ETSI TR 102 273-1-2 V1.2.1 (2001-12)

Technical Report

Electromagnetic compatibility and Radio spectrum Matters (ERM); Improvement on Radiated Methods of Measurement (using test site) and evaluation of the corresponding measurement uncertainties; Part 1: Uncertainties in the measurement of mobile radio equipment characteristics; Sub-part 2: Examples and annexes

Reference

RTR/ERM-RP02-057-1-2

Keywords

analogue, data, measurement uncertainty,
mobile, radio, testing

ETSI

650 Route des Lucioles
F-06921 Sophia Antipolis Cedex - FRANCE

Tel.: +33 4 92 94 42 00 Fax: +33 4 93 65 47 16

Siret N° 348 623 562 00017 - NAF 742 C
Association à but non lucratif enregistrée à la
Sous-Préfecture de Grasse (06) N° 7803/88

Important notice

Copyright Notification

Contents

Intellectual Property Rights

IPRs essential or potentially essential to the present document may have been declared to ETSI. The information pertaining to these essential IPRs, if any, is publicly available for **ETSI members and non-members**, and can be found in ETSI SR 000 314: *"Intellectual Property Rights (IPRs); Essential, or potentially Essential, IPRs notified to ETSI in respect of ETSI standards"*, which is available from the ETSI Secretariat. Latest updates are available on the ETSI Web server (http://webapp.etsi.org/IPR/home.asp).

Pursuant to the ETSI IPR Policy, no investigation, including IPR searches, has been carried out by ETSI. No guarantee can be given as to the existence of other IPRs not referenced in ETSI SR 000 314 (or the updates on the ETSI Web server) which are, or may be, or may become, essential to the present document.

Foreword

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

The present document is part 1, sub-part 2 of a multi-part deliverable covering Improvement on radiated methods of measurement (using test site) and evaluation of the corresponding measurement uncertainties, as identified below:

Part 1: "Uncertainties in the measurement of mobile radio equipment characteristics";

Sub-part 1: "Introduction";

Sub-part 2: "Examples and annexes";

Part 2: "Anechoic chamber";

Part 3: "Anechoic chamber with a ground plane";

Part 4: "Open area test site";

Part 5: "Striplines";

Part 6: "Test fixtures";

Part 7: "Artificial human beings".

1 Scope

The present document provides background to the subject of measurement uncertainty and proposes extensions and improvements relevant to radiated measurements. It also details the methods of radiated measurements (test methods for mobile radio equipment parameters and verification procedures for test sites) and additionally provides the methods for evaluating the associated measurement uncertainties.

The present document provides a method to be used together with all the applicable standards and (E)TRs, supports TR 100 027 [4] and can be used with TR 100 028 [5].

The present document acts as a complement to part 1 subpart 1, including examples and annexes.

2 References

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

[1] ITU-T Recommendation O.41 (1994): "Psophometer for use on telephone-type circuits".

[2] ITU-T Recommendation O.153 (1992): "Basic parameters for the measurement of error performance at bit rates below the primary rate".

[3] EN 55020: "Electromagnetic immunity of broadcast receivers and associated equipment".

[4] ETSI TR 100 027: "ElectroMagnetic Compatibility and Radio Spectrum Matters (ERM); Methods of measurement for private mobile radio equipment".

[5] ETSI TR 100 028 (V1.4.1) (parts 1 and 2): "Electromagnetic compatibility and Radio spectrum Matters (ERM); Uncertainties in the measurement of mobile radio equipment characteristics".

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

[7] "Guide to the Expression of Uncertainty in Measurement" (International Organization for Standardization, Geneva, Switzerland, 1995).

3 Definitions, symbols and abbreviations

3.1 Definitions

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

accuracy: this term is defined, in relation to the measured value, in clause 4.1.1; it has also been used in the remainder of the document in relation to instruments

Audio Frequency (**AF**) **load:** normally a resistor of sufficient power rating to accept the maximum audio output power from the EUT. The value of the resistor is normally that stated by the manufacturer and is normally the impedance of the audio transducer at 1 000 Hz

NOTE: In some cases it may be necessary to place an isolating transformer between the output terminals of the receiver under test and the load.

AF termination: any connection other than the audio frequency load which may be required for the purpose of testing the receiver (i.e. in a case where it is required that the bit stream be measured, the connection may be made, via a suitable interface, to the discriminator of the receiver under test)

NOTE: The termination device is normally agreed between the manufacturer and the testing authority and details included in the test report. If special equipment is required then it is normally provided by the manufacturer.

A-M1: test modulation consisting of a 1 000 Hz tone at a level which produces a deviation of 12 % of the channel separation

A-M2: test modulation consisting of a 1 250 Hz tone at a level which produces a deviation of 12 % of the channel separation

A-M3: test modulation consisting of a 400 Hz tone at a level which produces a deviation of 12 % of the channel separation. This signal is used as an unwanted signal for analogue and digital measurements

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

antenna factor: quantity relating the strength of the field in which the antenna is immersed to the output voltage across the load connected to the antenna. When properly applied to the meter reading of the measuring instrument, yields the electric field strength in V/m or the magnetic field strength in clause A/m

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

bit error ratio: the ratio of the number of bits in error to the total number of bits

combining network: network allowing the addition of two or more test signals produced by different sources (e.g. for connection to a receiver input)

NOTE: Sources of test signals are normally connected in such a way that the impedance presented to the receiver is 50 Ω. Combining networks are designed so that effects of any intermodulation products and noise produced in the signal generators are negligible.

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

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

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

DM-0: test modulation consisting of a signal representing an infinite series of "0" bits

DM-1: test modulation consisting of a signal representing an infinite series of "1" bits

DM-2: test modulation consisting of a signal representing a pseudorandom bit sequence of at least 511 bits in accordance with ITU-T Recommendation O.153

D-M3: test signal agreed between the testing authority and the manufacturer in the cases where it is not possible to measure a bit stream or if selective messages are used and are generated or decoded within an equipment

NOTE: The agreed test signal may be formatted and may contain error detection and correction. Details of the test signal are be supplied in the test report.

duplex filter: device fitted internally or externally to a transmitter/receiver combination to allow simultaneous transmission and reception with a single antenna connection.

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

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

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

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

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

A practical form of this formula is:

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

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

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

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

The mathematical definition of the expansion factor can be found in clause D.5.6.2.2 of TR 100 028-2 [5].

extreme test conditions: conditions defined in terms of temperature and supply voltage. Tests are normally made with the extremes of temperature and voltage applied simultaneously. The upper and lower temperature limits are specified in the relevant testing standard. The test report states the actual temperatures measured

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

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

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

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

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

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

intermittent operation: operation where the manufacturer states the maximum time that the equipment is intended to transmit and the necessary standby period before repeating a transmit period

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

limited frequency range: the limited frequency range is a specified smaller frequency range within the full frequency range over which the measurement is made

NOTE: The details of the calculation of the limited frequency range are normally given in the relevant testing standard.

maximum permissible frequency deviation: the maximum value of frequency deviation stated for the relevant channel separation in the relevant testing standard

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

measurement repeatability: 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.

measurement reproducibility: 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.

measurand: quantity subjected to measurement

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

nominal frequency: one of the channel frequencies on which the equipment is designed to operate

nominal mains voltage: the declared voltage or any of the declared voltages for which the equipment was designed

normal test conditions: the conditions defined in terms of temperature, humidity and supply voltage stated in the relevant testing standard

normal deviation: the frequency deviation for analogue signals which is equal to 12 % of the channel separation

psophometric weighting network: as described in ITU-T Recommendation O.41

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

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

rated audio output power: the maximum audio output power under normal test conditions, and at standard test modulations, as declared by the manufacturer

rated radio frequency output power: the maximum carrier power under normal test conditions, as declared by the manufacturer

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

SINAD sensitivity: the minimum standard modulated carrier-signal input required to produce a specified SINAD ratio at the receiver output

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

test load: the test load is a 50 Ω substantially non-reactive, non-radiating power attenuator which is capable of safely dissipating the power from the transmitter

test modulation: the test modulating signal is a baseband signal which modulates a carrier and is dependent upon the type of EUT and also the measurement to be performed

trigger device: circuit or mechanism to trigger the oscilloscope timebase at the required instant. It may control the transmit function or inversely receive an appropriate command from the transmitter

uncertainty (random): component of the uncertainty of measurement which, in the course of a number of measurements of the same measurand, varies in an unpredictable way (to be considered as a component for the calculation of the combined uncertainty when the effects it corresponds to have not been taken into consideration otherwise)

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

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

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

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

It is the standard deviation of the corresponding distribution.

uncertainty (combined standard): the combined standard uncertainty is calculated by combining appropriately the standard uncertainties for each of the individual contributions identified in the measurement considered or in the part of it, which has been considered

NOTE: In the case of additive components (linearly combined components where all the corresponding coefficients **are equal to one**) and when all these contributions are independent of each other (stochastic), this combination is calculated by using the Root of the Sum of the Squares (the RSS method). A more complete methodology for the calculation of the combined standard uncertainty is given in annex D, see in particular clause D.3.12, TR 100 028-2 [5].

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

The combined standard uncertainty is multiplied by a constant to obtain the expanded uncertainty limits (see clause 5.3 of TR 100 028-1 [5], and also clause D.5 (and more specifically clause D.5.6.2) of TR 100 028-2 [5]).

upper specified AF limit: the maximum audio frequency of the audio pass-band. It is dependent on the channel separation

wanted signal level: for conducted measurements a level of +6 dBμV emf referred to the receiver input under normal test conditions. Under *extreme test conditions* the value is +12 dBμV emf

NOTE: For analogue measurements the wanted signal level has been chosen to be equal to the limit value of the measured usable sensitivity. For bit stream and message measurements the wanted signal has been chosen to be +3 dB above the limit value of measured usable sensitivity.

3.2 Symbols

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

β	$2\pi/\lambda$ (radians/m)
γ	incidence angle with ground plane (°)
λ	wavelength (m)
ϕ_H	phase angle of reflection coefficient (°)
η	120π Ohms - the intrinsic impedance of free space (Ω)
μ	permeability (H/m)

AF_R	antenna factor of the receive antenna (dB/m)
AF_T	antenna factor of the transmit antenna (dB/m)
AF_{TOT}	mutual coupling correction factor (dB)
c	calculated on the basis of given and measured data
C_{cross}	cross correlation coefficient
d	derived from a measuring equipment specification
$D(\theta,\phi)$	directivity of the source
d	distance between dipoles (m)
δ	skin depth (m)
d_1	an antenna or EUT aperture size (m)
d_2	an antenna or EUT aperture size (m)
d_{dir}	path length of the direct signal (m)
d_{refl}	path length of the reflected signal (m)
E	electric field intensity (V/m)
E_{DH}^{max}	calculated maximum electric field strength in the receiving antenna height scan from a half wavelength dipole with 1 pW of radiated power (for horizontal polarization) (µV/m)
E_{DV}^{max}	calculated maximum electric field strength in the receiving antenna height scan from a half wavelength dipole with 1 pW of radiated power (for vertical polarization) (µV/m)
e_{ff}	antenna efficiency factor
ϕ	angle (°)
Δf	bandwidth (Hz)
f	frequency (Hz)
$G(\theta,\phi)$	gain of the source (which is the source directivity multiplied by the antenna efficiency factor)
H	magnetic field intensity (A/m)
I_0	the (assumed constant) current (A)
I_m	the maximum current amplitude
k	$2\pi/\lambda$
k	a factor from Student's t distribution
k	Boltzmann's constant (1,38 x 10-23 Joules/Kelvin)
K	relative dielectric constant
l	the length of the infinitesimal dipole (m)
L	the overall length of the dipole (m)
l	the point on the dipole being considered (m)
m	measured
p	power
$Pe_{(n)}$	probability of error n
$Pp_{(n)}$	probability of position n
P_r	antenna noise power (W)
P_{rec}	power received (W)
P_t	power transmitted (W)
θ	angle (°)
ρ	reflection coefficient
r	rectangular distribution
r	the distance to the field point (m)
ρ_g	reflection coefficient of the generator part of a connection
ρ_l	reflection coefficient of the load part of the connection
R_s	equivalent surface resistance (Ω)
σ	conductivity (S/m)
σ	standard deviation
SNR_{b*}	Signal to Noise Ratio at a specific BER
SNR_b	Signal to Noise Ratio per bit
T_A	antenna temperature (Kelvin)
u	U-distribution
U	the expanded uncertainty corresponding to a confidence level of x %: $U = k \times u_c$
u_c	the combined standard uncertainty

u_i	general type A standard uncertainty
u_{i01}	random uncertainty
u_j	general type B uncertainty
u_{j01}	reflectivity of absorbing material: EUT to the test antenna
u_{j02}	reflectivity of absorbing material: substitution or measuring antenna to the test antenna
u_{j03}	reflectivity of absorbing material: transmitting antenna to the receiving antenna
u_{j04}	mutual coupling: EUT to its images in the absorbing material
u_{j05}	mutual coupling: de-tuning effect of the absorbing material on the EUT
u_{j06}	mutual coupling: substitution, measuring or test antenna to its image in the absorbing material
u_{j07}	mutual coupling: transmitting or receiving antenna to its image in the absorbing material
u_{j08}	mutual coupling: amplitude effect of the test antenna on the EUT
u_{j09}	mutual coupling: de-tuning effect of the test antenna on the EUT
u_{j10}	mutual coupling: transmitting antenna to the receiving antenna
u_{j11}	mutual coupling: substitution or measuring antenna to the test antenna
u_{j12}	mutual coupling: interpolation of mutual coupling and mismatch loss correction factors
u_{j13}	mutual coupling: EUT to its image in the ground plane
u_{j14}	mutual coupling: substitution, measuring or test antenna to its image in the ground plane
u_{j15}	mutual coupling: transmitting or receiving antenna to its image in the ground plane
u_{j16}	range length
u_{j17}	correction: off boresight angle in the elevation plane
u_{j18}	correction: measurement distance
u_{j19}	cable factor
u_{j20}	position of the phase centre: within the EUT volume
u_{j21}	positioning of the phase centre: within the EUT over the axis of rotation of the turntable
u_{j22}	position of the phase centre: measuring, substitution, receiving, transmitting or test antenna
u_{j23}	position of the phase centre: LPDA
u_{j24}	Stripline: mutual coupling of the EUT to its images in the plates
u_{j25}	Stripline: mutual coupling of the three-axis probe to its image in the plates
u_{j26}	Stripline: characteristic impedance
u_{j27}	Stripline: non-planar nature of the field distribution
u_{j28}	Stripline: field strength measurement as determined by the three-axis probe
u_{j29}	Stripline: transform Factor
u_{j30}	Stripline: interpolation of values for the transform factor
u_{j31}	Stripline: antenna factor of the monopole
u_{j32}	Stripline: correction factor for the size of the EUT
u_{j33}	Stripline: influence of site effects
u_{j34}	ambient effect
u_{j35}	mismatch: direct attenuation measurement
u_{j36}	mismatch: transmitting part
u_{j37}	mismatch: receiving part
u_{j38}	signal generator: absolute output level
u_{j39}	signal generator: output level stability
u_{j40}	insertion loss: attenuator
u_{j41}	insertion loss: cable
u_{j42}	insertion loss: adapter
u_{j43}	insertion loss: antenna balun
u_{j44}	antenna: antenna factor of the transmitting, receiving or measuring antenna
u_{j45}	antenna: gain of the test or substitution antenna
u_{j46}	antenna: tuning
u_{j47}	receiving device: absolute level

u_{j48}	receiving device: linearity
u_{j49}	receiving device: power measuring receiver
u_{j50}	EUT: influence of the ambient temperature on the ERP of the carrier
u_{j51}	EUT: influence of the ambient temperature on the spurious emission level
u_{j52}	EUT: degradation measurement
u_{j53}	EUT: influence of setting the power supply on the ERP of the carrier
u_{j54}	EUT: influence of setting the power supply on the spurious emission level
u_{j55}	EUT: mutual coupling to the power leads
u_{j56}	frequency counter: absolute reading
u_{j57}	frequency counter: estimating the average reading
u_{j58}	salty man/salty-lite: human simulation
u_{j59}	salty man/salty-lite: field enhancement and de-tuning of the EUT
u_{j60}	test fixture: effect on the EUT
u_{j61}	test fixture: climatic facility effect on the EUT
V_{direct}	received voltage for cables connected via an adapter (dBμV/m)
V_{site}	received voltage for cables connected to the antennas (dBμV/m)
W_0	radiated power density (W/m^2)

3.3 Abbreviations

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

AF	Audio Frequency
BER	Bit Error Ratio
dB	decibel
emf	Electromotive force
ERP	Effective Radiated Power
EUT	Equipment Under Test
LPDA	Log Periodic Dipole Antenna
NSA	Normalized Site Attenuation
RF	Radio Frequency
RSS	Root-Sum-of Squares
SINAD	Signal Noise And Distortion
TEM	Transverse ElectroMagnetic
VSWR	Voltage Standing Wave Ratio

4 Examples of measurement uncertainty analysis (free field test sites)

4.1 Introduction

This clause contains detailed worked examples of the calculation of expanded uncertainty of the radiated tests on free field test sites i.e. Anechoic Chambers, Anechoic Chambers with Ground Planes and Open Area Test Sites.

The example tests given are limited to:

- a verification procedure;
- the measurement of a transmitter parameter (spurious emission);
- the measurement of a receiver parameter (sensitivity).

All the example tests are assumed to have been carried out in an Anechoic Chamber with a Ground Plane since this type of test site will contribute virtually all the uncertainty contributions involved in radiated tests on any free field test site (i.e. all uncertainties associated with absorbing materials and ground planes).

NOTE 1: The values given to the uncertainty components in these examples are only to illustrate the uncertainty calculations. In practice, values should be derived by consulting annex A.

All radiated tests consist of two stages. For a verification procedure, the first stage is to set a reference level whilst the second stage involves the measurement of path loss between two antennas. For the measurement of a particular parameter from an EUT, the first stage is usually to measure the relevant parameter whilst the second stage compares this measurement against that from a known standard.

Within any radiated test there are uncertainty components that are common to both stages of the test. By their different natures some of these common uncertainties will cancel (e.g. the uncertainty of the insertion loss of a cable common to both parts) whilst others may contribute twice (e.g. the level stability of a signal generator in receiver tests). In each of the following uncertainty analyses, uncertainty components common to both stages are shown as shaded areas in the accompanying schematic diagrams.

As shown in the examples, all the individual uncertainty components for any test are combined in the manner described in TR 102 273-1-1 [6], clauses 4 and 5 in order to derive an expanded uncertainty figure for the measurement. The values of the individual components are either provided in annex A or should be taken from manufacturer's data sheets. Whenever they are obtained from data sheets, worst case figures given over a frequency band should be used. For example, in the case of a signal generator whose absolute level accuracy is quoted as ±1 dB over 30 MHz to 300 MHz, ±2 dB over 300 MHz to 1 000 MHz the figure for the band containing the test frequency should be used. This approach should be adopted for all uncertainty components, taking the uncertainty figures over as broad a band a possible. This is normally satisfactory when the variation with frequency is not large and provides a simple and flexible approach. The resulting expanded uncertainty figure is valid across a broad range of frequencies and measurement conditions and avoids the necessity of repeated calculation for minor frequency changes.

NOTE 2: Taking specific frequency values may result in a lower expanded uncertainty value, but this lower value is only valid when that specific set of circumstances apply for which the value was derived.

4.2 Example 1: Verification procedure

The verification procedure is a process carried out to prove a facility's suitability as a free field test site. It involves the transmission of a known signal level from one calibrated antenna (usually a dipole) and the measurement of the received signal level in a second calibrated antenna (also usually a dipole). By comparison of the transmitted and received signal levels, an 'insertion loss' can be deduced.

For the measurement of NSA two stages are involved. The first is a direct attenuation measurement (V_{direct}) whilst the second is a radiated attenuation measurement (V_{site}). After inclusion of any correction factors relevant to the measurement, the figure of loss which results from the verification procedure is known as 'site attenuation'.

NSA is determined from the value of site attenuation by subtraction of the antenna factors and mutual coupling effects. The subtraction of the antenna factors and any mutual coupling effects makes NSA independent of antenna type.

Symbolically,

$\mathrm{NSA} = \mathrm{V_{direct}} - \mathrm{V_{site}} - \mathrm{AF_T} - \mathrm{AF_R} - \mathrm{AF_{TOT}}$

where:

V_{direct} = received voltage using the "in-line" adapter;

V_{site} = received voltage using the antennas;

AF_T = antenna factor of the transmitting antenna;

AF_R = antenna factor of the receiving antenna;

AF_{TOT} = mutual coupling correction factor.

The verification procedure measures both V_{direct} and V_{site} and then (after relevant corrections and calculations) compares the measured value of NSA against the theoretical figure calculated for that particular type of facility. The difference between the two values at any specific frequency is a measure of the quality of the facility at that frequency.

4.2.1 Uncertainty contributions: stage 1: direct attenuation measurement

The first stage of the verification procedure is the direct attenuation measurement. This is carried out with all the items of test equipment connected directly together via an "in line" adapter between the attenuators as shown in figure 1. The components shown shaded are common to both stages of the procedure.

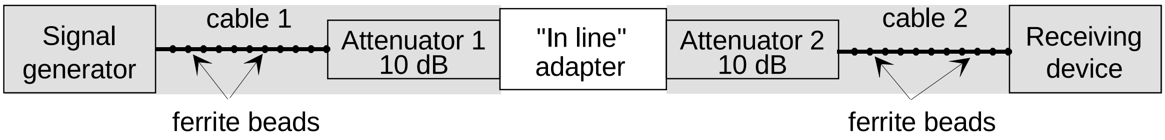


Figure 1: Stage 1: direct attenuation measurement

Despite the commonality of most of the components to both stages of this procedure, the mismatch uncertainty contribution for both stages has to be calculated and included in the uncertainty calculations. This is a result of load conditions varying (i.e. antennas replacing the adapter in the second stage). Conversely, as a result of this commonality, the uncertainty contributions of some of the individual components will cancel.

Whereas figure 1 shows, schematically, the test equipment set-up for this stage of the verification procedure, an analysis diagram of the individual components (each of which contributes its own uncertainty) for this stage of the measurement is shown in figure 2. Again, as stated above, the shaded areas represent components common to both stages of the verification procedure.

4.2.1.1 Contributions from the mismatch components

Mismatch: direct attenuation measurement: The value of the combined standard uncertainty of the contribution due to the mismatch from the source to the receptor, i.e. between the signal generator and the receiving device, is calculated from the approach described in annex D. All the individual contributions are U-distributed.

NOTE 1: In this example the value taken for the signal generator output reflection coefficient is the worst case value over the frequency band of interest. Similarly for the cable, adapter and attenuator VSWRs.

NOTE 2: The attenuation values of the cables and attenuators should be obtained from the data sheets/calibration records at the specific frequency of the test, along with the associated uncertainties for these values.

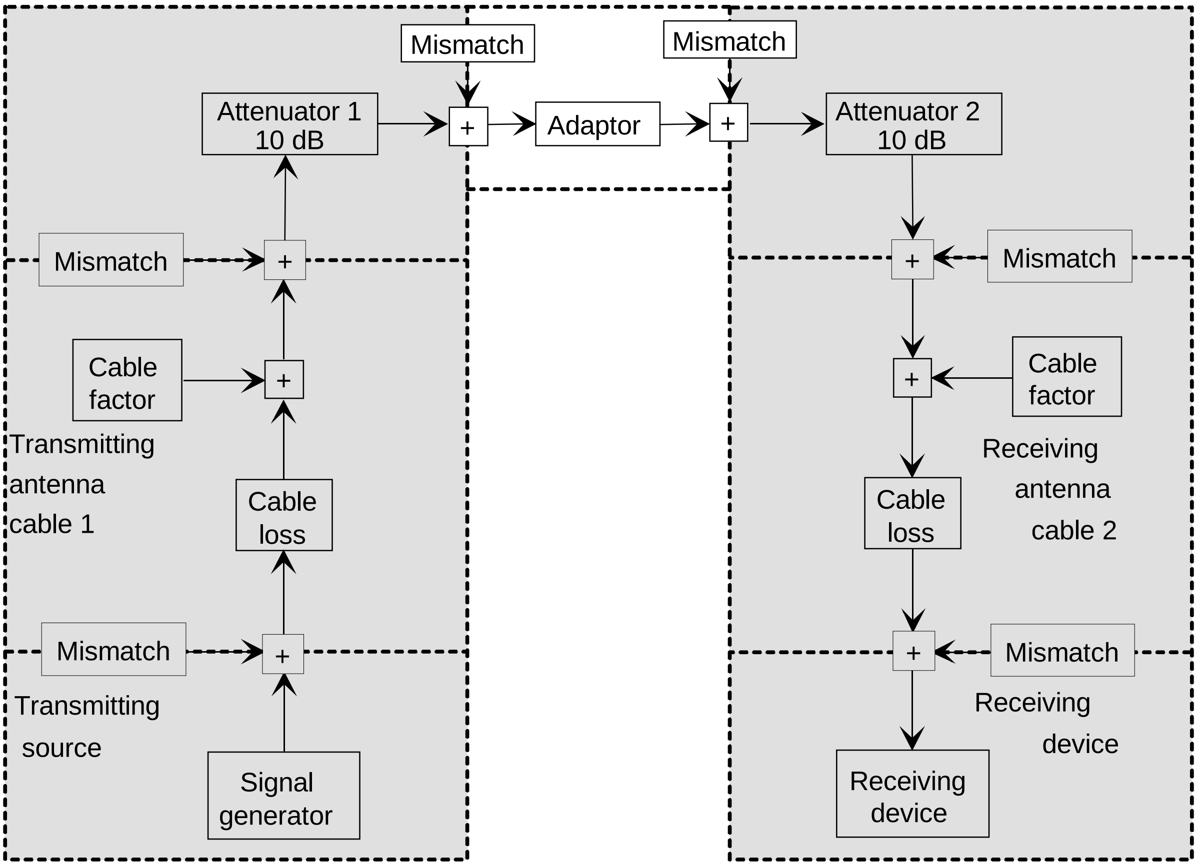


Figure 2: Stage 1: direct attenuation measurement individual uncertainty components

Signal generator:	Output reflection coefficient: $\|\rho_G\|$	= 0,20
Cable:	Input and output reflection coefficients: $\|S_{11}\| = \|S_{22}\|$	= 0,07
	Attenuation: 1 dB = $\|S_{12}\| = \|S_{21}\|$	= 0,891
Attenuator:	Input and output reflection coefficients $\|S_{11}\| = \|S_{22}\|$	= 0,05
	Attenuation = 10 dB $\|S_{12}\| = \|S_{21}\|$	= 0,3162
Adapter:	Input and output reflection coefficients $\|S_{11}\| = \|S_{22}\|$	= 0,02
	Attenuation = 0,1 dB $\|S_{12}\| = \|S_{21}\|$	= 0,9886
Attenuator:	Input and output reflection coefficients $\|S_{11}\| = \|S_{22}\|$	= 0,05
	Attenuation = 10 dB $\|S_{12}\| = \|S_{21}\|$	= 0,3162
Cable:	Input and output reflection coefficients: $\|S_{11}\| = \|S_{22}\|$	= 0,07
	Attenuation: 1 dB = $\|S_{12}\| = \|S_{21}\|$	= 0,891
Receiving device:	Input reflection coefficient: $\|\rho_{RD}\|$	= 0,20

Mismatch uncertainty in the direct attenuation measurement: In the following the transmitting antenna cable is named cable 1, the transmitting antenna attenuator is named attenuator 1, the receiving antenna cable is named cable 2, the receiving attenuator is named attenuator 2. Those uncertainty components that are constant for both stages 1 and 2 are not calculated as they do not contribute to the overall uncertainty.

Mismatch between:

$u_{j \text{ generator and cable 1}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$u_{j \text{ cable 1 and attenuator 1}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$$u_{j\ mismatch: attenuator\ 1 and\ adapter} = \frac{0{,}05 \times 0{,}02 \times 100}{\sqrt{2}} \% = 0{,}071\ \%$$

$$u_{j\ mismatch: adapter\ and\ attenuator\ 2} = \frac{0{,}02 \times 0{,}05 \times 100}{\sqrt{2}} \% = 0{,}071\ \%$$

$u_{j \text{ attenuator 2 and cable 2}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$u_{j \text{ cable 2 and receiving device}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$u_{j \text{ generator and attenuator 1}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$$u_{j\ mismatch: cable\ 1 and\ adapter} = \frac{0{,}07 \times 0{,}07 \times 0{,}316^2 \times 100}{\sqrt{2}} \% = 0{,}035\ \%$$

$$u_{j\ mismatch: attenuator\ 1 and\ attenuator\ 2} = \frac{0{,}05 \times 0{,}05 \times 0{,}988^2 \times 100}{\sqrt{2}} \% = 0{,}173\ \%$$

$$u_{j\ mismatch: adapter\ and\ cable\ 2} = \frac{0{,}02 \times 0{,}07 \times 0{,}316^2 \times 100}{\sqrt{2}} \% = 0{,}010\ \%$$

$u_{j \text{ attenuator 2 and receiving device}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$$u_{j\ mismatch: generator\ and\ adapter} = \frac{0{,}2 \times 0{,}02 \times 0{,}891^2 \times 0{,}316^2 \times 100}{\sqrt{2}} \% = 0{,}022\ \%$$

$$u_{j\ mismatch: cable\ 1 and\ attenuator\ 2} = \frac{0{,}07 \times 0{,}05 \times 0{,}316^2 \times 0{,}988^2 \times 100}{\sqrt{2}} \% = 0{,}024\ \%$$

$$u_{j\ mismatch: attenuator\ 1 and\ cable\ 2} = \frac{0{,}05 \times 0{,}07 \times 0{,}988^2 \times 0{,}316^2 \times 100}{\sqrt{2}} \% = 0{,}024\ \%$$

$$u_{j\ mismatch: adapter\ and\ receiving\ device} = \frac{0{,}02 \times 0{,}2 \times 0{,}316^2 \times 0{,}891^2 \times 100}{\sqrt{2}} \% = 0{,}022\ \%$$

$$u_{j\ mismatch: generator\ and\ attenuator\ 2} = \frac{0{,}2 \times 0{,}05 \times 0{,}891^2 \times 0{,}316^2 \times 0{,}988^2 \times 100}{\sqrt{2}} \% = 0{,}055\ \%$$

$u_{j \text{ mismatch: cable 1 and cable 2}}$: Less than 0,01 % due to the two attenuators, therefore neglected.

$$u_{j\ mismatch: attenuator\ 1 and\ receiving\ device} = \frac{0{,}05 \times 0{,}2 \times 0{,}988^2 \times 0{,}316^2 \times 0{,}891^2 \times 100}{\sqrt{2}} \% = 0{,}055\ \%$$

$u_{j \text{ mismatch: generator and cable 2}}$: Less than 0,01 % due to the two attenuators, therefore neglected.

$u_{j \text{ mismatch: cable 1 and receiving device}}$: Less than 0,01 % due to the two attenuators, therefore neglected.

$u_{j \text{ mismatch: generator and receiving device}}$: Less than 0,01 % due to the two attenuators, therefore neglected.

The combined standard uncertainty of the mismatch is then calculated:

$$u_{c\,mismatch:direct\,att.} = \sqrt{0{,}071^2 + 0{,}071^2 + \ldots + 0{,}055^2 + 0{,}055^2} = 0{,}306\ \%$$

transforming to logarithmic form (see annex C): 0,306 %/11,5 = 0,026 dB

The standard uncertainty of the contribution, due to the mismatch in the direct attenuation measurement, is designated throughout all parts of the present document as u_{j35}. Its value in this example is 0,026 dB.

4.2.1.2 Contributions from individual components

4.2.1.2.1 Signal generator

Signal generator: absolute output level: In a verification procedure, the signal generator's absolute level uncertainty contributes equally to both stages of the measurement. The standard uncertainty of the contribution due to the signal generator absolute output level uncertainty is designated throughout all parts of the present document as u_{j38}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the signal generator absolute output level uncertainty is taken to be 0,00 dB since, once the level has been set in stage one of the procedure, the level is not further adjusted. The uncertainty is therefore assumed to be systematic i.e. it produces the same offset in both stages.

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

NOTE 2: In this example case the uncertainty of the contribution due to the signal generator output level stability is obtained from the manufacturer's data sheet as ±0,02 dB. As nothing is said about the distribution of this uncertainty, a rectangular distribution (see TR 102 273-1-1 [6], clause 5.1.2) in logs is assumed, and the standard uncertainty is calculated as 0,01155 dB. This is rounded down to 0,01 dB.

4.2.1.2.2 Transmitting antenna cable

Insertion loss: transmitting antenna cable: The transmitting antenna cable has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the cable is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution due to the insertion loss uncertainty of the transmitting antenna cable is designated throughout all parts of the present document as u_{j41}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the insertion loss uncertainty of the transmitting antenna cable is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

Cable factor: transmitting antenna: Cable factor is defined as the total effect of the antenna cable's influence on the measuring system including its interaction with the site. It consists of the leakage caused by cable screening inefficiency, parasitic effects on the transmitting antenna (acting as a director or reflector) and introducing an unbalanced, common mode current into the dipole balun. In a radiated measurement the standard uncertainty of the cable factor, associated with each cable, is 0,5 dB provided that the precautions detailed in the methods have been observed i.e. routing and dressing of cables with ferrites. If no prevention has been attempted the standard uncertainty is 4,0 dB (justification for these values is given in annex E). The standard uncertainty of the contribution due to the cable factor of the transmitting antenna cable is designated throughout all parts of the present document as u_{j19}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the cable factor of the transmitting antenna cable is taken as 0,00 dB since there are no external fields involved other than leakage, which is assumed to have a negligible effect on the measurement.

4.2.1.2.3 Transmitting antenna attenuator

Insertion loss: transmitting antenna attenuator: The transmitting antenna attenuator has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the attenuator is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution, due to the insertion loss uncertainty of the transmitting antenna attenuator, is designated throughout all parts of the present document as u_{j40}.

NOTE: In this example case the standard uncertainty of the contribution due to the insertion loss uncertainty of the transmitting antenna attenuator is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

4.2.1.2.4 Adapter

Insertion loss: adapter: The adapter has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the adapter is not used outside the manufacturer's specification. The standard uncertainty of the contribution due to the insertion loss uncertainty of the adapter is designated throughout all parts of the present document as u_{j42}. Its value can be derived from the manufacturer's data sheet.

NOTE: In this example case the uncertainty of the contribution due to the insertion loss uncertainty of the adapter is obtained from the manufacturer's data sheet as ±0,10 dB. As nothing is said about the distribution of this uncertainty, a rectangular distribution (see TR 102 273-1-1 [6], clause 5.1.2) in logs is assumed, and the standard uncertainty is calculated as 0,06 dB.

4.2.1.2.5 Receiving antenna attenuator

Insertion loss: receiving antenna attenuator: The attenuator has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the attenuator is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution due to the insertion loss uncertainty of the receiving antenna attenuator is designated throughout all parts of the present document as u_{j40}.

NOTE: In this example case the standard uncertainty of the contribution due to the insertion loss uncertainty of the receiving antenna attenuator is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

4.2.1.2.6 Receiving antenna cable

Insertion loss: receiving antenna cable: The receiving antenna cable has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the cable is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution, due to the insertion loss uncertainty of the receiving antenna cable, is designated throughout all parts of the present document as u_{j41}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the insertion loss uncertainty of the receiving antenna cable is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

Cable factor: receiving antenna cable: Cable factor is defined as the total effect of the antenna cable's influence on the measuring system including its interaction with the site. It consists of the leakage caused by cable screening inefficiency, parasitic effects on the receiving antenna (acting as a director or reflector) and introducing an unbalanced, common mode current into the dipole balun. In a radiated measurement the standard uncertainty of the cable factor, associated with each cable is 0,5 dB provided that the precautions detailed in the methods have been observed, i.e. routing and dressing of cables with ferrites. If no prevention has been attempted the standard uncertainty is 4,0 dB (justification for these values is given in annex E). The standard uncertainty of the contribution due to the cable factor of receiving antenna cable is designated throughout all parts of the present document as u_{j19}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the cable factor of the receiving antenna cable is taken as 0,00 dB since there are no external fields involved other than leakage, which is assumed to have a negligible effect on the measurement.

4.2.1.2.7 Receiving device

In this, the first stage of the verification procedure, a reference level is recorded from the receiving device for a particular output level from the signal generator. In the second stage (where the path loss between the two antennas is measured), a second level is recorded on the receiving device. Only in the second stage do the linearity and absolute level uncertainties of the receiver become involved in the calculation of the combined standard uncertainty of the measurement.

Receiving device: absolute level: The standard uncertainty of the contribution due to the absolute level uncertainty of the receiving device is designated throughout all parts of the present document as u_{j47}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the absolute level uncertainty of the receiving device is assumed to be 0,00 dB since, in this part of the measurement, a reference level is recorded.

Receiving device: linearity: The standard uncertainty of the contribution due to the receiving device linearity is designated throughout all parts of the present document as u_{j48}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the receiving device linearity is assumed to be 0,00 dB since, in this part of the measurement, a reference level is recorded.

4.2.1.3 Contribution from the random component

Random uncertainty: The magnitude can be assessed from multiple measurements of the direct attenuation measurement. The standard uncertainty of the contribution due to the random uncertainty is designated throughout all parts of the present document as u_{i01}. Its value can then be calculated. See also clause 5.5 and the note in clause 6.4.7 of TR 102 273-1-1, as well as note in clause A.18 of the present document.

The direct attenuation measurement was repeated ten times. The following results (dBμV) in were obtained (before correcting for cabling and attenuator network insertion loss):

106,8; 107,2; 106,7; 107,0; 107,2; 106,7; 107,1; 106,8; 107,1; 107,0.

Converting to linear terms (V).

0,218 8; 0,229 1; 0,216 3; 0,223 9; 0,229 1; 0,216 3; 0,226 5; 0,218 8; 0,226 5; 0,223 9.

The two sums X and Y are calculated:

X = the sum of the measured values = 2,229 2 V

Y = the sum of the squares of the measured values = 0,497 2 V^2

$$u_{c\ random} = \sqrt{\frac{Y - \frac{X^2}{n}}{n-1}} = \sqrt{\frac{0{,}4972 - \frac{2{,}2292^2}{10}}{10-1}} = 5{,}444 \times 10^{-3} \qquad \text{(formula 5.6)}$$

As the result is obtained as the mean value of ten measurements and the standard uncertainty of the random uncertainty is:

$$u_{j\ random} = \frac{5{,}444 \times 10^{-3}}{0{,}22292} \times \frac{100}{11{,}5} = 0{,}212 \text{ dB}$$

NOTE: In this example case the standard uncertainty of the contribution due to the random uncertainty is 0,212 dB.

4.2.1.4 Summary table of contributory components

The uncertainty contributions for stage 1 of the verification procedure are listed in table 1.

Table 1: Contributions from the direct attenuation measurement

$u_{j\ or\ i}$	Description of uncertainty contributions	dB
u_{j35}	*mismatch: direct attenuation measurement*	0,03
u_{j38}	*signal generator: absolute output level*	0,00
u_{j39}	*signal generator: output level stability*	0,01
u_{j41}	*insertion loss: transmitting antenna cable*	0,00
u_{j19}	*cable factor: transmitting antenna*	0,00
u_{j40}	*insertion loss: transmitting antenna attenuator*	0,00
u_{j42}	*insertion loss: adapter*	0,06
u_{j40}	*insertion loss: receiving antenna attenuator*	0,00
u_{j41}	*insertion loss: receiving antenna cable*	0,00
u_{j19}	*cable factor: receiving antenna*	0,00
u_{j47}	*receiving device: absolute level*	0,00
u_{j48}	*receiving device: linearity*	0,00
u_{i01}	*random uncertainty (see note in clause A.18 of the present document and note in clause 6.4.7 of TR 102 273-1-1)*	0,21

The standard uncertainties from table 1 should be combined by RSS in accordance with TR 102 273-1-1 [6], clause 5. This gives the combined standard uncertainty ($u_{c\ direct\ attenuation\ measurement}$) for the direct attenuation measurement in dB.

The value of $u_{c\ direct\ attenuation\ measurement}$ is calculated as 0,221 dB.

4.2.2 Uncertainty contributions: stage 2: radiated attenuation measurement

The second stage of the verification procedure is the radiated attenuation measurement which is carried out by removing the adapter and connecting each attenuator to an antenna as shown in figure 3, and recording the new level on the receiving device. The difference in received levels (after allowance for any correction factors and calculations which may be appropriate), for the same signal generator output level, reveals the NSA.

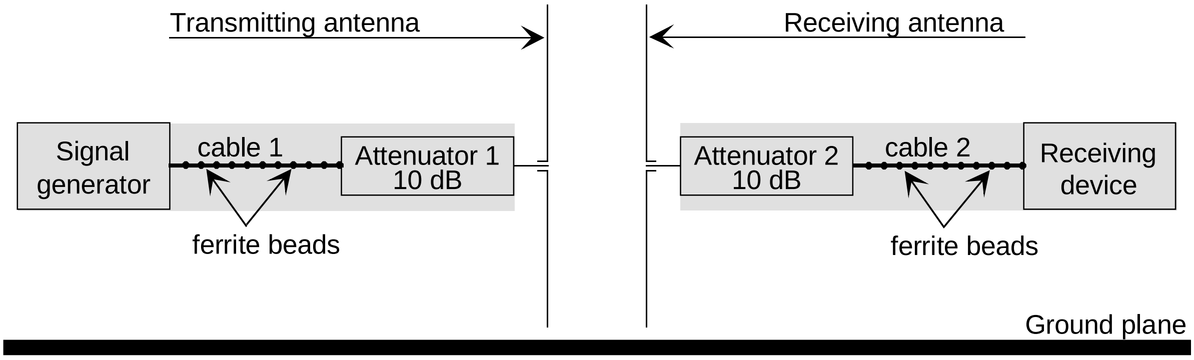


Figure 3: stage 2: radiated attenuation measurement

Whereas figure 3 shows, schematically, the test equipment set-up for this stage of the verification procedure an analysis diagram of the individual components (each of which contributes its own uncertainty) for this stage of the measurement is shown in figure 4. Again, as stated above, the shaded areas represent components common to both stages of the verification procedure.

4.2.2.1 Contributions from the mismatch components

Mismatch uncertainty transmitting and receiving parts: The value of the combined standard uncertainty of the contribution due to the mismatch are calculated from the approach described in annex D. For this stage is calculated in two parts. Firstly the standard uncertainty of the contribution due to the mismatch in the transmitting part, i.e. between the signal generator, cable, attenuator and the transmitting antenna and secondly, that for the receiving part, i.e. between the receiving antenna, attenuator, cable and the receiving device.

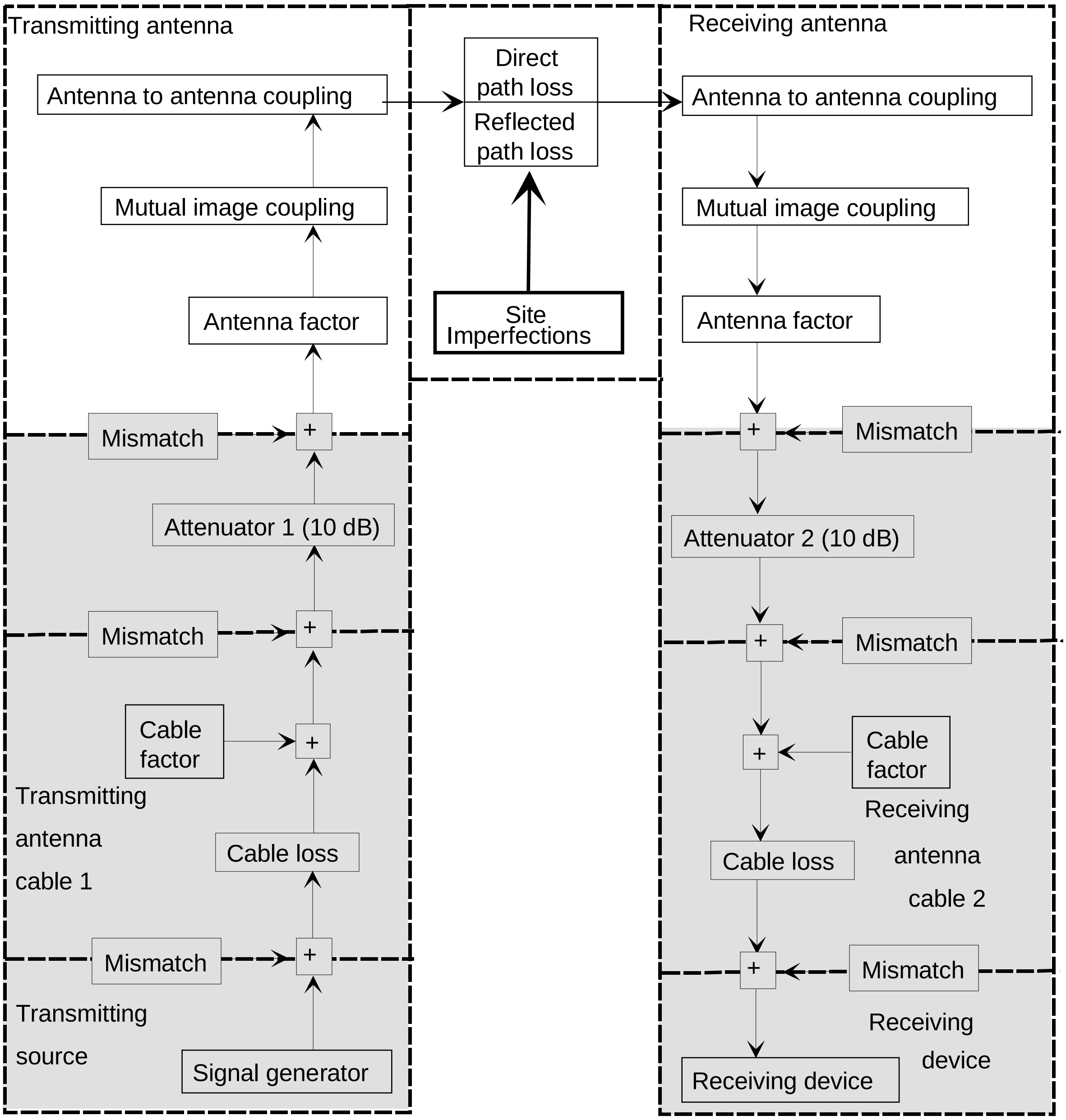


Figure 4: Stage 2: Radiated attenuation measurement individual uncertainty components

Mismatch: transmitting part:

Signal generator:	Output reflection coefficient: $\lvert \rho_G \rvert$	= 0,20
Cable:	Input and output reflection coefficients: $\lvert S_{11} \rvert$ and $\lvert S_{22} \rvert$	= 0,07
	Attenuation: 1 dB = $\lvert S_{12} \rvert = \lvert S_{21} \rvert$	= 0,891

Attenuator:	Input and output reflection coefficients $\lvert S_{11}\rvert = \lvert S_{22}\rvert$	= 0,05
	Attenuation = 10 dB $\lvert S_{12}\rvert = \lvert S_{21}\rvert$	= 0,3162
Transmitting antenna:	Input reflection coefficient: $\lvert \rho_{TA}\rvert$	= 0,333

All these contributions are U-distributed. Those components that cancel are not calculated. Other contributions are (see annex D):

$u_{\text{j mismatch: generator and cable 1}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$u_{\text{j mismatch: cable 1 and attenuator 1}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$$u_{j\ mismatch: attenuator\ 1 and\ antenna} = \frac{0{,}05 \times 0{,}333 \times 100}{\sqrt{2}} \% = 1{,}177\ \%$$

$u_{\text{j generator and attenuator 1}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$$u_{j\ mismatch: cable\ 1 and\ antenna} = \frac{0{,}07 \times 0{,}333 \times 0{,}316^2 \times 100}{\sqrt{2}} \% = 0{,}165\ \%$$

$$u_{j\ mismatch: generator\ and\ antenna} = \frac{0{,}2 \times 0{,}333 \times 0{,}891^2 \times 0{,}316^2 \times 100}{\sqrt{2}} \% = 0{,}373\ \%$$

The combined standard uncertainty of the mismatch is then calculated:

$$u_{c\ mismatch: transmitting\ part} = \sqrt{1{,}177^2 + 0{,}165^2 + 0{,}373^2} = 1{,}25\%$$

transforming to the logarithmic form (see annex C): 1,25 %/11,5 = 0,11 dB.

The standard uncertainty of the contribution due to the mismatch in the transmitting part, is designated throughout all parts of the present document as u_{j36}. Its value in this example is 0,11 dB.

Mismatch: receiving part:

Receiving antenna:	Input reflection coefficient: $\lvert \rho_{RA}\rvert$	= 0,333
Attenuator:	Input and output reflection coefficients $\lvert S_{11}\rvert = \lvert S_{22}\rvert$	= 0,05
	Attenuation = 10 dB $\lvert S_{12}\rvert = \lvert S_{21}\rvert$	= 0,3162
Cable:	Input and output reflection coefficients: $\lvert S_{11}\rvert$ and $\lvert S_{22}\rvert$	= 0,07
	Attenuation: 1 dB = $\lvert S_{12}\rvert = \lvert S_{21}\rvert$	= 0,891
Receiving device:	Input reflection coefficient: $\lvert \rho_{RD}\rvert$	= 0,20

$$u_{j\ mismatch: antenna\ and\ attenuator\ 2} = \frac{0{,}333 \times 0{,}05 \times 100}{\sqrt{2}} \% = 1{,}177\ \%$$

$u_{\text{j attenuator 2 and cable 2}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$u_{\text{j cable 2 and receiving device}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$$u_{j\ mismatch: antenna\ and\ cable\ 2} = \frac{0{,}333 \times 0{,}07 \times 0{,}316^2 \times 100}{\sqrt{2}} \% = 0{,}165\ \%$$

$u_{\text{j attenuator 2 and receiving device}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$$u_{j\,mismatch:antenna\,and\,receiving\,device} = \frac{0{,}333 \times 0{,}2 \times 0{,}316^2 \times 0{,}891^2 \times 100}{\sqrt{2}}\% = 0{,}374\ \%$$

The combined standard uncertainty of the mismatch is then calculated:

$$u_{c\,mismatch:receiving\,part} = \sqrt{1{,}177^2 + 0{,}165^2 + 0{,}373^2} = 1{,}25\%$$

transforming to the logarithmic form (see annex C): 1,25 %/11,5 = 0,11 dB.

The standard uncertainty of the contribution due to the mismatch in the receiving part is designated throughout all parts of the present document as u_{j37}. Its value in this example is 0,11 dB.

4.2.2.2 Contributions from individual components

4.2.2.2.1 Signal generator

Signal generator: absolute output level: In a verification procedure, the signal generator's absolute level uncertainty contributes equally to both stages of the measurement. The standard uncertainty of the contribution due to the signal generator absolute output level uncertainty is designated throughout all parts of the present document as u_{j38}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the signal generator absolute output level uncertainty is taken to be 0,00 dB since, once the level has been set in stage one of the procedure, the level is not further adjusted. The uncertainty is therefore assumed to be systematic i.e. it produces the same offset in both stages.

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

NOTE 2: In this example case the uncertainty of the contribution due to the signal generator output level stability is obtained from the manufacturer's data sheet as ±0,02 dB.
As nothing is said about the distribution of this uncertainty, a rectangular distribution (see TR 102 273-1-1 [6], clause 5.1.2) in logs is assumed, and the standard uncertainty is calculated as 0,01155 dB. This is rounded down to 0,01 dB.

4.2.2.2.2 Transmitting antenna cable

Insertion loss: transmitting antenna cable: The transmitting antenna cable has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the cable is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution, due to the insertion loss uncertainty of the transmitting antenna cable, is designated throughout all parts of the present document as u_{j41}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the insertion loss uncertainty of the transmitting antenna cable is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

Cable factor: transmitting antenna cable: Cable factor is defined as the total effect of the antenna cable's influence on the measuring system including its interaction with the site. It consists of the leakage caused by cable screening inefficiency, parasitic effects on the transmitting antenna (acting as a director or reflector) and introducing an unbalanced, common mode current into the dipole balun. In a radiated measurement the standard uncertainty of the cable factor, associated with each cable, is 0,5 dB provided that the precautions detailed in the methods have been observed, i.e. routing and dressing of cables with ferrites. If no prevention has been attempted the standard uncertainty is 4,0 dB (justification for these values is given in annex E). The standard uncertainty of the contribution due to the cable factor of the receiving antenna cable is designated throughout all parts of the present document as u_{j19}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the cable factor of the transmitting antenna cable is taken as 0,50 dB since the precautions detailed in the methods are assumed to have been observed.

4.2.2.2.3 Transmitting antenna attenuator

Insertion loss: transmitting antenna attenuator: The transmitting antenna attenuator has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the attenuator is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution, due to the insertion loss uncertainty of the transmitting antenna attenuator, is designated throughout all parts of the present document as u_{j40}.

NOTE: In this example case the standard uncertainty of the contribution due to the insertion loss uncertainty of the transmitting antenna attenuator is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

4.2.2.2.4 Transmitting antenna

Antenna: antenna factor of the transmitting antenna: Uncertainty is introduced as a result of the inaccurate knowledge of the antenna factor of the transmitting antenna. The antenna factor contributes only to the radiated part of this procedure. The standard uncertainty of the contribution due to the antenna factor uncertainty of the transmitting antenna is designated throughout all parts of the present document as u_{j44}. For ANSI dipoles the value should be obtained from table 2.

Table 2: Uncertainty contribution of the antenna factor of the transmitting antenna

Frequency	Standard uncertainty of the contribution
30 MHz ≤ frequency < 80 MHz	1,73 dB
80 MHz ≤ frequency < 180 MHz	0,60 dB
frequency ≥ 180 MHz	0,30 dB
NOTE: For other antenna types the values should be taken from manufacturer's data sheets. If a value is not given the standard uncertainty is 1,0 dB.	

NOTE 1: In this example case the standard uncertainty of the contribution due to the antenna factor uncertainty of the transmitting antenna is 0,30 dB since ANSI dipoles have been used and the frequency is above 180 MHz.

Antenna: tuning of the transmitting antenna: Uncertainty is introduced as a result of the inaccurate tuning of the transmitting antenna. This only occurs in stage two of the measurement and therefore only contributes to this stage. The standard uncertainty of the contribution, due to the tuning uncertainty of the transmitting antenna, is designated throughout all parts of the present document as u_{j46}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the tuning uncertainty of the transmitting antenna is taken as 0,06 dB (see annex A).

Position of the phase centre: transmitting antenna: Uncertainty is introduced as a result of the inaccurate positioning of the phase centre of the transmitting antenna. This only occurs in stage two of the measurement. The standard uncertainty of the contribution, due to the uncertainty in the position of the phase centre of the transmitting antenna, is designated throughout all parts of the present document as u_{j22}.

NOTE 3: In this example case the standard uncertainty of the contribution due to the uncertainty in the position of the phase centre of the transmitting antenna has been calculated from (±(the offset from axis of rotation)/(range length) x 100 %). The positioning uncertainty is ±0,01 m and therefore the worst case uncertainty = 0,01/3,0 = 0,333 %. As the offset can be anywhere between these limits, the uncertainty is taken to be rectangularly distributed (see TR 102 273-1-1 [6], clause 5.1.2) and the standard uncertainty is calculated as 0,192 %. This is transformed to the logarithmic form (see annex C), to be 0,02 dB.

4.2.2.2.5 Site factors

Ambient effect: Uncertainty is introduced as a result of local ambient signals raising the noise floor at the measurement frequency. The standard uncertainty of the contribution due to the ambient effect is designated throughout all parts of the present document as u_{j34}. The values of the standard uncertainty should be taken from table 3.

Table 3: Uncertainty contribution: Ambient effect

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

NOTE 1: In this example case the standard uncertainty of the contribution due to the ambient effect is taken as 0,00 dB, since the chamber is assumed to be shielded.

Mutual coupling: transmitting antenna to its images in the absorbing material: This uncertainty is the effect of the change produced in the antenna's input impedance and/or gain. The standard uncertainty of the contribution due to the mutual coupling of the transmitting antenna to its images in the absorbing materials is designated throughout all parts of the present document as u_{j07}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the mutual coupling of the transmitting antenna to its images in the absorbing materials is taken as 0,5 dB (see annex A).

Mutual coupling: transmitting antenna to its image in the ground plane: This uncertainty is the effect of the change produced in the antenna's input impedance and/or gain. The standard uncertainty of the contribution due to the mutual coupling of the transmitting antenna to its image in the ground plane, designated throughout all parts of the present document as u_{j15}, has a value of 0,00 dB for ANSI dipoles since it is included, where significant, in the mutual coupling and mismatch loss correction factors (see table A.20). For other dipoles the value can be obtained from table 4.

Table 4: Uncertainty contribution of the mutual coupling between the transmitting antenna to its image in the ground plane

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

NOTE 3: In this example case the standard uncertainty of the contribution due to mutual coupling between the transmitting antenna and its image in the ground plane is taken as 0,00 dB as we are assuming the use of ANSI dipoles.

Mutual coupling: transmitting antenna to receiving antenna: This is the effect produced by any change in the gains of the antennas which results from their close spacing. The standard uncertainty of the contribution due to the mutual coupling of the transmitting antenna to receiving antenna, is designated throughout all parts of the present document as u_{j10}. It has a standard uncertainty of 0,00 dB for ANSI dipoles since it is included, where significant, in the mutual coupling and mismatch loss correction factors. For non-ANSI dipoles the standard uncertainty can be taken from table 5.

Table 5: Uncertainty contribution of the mutual coupling between the transmitting and receiving antenna

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

NOTE 4: In this example case the standard uncertainty of the contribution due to mutual coupling between the transmitting and receiving antennas is taken as 0,00 dB as we are using ANSI dipoles.

Mutual coupling: interpolation of mutual coupling and mismatch loss correction factors, only for ANSI dipoles: The standard uncertainty of the contribution, due to the interpolation of mutual coupling and mismatch loss correction factors, is designated throughout all parts of the present document as u_{j12}. It has, for spot frequencies given in table A.20, a value of 0,00 dB. However, for all other frequencies, the standard uncertainty should be obtained from table 6.

Table 6: Uncertainty contribution of the interpolation of mutual coupling and mismatch loss correction factors

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

NOTE 5: In this example case the standard uncertainty of the contribution, due to the interpolation of mutual coupling and mismatch loss correction factors, is taken as 0,00 dB as the frequency is above 180 MHz.

Range length: This contribution is associated with the curvature of the phase front from the transmitting antenna to the receiving antenna. The standard uncertainty of the contribution, due to range length, is designated throughout all parts of the present document as u_{j16}. The standard uncertainty is 0,00 dB if ANSI dipoles are used. For other types of antenna the standard uncertainty of the contribution should be obtained from table 7.

Table 7: Uncertainty contribution of the range length (verification)

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

NOTE 6: In this example case the standard uncertainty of the contribution, due to the range length, is taken as 0,00 dB as we are using ANSI dipoles.

Reflectivity of absorbing material: transmitting antenna to the receiving antenna: This uncertainty is associated with the magnitude of the reflections occurring from the side walls, end walls and ceiling. These magnitudes are a function of the quality of the absorber at the frequency of test. The standard uncertainty of the contribution, due to reflectivity of the absorber material between the transmitting antenna and the receiving antenna, is designated throughout all parts of the present document as u_{j03}. The relevant value for this contribution should be taken from table 8.

Table 8: Uncertainty contribution of the reflectivity of absorbing material between the transmitting and receiving antennas

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

NOTE 7: In this example case the standard uncertainty of the contribution, due to the reflectivity of absorber material between the transmitting antenna and the receiving antenna, is taken as 2,56 dB since it is assumed that the absorber has a reflectivity in the range 15 dB to 20 dB.

Mutual coupling: receiving antenna to its images in the absorbing material: This uncertainty is the effect of the change produced in the antenna's input impedance and/or gain. The standard uncertainty of the contribution, due to the mutual coupling of the receiving antenna to its images in the absorbing material, is designated throughout all parts of the present document as u_{j07}.

NOTE 8: In this example case the standard uncertainty of the contribution due to the mutual coupling of the receiving antenna to its images in the absorbing material is taken as 0,5 dB.

Mutual coupling: receiving antenna to its image in the ground plane: This uncertainty is the effect of the change produced in the antenna's input impedance and/or gain. The standard uncertainty of the contribution, due to the mutual coupling of the receiving antenna to its image in the ground plane, is designated throughout all parts of the present document as u_{j15}. It has a value of 0,00 dB for ANSI dipoles since it is included, where significant, in the mutual coupling and mismatch loss correction factors. For other antennas the value can be obtained from table 9.

Table 9: Uncertainty contribution of the mutual coupling between the receiving antenna and its image in the ground plane

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

NOTE 9: In this example case the standard uncertainty of the contribution due to the mutual coupling between the receiving dipole and its image in the ground plane is taken as 0,00 dB as we are using ANSI dipoles.

4.2.2.2.6 Receiving antenna

Correction: measurement distance: For verification procedures only one stage involves a radiated measurement and hence no correction can be applied i.e. the uncertainty contribution is 0,00 dB. The standard uncertainty of the contribution, due to the correction for measurement distance, is designated throughout all parts of the present document as u_{j18}.

Correction: off boresight angle in elevation plane: For verification procedures only one stage involves a radiated measurement and hence no correction can be applied i.e. the uncertainty contribution is 0,00 dB. The standard uncertainty of the contribution, due to the correction for off boresight angle in elevation plane is designated throughout all parts of the present document as u_{j17}.

Antenna: antenna factor of the receiving antenna: Uncertainty is introduced as a result of the inaccurate knowledge of the antenna factor of the receiving antenna. The antenna factor contributes only to the radiated part of this procedure. The standard uncertainty of the contribution due to the antenna factor uncertainty of the receiving antenna is designated throughout all parts of the present document as u_{j44}. For ANSI dipoles the value should be obtained from table 10.

Table 10: Uncertainty contribution of the antenna factor of the receiving antenna

Frequency	Standard uncertainty of the contribution
30 MHz ≤ frequency < 80 MHz	1,73 dB
80 MHz ≤ frequency < 180 MHz	0,60 dB
frequency ≥ 180 MHz	0,30 dB
NOTE: For other antenna types the figures should be taken from manufacturer's data sheets. If a figure is not given the standard uncertainty is 1,0 dB.	

NOTE 1: In this example case the standard uncertainty of the contribution due to the antenna factor uncertainty of the receiving antenna is 0,30 dB since ANSI dipoles have been used and the frequency is above 180 MHz.

Antenna: tuning of the receiving antenna: Uncertainty is introduced as a result of the inaccurate tuning of the receiving antenna. This only occurs in stage two of the measurement and therefore does not cancel. The standard uncertainty of the contribution, due to the tuning uncertainty of the receiving antenna, is designated throughout all parts of the present document as u_{j46}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the tuning uncertainty of the receiving antenna is taken as 0,06 dB (see annex A).

Position of the phase centre: receiving antenna: Uncertainty is introduced as a result of the inaccurate positioning of the phase centre of the receiving antenna. This only occurs in stage two of the measurement. The standard uncertainty of the contribution, due to the uncertainty in the position of the phase centre of the receiving antenna, is designated throughout all parts of the present document as u_{j22}.

NOTE 3: In this example case the standard uncertainty of the contribution due to the position of the phase centre of the receiving antenna has been calculated from ± (the offset) / (range length) x 100 %). The positioning uncertainty is ±0,01 m and therefore the worst case uncertainty = 0,01/3,0 = 0,333 %. As the offset can be anywhere between these limits, the uncertainty is taken to be rectangularly distributed (see TR 102 273-1-1 [6], clause 5.1.2) and the standard uncertainty is calculated as 0,192 %. This is transformed to the logarithmic form (see annex C), to be 0,02 dB.

4.2.2.2.7 Receiving antenna attenuator

Insertion loss: receiving antenna attenuator: The attenuator has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the attenuator is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution due to the insertion loss uncertainty of the receiving antenna attenuator is designated throughout all parts of the present document as u_{j40}.

NOTE: In this example case the standard uncertainty of the contribution, due to the insertion loss uncertainty of the transmitting antenna attenuator, is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

4.2.2.2.8 Receiving antenna cable

Insertion loss: receiving antenna cable: The receiving antenna cable has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the cable is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution due to the insertion loss uncertainty of the receiving antenna cable is designated throughout all parts of the present document as u_{j41}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the insertion loss uncertainty of the transmitting antenna cable is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

Cable factor: receiving antenna: Cable factor is defined as the total effect of the antenna cable's influence on the measuring system including its interaction with the site. It consists of the leakage caused by cable screening inefficiency, parasitic effects on the receiving antenna (acting as a director or reflector) and introducing an unbalanced, common mode current into the dipole balun. In a radiated measurement the standard uncertainty of the cable factor, associated with each cable, is 0,5 dB provided that the precautions detailed in the methods have been observed, i.e. routing and dressing of cables with ferrites. If no prevention has been attempted the standard uncertainty is 4,0 dB (justification for these values is given in annex E). The standard uncertainty of the contribution due to the cable factor of the receiving antenna cable is designated throughout all parts of the present document as u_{j19}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the cable factor of the receiving antenna cable is taken as 0,50 dB since the precautions detailed in the methods are assumed to have been observed.

4.2.2.2.9 Receiving device

The first stage of the verification procedure involved setting a reference level on the receiving device for a particular output level from the signal generator. In this the second stage (where the path loss between two antennas is measured), a second level is obtained which results in linearity and absolute level uncertainties becoming involved in the calculation of the combined standard uncertainty for the measurement.

Receiving device: absolute level: This uncertainty only contributes during the second stage of the procedure if the input attenuation range setting on the receiving device has been changed from its setting in the first stage. The standard uncertainty of the contribution due to the receiving device absolute level uncertainty is designated throughout all parts of the present document as u_{j47}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the receiving device absolute level uncertainty (a range change is assumed) is obtained from the manufacturer's data as ±1,0 dB. This is taken as being rectangularly distributed (see TR 102 273-1-1 [6], clause 5.1.2), so the standard uncertainty is calculated as 0,58 dB.

Receiving device: linearity: The standard uncertainty of the contribution due to the receiving device linearity, designated throughout all parts of the present document as u_{j48}, always contributes during the second stage of the procedure unless there has been a range change in which case it is included in the receiving device absolute level uncertainty u_{j47}.

NOTE 2: In this example case a range change has been assumed therefore the contribution is 0,00 dB.

4.2.2.3 Contribution from the random component

Random uncertainty: The magnitude can be assessed from multiple measurements of the radiated attenuation measurements. The standard uncertainty of the contribution due to the random uncertainty is designated throughout all parts of the present document as u_{i01}. See also clause 5.5 and the note in clause 6.4.7 of TR 102 273-1-1, as well as note in clause A.18 of the present document.

The radiated attenuation measurement was repeated ten times. The following results were obtained in dBμV (before correcting for cabling and attenuator network insertion loss):

65,4; 63,4; 66,0; 65,3; 63,0; 64,9; 65,2; 66,8; 65,5; 63,7.

Converting to linear terms (V):

$1{,}862 \times 10^{-3}$; $1{,}479 \times 10^{-3}$; $1{,}995 \times 10^{-3}$; $1{,}841 \times 10^{-3}$; $1{,}413 \times 10^{-3}$; $1{,}758 \times 10^{-3}$; $1{,}820 \times 10^{-3}$; $2{,}188 \times 10^{-3}$; $1{,}884 \times 10^{-3}$; $1{,}531 \times 10^{-3}$;

The two sums X and Y are calculated:

X = the sum of the measured values = $17{,}77 \times 10^{-3}$ (V):

Y = the sum of the squares of the measured values = $32{,}10 \times 10^{-6}$ V^2

$$u_{c\ random} = \sqrt{\frac{Y - \frac{X^2}{n}}{n-1}} = \sqrt{\frac{32{,}10 \times 10^{-6} - \frac{\left(17{,}77 \times 10^{-3}\right)^2}{10}}{10-1}} = 238{,}3 \times 10^{-6} \qquad \text{(formula 5.6)}$$

As the result is obtained as the mean value of ten measurements and the standard uncertainty of the random uncertainty is:

$$u_{j\ random} = \frac{238{,}3 \times 10^{-6}}{1{,}777 \times 10^{-3}} \times \frac{100}{11{,}5} = 1{,}17\ \text{dB}$$

NOTE: In this example case the standard uncertainty of the contribution due to the random uncertainty is 1,17 dB.

4.2.2.4 Summary table of contributory components

All the uncertainty contributions to this part of the procedure are listed in table 11.

Table 11: Contributions from the radiated attenuation measurement

$u_{j\ or\ i}$	**Description of uncertainty contributions**	**dB**
u_{j36}	*mismatch: transmitting part*	0,11
u_{j37}	*mismatch: receiving part*	0,11
u_{j38}	*signal generator: absolute output level*	0,00
u_{j39}	*signal generator: output level stability*	0,01
u_{j41}	*insertion loss: transmitting antenna cable*	0,00
u_{j19}	*cable factor: transmitting antenna*	0,50
u_{j40}	*insertion loss: transmitting antenna attenuator*	0,00
u_{j44}	*antenna: antenna factor of the transmitting antenna*	0,30
u_{j46}	*antenna: tuning of the transmitting antenna*	0,06
u_{j22}	*position of the phase centre: transmitting antenna*	0,02
u_{j34}	*ambient effect*	0,00
u_{j07}	*mutual coupling: transmitting antenna to its images in the absorbing material*	0,50
u_{j15}	*mutual coupling: transmitting antenna to its image in the ground plane*	0,00
u_{j10}	*mutual coupling: transmitting antenna to the receiving antenna*	0,00
u_{j12}	*mutual coupling: interpolation of mutual coupling and mismatch loss correction factors*	0,00
u_{j16}	*range length*	0,00
u_{j03}	*reflectivity of absorber material: transmitting antenna to the receiving antenna*	2,56
u_{j07}	*mutual coupling: receiving antenna to its images in the absorbing material*	0,50
u_{j15}	*mutual coupling: receiving antenna to its image in the ground plane*	0,00
u_{j18}	*correction: measurement distance*	0,00
u_{j17}	*correction: off boresight angle in the elevation plane*	0,00
u_{j44}	*antenna: antenna factor of the receiving antenna*	0,30
u_{j46}	*antenna: tuning of the receiving antenna*	0,06
u_{j22}	*position of the phase centre: receiving antenna*	0,02
u_{j40}	*insertion loss: receiving antenna attenuator*	0,00
u_{j41}	*insertion loss: receiving antenna cable*	0,00
u_{j19}	*cable factor: receiving antenna*	0,50
u_{j47}	*receiving device: absolute level*	0,58
u_{j48}	*receiving device: linearity*	0,00
u_{i01}	*random uncertainty (see note in clause A.18 of the present document and note in clause 6.4.7 of TR 102 273-1-1)*	1,17

The standard uncertainties from table 11 should be combined by RSS in accordance with TR 102 273-1-1 [6], clause 5. This gives the combined standard uncertainty ($u_{c\ NSA\ measurement}$) for the NSA measurement in dB.

The value of $u_{c\ NSA\ measurement}$ is calculated as 3,08 dB.

4.2.2.5 Expanded uncertainty for the verification procedure

The combined standard uncertainty of the results of the verification procedure is the combination of the components outlined in clauses 4.2.1.4 and 4.2.2.4. The components to be combined are ($u_{c\ direct\ attenuation\ measurement}$) and ($u_{c\ NSA\ measurement}$).

$$u_c = \sqrt{0{,}221^2 + 3{,}08^2} = 3{,}08\ \text{dB}$$

The expanded uncertainty is ±1,96 x 3,08 dB = ±6,04 dB at a 95 % confidence level.

4.3 Example 2: measurement of a transmitter parameter (spurious emission)

For the measurement of the effective radiated power in a spurious emission two stages of test are involved. The first stage (the EUT measurement) is to measure on the receiving device, a level from the EUT. The second stage (the substitution) involves replacing the EUT with a substitution antenna and signal source and adjusting the output level of the signal generator until the same level as in stage one is achieved on the receiving device.

4.3.1 Uncertainty contributions: stage 1: EUT measurement

The first stage of the spurious emission measurement is to measure on the receiving device, a level from the EUT. This is normally carried out with a broadband antenna and receiver combination as shown in figure 5. The components shown shaded are common to both stages of the test.

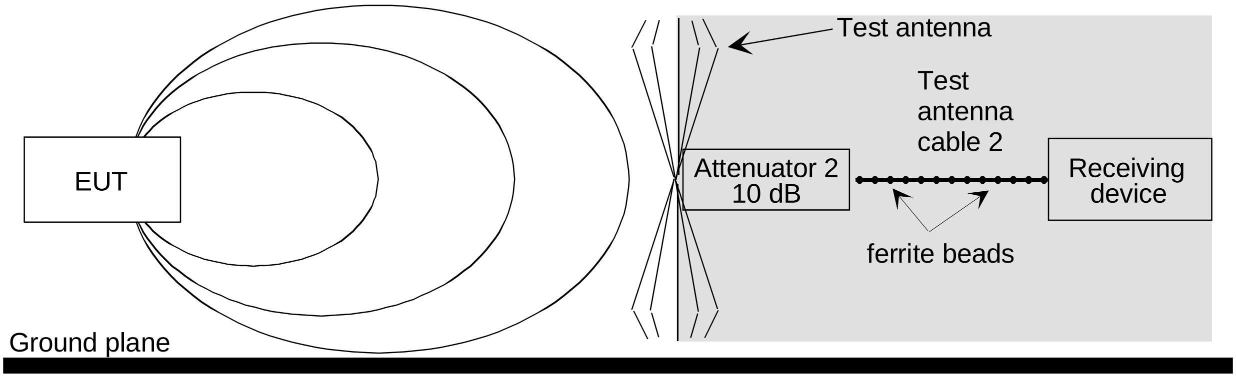


Figure 5: Stage 1: EUT measurement

Due to the commonality of all of the components from the test antenna to the receiver in both stages of the test, the mismatch uncertainty contributes identically to both stages and hence does not contribute to the combined standard uncertainty of the measurement. Similarly, for the systematic uncertainty contributions (e.g. test antenna cable loss etc.) of the individual components.

Whereas figure 5 shows, schematically, the test equipment set-up for this stage of the spurious emission measurement, an analysis diagram of the individual components (each of which contributes its own uncertainty) for this stage of the measurement is shown in figure 6. Again, as stated above, the shaded areas represent components common to both stages of the spurious emissions measurement.

4.3.1.1 Contributions from the mismatch components

Mismatch: receiving part: The uncertainty contribution due to the mismatch for the receiving part from the test antenna to the receiver, can be calculated from the approach described in annex D. All the individual contributions are U-distributed.

NOTE 1: In this example the value taken for the signal generator output reflection coefficient is the worst case value over the frequency band of interest. Similarly for the cable, adapter and attenuator VSWRs.

NOTE 2: The attenuation values of the cables and attenuators should be obtained from the data sheets/calibration records at the specific frequency of the test, along with the associated uncertainties for these values.

The mismatch uncertainty between the test antenna and the receiving device however, contributes equally to both stages of the test and therefore has no contribution to the combined standard uncertainty. Therefore it is not calculated.

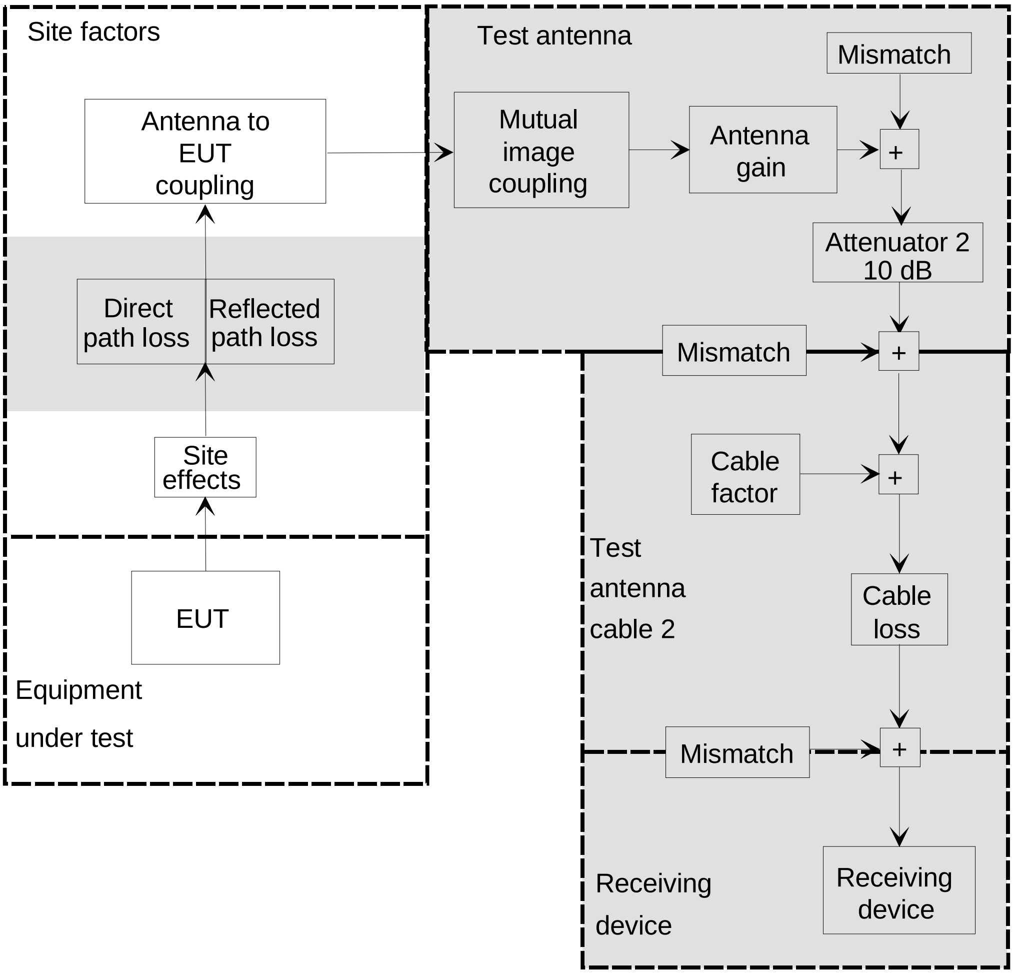


Figure 6: Stage 1: EUT measurement individual uncertainty components

The standard uncertainty of the contribution, due to the mismatch in the receiving part, is designated throughout all parts of the present document as u_{j37}.

NOTE 3: In this example case the standard uncertainty of the contribution due to mismatch in the receiving part is taken as 0,00 dB, since the uncertainty is assumed to be systematic i.e. it is assumed constant and common to both stages of the measurement.

4.3.1.2 Contributions from the individual components

4.3.1.2.1 EUT

EUT: influence of setting the power supply on the spurious emission level: This is the resulting uncertainty caused by the uncertainty of setting of the power supply level. In this case normal supply conditions are assumed, not extreme. The supply voltage uncertainty is taken to be ±100 mV so the uncertainty caused by this supply voltage uncertainty is calculated using the dependency function (TR 100 028 [5]) whose mean value is 10 %/V and whose standard uncertainty is 3 %/V. The standard uncertainty of the spurious emission level uncertainty caused by power supply voltage uncertainty (using formula 5.3) is:

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

This is then transformed to logarithmic form: 0,60/23,0 % = 0,03 dB (see annex C).

The standard uncertainty of the contribution, due to the influence of setting the power supply on the spurious emission level, is designated throughout all parts of the present document as u_{j54}.

NOTE 1: In this example case the standard uncertainty of the contribution, due to the influence of setting the power supply on the spurious emission level, is calculated above as 0,03 dB.

EUT: influence of the ambient temperature on the spurious emissions: This is the uncertainty in the power level of the spurious emission caused by the uncertainty in knowing the ambient temperature. The ambient temperature uncertainty is ±1 °C. The uncertainty caused by this temperature uncertainty is calculated using the dependency function (TR 100 028 [5]) whose mean value is 4 %/°C and whose standard uncertainty is 1,2 %/°C. The standard uncertainty of the spurious emission power level uncertainty caused by ambient temperature uncertainty (using formula 5.3) is:

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

This is then transformed to logarithmic form: 2,41/23,0 % = 0,10 dB (see annex C).

The standard uncertainty of the contribution, due to the influence of the ambient temperature on the spurious emissions, is designated throughout all parts of the present document as u_{j51}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the influence of the ambient temperature on the spurious emissions level is calculated above as 0,10 dB.

EUT: mutual coupling to the power leads: This is the uncertainty associated with the influence (reflections, parasitic effects, etc.) of the power leads on the EUT. The standard uncertainty associated with this effect is 0,5 dB provided that the precautions detailed in the methods have been observed, i.e. routing and dressing of cables with ferrites. If no prevention has been attempted the standard uncertainty is 2,0 dB. The standard uncertainty of the contribution, due to the mutual coupling to the power leads, is designated throughout all parts of the present document as u_{j54}.

NOTE 3: In this example case the standard uncertainty of the contribution due to the mutual coupling to the power leads is taken as 0,5 dB since the precautions detailed in the methods are assumed to have been observed.

Position of the phase centre: within the EUT volume: This contribution is associated with the uncertainty with which the actual radiating point within the equipment volume is known. If this point is known exactly the contribution is 0,00 dB. The standard uncertainty of the contribution, due to the position of the phase centre within the EUT volume, is designated throughout all parts of the present document as u_{j20}.

NOTE 4: In this example case the standard uncertainty of the contribution due to the position of the phase centre within the EUT volume has been calculated from (± (the maximum dimension of device) / (2 × range length) × 100 %). In this example the position is not known. Hence, the uncertainty of the position of the phase centre within the EUT of 0,15 m maximum dimension is 0,15/2 m = 0,075 m, and the worst case uncertainty due to this offset is therefore ± (0,075/3,0) × 100 % = ±2,50 %. As the phase centre can be anywhere inside the EUT, the uncertainty is taken as rectangularly distributed and the standard uncertainty is calculated as 1,44 %. This is then transformed to the logarithmic form (1,44/11,5) = 0,12 dB (see annex C).

Positioning of the phase centre: within the EUT over the axis of rotation of the turntable: This contribution is associated with the uncertainty with which the actual radiating point within the equipment is placed over the centre of the turntable. If the point is placed exactly, the contribution is 0,00 dB. The standard uncertainty of the contribution due to the positioning of the EUT phase centre over the axis of rotation of the turntable, is designated throughout all parts of the present document as u_{j21}.

NOTE 5: In this example case the standard uncertainty of the contribution due to the positioning of the EUT phase centre over the axis of rotation of the turntable is calculated from (± (the estimated offset from the axis of rotation) / (2 × range length) × 100 %). In this case, the uncertainty of the positioning is taken as ±0,01 m, and the worst case uncertainty is ± (0,01/3,0) × 100 = ±0,333 %. As the offset can be anywhere between the limits the uncertainty is rectangularly distributed and the standard uncertainty is calculated as 0,192 %. This is then transformed to the logarithmic form (0,192/11,5) = 0,02 dB (see annex C).

Range length: This contribution is associated with the curvature of the phase front from the EUT to the test antenna. The standard uncertainty of the contribution due to the range length is designated throughout all parts of the present document as u_{j16}. The standard uncertainty of the contribution should be obtained from table 12.

Table 12: Uncertainty contribution of the range length (verification)

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

NOTE 6: In this example case the standard uncertainty of the contribution due to the range length is taken as 0,00 dB since the range length is $\geq 2\ (d_1+d_2)^2/\lambda$.

4.3.1.2.2 Site factors

Ambient effect: Ambient effect is the uncertainty caused by local ambient signals raising the noise floor at the measurement frequency. The standard uncertainty of the contribution, due to the ambient effect, is designated throughout all parts of the present document as u_{j34}. The values of the standard uncertainty should be taken from table 13.

Table 13: Uncertainty contribution: ambient effect

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

NOTE 1: In this example case the standard uncertainty of the contribution due to the ambient effect is taken as 0,00 dB, since the chamber is assumed to be shielded.

Mutual coupling: amplitude effect of the test antenna on the EUT: This uncertainty results from the interaction between the EUT and the test antenna when placed close together. The standard uncertainty of the contribution due to the amplitude effect of the mutual coupling between the test antenna and the EUT, is designated throughout all parts of the present document as u_{j08}. The standard uncertainty should be taken from table 14.

Table 14: Uncertainty contribution: mutual coupling: amplitude effect of the test antenna on the EUT

Range length	Standard uncertainty of the contribution
$0{,}62\sqrt{((d_1+d_2)^3/\lambda)} \leq$ range length $< 2(d_1+d_2)^2/\lambda$	0,50 dB
range length $\geq 2(d_1+d_2)^2/\lambda$	0,00 dB

NOTE 2: In this example case the standard uncertainty of the contribution due to the amplitude effect of the mutual coupling between the test antenna and the EUT is 0,00 dB since the distance is $\geq 2\ (d_1+d_2)^2/\lambda$.

Mutual coupling: EUT to its images in the absorbing material: This uncertainty is dependant on the quality of the absorbing material and the effect imaging of the EUT in the ceiling, side and end walls has on the input impedance and/or gain of the integral antenna. The standard uncertainty of the contribution, due to the mutual coupling of the EUT to its images in the absorbing material, is designated throughout all parts of the present document as u_{j04}.

NOTE 3: In this example case the standard uncertainty of the contribution due to the mutual coupling amplitude effect of the absorbing material on the EUT is assumed to be 0,5 dB (see annex A).

Mutual coupling: EUT to its image in the ground plane: This uncertainty results from the change in the EUT spurious emission level as a result of being placed close to the ground plane. The standard uncertainty of the contribution, due to the mutual coupling of the EUT to its image in the ground plane, is designated throughout all parts of the present document as u_{j13}. Its value can be obtained from table 15.

Table 15: Uncertainty contribution of the mutual coupling between the EUT to its image in the ground plane

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

NOTE 4: In this example case the standard uncertainty of the contribution, due to the mutual coupling of the EUT to its image in the ground plane, (assuming the polarization is vertical and the spacing above the ground plane is < 1,25 λ at the test frequency) is taken as 0,15 dB.

Reflectivity of absorbing material: EUT to the test antenna: This uncertainty is associated with the magnitudes of the reflections occurring from the side walls, end walls and ceiling. These magnitudes are a function of the quality of the absorber at the frequency of test. The standard uncertainty of the contribution, due to the reflectivity of the absorbing material between the EUT and the test antenna, is designated throughout all parts of the present document as u_{j01}. The relevant value for this contribution should be taken from table 16.

Table 16: Uncertainty contribution of the reflectivity of absorbing material between the EUT and test antenna

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

NOTE 5: In this example case the standard uncertainty of the contribution due to the reflectivity of the absorbing material between the EUT and the test antenna is taken as 0,00 dB since this is a substitution measurement and the contribution cancels (see annex A).

Mutual coupling: test antenna to its images in the absorbing material: This is the uncertainty due to the mutual coupling between the test antenna and its images in the ceiling, side and end walls and is the effect of the change produced in the antenna's input impedance and/or gain. As this is the first stage of a substitution measurement and the uncertainty is common to both stages it will only contribute in the second stage if the test antenna is located at a different height on the antenna mast. The standard uncertainty of the contribution, due to the mutual coupling between the test antenna and its images in the absorbing material, is designated throughout all parts of the present document as u_{j06}.

NOTE 6: In this example case the standard uncertainty of the contribution due to the mutual coupling between the test antenna and its images in the absorbing material is taken as 0,00 dB since this is the reference position.

Mutual coupling: test antenna to its image in the ground plane: This is the uncertainty due to the mutual coupling between the test antenna and its image in the ground plane and is the effect of the change produced in the antenna's input impedance and/or gain when placed close to a ground plane. As this is the first stage of a substitution measurement and the uncertainty is common to both stages, it will only contribute in the second stage if the test antenna is located at a different height on the antenna mast. The standard uncertainty of the contribution, due to the mutual coupling between the test antenna and its image in the ground plane, is designated throughout all parts of the present document as u_{j14}.

NOTE 7: In this example case the standard uncertainty of the contribution due to the mutual coupling between the test antenna and its image in the ground plane is taken as 0,00 dB since this is the reference position.

4.3.1.2.3 Test antenna

Correction: measurement distance: For those tests in which the test antenna on the mast peaks at different heights in the two stages, a correction for the measurement distance should be made to account for the different measurement distances. The standard uncertainty of the contribution due to the correction for measurement distance is designated throughout all parts of the present document as u_{j18}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the correction for measurement distance is taken as 0,00 dB since, in this, the first stage of the measurement, only a reference height is being set.

Correction: off boresight angle in elevation plane: For those tests in which the test antenna on the mast peaks at different heights in the two stages, a correction needs to be made to account for the different angles subtended by the EUT/substitution antenna. The standard uncertainty of the contribution, due to the correction for off boresight angle in elevation plane, is designated throughout all parts of the present document as u_{j17}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the correction for off boresight angle in elevation plane is taken as 0,00 dB since in this, the first stage of the measurement, only a reference height is being set.

Antenna: gain of the test antenna: The gain, and its uncertainty, of the test antenna act as systematic offsets since they are present in both stages of the test. The standard uncertainty of the contribution, due to the uncertainty of the gain of the test antenna, is designated throughout all parts of the present document as u_{j45}.

NOTE 3: In this example case the standard uncertainty of the contribution due to the uncertainty of the gain of the test antenna is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

Antenna: tuning of the test antenna: This uncertainty is introduced as a result of inaccurate tuning of the test antenna. The standard uncertainty of the contribution, due to the tuning of the test antenna, is designated throughout all parts of the present document as u_{j46}.

NOTE 4: In this example case the standard uncertainty of the contribution due to the tuning of the test antenna is taken as 0,00 dB since the uncertainty is systematic i.e. it is assumed constant and common to both stages of the measurement and, provided that once set in stage one of the test it is not subsequently re-tuned, its contribution is the same in both stages.

Position of the phase centre: test antenna: The horizontal position of the test antenna defines one end of the range length. The standard uncertainty of the contribution, due to the position of the phase centre of the test antenna, is designated throughout all parts of the present document as u_{j22}.

NOTE 5: In this example case the test antenna is assumed to describe a vertical straight line as its height on the mast is changed. The standard uncertainty of the contribution due to the position of the phase centre of the test antenna is assumed to be 0,00 dB (see annex A).

4.3.1.2.4 Test antenna attenuator

Insertion loss: test antenna attenuator: The attenuator has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the attenuator is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution due to the insertion loss of the test antenna attenuator is designated throughout all parts of the present document as u_{j40}.

NOTE: In this example case the standard uncertainty of the contribution, due to the insertion loss uncertainty of the test antenna attenuator, is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

4.3.1.2.5 Test antenna cable

Insertion loss: test antenna cable: The test antenna cable has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the cable is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution, due to the insertion loss uncertainty of the test antenna cable, is designated throughout all parts of the present document as u_{j41}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the insertion loss uncertainty of the test antenna cable is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

Cable factor: test antenna cable: Cable factor is defined as the total effect of the antenna cable's influence on the measuring system including its interaction with the site. It consists of the leakage caused by cable screening inefficiency, parasitic effects (acting as a director or reflector) on the test antenna and introducing an unbalanced, common mode current into the dipole balun. In a radiated measurement the standard uncertainty of the cable factor, associated with each cable, is 0,5 dB provided that the precautions detailed in the methods have been observed, i.e. routing and dressing of cables with ferrites. If no prevention has been attempted the standard uncertainty is 4,0 dB (justification for these values is given in annex E). The standard uncertainty of the contribution due to the cable factor of the test antenna cable is designated throughout all parts of the present document as u_{j19}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the cable factor of the test antenna cable is taken as 0,50 dB since in this measurement, the cable changes position in both stages (the height of the test antenna being optimized in both stages) even though the precautions detailed in the methods have been observed.

4.3.1.2.6 Receiving device

Whereas the first stage of a spurious emission test is to observe and record the received level from the EUT on the receiving device, the second stage involves the adjustment of the output level of a signal generator to achieve the same received level from a substitution antenna. As a consequence of this methodology, the receiving device contributes neither linearity nor absolute level uncertainty to either stage of the test.

Receiving device: absolute level: The standard uncertainty of the contribution, due to the absolute level uncertainty of the receiving device, is designated throughout all parts of the present document as u_{j47}.

NOTE 1: In this example case the standard uncertainty of the contribution, due to the absolute level uncertainty of the receiving device is taken as 0,00 dB.

Receiving device: linearity: The standard uncertainty of the contribution, due to the receiving device linearity, is designated throughout all parts of the present document as u_{j48}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the receiving device linearity is taken as 0,00 dB.

4.3.1.3 Contribution from the random component

Random uncertainty: The magnitude can be assessed from multiple measurements of the spurious emission. The standard uncertainty of the contribution due to the random uncertainty is designated throughout all parts of the present document as u_{i01}. See also clause 5.5 and the note in clause 6.4.7 of TR 102 273-1-1, as well as note in clause A.18 of the present document.

The EUT measurement was repeated ten times. The following results were obtained in dBμV (before correcting for cabling and attenuator network insertion loss):

65,4; 63,4; 66,0; 65,3; 63,0; 64,9; 65,2; 66,8; 65,5; 63,7.

Converting to linear terms (V):

$1{,}862 \times 10^{-3}$; $1{,}479 \times 10^{-3}$; $1{,}995 \times 10^{-3}$; $1{,}841 \times 10^{-3}$; $1{,}413 \times 10^{-3}$; $1{,}758 \times 10^{-3}$; $1{,}820 \times 10^{-3}$;
$2{,}188 \times 10^{-3}$; $1{,}884 \times 10^{-3}$; $1{,}531 \times 10^{-3}$;

The two sums X and Y are calculated:

X = the sum of the measured values = $17{,}77 \times 10^{-3}$ V;

Y = the sum of the squares of the measured values = $32{,}10 \times 10^{-6}$ V^2

$$u_{c\ random} = \sqrt{\frac{Y - \frac{X^2}{n}}{n-1}} = \sqrt{\frac{32{,}10 \times 10^{-6} - \frac{\left(17{,}77 \times 10^{-3}\right)^2}{10}}{10-1}} = 238{,}3 \times 10^{-6} \qquad \text{(formula 5.6)}$$

As the result is obtained as the mean value of ten measurements and the standard uncertainty of the random uncertainty is:

$$u_{j\ random} = \frac{238{,}3 \times 10^{-6}}{1{,}777 \times 10^{-3}} \times \frac{100}{11{,}5} = 1{,}17 \text{ dB}$$

NOTE: In this example case the standard uncertainty of the contribution due to the random uncertainty is 1,17 dB.

4.3.1.4 Summary table of contributory components

All the uncertainty contributions for this part of the procedure are listed in table 17.

Table 17: Contributions from the EUT measurement

$u_{j \text{ or } i}$	**Description of uncertainty contributions**	**dB**
u_{j37}	*mismatch: receiving part*	0,00
u_{j54}	*EUT: influence of setting the power supply on the spurious emission level*	0,03
u_{j51}	*EUT: influence of the ambient temperature on the spurious emission level*	0,03
u_{j55}	*EUT: mutual coupling to the power leads*	0,50
u_{j20}	*position of the phase centre: within the EUT volume*	0,12
u_{j21}	*positioning of the phase centre: within the EUT over the axis of rotation of the turntable*	0,02
u_{j16}	*range length*	0,00
u_{j34}	*ambient effect*	0,00
u_{j08}	*mutual coupling: amplitude effect of the test antenna on the EUT*	0,00
u_{j04}	*Mutual coupling: EUT to its images in the absorbing material*	0,50
u_{j13}	*mutual coupling: EUT to its image in the ground plane*	0,15
u_{j01}	*reflectivity of absorbing material: EUT to the test antenna*	0,00
u_{j06}	*mutual coupling: test antenna to its images in the absorbing material*	0,00
u_{j14}	*mutual coupling: test antenna to its image in the ground plane*	0,00
u_{j18}	*correction: measurement distance*	0,00
u_{j17}	*correction: off boresight angle in elevation plane*	0,00
u_{j45}	*antenna: gain of the test antenna*	0,00
u_{j46}	*antenna: tuning of the test antenna*	0,00
u_{j22}	*position of the phase centre: test antenna*	0,00
u_{j40}	*insertion loss: test antenna attenuator*	0,00
u_{j41}	*insertion loss: test antenna cable*	0,00
u_{j19}	*cable factor: test antenna cable*	0,50
u_{j47}	*receiving device: absolute level*	0,00
u_{j48}	*receiving device: linearity*	0,00
u_{i01}	*random uncertainty (see note in clause A.18 of the present document and note in clause 6.4.7 of TR 102 273-1-1)*	1,17

The standard uncertainties from table 17 should be combined by RSS in accordance with TR 102 273-1-1 [6], clause 5. This gives the combined standard uncertainty ($u_{c \text{ contribution from the EUT measurement}}$) for the EUT measurement in dB.

The value of $u_{c \text{ contribution from the EUT measurement}}$ is calculated as 1,47 dB.

4.3.2 Uncertainty contributions: stage 2: substitution measurement

The second stage of the spurious emission test (the substitution) involves replacing the EUT with a substitution antenna and signal source as shown in figure 7, and adjusting the output level of the signal generator until the same level as in stage one is achieved on the receiving device.

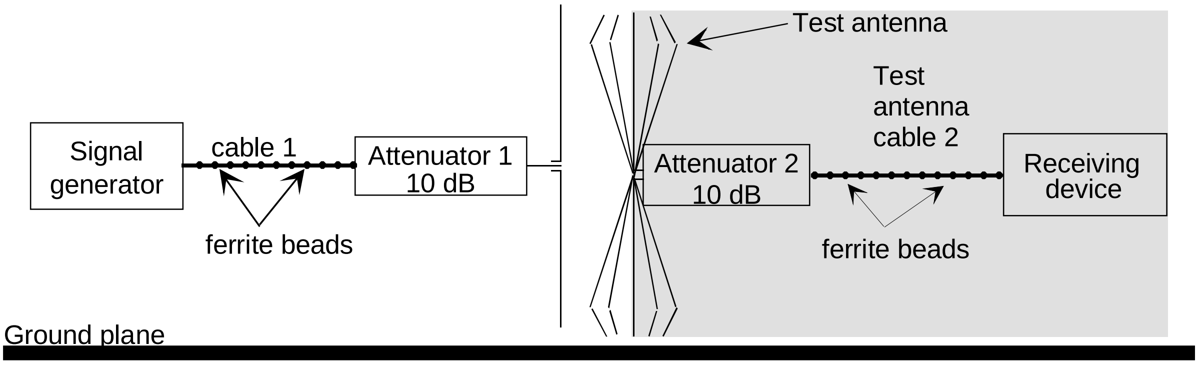


Figure 7: Stage two: typical emission substitution test

Whereas figure 7 shows, schematically, the test equipment set-up for this substitution stage of the spurious emission test, figure 8, an analysis diagram, provides a detailed picture of the individual uncertainty components (each of which contributes its own uncertainty) for this stage in the measurement. As stated above, the shaded areas represent components common to both stages of the test method.

4.3.2.1 Contributions from the mismatch components

Mismatch uncertainty transmitting and receiving parts: The value of the combined standard uncertainty of the contribution due to the mismatch for the substitution measurement are calculated from the approach described in annex D. For this stage it is calculated in two parts. Firstly the standard uncertainty of the contribution due to the mismatch in the transmitting part, i.e. between the signal generator, cable, attenuator and the substitution antenna and secondly, that for the receiving part, i.e. between the test antenna, attenuator, cable and the receiver. However, only the contribution for the transmitting part is actually calculated since the receiving part is common to both stages of the test and its uncertainty contribution therefore largely cancels.

Mismatch: transmitting part:

Signal generator:	Output reflection coefficient: $\lvert\rho_G\rvert$	= 0,20
Cable:	Input and output reflection coefficients: $\lvert S_{11}\rvert$ and $\lvert S_{22}\rvert$	= 0,07
	Attenuation: 1 dB = $\lvert S_{12}\rvert = \lvert S_{21}\rvert$	= 0,891
Attenuator:	Input and output reflection coefficients $\lvert S_{11}\rvert = \lvert S_{22}\rvert$	= 0,05
	Attenuation = 10 dB $\lvert S_{12}\rvert = \lvert S_{21}\rvert$	= 0,3162
Transmitting antenna:	Input reflection coefficient: $\lvert\rho_{TA}\rvert$	= 0,333

All these contributions are U-distributed. Those components that cancel are not calculated. Other contributions are (see annex D):

$u_{j\ \text{generator and cable 1}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$u_{j\ \text{cable 1 and attenuator 1}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$$u_{j\ attenuator\ 1 and\ antenna} = \frac{0{,}05 \times 0{,}333 \times 100}{\sqrt{2}}\,\% = 1{,}177\ \%$$

$u_{j\ \text{generator and attenuator 1}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$$u_{j\ cable\ 1 and\ antenna} = \frac{0{,}07 \times 0{,}333 \times 0{,}316^2 \times 100}{\sqrt{2}}\,\% = 0{,}165\ \%$$

$$u_{j\ generator\ and\ antenna} = \frac{0{,}2 \times 0{,}333 \times 0{,}891^2 \times 0{,}316^2 \times 100}{\sqrt{2}}\,\% = 0{,}373\ \%$$

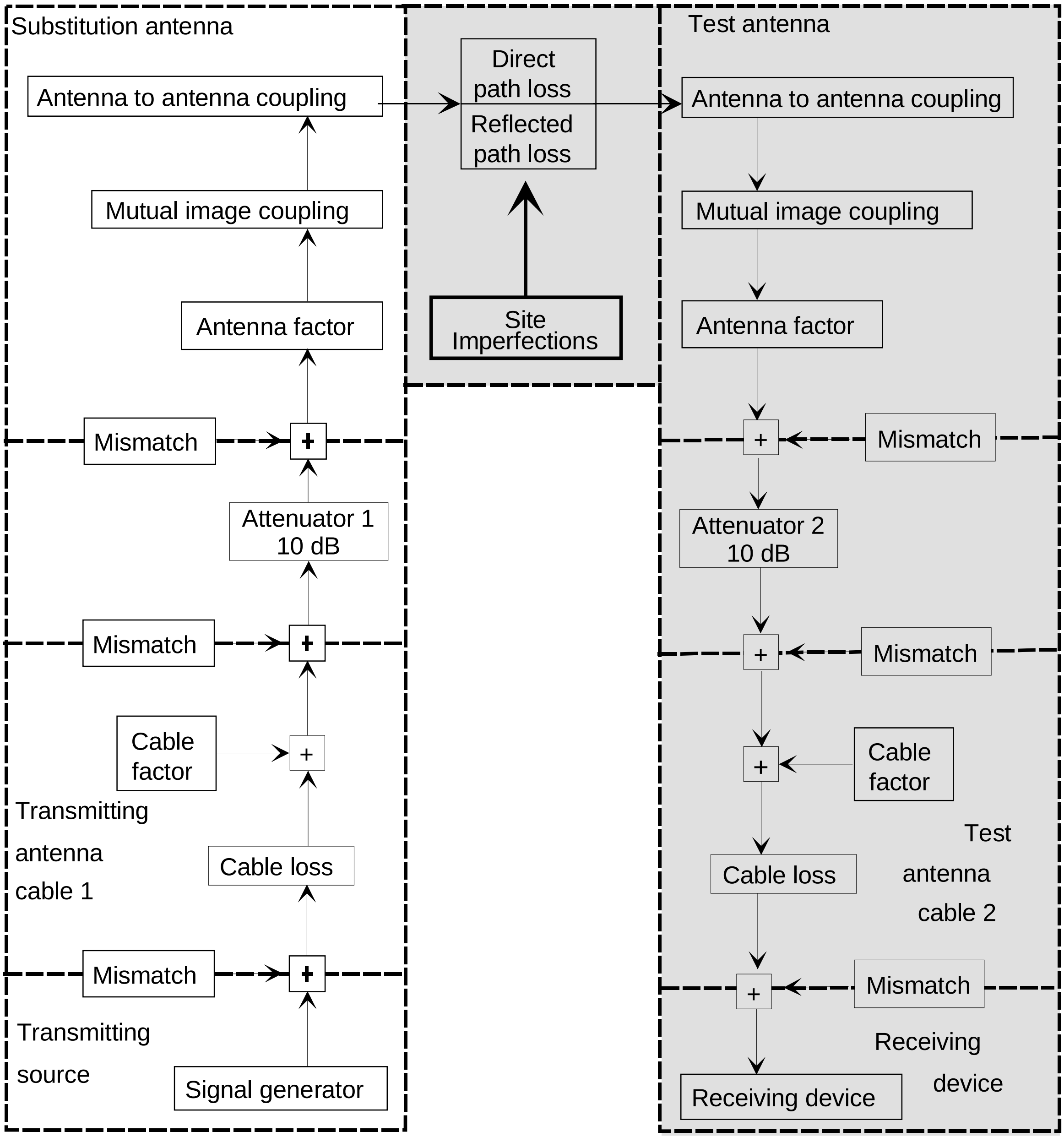


Figure 8: Stage two: Substitution measurement individual uncertainty components

The combined standard uncertainty of the mismatch is then calculated:

$$u_{c\,mismatch:substitution} = \sqrt{1{,}177^2 + 0{,}165^2 + 0{,}373^2} = 1{,}25\ \%$$

transforming to the logarithmic form (see annex C): 1,24 %/11,5 = 0,11 dB.

The standard uncertainty of the contribution due to the mismatch in the transmitting part, is designated throughout all parts of the present document as u_{j36}. Its value in this example is 0,11 dB.

Mismatch: receiving part:

The mismatch uncertainty between the test antenna and the receiving device contributes equally to both stages of the test and therefore has no contribution to the combined standard uncertainty. Therefore it is not calculated. The standard uncertainty of the contribution due to mismatch in the receiving part is designated throughout all parts of the present document as u_{j37}.

NOTE: In this example case the standard uncertainty of the contribution due to mismatch in the receiving part is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

4.3.2.2 Contributions from the individual components

4.3.2.2.1 Signal generator

Signal generator: absolute output level: The signal generator replaces the EUT in the substitution part of this test and, as a result, should be included in the combined standard uncertainty since it does not cancel as a systematic offset. The standard uncertainty of the contribution, due to the signal generator absolute output level, is designated throughout all parts of the present document as u_{j38}.

NOTE 1: In this example case the uncertainty of the contribution due to the signal generator absolute output level uncertainty is obtained from the manufacturer's data sheet as ±1,0 dB. As nothing is said about the distribution of this uncertainty, a rectangular distribution (see TR 102 273-1-1 [6], clause 5.1.2) in logs is assumed, and the standard uncertainty is calculated as 0,58 dB.

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

NOTE 2: In this example case the standard uncertainty of the contribution due to the signal generator output level stability is taken as 0,00 dB as it is covered by the absolute level uncertainty.

4.3.2.2.2 Substitution antenna cable

Insertion loss: substitution antenna cable: The substitution antenna cable has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the cable is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution due to the insertion loss uncertainty of the substitution antenna cable, is designated throughout all parts of the present document as u_{j41}.

NOTE 1: In this example case the uncertainty of the contribution due to the insertion loss uncertainty of the substitution antenna cable is taken from the manufacturer's data sheet as ±0,5 dB. As nothing is said about the distribution, a rectangular distribution (see TR 102 273-1-1 [6], clause 5.1.2) in logs is assumed and the standard uncertainty is calculated as 0,29 dB.

Cable factor: substitution antenna cable: Cable factor is defined as the total effect of the antenna cable's influence on the measuring system including its interaction with the site. It consists of the leakage caused by cable screening inefficiency, parasitic effects (acting as a director or reflector) and introducing an unbalanced, common mode current into the dipole balun. In a radiated measurement the standard uncertainty of the cable factor, associated with the substitution antenna cable is 0,5 dB provided the precautions detailed in the methods have been observed, i.e. routing and dressing of cables with ferrites. If no prevention has been attempted the standard uncertainty is 4,0 dB (justification for these values is given in annex E). The standard uncertainty of the contribution, due to the cable factor of the substitution antenna cable, is designated throughout all parts of the present document as u_{j19}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the cable factor of the substitution antenna cable is taken as 0,50 dB since the precautions detailed in the methods are assumed to have been observed.

4.3.2.2.3 Substitution antenna attenuator

Insertion loss: substitution antenna attenuator: The attenuator has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the attenuator is not used outside the manufacturer's specification. At any given frequency the insertion loss is taken from the manufacturer's data sheet since it does not cancel as a systematic offset (it only appears in one stage of the test). The standard uncertainty of the contribution, due to the insertion loss uncertainty of the substitution antenna attenuator, is designated throughout all parts of the present document as u_{j40}.

NOTE: In this example case the uncertainty of the contribution, due to the insertion loss uncertainty of the substitution antenna attenuator, is obtained from the manufacturer's data sheet as ±0,3 dB. As nothing is said about the distribution, a rectangular distribution (see TR 102 273-1-1 [6], clause 5.1.2) in logs is assumed and the standard uncertainty is calculated as 0,17 dB.

4.3.2.2.4 Substitution antenna

Antenna: gain of the substitution antenna: The gain (and its uncertainty) of the substitution antenna is only involved in the second stage of the test. The standard uncertainty of the contribution due to the gain of the substitution antenna is designated throughout all parts of the present document as u_{j45}. For ANSI dipoles the value should be obtained from table 18.

Table 18: Uncertainty contribution: antenna: gain of the test or substitution antenna

Frequency	Standard uncertainty of the contribution
30 MHz ≤ frequency ≤ 80 MHz	1,73 dB
80 MHz < frequency ≤ 180 MHz	0,60 dB
frequency > 180 MHz	0,30 dB
NOTE: For other antenna types the figures should be taken from manufacturer's data sheets. If a figure is not given the standard uncertainty is 1,0 dB.	

NOTE 1: In this example case the standard uncertainty of the contribution due to the gain of the substitution antenna is taken as 0,3 dB as an ANSI dipole is used and the frequency is above 180 MHz.

Antenna: tuning of the substitution antenna: Uncertainty is introduced as a result of the inaccurate tuning of the substitution antenna. This only occurs in stage two of the measurement. The standard uncertainty of the contribution, due to the tuning of the substitution antenna, is designated throughout all parts of the present document as u_{j46}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the tuning of the substitution antenna is taken as 0,06 dB.

Position of the phase centre: substitution antenna: Uncertainty is introduced as a result of the inaccurate positioning of the phase centre of the substitution antenna. This only occurs in stage two of the measurement. The standard uncertainty of the contribution, due to the position of the phase centre of the substitution antenna, is designated throughout all parts of the present document as u_{j22}.

NOTE 3: In this example case the standard uncertainty of the contribution due to the uncertainty in the position of the phase centre of the substitution antenna has been calculated from (± (the offset from axis of rotation) / (range length) x 100 %). The positioning uncertainty is ±0,01 m and therefore the worst case uncertainty = 0,01 / 3,0 = 0,333 %. As the offset can be anywhere between these limits, the uncertainty is taken to be rectangularly distributed (see TR 102 273-1-1 [6], clause 5.1.2) and the standard uncertainty is calculated as 0,192 %. This is transformed to the logarithmic form (see annex C), to be 0,02 dB.

4.3.2.2.5 Site factors

Ambient effect: Uncertainty is introduced as a result of local ambient signals raising the noise floor at the measurement frequency. The standard uncertainty of the contribution due to the ambient effect is designated throughout all parts of the present document as u_{j34}. The values of the standard uncertainty should be taken from table 19.

Table 19: Uncertainty contribution: Ambient effect

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

NOTE 1: In this example case the standard uncertainty of the contribution due to the ambient effect is taken as 0,00 dB, since the chamber is assumed to be shielded.

Mutual coupling: substitution antenna to its images in the absorbing material: This uncertainty is the effect of the change produced in the antenna's input impedance and/or gain. The standard uncertainty of the contribution due to the mutual coupling of the substitution antenna to its images in the absorbing material is designated throughout all parts of the present document as u_{j06}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the mutual coupling of the transmitting antenna to its images in the absorbing materials is taken as 0,5 dB (see annex A).

Mutual coupling: substitution antenna to its image in the ground plane: This uncertainty is the effect of the change produced in the antenna's input impedance and/or gain. The standard uncertainty of the contribution due to the mutual coupling of the substitution antenna to its image in the ground plane, designated throughout all parts of the present document as u_{j14} has a value of 0,00 dB for ANSI dipoles since it is included, where significant, in the mutual coupling and mismatch loss correction factors (see table A.20). For other dipoles the value can be obtained from table 20.

Table 20: Uncertainty contribution of the mutual coupling between the substitution antenna and its image in the ground plane

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

NOTE 3: In this example case the standard uncertainty of the contribution due to mutual coupling between the substitution antenna and its image in the ground plane is taken as 0,58 dB.

Mutual coupling: substitution antenna to the test antenna: This is the effect produced by any change in gain of the antennas which results from their close spacing. The standard uncertainty of the contribution due to the mutual coupling of the substitution antenna to the test antenna, designated throughout all parts of the present document as u_{j11}. For ANSI dipoles the value of this uncertainty is 0,00 dB as it is included, where significant, in the mutual coupling and mismatch loss correction factors. For non-ANSI dipoles the standard uncertainty for frequencies can be taken from table 21.

Table 21: Uncertainty contribution of the mutual coupling between the substitution and test antennas

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

NOTE 4: In this example case the standard uncertainty of the contribution due to mutual coupling between the substitution and test antennas is taken as 0,00 dB as the frequency is above 180 MHz.

Mutual coupling: interpolation of mutual coupling and mismatch loss correction factors, only for ANSI dipoles: The standard uncertainty of the contribution due to the interpolation of mutual coupling and mismatch loss correction factors, is designated throughout all parts of the present document as u_{j12}. For spot frequencies given in table A.20, the value of the contribution is 0,00 dB. However, for all other frequencies, the standard uncertainty should be obtained from table 22.

Table 22: Uncertainty contribution of the interpolation of mutual coupling and mismatch loss correction factors

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

NOTE 5: In this example case the standard uncertainty of the contribution due to the interpolation of mutual coupling and mismatch loss correction factors is taken as 0,00 dB as the frequency is above 180 MHz.

Range length: This contribution is associated with the curvature of the phase front from the substitution antenna to the test antenna. The standard uncertainty of the contribution, due to range length, is designated throughout all parts of the present document as u_{j16}. The standard uncertainty is 0,00 dB if ANSI dipoles are used. For other types of antenna the standard uncertainty of the contribution should be obtained from table 23.

Table 23: Uncertainty contribution of the range length (verification)

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

NOTE 6: The standard uncertainty of the contribution due to the range length is taken as 0,00 dB since in this case the range length is $\geq 2\ (d_1+d_2)^2/\lambda$.

Reflectivity of absorbing material: substitution antenna to the test antenna: This uncertainty is associated with the magnitude of the reflections occurring from the side walls, end walls and ceiling. These magnitudes are a function of the quality of the absorber at the frequency of test. However, in this, a substitution measurement, the contribution is only concerned with taking into account the possible differences in the antenna patterns (principally in the vertical plane) between the EUT and substitution antenna. The standard uncertainty of the contribution due to the reflectivity of the absorbing material between the substitution and test antenna is designated throughout all parts of the present document as u_{j02}.

NOTE 7: In this example case the standard uncertainty of the contribution due to the reflectivity of the absorbing material between the substitution and test antenna is 0,50 dB (see annex A).

Mutual coupling: test antenna to its images in the absorbing material: This is the uncertainty due to the mutual coupling between the test antenna and its images in the ceiling, side and end walls and is the effect of the change produced in the antenna's input impedance and/or gain. As this is the second stage of a substitution measurement and the uncertainty is common to both stages it will only contribute in this stage if the test antenna is located at a different height on the antenna mast from the first stage. The standard uncertainty of the contribution, due to the mutual coupling of the test antenna to its images in the absorbing material, is designated throughout all parts of the present document as u_{j06}.

NOTE 8: In this example case the standard uncertainty of the contribution due to the mutual coupling of the test antenna to its images in the absorbing material is taken as 0,50 dB since this is the second stage of a substitution measurement and the test antenna is assumed to be located at a different height to stage one and therefore the contribution does not cancel.

Mutual coupling: test antenna to its image in the ground plane: As this is the second stage of a substitution measurement and the uncertainty is common to both stages it will only contribute in this stage if the test antenna is located at a different height on the antenna mast from the first stage. The standard uncertainty of the contribution, due to the mutual coupling of the test antenna to its image in the ground plane, is designated throughout all parts of the present document as u_{j14}.

NOTE 9: In this example case the standard uncertainty of the contribution due to the mutual coupling of the test antenna to its image in the ground plane is taken as 0,50 dB since this is the second stage of a substitution measurement and the test antenna is assumed to be located at a different height to stage one and therefore the contribution does not cancel.

4.3.2.2.6 Test antenna

Correction: measurement distance: For those tests in which the test antenna on the mast peaks at different heights in the two stages, a correction should be made to account for the different measurement distances. Where a correction is required the standard uncertainty of the correction factor should be taken as 0,10 dB. The standard uncertainty of the contribution due to the correction for measurement distance is designated throughout all parts of the present document as u_{j18}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the correction for measurement distance is taken as 0,10 dB since it is assumed that, in this second stage, a different height of test antenna has been necessary and the correction applied.

Correction: off boresight angle in elevation plane: For those tests in which the test antenna on the mast peaks at different heights in the two stages, a correction should be made to account for the different angles subtended by the EUT/substitution antenna. Where a correction is required the standard uncertainty of the correction factor should be taken as 0,10 dB. The standard uncertainty of the contribution due to the correction for off boresight angle in elevation plane is designated throughout all parts of the present document as u_{j17}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the correction for off boresight angle in the elevation plane is taken as 0,10 dB since it is assumed that, in this second stage, a different height of test antenna has been necessary and the correction applied.

Antenna: gain of the test antenna: The gain, and its uncertainty, of the test antenna act as systematic offsets since they are present in both stages of the test. The standard uncertainty of the contribution, due to the uncertainty of the gain of the test antenna, is designated throughout all parts of the present document as u_{j45}.

NOTE 3: In this example case the standard uncertainty of the contribution due to the uncertainty of the gain of the test antenna is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

Antenna: tuning of the test antenna: This uncertainty is introduced as a result of inaccurate tuning of the test antenna. The standard uncertainty of the contribution, due to the tuning of the test antenna, is designated throughout all parts of the present document as u_{j46}.

NOTE 4: In this example case the standard uncertainty of the contribution due to the tuning of the test antenna is taken as 0,00 dB since the uncertainty is systematic i.e. it is assumed constant and common to both stages of the measurement and, provided that once set in stage one of the test it is not subsequently re-tuned, its contribution is the same in both stages.

Position of the phase centre: test antenna: The horizontal position of the test antenna defines one end of the range length. The standard uncertainty of the contribution, due to the position of the phase centre of the test antenna, is designated throughout all parts of the present document as u_{j22}.

NOTE 5: In this example case the test antenna is assumed to describe a vertical straight line as its height on the mast is changed. The standard uncertainty of the contribution due to the position of the phase centre of the test antenna is assumed to be 0,00 dB (see annex A).

4.3.2.2.7 Test antenna attenuator

Insertion loss: test antenna attenuator: The attenuator has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the attenuator is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution due to the insertion loss of the test antenna attenuator is designated throughout all parts of the present document as u_{j40}.

NOTE: In this example case the standard uncertainty of the contribution, due to the insertion loss uncertainty of the test antenna attenuator, is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

4.3.2.2.8 Test antenna cable

Insertion loss: test antenna cable: The test antenna cable has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the cable is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution, due to the insertion loss uncertainty of the test antenna cable, is designated throughout all parts of the present document as u_{j41}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the insertion loss uncertainty of the test antenna cable is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

Cable factor: test antenna cable: Cable factor is defined as the total effect of the antenna cable's influence on the measuring system including its interaction with the site. It consists of the leakage caused by cable screening inefficiency, parasitic effects (acting as a director or reflector) on the test antenna and introducing an unbalanced, common mode current into the dipole balun. In a radiated measurement the standard uncertainty of the cable factor, associated with each cable, is 0,5 dB provided that the precautions detailed in the methods have been observed, i.e. routing and dressing of cables with ferrites. If no prevention has been attempted the standard uncertainty is 4,0 dB (justification for these values is given in annex E). The standard uncertainty of the contribution due to the cable factor of the test antenna cable is designated throughout all parts of the present document as u_{j19}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the cable factor of the test antenna cable is taken as 0,50 dB since in this measurement, the cable changes position in both stages (the height of the test antenna being optimized in both stages) even though the precautions detailed in the methods have been observed.

4.3.2.2.9 Receiving device

Whereas the first stage of a spurious emission test is to observe and record the received level from the EUT on the receiving device, the second stage involves the adjustment of the output level of a signal generator to achieve the same received level from a substitution antenna. As a consequence of this methodology, the receiving device contributes neither linearity nor absolute level uncertainty to either stage of the test.

Receiving device: absolute level: The standard uncertainty of the contribution, due to the absolute level uncertainty of the receiving device, is designated throughout all parts of the present document as u_{j47}.

NOTE 1: In this example case the standard uncertainty of the contribution, due to the absolute level uncertainty of the receiving device is taken as 0,00 dB.

Receiving device: linearity: The standard uncertainty of the contribution, due to the receiving device linearity, is designated throughout all parts of the present document as u_{j48}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the receiving device linearity is taken as 0,00 dB.

4.3.2.3 Contribution from the random component

Random uncertainty: The magnitude can be assessed from multiple measurements of the substitution measurement. The standard uncertainty of the contribution due to the random uncertainty is designated throughout all parts of the present document as u_{i01}. See also clause 5.5 and the note in clause 6.4.7 of TR 102 273-1-1, as well as note in clause A.18 of the present document.

The substitution measurement was repeated ten times. The following levels were set on the signal generator in dBm (before correcting for cabling and attenuator network insertion loss):

-20,1; -20,1; -20,2; -20,2; -20,1; -20,1; -20,2; -20,3; -20,3; -20,3.

Converting to linear terms:

$9{,}772 \times 10^{-3}$; $9{,}772 \times 10^{-3}$; $9{,}550 \times 10^{-3}$; $9{,}550 \times 10^{-3}$; $9{,}772 \times 10^{-3}$; $9{,}772 \times 10^{-3}$; $9{,}550 \times 10^{-3}$; $9{,}333 \times 10^{-3}$; $9{,}333 \times 10^{-3}$; $9{,}333 \times 10^{-3}$;

The two sums X and Y are calculated:

X = the sum of the measured values = $95{,}737 \times 10^{-3}$ (W);

Y = the sum of the squares of the measured values = $916{,}89 \times 10^{-6}$ W^2

$$u_{c\ random} = \sqrt{\frac{Y - \frac{X^2}{n}}{n-1}} = \sqrt{\frac{916{,}89 \times 10^{-6} - \frac{\left(95{,}737 \times 10^{-3}\right)^2}{10}}{10-1}} = 192{,}3 \times 10^{-6} \qquad \text{(formula 5.6)}$$

As the result is obtained as the mean value of 10 measurements and the standard uncertainty of the random uncertainty is:

$$u_{j\ random} = \frac{192{,}3 \times 10^{-6}}{9{,}5737 \times 10^{-3}} \times \frac{100}{23{,}0} = 0{,}175 \text{ dB}$$

NOTE: In this example case the standard uncertainty of the contribution due to the random uncertainty is 0,05 dB.

4.3.2.4 Summary table of contributory components

All the uncertainties contributions for this part of the procedure are listed in table 24.

Table 24: Contributions from the substitution

$u_{j\ or\ i}$	Description of uncertainty contributions	dB
u_{j36}	*mismatch: transmitting part*	0,11
u_{j37}	*mismatch: receiving part*	0,00
u_{j38}	*signal generator: absolute output level*	0,58
u_{j39}	*signal generator: output level stability*	0,00
u_{j41}	*insertion loss: substitution antenna cable*	0,29
u_{j19}	*cable factor: substitution antenna cable*	0,50
u_{j40}	*insertion loss: substitution antenna attenuator*	0,17
u_{j45}	*antenna: gain of the substitution antenna*	0,30
u_{j46}	*antenna: tuning of the substitution antenna*	0,06
u_{j22}	*position of the phase centre: substitution antenna*	0,02
u_{j34}	*ambient effect*	0,00
u_{j06}	*mutual coupling: substitution antenna to its images in the absorbing material*	0,50
u_{j14}	*mutual coupling: substitution antenna to its image in the ground plane*	0,58
u_{j11}	*mutual coupling: substitution antenna to the test antenna*	0,00
u_{j12}	*mutual coupling: interpolation of mutual coupling and mismatch loss correction factors*	0,00
u_{j16}	*range length*	0,00
u_{j02}	*reflectivity of absorbing material: substitution antenna to the test antenna*	0,50
u_{j06}	*mutual coupling: test antenna to its images in the absorbing material*	0,50
u_{j14}	*mutual coupling: test antenna to its image in the ground plane*	0,50
u_{j18}	*correction: measurement distance*	0,10
u_{j17}	*correction: off boresight angle in elevation plane*	0,10
u_{j45}	*antenna: gain of the test antenna*	0,00
u_{j46}	*antenna: tuning of the test antenna*	0,00
u_{j22}	*position of the phase centre: test antenna*	0,00
u_{j40}	*insertion loss: test antenna attenuator*	0,00
u_{j41}	*insertion loss: test antenna cable*	0,00
u_{j19}	*cable factor: test antenna cable*	0,50
u_{j47}	*receiving device: absolute level*	0,00
u_{j48}	*receiving device: linearity*	0,00
u_{i01}	*random uncertainty (see note in clause A.18 of the present document and note in clause 6.4.7 of TR 102 273-1-1)*	0,175

The standard uncertainties from table 24 should be combined by RSS in accordance with TR 102 273-1-1 [6], clause 5. This gives the combined standard uncertainty ($u_{c\ substitution\ measurement}$) for the NSA measurement in dB.

The value of $u_{c\ substitution\ measurement}$ is calculated as 1,56 dB.

4.3.2.5 Expanded uncertainty for the spurious emission test

The combined standard uncertainty of the results of the spurious emissions test is the combination of the components outlined in clauses 4.3.1.4 and 4.3.2.4. The components to be combined are $u_{c\ EUT\ measurement}$ and $u_{c\ substitution\ measurement}$.

$$u_c = \sqrt{1{,}47^2 + 1{,}56^2} = 2{,}15 \text{ dB}$$

The expanded uncertainty is ±1,96 x 2,15 dB = ±4,21 dB at a 95 % confidence level.

4.4 Example 3: measurement of a receiver parameter (sensitivity)

For the measurement of receiver sensitivity two stages of test are involved. The first stage (determining the transform factor of the site) involves measuring the field strength at the point where the receiver will be placed and determining the relationship between the signal generator output power level and the resulting field strength. The second stage (the EUT measurement) involves replacing the measuring antenna with the EUT and adjusting the output level of the signal generator until the required response is obtained on the receiver. The signal generator output power level is then converted to field strength using the transform factor.

4.4.1 Uncertainty contributions: stage 1: transform factor measurement

The first stage of the receiver sensitivity test is to determine the transform factor of the site. This is normally carried out by placing a measuring antenna in the volume occupied by the EUT and determining the relationship between the signal generator output power and the resulting field strength. The test equipment configuration is shown in figure 9. The components shown shaded are common to both stages of the test.

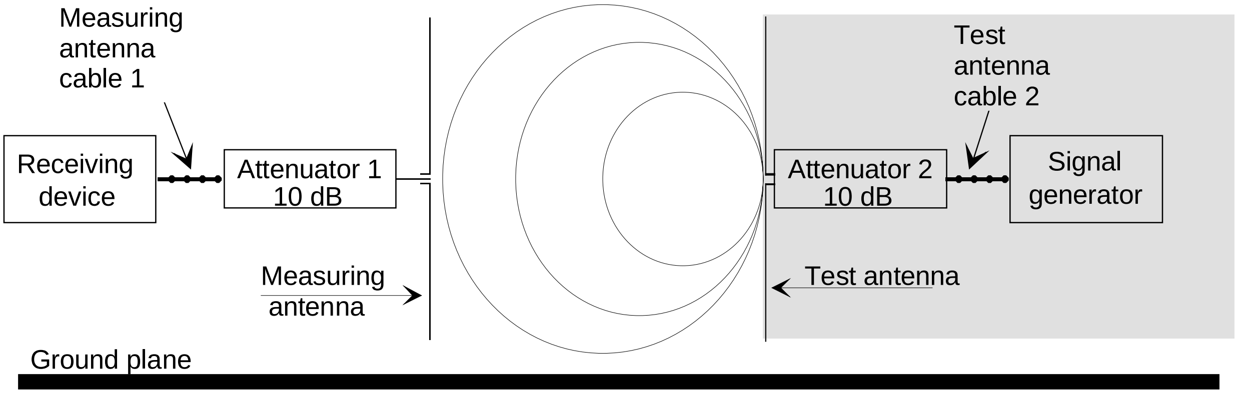


Figure 9: stage 1: transform factor measurement

Due to the commonality of all of the components from the test antenna to the receiver in both stages of the test, the mismatch uncertainty contributes identically to both stages and hence does not contribute to the combined standard uncertainty of the measurement. Similarly, for the systematic uncertainty contributions (e.g. test antenna cable loss etc.) of the individual components.

Whereas figure 9 shows, schematically, the equipment set-up for this stage of the receiver sensitivity test, an analysis diagram of the individual components (each of which contributes its own uncertainty) for this stage of the measurement is shown in figure 10. Again, as stated above, the shaded areas represent components common to both stages of the receiver sensitivity test.

4.4.1.1 Contributions from the mismatch components

Mismatch in the transmitting and receiving part: The value of the combined standard uncertainty of the contribution due to the mismatch are calculated from the approach described in annex D. For this stage is calculated in two parts. Firstly the standard uncertainty of the contribution due to the mismatch in the transmitting part, i.e. between the signal generator, cable, attenuator and the test antenna and secondly, that for the receiving part, i.e. between the receiving antenna, attenuator, cable and the receiving device.

Mismatch: transmitting part:

The standard uncertainty of the contribution due to mismatch in the transmitting part is designated throughout all parts of the present document as u_{j36}.

NOTE: In this example case the uncertainty due to mismatch in the receiving part is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

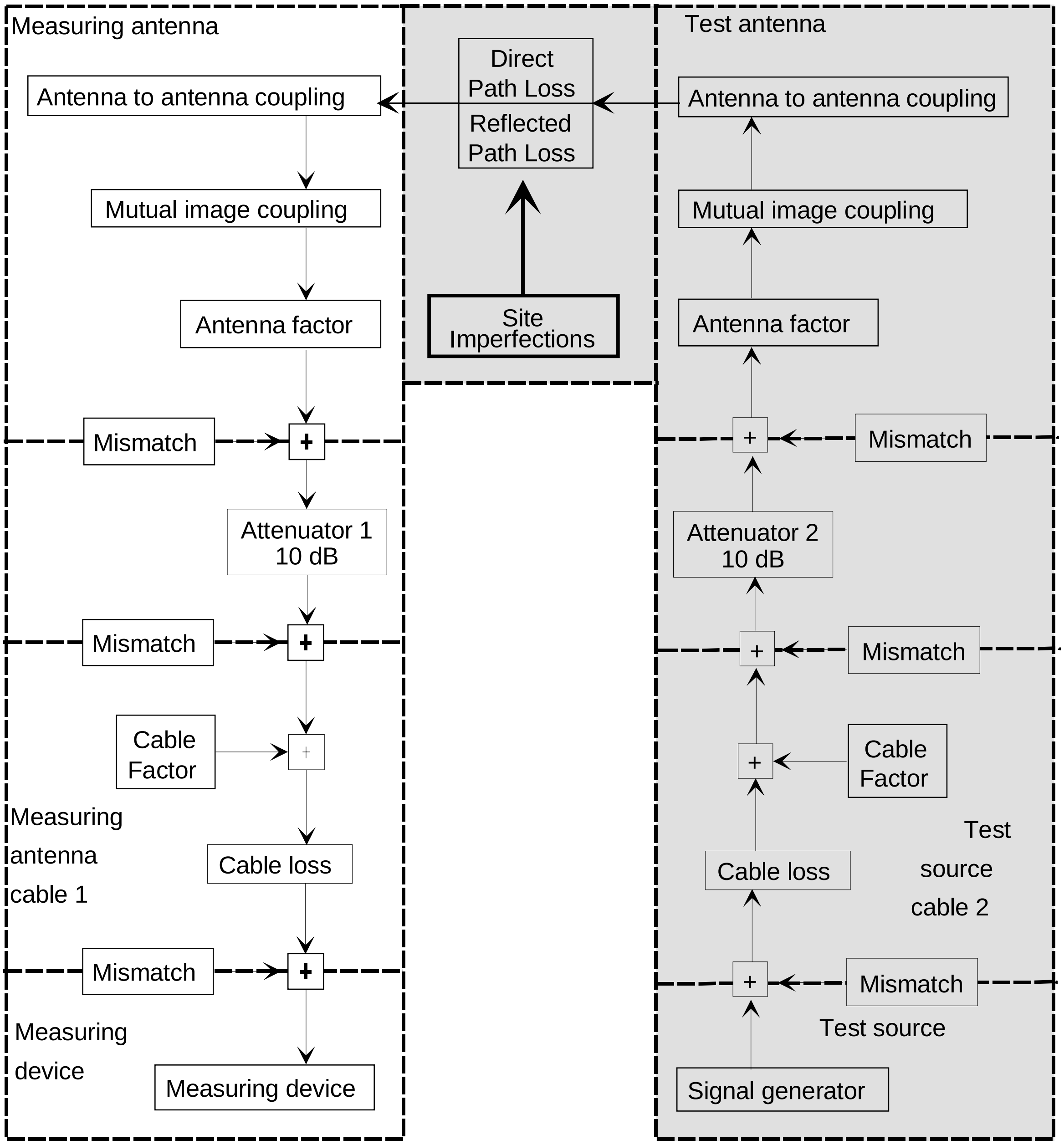


Figure 10: Schematic of the transform factor measurement

Mismatch: receiving part:

Measuring antenna:	Input reflection coefficient: $|\rho_{RA}|$	= 0,333
Attenuator:	Input and output reflection coefficients $|S_{11}| = |S_{22}|$	= 0,05
	Attenuation = 10 dB $|S_{12}| = |S_{21}|$	= 0,3162
Cable:	Input and output reflection coefficients: $|S_{11}|$ and $|S_{22}|$	= 0,07
	Attenuation: 1 dB = $|S_{12}| = |S_{21}|$	= 0,891
Measuring device:	Input reflection coefficient: $|\rho_{RD}|$	= 0,20

$$u_{j\ mismatch: antenna\ and\ attenuator\ 2} = \frac{0{,}333 \times 0{,}05 \times 100}{\sqrt{2}}\,\% = 1{,}177\ \%$$

$u_{j\ attenuator\ 2\ and\ cable\ 2}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$u_{j\ cable\ 2\ and\ receiving\ device}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$$u_{j\ cable 1 and\ antenna} = \frac{0{,}333 \times 0{,}07 \times 0{,}316^2 \times 100}{\sqrt{2}} \% = 0{,}165\ \%$$

$u_{j\ attenuator\ 2\ and\ receiving\ device}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$$u_{j\ antenna\ and\ receiving\ device} = \frac{0{,}333 \times 0{,}2 \times 0{,}316^2 \times 0{,}891^2 \times 100}{\sqrt{2}} \% = 0{,}373\ \%$$

The combined standard uncertainty of the mismatch is then calculated:

$$u_{j\ mismatch: measuring\ part} = \sqrt{1{,}177^2 + 0{,}165^2 + 0{,}373^2} = 1{,}25\ \%$$

transforming to the logarithmic form (see annex C): 1,24 %/11,5 = 0,11 dB

The standard uncertainty of the contribution, due to the mismatch in the direct attenuation measurement, is designated throughout all parts of the present document as u_{j37}. Its value in this example is 0,11 dB.

4.4.1.2 Contributions from the individual components

4.4.1.2.1 Signal generator

Signal generator: absolute output level: There is not necessarily any similarity between the output levels from the signal generator in the two stages of this test. As a result it contributes to both stages. The standard uncertainty of the contribution, due to the signal generator absolute output level, is designated throughout all parts of the present document as u_{j38}. Its value can be derived from manufacturer's data sheet.

NOTE 1: In this example case the uncertainty of the contribution due to the signal generator absolute output level uncertainty is taken from the manufacturer's data sheet as ±1,0 dB. As nothing is said about the distribution of this uncertainty, a rectangular distribution (see TR 102 273-1-1 [6], clause 5.1.2) in logs is assumed, and the standard uncertainty is calculated as 0,58 dB.

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

NOTE 2: In this example case the standard uncertainty of the contribution due to the signal generator output level stability is taken as 0,0 dB as it is covered by the absolute level uncertainty.

4.4.1.2.2 Test antenna cable

Insertion loss: test antenna cable: The test antenna cable has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the cable is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution due to the insertion loss uncertainty of the test antenna cable, is designated throughout all parts of the present document as u_{j41}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the insertion loss uncertainty of the test antenna cable is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

Cable factor: test antenna cable: Cable factor is defined as the total effect of the antenna cable's influence on the measuring system including its interaction with the site. It consists of the leakage caused by cable screening inefficiency, parasitic effects (acting as a director or reflector) on the test antenna and introducing an unbalanced, common mode current into the dipole balun. In a radiated measurement the standard uncertainty of the cable factor, associated with each cable, is 0,5 dB provided that the precautions detailed in the methods have been observed, i.e. routing and dressing of cables with ferrites. If no prevention has been attempted the standard uncertainty is 4,0 dB (justification for these values is given in annex E). The standard uncertainty of the contribution due to the cable factor of the test antenna cable is designated throughout all parts of the present document as u_{j19}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the cable factor of the test antenna cable is taken as 0,00 dB since in this measurement, the cable position, once set in this stage is not subsequently changed during the test.

4.4.1.2.3 Test antenna attenuator

Insertion loss: test antenna attenuator: The attenuator has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the attenuator is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution due to the insertion loss of the test antenna attenuator is designated throughout all parts of the present document as u_{j40}.

NOTE: In this example case the standard uncertainty of the contribution, due to the insertion loss uncertainty of the test antenna attenuator, is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

4.4.1.2.4 Test antenna

Correction: measurement distance: For those tests in which the test antenna on the mast peaks at different heights in the two stages, a correction for measurement distance needs to be made to account for the different measurement distances. In this test, once the position of the test antenna is set in stage one no further adjustment to its position is subsequently made during the test. The standard uncertainty of the contribution due to the correction for measurement distance is designated throughout all parts of the present document as u_{j18}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the correction for measurement distance is taken as 0,00 dB.

Correction: off boresight angle in elevation plane: For those tests in which the test antenna on the mast peaks at different heights in the two stages, a correction needs to be made to account for the different angles subtended by the EUT/substitution antenna. In this test, once the position of the test antenna is set in stage one no further adjustment to its position is subsequently made during the test. The standard uncertainty of the contribution due to the correction for off boresight angle in elevation plane is designated throughout all parts of the present document as u_{j17}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the correction for off boresight angle in elevation plane is taken as 0,00 dB.

Antenna: gain of the test antenna: The gain, and its uncertainty, of the test antenna act as systematic offsets since they are present in both stages of the test. The standard uncertainty of the contribution, due to the uncertainty of the gain of the test antenna, is designated throughout all parts of the present document as u_{j45}.

NOTE 3: In this example case the standard uncertainty of the contribution due to the uncertainty of the gain of the test antenna is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

Antenna: tuning of the test antenna: This uncertainty is introduced as a result of inaccurate tuning of the test antenna. The standard uncertainty of the contribution, due to the tuning of the test antenna, is designated throughout all parts of the present document as u_{j46}.

NOTE 4: In this example case the standard uncertainty of the contribution due to the tuning of the test antenna is taken as 0,00 dB since the uncertainty is systematic i.e. it is assumed constant and common to both stages of the measurement and, provided that once set in stage one of the test it is not subsequently re-tuned, its contribution is the same in both stages.

Position of the phase centre: test antenna: The horizontal position of the test antenna defines one end of the range length. The standard uncertainty of the contribution, due to the position of the phase centre of the test antenna, is designated throughout all parts of the present document as u_{j22}.

NOTE 5: In this example case the test antenna is assumed to describe a vertical straight line as its height on the mast is changed. The standard uncertainty of the contribution due to the position of the phase centre of the test antenna is assumed to be 0,00 dB (see annex A).

4.4.1.2.5 Site factors

Ambient effect: ambient effect: Ambient effect is the uncertainty caused by local ambient signals raising the noise floor at the measurement frequency. The standard uncertainty of the contribution, due to the ambient effect, is designated throughout all parts of the present document as u_{j34}. The values of the standard uncertainty should be taken from table 25.

Table 25: Uncertainty contribution: ambient effect

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

NOTE 1: In this example case the standard uncertainty of the contribution due to the ambient effect is taken as 0,00 dB, since the chamber is assumed to be shielded.

Mutual coupling: test antenna to its images in the absorbing material: This is the uncertainty due to the mutual coupling between the test antenna and its images in the ceiling, side and end walls and is the effect of the change produced in the antenna's input impedance and/or gain. The standard uncertainty of the contribution due to the mutual coupling between the test antenna and its images in the absorbing material is designated throughout all parts of the present document as u_{j06}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the mutual coupling between the test antenna and its images in the absorbing material is taken as 0,00 dB since this is the first stage of a two stage measurement, where, in the second stage, the test antenna is located at the same height on the mast as in this, the first stage.

Mutual coupling: test antenna to its image in the ground plane: This is the uncertainty due to the mutual coupling between the test antenna and its image in the ground plane and is the effect of the change produced in the antenna's input impedance and/or gain when placed close to a ground plane. The standard uncertainty of the contribution due to the mutual coupling between the test antenna and its image in the ground plane is designated throughout all parts of the present document as u_{j14}.

NOTE 3: In this example case the standard uncertainty of the contribution due to the mutual coupling between the test antenna and its image in the ground plane is taken as 0,00 dB since this is the first stage of a two stage measurement, where, in the second stage, the test antenna is located at the same height on the mast as in this, the first stage.

Mutual coupling: measuring antenna to the test antenna: This is the effect produced by any change in gain of the antennas which results from their close spacing. The standard uncertainty of the contribution due to the mutual coupling of the measuring antenna to the test antenna, designated throughout all parts of the present document as u_{j11}, It has a standard uncertainty of 0,00 dB for ANSI dipoles since it is included, where significant, in the mutual coupling and mismatch loss correction factors. For non-ANSI dipoles the standard uncertainty can be taken from table 26.

Table 26: Uncertainty contribution of the mutual coupling between the measuring and test antenna

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

NOTE 4: In this example case the standard uncertainty of the contribution due to mutual coupling between the measuring and test antennas is taken as 0,00 dB as we are using ANSI dipoles.

Mutual coupling: interpolation of mutual coupling and mismatch loss correction factors, only for ANSI dipoles: The standard uncertainty of the contribution, due to the interpolation of mutual coupling and mismatch loss correction factors, is designated throughout all parts of the present document as u_{j12}. It has, for spot frequencies given in table A.20, a value of 0,00 dB. However, for all other frequencies, the standard uncertainty should be obtained from table 27.

Table 27: Uncertainty contribution of the interpolation of mutual coupling and mismatch loss correction factors

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

NOTE 5: In this example case the standard uncertainty of the contribution, due to the interpolation of mutual coupling and mismatch loss correction factors, is taken as 0,00 dB as the frequency is above 180 MHz.

Range length: This contribution is associated with the curvature of the phase front from the measuring antenna to the test antenna. The standard uncertainty of the contribution, due to range length, is designated throughout all parts of the present document as u_{j16}. The standard uncertainty is 0,00 dB if ANSI dipoles are used. For other types of antenna the standard uncertainty of the contribution should be obtained from table 28.

Table 28: Uncertainty contribution of the range length (verification)

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

NOTE 6: In this example case the standard uncertainty of the contribution, due to the range length, is taken as 0,00 dB.

Reflectivity of absorbing material: measuring antenna to the test antenna: This uncertainty is the residual effect of the reflections in the absorbing materials which result from the measuring antenna and EUT having different elevation patterns. The standard uncertainty of the contribution due to the reflectivity of absorbing material between the measuring and test antenna is designated throughout all parts of the present document as u_{j02}.

NOTE 7: In this example case the standard uncertainty of the contribution due to the reflectivity of absorbing material between the measuring and test antenna is taken as 0,00 dB since a reference is set.

Mutual coupling: measuring antenna to its images in the absorbing material: This uncertainty is the effect of the change produced in the antenna's input impedance and/or gain. The standard uncertainty of the contribution, due to the mutual coupling between the measuring antenna and its images in the absorbing material, is designated throughout all parts of the present document as u_{j06}.

NOTE 8: In this example case the standard uncertainty of the contribution due to the mutual coupling between the measuring antenna and its images in the absorbing material is taken as 0,5 dB.

Mutual coupling: measuring antenna to its image in the ground plane: This uncertainty is the effect of the change produced in the antenna's input impedance and/or gain. The standard uncertainty of the contribution, due to the mutual coupling of the measuring antenna to its image in the ground plane, is designated throughout all parts of the present document as u_{j14}. Its value can be obtained from table 29.

Table 29: Uncertainty contribution of the mutual coupling between the measuring antenna and its image in the ground plane

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

NOTE 9: In this example case the standard uncertainty of the contribution due to the mutual coupling of the measuring antenna to its image in the ground plane is taken as 0,15 dB since we are assuming vertical polarization and a spacing of < 1,25 λ.

4.4.1.2.6 Measuring antenna

Antenna: antenna factor of the measuring antenna: Uncertainty is introduced as a result of the inaccurate knowledge of the antenna factor of the measuring antenna. The antenna factor of the measuring antenna is only involved in the second stage of the test and therefore does not act as a systematic offset. The standard uncertainty of the contribution, due to the antenna factor of the measuring antenna, is designated throughout all parts of the present document as u_{j44}. For ANSI dipoles the value should be obtained from table 30.

Table 30: Uncertainty contribution of the antenna factor of the measuring antenna

Frequency	Standard uncertainty of the contribution
30 MHz ≤ frequency < 80 MHz	1,73 dB
80 MHz ≤ frequency < 180 MHz	0,60 dB
frequency ≥ 180 MHz	0,30 dB
NOTE: For other antenna types the figures should be taken from manufacturer's data sheets. If a figure is not given the standard uncertainty is 1,0 dB.	

NOTE 1: In this example case the standard uncertainty of the contribution due to the antenna factor uncertainty of the receiving antenna is 0,30 dB since ANSI dipoles have been used and the frequency is above 180 MHz.

Antenna: tuning of the measuring antenna: Uncertainty is introduced as a result of the inaccurate tuning of the measuring antenna. The standard uncertainty of the contribution due to the tuning of the measuring antenna is designated in all parts of the present document by u_{j46}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the tuning of the measuring antenna is taken to be 0,06 dB (see annex A) since the tuning of the measuring antenna is only involved in this stage of the test and therefore does not act as a systematic offset.

Position of the phase centre: measuring antenna: Uncertainty is introduced as a result of the inaccurate positioning of the phase centre of the measuring antenna, since it affects the range length i.e. the horizontal distance between itself and the test antenna. The standard uncertainty of the contribution, due to the position of the phase centre of the measuring antenna, is designated throughout all parts of the present document as u_{j22}.

NOTE 3: In this example case the standard uncertainty of the contribution due to the position of the phase centre of the receiving antenna has been calculated from ± (the offset) / (range length) x 100 %). The positioning uncertainty is ±0,01 m and therefore the worst case uncertainty = 0,01/3,0 = 0,333 %. As the offset can be anywhere between these limits, the uncertainty is taken to be rectangularly distributed (see TR 102 273-1-1 [6], clause 5.1.2) and the standard uncertainty is calculated as 0,192 %. This is transformed to the logarithmic form (see annex C), to be 0,02 dB.

4.4.1.2.7 Measuring antenna attenuator

Insertion loss: measuring antenna attenuator: The attenuator has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the attenuator is not used outside the manufacturer's specification. At any given frequency the insertion loss is taken from the manufacturer's data sheet since it does not cancel as a systematic offset (it only appears in one stage of the test). The standard uncertainty of the contribution, due to the insertion loss uncertainty of the measuring antenna attenuator, is designated throughout all parts of the present document as u_{j40}.

NOTE: In this example case the uncertainty of the contribution, due to the insertion loss uncertainty of the measuring antenna attenuator, is taken from the manufacturer's data sheet as ±0,3 dB as nothing is said about the distribution, a rectangular distribution (see TR 102 273-1-1 [6], clause 5.1.2) in logs is assumed and the standard uncertainty is calculated as 0,17 dB.

4.4.1.2.8 Measuring antenna cable

Insertion loss: measuring antenna cable: The measuring antenna cable has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the cable is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution due to the insertion loss uncertainty of the measuring antenna cable, is designated throughout all parts of the present document as u_{j41}.

NOTE 1: In this example case the uncertainty of the contribution due to the insertion loss uncertainty of the measuring antenna cable is taken from the manufacturer's data sheet as ±0,5 dB. As nothing is said about the distribution, a rectangular distribution (see TR 102 273-1-1 [6], clause 5.1.2) in logs is assumed and the standard uncertainty is calculated as 0,29 dB.

Cable factor: measuring antenna cable: Cable factor is defined as the total effect of the antenna cable's influence on the measuring system including its interaction with the site. It consists of the leakage caused by cable screening inefficiency, parasitic effects (acting as a director or reflector) and introducing an unbalanced, common mode current into the dipole balun. In a radiated measurement the standard uncertainty of the cable factor associated with the measuring antenna cable is 0,5 dB provided the precautions detailed in the method have been observed i.e. routing and dressing the cables with ferrites. If no prevention has been attempted the standard uncertainty is 4,0 dB (justification for these values is given in annex E). The standard uncertainty of the contribution, due to the cable factor of the measuring antenna cable, is designated throughout all parts of the present document as u_{j19}.

NOTE 2: In the example case the standard uncertainty of the contribution due to the cable factor of the measuring antenna cable is taken as 0,50 dB since the precautions detailed in the methods are assumed to have been observed.

4.4.1.2.9 Receiving device

The receiving device is only used in the first stage of this test. Therefore, the absolute level uncertainty contributes fully to this stage although the linearity does not.

Receiving device: absolute level: This uncertainty only contributes during the first stage of the measurement. The standard uncertainty of the contribution due to the receiving device absolute level uncertainty is designated throughout all parts of the present document as u_{j47}. Its value can be derived from manufacturer's data.

> NOTE 1: In this example case the uncertainty of the contribution due to the receiving device absolute level uncertainty) is obtained from the manufacturer's data as ±1 dB with a rectangular distribution (see TR 102 273-1-1 [6], clause 5.1.2) in logs. The standard uncertainty of the contribution due to the receiving device absolute level uncertainty is calculated as 0,58 dB.

Receiving device: linearity: In any test in which the contribution of the absolute level uncertainty of the receiving device contributes to the combined standard uncertainty of the test i.e. it does not cancel due to the methodology, the contribution from the receiving device linearity is considered to have been included in u_{j47}. Conversely, for any test in which the absolute level uncertainty of the receiving device does not contribute to the combined standard uncertainty the linearity of the receiving device should be included. The standard uncertainty of the contribution due to the receiving device linearity is designated throughout all parts of the present document as u_{j48}.

> NOTE 2: In this example case the standard uncertainty of the contribution due to the receiving device linearity is taken as 0,00 dB.

4.4.1.3 Contribution from the random component

Random uncertainty: The magnitude can be assessed from multiple measurements of the transform factor. The standard uncertainty of the contribution due to the random uncertainty is designated throughout all parts of the present document as u_{i01}. See also clause 5.5 and the note in clause 6.4.7 of TR 102 273-1-1, as well as note in clause A.18 of the present document.

The transform factor measurement was repeated ten times. The following results were obtained in dBμV (before correcting for cabling and attenuator network insertion loss):

65,4; 63,4; 66,0; 65,3; 63,0; 64,9; 65,2; 66,8; 65,5; 63,7.

Converting to linear terms (V):

$1,862 \times 10^{-3}$; $1,479 \times 10^{-3}$; $1,995 \times 10^{-3}$; $1,841 \times 10^{-3}$; $1,413 \times 10^{-3}$; $1,758 \times 10^{-3}$; $1,820 \times 10^{-3}$; $2,188 \times 10^{-3}$; $1,884 \times 10^{-3}$; $1,531 \times 10^{-3}$;

The two sums X and Y are calculated:

X = the sum of the measured values = $17,77 \times 10^{-3}$ V;

Y = the sum of the squares of the measured values = $32,10 \times 10^{-6}$ V^2

$$u_{c\ random} = \sqrt{\frac{Y - \frac{X^2}{n}}{n-1}} = \sqrt{\frac{32,10 \times 10^{-6} - \frac{\left(17,77 \times 10^{-3}\right)^2}{10}}{10-1}} = 238,3 \times 10^{-6} \qquad \text{(formula 5.6)}$$

As the result is obtained as the mean value of 10 measurements and the standard uncertainty of the random uncertainty is:

$$u_{j\ random} = \frac{238,3 \times 10^{-6}}{1,777 \times 10^{-3}} \times \frac{100}{11,5} = 1,17 \text{ dB}$$

> NOTE: In this example case the standard uncertainty of the contribution due to the random uncertainty is 1,17 dB.

4.4.1.4 Summary table of contributory components

All the uncertainties for this part of the procedure are listed in table 31.

Table 31: Contributions from the transfer factor measurement

$u_{j\ or\ i}$	**Description of uncertainty contributions**	**dB**
u_{j36}	*mismatch: transmitting part*	0,00
u_{j37}	*mismatch: receiving part*	0,11
u_{j38}	*signal generator: absolute output level*	0,58
u_{j39}	*signal generator: output level stability*	0,00
u_{j41}	*insertion loss: test antenna cable*	0,00
u_{j19}	*cable factor: test antenna cable*	0,00
u_{j40}	*insertion loss: test antenna attenuator*	0,00
u_{j18}	*correction: measurement distance*	0,00
u_{j17}	*correction: off boresight angle in elevation plane,*	0,00
u_{j45}	*antenna: gain of the test antenna*	0,00
u_{j46}	*antenna: tuning of the test antenna*	0,00
u_{j22}	*position of the phase centre: test antenna*	0,00
u_{j34}	*ambient effect*	0,00
u_{j06}	*mutual coupling: test antenna to its images in the absorbing material*	0,00
u_{j14}	*mutual coupling: test antenna to its image in the ground plane*	0,00
u_{j11}	*mutual coupling: measuring antenna to the test antenna*	0,00
u_{j12}	*mutual coupling: interpolation of mutual coupling and mismatch loss correction factors*	0,00
u_{j16}	*range length*	0,00
u_{j02}	*reflectivity of absorber material: measuring antenna to the test antenna*	0,00
u_{j06}	*mutual coupling: measuring antenna to its images in the absorbing material*	0,50
u_{j14}	*mutual coupling: measuring antenna to its image in the ground plane*	0,15
u_{j44}	*antenna: antenna factor of the measuring antenna*	0,30
u_{j46}	*antenna: tuning of the measuring antenna*	0,06
u_{j22}	*position of the phase centre: measuring antenna*	0,02
u_{j40}	*insertion loss: measuring antenna attenuator*	0,17
u_{j41}	*insertion loss: measuring antenna cable*	0,29
u_{j19}	*cable factor: measuring antenna cable*	0,50
u_{j47}	*receiving device: absolute level*	0,58
u_{j48}	*receiving device: linearity*	0,00
u_{i01}	*random uncertainty (see note in clause A.18 of the present document and note in clause 6.4.7 of TR 102 273-1-1)*	1,17

The standard uncertainties from table 31 should be combined by RSS in accordance with TR 102 273-1-1 [6], clause 5. This gives the combined standard uncertainty ($u_{c\ transform\ factor}$) for the transform factor measurement in dB.

The value of $u_{c\ transform\ factor}$ is calculated as 1,67 dB.

4.4.2 Uncertainty contributions: stage 2: EUT measurement

The second stage of the measurement (EUT sensitivity measurement) is to determine the minimum signal generator output level which produces the required response from the EUT and converting the output level of the signal generator, to a field strength using the transform factor derived in stage one. The test equipment set-up is shown in figure 11. The components shown shaded are common to both stages of the test.

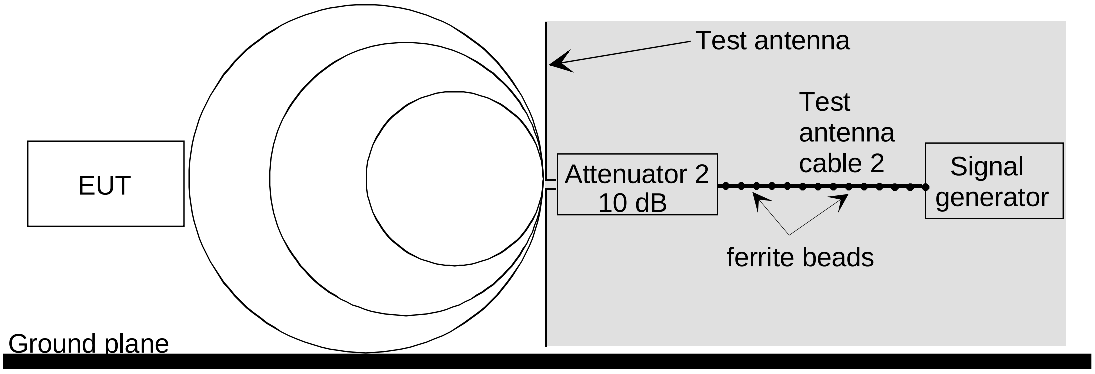


Figure 11: EUT measurement

Whereas figure 11 shows, schematically, the test equipment for the EUT sensitivity measurement, figure 12 an analysis diagram, provides a detailed picture of the individual uncertainty components (each of which contributes its own uncertainty) for this stage in the measurement. As stated above, the shaded areas represent components common to both stages of the test method.

4.4.2.1 Contributions from the mismatch components

Mismatch: transmitting part: Only the transmitting part of the test equipment set-up is involved in this stage of the test. The standard uncertainty of the contribution due to mismatch is 0,00 dB since, as stated in clause 4.4.1.1 the transmitting part is common to both stages of the test.

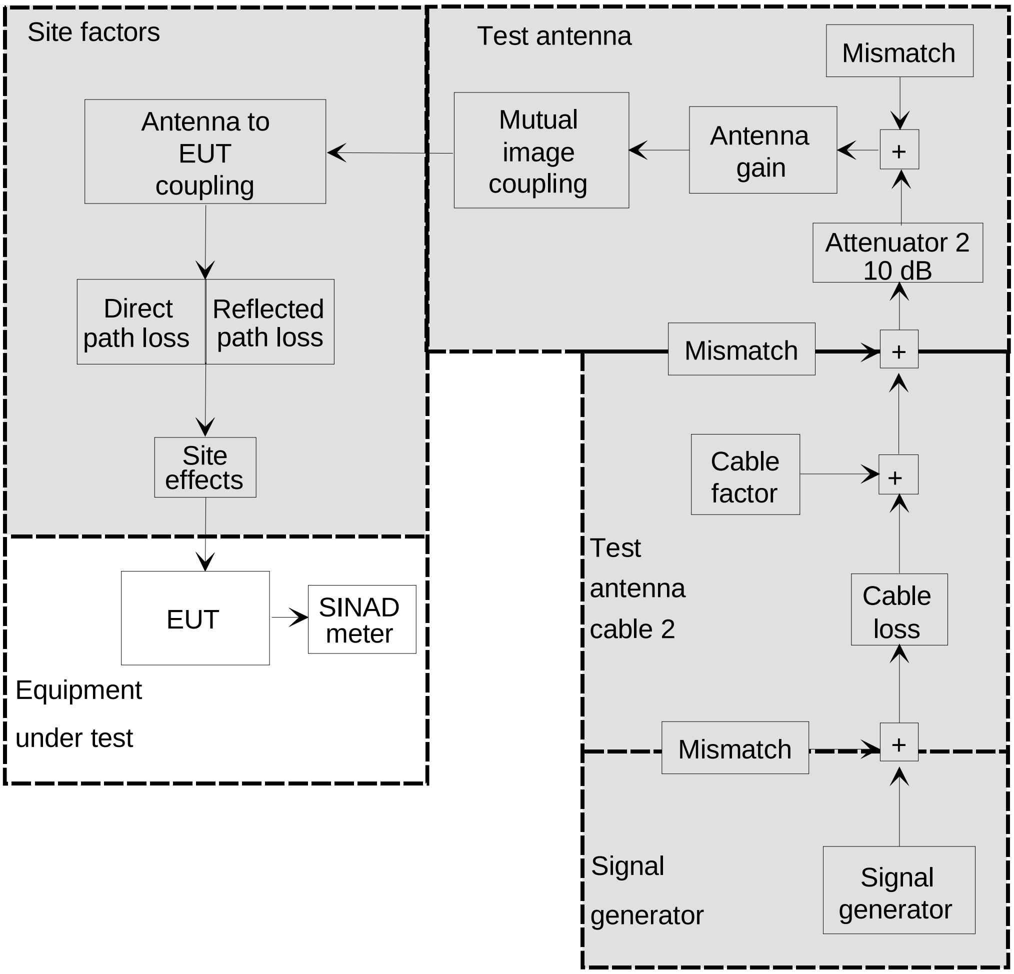


Figure 12: Reference for the measurement on the equipment (sensitivity)

The mismatch uncertainty between the signal generator and the test antenna contributes equally to both stages of the test and therefore it does not contribute to the combined standard uncertainty and is not calculated. The standard uncertainty of the contribution due to mismatch in the transmitting part is designated throughout all parts of the present document as u_{j35}.

NOTE: In this example case the standard uncertainty of the contribution due to mismatch in the transmitting part is taken as 0,00 dB, since the uncertainty is systematic i.e. it produces the same offset in both stages.

4.4.2.2 Contributions from the individual components

4.4.2.2.1 Signal generator

Signal generator: absolute output level: There is not necessarily any similarity between the output levels from the signal generator in the two stages of this test. As a result it contributes to both stages. The standard uncertainty of the contribution, due to the signal generator absolute output level, is designated throughout all parts of the present document as u_{j38}. Its value can be derived from manufacturer's data sheet.

NOTE 1: In this example case the uncertainty of the contribution due to the signal generator absolute output level uncertainty is taken from the manufacturer's data sheet as ±1,0 dB. As nothing is said about the distribution of this uncertainty, a rectangular distribution (see TR 102 273-1-1 [6], clause 5.1.2) in logs is assumed, and the standard uncertainty is calculated as 0,58 dB.

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

NOTE 2: In this example case the standard uncertainty of the contribution due to the signal generator output level stability is taken as 0,00 dB as it is covered by the absolute level uncertainty.

4.4.2.2.2 Test antenna cable

Insertion loss: test antenna cable: The test antenna cable has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the cable is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution due to the insertion loss uncertainty of the test antenna cable is designated throughout all parts of the present document as u_{j41}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the insertion loss uncertainty of the test antenna cable is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

Cable factor: test antenna cable: Cable factor is defined as the total effect of the antenna cable's influence on the measuring system including its interaction with the site. It consists of the leakage caused by cable screening inefficiency, parasitic effects (acting as a director or reflector) on the test antenna and introducing an unbalanced, common mode current into the dipole balun. In a radiated measurement the standard uncertainty of the cable factor, associated with each cable, is 0,5 dB provided that the precautions detailed in the methods have been observed, i.e. routing and dressing of cables with ferrites. If no prevention has been attempted the standard uncertainty is 4,0 dB (justification for these values is given in annex E). The standard uncertainty of the contribution due to the cable factor of the test antenna cable is designated throughout all parts of the present document as u_{j19}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the cable factor of the test antenna cable is taken as 0,00 dB since in this measurement, the cable position, once set in stage 1, is not subsequently changed during the test.

4.4.2.2.3 Test antenna attenuator

Insertion loss: test antenna attenuator: The test antenna attenuator has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the attenuator is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution due to the insertion loss of the test antenna attenuator is designated throughout all parts of the present document as u_{j40}.

NOTE: In this example case the standard uncertainty of the contribution, due to the insertion loss uncertainty of the test antenna attenuator, is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

4.4.2.2.4 Test antenna

Correction: measurement distance: For those tests in which the test antenna on the mast peaks at different heights in the two stages, a correction for measurement distance needs to be made to account for the different measurement distances. In this test, once the position of the test antenna is set in stage one no further adjustment to its position is subsequently made during the test. The standard uncertainty of the contribution due to the correction for measurement distance is designated throughout all parts of the present document as u_{j18}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the correction for measurement distance is taken as 0,00 dB.

Correction: off boresight angle in elevation plane: For those tests in which the test antenna on the mast peaks at different heights in the two stages, a correction needs to be made to account for the different angles subtended by the EUT/substitution antenna. In this test, once the position of the test antenna is set in stage one no further adjustment to its position is subsequently made during the test. The standard uncertainty of the contribution due to the correction for off boresight angle in elevation plane is designated throughout all parts of the present document as u_{j17}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the correction for off boresight angle in elevation plane is taken as 0,00 dB since the uncertainty is assumed to be systematic i.e. it is assumed constant and common to both stages of the measurement.

Antenna: gain of the test antenna: The gain of the test antenna acts as a systematic offset since it is present in both stages of the test. The standard uncertainty of the contribution due to the gain of the test antenna is designated throughout all parts of the present document as u_{j45}.

NOTE 3: In this example case the standard uncertainty of the contribution due to the gain of the test antenna is taken as 0,00 dB since the uncertainty is assumed to be systematic i.e. it is assumed constant and common to both stages of the measurement.

Antenna: tuning of the test antenna: This uncertainty is introduced as a result of inaccurate tuning of the test antenna. The standard uncertainty of the contribution due to the tuning of the test antenna is designated throughout all parts of the present document as u_{j46}.

NOTE 4: In this example case the standard uncertainty of the contribution due to the tuning of the test antenna is taken as 0,00 dB since the uncertainty is assumed to be systematic i.e. it is assumed constant and common to both stages of the measurement (provided that once set in stage one of the test it is not subsequently re-tuned).

Position of the phase centre: test antenna: The horizontal position of the test antenna defines one end of the range length. Since the test antenna position on the mast is not changed after being set in this stage the standard uncertainty of the contribution due to the position of the phase centre of the test antenna is designated throughout all parts of the present document as u_{j22}.

NOTE 5: In this example case the standard uncertainty of the contribution due to the position of the phase centre of the test antenna is taken as 0,00 dB since the uncertainty is assumed to be systematic i.e. it is assumed constant and common to both stages of the measurement.

4.4.2.2.5 Site factors

Ambient effect: Ambient effect is the uncertainty caused by local ambient signals raising the noise floor at the measurement frequency. The standard uncertainty of the contribution due to the ambient effect is designated throughout all parts of the present document as u_{j34}. The values of the standard uncertainties for this part of the test should be the same as for stage 1.

NOTE 1: In this example case the standard uncertainty of the contribution due to the ambient effect is taken as 0,00 dB as this was the value in stage 1.

Range length: This contribution is associated with the curvature of the phase front from the EUT to the test antenna. The standard uncertainty of the contribution, due to range length, is designated throughout all parts of the present document as u_{j16}. The standard uncertainty is 0,00 dB if ANSI dipoles are used. For other types of antenna the standard uncertainty of the contribution should be obtained from table 32.

Table 32: Uncertainty contribution of the range length (verification)

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

NOTE 2: In this example case the standard uncertainty of the contribution due to the range length is taken as 0,00 dB since the range length is $\geq 2\ (d_1+d_2)^2/\lambda$..

Mutual coupling: amplitude effect of the test antenna on the EUT: This uncertainty results from the interaction between the EUT and the test antenna when placed close together. The standard uncertainty of the contribution due to the amplitude effect of the mutual coupling between the test antenna and the EUT, is designated throughout all parts of the present document as u_{j08}. The standard uncertainty should be taken from table 33.

Table 33: Uncertainty contribution: mutual coupling: amplitude effect of the test antenna on the EUT

Range length	Standard uncertainty of the contribution
$0{,}62\sqrt{((d_1+d_2)^3/\lambda)} \leq$ range length $< 2(d_1+d_2)^2/\lambda$	0,50 dB
range length $\geq 2(d_1+d_2)^2/\lambda$	0,00 dB

NOTE 3: In this example case the standard uncertainty of the contribution due to the amplitude effect of the mutual coupling between the test antenna and the EUT is 0,00 dB since the distance is $\geq 2\ (d_1+d_2)^2/\lambda$.

Mutual coupling: EUT to its images in the absorbing material: This uncertainty is dependant on the quality of the absorbing material and the effect imaging of the EUT in the ceiling, side and end walls has on the input impedance and/or gain of the integral antenna. The standard uncertainty of the contribution, due to the mutual coupling of the EUT to its images in the absorbing material, is designated throughout all parts of the present document as u_{j04}.

NOTE 4: In this example case the standard uncertainty of the contribution due to the mutual coupling amplitude effect of the absorbing material on the EUT is assumed to be 0,5 dB (see annex A).

Mutual coupling: EUT to its image in the ground plane: This uncertainty results from the change in the EUT spurious emission level as a result of being placed close to the ground plane. The standard uncertainty of the contribution, due to the mutual coupling of the EUT to its image in the ground plane, is designated throughout all parts of the present document as u_{j13}. Its value can be obtained from table 34.

Table 34: Uncertainty contribution of the mutual coupling between the EUT to its image in the ground plane

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

NOTE 5: In this example case the standard uncertainty of the contribution, due to the mutual coupling of the EUT to its image in the ground plane, (assuming the polarization is vertical and the spacing above the ground plane is < 1,25 λ at the test frequency) is taken as 0,15 dB.

Reflectivity of absorbing material: EUT to the test antenna: This uncertainty is associated with the magnitudes of the reflections occurring from the side walls, end walls and ceiling. These magnitudes are a function of the quality of the absorber at the frequency of test. The standard uncertainty of the contribution, due to the reflectivity of the absorbing material between the EUT and the test antenna, is designated throughout all parts of the present document as u_{j01}. The relevant value for this contribution should be taken from table 35.

Table 35: Uncertainty contribution of the reflectivity of absorbing material between the EUT and test antenna

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

NOTE 6: In this example case the standard uncertainty of the contribution due to the reflectivity of the absorbing material between the EUT and the test antenna is taken as 1,24 dB.

Mutual coupling: test antenna to its images in the absorbing material: This is the uncertainty due to the mutual coupling between the test antenna and its images in the ceiling, side and end walls and is the effect of the change produced in the antenna's input impedance and/or gain. The standard uncertainty of the contribution, due to the mutual coupling between the test antenna and its images in the absorbing material, is designated throughout all parts of the present document as u_{j06}.

NOTE 7: In this example case the standard uncertainty of the contribution due to the mutual coupling between the test antenna and its images in the absorbing material is taken as 0,00 dB since in this, the second stage of the measurement, the uncertainty will only contribute if the test antenna is located at a different height to the first stage which is not allowed by the methodology hence the uncertainty is assumed to be systematic i.e. it is assumed constant and common to both stages of the measurement.

Mutual coupling: test antenna to its image in the ground plane: This is the uncertainty due to the mutual coupling between the test antenna and its image in the ground plane and is the effect of the change produced in the antenna's input impedance and/or gain when placed close to a ground plane. The standard uncertainty of the contribution, due to the mutual coupling of the test antenna to its image in the ground plane, is designated throughout all parts of the present document as u_{j14}.

NOTE 8: In this example case the standard uncertainty of the contribution due to the mutual coupling of the test antenna to its image in the ground plane is taken as 0,00 dB since in this, the second stage of the measurement, the uncertainty will only contribute if the test antenna is located at a different height to the first stage which is not allowed by the methodology hence the uncertainty is assumed to be systematic i.e. it is assumed constant and common to both stages of the measurement.

4.4.2.2.6 EUT

EUT: mutual coupling to the power leads: This is the uncertainty associated with the influence (reflections, parasitic effects, etc.) of the power leads on the EUT. The standard uncertainty associated with this effect is 0,5 dB provided that the precautions detailed in the methods have been observed, i.e. routing and dressing of cables with ferrites. If no prevention has been attempted the standard uncertainty is 2,0 dB. The standard uncertainty of the contribution, due to the mutual coupling of the EUT to the power leads, is designated throughout all parts of the present document as u_{j54}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the mutual coupling of the EUT to the power leads is taken as 0,5 dB since the precautions detailed in the methods have been observed.

Position of the phase centre: within the EUT volume: This contribution is associated with the uncertainty with which the actual radiating point within the equipment volume is known. If this point is known exactly the contribution is 0,00 dB. The standard uncertainty of the contribution due to the position of the phase centre within the EUT volume is designated throughout all parts of the present document as u_{j20}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the position of the phase centre within the EUT volume has been calculated from (± (the maximum dimension of device) / (2 × range length) × 100 %). In this example the position is not known. Hence, the uncertainty of the position of the phase centre within the EUT of 0,15 m maximum dimension is 0,15 / 2 m = 0,075 m, and the worst case uncertainty due to this offset is therefore (0,075 / 3,0) × 100 % = ±2,50 %. As the phase centre can be anywhere inside the EUT, the uncertainty is taken as rectangularly distributed and the standard uncertainty is calculated as 1,44 %. This is then transformed to the logarithmic form (1,44 / 11,5) = 0,12 dB (see annex C).

Positioning of the phase centre: within the EUT over the axis of rotation of the turntable: This contribution is associated with the uncertainty with which the actual radiating point within the equipment is placed over the centre of the turntable. If the point is placed exactly, the contribution is 0,00 dB. The standard uncertainty of the contribution, due to the positioning of the phase centre within the EUT over the axis of rotation of the turntable, is designated throughout all parts of the present document as u_{j21}.

NOTE 3: In this example case the standard uncertainty of the contribution due to the positioning of the EUT phase centre over the axis of rotation of the turntable is calculated from (± (the estimated offset from the axis of rotation) / (2 × range length) × 100 %). In this case, the uncertainty is taken as ±0,01 m, and the worst case uncertainty is ± (0,01 / 3,0) × 100 = ±0,333 %. As the offset can be anywhere between the limits the uncertainty is rectangularly distributed and the standard uncertainty is calculated as 0,192 %. This is then transformed to the logarithmic form (0,192 / 11,5) = 0,02 dB (see annex C).

EUT: degradation measurement: This contribution is a RF level uncertainty associated with the uncertainty of measuring 20 dB SINAD, 10^{-2} bit stream or 80 % message acceptance ratio. The standard uncertainty of the contribution, due to the EUT degradation measurement, is designated throughout all parts of the present document as u_{j52}. Its value can be obtained from TR 100 028 [5].

NOTE 4: In this example case, the standard uncertainty of the contribution is obtained from TR 100 028 [5] and its value is 0,68 dB.

4.4.2.3 Contribution from the random component

Random uncertainty: The magnitude can be assessed from multiple measurements of the receiver sensitivity. The standard uncertainty of the contribution due to the random uncertainty is designated throughout all parts of the present document as u_{i01}. See also clause 5.5 and the note in clause 6.4.7 of TR 102 273-1-1, as well as note in clause A.18 of the present document.

The receiver sensitivity measurement was repeated ten times. The following results were obtained in dBμV (before correcting for cabling and attenuator network insertion loss):

65,4; 63,4; 66,0; 65,3; 63,0; 64,9; 65,2; 66,8; 65,5; 63,7.

Converting to linear terms (V):

$1{,}862 \times 10^{-3}$; $1{,}479 \times 10^{-3}$; $1{,}995 \times 10^{-3}$; $1{,}841 \times 10^{-3}$; $1{,}413 \times 10^{-3}$; $1{,}758 \times 10^{-3}$; $1{,}820 \times 10^{-3}$; $2{,}188 \times 10^{-3}$; $1{,}884 \times 10^{-3}$; $1{,}531 \times 10^{-3}$.

The two sums X and Y are calculated:

X = the sum of the measured values = $17{,}77 \times 10^{-3}$ (V);

Y = the sum of the squares of the measured values = $32{,}10 \times 10^{-6}\ \mathrm{V}^2$

$$u_{c\ random} = \sqrt{\frac{Y - \frac{X^2}{n}}{n-1}} = \sqrt{\frac{32{,}10 \times 10^{-6} - \frac{\left(17{,}77 \times 10^{-3}\right)^2}{10}}{10-1}} = 238{,}3 \times 10^{-6} \qquad \text{(formula 5.6)}$$

As the result is obtained as the mean value of 10 measurements and the standard uncertainty of the random uncertainty is:

$$u_{j\ random} = \frac{238{,}3 \times 10^{-6}}{1{,}777 \times 10^{-3}} \times \frac{100}{11{,}5} = 1{,}17\ \text{dB}$$

NOTE: In this example case the standard uncertainty of the contribution due to the random uncertainty is 1,17 dB.

4.4.2.4 Summary table of contributory components

All the uncertainty contributions for this part of the procedure are listed in table 36.

Table 36: Contributions from the EUT measurement

$u_{j\ or\ i}$	**Description of uncertainty contributions**	**dB**
u_{j36}	*mismatch: transmitting part*	0,00
u_{j38}	*signal generator: absolute output level*	0,58
u_{j39}	*signal generator: output level stability*	0,00
u_{j41}	*insertion loss: test antenna cable*	0,00
u_{j19}	*cable factor: test antenna cable*	0,00
u_{j40}	*insertion loss: test antenna attenuator*	0,00
u_{j17}	*correction: off boresight angle in elevation plane*	0,00
u_{j18}	*correction: measurement distance*	0,00
u_{j45}	*antenna: gain of the test antenna*	0,00
u_{j46}	*antenna: tuning of the test antenna*	0,00
u_{j22}	*position of the phase centre: test antenna*	0,00
u_{j34}	*ambient effect*	0,00
u_{j08}	*mutual coupling: amplitude effect of the test antenna on the EUT*	0,00
u_{j04}	*mutual coupling: EUT to its images in the absorbing material*	0,50
u_{j13}	*mutual coupling: EUT to its image in the ground plane*	0,15
u_{j01}	*reflectivity of absorber material: EUT to the test antenna*	1,24
u_{j06}	*mutual coupling: test antenna to its images in the absorbing material*	0,00
u_{j14}	*mutual coupling: test antenna to its image in the ground plane*	0,00
u_{j55}	*EUT: mutual coupling to the power leads*	0,50
u_{j20}	*position of the phase centre: within the EUT volume*	0,12
u_{j22}	*positioning of the phase centre: within the EUT over the axis of rotation of the turntable*	0,02
u_{j16}	*range length*	0,00
u_{j52}	*EUT: degradation measurement*	0,68
u_{i01}	*random uncertainty (see note in clause A.18 of the present document and note in clause 6.4.7 of TR 102 273-1-1)*	1,17

The standard uncertainties from table 36 should be combined by RSS in accordance with TR 102 273-1-1 [6], clause 5. This gives the combined standard uncertainty ($u_{c\ EUT\ measurement}$) for the NSA measurement in dB.

The value of $u_{c\ EUT\ measurement}$ is calculated as 2,06 dB.

4.4.2.5 Expanded uncertainty for the receiver sensitivity measurement

The combined standard uncertainty of the results of the verification procedure is the combination of the components outlined in clauses 4.2.1.4 and 4.2.2.4. The components to be combined are $u_{c\ transform\ factor}$ and $u_{c\ EUT\ measurement}$.

$$u_{c\ Sensitivity\ measurement} = \sqrt{1{,}67^2 + 2{,}06^2} = 2{,}65 \text{ dB}$$

The expanded uncertainty is ±1,96 x 2,65 dB = ±5,19 dB at a 95 % confidence level.

5 Examples of measurement uncertainty analysis (Stripline)

5.1 Introduction

This clause contains detailed worked examples of the calculation of expanded uncertainty of radiated tests in a Stripline test facility.

The example tests given are limited to:

- a verification procedure;
- the measurement of a receiver parameter (sensitivity).

Both of the example tests are assumed to have been carried out in the two-plate open Stripline described in EN 55020 [3].

NOTE 1: The values given to all of the uncertainty components in these examples are only to illustrate the uncertainty calculation. In practice, values should be derived by consulting annex A.

All radiated tests consist of two stages. For the verification procedure, the first stage is to set a reference level whilst the second stage involves the measurement of path loss/attenuation through the Stripline. For the measurement of the receive sensitivity of an EUT, the first stage is to find the minimum (or average) signal generator output that produces the required receiver response, whilst the second stage determines the field strength in the Stripline corresponding to that generator output level.

Within any radiated test there are uncertainty components that are common to both stages of the test. By their different natures some of these common uncertainties will cancel (e.g. the uncertainty of the insertion loss of a cable common to both parts), others will contribute once (e.g. the increase in the field strength caused by a large EUT) whilst others may contribute twice (e.g. the level stability of a signal generator in receiver tests). In each of the following uncertainty analyses, uncertainty components common to both stages are shown as shaded areas in the accompanying schematic diagrams.

As shown in the examples, all the individual uncertainty components for any test are combined in the manner described in TR 102 273-1-1 [6], clauses 4 and 5 in order to derive an expanded uncertainty figure for the measurement. The values of the individual components are either provided in annex A or should be taken from manufacturer's data sheets. Whenever they are obtained from data sheets, worst case figures given over a frequency band should be used. For example, in the case of a signal generator whose absolute level accuracy is quoted as ±1 dB over 30 MHz to 300 MHz, ±2 dB over 300 MHz to 1 000 MHz the figure for the band containing the test frequency should be used. This approach should be adopted for all uncertainty components, taking the uncertainty figures over as broad a band a possible. This is normally satisfactory when the variation with frequency is not large and provides a simple and flexible approach. The resulting expanded uncertainty figure is valid across a broad range of frequencies and measurement conditions and avoids the necessity of repeated calculation for minor frequency changes.

NOTE 2: Taking specific frequency values may result in a lower expanded uncertainty value, but this lower value is only valid when that specific set of circumstances apply for which the value was derived.

5.2 Example 1: verification procedure

The Stripline verification procedure involves two different measurement stages and it results in values for both the attenuation through the Stripline and its transform factor (i.e. the relationship between the input voltage to the Stripline and the resulting field strength between the plates).

5.2.1 Uncertainty contributions: stage 1: direct attenuation measurement

The first stage of the verification procedure is the direct attenuation measurement. This is carried out with all the items of test equipment connected directly together via an "in line" adapter between the attenuators as shown in figure 13. The components shown shaded are common to both stages of the procedure.

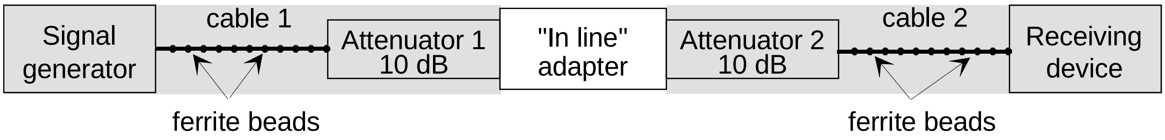


Figure 13: Stage 1: Direct attenuation measurement

Despite the commonality of most of the components to both stages of this procedure, the mismatch uncertainty contribution for both stages has to be calculated and included in the uncertainty calculations. This is the result of load conditions varying (i.e. the Stripline and monopole replaces the adapter in the second stage). Conversely, as a result of this commonality, the uncertainty contributions of some of the individual components will cancel.

Whereas figure 13 shows, schematically, the test equipment set-up for this stage of the verification procedure, an analysis diagram of the individual components (each of which contributes its own uncertainty) for this stage of the measurement is shown in figure 14. Again, as stated above, the shaded areas represent components common to both stages of the verification procedure.

5.2.1.1 Contributions from the mismatch components

Mismatch: direct attenuation measurement: The value of the combined standard uncertainty of the contribution due to the mismatch from the source to the receptor, i.e. between the signal generator and the receiving device, is calculated from the approach described in annex D. All the individual contributions are U-distributed.

NOTE 1: In this example the signal generator output reflection coefficient used is the worst case magnitude over the frequency band of interest, as is the case with the cable, adapter and attenuator VSWRs.

NOTE 2: The attenuation values of the cables and attenuators should be obtained from the manufacturer's data sheet/calibration records at the specific frequency of the test, along with the associated uncertainties for these values.

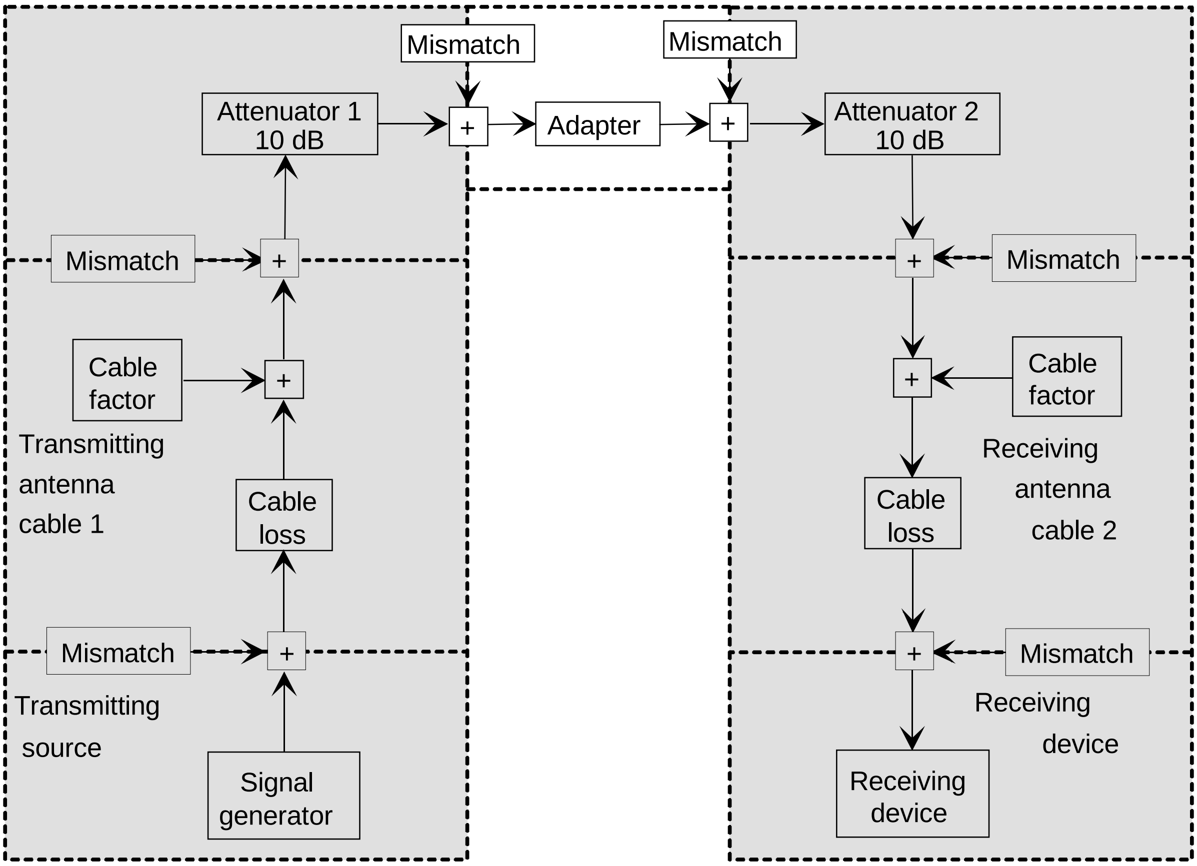


Figure 14: Stage 1:direct attenuation measurement individual uncertainty components

Signal generator:	Output reflection coefficient: $\|\rho_G\|$	= 0,20
Cable:	Input and output reflection coefficients: $\|S_{11}\| = \|S_{22}\|$	= 0,07
	Attenuation: 1 dB = $\|S_{12}\| = \|S_{21}\|$	= 0,891
Attenuator:	Input and output reflection coefficients $\|S_{11}\| = \|S_{22}\|$	= 0,05
	Attenuation = 10 dB $\|S_{12}\| = \|S_{21}\|$	= 0,3162
Adapter:	Input and output reflection coefficients $\|S_{11}\| = \|S_{22}\|$	= 0,02
	Attenuation = 0,1 dB $\|S_{12}\| = \|S_{21}\|$	= 0,9886
Attenuator:	Input and output reflection coefficients $\|S_{11}\| = \|S_{22}\|$	= 0,05
	Attenuation = 10 dB $\|S_{12}\| = \|S_{21}\|$	= 0,3162
Cable:	Input and output reflection coefficients: $\|S_{11}\| = \|S_{22}\|$	= 0,07
	Attenuation: 1 dB = $\|S_{12}\| = \|S_{21}\|$	= 0,891
Receiving device:	Input reflection coefficient: $\|\rho_{RD}\|$	= 0,20

Mismatch uncertainty in the direct attenuation measurement: In the following the transmitting antenna cable is named cable 1, the transmitting antenna attenuator is named attenuator 1, the receiving antenna cable is named cable 2, the receiving attenuator is named attenuator 2. Those components that are constant for both stages 1 and 2 are not calculated as they do not contribute to the overall uncertainty.

Mismatch between:

$u_{\text{j generator and cable 1}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$u_{\text{j cable 1 and attenuator 1}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$$u_{j\ mismatch: attenuator\ 1 and\ adapter} = \frac{0{,}05 \times 0{,}02 \times 100}{\sqrt{2}} \% = 0{,}071\ \%$$

$$u_{j\ mismatch: adapter\ and\ attenuator\ 1} = \frac{0{,}02 \times 0{,}05 \times 100}{\sqrt{2}} \% = 0{,}071\ \%$$

$u_{\text{j attenuator 2 and cable 2}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$u_{\text{j cable 2 and receiving device}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$u_{\text{j generator and attenuator 1}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$$u_{j\ mismatch: cable\ 1 and\ adapter} = \frac{0{,}07 \times 0{,}07 \times 0{,}316^2 \times 100}{\sqrt{2}} \% = 0{,}035\ \%$$

$$u_{j\ mismatch: attenuator\ 1 and\ attenuator\ 2} = \frac{0{,}05 \times 0{,}05 \times 0{,}988^2 \times 100}{\sqrt{2}} \% = 0{,}173\ \%$$

$$u_{j\ mismatch: adapter\ and\ cable\ 2} = \frac{0{,}02 \times 0{,}07 \times 0{,}316^2 \times 100}{\sqrt{2}} \% = 0{,}010\ \%$$

$u_{\text{j attenuator 2 and receiving device}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$$u_{j\ mismatch: generator\ and\ adapter} = \frac{0{,}2 \times 0{,}02 \times 0{,}891^2 \times 0{,}316^2 \times 100}{\sqrt{2}} \% = 0{,}022\ \%$$

$$u_{j\ mismatch: cable\ 1 and\ attenuator\ 2} = \frac{0{,}07 \times 0{,}05 \times 0{,}316^2 \times 0{,}988^2 \times 100}{\sqrt{2}} \% = 0{,}024\ \%$$

$$u_{j\ mismatch: attenuator\ 1 and\ cable\ 2} = \frac{0{,}05 \times 0{,}07 \times 0{,}988^2 \times 0{,}316^2 \times 100}{\sqrt{2}} \% = 0{,}024\ \%$$

$$u_{j\ mismatch: adapter\ and\ receiving\ device} = \frac{0{,}02 \times 0{,}2 \times 0{,}316^2 \times 0{,}891^2 \times 100}{\sqrt{2}} \% = 0{,}022\ \%$$

$$u_{j\ mismatch: generator\ and\ attenuator\ 2} = \frac{0{,}2 \times 0{,}05 \times 0{,}891^2 \times 0{,}316^2 \times 0{,}988^2 \times 100}{\sqrt{2}} \% = 0{,}055\ \%$$

$u_{\text{j mismatch: cable 1 and cable 2}}$: Less than 0,01 % due to the two attenuators, therefore neglected.

$$u_{j\ mismatch: attenuator\ 1 and\ receiving\ device} = \frac{0{,}05 \times 0{,}2 \times 0{,}988^2 \times 0{,}316^2 \times 0{,}891^2 \times 100}{\sqrt{2}} \% = 0{,}055\ \%$$

$u_{\text{j mismatch: generator and cable 2}}$: Less than 0,01 % due to the two attenuators, therefore neglected.

$u_{\text{j mismatch: cable 1 and receiving device}}$: Less than 0,01 % due to the two attenuators, therefore neglected.

$u_{\text{j mismatch: generator and receiving device}}$: Less than 0,01 % due to the two attenuators, therefore neglected.

The combined standard uncertainty of the mismatch is then calculated:

$$u_{c\,mismatch:direct\,att.} = \sqrt{0{,}071^2 + 0{,}071^2 + ... + 0{,}055^2 + 0{,}055^2} = 0{,}306\ \%$$

transforming to logarithmic form (see annex C): 0,306 %/11,5 = 0,026 dB.

The standard uncertainty of the contribution, due to the mismatch in the direct attenuation measurement, is designated throughout all parts of the present document as u_{j35}. Its value in this example is 0,026 dB.

5.2.1.2 Contributions from individual components

5.2.1.2.1 Signal generator

Signal generator: absolute output level: In a verification procedure, the signal generator's absolute level uncertainty contributes equally to both stages of the measurement. The standard uncertainty of the contribution due to the signal generator absolute output level uncertainty is designated throughout all parts of the present document as u_{j38}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the signal generator absolute output level uncertainty is taken to be 0,00 dB since, once the level has been set in stage one of the procedure, the level is not further adjusted. The uncertainty is therefore assumed to be systematic i.e. it produces the same offset in both stages.

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

NOTE 2: In this example case the uncertainty of the contribution due to the signal generator output level stability is obtained from the manufacturer's data sheet as ±0,02 dB.
As nothing is said about the distribution of this uncertainty, a rectangular distribution
(see TR 102 273-1-1 [6], clause 5.1.2) in logs is assumed, and the standard uncertainty is calculated as 0,01155 dB. This is rounded down to 0,01 dB.

5.2.1.2.2 Signal generator cable

Insertion loss: signal generator cable: The signal generator cable has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the cable is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution due to the insertion loss uncertainty of the signal generator cable is designated throughout all parts of the present document as u_{j41}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the insertion loss uncertainty of the transmitting antenna cable is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

Cable factor: signal generator cable: Cable factor is defined as the total effect of the signal generator cable's influence on the measuring system including its interaction with the Stripline. It consists of the leakage caused by cable screening inefficiency and introducing an unbalanced current into the Stripline. In a radiated measurement the standard uncertainty of the cable factor, associated with each cable, is 0,5 dB provided that the precautions detailed in the methods have been observed, i.e. routing and dressing of cables with ferrites. If no prevention has been attempted the standard uncertainty is 4,0 dB (justification for these values is given in annex E). The standard uncertainty of the contribution due to the cable factor of the signal generator cable is designated throughout all parts of the present document as u_{j19}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the cable factor of the signal generator is taken as 0,00 dB since there are no external fields involved other than leakage, which is assumed to have a negligible effect on the measurement.

5.2.1.2.3 Signal generator attenuator

Insertion loss: signal generator attenuator: The signal generator attenuator has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the attenuator is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution, due to the insertion loss uncertainty of the signal generator attenuator, is designated throughout all parts of the present document as u_{j40}.

NOTE: In this example case the standard uncertainty of the contribution due to the insertion loss uncertainty of the signal generator attenuator is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

5.2.1.2.4 Adaptor

Insertion loss: adapter: The adapter has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the adapter is not used outside the manufacturer's specification. The standard uncertainty of the contribution due to the insertion loss uncertainty of the adapter is designated throughout all parts of the present document as u_{j42}. Its value can be derived from the manufacturer's data sheet.

NOTE: In this example case the uncertainty of the contribution due to the insertion loss uncertainty of the adapter is obtained from the manufacturer's data sheet as ±0,10 dB. As nothing is said about the distribution of this uncertainty, a rectangular distribution (see TR 102 273-1-1 [6], clause 5.1.2) in logs is assumed, and the standard uncertainty is calculated as 0,06 dB.

5.2.1.2.5 Receiving device attenuator

Insertion loss: receiving device attenuator: The attenuator has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the attenuator is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution due to the insertion loss uncertainty of the receiving device attenuator is designated throughout all parts of the present document as u_{j40}.

NOTE: In this example case the standard uncertainty of the contribution due to the insertion loss uncertainty of the receiving device attenuator is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

5.2.1.2.6 Receiving device cable

Insertion loss: receiving device cable: The receiving device cable has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the cable is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution, due to the insertion loss uncertainty of the receiving device cable, is designated throughout all parts of the present document as u_{j41}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the insertion loss uncertainty of the receiving device cable is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

Cable factor: receiving device cable: Cable factor is defined as the total effect of the receiving device cable's influence on the measuring system including its interaction with the Stripline. It consists of the leakage caused by cable screening inefficiency and introducing an unbalanced current into the Stripline. In a radiated measurement the standard uncertainty of the cable factor, associated with each cable, is 0,5 dB provided that the precautions detailed in the methods have been observed i.e. routing and dressing of cables with ferrites. If no prevention has been attempted the standard uncertainty is 4,0 dB (justification for these values is given in annex E). The standard uncertainty of the contribution due to the cable factor of the receiving device cable is designated throughout all parts of the present document as u_{j19}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the cable factor of the receiving device cable is taken as 0,00 dB since there are no external fields involved other than leakage, which is assumed to have a negligible effect on the measurement.

5.2.1.2.7 Receiving device

In this, the first stage of the Stripline verification procedure, a reference level is set on the receiving device for a particular output level from the signal generator. In the second stage (where the path loss through the Stripline is measured), a second level is obtained on the receiving device. Only in the second stage do the linearity and absolute level uncertainties of the receiver become involved in the calculation of the combined standard uncertainty for the measurement.

Receiving device: absolute level: The standard uncertainty of the contribution due to the receiving device absolute level uncertainty is designated throughout all parts of the present document as u_{j47}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the absolute level uncertainty of the receiving device is assumed to be 0,00 dB since, in this part of the measurement, a reference level is recorded.

Receiving device: linearity: The standard uncertainty of the contribution due to the receiving device linearity is designated throughout all parts of the present document as u_{j48}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the receiving device linearity is assumed to be 0,00 dB since, in this part of the measurement, a reference level is recorded.

5.2.1.3 Contribution from the random component

Random uncertainty: The magnitude can be assessed from multiple measurements of the direct attenuation measurement. The standard uncertainty of the contribution due to the random uncertainty is designated throughout all parts of the present document as u_{i01}. Its value can then be calculated. See also clause 5.5 and the note in clause 6.4.7 of TR 102 273-1-1, as well as note in clause A.18 of the present document.

The direct attenuation measurement was repeated 10 times. The following results (dBμV) in were obtained (before correcting for cabling and attenuator network insertion loss):

106,8; 107,2; 106,7; 107,0; 107,2; 106,7; 107,1; 106,8; 107,1; 107,0.

Converting to linear terms (V):

0,2188; 0,2291; 0,2163; 0,2239; 0,2291; 0,2163; 0,2265; 0,2188; 0,2265; 0,2239.

The two sums X and Y are calculated:

X = the sum of the measured values = 2,2292 V

Y = the sum of the squares of the measured values = 0,4972 V^2

$$u_{c\ random} = \sqrt{\frac{Y - \frac{X^2}{n}}{n-1}} = \sqrt{\frac{0{,}4972 - \frac{2{,}2292^2}{10}}{10-1}} = 5{,}444 \times 10^{-3} \qquad \text{(formula 5.6)}$$

As the result is obtained as the mean value of 10 measurements and the standard uncertainty of the random uncertainty is:

$$u_{j\ random} = \frac{5{,}444 \times 10^{-3}}{0{,}22292} \times \frac{100}{11{,}5} = 0{,}212\ \text{dB}$$

NOTE: In this example case the standard uncertainty of the contribution due to the random uncertainty is 0,212 dB.

5.2.1.4 Summary table of contributory components

A complete list of all the contributions to this part of the verification procedure is given in table 37.

Table 37: Contributions from the reference, direct measurement

uj or i	**Description of uncertainty contributions**	**dB**
u_{j35}	*mismatch: direct attenuation measurement*	0,03
u_{j38}	*signal generator: absolute output level*	0,00
u_{j39}	*signal generator: output level stability*	0,01
u_{j41}	*insertion loss: signal generator cable*	0,00
u_{j19}	*cable factor: signal generator cable*	0,00
u_{j40}	*insertion loss: signal generator attenuator*	0,00
u_{j42}	*insertion loss: adapter*	0,06
u_{j40}	*insertion loss: receiving device attenuator*	0,00
u_{j41}	*insertion loss: receiving device cable*	0,00
u_{j19}	*cable factor: receiving device cable*	0,00
u_{j47}	*receiving device: absolute level*	0,00
u_{j48}	*receiving device: linearity*	0,00
u_{i01}	*random uncertainty (see note in clause A.18 of the present document and note in clause 6.4.7 of TR 102 273-1-1)*	0,21

The standard uncertainties from table 37 should be combined by RSS in accordance with TR 102 273-1-1 [6], clause 5. This gives the combined standard uncertainty ($u_{c\ direct\ attenuation\ measurement}$) for the direct attenuation measurement in dB.

The value of $u_{c\ direct\ attenuation\ measurement}$ is calculated as 0,223 dB.

5.2.2 Uncertainty contributions: stage 2: radiated attenuation measurement

The second stage of the verification procedure is the Stripline radiated attenuation measurement. This involves mounting a monopole antenna through a hole in the lower plate of the Stripline, so that the feed point to the monopole is flush with the surface of the lower plate. The radiated attenuation measurement is carried out by removing the adapter and connecting the signal generator attenuator to the Stripline and connecting the receiving device attenuator to the monopole output (see figure 15). The difference in received levels (after allowance for any correction factors which may be appropriate), for the same signal generator output level, is the Stripline radiated attenuation.

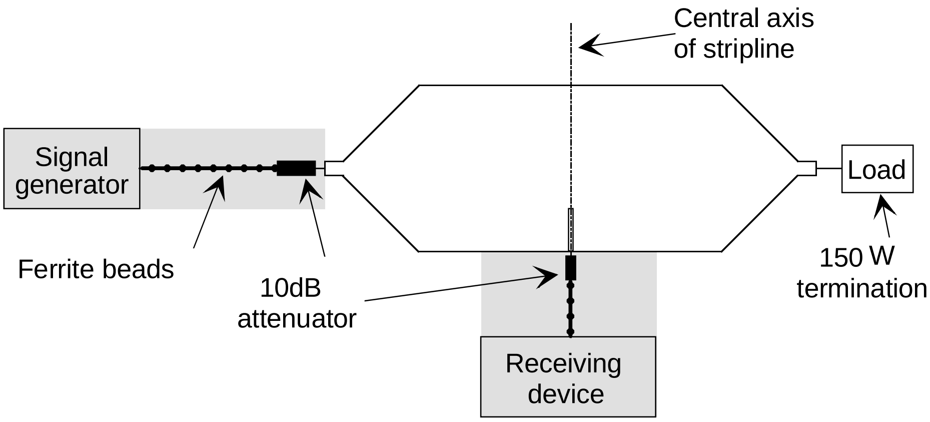


Figure 15: Stage 2: Radiated attenuation measurement

Whereas figure 15 shows, schematically, the test equipment set-up for this stage of the verification procedure, an analysis diagram of the individual components (each of which contributes its own uncertainty) for this stage of the measurement is shown in figure 16. Again, as stated above, the shaded areas represent components common to both stages of the verification procedure.

5.2.2.1 Contributions from the mismatch components

Mismatch in the transmitting and receiving parts: The value of the combined standard uncertainty of the contributions due to the mismatch are calculated from the approach described in annex D. It is calculated in two parts. Firstly the standard uncertainty of the contribution due to the mismatch in the transmitting part, i.e. between the signal generator, cable, attenuator and the input to the Stripline and secondly, that for the receiving part, i.e. between the receiving monopole antenna, attenuator, cable and the receiving device.

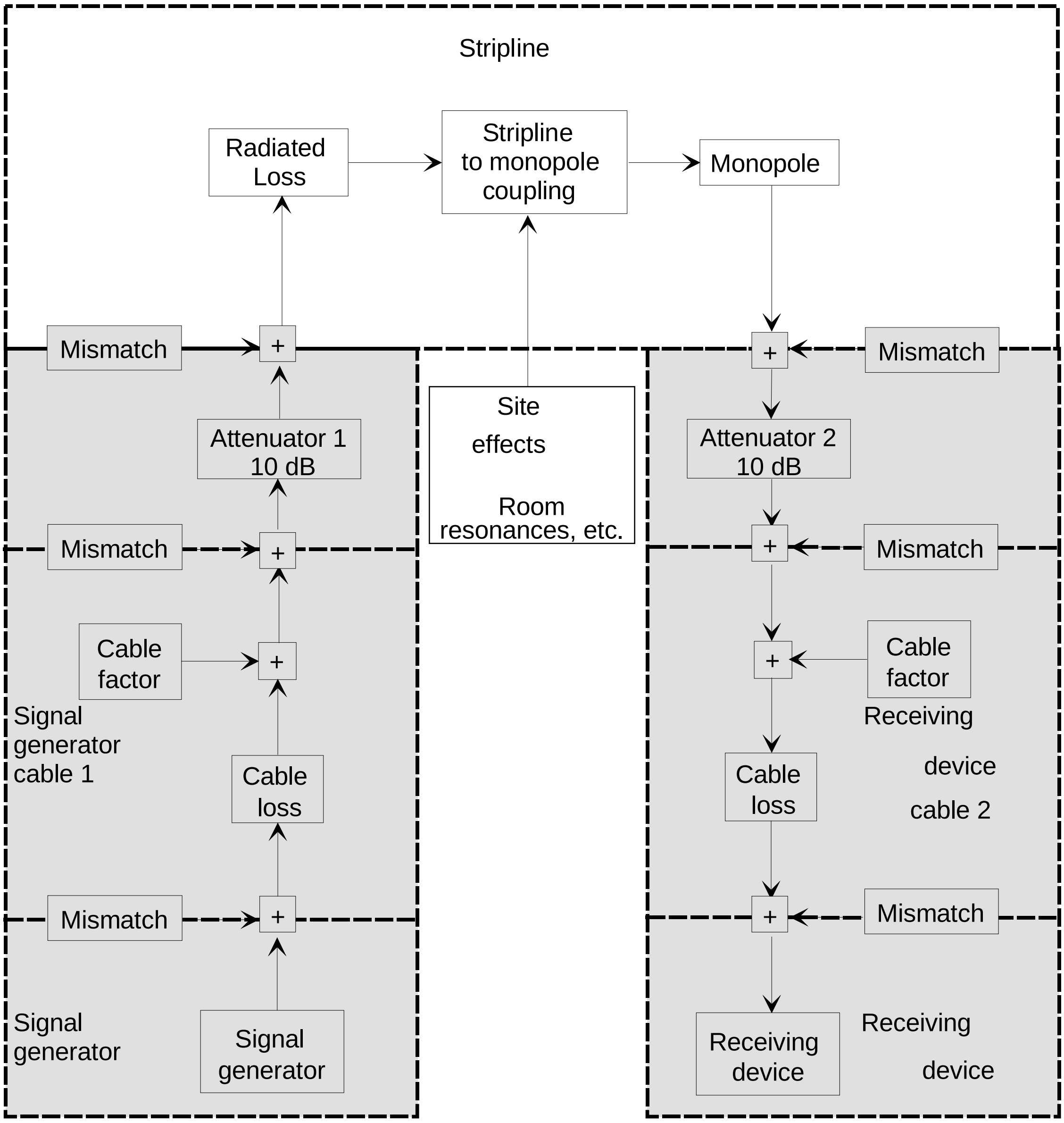


Figure 16: stage 2: radiated attenuation measurement

All the individual contributions are U-distributed.

NOTE 1: In this example value taken for the signal generator output reflection coefficient is the worst case over the frequency band of interest, similarly, for the cable, adapter and attenuator VSWRs.

NOTE 2: The attenuation values of the cables and attenuators should be obtained from the data sheets/calibration records at the specific frequency of the test, along with the associated uncertainties for these values.

Mismatch: transmitting part:

Signal generator:	Output reflection coefficient: $|\rho_G|$	= 0,20
Cable:	Input and output reflection coefficients: $|S_{11}|$ and $|S_{22}|$	= 0,07
	Attenuation: 1 dB = $|S_{12}| = |S_{21}|$	= 0,891
Attenuator:	Input and output reflection coefficients $|S_{11}| = |S_{22}|$	= 0,05
	Attenuation = 10 dB $|S_{12}| = |S_{21}|$	= 0,3162
Stripline:	Input reflection coefficient: $|\rho_{SL}|$	= 0,333

Those components that cancel are not calculated. Other contributions are (see annex D):

$u_{\text{j mismatch: generator and cable 1}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$u_{\text{j mismatch: cable 1 and attenuator 1}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$$u_{j\ mismatch: attenuator\ 1 and\ Stripline} = \frac{0{,}05 \times 0{,}333 \times 100}{\sqrt{2}} \% = 1{,}177\ \%$$

$u_{\text{j generator and attenuator 1}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$$u_{j\ mismatch: cable\ 1 and\ Stripline} = \frac{0{,}07 \times 0{,}333 \times 0{,}316^2 \times 100}{\sqrt{2}} \% = 0{,}165\ \%$$

$$u_{j\ mismatch: generator\ and\ Stripline} = \frac{0{,}2 \times 0{,}333 \times 0{,}891^2 \times 0{,}316^2 \times 100}{\sqrt{2}} \% = 0{,}373\ \%$$

The combined standard uncertainty of the mismatch is then calculated:

$$u_{c\ mismatch: transmitting\ part} = \sqrt{1{,}177^2 + 0{,}165^2 + 0{,}373^2} = 1{,}25\%$$

transforming to the logarithmic form (see annex C): 1,25 %/11,5 = 0,11 dB.

The standard uncertainty of the contribution due to the mismatch in the transmitting part, is designated throughout all parts of the present document as u_{j36}. Its value in this example is 0,11 dB.

Mismatch: receiving part:

Monopole:	Input reflection coefficient: $\lvert\rho_M\rvert$	= 0,333
Attenuator:	Input and output reflection coefficients $\lvert S_{11}\rvert = \lvert S_{22}\rvert$	= 0,05
	Attenuation = 10 dB $\lvert S_{12}\rvert = \lvert S_{21}\rvert$	= 0,3162
Cable:	Input and output reflection coefficients: $\lvert S_{11}\rvert$ and $\lvert S_{22}\rvert$	= 0,07
	Attenuation: 1 dB = $\lvert S_{12}\rvert = \lvert S_{21}\rvert$	= 0,891
Receiving device:	Output reflection coefficient: $\lvert\rho_{RD}\rvert$	= 0,20

$$u_{j\ mismatch: monopole\ and\ attenuator} = \frac{0{,}333 \times 0{,}05 \times 100}{\sqrt{2}} \% = 1{,}177\ \%$$

$u_{\text{j attenuator 2 and cable 2}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$u_{\text{j cable 2 and receiving device}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$$u_{j\ mismatch: monopole\ and\ cable\ 2} = \frac{0{,}333 \times 0{,}07 \times 0{,}316^2 \times 100}{\sqrt{2}} \% = 0{,}165\ \%$$

$u_{\text{j attenuator 2 and receiving device}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$$u_{j\ mismatch: monopole\ and\ receiving\ device} = \frac{0{,}333 \times 0{,}2 \times 0{,}316^2 \times 0{,}891^2 \times 100}{\sqrt{2}} \% = 0{,}373\ \%$$

The combined standard uncertainty of the mismatch is then calculated:

$$u_{c\,mismatch:receiving\ part} = \sqrt{1{,}177^2 + 0{,}165^2 + 0{,}373^2} = 1{,}25\%$$

transforming to the logarithmic form (see annex C): 1,25 %/11,5 = 0,11 dB.

The standard uncertainty of the contribution due to the mismatch in the receiving part is designated throughout all parts of the present document as u_{j37}. Its value in this example is 0,11 dB.

5.2.2.2 Contributions from individual components

5.2.2.2.1 Signal generator

Signal generator: absolute output level: In a verification procedure, the signal generator's absolute level uncertainty contributes equally to both stages of the measurement. The standard uncertainty of the contribution due to the signal generator absolute output level uncertainty is designated throughout all parts of the present document as u_{j38}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the signal generator absolute output level uncertainty is taken to be 0,00 dB since, once the level has been set in stage one of the procedure, the level is not further adjusted. The uncertainty is therefore assumed to be systematic i.e. it produces the same offset in both stages.

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

NOTE 2: In this example case the uncertainty of the contribution due to the signal generator output level stability is obtained from the manufacturer's data sheet as ±0,02 dB.
As nothing is said about the distribution of this uncertainty, a rectangular distribution (see TR 102 273-1-1 [6], clause 5.1.2) in logs is assumed, and the standard uncertainty is calculated as 0,011 55 dB. This is rounded down to 0,01 dB.

5.2.2.2.2 Signal generator cable

Insertion loss: signal generator cable: The signal generator cable has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the cable is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution, due to the insertion loss uncertainty of the signal generator cable, is designated throughout all parts of the present document as u_{j41}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the insertion loss uncertainty of the signal generator cable is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

Cable factor: signal generator cable: Cable factor is defined as the total effect of the signal generator cable's influence on the measuring system including its interaction with the Stripline. It consists of the leakage caused by cable screening inefficiency and introducing an unbalanced current into the Stripline. In a radiated measurement the standard uncertainty of the cable factor, associated with each cable, is 0,5 dB provided that the precautions detailed in the methods have been observed, i.e. routing and dressing of cables with ferrites. If no prevention has been attempted the standard uncertainty is 4,0 dB (justification for these values is given in annex E). The standard uncertainty of the contribution due to the cable factor of the signal generator cable is designated throughout all parts of the present document as u_{j19}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the cable factor of the transmitting antenna cable is taken as 0,50 dB since the precautions detailed in the methods are assumed to have been observed.

5.2.2.2.3 Signal generator attenuator

Insertion loss: signal generator attenuator: The signal generator attenuator has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the attenuator is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution, due to the insertion loss uncertainty of the signal generator attenuator, is designated throughout all parts of the present document as u_{j40}.

NOTE: In this example case the standard uncertainty of the contribution due to the insertion loss uncertainty of the signal generator attenuator is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

5.2.2.2.4 Site factors

Ambient effect: Uncertainty is introduced as a result of local ambient signals raising the noise floor at the measurement frequency. The standard uncertainty of the contribution due to the ambient effect is designated throughout all parts of the present document as u_{j34}. The values of the standard uncertainty should be taken from table 38.

Table 38: Uncertainty contribution: ambient effect

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

NOTE 1: In this example case the standard uncertainty of the contribution due to the ambient effect is taken as 0,00 dB since the Stripline is assumed to be placed in a shielded room.

Stripline: influence of site effects: The influence of site effects comprise those effects resulting from not observing the recommendations given in EN 55020 [3] regarding positioning of the Stripline and layout of the absorber. These can lead to incorrect received levels i.e. values which differ from theoretical calculations. The standard uncertainty of the contribution due to the influence of site effects is designated throughout all parts of the present document as u_{j33}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the influence of site effects is taken to have a standard uncertainty of 3,0 dB (see annex A). In the verification procedure, site effects only contribute to the Stripline radiated attenuation part.

5.2.2.2.5 Antenna factor of the monopole

Stripline: antenna factor of the monopole: This has been derived from measurements taken within the Stripline. Therefore, the given values incorporate several of the field disturbance factors which the Stripline possesses and which therefore do not have to be allowed for as individual contributions. Amongst these included effects are imaging, characteristic impedance of the line, non-planar nature of the field etc. The standard uncertainty of the contribution due to the antenna factor of the monopole is designated throughout all parts of the present document as u_{j30}.

NOTE: In this example case the standard uncertainty of the contribution due to the antenna factor of the monopole is taken as 1,15 dB. This combined uncertainty source is only present in the Stripline radiated attenuation measurement.

5.2.2.2.6 Receiving device attenuator

Insertion loss: receiving device attenuator: The receiving device attenuator has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the attenuator is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution due to the insertion loss uncertainty of the receiving device attenuator is designated throughout all parts of the present document as u_{j40}.

NOTE: In this example case the standard uncertainty of the contribution due to the insertion loss uncertainty of the receiving device attenuator is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

5.2.2.2.7 Receiving device cable

Insertion loss: receiving device cable: The receiving device cable has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the cable is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution, due to the insertion loss uncertainty of the receiving device cable, is designated throughout all parts of the present document as u_{j41}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the insertion loss uncertainty of the receiving device cable is taken as 0,00 dB since the uncertainty is systematic i.e. it produces the same offset in both stages.

Cable factor: receiving device cable: Cable factor is defined as the total effect of the receiving device cable's influence on the measuring system including its interaction with the site. It consists of the leakage caused by cable screening inefficiency and introducing an unbalanced current into the monopole. In a radiated measurement the standard uncertainty of the cable factor, associated with each cable, is 0,5 dB provided that the precautions detailed in the methods have been observed i.e. routing and dressing of cables with ferrites. If no prevention has been attempted the standard uncertainty is 4,0 dB (justification for these values is given in annex E). The standard uncertainty of the contribution due to the cable factor of the receiving device cable is designated throughout all parts of the present document as u_{j19}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the cable factor of the receiving antenna cable is taken as 0,50 dB since the precautions detailed in the methods have been observed.

5.2.2.2.8 Receiving device

The first stage of the verification procedure involved setting a reference level on the receiving device for a particular output level from the signal generator. In this the second stage (where the radiated attenuation through the Stripline is measured), a second level is obtained which results in linearity and absolute level uncertainties becoming involved in the calculation of the combined standard uncertainty for the measurement.

Receiving device: absolute level: This uncertainty only contributes during the second stage of the procedure if the input attenuation range setting on the receiving device has been changed from its setting in the first stage. The standard uncertainty of the contribution due to the receiving device absolute level uncertainty is designated throughout all parts of the present document as u_{j47}.

NOTE 1: In this example case the uncertainty of the contribution due to the receiving device absolute level uncertainty (a range change is assumed) is obtained from the manufacturer's data as ±0,5 dB. As nothing is said about the distribution of this uncertainty, a rectangular distribution (see TR 102 273-1-1 [6], clause 5.1.2) in logs is assumed. The standard uncertainty of the contribution due to the receiving device absolute level uncertainty is calculated as 0,29 dB.

Receiving device: linearity: In any test in which the contribution of the absolute level uncertainty of the receiving device contributes to the combined standard uncertainty of the test i.e. it does not cancel due to the methodology, the contribution from the receiving device linearity is considered to have been included in u_{j47}. Conversely, for any test in which the absolute level uncertainty of the receiving device does not contribute to the combined standard uncertainty the linearity of the receiving device should be included. The standard uncertainty of the contribution due to the receiving device linearity is designated throughout all parts of the present document as u_{j48}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the receiving device linearity is taken as 0,00 dB.

5.2.2.3 Contribution from the random component

Random uncertainty: The magnitude can be assessed from multiple measurements of the radiated attenuation measurement. The standard uncertainty of the contribution due to the random uncertainty is designated throughout all parts of the present document as u_{i01}. See also clause 5.5 and the note in clause 6.4.7 of TR 102 273-1-1, as well as note in clause A.18 of the present document.

The radiated attenuation measurement was repeated ten times. The following results were obtained in dBμV (before correcting for cabling and attenuator network insertion loss):

65,4; 63,4; 66,0; 65,3; 63,0; 64,9; 65,2; 66,8; 65,5; 63,7.

Converting to linear terms (V):

$1,862 \times 10^{-3}$; $1,479 \times 10^{-3}$; $1,995 \times 10^{-3}$; $1,841 \times 10^{-3}$; $1,413 \times 10^{-3}$; $1,758 \times 10^{-3}$; $1,820 \times 10^{-3}$; $2,188 \times 10^{-3}$; $1,884 \times 10^{-3}$; $1,531 \times 10^{-3}$;

The two sums X and Y are calculated:

X = the sum of the measured values = $17,77 \times 10^{-3}$ (V);

Y = the sum of the squares of the measured values = $32,10 \times 10^{-6}$ V^2

$$u_{c\ random} = \sqrt{\frac{Y - \frac{X^2}{n}}{n-1}} = \sqrt{\frac{32,10 \times 10^{-6} - \frac{\left(17,77 \times 10^{-3}\right)^2}{10}}{10-1}} = 238,3 \times 10^{-6} \qquad \text{(formula 5.6)}$$

As the result is obtained as the mean value of 10 measurements and the standard uncertainty of the random uncertainty is:

$$u_{j\ random} = \frac{238,3 \times 10^{-6}}{1,777 \times 10^{-3}} \times \frac{100}{11,5} = 1,17 \text{ dB}$$

NOTE: In this example case the standard uncertainty of the contribution due to the random uncertainty is 0,673 dB.

5.2.2.4 Summary table of contributory components

A complete list of all the contributions to this part of the verification procedure is given in table 39.

Table 39: Contributions from the radiated attenuation measurement

$u_{j\ or\ i}$	Description of uncertainty contributions	dB
u_{j36}	*mismatch: transmitting part*	0,11
u_{j37}	*mismatch: receiving part*	0,11
u_{j38}	*signal generator: absolute output level*	0,00
u_{j39}	*signal generator: output level stability*	0,01
u_{j41}	*insertion loss: signal generator cable*	0,00
u_{j19}	*cable factor: signal generator cable*	0,50
u_{j40}	*insertion loss: signal generator attenuator*	0,00
u_{j34}	*ambient effect*	0,00
u_{j33}	*Stripline: influence of site effects*	3,00
u_{j31}	*Stripline: antenna factor of the monopole*	1,15
uj_{40}	*insertion loss: receiving device attenuator*	0,00
u_{j41}	*insertion loss: receiving device cable*	0,00
u_{j19}	*cable factor: receiving device cable*	0,50
u_{j47}	*receiving device: absolute level*	0,29
u_{j48}	*receiving device: linearity*	0,00
u_{i01}	*random uncertainty (see note in clause A.18 of the present document and note in clause 6.4.7 of TR 102 273-1-1)*	1,17

The standard uncertainties from table 39 should be combined by RSS in accordance with TR 102 273-1-1 [6], clause 5. This gives the combined standard uncertainty ($u_{c\ Stripline\ attenuation\ measurement}$) for the Stripline attenuation measurement in dB.

The value of $u_{c\ Stripline\ attenuation\ measurement}$ is calculated as 3,51 dB.

5.2.2.5 Expanded uncertainty for the verification procedure

The combined standard uncertainty of the results of the verification procedure is the combination of the components outlined in clauses 5.2.1.4 and 5.2.2.4. The components to be combined are $u_{c\ direct\ attenuation\ measurement}$ and $u_{c\ Stripline\ attenuation\ measurement}$.

$$u_{c\ Stripline\ verification\ procedure} = \sqrt{0{,}223^2 + 3{,}51^2} = 3{,}51\text{ dB}$$

The expanded uncertainty is ±1,96 x 3,51 = ±6,89 dB at a 95 % confidence level.

5.3 Example 2: the measurement of a receiver parameter (sensitivity)

For the measurement of receiver sensitivity two stages of test are involved. The first stage (determining the transform factor of the Stripline) involves measuring the field strength at the point where the receiver will be placed and determining the relationship between the signal generator output power level and the resulting field strength. The second stage (the EUT measurement) involves placing the EUT within the Stripline and adjusting the output level of the signal generator until the required response is obtained on the receiver. The signal generator output power level is then converted to field strength using the transform factor.

5.3.1 Uncertainty contributions: stage 1: EUT measurement

The first stage of the measurement is to determine the minimum signal generator output level which produces the required response from the EUT. The test equipment set-up is shown in see figure 17.

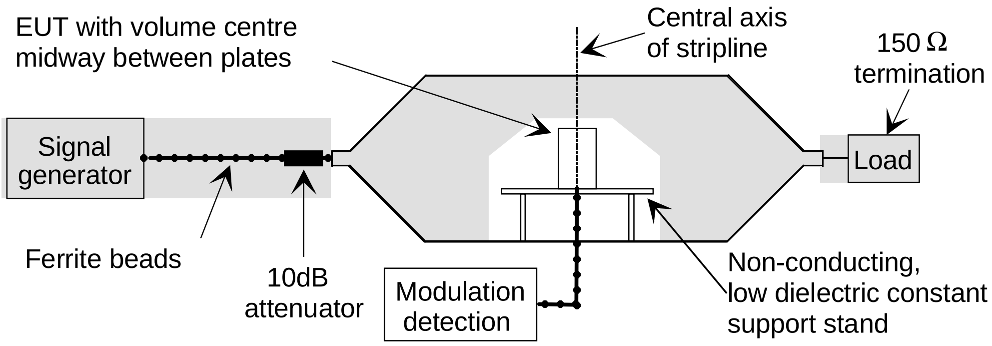


Figure 17: stage 1: EUT measurement

Whereas figure 17 shows, schematically, the test equipment set-up for the EUT sensitivity measurement, figure 18, an analysis diagram, provides a detailed picture of the individual uncertainty components (each of which contributes its own uncertainty) for this stage in the measurement. As stated above, the shaded areas represent components common to both stages of the test method.

5.3.1.1 Contributions from the mismatch components

Mismatch: transmitting part: The uncertainty due to mismatch for the measurement on the EUT concerns only the signal generator, the signal generator cable, the signal generator attenuator and the input to the Stripline. The mismatch uncertainty through this network does, however, contribute equally to both stages of the test for cases in which a field strength measurement is subsequently performed.

If, however, the results of the verification procedure are used to calculate the field strength, the contribution of the mismatch uncertainty needs to be calculated, from the approach described in annex D. All the contributions are U-distributed.

Signal generator:	Output reflection coefficient: $|\rho_G|$	= 0,20
Cable:	Input and output reflection coefficients: $|S_{11}|$ and $|S_{22}|$	= 0,07
	Attenuation: 1 dB = $|S_{12}| = |S_{21}|$	= 0,891
Attenuator:	Input and output reflection coefficients $|S_{11}| = |S_{22}|$	= 0,05
	Attenuation = 10 dB $|S_{12}| = |S_{21}|$	= 0,3162
Stripline:	Input reflection coefficient: $|\rho_{SL}|$	= 0,333

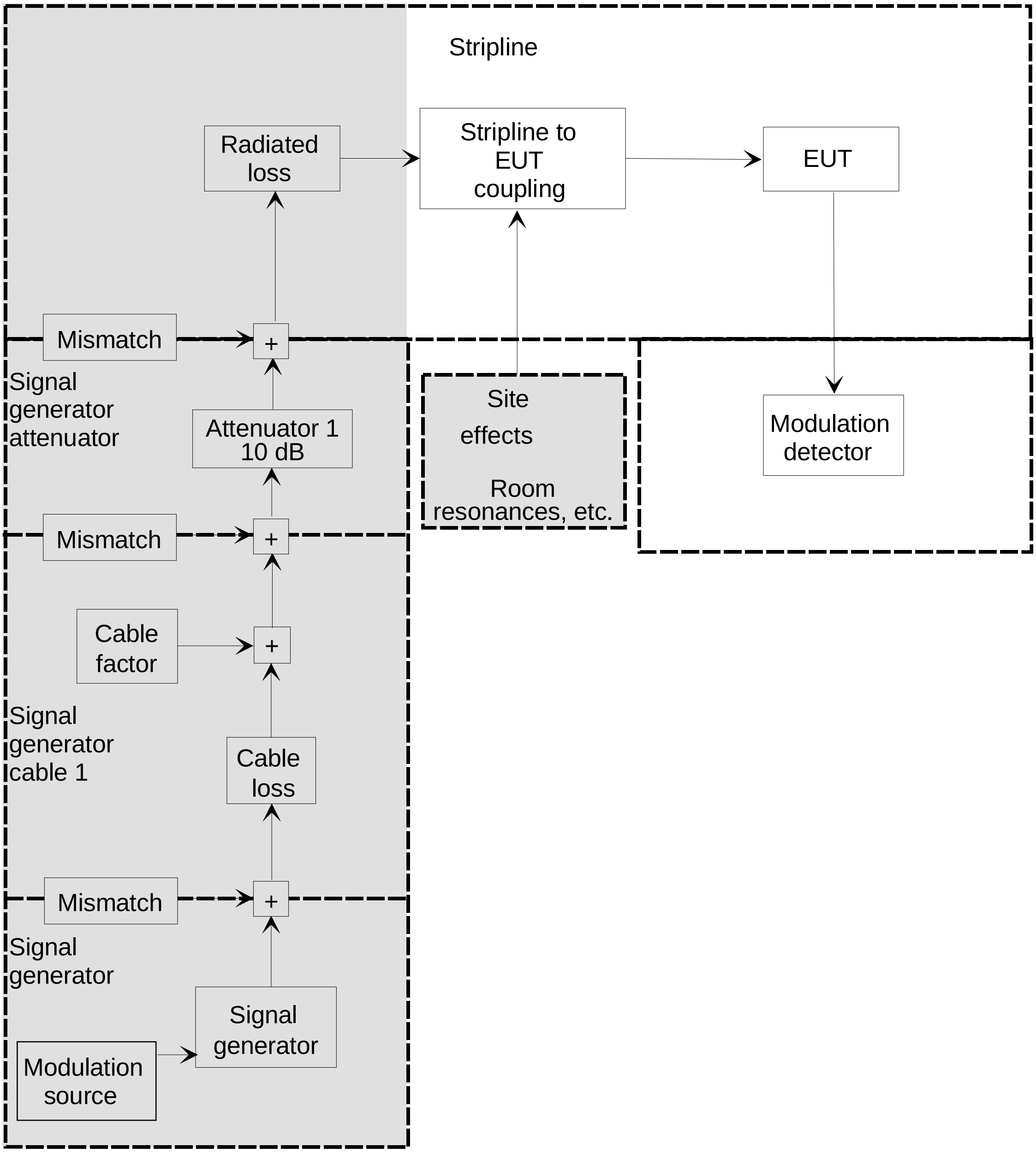


Figure 18: Schematic of the sensitivity measurement on the EUT

Mismatch: transmitting part:

All these contributions are U-distributed. Those components that cancel are not calculated. Other contributions are (see annex D):

$u_{j\ \text{mismatch: generator and cable 1}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$u_{j\ \text{mismatch: cable 1 and attenuator 1}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$$u_{j\,mismatch: attenuator\,1 and\ Stripline} = \frac{0{,}05 \times 0{,}333 \times 100}{\sqrt{2}} \% = 1{,}177\ \%$$

$u_{j\ \text{generator and attenuator 1}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$$u_{j\,mismatch: cable\,1 and\ Stripline} = \frac{0{,}07 \times 0{,}333 \times 0{,}316^2 \times 100}{\sqrt{2}} \% = 0{,}165\ \%$$

$$u_{j\ mismatch:\ generator\ and\ Stripline} = \frac{0{,}2 \times 0{,}333 \times 0{,}891^2 \times 0{,}316^2 \times 100}{\sqrt{2}} \% = 0{,}373\ \%$$

The combined standard uncertainty of the mismatch is then calculated:

$$u_{c\ mismatch:\ transmitting\ part} = \sqrt{1{,}177^2 + 0{,}165^2 + 0{,}373^2} = 1{,}25\%$$

transforming to the logarithmic form (see annex C): 1,25 %/11,5 = 0,11 dB.

The standard uncertainty of the contribution due to the mismatch in the transmitting part, is designated throughout all parts of the present document as u_{j36}. Its value in this example is 0,11 dB.

5.3.1.2 Contributions from the individual components

5.3.1.2.1 Signal generator

Signal generator: absolute output level: In this test method, the uncertainty due to the setting of the signal generator's absolute output level contributes to both stages. In stage 1, the output level is individually adjusted at each of eight different positioning angles whilst in stage 2, after an inspection (or calculation) of the eight different values, the signal generator is set to a specific output level. The standard uncertainty of the contribution due to the signal generator absolute output level uncertainty is designated throughout all parts of the present document as u_{j38}. Its value can be obtained from the manufacturer's data sheet.

NOTE 1: In this example case the uncertainty of the contribution due to the signal generator absolute output level is obtained from the manufacturer's data sheet as ±1,0 dB. As nothing is said about the distribution of this uncertainty, a rectangular distribution (see TR 102 273-1-1 [6], clause 5.1.2) in logs is assumed, and the standard uncertainty is calculated as 0,58 dB.

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

NOTE 2: In this example case the standard uncertainty of the contribution due to the signal generator output level stability is taken as 0,0 dB as it is covered by the absolute level uncertainty.

5.3.1.2.2 Signal generator cable

Insertion loss: signal generator cable: The signal generator cable has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the cable is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution due to the insertion loss uncertainty of the signal generator cable is designated throughout all parts of the present document as u_{j41}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the insertion loss uncertainty of the signal generator cable is taken as 0,20 dB as the results of the verification procedure have been used to determine the field strength and this value has been taken from the manufacturer's or calibration data.

NOTE 2: If a field measurement had been performed using either a monopole of three-axis probe the value **would have been** 0,00 dB as the uncertainty is systematic i.e. it produces the same offset in both stages.

Cable factor: signal generator cable: Cable factor is defined as the total effect of the signal generator cable's influence on the measuring system including its interaction with the site. It consists of the leakage caused by cable screening inefficiency and introducing an unbalanced current into the Stripline. In a radiated measurement the standard uncertainty of the cable factor, associated with each cable, is 0,5 dB provided that the precautions detailed in the methods have been observed, i.e. routing and dressing of cables with ferrites. If no prevention has been attempted the standard uncertainty is 4,0 dB (justification for these values is given in annex E). The standard uncertainty of the contribution due to the cable factor of the signal generator cable is designated throughout all parts of the present document as u_{j19}.

NOTE 3: In this example case the standard uncertainty of the contribution due to the cable factor of the signal generator cable is taken as 0,5 dB since the precautions detailed in the test method have been observed.

5.3.1.2.3 Signal generator attenuator

Insertion loss: signal generator attenuator: The signal generator attenuator has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the attenuator is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution due to the insertion loss of the signal generator attenuator is designated throughout all parts of the present document as u_{j40}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the insertion loss uncertainty of the signal generator cable is taken as 0,20 dB as the results of the verification procedure have been used to determine the field strength and this value has been taken from the manufacturer's or calibration data.

NOTE 2: If a field measurement had been performed using either a monopole of three-axis probe the value would have been 0,00 dB as the uncertainty is systematic i.e. it produces the same offset in both stages.

5.3.1.2.4 Site factors

Ambient effect: Uncertainty is introduced as a result of local ambient signals raising the noise floor at the measurement frequency. The standard uncertainty of the contribution due to the ambient effect is designated throughout all parts of the present document as u_{j34}. The value of the standard uncertainty is the same as for the second stage.

NOTE 1: In this example case the standard uncertainty of the contribution due to the ambient effect is taken as 0,00 dB since the Stripline is assumed to have been placed in a shielded room.

Stripline: influence of site effects: The influence of site effects comprise those effects, resulting from not observing the recommendations given in EN 55020 [3] regarding positioning of the Stripline and layout of absorber. These can lead to incorrect received levels i.e. values which differ from theoretical calculations. In this example, the recommendations are assumed not to have been fully observed. The standard uncertainty of the contribution due to the influence of site effects is designated throughout all parts of the present document as u_{j33}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the influence of site effects is taken as 3,0 dB since in the verification procedure, site effects only contribute to the Stripline attenuation part and therefore do not cancel.

NOTE 3: If a field measurement had been performed using either a monopole of three-axis probe the value **would have been** 0,00 dB as the uncertainty is systematic i.e. it produces the same offset in both stages.

5.3.1.2.5 EUT

Stripline: mutual coupling of the EUT to its images in the plates: The magnitude is dependent on the EUT's size. The EUT is assumed to be positioned midway between the plates. The standard uncertainty of the contribution due to the mutual coupling of the EUT to its images in the plates is designated throughout all parts of the present document as u_{j24}. Its value can be obtained from table 40.

Table 40: Uncertainty contribution of the mutual coupling of the EUT to its images in the plates

Size of the EUT relative to the plate separation	Standard uncertainty of the contribution
size/separation < 33 %	1,15 dB
33 % ≤ size/separation < 50 %	1,73 dB
50 % ≤ size/separation < 70 %	2,89 dB
70 % ≤ size/separation ≤ 87,5 % (max.)	5,77 dB

NOTE 1: In this example case the standard uncertainty of the contribution due to the mutual coupling of the EUT to its images in the plates is 1,15 dB since it is assumed the equipment size is <33 % of the plate separation.

Stripline: characteristic impedance: This uncertainty contribution results from the difference between the free-space wave impedance (377 Ω) for which the EUT had been developed and that for the Stripline (150 Ω). The standard uncertainty of the contribution due to the characteristic impedance of the Stripline is designated throughout all parts of the present document as u_{j26}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the characteristic impedance of the Stripline is taken as having a standard uncertainty of 0,58 dB.

Stripline: correction factor for the size of the EUT: This uncertainty is the result of changes in the intensity of the electric field between the plates resulting from the presence, and metal content of the EUT. The larger the size of the EUT in the vertical plane of the Stripline, the greater the field intensification effect. Correction factors are supplied within the test method, and the associated standard uncertainty of the contribution of the uncertainty due to the correction factor for the size of the EUT is designated throughout all parts of the present document as u_{j32}. For an EUT mounted centrally in the Stripline, values can be obtained from table 41.

Table 41: Uncertainty contribution: Stripline: correction factor for the size of the EUT

Height of the EUT (in the E-plane) is:	Standard uncertainty of the contribution
height < 0,2 m	0,30 dB
0,2 m ≤ height < 0,4 m	0,60 dB
0,4 m ≤ height ≤ 0,7 m	1,20 dB

NOTE 3: In this example case the standard uncertainty of the contribution of the uncertainty due to the correction factor for the size of the EUT is taken as 0,60 dB as the EUT is 0,22 m high.

EUT: mutual coupling to the power leads: This is the uncertainty associated with the influence (reflections, parasitic effects, etc.) of the power leads on the EUT. The standard uncertainty associated with this effect is 0,5 dB provided that the precautions detailed in the methods have been observed, i.e. routing and dressing of cables with ferrites. If no prevention has been attempted the standard uncertainty is 2,0 dB. The standard uncertainty of the contribution due to the mutual coupling of the EUT to the power leads is designated throughout all parts of the present document as u_{j54}.

NOTE 4: In this example case the standard uncertainty of the contribution due to the mutual coupling of the EUT to the power leads is taken as 0,5 dB since the precautions detailed in the methods have been observed.

Stripline: non-planar nature of the field distribution: This uncertainty results from the non-uniform amplitude and phase distribution of the electric field across the EUT. The non-uniformity results from room resonances, constructional problems, moding, reflections, etc. The standard uncertainty of the contribution due to the non-planar nature of the field distribution is designated throughout all parts of the present document as u_{j27}.

NOTE 5: In this example case the standard uncertainty of the contribution due to the non-planar nature of the field distribution is taken as 0,29 dB.

EUT: degradation measurement: This contribution is a RF level uncertainty associated with the uncertainty of measuring 20 dB SINAD, 10^{-2} bit stream or 80 % message acceptance ratio. The standard uncertainty of the contribution due to the EUT degradation measurement, designated throughout all parts of the present document as u_{j52}, can be obtained from TR 100 028 [5].

NOTE 6: In this example case, the standard uncertainty of the contribution is obtained from TR 100 028 [5] and its value is 0,68 dB.

5.3.1.3 Contribution from the random component

Random uncertainty: The magnitude can be assessed from multiple measurements of the receiver sensitivity measurement. The standard uncertainty of the contribution due to the random uncertainty is designated throughout all parts of the present document as u_{i01}. See also clause 5.5 and the note in clause 6.4.7 of TR 102 273-1-1, as well as note in clause A.18 of the present document.

The receiver sensitivity measurement was repeated ten times. The following results were obtained in dBμV (before correcting for cabling and attenuator network insertion loss):

65,4; 63,4; 66,0; 65,3; 63,0; 64,9; 65,2; 66,8; 65,5; 63,7.

Converting to linear terms (V):

$1{,}862 \times 10^{-3}$; $1{,}479 \times 10^{-3}$; $1{,}995 \times 10^{-3}$; $1{,}841 \times 10^{-3}$; $1{,}413 \times 10^{-3}$; $1{,}758 \times 10^{-3}$; $1{,}820 \times 10^{-3}$; $2{,}188 \times 10^{-3}$; $1{,}884 \times 10^{-3}$; $1{,}531 \times 10^{-3}$;

The two sums X and Y are calculated:

X = the sum of the measured values = $17{,}77 \times 10^{-3}$ (V);

Y = the sum of the squares of the measured values = $32{,}10 \times 10^{-6}\ \mathrm{V}^2$

$$u_{c\ random} = \sqrt{\frac{Y - \frac{X^2}{n}}{n-1}} = \sqrt{\frac{32{,}10\times10^{-6} - \frac{\left(17{,}77\times10^{-3}\right)^2}{10}}{10-1}} = 238{,}3 \times 10^{-6} \qquad \text{(formula 5.6)}$$

As the result is obtained as the mean value of 10 measurements and the standard uncertainty of the random uncertainty is:

$$u_{j\ random} = \frac{238{,}3\times10^{-6}}{1{,}777\times10^{-3}} \times \frac{100}{11{,}5} = 1{,}17\ \mathrm{dB}$$

NOTE: In this example case the standard uncertainty of the contribution due to the random uncertainty is 1,17 dB.

5.3.1.4 Summary table of contributory components

A complete list of all the contributions to this part of the test method is given in table 42.

Table 42: Contributions from the measurement on the EUT

$u_{j \text{ or } i}$	Description of uncertainty contributions	dB
u_{j36}	*mismatch: transmitting part:* *a) Using results of the verification procedure* *b) Using a monopole for field measurement* *c) Using a 3-axis probe for field measurement*	 0,11 0,00 0,00
u_{j38}	*signal generator: absolute output level*	0,58
u_{j39}	*signal generator: output level stability*	0,00
u_{j41}	*insertion loss: signal generator cable* *a) Using results of the verification procedure* *b) Using a monopole for field measurement* *c) Using three-axis probe for field measurement*	 0,20 0,00 0,00
u_{j19}	*cable factor: signal generator cable*	0,50
u_{j40}	*insertion loss: signal generator attenuator* *a) Using results of the verification procedure* *b) Using a monopole for field measurement* *c) Using a three-axis probe for field measurement*	 0,20 0,00 0,00
u_{j34}	*ambient effect*	0,00
u_{j33}	*Stripline: influence of site effects* *a) Using results of the verification procedure* *b) Using a monopole for field measurement* *c) Using a three-axis probe for field measurement*	 3,00 0,00 0,00
u_{j24}	*Stripline: mutual coupling of the EUT to its images in the plates*	1,15
u_{j26}	*Stripline: characteristic impedance*	0,58
u_{j32}	*Stripline: correction factor for the size of the EUT*	0,60
u_{j55}	*EUT: mutual coupling to the power leads*	0,50
u_{j27}	*Stripline: non-planar nature of the field distribution*	0,29
u_{j52}	*EUT: degradation measurement*	0,68
u_{i01}	*random uncertainty (see note in clause A.18 of the present document and note in clause 6.4.7 of TR 102 273-1-1)*	1,17

The standard uncertainties from table 42 should be combined by RSS in accordance with TR 102 273-1-1 [6], clause 5. This gives the combined standard uncertainty for the direct attenuation measurement in dB as follows:

- using results of the verification procedure = $u_{c \text{ measurement of the EUT}}$ = 3,72 dB;
- using a monopole for field measurement = $u_{c \text{ measurement of the EUT}}$ = 2,18 dB;
- using a three-axis probe for field measurement = $u_{c \text{ measurement of the EUT}}$ = 2,18 dB.

5.3.2 Uncertainty contributions: stage 2: field measurement using the results of the verification procedure

Stripline: interpolation of values for the transform factor: In this case, the frequency of test does not coincide with a frequency at which the verification procedure was carried out. Therefore, a contribution is included to account for the interpolation between transform factor values. The standard uncertainty of the contribution due to the interpolation of values for the transform factor of the Stripline is designated throughout all parts of the present document as u_{j30}.

NOTE: In this example case the standard uncertainty of the contribution due to the interpolation of values for the transform factor is taken as 0,29 dB.

The appropriate standard uncertainties from table 42 should be combined with u_{j30} by RSS in accordance with TR 102 273-1-1 [6], clause 5. This gives the combined standard uncertainty ($u_{c \text{ EUT measurement}}$) for the EUT measurement in dB.

The value of $u_{c\ EUT\ measurement}$ is calculated as 3,56 dB.

5.3.2.1 Expanded uncertainty for the receiver sensitivity measurement

The combined standard uncertainty of the results of the receiver sensitivity measurement is the combination of $u_{c\ Stripline\ attenuation\ measurement}$ and $u_{c\ EUT\ measurement}$.

$$u_{c\,receiver\ sensitivity\ measurement} = \sqrt{3{,}51^2 + 3{,}72^2} = 5{,}11 \text{ dB}$$

The expanded uncertainty is ±1,96 x 5,11 = ±10,0 dB at a 95 % confidence level.

5.3.3 Uncertainty contributions: stage 2: field measurement using a monopole

The second stage involves replacing the EUT with a field measuring device (either a monopole antenna or a three-axis probe) and, setting a particular output level from the signal generator (minimum or average), measuring the corresponding field strength, see figure 19.

NOTE: In this case monopole field measurement involves mounting the monopole through a hole in the lower plate of the Stripline (so that the feed point to the monopole is flush with the surface of the lower plate) and measuring the field strength.

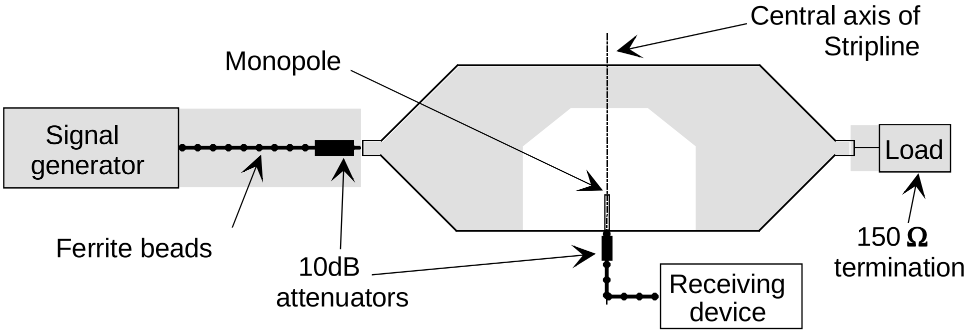


Figure 19: stage 2: field measurement using a monopole

5.3.3.1 Contributions from the mismatch components

Mismatch in the transmitting and receiving parts: Whereas figure 19 shows schematically the equipment set-up for field measurement using a monopole, figure 20 provides a detailed picture of the individual uncertainty contributions.

Mismatch: transmitting part: The mismatch uncertainty between the signal generator, signal generator cable, signal generator attenuator and the Stripline input can be calculated from the approach described in annex D. The mismatch uncertainty through this network does, however, contribute equally to both stages of the test for cases in which a field strength measurement is subsequently performed since there are no changes from stage 1 to this part of the test set-up. The standard uncertainty of the contribution due to the mismatch in the transmitting part is designated throughout all parts of the present document as u_{j36}.

NOTE: In this example case the standard uncertainty of the contribution due to mismatch in the transmitting part is taken as 0,00 dB, since the uncertainty is systematic i.e. it produces the same offset in both stages.

Mismatch: receiving part: The mismatch uncertainty in the receiving part i.e. between the monopole, receiving device attenuator, receiving device cable and the receiving device is calculated from the approach described in annex D. This mismatch uncertainty contributes only during the field measurement part of the test and therefore contributes to the combined standard uncertainty.

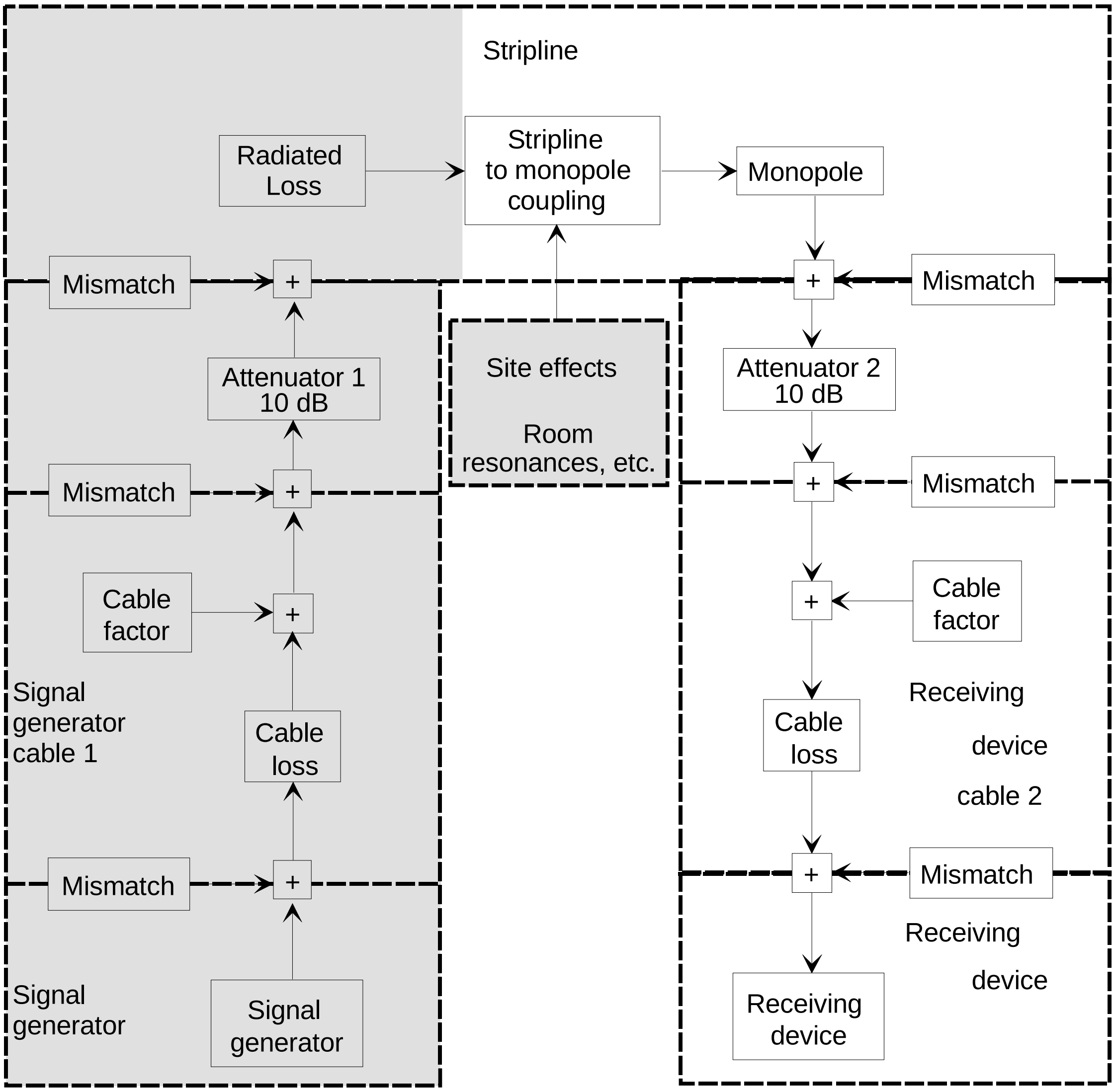


Figure 20: Schematic of the field measurement using a monopole

Monopole:	Input reflection coefficient: $|\rho_M|$	= 0,333
Attenuator:	Input and output reflection coefficients $|S_{11}| = |S_{22}|$	= 0,05
	Attenuation = 10 dB $|S_{12}| = |S_{21}|$	= 0,3162
Cable:	Input and output reflection coefficients: $|S_{11}|$ and $|S_{22}|$	= 0,07
	Attenuation: 1 dB = $|S_{12}| = |S_{21}|$	= 0,891
Receiving device:	Output reflection coefficient: $|\rho_{RD}|$	= 0,20

All these contributions are U-distributed. Other contributions are (see annex D):

$$u_{j\,mismatch:\,antenna\,and\,attenuator} = \frac{0{,}333 \times 0{,}05 \times 100}{\sqrt{2}}\,\% = 1{,}177\ \%$$

$u_{j\ \text{attenuator 2 and cable 2}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$u_{j\ \text{cable 2 and receiving device}}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$$u_{j\ mismatch: antenna\ and\ cable\ 2} = \frac{0{,}333 \times 0{,}07 \times 0{,}316^2 \times 100}{\sqrt{2}} \% = 0{,}165\ \%$$

$u_{j\ attenuator\ 2\ and\ receiving\ device}$: Constant for both stage 1 and 2. Hence this value does not contribute.

$$u_{j\ mismatch: antenna\ and\ receiving\ device} = \frac{0{,}333 \times 0{,}2 \times 0{,}316^2 \times 0{,}891^2 \times 100}{\sqrt{2}} \% = 0{,}373\ \%$$

The combined standard uncertainty of the mismatch is then calculated:

$$u_{j\ mismatch: receiving\ part} = \sqrt{1{,}177^2 + 0{,}165^2 + 0{,}373^2} = 1{,}25\%$$

transforming to the logarithmic form (see annex C): 1,25 % / 11,5 = 0,11 dB.

The standard uncertainty of the contribution, due to the mismatch in the receiving part, is designated throughout all parts of the present document as u_{j37}. Its value in this example is 0,11 dB.

5.3.3.2 Contributions from the individual components

5.3.3.2.1 Signal generator

Signal generator: absolute output level: In this test method, the uncertainty due to the setting of the signal generator's absolute output level contributes to both stages. In stage 1, the output level is individually adjusted at each of eight different positioning angles whilst in stage 2, after an inspection (or calculation) of the eight different values, the signal generator is set to a specific output level. The standard uncertainty of the contribution due to the signal generator absolute output level is designated throughout all parts of the present document as u_{j38}. Its value can be obtained from the manufacturer's data sheet.

NOTE 1: In this example case the uncertainty of the contribution due to the signal generator absolute output level uncertainty from the manufacturer's data sheet is ±1,0 dB.
As nothing is said about the distribution of this uncertainty, a rectangular distribution (see TR 102 273-1-1 [6], clause 5.1.2) in logs is assumed, and the standard uncertainty is calculated as 0,58 dB.

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

NOTE 2: In this example case the standard uncertainty of the contribution due to the signal generator output level stability is taken as 0,00 dB as it is covered by the absolute level uncertainty.

5.3.3.2.2 Signal generator cable

Insertion loss: signal generator cable: The signal generator cable has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the cable is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution due to the insertion loss uncertainty of the signal generator cable is designated throughout all parts of the present document as u_{j41}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the insertion loss uncertainty of the signal generator cable is taken as 0,00 dB since the uncertainty is systematic i.e. it is assumed constant and common to both stages of the measurement.

Cable factor: signal generator cable: Cable factor is defined as the total effect of the signal generator cable's influence on the measuring system including its interaction with the site. It consists of the leakage caused by cable screening inefficiency and introducing an unbalanced current into the Stripline. In a radiated measurement the standard uncertainty of the uncertainty due to cable factor, associated with each cable, is 0,5 dB provided that the precautions detailed in the methods have been observed, i.e. routing and dressing of cables with ferrites. If no prevention has been attempted the standard uncertainty is 4,0 dB (justification for these values is given in annex E). The standard uncertainty of the contribution due to the cable factor of the signal generator cable is designated throughout all parts of the present document as u_{j19}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the cable factor of the signal generator cable is taken as 0,00 dB since the precautions detailed in the methods have been observed and the field strength is to be measured.

5.3.3.2.3 Signal generator attenuator

Insertion loss: signal generator attenuator: The signal generator attenuator has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the attenuator is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution due to the insertion loss uncertainty of the signal generator attenuator is designated throughout all parts of the present document as u_{j40}.

NOTE: In this example case the standard uncertainty of the contribution due to the insertion loss uncertainty of the signal generator attenuator is 0,00 dB since the precautions detailed in the methods have been observed and the field strength is to be measured.

5.3.3.2.4 Site factors

Ambient effect: Ambient effect is the uncertainty caused by local ambient signals raising the noise floor at the measurement frequency. The standard uncertainty of the contribution due to the ambient effect is designated throughout all parts of the present document as u_{j34}. The value of the standard uncertainty should be taken from table 43.

Table 43: Uncertainty contribution: ambient effect

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

NOTE 1: In this example case the standard uncertainty of the contribution due to the ambient effect is taken as 0,00 dB since the Stripline is assumed to have been placed in a shielded room.

Stripline: influence of site effects: The influence of site effects comprise those effects, resulting from not observing the recommendations given in EN 55020 [3] regarding positioning of the Stripline and layout of the absorber. These can lead to incorrect received levels i.e. values which differ from theoretical calculations. The standard uncertainty of the contribution due to the influence of site effects is designated throughout all parts of the present document as u_{j33}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the influence of site effects is taken to be 0,00 dB since in this test method, site effects contribute equally to both stages as the recommendations are assumed to have been fully observed.

5.3.3.2.5 Antenna factor of the monopole

Stripline: antenna factor of the monopole: This has been derived from measurements taken within the Stripline. Therefore, the given values incorporate several of the field disturbance factors which the Stripline possesses and which therefore do not have to be allowed for as individual contributions. Amongst these included effects are imaging, characteristic impedance of the line, non-planar nature of the field etc. The standard uncertainty of the contribution due to the antenna factor of the monopole is designated throughout all parts of the present document as u_{j30}.

NOTE: In this example case the standard uncertainty of the contribution due to the antenna factor of the monopole is taken as 1,15 dB. This combined uncertainty source is only present in the actual measurement.

5.3.3.2.6 Monopole attenuator

Insertion loss: monopole attenuator: The monopole attenuator has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the attenuator is not used outside the manufacturer's specification. The standard uncertainty of the contribution due to the insertion loss uncertainty of the monopole attenuator is designated throughout all parts of the present document as u_{j40}.

NOTE: In this example case the standard uncertainty of the contribution due to the insertion loss uncertainty of the monopole attenuator is taken as 0,1 dB since the uncertainty contributes only to stage 2 of this test method.

5.3.3.2.7 Receiving device cable

Insertion loss: receiving device cable: The receiving device cable has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the cable is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution due to the insertion loss uncertainty of the receiving device cable is designated throughout all parts of the present document as u_{j41}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the insertion loss uncertainty of the receiving device cable is taken as 0,15 dB since the uncertainty is only present in the second stage of this test method.

Cable factor: receiving device cable: Cable factor is defined as the total effect of the receiving device cable's influence on the measuring system including its interaction with the site. It consists of the leakage caused by cable screening inefficiency and introducing an unbalanced current into the monopole. In a radiated measurement the standard uncertainty of the cable factor, associated with each cable, is 0,5 dB provided that the precautions detailed in the methods have been observed, i.e. routing and dressing of cables with ferrites. If no prevention has been attempted the standard uncertainty is 4,0 dB (justification for these values is given in annex E). The standard uncertainty of the contribution due to the cable factor of the receiving device cable is designated throughout all parts of the present document as u_{j19}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the cable factor of the receiving antenna cable is taken as 0,50 dB since the precautions detailed in the methods are assumed to have been observed.

5.3.3.2.8 Receiving device

Receiving device: absolute level: This uncertainty only contributes during the second stage of the procedure if the input attenuation range setting on the receiving device has been changed from its setting in the first stage. The standard uncertainty of the contribution due to the receiving device absolute level uncertainty is designated throughout all parts of the present document as u_{j47}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the receiving device absolute level uncertainty (a range change is assumed) is obtained from the manufacturer's data as ±0,5 dB. As nothing is said about the distribution of this uncertainty, a rectangular distribution (see TR 102 273-1-1 [6], clause 5.1.2) in logs is assumed, and the standard uncertainty is calculated as 0,29 dB.

Receiving device: linearity: In any test in which the contribution of the absolute level uncertainty of the receiving device contributes to the combined standard uncertainty of the test i.e. it does not cancel due to the methodology, the contribution from the receiving device linearity is considered to have been included in u_{j47}. Conversely, for any test in which the absolute level uncertainty of the receiving device does not contribute to the combined standard uncertainty the linearity of the receiving device should be included. The standard uncertainty of the contribution due to the receiving device linearity is designated throughout all parts of the present document as u_{j48}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the receiving device linearity is taken as 0,00 dB.

5.3.3.3 Contribution from the random component

Random uncertainty: The magnitude can be assessed from multiple measurements of the field strength measurement. The standard uncertainty of the contribution due to the random uncertainty is designated throughout all parts of the present document as u_{i01}. See also clause 5.5 and the note in clause 6.4.7 of TR 102 273-1-1, as well as note in clause A.18 of the present document.

The field strength measurement was repeated ten times. The following results were obtained in dBμV (before correcting for cabling and attenuator network insertion loss):

65,4; 63,4; 66,0; 65,3; 63,0; 64,9; 65,2; 66,8; 65,5; 63,7.

Converting to linear terms (V):

$1{,}862 \times 10^{-3}$; $1{,}479 \times 10^{-3}$; $1{,}995 \times 10^{-3}$; $1{,}841 \times 10^{-3}$; $1{,}413 \times 10^{-3}$; $1{,}758 \times 10^{-3}$; $1{,}820 \times 10^{-3}$;
$2{,}188 \times 10^{-3}$; $1{,}884 \times 10^{-3}$; $1{,}531 \times 10^{-3}$;

The two sums X and Y are calculated:

X = the sum of the measured values = $17{,}77 \times 10^{-3}$ V;

Y = the sum of the squares of the measured values = $32{,}10 \times 10^{-6}$ V^2

$$u_{c\ random} = \sqrt{\frac{Y - \frac{X^2}{n}}{n-1}} = \sqrt{\frac{32{,}10 \times 10^{-6} - \frac{\left(17{,}77 \times 10^{-3}\right)^2}{10}}{10-1}} = 238{,}3 \times 10^{-6} \qquad \text{(formula 5.6)}$$

As the result is obtained as the mean value of 10 measurements and the standard uncertainty of the random uncertainty is:

$$u_{j\ random} = \frac{238{,}3 \times 10^{-6}}{1{,}777 \times 10^{-3}} \times \frac{100}{11{,}5} = 1{,}17 \text{ dB}$$

NOTE: In this example case the standard uncertainty of the contribution due to the random uncertainty is 1,17 dB.

5.3.3.4 Summary table of contributions

A complete list of all the contributions to this part of the test method is given in table 44.

Table 44: Contributions from the monopole field measurement

$u_{j \text{ or } i}$	**Description of uncertainty contributions**	**dB**
u_{j36}	*mismatch: transmitting part*	0,00
u_{j37}	*mismatch: receiving part*	0,11
u_{j38}	*signal generator: absolute output level*	0,58
u_{j39}	*signal generator: output level stability*	0,00
u_{j41}	*insertion loss: signal generator cable*	0,00
u_{j19}	*cable factor: signal generator cable*	0,50
u_{j40}	*insertion loss: signal generator attenuator*	0,00
u_{j34}	*ambient effect*	0,00
u_{j33}	*Stripline: influence of site effects*	0,00
u_{j31}	*Stripline: antenna factor of the monopole*	1,15
u_{j40}	*insertion loss: monopole attenuator*	0,10
u_{j41}	*insertion loss: receiving device cable*	0,15
u_{j19}	*cable factor: receiving device cable*	0,50
u_{j47}	*receiving device: absolute level*	0,29
u_{j48}	*receiving device: linearity*	0,00
u_{i01}	*random uncertainty (see note in clause A.18 of the present document and note in clause 6.4.7 of TR 102 273-1-1)*	1,17

The standard uncertainties from table 44 should be combined by RSS in accordance with TR 102 273-1-1 [6], clause 5. This gives the combined standard uncertainty ($u_{c \text{ field measurement using a monopole}}$) for the field measurement using a monopole in dB.

The value of $u_{c \text{ field measurement using a monopole}}$ is calculated as 1,91 dB.

5.3.3.5 Expanded uncertainty for the receiver sensitivity measurement

The combined standard uncertainty of the results of the receiver sensitivity measurement is the combination of the components outlined in clauses 5.3.1.4 and 5.2.4.4. The components to be combined are $u_{c \text{ measurement of the EUT}}$ and $u_{c \text{ field measurement using a monopole}}$.

$$u_c = \sqrt{2{,}18^2 + 1{,}91^2} = 2{,}90 \text{ dB}$$

The expanded uncertainty is ±1,96 x 2,90 = ±5,68 dB at a 95 % confidence level.

5.3.4 Uncertainty contributions: stage 2: field measurement using three-axis probe

In this case, field measurement involves the use of a three-axis probe and measuring the vertical component of the electric field.

5.3.4.1 Contributions from the mismatch components

Whereas figure 21 shows schematically the equipment set-up for field measurement using a three-axis probe, figure 22 provides a detailed picture of the individual uncertainty contributions.

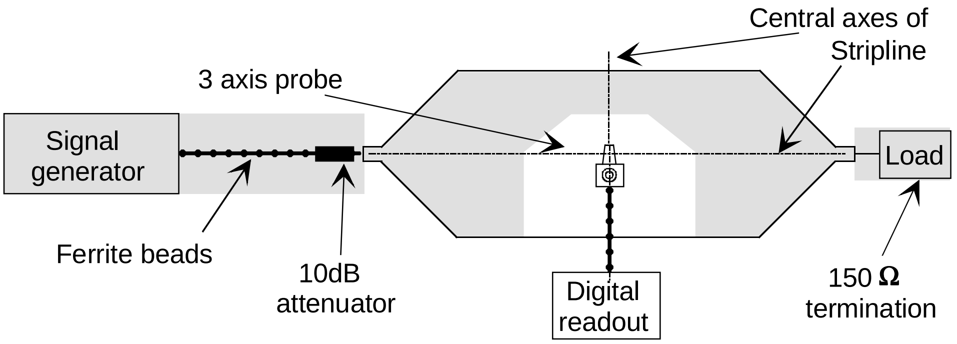


Figure 21: Stage 2: Field measurement using a 3-axis probe

Mismatch: transmitting part: The mismatch uncertainty between the signal generator, signal generator cable, signal generator attenuator and the Stripline input can be calculated from the approach described in annex D. The mismatch uncertainty through this network does, however, contribute equally to both stages of the test for cases in which a field strength measurement is subsequently performed since there are no changes from stage 1 to this part of the test set-up. The standard uncertainty of the contribution due to the mismatch in the transmitting part is designated throughout all parts of the present document as u_{j36}.

NOTE: In this example case the standard uncertainty of the contribution due to mismatch in the transmitting part is taken as 0,00 dB, since the uncertainty is systematic i.e. it produces the same offset in both stages.

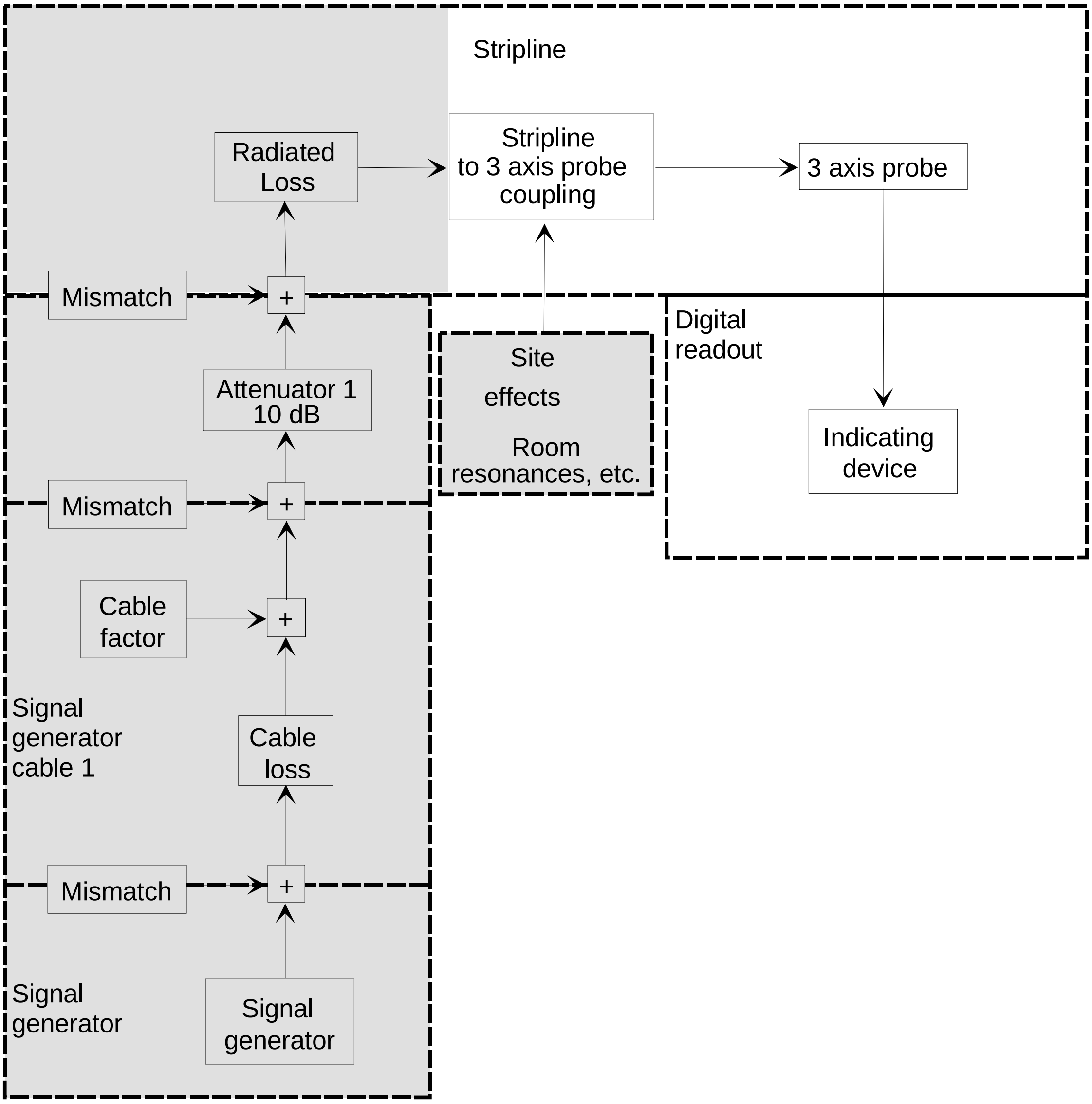


Figure 22: Schematic of the field measurement using a three-axis probe

5.3.4.2 Contributions from the individual components

5.3.4.2.1 Signal generator

Signal generator: absolute output level: In this test method, the uncertainty due to the setting of the signal generator's absolute output level contributes to both stages. In stage 1, the output level is individually adjusted at each of 8 different positioning angles whilst in stage 2, after an inspection (or calculation) of the 8 different values, the signal generator is set to a specific output level. The standard uncertainty of the contribution due to the signal generator absolute output level uncertainty is designated throughout all parts of the present document as u_{j38}. Its value can be obtained from the manufacturer's data.

NOTE 1: In this example case the uncertainty of the contribution due to the signal generator absolute output level is obtained from the manufacturer's data sheet as ±1,0 dB. As nothing is said about the distribution of this uncertainty, a rectangular distribution (see TR 102 273-1-1 [6], clause 5.1.2) in logs is assumed, and the standard uncertainty is calculated as 0,58 dB.

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

NOTE 2: In this example case the standard uncertainty of the contribution due to the signal generator output level stability is taken as 0,00 dB as it is covered by the absolute level uncertainty.

5.3.4.2.2 Signal generator cable

Insertion loss: signal generator cable: The signal generator cable has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the cable is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution due to the insertion loss uncertainty of the signal generator cable is designated throughout all parts of the present document as u_{j41}.

NOTE 1: In this example case the standard uncertainty of the contribution due to the insertion loss uncertainty of the signal generator cable is taken as 0,00 dB as a field strength measurement is performed using the three-axis probe.

Cable factor: signal generator cable: Cable factor is defined as the total effect of the signal generator cable's influence on the measuring system including its interaction with the site. It consists of the leakage caused by cable screening inefficiency and introducing an unbalanced current into the Stripline. In a radiated measurement the standard uncertainty of the uncertainty due to cable factor, associated with each cable, is 0,5 dB provided that the precautions detailed in the methods have been observed, i.e. routing and dressing of cables with ferrites. If no prevention has been attempted the standard uncertainty is 4,0 dB (justification for these values is given in annex E). The standard uncertainty of the contribution due to the cable factor of the signal generator cable is designated throughout all parts of the present document as u_{j19}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the cable factor of the signal generator cable is taken as 0,00 dB since the precautions detailed in the methods have been observed and the field strength is to be measured.

5.3.4.2.3 Signal generator attenuator

Insertion loss: signal generator attenuator: The signal generator attenuator has an insertion loss as well as an uncertainty associated with the measurement of its magnitude. The value of insertion loss and its uncertainty remain valid provided the attenuator is not used outside the manufacturer's specification. At any given frequency the insertion loss acts as a systematic offset and contributes equally to both stages of the measurement. The standard uncertainty of the contribution due to the insertion loss uncertainty of the signal generator attenuator is designated throughout all parts of the present document as u_{j40}.

NOTE: In this example case the standard uncertainty of the contribution due to the insertion loss uncertainty of the signal generator attenuator is 0,00 dB since the precautions detailed in the methods have been observed and the field strength is to be measured.

5.3.4.2.4 Site factors

Ambient effect: Uncertainty is introduced as a result of local ambient signals raising the noise floor at the measurement frequency. The standard uncertainty of the contribution due to the ambient effect is designated throughout all parts of the present document as u_{j34}. The values of the standard uncertainties should be taken from table 45.

Table 45: Uncertainty contribution: Ambient effect

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

NOTE 1: In this example case the standard uncertainty of the contribution due to the ambient effect is taken as 0,00 dB since the Stripline is assumed to have been placed in a shielded room.

Stripline: influence of site effects: The influence of site effects comprise those effects, resulting from not observing the recommendations given in EN 55020 [3] regarding positioning of the Stripline and layout of absorber. These can lead to incorrect received levels i.e. values which differ from theoretical calculations. The standard uncertainty of the contribution due to the influence of site effects is designated throughout all parts of the present document as u_{j33}.

NOTE 2: In this example case the standard uncertainty of the contribution due to the influence of site effects is taken to be 0,00 dB since in this test method, site effects contribute equally to both stages as the recommendations are assumed to have been fully observed.

Stripline: characteristic impedance: This uncertainty contribution results from the difference between the free-space wave impedance (377 Ω) for which the three-axis probe had been developed and that for the Stripline (150 Ω). The standard uncertainty of the contribution due to the characteristic impedance of the Stripline is designated throughout all parts of the present document as u_{j26}.

NOTE 3: In this example case the standard uncertainty of the contribution due to the characteristic impedance of the Stripline is taken as having a standard uncertainty of 0,58 dB.

Stripline: mutual coupling of the three-axis probe to its image in the plates: This contribution is to take account of the fact that the probe has images in both plates of the Stripline. The standard uncertainty of the contribution due to the mutual coupling of the three-axis probe to its image in the plates is designated throughout all parts of the present document as u_{j25}.

NOTE 4: In this example case the uncertainty of the contribution due to the mutual coupling of the three-axis probe to its image in the plates is taken as ± 0,5 dB. As nothing is said about the distribution of this uncertainty, a rectangular distribution (see TR 102 273-1-1 [6], clause 5.1.2) in logs is assumed, and the standard uncertainty is calculated as 0,29 dB.

5.3.4.2.5 Three-axis probe field measurement

Stripline: field strength measurement as determined by the three-axis probe: The standard uncertainty of the contribution, due to the field strength measurement uncertainty as determined by the three-axis probe, is designated throughout all parts of the present document as u_{j28}. Its value can be derived from the manufacturer's data sheet.

NOTE: In this example case the uncertainty of the contribution due to the field strength measurement as determined by the three-axis probe is obtained from the manufacturer's data sheet as ±1 dB. As nothing is said about the distribution of this uncertainty, a rectangular distribution (see TR 102 273-1-1 [6], clause 5.1.2) in logs is assumed, and the standard uncertainty is calculated as 0,58 dB.

5.3.4.3 Contribution from the random component

Random uncertainty: The magnitude can be assessed from multiple measurements of the receiver sensitivity. The standard uncertainty of the contribution due to the random uncertainty is designated throughout all parts of the present document as u_{i01}. See also clause 5.5 and the note in clause 6.4.7 of TR 102 273-1-1, as well as note in clause A.18 of the present document.

The field strength measurement was repeated ten times. The following results were obtained in dBμV (before correcting for cabling and attenuator network insertion loss):

65,4; 63,4; 66,0; 65,3; 63,0; 64,9; 65,2; 66,8; 65,5; 63,7.

Converting to linear terms (V):

$1{,}862 \times 10^{-3}$; $1{,}479 \times 10^{-3}$; $1{,}995 \times 10^{-3}$; $1{,}841 \times 10^{-3}$; $1{,}413 \times 10^{-3}$; $1{,}758 \times 10^{-3}$; $1{,}820 \times 10^{-3}$; $2{,}188 \times 10^{-3}$; $1{,}884 \times 10^{-3}$; $1{,}531 \times 10^{-3}$;

The two sums X and Y are calculated:

X = the sum of the measured values = $17{,}77 \times 10^{-3}$ (V);

Y = the sum of the squares of the measured values = $32{,}10 \times 10^{-6}\ \mathrm{V}^2$

$$u_{c\ random} = \sqrt{\frac{Y - \frac{X^2}{n}}{n-1}} = \sqrt{\frac{32{,}10 \times 10^{-6} - \frac{\left(17{,}77 \times 10^{-3}\right)^2}{10}}{10-1}} = 238{,}3 \times 10^{-6} \qquad \text{(formula 5.6)}$$

As the result is obtained as the mean value of 10 measurements and the standard uncertainty of the random uncertainty is:

$$u_{j\ random} = \frac{238{,}3 \times 10^{-6}}{1{,}777 \times 10^{-3}} \times \frac{100}{11{,}5} = 1{,}17\ \mathrm{dB}$$

NOTE: In this example case the standard uncertainty of the contribution due to the random uncertainty is 1,17 dB.

5.3.4.4 Summary table of contributory components

A complete list of all the contributions to this part of the test method is given in table 46.

Table 46: Contributions from the 3-axis probe field measurement

$u_{j\ \text{or}\ i}$	Description of uncertainty contributions	dB
u_{j36}	*mismatch: transmitting part*	0,00
u_{j38}	*signal generator: absolute output level*	0,58
u_{j39}	*signal generator: output level stability*	0,00
u_{j41}	*insertion loss: signal generator cable*	0,00
u_{j19}	*cable factor: signal generator cable*	0,50
u_{j40}	*insertion loss: signal generator attenuator*	0,00
u_{j34}	*ambient effect*	0,00
u_{j33}	*Stripline: influence of site effects*	0,00
u_{j26}	*Stripline: characteristic impedance*	0,58
u_{j25}	*Stripline: mutual coupling of the 3-axis probe to its image in the plates*	0,29
uj_{28}	*Stripline: field strength measurement as determined by the 3-axis probe*	0,58
u_{i01}	*random uncertainty (see note in clause A.18 of the present document and note in clause 6.4.7 of TR 102 273-1-1)*	1,17

The standard uncertainties from table 46 should be combined by RSS in accordance with TR 102 273-1-1 [6], clause 5. This gives the combined standard uncertainty ($u_{c\ 3\text{-}axis\ probe}$) for the receiver sensitivity measurement in dB.

The value of $u_{c\ 3\text{-}axis\ probe}$ is calculated as 1,65 dB.

5.3.4.5 Expanded uncertainty for the receiver sensitivity measurement

The combined standard uncertainty of the results of the receiver sensitivity measurement is the combination of the components outlined in clauses 5.3.1.4 and 5.3.4.4. The components to be combined are $u_{c\ EUT\ measurement}$ and $u_{c\ 3\text{-}axis\ probe}$.

$$u_c = \sqrt{2{,}18^2 + 1{,}65^2} = 2{,}73 \text{ dB}$$

The expanded uncertainty is ±1,96 x 2,73 = ±5,36 dB at a 95 % confidence level.

6 Wash-up

6.1 Introduction

TR 100 028 [5] gives values of maximum measurement uncertainty for all types of radio measurements and these values should not be exceeded for any test set-up. However, 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 has to 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 deciding if test equipment is suitable for making a particular measurement the following points should be taken into account:

- the test equipment resolution is appropriate to its uncertainty and is at least an order of magnitude better than the limits of measurement variation;
- the test equipment measurement uncertainty is appropriate to the required uncertainty;
- the overall measurement uncertainty is equal to, or better than that required by the appropriate Standard.

If the uncertainty of a particular parameter of an item of test equipment is known, and if that parameters interaction within a test configuration is understood, the overall measurement error can be predicted by calculation and hence controlled.

6.2 Considerations in testing

Performance is normally associated with a particular EUTs actual performance, whereas conformance is whether or not it conforms to a standard (it meets a minimum requirement). For example, a receiver adjacent channel selectivity is measured to be 75 dB in a particular test equipment set-up. In another set-up (where it is known that the test equipment is capable of measuring to 90 dB due to the use of a higher quality signal generator with lower single sideband phase noise) it is measured as 82 dB.

In the first case (75 dB) the limit of the test equipment has been reached, but the EUT **conforms** to the standard requirement of ≥ 70 dB. In the second case of 82 dB the **performance** of the receiver has been measured, the EUT still **conforms** to the standard's requirement of ≥ 70 dB but now there is a true measure of how well it exceeds the requirement.

Also from this example it can be seen that as measurements approach and in some cases exceed the dynamic range of the test equipment, measurement uncertainty increases at an alarming rate. Therefore measurement engineers should avoid approaching the dynamic range limit of the measuring system.

Another consideration when applying a single limit (≥ equal to or greater than; > greater than; ≤ equal to or less than; < less than), and where the dynamic range of the measuring system is not exceeded, is; is the uncertainty of your measurement sufficiently small in comparison with the limit?

In this situation the measurement uncertainty may become much less significant when assessing **conformance**. For example: a specification limit is < -30 dBm and the measured result is -60 dBm ±10 dB. The measurement uncertainty is sufficient to give confidence that the measured value is at least 20 dB below the specification requirement and the result **conforms** to the standard.

Conversely if the result had been 0 dBm the measurement uncertainty is sufficient to give confidence that the measured value is at least 20 dB above the specification requirement and the result **does not conform** to the standard.

In these cases there is no advantage to know the result to within 1 or 0,5 dB, they are in and, more importantly, out of specification respectively.

Obviously the acceptability of the uncertainty of measurement has been influenced by the measurement itself. Although this argument is true, it tends to be of little value except to highlight that the uncertainty of measurement is critical only in the boundary condition (i.e. where the result of a measurement is close to the limit).

6.3 Measurement specification

Normally test houses expect the measurement to be well defined and well specified. The least uncertainty is (often unreasonably) preferred. However it is generally accepted that in the measurement of a quantity, the measuring equipment should have an associated combined standard uncertainty of an order better than the required limit (in calibration terms).

For example: If a power measurement is required to the effect "x dB of power was delivered into a 50 Ω load ±0,3 dB" this measurement is practical, if however it is the required uncertainty for a radiated spurious emission the requirement (in useful terms) is not-achievable.

A question that we should answer before attempting to make a measurement is: Is it practical to carry out this measurement to the stated uncertainty limits using the available test equipment and methodology? It would not be easy to explain why, for example, an equipment had failed by 3 dB when your measurement uncertainty was, when investigated, found to be ±6 dB and the standard required the uncertainty to be within ±2 dB.

6.4 Specification limits

The last point to consider is that measurement uncertainty and specification limits are completely separate. Consideration of both should only occur when comparing the suitability of the measurement uncertainty with the specification limits or during the development of new standards.

For example, comparison of both uncertainty and limit are required when deciding if the uncertainty of the measurement is sufficiently small in comparison with the specification limit or when deciding if the measured result is in or out of a given specification limit.

There are two distinct types of specification limits. One type is the case where there is only one limit that the measured value is required to exceed. In this case the measurement uncertainty and thereby the quality of the measurement is especially important if the measured value is close to the limit. The other is the case where the measured value is required to be within a two sided interval. In this case the required measurement uncertainty depends on the distance between the two limits, and care needs to be taken not only in the construction of the test system but also when the limits are decided during the development of the standard.

Regulators only want to know "Does this EUT conform to the standard or not?", whereas manufacturers usually want to publicize "not only does it conform to standard XYZ, but its more than XX% better than the requirement".

Now, in the real world, suppose you are a manufacturer of radios, and are having a radio re-tested by a regulator due to a suspected non-compliance with a standard. When the radio was first tested it was a comfortable pass, now however, it is an uncomfortable failure. The original test laboratory says "the one I tested passed, here's all the test results". The regulator says "well it's exactly the same radio but it fails now, here's the test results, take it off the market".

The real problem here of course is that the laboratory and the regulator can both be correct, since the Laboratory cannot state categorically that the radio passes, as the result when extended by the measurement uncertainty of the laboratory is above the specification limit. The regulator cannot state categorically that the radio fails as the result when extended by the measurement uncertainty of the regulator is below the specification limit. It is interesting to see this argument develop. What is required is an agreed approach to various questions that arise out of this situation:

- did the pass/fail criteria include reproducibility?
- did the pass/fail criteria include repeatability?
- did the pass/fail criteria include variability of data?
- were uncertainties discussed in the formulation of the limits?

The answers to all these questions are: yes, no and maybe. How will the regulator then address the uncertainty of the measured test results?

Particularly if the equipment is suspected of non-compliance and is subsequently re-measured, is it correct to apply the shared risk rule to the Second measurement?

6.5 Conclusions

Before the first document on measurement uncertainty was published by ETSI in 1991, a formal agreement was reached for treating uncertainty among regulators, manufacturer's and testing laboratories that produced products firstly as Private Mobile Radios (within RES 02, the "LMR" STC) and later in other areas of the ETSI's endeavours. This agreement is called the "shared risk".

Under the "shared risk" agreement there is:

- an agreed method of calculating the measurement uncertainty (so that everyone includes all relevant information);
- a maximum acceptable value for this uncertainty (stated in the Standard);
- an agreement to use the numerical value of a measurement as the pass/fail criteria.

The reason for the expression "shared risk" is that if the true value of a measurand lies exactly on the limit value all parties agree to take the risk (and the consequences) that the EUT is outside the specification limits.

This approach provides the following solutions:

- manufacturers have a 50 % chance of a borderline equipment failing when it should have passed;
- regulators have a 50 % chance of a borderline equipment passing when it should have failed;
- test houses no longer have to admit that they do not know if a borderline equipment passes or fails.

This approach to measurement uncertainty provides a level playing field to all testing laboratories without giving arbitrary advantage to those with better or worse equipment and facilities.

The shared risk is only correct however for cases in which a single measurement has been made. If the true value is **on the limit** in several (n) measurements, the probability of a pass is reduced to $0,5^n$ as all measured values have to be within the specification to give a pass; only one outside will give a fail but this should be balanced against the measured parameters general independence of each other.

Finally, within this documentation, we have laid the foundations of the approach to measurement uncertainty by tackling the problems from a practical viewpoint. Although some might comment that 0,01 dB is negligible, why have you included it? The answer is of course it's 0,01 dB in this case, but in others it might be larger. It might not be larger as well of course, but it is up to the individual to decide this and assign a value in his calculations.

The relevant uncertainty contributions have been identified for the test methods and the methods simplified and improved (i.e. the use of ferrite beads). The verification procedures have been improved and now apply to the basic 1,5 m height of the ETSs.

This documentation provides a new approach to the calculation of measurement uncertainty based on ISOTAG 4 [7], modified and extended where necessary. In modelling the sites, differences between ETSI and others have been traced to the fact that use is made of a sin theta approximation whereas the ETSI approach makes no such assumption. Differences between MiniNEC and Friis have been linked to the fact that MiniNEC models the balun but Friis does not. With improvements to the formulae of others and by allowing for the differences in MiniNEC and Friis, the results of modelling by any of these methods gave Identical (within 0,2 dB) results.

(optional, unnumbered)

Annex A:
Uncertainty contributions

This annex contains a list of the uncertainties identified as being involved in radiated tests and gives details on how their magnitudes should be derived. Numerical and alphabetical lists of the uncertainties are given in tables A.21 and A.22.

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

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

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

Mismatch uncertainties have 'U' shaped distributions. If the limits are ±a the standard uncertainty is: $a/\sqrt{2}$.

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

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

For conversion of % to dB, table A.1 should be used (for more information on the derivation of the table see annex C).

Table A.1: Standard uncertainty conversion factors

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

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

- "Free field test sites": are Anechoic Chambers, Anechoic Chambers with Ground Planes and Open Area Test Sites.
- "Stripline": refers to the EN 55020 [3] design of two plate open Stripline.
- "Verification": refers to the measurement in which the test site is compared to its theoretical model.
- "Test methods": refers to all radiated tests apart from the verification procedure.
- "Transmitting" and "receiving" antennas: are used in the verification procedure only; all other references to antennas (i.e. substitution, measuring and test) are for test methods.

A.1 Reflectivity

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

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

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

How to evaluate for free field test sites

Verification: Not applicable.

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

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

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

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

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

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

How to evaluate for free field test sites

Verification: Not applicable.

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

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

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

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

How to evaluate for free field test sites

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

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

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

Test methods: Not applicable.

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

A.2 Mutual coupling

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

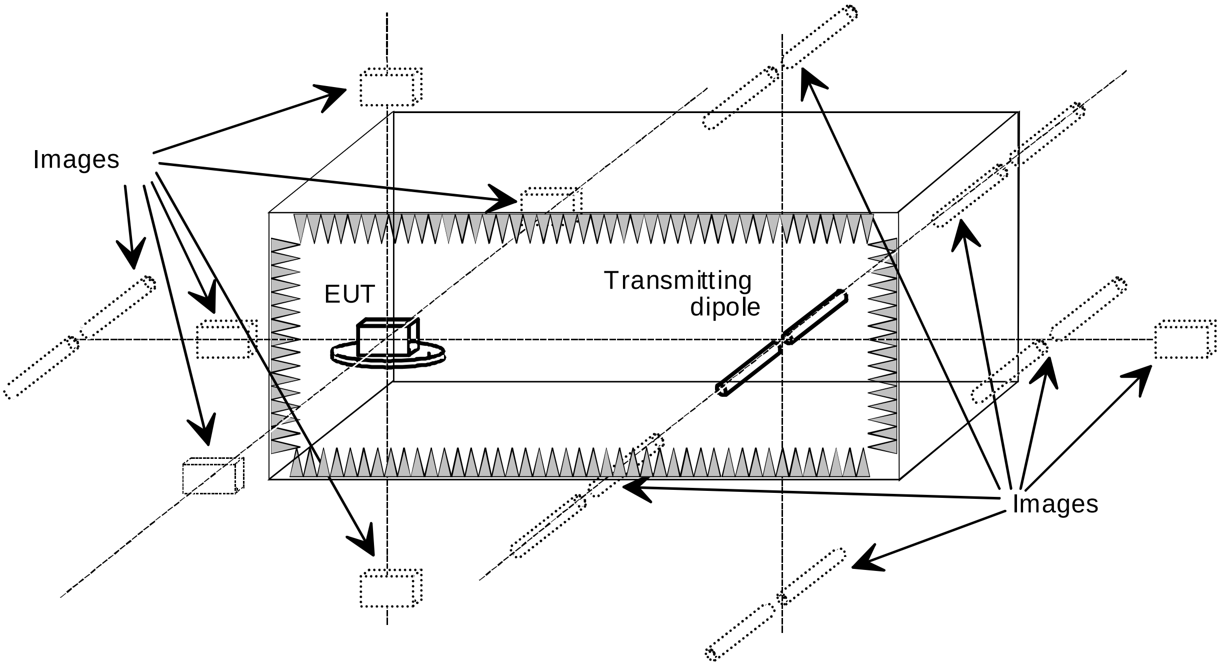


Figure A.1: Mutual coupling (Anechoic Chamber illustrated)

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

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

How to evaluate for free field test sites

Verification: Not applicable.

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

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

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

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

How to evaluate for free field test sites

Verification: Not applicable.

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

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

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

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

How to evaluate for free field test sites

Verification: Not applicable.

Test methods:

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

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

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

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

How to evaluate for free field test sites

Verification:

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

Test methods: Not applicable.

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

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

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

How to evaluate for free field test sites

Verification: Not applicable.

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

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

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

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

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

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

How to evaluate for free field test sites

Verification: Not applicable.

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

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

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

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

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

How to evaluate for free field test sites

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

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

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

Test methods: Not applicable.

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

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

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

How to evaluate for free field test sites

Verification: Not applicable.

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

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

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

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

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

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

How to evaluate for free field test sites

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

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

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

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

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

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

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

How to evaluate for free field test sites

Verification: Not applicable.

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

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

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

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

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

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

How to evaluate for free field test sites

Verification: Not applicable.

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

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

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

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

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

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

How to evaluate for free field test sites

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

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

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

Test methods: Not applicable.

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

A.3 Range length

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

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

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

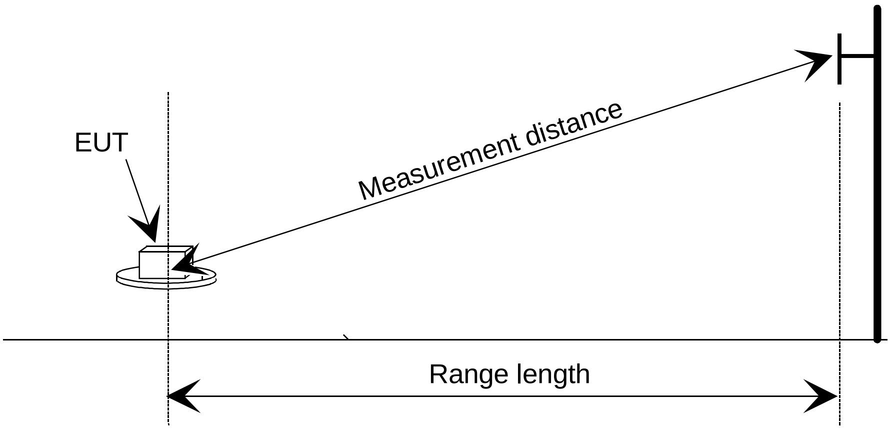


Figure A.2: Range length and measurement distance

It is important to distinguish clearly between these two terms.

u_{j16} *Range length*

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

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

How to evaluate for free field test sites

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

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

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

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

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

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

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

A.4 Corrections

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

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

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

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

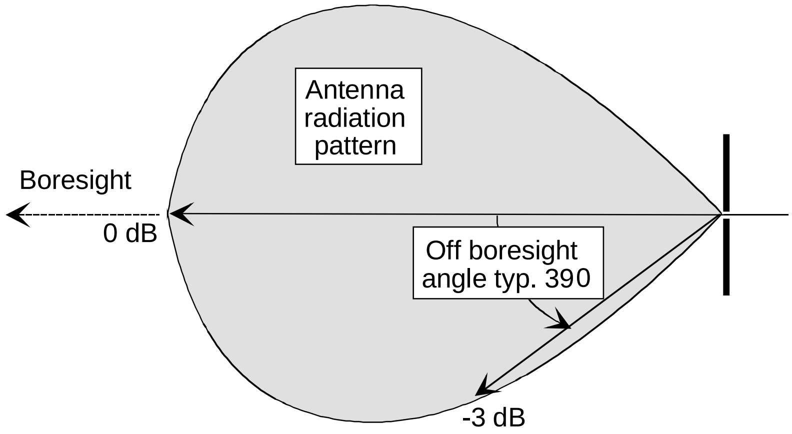


Figure A.3: Off boresight correction

How to evaluate for free field test sites

Verification: Not applicable.

Test methods:

For any antenna:

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

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

u_{j18} *Correction: measurement distance*

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

How to evaluate for free field test sites

Verification: Not applicable.

Test methods:

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

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

A.5 Radio frequency cables

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

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

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

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

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

u_{j19} *Cable factor*

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

How to evaluate for free field test sites

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

Test methods: The standard uncertainty for each cable is 0,5 dB provided the precautions detailed in the method have been observed. If the precautions have not been observed the contributions have a standard uncertainty of 4,0 dB (justification for these values is given in annex E).

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

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

How to evaluate for Striplines

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

Test methods: The standard uncertainty for each cable is 0,5 dB provided that the precautions detailed in the method have been observed. If the precautions have not been observed the contribution has a standard uncertainty of 4,0 dB (justification for these values is given in annex E).

A.6 Phase centre positioning

Background: The phase centre of an EUT or antenna is the point from which the device is considered to radiate. If the device is rotated about this point the phase of the signal, as seen by a fixed antenna, does not change. It is therefore critical to (a) Identify the phase centre of an EUT or antenna and (b) to position it correctly on the test site.

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

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

How to evaluate for free field test sites

Verification: Not applicable.

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

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

As the phase centre can be anywhere inside the EUT this uncertainty is assumed to be rectangularly distributed (see TR 102 273-1-1 [6], clause 5.1.2). The standard uncertainty can therefore be calculated and converted to the logarithmic form (see annex C).

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

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

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

How to evaluate for free field test sites

Verification: Not applicable.

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

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

As this error source can be anywhere between these limits this uncertainty is assumed to be rectangularly distributed (see TR 102 273-1-1 [6], clause 5.1.2). The standard uncertainty can therefore be calculated and converted to the logarithmic form (see annex C).

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

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

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

How to evaluate for free field test sites

Verification:

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

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

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

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

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

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

As this error source can be anywhere between these limits this uncertainty is assumed to be rectangularly distributed (see TR 102 273-1-1 [6], clause 5.1.2). The standard uncertainty can therefore be calculated and converted to the logarithmic form (see annex C).

Test methods:

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

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

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

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

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

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

As this error source can be anywhere between these limits this uncertainty is assumed to be rectangularly distributed (see TR 102 273-1-1 [6], clause 5.1.2). The standard uncertainty can therefore be calculated and converted to the logarithmic form (see annex C).

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

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

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

How to evaluate for free field test sites

Verification: The maximum value should be calculated from:

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

As this error source can be anywhere between these limits this uncertainty is assumed to be rectangularly distributed (see TR 102 273-1-1 [6], clause 5.1.2). The standard uncertainty can therefore be calculated and converted to the logarithmic form (see annex C).

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

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

As this error source can be anywhere between these limits this uncertainty is assumed to be rectangularly distributed (see TR 102 273-1-1 [6], clause 5.1.2). The standard uncertainty can therefore be calculated and converted to the logarithmic form (see annex C).

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

A.7 Stripline

Background: The Stripline is an alternative test site to a free field test site. It is essentially a large open transmission line comprising two flat metal plates between which a TEM wave is generated. The resulting field is assumed to exhibit a planar distribution of amplitude and phase.

u_{j24} *Stripline: mutual coupling of the EUT to its images in the plates*

This uncertainty only contributes to Stripline test methods. It is the uncertainty which results from the imaging of the EUT in the plates of the Stripline.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: Not applicable.

How to evaluate for Striplines

Verification: Not applicable.

Test methods: The magnitude is dependent on the size of the EUT (which is assumed to be placed midway between the plates). The value of the uncertainty contribution can be obtained from table A.13.

Table A.13: Uncertainty contribution: s tripline: mutual coupling of the EUT to its images in the plates

Size of the EUT relative to the plate separation	Standard uncertainty of the contribution
size/separation < 33 %	1,15 dB
33 % ≤ size/separation < 50 %	1,73 dB
50 % ≤ size/separation < 70 %	2,89 dB
70 % ≤ size/separation ≤ 87,5 % (max.)	5,77 dB

u_{j25} *Stripline: mutual coupling of the three-axis probe to its image in the plates*

This uncertainty only contributes to Stripline test methods. It is the uncertainty which results from the imaging of the three-axis probe in the plates of the Stripline.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: Not applicable.

How to evaluate for Striplines

Verification: Not applicable

Test methods: The standard uncertainty is 0,29 dB.

u_{j26} *Stripline: characteristic impedance*

This uncertainty only contributes to Stripline test methods. This uncertainty contribution results from the difference between the free space wave independence (377 Ω) for which the EUT has been developed and that for the Stripline (150 Ω).

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: Not applicable.

How to evaluate for Striplines

Verification: Not applicable.

Test methods: The standard uncertainty is 0,58 dB.

u_{j27} *Stripline: non-planar nature of the field distribution*

This uncertainty only contributes to Stripline test methods. It is the uncertainty which results from the non-planar nature of the field distribution within the Stripline.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: Not applicable.

How to evaluate for Striplines

Verification: Not applicable.

Test methods: The standard uncertainty is 0,29 dB.

u_{j28} *Stripline: field strength measurement as determined by the three-axis probe*

This uncertainty only contributes to Stripline test methods. It is the uncertainty which results from using a three-axis probe to measure the electric field strength within the Stripline.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: Not applicable.

How to evaluate for Striplines

Verification: Not applicable.

Test methods: The measurement uncertainty of the three-axis probe is taken from manufacturer's data sheet and converted to a standard uncertainty if necessary.

u_{j29} *Stripline: transform factor*

This uncertainty only contributes to Stripline test methods. It is the uncertainty with which the transform factor (i.e. the relationship between the input voltage to the Stripline and the resulting electric field strength between the plates) is determined.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: Not applicable.

How to evaluate for Striplines

Verification: Not applicable.

Test methods: If the verification procedure results are used, the standard uncertainty is the combined standard uncertainty of the verification procedure.

u_{j30} *Stripline: interpolation of values for the transform factor*

This uncertainty only contributes to Stripline test methods. It is the uncertainty associated with interpolating between two adjacent transform factors for the Stripline.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: Not applicable.

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Where the frequency of test corresponds to a set frequency in the verification procedure, this contribution to the combined uncertainty is 0,00 dB. For any other frequency, the value of the standard uncertainty is taken as 0,29 dB.

u_{j31} *Stripline: antenna factor of the monopole*

This uncertainty only contributes to Stripline test methods and the verification procedure. It is the uncertainty with which the antenna factor/gain of the monopole is known.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: Not applicable.

How to evaluate for Striplines

Verification: Not applicable.

Test methods: The standard uncertainty is 1,15 dB.

u_{j32} *Stripline: correction factor for the size of the EUT*

This uncertainty only contributes to Stripline test methods. It is the uncertainty due to the EUT being mounted in the Stripline where the height of the EUT is significant in the E-plane compared to the plate separation.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: Not applicable.

How to evaluate for Striplines

Verification: Not applicable.

Test methods: For EUT mounted centrally in the Stripline, values can be obtained from table A.14.

Table A.14: Uncertainty contribution: Stripline: correction factor for the size of the EUT

Height of the EUT (in the E-plane) is:	Standard uncertainty of the contribution
height < 0,2 m	0,30 dB
0,2 m ≤ height < 0,4 m	0,60 dB
0,4 m ≤ height ≤ 0,7 m	1,20 dB

u_{j33} *Stripline: influence of site effects*

This uncertainty only contributes to Stripline test methods. It is the uncertainty which results from the possible interaction between the fields of the Stripline and objects in its immediate environment.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: Not applicable.

How to evaluate for Striplines

Verification: Not applicable.

Test methods: For any method of field strength measurement, it is assumed that, provided none of the absorbing panels placed around the Stripline or the Stripline itself are moved either between the verification procedure and the test or between the measurement on the EUT and the field measurement parts of the test (for monopole or three-axis probe). The standard uncertainty of the contribution is 0,00 dB. If, however, the arrangement has been changed, the standard uncertainty of the contribution is 3,00 dB.

A.8 Ambient signals

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

u_{j34} *Ambient effect*

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

How to evaluate for free field test sites

Verification: The values of the standard uncertainties should be taken from table A.15.

Table A.15: Uncertainty contribution: ambient effect

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

Test methods: The values of the standard uncertainties should be taken from table A.15.

How to evaluate for Striplines

Verification: The values of the standard uncertainties should be taken from table A.15.

Test methods: The values of the standard uncertainties should be taken from table A.15.

A.9 Mismatch

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

u_{j35} *Mismatch: direct attenuation measurement*

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

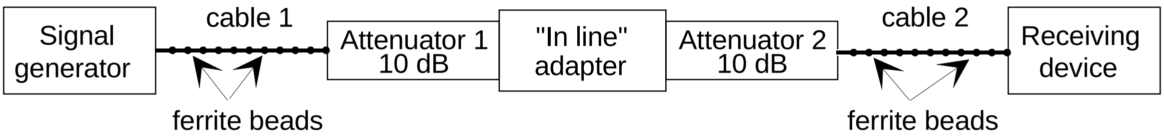


Figure A.4: Equipment set-up for the direct attenuation measurement

How to evaluate for free field test sites

Verification: The magnitude of the uncertainty contribution due to the mismatch in the direct attenuation measurement, is calculated from the approach described in annex D.

Test methods: Not applicable

How to evaluate for Striplines

Verification: The magnitude of the uncertainty contribution due to the mismatch in the direct attenuation measurement, is calculated from the approach described in annex D.

Test methods: Not applicable

u_{j36} *Mismatch: transmitting part*

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

- the transmitting part of a free field test site verification procedure;
- the transmitting part of a Stripline verification procedure (where the antenna in the figure is replaced by the Stripline input);
- the transmitting part of the substitution measurement in a transmitter test method;
- the transmitting part when generating a field in a receiver test method.

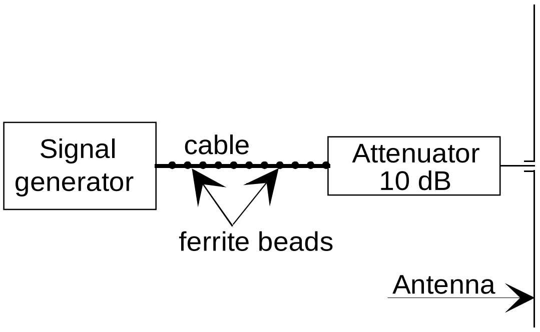


Figure A.5: Equipment set-up for the transmitting part

How to evaluate for free field test sites

Verification: The uncertainty contribution due to the mismatch in the transmitting part is calculated from the approach described in annex D.

Test methods: As for the verification.

How to evaluate for Striplines

Verification: The uncertainty contribution due to the mismatch in the transmitting part is calculated from the approach described in annex D.

Test methods: As for the verification.

u_{j37} *Mismatch: receiving part*

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

- the receiving part of a free field test site verification procedure;
- the receiving part of a Stripline verification procedure (where the antenna is a Monopole);

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

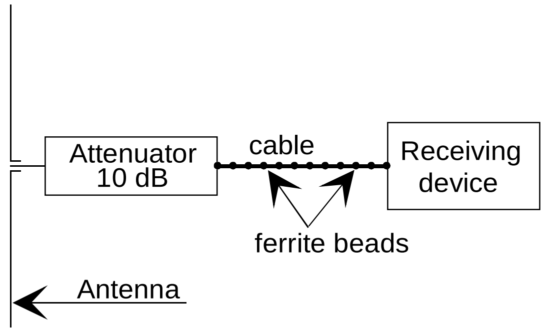


Figure A.6: Equipment set-up for the receiving part

How to evaluate for free field test sites

Verification: The uncertainty contribution due to the mismatch in the receiving part is calculated from the approach described in annex D.

Test methods: As for the verification.

How to evaluate for Striplines

Verification: The uncertainty contribution due to the mismatch in the receiving part is calculated from the approach described in annex D.

Test methods: As for the verification.

A.10 Signal generator

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

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

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

How to evaluate for free field test sites

Verification: The standard uncertainty is 0,00 dB.

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

How to evaluate for Striplines

Verification: The standard uncertainty is 0,00 dB.

Test methods:

- For cases where the field strength in a Stripline is determined from the results of the verification procedure, the uncertainty is taken from the manufacturer's data sheet and converted into standard uncertainty if necessary.
- Where an electric field strength measurement is made in the Stripline this contribution is assumed to be zero.

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

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

How to evaluate for free field test sites

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

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

How to evaluate for Striplines

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

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

A.11 Insertion losses

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

u_{j40} *insertion loss: attenuator*

This uncertainty only contributes to test methods.

How to evaluate for free field test sites

Verification: This value is 0,00 dB.

Test methods:

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

How to evaluate for Striplines

Verification: The value is 0,00 dB.

Test methods:

- where the field strength in a Stripline is determined from the results of the verification procedure, for the attenuator associated with the Stripline input this uncertainty contribution is taken either from the manufacturer's data sheet or from the combined standard uncertainty figure of its measurement.

- where a monopole or three-axis probe is used to determine the field strength, for the attenuator associated with the Stripline input this uncertainty contribution is assumed to be 0,00 dB due to the methodology.
- where a monopole is used to determine the field strength, for the attenuator associated with the monopole antenna this uncertainty contribution is taken either from the manufacturer's data sheet or from the combined standard uncertainty figure of its measurement.

u_{j41} *Insertion loss: cable*

This uncertainty only contributes to the test methods.

How to evaluate for free field test sites

Verification: This value is 0,00 dB.

Test methods:

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

How to evaluate for Striplines

Verification: This value is 0,00 dB.

Test methods:

- where the field strength in a Stripline is determined from the results of the verification procedure, for the cable associated with the signal generator this uncertainty contribution is taken either from the manufacturer's data sheet or from the combined standard uncertainty figure of its measurement.
- where a monopole or three-axis probe is used to determine the field strength, for the cable associated with the signal generator this uncertainty contribution is assumed to be 0,00 dB due to the methodology.
- where a monopole is used to determine the field strength, for the cable associated with the monopole antenna this uncertainty contribution is taken either from the manufacturer's data sheet or from the combined standard uncertainty figure of its measurement.

u_{j42} *Insertion loss: adapter*

This uncertainty only contributes to the verification procedures.

How to evaluate for free field test sites

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

Test methods: Not applicable.

How to evaluate for Striplines

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

Test methods: Not applicable.

u_{j43} *Insertion loss: antenna balun*

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

How to evaluate for free field test sites

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

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

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

A.12 Antennas

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

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

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

How to evaluate for free field test sites

Verification: The antenna factor contributes only to the radiated part of this procedure. For ANSI dipoles the value should be obtained from table A.16. For other antenna types the figures should be taken from manufacturer's data sheets. If a figure is not given the standard uncertainty is 1,0 dB.

Table A.16: Uncertainty contribution: antenna: antenna factor of the transmitting, receiving or measuring antenna

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

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

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

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

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

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: For ANSI dipoles the value should be obtained from table A.17. For other antenna types the figures should be taken from manufacturer's data sheets. If a figure is not given the standard uncertainty is 1,0 dB.

Table A.17: Uncertainty contribution: antenna: gain of the test or substitution antenna

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

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

u_{j46} *Antenna: tuning*

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

How to evaluate for free field test sites

Verification: The standard uncertainty is 0,06 dB.

Test methods:

- In the test antenna case the uncertainty is equal in both stages of the test method so its contribution to the uncertainty is assumed to be 0,00 dB.
- In the substitution/measuring antenna case, the standard uncertainty is 0,06 dB.

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

A.13 Receiving device

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

u_{j47} *Receiving device: absolute level*

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

How to evaluate for free field test sites

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

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

How to evaluate for Striplines

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

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

u_{j48} *Receiving device: linearity*

This uncertainty only contributes to the verification procedures.

How to evaluate for free field test sites

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

Test methods: Not applicable.

How to evaluate for Striplines

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

Test methods: Not applicable.

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

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

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

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: Contributions are the same as for the conducted case, see TR 100 028 [5].

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

A.14 Equipment under test

Background: There are uncertainties associated with the EUT due to the following reasons:

- temperature effects: this is the uncertainty caused by the uncertainty in the ambient temperature;
- degradation measurement: this contribution is a RF level uncertainty associated with the uncertainty of measuring, 20 dB SINAD, 10^{-2} bit stream or 80 % message acceptance ratio;
- power supply effects. this is the uncertainty caused by the uncertainty in the power supply voltage;
- mutual coupling to its power leads.

u_{j50} *EUT: influence of the ambient temperature on the ERP of the carrier*

This uncertainty only contributes to the ERP test method. It is the uncertainty in the carrier power level caused by the uncertainty in knowing the ambient temperature.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: Only applicable in stage one where the measurement is made on the EUT. The uncertainty caused is calculated using the dependency function (TR 100 028 [5]) whose mean value is 4 %/°C and whose standard deviation is 1,2 %/°C. The standard uncertainty of the ERP of the carrier caused by this ambient temperature uncertainty should be calculated using the appropriate formula of TR 100 028 [5] and then converted to dB.

For example, an ambient temperature uncertainty of ±1 °C, results in the standard uncertainty of the ERP of the carrier of:

$$\sqrt{\left(\frac{(1^\circ C)^2}{3}\right) x \left((4{,}0\%/^\circ C)^2 + (1{,}2\%/^\circ C)^2\right)} = 2{,}41\ \%, \text{ transformed to dB: } 2{,}41/23{,}0 = 0{,}1\ \text{dB}$$

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

u_{j51} *EUT: influence of the ambient temperature on the spurious emission level*

This uncertainty contribution only applies to the test methods on free field test sites. It is the uncertainty in the power level of the spurious emission caused by the uncertainty in knowing the ambient temperature.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: Only applicable in stage one where the measurement is made on the EUT. The uncertainty caused is calculated using the dependency function (TR 100 028 [5]) whose mean value is 4 %/°C and whose standard deviation is 1,2 %/°C. The standard uncertainty of the spurious emission level caused by this ambient temperature uncertainty should be calculated using the appropriate formula of TR 100 028 [5] and then converted to dB.

For example, an ambient temperature uncertainty of ±1 °C, results in the standard uncertainty of the spurious emission level of:

$$\sqrt{\left(\frac{(1^\circ C)^2}{3}\right) x \left((4{,}0\%/^\circ C)^2 + (1{,}2\%/^\circ C)^2\right)} = 2{,}41\ \%, \text{ transformed to dB: } 2{,}41/23{,}0 = 0{,}1\ \text{dB.}$$

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

u_{j52} *EUT: degradation measurement*

This uncertainty only contributes to receiver test methods and is the resulting RF level uncertainty associated with the uncertainty of measuring 20 dB SINAD, 10^{-2} bit stream or 80 % message acceptance ratio.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: The magnitude can be obtained from TR 100 028 [5].

How to evaluate for Striplines

Verification: Not applicable.

Test methods: The magnitude can be obtained from TR 100 028 [5].

u_{j53} *EUT: influence of setting the power supply on the ERP of the carrier*

This uncertainty only applies to the effective radiated power test method and is caused by the uncertainty in setting the power supply level.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: Only applicable in stage one where the measurement is made on the EUT. The uncertainty caused is calculated using the dependency function (TR 100 028 [5]) whose mean value is 10 %/V and whose standard deviation is 3 %/V. The standard uncertainty of the ERP of the carrier caused by power supply voltage uncertainty should be calculated using the appropriate formula of TR 100 028 [5] and then converted to dB.

For example, a supply voltage uncertainty of ±100 mV results in the standard uncertainty of the ERP of the carrier of:

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

, transformed to dB: 0,60/23,0 = 0,03 dB.

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

u_{j54} *EUT: influence of setting the power supply on the spurious emission level*

This uncertainty only applies to the spurious emissions test method and is caused by the uncertainty in setting the power supply level.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: Only applicable in stage one where the measurement is made on the EUT. The uncertainty caused is calculated using the dependency function (TR 100 028 [5]) whose mean value is 10 %/V and whose standard deviation is 3 %/V. The standard uncertainty of the spurious emission level caused by power supply voltage uncertainty should be calculated using formula (2) of TR 100 028 [5] and then converted to dB.

For example, a supply voltage uncertainty of ±100 mV results in the standard uncertainty of the spurious emission level of:

$\sqrt{\frac{(0,1V)^2}{3} x ((10\% / V)^2 + (3\% / V)^2)}$ = 0,06 %, transformed to dB: 0,60/23,0 = 0,03 dB.

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

u_{j55} *EUT: mutual coupling to the power leads*

This uncertainty only contributes to test methods. It is the uncertainty which results from interaction (reflections, parasitic effects, etc.) between the EUT and the power leads.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: The standard uncertainty is 0,5 dB provided that the precautions detailed in the methods have been observed, i.e. routing and dressing of cables with ferrites. If the precautions have not been observed the standard uncertainty is 2,0 dB.

How to evaluate for Striplines

Verification: Not applicable.

Test methods: The standard uncertainty is 0,5 dB provided that the precautions detailed in the methods have been observed, i.e. routing and dressing of cables with ferrites. If the precautions have not been observed the standard uncertainty is 2,0 dB.

A.15 Frequency counter

u_{j56} *Frequency counter: absolute reading*

This uncertainty only contributes to frequency error test methods performed using a frequency counter. It is the uncertainty of frequency measurement.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: The uncertainty of frequency measurement is taken from the manufacturer's data sheet.

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

u_{j57} *Frequency counter: estimating the average reading*

This uncertainty only contributes to frequency error test methods performed using a frequency counter. It is the uncertainty with which the average frequency can be estimated.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: The standard uncertainty should be taken as 0,33 × (highest frequency - lowest frequency) / 2.

How to evaluate for Striplines

Verification: Not applicable.

Test methods: The standard uncertainty should be taken as 0,33 × (highest frequency - lowest frequency) / 2.

A.16 Salty man and salty-lite

Background: The human body has a significant effect on the electrical performance of a body worn EUT. For test purposes the artificial human body should simulate the average human body. Two main types of artificial human bodies are used in testing: Salty man and Salty-lite.

u_{j58} *Salty man/Salty-lite: human simulation*

This uncertainty only contributes to test methods on free field test sites. It is the uncertainty which results from the differences between the average human being and the artificial one used.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: The standard uncertainty should be taken from table A.18.

Table A.18: Uncertainty contribution: human simulation

Test Facility	Frequency Range	Standard Uncertainty
Salty man	30 MHz to 150 MHz	0,58 dB
	150 MHz to 1 000 MHz	1,73 dB
Salty-lite in Anechoic Chamber	100 MHz to 150 MHz	1,73 dB
	150 MHz to 1 000 MHz	0,58 dB
Salty-lite in Open Area Test Site or Anechoic Chamber with Ground Plane	70 MHz to 150 MHz	1,73 dB
	150 MHz to 1 000 MHz	0,58 dB

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

u_{j59} *Salty man/salty-lite: field enhancement and de-tuning of the EUT*

This uncertainty only contributes to test methods on free field test sites. It is the uncertainty associated with the variation of the enhanced magnetic field effect produced by the body and the de-tuning of the circuitry of the EUT with spacing away from the outer surface of the salty body.

How to evaluate for free field test sites

Verification: Not applicable.

Test methods: The standard uncertainty of this effect is estimated as 1,00 dB.

How to evaluate for Striplines

Verification: Not applicable.

Test methods: Not applicable.

A.17 Test Fixture

Background: A Test Fixture is a type of test site which enables the performance of an integral antenna EUT to be measured at extreme conditions.

u_{j60} *Test Fixture: effect on the EUT*

Since it is proven on the accredited test site that the Test Fixture does not have an adverse effect on the EUT (e.g. more than a 0,5 dB change in the received level), it is assumed that the maximum uncertainty introduced by the presence of the Test Fixture is ±0,5 dB. The corresponding standard uncertainty is 0,29 dB.

u_{j61} *Test Fixture: climatic facility effect on the EUT*

Since it is proven that the climatic facility does not have an adverse effect on the EUT (e.g. more than a 0,5 dB change in the received level), it is assumed that the maximum uncertainty introduced by the presence of the Test Fixture is ±0,5 dB. The corresponding standard uncertainty is 0,29 dB.

A.18 Random uncertainty

u_{i01} *Random uncertainty*

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

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

How to evaluate for free field test sites

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

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

How to evaluate for Striplines

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

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

A.19 Summary, tables and figures

Table A.19: Mutual coupling and mismatch loss correction factors (Anechoic Chamber)

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

Table A.20: Mutual coupling and mismatch loss correction factors (over a ground plane)

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

Table A.21: Summary table of all contributions (numerical sort)

	Description
u_{j01}	*reflectivity of absorbing material: EUT to the test antenna*
u_{j02}	*reflectivity of absorbing material: substitution or measuring antenna to the test antenna*
u_{j03}	*reflectivity of absorbing material: transmitting antenna to the receiving antenna*
u_{j04}	*mutual coupling: EUT to its images in the absorbing material*
u_{j05}	*mutual coupling: de-tuning effect of the absorbing material on the EUT*
u_{j06}	*mutual coupling: substitution, measuring or test antenna to its image in the absorbing material*
u_{j07}	*mutual coupling: transmitting or receiving antenna to its image in the absorbing material*
u_{j08}	*mutual coupling: amplitude effect of the test antenna on the EUT*
u_{j09}	*mutual coupling: de-tuning effect of the test antenna on the EUT*
u_{j10}	*mutual coupling: transmitting antenna to the receiving antenna*
u_{j11}	*mutual coupling: substitution or measuring antenna to the test antenna*
u_{j12}	*mutual coupling: interpolation of mutual coupling and mismatch loss correction factors*
u_{j13}	*mutual coupling: EUT to its image in the ground plane*
u_{j14}	*mutual coupling: substitution, measuring or test antenna to its image in the ground plane*
u_{j15}	*mutual coupling: transmitting or receiving antenna to its image in the ground plane*
u_{j16}	*range length*
u_{j17}	*correction: off boresight angle in the elevation plane*
u_{j18}	*correction: measurement distance*
u_{j19}	*cable factor*
u_{j20}	*position of the phase centre: within the EUT volume*
u_{j21}	*positioning of the phase centre: within the EUT over the axis of rotation of the turntable*
u_{j22}	*position of the phase centre: measuring, substitution, receiving, transmitting or test antenna*
u_{j23}	*position of the phase centre: LPDA*
u_{j24}	*Stripline: mutual coupling of the EUT to its images in the plates*
u_{j25}	*Stripline: mutual coupling of the 3-axis probe to its image in the plates*
u_{j26}	*Stripline: characteristic impedance*
u_{j27}	*Stripline: non-planar nature of the field distribution*
u_{j28}	*Stripline: field strength measurement as determined by the 3-axis probe*
u_{j29}	*Stripline: transfer factor*
u_{j30}	*Stripline: interpolation of values for the transfer factor*
u_{j31}	*Stripline: antenna factor of the monopole*
u_{j32}	*Stripline: correction factor for the size of the EUT*
u_{j33}	*Stripline: influence of site effects*
u_{j34}	*ambient effect*
u_{j35}	*mismatch: direct attenuation measurement*
u_{j36}	*mismatch: transmitting part*
u_{j37}	*mismatch: receiving part*
u_{j38}	*signal generator: absolute output level*
u_{j39}	*signal generator: output level stability*
u_{j40}	*insertion loss: attenuator*
u_{j41}	*insertion loss: cable*
u_{j42}	*insertion loss: adapter*
u_{j43}	*insertion loss: antenna balun*
u_{j44}	*antenna: antenna factor of the transmitting, receiving or measuring antenna*
u_{j45}	*antenna: gain of the test or substitution antenna*
u_{j46}	*antenna: tuning*
u_{j47}	*receiving device: absolute level*
u_{j48}	*receiving device: linearity*
u_{j49}	*receiving device: power measuring receiver*

	Description
u_{j50}	*EUT: influence of the ambient temperature on the ERP of the carrier*
uj_{51}	*EUT: influence of the ambient temperature on the spurious emission level*
u_{j52}	*EUT: degradation measurement*
u_{j53}	*EUT: influence of setting the power supply on the ERP of the carrier*
u_{j54}	*EUT: influence of setting the power supply on the spurious emission level*
u_{j55}	*EUT: mutual coupling to the power leads*
u_{j56}	*frequency counter: absolute reading*
u_{j57}	*frequency counter: estimating the average reading*
u_{j58}	*Salty man/Salty-lite: human simulation*
u_{j59}	*Salty man/Salty-lite: field enhancement and de-tuning of the EUT*
u_{j60}	*Test Fixture: effect on the EUT*
u_{j61}	*Test Fixture: climatic facility effect on the EUT*
u_{i01}	*Random (see note in clause A.18 of the present document and note in clause 6.4.7 of TR 102 273-1-1)*

Table A.22: Summary table of all contributions (alphabetical sort)

	Description
u_{j34}	*ambient effect*
u_{j44}	*antenna: antenna factor of the transmitting, receiving or measuring antenna*
u_{j45}	*antenna: gain of the test or substitution antenna*
u_{j46}	*antenna: tuning*
u_{j19}	*cable factor*
u_{j18}	*correction: measurement distance*
u_{j17}	*correction: off boresight angle in the elevation plane*
u_{j53}	*EUT: influence of setting the power supply on the ERP of the carrier*
u_{j54}	*EUT: influence of setting the power supply on the spurious emission level*
u_{j50}	*EUT: influence of the ambient temperature on the ERP of the carrier*
u_{j51}	*EUT: influence of the ambient temperature on the spurious emission level*
u_{j52}	*EUT: degradation measurement*
u_{j55}	*EUT: mutual coupling to the power leads*
u_{j56}	*frequency counter: absolute reading*
u_{j57}	*frequency counter: estimating the average reading*
u_{j42}	*insertion loss: adapter*
u_j43	*insertion loss: antenna balun*
u_{j40}	*insertion loss: attenuator*
u_{j41}	*insertion loss: cable*
u_{j35}	*mismatch: direct attenuation measurement*
u_{j37}	*mismatch: receiving part*
u_{j36}	*mismatch: transmitting part*
u_{j04}	*mutual coupling: EUT to its images in the absorbing material*
u_{j08}	*mutual coupling: amplitude effect of the test antenna on the EUT*
u_{j05}	*mutual coupling: de-tuning effect of the absorbing material on the EUT*
u_{j09}	*mutual coupling: de-tuning effect of the test antenna on the EUT*
u_{j13}	*mutual coupling: EUT to its image in the ground plane*
u_{j12}	*mutual coupling: interpolation of mutual coupling and mismatch loss correction factors*
u_{j11}	*mutual coupling: substitution or measuring antenna to the test antenna*
u_{j06}	*mutual coupling: substitution, measuring or test antenna to its image in the absorbing material*
u_{j14}	*mutual coupling: substitution, measuring or test antenna to its image in the ground plane*
u_{j10}	*mutual coupling: transmitting antenna to the receiving antenna*
u_{j07}	*mutual coupling: transmitting or receiving antenna to its image in the absorbing material*
u_{j15}	*mutual coupling: transmitting or receiving antenna to its image in the ground plane*
u_{j23}	*position of the phase centre: LPDA*
u_{j22}	*position of the phase centre: measuring, substitution, receiving, transmitting or test antenna*
u_{j20}	*position of the phase centre: within the EUT volume*
u_{j21}	*positioning of the phase centre: within the EUT over the axis of rotation of the turntable*
u_{i01}	*Random (see note in clause A.18 of the present document and note in clause 6.4.7 of TR 102 273-1-1)*
u_{j16}	*range length*
u_{j47}	*receiving device: absolute level*
u_{j48}	*receiving device: linearity*
u_{j49}	*receiving device: power measuring receiver*
u_j01	*reflectivity of absorbing material: EUT to the test antenna*
u_{j02}	*reflectivity of absorbing material: substitution or measuring antenna to the test antenna*
u_{j03}	*reflectivity of absorbing material: transmitting antenna to the receiving antenna*
u_{j59}	*Salty man/Salty-lite: field enhancement and de-tuning of the EUT*
u_j58	*Salty man/Salty-lite: human simulation*
u_j38	*signal generator: absolute output level*
u_{j39}	*signal generator: output level stability*

	Description
u_{j31}	*Stripline: antenna factor of the monopole*
u_{j26}	*Stripline: characteristic impedance*
u_{j32}	*Stripline: correction factor for the size of the EUT*
u_{j28}	*Stripline: field strength measurement as determined by the 3-axis probe*
u_{j33}	*Stripline: influence of site effects*
u_{j30}	*Stripline: interpolation of values for the transfer factor*
u_{j25}	*Stripline: mutual coupling of the 3-axis probe to its image in the plates*
u_{j24}	*Stripline: mutual coupling of the EUT to its images in the plates*
u_{j27}	*Stripline: non-planar nature of the field distribution*
u_{j29}	*Stripline: transfer factor*
u_{j61}	*Test Fixture: climatic facility effect on the EUT*
u_{j60}	*Test Fixture: effect on the EUT*

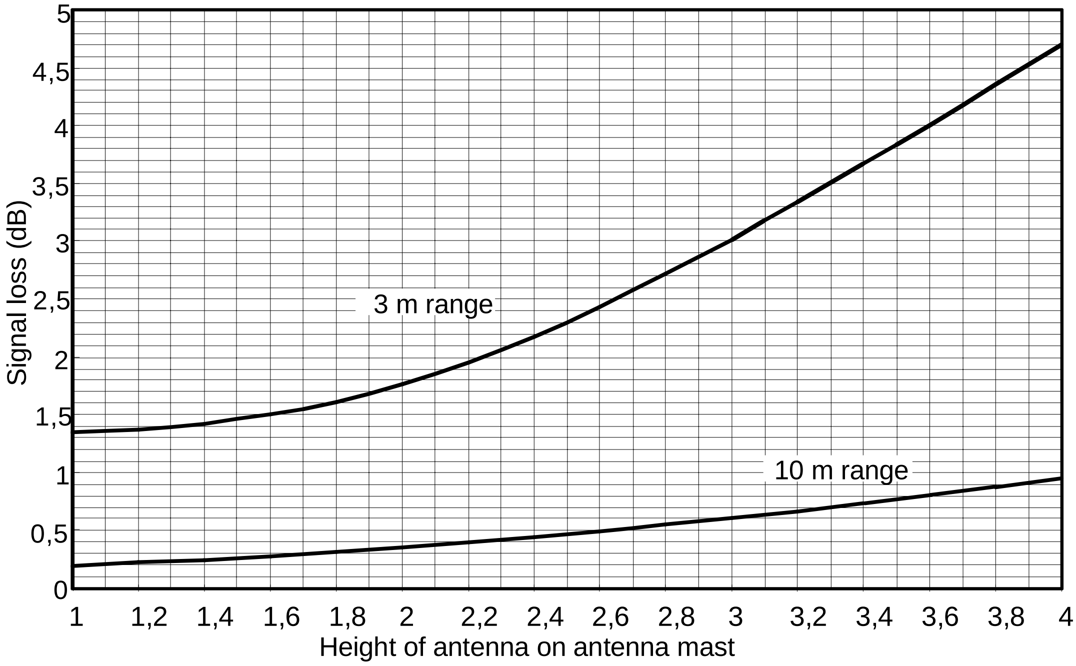


Figure A.7: Signal attenuation with increasing elevation offset angle

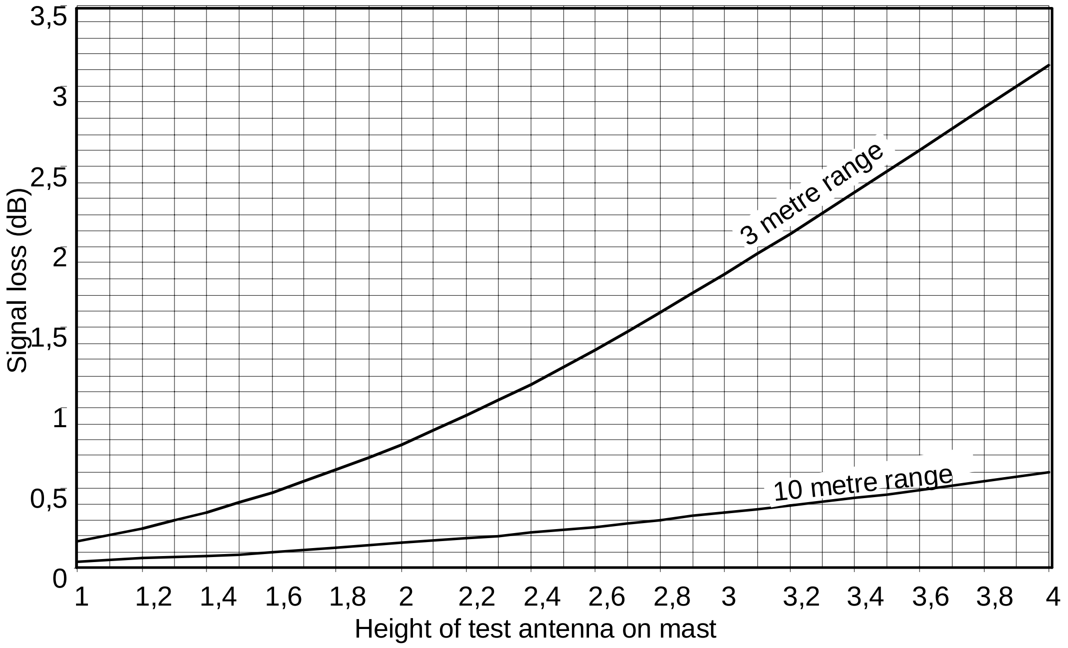


Figure A.8: Signal attenuation for antenna height on mast

Annex B: Calculating means and standard deviations and further theoretical support

B.1 Properties of distributions

B.1.1 Introduction

When a random variable x can take any of a continuum of values at a particular instant in time, the probability of it taking a specific value tends towards zero. It is conventional to describe this situation in terms of a probability density function *p(x)*.

B.1.2 Mathematical tools and properties

The probability of an occurrence is represented by the area under the probability curve. for example the probability of the variable x lying between x_1 and x_2 is given by:

$$\int_{x_1}^{x_2} p(x)dx$$

Since x assumes a value in the range $-\infty$ to $+\infty$ and $p\ (x)$ is the distribution

$$\int_{-\infty}^{+\infty} p(x)dx = 1$$

The mean of a continuous random variable probability density function is given by:

$$x_m = \int_{-\infty}^{+\infty} xp(x)dx$$

Variance

The second moment of a probability density function $p\ (x)$ about the origin is:

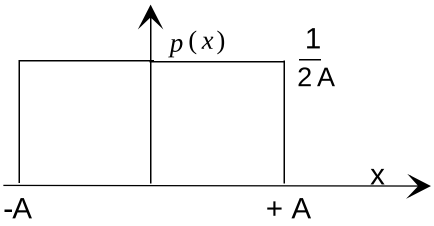
$$x_m^2 = \int_{-\infty}^{+\infty} x^2 p(x)$$

where x_m^2 is the mean square value of process x. If the distribution is non-symmetrical, it is usual to take the 2nd moment about the mean as a measure of dispersion. The second moment is often termed the variance (σ^2) of the probability distribution function, hence:

$$s^2 = \int_{-\infty}^{+\infty} (x - x_m)^2 p(x)dx$$

B.2 Calculations

B.2.1 Rectangular distributions



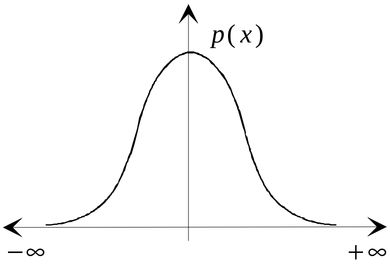
$$x \in [-A,+A] \rightarrow p(x) = \frac{1}{2A}$$
$$x \notin [-A,+A] \rightarrow p(x) = 0$$

Mean value = 0; Standard deviation = $A/\sqrt{3}$

In the interval $-A$ to $+A$ where x occurs with equal probability, i.e. Unknown systematic error distribution are assumed to be rectangularly distributed: i.e. $\pm A$.

If two identical rectangular distributions are combined then a triangular distribution results with the mean value = 0, and the standard deviation = $A/\sqrt{6}$.

B.2.2 Gaussian distributions



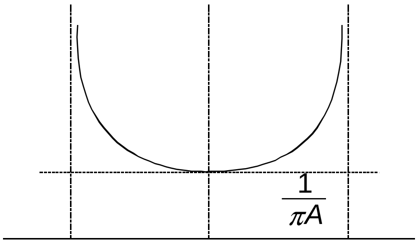
$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp^{-\frac{x^2}{2\sigma^2}}$$

Mean value = 0; Standard deviation = σ

This function is characterized, for example, by the distribution of random noise, the distribution of a number of measurements or the combination of a number of stochastic variables.

B.2.3 'U' shaped distributions

Mathematical tools and properties



$$x \in [-A,+A] \rightarrow p(x) = \frac{1}{2A}$$
$$x \notin [-A,+A] \rightarrow p(x) = 0$$

$$p[x] = \frac{1}{\pi\sqrt{A^2 - x^2}}$$

Mean value = 0; Standard deviation = $A/\sqrt{2}$

The "U" shaped distribution is used when sine functions are involved. This occurs with mismatch errors, temperature regulators and other sinusoidal cyclic variations.

B.3 Reference to theoretical support for the evaluation of measurement uncertainties, including mathematical tools and properties of distributions

More detailed theoretical support for the handling of measurement uncertainties is provided in TR 100 028-2 [5] annex D. "Theoretical support for the evaluation of measurement uncertainties, including mathematical tools and properties of distributions". The methods proposed there are based on the usage of random variables (and combinations thereof).

The aim of TR 100 028-2 [5] annex D is, in particular, to provide guidance on how to use random variables in support of the evaluation of measurement uncertainties and to provide methods for handling and combining random variables.

The annex gives the reader a chance to become more familiar with:

- a number of definitions and properties of distributions;
- the result of the combination of random variables and how to use all these tools in order to more accurately evaluate the uncertainties relating to a particular test set up;
- mathematical support using logs and dBs;
- confidence levels.

For a concise summary of results for different combinations of distributions (as calculated in TR 100 028-2 [5] clause D.3) see table B.1, taken from TR 100 028-2 [5] clause D.3.12.

Table B.1 Combination of distributions – Summary

Operations relating to random variables			Equations (1)	Resulting distribution	Mean value	Standard deviation	Clause
One random variable	Addition of a constant value		$H=F+\alpha$	$h(z)=f(z-\alpha)$	$m_h=m_f+\alpha$	$\sigma_h=\sigma_f$	D.3.1
	Multiplication by pos. const.		$H=(\lambda)F$	$h(z)=(1/\lambda)f(z/\lambda)$	$m_h=\lambda m_f$	$\sigma_h=\lambda\sigma_f$	D.3.2
	Multiplication by neg. const.		$H=(-\lambda)F$	$h(z)=-(1/\lambda)f(z/\lambda)$	$m_h=\lambda m_f$	$\sigma_h^2=\lambda^2\sigma_f^2$	D.3.2
	Inverse function		$H= 1 / F$	$h(z)= f(1/z) / z^2$	$m_h=\int (f(z) / z)\, dz$	$\sigma_h^2+m_h^2=\int (f(z) / z^2)\, dz$	D.3.7
Two random variables	***Sum***		$H=F+G$	$h(z)=\int g(z-x)f(x)dx$	$m_h=m_f+m_g$	$\sigma_h^2=\sigma_f^2+\sigma_g^2$ (note 3)	D.3.3
	independent variables		$H=\lambda F+\mu G$	$h(z)=\int(1/\lambda\mu)f(x/\lambda)g((z-x)/\mu)dx$	$m_h=\lambda m_f+\mu m_g$	$\sigma_h^2=\lambda^2\sigma_f^2 + \mu^2\sigma_g^2$	D.3.4
	non independent variables		$H=\lambda F+\mu G$ where $F=kG$	$h(z)=(1/(\lambda k+\mu))g(z/(\lambda k+\mu))$	$m_h=(\lambda k+\mu)m_g$	$\sigma_h^2=(\lambda k+\mu)^2\sigma_g^2$	D.3.4.6
	Subtraction		$H=F-G$	$h(z)=\int g(x-z)f(x)dx$	$m_h=m_f-m_g$	$\sigma_h^2=\sigma_f^2+\sigma_g^2$	D.3.5
	Multiplication		$H=FG$	$h(z)=\int(1/ \lvert x \rvert)g(z/x)f(x)dx$	$m_h=m_f\, m_g$	$\sigma_h^2+m_h^2=(\sigma_f^2+m_f^2)(\sigma_g^2+m_g^2)$	D.3.6
	Division		$H=F/G$	$h(z)=\int g(x/z) (\lvert x \rvert / z^2) f(x)dx$	$m_h= m_f (\int (g(z) / z)\, dz)$	$\sigma_h^2+m_h^2=(\sigma_f^2+m_f^2)(\int(g(z)/z^2)dz)$	D.3.7
Using Logs	Using Logs		$H=\mathrm{Log}(F)$	$h(z)=e^z f (e^z)$	$m_h= \int \mathrm{Log}(x)\, f(x)\, dx$	$\sigma_h^2= (\int \mathrm{Log}^2(x)\, f(x)\, dx) - m_h^2$	D.3.8
	Powers	Linear terms ➔dB	$H=10 \log(F)$	$h(z)=10^{z/10}(\mathrm{Log}(10)f(10^{z/10})/10)$	$m_h=\int 10 \log(x)f(x)dx$	$\sigma_h^2=(\int (10\log(x))^2f(x)\, dx) - m_h^2$	D.3.8.4.1
		dB ➔ linear terms	$H= 10^{(F/10)}$	$h(z)=10(f(10\log(z)))/(z\mathrm{Log}10)$	$m_h=\int e^{(x/10)\,\mathrm{Log}10} f(x)dx$	$\sigma_h^2=(\int(e^{(x/10)}\mathrm{Log}10)^2f(x)dx)-m_h^2$	D.3.8.4.2
	Volts	Linear terms ➔dB	$H=20 \log(F)$	$h(z)=10^{z/20}(\mathrm{Log}(10)f(10^{z/20})/20)$	$m_h=\int 20 \log(x)f(x)dx$	$\sigma_h^2=(\int (20\log(x))^2f(x)\, dx) - m_h^2$	D.3.8.4.1
		dB ➔ linear terms	$H= 10^{(F/20)}$	$h(z)=20(f(20\log(z)))/(z\mathrm{Log}10)$	$m_h=\int e^{(x/20)\,\mathrm{Log}10} f(x)dx$	$\sigma_h^2=(\int(e^{(x/20)}\mathrm{Log}10)^2f(x)dx)-m_h^2$	D.3.8.4.2
Using a function	One variable		$H=g(F)$	$h(z)=(f(g^{-1}(z)))/ \lvert g'(g^{-1}(z) \rvert)$	$m_h= \int g(x)\, f(x)\, dx$	$\sigma_h^2= (\int g^2(x)\, f(x)\, dx) - m_h^2$	D.3.9
	Two variables		$H=g(F, K)$	$h(z)=\int((k(\Upsilon(z,x))/ \lvert \delta g/\delta y \rvert)f(x)dx$	$m_h=\iint g(x,y)f(x)dx\, k(y)dy$	$\sigma_h^2=(\iint g^2(x,y)f(x)dx\, k(y)dy)-m_h^2$	D.3.11
Substitutions	t replaces x in a distribution		x ➔ k(t)	X(x) ➔ $T(t) = X(k(t))\, \lvert k'(t) \rvert$	See clause D.9.3	See clause D.9.3	D.3.10.3
Reciprocals	y = g (x) ⬄ x = k (y)		See clause D.3.10.5	See clause D.3.10.5			D.3.10.5

NOTE 1: The symbol $\int$ stands for: $\int_{-\infty}^{+\infty}$.

NOTE 2: The effect of the sign of a multiplicative constant has been highlighted. Great care is recommended with regard to possible effects on the validity of these expressions due to signs and possible zeros of expressions used above. Functions like ***g*** are supposed to be monotonous; for more details, please refer to the appropriate clause.
The equations are related to independent variables, unless otherwise stated.
The lines in ***bold italic*** correspond to those used more often. Table 1, see clause 5.2 of TR 102 273-1-1, provides first order approximations corresponding to entries for conversions found in table B.1.

NOTE 3: TR 100 028 [5] and TR 102 273 use this formula extensively.

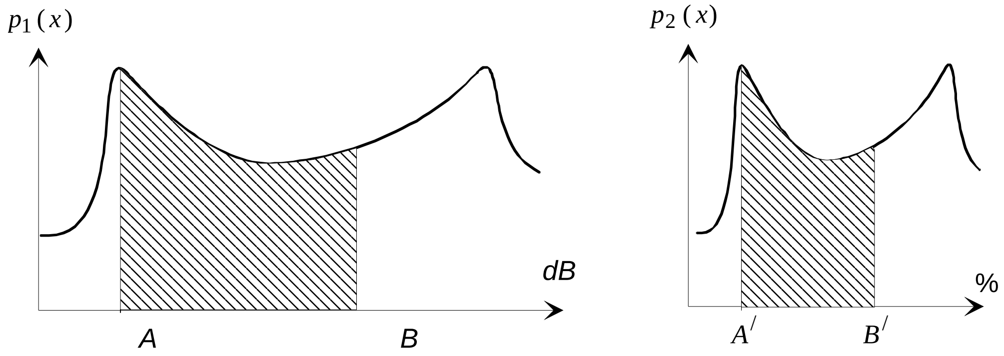
Annex C:
Mathematical transforms

This annex shows how direct methods can be used to transform distributions. Other methods (less specific) for transforming (or converting) distributions are presented in clause D.3.9 of TR 100 028 [5].

C.1 Principles of derivation of formulas when transforming from log to linear

When transforming from one co-ordinate system to another the following applies.

The probability of an event being within an interval is the same no matter which scale on the co-ordinate system you look at:



$A^/$% corresponds to A dB and $B^/$% corresponds to B dB

$$\int_A^B p_1(x)dx = \int_{A^/}^{B^/} p_2(x_1)dx_1$$

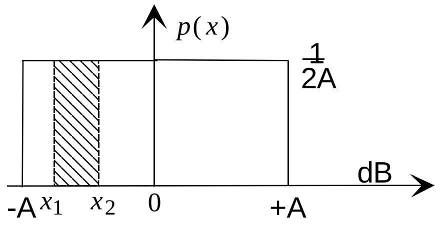
which also means that:

$$\int_{-\infty}^{+\infty} p_1(x)dx = \int_{-\infty}^{+\infty} p_2(x_1)dx_1 = 1$$

Based on this, the converted distribution can now be derived.

C.1.1 A rectangular distribution in logarithmic terms converted to linear terms

In this example a rectangular distribution in logarithmic terms is converted to linear terms:



$p(x) = \frac{1}{2A}$ for $-A \leq x \leq A$

$p(x) = 0$ for all other values of x

The probability of x being in the interval between x_1 and x_2 is:

$$\int_{x_1}^{x_2} \frac{1}{2A}\,dx = \left(\frac{1}{2A}x_2 - \frac{1}{2A}x_1\right)$$

$$= \frac{1}{2A}\left(x_2 - x_1\right)$$

In log terms. Therefore in linear terms this becomes:

$$\int_{10^{\frac{x_1}{20}}}^{10^{\frac{x_2}{20}}} p_2\left(x_1\right)dx = \frac{1}{2A}\left(x_2 - x_1\right)$$

$$= P_2\left(10^{\frac{x_2}{20}}\right) - P_2\left(10^{\frac{x_1}{20}}\right)$$

where $P_2(x) = \int p_2(x)$ or in other words $P_2\left(10^{\frac{x_2}{20}}\right) = \frac{x_2}{2A}$

Substituting $P_2 = K^{/}Log_{10}$ gives

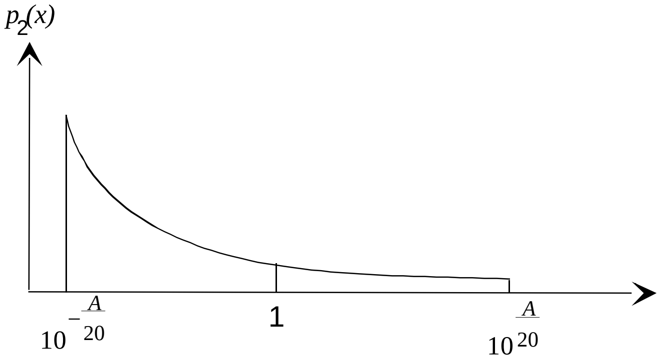
$$K^{/}Log_{10}\left(10^{\frac{x_2}{20}}\right) = K^{/}\frac{x_2}{20} = \frac{x_2}{2A}$$

$$K^{/} = \frac{10}{A}$$

$$\frac{10}{A}Log_{10}(x) = \frac{10}{A\,Ln(10)}Ln(x)$$

$$As \quad \frac{dLn(x)}{dx} = \frac{1}{x}$$

$$p_2(x) = \frac{10}{A\,Ln(10)}\;\frac{1}{x}$$



From $p_2(x)$ the mean value x_m and the standard deviation can be found.

General formula: $x_m = \int x p_2(x) dx$

$$x_m = \int_B^C K \frac{1}{x} x \, dx = \int_B^C K \, dx$$

$$x_m = [Kx]_B^C = K(C\text{-}B)$$

where $K = \dfrac{10}{A \, Ln(10)}$; $B = 10^{\frac{-A}{20}}$; $C = 10^{\frac{A}{20}}$

Then the standard deviation σ can be found. The general formula is: $\sigma^2 = \int_{-\infty}^{+\infty} (x - x_m)^2 p(x) dx$

$$\sigma^2 = \int_B^C (x - x_m)^2 K \frac{1}{x} dx$$

$$= \int_B^C \left({x_m}^2 + x^2 - 2x_m x \right) \frac{K}{x} dx$$

$$= \int_B^C \left(\frac{K{x_m}^2}{x} + Kx - 2x_m K \right) dx$$

$$= \left[K{x_m}^2 Ln(x) + \frac{Kx^2}{2} - 2x_m Kx \right]_B^C$$

$$K\left({x_m}^2 \left(Ln(C) - Ln(B) + \frac{1}{2}\left(C^2 - B^2\right) - 2x_m (C - B) \right) \right)$$

$$As \quad K\left(Ln(C) - Ln(B) \right) = 1$$

Therefore

$$\sigma^2 = {x_m}^2 - 2x_m K(C - B) + \frac{1}{2} K\left(C^2 - B^2\right)$$

and $x_m = K(C - B)$ hence:

$$\sigma^2 = K^2 (C - B)^2 - 2K^2 (C - B)^2 + \frac{1}{2} K\left(C^2 - B^2\right)$$

$$= \frac{1}{2} K\left(C^2 - B^2\right) - K^2 (C - B)^2$$

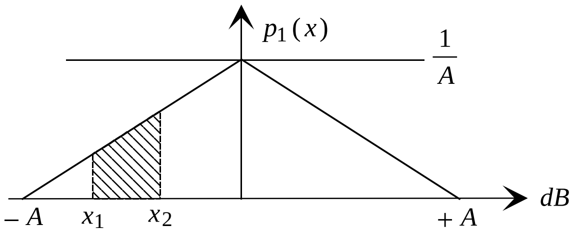
therefore:

$$\sigma = \sqrt{0{,}5K\left(C^2 - B^2\right) - K^2 (C - B)^2}$$

This procedure can (in principle) be applied to any conversion of any distribution.

C.1.2 A triangular distribution in logarithmic terms converted to linear terms

In the same way as with the rectangular distribution the conversion from logs to linear terms are made:



$p_1(x) = \frac{1}{A^2}(A + x)$ for $0 > x \geq -A$

$p_1(x) = \frac{1}{A^2}(A - x)$ for $A \geq x \geq 0$

$p_1(x) = 0$ for all other values of x

In the negative interval:

$$\int_{x_1}^{x_2} p_1(x)dx = \int_{x_1}^{x_2}\left(\frac{1}{A}+\frac{x}{A^2}\right)dx = \left[\frac{x}{A}+\frac{x^2}{2A^2}\right]_{x_1}^{x_2}$$

$$\left(\frac{x_2}{A}+\frac{x_2^2}{2A^2}-\frac{x_1}{A}+\frac{x_1^2}{2A^2}\right) = P_2\left(10^{\frac{x_2}{20}}\right)-P_2\left(10^{\frac{x_1}{20}}\right)$$

$$P_2\left(10^{\frac{x}{20}}\right) = \frac{x}{A}+\frac{x^2}{2A^2}$$

Solution: $K_1 Log(y) + K_2\left(Log(y)\right)^2$

$$K_1 Log\left(10^{\frac{x}{20}}\right) = K_1\frac{x}{20} = \frac{x}{A}$$

$$K_1 = \frac{20}{A}$$

$$K_2\left(Log\left(10^{\frac{x}{20}}\right)\right)^2 = \frac{x^2}{2A^2}$$

$$K_2\frac{x^2}{20^2} = \frac{x^2}{2A^2}$$

$$K_2 = \frac{20^2}{2A^2} = \frac{1}{2}K_1^2$$

Logs converted to Ln:

$$K_1 = \frac{20}{A\,Ln(10)}$$

$$P_2(y) = K_1 Ln(y) + \frac{1}{2}K_1^2\left(Ln(y)\right)^2$$

$$\frac{dP(y)}{dy} = K_1 \frac{1}{y} + K_1^2 \frac{Ln(y)}{y}$$

$$K_1 \frac{1}{y} + K_1^2 \frac{Ln(y)}{y} \text{ for } 10^{\frac{-A}{20}} \le y \le 1$$

and

$$K_1 \frac{1}{y} - K_1^2 \frac{Ln(y)}{y} \text{ for } 1 \le y \le 10^{\frac{A}{20}}$$

$$B = 10^{\frac{-A}{20}} \ and\ C = 10^{\frac{A}{20}}$$

Mean value:

$$x_m = \int_B^1 \left(K_1 \frac{1}{x} + K_1^2 \frac{Ln(x)}{dx} \right) x dx + \int_1^C \left(K_1 \frac{1}{x} - K_1^2 \frac{Ln(x)}{dx} \right) x dx$$

$$= \int_B^1 \left(K_1 + K_1^2 Ln(x) \right) dx + \int_1^C \left(K_1 - K_1^2 Ln(x) \right) dx$$

$$= \int_B^C K_1 + K_1^2 \int_B^1 Ln(x) dx - K_1^2 \int_1^C Ln(x) dx$$

$$= \left[K_1 x \right]_B^C + K_1^2 \left[xLn(x) - x \right]_B^1 - K_1^2 \left[xLn(x) - x \right]_1^C$$

$$= K_1(C - B) + K_1^2\ 1 - K_1^2 \left(B\,Ln(B) - B \right) - K_1^2 \left(C\,Ln(C) - C \right) - k_1^2\ 1$$

$$= K_1(C - B) - 2K_1^2 - K_1^2 B \left(\frac{-1}{k_1} - 1 \right) - K_1^2 c \left(\frac{1}{k_1} - 1 \right)$$

$$= K_1(C - B) - 2K_1^2 + K_1 B + K_1^2 \times B - K_1 C + K_1^2 C$$

$$x_m = K_1^2 (B + C - 2)$$

Standard deviation:

$$\sigma^2 = \int_{-\infty}^{+\infty} \left(x - x_m \right)^2 p(x)dx$$

$$= \int_B^1 \left(x - x_m \right)^2 \left(K_1 \frac{1}{x} + K_1^2 \frac{Ln(x)}{x} \right) dx + \int_1^C \left(x - x_m \right)^2 \left(K_1 \frac{1}{x} - K_1^2 \frac{Ln(x)}{x} \right) dx$$

$$= \int_B^C \left(x - x_m \right)^2 K_1 \frac{1}{x} + \int_B^1 \left(x - x_m \right)^2 K_1^2 \frac{Ln(x)}{x} dx - \int_1^C \left(x - x_m \right)^2 K_1^2 \frac{Ln(x)}{x} dx$$

$$= K_1 \int_B^C \left(x_m{}^2 + x^2 - 2x_m x\right)\frac{1}{x} + \int_B^1 \left(x_m{}^2 + x^2 - 2x_m x\right) K_1^2 \frac{Ln(x)}{x} dx - \int_1^C \left(x_m{}^2 + x^2 - 2x_m x\right) K_1^2 \frac{Ln(x)}{x} dx$$

$$= \int_B^C \left(\frac{x_m{}^2 K_1}{x} + K_1 x - 2x_m K_1\right) dx + K_1^2 \int_B^1 \left(x_m{}^2 \frac{Ln(x)}{x} + xLn(x) - 2x_m Ln(x)\right) dx - K_1^2 \int_1^C \left(x_m{}^2 \frac{Ln(x)}{x} + xLn(x) - 2x_m Ln(x)\right) dx$$

$$\left(\int xLn(x) = \frac{1}{2}x^2 Ln(x) - \frac{1}{4}x^2 \right)$$

$$= K_1 \left[x_m{}^2 Ln(x) + \frac{1}{2}x^2 - 2x_m x \right]_B^C$$

$$+ K_1^2 \left[\frac{1}{2} x_m{}^2 (Ln(x))^2 + \frac{1}{2}x^2\left(Ln(x) - \frac{1}{2}\right) - 2x_m\left(xLn(x) - x\right) \right]_B^1$$

$$- K_1^2 \left[\frac{1}{2} x_m{}^2 (Ln(x))^2 + \frac{1}{2}x^2\left(Ln(x) - \frac{1}{2}\right) - 2x_m\left(xLn(x) - x\right) \right]_1^C$$

$$= K_1 \left[\overline{m}^2 \left(Ln(C) - Ln(B)\right) + \frac{1}{2}\left(C^2 - B^2\right) - 2x_m (C - B) \right]$$

$$+ K_1^2 \left[\frac{1}{2}\left(-\frac{1}{2}\right) - 2x_m(-1) - \frac{1}{2}x_m{}^2 (Ln(B))^2 - \frac{1}{2}B^2\left(Ln(B) - \frac{1}{2}\right) + 2x_m\left(BLn(B) - B\right) \right]$$

$$- K_1^2 \left[\frac{1}{2}x_m{}^2 (Ln(C))^2 + \frac{1}{2}C^2\left(Ln(C) - \frac{1}{2}\right) - 2x_m\left(CLn(C) - C\right) + \frac{1}{4} - 2x_m \right]$$

$$\left(K_1\left(Ln(c) - Ln(B)\right) = 1,\ Ln(C) = \frac{1}{K_1},\ Ln(B) = -\frac{1}{K_1} \right)$$

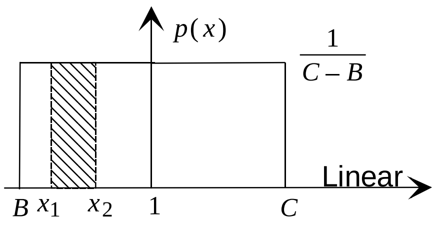
$$= K_1^2 \left(4x_m - \frac{1}{2} + \frac{1}{4}\left(B^2 + C^2\right) - 2x_m(B + C) \right) + x_m{}^2$$

and

$$\sigma = \sqrt{K_1^2 \left(4x_m - \frac{1}{2} + \frac{1}{4}\left(B^2 + C^2\right) - 2x_m(B + C) \right) + x_m{}^2}$$

C.1.3 A rectangular distribution in linear terms converted to logarithmic terms

In this example a rectangular distribution in linear terms is converted in to logarithmic terms



$B = 1 - A$

$C = 1 + A$

$K_1 = \frac{1}{2A}$

$$\int_{x_1}^{x_2} K_1 dx \quad = \int_{20\,Log\,x_1}^{20\,Log\,x_2} p_2(y) dy$$

$$\left(K_2 x_2 - K_1 x_1\right) = p_2\left(20\ Log\ x_2\right) - p_2\left(20\ Log\ x_1\right)$$

In other words: $K_1 X = p_2\left(20\ Log(x)\right)$, the solution: $p_2(x)=K_3 10^{K_2 x}$ where $K_2 = \frac{1}{20} =$

$K_1 x_1 = K_3 10^{K_2 20 Log(x_1)} = K_3 x_1$ Now $K_3 = K_1$ $\quad p_2(x) = K_3 10^{K_2 x} \quad = K_3 e^{K_2 Ln(10) x}$

Then $K_2 = \frac{Ln(10)}{20}$

Now $\left(K_1 = \frac{1}{C-B}, \quad K_2 = \frac{Ln(10)}{20}\right)$

$$p_2(x) = \frac{dp_2(x)}{dx} = K_1 K_2 e^{K_2 x}$$

$$K_3 = K_1 K_2$$

Check: $\int_{-\infty}^{+\infty} p_2(x) = 1$

$$\int_{20Log(1-A)}^{20Log(1+A)} K_3 e^{K_2 x} dx = \frac{K_3}{K_2}\left[e^{K_2 x}\right]_{20Log(1-A)}^{20Log(1+A)}$$

$$= \frac{K_3}{K_2}\left(e^{K_2 20Log(1+A)} - e^{K_2 20Log(1-A)}\right)$$

$$= \frac{1}{2A}\left(e^{\frac{Ln(10)}{20}\times 20 \times Log(1+A)} - e^{\frac{Ln(10)}{20}\times 20 \times Log(1-A)}\right)$$

$$= \frac{1}{2A}\left((1+A) - (1-A)\right) = 1$$

Mean Value:

$$C = 1 + A, \quad B = 1 - A$$

$$\int_{20Log\ B}^{20Log\ C} x K_3 e^{K_2 x} dx$$

$$= K_3\left[\frac{1}{K_2} x e^{K_2 x} - \frac{1}{K_2^2} e^{K_2 x}\right]_{20Log\ B}^{20Log\ C}$$

$$= \frac{K_3}{K_2}\left[e^{K_2 x}\left(x - \frac{1}{K_2}\right)\right]_{20Log\ B}^{20Log\ C}$$

$$= \frac{K_3}{K_2}\left[C\left(20Log(C) - \frac{1}{K_2}\right) - B\left(20Log(B) - \frac{1}{K_2}\right)\right]$$

$$= \frac{K_3}{K_2^2}\left[C\left(K_2 20Log(C)-1\right)-B\left(K_2 20Log(B)-1\right)\right]$$

$$x_m = \frac{K_1}{K_2}\left[C\left(Ln(C)-1\right)-B\left(Ln(B)-1\right)\right]$$

Standard deviation:

$$\sigma^2 = \int\left(x-x_m\right)^2 p(x)dx$$

$$\sigma^2 = \int_{20Log(1-A)=D}^{20Log(1+A)=E}\left({x_m}^2 + x^2 - 2x_m x\right)K_3 e^{K_2 x}dx$$

$$=\left[\frac{{x_m}^2 K_3}{K_2}e^{K_2 x}\right]_D^E + \left[\frac{K_3}{K_2}e^{K_2 x}\left(x^2-\frac{2x}{K_2}-\frac{2}{K_2^2}\right)\right]_D^E - \left[\frac{2\overline{m}K^3}{K_2}e^{K_2 x}\left(x-\frac{1}{K_2}\right)\right]_D^E$$

Now $\int xe^{Kx} = \frac{1}{K}e^{Kx}\left(x+\frac{1}{K}\right)$ and $\int x^2 e^{Kx} = \frac{1}{K}e^{Kx}\left(x^2-\frac{2x}{K}+\frac{2}{K^2}\right)$ and $\frac{K_3}{K_2} = K_1$

$$\sigma = \sqrt{K_1\left[2A\left({x_m}^2+\frac{2}{K_2^2}+\frac{2x_m}{K_2}\right)+(1+A)\left(E^2-\frac{2E}{K_2}-2x_m E\right)-(1-A)\left(D^2-\frac{2D}{K_2}-2x_m D\right)\right]}$$

The four curves in figure C.1 give the relationship between the standard deviation of different distributions in logarithmic units (dB) and the standard deviation of the same distributions when converted to linear units (%). The curves for the rectangular distribution and the triangular distributions are based on the formulas derived previously in this annex whilst the curves for the U-distribution and the Normal distribution are based on computer simulations.

As can be seen from figure C.1 the curves coincide for standard deviations less than 1,5 dB.
This indicates that for small standard deviations the actual shape of the distributions is of no importance.

For larger standard deviations the standard deviations of the converted distributions differ; and the larger the standard deviation, the larger the difference. In other words the shape of the distribution starts to influence the conversion, but as can be seen from the figure, the difference is small compared to the magnitude as long as the standard deviation is below 2,5 to 3 dB.

The curves indicate that for small standard deviations the relationship can be approximated by a straight line given by the constant factor = 11,5 %/dB.

This approximation can also be derived mathematically from the first order approximation for the function $10^{x/20}$ (giving the conversion between dB and %):

$$10^{\frac{x}{20}} \approx 1 + \frac{x}{20} \times \ln(10)$$

The factor $\frac{\ln(10)}{20} = 0{,}115129$ gives the first order conversion.

C.2 Conversion factors

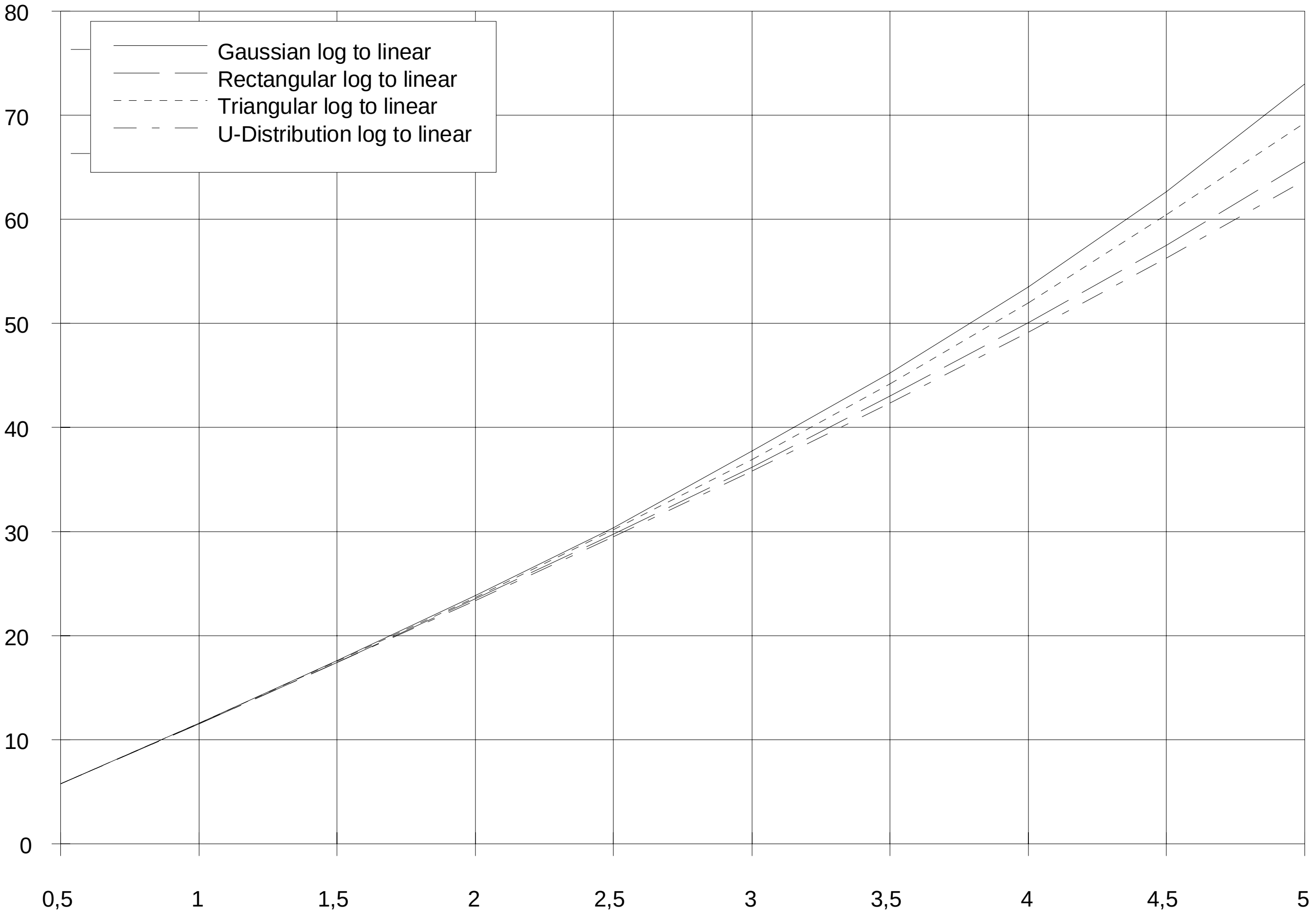


Figure C.1: Standard deviations

Figure C.1 shows that if the standard deviation of a distribution in logarithms is smaller than 2,5 dB to 3,0 dB (resembling errors in the region of 5 dB to 6 dB), the following formula is a good approximation:

$\sigma_{lin} = 11,5 \times \sigma_{log}$

Annex D: Mismatch uncertainties

D.1 Introduction

Mismatch uncertainties are calculated in the present document using *S*-parameters.

A two-port network connects a generator and a load with reflection coefficients ρ_G and ρ_L respectively. Input and output wave amplitudes a_1 and a_2, b_1 and b_2 exist at the planes shown in figure D.1. The performance of this two-port network can be specified in terms of four complex quantities known as *S*-parameters where:

$b_1 = S_{11}a_1 + S_{12}a_2$

$b_2 = S_{21}a_1 + S_{22}a_2$

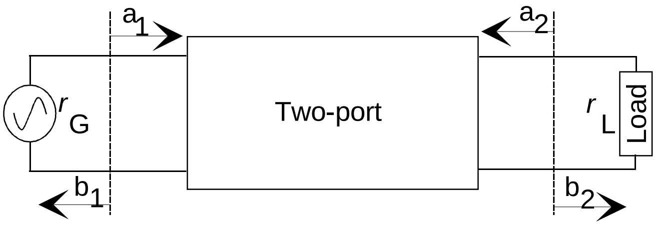


Figure D.1: Two-port network

The corresponding matrix of the network can be described by an *S*-parameter (*S* for scattering) matrix:

$$S = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}$$

Where S_{11} is the complex reflection coefficient at port 1 when port 2 is perfectly terminated (and vice versa). S_{21} is the complex transmission coefficient (or gain) from port 1 to port 2 when both ports are perfectly terminated (and vice versa). For passive, linear networks $S_{21} = S_{12}$.

From the definition of *S* parameters it is easy to see that mismatch loss is covered by the transmission coefficients. In other words it is of no importance whether the attenuation of a network is caused by power dissipation in the network or by reflection at the input.

To illustrate this consider an ideal filter (ideal means it is lossless). All of the filtering is due to reflections at the input, as in an ideal filter, no power can be dissipated inside itself. Therefore if a loss (or gain) has been measured, the mismatch loss has already been taken into account and only the mismatch uncertainty remains. Therefore no correction due to mismatch loss is required.

D.1.1 Cascading networks

If two networks are cascaded the resulting network *S*-parameter matrix is a combination of the two original *S*-parameters. First each individual *S*-parameter matrix needs to be transformed to a *T*-matrix (T for transformation).

$$T = \frac{1}{S_{21}} \begin{bmatrix} 1 & -S_{22} \\ S_{11} & -\det S \end{bmatrix}$$

Where *det S* is the determinant of *S*

Then the resulting *T* matrix is calculated.

For example:

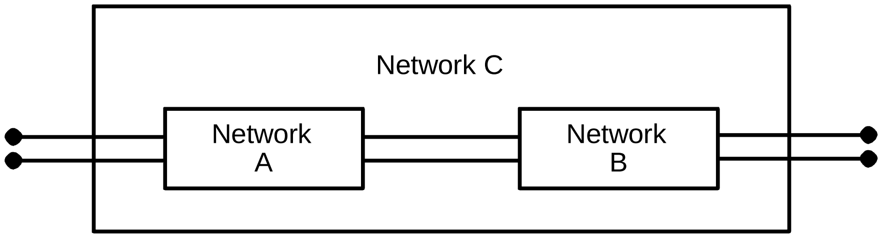


Figure D.2: Cascading networks

S-parameters

$$S_A = \begin{bmatrix} S_{A11} & S_{A12} \\ S_{A21} & S_{A22} \end{bmatrix} \qquad S_B = \begin{bmatrix} S_{B11} & S_{B12} \\ S_{B21} & S_{B22} \end{bmatrix}$$

Which gives:

$$T_A = \begin{bmatrix} T_{A11} & T_{A12} \\ T_{A21} & T_{A22} \end{bmatrix} \qquad T_B = \begin{bmatrix} T_{B11} & T_{B12} \\ T_{B21} & T_{B22} \end{bmatrix}$$

The *T*-matrix for the resulting (combined) network (c) is then:

$T_C = T_A T_B$

$$T_A T_B = \begin{bmatrix} T_{A11} & T_{A12} \\ T_{A21} & T_{A22} \end{bmatrix} \begin{bmatrix} T_{B11} & T_{B12} \\ T_{B21} & T_{B22} \end{bmatrix}$$

$$= \begin{bmatrix} T_{A11}T_{B11} + T_{A12}T_{B21} & T_{A11}T_{B12} + T_{A12}T_{B22} \\ T_{A21}T_{B11} + T_{A22}T_{B21} & T_{A21}T_{B12} + T_{A22}T_{B22} \end{bmatrix}$$

From the resulting T_C back to *S* parameters:

$$S = \frac{1}{T_{11}} \begin{bmatrix} T_{21} & -\det T \\ 1 & -T_{12} \end{bmatrix}$$

From these general methods some useful formulas can be derived:

Applying the methods on the two *A* and *B*, T_A is found:

$$T_A = \frac{1}{S_{A21}} \begin{bmatrix} 1 & -S_{A22} \\ S_{A11} & -\det S_A \end{bmatrix}$$

$$= \frac{1}{S_{A21}} \begin{bmatrix} 1 & -S_{A22} \\ S_{A11} & -S_{A11}S_{A22} + S_{A12}S_{A21} \end{bmatrix}$$

In the same way T_B is found:

$$= \frac{1}{S_{B21}} \begin{bmatrix} 1 & -S_{B22} \\ S_{B11} & S_{B11}S_{B22} + S_{B12}S_{B21} \end{bmatrix}$$

The combination therefore is:

$$T_A T_B = \begin{bmatrix} T_{A11} & T_{A12} \\ T_{A21} & T_{A22} \end{bmatrix} \begin{bmatrix} T_{B11} & T_{B12} \\ T_{B21} & T_{B22} \end{bmatrix}$$

$$= \frac{1}{S_{A21}S_{B21}}\begin{bmatrix} 1 & -S_{A22} \\ S_{A11} & -S_{A11}S_{A22}+S_{A12}S_{A21}\end{bmatrix}\begin{bmatrix} 1 & -S_{B22} \\ S_{B11} & -S_{B11}S_{B22}+S_{B12}S_{B21}\end{bmatrix}$$

$$= \frac{1}{S_{A21}S_{B21}}\begin{bmatrix} 1-S_{A22}S_{B11} & -S_{B22}S_{A22}\left(S_{B12}S_{B21}-S_{B11}S_{B22}\right) \\ S_{A11}+S_{B11}\left(S_{A21}S_{A12}-S_{A11}S_{A22}\right) & -S_{A11}S_{B22}\left(S_{A21}S_{A12}-S_{A11}S_{A22}\right)\left(S_{B21}S_{B12}-S_{B11}S_{B22}\right)\end{bmatrix}$$

Which gives:

$$Tc_{11} = \frac{1-S_{A22}S_{B11}}{S_{A21}S_{B21}}$$

$$Tc_{21} = \frac{S_{A11}+S_{B11}\left(S_{A21}S_{A1}-S_{A11}S_{A22}\right)}{S_{A21}S_{B21}}$$

$$Tc_{12} = \frac{-S_{B22}-S_{A22}\left(S_{B12}S_{B21}-S_{B11}S_{B22}\right)}{S_{A21}S_{B21}}$$

$$Tc_{22} = \frac{-S_{A11}S_{B22}+\left(S_{A21}S_{A12}-S_{A11}S_{A22}\right)\left(S_{B21}S_{B12}-S_{B11}S_{B22}\right)}{S_{A21}S_{B21}}$$

$$Sc = \begin{bmatrix} Sc_{11} & Sc_{12} \\ Sc_{21} & Sc_{22}\end{bmatrix} = \frac{1}{tc_{11}}\begin{bmatrix} tc_{21} & -\det Tc \\ 1 & -tc_{12}\end{bmatrix}$$

$$Sc_{11} = \frac{tc_{21}}{tc_{11}} = \frac{S_{A21}S_{B21}}{1-S_{A22}S_{B11}} \times \frac{S_{A11}+S_{B11}\left(S_{A21}S_{A12}-S_{A11}S_{A22}\right)}{S_{A21}S_{B21}} \times \frac{S_{A11}+S_{B11}\left(S_{A21}S_{A12}-S_{A11}S_{A22}\right)}{1-S_{A22}S_{B11}}$$

$$Sc_{11} = \frac{S_{A11}+S_{B11}S_{A21}S_{A12}-S_{B11}S_{A11}S_{A22}}{1-S_{A22}S_{B11}}$$

$$Sc_{11} = \frac{S_{A11}\left(1-S_{A22}S_{B11}\right)+S_{B11}S_{A21}S_{A12}}{1-S_{A22}S_{B11}}$$

$$Sc_{11} = S_{A11}+\frac{S_{B11}S_{A21}S_{A12}}{1-S_{A22}S_{B11}} \qquad (1)$$

$$Sc_{21} = \frac{1}{tc_{11}} = \frac{S_{A21}S_{B21}}{1-S_{A22}S_{B11}} \qquad (2)$$

Sc_{11} is the input reflection coefficient of the combined network and Sc_{21} is the forward transmission coefficient. For symmetry reasons Sc_{22} and Sc_{12} can be derived directly from Sc_{11} and Sc_{21}:

$$Sc_{22} = S_{B22}+\frac{S_{A22}S_{B12}S_{B21}}{1-S_{A22}S_{B11}} \qquad (3)$$

$$Sc_{12} = \frac{S_{A12}S_{B12}}{1-S_{A22}S_{B11}} \qquad (4)$$

From formula it can be seen that now the reflection coefficient in the connection between the two networks becomes part of the total transfer function: the denominator 1 - S_{A22} S_{B11}.

This causes the mismatch uncertainty as only the magnitudes of S_{A22} and S_{B11} are known, the phase of the product is unknown.

The two worst case values of the term 1 - $S_{A22}\ S_{B11}$ are: 1 + $|S_{A22}|\times|S_{B11}|$ and 1 - $|S_{A22}|\times|S_{B11}|$. The magnitude of the denominator is the magnitude of the sum of two vectors as shown in figure D.3 (where the circle of radius $S_{A22}S_{B11}$ is normally much smaller than 1).

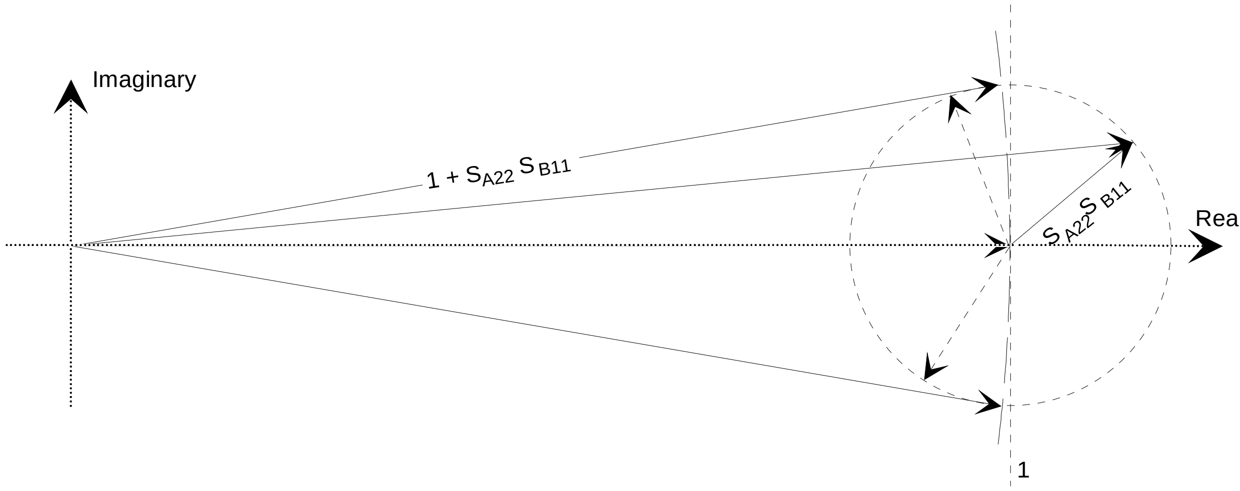


Figure D.3: Vector summation

As can be seen from figure D3 the denominator can be anywhere in the circle with the radius $|S_{A22}|\times|S_{B11}|$. It can also be seen that there are angles for which the argument of the denominator is 1. The magnitude of the denominator is:

$$\sqrt{(1+a\cos\phi)^2+(a\sin\phi)^2}=\sqrt{1+a^2\cos^2\phi+2a\cos\phi+a^2\sin^2\phi}$$

where:

a = $|S_{A22}|\times|S_{B11}|$

$\sqrt{1+a^2\left(\sin^2\phi+\cos^2\phi\right)+2a\cos\phi}$ (as $\sin^2\phi + \cos^2\phi = 1$)

$\sqrt{1+a^2+2a\cos\phi}$ (since $a << 1$: $a^2 \approx 0$ and $1+2a\cos\phi \approx (1+a\cos\phi)^2$:

$\sqrt{(1+a\cos\phi)^2}$ = $1+ a\cos\phi$

The mismatch error magnitude is $a\cos\phi$ where ϕ is unknown (random). This function has the U distribution described in annex B.

From the formula for Sc_{11} and Sc_{22} it can also be seen that the resulting input (or output) reflection coefficient is a combination of the reflection coefficient of network A and a contribution from the reflection coefficient of network B connected at the far end of the network.

For a passive linear network (like attenuators, cables and passive filters) $S_{12} = S_{21}$. In other words the transmission coefficient and therefore the attenuation is the same in both directions.

In this case the resulting input reflection coefficient is S_{11} (which is the input reflection coefficient when the output is perfectly terminated) plus the reflection coefficient of the network connected to the output times the transmission coefficient squared (and with the mismatch in the connector at the far end expressed by the denominator of the second term of the formula).

This also shows that if two components with poor VSWRs are connected together, it does not minimize the mismatch uncertainty to use a perfect cable between the two components. The resulting input reflection coefficient of the cable and the component is merely the reflection coefficient of the component phase shifted by the length of the cable.

From the formulas for Sc_{21} and Sc_{12} it can be seen that the resulting transmission coefficient (S_{21} / S_{12}) of the combined network is the individual transmission coefficients multiplied and combined with the mismatch in the connection between the two networks (as expressed by the denominator).

D.1.2 Mismatch uncertainty calculations

Having discussed the individual uncertainty components of the test equipment an analysis is required, when they are connected together, to determine the combined standard uncertainty contribution. From the formulas derived in annex D the uncertainties due to mismatch can be assessed.

A measurement set-up where absolute RF levels are important parts of the measurement often consist of some RF modules connected in series, see figure D.4. (Cables, attenuators, filters, combiners, amplifiers, etc.)

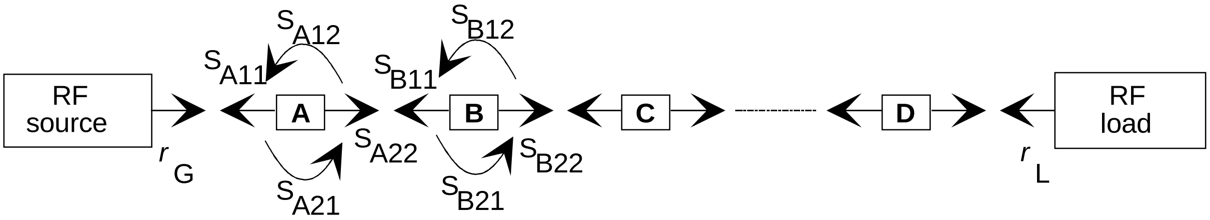


Figure D.4: Typical network

For each individual component in this chain, transmission coefficients and reflection coefficients (or VSWRs) needs to be known or assumed. Often the transmission coefficients are well known from data or measurements.

The exact values of the reflection coefficients VSWRs (which in RF circuits are complex values) are normally not known as they do not have direct influence on the measured results. Even if the magnitude is known, generally, the phase is unknown.

More often worst case values are known. This will generally cause the calculated mismatch uncertainties to be more conservative (or worse) than they actually are.

The uncertainty due to mismatches of the RF level at the RF load (which can be an antenna, a detector, an EUT) in a network like the one shown in figure D.5 can be calculated in the following ways:

The simplest case for assessing the uncertainty due to mismatch is a generator connected to a load through a coupling network.

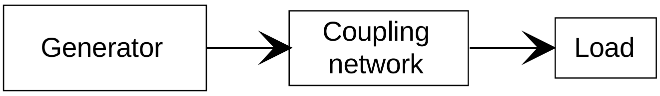


Figure D.5: Generator to load through a coupling network

For the purpose of the calculations the generator is modelled as a perfect generator (output reflection coefficient = 0) connected to a network with an output reflection coefficient equal to the actual generator output reflection coefficient. (Also the network only has a forward transmission of 1,0 and a backwards coefficient of 0,0).

In the same way the load is modelled as a network connected to a perfect matched load. Also with a forward transmission coefficient of 1,0 and a backwards coefficient of 0,0. The set-up of figure D5 now appears as shown in figure D.6.

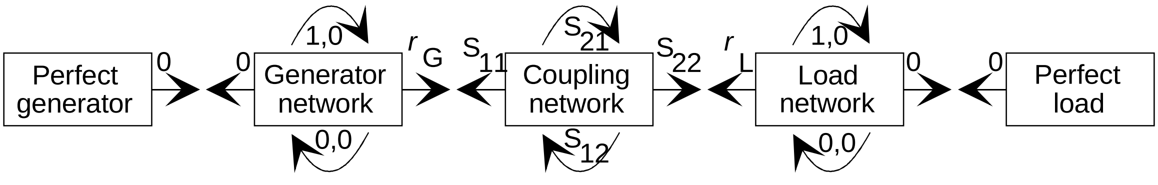


Figure D.6: Perfect generator to perfect load through a coupling network

The *S* matrices for each component in figure D.6 is:

Generator network: $\begin{bmatrix} 0{,}0 & 0{,}0 \\ 1{,}0 & \rho_G \end{bmatrix}$ (S_G)

Coupling network: $\begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix}$ (S)

Load network: $\begin{bmatrix} \rho_L & 0{,}0 \\ 1{,}0 & 0{,}0 \end{bmatrix}$ (S_L)

The total transmission from the generator to the load can then be characterized by the combined network of the three components.

As the input and output reflection coefficients of the combined network is zero, the forward and reverse transmission coefficients of the network fully describes the RF signal flow between the generator and the load, including all mismatch uncertainties.

The forward transmission coefficient is calculated as follows:

The S-parameter matrix for the combined network is:

$$S_G\, S\, S_L:$$

$S' = S_G\, S$: Using formulas (1), (2), (3) and (4) the resulting matrix is:

$$S'_{11} = S_{G11} + \frac{S_{11} S_{G21} S_{G12}}{1 - S_{G22} S_{11}}$$

$$= 0 + \frac{S_{11} \times 1 \times 0}{1 + \rho_G \times S_{11}} = 0 \ \text{(formula 1)}$$

$$S'_{21} = \frac{S_{G21} S_{21}}{1 - S_{G22} S_{11}} = \frac{1 \times S_{21}}{1 - \rho_G S_{11}}$$

$$= \frac{S_{21}}{1 - \rho_G S_{11}} \ \text{(formula 2)}$$

$$S'_{22} = S_{22} + \frac{S_{G22} S_{21} S_{12}}{1 - S_{G22} S_{11}}$$

$$= S_{22} + \frac{G_G S_{21} S_{12}}{1 - \rho_G S_{11}} \ \text{(formula 3)}$$

$$S'_{12} = \frac{S_{G12} S_{12}}{1 - \rho_G S_{11}} = \frac{0 \times S_{12}}{1 - \rho_G S_{11}} = 0 \ \text{(formula 4)}$$

$$S' = \begin{bmatrix} 0 & 0 \\ \dfrac{S_{21}}{1 - \rho_G S_{11}} & S_{22} + \dfrac{\rho_G S_{21} S_{12}}{1 - \rho_G S_{11}} \end{bmatrix}$$

Now only S_{21}'' needs to be calculated:

$$S''_{21} = \frac{S'_{21} S_{L21}}{1 - S'_{22} S_{L11}}$$

$$= \frac{\dfrac{S_{21}}{1-\rho_G S_{11}} \times 1}{1-\left(S_{22}+\dfrac{\rho_G S_{12} S_{21}}{1-\rho_G S_{11}}\right)\times \rho_L}$$

$$= \frac{\dfrac{S_{21}}{1-\rho_G S_{11}}}{1-\rho_L S_{22}+\dfrac{\rho_G \rho_L S_{12} S_{21}}{1-\rho_G S_{11}}}$$

$$= \frac{S_{21}}{(1-\rho_G S_{11})(1-\rho_L S_{22})+\rho_G \rho_L S_{12} S_{21}} \qquad (5)$$

From the formula it can be seen that there are three mismatch contributions: One at each end of the coupling network (characterized by the brackets in the denominator of (5)) and one caused by direct interaction between the generator and the load. It is also seen that this direct interaction is depending on the transmission coefficients of the network. The greater the attenuation the less the interaction.

If the coupling network between the source and the load consists of more than one component there will be more contributions to the mismatch uncertainty, unless the coupling network has been measured as one component. Mismatch uncertainty at the connections between the individual components in the network.

For all network consisting of two components *A* and *B*, figure D.7.

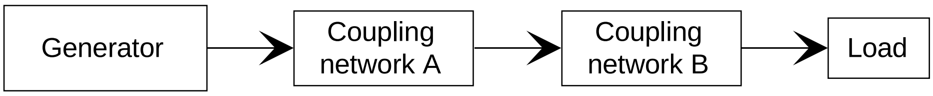


Figure D.7: Generator to load through two coupling networks

The input and output reflection coefficients are calculated using formulas (1) and (3):

$$S_{11} = a_{11} + \frac{b_{11} a_{12} a_{21}}{1-a_{22} b_{11}} \qquad (6)$$

$$S_{22} = b_{22} + \frac{a_{22} b_{12} b_{21}}{1-a_{22} b_{11}} \qquad (7)$$

and the transmission coefficients are calculated using formulas (2) and (4)

$$S_{21} = \frac{a_{21} b_{21}}{1-a_{22} b_{11}} \qquad (8)$$

$$S_{12} = \frac{a_{12} b_{12}}{1-a_{22} b_{11}} \qquad (9)$$

$$A = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} \qquad B = \begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}$$

For the purpose of calculating mismatch uncertainties the derived *S*-parameters are put into formula (5):

$$= \frac{a_{21} b_{21}}{(1-a_{22} b_{11})\left(1-\rho_G\left(a_{11}-\dfrac{b_{11} a_{12} a_{21}}{1-a_{22} b_{11}}\right)\right)\left(1-\rho_L\left(b_{22}-\dfrac{a_{22} b_{12} b_{21}}{1-a_{22} b_{11}}\right)\right)+\dfrac{\rho_G \rho_L a_{21} a_{12} b_{12} b_{21}}{1-a_{22} b_{11}}} \qquad (10)$$

From formula (10) it can be seen that there are 4 mismatch uncertainty contributions:

Mismatch uncertainty between *A* and *B*: $\pm a_{22}b_{11}$

Mismatch uncertainty at the generator: $\pm \rho_G \left(a_{11} + \frac{b_{11}a_{12}a_{21}}{1 - a_{22}b_{11}} \right)$

Mismatch uncertainty at the load: $\pm \rho_L \left(b_{22} + \frac{a_{22}b_{12}b_{21}}{1 - a_{22}b_{11}} \right)$

Mismatch uncertainty due to direct interaction between the generator and the load: $\pm \frac{\rho_G \rho_L a_{21}a_{12}b_{12}b_{21}}{1 - a_{22}b_{11}}$

In the three later cases the denominator form of 1- $a_{22}b_{11}$ can be ignored as the average is 1. Therefore it does not contribute to the mismatch uncertainty. Furthermore the two formulas with brackets consist of components which are not correlated. These components needs to be treated individually. This gives the following contributions:

Mismatch uncertainty between *A* and *B*: $\pm a_{22} \times b_{11}$

Mismatch uncertainty at the generator: $\pm \rho_G \times a_{11}$ and $\pm \rho_G \times b_{11} \times a_{12} \times a_{21}$

Mismatch uncertainty at the load: $\pm \rho_L \times b_{22}$ and $\pm \rho_L \times a_{22} \times b_{12} \times b_{21}$

Mismatch uncertainty due to the direct interaction between the generator and the load:

$\pm \rho_G \times \rho_L \times a_{12} \times a_{21} \times b_{12} \times b_{21}$

D.2 General approach

A general method for the calculation of the total mismatch uncertainty of a network consisting of any number N of components between the generator and the load is as follows:

Each individual component is characterized by its S-parameter matrix

$$Si = \begin{bmatrix} Si_{11} & Si_{12} \\ Si_{21} & Si_{22} \end{bmatrix} \rho_i \, \rho_1, \, i(n)$$

The generator reflection coefficient is $S_{(0)22}$ and the load reflection coefficient is $S_{(n+1)11}$; the mismatch uncertainty is the combination of all possible products of the form:

$\mathrm{Si}_{22} \times \mathrm{Sj}_{11} \times \mathrm{S}\,(i+1)_{12} \times \mathrm{S}\,(i+1)_{21} \times \mathrm{S}\,(i+2)_{12} \times .... \times \mathrm{S}\,(j-2)_{12} \times \mathrm{S}\,(j-2)_{21} \times \mathrm{S}\,(j-1)_{12} \times \mathrm{S}\,(j-1)_{21}$

(0 (i (n) and (1 (j (n+1) and i (j-2)

D.3 Networks comprising power combiners/splitters

In some tests power combiners/splitters are involved either to combine the signals from several signal sources or to split the signals to several detectors or measuring instruments. Under these circumstances there may be mismatch uncertainty contributions from the other branches of the splitters/divider as well as those from the branch of interest. If there is a high isolation between some of the ports, this can normally be ignored. It plays, however, a vital part where isolation between input ports is needed. (i.e. between generators to avoid third order intermodulation). Consider the network shown in figure D.8.

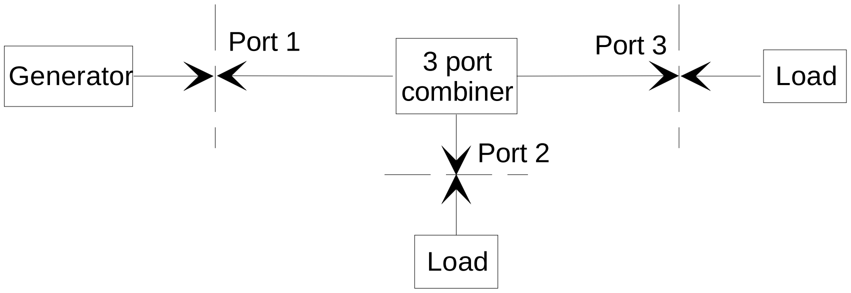


Figure D.8: Three port combiner

The 3 port combiner is characterized by the *S*-matrix $S = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix}$

Based on the general formula *B* = *S* × *A*, where:

$B = \begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix}$ where b_n is the output signal from port *n*,

$A = \begin{bmatrix} a_1 \\ a_2 \\ a_3 \end{bmatrix}$ where a_n is the input signal to port *n*, and

each port n is connected to a reflection coefficient ρ_n, the transfer function from the generator connected to port 1 to the load connected to port 3 can be derived.

For a linear and symmetrical network (where $S_{in} = S_{ni}$ for all *S*) the transfer function (formula 5) is

$$\frac{\rho_2 \times S_{12}(S_{31} \times S_{12} \times \rho_1 + S_{32}(1 - S_{11} \times \rho_1)) + S_{31}((1 - S_{11} \times \rho_1)(1 - S_{22} \times \rho_2) - S_{12}^2 \times \rho_1 \times \rho_2)}{((1 - S_{11} \times \rho_1)(1 - S_{33} \times \rho_3) - S_{13}^2 \times \rho_1 \times \rho_3)((1 - S_{11} \times \rho_1)(1 - S_{22} \times \rho_2) - S_{12}^2 \times \rho_1 \times \rho_2) - \rho_2 \times \rho_3(S_{13} \times S_{12} \times \rho_1 + S_{32}(1 - S_{11} \times \rho_1))^2}$$

As can be seen in the following the 3. port (in this case port 2) adds to the mismatch uncertainty between the generator and the load connected to port 3.

If all reflection coefficients except S_{22} and ρ_2 are 0,0 formula 5 is reduced to the following: (formula 6)

$$\frac{\rho_2 \times S_{12} \times S_{32} + S_{31}(1 - S_{22} \times \rho_2)}{(1 - S_{22} \times \rho_2)} = S_{31}\left(1 + \frac{\rho_2 \times S_{12} \times S_{32}}{S_{31}(1 - S_{22} \times \rho_2)}\right) \qquad (6)$$

If the denominator second order uncertainty is disregarded in formula 6 an additional mismatch uncertainty contribution appears: $\rho_2 \times \frac{S_{12} \times S_{32}}{S_{31}}$. As can be seen S_{22} does not directly contribute.

This mismatch component has a u-shaped distribution like the conventional mismatch uncertainty contributions. If all reflection coefficients except ρ_1 and ρ_2 are 0,0 formula 5 is reduced to the following: (formula 7)

$$\frac{\rho_2 \times S_{12}(S_{31} \times S_{12} \times \rho_1 + S_{32}) + S_{31}(1 - S_{12}^2 \times \rho_1 \times \rho_2)}{(1 - S_{12}^2 \times \rho_1 \times \rho_2)} = \frac{\rho_2 \times S_{12} \times S_{32} + S_{31}}{(1 - S_{12}^2 \times \rho_1 \times \rho_2)} = \frac{S_{31}\left(1 + \frac{\rho_2 \times S_{12} \times S_{32}}{S_{31}}\right)}{(1 - S_{12}^2 \times \rho_1 \times \rho_2)} \qquad (7)$$

In the nominator we see the term already found in formula 6. In addition to this there is a contribution from the denominator: $S_{12}^2 \times \rho_1 \times \rho_2$

In the same way if only ρ_2 and ρ_3 are different from 0,0:

$$\frac{\rho_2 \times S_{12} \times S_{32} + S_{31}}{(1 - S_{32}^2 \times \rho_2 \times \rho_3)} = \frac{S_{31}(1 + \frac{\rho_2 \times S_{12} \times S_{32}}{S_{31}})}{(1 - S_{32}^2 \times \rho_2 \times \rho_3)} \qquad (8)$$

giving the mismatch uncertainty contribution: $S_{32}^2 \times \rho_2 \times \rho_3$

From these 3 additional mismatch contributions it can be concluded that in networks comprising combiners or splitters, all other ports than the ports in the main path can contribute to the mismatch uncertainty in the main path.

If all other ports are connected to perfect terminations, they do not contribute, and the network can be regarded as one path.

If, however, the other ports (n) are connected to reflection coefficients ρ_n different from 0,0, these reflection coefficients contributes to the total reflection coefficient at both the input and the output of the combiner, thereby combining to the total mismatch uncertainty in the main path.

But in addition there is a contribution which is not the usual combination of two reflection coefficients: $\rho_n \times \frac{S_{in} \times S_{no}}{S_{io}}$,

where port *i* is the input port, port *o* is the output port, and port *n* is any of the other ports.

It contains only one reflection coefficient and some transmission coefficients. As the transmission coefficients can be very high (close to 1 or even higher if amplifiers are involved) this contribution can be dominating. It can cause much bigger mismatch uncertainty than the sum of the rest of the components, and it can cause lack of isolation between ports, where isolation is needed.

It should be noted that there are such mismatch uncertainty contributions from all ports except the two ports in the main path.

Imagine an ideal 3 port hybrid combiner with a transfer function of ∞ dB between the two input ports and 3 dB from each port to the output. If the output of the hybrid combiner is connected to a load with reflection coefficient 0,1 the **effective** isolation between the two input ports is:

$$\frac{0{,}1 \times \sqrt{2} \times \sqrt{2}}{\sqrt{2}} = 0{,}1414 \approx 17 \text{ dB}$$

Therefore the matching of the unused ports is very important. In these cases the mismatch uncertainty between the input port and the output port (e.g. port 1 to port 3 of a combiner) are then calculated as follows:

1) all the "normal" mismatch uncertainty contributions are found;

2) the reflection coefficients connected to port 2 are taken into account;

3) In addition to this there is an extra uncertainty component.

NOTE 1: This uncertainty component is not a normal mismatch component, it is calculated from: $\rho_2 \times S_{21} \times S_{32} / S_{31}$. Where ρ_2 is the reflection coefficient of the network connected to port 2 of the combiner. If a resistive combiner - for instance with an attenuation of 6 dB between the ports - is involved, this last contribution can be a dominant one if ρ_2 is big.

NOTE 2: This contribution is in the numerator of the transfer function, whereas the "normal" uncertainty contributions come from the denominator. The formula shown is consistent with the fact that if S_{31} approaches zero this uncertainty will grow to be greater than one, and the combiner will act as a reflection measuring bridge.

EXAMPLE: A 6 dB resistive combiner has a signal generator (1) connected to port 1 and a second signal generator (2) connected to port 2 (both input ports). The combiner port 3 (the output port) is connected to an EUT. The signal generator and combiner reflection coefficients are 0,2 and the EUT has a reflection coefficient of 0,8. The mismatch uncertainty is calculated as follows:

The standard uncertainty of the mismatch between the signal generator 1 and combiner input:

$$u_{j\ \text{generator 1 and combiner}} = \frac{0{,}2 \times 0{,}2 \times 100}{\sqrt{2}} \% = 2{,}828\,\%$$

The standard uncertainty of the mismatch between the combiner output and the EUT:

$$u_{j\ combiner\ and\ EUT} = \frac{0{,}2 \times 0{,}8 \times 100}{\sqrt{2}} \% = 11{,}31\,\%$$

The standard uncertainty of the mismatch between the signal generator 1 and the EUT:

$$u_{j\ generator\ 1\ and\ EUT} = \frac{0{,}2 \times 0{,}8 \times 0{,}5^2 \times 100}{\sqrt{2}} \% = 2{,}828\,\%$$

The standard uncertainty of the mismatch between the signal generator 1 and signal generator 2:

$$u_{j\ \text{generator 1 and generator 2}} = \frac{0{,}2 \times 0{,}2 \times 0{,}5^2 \times 100}{\sqrt{2}} \% = 0{,}707\,\%$$

The standard uncertainty of the mismatch between the signal generator 2 and the combiner:

$$u_{j\ \text{generator 2 and combiner}} = \frac{0{,}2 \times 0{,}2 \times 100}{\sqrt{2}} \% = 2{,}828\,\%$$

The additional component is calculated as:

$$u_{j\ \text{additional component}} = \frac{0{,}2 \times 0{,}5^2 \times 100}{0{,}5 \times \sqrt{2}} \% = 7{,}071\%$$

The combined standard uncertainty of the mismatch is:

$$\sqrt{2{,}828^2 + 11{,}31^2 + 2{,}828^2 + 0{,}707^2 + 2{,}828^2 + 2{,}828^2 + 7{,}071^2}\ \% = 14{,}50\%$$

An extreme situation would be if all the components - except the load on port 2 - were exactly 50 Ω; in this case the only mismatch component would be the additional component (7 %).

Figure D.9 shows the distribution where all reflection coefficients are 0,1 and all transfer functions are 0,5 (simulated 200 000 000 times). The standard deviation based on the simulation is found to be 3,687 1 %. The **calculated** standard deviation is 3,754 1 %. (The difference is due to that some second order components are disregarded in the calculation).

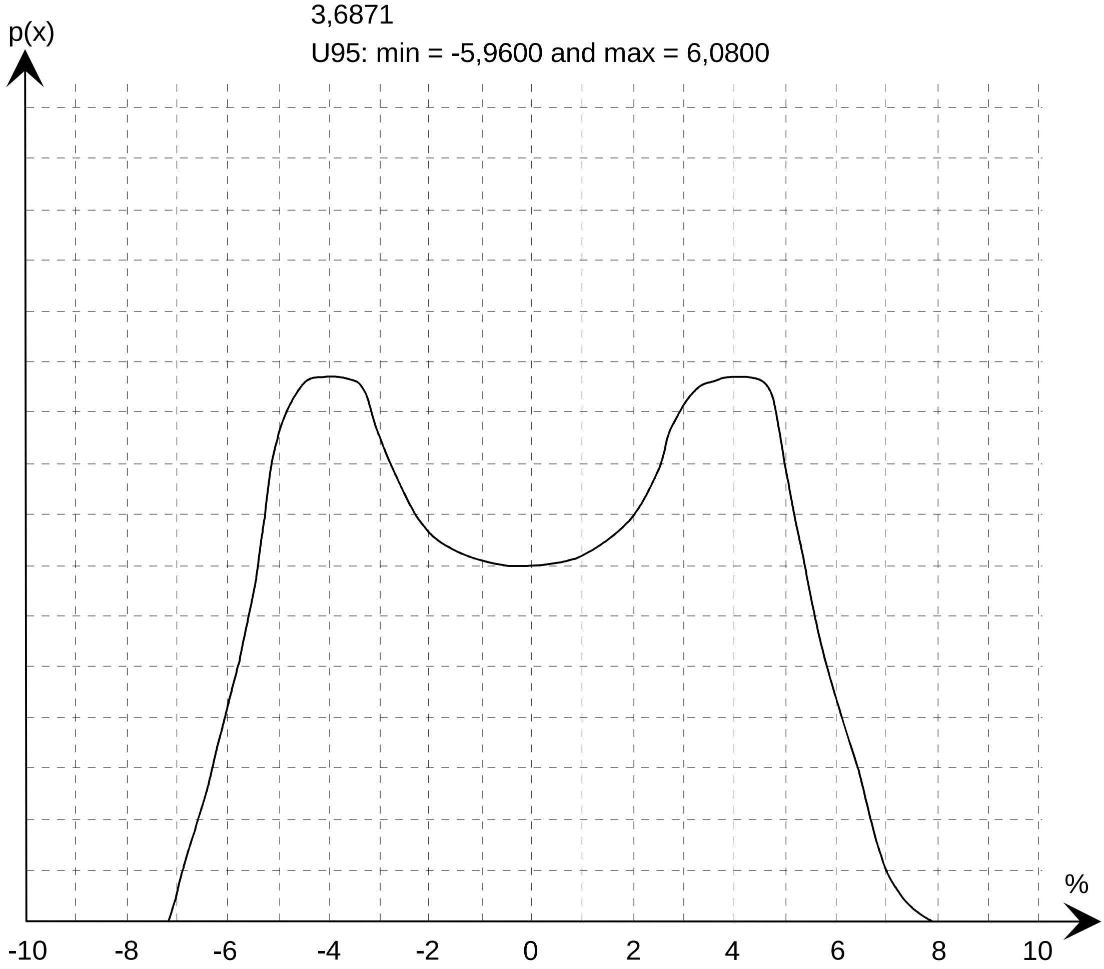


Figure D.9: Distribution from the simulation

The formulae shown are also applicable to non symmetrical networks. Instead of the squared terms the products of the transfer coefficients in both directions must be used.

Example:

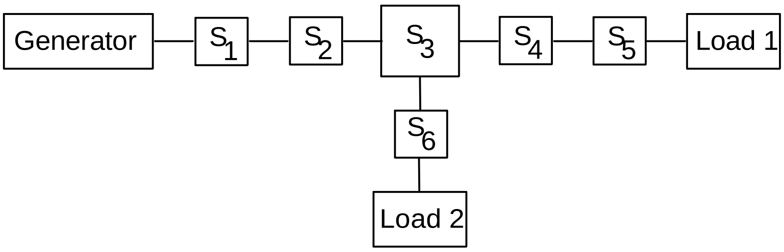


Figure D.10: Example path between the generator and load

$$S_1 = \begin{bmatrix} 0{,}050 & 0{,}79433 \\ 0{,}79433 & 0{,}050 \end{bmatrix} \qquad S_2 = \begin{bmatrix} 0{,}060 & 0{,}89125 \\ 0{,}89125 & 0{,}060 \end{bmatrix}$$

$$S_3 = \begin{bmatrix} 0{,}07 & 0{,}707095 & 0{,}70795 \\ 0{,}70795 & 0{,}07 & 0{,}70795 \\ 0{,}70795 & 0{,}70795 & 0{,}07 \end{bmatrix} \qquad S_4 = \begin{bmatrix} 0{,}080 & 1{,}0 \\ 1{,}0 & 0{,}080 \end{bmatrix}$$

$$S_5 = \begin{bmatrix} 0{,}1 & 0{,}94406 \\ 0{,}94406 & 0{,}1 \end{bmatrix} \qquad S_6 = \begin{bmatrix} 0{,}1 & 0{,}5 \\ 0{,}5 & 0{,}1 \end{bmatrix}$$

$\rho_G = 0{,}2 = S_{(0)22}$ $\rho_{L1} = 0{,}333$ $\rho_{L2} = 0{,}2$

All possible contributions are:

Contributions in the main path between

$$u_{j\ generator\ and\ input\ of\ S_1} = \frac{0{,}20 \times 0{,}05 \times 100}{\sqrt{2}}\% = 0{,}707\%$$

$$u_{j\ output\ of\ S_1\ and\ input\ of\ S_2} = \frac{0{,}05 \times 0{,}06 \times 100}{\sqrt{2}}\% = 0{,}212\%$$

$$u_{j\ output\ of\ S_2\ and\ input\ of\ S_3} = \frac{0{,}06 \times 0{,}07 \times 100}{\sqrt{2}}\% = 0{,}297\%$$

$$u_{j\ output\ of\ S_3\ and\ input\ of\ S_4} = \frac{0{,}07 \times 0{,}08 \times 100}{\sqrt{2}}\% = 0{,}396\%$$

$$u_{j\ output\ of\ S_4\ and\ input\ of\ S_5} = \frac{0{,}08 \times 0{,}10 \times 100}{\sqrt{2}}\% = 0{,}566\%$$

$$u_{j\ output\ of\ S_5\ and\ load\ 1} = \frac{0{,}10 \times 0{,}333 \times 100}{\sqrt{2}}\% = 2{,}35\%$$

$$u_{j\ generator\ and\ input\ of\ S_2} = \frac{0{,}20 \times 0{,}06 \times 0{,}794^2 \times 100}{\sqrt{2}}\% = 0{,}535\ \%$$

$$u_{j\ output\ of\ S_1\ and\ input\ of\ S_3} = \frac{0{,}05 \times 0{,}07 \times 0{,}891^2 \times 100}{\sqrt{2}}\% = 0{,}157\ \%$$

$$u_{j\ output\ of\ S_2\ and\ input\ of\ S_4} = \frac{0{,}06 \times 0{,}08 \times 0{,}708^2 \times 100}{\sqrt{2}}\% = 0{,}170\ \%$$

$$u_{j\ output\ of\ S_3\ and\ input\ of\ S_5} = \frac{0{,}07 \times 0{,}10 \times 1{,}0^2 \times 100}{\sqrt{2}}\% = 0{,}495\ \%$$

$$u_{j\ output\ of\ S_4\ and\ load\ 1} = \frac{0{,}08 \times 0{,}333 \times 0{,}944^2 \times 100}{\sqrt{2}}\% = 1{,}68\ \%$$

$$u_{j\ generator\ and\ input\ of\ S_3} = \frac{0{,}20 \times 0{,}07 \times 0{,}794^2 \times 0{,}891^2 \times 100}{\sqrt{2}}\% = 0{,}495\ \%$$

$$u_{j\ output\ of\ S_1\ and\ input\ of\ S_4} = \frac{0{,}05 \times 0{,}08 \times 0{,}891^2 \times 0{,}708^2 \times 100}{\sqrt{2}}\% = 0{,}113\ \%$$

$$u_{j\ output\ of\ S_2\ and\ input\ of\ S_5} = \frac{0{,}08 \times 0{,}10 \times 0{,}708^2 \times 1{,}0^2 \times 100}{\sqrt{2}}\% = 0{,}284\ \%$$

$$u_{j\ output\ of\ S_3\ and\ load\ 1} = \frac{0{,}07 \times 0{,}333 \times 1{,}0^2 \times 0{,}944^2 \times 100}{\sqrt{2}}\% = 1{,}47\ \%$$

$$u_{j\ generator\ and\ input\ of\ S_4} = \frac{0{,}20 \times 0{,}08 \times 0{,}794^2 \times 0{,}891^2 \times 0{,}708^2 \times 100}{\sqrt{2}}\% = 0{,}284\ \%$$

$$u_{j\ \mathit{output\ of}\ S_1\ \mathit{and\ input\ of}\ S_5} = \frac{0{,}05 \times 0{,}10 \times 0{,}891^2 \times 0{,}708^2 \times 1{,}0^2 \times 100}{\sqrt{2}}\,\% = 0{,}141\ \%$$

$$u_{j\ \mathit{output\ of}\ S_2\ \mathit{and\ load}\ 1} = \frac{0{,}06 \times 0{,}333 \times 0{,}708^2 \times 1{,}0^2 \times 0{,}944^2 \times 100}{\sqrt{2}}\,\% = 0{,}631\ \%$$

$$u_{j\ \mathit{generator\ and\ input\ of}\ S_5} = \frac{0{,}20 \times 0{,}10 \times 0{,}794^2 \times 0{,}891^2 \times 0{,}708^2 \times 1{,}0^2 \times 100}{\sqrt{2}}\,\% = 0{,}355\ \%$$

$$u_{j\ \mathit{output\ of}\ S_1\ \mathit{and\ load}\ 1} = \frac{0{,}05 \times 0{,}333 \times 0{,}891^2 \times 0{,}708^2 \times 1{,}0^2 \times 0{,}944^2 \times 100}{\sqrt{2}}\,\% = 0{,}418\ \%$$

$$u_{j\ \mathit{generator\ and\ load}\ 1} = \frac{0{,}20 \times 0{,}333 \times 0{,}794^2 \times 0{,}891^2 \times 0{,}708^2 \times 1{,}0^2 \times 0{,}944^2 \times 100}{\sqrt{2}}\,\% = 1{,}053\ \%$$

Contributions from the network connected to the 3rd port of S3:

Contributions:

$$u_{j\ \mathit{output\ of}\ S_2\ \mathit{and\ input\ of}\ S_6} = \frac{0{,}06 \times 0{,}10 \times 0{,}708^2 \times 100}{\sqrt{2}}\,\% = 0{,}212\ \%$$

$$u_{j\ \mathit{input\ of}\ S_6\ \mathit{and\ input\ of}\ S_4} = \frac{0{,}10 \times 0{,}08 \times 0{,}708^2 \times 100}{\sqrt{2}}\,\% = 0{,}284\ \%$$

$$u_{j\ \mathit{output\ of}\ S_1\ \mathit{and\ input\ of}\ S_6} = \frac{0{,}05 \times 0{,}1 \times 0{,}891^2 \times 0{,}708^2 \times 100}{\sqrt{2}}\,\% = 0{,}141\ \%$$

$$u_{j\ \mathit{output\ of}\ S_2\ \mathit{and\ load}\ 2} = \frac{0{,}06 \times 0{,}20 \times 0{,}708^2 \times 0{,}50^2 \times 100}{\sqrt{2}}\,\% = 0{,}106\ \%$$

$$u_{j\ \mathit{input\ of}\ S_6\ \mathit{and\ input\ of}\ S_5} = \frac{0{,}10 \times 0{,}10 \times 0{,}708^2 \times 1{,}0^2 \times 100}{\sqrt{2}}\,\% = 0{,}354\ \%$$

$$u_{j\ \mathit{load}\ 2\ \mathit{and\ input\ of}\ S_4} = \frac{0{,}20 \times 0{,}08 \times 0{,}50^2 \times 0{,}708^2 \times 100}{\sqrt{2}}\,\% = 0{,}142\ \%$$

$$u_{j\ \mathit{generator\ and\ input\ of}\ S_6} = \frac{0{,}20 \times 0{,}10 \times 0{,}794^2 \times 0{,}891^2 \times 0{,}708^2 \times 100}{\sqrt{2}}\,\% = 0{,}354\ \%$$

$$u_{j\ \mathit{output\ of}\ S_1\ \mathit{and\ load}\ 2} = \frac{0{,}05 \times 0{,}20 \times 0{,}891^2 \times 0{,}708^2 \times 0{,}50^2 \times 100}{\sqrt{2}}\,\% = 0{,}070\ \%$$

$$u_{j\ \mathit{input\ of}\ S_6\ \mathit{and\ load}\ 1} = \frac{0{,}10 \times 0{,}333 \times 0{,}708^2 \times 1{,}0^2 \times 0{,}944^2 \times 100}{\sqrt{2}}\,\% = 1{,}052\ \%$$

$$u_{j\ \mathit{load}\ 2\ \mathit{and\ input}\ S_5} = \frac{0{,}20 \times 0{,}10 \times 0{,}50^2 \times 0{,}708^2 \times 1{,}0^2 \times 100}{\sqrt{2}}\,\% = 0{,}177\ \%$$

$$u_{j\ \mathit{generator\ and\ load}\ 2} = \frac{0{,}20 \times 0{,}20 \times 0{,}794^2 \times 0{,}891^2 \times 0{,}708^2 \times 0{,}50^2 \times 100}{\sqrt{2}}\,\% = 0{,}177\ \%$$

$$u_{j\ \mathit{load}\ 2\ \mathit{and\ load}\ 1} = \frac{0{,}20 \times 0{,}333 \times 0{,}50^2 \times 0{,}708^2 \times 1{,}0^2 \times 0{,}944^2 \times 100}{\sqrt{2}}\,\% = 0{,}526\ \%$$

Contributions from the 3rd port:

$$u_{j\,contribution\;from\,S_6} = \frac{0{,}10 \times 0{,}708^2 \times 100}{0{,}708 \times \sqrt{2}}\% = 5{,}01\ \%$$

$$u_{j\,contribution\;from\,load\,2} = \frac{0{,}20 \times 0{,}50^2 \times 0{,}708^2 \times 100}{0{,}708 \times \sqrt{2}}\% = 2{,}50\ \%$$

The root sum of the squares of all these components is 6,90 %.

As can be seen from the calculations the major contributions to the mismatch uncertainty is from the reflection coefficients connected to the 3rd port of the network. This means that the matching of that port is of great importance to keep the uncertainty low.

Alternatively the total insertion loss and the reflection coefficients at the generator and at load 1 should be measured with S_6 and load 2 connected. This would minimize the mismatch uncertainty.

These formulations can now be applied to the actual circuits encountered during testing.

Annex E:
Antenna cabling measurements

E.1 Introduction

This is a discussion of the results of testing a vertically polarized biconic antenna over a ground plane with differing RF cable configurations.

E.2 Experimental measurements

When the antenna is vertically polarized the antenna cable lies parallel to the axis of the antenna elements and maximum coupling results. In the horizontally polarized case the cable is perpendicular to the axis of the antenna elements and minimum coupling occurs. To avoid the complication of a ground reflected wave, the tests were carried out using a monopole as a source.

E.2.1 Measurement procedure

The configurations were:

- the receive antenna RF cable hanging freely from the antenna, see figure E.1 (a);
- the RF cable running 2 m perpendicular to the axis of the elements, behind the antenna, and then allowed to hang freely from the support, see figure E.1 (b);
- the RF cable, dressed with ferrites every 15 cm, running 2 m perpendicular to the axis of the elements, behind the antenna, and then allowed to hang freely from the support, see figure E.1 (c).

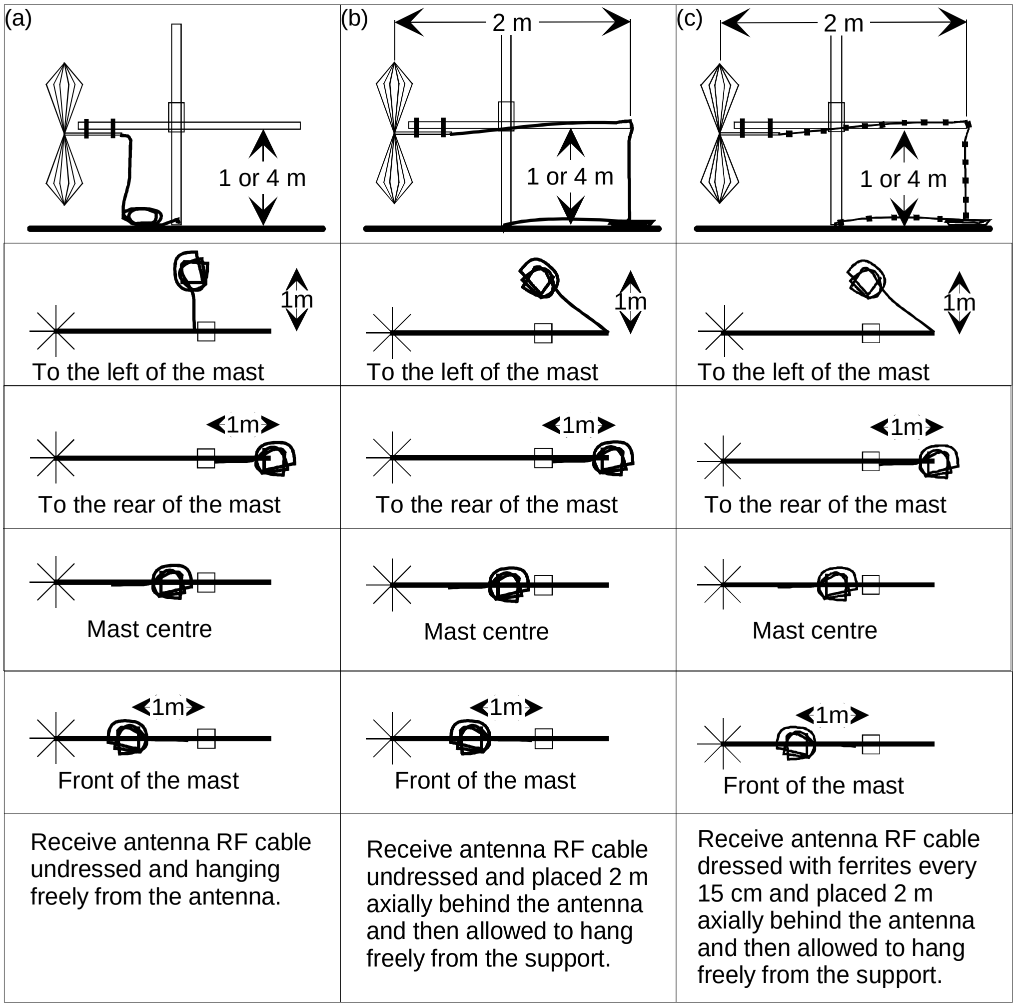
These measurements were carried out over a frequency range of 30 MHz to 300 MHz with the receiving biconic antenna at two heights on the mast, 1 and 4 m respectively.

E.2.2 Discussion of results

The overall effects are shown in figures E.2 and E.3. The graphs represent the total effect of three individual components:

- balun balance;

NOTE 1: An antenna (usually a balanced device) is normally connected to a coaxial cable (unbalanced), with or without impedance matching. However, the inner and outer conductors of the coaxial line do not couple to the antenna in the same way and a net current flows in the outer sheath, or shield, of the coaxial cable. The amount of current is determined by the shields impedance to ground, the higher the impedance the less current flow. A balun is the device that is used to transform from a balanced to an unbalanced line and can be helpful at increasing the shield impedance. The ability of the balun to match the impedance of the antenna to the coaxial line at all frequencies of interest is also critical to the relative level of the shield current. A good match gives negligible shield current whilst a bad match will increase it to significant proportions.



Receive antenna RF cable undressed and hanging freely from the antenna.

Receive antenna RF cable undressed and placed 2 m axially behind the antenna and then allowed to hang freely from the support.

Receive antenna RF cable dressed with ferrites every 15 cm and placed 2 m axially behind the antenna and then allowed to hang freely from the support.

Figure E.1: Test configurations for the cable tests

- parasitic effects of the cable.

NOTE 2: Whether the antenna is receiving or transmitting a signal, the signal will energize the free falling cable behind the antenna, which can act as a parasitic element i.e. it couples to the antenna either reflecting or directing the incident energy. Because the incident wave contains both electric and magnetic fields, mixed coupling occurs on the antenna cable. The induced voltage is very dependant on the relative orientations of the cable and the electric and magnetic fields. The antenna and parasitic element behave as coupled circuits with self and mutual impedance depending on their lengths and spacing. The phase angle of the induced shield current relative to the antenna depends on the position of the cable and on its effective length. As the major effect of this is addition and subtraction of the wanted signal brought about by the phase differences, the placement of the cable can be critical to reducing its impact on the measurement configuration. Cable positioning is only a problem when coupling can occur. If the cables are positioned correctly minimal coupling will result. The presence of the parasitic element also loads the antenna and as a result the antennas input impedance is reduced.

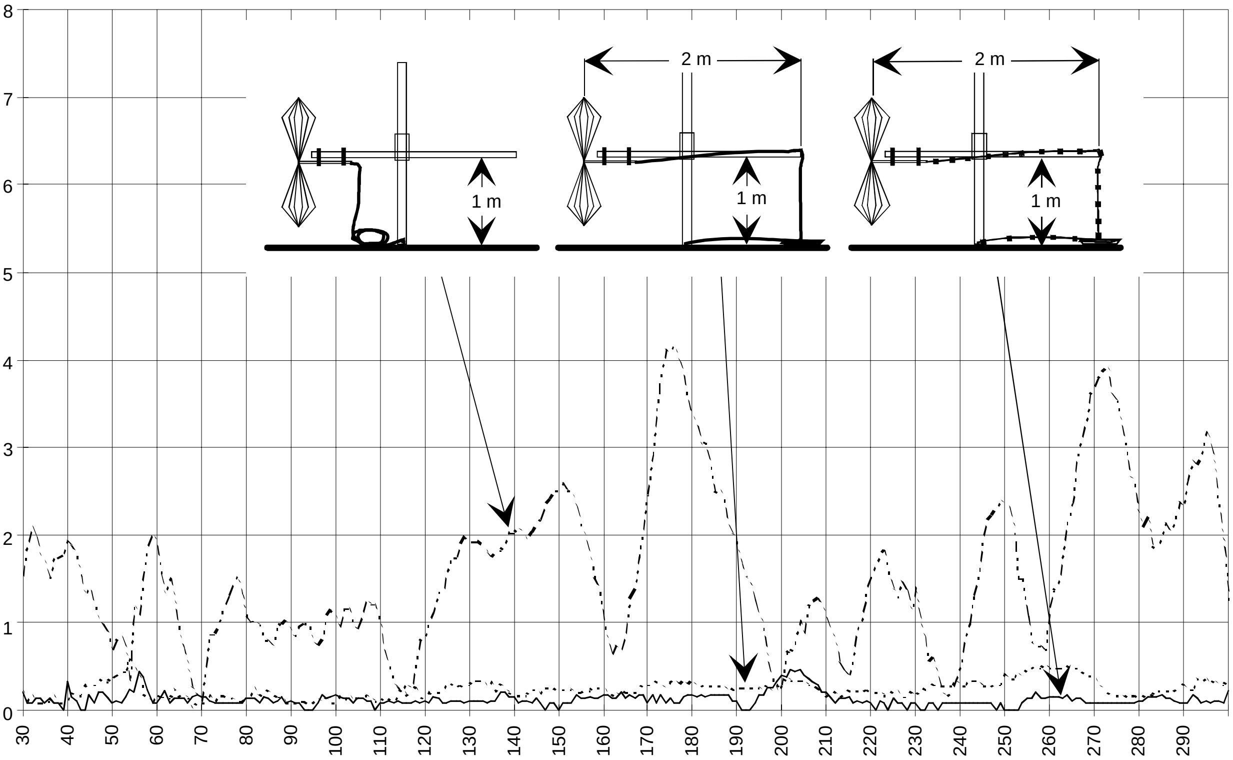


Figure E.2: Standard uncertainties of the results, antenna 1 m above the ground plane-cable leakage caused by the efficiency of the cable screening

NOTE 3: Cable leakage probably has the least effect on the measured results except in extreme cases of signal attenuation, (i.e. excessive antenna factors equivalent to losses of over 60 dB. An example of this is the antenna factor of a loop antenna at 10 Hz being in the order of 70 dB, or detecting a magnetic field by the voltage it induces which is subjected to an attenuation of 51,5 dB). If the cable screening is not sufficiently high, serious measurement errors can result.

Whilst some good results are seen with no cable routing or loading at 1 m above the ground plane, this configuration was the worst at 4 m. The standard uncertainty of the signal variation for all the cable positions varies between 0,5 dB and 7 dB, depending on the frequency and height above the ground. Taking the cable, axially, 2 m back from the antenna before allowing it to fall improves the variation in standard uncertainty to between 0,5 dB to 4 dB. Taking the cable back 2 m and placing ferrite clamps every 15 cm resulted in the standard uncertainty remaining below 0,5 dB at all frequencies and at 1 m and 4 m above the ground plane. These results are summarized in table E.1.

Table E.1: Summary of the standard deviations

Height	Free hanging	Routing 2 m	Routing 2 m & ferrites
1 m	up to 4,2 dB	up to 0,5 dB	up to 0,5 dB
4 m	up to 7 dB	up to 3,6 dB	up to 0,5 dB

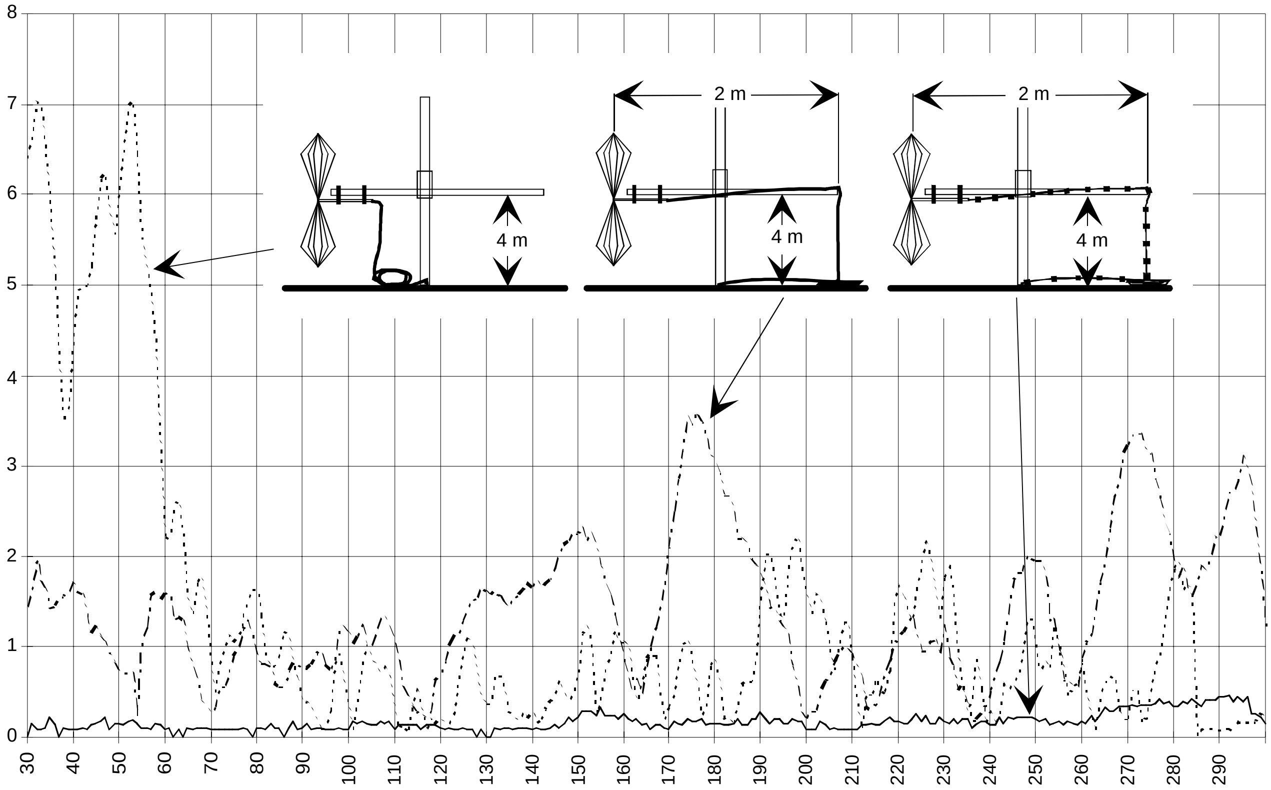


Figure E.3: standard uncertainties of the results, antenna 4 m above the ground plane

Annex F: Near-field/far-field measurements

F.1 Introduction

Initial discussions concerning the near and far-field parameters of antennas created many possible assertions about the effects on measurements. There are currently two accepted methods of determining the far-field boundary $\lambda/2$ (often used incorrectly on broadband antennas) and $2d^2/\lambda$ (which only considers the situation of a point source and a receive aperture of appreciable size). A further method which has been proposed in the present document is $2(d_1+d_2)^2/\lambda$ (which considers the situation of a source and a receive aperture both of appreciable size).

Traditionally, $\lambda/2$ is used for the far-field parameter, but was based on the fact that for the dipole $2d^2/\lambda$ gives $\lambda/2$ for a half wavelength tuned dipole.

$$\frac{2d^2}{\lambda} \text{ and when } d = \frac{\lambda}{2} \qquad \frac{2\left(\frac{\lambda}{2}\right)^2}{\lambda} = \frac{2\left(\frac{\lambda^2}{4}\right)}{\lambda} = \frac{\lambda}{2}$$

A graphical representation of the problem that results in having three definitions is shown in figure F.1 for the example of a bicone of length 1,315 m approximately over a 3 m range.

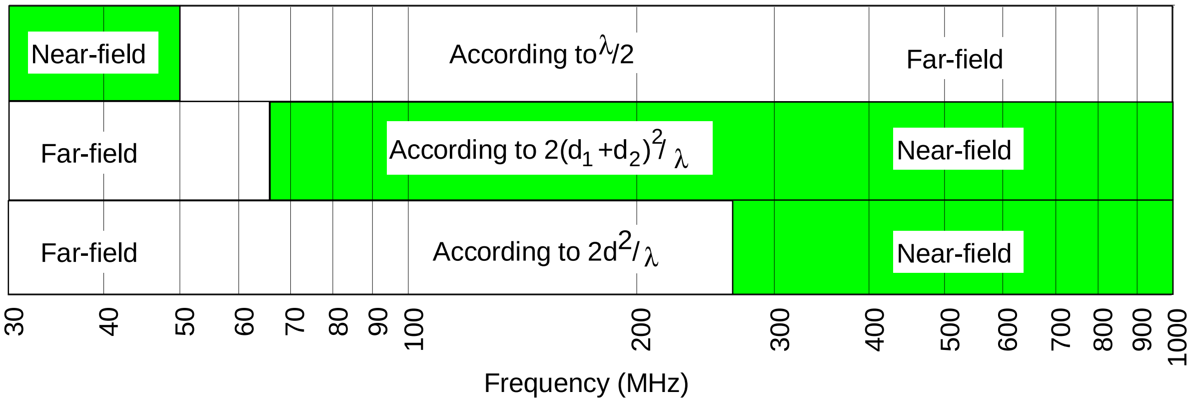


Figure F.1: Comparison of formula for "far-field" conditions for the measurement between two 1,315 m bicones (3 m range length)

The unshaded areas in figure F.1 reveal the far-field distance for the three formulas. As can be seen they are completely different:

- $\lambda/2$ (this abbreviated form takes no account of structure size) determines all measurements below 50 MHz are in the near-field and all measurements above 50 MHz are in the far-field. This is exactly the opposite of the other two determinations;
- $2d^2/\lambda$ determines all measurements below 260 MHz are in the far-field and all measurements above 260 MHz are in the near-field;
- $2(d_1+d_2)^2/\lambda$ determines all measurements below 65 MHz are in the far-field and all measurements above 65 MHz are in the near-field.

F.2 Experimental measurements

A series of measurements were carried out to try to determine the appropriate formula to use to calculate the far-field condition. These tests are outlined below.

F.3 Measurement procedure

Using an Anechoic Chamber, two biconic antennas were mounted, one on the turntable and one mounted on the mast, as shown in figure F.2. The range length between the bicones was set to 0,6 m between the axis of the antenna (this is the axis perpendicular to the central axis of the chamber), and a frequency sweep was made from 30 MHz to 300 MHz using a 1 MHz step size. At each frequency the received level was recorded.

The range length between the bicones was increased in 0,1 m steps and the frequency sweep was repeated, recording the received level at each frequency. This procedure was repeated until the range length was 3,0 m. A graph of all the results (received level and frequency) is shown in figure F.3.

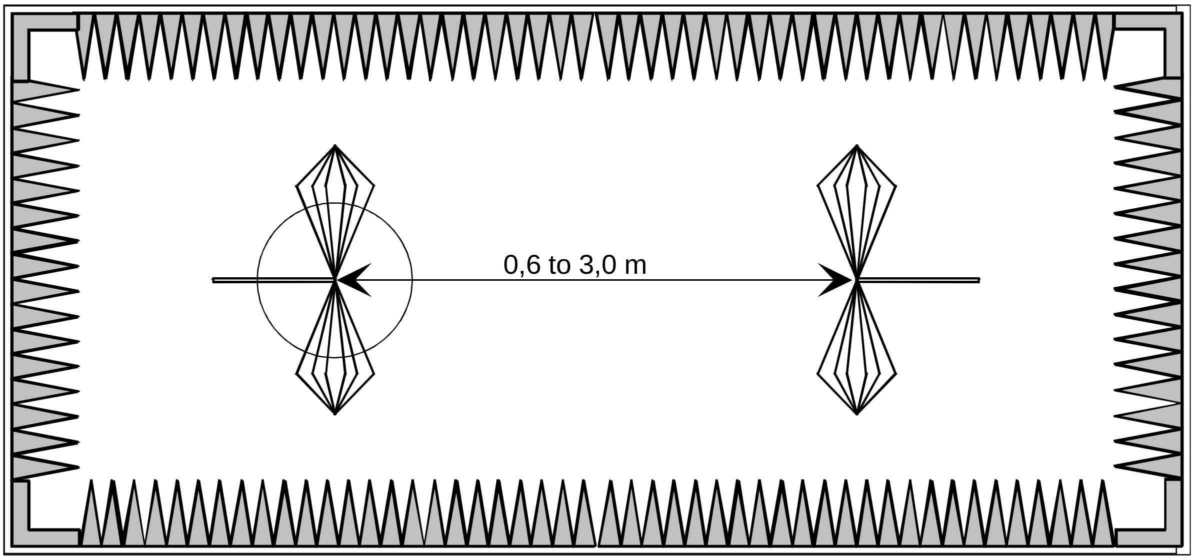


Figure F.2: Measurement set-up

F.4 Discussion of results

Figure F.3 is a plot of the received signal level without any corrections for antenna factor, hence the general shape of the graph. Each plot represents the received level at a given separation, the separations incrementing from 0,6 m (generally the highest received level) to 3,0 m (generally the lowest received level).

Figure F.4 is a plot of those parts of the plots of received level (see figure F.3) that fall within the criteria of $2\,(d_1+d_2)^2/\lambda$ and are therefore all in the far-field.

Different subsets of the same data are used to obtain the standard uncertainty. As can be seen, the only qualifying measurements lie between 30 MHz and 65 MHz and range lengths of 1,4 m to 3,0 m. Some 316 data points are shown and these have been compared to the theoretical received levels and standard deviations calculated. The same calculation has been performed for the other formulations of far-field and the results are tabulated in table F.1. It can be seen that the fit of $2(d_1+d_2)^2/\lambda$ (maximum 0,25 dB) is very much lower than $2d^2/\lambda$ for which 809 data points have been used. At first glance the $\lambda/2$ formulation seems reasonable but only 54 data points qualified and the result is not considered representative.

Table F.1: Comparison of formula

Formula:	**$2(d_1+d_2)^2/\lambda$**	**$2d^2/\lambda$**	**$\lambda/2$**
Standard uncertainty	0,247 dB	1,39 dB	0,38 dB
Expanded uncertainty (U_{95})	0,484 dB	2,72 dB	0,74 dB
NOTE: Different, but overlaying, subsets of the same data (i.e. that displayed in figure F.3) have been used to obtain standard uncertainties.			

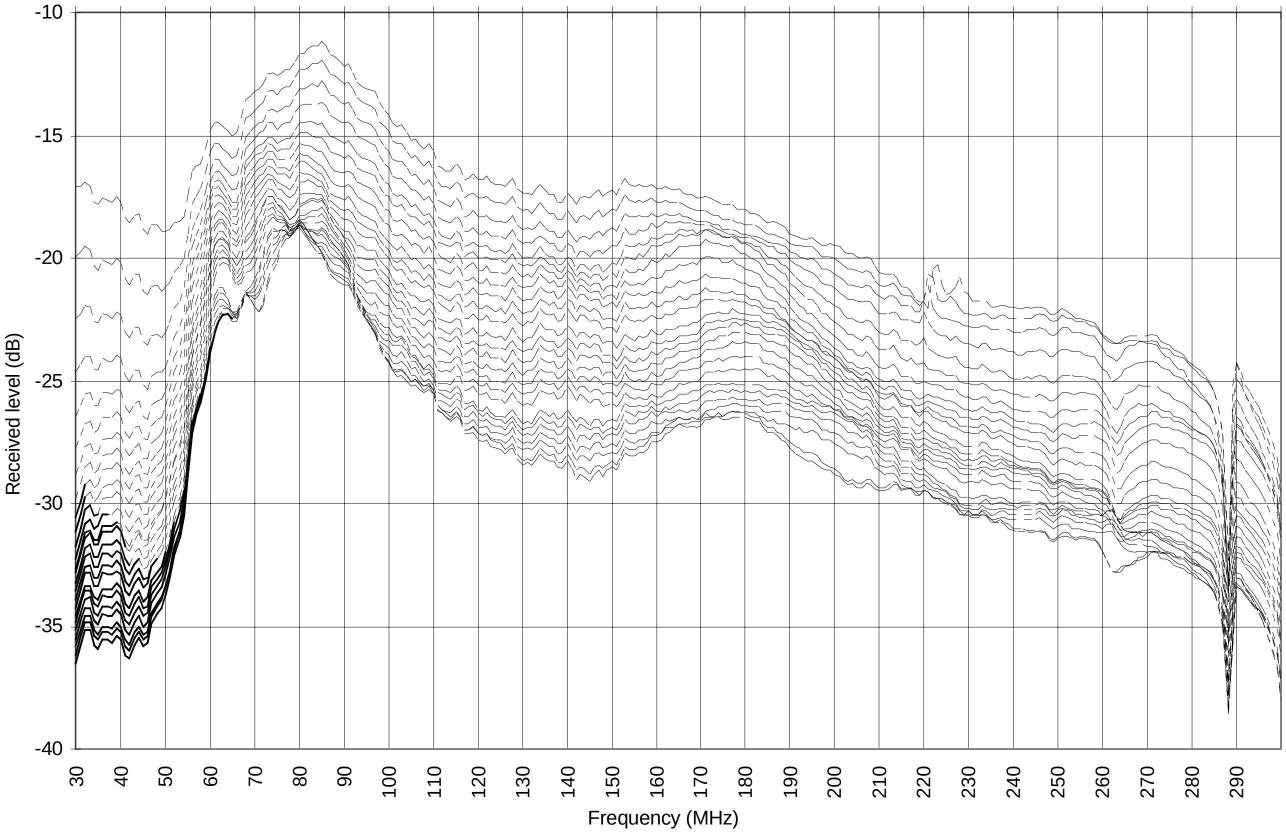


Figure F.3: Received level 0,6 m to 3,0 m in 0,1 m steps

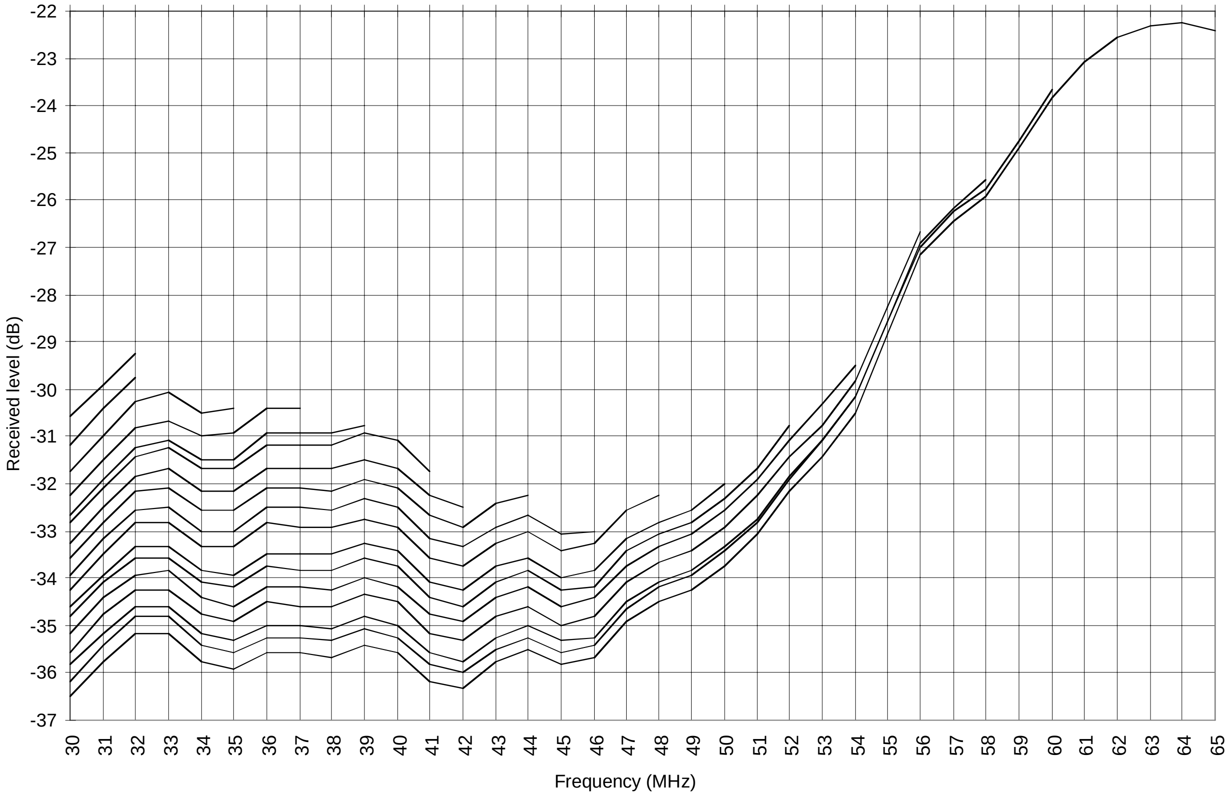


Figure F.4: received levels that fall within the criteria of $2(d_1+d_2)^2/\lambda$

Annex G: Bibliography

- "Advanced National certificate mathematics", PEDOE, Hodder and Stoughton Volumes I and II, 1978.
- "Analysis of trials on Artificial Human Body", I. L. Gallan and P. R. Brown Interference technology international consultants ltd. Contract ref. MC/078.
- "Vocabulary of metrology" British Standard Institution (BSI): PD 6461: Part 2: September 1980. (English and French).
- "Calculation of site attenuation from antenna factors" A. A. Smith Jr, RF German and J B Pate. IEEE transactions EMC. Vol. EMC 24 pp 301-316 Aug 1982.
- "Specifications for equipment's for use in the Land Mobile Service", CEPT Recommendation T/R 24-01.
- "Chambers Science and Technology dictionary" 1988. Published by Chambers Cambridge.
- "Computer simulation and measurements of electromagnetic fields close to phantom Humans", Electricity and magnetism in biology and medicine by Martin Blank, Ed 1993 San Francisco Press.
- "Getting better results from an Open Area Test Site", Joseph DeMarinus.
- "Fundamentals of RF and Microwave Power Measurements". Hewlett Packard: Application note 64-1: August 1977.
- "Techniques for measuring narrowband and broadband EMI signals using spectrum analysers". Hewlett Packard RF and microwave measurement symposium and exhibition.
- "A designers guide to shielding". Hewlett Packard: RF and microwave measurement symposium and exhibition.
- "Digital Communications", John G. Proakis, McGraw-Hill International Editions, second edition.
- "Guide to the evaluation and expression of the uncertainties associated with the results of electrical measurements", Ministry of Defence: 00-26/Issue 2: September 1988.
- "The expression of uncertainty in electrical measurement". National Measurement Accreditation Service (NAMAS) B3003 November 1987.
- "Uncertainties of Measurement for NATLAS electrical testing laboratories. NAMAS policy and general notes", National Testing Laboratory Accreditation Scheme (NATLAS): NIS20 July 1986.
- "Usikkerhed på måleresultater", Per Bennich, Institut for Produktudvikling: (Per Bennich, Institute for Product Development: "Uncertainty of measured results"). October 1988. (Danish).
- "Radiowave propagation and antennas for personal communications" K. Siwiak, Artech House Publications.
- "Standard site method for determining antenna factors" A. A. Smith Jr. IEEE transactions EMC. Vol. EMC 24 pp 316-322 Aug 1982.
- "Measurement uncertainty generally", Statens Tekniske Prøvenævn (STP): "- generelt" (The Danish Accreditation Committee). June 1988 (Danish).
- "The telecommunications factbook and illustrated dictionary", Kahn, Delmar publications Inc. New York 1992.
- "Use of Simulated Human Bodies in pager receiver sensitivity measurements", K. Siwiak and W. Elliott III. Southcom /92 conference, Orlando 1992. pp 189/92.

History

Document history		
Edition 1	February 1998	Publication as ETR 273-1-2
V1.2.1	December 2001	Publication