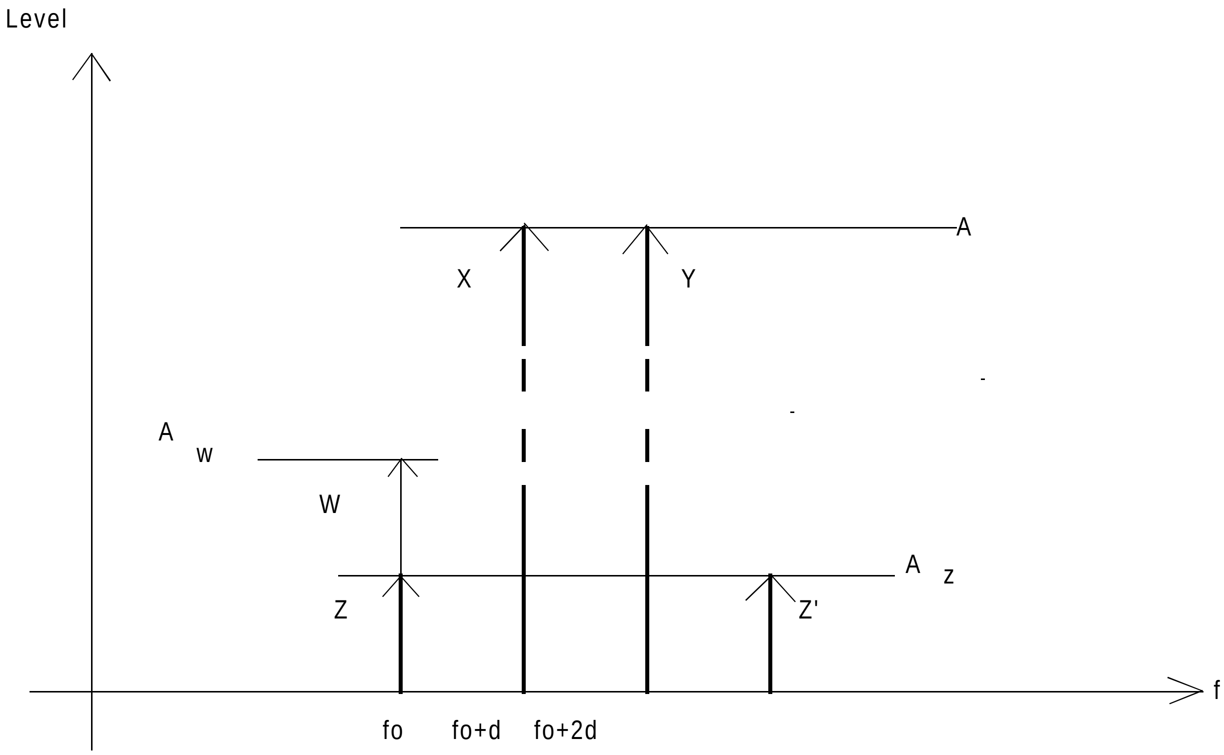


Figure 7: Third order intermodulation components

Three signal generators are connected to the input of the EUT.

Generator 1 is adjusted to a specified level at the receiving frequency of (the wanted signal W).

Generator 2 is adjusted to frequency fo+d (unwanted signal X) and generator 3 is adjusted to frequency fo+2d (unwanted signal Y). The level of X and Y (l_χ and l_y) are maintained equal during the measurement.

$l\chi$ and ly are increased to level A which causes a specified degradation of AF output signal.

The level of the wanted signal W is Aw (see figure 7).

The measured result is the difference between the level of the wanted signal Aw and the level of the two unwanted signals A. This is the ideal measurement.

5.4.3 Uncertainties involved in the measurement

The predominant error sources related to the measurement are the uncertainty of the levels of the applied RF signals and uncertainty of the degradation (the SINAD measurement). The problems about the SINAD uncertainty are exactly the same as those involved in the co-channel rejection measurement if the intermodulation product Z in the receiving channel is looked upon as the unwanted signal in this measurement. Therefore the noise gradient is the same, but due to the third order function the influence on the total uncertainty is reduced by a factor 3.

5.4.3.1 Uncertainty due to the signal level uncertainty of the two unwanted signals

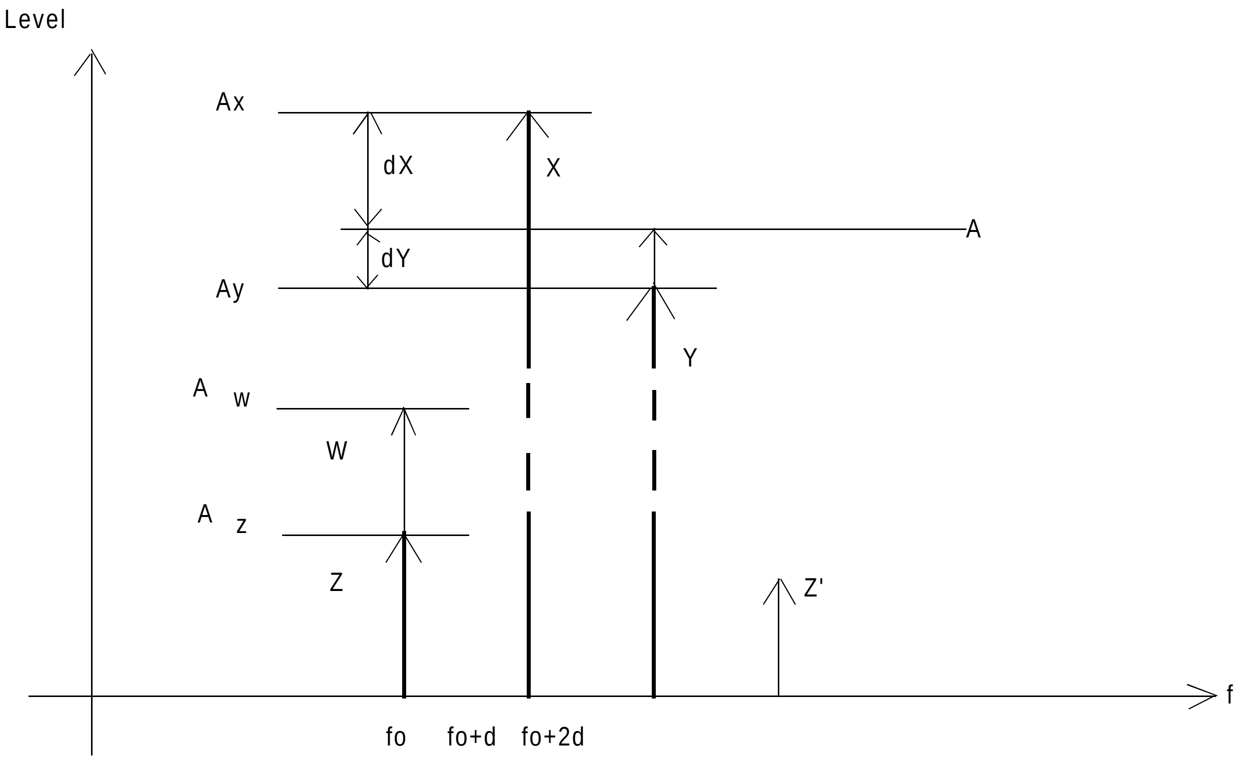


Figure 8: Level uncertainty of two unwanted signals

A is the assumed level of the two unwanted signals (the indication of the two unwanted signal generators).

A_x is the true level of X and A_y is the true level of Y. (A_x is A+dx and A_y is A+dy).
A_z is the level of Z (the same as in the ideal measurement).

If A_x and A_y were known the correct measuring result would be obtained by adjusting the two unwanted signals to the level A_t (true value) which still caused the level A_z of Z.

A change of the level of X causes the double change of the level of Z (in dB) while a change of the level of Y causes an equal change of the level of Z. Therefore:

$$A_t = A + \frac{2d_x}{3} + \frac{d_y}{3} \quad (12)$$

The difference A_t- A is the error of the measurement because dx and dy are not known, so A is the value used.

When looking at the problem in linear terms, formula (12) is valid for small values of dx and dy due to the fact that the higher order components of the third order function can be neglected.

dx and dy are the relative RF level errors at the input of the EUT. They are combinations of signal generator level uncertainty, matching network attenuation uncertainty and mismatch uncertainties at the inputs and the output of the matching network.

The standard deviations related to the uncertainties of the levels of X and Y are σ_x and σ_y.

The standard deviation σ1 related to the uncertainty caused by level uncertainty of the two unwanted signals are thus:

$$\sigma_1 = \sqrt{\left(\frac{2 \text{ x } \sigma_x}{3}\right)^2 + \left(\frac{\sigma_y}{3}\right)^2} \qquad (13)$$

5.4.3.2 Error caused by level uncertainty of the wanted signal

Under the assumption that equal change of both the level of the wanted signal and the intermodulation product will cause no change of the SINAD, the error contribution from the uncertainty of the level of the wanted signal may be calculated:

equal change of the level of the two disturbing signals causes 3 times this change in the level of the intermodulation product (valid for small changes).

Therefore if the error of the level of the wanted signal is dw, the error contribution to the measured results is:

$$\frac{2}{3} \text{ x } dw$$

Assuming the same types of errors as previous the standard deviation for this uncertainty σ_2 is:

$$\sigma_2 = \left(\frac{2 \text{ x} \sigma_w}{3}\right) \qquad (14)$$

where σ_w is the standard deviation of the level uncertainty of the wanted signal.

5.4.3.3 Error caused by SINAD measurement uncertainty

Under the assumption that only the intermodulation product in the receiving channel is degrading the signal, the figures from table C.1 can be used to transform the SINAD measurement uncertainty to a level uncertainty by means of formula (2) as described in subclause 5.1.4.

5.5 Uncertainty in measuring continuous bit streams

5.5.1 General

If the EUT is equipped with data facilities an important characteristic used to assess the performance of the equipment is the Bit Error Ratio (BER). The BER is the ratio of the number of bits in error to the total number of bits in a received signal and is a good measure of receiver performance in digital radio systems just as SINAD is a good measure of receiver performance in analogue radios. The BER measurements, therefore, are used in a very similar way to SINAD measurements, particularly in sensitivity and immunity measurements.

5.5.2 Statistics involved in the measurement

Data transmissions depend upon a received bit actually being that which was transmitted. As the level of the received signal approaches the noise floor (and therefore the signal to noise ratio decreases), the probability of bit errors (and the BER) increases. The first assumption for this statistical analysis of BER measurements is that each bit received (with or without error) is independent of all other bits received. This is a reasonable assumption for measurements on land mobile radios, using binary modulation, as all measurements are carried out in steady state conditions; (if for instance fading was introduced it would not be a reasonable assumption).

The measurement of BER is normally carried out by comparing the received data with that which was actually transmitted. The statistics involved in this measurement can be studied using the following population of stones: one black and (1/BER)-1 white stones. If a stone is taken randomly from this population, its colour recorded and the stone replaced N times, the black stone ratio can be defined as the number of occurrences of black stones divided by N. This is equivalent to measuring BER.

The statistical distribution for this measurement is the binomial distribution. This is valid for discrete events and gives the probability that _ samples out of N are black stones (or _ bits out of N received bits are in error):

$$P_{(x)} = \frac{N!}{x! \text{ x } (N-x)!} \text{ x } BER^{x} \text{ x } (1-BER)^{N-x} \qquad (15)$$

The mean value of this distribution is BER x N and the standard deviation is:

$$\sqrt{BER \text{ x } (1-BER)} \text{ x } \sqrt{N}$$

and for large values of N the shape of the distribution approximates a Gaussian distribution.

Normalising the mean value and standard deviation (by dividing by N) gives:

Mean value = BER (16)

$$\sigma = \sqrt{\frac{BER \text{ x } (1-BER)}{N}} \qquad (17)$$

From these two formulas it is easy to see that the larger number of bits, the smaller the random uncertainty, and the relation between number of bits and uncertainty is the same as for random uncertainty in general.

By means of formula (17) it is possible to calculate the number of bits needed to be within a specific uncertainty.

Example:

A BER in the region of 0,01 is to be measured.

a) If the standard deviation of the uncertainty, due to the random behaviour discussed above, should be 0,001, then the number of bits to be compared, N, in order to fulfil this demand is calculated from the rearranged formula (17);

$$N = \frac{BER \text{ x } (1 - BER)}{\sigma_{BER}{}^2} = \frac{0{,}01 \text{ x } 0{,}99}{0{,}001^2} = 9\ 900$$

b) If the number of bits compared, N, is defined, i.e. 2 500 then the standard deviation of the uncertainty is given directly by formula (17):

$$\sigma = \sqrt{\frac{0{,}01 \text{ x } (1 - 0{,}01)}{2\ 500}} = 0{,}002$$

5.5.3 Uncertainty caused by BER resolution

The resolution of the BER meter will have an effect on the error contribution and should be considered.

For example a meter has a resolution of 1 x 10^{-3} (the meter can resolve BER from 09 to 11 x 10^{-3} when the requirement is 10 x 10^{-3}). How much additional error does this resolution cause?

From the above calculations the error at:

09 x 10^{-3} gives 6,58 %   10 x 10^{-3} gives 6,93 %   11 x 10^{-3} gives 7,27 %

The variation of results is within 0,35 % which is less than 5 % of the total BER error of this step. The additional error can be considered to be negligible at this BER, at other BER or at other resolutions this may not be the case.

5.5.4 BER dependency functions

As in SINAD measurements, the BER of a receiver is a function of the signal to noise ratio of the RF signal at the input of the receiver.

Several modulation and demodulation techniques are used in data communication and the dependency functions are related to these techniques.

This subclause covers the following types of modulation:

- coherent modulation/demodulation of the RF signal;
- non coherent modulation/demodulation of the RF signal;
- FM modulation.

The following assumes throughout that the data modulation uncertainty combines linearly to the carrier to noise ratio uncertainty.

5.5.4.1 Coherent data communications

Coherent demodulation techniques are techniques which use absolute phase as part of the information. Therefore the receiver should be able to retrieve the absolute phase from the received signal. This involves very stable oscillators and sophisticated demodulation circuitry, but there is a gain in performance under noise conditions compared to non coherent data communication. Coherent demodulation is used in for example the GSM system with Gaussian Minimum Shift Keying (GUSK).

5.5.4.1.1 Coherent data communications (direct modulation)

The BER as a function of SNR_b, the signal to noise ratio per bit for coherent binary systems is:

$$BER(SNR_b) = 0{,}5 \text{ x } erfc(\sqrt{SNR_b}) \quad (18)$$

where erfc (x) is defined as

$$erfc(x) = \frac{2}{\sqrt{\Pi}} \text{ x } \int_{x}^{\infty} e^{-txt} dt \quad (19)$$

It is not possible to calculate the integral part of (19) analytically, but the BER as a function of the signal to noise ratio is shown on figure 9 together with the function for non coherent binary data communication.

There are different types of coherent modulation and the noise dependency of each varies, but the shape of the function remains the same. The slope, however, is easily calculated: (in fact the slope is negative, but the sign has no meaning for the following uncertainty calculations)

$$BER'(SNR_b) = \frac{1}{2 \text{ x} \sqrt{\Pi \text{ x } SNR_b}} \text{ x } e^{-SNR_b} \quad (20)$$

The SNR_b* at a specific BER can be read from the function shown in figure 10. This SNR_b* is then applied to formula (20).

If the purpose is to transform RF input level uncertainty to BER uncertainty the standard deviation of the level uncertainty is multiplied with BER'(SNR_b*)

$$\sigma_{BER} = BER'(SNR_b *) \text{ x } \sigma_{level} \quad (21)$$

If the aim is to transform BER uncertainty to level uncertainty - which is the most likely case in PMR measurements, the inverse dependency function must be used (the result is in percentage power terms as it is normalised by division with SNR_b*):

$$\sigma_{level} = \left[\frac{\sigma_{BER}}{BER'(SNR_b *) \text{ x } SNR_b *} \right] \text{x } 100\,\% \quad (22)$$

Before it can be combined with the other part uncertainties at the input of the receiver it must be transformed to linear voltage terms.

Example:

The sensitivity of a receiver is measured. The RF input level to the receiver is adjusted to obtain a BER of 10^{-2}. The measured result is the RF level giving this BER. The BER is measured over a series of 2 500 bits. The uncertainty of the RF signal at the input is 5,0 % (σ). The resulting BER uncertainty is then calculated using formula (17):

$$\sigma_{BER} = \sqrt{\frac{0{,}01 \text{ x } (1 - 0{,}01)}{2\,500}} = 2{,}0 \text{ x } 10^{-3}$$

The signal to noise ratio giving this BER is then read from figure 10: $SNR_b(0,01) = 2,8$ and the dependency function at this level is

$$BER'(2,8) = \frac{1}{2 \text{ x } \sqrt{\Pi \, x \, 2,8}} \text{ x } e^{-2,8} = 10,25 \text{ x } 10^{-3}$$

The BER uncertainty is then transformed to level uncertainty using formula (22):

$$\sigma_{level} = \left[\frac{2,0 \text{ x } 10^{-3}}{10,25 \text{ x } 10^{-3} \, x \, 2,8} \right] \text{ x } 100 \ \% = 6,97 \, \% \, (p)$$

which is equal to 3,43 % (σ) in voltage terms. This RF level uncertainty is then combined with the rest of the part uncertainties to give the total RF level uncertainty:

$$\sigma_t = \sqrt{(5,0^2 + 3,43^2} = 6,06$$

5.5.4.1.2 Coherent data communications (sub carrier modulation)

If a sub carrier frequency modulation is used in the data communication the functions related to direct coherent data communication apply, but in this case they give the relationship between BER and the signal to noise of the sub carrier. To be able to transform BER uncertainty of RF input level uncertainty the relationship between the sub carrier to noise ratio and the RF carrier signal to noise ratio is calculated.

If the BER is measured at a RF level much higher than the sensitivity this relation is assumed to be 1:1 as described in subclause 5.3.2.

In FM systems, if the BER is measured in the sensitivity region (below the knee point) the relationship as for analogue receivers is assumed and the same value taken from table C.1. 0,375 $dB_{RF\ INPUT\ LEVEL}/dB_{SINAD}$ and standard deviation 0,075 $dB_{RF\ INPUT\ LEVEL}/dB_{SINAD}$. (see subclause 5.3.2)

Example:

This sensitivity of an FM receiver is measured. The RF input level to the receiver is adjusted to obtain a BER of 10^{-2}. The measured result is the RF level giving this BER. The BER is measured over a series of 2 500 bits. The uncertainty of the RF signal at the input is 5,0 % (σ). The resulting BER uncertainty is then calculated using formula (17):

$$\sigma_{BER} = \sqrt{\frac{0,01 \text{ x } 0,99)}{2\,500}} = 2,00 \text{ x } 10^{-3}$$

The signal to noise ration giving this BER is then read from figure 10: $SNR_b(0,01) = 2,8$
The dependency function at this level is

$$BER'(2,8) = \frac{1}{2 \text{ x } \sqrt{\Pi \text{ x } 2,8}} \text{ x } e^{-2,8} = 10,25 \text{ x } 10^{-3}$$

The BER uncertainty is then transformed to level uncertainty using formula (22):

$$\sigma_{level} = \left[\frac{2,0 \text{ x } 10^{-3}}{10,25 \text{ x } 10^{-3} \text{ x } 2,8} \right] \text{ x } 100 \ \% = 6,97 \ \% \left(p \right)$$

which is equal to 3,43 % (σ) in voltage terms.

This uncertainty is then by means of formula (2) and the relationship taken from table C.1. converted to RF input level uncertainty:

$$\sigma_{level} = \sqrt{0,5^2 \text{ x } ((0,375\, dB_{RF\ INPUT\ LEVEL} / dB_{SINAD})^2 + (0,075\, dB_{RF\ INPUT\ LEVEL} / dB_{SINAD})^2)} = 1,31\%$$

NOTE: As the uncertainty is small the dependency function can be used directly without transforming to dB.

This RF level uncertainty is then combined with the uncertainty of the level of the input signal to obtain the total uncertainty of the sensitivity:

$$\sigma_t = \sqrt{(5,0\ \%)^2 + (1,31\ \%)^2} = 5,17\ \%$$

5.5.4.2 Non coherent data communication

Non coherent modulation techniques disregard absolute phase information. Communications based on non-coherent modulation tend to be more sensitive to noise, and the techniques used may be much simpler. A typical non coherent demodulation technique is used with FSK, where only the information of the frequency of the signal is required.

5.5.4.2.1 Non coherent data communications (direct modulation)

The cross correlation coefficient c_{cross} of two FSK signals with frequency separation fδ and the bit time T is:

$$\left|C_{cross}\right| = \left|\frac{\sin(\Pi \text{ x } T \text{ x } f_\delta)}{\Pi \text{ x } T \text{ x } f_\delta}\right| \quad (24)$$

It is assumed that the cross correlation coefficient for land mobile radio systems is so small that the formulas for c_{cross}= 0 apply, and as c_{cross} is 0 the BER, as a function of the SNR_b for non coherent modulation is:

$$BER(SRN_b) = \frac{1}{2} \text{ x } e^{-\frac{SNR_b}{2}} \quad (25)$$

The slope of the function (in fact the slope is negative, but the sign is of no interest for the uncertainty calculation). The BER(SNR_b) function for non coherent data communication is shown in figure 9.

The inverse function SNR_b(BER) = -2 x ln(2 x BER) (26)

From (26) the slope SNR_b(BER) is:

$$SNR_b'(BER) = -\frac{2}{BER} \quad (27)$$

The slope of the function is the inverse of (27): BER'(SNR_b) = 0,5 x BER

The SNR_b* can be calculated by means of formula (26) or read from the function shown in figure 7.
The SNR_b* is then applied to formula (27). If the purpose is to transform RF input level uncertainty to BER uncertainty formula (21) is used.

$$\sigma_{BER} = BER'(SNR_b\, *) \text{ x } \sigma_{level}$$

If the aim is to transform BER uncertainty to level uncertainty - which is generally the case in PMR measurements, formula (22) is used.

$$\sigma_{level} = \frac{\sigma_{BER}}{BER'\left(SNR_b *\right) \text{ x } SNR_b *}$$

Before it can be combined with the other part uncertainties at the input of the receiver it should be transformed to linear voltage terms.

Example:

The sensitivity of a receiver is measured. The RF input level to the receiver is adjusted to obtain a BER of 10^{-2}. The measured result is the RF level giving this BER. The BER is measured over a series of 2 500 bits. The uncertainty of the RF signal at the input is 5,0 % (σ).

The resulting BER uncertainty is then calculated using formula (17):

$$\sigma_{BER} = \sqrt{\frac{0{,}01 \text{ x } 0{,}99}{2\,500}} = 2{,}00 \text{ x } 10^{-3}$$

The signal to noise ratio giving this BER is then calculated using formula (17).

$SNR_b(0{,}01) = -2 \text{ x } \ln(2 \text{ x } 0{,}01) = 7{,}824$

The dependency function at this level is

BER'(7,824) = 0,5 x 0,01 (formula (27))

The BER uncertainty is then transformed to level uncertainty using formula (22):

$$\sigma_{level} = \left[\frac{2{,}00 \text{ x } 10^{-3}}{0{,}5 \text{ x } 10^{-2} \text{ x } 7{,}824}\right] \text{ x } 100\,\% = 5{,}11\,\% \ (p)$$

which is equal to 2,52 % (σ) in voltage terms.

This RF level uncertainty is then combined with the rest of the part uncertainties to give the total RF level uncertainty.

$$\sigma_t = \sqrt{(5{,}0\,\%)^2 + (2{,}52\,\%)^2} = 5{,}60\,\%$$

5.5.4.2.2 Non coherent data communications (sub carrier modulation)

If a sub carrier frequency modulation is used in the data communication the functions related to direct coherent data communication apply, but in this case they give the relationship between BER and the signal to noise of the sub carrier. To be able to transform BER uncertainty to RF input level uncertainty the relationship between the sub carrier signal to noise ratio and the RF carrier signal to noise ratio should be calculated.

If the BER is measured at a RF level much higher than the sensitivity this relation is assumed to be 1:1 as described in subclause 5.3.2.

In FM systems, if the BER is measured in the sensitivity region (below the knee point) the relationship as for analogue receivers is assumed and the same value taken from table C.1. 0,375 $dB_{RF\ INPUT\ LEVEL}/dB_{SINAD}$ and standard deviation 0,075 $dB_{RF\ INPUT\ LEVEL}/dB_{SINAD}$. (see subclause 5.3.2)

Example:

The sensitivity of an FM receiver is measured. The RF input level to the receiver is adjusted to obtain a BER of 10^{-2}. The measured result is the RF level giving this BER. The BER is measured over a series of 2 500 bits. The uncertainty of the RF signal at the input is 5,0 % (σ).

The resulting BER uncertainty is then calculated using formula (17):

$$\sigma_{BER} = \sqrt{\frac{0{,}01 \text{ x } 0{,}99)}{2\,500}} = 2{,}00 \text{ x } 10^{-3}$$

The signal to noise ratio giving this BER is then calculated using formula (26).

$SNR_b(0{,}01) = -2 \text{ x } \ln (2 \text{ x } 0{,}01) = 7{,}824$

The dependency function at this level is: BER'(7,824) = 0,5 x 0,01 (formula (27). This BER uncertainty is then transformed to level uncertainty using formula (22):

$$\sigma_{level} = \left[\frac{2{,}00 \text{ x } 10^{-3}}{0{,}5 \text{ x } 10^{-2} \text{ x } 7{,}824}\right] \text{ x } 100\,\% = 5{,}11\,\% \; (p)$$

which is equal to 2,52 % (σ) in voltage terms.

This sub carrier level uncertainty is then transformed to RF level uncertainty.

$$\sigma_t = \sqrt{(2{,}52\,\%)^2 \text{ x } \left(\left(0{,}375\, dB_{RF\ INPUT\ LEVEL} / dB_{SINAD}\right)^2 + \left(0{,}075\, dB_{RF\ INPUT\ LEVEL} / dB_{SINAD}\right)^2\right)} = 0{,}96\,\%$$

NOTE: As the uncertainty is small the dependency function can be used directly without transforming to dB.

This RF level uncertainty is then combined with the uncertainty of the level of the input signal to obtain the total uncertainty of the sensitivity:

$$\sigma_t = \sqrt{(5{,}0\,\%)^2 + (0{,}96\,\%)^2} = 5{,}09\,\%$$

5.5.5 Effect of BER on the RF level uncertainty

The SNR_b to BER function is used to transform BER uncertainty to RF input level uncertainty. In the measurements on PMR equipment the RF input level is adjusted to obtain a specified BER. A sufficiently large number of bits are examined to measure the BER, but still there is a (small) measurement uncertainty contribution σ_{BER}. (see subclause 5.5.2).

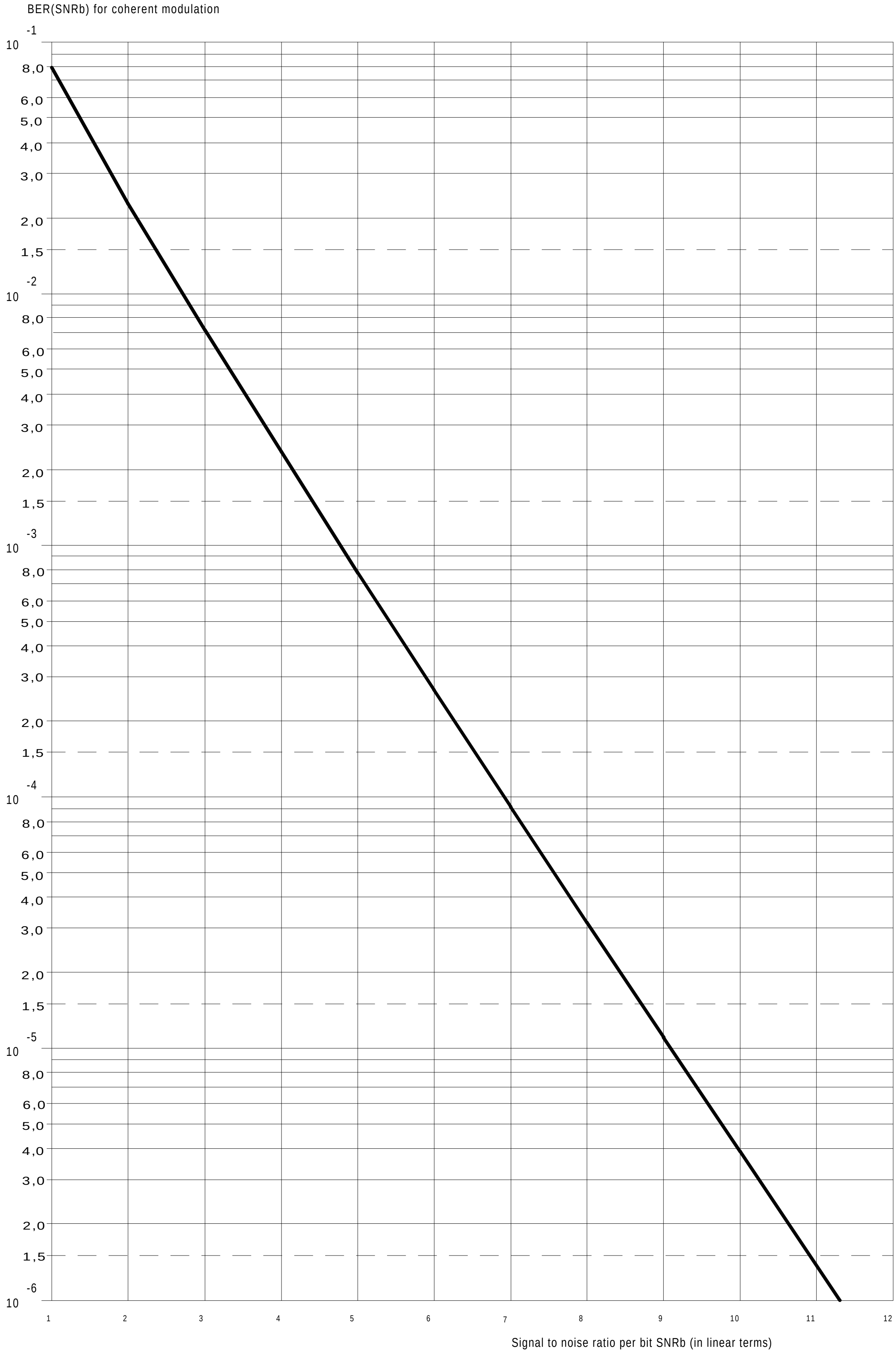


Figure 9: BER(SNR_b) against SNR_b

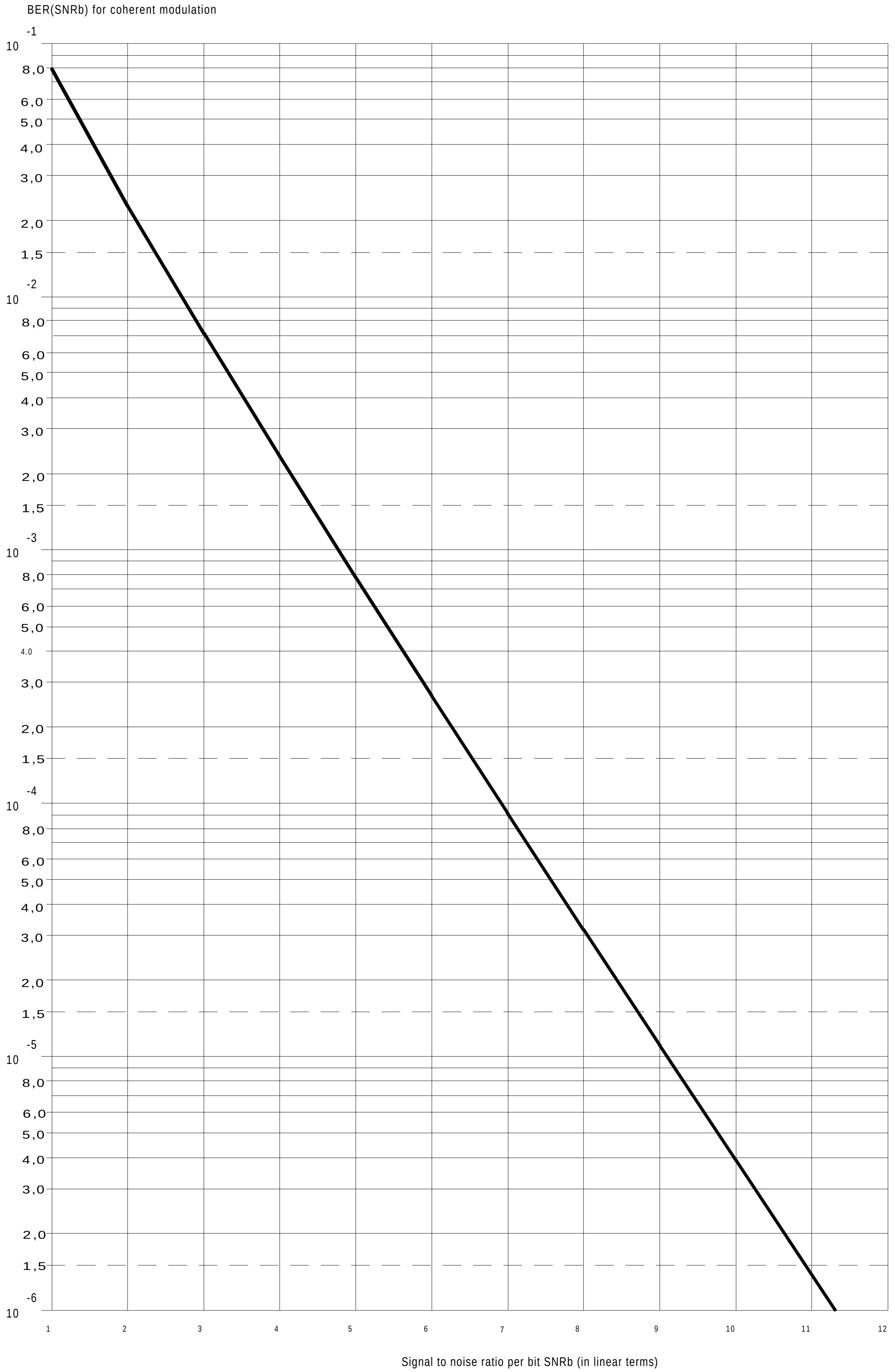


Figure 10: BER(SNR_b) against SNR_b

5.6 Uncertainty in measuring messages

5.6.1 General

If the EUT is equipped with message facilities an important characteristic used to assess the performance of the equipment is the message acceptance ratio. The message acceptance ratio is the ratio of the number of messages accepted to the total number of message sent.

Normally it is required to assess the receiver performance at a message acceptance ratio of 80 %. The message acceptance ratio is used as a measure of receiver performance in digital radio systems in a similar way that SINAD and BER ratios are used as a measure of receiver performance in analogue and bit stream measurements, particularly in sensitivity and immunity measurements.

5.6.2 Statistics involved in the measurement

When considering messages, parameters such as message length (in bits), type of modulation (direct or sub-carrier, coherent or non-coherent), affect the statistics that describe the behaviour of the receiver system.

Performance of the receiver is assessed against a message acceptance ratio set by the appropriate standard and/or methodology used. To assess the uncertainty the cumulative probability distribution curves for message acceptance are required, these may be calculated from (28)

$$Pe_{(0)} + Pe_{(1)} + Pe_{(3)} \ldots + Pe_{(n)} \qquad (28)$$

Where: n is the message length

$Pe_{(0)}$ is the probability of no errors

$Pe_{(1)}$ is the probability of 1 error

$Pe_{(2)}$ is the probability of 2 errors

$Pe_{(3)}$ is the probability of 3 errors

$Pe_{(n)}$ is the probability of n errors

The individual contribution of each probability $Pe_{(x)}$ in formula (28) is calculated using formula (15). Curves for a theoretical 50 bit system with 1, 2, 3, 4, 5, and 6 bits of error correction are shown in figure 11.

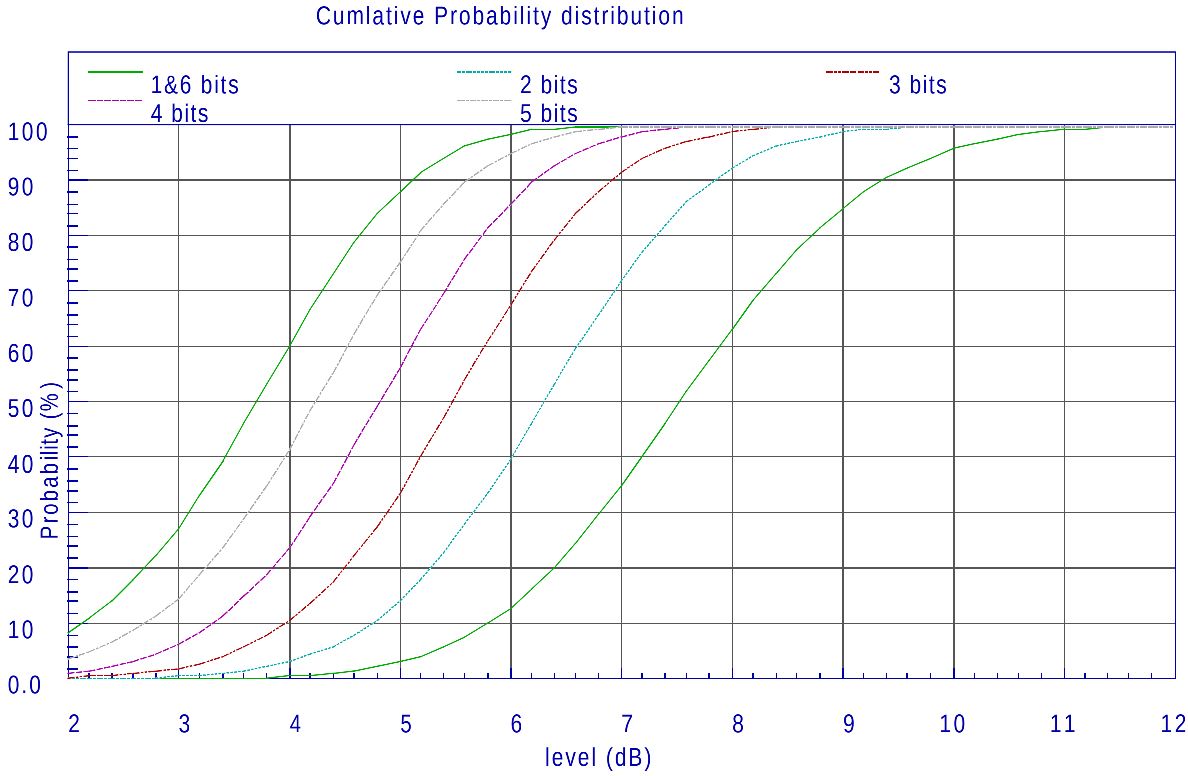


Figure 11: Cumulative probability (error correction for messages)

As the number of bits of error correction increase so does the slope of the relevant portion of the cumulative probability density function, and as the slope increases less carrier to noise (or RF input level) variation is required to cause the message acceptance ratio to vary between 0 % and 100 %.

This effect is increased in non-linear systems by a factor of approximately 3:1. Due to the increased slope associated with sub-carrier modulation, as a result of this in the theoretical 50 bit system, 6 bits of error correction will result in a very well defined level of 0 % acceptance to 100 % acceptance, (with 1 dB level variation), however, with no error correction, the level variation between 0 % and 100 % acceptance will be several dB.

As a method of testing receivers the up-down method is used. The usage of the up down method will result in a series of transmissions using a limited number of RF levels

5.6.3 Analysis of the situation where the up down method results in a shift between two levels

With some systems (e.g. 6 bits of error correction) the up-down method will typically result in a pattern shifting between two levels, where at the lower level the message acceptance ratio will approach zero and at the higher level (+1 dB) the message acceptance ratio will approach 100 %. In this case the measurement uncertainty is of the simplest form for this contribution.

The RF is switching between two levels, the mean value is calculated, usually from 10 or 11 measurements. The measurement uncertainty cannot be calculated as though random, independent sources are involved. The RF is switching between two output levels of the same signal generator, the levels therefore are correlated and only have two values (upper and lower), hence the standard deviation of the measurement uncertainty for a signal generator with output level uncertainty of +/- 1 dB is:

$$\sigma^+ = \sqrt{\frac{(12{,}20\ \%)^2}{\sqrt{2}}} \qquad \sigma^- = \sqrt{\frac{(10{,}87\ \%)^2}{\sqrt{2}}}$$

Also there is a quantisation error associated with half of the step size (in this case 1 dB which gives +/- 0,5 dB).

+ 0,5 dB = + 5,93 % and - 0,5 dB = - 5,59 %

Therefore the standard deviation of the contribution to measurement uncertainty of this step will be:

$$\sigma^+ = \sqrt{\left(\frac{(12{,}20\ \%)^2}{\sqrt{2}}\right) + \left(\frac{(5{,}93\ \%)^2}{\sqrt{3}}\right)} = 11{,}20\ \%$$

$$\sigma^- = \sqrt{\left(\frac{(10{,}87\ \%)^2}{\sqrt{2}}\right) + \left(\frac{(5{,}59\ \%)^2}{\sqrt{3}}\right)} = 8{,}41\%$$

For the case of no error correction the pattern of the measured results will spread beyond a single dB step and measurement uncertainty calculations are more complex.

5.6.4 Detailed example of uncertainty in measuring messages

For this example a theoretical system with 50 bit message length and 1 bit error correction will be considered, although the principles may be applied to all practicable message and correction lengths.

a) Calculate the message acceptance ratio (formula (28)) for the given message length and given number of bit error corrections, using bit error ratios corresponding to a convenient step size (in this case 1 dB) using either formula (21) for non-coherent, or, formula (18) for coherent, and if sub-carrier modulation is used, use the appropriate SINAD conversion in table C.1.

b) Now the probability of being at a given point on the curve should be assessed. For example the probability of being at a particular point (in figure 11) is:

- the probability of being below a particular point times the probability of going up from this point; plus

- the probability of being above a particular point times the probability of going down from this point.

The method requires three successful responses, therefore the probability of going up is:

$$Pp_{(up)} = 1 - (\text{message acceptance})^3 = 1 - (MA)^3 \qquad (29)$$

and the probability of going down is:

$$Pp_{(down)} = (\text{message acceptance})^3 = (MA)^3 \qquad (30)$$

$(Pe_{(0)} + Pe_{(1)})$ = Probability of 0 errors + the probability of 1 error; (see formula (28)).

dB	Linear	BER	$(Pe_{(0)}+Pe_{(1)})$%	$Pp_{(up)}=1-(MA)^3$	$Pp_{(down)}=(MA)^3$
2	12,679	$0,8826 \times 10^{-3}$	99,91	$2,698 \times 10^{-3}$	$997,3 \times 10^{-3}$
+1	10,071	$3,251 \times 10^{-3}$	98,83	$34,69 \times 10^{-3}$	$965,3 \times 10^{-3}$
0	8,000	$9,158 \times 10^{-3}$	92,30	$213,7 \times 10^{-3}$	$786,3 \times 10^{-3}$
-1	6,355	$20,84 \times 10^{-3}$	72,02	$626,4 \times 10^{-3}$	$373,6 \times 10^{-3}$
-2	5,048	$40,07 \times 10^{-3}$	39,95	$936,2 \times 10^{-3}$	$63,76 \times 10^{-3}$
-3	4,010	$67,33 \times 10^{-3}$	14,13	$997,2 \times 10^{-3}$	$2,821 \times 10^{-3}$
-4	3,185	$101,7 \times 10^{-3}$	3,123	1,000	$30,46 \times 10^{-6}$
-5	2,530	$141,1 \times 10^{-3}$	0,459	1,000	$96,55 \times 10^{-9}$

Based on equations (29) and (30), and the fact that the sum of all probabilities equals 1, the individual probabilities of being at each step of the signal to noise ratio per bit (SNR_b) can be calculated.

Assuming that at SNR_b greater than + 1 dB all messages are accepted (therefore can only move down from here) and, assuming that at SNR_b less than - 4 dB all messages are rejected (therefore can only move up from here), gives rise to two boundary positions - 5 dB and + 2 dB.

The probability of being at any one of the points - 5, - 4, - 3, - 2, - 1, 0, + 1, + 2 is Pp_{-5}, Pp_{-4}, Pp_{-3}, Pp_{-2}, Pp_{-1}, Pp_0, Pp_{+1}, and Pp_{+2} respectively.

The analysis of the possible transitions between these points provide:

$Pp_{-5} = (Pp_{-4} + 30{,}46 \times 10^{-6}) + (Pp_{-6} \times 1)$

$Pp_{-4} = (Pp_{-3} \times 2{,}821 \times 10^{-3}) + (Pp_{-5} \times 1)$

$Pp_{-3} = (Pp_{-2} \times 63{,}76 \times 10^{-3}) + (Pp_{-4} \times 1)$

$Pp_{-2} = (Pp_{-1} \times 373{,}6 \times 10^{-3}) + (Pp_{-3} \times 997{,}2 \times 10^{-3})$

$Pp_{-1} = (Pp_{0} \times 786{,}3 \times 10^{-3}) + (Pp_{-2} \times 936{,}2 \times 10^{-3})$

$Pp_{0} = (Pp_{+1} \times 965{,}3 \times 10^{-3}) + (Pp_{-1} \times 626{,}4 \times 10^{-3})$

$Pp_{+1} = (Pp_{+2} \times 1) + (Pp_{0} \times 213{,}7 \times 10^{-3})$

$Pp_{+2} = (Pp_{+3} \times 1) + (Pp_{+1} \times 34{,}69 \times 10^{-3})$

NOTE: The probability of being at point Pp_{-6} or Pp_{+3} is zero, hence $Pp_{-6} \times 1$ and $Pp_{+3} \times 1$ are both equal to zero.

Based on seven out of these eight equations and the fact that the sum of Pp_{-5} to Pp_{+2} is one, each individual probability Pp_{-5} to Pp_{+2} is calculated as follows:

rearranging the above equations gives:

$Pp_{-6} \times 1 - Pp_{-5} + Pp_{-4} \times 30{,}46 \times 10^{-6} = 0$

$Pp_{-5} \times 1 - Pp_{-4} + Pp_{-3} \times 2{,}821 \times 10^{-3} = 0$

$Pp_{-4} \times 1 - Pp_{-3} + Pp_{-2} \times 63{,}76 \times 10^{-3} = 0$

$Pp_{-3} \times 997{,}3 \times 10^{-3} - Pp_{-2} + Pp_{-1} \times 373{,}6 \times 10^{-3} = 0$

$Pp_{-2} \times 936{,}2 \times 10^{-3} - Pp_{-1} + Pp_{0} \times 786{,}3 \times 10^{-3} = 0$

$Pp_{-1} \times 626{,}4 \times 10^{-3} - Pp_{0} + Pp_{+1} \times 965{,}3 \times 10^{-3} = 0$

$Pp_{0} \times 213{,}7 \times 10^{-3} - Pp_{+1} + Pp_{+2} \times 1 = 0$

$Pp_{+1} \times 34{,}69 \times 10^{-3} - Pp_{+2} + Pp_{+3} \times 1 = 0$

$Pp_{-5} + Pp_{-4} + Pp_{-3} + Pp_{-2} + Pp_{-1} + Pp_{0} + Pp_{+1} + Pp_{+2} = 1$

$Pp_{-6} = 0 \quad Pp_{+3} = 0$

	Pp_{-5}	Pp_{-4}	Pp_{-3}	Pp_{-2}	Pp_{-1}	Pp_{0}	Pp_{+1}	Pp_{+2}	
1	1	- 1	2,821 x 10^{-3}						
2		1	- 1	63,76 x 10^{-3}					
3			997,3 x 10^{-3}	- 1	373,6 x 10^{-3}				
4				936,2 x 10^{-3}	- 1	786,3 x 10^{-3}			
5					626,4 x 10^{-3}	- 1	965,3 x 10^{-3}		
6						213,7 x 10^{-3}	- 1	1	
7							34,69 x 10^{-3}	-1	
8	1	1	1	1	1	1	1	1	1

solving this by means of row operations on row 8, gives:

1	1	- 1	2,821 x 10^{-3}						
2		1	- 1	63,76 x 10^{-3}					
3			997,3 x 10^{-3}	- 1	373,6 x 10^{-3}				
4				936,2 x 10^{-3}	- 1	786,3 x 10^{-3}			
5					626,4 x 10^{-3}	- 1	965,3 x 10^{-3}		
6						213,7 x 10^{-3}	- 1	1	
7							34,69 x 10^{-3}	- 1	
8								382.6	1

From this we have:

$382{,}6 \times Pp_{-2} = 1$ $\qquad Pp_{-2} = 2{,}614 \times 10^{-3}$

this is then used in row 7 to determine Pp_{+1}:

$$Pp_{-1} = \frac{2{,}614 \ \text{x} \ 10^{-3}}{34{,}69 \ \text{x} \ 10^{-3}} = 0{,}07534$$

this is used in row 6 to determine Pp_0:

$$Pp_0 \frac{0{,}07534 - 2{,}614 \text{ x } 10^{-3} \text{ x } 1}{213{,}7 \text{ x } 10^{-3}} = 340{,}33 \text{ x } 10^{-3}$$

this is used in row 5 to determine Pp_{-1}:

$$Pp_{-1} = \frac{340{,}34 \text{ x } 10^{-3} - \left(75{,}344 \text{ x } 10^{-3} \text{ x } 965{,}3 \text{ x } 10^{-3}\right)}{626{,}4 \text{ x } 10^{-3}} = 427{,}22 \text{ x } 10^{-3}$$

this is used in row 4 to determine Pp_{-2}:

$$Pp_{-2} = \frac{427{,}22 \text{ x } 10^{-3} - \left(0{,}34033 \text{ x } 0{,}7863\right)}{0{,}9362} = 0{,}170496$$

this is used in row 3 to determine Pp_{-3}:

$$Pp_{-3} = \frac{170{,}36 \text{ x } 10^{-3} - \left(0{,}2722 \text{ x } 0{,}376\right)}{0{,}9973} = 10{,}916 \text{ x } 10^{-3}$$

this is used in row 2 to determine Pp_{-4}:

$$Pp_{-4} = \frac{10{,}916 \text{ x } 10^{-3} - \left(170{,}5 \text{ x } 10^{-3} \text{ x } 63{,}76 \text{ x } 10^{-3}\right)}{1} 45{,}18 \text{ x } 10^{-6}$$

this is used in row 1 to determine Pp_{-5}:

$$Pp_{-5} = \frac{45{,}18 \text{ x } 10^{-6} - \left(10{,}916 \text{ x } 10^{-3} \text{ x } 2{,}821 \text{ x } 10^{-3}\right)}{1} = 14{,}38 \text{ x } 10^{-6}$$

$$\sum_{i=1}^{i=8} Pp_i * i = 5{,}235 \qquad \sum_{i=1}^{i=8} (Pp_i)^2 * i = 28{,}51$$

and the standard deviation:

$$\frac{1{,}051}{\sqrt{10}} = 0{,}332dB$$

and at 95 % confidence level 1,96 x 0,332 = +/- 0,651 dB

Therefore the method introduces an additional +/- 0,651 dB of error on the level.

5.7 Detailed example of the calculation of measurement uncertainty (Carrier power)

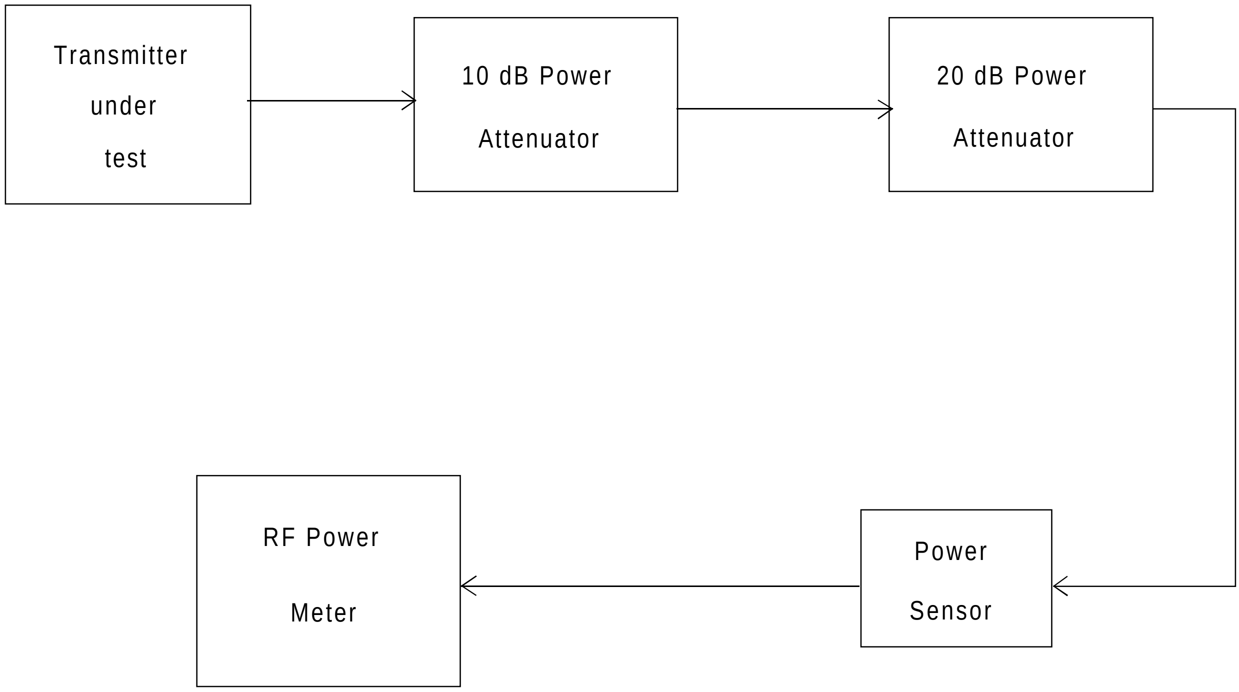


Figure 12: Carrier power measurement configuration

The power meter uses a thermocouple power sensor module and contains a power reference.

The attenuating network consists of two power attenuators: one of 10 dB and one of 20 dB connected by a cable. The nominal carrier power is 25 Watts, so the power level at the input of the power sensor module is said to be 25 mW.

The carrier frequency is 460 MHz.

The transmitter under test is in a temperature chamber at +55°C.

The transmitter is designed for continuous use.

5.7.1 Power meter and sensor module uncertainty

NOTE: Subclauses 3.2 and 3.3 refer to symbols and abbreviations used in the following calculations.

Reference level uncertainty:	(± 1,2 %) (p) (d)	± 0,6 % (r)
Mismatch uncertainty when calibrating: $VSWR_g$ = 1,05, $VSWR_l$ = 1,15 which gives R_g = 0,024 and R_l = 0,070	(c) (d)	± 0,17 % (u)
Calibration factor uncertainty	(± 2,3 %) (p) (d)	± 1,14 % (r)
Range to range change error (one range change)	(± 0,5 %) (p) (d)	± 0,25 % (r)
Meter linearity	(± 0,5 %) (p) (d)	± 0,25 % (r)

Noise and drift is negligible at this power level and can be ignored.

$$\sigma_1 = \sqrt{\frac{(0{,}6\,\%)^2 + (1{,}14\,\%)^2 + (0{,}25\,\%)^2}{3} + \frac{(0{,}17\,\%)^2}{2}} = 0{,}78\,\% \qquad \text{formula (1)}$$

5.7.2 Matching network and mismatch uncertainties

The error sources connected with the cables and the attenuator can be derived in different ways:

Either the available data of the attenuators and cables can be used directly (subclause 5.7.2.1) or the attenuation and reflection coefficients can be measured (subclause 5.7.2.2). This will provide two sets of values e.g. $\sigma_t(1)$ and $\sigma_t(2)$ respectively.

5.7.2.1 Calculations based on available data

Attenuator uncertainty	± 0,4 dB (d)	+ 4,71/- 4,50 % (r)
Cable attenuation 0,3 dB	(m)	
Cable attenuation uncertainty ± 0,1 dB		+ 1,16/- 1,15 % (r)

Mismatch uncertainties at the antenna connector of the transmitter: ($VSWR_{att}$ 1,2 which gives R_l = 0,091 and R_g of the transmitter under test is taken from table C.1 (Annex C): Mean value = 0,5, standard deviation = 0,2)

M_{iu} = 0,091 x 0,5 x 100 % = ± 4,55 % (u) (c) formula (8)

Normalised standard deviation of R_g = 0,2/0,5 = 0,4, Uncertainty correction factor (taken from figure 4 in subclause 5.2.2) = 1,075, Standard deviation of mismatch uncertainty at the antenna connector:

$$1{,}075 \times \frac{(4{,}55\,\%)}{\sqrt{2}} = \qquad \text{formula (9)} \qquad \pm 3{,}46\,\%\ (\sigma)$$

Mismatch uncertainty at power sensor module: R_l = 0,07 and VSWR of the cable connector is 1,3 which gives R_g = 0,13

M_{iu} = 0,13 x 0,07 x 100 % = (c) formula (8) ± 0,91 % (u)

$$\sigma_{2+} = \sqrt{\frac{(4{,}71\%)^2 + (1{,}16\,\%)^2}{3} + (3{,}46\%)^2 + \frac{(0{,}91\ \%)^2}{2}} = 4{,}50\ \%\ (\sigma) \qquad \text{formula (1)}$$

$$\sigma_{2+} = \sqrt{\frac{(4{,}50\,\%)^2 + (1{,}15\,\%)^2}{3} + (3{,}46\%)^2 + \frac{(0{,}91\ \%)^2}{2}} = 4{,}42\ \%\ (\sigma) \qquad \text{formula (1)}$$

5.7.2.2 Calculations based on measured data

(The measurements carried out at 23 °C)

Measured attenuation of network: 30,5 dB

The attenuation is measured with a signal generator and a measuring receiver. At both the input and output connector a 6 dB attenuator with low reflection coefficients has been inserted (see subclause 5.2.1 about the method and the uncertainty calculation concerning the method).

Detector uncertainty 0,06 dB (d) ± 0,69 % (r)

Mismatch uncertainty:
(The reflection coefficients of the measuring system R_g and R_l < 0,025 and the network reflection coefficients R_i and R_o < 0,1)
Limits = 0,6 % voltage (c) ± 0,6 % (t)
Temperature influence: 0,0001 dB/degree,
which is negligible and can be ignored (d)

Power influence 0,0001 dB/dB x Watt (10 dB attenuator):
0,001 x 2,5 x 10 = 0,25 dB (d) (c) + 2,92/- 2,84 % (r)

Power influence 0,001 dB/dB x Watt (20 dB attenuator):
0,001 x 2,5 x 20 = 0,05 dB (d) (c) + 0,58/- 0,57 % (r)

Mismatch uncertainties at the antenna connector of the transmitter: ($VSWR_{att}$ 1,2 which gives R_l = 0,091 and R_g of the transmitter under test is taken from table C.1: Mean value = 0,5, standard deviation = 0,2)

M_{iu} = 0,091 x 0,5 x 100 % = ± 4,55 % (u) (c) formula (8)

Normalised standard deviation of R_g = 0,2/0,5 = 0,4 Uncertainty correction factor (taken from the figure 4 in subclause 5.2.2) = 1,075 Standard deviation of mismatch uncertainty at the antenna connector

$$1{,}075 \text{ x } \frac{(4{,}55\ \%)}{\sqrt{2}} =$$ formula (9) ± 3,46 % (σ)

Mismatch uncertainty at power sensor module: (R_l = 0,07 and VSWR of the cable connector is 1,3 which gives R_g = 0,13)

M_{iu} = 0,07 x 0,13 x 100 % (c) ± 0,91 % (u)

$$\sigma_{3+} = \sqrt{\frac{(0{,}69\,\%)^2 + (2{,}92\,\%)^2 + (0{,}58\ \%)^2}{3} + \frac{(0{,}6\ \%)^2}{6} + (3{,}46\,\%)^2 + \frac{(0{,}91\ \%)^2}{2}} =$$ 3,94 %

$$\sigma_{3-} = \sqrt{\frac{(0{,}69\,\%)^2 + (2{,}84\,\%)^2 + (0{,}57\ \%)^2}{3} + \frac{(0{,}6\ \%)^2}{6} + (3{,}46\,\%)^2 + \frac{(0{,}91\ \%)^2}{2}} =$$ 3,92 %

As the difference between σ_{3+} and σ_{3-} is small $\sigma_3 = \sigma_{3+}$ will be used in the following calculation.

As can be seen, the uncertainty can be reduced by measuring the measurement configuration characteristics involved.

5.7.3 Uncertainty caused by influence quantities

Other uncertainties are common to both examples.

Ambient temperature = 20 °C ± 1 °C , (r), Uncertainty caused by temperature uncertainty: Dependency function (from table C.1): Mean value 4 %/°C and standard deviation: 1,2 %/°C

Standard deviation of the power uncertainty caused by ambient temperature uncertainty formula (2)

$$\sqrt{\left(\frac{(1^\circ C)^2}{3}\right) \text{ x } \left((4{,}0\ \%/^\circ C)^2 + (1{,}2\ \%/^\circ C)^2\right)} =$$ (p) (σ) 2,41 %

This is then transformed to voltage: 2,41/2 % = 1,20 % (σ)

Supply voltage = V_{set} ± 100 mV (r)

Uncertainty caused by supply voltage uncertainty: Dependency function (from table C.1): Mean: 10 %/V and standard deviation: 3 %/V, (p), Standard deviation of the power uncertainty caused by power supply voltage uncertainty (formula (2)) =

$$\sqrt{\frac{(0{,}1V)^2}{3} \text{ x } \left((10\ \%/V)^2 + (3\ \%/V)^2\right)} = 0{,}60\ \%$$

This is then converted to voltage: 0,60/2 % = 0,30 % (σ)

$$\sigma_4 = \sqrt{(1{,}21\ \%)^2 + (0{,}30\ \%)^2} = \quad (\sigma) \quad 1{,}25\ \%$$

5.7.4 Random uncertainty

The measurement was repeated 9 times The following results were obtained:

21,8 mW 22,8 mW 23,0 mW 22,5 mW 22,1 mW 22,7 mW 21,7 mW 22,3 mW 22,7 mW

Mean value = 22,4 mW Standard deviation = 0,455 mW (Calculated by means of formula (5)).

As the result is obtained as the mean value of 9 measurements, the standard deviation of the random uncertainty is:

$$\sigma_5 = \frac{(0{,}455mW)}{(22{,}4mW) \text{ x } \sqrt{9}} \text{ x } 100\ \% = 0{,}68\ \% \quad \text{formula (6)} \quad (p)\ (\sigma)$$

This is converted to linear voltage: 0,68/2 % = 0,34 % (σ)

5.7.5 Total uncertainty

The standard deviation of the accumulated error (for example 1) is then:

$$\sigma_t(1) = \sqrt{\sigma_1{}^2 + \sigma_2{}^2 + \sigma_4{}^2 + \sigma_5{}^2}:$$

$$\sigma_{t+} = \sqrt{(0{,}78\ \%)^2 + (4{,}50\ \%)^2 + (1{,}25\ \%)^2 + (0{,}34\ \%)^2} = \quad (\sigma) \quad 4{,}75\ \%$$

$$\sigma_{t-} = \sqrt{(0{,}78\ \%)^2 + (4{,}42\ \%)^2 + (1{,}25\ \%)^2 + (0{,}34\ \%)^2} = \quad (\sigma) \quad 4{,}67\ \%$$

At a confidence level of 95 % the two measurement uncertainty figures are:

U_{95} (1) = + 1,96 x 4,75 %/- 1,96 x 4,67 % = + 9,31 %/- 9,15 %

and, the standard deviation of the accumulated error (for example 2) is then:

$$\sigma_t(2) = \sqrt{\sigma_1{}^2 + \sigma_3{}^2 + \sigma_4{}^2 + \sigma_5{}^2} =$$

$$\sigma_t(2) = \sqrt{(0{,}78\ \%)^2 + (3{,}94\ \%)^2 + (1{,}25\ \%)^2 + (0{,}34\ \%)^2} = \quad (\sigma) \quad 4{,}22\ \%$$

U_{95} (2) = ± 1,96 x 4,22 % = ± 8,27 %

The mean value of the readings was 22,4 mW

This figure is then corrected with the attenuation of the matching network and the mismatch loss at input and output of the network.

Mismatch loss at input (R_l = 0,091) = 0,036 dB and at the output (R_l = 0,07) = 0,021 dB (formula (10))

The total correction is then:

0,036 + 0,021 + 30 + 0,3 = 30,36 dB = 1086 (1) or
0,036 + 0,021 + 30,5 = 30,56 dB = 1138 (2)

Carrier power = 22,4 mW x 1086 = 24,3 Watts (Example 1)

or, 22,4 mW x 1138 = 25,5 Watts (Example 2)

When measuring the carrier power of a transmitter designed for intermittent use there is an additional uncertainty due to the fact that the transmitter is not in thermal stability, and that the time when the measurement is made, is not sufficiently defined.

The uncertainty is taken from table C.1: "Time-duty cycle dependency": 3 % (p) (r) which in both example 1 and 2 would add approximately 1 % (p) to the total uncertainty.

6 Transmitter measurement examples

The following pages of Clause 6 are examples of test configurations with corrections and error sources.

Components essential for the measurement uncertainty calculations are shown in the drawings. Influence quantities (such as supply voltage, ambient temperature) are not shown in the drawing although they are present in all the examples.

Symbols and abbreviations used in the examples are explained in subclause 3.2 and subclause 3.3.

Each example includes calculation of the measurement uncertainty at a confidence level of 95 %.

The test configuration, the list of error sources and the calculations are examples only and may not include all the possibilities. It is important that, where applicable, the errors are identified as either systematic or random for the purpose of making the calculations.

6.1 Frequency error

Figure 13: Frequency error measurement configuration

The signal is applied to a frequency counter through a matching network. The frequency is read directly. The equipment is designed for intermittent use, the nominal frequency is 900 MHz and the temperature is 25°C ± 3°C.

Measurement uncertainty: the time-base of the counter used has a drift of 1 x 10^{-9} per day. With a calibration period of less than 10 days, the time base uncertainty is less then 1 x 10^{-8}.

The least significant digit is 10 Hz.

The overall uncertainty is time base uncertainty + 3 counts of least significant digit or 30 Hz whichever is larger.

The uncertainty related to the measurement of 1 GHz is then:

Time base uncertainty	(c) (d)	± 10 Hz (r)
Counter uncertainty	(d)	± 30 Hz (r)

Uncertainty due to ambient temperature uncertainty: Standard deviation of ambient temperature uncertainty =

$$\frac{3°C}{\sqrt{3}} = 1{,}73°C \qquad (\sigma)$$

Dependency function taken from table C.1: mean value = 0,02 ppm/°c and standard deviation = 0,01 ppm/°c , which gives: 20 x 10^{-9} Hz/°C x 900 x 10^{6} = 18 Hz/°C and 10 x 10^{-9} Hz/°C x 900 x 10^{6} = 9 Hz/°C.

Uncertainty due to ambient temperature:

$\sqrt{(1{,}73°\,C)^2 \ \text{x} \ \left((18\ Hz/°\,C)^2 + (9\ Hz/°\,C)^2\right)}$ formula (2) 35 Hz (σ)

$$\sigma_t = \sqrt{\frac{\left((10\ Hz)^2 + (30\ Hz)^2\right)}{3} + (35\ Hz)^2} = 39\ Hz\ (\sigma)$$

U_{95} = ± 1,96 x 39 Hz = ± 76 Hz

6.2 Carrier power

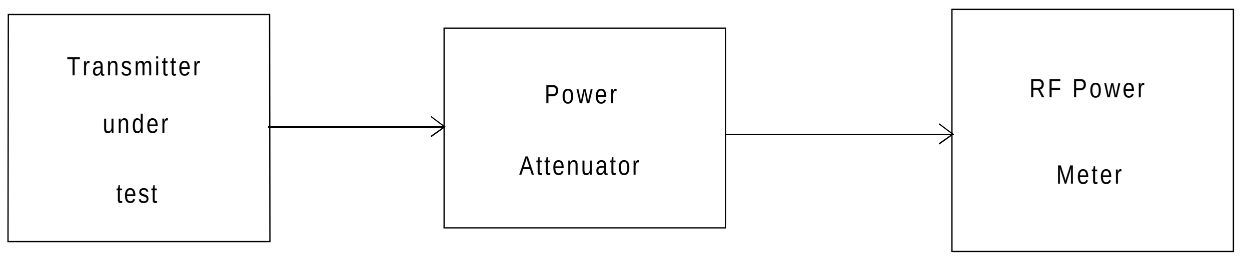


Figure 14: Carrier power measurement configuration

The power meter is a thermocouple power sensor module and a meter with a built in power reference. The attenuating network consists of two power attenuators: one of 10 dB and one of 20 dB connected by a cable. The nominal carrier power is 25 Watts, so the nominal power level at the input of the power sensor module is 25 mW.

The carrier frequency is 460 MHz, and the equipment is designed for intermittent use.

The transmitter under test is in a temperature chamber at + 55°C ± 1°C.

Measurement uncertainty:

a) Power meter and sensor module:

Reference level uncertainty: (± 1,2 %)	(p) (d)	± 0,6 % (r)
Mismatch uncertainty when calibrating ($VSWR_g$ = 1,05, $VSWR_l$ = 1,15 which gives R_g = 0,024 and R_l = 0,070)	formula (8) (c) (d)	± 0,17 % (u)
Calibration factor uncertainty:	± 2,3 % (d) (p)	± 1,14 % (r)
Range to range change error: (one range change)	± 0,5 % (p) (d)	± 0,25 % (r)
Meter linearity	± 0,5 % (p) (d)	± 0,25 % (r)

Noise and drift is negligible at this power level and can be ignored.

$$\sigma_1 = \sqrt{\frac{(0{,}6\ \%)^2 + (1{,}14\ \%)^2 + (0{,}25\ \%)^2 + (0{,}25\ \%)^2}{3} + \frac{(0{,}17\ \%)^2}{2}} =$$ 0,78 % (σ)

Matching network and mismatch:

Detector uncertainty 0,06 dB (d) ± 0,69 % (r)

Mismatch uncertainty: (The reflection coefficients of the measuring system R_g and R_l < 0,025 and the network reflection coefficients R_i and R_o < = 0,1)
Limits = 0,6 % voltage (c) formula (7) ± 0,6 % (t)

Temperature influence: 0,0001 dB/degree which is negligible and can be ignored. (d)

Power influence 0,001 dB/dB x Watt (10 dB attenuator):

0,001 x 25 x 10 = 0,25 dB (d) (c) + 2,92/- 2,84 % (r)

Power influence 0,001 dB/dB x Watt (20 dB attenuator):

0,001 x 2,5 x 20 = 0,05 dB (d) (c) + 0,58/- 0,57 % (r)

Mismatch uncertainties at the antenna connector of the transmitter: ($VSWR_{att}$ 1,2 which gives R_l = 0,091 and R_g of the transmitter under test taken from table C.1: Mean value = 0,5, standard deviation = 0,2)

M_{iu} = 0,091 x 0,5 x 100 % = ±4,55 % (u) (c) formula (8)

Normalised standard deviation of R_g = 0,2/0,5 = 0,4 Uncertainty correction factor (taken from the figure 4 in subclause 5.2.2) = 1,075 Standard deviation of mismatch uncertainty at the antenna connector is:

$$1{,}075 \text{ x } \frac{(4{,}55\ \%)}{\sqrt{2}}$$ formula (9) 3,46 % (σ)

Mismatch uncertainty at power sensor module: (R_l = 0,07 and VSWR of the cable connector is 1,3 which gives R_g = 0,13)

M_{iu} = 0,07 x 0,13 x 100 % (c) ± 0,91 % (u)

$$\sigma_{2+} = \sqrt{\frac{(0{,}69\,\%)^2 + (2{,}92\,\%)^2 + (0{,}58\ \%)^2}{3} + \frac{(0{,}6\ \%)^2}{6} + (3{,}46\,\%)^2 + \frac{(0{,}91\ \%)^2}{2}} = \quad 3{,}94\ \%$$

$$\sigma_{2-} = \sqrt{\frac{(0{,}69\,\%)^2 + (2{,}84\,\%)^2 + (0{,}57\ \%)^2}{3} + \frac{(0{,}6\ \%)^2}{6} + (3{,}46\,\%)^2 + \frac{(0{,}91\ \%)^2}{2}} = \quad 3{,}92\ \%$$

As the difference between σ_{2+} and σ_{2-} is small $\sigma_2 = \sigma_{2+}$ will be used in the following calculation.

b) Uncertainty due to influence quantities:

Ambient temperature = 55°C ± 1°C ,(r), Uncertainty caused by temperature uncertainty: Dependency function (from table C.1): Mean value : 4 %/°C and standard deviation: 1,2 %/°C

Standard deviation of the power uncertainty caused by ambient temperature uncertainty formula (2) =

$$\sqrt{\left(\frac{(1^\circ C)^2}{3}\right) \text{ x } \left((4{,}0\ \%/C)^2 + (1{,}2\ \%/^\circ C)^2\right)} =$$ (p)(σ) 2,40 %

This is then converted to voltage: 2,41/2 % = 1,21 % (σ)

Supply voltage = Vset ± 100 mV (r)
Uncertainty caused by supply voltage uncertainty: Dependency function (from table C.1): Mean value: 10 %/V and standard deviation 3 %/V ,(p), Standard deviation of the power uncertainty caused by power supply voltage uncertainty (formula (2)) is:

$$\sqrt{\frac{(0{,}1\ V)^2}{3}\ \text{x}\ \left((10\ \%/V)^2+(3\ \%/V)^2\right)} = \quad \text{(p) } (\sigma) \quad 0{,}60\ \%$$

This is then converted to voltage: 0,60/2 % = 0,30 % (σ)

$$\sigma_3 = \sqrt{(1{,}21\ \%)^2+(0{,}30\ \%)^2} = \quad 1{,}25\ \%\ (\sigma)$$

c) Investigation into random uncertainty:

The measurement was repeated 9 times. The following results were obtained:

21,8 mW 22,8 mW 23,0 mW 22,5 mW 22,1 mW 22,7 mW 21,7 mW 22,3 mW 22,7 mW

Mean value = 22,4 mW Standard deviation = 0,455 mW

As the result is obtained as the mean value of 9 measurements, the standard deviation of the random uncertainty is:

$$\sigma_4 = \frac{0{,}455 mW}{22{,}4 mW\ \ \text{x}\ \ \sqrt{9}}\ \text{x}\ 100\ \% = 0{,}68\ \% \quad \text{(p) } (\sigma)$$

This is converted to linear voltage: 0,68/2 % = 0,34 % (σ)

d) Time-duty-cycle uncertainty:

The standard deviation of the time-duty-cycle error = 2 % (p). (Taken from table C.1)

This is converted to voltage: σ_5 = 2/2 % = 1,0 % (σ)

e) Total uncertainty:

$$\sigma_t = \sqrt{(0{,}78\ \%)^2+(3{,}94\ \%)^2+(1{,}25\ \%)^2+(0{,}34\ \%)^2+(1{,}0\ \%)^2} = 4{,}34\ \%\ (\sigma)$$

U_{95} =± 1,96 x 4,34 % = 8,50 % = + 0,71/- 0,77 dB

6.3 Frequency deviation

6.3.1 Maximum frequency deviation

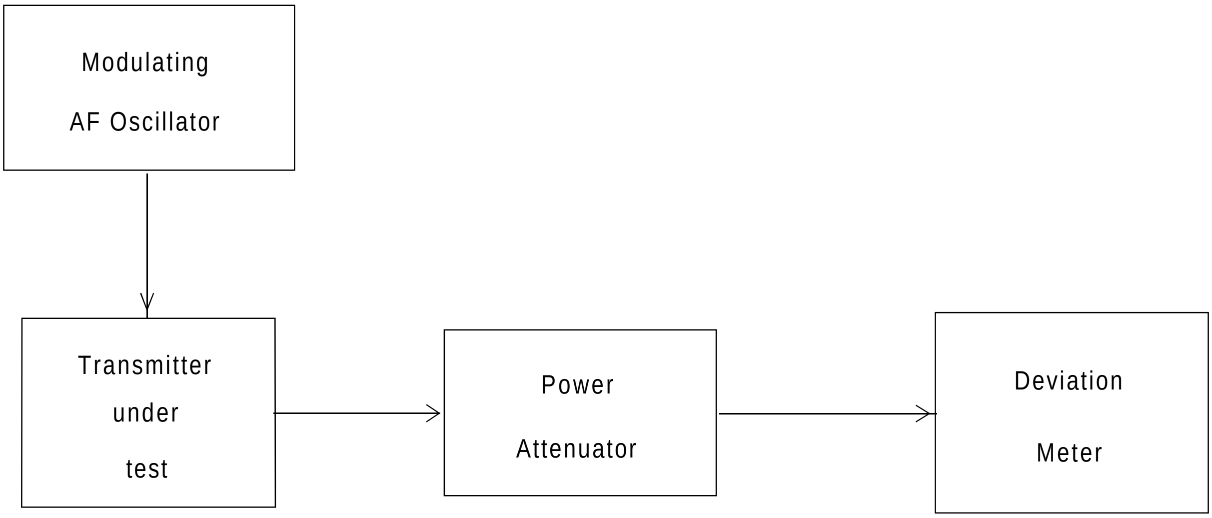


Figure 15: Frequency deviation measurement configuration

The AF signal from the audio frequency oscillator is applied to the modulation input of the transmitter under test.

The RF from the transmitter under test is applied to a deviation meter through a power attenuator. The maximum deviation is measured to be 4,0 kHz.

Measurement uncertainty: (It is assumed that the AF level uncertainty has no influence)

Demodulator uncertainty: ± 1 % (d) (r)

± 1 digit = 10 Hz =(10/4 000) x 100 % = ± 0,25 % (r)

Residual modulation ± 20 Hz (d) = (20/4 000) x 100 % = ± 0,5 % (r)

$$\sigma_t = \sqrt{\frac{(1{,}0\ \%)^2 + (0{,}25\ \%)^2 + (0{,}5\ \%)^2}{3}} = \quad (\sigma) \quad 0{,}66\ \%$$

U_{95} is ± 1,96 x 0,66 % = ± 1,3 %

6.3.2 Modulation frequencies above 3 kHz

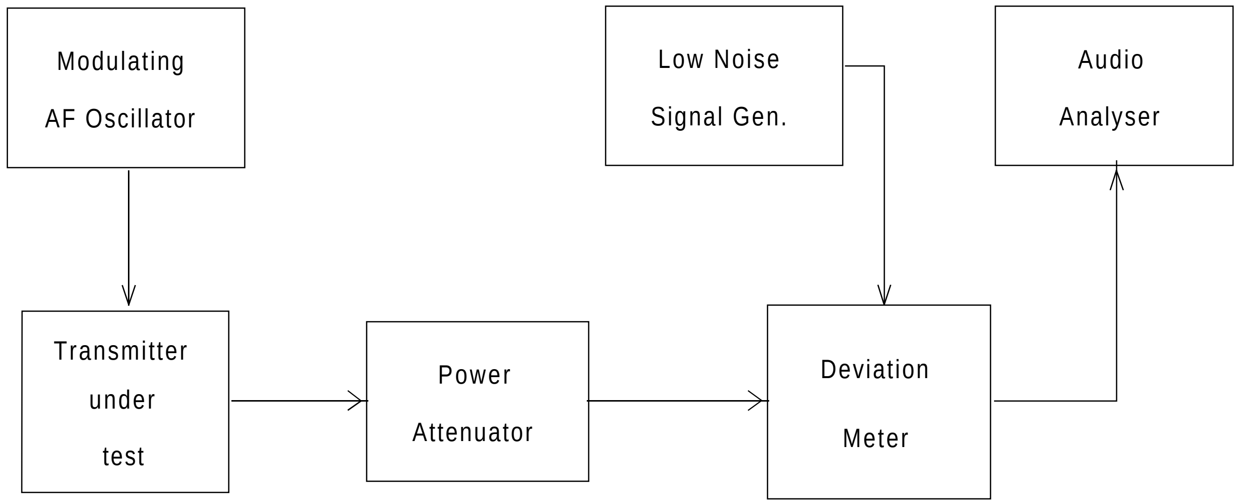


Figure 16: Measurement configuration for modulation frequencies above 3 kHz

The AF signal from the audio frequency oscillator is applied to the modulation input of the transmitter under test. The RF signal from the transmitter under test is applied to a deviation meter through a power attenuator. The demodulated signal is then applied to the audio analyser. A low noise signal generator is used as local oscillator for the deviation meter for demodulating signals with modulation frequencies above 3 kHz, to improve the noise behaviour. The result is corrected for AF gain and AF filter shaping.

Measurement uncertainty:

AF oscillator uncertainty	± 0,7 % (d)(r)
Demodulator uncertainty	± 1 % (d)(r)
AC voltmeter uncertainty	± 4 % (d)(r)
AF gain uncertainty	± 2 % (d)(r)

$$\sigma_t = \sqrt{\frac{(0{,}7\ \%)^2 + (1\ \%)^2 + (4\ \%)^2 + (2\ \%)^2}{3}} = \qquad (\sigma) \qquad 2{,}68\ \%$$

U_{95} = ± 1,96 x 2,68 % = ± 5,25 % = + 0,44 dB/- 0,47 dB

NOTE: Valid for measuring the modulation characteristics at levels at least 10 dB beyond measuring system noise level.

6.4 Adjacent channel power

6.4.1 Adjacent channel power method 1 (Using an adjacent channel power meter)

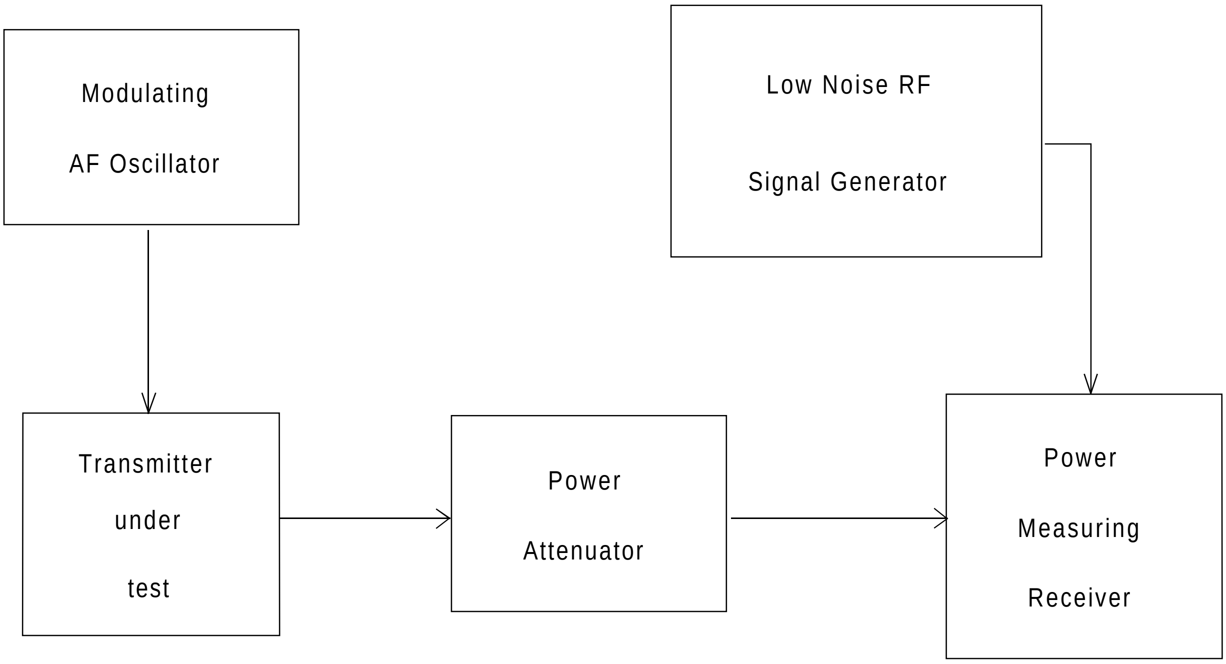


Figure 17: Measurement configuration for adjacent channel power measurement (method 1)

The transmitter under test is connected to an adjacent channel power meter (power measuring receiver) through a matching and attenuating network. The local oscillator signal to the adjacent channel power meter is supplied from a low noise signal generator.

The carrier power is approximately 25 Watts. The measured result is obtained as the mean value of 20 measurements in order to characterise, and reduce, the random error caused by the noise. The transmitter is designed for intermittent use.

Measurement uncertainty:

Filter power band width uncertainty	± 0,2 dB (d)	+ 2,33/- 2,28 % (r)
Relative accuracy	± 0,5 dB (d)	+ 5,93/- 5,59 % (r)
Standard deviation of random error	± 0,11 dB (m) (c)	± 1,27 % (σ)

Uncertainty caused by deviation uncertainty = (± 30 Hz (r)) .(Dependency function: Mean value = 0,05 % (p)/Hz and standard deviation = 0,02 % (p)/Hz taken from table C.1)

$$\sqrt{\left(\frac{(30\ Hz)^2}{3}\right) \text{ x } \left((0{,}05\ \%/Hz)^2 + (0{,}02\ \%/Hz)^2\right)} =$$ formula (2) = 0,93 % (p) = 0,47 % (σ)

Uncertainty caused by filter position: Uncertainty of 6 dB point ± 75 Hz

(Dependency function: Mean value = 15 dB/kHz, and standard deviation = 4 dB/kHz taken from table C.1)

$$\sqrt{\left(\frac{(0{,}075\ kHz)^2}{3}\right) \times \left((15\ dB/kHz)^2 + (4\ dB/kHz)^2\right)} \quad = 0{,}67\ \text{dB} = \quad +8{,}0/-7{,}4\ \%\ (\sigma)$$

Time-duty-cycle uncertainty (taken from table C.1): Mean value = 0 % (p),
standard deviation = 2 %(p) = 1,0 % (σ)

The measurement is purely relative, therefore the mismatch uncertainties and the attenuation uncertainties do not contribute to the measurement uncertainty.

$$\sigma_{t+} = \sqrt{\frac{(2{,}33\,\%)^2 + (5{,}93\,\%)^2}{3} + (1{,}27\,\%)^2 + (1{,}27\,\%)^2 + (0{,}47\ \%)^2 + (8{,}0\ \%)^2 + (1{,}0\ \%)^2} = \quad 8{,}96\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{\frac{(2{,}28\,\%)^2 + (5{,}59\,\%)^2}{3} + (1{,}27\,\%)^2 + (0{,}47\ \%)^2 + (7{,}4\ \%)^2 + (1{,}0\ \%)^2} = \quad 8{,}42\ \%\ (\sigma)$$

U_{95}= + 1,96 x 8,96 %/- 1,96 x 8,42 % = + 17,6 %/- 16,5 % = + 1,4/- 1,6 dB

The uncertainty figure is valid for results > - 95 dB.

6.4.2 Adjacent channel power method 2 (Using a spectrum analyser)

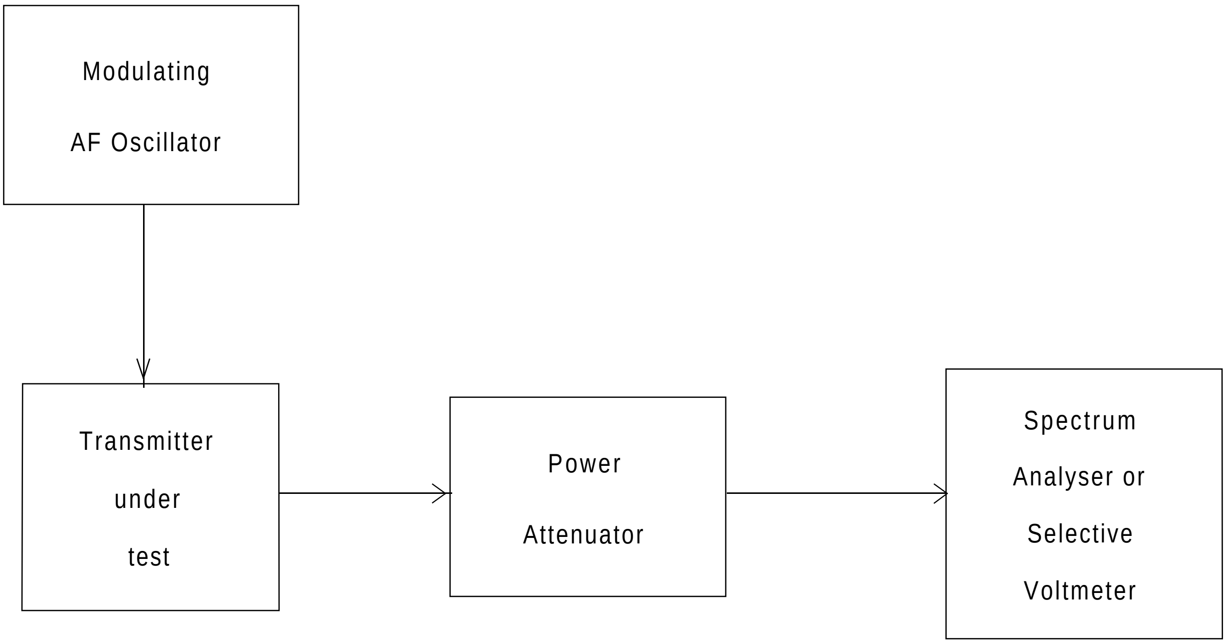


Figure 18: Measurement configuration for adjacent channel power (method 2)

The transmitter under test is connected to spectrum analyzer via a matching and attenuating network and the carrier is recorded as reference. The adjacent channel power is calculated from spectrum analyzer reading (9 samples) by means of Simpson's Rule.

Measurement uncertainty:

Reference level uncertainty:

Frequency flatness	± 0,6 dB (d)	+ 7,15/- 6,67 % (r)
Log fidelity	± 1,0 dB (d)	+ 12,2/- 10,9 % (r)
Calibrator uncertainty	± 0,3 dB (d)	+ 3,51/- 3,39 % (r)
Absolute amplitude calibration	± 0,6 dB (d)	+ 7,15/- 6,67 % (r)
Resolution bandwidth switching	± 0,5 dB (d)	+ 5,93/- 5,59 % (r)
IF gain uncertainty	± 1,0 dB (d)	+ 12,2/- 10,9 % (r)
RF gain uncertainty	± 0,2 dB (d)	+ 2,33/- 2,28 % (r)

Total reference level uncertainty:

$$\sigma_{1+} = \sqrt{\frac{(7{,}15\,\%)^2 + (12{,}2\,\%)^2 + (3{,}51\,\%)^2 + (7{,}15\,\%)^2 + (5{,}93\,\%)^2 + (12{,}2\,\%)^2 + (2{,}33\,\%)^2}{3}} = \quad 12{,}29\,\%\ (\sigma)$$

$$\sigma_{1-} = \sqrt{\frac{(6{,}67\,\%)^2 + (10{,}9\,\%)^2 + (3{,}39\,\%)^2 + (6{,}67\,\%)^2 + (5{,}59\,\%)^2 + (10{,}9\,\%)^2 + (2{,}28\,\%)^2}{3}} = \quad 11{,}17\,\%\ (\sigma)$$

Uncertainty of calculation caused by log fidelity: (The circles on the figure are showing the readings)

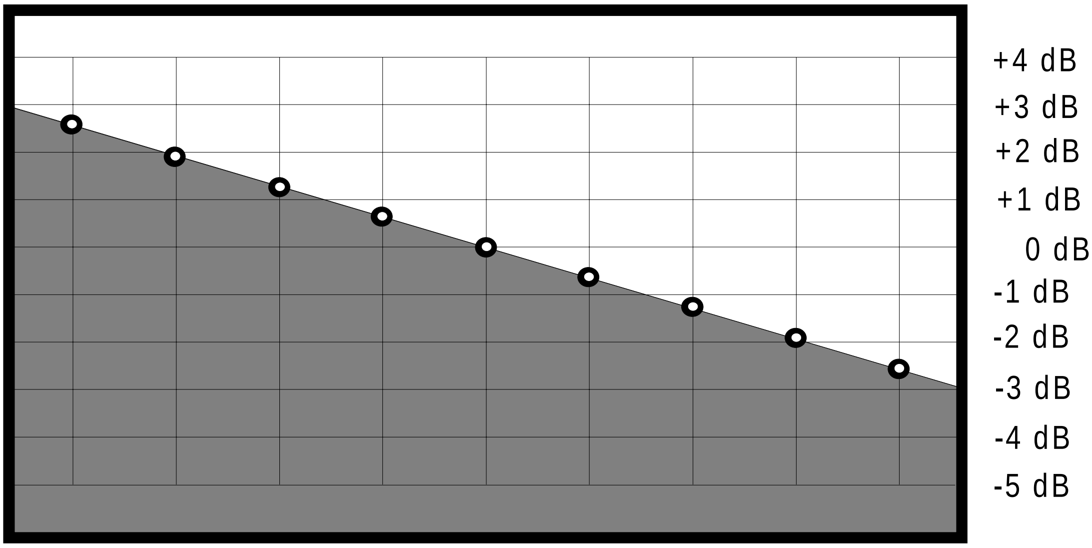


Figure 19: Typical screen view

Reading Number	Reading	Log Fidelity	Linear error +	-
1	2,50	0,250	2,92 %	2,84 %
2	1,87	0,187	2,18 %	2,13 %
3	1,25	0,125	1,45 %	1,43 %
4	0,62	0,062	0,72 %	0,71 %
5	0	0	0 %	0 %
6	-0,62	0,062	0,72 %	0,71 %
7	-1,25	0,125	1,45 %	1,43 %
8	-1,87	0,187	2,18 %	2,13 %
9	-2,50	0,250	2,92 %	2,84 %

$$\sigma_{2+} = \sqrt{\frac{(2{,}92\ \%)^2 + (2{,}18\ \%)^2 + (1{,}45\ \%)^2 + (0{,}72\ \%)^2 + (0{,}72\ \%)^2 + (1{,}45\ \%)^2 + (2{,}18\ \%)^2 + (2{,}92\ \%)^2}{3}} = 3{,}26\ \%\ (\sigma)$$

$$\sigma_{2-} = \sqrt{\frac{(2{,}84\ \%)^2 + (2{,}13\ \%)^2 + (1{,}43\ \%)^2 + (0{,}71\ \%)^2 + (0{,}71\ \%)^2 + (1{,}43\ \%)^2 + (2{,}13\ \%)^2 + (2{,}84\ \%)^2}{3}} = 3{,}18\ \%\ (\sigma)$$

Frequency flatness ± 0,6 dB (d) + 7,15/- 6,67 % (r)

Standard deviation of random error ± 0,11 dB (m)(c) ± 1,27 % (σ)

Uncertainty caused by deviation uncertainty ± 30 Hz (r)

(Dependency function: Mean value = 0,05 % (p)/Hz and standard deviation = 0,02 % (p)/Hz taken from table C.1)

$$\sqrt{\left(\frac{(30\ Hz)^2}{3}\right) \text{x} \left((0{,}05\ \% / Hz)^2 + (0{,}02\ \% / Hz)^2\right)} =$$ formula (2) = 0,93 % (p) = 0,47 % (σ)

Time-duty-cycle uncertainty (Taken from table C.1): Standard deviation = 2 % (p) = 1,0 % (σ)

The measurement is purely relative, therefore the mismatch uncertainties and the attenuation uncertainties do not contribute to the measurement uncertainty.

Total uncertainty:

$$\sigma_{t+} = \sqrt{\frac{(12{,}29\ \%)^2 + (3{,}26\ \%)^2 + (7{,}15\ \%)^2}{3} + (1{,}27\,\%)^2 + (0{,}47\ \%)^2 + (1\ \%)^2} = 13{,}47\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{\frac{(11{,}17\,\%)^2 + (3{,}18\,\%)^2 + (6{,}67\ \%)^2}{3} + (1{,}27\,\%)^2 + (0{,}47\ \%)^2 + (1\ \%)^2} = 12{,}35\ \%\ (\sigma)$$

U_{95} = + 1,96 x 13,47 %/- 1,96 x 12,35 % = + 26,4 %/- 24,2 % = + 2,0/- 2,4 dB

6.5 Conducted spurious emissions

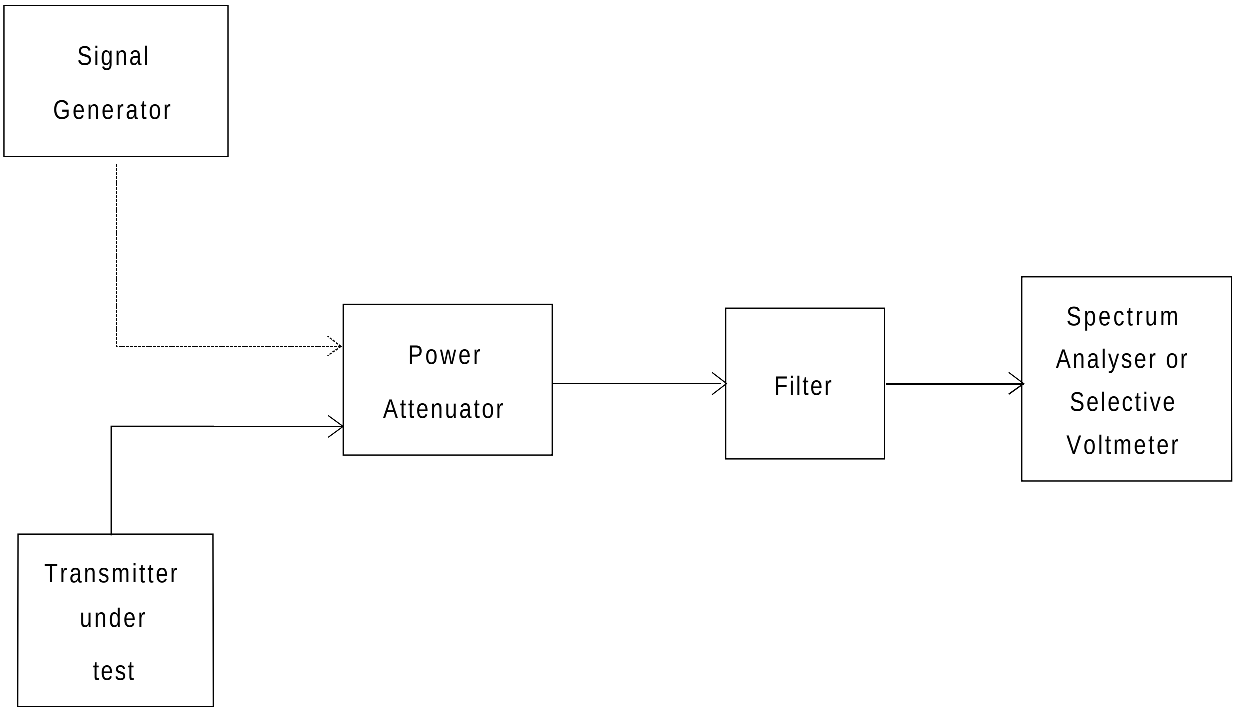


Figure 20: Conducted spurious emissions measurement configuration

The transmitter is connected to a spectrum analyser, or selective voltmeter, through a matching and attenuating network. The matching network includes a bandpass filter during measurements below 2,9 GHz in order to avoid overloading of the spectrum analyser. During measurements beyond 2,9 GHz the built in preselector of the spectrum analyser is active.

The individual spurious components are found and read from the analyser and corrected for attenuation and mismatch loss in the matching network, or they are substituted by means of a signal generator signal. Both calculations are given.

Measurement uncertainty:

1) Substitution method:

Power coefficient of attenuator ± 0,3 dB (d) + 3,51/- 3,39 % (r)

Mismatch uncertainties at input: (With transmitter connected):

Transmitter reflection coefficient taken from table C.1: Mean value = 0,7 and standard deviation = 0,1 Normalised standard deviation from table C.1 = 0,1/0,7 = 0,14. Network reflection coefficient 0,05 (m), m_{iu} = 0,05 x 0,7 x 100 = ± 3,5 % ,(u),

Uncertainty correction factor from the figure 4 in subclause 5.2.2 = 1,02. Mismatch uncertainty =

$$1{,}02 \text{ x } \frac{(3{,}5\ \%)}{\sqrt{2}} =$$ 2,52 % (σ)

With generator connected:

Generator reflection coefficient 0,2 (d),network reflection coefficient 0,05 (m),

M_{iu} = ± 0,05 x 0,2 x 100 % (c) ± 1,0 % (u)

Signal generator substitution signal uncertainty ± 1 dB (d) +12,2/- 10,9 % (r)

Uncertainty due to supply voltage: Supply voltage uncertainty ± 100 mV,(r), Dependency function taken from table C.1: Mean value = 10 % (p)/V and standard deviation =3,0 % (p)/V 3.0 %

and the supply voltage uncertainty is:

$$\sqrt{\left(\frac{(0{,}1\ V)^2}{3}\right) \text{ x } \left((10{,}0\ \%/V)^2 + (3{,}0\ \%/V)^2\right)} =$$ formula (2) 0,60 % (σ) (p) = 0,30 % (σ)

$$\sigma_{t+} = \sqrt{\frac{(3{,}51\%)^2 + (12{,}2\%)^2}{3} + \frac{(1\ \%)^2}{2} + (2{,}52\%)^2 + (0{,}3\ \%)^2} =$$ 7,79 % (σ)

$$\sigma_{t-} = \sqrt{\frac{(3{,}39\%)^2 + (10{,}9\%)^2}{3} + \frac{(1\ \%)^2}{2} + (2{,}52\%)^2 + (0{,}3\ \%)^2} =$$ 7,10 % (σ)

U_{95} = + 1,96 x 7.79 %/- 1,96 x 7,10 % = + 15,3 %/- 13,9 % = + 1,2/- 1,3 dB

2) Direct reading from spectrum analyser:

Mismatch and matching network uncertainty:
Matching and filtering network attenuation uncertainty ± 0,3 dB (m) + 3,51/- 3,39 % (r)
Power coefficient of attenuator ± 0,3 dB (d) + 3,51/- 3,39 % (r)

Mismatch uncertainty at input:

Network reflection coefficient 0,13 (d) Transmitter reflection coefficient taken from table C.1 : Mean value = 0,7 and standard deviation = 0,1 Network reflection coefficient 0,05 (m)

m_{iu} = 0,13 x 0,7 x 100 % = ± 9,1 % (u)

Normalised standard deviation = 0,1/0,7 = 0,14 Uncertainty correction factor from figure 4 in = 1,02: Mismatch uncertainty is:

$$1{,}02 \text{ x } \frac{(9{,}1\ \%)}{\sqrt{2}} =$$ 6,56 % (σ)

Mismatch uncertainty at spectrum analyser: Spectrum analyser reflection coefficient 0,4 (d), network reflection coefficient 0,13 (d)

m_{iu} = 0,13 x 0,4 x 100 % ± 5,2 % (u)

Mismatch and matching network uncertainty:

$$\sigma_{1+} = \sqrt{\frac{(3{,}51\%)^2 + (3{,}51\%)^2}{3} + \frac{(5{,}2\ \%)^2}{2} + (6{,}56\%)^2} =$$ 8,05 % (σ)

$$\sigma_{1-} = \sqrt{\frac{(3{,}39\%)^2 + (3{,}39\%)^2}{3} + \frac{(5{,}2\ \%)^2}{2} + (6{,}56\%)^2} =$$ 8,01 % (σ)

Spectrum analyser uncertainty:

Calibration mismatch uncertainty:

Both reflection coefficients = 0,2

m_{iu} = 0,2 x 0,2 x 100 % ± 4,0 % (u)

300 MHz reference uncertainty ± 0,3 dB (d)+ 3,51/- 3,39 % (r)

Frequency response uncertainty	± 2,5 dB (d)	+ 33,4/- 25,0 % (r)
Bandwidth switching uncertainty	± 0,5 dB (d)	+ 5,93/- 5,59 % (r)
Log fidelity	± 1,5 dB (d)	+ 18,9/- 15,9 % (r)

$$\sigma_{2+} = \sqrt{\frac{(3{,}51\%)^2 + (33{,}4\%)^2 + (5{,}93\%)^2 + (18{,}9\%)^2}{3} + \frac{(4{,}0\ \%)^2}{2}} =$$ 22,7 % (σ)

$$\sigma_{2-} = \sqrt{\frac{(3{,}39\ \%)^2 + (25{,}0\%)^2 + (5{,}59\%)^2 + (19{,}9\%)^2}{3} + \frac{(4{,}0\ \%)^2}{2}} =$$ 17,7 % (σ)

Uncertainty due to supply voltage: Supply voltage uncertainty ± 100 mV, (r), Dependency function taken from table C.1: Mean value = 10 % (p)/V and standard deviation = 3 % (p)/V

and the supply voltage uncertainty is:

$$\sqrt{\frac{(0{,}1\ V)^2}{3}\ \text{x}\ \left((10{,}0\ \%/V)^2 + (3{,}0\ \%/V)^2\right)} =$$ 0,60 % (σ) (p) = formula (2) 0,30 % (σ)

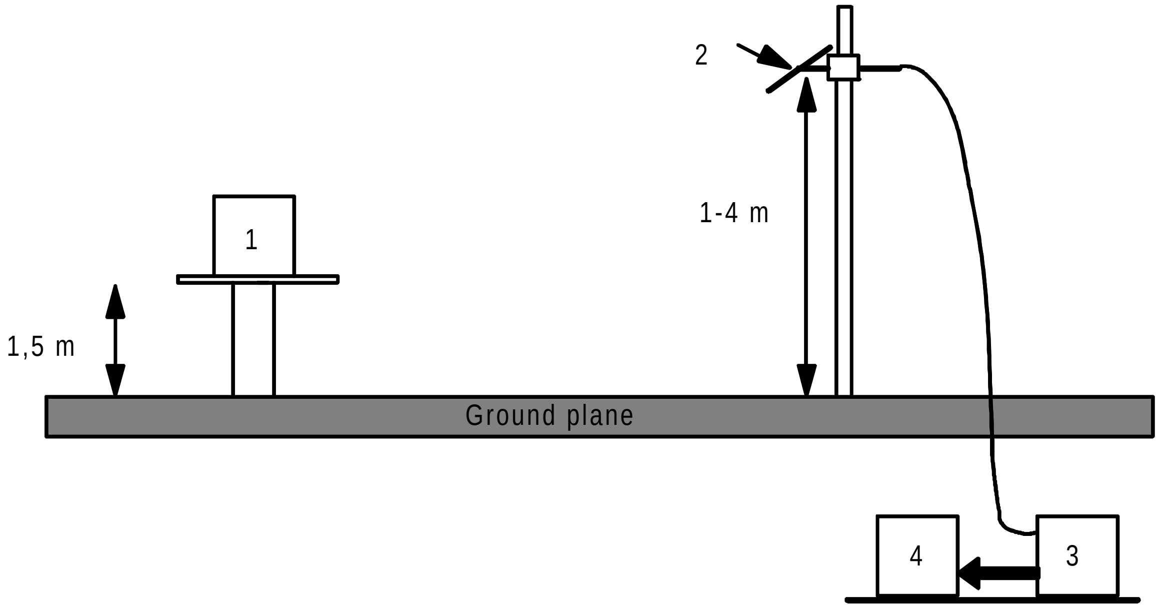
Total uncertainty:

$$\sigma_{t+} = \sqrt{(8{,}05\ \%)^2 + (22{,}7\ \%)^2 + (0{,}3\ \%)^2} =$$ 24,1 % (σ)

$$\sigma_{t-} = \sqrt{(8{,}01\ \%)^2 + (17{,}7\ \%)^2 + (0{,}3\ \%)^2} =$$ 19,4 % (σ)

U_{95} = + 1,96 x 24,1 %/- 1,96 x 19,4 % = + 47,2 %/- 38,0 % = + 3,36 dB/- 4,15 dB

6.6 Cabinet radiation



1) Equipment under test.

2) Test antenna.

3) High pass filter (necessary for strong fundamental Tx radiation).

4) Spectrum analyser or selective voltmeter.

Figure 21: Measurement configuration

Several test sites may be used to measure the effective radiated power of spurious emissions:

- open air test site;
- an indoor test site with absorbing material on the wall behind the test item;
- a semi-anechoic chamber;
- an anechoic chamber.

Also different antennas may be used:

- ½λ dipole;
- horn.

The measured quantity should be determined by a substitution method. Usually the test site has been calibrated by means of the substitution method and a site attenuation curve has been recorded.

The list of error sources are examples only and may not include all the possibilities. It is important that, where applicable, the errors are identified as either systematic or random for the purpose of making the calculations.

Some error sources that can contribute to the total uncertainty:

- standing wave patterns on test site;
- reflected waves;
- distance from test item to receiving antenna;
- test site attenuation uncertainty;
- disturbance caused by electronic equipment;
- cable and mismatch network attenuation uncertainty;
- antenna gain uncertainty;
- mismatch uncertainties;
- humidity;
- ambient radio frequency environment;
- log fidelity and linearity of detecting instrument;
- size and location of the test item and connected cables.

An attempt should be made to obtain a satisfactory analytical basis for calculating the maximum acceptable accumulated measurement uncertainty for transmitter and receiver radiated spurious emissions based upon the methods of measurement recommended in ETS 300 086 [2], I-ETS 300 113 [3] and CEPT Recommendation T/R 24-01 Annex I to VI [4] (see Clause 2).

However, all three methods are inadequately definitive over issues of ground plane characteristics, antenna separation, antenna heights, antenna types, cable positions, and most important of all, site calibration.

Further work is being carried out. The corresponding results will be incorporated in a future edition of this ETR.

6.7 Intermodulation attenuation

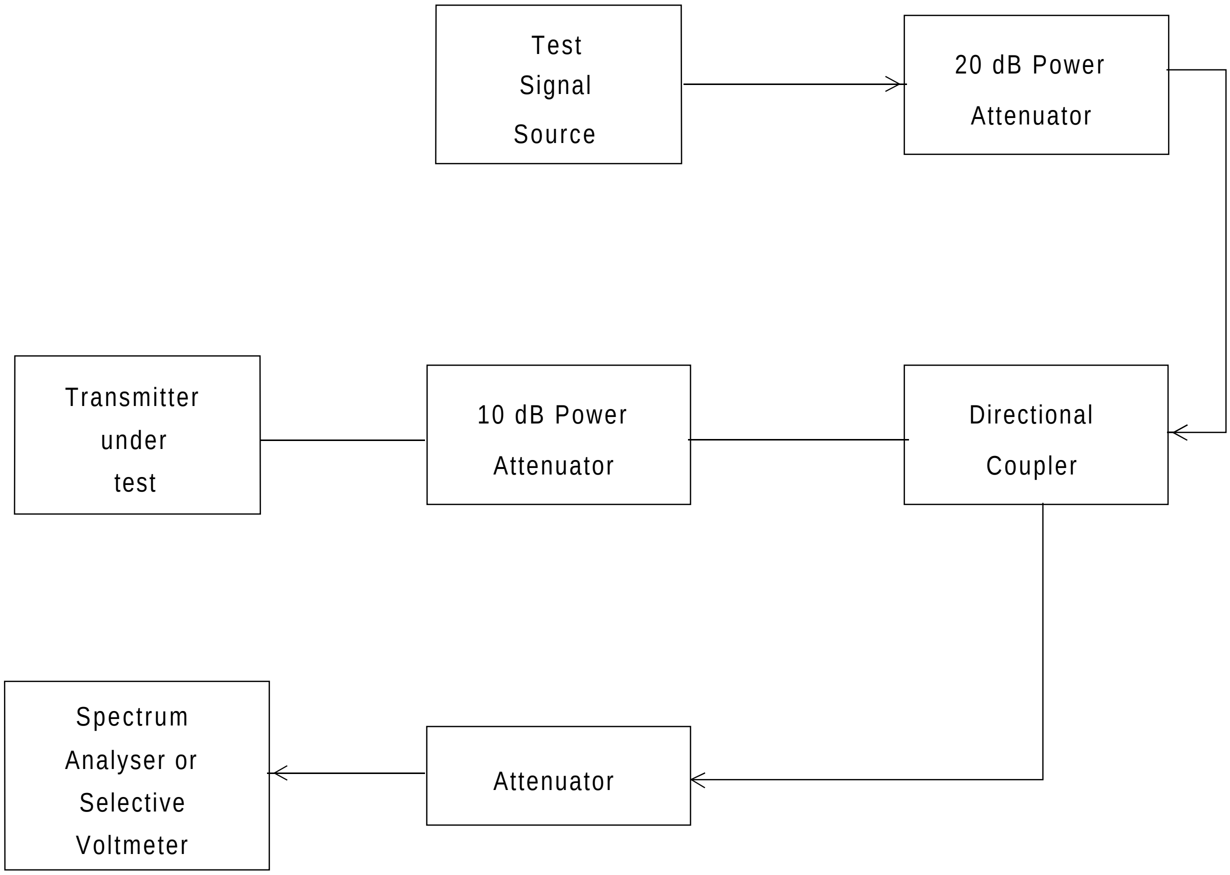


Figure 22: Intermodulation attenuation measurement configuration

The transmitter is connected to a signal generator through a matching network. The network contains two power attenuators in order to prevent intermodulation in the signal generator, and a directional coupler.

The level of the signal from the signal generator is measured with a power meter at the output of the matching network (the connector which during the actual measurement is connected to the transmitter output). The transmitter output is connected to a spectrum analyser via the directional coupler. The intermodulation products are compared directly by means of the spectrum analyser.

Measurement uncertainty:

Uncertainty of the level of the unwanted signal supplied to the output connector of the receiver:

Uncertainty of transmitter carrier power (taken from example 6.2) σ_1 = 4,34 % (σ)

Uncertainty of measuring the level of the unwanted signal:

Uncertainty of power meter (taken from example 6.2) σ_2 = 0,78 % (σ)

Mismatch uncertainty: $VSWR_g$ = 1,1 which gives R_g = 0,048, $VSWR_l$ = 1,15 which gives R_l = 0,07

M_{iu} = 0,048 x 0,07 x 100 % = ± 0,34 % (c)(u)

Total uncertainty of the adjustment of the unwanted signal:

$$\sigma_3 = \sqrt{(4{,}34\ \%)^2 + (0{,}78\ \%)^2 + \frac{(0{,}34\ \%)^2}{2}} = \qquad 4{,}42\ \%\ (\sigma)$$

Mismatch uncertainty of the application of the unwanted signal:

Network reflection coefficient 0,1(d). Transmitter reflection coefficient taken from table C.1: Mean value = 0,7 and standard deviation = 0,1 Network reflection coefficient 0,05 (m).

m_{iu} = 0,1 x 0,5 x 100 % = ± 5,0 % (u)

Normalised standard deviation from table C.1 = 0,2/0,5 = 0,4 Uncertainty correction factor from figure 4 in subclause 5.2.2 = 1,075. Mismatch uncertainty =

$$1{,}075 \text{ x } \frac{(5{,}0\ \%)}{\sqrt{2}} = \qquad 3{,}80\ \%\ (\sigma)$$

total uncertainty of unwanted signal level:

$$\sigma_4 = \sqrt{(4{,}42\ \%)^2 + (3{,}8\ \%)^2} = \qquad 5{,}83\ \%\ (\sigma)$$

Log fidelity of spectrum analyser 1,5 dB (d) + 18,85/- 15,86 % (r)

Uncertainty caused by supply voltage uncertainty is included in σ_1

Total uncertainty:

$$\sigma_{t+} = \sqrt{(5{,}83\ \%)^2 + \frac{(15{,}85\ \%)^2}{3}} = \qquad 12{,}3\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{(5{,}83\ \%)^2 + \frac{(15{,}86\ \%)^2}{3}} = \qquad 10{,}9\ \%\ (\sigma)$$

U_{95} = + 1,96 x 12,3 %/- 1,96 x 10,9 % = + 24,2 %/- 21,4 % = + 1,9 dB/- 2,1 dB

6.8 Transmitter attack/release time

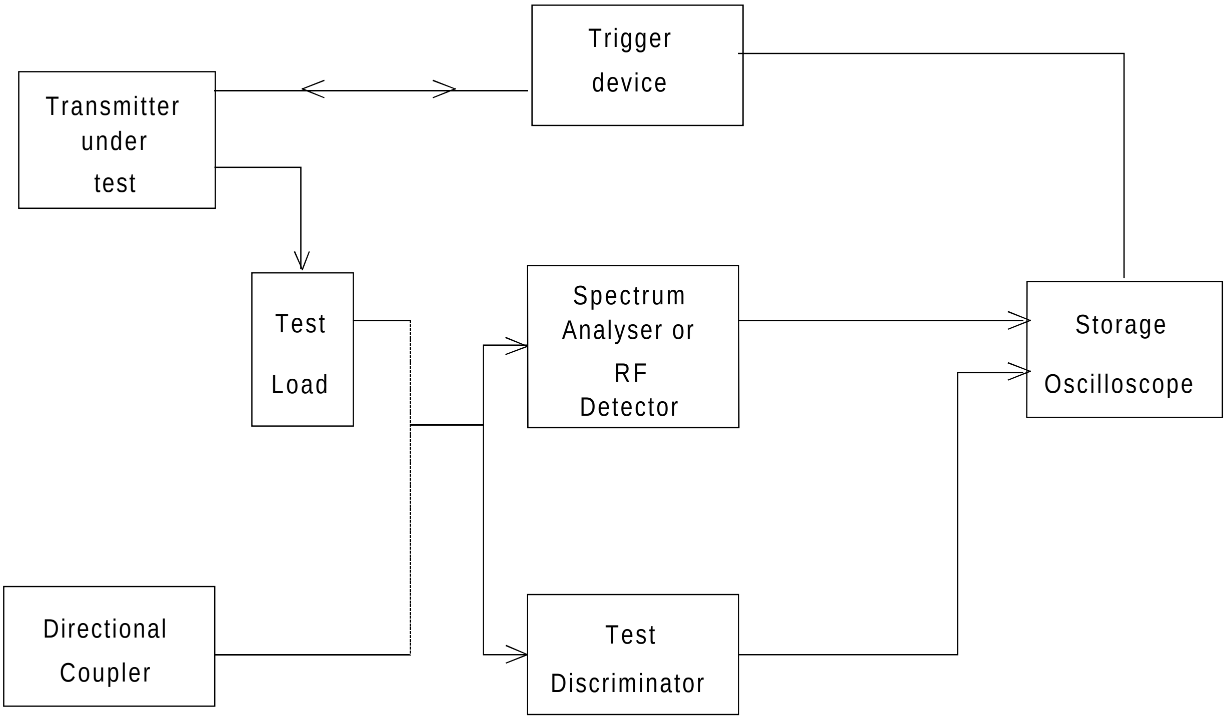


Figure 23: Transmitter attack/release time measurement configuration

The power level and the frequency variation as a function of time is measured by a spectrum analyser and a test discriminator connected to a storage oscilloscope. The attack time is the time elapsed between switching on the transmitter and the moment where the carrier power level and the carrier frequency is within defined limits. The release time is the time elapsed between switching off the transmitter and the moment where the carrier power level is lower than a defined limit.

The spectrum analyser and the discriminator are calibrated by means of the signal generator. The nominal transmitter frequency is 1 GHz.

Measurement uncertainty:

6.8.1 Frequency behaviour (applicable to attack time measurement)

Signal generator frequency uncertainty (see example in subclause 6.1) ± 10 Hz (d)(c)

Calibration uncertainty of discriminator (including the storage oscilloscope) ± 100 Hz (r)

DC drift of discriminator ± 100 Hz (r)

Standard deviation of frequency error measurement:

$$\sigma_1 = \sqrt{\frac{\left((100\ Hz)^2 + (100\ Hz)^2 + (10\ Hz)^2\right)}{3}} =$$ 81,9 Hz (σ)

The frequency error uncertainty is then by means of the time versus frequency error gradient (taken from table C.1) converted to time uncertainty: (Table C.1 gradient: Mean value = 1,0 ms/kHz, Standard deviation = 0,3 ms/kHz).

$$\sigma_2 = \sqrt{(0{,}0819\ kHz)^2\ \mathrm{x}\ \left((1{,}0\ ms/kHz)^2 + (0{,}3\ ms/kHz)^2\right)} =$$ formula (2) 0,086 ms (σ)

Oscilloscope timing uncertainty ± 1,0 ms (r)
Trigger moment uncertainty ± 1,0 ms (r)
Random uncertainty (m)(c) 0,5 ms (σ)

Total uncertainty:

$$\sigma_t = \sqrt{(0{,}086\ ms)^2 + (0{,}5\ ms)^2 + \left(\frac{(1\ ms)^2 + (1\ ms)^2}{3}\right)} = \quad 0{,}961\ \text{ms}\ (\sigma)$$

U_{95} = ± 1,96 x 0,961 ms = ± 1,9 ms

6.8.2 Power level behaviour (applicable to attack and release time measurements)

Spectrum analyser log fidelity ± 0,4 dB (d) = + 4,7/- 4,5 % (r)

The power level difference uncertainty is then by means of the time/difference gradient (table C.1) converted to time uncertainty: (Table C.1 gradient : Mean value = 0,3 ms/%, Standard deviation = 0,1 ms/%).

$$\sigma_{1+} = \sqrt{\left(\frac{(4{,}7\ \%)^2}{3}\right) \text{x} \left((0{,}3\ ms/\ \%)^2 + (0{,}1\ ms/\ \%)^2\right)} = \quad \text{formula (2)} \quad 0{,}856\ \text{ms}\ (\sigma)$$

$$\sigma_{1-} = \sqrt{\left(\frac{(4{,}5\ \%)^2}{3}\right) \text{x} \left((0{,}3\ ms/\ \%)^2 + (0{,}1\ ms/\ \%)^2\right)} = \quad \text{formula (2)} \quad 0{,}822\ \text{ms}\ (\sigma)$$

Oscilloscope timing uncertainty ± 1,0 ms (r)
Trigger moment uncertainty ± 1,0 ms (r)
Random uncertainty (m)(c) 0,5 ms (σ)

Total uncertainty:

$$\sigma_{t+} = \sqrt{(0{,}856\ ms)^2 + \frac{(1{,}0\ ms)^2 + (1{,}0\ ms)^2 + (0{,}5\ ms)^2}{3}} = \quad 1{,}22\ \text{ms}\ (\sigma)$$

$$\sigma_{t-} = \sqrt{(0{,}822\ ms)^2 + \frac{(1{,}0\ ms)^2 + (1{,}0\ ms)^2 + (0{,}5\ ms)^2}{3}} = \quad 1{,}20\ \text{ms}\ (\sigma)$$

U_{95} = +1,96 x 1,22 ms/- 1,96 x 1,20 ms = + 2,39 ms/- 2,35 ms

6.9 Transient behaviour of the transmitter

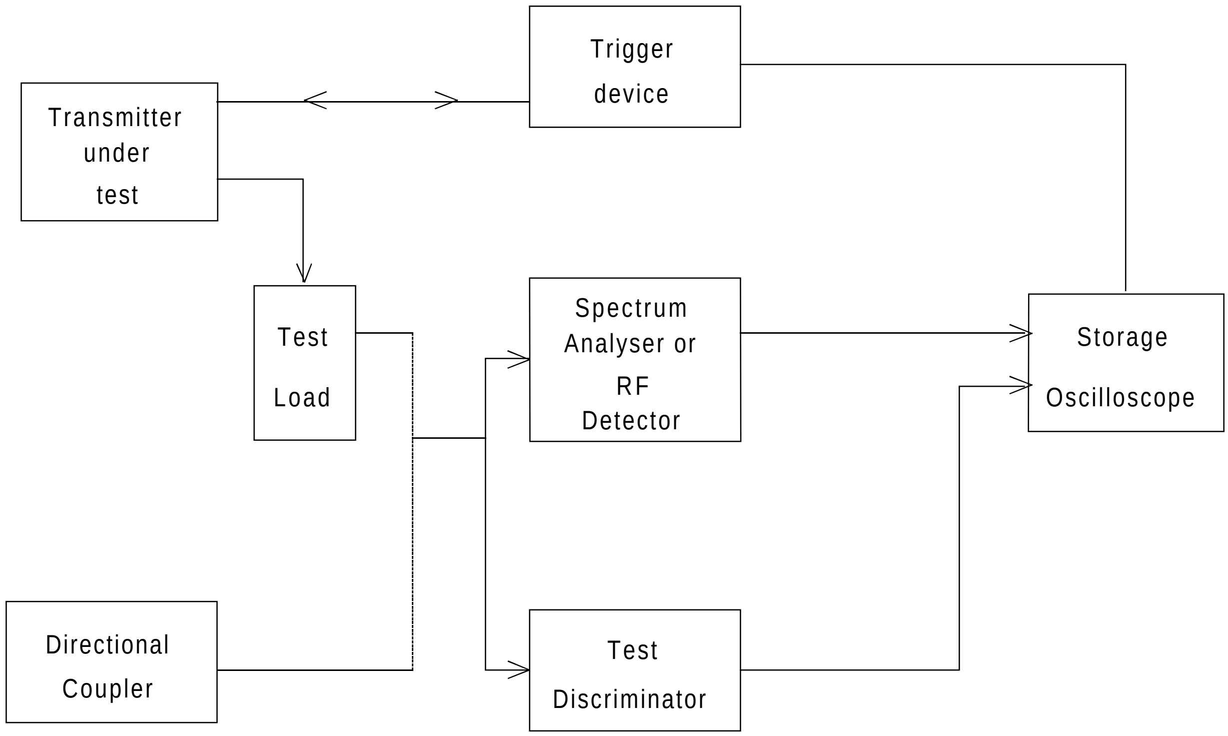


Figure 24: Transient behaviour of the transmitter measurement configuration

The power level as a function of time and the frequency error is measured by means of a spectrum analyser and a test discriminator connected to a storage oscilloscope.

The slope of the power level and the frequency error during turn on and turn off is measured.

The spectrum analyser and the discriminator are calibrated by means of the signal generator. The nominal transmitter frequency is 1 GHz. When the power level slope is measured the spectrum analyser is in zero span mode and the sweep is adjusted so that the -6 dB point and the -30 dB point are at both extremes of the screen.

Measurement uncertainty:

6.9.1 Uncertainty in measuring frequency error

Signal generator frequency uncertainty =(see example 6.1) ± 10 Hz (d)(c)

Calibration uncertainty of discriminator (including the storage oscilloscope) ± 100 Hz (r)

DC drift of discriminator ± 100 Hz (r)

Standard deviation of frequency error measurement:

$$\sigma_t = \sqrt{\frac{(100\ Hz)^2 + (100\ Hz)^2 + (10\ Hz)^2}{3}} = \qquad 81{,}9\ \text{Hz}\ (\sigma)$$

U_{95} = ± 1,96 x 81,9 Hz = ± 161 Hz

6.9.2 Uncertainty in measuring power level slope

(The following calculations are based on the assumption that the power level versus time is linear in logarithmic terms).

Spectrum analyser log fidelity at -6 dB: ± 0,6 dB (d)(r)
This is converted to time uncertainty: ± 0,6/(- 6 + 30) % ± 2,5 % (c)(r)

Spectrum analyser log fidelity at - 30 dB: ± 1,5 dB (d)(r)
This is converted to time uncertainty: ± 1,5/(- 6 + 30) % ± 6,25 % (c)(r)

Time measurement uncertainty (counts twice) ± 2 % (r) of full screen ± 2 % (d)(r)

Random uncertainty (m) 1 % (σ)

Total uncertainty:

$$\sigma_{t+} = \sqrt{\frac{(2{,}5\ \%)^2 + (6{,}25\ \%)^2 + (2\ \%)^2 + (2\ \%)^2}{3} + (1\ \%)^2} = \qquad 4{,}33\ \%\ (\sigma)$$

U_{95} = ± 1,96 x 4,33 % = ± 8,5 %

7 Receiver measurement examples

7.1 Maximum usable sensitivity

7.1.1 Maximum usable sensitivity (analogue speech)

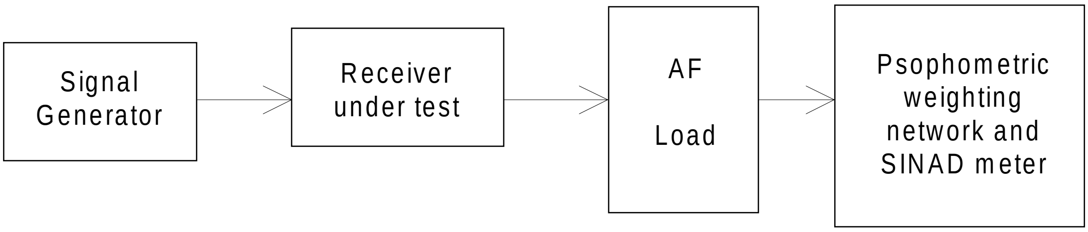


Figure 25: Maximum usable sensitivity measurement configuration (analogue speech)

The signal generator is connected to the antenna connector of the receiver under test through a matching network. The low frequency output of the receiver is suitably terminated and fed to a psophometric filter connected to a SINAD meter. The signal generator signal is modulated with normal modulation.

The level is decreased until 20 dB SINAD as read from the SINAD meter obtained. The result is the signal generator level corrected for mismatch loses and attenuation of matching network.

Measurement uncertainty:

RF level uncertainty:

Signal generator level uncertainty ± 1 dB (d) + 12,2/- 10,9 % (r)

Mismatch uncertainties at the antenna connector of the receiver: (VSWR$_{att}$ 1,2 which gives R_l = 0,091 and R_g of the receiver under test taken from table C.1: Mean value = 0,2 standard deviation = 0,05

M_{iu} = 0,091 x 0,2 x 100 % = ± 1,82 % (u) (c) formula (8)

Normalised standard deviation of R_g = 0,05/0,2 = 0,25 Correction factor (taken from figure 4 in subclause 5.2.2) = 1,03

Standard deviation of mismatch uncertainty at the antenna connector=

$$1{,}03 \ \text{x} \ \frac{(1{,}82\ \%)}{\sqrt{2}} =$$ formula (9) 1,33 % (σ)

Uncertainty of cable attenuation ± 1,2 % (c) (σ)

Total level uncertainty:

$$\sigma_{1+} = \sqrt{\frac{(12{,}2\ \%)^2}{3} + (1{,}33\ \%)^2 + (1{,}2\ \%)^2} =$$ 7,26 % (σ)

$$\sigma_{1-} = \sqrt{\frac{(10{,}9\ \%)^2}{3} + (1{,}33\ \%)^2 + (1{,}2\ \%)^2} =$$ 6,54 % (σ)

SINAD measurement uncertainty:

SINAD meter uncertainty ± 1 dB (d) + 12,2/- 10,9 % (r)

Deviation uncertainty ± 5,3 % (d) (r)

Total SINAD uncertainty:

$$\sigma_{2+} = \sqrt{\frac{(12{,}2\ \%)^2 + (5{,}3\ \%)^2}{3}} = 7{,}68\ \%\ (\sigma)$$

$$\sigma_{2-} = \sqrt{\frac{(10{,}8\ \%)^2 + (5{,}3\ \%)^2}{3}} = 6{,}95\ \%\ (\sigma)$$

The SINAD uncertainty is then by means of formula (2) converted to level uncertainty.

Dependency function taken from table C.1: Mean value = 1,0 $dB_{RF\ INPUT\ LEVEL}/dB_{SINAD}$ and the standard deviation 0,2 $dB_{RF\ INPUT\ LEVEL}/dB_{SINAD}$.

$$\sigma_{3+} = \sqrt{(7{,}68\ \%)^2\ \text{x}\ \left(\left(1{,}0\ dB_{RF\ INPUT\ LEVEL}\ /\ dB_{SINAD}\right)^2 + \left(0{,}2\ dB_{RF\ INPUT\ LEVEL}\ /\ dB_{SINAD}\right)^2\right)} = 7{,}83\ \%\ (\sigma)$$

$$\sigma_{3-} = \sqrt{(6{,}95\ \%)^2\ \text{x}\ \left(\left(1{,}0\ dB_{RF\ INPUT\ LEVEL}\ /\ dB_{SINAD}\right)^2 + \left(0{,}2\ dB_{RF\ INPUT\ LEVEL}\ /\ dB_{SINAD}\right)^2\right)} = 7{,}09\ \%\ (\sigma)$$

Uncertainty due to uncertainty of ambient temperature : (25 °C ± 3°C):

Dependency function taken from table C.1: Mean value = 2,5 %/°C and Standard deviation = 1,2 %/°C

$$\sigma_4 = \sqrt{\left(\frac{(3°C)^2}{3}\right)\ \text{x}\ \left((2{,}5\ \%/°C)^2 + (1{,}2\ \%/°C)^2\right)} = \quad \text{formula (2)} \quad 4{,}8\ \%\ (\sigma)$$

Random uncertainty 2,0 % (σ) (m)

Total uncertainty:

$$\sigma_{t+} = \sqrt{(7{,}26\ \%)^2 + (7{,}83\ \%)^2 + \left(\frac{(5{,}3\ \%)^2}{3}\right) + (4{,}8\ \%)^2 + (2{,}0\ \%)^2} = \quad 12{,}2\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{(6{,}54\ \%)^2 + (7{,}09\ \%)^2 + \left(\frac{(5{,}3\ \%)^2}{3}\right) + (4{,}8\ \%)^2 + (2{,}0\ \%)^2} = \quad 11{,}3\ \%\ (\sigma)$$

U_{95} = + 1,96 x 12,2 %/- 1,96 x 11,3 % = + 24,0 %/- 22,2 % = + 1,9 dB/- 2,2 dB

7.1.2 Maximum usable sensitivity (bit stream)

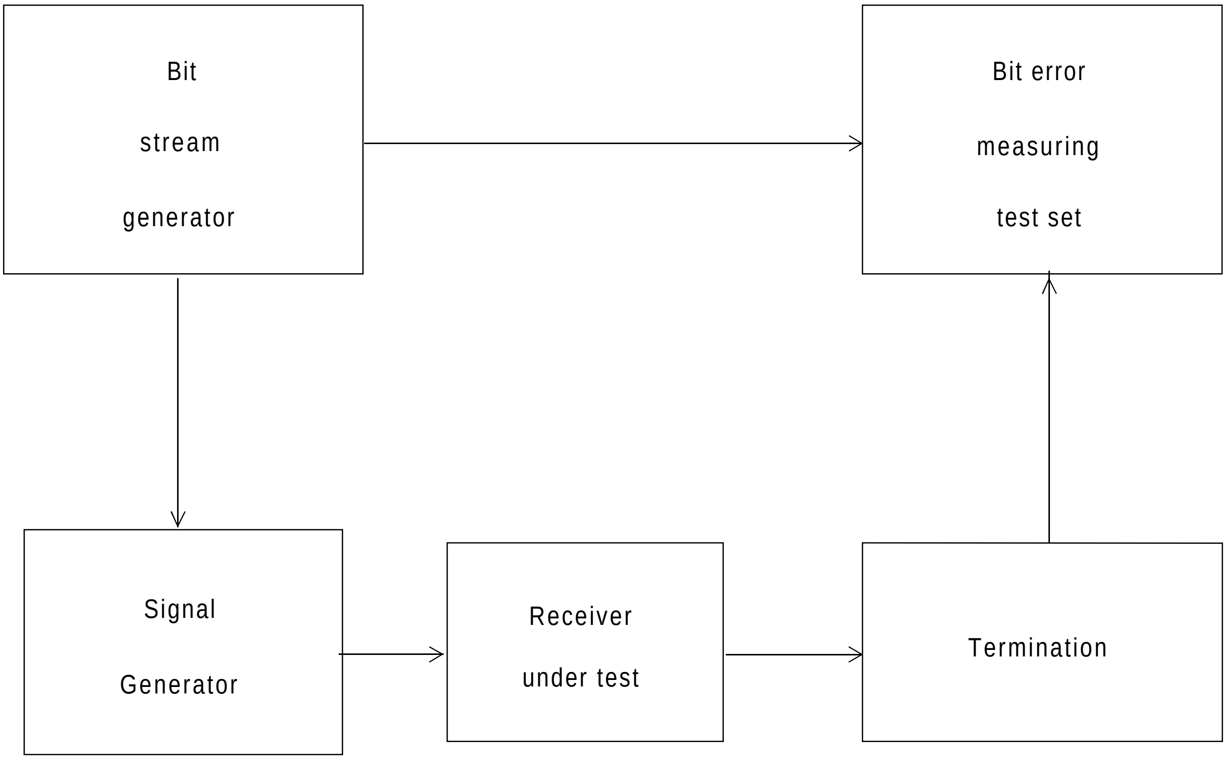


Figure 26: Maximum usable sensitivity measurement configuration (bit stream)

The signal generator is connected to the antenna connector of the receiver. The signal generator is at the nominal frequency of the receiver and is modulated by the appropriate test modulation. The amplitude of the signal generator is adjusted until the specified BER is obtained. The measured usable sensitivity for bit stream is recorded. The result is the signal generator level corrected for mismatch loses and attenuation of matching network.

Measurement uncertainty:

RF level uncertainty:

Signal generator level uncertainty ± 1 dB (d) + 12,2/- 10,9 % (r)

Mismatch uncertainties at the antenna connector of the receiver: (VSWR$_{att}$ 1,2 which gives R_l = 0,091 and R_g of the receiver under test taken from table C.1: Mean value = 0,2 standard deviation = 0,05

M_{iu} = 0,091 x 0,2 x 100 % = ± 1,82 % (u) (c) formula (8)

Normalised standard deviation of R_g = 0,05/0,2 = 0,25 Correction factor (taken from figure 4 in subclause 5.2.2) = 1,03. Standard deviation of mismatch uncertainty at the antenna connector

$$1{,}03 \text{ x } \frac{(1{,}82\ \%)}{\sqrt{2}} =$$ formula (9) 1,33 % (σ)

Uncertainty of cable attenuation ± 1,2 % (c) (σ)

Total level uncertainty:

$$\sigma_{1+} = \sqrt{\frac{(12{,}2\ \%)^2}{3} + (1{,}33\ \%)^2 + (1{,}2\ \%)^2} = \qquad 7{,}26\ \%\ (\sigma)$$

$$\sigma_{1-} = \sqrt{\frac{(10{,}9\ \%)^2}{3} + (1{,}33\ \%)^2 + (1{,}2\ \%)^2} = \qquad 6{,}54\ \%\ (\sigma)$$

Deviation uncertainty ± 5,3 % (d) (r)
Random uncertainty 2,0 % (σ) (m)

Uncertainty due to uncertainty of ambient temperature : (25 °C ± 3°C):Dependency function taken from table C.1: Mean value = 2,5 %/°C Standard deviation = 1,2 %/°C

$$\sigma_4 = \sqrt{\left(\frac{(3\ ^\circ C)^2}{3}\right) \text{x} \left((2{,}5\ \%/^\circ C)^2 + (1{,}2\ \%/^\circ C)^2\right)} = \qquad \text{formula (2)} \qquad 4{,}8\ \%\ (\sigma)$$

Case 1: Error associated with digital non-coherent direct modulation

The RF signal is directly modulated. It has been assumed that the SNR_b is proportional to the RF input level. sBER is transformed to RF input level uncertainty by means of the SNR_b(BER) function. The RF input level to a receiver is adjusted to obtain a BER of 10-2. The measurement result is the RF level giving this BER. The BER is measured over a series of 2 500 bit. The resulting BER uncertainty is then calculated using formula (17):

$$\sigma_{BER} = \sqrt{\frac{0{,}01\ \text{x}\ 0{,}99}{2\,500}} = 2\ \text{x}\ 10^{-3}$$

The signal to noise ratio giving this BER (0,01) is then calculated using formula (22):

SNR_b = - 2 x ln(2 x 0,01) = 7,824

The transforming dependency function at this level is:

SNR_b' = - 2/0,01 = - 200 formula (23)

The resulting level uncertainty (using (22)) is then:

$$\sigma_{LEVEL} = \frac{2\ \text{x}\ 10^{-3}}{0{,}5\ x\ 10^{-3}\ \text{x}\ 7{,}824}\ \text{x}\ 100\ \% = 5{,}11\ \%$$

which is equal to 2,52 % (σ) in voltage terms. This RF level uncertainty is then combined with the rest of the part uncertainties to give the total RF level uncertainty.

Case 2a: Error associated with digital non-coherent sub carrier modulation above the knee point

For above the knee point case 1 applies because the C/N to S/N ratio is still 1:1.

Case 2b: Error associated with digital non-coherent sub carrier modulation below the knee point

To obtain the RF level uncertainty for sub carrier modulation, the relevant dependency functions listed in table C.1 from the equivalent analogue measurements is applied to the results of case 1. The value for the dependency function (noise gradient, below the knee point) taken from table C.1 is:

Mean value: 0,375 $dB_{RF\ INPUT\ LEVEL}/dB_{SINAD}$ and the standard deviation 0,075 $dB_{RF\ INPUT}/dB_{SINAD}$.The sub carrier signal to noise ratio uncertainty is 2,52 (σ) from case 1. The subcarrier signal to noise uncertainty is then by means of formula (2) converted to RF level uncertainty:

$$\sigma_{level} = \sqrt{(2{,}52\ \%)^2 \text{ x} \left((0{,}375\, dB_{RF\ INPUT\ LEVEL} / dB_{SINAD})^2 + (0{,}075\, dB_{RF\ INPUT\ LEVEL} / dB_{SINAD})^2 \right)} = 0{,}964\ \%(\sigma)$$

which can then be combined with the rest of the part uncertainties to give the total RF level uncertainty.

Case 3: Error associated with digital coherent direct modulation

The RF input level to the receiver is adjusted to obtain a BER of 10-2. The measured result is the RF level giving this BER. The BER is measured over a series of 2 500 bits. The uncertainty of the RF signal at the input is 5,0 % (σ). The resulting BER is then calculated using formula (17):

$$\sigma_{BER} = \sqrt{\frac{0{,}01 \text{ x } 0{,}99}{2\ 500}} = 2{,}0 \text{ x } 10^{-3}$$

The signal to noise ratio giving this BER is then read from figure 8: $SNR_b(0{,}01) = 2{,}8$ and the dependency function at this level is:

$$BER'(2{,}8) = \frac{1}{2 \text{ x } \sqrt{\Pi \text{ x } 2{,}8}} \text{ x } e^{-2{,}8} = 10{,}25 \text{ x } 10^{-3}$$

The BER uncertainty is then transformed to level uncertainty using formula (22):

$$\sigma_{level} = \frac{2 \text{ x } 10^{-3}}{10{,}25 \text{ x } 10^{-3} \text{ x } 2{,}8} \; x\ 100\ \% = 6{,}97\ \%\ (p)$$

which is equal to 3,43 % (σ) in voltage terms. This RF level uncertainty is then combined with the rest of the part uncertainties to give the total RF level uncertainty.

Case 4a: Error associated with digital coherent sub carrier modulation operating above the knee point

For above the knee point case 3 applies.

Case 4b: Error associated with digital coherent sub carrier modulation below the knee point

To obtain the RF level uncertainty for sub carrier modulation, the relevant dependency functions listed in table C.1 from the equivalent analogue measurements is applied to the results of case 3. The value for the dependency function (noise gradient, above the knee point) taken from table C.1 is: Mean value: 0,375 $dB_{RF\ INPUT\ LEVE}/dB_{SINAD}$ and the standard deviation 0,075 $dB_{RF\ INPUT\ LEVE}/dB_{SINAD}$. The sub carrier signal to noise ratio uncertainty is 3,43 % (σ) (from case 3. The subcarrier signal to noise uncertainty is then by means of formula (2) converted to RF level uncertainty:

$$\sigma_{LEVEL} = \sqrt{(3{,}43\ \%)^2 \text{ x} \left((0{,}375\, dB_{RF\ INPUT\ LEVEL} / dB_{SINAD})^2 + (0{,}075\, dB_{RF\ INPUT\ LEVEL} / dB_{SINAD})^2 \right)} = 1{,}31\ \%$$

This RF level uncertainty is then combined with the uncertainty of the level of the input signal to obtain the total uncertainty of the sensitivity:

Total uncertainty: Case 1

$$\sigma_{t+} = \sqrt{(7{,}26\ \%)^2 + \left(\frac{(3{,}94\ \%)^2 + (4{,}8\ \%)^2 + (5{,}3\ \%)^2}{3}\right) + (2{,}52\ \%)^2 + (2{,}0\ \%)^2} = \qquad 9{,}23\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{(6{,}54\ \%)^2 + \left(\frac{(3{,}94\ \%)^2 + (4{,}8\ \%)^2 + (5{,}3\ \%)^2}{3}\right) + (2{,}52\ \%)^2 + (2{,}0\ \%)^2} = \qquad 8{,}68\ \%\ (\sigma)$$

U_{95} = + 1,96 x 9,733 %/- 1,96 x 9,193 % = + 19,08 %/- 18,018 % = + 1,52 dB/- 1,73 dB

Total uncertainty: Case 2b

$$\sigma_{t+} = \sqrt{(7{,}26\ \%)^2 + \left(\frac{(3{,}94\ \%)^2 + (4{,}8\ \%)^2 + (5{,}3\ \%)^2}{3}\right) + (0{,}96\ \%)^2 + (2{,}0\ \%)^2} = \qquad 9{,}011\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{(6{,}54\ \%)^2 + \left(\frac{(3{,}94\ \%)^2 + (4{,}8\ \%)^2 + (5{,}3\ \%)^2}{3}\right) + (0{,}96\ \%)^2 + (2{,}0\ \%)^2} = \qquad 8{,}442\ \%\ (\sigma)$$

U_{95} = +1,96 x 9,01/-1,96 x 8,44 % = +17,66/-16,55 % = +1,41/-1,57 dB

Total uncertainty: Case 3

$$\sigma_{t+} = \sqrt{(7{,}26\ \%)^2 + \left(\frac{(3{,}94\ \%)^2 + (4{,}8\ \%)^2 + (5{,}3\ \%)^2}{3}\right) + (3{,}43\ \%)^2 + (2{,}0\ \%)^2} = \qquad 8{,}914\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{(6{,}54\ \%)^2 + \left(\frac{(3{,}94\ \%)^2 + (4{,}8\ \%)^2 + (5{,}3\ \%)^2}{3}\right) + (3{,}43\ \%)^2 + (2{,}0\ \%)^2} = \qquad 8{,}321\ \%\ (\sigma)$$

U_{95} = + 1,96 x 8,914/- 1,96 x 8,321 % = + 17,5/- 16,3 % = + 1,40/- 1,55 dB

Total uncertainty: Case 4b

$$\sigma_{t+} = \sqrt{(7{,}26\ \%)^2 + \left(\frac{(3{,}94\ \%)^2 + (4{,}8\ \%)^2 + (5{,}3\ \%)^2}{3}\right) + (1{,}31\ \%)^2 + (2{,}0\ \%)^2} = \qquad 8{,}902\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{(6{,}54\ \%)^2 + \left(\frac{(3{,}94\ \%)^2 + (4{,}8\ \%)^2 + (5{,}3\ \%)^2}{3}\right) + (1{,}31\ \%)^2 + (2{,}0\ \%)^2} = \qquad 8{,}308\ \%\ (\sigma)$$

U_{95} = + 1,96 x 8,902/- 1,96 x 8,308 % = + 17,4/- 16,3 % = + 1,40/- 1,54 dB

7.1.3 Maximum usable sensitivity (messages)

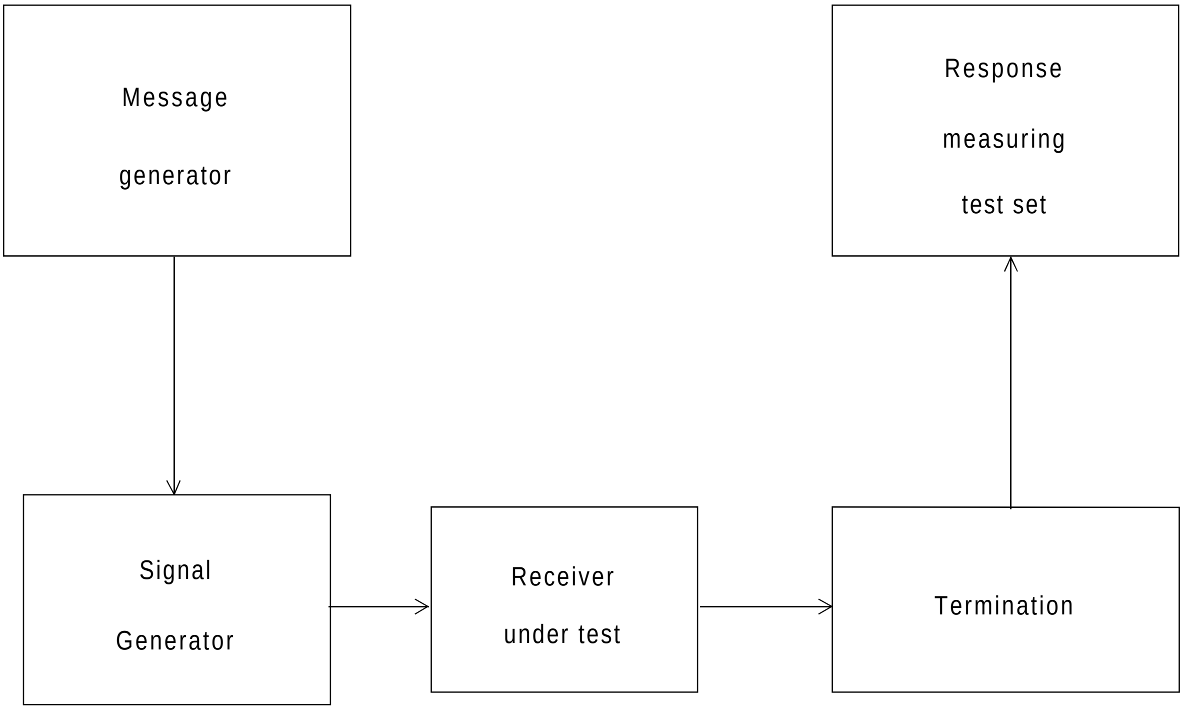


Figure 27: Maximum usable sensitivity measurement configuration (messages)

The signal generator is connected to the antenna connector of the receiver under test through a matching network. The signal generator is at the nominal frequency of the receiver and is modulated by the appropriate modulation. The test signal is applied repeatedly until the specified success calling rate is achieved. The result is the average of the signal generator level recorded corrected for mismatch loses and attenuation of matching network.

Measurement uncertainty:

RF level uncertainty:

Signal generator level uncertainty ± 1 dB (d) + 12,2/- 10,9 % (r)
Mismatch uncertainties at the antenna connector of the receiver: ($VSWR_{att}$ 1,2 which gives R_l = 0,091 and R_g of the receiver under test taken from table C.1: Mean value = 0,2 standard deviation = 0,05

M_{iu} = 0,091 x 0,2 x 100 % = ± 1,82 % (u) (c) formula (8)

Normalised standard deviation of R_g = 0,05/0,2 = 0,25 Correction factor (taken from figure 4 in subclause 5.2.2) = 1,03. Standard deviation of mismatch uncertainty at the antenna connector:

$$1{,}03 \text{ x} \frac{(1{,}82\ \%)}{\sqrt{2}} =$$ formula (9) 1,33 % (σ)

Uncertainty of attenuation in cable ± 1,2 % (c) (σ)

Total level uncertainty:

$$\sigma_{1+} = \sqrt{\frac{(12,2\ \%)^2}{3} + (1,33\ \%)^2 + (1,2\ \%)^2} = \qquad 7,26\ \%\ (\sigma)$$

$$\sigma_{1-} = \sqrt{\frac{(10,9\ \%)^2}{3} + (1,33\ \%)^2 + (1,2\ \%)^2} = \qquad 6,54\ \%\ (\sigma)$$

Using the value of +/- 0,332 dB, the standard deviation from the example in subclause 5.6.4, the uncertainty contribution is: + 3,90 % - 3,75 %

Uncertainty due to uncertainty of ambient temperature : (25 °C ± 3°C): Dependency function taken from table C.1: Mean value = 2,5 %/°C and Standard deviation = 1,2 %/°C

$$\sigma_4 = \sqrt{\left(\frac{(3\ ^\circ C)^2}{3}\right) \text{ x } \left((2,5\ \%/^\circ C)^2 + (1,2\ \%/^\circ C)^2\right)} = \qquad \text{formula (2)} \qquad 4,8\ \%\ (\sigma)$$

Random uncertainty 2,0 % (σ) (m)

Total uncertainty:

$$\sigma_{t+} = \sqrt{(7,26\ \%)^2 + (7,83\ \%)^2 + \left(\frac{(5,3\ \%)^2}{3}\right) + (3,90\ \%)^2 + (4,8\ \%)^2 + (2,0\ \%)^2} = \qquad 12,87\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{(6,54\ \%)^2 + (7,09\ \%)^2 + \left(\frac{(5,3\ \%)^2}{3}\right) + (3,75\ \%)^2 + (4,8\ \%)^2 + (2,0\ \%)^2} = \qquad 11,98\ \%\ (\sigma)$$

U_{95} = + 1,96 x 12,87 %/- 1,96 x 11,98 % = + 25,22 %/- 23,48 % = + 1,95 dB/- 2,32 dB

7.2 Amplitude characteristic

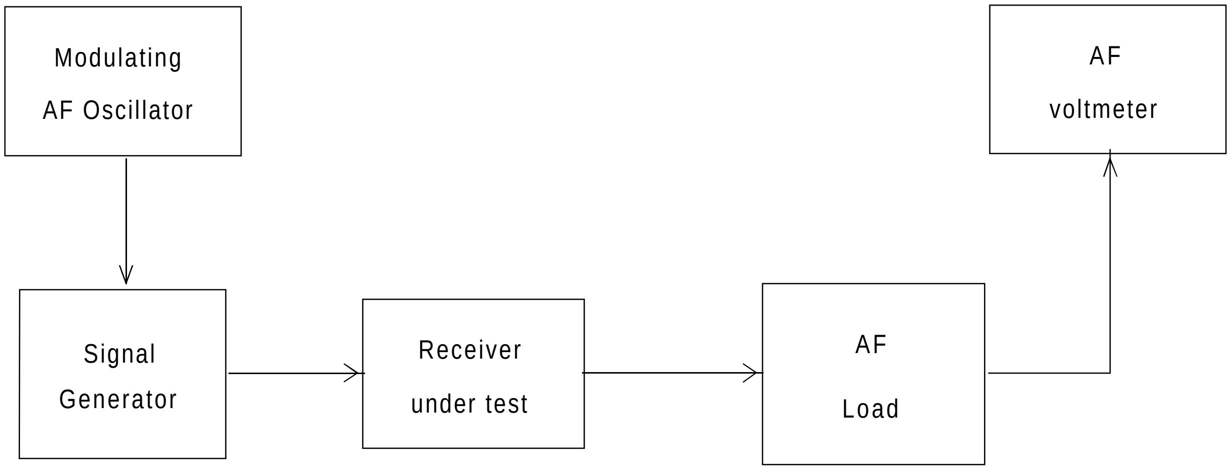


Figure 28: Amplitude characteristic measurement configuration

The receiver under test is connected to a signal generator through a matching network. The low frequency output from the receiver is suitably terminated and connected to an AC voltmeter or audio analyser.

The result is read from the AC voltmeter.

Measurement uncertainty:

RF level uncertainty: Signal generator level uncertainty ± 1 dB (d) + 12,2/- 10,9 % (r)

Mismatch uncertainties at the antenna connector of the receiver: ($VSWR_{att}$ 1,2 which gives R_l = 0,091 and R_g of the receiver under test taken from table C.1: Mean value = 0,2, standard deviation = 0,05)

M_{iu} = 0,091 x 0,2 x 100 % = ± 1,82 % (u) (c) formula (8)

Normalised standard deviation of R_g = 0,05/0,2 = 0,25

Correction factor (taken from figure 4) = 1,03 Standard deviation of mismatch uncertainty at the antenna connector

$1{,}03 \text{ x } \frac{(1{,}82\ \%)}{\sqrt{2}} =$ formula (9) 1,33 % (σ)

Uncertainty of attenuation in cable ± 1,2 % (c) (σ)

Total level uncertainty:

$$\sigma_{1+} = \sqrt{\frac{(12{,}2\ \%)^2}{3} + (1{,}33\ \%)^2 + (1{,}2\ \%)^2} =$$ 7,27 % (σ)

$$\sigma_{1-} = \sqrt{\frac{(10{,}9\ \%)^2}{3} + (1{,}33\ \%)^2 + (1{,}2\ \%)^2} =$$ 6,54 % (σ)

Uncertainties caused by RF level uncertainty σ_2:

Dependency function taken from table C.1: Mean value = 0,05 %/% level. Standard deviation = 0,02 %/% level

$$\sigma_{2+} = \sqrt{(7{,}26\ \%)^2 \text{ x } \left((0{,}05\ \%/\%)^2 + (0{,}02\ \%/\%)^2\right)} =$$ 0,41 % (σ)

$$\sigma_{2-} = \sqrt{(6{,}54\ \%)^2 \text{ x } \left((0{,}05\ \%/\%)^2 + (0{,}02\ \%/\%)^2\right)} =$$ formula (2) 0,37 % (σ)

($\sigma_2 = \sigma_2+$ = 0,41 % will be used in the following calculation)

Noise variation at low RF level 2,0 % (a) (σ)

AC volt meter uncertainty (Must be allowed for twice) ± 2,0 % (d) (r)

The AC level is well above the measuring system noise floor.

$$\sigma_t = \sqrt{\frac{(2\ \%)^2 + (2\ \%)^2}{3} + (2\ \%)^2 + (0{,}41\ \%)^2} =$$ 2,61 % (σ)

U_{95} = 1,96 x 2,61 % = ± 5,1 % = + 0,43 dB/- 0,45 dB

7.3 Two signal measurements

7.3.1 Two signal measurements (analogue speech)

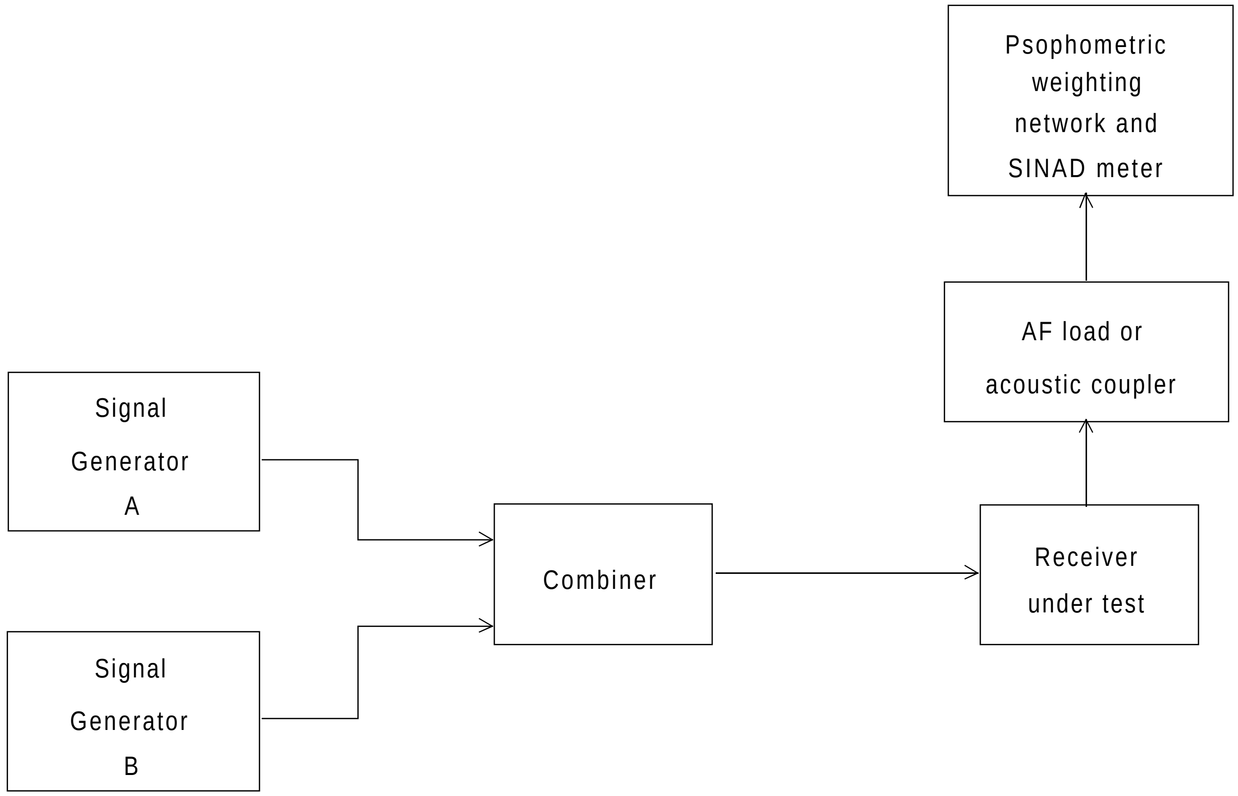


Figure 29: Two signal measurement configuration (analogue speech)

The receiver under test is connected to two signal generators through a combining network. The low frequency output of the receiver is connected, suitably terminated to a SINAD meter through a psophometric filter. The result is obtained as the difference between the signal levels of the two signal generators.

7.3.1.1 In band measurements

Measurement uncertainty:

Generator level uncertainty (wanted signal) ± 1 dB(d) +12,2/-10,9 % (r)

Generator level uncertainty (unwanted signal) ± 1 dB(d) + 12,2/-10,9 % (r)

Matching network attenuation uncertainty ± 1,5 % (σ)

Mismatch uncertainties:

Test signals at generator output: Generator reflection coefficient 0,2. Matching network reflection coefficient 0,07 (A symmetrical matching network is assumed)

M_{iu} = ± 0,2 x 0,07 x 100 % ± 1,4 % (u)

Mismatch uncertainties at the antenna connector of the receiver (wanted signal): ($VSWR_{att}$ 1,2 which gives R_l = 0,091 and R_g of the receiver under test taken from table C.1: Mean value = 0,2, standard deviation = 0,05

M_{iu} = 0,091 x 0,2 x 100 % = ± 1,82 % (u) (c) formula (8)

Normalised standard deviation of R_g = 0,05/0,2 = 0,25 and the Correction factor (taken from figure 4 in subclause 5.2.2) = 1,03. Standard deviation of mismatch uncertainty at the antenna connector

$$1{,}03 \text{ x } \frac{(1{,}82\ \%)}{\sqrt{2}} =$$ formula (9) 1,33 % (σ)

Mismatch uncertainty at the antenna connector of the receiver (unwanted signal):

- the same as for the wanted signal 1,33 % (σ)

Total level difference uncertainty:

$$\sigma_{1+} = \sqrt{\frac{\left((12{,}2\ \%)^2 + (12{,}2\ \%)^2\right)}{3} + (1{,}5\ \%)^2 + \frac{(1{,}4\ \%)^2}{2} + (1{,}33\ \%)^2 + (1{,}33\ \%)^2} =$$ 10,3 % (σ)

$$\sigma_{1-} = \sqrt{\frac{\left((10{,}9\ \%)^2 + (10{,}9\ \%)^2\right)}{3} + (1{,}5\ \%)^2 + \frac{(1{,}4\ \%)^2}{2} + (1{,}33\ \%)^2 + (1{,}33\ \%)^2} =$$ 9,27 % (σ)

Total level uncertainty of wanted signal:

$$\sigma_{2+} = \sqrt{\frac{(12{,}2\ \%)^2}{3} + (1{,}5\ \%)^2 + \frac{(1{,}4\ \%)^2}{2} + (1{,}33\ \%)^2} =$$ 7,39 % (σ)

$$\sigma_{2-} = \sqrt{\frac{(10{,}9\ \%)^2}{3} + (1{,}5\ \%)^2 + \frac{(1{,}4\ \%)^2}{2} + (1{,}33\ \%)^2} =$$ 6,68 % (σ)

Uncertainty caused by level uncertainty of wanted signal: Dependency function taken from table C.1: Mean value = 0,5 %/% level and Standard deviation = 0,2 %/% level

$$\sigma_{3+} = \sqrt{(7{,}39\ \%)^2 \text{ x } \left((0{,}5\ \%\ \%)^2 + (0{,}2\ \%\ \%)^2\right)} =$$ 3,98 % (σ)

$$\sigma_{3-} = \sqrt{(6{,}68\ \%)^2 \text{ x } \left((0{,}5\ \%\ \%)^2 + (0{,}2\ \%\ \%)^2\right)} =$$ 3,60 % (σ)

SINAD measurement uncertainty:

SINAD meter uncertainty ± 1 dB (d) + 12,2/- 10,9 % (r)

Deviation uncertainty (wanted signal) ± 5,3 % (r) (d)

Deviation uncertainty (unwanted signal) ± 5,3

= (5,3 %/100) x 3,0 kHz = (r) (d) ± 159 Hz

Deviation uncertainty of unwanted signal converted to SINAD uncertainty by means of table C.1: Dependency function: Mean value = 0,05 %/Hz and Standard deviation = 0,02 %/Hz

$$\sigma_4 = \sqrt{\left(\frac{(159\ Hz)^2}{3}\right) \text{ x } \left((0{,}05\ \%/Hz)^2 + (0{,}02\ \%/Hz)^2\right)} =$$ formula (2) 4,94 % (σ)

Total SINAD uncertainty:

$$\sigma_{5+} = \sqrt{\left(\frac{(12{,}2\ \%)^2 + (5{,}3\ \%)^2}{3}\right) + (4{,}94\ \%)^2} =$$ 9,12 % (σ)

$$\sigma_{5-} = \sqrt{\left(\frac{(10{,}9\ \%)^2 + (5{,}3\ \%)^2}{3}\right) + (4{,}94\ \%)^2} =$$ 8,57 % (σ)

The SINAD uncertainty is then by means of formula (2) converted to level uncertainty.

Dependency function taken from table C.1: Mean value = 0,7 $dB_{RF\ INPUT\ LEVEL}/dB_{SINAD}$ and the standard deviation 0,2 $dB_{RF\ INPUT\ LEVEL}/dB_{SINAD}$.

$$\sigma_{6+} = \sqrt{(9{,}12\ \%)^2 \text{ x } \left((0{,}7\ dB_{RF\ INPUT\ LEVEL}/dB_{SINAD})^2 + (0{,}2 dB_{RF\ INPUT\ LEVEL}/dB_{SINAD})^2\right)} =$$ 6,64 % (σ)

$$\sigma_{6-} = \sqrt{(8{,}57\ \%)^2 \text{ x } \left((0{,}7\ dB_{RF\ INPUT\ LEVEL}/dB_{SINAD})^2 + (0{,}2 dB_{RF\ INPUT\ LEVEL}/dB_{SINAD})^2\right)} =$$ 6,24 % (σ)

Random uncertainty (valid for all measurements) 2,0 % (σ) (m)

Total uncertainty:

$$\sigma_{t+} = \sqrt{(10{,}3\ \%)^2 + (7{,}39\ \%)^2 + (3{,}98\ \%)^2 + (6{,}64\ \%)^2 + (2{,}0\ \%)^2} =$$ 15,0 % (σ)

$$\sigma_{t-} = \sqrt{(9{,}27\ \%)^2 + (6{,}68\ \%)^2 + (3{,}60\ \%)^2 + (6{,}24\ \%)^2 + (2{,}0\ \%)^2} =$$ 15,0 % (σ)

U_{95} = + 1,96 x 15,0 %/- 1,96 x 13,7 % = + 29,4 %/- 26,1 % = + 2,2 dB/- 2,7 dB

7.3.1.2 Out of band measurements

Measurement uncertainty:

Generator level uncertainty (wanted signal) (± 1 dB (d)) + 12,2/- 10,9 % (r)
Generator level uncertainty (unwanted signal) (± 1 dB (d)) + 12,2/- 10,9 % (r)
Matching network attenuation uncertainty ± 1,5 % (σ)

Mismatch uncertainties:

Test signals at generator output: Generator reflection coefficient 0,2 Matching network reflection coefficient 0,07 (A symmetrically matching network is assumed)

M_{iu} = ± 0,2 x 0,07 x 100 % ± 1,4 % (u)

Mismatch uncertainties at the antenna connector of the receiver (wanted signal): ($VSWR_{att}$ 1,2 which gives R_l = 0,091 and R_g of the receiver under test taken from table C.1: Mean value = 0,2, standard deviation = 0,05

M_{iu} = 0,091 x 0,2 x 100 % = ± 1,82 % (u) (c) formula (8)

Normalised standard deviation of R_g = 0,05/0,2 = 0,25 Correction factor (taken from figure 4 = 1,03

Standard deviation of mismatch uncertainty at the antenna connector

$$1{,}03 \text{ x } \frac{(1{,}82\ \%)}{\sqrt{2}} =$$ formula (9) 1,33 % (σ)

Mismatch uncertainty at the antenna connector of the receiver (unwanted signal): ($VSWR_{att}$ 1,2 which gives R_l = 0,091 and R_g of the receiver under test taken from table C.1: Mean value = 0,8, standard deviation = 0,1

M_{iu} = 0,091 x 0,8 x 100 % = (u) (c) formula (8) ± 7,28 %

Normalised standard deviation of R_g = 0,1/0,8 = 0,125 Correction factor (taken from figure 4 = 1,01

Standard deviation of mismatch uncertainty at the antenna connector =

$$1{,}01 \text{ x } \frac{(7{,}28\ \%)}{\sqrt{2}} =$$ formula (9) 5,20 % (σ)

Total level difference uncertainty:

$$\sigma_{1+} = \sqrt{\left(\frac{(12{,}2\ \%)^2 + (12{,}2\ \%)^2}{3}\right) + (1{,}5\ \%)^2 + \left(\frac{(1{,}4\ \%)^2}{2}\right) + (1{,}33\ \%)^2 + (5{,}2\ \%)^2} =$$ 11,5 % (σ)

$$\sigma_{1-} = \sqrt{\left(\frac{(10{,}9\ \%)^2 + (10{,}9\ \%)^2}{3}\right) + (1{,}5\ \%)^2 + \left(\frac{(1{,}4\ \%)^2}{2}\right) + (1{,}33\ \%)^2 + (5{,}2\ \%)^2} =$$ 10,5 % (σ)

Total level uncertainty of wanted signal:

$$\sigma_{2+} = \sqrt{\left(\frac{(12{,}2\ \%)^2}{3}\right) + (1{,}5\ \%)^2 + \left(\frac{(1{,}4\ \%)^2}{2}\right) + (1{,}33\ \%)^2} =$$ 7,39 % (σ)

$$\sigma_{2-} = \sqrt{\left(\frac{(10{,}9\ \%)^2}{3}\right) + (1{,}5\ \%)^2 + \left(\frac{(1{,}4\ \%)^2}{2}\right) + (1{,}33\ \%)^2} =$$ 6,68 % (σ)

Uncertainty caused by level uncertainty of wanted signal:

Dependency function taken from table C.1: Mean value =0,5 %/% level and Standard deviation =0,2 %/% level

$$\sigma_{3+} = \sqrt{(7{,}39\ \%)^2\ \text{x}\ \left((0{,}5\ \%/\%)^2 + (0{,}2\ \%/\%)^2\right)} =$$ formula (2) 3,98 % (σ)

$$\sigma_{3-} = \sqrt{(6{,}68\ \%)^2\ \text{x}\ \left((0{,}5\ \%/\%)^2 + (0{,}2\ \%/\%)^2\right)} =$$ 3,60 % (σ)

SINAD measurement uncertainty:
SINAD meter uncertainty (± 1 dB (d)) + 12,2/- 10,9 % (r)
Deviation uncertainty (wanted signal) ± 5,3 % (r) (d)
Deviation uncertainty (unwanted signal) ± 5,3 (r) (d)
= (5,3 %/100) x 3,0 kHz = ± 159 Hz

Deviation uncertainty of unwanted signal converted to SINAD uncertainty by means of table C.1: Dependency function: Mean value = 0,05 %/Hz and Standard deviation = 0,02 %/Hz

$$\sigma_4 = \sqrt{\left(\frac{(159\ Hz)^2}{3}\right)\ \text{x}\ \left((0{,}05\ \%/\%)^2 + (0{,}02\ \%/\%)^2\right)} =$$ formula (2) 4,94 % (σ)

Total SINAD uncertainty:

$$\sigma_{5+} = \sqrt{\left(\frac{(12{,}2\ \%)^2 + (5{,}3\ \%)^2}{3}\right) + (4{,}94\ \%)^2} =$$ 9,12 % (σ)

$$\sigma_{5-} = \sqrt{\left(\frac{(10{,}9\ \%)^2 + (5{,}3\ \%)^2}{3}\right) + (4{,}94\ \%)^2} =$$ 8,57 % (σ)

The SINAD uncertainty is then by means of formula (2) converted to level uncertainty. Dependency function taken from table C.1: Mean value = 0,7 $dB_{RF\ INPUT\ LEVEL}/dB_{SINAD}$ and the standard deviation 0,2 $dB_{RF\ INPUT\ LEVEL}/dB_{SINAD}$.

$$\sigma_{6+} = \sqrt{(9{,}12\ \%)^2\ \text{x}\left(\left(0{,}7\,dB_{RF\ INPUT\ LEVEL}/dB_{SINAD}\right)^2 + \left(0{,}2dB_{RF\ INPUT\ LEVEL}/dB_{SINAD}\right)^2\right)} =$$ 6,64 % (σ)

$$\sigma_{6-} = \sqrt{(8{,}57\ \%)^2\ \text{x}\left(\left(0{,}7\,dB_{RF\ INPUT\ LEVEL}/dB_{SINAD}\right)^2 + \left(0{,}02dB_{RF\ INPUT\ LEVEL}/dB_{SINAD}\right)^2\right)} =$$ 6,24 % (σ)

Random uncertainty 2,0 % (σ) (m)

Total uncertainty:

$$\sigma_{t+} = \sqrt{(11{,}5\ \%)^2 + (7{,}39\ \%)^2 + (3{,}98\ \%)^2 + (6{,}64\ \%)^2 + (2{,}0\ \%)^2} =$$ 15,9 % (σ)

$$\sigma_{t-} = \sqrt{(10{,}5\ \%)^2 + (6{,}68\ \%)^2 + (3{,}60\ \%)^2 + (6{,}24\ \%)^2 + (2{,}0\ \%)^2} =$$ 14,5 % (σ)

U_{95} = + 1,96 x 15,9 %/- 1,96 x 14,5 % = + 31,2 %/- 28,4 % = + 2,4 dB/- 2,9 dB

7.3.2 Two signal measurements (bit stream)

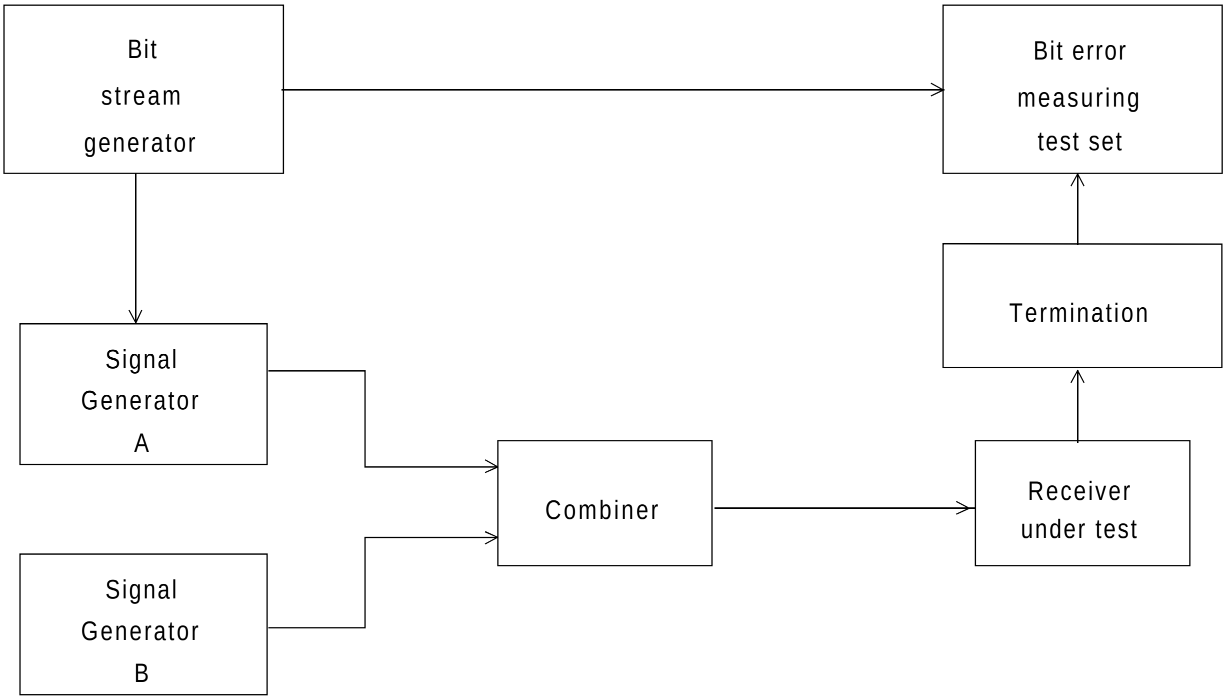


Figure 30: Two signal measurement configuration (Bit stream)

The receiver under test is connected to two signal generators through a combining network. The wanted signal is at the nominal frequency of the receiver, and modulated as appropriate, The unwanted signal, also modulated as appropriate, are combined and applied to the receiver input. The result is obtained as the difference between the signal levels of the two signal generators.

7.3.2.1 In band measurements

Measurement uncertainty:

Generator level uncertainty (wanted signal) ± 1 dB (d) + 12,2/- 10,9 % (r)

Generator level uncertainty (unwanted signal) ± 1 dB (d) + 12,2/- 10,9 % (r)

Matching network attenuation uncertainty ± 1,5 % (σ)

Mismatch uncertainties:

Test signals at generator output: Generator reflection coefficient 0,2 Matching network reflection coefficient 0,07 (A symmetrically matching network is assumed).

M_{iu} = ± 0,2 x 0,07 ± 1,4 % (u)

Mismatch uncertainties at the antenna connector of the receiver (wanted signal): ($VSWR_{att}$ 1,2 which gives R_l = 0,091 and R_g of the receiver under test taken from table C.1: Mean value = 0,2, standard deviation = 0,05

M_{iu} = 0,091 x 0,2 x 100 % = (u) (c) formula (8) ± 1,82 %

Normalised standard deviation of R_g = 0,05/0,2 = 0,25 Correction factor (taken from figure 4 = 1,03. Standard deviation of mismatch uncertainty at the antenna connector

$$1{,}03 \text{ x } \frac{(1{,}82\ \%)}{\sqrt{2}} =$$ formula (9) 1,33 % (σ)

Mismatch uncertainty at the antenna connector of the receiver (unwanted signal):

- the same as for the wanted signal 1,33 % (σ)

Total level difference uncertainty:

$$\sigma_{1+} = \sqrt{\frac{\left((12{,}2\ \%)^2 + (12{,}2\ \%)^2\right)}{3} + (1{,}5\ \%)^2 + \frac{(1{,}4\ \%)^2}{2} + (1{,}33\ \%)^2 + (1{,}33\ \%)^2} =$$ 10,3 % (σ)

$$\sigma_{1-} = \sqrt{\frac{\left((10{,}9\ \%)^2 + (10{,}9\ \%)^2\right)}{3} + (1{,}5\ \%)^2 + \frac{(1{,}4\ \%)^2}{2} + (1{,}33\ \%)^2 + (1{,}33\ \%)^2} =$$ 9,27 % (σ)

Total level uncertainty of wanted signal:

$$\sigma_{2+} = \sqrt{\left(\frac{(12{,}2\ \%)^2}{3}\right) + (1{,}5\ \%)^2 + \left(\frac{(1{,}4\ \%)^2}{2}\right) + (1{,}33\ \%)^2} =$$ 7,39 % (σ)

$$\sigma_{2-} = \sqrt{\left(\frac{(10{,}9\ \%)^2}{3}\right) + (1{,}5\ \%)^2 + \left(\frac{(1{,}4\ \%)^2}{2}\right) + (1{,}33\ \%)^2} =$$ 6,68 % (σ)

Uncertainty caused by level uncertainty of wanted signal:

Dependency function taken from table C.1: Mean value = 0,5 %/% level and Standard deviation = 0,2 %/% level

$$\sigma_{3+} = \sqrt{(7{,}39\ \%)^2 \text{ x } \left((0{,}5\ \%/\%)^2 + (0{,}2\ \%/\%)^2\right)} =$$ 3,98 % (σ)

$$\sigma_{3-} = \sqrt{(6{,}68\ \%)^2 \text{ x } \left((0{,}5\ \%/\%)^2 + (0{,}2\ \%/\%)^2\right)} =$$ 3,60 % (σ)

Random uncertainty (valid for all measurements) 2,0 % (σ) (m)

Total uncertainty: Case 1

$$\sigma_{t+} = \sqrt{(10{,}3\ \%)^2 + (7{,}39\ \%)^2 + (3{,}98\ \%)^2 + (6{,}64\ \%)^2 + (2{,}0\ \%)^2 + (3{,}94\ \%)^2} =$$ 15,49 % (σ)

$$\sigma_{t-} = \sqrt{(9{,}27\ \%)^2 + (6{,}68\ \%)^2 + (3{,}60\ \%)^2 + (6{,}24\ \%)^2 + (2{,}0\ \%)^2 + (3{,}94\ \%)^2} =$$ 14,21 % (σ)

U_{95} = + 1,96 x 15,49 %/- 1,96 x 14,21 % = + 30,36 %/- 27,85 % = + 2,30 dB/- 2,84 dB

Total uncertainty: Case 2b

$$\sigma_{t+} = \sqrt{(10,3\ \%)^2 + (7,39\ \%)^2 + (3,98\ \%)^2 + (6,64\ \%)^2 + (2,0\ \%)^2 + (1,51\ \%)^2} = \quad 15,06\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{(9,27\ \%)^2 + (6,68\ \%)^2 + (3,60\ \%)^2 + (6,24\ \%)^2 + (2,0\ \%)^2 + (1,51\ \%)^2} = \quad 13,74\ \%\ (\sigma)$$

U_{95} = + 1,96 x 15,06 %/- 1,96 x 13,74 % = + 29,52 %/- 26,93 % = + 2,25 dB/- 2,72 dB

Total uncertainty: Case 3

$$\sigma_{t+} = \sqrt{(10,3\ \%)^2 + (7,39\ \%)^2 + (3,98\ \%)^2 + (6,64\ \%)^2 + (2,0\ \%)^2 + (0,55\ \%)^2} = \quad 15,00\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{(9,27\ \%)^2 + (6,68\ \%)^2 + (3,60\ \%)^2 + (6,24\ \%)^2 + (2,0\ \%)^2 + (0,55\ \%)^2} = \quad 13,66\ \%\ (\sigma)$$

U_{95} = + 1,96 x 15,00 %/- 1,96 x 13,66 % = + 29,40 %/- 26,78 % = + 2,24 dB/- 2,71 dB

Total uncertainty: Case 4b

$$\sigma_{t+} = \sqrt{(10,3\ \%)^2 + (7,39\ \%)^2 + (3,98\ \%)^2 + (6,64\ \%)^2 + (2,0\ \%)^2 + (0,19\ \%)^2} = \quad 15,00\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{(9,27\ \%)^2 + (6,68\ \%)^2 + (3,60\ \%)^2 + (6,24\ \%)^2 + (2,0\ \%)^2 + (0,19\ \%)^2} = \quad 13,66\ \%\ (\sigma)$$

U_{95} = + 1,96 x 15,00 %/- 1,96 x 13,66 % = + 29,40 %/- 26,78 % = + 2,24 dB/- 2,71 dB

7.3.2.2 Out of band measurements

Measurement uncertainty:

Generator level uncertainty (wanted signal) ± 1 dB (d) + 12,2/- 10,9 % (r)
Generator level uncertainty (unwanted signal) ± 1 dB (d) + 12,2/- 10,9 % (r)
Matching network attenuation uncertainty ± 1,5 % (σ)

Mismatch uncertainties:

Test signals at generator output: Generator reflection coefficient 0,2 Matching network reflection coefficient 0,07 (A symmetrically matching network is assumed)

M_{iu} = ± 0,2 x 0,07 x 100 % ± 1,4 % (u)

Mismatch uncertainties at the antenna connector of the receiver (wanted signal):

($VSWR_{att}$ 1,2 which gives R_l = 0,091 and R_g of the receiver under test taken from table C.1: Mean value = 0,2, standard deviation = 0,05)

M_{iu} = 0,091 x 0,2 x 100 % = ± 1,82 % (u) (c) formula (8)

Normalised standard deviation of R_g = 0,05/0,2 = 0,25. Correction factor (taken from figure 4 in subclause 5.2.2) = 1,03. Standard deviation of mismatch uncertainty at the antenna connector

$$1{,}03 \text{ x } \frac{(1{,}82\ \%)}{\sqrt{2}} =$$ formula (9) 1,33 % (σ)

Mismatch uncertainty at the antenna connector of the receiver (unwanted signal):

($VSWR_{att}$ 1,2 which gives R_l = 0,091 and R_g of the receiver under test taken from table C.1: Mean value = 0,8, standard deviation = 0,1

M_{iu} = 0,091 x 0,8 x 100 % = ± 7,28 % (u) (c) formula (8)

Normalised standard deviation of R_g = 0,1/0,8 = 0,125. Correction factor (taken from figure 4 = 1,01 Standard deviation of mismatch uncertainty at the antenna connector

$$1{,}01 \text{ x } \frac{(7{,}28\ \%)}{\sqrt{2}} =$$ formula (9) 5,20 % (σ)

Total level difference uncertainty:

$$\sigma_{1+} = \sqrt{\frac{\left((12{,}2\ \%)^2 + (12{,}2\ \%)^2\right)}{3} + (1{,}5\ \%)^2 + \frac{(1{,}4\ \%)^2}{2} + (1{,}33\ \%)^2 + (5{,}2\ \%)^2} =$$ 11,5 % (σ)

$$\sigma_{1-} = \sqrt{\frac{\left((10{,}9\ \%)^2 + (10{,}9\ \%)^2\right)}{3} + (1{,}5\ \%)^2 + \frac{(1{,}4\ \%)^2}{2} + (1{,}33\ \%)^2 + (5{,}2\ \%)^2} =$$ 10,5 % (σ)

Total level uncertainty of wanted signal:

$$\sigma_{2+} = \sqrt{\left(\frac{(12{,}2\ \%)^2}{3}\right) + (1{,}5\ \%)^2 + \left(\frac{(1{,}4\ \%)^2}{2}\right) + (1{,}33\ \%)^2} =$$ 7,39 % (σ)

$$\sigma_{2-} = \sqrt{\left(\frac{(10{,}9\ \%)^2}{3}\right) + (1{,}5\ \%)^2 + \left(\frac{(1{,}4\ \%)^2}{2}\right) + (1{,}33\ \%)^2} =$$ 6,68 % (σ)

Uncertainty caused by level uncertainty of wanted signal:

Dependency function taken from table C.1:Mean value = 0,5%/% level, Standard deviation = 0,2 %/% level

$$\sigma_{3+} = \sqrt{(7{,}39\ \%)^2\ \mathrm{x}\ \left((0{,}5\ \%/\%)^2 + (0{,}2\ \%/\%)^2\right)} = \quad \text{formula (2)} \quad 3{,}98\ \%\ (\sigma)$$

$$\sigma_{3-} = \sqrt{(6{,}68\ \%)^2\ \mathrm{x}\ \left((0{,}5\ \%/\%)^2 + (0{,}2\ \%/\%)^2\right)} = \quad 3{,}60\ \%\ (\sigma)$$

Random uncertainty 2,0 % (σ) (m)

Total uncertainty: Case 1

$$\sigma_{t+} = \sqrt{(11{,}5\ \%)^2 + (7{,}39\ \%)^2 + (3{,}98\ \%)^2 + (6{,}64\ \%)^2 + (2{,}0\ \%)^2 + (3{,}94\ \%)^2} = \quad 16{,}32\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{(10{,}5\ \%)^2 + (6{,}68\ \%)^2 + (3{,}60\ \%)^2 + (6{,}24\ \%)^2 + (2{,}0\ \%)^2 + (3{,}94\ \%)^2} = \quad 15{,}04\ \%\ (\sigma)$$

U_{95} = + 1,96 x 16,32 %/- 1,96 x 15,04 % = + 31,99 %/- 29,48 % = + 2,41 dB/- 3,03 dB

Total uncertainty: Case 2b

$$\sigma_{t+} = \sqrt{(11{,}5\ \%)^2 + (7{,}39\ \%)^2 + (3{,}98\ \%)^2 + (6{,}64\ \%)^2 + (2{,}0\ \%)^2 + (1{,}51\ \%)^2} = \quad 15{,}91\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{(10{,}5\ \%)^2 + (6{,}68\ \%)^2 + (3{,}60\ \%)^2 + (6{,}24\ \%)^2 + (2{,}0\ \%)^2 + (1{,}51\ \%)^2} = \quad 14{,}60\ \%\ (\sigma)$$

U_{95} = + 1,96 x 15,91%/- 1,96 x 14,60 % = + 31,18 %/- 28,61 % = + 2,36 dB/- 2,93 dB

Total uncertainty: Case 3

$$\sigma_{t+} = \sqrt{(11{,}5\ \%)^2 + (7{,}39\ \%)^2 + (3{,}98\ \%)^2 + (6{,}64\ \%)^2 + (2{,}0\ \%)^2 + (0{,}55\ \%)^2} = \quad 15{,}84\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{(10{,}5\ \%)^2 + (6{,}68\ \%)^2 + (3{,}60\ \%)^2 + (6{,}24\ \%)^2 + (2{,}0\ \%)^2 + (0{,}55\ \%)^2} = \quad 14{,}53\ \%\ (\sigma)$$

U_{95} = + 1,96 x 15,84 %/- 1,96 x 14,53 % = + 31,05 %/- 28,74 % = + 2,35 dB/- 2,91 dB

Total uncertainty: Case 4b

$$\sigma_{t+} = \sqrt{(11{,}5\ \%)^2 + (7{,}39\ \%)^2 + (3{,}98\ \%)^2 + (6{,}64\ \%)^2 + (2{,}0\ \%)^2 + (0{,}19\ \%)^2} = \quad 15{,}84\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{(10{,}5\ \%)^2 + (6{,}68\ \%)^2 + (3{,}60\ \%)^2 + (6{,}24\ \%)^2 + (2{,}0\ \%)^2 + (0{,}19\ \%)^2} = \quad 14{,}52\ \%\ (\sigma)$$

U_{95} = + 1,96 x 15,84 %/- 1,96 x 14,52 % = + 31,04 %/- 28,46 % = + 2,35 dB/- 2,91 dB

7.3.3 Two signal measurements (messages)

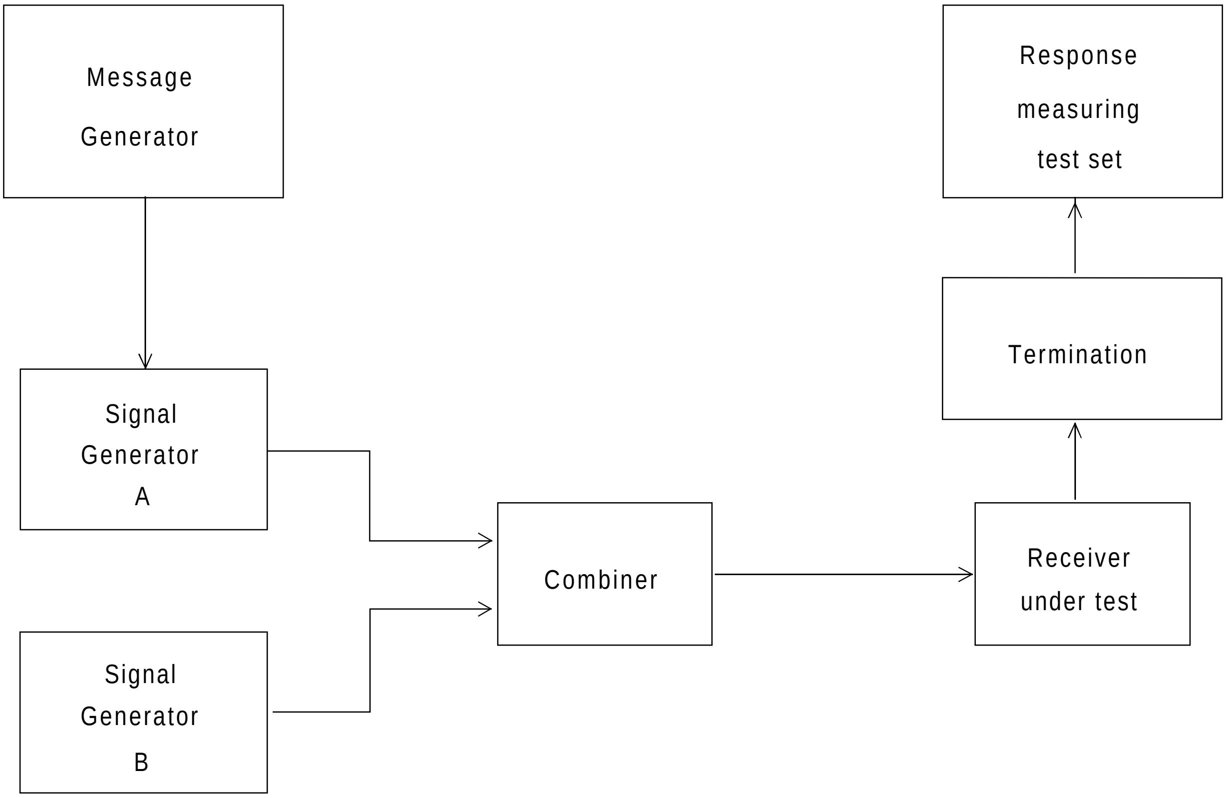


Figure 31: Two signal measurement configuration (messages)

The receiver under test is connected to two signal generators through a combining network.

The wanted signal is at the nominal frequency of the receiver, and modulated as appropriate, The unwanted signal, also modulated as appropriate, are combined and applied to the receiver input.

The test signal is applied repeatedly, whilst varying the level of the unwanted signal, until the specified success calling rate is achieved.

The result is the average of the wanted signal generator level to the unwanted signal generator level recorded , corrected for mismatch loses and attenuation of matching network.

7.3.3.1 In band measurements

Measurement uncertainty:

Generator level uncertainty (wanted signal) ± 1 dB (d)	+ 12,2/- 10,9 % (r)
Generator level uncertainty (unwanted signal) ± 1 dB (d)	+ 12,2/- 10,9 % (r)
Matching network attenuation uncertainty	± 1,5 % (σ)

Mismatch uncertainties:

Test signals at generator output: Generator reflection coefficient 0,2. Matching network reflection coefficient 0,07 (A symmetrically matching network is assumed).

M_{iu} = ± 0,2 x 0,07 x 100 % ± 1,4 % (u)

Mismatch uncertainties at the antenna connector of the receiver (wanted signal): ($VSWR_{att}$ 1,2 which gives R_l = 0,091 and R_g of the receiver under test taken from table C.1: Mean value = 0,2, standard deviation = 0,05)

M_{iu} = 0,091 x 0,2 x 100 % = ± 1,82 % (u) (c) formula (8)

Normalised standard deviation of R_g = 0,05/0,2 = 0,25. Correction factor (taken from figure 4 = 1,03 Standard deviation of mismatch uncertainty at the antenna connector

$$1{,}03 \text{ x } \frac{(1{,}82\ \%)}{\sqrt{2}} =$$ formula (9) 1,33 % (σ)

Mismatch uncertainty at the antenna connector of the receiver (unwanted signal):

- the same as for the wanted signal 1,33 % (σ)

Total level difference uncertainty:

$$\sigma_{1+} = \sqrt{\frac{\left((12{,}2\ \%)^2 + (12{,}2\ \%)^2\right)}{3} + (1{,}5\ \%)^2 + \frac{(1{,}4\ \%)^2}{2} + (1{,}33\ \%)^2 + (1{,}33\ \%)^2} =$$ 10,3 % (σ)

$$\sigma_{1-} = \sqrt{\frac{\left((10{,}9\ \%)^2 + (10{,}9\ \%)^2\right)}{3} + (1{,}5\ \%)^2 + \frac{(1{,}4\ \%)^2}{2} + (1{,}33\ \%)^2 + (1{,}33\ \%)^2} =$$ 9,27 % (σ)

Total level uncertainty of wanted signal:

$$\sigma_{2+} = \sqrt{\left(\frac{(12{,}2\ \%)^2}{3}\right) + (1{,}5\ \%)^2 + \left(\frac{(1{,}4\ \%)^2}{2}\right) + (1{,}33\ \%)^2} =$$ 7,39 % (σ)

$$\sigma_{2-} = \sqrt{\left(\frac{(10{,}9\ \%)^2}{3}\right) + (1{,}5\ \%)^2 + \left(\frac{(1{,}4\ \%)^2}{2}\right) + (1{,}33\ \%)^2} =$$ 6,68 % (σ)

Uncertainty caused by level uncertainty of wanted signal:

Dependency function taken from table C.1:Mean value = 0,5%/% level Standard deviation = 0,2 %/% level

$$\sigma_{3+} = \sqrt{(7{,}39\ \%)^2 \text{ x } \left((0{,}5\ \%/\%)^2 + (0{,}2\ \%/\%)^2\right)} =$$ 3,98 % (σ)

$$\sigma_{3-} = \sqrt{(6{,}68\ \%)^2 \text{ x } \left((0{,}5\ \%/\%)^2 + (0{,}2\ \%/\%)^2\right)} =$$ 3,60 % (σ)

Random uncertainty (valid for all measurements) 2,0 % (σ) (m)

Using the value of +/- 0,332 dB, the standard deviation from the example in subclause 5.6.4, the uncertainty contribution is: +3,90 % -3,75 %

Total uncertainty:

$$\sigma_{t+} = \sqrt{(10,3\ \%)^2 + (7,39\ \%)^2 + (3,98\ \%)^2 + (6,64\ \%)^2 + (3,90\ \%)^2 + (2,0\ \%)^2} = \quad 15,49\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{(9,27\ \%)^2 + (6,68\ \%)^2 + (3,60\ \%)^2 + (6,24\ \%)^2 + (3,75\ \%)^2 + (2,0\ \%)^2} = \quad 14,16\ \%\ (\sigma)$$

U_{95} = + 1,96 x 15,49 %/- 1,96 x 14,16 % = + 30,35 %/- 27,75 % = + 2,30 dB/- 2,82 dB

7.3.3.2 Out of band measurements

Measurement uncertainty:

Generator level uncertainty (wanted signal) ± 1 dB (d) + 12,2/- 10,9 % (r)

Generator level uncertainty (unwanted signal) ± 1 dB (d) + 12,2/- 10,9 % (r)

Matching network attenuation uncertainty ± 1,5 % (σ)

Mismatch uncertainties:

Test signals at generator output: Generator reflection coefficient 0,2. Matching network reflection coefficient 0,07. (A symmetrically matching network is assumed)

M_{iu} = ± 0,2 x 0,07 x 100 % ± 1,4 % (u)

Mismatch uncertainties at the antenna connector of the receiver (wanted signal):

($VSWR_{att}$ 1,2 which gives R_l = 0,091 and R_g of the receiver under test taken from table C.1: Mean value = 0,2, standard deviation = 0,05)

M_{iu} = 0,091 x 0,2 x 100 % = ± 1,82 % (u) (c) formula (8)

Normalised standard deviation of R_g = 0,05/0,2 = 0,25 Correction factor (taken from figure 4 = 1,03 Standard deviation of mismatch uncertainty at the antenna connector:

$$1,03 \text{ x } \frac{(1,82\ \%)}{\sqrt{2}} =$$ formula (9) 1,33 % (σ)

Mismatch uncertainty at the antenna connector of the receiver (unwanted signal):

($VSWR_{att}$ 1,2 which gives R_l = 0,091 and R_g of the receiver under test taken from table C.1: Mean value = 0,8, standard deviation = 0,1)

M_{iu} = 0,091 x 0,8 x 100 % = ± 7,28 % (u) (c) formula (8)

Normalised standard deviation of R_g = 0,1/0,8 = 0,125 Correction factor (Taken from figure 4 in subclause 5.2.2) = 1,01 Standard deviation of mismatch uncertainty at the antenna connector

$$1,01 \text{ x } \frac{(7,28\ \%)}{\sqrt{2}} =$$ formula (9) 5,20 % (σ)

Total level difference uncertainty:

$$\sigma_{1+} = \sqrt{\frac{\left((12{,}2\ \%)^2 + (12{,}2\ \%)^2\right)}{3} + (1{,}5\ \%)^2 + \frac{(1{,}4\ \%)^2}{2} + (1{,}33\ \%)^2 + (5{,}2\ \%)^2} = \quad 11{,}5\ \%\ (\sigma)$$

$$\sigma_{1-} = \sqrt{\frac{\left((10{,}9\ \%)^2 + (10{,}9\ \%)^2\right)}{3} + (1{,}5\ \%)^2 + \frac{(1{,}4\ \%)^2}{2} + (1{,}33\ \%)^2 + (5{,}2\ \%)^2} = \quad 10{,}5\ \%\ (\sigma)$$

Total level uncertainty of wanted signal:

$$\sigma_{2+} = \sqrt{\left(\frac{(12{,}2\ \%)^2}{3}\right) + (1{,}5\ \%)^2 + \left(\frac{(1{,}4\ \%)^2}{2}\right) + (1{,}33\ \%)^2} = \quad 7{,}39\ \%\ (\sigma)$$

$$\sigma_{2-} = \sqrt{\left(\frac{(10{,}9\ \%)^2}{3}\right) + (1{,}5\ \%)^2 + \left(\frac{(1{,}4\ \%)^2}{2}\right) + (1{,}33\ \%)^2} = \quad 6{,}68\ \%\ (\sigma)$$

Uncertainty caused by level uncertainty of wanted signal:

Dependency function taken from table C.1: Mean value = 0,5 %/% level Standard deviation = 0,2 %/% level

$$\sigma_{3+} = \sqrt{(7{,}39\ \%)^2\ \text{x}\ \left((0{,}5\ \%/\%)^2 + (0{,}2\ \%/\%)^2\right)} = \quad \text{formula (2)} \quad 3{,}98\ \%\ (\sigma)$$

$$\sigma_{3-} = \sqrt{(6{,}68\ \%)^2\ \text{x}\ \left((0{,}5\ \%/\%)^2 + (0{,}2\ \%/\%)^2\right)} = \quad 3{,}60\ \%\ (\sigma)$$

Using the value of +/- 0,332 dB, the standard deviation from the example in subclause 5.6.4, the uncertainty contribution is: +3,90 % -3,75 %

Random uncertainty 2,0 % (σ) (m)

Total uncertainty:

$$\sigma_{t+} = \sqrt{(11{,}5\ \%)^2 + (7{,}39\ \%)^2 + (3{,}98\ \%)^2 + (6{,}64\ \%)^2 + (3{,}90\ \%)^2 + (2{,}0\ \%)^2} = \quad 16{,}31\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{(10{,}5\ \%)^2 + (6{,}68\ \%)^2 + (3{,}60\ \%)^2 + (6{,}24\ \%)^2 + (3{,}75\ \%)^2 + (2{,}0\ \%)^2} = \quad 14{,}99\ \%\ (\sigma)$$

U_{95} = + 1,96 x 16,31 %/- 1,96 x 14,99 % = + 31,97 %/- 29,40 % = + 2,41 dB/- 3,02 dB

7.4 Intermodulation response

7.4.1 Intermodulation response (analogue speech)

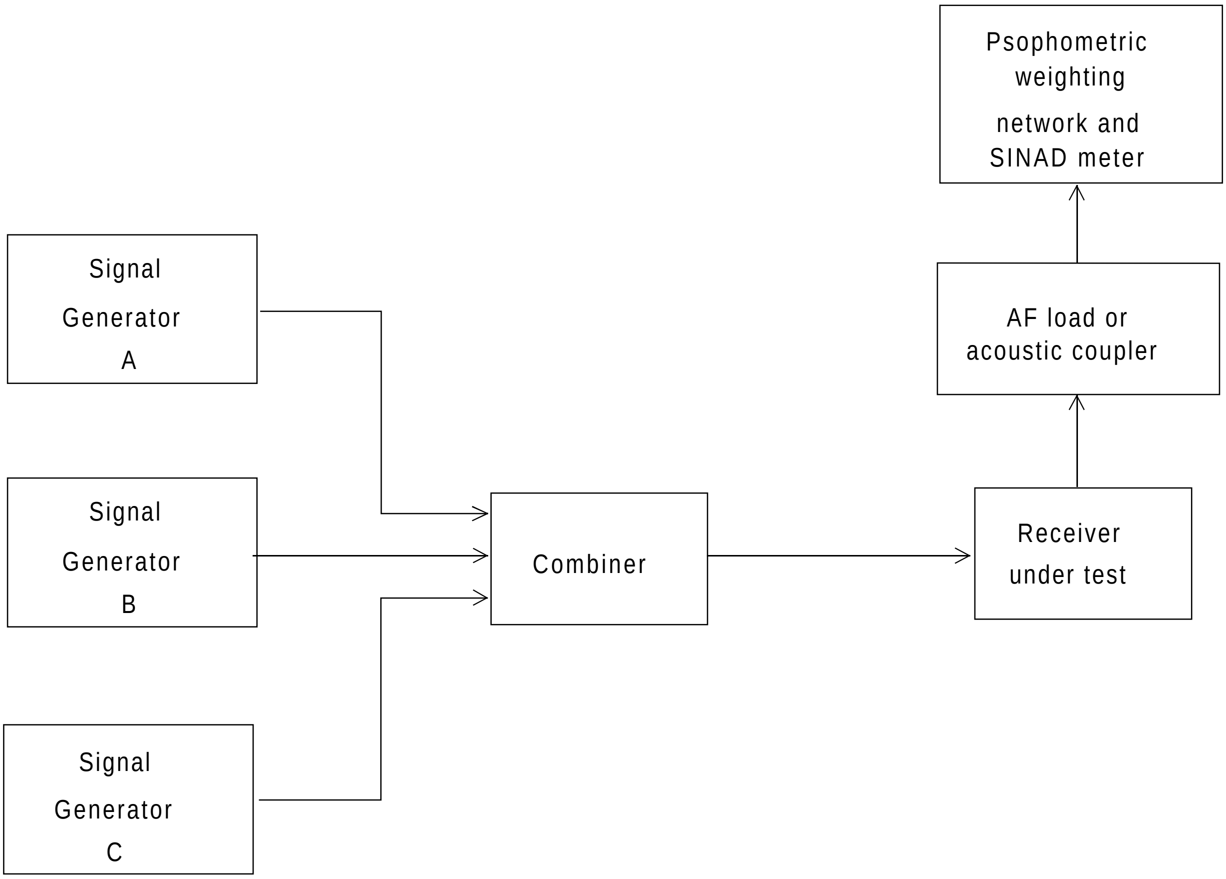


Figure 32: Intermodulation response measurement configuration (analogue speech)

The receiver under test is connected to three signal generators through a combining network which may contain isolators and attenuators. The low frequency output of the receiver is connected to a suitable termination and a SINAD meter via a psophometric filter. The result is the signal level of the unwanted signal generators. All signal generator levels are corrected for combining network attenuation and mismatch loss.

Measurement uncertainty:

Error caused by uncertainty of the level of the unwanted signals:

Signal generator A level uncertainty ± 1 dB (d) + 12,2/- 10,9 % (r)

Mismatch uncertainty, generator A: Generator reflection coefficient 0,2 Matching network reflection coefficient 0,07

M_{iu} = ± 0,2 x 0,07 x 100 % ± 1,4 % (u)

Matching network attenuation uncertainty (Generator A to EUT) ± 1,5 % (σ) (c)

Total level uncertainty, generator A:

$$\sigma_{A+} = \sqrt{\left(\frac{(12,2\ \%)^2}{3}\right) + (1,5\ \%)^2 + \left(\frac{(1,4\ \%)^2}{2}\right)} =$$ 7,27 % (σ)

$$\sigma_{A-} = \sqrt{\left(\frac{(10,9\ \%)^2}{3}\right) + (1,5\ \%)^2 + \left(\frac{(1,4\ \%)^2}{2}\right)} =$$ 6,54 % (σ)

Signal generator B level uncertainty (± dB (d)) + 12,2/- 10,9 % (r)

Mismatch uncertainty, generator B: Generator reflection coefficient 0,2 Matching network reflection coefficient 0,07

M_{iu} = ± 0,2 x 0,07 x 100 % ± 1,4 % (u)

Matching network attenuation uncertainty (Generator B to EUT) ± 1,5 % (σ) (c)

Uncertainty caused by unwanted signal levels:

Total level uncertainty, generator B:

$$\sigma_{B+} = \sqrt{\left(\frac{(12,2\ \%)^2}{3}\right) + (1,5\ \%)^2 + \left(\frac{(1,4\ \%)^2}{2}\right)} =$$ 7,26 % (σ)

$$\sigma_{B-} = \sqrt{\left(\frac{(10,9\ \%)^2}{3}\right) + (1,5\ \%)^2 + \left(\frac{(1,4\ \%)^2}{2}\right)} =$$ 6,54 % (σ)

Uncertainty due to unwanted signal level uncertainty:

$$\sigma_{1+} = \sqrt{\left(\frac{2\ \text{x}\ (7,27\ \%)}{3}\right)^2 + \left(\frac{(7,27\ \%)}{3}\right)^2} =$$ 5,42 % (σ)

$$\sigma_{1-} = \sqrt{\left(\frac{2\ \text{x}\ (6,54\ \%)}{3}\right)^2 + \left(\frac{(6,54\ \%)}{3}\right)^2} =$$ formula (13) = 4,87 % (σ)

Error caused by uncertainty of the level of the wanted signal:

Uncertainty of wanted signal generator level (generator C) ± dB (d) + 12,2/- 10,9 % (r)

Uncertainty of attenuation in matching network ± 1,5 % (σ) (c)

Mismatching uncertainty at generator: Generator reflection coefficient = 0,2 (d) Matching network reflection coefficient = 0,07 (m)

M_{iu} = 0,2 x 0,07 x 100 % ± 1,4 % (u)

Mismatch uncertainties at the antenna connector of the receiver (wanted signal):

($VSWR_{att}$ 1,2 which gives R_l = 0,091 and R_g of the receiver under test taken from table C.1: Mean value = 0,2, standard deviation = 0,05)

M_{iu} = 0,091 x 0,2 x 100 % = ± 1,82 % (u) (c) formula (8)

Normalised standard deviation of R_g = 0,05/0,2 = 0,25

Correction factor (taken from figure 4 in subclause 5.2.2) = 1,03 Standard deviation of mismatch uncertainty at the antenna connector

$$1{,}03 \text{ x } \frac{(1{,}82\ \%)}{\sqrt{2}} =$$ formula (9) 1,33 % (σ)

Total uncertainty of wanted signal:

$$\sigma_{C+} = \sqrt{\left(\frac{(12{,}2\ \%)^2}{3}\right) + (1{,}5\ \%)^2 + \left(\frac{(1{,}4\ \%)^2}{2}\right) + (1{,}33\ \%)^2} =$$ 7,39 % (σ)

$$\sigma_{C-} = \sqrt{\left(\frac{(10{,}9\ \%)^2}{3}\right) + (1{,}5\ \%)^2 + \left(\frac{(1{,}4\ \%)^2}{2}\right) + (1{,}33\ \%)^2} =$$ 6,68 % (σ)

Uncertainty due to wanted signal level uncertainty:

a) Uncertainty due to intermodulation:

$$\sigma_{2a^+} = 2 \text{ x } \frac{(7{,}39\ \%)}{3}$$ formula (14) 4,93 % (σ)

$$\sigma_{2a^-} = 2 \text{ x } \frac{(6{,}68\ \%)}{3}$$ formula (14) 4,45 % (σ)

b) Uncertainty due to change in capture ratio as function of wanted signal level:

Dependency function taken from table C.1: Mean value = 0,1, Standard deviation = 0,03

$$\sigma_{2b} = \sqrt{(7{,}39\ \%^2) \text{ x } \left((0{,}1\ \%/\%)^2 + (0{,}03\ \%/\%)^2\right)} =$$ 0,77 % (σ)

$$\sigma_{2b-} = \sqrt{(6{,}68\ \%^2) \text{ x } \left((0{,}1\ \%/\%)^2 + (0{,}03\ \%/\%)^2\right)} =$$ formula (2) 0,70 % (σ)

$$\sigma_{2+} = \sqrt{(4{,}93\ \%)^2 + (0{,}77\ \%)^2} =$$ 4,99 % (σ)

$$\sigma_{2-} = \sqrt{(4{,}45\ \%)^2 + (0{,}70\ \%)^2} =$$ 4,51 % (σ)

Uncertainty of SINAD measurement:

SINAD meter uncertainty ± 1 dB (d) + 12,2/- 10,9 % (r)

Test signal deviation uncertainty (Must be allowed for twice) ± 5 % (r)

$$\sigma_{3+} = \sqrt{\left(\frac{(5,0\ \%)^2 + (5,0\ \%)^2 + (12,2\ \%)^2}{3}\right)} = \quad 8,14\ \%\ (\sigma)$$

$$\sigma_{3-} = \sqrt{\left(\frac{(5,0\ \%)^2 + (5,0\ \%)^2 + (10,9\ \%)^2}{3}\right)} = \quad 7,50\ \%\ (\sigma)$$

The SINAD uncertainty is then by means of formula (2) converted to level uncertainty:
Dependency function taken from table C.1: Mean value = 0,5 Standard deviation = 0,1

SINAD uncertainty converted to (unwanted) level uncertainty:

$$\sigma_{4+} = \sqrt{(8,14\ \%)^2 \ \text{x} \ \left((0,5\ \%/\%)^2 + (0,1\ \%/\%)^2\right)} = \quad 4,15\ \%\ (\sigma)$$

$$\sigma_{4-} = \sqrt{(7,50\ \%)^2 \ \text{x} \ \left((0,5\ \%/\%)^2 + (0,1\ \%/\%)^2\right)} = \quad \text{formula (2)} \quad 3,82\ \%\ (\sigma)$$

Standard deviation of random uncertainty = 2,4 % (m) (σ)

Total uncertainty:

$$\sigma_{t+} = \sqrt{(5,42\ \%^2\ ) + (4,99\ \%)^2 + (4,15\ \%\ )^2 + (2,4\ \%)^2} = \quad 8,79\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{(4,87\ \%^2\ ) + (4,51\ \%)^2 + (3,82\ \%\ )^2 + (2,4\ \%)^2} = \quad 8,02\ \%\ (\sigma)$$

U_{95} = + 1,96 x 8,79 %/- 1,96 x 8,02 % = + 17,2 %/- 15,7 % = + 1,4 dB/- 1,5 dB

7.4.2 Intermodulation response (bit stream)

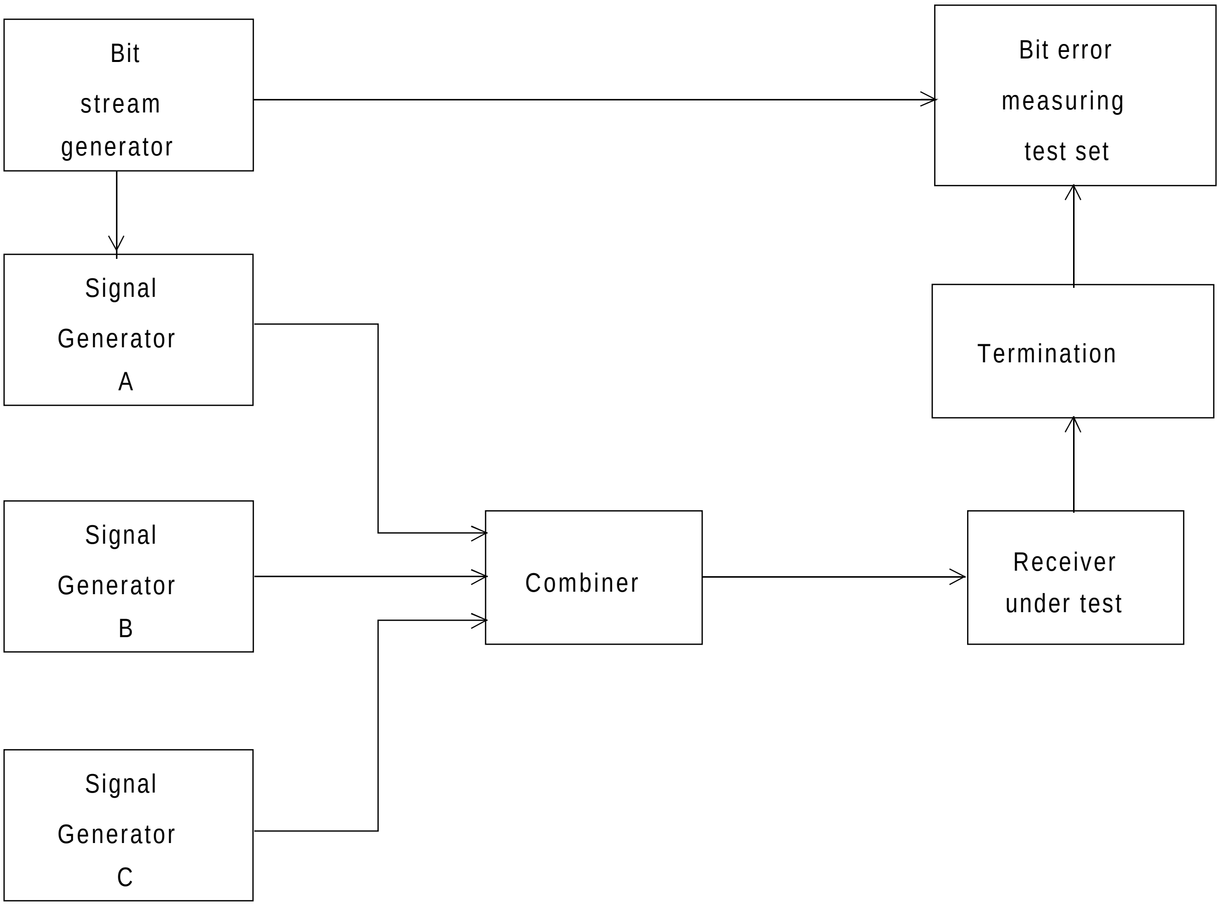


Figure 33: Intermodulation response measurement configuration (bit stream)

The receiver under test is connected to three signal generators through a combining network which may contain isolators and attenuators. The wanted signal is at the nominal frequency of the receiver, and modulated as appropriate, The unwanted signals, also modulated as appropriate, are combined and applied to the receiver input. The result is obtained as the difference between the unwanted signal levels and the wanted signal level, corrected for combining network attenuation and mismatch loss.

Measurement uncertainty:

Error caused by uncertainty of the level of the unwanted signals:

Signal generator A level uncertainty ± 1 dB (d) + 12,2/- 10,9 % (r)

Mismatch uncertainty, generator A:

Generator reflection coefficient 0,2 Matching network reflection coefficient 0,07

M_{iu} = ± 0,2 x 0,07 x 100 % ± 1,4 % (u)

Matching network attenuation uncertainty (Generator A to EUT) ± 1,5 % (σ) (c)

Total level uncertainty, generator A:

$$\sigma_{A+} = \sqrt{\left(\frac{(12{,}2\ \%)^2}{3}\right) + (1{,}5\ \%)^2 + \left(\frac{(1{,}4\ \%)^2}{2}\right)} =$$ 7,27 % (σ)

$$\sigma_{A-} = \sqrt{\left(\frac{(10{,}9\ \%)^2}{3}\right) + (1{,}5\ \%)^2 + \left(\frac{(1{,}4\ \%)^2}{2}\right)} =$$ 6,54 % (σ)

Signal generator B level uncertainty (± dB (d)) + 12,2/- 10,9 % (r)

Mismatch uncertainty, generator B:

Generator reflection coefficient 0,2 Matching network reflection coefficient 0,07

M_{iu} = ± 0,2 x 0,07 x 100 % ± 1,4 % (u)

Matching network attenuation uncertainty (Generator B to EUT) ± 1,5 % (σ) (c)

Uncertainty caused by unwanted signal levels:

Total level uncertainty, generator B:

$$\sigma_{B+} = \sqrt{\left(\frac{(12{,}2\ \%)^2}{3}\right) + (1{,}5\ \%)^2 + \left(\frac{(1{,}4\ \%)^2}{2}\right)} =$$ 7,26 % (σ)

$$\sigma_{B-} = \sqrt{\left(\frac{(10{,}9\ \%)^2}{3}\right) + (1{,}5\ \%)^2 + \left(\frac{(1{,}4\ \%)^2}{2}\right)} =$$ 6,54 % (σ)

Uncertainty due to unwanted signal level uncertainty:

$$\sigma_{1+} = \sqrt{\left(\frac{2\ \text{x}\ (7{,}27\ \%)}{3}\right)^2 + \left(\frac{(7{,}27\ \%)}{3}\right)^2} =$$ 5,42 % (σ)

$$\sigma_{1-} = \sqrt{\left(\frac{2\ \text{x}\ (6{,}54\ \%)}{3}\right)^2 + \left(\frac{(6{,}54\ \%)}{3}\right)^2} =$$ formula (13) = 4,87 % (σ)

Error caused by uncertainty of the level of the wanted signal:

Uncertainty of wanted signal generator level (generator C) ± dB (d) + 12,2/- 10,9 % (r)

Uncertainty of attenuation in matching network ± 1,5 % (σ) (c)

Mismatching uncertainty at generator: Generator reflection coefficient = 0,2 (d)
Matching network reflection coefficient = 0,07 (m)

M_{iu} = 0,2 x 0,07 x 100 % ± 1,4 % (u)

Mismatch uncertainties at the antenna connector of the receiver (wanted signal): ($VSWR_{att}$ 1,2 which gives R_l = 0,091 and R_g of the receiver under test taken from table C.1: Mean value = 0,2, standard deviation = 0,05)

M_{iu} = 0,091 x 0,2 x 100 % = ± 1,82 % (u) (c) formula (8)

Normalised standard deviation of R_g = 0,05/0,2 = 0,25. The correction factor (taken from figure 4 = 1,03 Standard deviation of mismatch uncertainty at the antenna connector

$$1{,}03 \text{ x } \frac{(1{,}82\ \%)}{\sqrt{2}} = \quad \text{formula (9)} \quad 1{,}33\ \%\ (\sigma)$$

Total uncertainty of wanted signal:

$$\sigma_{C+} = \sqrt{\left(\frac{(12{,}2\ \%)^2}{3}\right) + (1{,}5\ \%)^2 + \left(\frac{(1{,}4\ \%)^2}{2}\right) + (1{,}33\ \%)^2} = \quad 7{,}39\ \%\ (\sigma)$$

$$\sigma_{C-} = \sqrt{\left(\frac{(10{,}9\ \%)^2}{3}\right) + (1{,}5\ \%)^2 + \left(\frac{(1{,}4\ \%)^2}{2}\right) + (1{,}33\ \%)^2} = \quad 6{,}68\ \%\ (\sigma)$$

Uncertainty due to wanted signal level uncertainty:

a) Uncertainty due to intermodulation:

$$\sigma_{2a^+} = 2 \text{ x } \frac{(7{,}39\ \%)}{3} = \quad \text{formula (14)} \quad 4{,}93\ \%\ (\sigma)$$

$$\sigma_{2a^-} = 2 \text{ x } \frac{(6{,}68\ \%)}{3} = \quad \text{formula (14)} \quad 4{,}45\ \%\ (\sigma)$$

b) Uncertainty due to change in capture ratio as function of wanted signal level:

Dependency function taken from table C.1: Mean value = 0,1, Standard deviation = 0,03

$$\sigma_{2b} = \sqrt{(7{,}39\ \%)^2 \text{ x } \left((0{,}1\ \%/\%)^2 + (0{,}03\ \%/\%)^2\right)} = \quad 0{,}77\ \%\ (\sigma)$$

$$\sigma_{2b-} = \sqrt{(6{,}68\ \%)^2 \text{ x } \left((0{,}1\ \%/\%)^2 + (0{,}03\ \%/\%)^2\right)} = \quad \text{formula (2)} \quad 0{,}70\ \%\ (\sigma)$$

$$\sigma_{2+} = \sqrt{(4{,}93\ \%)^2 + (0{,}77\ \%)^2} = \quad 4{,}99\ \%\ (\sigma)$$

$$\sigma_{2-} = \sqrt{(4{,}45\ \%)^2 + (0{,}70\ \%)^2} = \quad 4{,}51\ \%\ (\sigma)$$

standard deviation of random uncertainty 2 % (σ)

Total uncertainty Case 1

$$\sigma_{t+} = \sqrt{(5{,}42\ \%)^2 + (4{,}99\ \%)^2 + (4{,}15\ \%)^2 + (3{,}94\ \%)^2 + (2{,}4\ \%)^2} = \quad 9{,}63\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{(4{,}87\ \%)^2 + (4{,}51\ \%)^2 + (3{,}82\ \%)^2 + (3{,}94\ \%)^2 + (2{,}4\ \%)^2} = \quad 8{,}94\ \%\ (\sigma)$$

U_{95} = + 1,96 x 9,63 %/- 1,96 x 8,94 % = + 18,88 %/- 17,52 % = + 1,50 dB/- 1,67 dB

Total uncertainty Case 2b

$$\sigma_{t+} = \sqrt{(5{,}42\ \%)^2 + (4{,}99\ \%)^2 + (4{,}15\ \%)^2 + (1{,}51\ \%)^2 + (2{,}4\ \%)^2} = \quad 8{,}92\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{(4{,}87\ \%)^2 + (4{,}51\ \%)^2 + (3{,}82\ \%)^2 + (1{,}51\ \%)^2 + (2{,}4\ \%)^2} = \quad 8{,}17\ \%\ (\sigma)$$

U_{95} = + 1,96 x 8,92 %/- 1,96 x 8,17 % = + 17,48 %/- 16,01 % = + 1,40 dB/- 1,52 dB

Total uncertainty Case 3

$$\sigma_{t+} = \sqrt{(5{,}42\ \%)^2 + (4{,}99\ \%)^2 + (4{,}15\ \%)^2 + (0{,}55\ \%)^2 + (2{,}4\ \%)^2} = \quad 8{,}81\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{(4{,}87\ \%)^2 + (4{,}51\ \%)^2 + (3{,}82\ \%)^2 + (0{,}55\ \%)^2 + (2{,}4\ \%)^2} = \quad 8{,}04\ \%\ (\sigma)$$

U_{95} = + 1,96 x 8,81 %/- 1,96 x 8,04 % = + 17,26 %/- 15,77 % = + 1,38 dB/- 1,49 dB

Total uncertainty Case 4b

$$\sigma_{t+} = \sqrt{(5{,}42\ \%)^2 + (4{,}99\ \%)^2 + (4{,}15\ \%)^2 + (0{,}19\ \%)^2 + (2{,}4\ \%)^2} = \quad 8{,}79\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{(4{,}87\ \%)^2 + (4{,}51\ \%)^2 + (3{,}82\ \%)^2 + (0{,}19\ \%)^2 + (2{,}4\ \%)^2} = \quad 8{,}02\ \%\ (\sigma)$$

U_{95} = + 1,96 x 8,79 %/- 1,96 x 8,02 % = + 17,2 %/- 15,7 % = + 1,4 dB/- 1,5 dB

7.4.3 Intermodulation response (messages)

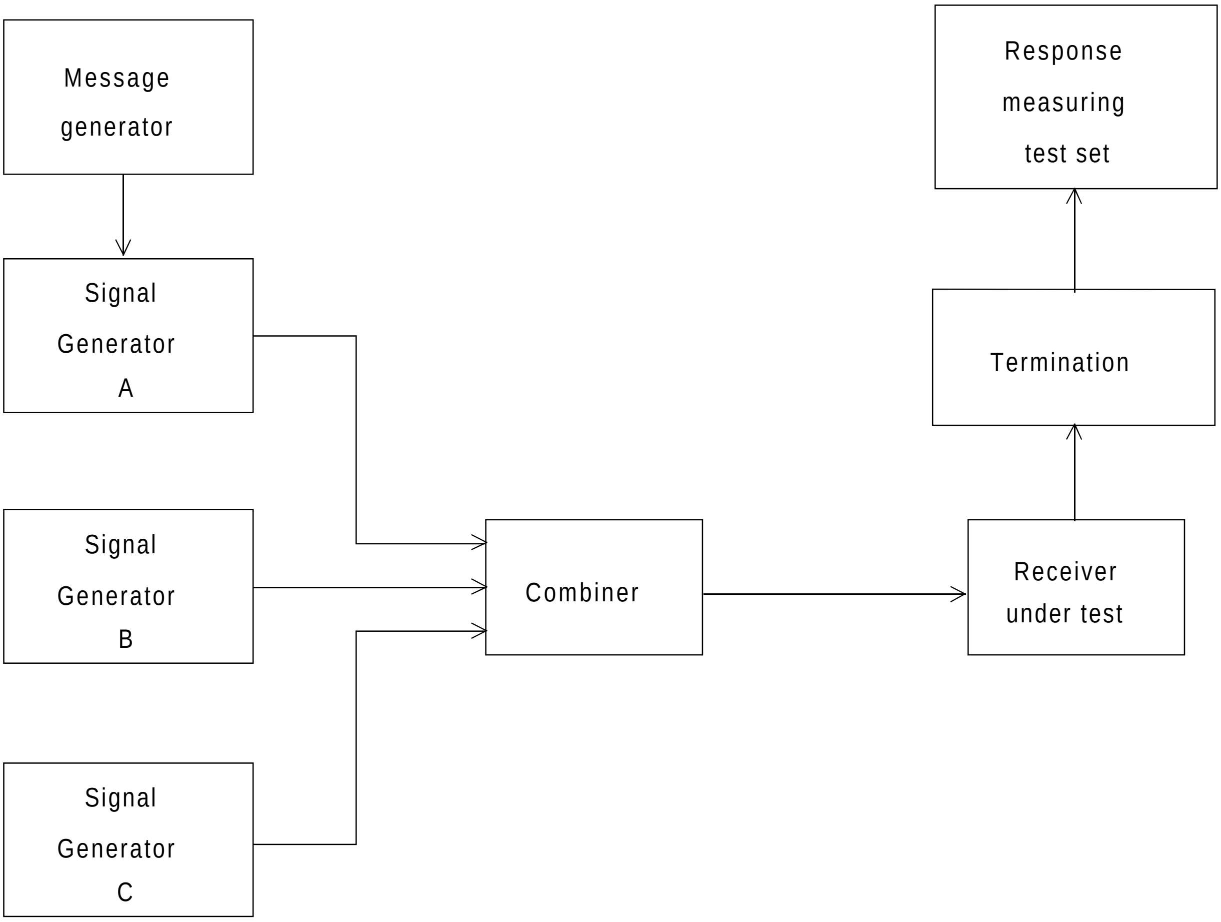


Figure 34: Intermodulation response measurement configuration (messages)

The receiver under test is connected to three signal generators through a combining network which may contain isolators and attenuators. The wanted signal is at the nominal frequency of the receiver, and modulated as appropriate, The unwanted signals, also modulated as appropriate, are combined and applied to the receiver input. The test signal is applied repeatedly, whilst varying the level of both of the unwanted signals, until the specified success calling rate is achieved. The result is the average of the wanted signal generator level to the unwanted signal generator levels recorded , corrected for mismatch loses and attenuation of matching network.

Measurement uncertainty: Error caused by uncertainty of the level of the unwanted signals:

Signal generator A level uncertainty ± 1 dB (d) + 12,2/- 10,9 % (r)

Mismatch uncertainty, generator A reflection coefficient 0,2 Matching network reflection coefficient 0,07

M_{iu} = ± 0,2 x 0,07 x 100 % ± 1,4 % (u)

Matching network attenuation uncertainty (Generator A to EUT) ± 1,5 % (σ) (c)

Total level uncertainty, generator A:

$$\sigma_{A+} = \sqrt{\left(\frac{(12{,}2\ \%)^2}{3}\right) + (1{,}5\ \%)^2 + \left(\frac{(1{,}4\ \%)^2}{2}\right)} =$$ 7,27 % (σ)

$$\sigma_{A-} = \sqrt{\left(\frac{(10,9\ \%)^2}{3}\right) + (1,5\ \%)^2 + \left(\frac{(1,4\ \%)^2}{2}\right)} =$$ 6,54 % (σ)

Signal generator B level uncertainty (± dB (d)) + 12,2/- 10,9 % (r)

Mismatch uncertainty, generator B:

Generator reflection coefficient 0,2 Matching network reflection coefficient 0,07
M_{iu} = ± 0,2 x 0,07 x 100 % ± 1,4 % (u)

Matching network attenuation uncertainty (Generator B to EUT) ± 1,5 % (σ) (c)
Uncertainty caused by unwanted signal levels:

Total level uncertainty, generator B:

$$\sigma_{B+} = \sqrt{\left(\frac{(12,2\ \%)^2}{3}\right) + (1,5\ \%)^2 + \left(\frac{(1,4\ \%)^2}{2}\right)} =$$ 7,26 % (σ)

$$\sigma_{B-} = \sqrt{\left(\frac{(10,9\ \%)^2}{3}\right) + (1,5\ \%)^2 + \left(\frac{(1,4\ \%)^2}{2}\right)} =$$ 6,54 % (σ)

Uncertainty due to unwanted signal level uncertainty:

$$\sigma_{1+} = \sqrt{\left(\frac{2\ x\ (7,27\ \%)}{3}\right)^2 + \left(\frac{(7,27\ \%)}{3}\right)^2} =$$ 5,42 % (σ)

$$\sigma_{1-} = \sqrt{\left(\frac{2\ x\ (6,54\ \%)}{3}\right)^2 + \left(\frac{(6,54\ \%)}{3}\right)^2} =$$ formula (13) = 4,87 % (σ)

Error caused by uncertainty of the level of the wanted signal:

Uncertainty of wanted signal generator level (generator C) ± dB (d) + 12,2/- 10,9 % (r)

Uncertainty of attenuation in matching network ± 1,5 % (σ) (c)

Mismatching uncertainty at generator: Generator reflection coefficient = 0,2 (d)
Matching network reflection coefficient = 0,07 (m)

M_{iu} = 0,2 x 0,07 x 100 % ± 1,4 % (u)

Mismatch uncertainties at the antenna connector of the receiver (wanted signal):

($VSWR_{att}$ 1,2 which gives R_l = 0,091 and R_g of the receiver under test taken from table C.1: Mean value = 0,2, standard deviation = 0,05)

M_{iu} = 0,091 x 0,2 x 100 % = ± 1,82 % (u) (c) formula (8)

Normalised standard deviation of R_g = 0,05/0,2 = 0,25

Correction factor (taken from figure 4 = 1,03. Standard deviation of mismatch uncertainty at the antenna connector

$$1{,}03 \text{ x } \frac{(1{,}82\ \%)}{\sqrt{2}} =$$ formula (9) 1,33 % (σ)

Total uncertainty of wanted signal:

$$\sigma_{C+} = \sqrt{\left(\frac{(12{,}2\ \%)^2}{3}\right) + (1{,}5\ \%)^2 + \left(\frac{(1{,}4\ \%)^2}{2}\right) + (1{,}33\ \%)^2} =$$ 7,39 % (σ)

$$\sigma_{C-} = \sqrt{\left(\frac{(10{,}9\ \%)^2}{3}\right) + (1{,}5\ \%)^2 + \left(\frac{(1{,}4\ \%)^2}{2}\right) + (1{,}33\ \%)^2} =$$ 6,68 % (σ)

Uncertainty due to wanted signal level uncertainty:

a) Uncertainty due to intermodulation:

$$\sigma_{2a^+} = 2 \text{ x } \frac{(7{,}39\ \%)}{3} =$$ formula (14) 4,93 % (σ)

$$\sigma_{2a^-} = 2 \text{ x } \frac{(6{,}68\ \%)}{3} =$$ formula (14) 4,45 % (σ)

b) Uncertainty due to change in capture ratio as function of wanted signal level:

Dependency function taken from table C.1: Mean value = 0,1, Standard deviation = 0,03

$$\sigma_{2b} = \sqrt{(7{,}39\ \%)^2 \text{ x } \left((0{,}1\ \%/\%)^2 + (0{,}03\ \%/\%)^2\right)} =$$ 0,77 % (σ)

$$\sigma_{2b-} = \sqrt{(6{,}68\ \%)^2 \text{ x } \left((0{,}1\ \%/\%)^2 + (0{,}03\ \%/\%)^2\right)} =$$ formula (2) 0,70 % (σ)

$$\sigma_{2+} = \sqrt{(4{,}93\ \%)^2 + (0{,}77\ \%)^2} =$$ 4,99 % (σ)

$$\sigma_{2-} = \sqrt{(4{,}45\ \%)^2 + (0{,}70\ \%)^2} =$$ 4,51 % (σ)

Using the value of +/- 0,332 dB, the standard deviation from the example in subclause 5.6.4, the uncertainty contribution is: +3,90 % -3,75 %

Standard deviation of random uncertainty = 2,4 % (m) (σ)

Total uncertainty:

$$\sigma_{t+} = \sqrt{(5{,}42\ \%)^2 + (4{,}99\ \%)^2 + (4{,}15\ \%)^2 + (3{,}90\ \%)^2 + (2{,}4\ \%)^2} =$$ 9,62 % (σ)

$$\sigma_{t-} = \sqrt{(4{,}87\ \%)^2 + (4{,}51\ \%)^2 + (3{,}82\ \%)^2 + (3{,}75\ \%)^2 + (2{,}4\ \%)^2} =$$ 8,86 % (σ)

U_{95} = + 1,96 x 9,62 %/- 1,96 x 8,86 % = + 18,85 %/- 17,36 % = + 1,50 dB/- 1,66 dB

7.5 Conducted spurious emissions

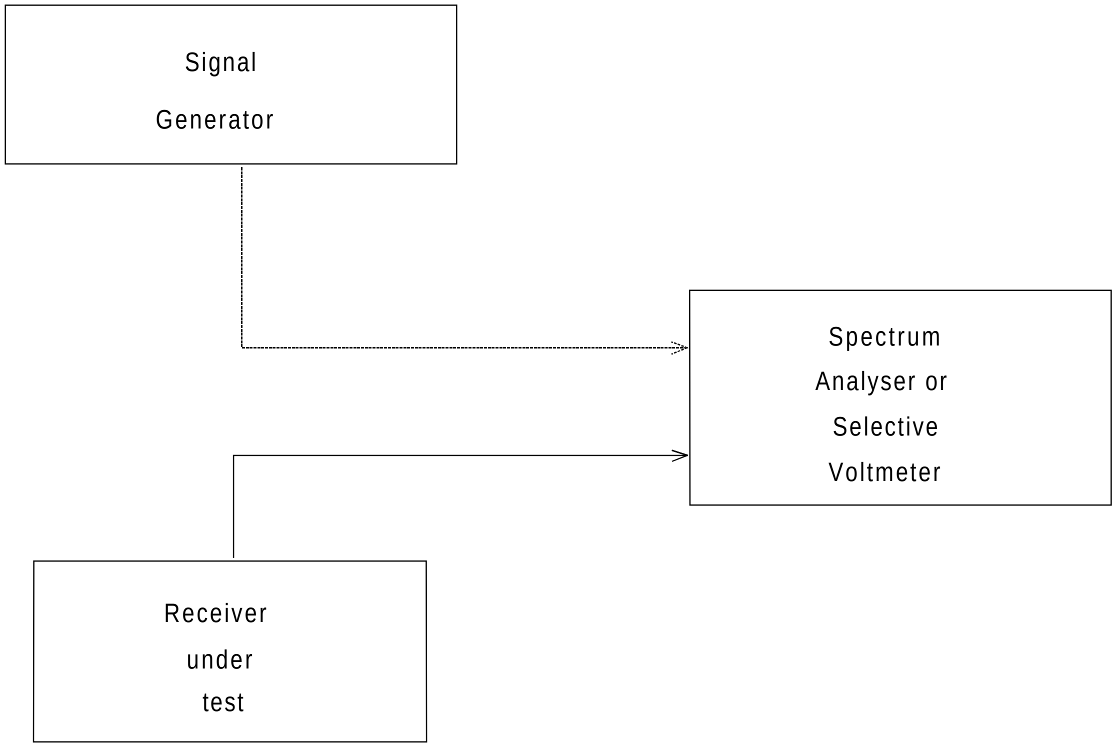


Figure 35: Conducted spurious emission measurement configuration

The receiver is connected to a spectrum analyser.

The individual spurious components are found and read from the analyser and corrected for attenuation and mismatch loss in the matching network, or they are substituted by a signal generator signal.

Measurement uncertainty: Substitution method:

Mismatch uncertainties at input:

a) With receiver connected: Receiver reflection coefficient taken from Table C.1 : Mean value = 0,7 and standard deviation = 0,1 Spectrum analyser reflection coefficient 0,15 (d)

M_{iu} = 0,15 x 0,7 x 100 = ± 10,5 % (u)

Normalised standard deviation from table C.1 = 0,1/0,7 = 0,14 Uncertainty correction factor (from figure 4) = 1,02. Mismatch uncertainty:

$$1{,}02 \times \frac{(10{,}5\ \%)}{\sqrt{2}} = \qquad 7{,}56\ \%\ (\sigma)$$

b) With generator connected:

Generator reflection coefficient 0,2 (d). Spectrum analyser reflection coefficient 0,15 (d)

M_{iu} = ± 0,15 x 0,2 x 100 % (c) ± 3,0 % (u)

Signal generator substitution Signal uncertainty ± 1 dB (d) + 12,2/- 10,9 % (r)

Uncertainty due to supply voltage: Supply voltage uncertainty ± 100 mV (r) Dependency function taken from table C.1: Mean value = 10 % (p)/V and standard deviation = 3 % (p)/V. Uncertainty:

$$\sqrt{\left(\frac{(0{,}1\ V)^2}{3}\right) \text{ x } \left((10{,}0\ \%/V)^2 + (3{,}0\ \%/V)^2\right)} = 0{,}60\ \%\ (\sigma)\ (p)$$ formula (2) 0,3 % (σ)

$$\sigma_{y^+} = \sqrt{\frac{(12{,}2\ \%)^2}{3} + \frac{(3\ \%)^2}{2} + (7{,}56\ \%)^2 + (0{,}3\ \%)^2} =$$ 10,6 % (σ)

$$\sigma_{t-} = \sqrt{\frac{(10{,}9\ \%)^2}{3} + \frac{(3\ \%)^2}{2} + (7{,}56\ \%)^2 + (0{,}3\ \%)^2} =$$ 10,1 % (σ)

U_{95} = + 1,96 x 10,6 %/- 1,96 x 10,1 % = + 20,8 %/- 19,8 % = + 1,6 dB/- 1,9 dB

Direct reading from spectrum analyser:

Mismatch uncertainties at input: With receiver connected: Receiver reflection coefficient taken from table C.1: Mean value = 0,7 and standard deviation = 0,1 Spectrum analyser reflection coefficient 0,15 (d)

M_{iu} = 0,15 x 0,7 x 100 % = ± 10,5 % (u)

Normalised standard deviation from table C.1 = 0,1/0,7 = 0,14. Uncertainty correction factor (from figure 4) = 1,02. Mismatch uncertainty

$$1{,}02 \text{ x } \frac{(10{,}5\ \%)}{\sqrt{2}} =$$ 7,56 % (σ)

Spectrum analyser uncertainty:

Calibration mismatch uncertainty: Both reflection coefficients = 0,2
M_{iu} = 0,2 x 0,2 x 100 % ± 4,0 % (u)

300 MHz reference uncertainty	± 0,3 dB (d)	+ 3,51/- 3,39 % (r)
Frequency response uncertainty	± 2,5 dB (d)	+ 33,4/- 25,0 % (r)
Band switch uncertainty	± 0,5 dB (d)	+ 5,93/- 5,59 % (r)
Log fidelity	± 1,5 dB (d)	+ 18,9/- 15,9 % (r)

Uncertainty due to supply voltage: Supply voltage uncertainty ± 100 mV (r) Dependency function taken from table C.1: Mean value = 10 % (p)/V and standard deviation = 3 % (p)/V: uncertainty:

$$\sqrt{\left(\frac{(0{,}1\ V)^2}{3}\right) \text{ x } \left((10{,}0\ \%/V)^2 + (3{,}0\ \%/V)^2\right)} = 0{,}60\ \%\ (\sigma)\ (p)$$ formula (2) 0,30 % (σ)

total uncertainty:

$$\sigma_{t+} = \sqrt{\frac{\left((3{,}51\%)^2 + (33{,}4\%)^2 + (5{,}93\%)^2 + (18{,}9\%)^2\right)}{3} + \frac{(4{,}0\%)^2}{2} + (0{,}3\%)^2 + (7{,}56\%)^2} =$$ 23,9 % (σ)

$$\sigma_{t-} = \sqrt{\frac{\left((3{,}39\%)^2 + (25{,}0\%)^2 + (5{,}59\%)^2 + (15{,}9\%)^2\right)}{3} + \frac{(4{,}0\%)^2}{2} + (0{,}3\%)^2 + (7{,}56\%)^2} =$$ 19,3 % (σ)

U_{95} = + 1,96 x 23,9 %/- 1,96 x 19,3 % = + 46,8 %/- 37,8 % = + 3,34 dB/- 4,12 dB

7.6 Cabinet radiation

See subclause 6.6.

8 Duplex operation measurements

8.1 Receiver desensitisation

8.1.1 Desensitisation (analogue speech)

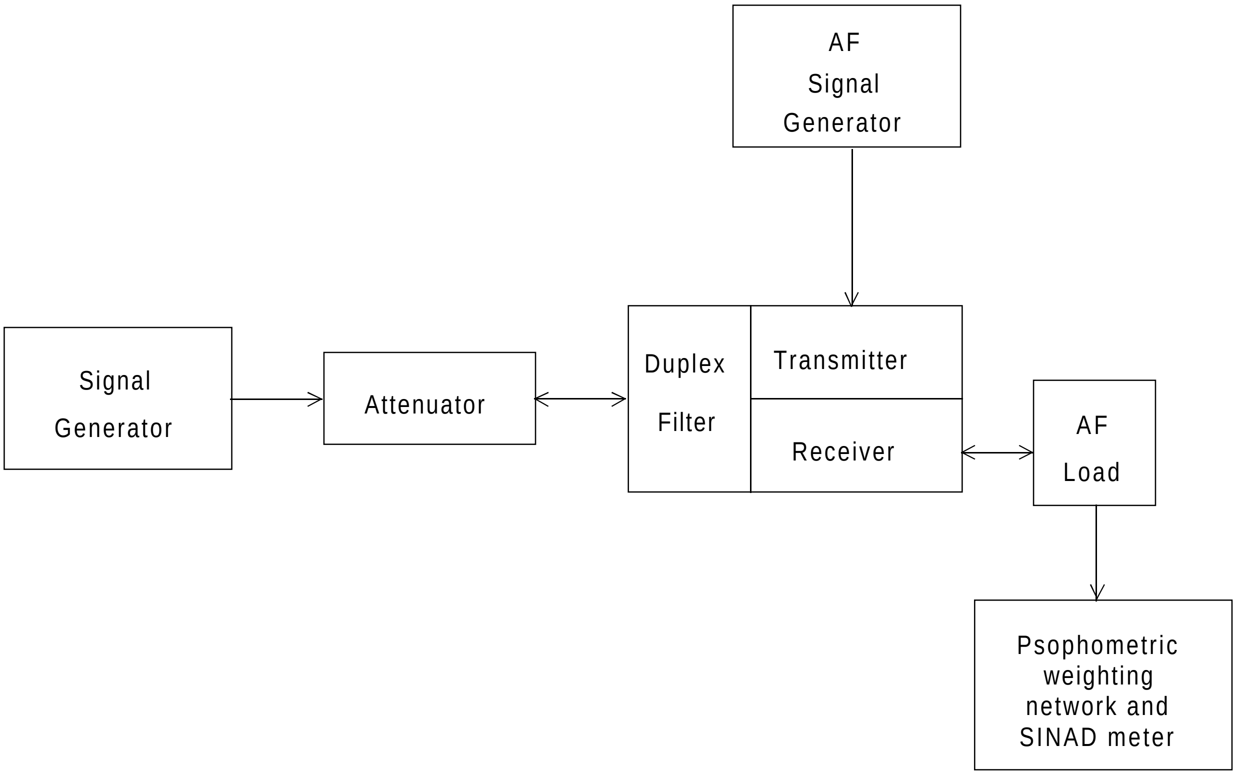


Figure 36: Receiver desensitisation configuration for equipment with duplex filter (analogue speech)

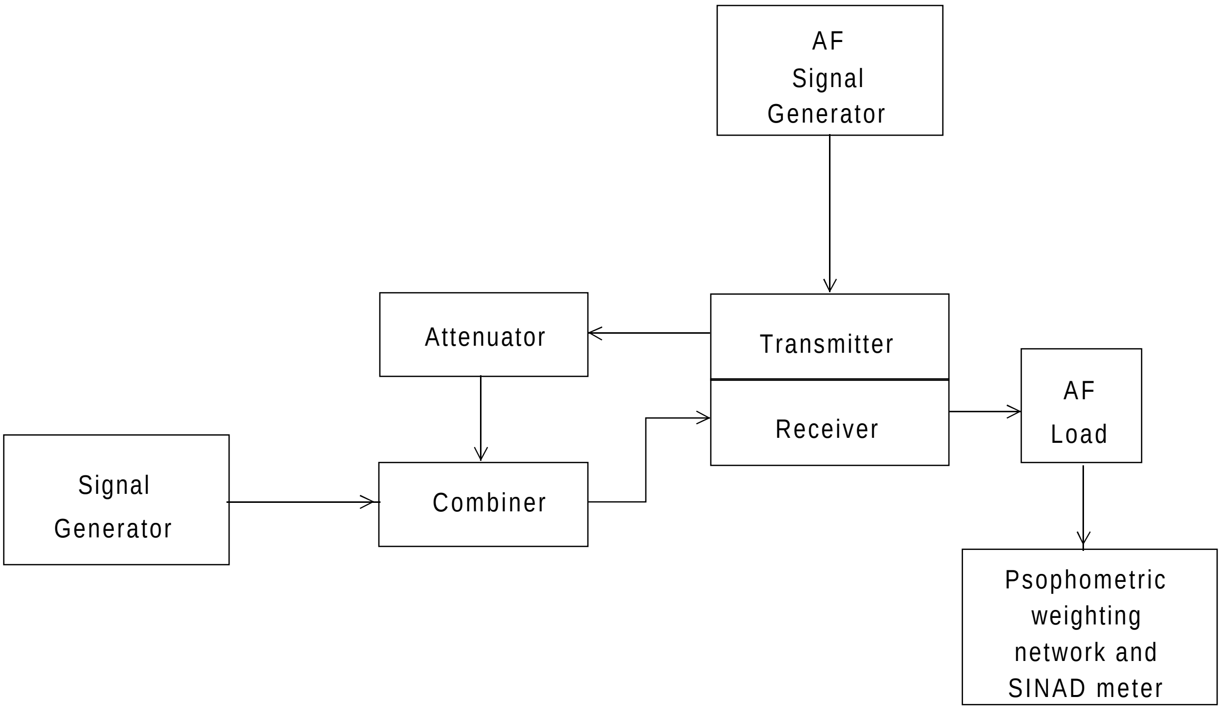


Figure 37: Receiver desensitisation configuration for equipment without duplex filter (analogue speech)

The radio under test is connected to a signal generator via a matching and attenuating network which may contain an isolator or circulator. The low frequency output is connected to an AF load and a SINAD meter through a psophometric filter.

The sensitivity is measured twice, once with the transmitter in stand by, and once with the transmitter activated. The result is the difference between the two signal levels of the signal generator.

Measurement uncertainty:

Power behaviour of the attenuator in matching network:

Power coefficient 0,001 dB/dB x Watt 10 dB attenuator

0,001 x 25 W x 10 dB =	± 0,25 dB (d)	+ 2,92/- 2,84 % (r)
Linearity of signal generator	± 0,3 dB (d)	+ 3,51/- 3,39 % (r)

Mismatch uncertainties at the antenna connector of the receiver: ($VSWR_{att}$ 1,2 which gives R_l = 0,091 and R_g of the receiver under test taken from table C.1: Mean value = 0,2, standard deviation = 0,05)

M_{iu} = 0,091 x 0,2 x 100 % = ± 1,82 % (u) (c) formula (8)
Normalised standard deviation of R_g = 0,05/0,2 = 0,25. Correction factor (taken from the figure 4) = 1,03
Standard deviation of mismatch uncertainty at the antenna connector

$$1{,}03 \text{ x } \frac{(1{,}82\ \%)}{\sqrt{2}} =$$ formula (9) 1,33 % (σ)

(Counts twice under the assumption that the reflection coefficient changes when the transmitter is activated).

Total signal level difference uncertainty:

$$\sigma_{1+} = \sqrt{\frac{(2{,}92\ \%)^2 + (3{,}51\ \%)^2}{3} + (1{,}33\ \%)^2 + (1{,}33\ \%)^2} =$$ 3,24 % (σ)

$$\sigma_{1-} = \sqrt{\frac{(2{,}84\ \%)^2 + (3{,}39\ \%)^2}{3} + (1{,}33\ \%)^2 + (1{,}33\ \%)^2} = \qquad 3{,}17\ \%\ (\sigma)$$

SINAD measurement uncertainty: (the systematic SINAD uncertainty is balanced out)

Uncertainty due to uncertainty of ambient temperature : (25°C ± 3°C): Dependency function taken from table C.1: Mean value = 2,5 %/°C, Standard deviation = 1,2 %/°C

$$\sigma_2 = \sqrt{\left(\frac{(3\ ^\circ C)^2}{3}\right) \text{x} \left((2{,}5\ \%/^\circ C)^2 + (1{,}2\ \%/^\circ C)^2\right)} = \qquad \text{formula (2) =} \qquad 4{,}8\ \%\ (\sigma)$$

Random uncertainty 2,5 % (σ) (m)

Total uncertainty:

$$\sigma_{t+} = \sqrt{(3{,}24\ \%)^2 + (2{,}5\ \%)^2 + (4{,}8\ \%)^2} = \qquad 6{,}31\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{(3{,}17\ \%)^2 + (2{,}5\ \%)^2 + (4{,}8\ \%)^2} = \qquad 6{,}27\ \%\ (\sigma)$$

U_{95} = + 1,96 x 6,31 %/- 1,96 x 6,27 % = + 12,37 %/- 12,29 % = + 1,01 dB/- 1,14 dB

8.1.2 Desensitisation (bit stream)

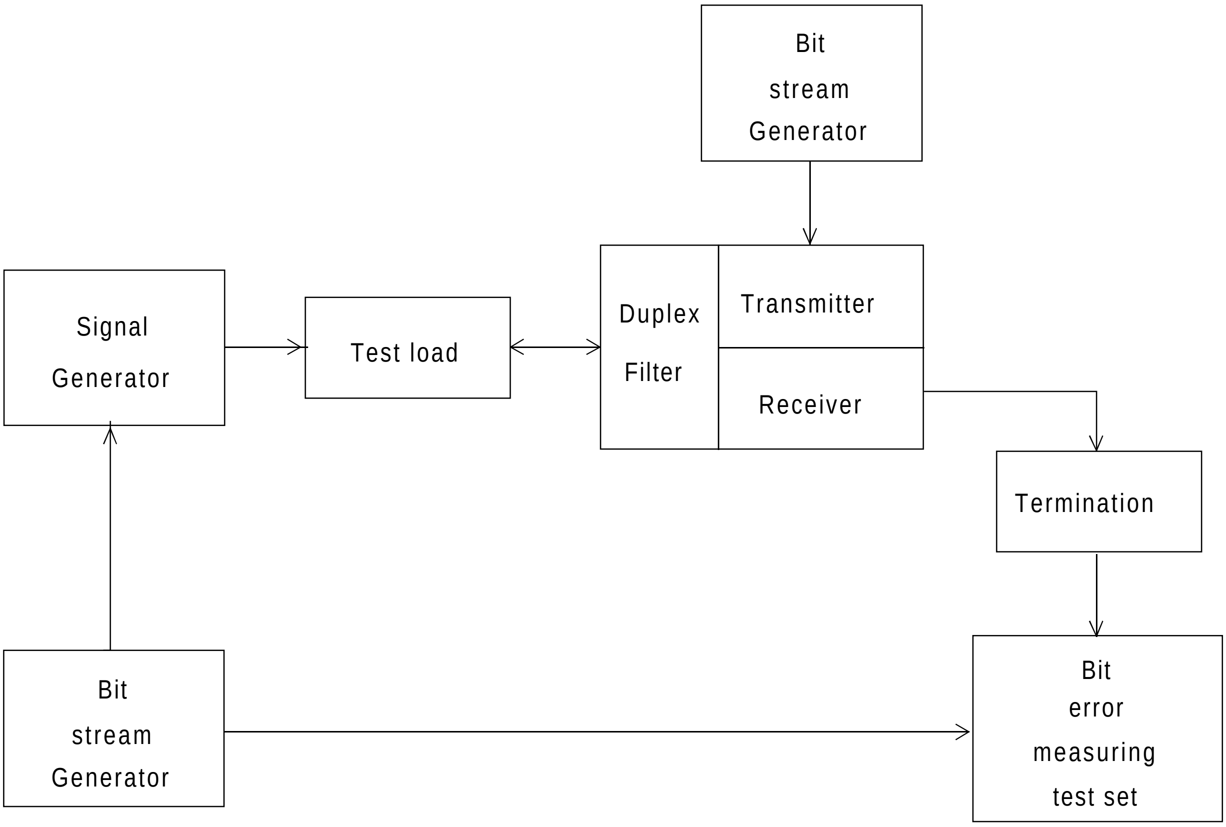


Figure 38: Receiver desensitisation configuration for equipment with duplex filter (bit stream)

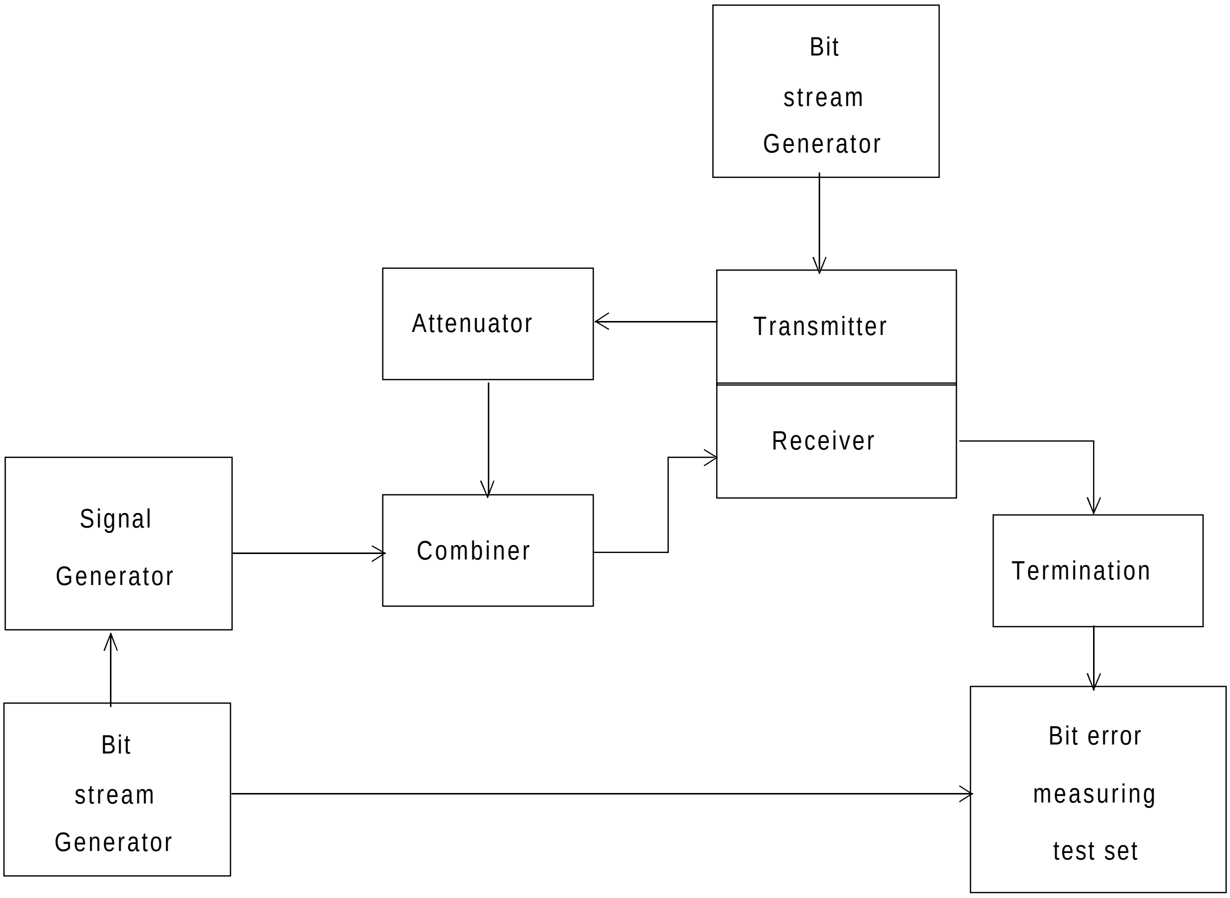


Figure 39: Receiver desensitisation configuration for equipment without duplex filter (bit stream)

The radio under test is connected to a signal generator via a matching and attenuating network which may contain an isolator or circulator. The low frequency output is connected to an AF load and a SINAD meter through a psophometric filter.

The sensitivity is measured twice: once with the transmitter in stand by and once with the transmitter activated. The result is the difference between the two signal levels of the signal generator.

Measurement uncertainty:

Power behaviour of the attenuator in matching network:
Power coefficient 0,001 dB/dB x Watt 10 dB attenuator
0,001 x 25 W x 10 dB = ± 0,25 dB (d) + 2,92/- 2,84 % (r)

Linearity of signal generator ± 0,3 dB (d) + 3,51/- 3,39 % (r)

Mismatch uncertainties at the antenna connector of the receiver: (VSWR$_{att}$ 1,2 which gives R_l = 0,091 and R_g of the receiver under test taken from table C.1: Mean value = 0,2, standard deviation = 0,05

M_{iu} = 0,091 x 0,2 x 100 % = ± 1,82 % (u) (c) formula (8)

Normalised standard deviation of R_g = 0,05/0,2 = 0,25
Correction factor (taken from figure 4 = 1,03. Standard deviation of mismatch uncertainty at the antenna connector

$$1{,}03 \text{ x } \frac{(1{,}82\ \%)}{\sqrt{2}} =$$ formula (9) 1,33 % (σ)

(Counts twice under the assumption that the reflection coefficient changes when the transmitter is activated).

Total signal level difference uncertainty:

$$\sigma_{1+} = \sqrt{\frac{(2{,}92\ \%)^2 + (3{,}51\ \%)^2}{3} + (1{,}33\ \%)^2 + (1{,}33\ \%)^2} =$$ 3,24 % (σ)

$$\sigma_{1-} = \sqrt{\frac{(2{,}84\ \%)^2 + (3{,}39\ \%)^2}{3} + (1{,}33\ \%)^2 + (1{,}33\ \%)^2} =$$ 3,17 % (σ)

Random uncertainty 2,5 % (σ) (m)

Total uncertainty case 1

$$\sigma_{t+} = \sqrt{(3{,}24\ \%)^2 + (2{,}5\ \%)^2 + (3{,}94\ \%)^2} =$$ 5,68 % (σ)

$$\sigma_{t-} = \sqrt{(3{,}17\ \%)^2 + (2{,}5\ \%)^2 + (3{,}94\ \%)^2} =$$ 5,64 % (σ)

U_{95} = + 1,96 x 5,68 %/- 1,96 x 5,64 % = + 11,13 %/- 11,06 % = + 0,92 dB/- 1,02 dB

Total uncertainty case 2b

$$\sigma_{t+} = \sqrt{(3{,}24\ \%)^2 + (2{,}5\ \%)^2 + (1{,}51\ \%)^2} = \quad 4{,}36\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{(3{,}17\ \%)^2 + (2{,}5\ \%)^2 + (1{,}51\ \%)^2} = \quad 4{,}31\ \%\ (\sigma)$$

U_{95} = + 1,96 x 4,36 %/- 1,96 x 4,31 % = + 8,55 %/- 8,45 % = + 0,71 dB/- 0,77 dB

Total uncertainty case 3

$$\sigma_{t+} = \sqrt{(3{,}24\ \%)^2 + (2{,}5\ \%)^2 + (0{,}55\ \%)^2} = \quad 4{,}13\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{(3{,}17\ \%)^2 + (2{,}5\ \%)^2 + (0{,}55\ \%)^2} = \quad 4{,}07\ \%\ (\sigma)$$

U_{95} = + 1,96 x 4,13 %/- 1,96 x 4,07 % = + 8,09 %/- 7,99 % = + 0,68 dB/- 0,72 dB

Total uncertainty case 4b

$$\sigma_{t+} = \sqrt{(3{,}24\ \%)^2 + (2{,}5\ \%)^2 + (0{,}19\ \%)^2} = \quad 4{,}10\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{(3{,}17\ \%)^2 + (2{,}5\ \%)^2 + (0{,}19\ \%)^2} = \quad 4{,}04\ \%\ (\sigma)$$

U_{95} = + 1,96 x 4,10 %/- 1,96 x 4,04 % = + 8,03 %/- 7,92 % = + 0,67 dB/- 0,72 dB

8.1.3 Desensitisation (messages)

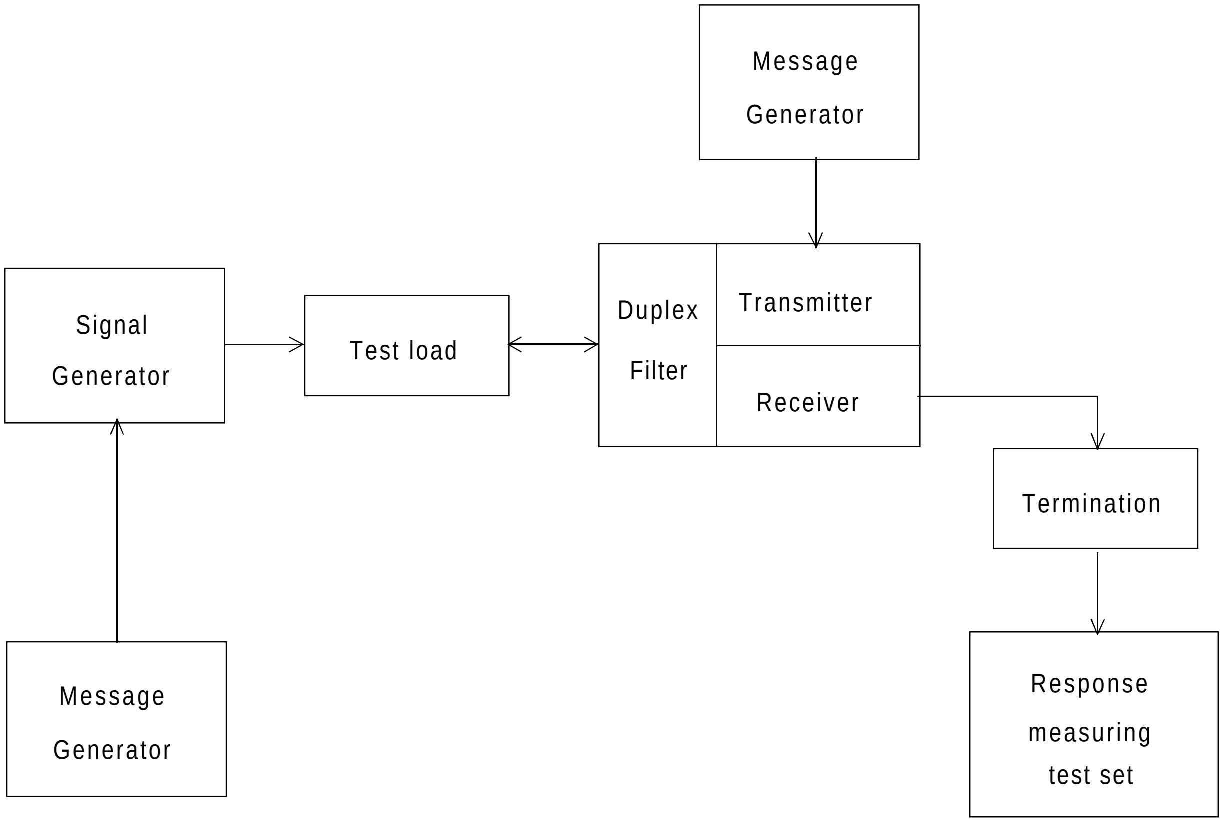


Figure 40: Receiver desensitisation configuration for equipment with duplex filter (messages)

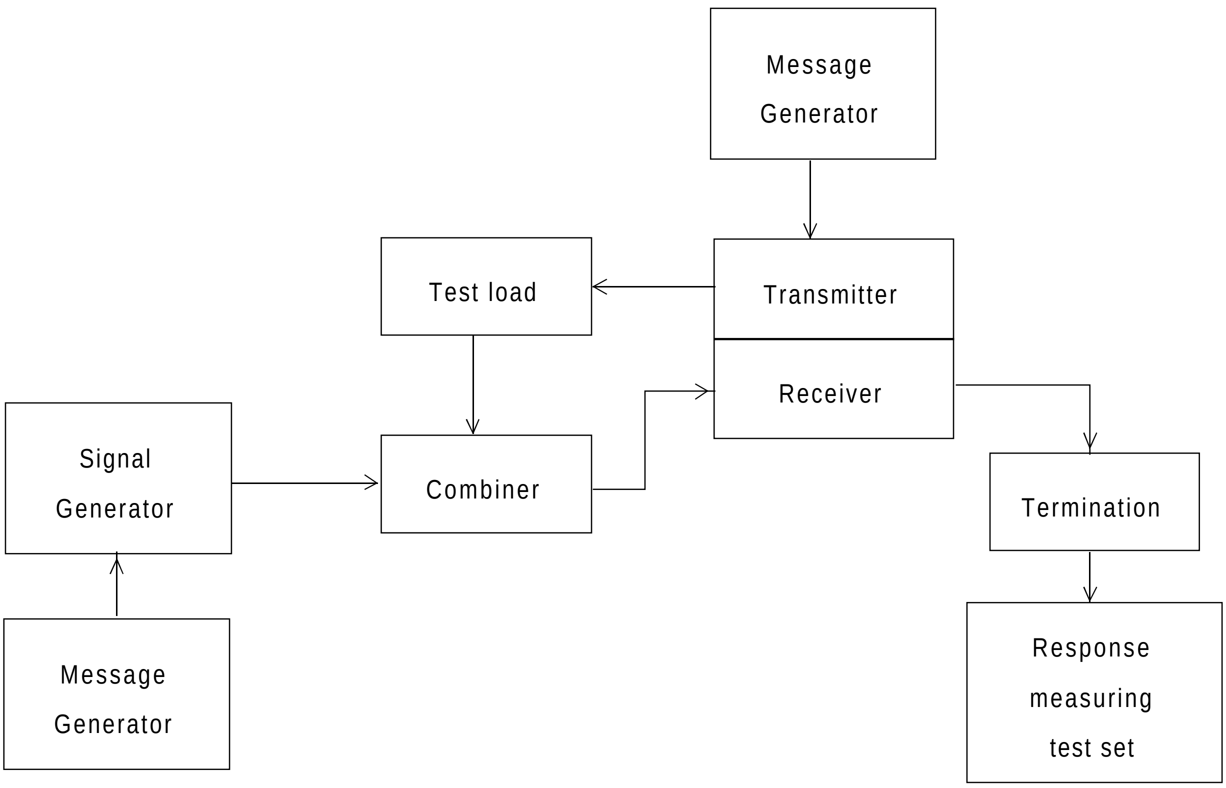


Figure 41: Receiver desensitisation configuration for equipment without duplex filter (messages)

The radio under test is connected to a signal generator via a matching and attenuating network which may contain an isolator or circulator. The low frequency output is connected to an AF load and a SINAD meter through a psophometric filter. The sensitivity is measured twice, once with the transmitter in stand by, and once with the transmitter activated.

The result is the difference between the two signal levels of the signal generator.

Measurement uncertainty:

Power behaviour of the attenuator in matching network:

Power coefficient 0,001 dB/dB x Watt 10 dB attenuator
0,001 x 25 W x 10 dB = ± 0,25 dB (d) + 2,92/- 2,84 % (r)

Linearity of signal generator ± 0,3 dB (d) + 3,51/- 3,39 % (r)

Mismatch uncertainties at the antenna connector of the receiver: (VSWR$_{att}$ 1,2 which gives R_l = 0,091 and R_g of the receiver under test taken from table C.1: Mean value = 0,2, standard deviation = 0,05

M_{iu} = 0,091 x 0,2 x 100 % = ± 1,82 % (u) (c) formula (8)

Normalised standard deviation of R_g = 0,05/0,2 = 0,25
Correction factor (taken from figure 4) = 1,03 Standard deviation of mismatch uncertainty at the antenna connector

$$1{,}03 \text{ x } \frac{(1{,}82\ \%)}{\sqrt{2}} =$$ formula (9) 1,33 % (σ)

NOTE: Counts twice under the assumption that the reflection coefficient changes when the transmitter is activated.

Total signal level difference uncertainty:

$$\sigma_{1+} = \sqrt{\frac{(2{,}92\ \%)^2 + (3{,}51\ \%)^2}{3} + (1{,}33\ \%)^2 + (1{,}33\ \%)^2} =$$ 3,24 % (σ)

$$\sigma_{1-} = \sqrt{\frac{(2{,}84\ \%)^2 + (3{,}39\ \%)^2}{3} + (1{,}33\ \%)^2 + (1{,}33\ \%)^2} =$$ 3,17 % (σ)

Using the value of +/- 0,332 dB, the standard deviation from the example in subclause 5.6.4, the uncertainty contribution is: +3,90 % -3,75 %

Random uncertainty 2,5 % (σ) (m)

Total uncertainty:

$$\sigma_{t+} = \sqrt{(3{,}24\ \%)^2 + (2{,}5\ \%)^2 + (3{,}90\ \%)^2} =$$ 5,65 % (σ)

$$\sigma_{t-} = \sqrt{(3{,}17\ \%)^2 + (2{,}5\ \%)^2 + (3{,}75\ \%)^2} =$$ 5,51 % (σ)

U_{95} = + 1,96 x 5,65 %/- 1,96 x 5,51 % = + 11,08 %/- 10,80 % = + 0,93 dB/- 0,99 dB

8.2 Receiver spurious response rejection

8.2.1 Spurious response rejection (analogue speech).

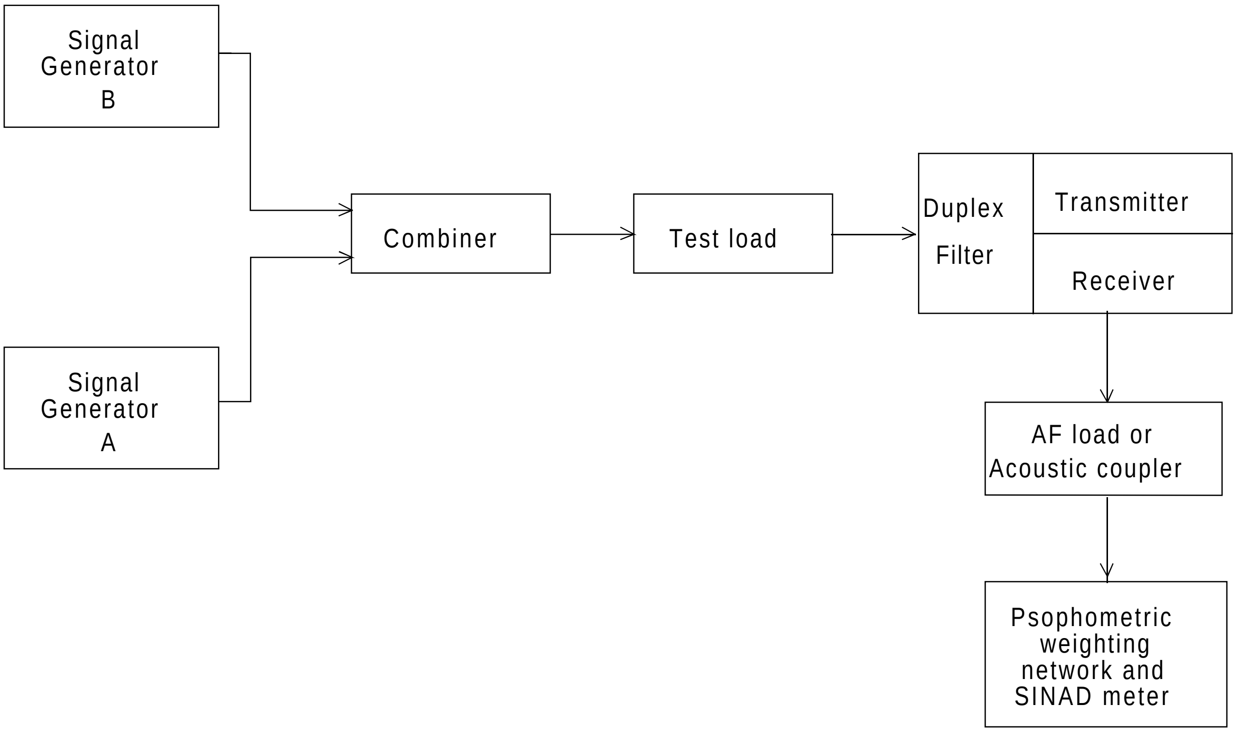


Figure 42: Spurious response rejection configuration with duplex filter (analogue speech)

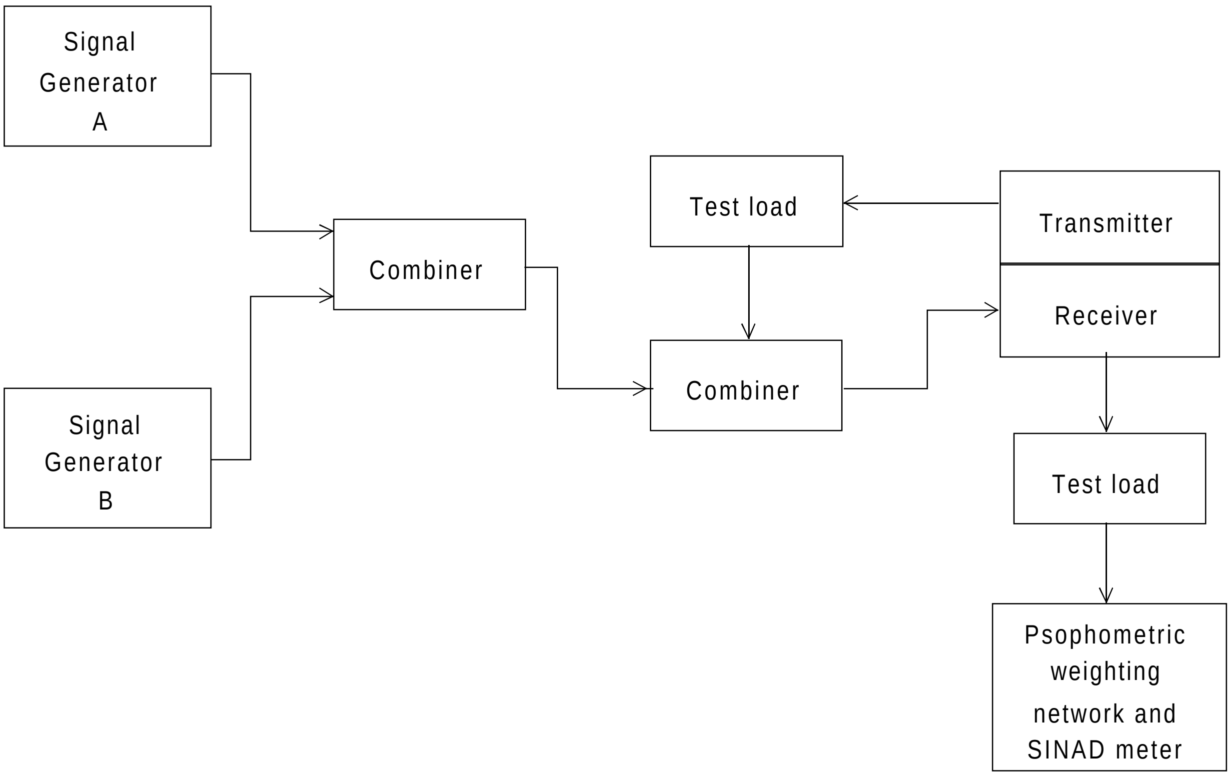


Figure 43: Spurious response rejection configuration without a duplex filter (analogue speech)

The radio under test is connected to two signal generators via a combining and attenuating network. The low frequency output of the receiver is connected to a suitable termination and a SINAD meter via a psophometric filter. The result is the signal level of the unwanted signal generator. Both signal generator levels are corrected for combining network attenuation and mismatch loss.

Measurement uncertainty:

The errors contributing to the total measurement uncertainty are the same as the example in subclause 6.2.3 with one additional error, the power behaviour of the matching network.

Uncertainty caused by power influence on matching network, (at a carrier power of 25 W):
0,001 dB/dB_{Att} x W (10 dB attenuator, 25 W):

0,001 x 25 x 10 dB = ± 0,25 dB = + 2,92/- 2,84 % (r)

Total uncertainty for in band measurements:

Standard deviation taken from example in subclause 6.2.3 = + 15,0/- 13,7 % (σ)

$$\sigma_{t+} = \sqrt{\frac{(15{,}0\ \%)^2 + (2{,}92\ \%)^2}{3}} = \quad 15{,}1\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{\frac{(13{,}7\ \%)^2 + (2{,}84\ \%)^2}{3}} = \quad 13{,}8\ \%\ (\sigma)$$

U_{95} = + 1,96 x 15,1 % - 1,96 x 13,8 % = + 29,6 % - 27,0 % = + 2,3 dB/- 2,7 dB

Total uncertainty for out of band measurements:

Standard deviation taken from example in subclause 7.3.1.2 = + 15,9/- 14,5 % (σ)

$$\sigma_{t+} = \sqrt{\frac{(15{,}9\ \%)^2 + (2{,}92\ \%)^2}{3}} = \quad 16{,}0\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{\frac{(14{,}5\ \%)^2 + (2{,}84\ \%)^2}{3}} = \quad 14{,}6\ \%\ (\sigma)$$

U_{95} = + 1,96 x 16,0 %/- 1,96 x 14,6 % = + 31,3 %/- 28,6 % = + 2,4 dB/- 2,9 dB

8.2.2 Spurious response rejection (bit stream)

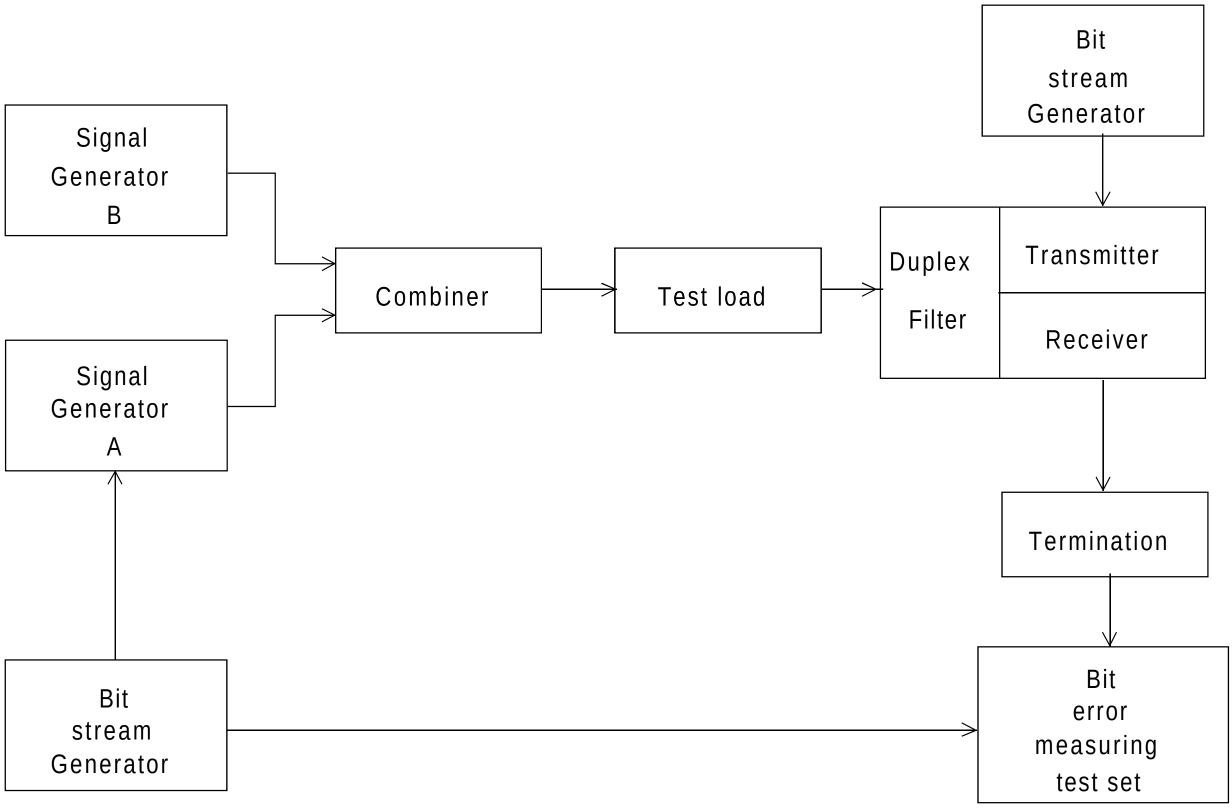


Figure 44: Spurious response rejection configuration with duplex filter (bit stream)

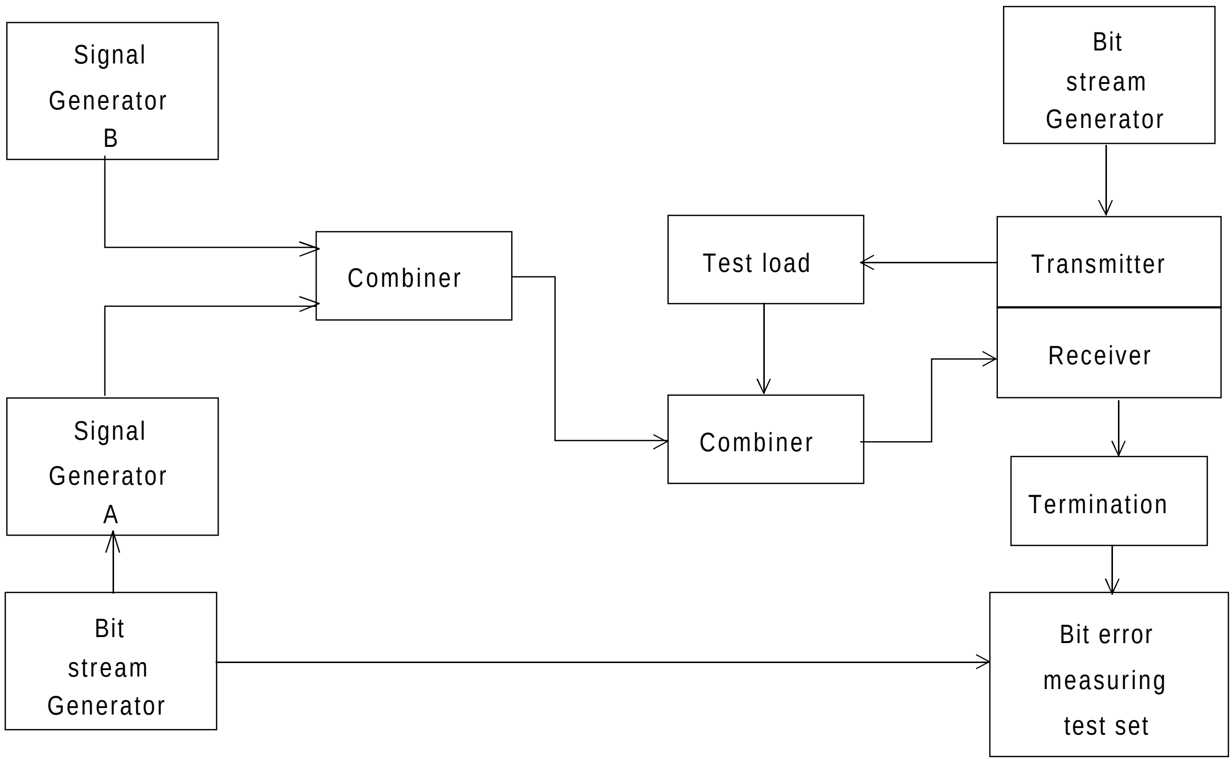


Figure 45: Spurious response rejection configuration without duplex filter (bit stream)

The radio under test is connected to two signal generators via a combining and attenuating network. The low frequency output of the receiver is connected to a suitable termination and a SINAD meter via a psophometric filter. The result is the signal level of the unwanted signal generator. Both signal generator levels are corrected for combining network attenuation and mismatch loss.

Measurement uncertainty:

The errors contributing to the total measurement uncertainty are the same as the example in subclause 6.2.3 with one additional error: the power behaviour of the matching network.

Uncertainty caused by power influence on matching network:
(At a carrier power of 25 W).
0,001 dB/dB_{Att} x W (10 dB attenuator, 25 W):
0,001 x 25 x 10 dB = ± 0,25 dB = + 2,92/- 2,84 % (r)

Total uncertainty for in band measurements:

Standard deviation taken from example in subclause 7.3.1.2 = + 15,0/- 13,7 % (σ)

$$\sigma_{t+} = \sqrt{\frac{(15{,}0\ \%)^2 + (2{,}92\ \%)^2}{3}} = \quad 15{,}1\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{\frac{(13{,}7\ \%)^2 + (2{,}84\ \%)^2}{3}} = \quad 13{,}8\ \%\ (\sigma)$$

U_{95} = + 1,96 x 15,1 %/- 1,96 x 13,8 % = + 29,6 %/- 27,0 % = + 2,3 dB/- 2,7 dB

Total uncertainty for out of band measurements:

Standard deviation taken from example in subclause 6.2.3 = + 15,9/- 14,5 % (σ)

$$\sigma_{t+} = \sqrt{\frac{(15{,}9\ \%)^2 + (2{,}92\ \%)^2}{3}} = \quad 16{,}0\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{\frac{(14{,}5\ \%)^2 + (2{,}84\ \%)^2}{3}} = \quad 14{,}6\ \%\ (\sigma)$$

U_{95} = + 1,96 x 16,0 %/- 1,96 x 14,6 % = + 31,3 %/- 28,6 % = + 2,4 dB/- 2,9 dB

8.2.3 Spurious response rejection (messages).

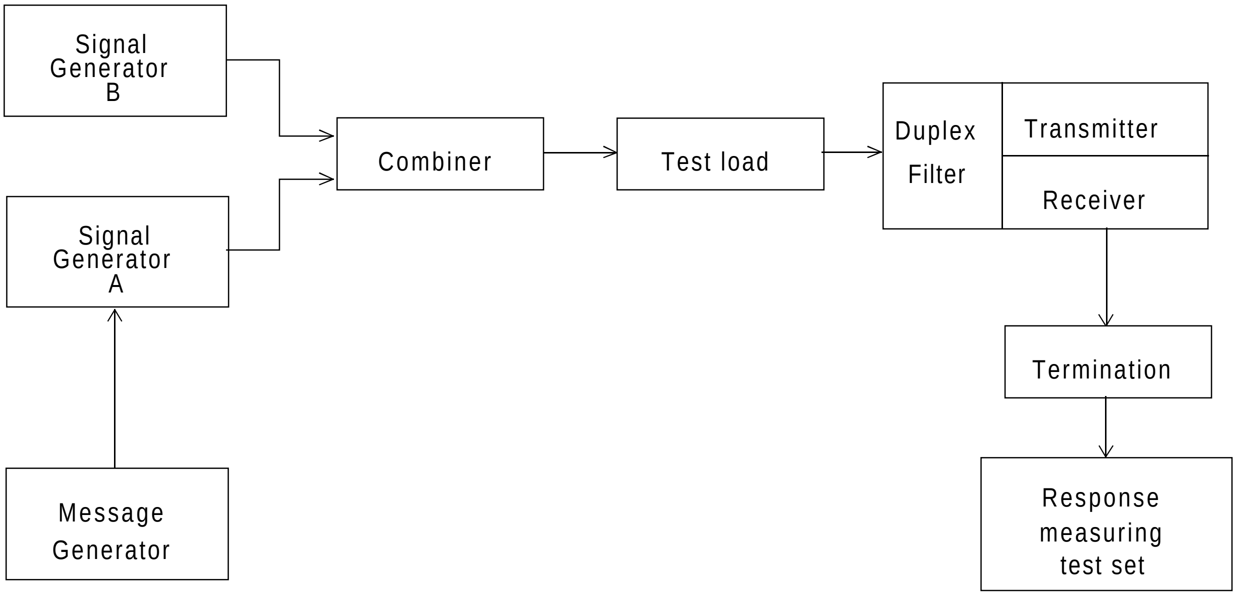


Figure 46: Spurious response rejection configuration with duplex filter (messages)

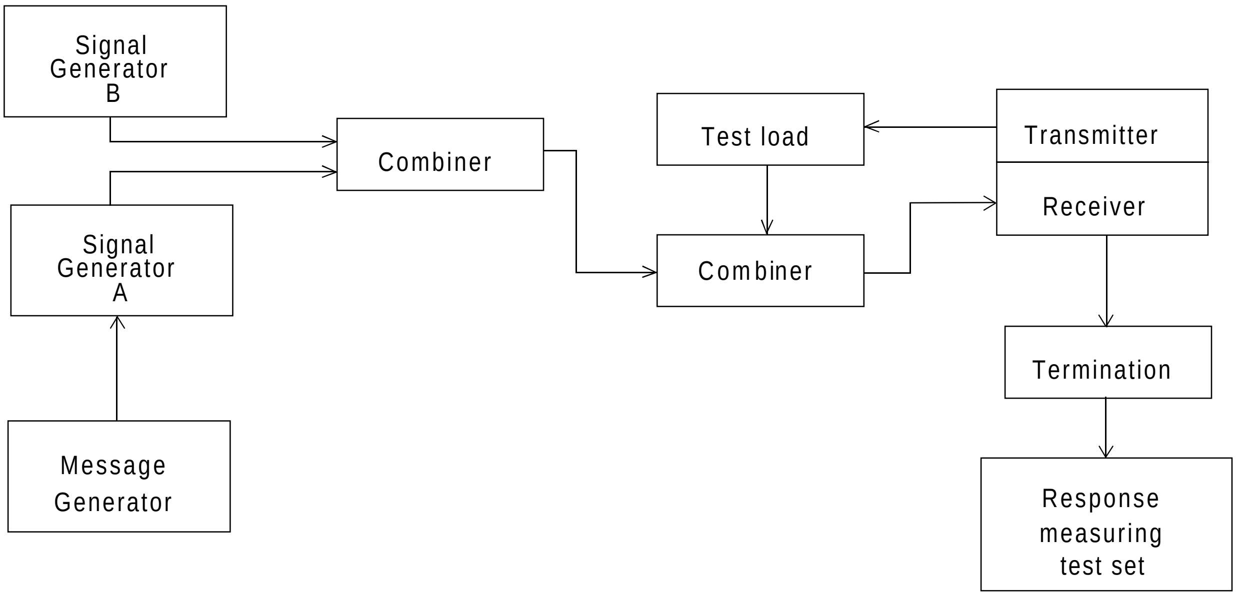


Figure 47: Spurious response rejection configuration without duplex filter (messages)

The radio under test is connected to two signal generators via a combining and attenuating network. The low frequency output of the receiver is connected to a suitable termination and a SINAD meter via a psophometric filter. The result is the signal level of the unwanted signal generator. Both signal generator levels are corrected for combining network attenuation and mismatch loss.

Measurement uncertainty:

The errors contributing to the total measurement uncertainty are the same as the example in subclause 6.2.3 with one additional error: the power behaviour of the matching network.

Uncertainty caused by power influence on matching network, (at a carrier power of 25 W):
0,001 dB/dB_{Att} x W (10 dB attenuator, 25 W):

0,001 x 25 x 10 dB = ± 0,25 dB = + 2,92/- 2,84 % (r)

Total uncertainty for in band measurements:

Standard deviation taken from example in subclause 7.3.1.2 = + 15,0/- 13,7 % (σ)

$$\sigma_{t+} = \sqrt{\frac{(15{,}0\ \%)^2 + (2{,}92\ \%)^2}{3}} = \quad 15{,}1\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{\frac{(13{,}7\ \%)^2 + (2{,}84\ \%)^2}{3}} = \quad 13{,}8\ \%\ (\sigma)$$

U_{95} = + 1,96 x 15,1 %/- 1,96 x 13,8 % = + 29,6 %/- 27,0 % = + 2,3 dB/- 2,7 dB

Total uncertainty for out of band measurements:

Standard deviation taken from example in subclause 6.2.3 = + 15,9/- 14,5 % (σ)

$$\sigma_{t+} = \sqrt{\frac{(15{,}9\ \%)^2 + (2{,}92\ \%)^2}{3}} = \quad 16{,}0\ \%\ (\sigma)$$

$$\sigma_{t-} = \sqrt{\frac{(14{,}5\ \%)^2 + (2{,}84\ \%)^2}{3}} = \quad 14{,}6\ \%\ (\sigma)$$

U_{95} = + 1,96 x 16,0 %/- 1,96 x 14,6 % = + 31,3 %/- 28,6 % = + 2,4 dB/- 2,9 dB

Annex A: Maximum accumulated measurement uncertainty

The accumulated measurement uncertainties of the test system in use for the parameters to be measured should not exceed those given in table A.1. This is in order to ensure that the measurements remain within an acceptable quality.

Table A.1: Recommended maximum acceptable uncertainties

RF frequency (1)	$\pm 1 \times 10^{-7}$ (2)
RF power (valid to 100 W) (1)	± 0,75 dB (2)
Maximum frequency deviation	
- within 300 Hz and 6 kHz of audio frequency (1)	± 5 % (2)
- within 6 kHz and 25 kHz of audio frequency (1)	± 3 dB (2)
Deviation limitation (1)	± 5 % (2)
Audio frequency response of transmitters (1)	± 0,5 dB (2)
Adjacent channel power (1)	± 3 dB (2)
Conducted emissions of transmitters (1)	± 4 dB (2)
Transmitter distortion (1)	± 2 % (2)
Transmitter residual modulation (1)	± 2 dB (2)
Audio output power (1)	± 0,5 dB (2)
Audio frequency response of receivers (1)	± 1 dB (2)
Amplitude characteristics of receiver limiter (1)	± 1,5 dB (2)
Hum and noise (1)	± 2 dB (2)
Receiver distortion (1)	± 2 % (2)
Sensitivity (1)	± 3 dB (2)
Conducted emissions of receivers (1)	± 4 dB (2)
Two-signal measurements (stop band) (1)	± 4 dB (2)
Three-signal measurements (1)	± 3 dB (2)
Radiated emissions of transmitters (1)	± 6 dB (2)
Radiated emissions of receivers (1)	± 6 dB (2)
Transmitter attack and release time (1)	± 4 ms (2)
Transmitter transient frequency (1)	± 250 Hz (2)
Transmitter intermodulation (1)	± 5 dB (2)
Receiver desensitization (duplex operation) (1)	± 0,5 dB (2)

NOTE 1: Test methods according to relevant ETSs.

NOTE 2: The uncertainty figures are valid for a confidence level of 95 %.

Annex B: Interpretation of the measurement results

The interpretation of the results recorded in a test report for the measurements described in the standard should be as follows:

1) the measurement value related to the corresponding limit should be used to decide whether an equipment meets the requirements of the relevant standards;

2) the measurement uncertainty value for the measurement of each parameter should be included in the test reports;

3) the recorded value for the measurement uncertainty should be, for each measurement, equal to or lower than the figures in the appropriate table of "maximum acceptable measurement uncertainties" of the appropriate ETS.

   NOTE: This procedure is recommended until superseded by other appropriate publications of ETSI.

Annex C: Influence quantity dependency functions

Table C.1 is a list of influence quantity dependency functions and uncertainties that are dependant on the equipment under test only. They are nevertheless necessary for the calculation of the absolute measurement uncertainty.

The table contains three types of parameters:

- reflection coefficients for the calculation of mismatch uncertainty;
- dependency factors for the conversion from influence quantity uncertainty to uncertainty related to the measurand;
- additional uncertainty caused by influence quantities.

The test laboratory making the measurements may, by means of additional measurements, estimate its own influence quantity dependencies, but if this is not carried out the values stated in table C.1 should be used.

Table C.1 is based on measurements on a variety of equipment types. Each dependency is expressed as a mean value with a standard deviation reflecting the variation from one EUT to another. Some dependencies related to the general test conditions (supply voltage, ambient temperature, etc.) theoretically influence the results of all the measurements, but in some of the measurements they are so small that they are considered to be negligible.

The table is divided into sub tables relating to each measurement example of Clause 6. The corresponding subclause numbers are shown in brackets.

Table C.1: EUT-dependency functions and uncertainties

	Mean	Standard deviation
Frequency error (see subclause 6.1)		
Temperature dependency	0,02	0,01 ppm/°C
Carrier power (see subclause 6.3)		
Reflection coefficient	0,5	0,2
Temperature dependency	4,0 %	1,2 %/°C
Time-duty cycle error	0	2 % (p)
Supply voltage dependency	10	3 % (p)/V
Frequency deviation (see subclause 6.3)		
Temperature dependency	0,02	0,01 ppm/°C
Adjacent channel power (see subclause 6.4)		
Deviation dependency	0,05	0,02 % (p)/Hz
Filter position dependency	15	4 dB/kHz
Time-duty cycle error	0	2 % (p)
Conducted spurious emissions (see subclause 6.5)		
Reflection coefficient	0,7	0,1
Time-duty cycle error	0	2 % (p)
Supply voltage dependency	10	3 % (p)/V
Intermodulation attenuation (see subclause 6.7)		
Reflection coefficient	0,5	0,2
Time-duty cycle error	0	2 % (p)
Supply voltage dependency	10	3 % (p)/V
Transmitter attack/release time (see subclause 6.8)		
Time/frequency error gradient	1,0	0,3 ms/kHz
Time/power level gradient	0,3	0,1 ms/%

(continued)

Table C.1: EUT-dependency functions and uncertainties (concluded)

Maximum usable sensitivity (see subclause 7.1)		
Reflection coefficient	0,2	0,05
Temperature dependency	2,5	1,2 %/°C
Noise gradient (below the knee point)	0,375	0,075 % level/% SINAD
Noise gradient (above the knee point)	1,0	0,2 % level/% SINAD
Noise gradient (direct carrier modulation)	1,0	0,2 % level/% SINAD
Amplitude characteristic (see subclause 7.2)		
Reflection coefficient	0,2	0,05
RF level dependency	0,05	0,02 %/% level
Two signal measurements (see subclause 7.3)		
Reflection coefficient (in band)	0,2	0,05
Reflection coefficient (out of band)	0,8	0,1
Noise gradient	0,7	0,2 % level/% SINAD
Deviation dependency	0,05	0,02 %/Hz
Absolute RF level dependency	0,5	0,2 %/% level
Intermodulation response (see subclause 7.4)		
Reflection coefficient	0,2	0,05
Noise gradient (unwanted signal)	0,5	0,1 % level/% SINAD
Deviation dependency	0,05	0,02 %/Hz
Capture ratio dependency	0,1	0,03 %/% level
Conducted spurious emission (see subclause 7.5)		
Reflection coefficient	0,7	0,1
Supply voltage dependency	10	3 %/V
Maximum usable sensitivity (see subclause 8.1)		
Reflection coefficient	0,2	0,05
Temperature dependency	2,5	1,2 %/°C
Noise gradient (below the knee point)	0,375	0,075 % level/% SINAD
Noise gradient (above the knee point)	1,0	0,2 % level/% SINAD
Noise gradient (direct carrier modulation)	1,0	0,2 % level/% SINAD
Spurious response rejection (see subclause 8.2)		
Reflection coefficient (pass band)	0,2	0,05
Reflection coefficient (stop band)	0,8	0,1
Noise gradient	0,7	0,2 % level/% SINAD
Deviation dependency	0,05	0,02 %/Hz
Absolute RF level dependency	0,5	0,2 %/% level

Annex D: Bibliography

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History

Document history	
March 1992	First Edition
March 1994	Second Edition
March 1997	Converted into Adobe Acrobat Portable Document Format (PDF)