

Basic standard for the in-situ measurement of electromagnetic field strength related to human exposure in the vicinity of base stations

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National foreword

This British Standard is the UK implementation of EN 50492:2008+A1:2014. It supersedes BS EN 50492:2008 which will be withdrawn on 6 January 2017.

The start and finish of text introduced or altered by amendment is indicated in the text by tags. Tags indicating changes to CENELEC text carry the number of the CENELEC amendment. For example, text altered by CENELEC amendment A1 is indicated by **A1** **A1**.

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Basic standard for the in-situ measurement of electromagnetic field strength related to human exposure in the vicinity of base stations

Norme de base pour la mesure du champ électromagnétique sur site, en relation avec l'exposition du corps humain à proximité des stations de base

Grundnorm für die Messung der elektromagnetischen Feldstärke am Aufstell- und Betriebsort von Basisstationen in Bezug auf die Sicherheit von in ihrer Nähe befindlichen Personen

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CENELEC

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Foreword

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Contents

1	Scope	7
2	Normative references	7
3	Terms and definitions	7
4	Physical quantities, units and constants	10
4.1	Quantities	10
4.2	Constants	10
5	General process	10
6	Site analysis and case determination	12
6.1	Introduction	12
6.2	RF sources to be considered	12
6.3	Case determination	12
7	Determination of field quantity to measure in relation to the distance to source antennas	13
8	Requirements of measurement systems	13
8.1	General	13
8.2	Technical requirements of measurement systems	14
9	Measurement procedures	16
9.1	General requirements	16
9.2	Field strength assessment	16
10	Assessment of the field strength at maximum traffic of a cellular network	18
11	Uncertainty	19
11.1	Requirement for expanded uncertainty	19
11.2	Uncertainty estimation	19
12	Presentation of results	22
	Annex A (informative) Main services operating RF	23
	Annex B (informative) Sweeping method	24
B.1	Measurement setup	24
B.2	Measurement method	24
B.3	Discussion on advantages and disadvantages of the method	24
B.4	References	25
	Annex C (informative) Example of broadband equipment use	26
C.1	General	26
C.2	Locating the point of maximum exposure	26
	Annex D (informative) Spectrum analyser settings	28
D.1	Introduction	28
D.2	Detection algorithms	28
D.3	Resolution bandwidth and channel power processing	29
D.4	Integration per service	31
	Annex E (informative) Measuring and evaluating different broadcast signals in respect to EMF	32
E.1	FM radio	32
E.2	DAB (Digital Audio Broadcasting; Digitalradio)	32
E.3	Long wave, medium wave and short wave service	32
E.4	DRM (Digital Radio Mondial)	33

E.5	Analog (PAL and SECAM modulation)	33
E.6	DVB-T.....	34
Annex F	(informative) WCDMA measurement and calibration using a code domain analyser	35
F.1	General.....	35
F.2	Requirements for the code domain analyser	35
F.3	Antenna factor	36
F.4	Calibration	37
Annex G	(informative) Influence of human body on probe measurements of the electrical field strength.....	40
G.1	Simulations of the influence of human body on probe measurements based on the method of moments (surface equivalence principle).....	40
G.2	Comparison with measurements.....	41
G.3	Conclusions	42
Annex H	(informative) Spatial averaging	43
H.1	Introduction.....	43
H.2	Small-scale fading variations	44
H.3	Error on the estimation of local average power density	44
H.4	Characterization of environment statistical properties	45
H.5	Characterisation of different averaging schemes.....	45
H.6	Example of uncertainty assessment	49
H.7	References	49
Annex I	(informative) Maximum traffic estimation of cellular network contribution.....	50
I.1	General.....	50
I.2	GSM and estimation of the exposure at maximum traffic	50
I.3	UMTS and estimation of the exposure at maximum traffic	51
I.4	Influence of traffic in real operating network	51
I.5	Maximum traffic estimation for TETRA and TETRAPOL PMR cellular network contribution	52
Annex J	(informative) WiFi measurements.....	55
J.1	General.....	55
J.2	Integration time for reproducible measurements	55
J.3	Channel occupation.....	56
J.4	Some considerations.....	56
J.5	Scalability by channel occupation	57
J.6	Influence of the application layers.....	57
Annex K	(informative) Examples of implementation of this standard in the context of Council Recommendation 1999/519/EC	58
K.1	Purpose	58
K.2	General considerations	58
K.3	Evaluation of broadband results.....	58
K.4	Evaluation of frequency selective results	59
Annex L	(informative) FDD LTE measurements.....	60
L.1	General	60
L.2	Maximum LTE exposure.....	61
L.2.1	Introduction	61
L.2.2	Method using a dedicated decoder	61
L.2.3	Method using a basic spectrum analyser.....	62
L.3	Instantaneous LTE exposure measurements.....	64 ^{A1}
Bibliography		65

Figures

Figure 1 – Alternative routes to determine in-situ the electromagnetic field for human exposure assessment.....	11
Figure 2 – Location of measurement points for spatial averaging.....	17
Figure D.1 – Spectral occupancy for GSM.....	29
Figure D.2 – Spectral occupancy for WCDMA.....	30
Figure F.1 – Channel allocation.....	35
Figure F.2 – Decoder power range versus antenna factor and cable losses for satisfying selective measurement requirements.....	37
Figure G.1 – Simulation arrangement.....	40
Figure G.2 – Body influence.....	41
Figure G.3 – Simulation arrangement.....	42
Figure H.1 – Physical model of small-scale fading variations.....	43
Figure H.2 – Example of field strength variations in line of sight of an antenna operating at 2,2 GHz.....	43
Figure H.3 – Error at 95 % on average power estimation.....	45
Figure H.4 – 343 measurement positions building a cube (centre) and different templates consisting of a different number of positions.....	46
Figure H.5 – Moving a template (Line 3) through the CUBE.....	47
Figure H.6 – Standard deviations for GSM 900, DCS 1 800 and UMTS.....	48
Figure I.1 – Time variation over 24 h of the exposure induced by GSM 1 800 MHz (left) and FM (right).....	52
Figure J.1 – Example of WiFi frames.....	55
Figure J.2 – Channel occupation versus the integration time.....	55
Figure J.3 – Channel occupation versus nominal throughput rate.....	56
Figure J.4 – WiFi spectrum trace snapshot.....	56
 Figure L.1 – LTE time-frequency plan.....	60
Figure L.2 – Illustration of the boosting factor BF, specific to each network operator.....	62
Figure L.3 – LTE spectrum: PBCH power higher than RS power.....	63 

Tables

Table 1 – Quantities to measure at different distances from radio-stations	13
Table 2 – Broadband measurement system requirements	15
Table 3 – Frequency selective measurement systems requirements	15
Table 4 – Uncertainty assessment in controlled environment.....	20
Table 5 – Uncertainty assessment <i>in-situ</i>	21
Table A.1 – Main services	23
Table D.1 – Example of spectrum analyser settings for an integration per service	31
Table F.1 – WCDMA decoder requirements	36
Table F.2 – Signals configuration	37
Table F.3 – WCDMA generator setting for power linearity.....	38
Table F.4 – WCDMA generator setting for decoder calibration.....	38
Table F.5 – WCDMA generator setting for reflection coefficient measurement.....	39
Table G.1 – Maximum simulated error due to the influence of a human body on the measurement values of an omni-directional probe.....	41
Table G.2 – Measured influence of a human body on omni-directional probe measurements.....	42
Table H.1 – Uncertainty a 95 % for different fading models.....	45
Table H.2 – Correlation coefficients for GSM 900 and DCS 1 800	47
Table H.3 – Variations of the standard deviations for the GSM 900, DCS 1 800 and UMTS frequency band	48
Table H.4 – Examples of total uncertainty calculation.....	49
Table K.1 – Example of a results table for broadband measurements of the electric field strength at one measurement point including an evaluation of compliance with exposure limits	59
Table K.2 – Example of a results table for frequency selective measurements of the electric field strength at one measurement point including an evaluation of compliance with exposure limits.....	59
 Table L.1 – Theoretical extrapolation factor, nRS as function of the bandwidth, assuming all subcarriers are at the same power level.....	62 

1 Scope

This European Standard specifies in the vicinity of base station as defined in 3.2 the measurement methods, the measurement systems and the post processing that shall be used to determine in-situ the electromagnetic field for human exposure assessment in the frequency range 100 kHz to 300 GHz.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 50383, Basic standard for the calculation and measurement of electromagnetic field strength and SAR related to human exposure from radio base stations and fixed terminal stations for wireless telecommunication systems (110 MHz - 40 GHz)

EN 50400, Basic standard to demonstrate the compliance of fixed equipment for radio transmission (110 MHz – 40 GHz) intended for use in wireless telecommunication networks with the basic restrictions or the reference levels related to general public exposure to radio frequency electromagnetic fields, when put into service

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1

antenna

device that serves as a transducer between a guided wave (e.g. coaxial cable) and a free space wave, or vice versa. In the present standard, if not mentioned, the term antenna is used only for emitting antenna(s)

3.2

base station (BS)

fixed equipment for radio transmission intended for use in wireless telecommunications networks, such as those used in cellular communication, Wireless Local Area Networks, point-to-point communication and point-to-multipoint communication according to ITU-R Recommendation F.592-3. Point to point and point to multi point communication equipment listed in “The European table of frequency allocations and utilisations covering the frequency range 9 kHz to 275 GHz” (ERC report 25) (see example in Annex A) are considered. For the purpose of this standard, the term “base station” includes the radio station and the antenna

3.3

average (temporal) power (P_{avg})

the time-averaged rate of energy transfer defined by:

$$P_{avg} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} P(t) dt$$

where t_1 and t_2 are the start and stop time of the measurement. The period $t_2 - t_1$ is the exposure duration time

3.4

averaging time (t_{avg})

appropriate time over which exposure is averaged for purposes of determining compliance with the limits

3.5

electric field strength (E)

magnitude of a field vector at a point that represents the force (F) on a small test charge (q) divided by the charge

$$\vec{E} = \frac{\vec{F}}{q}$$

The electric field strength is expressed in units of volt per metre (V/m)

3.6

intrinsic impedance

ratio of the electric field strength to the magnetic field strength of a propagating electromagnetic wave. The intrinsic impedance of a plane wave in free space is 377 ohm

3.7

hemispherical isotropy

maximum deviation of the field strength when rotating the probe around its major axis with the probe exposed to a reference wave, having varying incidence angles relative to the axis of the probe, incident from the half space in front of the probe

3.8

probe isotropy

degree to which the response of an electric field or magnetic field probe is independent of the polarization and direction of propagation of the incident wave

3.9

axial isotropy

maximum deviation of the field strength when rotating around the major axis of the probe housing while the probe is exposed to a reference wave impinging from a direction along the probe major axis

3.10

linearity

maximum deviation over the measurement range of the measured quantity from the closest linear reference curve defined over a given interval

3.11

magnetic flux density (B)

vector field quantity B which exerts on any charged particle having velocity v a force F equal to the product of the vector product $\vec{v} \times \vec{B}$ and the electric charge q of the particle:

$$\vec{F} = q\vec{v} \times \vec{B}$$

where

$\vec{F}$	is the vector force acting on the particle in newtons
q	is the charge on the particle in coulombs
$\vec{v}$	is the velocity of the particle in metres per second
$\vec{B}$	is the magnetic flux density in teslas

3.12

magnetic field strength (H)

vector quantity obtained at a given point by subtracting the magnetization M from the magnetic flux density B divided by the magnetic constant (permeability) μ :

$$\vec{H} = \frac{\vec{B}}{\mu} - \vec{M}$$

where

$\vec{H}$ is the magnetic field in amperes per metre

$\vec{B}$ is the magnetic flux density in teslas

μ is the magnetic constant (permeability) of the vacuum in henries per metre

$\vec{M}$ is the magnetization in amperes per metre

NOTE For the purposes of this standard, $\vec{M} = 0$ at all points.

3.13

multi-band

multi-band equipment is operating in more than one frequency band, e.g., GSM 900 and GSM 1 800

3.14

permeability (μ)

magnetic permeability of a material is defined by the magnetic flux density B divided by the magnetic field strength H :

$$\mu = \frac{\|\vec{B}\|}{\|\vec{H}\|}$$

where μ is the permeability of the medium expressed in Henry per metre (H/m)

3.15

permittivity (ϵ)

property of a dielectric material (e.g., biological tissue). In case of an isotropic material, it is defined by the electrical flux density D divided by the electrical field strength E

$$\epsilon = \frac{\|\vec{D}\|}{\|\vec{E}\|}$$

The permittivity is expressed in units of farads per metre (F/m)

3.16

root-mean-square (r.m.s.)

effective value or r.m.s. value obtained by taking the square root of the average of the square of the value of the periodic function taken throughout one period

3.17

power density (S)

radiant power incident perpendicular to a surface, divided by the area of the surface. The power density is expressed in units of watt per square metre (W/m²)

3.18

transmitter

device to generate radio frequency electrical power to be connected to an antenna for communication purpose

4 Physical quantities, units and constants

4.1 Quantities

The internationally accepted SI-units are used throughout the standard.

<u>Quantity</u>	<u>Symbol</u>	<u>Unit</u>	<u>Dimensions</u>
Current density	J	ampere per square metre	A/m ²
Electric field strength	E	volt per metre	V/m
Electric flux density	D	coulomb per square metre	C/m ²
Frequency	f	hertz	Hz
Magnetic field strength	H	ampere per metre	A/m
Magnetic flux density	B	tesla (Vs/m ²)	T
Permeability	μ	henry per metre	H/m
Permittivity	ε	farad per metre	F/m
Wavelength	λ	metre	m

4.2 Constants

<u>Physical constant</u>		<u>Magnitude</u>
Speed of light in a vacuum	c	$2,997 \times 10^8$ m/s
Permittivity of free space	ε_0	$8,854 \times 10^{-12}$ F/m
Permeability of free space	μ_0	$4 \pi \times 10^{-7}$ H/m
Impedance of free space	η_0	377 ohm (approx $120 \pi \Omega$)

5 General process

This clause describes the process that shall be followed to determine the methods, the measurement systems and the post processing that shall be used to estimate in-situ the electromagnetic field for human exposure assessment¹⁾.

Depending on the objectives (see Clause 6), the in-situ measurement shall be performed in compliance with the following flowchart:

¹⁾ This European Standard takes into account the CEPT-ECC Recommendation (02)04.

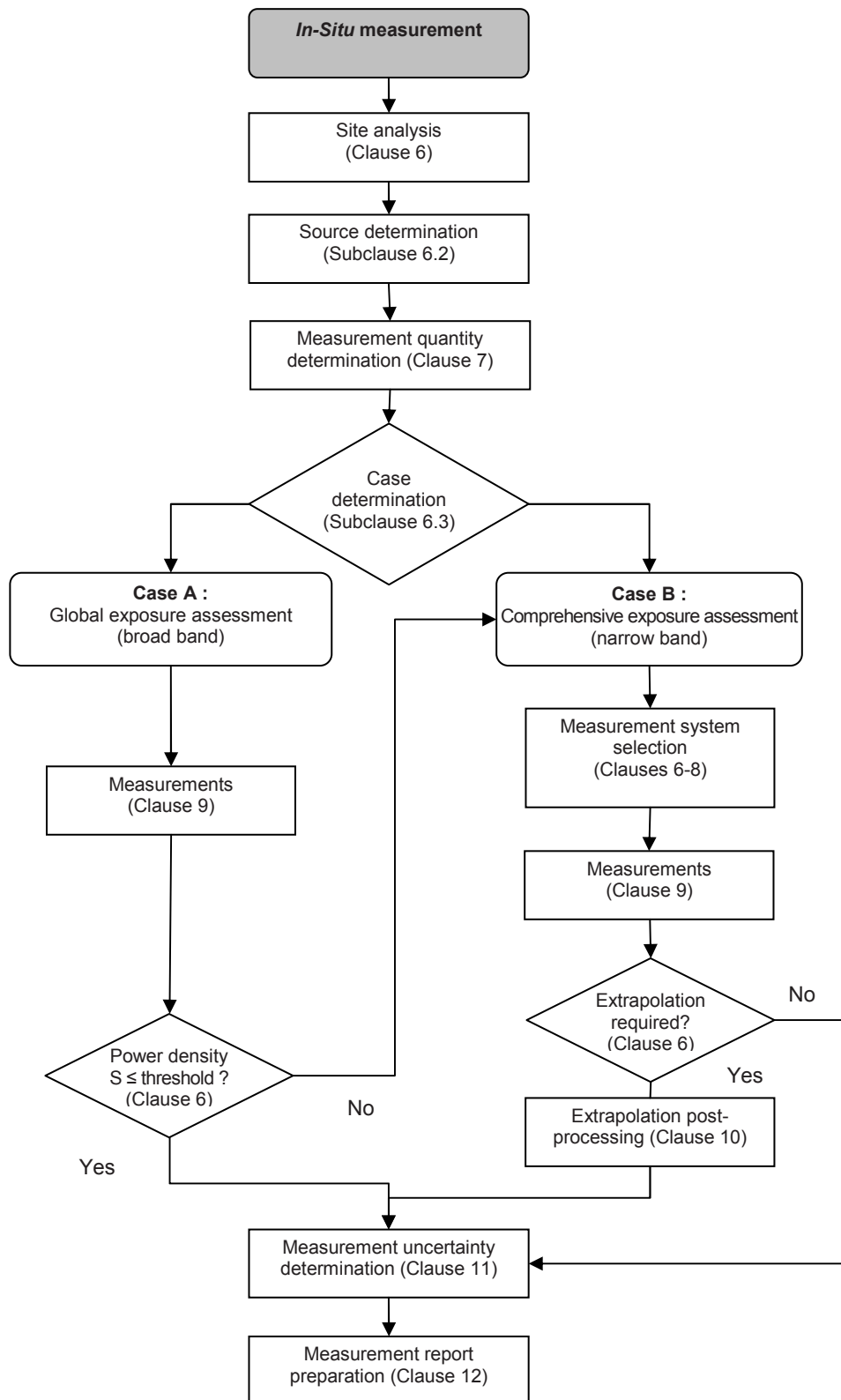


Figure 1 ± Alternative routes to determine in-situ the electromagnetic field for human exposure assessment

6 Site analysis and case determination

6.1 Introduction

This clause describes how to analyse the site and determine which type of measurement shall be performed depending on the objective.

6.2 RF sources to be considered

Reasonable endeavours shall be applied to identify all RF emissions between 100 kHz and 300 GHz.

Such sources can be identified e.g. through visual inspection, consulting databases as defined in EN 50400 and using frequency selective measurements. If sources are identified, then measurements shall be performed according to applicable standards. If the location to be evaluated is not in the main beam of antennas operating at frequencies above 6 GHz, then the fields produced by such sources can be generally ignored since in most cases they are not significant for human exposure assessment.

All fixed permanently installed identified RF sources operating between 100 kHz and 6 GHz shall be considered.

6.3 Case determination

6.3.1 Overview

The first decision is to choose between evaluation approaches (Cases A and B). Case A provides a single result covering all sources and frequencies. Case B provides a set of field values for sources, frequencies or frequency sub-bands.

If the objective of the in-situ measurement is a comprehensive exposure assessment, i.e. investigating every contribution from RF sources using a frequency selective analysis, then Case B is applicable.

If the objective of the in-situ measurement is a global exposure assessment, i.e. combining the contributions of all RF sources then the assessment shall be done either using Case B through a combination of all the measured contribution (i.e. Total Exposure Ratio defined in EN 50400) or Case A.

6.3.2 Case A

Case A corresponds to the situation where one wants to perform global exposure assessment using broadband equipment in compliance with Clause 8.

Broadband measurement may be used to indicate if it is necessary to perform a comprehensive exposure assessment (Case B). Evaluation of power density levels above a threshold of 10 mW/m² shall be completed according to Case B. However, if there are pre-existing national requirements, a different threshold between 5 mW/m² and 100 mW/m² may be used.

Broadband measurement may be used to give real-time environmental field-strength information "as observed".

Broadband measurement shall not be used for extrapolation (Clause 10). Without the ability to discriminate frequency, such extrapolation will result in a large overestimation of the maximum exposure.

6.3.3 Case B

Case B corresponds to the situation where one wants to perform a comprehensive exposure assessment including if needed an extrapolation to estimate the field at maximum traffic.

To perform this comprehensive exposure assessment the operator shall use frequency selective measurement equipment in compliance with Clause 8.

7 Determination of field quantity to measure in relation to the distance to source antennas

The objective of this clause is to determine, from site analysis and contributors, the quantities that have to be measured according to the distance from the source antennas (only electric and magnetic fields are covered conforming to the scope of this standard).

For each contributor (or group of contributors) and according to the site analysis, we have to measure either E or H , or both according to the Table 1.

Electromagnetic fields are composed of an electric field E (measured in V/m) and a magnetic field H (measured in A/m). Far from the sources (region III) the E -field and the H -field are mathematically interdependent, but closer to the sources (regions I and II) they might need to be measured separately.

Table 1 ± Quantities to measure at different distances from radio-stations

Region	Region I	Region II	Region III
Region edges, measured from antenna where λ wavelength D largest dimension of the antenna	$0 \cdots \max. \begin{pmatrix} \lambda \\ D \\ \frac{D^2}{4\lambda} \end{pmatrix}$	$\max. \begin{pmatrix} \lambda \\ D \\ \frac{D^2}{4\lambda} \end{pmatrix} \cdots \max. \begin{pmatrix} 5\lambda \\ 5D \\ \frac{0,6D^2}{\lambda} \end{pmatrix}$	$\max. \begin{pmatrix} 5\lambda \\ 5D \\ \frac{0,6D^2}{\lambda} \end{pmatrix} \cdots \infty$
$E \perp H$	No	Effectively yes	Yes
$\eta = E / H$	$\neq \eta_0$	$\approx \eta_0$	$= \eta_0$
Component to be measured	$E \text{ \& } H$	$E \text{ or } H$	$E \text{ or } H$
Comment	In region I, reactive power components are not negligible. The power density oscillates and depending on the measurement location, lower values might be obtained closer to the antenna in contrast to higher values further away. In this region both E and H have to be measured.	Antenna pattern according the specifications of the manufacturer not yet valid.	Far field conditions
		In regions II and III, it is acceptable to measure one field component E or H only.	

NOTE 1 These distance limits of the regions are applicable generally. Therefore, antennas might exist for which these limits are conservative, e.g. for region I, λ might be sufficient even if D or $D^2/(4\lambda)$ are larger. However, if resorting to these cases, they must be supported by sustainable proof.

NOTE 2 Nevertheless, the distance limits of the regions in Table 1 are already smaller than those proposed in textbooks covering exact descriptions of antennas. For exposure assessment, the original distance limits were reduced resulting in the values of Table 1, whose precision is still better than the uncertainty of the exposure assessment. FCC OET Bulletin 65 proposes these small distance limits and they have been confirmed by recent measurements and calculations.

8 Requirements of measurement systems

8.1 General

This clause describes the basic requirements applicable to measurement equipment that can be used to perform the measurement in this standard.

The measurement system generally consists of the following components:

- the probe (composed of E or H field antenna(s)) able to evaluate the field strength isotropically;
- measurement equipment (e.g. Spectrum analyser or receiver in case of frequency selective measurement);
- cable(s) or fibres(s) connecting the probe to the measurement equipment;
- tripod to hold and position the probe;
- either customised rotating system for the isotropic measurement using a single axis probe or switching or combining device for the isotropic measurement using a tri-axial probe.

The size of the antenna/probe should be smaller or comparable to a wavelength at the highest frequency. Directive antennas should only be used with the sweeping method (Annex B) or in cases where there is only a direct path to the source antenna.

In addition to these components, supplementary equipment may be used e.g. laptop computer to automate, control the measurement, to store and post-process the measurements.

Below 6 GHz, isotropic measurement shall be used to determine the field value used to assess the human exposure. Directive antennas may be used to assess the spatial peak value of the different field components (Annex B) but is not recommended for human exposure assessment.

To avoid spurious field pick up, ferrite beads are recommended on the coaxial cable connecting the probe to the measurement equipment. For frequencies below 800 MHz it is mandatory.

If used, the tripod shall be made of low reflective material such as plastic or wood.

8.2 Technical requirements of measurement systems

8.2.1 Broadband measurement system requirements

8.2.1.1 General requirements

Equipment for broadband measurements of the electric or the magnetic field strength usually consists of a broadband probe and a read-out unit (see Annex C). The measured level represents the total field strength within the frequency range covered by the probe.

Broadband measurements shall be performed using an electric or a magnetic field isotropic probe. Several probes may be used to cover the specified frequency range and the total field strength level shall then be calculated according to Equation (1).

$$E = \sqrt{\sum_{i=1}^N E_i^2}$$
$$H = \sqrt{\sum_{i=1}^N H_i^2}$$

N – number of probes (1)

NOTE The application of Equation (1) implies that the out of band response of the probe can be neglected, if this is not the case, then the indicated field level is an overestimation.

8.2.1.2 Frequency range

The measurement system(s) shall cover the frequency range from 100 kHz to 6 GHz at least and up to 300 GHz if required by the site analysis.

8.2.1.3 Frequency response, dynamic range, linearity and isotropy

The requirement for frequency response, dynamic range, linearity and isotropy shall be within the requirements described in Table 2.

Table 2 ± Broadband measurement system requirements

	Frequency response	Minimum detection limit	Dynamic range	Linearity	Isotropy
Below 900 MHz and above 3 GHz	± 3 dB	≤ 2 mW/m ² (i.e. 1 V/m or 0,003 A/m)	≥ 40 dB	± 1,5 dB	< 2 dB evaluated for the complete measurement system
Between 900 MHz and 3 GHz	± 1,5 dB				

8.2.1.4 Calibration

The measurement equipment shall be calibrated as a complete system at the measurement frequencies in compliance with EN 50383. For signals with high crest factors or combinations of several signals, additional calibration may be necessary in order to assess uncertainty.

8.2.2 Frequency selective measurement systems requirements

8.2.2.1 General

The measurement system shall cover in the frequency band from 100 kHz to 6 GHz at least the sources identified in site analysis 6.2.

If site analysis has identified emissions above 6 GHz to be evaluated, adequate measurement systems have to be used.

This range can be covered by the use of one or several antennas and measurement systems.

8.2.2.2 Dynamic range, linearity and isotropy

The requirement of dynamic range, linearity and isotropy shall be performed in compliance with EN 50383 and shall be within the requirements described in Table 3.

Table 3 ± Frequency selective measurement systems requirements

	Frequency response	Minimum detection limit	Dynamic range	Linearity	Isotropy
Below 900 MHz and above 3 GHz	± 3 dB	≤ 0,01 mW/m ² (i.e. 0,05 V/m) Noise ratio of at least 20 dB	≥ 66 dB	± 1,5 dB	< 2,5 dB evaluated for the complete measurement system In the case of the sweeping method, the isotropy may not be required.
Between 900 MHz and 3 GHz	± 1,5 dB				

8.2.2.3 Calibration and setting

8.2.2.3.1 Equipment based on a spectrum analyser

The measurement equipment shall be calibrated in compliance with EN 50383.

When measuring using a spectrum analyser the equipment settings shall be defined with due regard to the characteristics of the signal, especially bandwidth, time behaviour and crest factor. The instrument settings for different communication standards have to be chosen individually for accurate measurement results. E.g. the resolution bandwidth of the measurement system shall either be larger than the occupied bandwidth of the signal or all the contribution in the occupied bandwidth of the signal shall be added to find the amplitude value. Examples are provided in Annex D and also in Annex E for broadcasting signals.

8.2.2.3.2 Equipment based on a WCDMA receiver

The measurement equipment shall be calibrated on the code domain parameters of interest which are E_c , the power of the common pilot CPICH, and E_c/I_o , the signal to noise ratio (I_o is the total measured power over a 5 MHz bandwidth centred on the carrier frequency).

The first step is to calibrate the dynamic range. The receiver cable is connected to a WCDMA generator. The linearity deviation shall be lower than ± 2 dB for an input power covering the dynamic range. The measurements outside the linear range must not be considered.

The second step is to determine the confidence range for E_c/I_o regarding the noise level. This procedure determines the CPICH decoding range of the device. Typically, for an isolated single WCDMA emitter delivering the maximum power (maximum traffic), the measured signal to noise ratio E_c/I_o is approximately - 10 dB (3GPP standards indication for typical setting of the pilot power ratio). However, this value can be lower in the case of a multisource configuration. The measurement equipment shall be able to measure (decode) a signal down to an E_c/I_o of - 20 dB (UMTS cell limit). For this purpose, the output power of the generator is fixed while the CPICH allocated power ratio (referred to the total emitted power) is varied from - 3 dB to - 20 dB. The measured value shall be within ± 2 dB deviation.

For more information see Annex F.

9 Measurement procedures

9.1 General requirements

The measurement shall be performed using the measurement system selected in Clause 6 and Clause 7.

In case of comprehensive exposure assessment (Case B), the measurement of the amplitude shall be considered as the total power of the transmitted signal (Clause 8, Annex D and Annex E).

In all cases the minimum distance between the measurement probe tip and the body of the "operator" as well as any reflecting object shall be 1 m when measuring below 300 MHz and 0,5 m when measuring above 300 MHz (see Annex G).

9.2 Field strength assessment

9.2.1 General

Multi-path propagation means the signal at a given location is composed of different field components inducing fast fading (Annex H). The EM fields vary in time and in space therefore, the field strength used to assess the human exposure has to be evaluated by post processing (e.g. measurements performed over a given line or surface).

If a non-isotropic probe is used then a number of measurements shall be performed in relevant directions and polarization and combined in order to assess the exposure isotropically for each individual point.

9.2.2 Human exposure assessment in complex environment

To assess the whole body human exposure, a field-averaging protocol is required. The isotropic field values shall be determined at N measurement points as described in the Figure 2. For measurements in special environments, e.g. in kindergartens or bedrooms, additional measurements may be performed at alternative locations in an adequate manner. Three measurement points are recommended, but depending on the location (relative to the measurement point) and the accuracy required, the number of measurement points to averaged may be increased to six. The uncertainty of the estimation of the mean value with three measurement points is ~ 3 dB, uncertainty with six measurement points is ~ 2 dB (see Annex H).

If the objective is to assess the peak value of the different field components within a certain volume, protocols such as those described in Annex B or Annex C may be used.

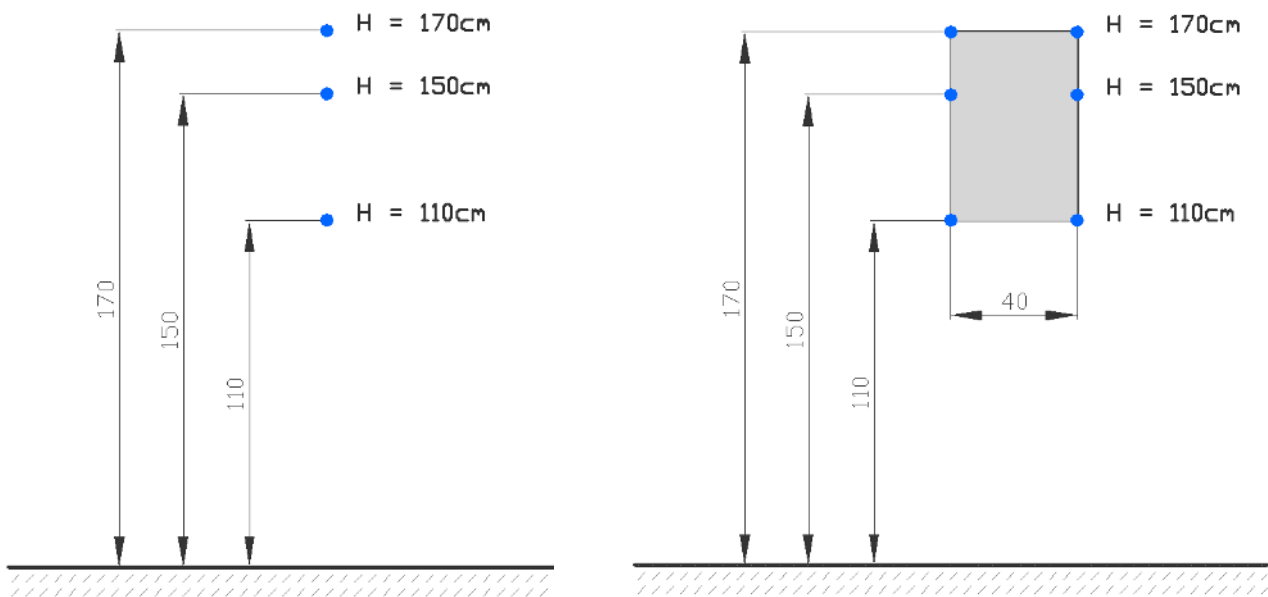


Figure 2 ± Location of measurement points for spatial averaging

The spatially averaged field value shall be established using the following equation for broadband measurement.

$$(E \text{ or } H)_{\text{spatial averaging}} = \sqrt{\frac{\sum_{i=1}^N (E_i \text{ or } H_i)^2}{N}} \quad \text{with} \quad \begin{cases} E_i = \sqrt{E_{i_x}^2 + E_{i_y}^2 + E_{i_z}^2} \\ H_i = \sqrt{H_{i_x}^2 + H_{i_y}^2 + H_{i_z}^2} \end{cases}$$

For frequency selective measurement, the above equation shall be evaluated separately for each frequency band, i.e. for each frequency band the reported spatial averaged field is the quadratic spatial averaging of these N points.

10 Assessment of the field strength at maximum traffic of a cellular network

The traffic induces time variations in the emitted power. In the case of GSM, the downlink power control, the discontinuous transmission as well as the design of the network also limit the emitted power. As a result of this the actual maximum emitted power is well below the theoretical emitted at maximum traffic (Annex I).

If the aim is to evaluate the maximum exposure taking into account traffic and transmitted power variations, then the instantaneous measurement data can be used with appropriate post-processing of measurement results. If post processing is used, care shall be taken to ensure that it does not underestimate exposure.

Extrapolation of instantaneous measurement data may overestimate exposure due to: time limited maximum load of the networks and the load of different networks is not fully correlated. Moreover, certain margin regarding maximum power and/or channel is used in the network planning (Annex I). Therefore, the probability of reaching such a maximum is very low.

Since the broadband measurement is not able to provide information about different services and traffic, any extrapolation must use the highest extrapolation factor (maximum traffic ...) and therefore, in line with previous explanation vast overestimation of the potential maximum exposure will result. As a consequence, broadband measurement shall not be used for extrapolation.

For GSM the instantaneous measurement of the Broadcast Control CHannel (BCCH) shall be used and the extrapolated electric field $E_{traffic\ max}$ shall be estimated by:

$$E_{traffic\ max} = \sqrt{n_{TRX}} E_{bcch}$$

where

n_{TRX} denotes the relevant ratio between the maximum base station power and the power allocated to the BCCH (usually the relevant number of transmitters), and

E_{bcch} denotes the instantaneous measured electric field from BCCH only.

For WCDMA, the instantaneous measurement of the base station Common Pilot CHannel (CPICH) shall be used and the extrapolated electric field $E_{traffic\ max}$ shall be estimated by:

$$E_{traffic\ max} = \sqrt{n_{cpich}} E_{cpich}$$

where

E_{cpich} denotes the instantaneous measured electric field from CPICH only and

n_{cpich} the relevant ratio between the maximum allocated power and the power allocated to the pilot channel.

The total field for one carrier frequency ($freq_0$) is expressed as the root-sum-square (r.s.s.) of all the detected CPICH channels:

$$E(freq_0) = \sqrt{\sum_{i=1}^n E_{traffic\ max}^2 (cpich)}$$

For PMR Digital networks, the instantaneous measurement of the Multicast Control CHannel (MCCH) shall be used and the extrapolated electric field $E_{traffic\ max}$ shall be estimated by:

$$E_{traffic\ max} = \sqrt{n_{TRX}} E_{mcch}$$

where

n_{TRX} denotes the number of transmitters and

E_{mcch} denotes the instantaneous measured electric field from MCCH only.

[A1] For Wifi and LTE the measurements and extrapolation shall take into account the specificity of these signals related to time occupation (technical parameters are described in Annex J and Annex L). **[A1]**

11 Uncertainty

11.1 Requirement for expanded uncertainty

The expanded uncertainty of the measurement performed in controlled environment (Table 4) e.g. calibration of the equipment shall not exceed 2 dB.

The expanded uncertainty of the measurement performed *in-situ* and taking into account the influence of the environment (Table 5) shall not exceed 4 dB.

11.2 Uncertainty estimation

This clause describes how to determine the uncertainty for the measurements made in this standard. It does not apply to extrapolations to address maximum traffic since an overestimation procedure is used (Annex I).

The contributions of each component of uncertainty shall be registered with their name, probability distribution, and sensitivity coefficient and uncertainty value. The results shall be recorded in a table of the following form. The combined uncertainty shall then be evaluated according to the following equation:

$$u_c = \sqrt{\sum_{i=1}^m c_i^2 \cdot u_i^2}$$

where c_i is the weighting coefficient (sensitivity coefficient). The expanded uncertainty shall be evaluated using a confidence interval of 95 %. See example of calculation in Annex H.