ECC Recommendation (12)03

Determination of the radiated power through field strength measurements in the frequency range from 400 MHz to 6000 MHz

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INTRODUCTION

The radiated power of a transmitter is one of the most important parameters which characterise a transmitter and its emissions. Usually it is not possible to measure the radiated power directly. However, there are two different methods to determine the radiated power indirectly. The first method would measure the transmitter output power and calculate the radiated power by taking into account cable losses and antenna gain (equivalent to an isotropic radiator). The second method measures the field strength and calculates the radiated power by taking into account the measurement distance and the propagation loss.

The purpose of this Recommendation is to provide a common measurement method which will enable CEPT administrations to determine the radiated power of a transmitter in the frequency range from 400 MHz to 6000 MHz from field strength measurements reducing as much as possible the uncertainty of the measurement.

ECC RECOMMENDATION (12)03 OF FEBRUARY 2013 ON DETERMINATION OF RADIATED POWER THROUGH FIELD STRENGTH MEASUREMENTS IN THE FREQUENCY RANGE FROM 400 MHz TO 6000 MHz

"The European Conference of Postal and Telecommunications Administrations,

considering

a) that the limitation of the radiated power of a transmitter is essential for the limitation of co-channel re-use distances and for interference mitigation in neighboring channels,

b) that radiated power is one of the parameters which is specified in authorisations,

c) that the verification of radio stations emissions for compliance with the authorisation conditions is an important task of the radio monitoring or inspection services,

d) that radiated power determination through measurements at the transmitter output are often impossible due to access problems or lacking test output,

e) that these measurements can be substituted by field strength measurements with subsequent conversion to radiated power under certain conditions,

f) that a radiated power determination through measurement at the transmitter output generally can only be done with the agreement and thus with the knowing about measurement activities of the operator or the operating company,

g) that the radiated power of some systems may vary in relation with many parameters such as traffic load of the network and/or downlink power control,

recommends

that the measurement method described in Annex 1 should be used to determine the radiated power of a transmitter based on field strength measurements in the frequency range from 400 MHz to 6000 MHz."

ANNEX 1: RADIATED POWER DETERMINATION BASED ON FIELD STRENGTH MEASUREMENTS IN THE FREQUENCY RANGE FROM 400 MHz TO 6000 MHz

A.1.1 INTRODUCTION

Field strength measurements are one of the basic tasks of all radio monitoring services. It is feasible to measure the field strength at a single location in the electromagnetic field but due to reflections and other propagation effects, the measured values may change extremely from one measurement location to the next. The following measurement method describes how these effects can be handled in order to retrieve reliable field strength values which may be used for the determination of the radiated power of a transmitter.

A.1.2 SCOPE OF APPLICATION AND LIMITATIONS

The measurement method relies on the correction of the influence of possible ground reflections from information gained through a height scan of the field strength at the location of reception which allows estimating the effective reflection coefficient. This method is basically frequency independent. However, there are many cautions to take into account in order to reduce external influence factors which may lead to errors in the measurement process.

The suggested measurement method loses accuracy for frequencies below 400 MHz because the height accessible by customary measurement antennas (10 m) will not be sufficient to capture both a maximum and a minimum of the field strength distribution.

Above about 3000 MHz the application of this method may be difficult because the maximum and the next minimum is very closely neighboured due to the small wavelength of the signal.

There are, however, even more constraints with regard to the applicability of the method. Field strength measurements have to be performed in the far field. The far field is usually defined as the range from $2D^2/\lambda$ to ∞ with D being the largest dimension of the transmitting antenna. If D=1 m (typical base station antenna) and λ=0.1 m (3 GHz) the measurement distance between the transmitter and the receiving antenna has to be at least 20 m.

It has further to be taken into account that the actual location where the effective ground reflection occurs is different for different heights of the measurement antenna. A valid estimate of the reflection coefficient from a field strength height scan can thus be obtained under the provision only that locations of reflection for the “maximum” and the “minimum” reflection nearly coincide. This condition is more easily achieved with higher frequencies and closer measurement distances. In contrast, in the case of typical high power broadcast transmitters, large transmitting antenna heights are prevailing. In addition, the radiation is confined to a vertically narrow lobe which meets the ground at distances of several kilometres from the transmitter only. This forces the measurements to be done at large distances from the transmitter and locations of reflections may be 50 or 100 metres apart under these circumstances.

The measurement method assumes free space propagation, i.e. a 20 dB path loss per decade of distance. Hence the method loses accuracy if this condition is not fulfilled, e.g. at larger measurement distances.

Finally it should be mentioned that measurement errors due to the aforementioned effects usually result in undervalued field strength or radiated power levels and not in increased levels.

This procedure may not be suitable for systems using advanced radio technology as such dynamic beam forming.

Moreover, it is crucial to perform a spectrum overview at the measurement location in order to avoid overloading the measurement chain and to take into account power contributions from different sources.

A.1.3 TERMS, DEFINITIONS, ABBREVIATIONS AND SYMBOLS

Table 1: Abbreviations

Abbreviation	Explanation
D	Largest dimension of the transmitting antenna
E	Field strength
e.i.r.p.	The equivalent isotropically radiated power of an antenna is the product of the antenna input power and the antenna gain, referenced to an isotropically radiating antenna
GNSS	Global Navigation Satellite System
GSM	Groupe Speciale Mobile (original) or Global Specification for Mobile
RLAN	Radio Local Area Networks
RMS	Root Mean Square which is the effective value
TDMA	Time Division Multiple Access
UMTS	Universal Mobile Telecommunications System
∞	Infinity

A.1.4 CONVERSION FROM RECEIVER INPUT LEVEL TO FIELD STRENGTH

The field strength E is generally calculated from RF level measurements. The subsequent sections assume that field strengths are measured in the far field region under free space conditions using receiving antennas with known antenna factors, cables with known losses, with adequate receiver bandwidth and sufficient signal to noise ratio. The formulas further assume an antenna load resistance of 50 Ω.

Measuring and calculating radiated power with a specific reference antenna is performed as follows:

$$P_{rad} = P_{TX}.G_{TX} = \frac{P_{RX}.R^2.16\pi^2}{G_{RX}.\lambda^2}$$ where

P_{rad} = effective radiated power in W relative to a specific reference antenna
P_{tx} = transmitter output in W
G_{tx} = transmit antenna gain relative to a specific reference antenna
G_{rx} = receive antenna gain relative to a specific reference antenna
R = distance in m

If the antenna gain G_{RX} is referenced to an isotropic antenna, P_{rad} equals e.i.r.p. In logarithmic form the e.i.r.p. is calculated as follows:

$$e.i.r.p. = E + 20\log R - 134.8$$ where

e.i.r.p. = effective radiated power in dBW relative to an isotropic antenna
E = field strength in dBμV/m

Recommendation ITU-R P.525-2 [1] as well as sections 6.3 and 6.4 of the ITU Handbook on Spectrum Monitoring [2] may be consulted for more detailed explanations on the calculation of free-space attenuation and conversion formulae. Correct level measurement of digital signals and field strength measurements are specified in sections 4.3 and 4.4 of the ITU Handbook on Spectrum Monitoring [2]. Additional information on field strength measurements can also be found in Recommendation ERC/REC 74-02 [3] and Recommendation ITU-R SM.378-7 [4].

A.1.5 THE IMPACT OF GROUND REFLECTIONS

Reflections have a substantial influence on field strength measurements. In extreme cases, they may cause the total elimination of the signal or amplification by 6 dB depending on the amplitude and phase difference between direct and reflected wave. Field strength measurements for the calculation of radiated power assume a direct line-of-sight position of the receiving antenna to the transmitter and an unobstructed propagation path with no objects causing considerable reflections in the vicinity. However, ground reflections will always be present and have necessarily to be taken into account when the radiated power of a transmitter is calculated from the measured field strength.

Ground reflections can be detected by varying the antenna height h. Considerable ground reflections exist if at least one sharp minimum and one maximum of the measured field strength can be detected. This effect occurs more distinctive with horizontally polarized signals. An example of the dependency of the field strength on height is shown in Figure 1.

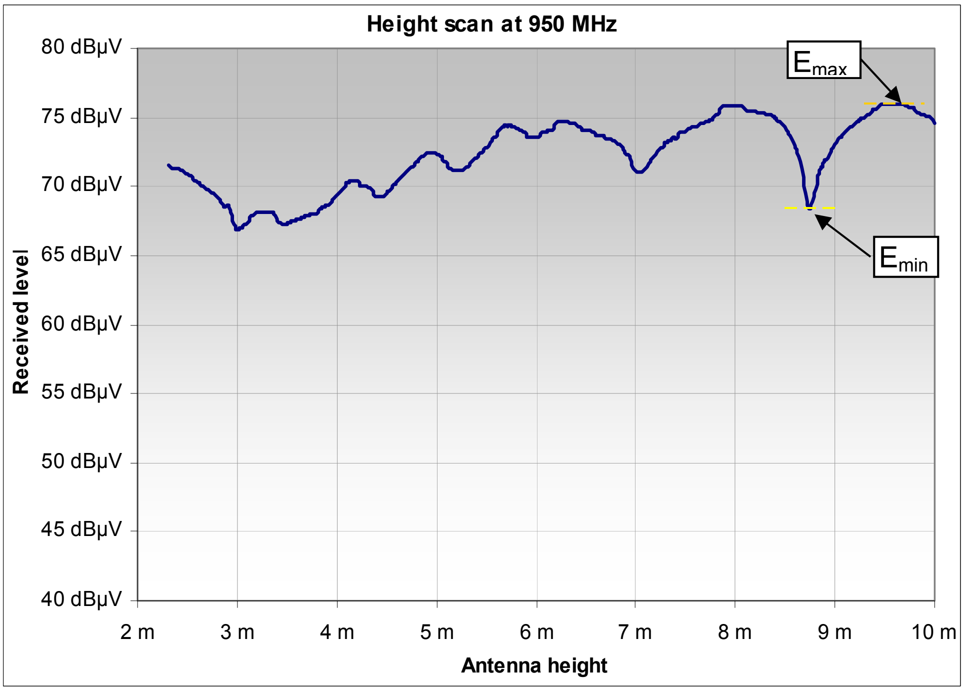

Figure 1: Example of the dependency of the measured field strength on measurement antenna height

For the elimination of effects due to ground reflections a correction value n_k has to be applied (see figure 2). It can be determined from the difference between the maximum field strength and the adjacent minimum field strength.

$$\Delta E = E_{\max} - E_{mim}$$

$$n_k = 20\log\left(\frac{1+10^{-\left(\frac{\Delta E}{20}\right)}}{2}\right)$$

with ΔE, E_{max} and E_{min} in dBµV/m. The result can also be taken from Figure 2.

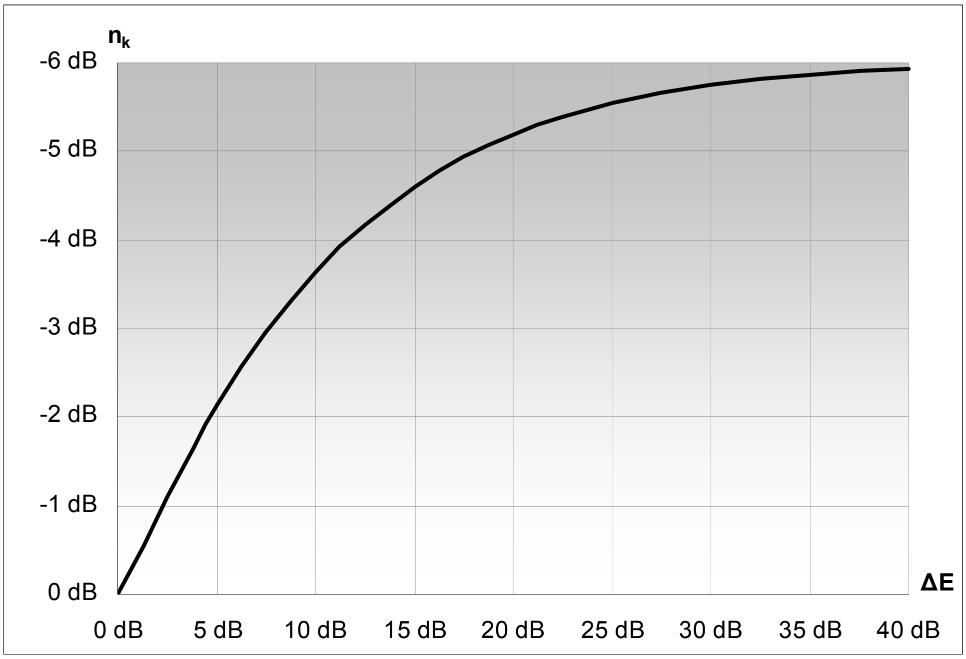

Figure 2: Correction curve for n_k

The free space field strength value E is determined by the following formula:

$$E = E_{\max} + n_k$$

A.1.6 MEASUREMENT PROCEDURE

The measurement procedure works as follows:

1. Inspect the installation
   The field strength measurement requires that the monitoring antenna can be positioned in the main lobe of the transmitter and that the area between transmitter and monitoring antenna is unobstructed. Height, directivity and down tilt of the transmitter antenna have to be determined.

2. Calculate at which distance the main lobe reaches 10 m above ground
   This is usually done with the help of an electronic map that includes terrain height or field strength prognosis tools. Alternatively, the measurement car can search the area in question until maximum field strength is reached. This is one of the key elements which allow defining the minimum distance between the transmitter and the measurement location.

3. Search a suitable measurement location
   The measurement location within the area determined in step 2 must have a line of sight to the transmitter. The measurement conditions applicable for field strength measurements as outlined in the relevant documents mentioned in section A.1.4 have also to be fulfilled. If directional transmit antennas are used, the monitoring antenna has to be placed in the direction of the main lobe. The distance will usually be in the range of one to several hundred meters so that far field conditions apply.

Measure the field strength at the predetermined location
Ensure that there are no other transmitters that are in close proximity or close in frequency that can impact the measurement. Using a directional measurement antenna mounted on a retractable mast on the measurement vehicle, first at roof height, to measure the field strength of the transmitter. Usually the measurement has to be done with an RMS detector. For continuous emissions, the measurement time has to be long enough to equalize any changes due to traffic or propagation. For pulsed

emissions (TDMA systems like RLAN), the average burst power has to be measured (this is the RMS power during the burst only). Some specific systems such as analogue TV require the use of the Peak detector.

The measurement bandwidth should be equal to or higher than the occupied bandwidth of the signal under investigation. The polarisation of the measurement antenna should be the same as used by the transmitter. In case of cross-polarized transmitter antennas the polarisation of the measurement antenna is not relevant. In this case, special care should be taken as in some situations the cross polarisation is used to transmit two different signals and both polarisations have to be addressed separately. Further details regarding field strength measurements may be found in section 4.4 of the ITU Handbook Spectrum Monitoring [2].

The field strength can be calculated using the antenna factor of the monitoring antenna (field strength = receive level + antenna factor).

4. Search for the location with the highest field strength
   The location with the highest field strength is searched by moving the measurement vehicle a few meters back and forth. This is done to ensure that possible reflections at the measurement location do not have significant influence in cancelling out with the direct wave. Once a local maximum is found it is necessary to ensure there are no powerful echo signals from buildings or signals from other transmitters operating on the same frequency. To do this, the receiving directional antenna mounted at a height of 10 meters is rotated in a horizontal plane. If a local maximum of the echo signal does not exceed -15 dB compared to the direct ray, the individual contribution of one scattered ray to the overall power level of the beam will not exceed 0.2 dB.

5. Determine the minimum height of the receiving antenna
   According to Recommendation ITU-R R.526 [5] line-of-sight (LoS) propagation is assumed, i.e. diffraction is negligible, if there is no obstacle within the first Fresnel ellipsoid. In order to ensure the validity of the formula in section A.1.4., the clearance of the first Fresnel ellipsoid has to be ensured. If you reduce the height of the receiving antenna even the Earth's surface may become an obstacle (see Figure 3).

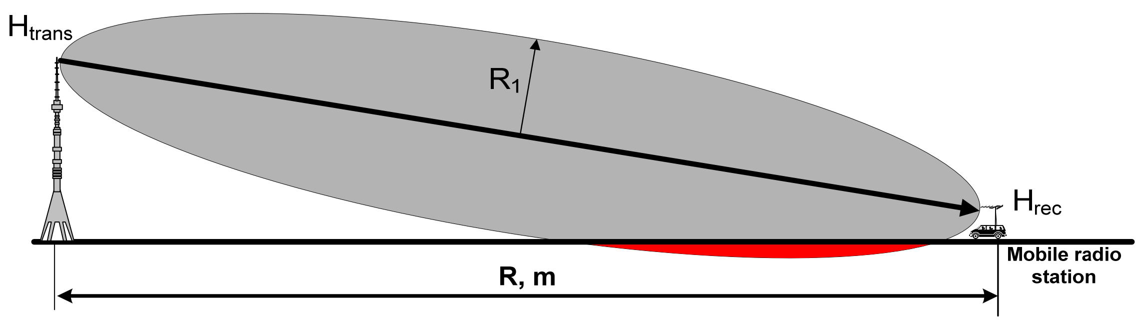

Figure 3: The first Fresnel zone and the effect of the Earth's surface to the direct ray

The minimum height of the receiving antenna is determined by using digital maps. In the case of quasi-plane earth's surface minimum height H_{rec} receiving antenna must satisfy the condition:

$$H_{rec} \geq 75 * R / (f * H_{trans}),$$

where:

f	= center measuring frequency in MHz;
H_{trans}	= height of the transmitting antenna in meter;
H_{rec}	= height of the measurement antenna in meter;
R	= separation distance between the transmitter and the receiver in meter.

Example: If the setup has the following settings: H_{trans} = 20 m, f = 500 MHz, R = 400 meters, the minimum height of the receiving antenna will be 3 meters. With R = 600 meters, H_{trans} is already - 4.5 meters.

6. Perform a height scan
This is done by permanently recording the receive field strength while the mast rises from minimum height defined in item 5 (or from car roof level) to 10 m above ground. The path difference of the direct and the reflected signals varies if the height of the receiving antenna is changed. The height difference between two adjacent peaks of the signal is approximately given by:

$$\Delta h = (\lambda * R) / (2 * H_{trans}).$$

λ = wavelength in meter;
H_{trans} = height of the transmitting antenna in meter;
Δh = height difference between two adjacent peaks in meter;
R = separation distance between the transmitter and the receiver in meter.

The result can also be taken from Figure 4.

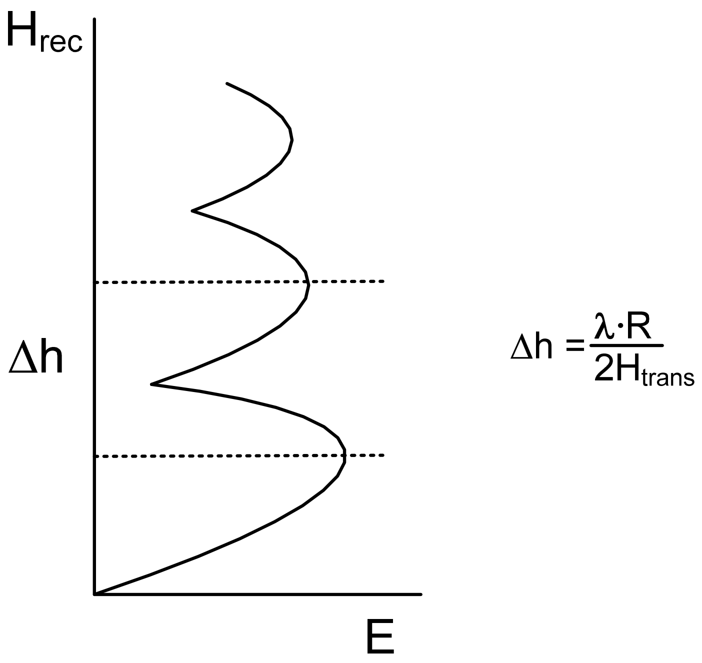

Figure 4: The change of the field strength at change of height of the receiving antenna

To accurately determine the minimum and maximum of the received signal it is necessary to conduct the height scan with incremental steps of S << Δh, e.g.

$$S = \Delta h/10 = (\lambda * R) / (20 * H_{trans})$$

Example: λ = 0.1 m (f = 3 GHz), R = 500 m, H_{trans} = 50 m results in S = (0.1 * 500) / (20 * 50) = 0.05 m.

7. Determine the maximum field strength from the height scan
The maximum field strength is designated as E_{max}. Depending on reflections, especially from the ground, E_{max} must not necessarily be at the maximum antenna height.

8. Determine the minimum field strength adjacent to the maximum field strength identified in Step 7
This local minimum is hereafter designated E_{min}. It is not the overall minimum of the complete height scan, but the minimum just next to the predetermined E_{max}. See also figure 1.

9. Calculate the final magnitude of the field strength
The final magnitude of E is determined according to section A.1.5. This cancels out the effect of the ground reflections that may have influenced the measurement result.

10. Calculate the radiated power.
The radiated power is calculated by using the free space propagation formula according to section A.1.4 from the measured field strength E and the measurement distance R.

11. Calculate and report the measurement uncertainty
Methods used to calculate the uncertainty from the experimental observation and input data should be clearly described. All the uncertainty components and their assessment should be listed and documented.

A.1.7 MEASUREMENT EQUIPMENT

A laser distance measuring device, a GNSS receiver, binoculars and a compass are usable tools for the visual inspection of the transmitter and the determination of the antenna height.

For the field strength measurement of many types of emissions a spectrum analyzer or measurement receiver may be used.

A.1.8 CONTRIBUTION OF THE ENVIRONMENT TO THE MEASUREMENT UNCERTAINTY

The described method assumes that the main contributor to the measurement uncertainty is caused by reflections, this is usually the case. Reflections from distant objects may be minimised by using a measurement antenna with high directivity or determining a horizontal field strength profile in addition to the vertical height scan as given in section A.1.6.

The accuracy of this method depends mainly on the local circumstances in between the transmitter to be tested and the measurement location. The accuracy of this method depends mainly on the local circumstances in between the transmitter to be tested and the measurement location. The following example may give an impression. Several 1000 measurements at base stations of mobile phone operators and verifications using test transmitters with known parameters have shown a maximum measurement uncertainty of 3 dB.

It is possible to verify the contribution of the spectrum environment (such as the impact of reflexions) on the error of the measurement. If the location of the transmitter antenna (roof, mast) is accessible, the general principle outlined as follows may be applied: A test transmitter with known parameters (power, antenna gain) is installed close to the antenna, operating on a free frequency close to the frequency of the transmitter to be measured. A height scan of the test transmitter at the predetermined measurement location is performed and its radiated power is calculated using the method described in this document. By comparing the result with the known true radiated power of the test transmitter the additional measurement error for the particular radio path can be determined. The calculated power of the transmitter to be measured can then be corrected by the magnitude of the error. Environmental effects may be assumed to be “zeroed out” this way. It should be noted that also this method may introduce uncertainties in the measurement result. For example, the used antenna may not be identical and the frequency is slightly different from those of the transmitter to be measured. The more such parameters are close to those of the transmitter to be measured, the more the uncertainty is negligible.

A.1.9 MEASUREMENT UNCERTAINTY CALCULATION

To ensure the reliability of the measurement, the uncertainty should be calculated. Keeping the previous chapter in mind a single calculation for the specific test set used is sufficient in many cases. This is called the typical measurement uncertainty of the test set.

Typical measurement uncertainty
For determining the typical measurement uncertainty all uncertainty sources that are normally present in the measurement system and during the measurement are identified and estimated and an overall uncertainty calculation is made. A typical measurement uncertainty between 1.5 dB and 2.5 dB for a 95% confidence interval can be considered a good achievement for a field strength measurement system but can only be achieved when all main contributing error sources are minimized and when the measurement is conducted very precisely.

Actual measurement uncertainty
For measurements where the procedure in A.1.8 cannot be applied completely, an individual measurement uncertainty calculation must be made, taking specific circumstances as they occur during the actual measurements into account. A good way to do this is to start with the typical measurement accuracy calculation examining all values in that calculation and correcting them for the specific circumstances that occurred during the measurement. An analysis of the measurement data in the height and horizontal profiles gives important input to this process. The value calculated this way is called the actual measurement uncertainty, and is unique for every measurement. This figure has to be mentioned in the measurement report, not the typical value.

Methodology
The measurement uncertainty calculation should be performed and presented conforming to applicable international standards, e.g. ISO “Guide to the Expression of Uncertainty in Measurements” [7]. When using this method, each measurement is described first, followed by the mathematical formula with which the end result is calculated from the individual variables involved. Then all these variables are described with their uncertainties and their weighting factors of their influence on the final result is established. When the source variables are expressed logarithmically, they first have to be converted to linear values. With this information, the uncertainty of the end result is calculated and is presented in the standardised form. Also the main contributors to the overall uncertainty are identified.

Example of a measurement uncertainty calculation
In this section, a practical example is given of an actual uncertainty calculation for radiated power measurement. The example illustrates the influence of different error sources, and is meant to assist the making of one’s own measurement uncertainty analysis. The spread sheet with calculations is incorporated in this Recommendation.

The values used in this example are typical for a particular setup and could in practice be worse or better depending on the effort made to optimize the design.

The example describes a radiated power measurement system. The power P_{RX} is measured at a distance R from the transmit antenna. This is done using a measurement antenna with antenna gain G_{RX} and a measurement receiver.

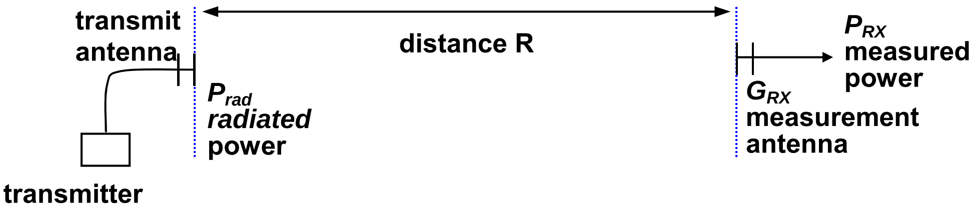

Figure 5: radiated power measurement

The calculation as given before is $$P_{rad} = \frac{P_{RX}.R^2.16\pi^2}{G_{RX}.\lambda^2}.A_{ref}$$

With the additional parameter A_{ref} representing reflections = interference of direct and reflected waves;
The measurement uncertainty of $P_{rad.}$ is a result of the measurement uncertainty of the input parameters. Some of these parameters again have multiple error sources creating their uncertainty. The error sources relevant in this example are discussed hereafter.

Frequency The frequency f used in the formula is that of the carrier frequency. In reality not all the power components measured are on that frequency due to the modulation of the transmitter. Assuming that most of the power is concentrated within known boundaries from the carrier, the relative uncertainty Δf is about 0.1%. The error distribution is assumed uniform.

Distance The uncertainty of the distance is caused by the measurement uncertainty of the position of the transmit antenna and of the measurement antenna.

Antenna gain The uncertainty of the antenna gain is caused by the calibration uncertainty of the antenna, the RF cables, the residual polarization mismatch, and the horizontal and vertical misalignment of the antenna.

In formula: $G_{RX} = G_{CAL}.A_{CBL}.A_{HOR}.A_{VERT}.A_{POL}$

This also includes possible misalignment in cases where a down-tilted base station antenna is used.

RX power The uncertainty of the received power is caused by the calibration uncertainty of the receiver, mismatch between antenna and receiver, IF filter losses due to excess bandwidth of the transmitter and leakage of adjacent channel transmitters.

In formula: $P_{RX} = P_{RX-CAL}.A_{MIS}.A_{FILT}.A_{NABU}$

Reflections One of the main contributors to the overall measurement uncertainty are reflections. The relative amplitude of the reflections depends on the reflectivity of the ground and the objects built on it. The reflection is attenuated by the relative path length difference between direct wave and reflected wave and by the vertical pattern of transmit antenna and receive antenna. The amount of reflections in this example has been derived from analysis of the actual measurements as described in section A.1.8, which is 1.7 dB in this case.

The calculation of the total measurement uncertainty in this example is shown in the Table below.

Table 2: Calculation of the total measurement uncertainty

Symbol	Source of uncertainty	Uncertainty		Distribution	Divisor	Sensitivity coefficient	Standard oncertainty of the source	Degrees of freedom
		± dB	%			c_i	$u_i(A_x)$ %	v_i or v_{eff}
Frequency								
f	Transmit frequency		0,075	uniform	1,7321	2	0,1	∞
Distance								
R	Distance between transmit and receive antenna		1,6	normal	2	2	1,6	∞
Antennagain								
$G_{RX\text{-}CAL}$	Antennagain calibration	1,2	32	normal	2	1	15,9	∞
A_{HOR}	Horizontal alignment error	0,1	2,3	uniform	1,7321	1	1,3	∞
A_{VERT}	Vertical alignment error	0,05	1,2	uniform	1,7321	1	0,7	∞
A_{POL}	Polarisation error	0,3	7,2	uniform	1,7321	1	4,1	∞
Antennapattern distortion of measurement antenna								
A_{MA}	Distortion by antennapattern of measeurment antenna	0,03	0,7	uniform	1,7321	1	0,4	∞
Power								
$P_{RX\text{-}CAL}$	Calibration testreceiver	0,7	17	normal	2	1	8,7	∞
A_{MIS}	Mismatch	0,09	2,1	u-shape	1,4142	1	1,5	∞
A_{FILT}	Filter losses	0,15	3,5	uniform	1,7321	1	2,0	∞
A_{NABU}	Adjacent channel interference	neglectable						
Reflections								
A_{REF}	Reflections	2	58,5	uniform	1,7321	1	33,8	∞
$U(P_{RAD})$	Combined standard uncertainty			normal			39	∞
U	Expanded standard uncertainty (95% conf.)			normal (k=2)			77	∞

Combined measurement uncertainty is 10*^{10}log(1+u(ERP)) 2,49 dB

A calculator containing the table is also incorporated in this report and may be used as the basis for someone's own application.

Uncertainty calculator.xlsx

Administrations implementing this recommendation should evaluate and express uncertainties of their individual measurement equipment according to ETSI TR 100 028-1 and TR 100 028-2 [6], Uncertainties in the measurement of mobile radio equipment characteristics (Parts 1 and 2 - version 1.4.1).

ANNEX 2: LIST OF REFERENCES

[1] Recommendation ITU-R P.525-2: Calculation of Free-Space Attenuation
[2] ITU Handbook Spectrum Monitoring Edition 2011
[3] Recommendation ERC/REC 74-02: Method of measuring the field strength at fixed points in the frequency range 29.7 – 960 MHz
[4] Recommendation ITU-R SM.378-7: Field-strength measurements at monitoring stations
[5] Recommendation ITU-R P.526-12: Propagation by diffraction
[6] ETSI TR 100 028-1 and TR 100 028-2: Electromagnetic and Radio spectrum Matters (ERM); Uncertainties in the measurement of mobile radio equipment characteristics (Parts 1 and 2 - version 1.4.1)
[7] JCGM 100:2008: Evaluation of measurement data - Guide to the expression of uncertainty in measurement