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IEC TC 106 : METHODS FOR THE ASSESSMENT OF ELECTRIC, MAGNETIC AND ELECTROMAGNETIC FIELDS ASSOCIATED WITH HUMAN EXPOSURE	
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OF INTEREST TO THE FOLLOWING COMMITTEES:	HORIZONTAL STANDARD: ☐
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TITLE:

Determination of RF field strength, power density and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure

NOTE FROM TC/SC OFFICERS:

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

DETERMINATION OF RF FIELD STRENGTH, POWER DENSITY AND *SAR* IN THE VICINITY OF RADIOCOMMUNICATION BASE STATIONS FOR THE PURPOSE OF EVALUATING HUMAN EXPOSURE

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International Standard IEC 62232 has been prepared by IEC technical committee 106: Methods for the assessment of electric, magnetic and electromagnetic fields associated with human exposure.

This second edition cancels and replaces the first edition published in 2011 and constitutes a technical revision.

The significant changes with respect to the previous edition are the following:

a) Increased frequency range from 110 MHz to 100 GHz (including consideration of ambient sources 100 kHz to 300 GHz);
b) product compliance – determination of compliance boundary information for an RBS product before it is placed on the market;
c) product installation compliance – determination of the total RF exposure levels before the product is put into service;

d) simplified document structure and methods of assessment for new technologies such as LTE–TDD, FDD and WiFi.

This publication contains attached files in the form of a CD-ROM for the paper version and embedded files for the electronic version. These files are intended to be used as a complement and do not form an integral part of the standard.

The text of this International Standard is based on the following documents:

FDIS	Report on voting
106/XX/FDIS	106/XX/RVD

Full information on the voting for the approval of this International Standard can be found in the report on voting indicated in the above table.

This document has been drafted in accordance with the ISO/IEC Directives, Part 2.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under "http://webstore.iec.ch" in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

The National Committees are requested to note that for this document the stability date is 2022.

THIS TEXT IS INCLUDED FOR THE INFORMATION OF THE NATIONAL COMMITTEES AND WILL BE DELETED AT THE PUBLICATION STAGE.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

INTRODUCTION

This document addresses the evaluation of radiofrequency (RF) field strength, power density or specific absorption rate (SAR) levels in the vicinity of radiocommunication base stations (RBS), also called product or Equipment Under Test (EUT), intentionally radiating in the frequency range 110 MHz to 100 GHz according to the scope (see Clause 1). It does not address the evaluation of current density which exposure guidelines often do not consider to be relevant when evaluating RF fields in the intended RBS operating frequency range.

This document specifies the RF exposure evaluation methods to be used for product compliance, product installation compliance and in-situ RF exposure assessments. It does not define human exposure limits, also called “exposure limits”. When implementing RF exposure assessments, the surveyor refers to the set of exposure limits applicable where exposure takes place.

Clause 2, Clause 3 and Clause 4 address normative references, terms and definitions, and symbols and abbreviated terms, respectively.

Clause 5 provides a quick start guide and details how to use this document.

Clause 6 describes the three main application areas of this document: RF exposure evaluation methods for product compliance, product installation compliance, and in-situ RF exposure assessments. Further details are provided in Annex C.

Clause 7 provides guidelines on how to select the evaluation method. Further details are provided in Annex A.

Clause 8 defines the RF exposure evaluation methods to be used and refers to further details in Annexes B and F.

Clause 9 addresses the estimation of uncertainty and refers to Annex E for further details.

Clause 10 describes reporting requirements for the evaluation or assessment.

Annexes and the bibliography are referenced extensively to provide useful clarifications or guidance.

Additional guidance can be found in IEC TR 62669 which includes a set of worked case studies giving practical examples of the application of this document.

DETERMINATION OF RF FIELD STRENGTH, POWER DENSITY AND *SAR* IN THE VICINITY OF RADIOCOMMUNICATION BASE STATIONS FOR THE PURPOSE OF EVALUATING HUMAN EXPOSURE

1 Scope

This document provides methods for the determination of radio-frequency (RF) field strength and specific absorption rate (*SAR*) in the vicinity of radiocommunication base stations (RBS) for the purpose of evaluating human exposure.

This document:

a) considers intentionally radiating RBS which transmit on one or more antennas using one or more frequencies in the range 110 MHz to 100 GHz;

b) considers the impact of ambient sources on RF exposure at least in the 100 kHz to 300 GHz frequency range;

c) specifies the methods to be used for RF exposure evaluation for compliance assessment applications, namely:

    1) product compliance – determination of compliance boundary information for an RBS product before it is placed on the market;

    2) product installation compliance – determination of the total RF exposure levels in accessible areas from an RBS product and other relevant sources before the product is put into service;

    3) in-situ RF exposure assessment – measurement of in-situ RF exposure levels in the vicinity of an RBS installation after the product has been taken into operation;

d) describes several RF field strength and *SAR* measurement and computation methodologies with guidance on their applicability to address both the in-situ evaluation of installed RBS and laboratory-based evaluations;

e) describes how surveyors, with a sufficient level of expertise, establish their specific evaluation procedures appropriate for their evaluation purpose;

f) provides guidance on how to report, interpret and compare results from different evaluation methodologies and, where the evaluation purpose requires it, determine a justified decision against a limit value;

g) provides short descriptions of the informative example case studies given in the companion Technical Report IEC TR 62669 [1].

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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.

IEC 62209-1, *Human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices – Human models, instrumentation, and procedures – Part 1: Procedure to determine the specific absorption rate (SAR) for hand-held devices used in close proximity to the ear (frequency range of 300 MHz to 3 GHz)*

IEC 62209-2, *Human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices – Human models, instrumentation, and procedures – Part 2: Procedure to determine the specific absorption rate (SAR) for wireless communication devices used in close proximity to the human body (frequency range of 30 MHz to 6 GHz)*

IEC 62479, *Assessment of the compliance of low power electronic and electrical apparatus with the basic restrictions related to human exposure to electromagnetic fields (10 MHz – 300 GHz)*

IEC 62311, *Assessment of electronic and electrical equipment related to human exposure restrictions for electromagnetic fields (0 Hz – 300 GHz)*

3 Terms and definitions

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

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.1
ambient field
background electromagnetic field in the frequency range from at least 100 kHz to 300 GHz other than the emissions from the EUT in the frequency range 110 MHz to 100 GHz

3.2
antenna factor
ratio of the electromagnetic field strength incident upon an antenna to the voltage (U) that is produced across a specified impedance (e.g. 50 Ω) terminating the line connection of the antenna

3.3
assessment
undertaking of an assessment in order to arrive at a judgement based on evidence, of the suitability of RF exposure induced by a product with regards to RF exposure limits

3.4
assessment configuration
set of parameters which together represent the RBS configuration to be assessed according to the evaluation purpose, e.g. for conformity assessment

3.5
average absorbed power
time-averaged absorbed power
ohmic power dissipated in a volume V given by

$$P_\mathrm{A} = \int_V \sigma \left[E(x,y,z) \right]^2 \mathrm{d}V$$

where

$E(x,y,z)$ is the r.m.s. value of the electric field strength in the tissue in volts per metre;

σ is the electric conductivity of the tissue in siemens per metre

3.6
average transmitted power
time-averaged transmitted power
rate of transmitted energy transfer expressed in watts given by

$$\overline{P}_{\text{avg}} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} P(t)\mathrm{d}t$$

where

t_1 is the start time of the observation in seconds;

t_2 is the stop time of the observation in seconds;

$P(t)$ is the instantaneous transmitted power in watts

Note 1 to entry: The transmitted power is the conducted power applied to the antenna input connector minus the reflected power at the antenna input connector and minus the power dissipated as heat within the antenna.

3.7
basic restriction
restriction on human exposure to time-varying electric, magnetic, and electromagnetic fields that is based on the applicable exposure guidelines

Note 1 to entry: For this document, the physical quantity used as a basic restriction is the specific absorption rate (SAR) or power density (S) depending on the frequency and defined by the relevant compliance standard.

3.8
base station
radio base station
BS
fixed equipment including the radio transmitter and associated antenna(s) as used in wireless telecommunications networks

EXAMPLE Base stations for mobile communicaitons, radio-relays, wireless local area network access points, base stations for cordless telephony, etc. that are not normally used in close proximity (i.e. within 20 cm) to the human body.

Note 1 to entry: Examples of wireless telecommunications networks include those used in mobile telecommunication systems according to ITU-R M.1224-1 [2], wireless local area networks, public safety networks and fixed wireless systems (including radio-relay systems, point-to-point communication and point-to-multipoint communication according to ITU-R F.592-4 [3] and ITU-R F.1339-1 [4]).

Note 2 to entry: Equipment for radar, TV and radio broadcast services are not considered to be an RBS.

3.9
collinear array antenna
antenna consisting of a linear array of radiating elements, usually dipoles, with their axes lying in a straight line

3.10
compliance boundary
CB
surface of arbitrary shape defining a volume outside of which the applicable limit condition is not exceeded

3.11
compliance distance
distance from the antenna to the compliance boundary for a stated direction and set of transmission conditions

Note 1 to entry: In the absence of qualifying direction, the compliance distance is the maximum distance from the antenna to the compliance boundary.

3.12
control boundary
set of locations which together define where human access to a compliance boundary is limited by either warnings or physical controls

3.13
lower detection limit
minimum quantifiable response of the measuring equipment

3.14
upper detection limit
maximum quantifiable response of the measuring equipment

3.15
directivity
D
<of an antenna, in a given direction> ratio of the radiation intensity produced by an antenna in a given direction to the value of the radiation intensities averaged in all directions in space

Note 1 to entry: If no direction is specified, the direction of maximum radiation intensity from the given antenna is implied.

Note 2 to entry: The directivity is independent of antenna losses and equal to the absolute gain in the same direction if the antenna has no internal losses.

Note 3 to entry: The ratio can also be expressed in decibels.

3.16
dish antenna
parabolic antenna usually used for radio-relays or point-to-point communications

Note 1 to entry: See ITU-R F.592-4 [3] and ITU-R F.1339-1 [4].

3.17
duty factor
ratio of the sum of pulse durations to a stated averaging time

Note 1 to entry: For waveforms showing periodical behaviour, the averaging time is assumed to be the minimum repetition interval of a waveform frame, e.g. the pulse repetition period for single-pulse TDMA waveforms.

3.18
dynamic range
quotient of the signal from the maximum measurable indication of a quantity divided by the signal from the minimum measurable value of that quantity

Note 1 to entry In some cases, the dynamic range can be expressed as an interval of the above-mentioned corresponding values.

[SOURCE: IEC 60050-394:2007, 394-40-17 [5]]

3.19
electric field strength
vector field quantity E which exerts on any charged particle at rest a force F equal to the product of E and the electric charge Q of the particle:

$$F = QE$$

[SOURCE: IEC 60050-121:1998, 121-11-18 [6]]

3.20
equivalent isotropic radiated power
EIRP
<in a given direction> product of the radiofrequency input power to an antenna and the absolute gain of the antenna in a given direction

[SOURCE: IEC 60050-712:1992, 712-02-51 [7], modified – In the term, "isotropically" has been replaced by "isotropic"; in the definition, "power supplied" has been replaced by "radiofrequency input power".]

3.21
evaluation
process of determining a value of an exposure metric

3.22
evaluation configuration
set of parameter values which together represent the RBS configuration used in the evaluation

3.23
evaluation location
specific physical location at which a single field parameter value has been measured or computed

Note 1 to entry: In the case of spatial averaging, this is the reference location defined in the averaging scheme.

3.24
exposure ratio
ER
<at a given location and for each operating frequency of the BS> ratio of the exposure metric and the relevant exposure limit, both expressed in terms of power

EXAMPLE $ER = S/S_{\mathrm{lim}}$, $ER = \max[(E/E_{\mathrm{lim}})^2, (H/H_{\mathrm{lim}})^2]$

Note 1 to entry: The exposure ratio can also be expressed as a percentage, i.e. ER % = ER (dimensionless) × 100 %.

3.25
field strength
<of a radio transmitter> magnitude of the electromagnetic (electric or magnetic) field created at a given point by a radio transmitting system operating at a specified characteristic frequency with specified installation and modulation conditions

[SOURCE: IEC 60050-705:1995, 705-08-31 [8]]

3.26
frequency response
curve representing the variations, with respect to frequency, of the indicated level of the exposure metric as a measuring instrument response to a known exposure metric

3.27
gain
G
<of an antenna, in a given direction> ratio of the radiation intensity produced by an antenna in a given direction to the value of the radiation intensities averaged in all directions in space reduced by a factor representing the antenna losses

Note 1 to entry: If no direction is specified, the direction of maximum radiation intensity from the given antenna is implied.

Note 2 to entry: The ratio can also be expressed in decibels.

3.28
general public
all persons not classified as worker

3.29
intended use
reasonably foreseeable use of an RBS for the purpose intended, over its full range of applicable functions, in accordance with the instructions provided by the manufacturer, including installation and operation instructions

3.30
linearity
deviation from a straight line of the curve representing the output quantity as a function of the input quantity

[SOURCE: IEC 60050-394:2007, 394-40-31 [5]]

3.31
localized exposure
maximum value of exposure averaged over a small volume or area as defined by applicable RF exposure guidelines

3.32
magnetic field strength
magnetizing field strength
vector quantity obtained at a given point by subtracting the magnetization M from the magnetic flux density B divided by the magnetic constant μ_0:

$$H = \frac{B}{\mu_0} - M$$

Note 1 to entry: In vacuum, the magnetic field strength is at all points equal to the magnetic flux density divided by the magnetic constant:

$$H = \frac{B}{\mu_0}$$

Note 2 to entry: The rotation of the magnetic field strength is the total current density J_t:

$$\mathrm{rot}\, H = J_t$$

Note 3 to entry: The magnetic flux density B is sometimes called “magnetic field”, risking confusion with the magnetic field strength H.

[SOURCE: IEC 60050-121:1998, 121-11-56 [6]]

3.33
measurement drift
power drift
gradual deviation over time from a reproducible reading of the measured value

3.34
partial-body exposure
localized exposure of part of the body, as distinct from a whole-body exposure

3.35
peak spatial-average *SAR*
maximal value of *SAR* averaged within a specific mass

3.36
planar array
<antenna> array in which corresponding points of the radiating elements lie in a plane

[SOURCE: IEC 60050-712:1992, 712-01-07 [7]]

3.37
plane wave equivalent power density
<of an electromagnetic wave> power density equal in magnitude to the power density of a plane wave

3.38
power density
power passing through a surface normal to the direction of propagation of energy of an electromagnetic wave divided by the area of the surface

3.39
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

3.40
RF field strength
electric field strength and/or magnetic field strength from an RF source

3.41
spatial-peak
<value> non-spatially averaged peak value of the electric field, magnetic field, or power density

3.42
specific absorption rate
SAR
time derivative of the incremental electromagnetic energy (dW) absorbed by (dissipated in) an incremental mass (dm) contained in a volume element (dV) of given mass density (ρ)

$$SAR = \frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{\mathrm{d}W}{\mathrm{d}m}\right) = \frac{\mathrm{d}}{\mathrm{d}t}\left(\frac{\mathrm{d}W}{\rho \mathrm{d}V}\right)$$

Note 1 to entry: *SAR* can be obtained using the following equation:

$$SAR = \frac{\sigma E^2}{\rho}$$

where

- SAR is the specific absorption rate in watts per kilogram (W/kg);
- E is the r.m.s. value of the electric field strength in the tissue in volts per metre;
- σ is the electric conductivity of the tissue in siemens per metre;
- ρ is the density of the tissue in kilograms per cubic metre.

3.43
source
RF source
electronic equipment intentionally transmitting an RF signal

3.44
source-environment plane
method to define the evaluation regions to be considered in the evaluation point selection based on environmental complexity and distance from the source

3.45
source region
spatial volume surrounding an antenna, divided into three regions according to the impact the field characteristics have on the evaluation of the RF field strength, power density or SAR

Note 1 to entry There are two source regions near the antenna, called source region I and source region II, and one at a larger distance, called source region III.

3.46
surveyor
person(s) responsible for planning, executing and reporting on the evaluation of RF field strength, power density or SAR levels

3.47
whole-body exposure
exposure averaged over the whole body, on reference location defined in the averaging scheme

3.48
worker
adult who is generally exposed to RF fields under known conditions and is trained to be aware of potential risks and to take appropriate precautions

4 Symbols and abbreviated terms

4.1 Physical quantities

The internationally accepted SI units are used throughout this document.

Symbol	Quantity	Unit	Dimensions
α	Attenuation coefficient	reciprocal metre	m^{-1}
B	Magnetic flux density	tesla	T, V s m^{-2}
c_h	Specific heat capacity	joule per kilogram per kelvin	J kg^{-1} K^{-1}
E	Electric field strength	volt per metre	V m^{-1}
f	Frequency	hertz	s^{-1}
H	Magnetic field strength	ampere per metre	A m^{-1}
J	Current density	ampere per square metre	A m^{-2}
T	Temperature	kelvin	K
ε	Permittivity	farad per metre	F m^{-1}
λ	Wavelength	metre	m
μ	Permeability	henry per metre	H m^{-1}
S	Power density	watts per square metre	W m^{-2}

Symbol	Quantity	Unit	Dimensions
Ω	Resistance	ohm	V A^{-1}
ρ	Mass density	kilogram per cubic metre	kg m^{-3}
σ	Electric conductivity	siemens per metre	S m^{-1}

NOTE 1 In this document, temperature is quantified in degrees Celsius, as defined by: T (°C) = T (K) – 273,16.

NOTE 2 Annex A and B.2 define additional symbols and variables used in this document.

4.2 Constants

Symbol	Physical constant	Magnitude
c	Speed of light in vacuum	$2{,}997\,9 \times 10^{8}$ m s^{-1}
η_0	Impedance of free space	376,730 3 Ω (approximately 120π Ω)
ε_0	Permittivity of free space	$8{,}854\,188 \times 10^{-12}$ F m^{-1}
μ_0	Permeability of free space	$4\pi \times 10^{-7}$ H m^{-1}

4.3 Abbreviated terms

ADB	assessment domain boundary
AMPS	Advanced Mobile Phone System
BCCH	broadcast control channel
BS	base station
CB	compliance boundary
CDD	cyclic delay diversity
CDMA	code division multiple access
CP	cyclic prefix
CPICH	common pilot channel
CRS	cell-specific reference signal
DECT	Digital Enhanced Cordless Telecommunications
DI	domain of investigation
DPCH	dedicated physical channel
ER	exposure ratio
EUT	equipment under test
FDD	frequency division duplex
FDMA	frequency division multiple access
FDTD	finite difference time domain
FEM	finite element method
FIT	finite integration technique
GSM	Global System for Mobile communications (originally *Groupe Spécial Mobile*)
HPBW	half power beamwidth
ICNIRP	International Commission on Non-Ionizing Radiation Protection
IP	Internet Protocol
LTE	Long Term Evolution

MAC	Media Access Control
MoM	method of moments
NMT	Nordic Mobile Telephone
OFDM	orthogonal frequency division multiplexing
P-SS	Primary Synchronization Signal
PBCH	Physical Broadcast Channel
PML	perfectly matched layer
PRACH	Physical Random Access Channel
RB	resource block
RBS	radiocommunication base station
RBW	resolution bandwidth
RE	resource element
RF	radio frequency
r.m.s.	root mean square
r.s.s.	root sum square
RS	reference signal
S-SS	Secondary Synchronization Signal
SA	spectrum analyser
SD	separation distance
TCP	Transmission Control Protocol
TDMA	time division multiple access
TER	total exposure ratio
TETRA	Terrestrial Trunked Radio
UDP	User Datagram Protocol
UMTS	Universal Mobile Telecommunications System
USDC	United States Digital Cellular
WCDMA	wideband code division multiple access
Wi-Fi®[1)]	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access

5 Quick start guide and how to use this document

5.1 Overview

Given the different types of evaluation methods of human exposure to EMF and their inherent complexities, this document contains a significant amount of technical detail. While such detail is necessary, care has been taken to layer the presentation of information, with content broadly separated into process, detail and additional information.

In Clause 5, high-level process information is provided from two perspectives: 5.2 outlines the structure of the document as applied to conducting an evaluation; and 5.3 is a high-level

1) Wi-Fi® is a trademark of the Wi-Fi Alliance. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC. While officially the term does not mean anything, it is typically used to describe Wireless Local Area Networks such as IEEE 802.11b/g/n/ac.

application based approach to applying the document to situations such as the determination of a compliance boundary.

5.2 Quick start guide

The quick start guide provides an overview of the evaluation process as a flow chart.

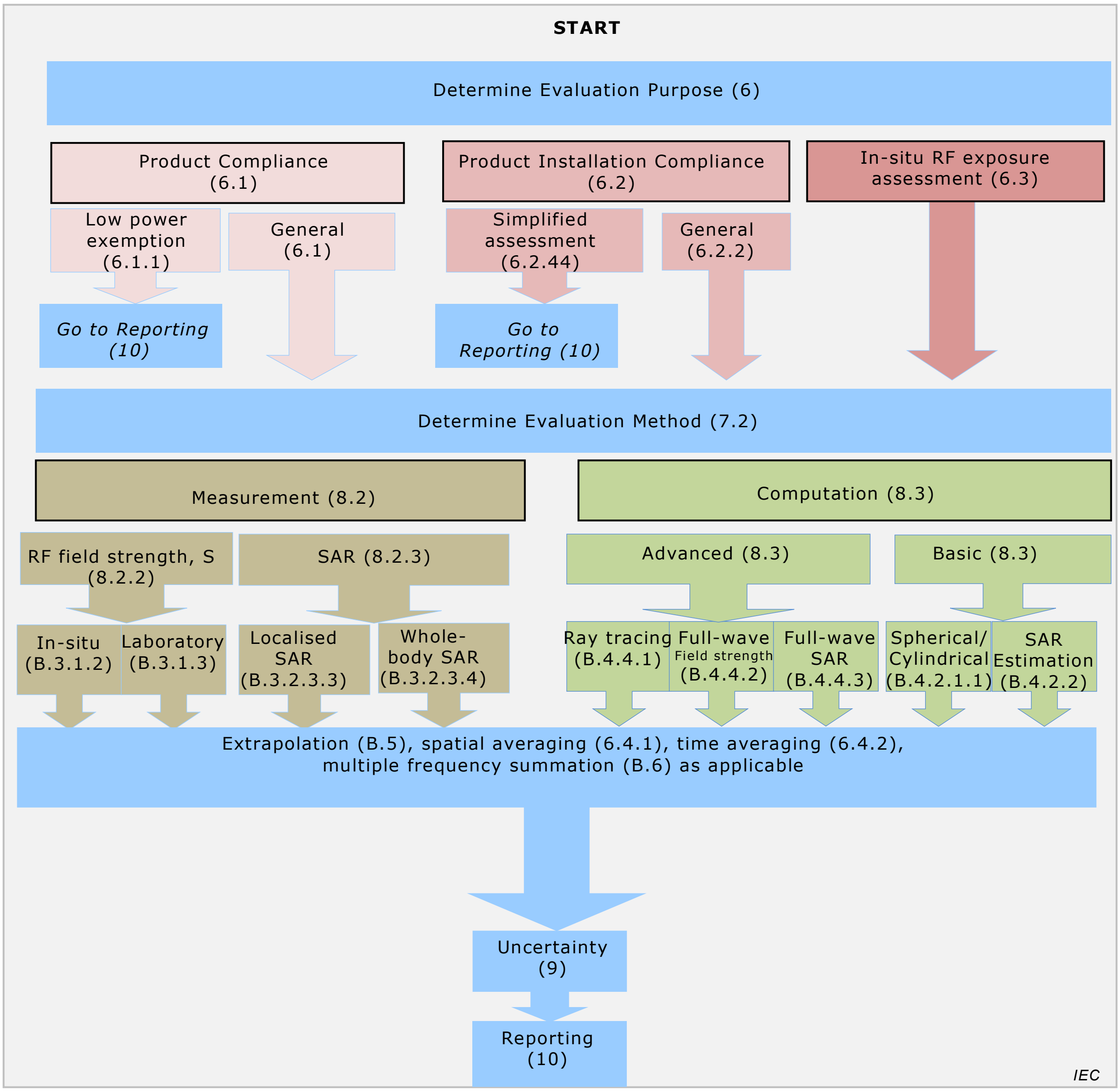


Figure 1 – Quick start guide to the evaluation process

The quick start guide shown in Figure 1 outlines the evaluation process along with the evaluation steps explained in Table 1. This sequence involves determining the evaluation purpose, method(s) of evaluation, as well as extrapolation, spatial averaging, time averaging and multiple frequency summation. The uncertainty and reporting stages complete the evaluation process. Report template is defined in 10.2. Worked case studies are introduced in 5.4.

Table 1 – Quick start guide evaluation steps

Stage	Evaluation steps	Action
Determine Evaluation Purpose (Clause 6)	Determine the purpose of the evaluation: – Product compliance – Product installation compliance, or – In-situ RF exposure evaluation	Confirm purpose of evaluation
RF exposure evaluation process (Clause 6)	Determine the applicable process to be used for the chosen evaluation purpose.	Run the evaluation process
Determine Evaluation Method (7.2)	Determine if a simplified evaluation process is applicable. Otherwise, select either a measurement or computation evaluation method, or both if required. Evaluation methods are ranked, and in general a higher ranked method takes precedence. However, lower ranking evaluations are valid within their applicability and may be more practical to implement, depending on cost, feasibility, and resource availability.	Select evaluation method
Measurement (8.2)	Determine applicable measurement procedures: – laboratory or in-situ measurement – SAR or RF field strength (broadband or narrowband) measurements	Select relevant measurement procedures if applicable
Computation (8.3)	Determine applicable computation methods. For example, a simple peak RF field strength evaluation, which is conservative, may be used. Even though higher ranking evaluation methods shall take precedence, they depend on the detailed information about the source and environment, as well as the availability of software packages capable of modelling such complexities.	Select relevant computation procedures if applicable
Extrapolation (B.5)	Determine if extrapolation is required. Where the test configuration differs from the required final evaluation configuration, an extrapolation factor will be required to adjust evaluated results (RF field strength, power density or SAR).	Determine extrapolation factor and apply to results
Summation (B.6)	Determine if the evaluation requires summation of combined exposure. Summation of combined RF field strength, power density or SAR value is required either when a single source emits RF fields on multiple frequency bands or when evaluating RF fields from multiple sources.	Sum test results if required
Uncertainty (Clause 9)	Any measurement or computation can only approximate the exposure metric within the uncertainty tolerance, and so a quantitative statement of uncertainty is required.	Determine uncertainty and complete the uncertainty table when applicable
Reporting (Clause 10)	The final report describes the results of the evaluation, provides sufficient technical details to allow for repeatability, and interprets the results by comparison with the relevant limit, if required.	Prepare final report and consider the report template in IEC TR 62669

5.3 How to use this document

There are three main applications of RF exposure evaluation defined in this document.

1) Product compliance: determination of compliance boundary information for an RBS product before it is placed on the market (see 6.1).
2) Product installation compliance: determination of the total RF exposure levels in accessible areas from an RBS product and other relevant sources before the product is put into service (see 6.2).
3) In-situ RF exposure assessment: measurement of RF exposure levels in the vicinity of an RBS installation after the product has been installed and is operating (see 6.3).

Clause 7 provides guidelines on how to select the evaluation method.

NOTE National regulatory agencies can have different requirements which override those specified by this document.

5.4 Worked case studies

A separate IEC Technical Report, IEC TR 62669 [1], contains worked evaluation examples of typical RBS sites using a range of methods described in this document. The example sites include roof-tops, towers, poles, small cells and in-building cells.

Each case study has been chosen to illustrate typical RBS sites and common evaluation tasks. Some of the case studies demonstrated multiple evaluation methods. However, in most scenarios, only one method would be required to complete an evaluation.

NOTE IEC TR 62669 was developed to address IEC 62232:2011. A new version of IEC TR 62669 is currently under development to reflect the updated evaluation procedures in this document.

6 Evaluation processes for product compliance, product installation compliance and in-situ RF exposure assessments

6.1 Evaluation process for product compliance

6.1.1 General

A manufacturer or other legal entity that will place an RBS product on the market is typically required to provide RF exposure information, including relevant compliance boundaries (exclusion zones), to the end user of the product. The compliance boundary shall be established for applicable RF exposure limits using RF field strength, power density or SAR assessment methods as described in 6.1.5.

Compliance boundary information is normally determined for a number of selected typical configurations (frequency band, number of transmitters, bandwidth, antenna, feeder, etc.) of the RBS product, assuming free-space conditions, and at the maximum power for each configuration.

NOTE Establishing compliance boundaries can be one of a range of requirements or methods that relate to product compliance.

Where a product complies with IEC 62479 and it applies depending on whether the applicable national regulatory agency recognizes it, then no compliance boundary is required. Otherwise, the compliance boundary shall be assessed according to 6.1.2 to 6.1.5.

6.1.2 Establishing compliance boundaries

The criteria defined in Table 3 and Clause 8 shall be used to select the exposure metric.

SAR or power density (depending on the frequency range) measurements are the most appropriate evaluation technique to determine accurate compliance boundary (CB) information for equipment designed for small stand-alone equipment/devices and multi-element base station antennas shorter than or equal to 1,5 m (see 8.2.2 and B.3.2). Examples of this type of equipment include medium range, local area, or home BS, picocell and microcell equipment 3GPP TS 25.104 [9], 3GPP TS 36.104 [10]. Alternatively, SAR can be calculated using estimation formulas or using advanced computational methods (see B.4.2.2 and B.4.4.3, respectively).

For all RBS products, in particular macrocell equipment but also small coverage area equipment, field strength or power density evaluations are applicable. Either laboratory measurements or computations may be used. (see B.3.1.3 and B.4, respectively). Alternatively, SAR can be calculated using estimation formulas or using advanced computational methods (see B.4.2.2 and B.4.4.3, respectively).

6.1.3 Iso-surface compliance boundary definition

The most accurate (smallest) compliance boundary is obtained as an iso-surface, with the iso-surface value given by the applicable RF exposure limit (see Figure 2).

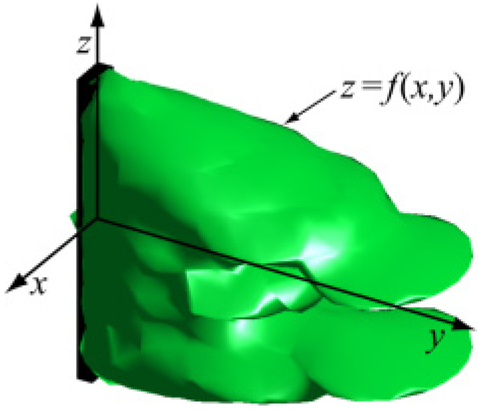


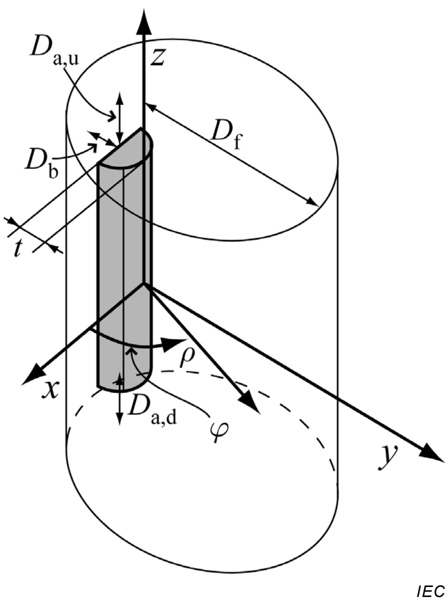
Figure 2 – Example of complex compliance boundary

In this case the shape of the compliance boundary shall be accurately described, e.g. in terms of a mathematical function $z = f(x,y)$.

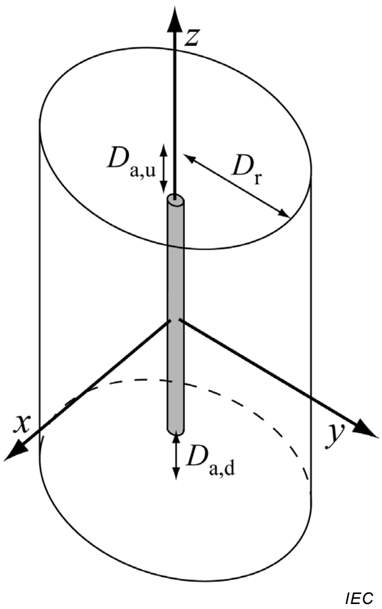
6.1.4 Simple compliance boundaries

The iso-surface compliance boundary defined in 6.1.3 may be enclosed in simpler shaped volumes to define more conservative compliance boundaries. Valid compliance boundary shapes are not limited to these examples.

In Figure 3 cases (a) and (b), two circular cylindrical compliance boundaries are illustrated for a sector coverage antenna and a horizontally omnidirectional antenna, respectively.



a) Sector coverage antenna



b) Horizontally omnidirectional antenna

Figure 3 – Example of circular cylindrical compliance boundaries

The compliance boundary for the sector coverage antenna is described in terms of D_f, D_b, $D_{a,d}$, $D_{a,u}$, and the antenna height and thickness according to Figure 3. Note that for the sector coverage antenna the distances D_f and D_b shall be determined so that the aforementioned iso-surface will be completely inscribed by the cylinder. In a similar way, the compliance boundary for the horizontally omnidirectional antenna is described in terms of D_r, $D_{a,d}$, $D_{a,u}$, and the height and radius of the antenna.

The box shaped compliance boundary shown in Figure 4 can be used for directional antennas, for example a panel antenna. In this case the boundary is described in terms of D_f, D_b, $D_{a,d}$, $D_{a,u}$, D_s, and the dimensions of the antenna.

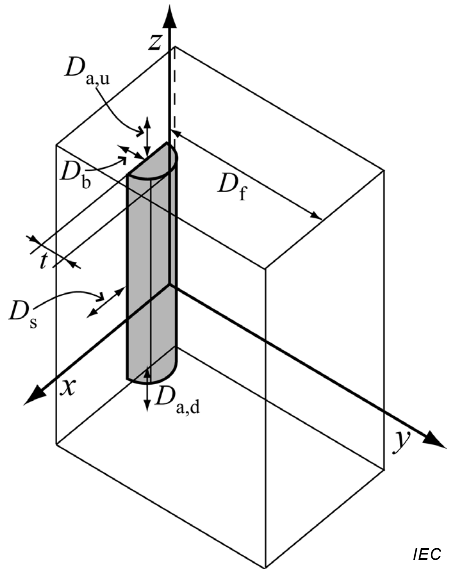
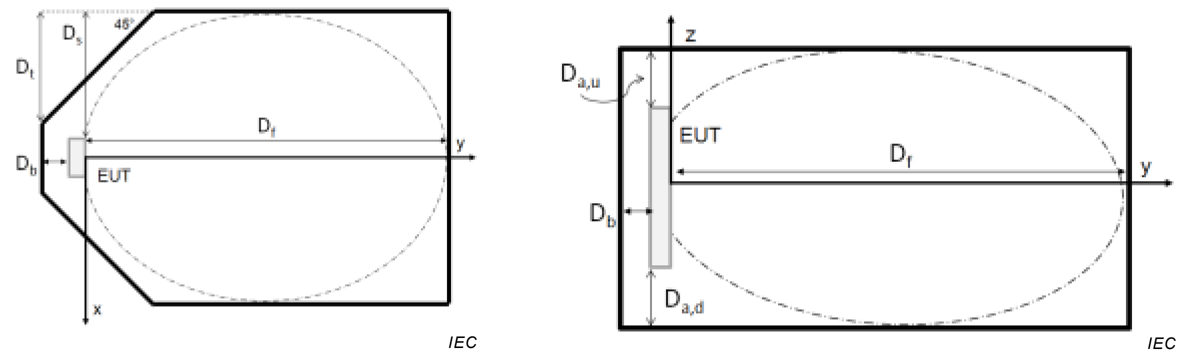


Figure 4 – Example of box shaped compliance boundary

In order to take into account the horizontal beamwidth of the antenna, the box shape may be truncated with 45° cut plane on the edges near the panel antenna. The truncated box shaped compliance boundary is described in Figure 5, which is defined by the truncation distance D_t in addition to the parameters of the box shaped compliance boundary (see Figure 4).



a) Top view b) Side view

Figure 5 – Example of truncated box shaped compliance boundary

For parabolic or dish antennas, the compliance boundary defined in Figure 7 and in F.11 can be used.

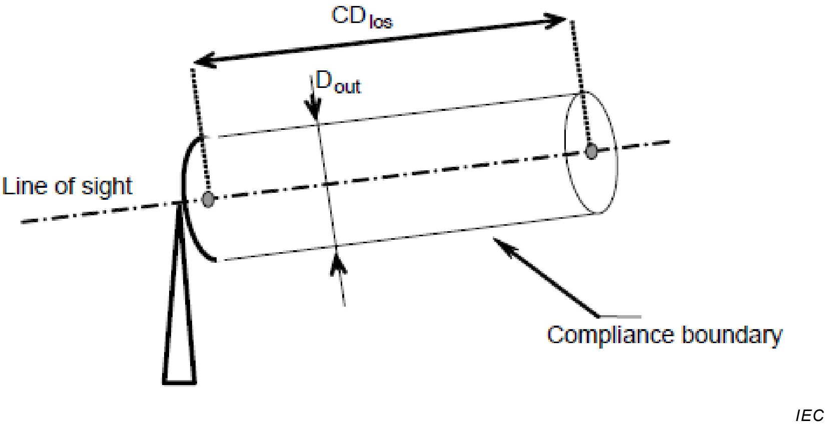


Figure 6 – Example of dish antenna compliance boundary (from [11])

6.1.5 Methods for establishing the compliance boundary

6.1.5.1 General

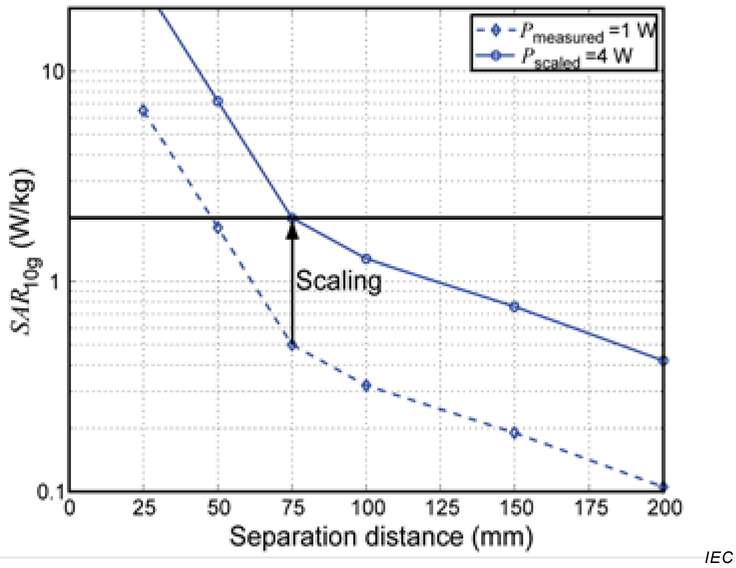
The compliance boundary shall be established according to 6.1.5.2 to 6.1.5.7 using evaluation methods defined in Clause 8 and Annex B.

6.1.5.2 Establishing compliance boundary using RF field strength measurements

Cylindrical or box shaped or truncated box shaped compliance boundaries shall be generated by measuring the RF field strength in suitable directions with respect to the transmitting antenna (e.g. front, back, side, and above/below), and then comparing the obtained RF field strength with applicable exposure limits (RF field strength or power density) (see B.3.1.3).

6.1.5.3 Establishing compliance boundary using *SAR* measurements

Cylindrical or box shaped or truncated box shaped compliance boundaries shall be generated by measuring *SAR* for suitable antenna orientations as a function of distance using the measurement procedure in B.3.2. By linear scaling of the *SAR* versus separation distance curve, compliance distances for different power levels shall be obtained by comparing the results with applicable exposure limits as illustrated in Figure 7.



NOTE Scaling to determine the compliance distance at a power level of 4 W, when the SAR measurements were performed at a power level of 1 W for a peak spatial-average SAR exposure limit of 2 W/kg over an averaging mass of 10 g.

Figure 7 – Example illustrating the linear scaling procedure

The scaled SAR values are computed from the measured by multiplying with the ratio between the scaled and the measured power levels. The compliance distance is then obtained from the figure by determining where the scaled SAR curve intersects with the pertinent SAR limit value.

6.1.5.4 Establishing compliance boundary using cylindrical and spherical formulas

The power density or field strength shall be calculated in a region surrounding the base station antenna for the maximum possible transmitted power using the formulas defined in B.4.2.1.1. Based on this evaluation, compliance boundaries in the form of various solids as described in 6.1.4 (sphere, cylinder or box) can be determined.

Alternatively, the basic algorithm defined in B.4.3 can be used to obtain an iso-surface compliance boundary by using the applicable RF exposure limit as the iso-surface value. Simpler and more conservative compliance boundaries can be obtained by inscribing the obtained iso-surface in various solids as discussed in 6.1.4.

6.1.5.5 Establishing compliance boundary using SAR estimation formulas

Cylindrical compliance boundaries (see Figure 3) shall be generated for sector coverage and horizontally omnidirectional antennas operating in the frequency range 700 MHz to 2 700 MHz by using the SAR estimation formulas of B.4.2.2 and applicable RF exposure limits according to the procedure described in [12]. For sector coverage antennas, the diameter of the cylinder is determined by the compliance distances in the front and back directions together with the antenna thickness t (see Figure 3a)). For horizontally omnidirectional antennas, the radius of the cylinder is determined by the main beam compliance distance and the radius of the antenna. The height of the cylinder is obtained by first multiplying the axial compliance distance with a factor of 2 (above and below antenna) and then adding the height of the antenna.

When implementing SAR estimation formulas for box shaped and truncated box shaped compliance boundaries, the SAR formulas defined in B.4.2.2 shall also be used.

6.1.5.6 Establishing compliance boundary using full wave analysis

After an accurate numerical model has been created following the procedure in B.4.4.2, the fields surrounding the base station antenna should be calculated for the maximum possible transmitted power. An iso-surface compliance boundary can then be obtained in a post-processing step by using the applicable RF exposure limit as the iso-surface value. Simpler and more conservative compliance boundaries can be obtained by inscribing the obtained iso-surface in various solids as discussed in 6.1.4.

6.1.5.7 Establishing compliance boundary for dish antennas

The compliance boundary is a cylinder and the compliance distance shall be established using the formula defined in F.11.

6.1.6 Uncertainty

Uncertainty analysis shall be performed according to Clause 9.

6.1.7 Reporting

Reporting shall be performed according to Clause 10. The RF exposure assessment report used for product compliance shall contain at least the following:

- Description of the EUT:
  - name, reference (e.g. serial number), technologies;
  - maximum transmitted power for each transmit frequency band;
  - antenna characteristics (gain, horizontal and vertical beamwidth) for each transmit frequency band, total $EIRP$, and, if the product is used with external antennas, a detailed description of at least one typical configuration[2], including antenna system (feeders, connectors, combiners, etc.);
- Description of the evaluation method and the exposure metric (SAR, S, E or H), the rationale for the choice (see Clause 7) and the relevant technical information required for repeatability and for documentation of the validity of the method, including:
  - for measurements:
    - probe(s) and measurement instrument(s) used, including characteristics, calibration details, and probe correction factors;
    - results of system validation check;
    - test setup and measurement conditions (temperature, etc.);
  - for calculations:
    - name and version of the calculation/simulation tool (if applicable);
    - limitations for the calculation/simulation tool (e.g. frequency range, near-field/far-field, etc.);
  - uncertainty analysis.
- Description of the compliance boundary:
  - compliance boundary shape (see 6.1.4);
  - compliance boundary dimensions for the relevant range of RF transmit powers, frequency bands, technologies and applicable exposure limits.
- Description of installation guidelines for the EUT, where relevant.

[2] Actual product installation parameters are reported according to 6.2.9.

6.2 Evaluation process used for product installation compliance

6.2.1 General

A network operator or other legal entity intending to put an RBS product into operation usually needs to evaluate the RF field strength levels; typically these evaluations are performed in accessible areas and in the vicinity of the base station, to verify compliance with relevant RF exposure limits and regulations. In such an evaluation, contributions from other relevant sources and possible effects of the environment need to be considered. Reasonable endeavours should be undertaken to consider other relevant sources.

The RF exposure levels from the RBS product and other relevant sources shall be determined at maximum transmit power of the equipment (theoretical or actual, see B.5) using measurements (see B.3.1.2) or computations (see B.4). Contributions from multiple sources shall be determined using summation formulas (see B.6).

6.2.2 General evaluation procedure for product installations

Where a new product is installed, the procedure described in Figure 8 shall be used to evaluate the RF exposure, taking into account other RF sources in the vicinity. In order to allow for accurate and efficient evaluations, different routes are possible depending on the characteristics of the product installation. In some specific cases, a simplified evaluation process of the product installation is possible without the necessity of conducting measurements or computations. Such a simplified evaluation process is defined in 6.2.4.

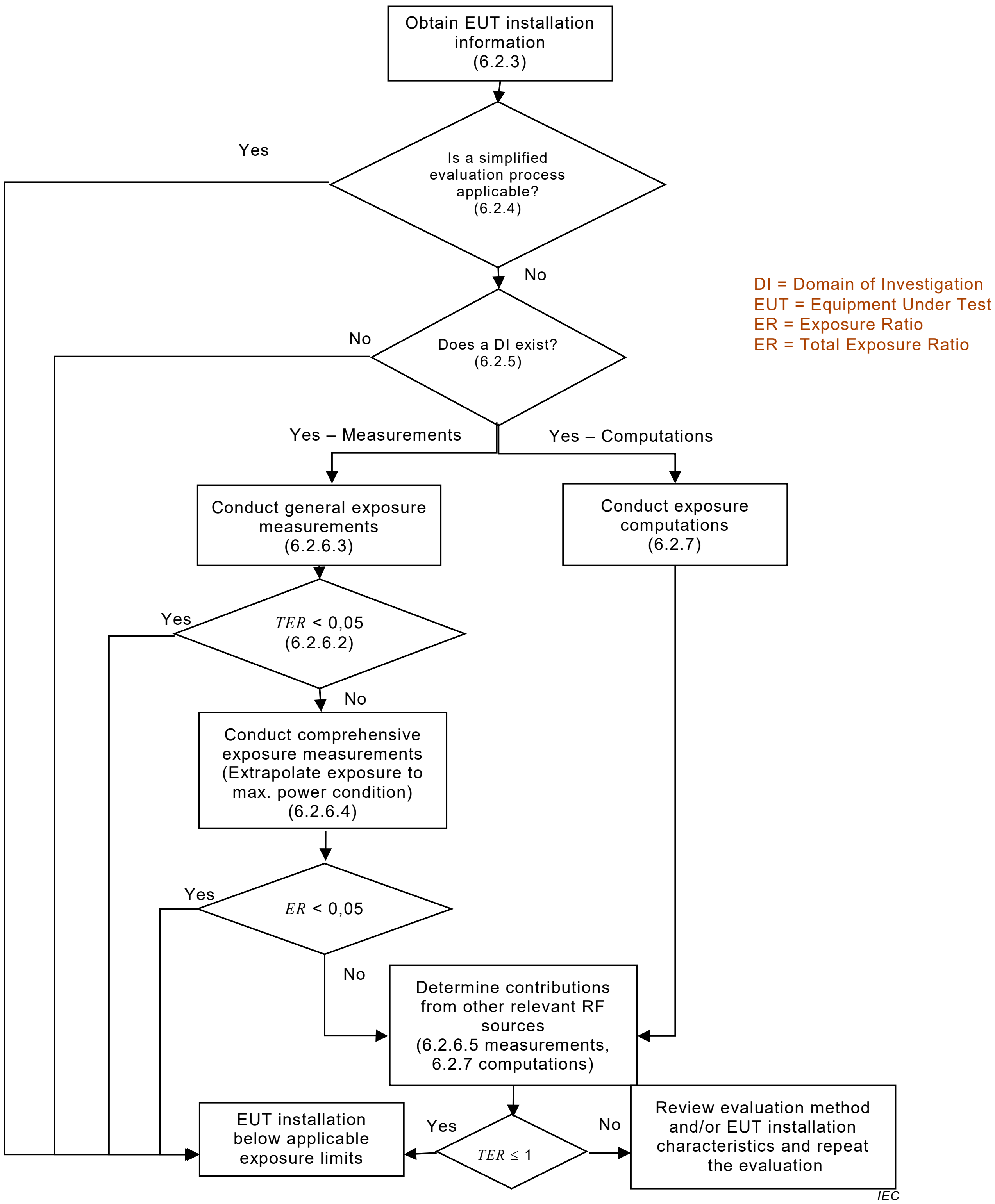


Figure 8 – Flowchart describing the product installation evaluation process

6.2.3 Product installation data collection

The following information shall be obtained for the product installation:

- maximum transmitted power for each transmit frequency band of the base station as installed;

- antenna characteristics (gain, horizontal and vertical beamwidth) for each transmit frequency band, total *EIRP*, and a detailed description of the configuration of the base station in its operational environment, including antenna system (feeders, connectors, combiners, etc.). If the product installation compliance has been assessed using the simplified evaluation process as defined in 6.2.4, then all parameters used to define the installation class in Table 2 shall be included;
- accessible area.

When comprehensive evaluations supporting extrapolation to maximum traffic is performed (see B.5) the following information is required:

- the reference name and frequency/bandwidth of any component of the whole signal which is to be used as a reference for extrapolation.
- the ratio between the component power level and the maximum power of the configuration to be extrapolated.

For example, the following information shall be used for GSM, WCDMA, and LTE:

- GSM: Central frequency of the broadcast channel (BCCH) and maximum number of carriers (channels) used by the product.
- WCDMA: Common pilot channel (CPICH) frequency and power level relative to total power.
- LTE: Centre frequency of the product channels and bandwidth.

6.2.4 Simplified product installation evaluation process

A simplified product installation process applies when no detailed measurements or computations are required to establish product installation compliance. The simplified evaluation process is based on easily accessible characteristics of the installation configuration, such as *EIRP*, direction of the main lobe, compliance boundary and installation positions of the transmitters/antennas with respect to accessible areas for the product and other relevant sources when applicable.

For the implementation of the simplified evaluation process, product specifications provided by the BS equipment and/or antenna manufacturer(s) shall be used, in particular transmitted power, antenna gain and compliance boundary dimensions evaluated in accordance with the requirements defined in 6.1.

Product installation evaluation is not required if the product complies with IEC 62479 or if the product compliance boundary dimensions are zero.

For products with antenna directivity of 30 dBi or above (e.g. dish antenna), product installation evaluation is not required if there is no access within the compliance boundary dimensions (see F.11). For such products, the antenna is usually installed to maintain line of sight conditions in order to prevent the radio link from being broken.

Product installation classes for which a simplified installation evaluation process is applicable can be developed based on applicable exposure limits. For example, the classes defined in Table 2 can be used with general public ICNIRP-based [13] exposure limits. The rationales used to establish those classes are presented in Annex C. If there are multiple equipment items co-located on the same site as the product, the *EIRP* criteria defined in Table 2 apply to the sum of *EIRP* of all co-located equipment.

Table 2 – Example of product installation classes where a simplified evaluation process is applicable (based on ICNIRP general public limits [13])

Class	$EIRP$[a] (W)	$EIRP$ (dBm)	Product installation criteria
E0	n/a	n/a	The product complies with IEC 62479 or the product compliance boundary dimensions are zero. No specific requirement for product installation.
E2	≤ 2	≤ 33	The product is installed according to instructions from the manufacturer and/or entity putting into service. Compliance with the exposure limits is generally obtained at zero distance or within a few centimetres.
E10	≤ 10	≤ 40	The product is installed according to instructions from the manufacturer and/or entity putting into service and the lowest radiating part of the antenna(s) is at a minimum height of 2,2 m above the general public walkway.
E100	≤ 100	≤ 50	The product is installed according to instructions from the manufacturer and/or entity putting into service and: (a) the lowest radiating part of the antenna(s) is at a minimum height of 2,5 m above the general public walkway, (b) the minimum distance to areas accessible to the general public in the main lobe direction is D_m [b], and (c) there is no pre-existing RF source with $EIRP$ above 10 W installed within a distance of 5 D_m metres in the main lobe direction (as determined by considering the half power beam width) and within D_m metres in other directions. D_m is the compliance distance in the main lobe assessed according to 6.1. If D_m is not available, a value of 2 m can be used or 1 m if all product transmit frequencies are equal to or above 1 500 MHz.[c]
E+	> 100	> 50	The product is installed according to instructions from the manufacturer and/or entity putting into service and: (a) the lowest radiating part of the antenna(s) is at a minimum height of H_m metres above the general public walkway, (b) the minimum distance to areas accessible to the general public in the main lobe direction is D_m [b] metres, and (c) there is no pre-existing RF source with $EIRP$ above 100 W installed within a distance of 5 D_m metres in the main lobe direction and within D_m metres in other directions. D_m is the compliance distance in the main lobe assessed according to 6.1 and H_m is given by Equations (6.1), (6.2) or (6.3).[d]

[a] $EIRP$ transmitted by the installed antenna(s) including all active bands.

[b] D_m is also defined as D_f or D_r in 6.1.4. For E10, the installation height is derived from the SAR estimation formula provided in B.4.2.2 and realistic antenna configurations. For E100, the installation height is derived from the SAR estimation formula provided in B.4.2.2 and realistic antenna configurations and D_m values of 1 m and 2 m are derived from the far-field spherical formula (Equation (B.21) in B.4.2.1.1.2) using a ground reflection factor of 0. For E+, H_m and D_m defined in Equations (6.1), (6.2) or (6.3) are derived from the far-field spherical formula (Equation (B.21) in B.4.2.1.1.2) using a ground reflection factor of 1.

[c] When such condition is not fulfilled, the installation is still compliant if the sum of the $EIRP$s of the EUT and nearby sources is less than 100 W. If the total $EIRP$ is above 100 W then the EUT is still compliant if it is installed at a minimum height of H_m metres above the general public walkway and at a minimum distance from areas accessible to the general public in the main lobe direction of D_m metres, where H_m and D_m are obtained using Equations (6.1), (6.2) or (6.3) for the sum of the $EIRP$s including those of nearby sources.

[d] When such condition is not fulfilled, the installation is still exempted from evaluations if the EUT is installed at a minimum height of H_m metres above the general public walkway and at a minimum distance from areas accessible to the general public in the main lobe direction of D_m metres, where H_m and D_m are obtained using Equations (6.1), (6.2) or (6.3) for the sum of the $EIRP$s including those of nearby sources.

The frequency dependent equations (6.1) to (6.3) below are applicable for calculation of the minimum installation height H_m and the compliance distance in the main lobe D_m defined in Table 2. These equations were introduced in [14]. To be conservative, f shall be chosen as the lowest limit of all frequency bands of the EUT.

For frequencies between 100 MHz and 400 MHz:

$$H_{\mathrm{m}} = \max\begin{cases} 2+\sqrt{\dfrac{EIRP\cdot A_{\mathrm{sl}}}{2\pi}} \\ 2+\sqrt{\dfrac{EIRP}{2\pi}}\sin(\alpha+1.129\theta_{\mathrm{bw}}) \end{cases} \qquad D_{\mathrm{m}} = \sqrt{\frac{EIRP}{2\pi}} \tag{6.1}$$

For frequencies between 400 MHz and 2 000 MHz:

$$H_{\mathrm{m}} = \max\begin{cases} 2+\sqrt{\dfrac{EIRP\cdot 200A_{\mathrm{sl}}}{f\pi}} \\ 2+\sqrt{\dfrac{200\cdot EIRP}{f\pi}}\sin(\alpha+1{,}129\theta_{\mathrm{bw}}) \end{cases} \qquad D_{\mathrm{m}} = \sqrt{\frac{EIRP\cdot 200}{f\pi}} \tag{6.2}$$

For frequencies between 2 000 MHz and 100 000 MHz (i.e. 100 GHz):

$$H_{\mathrm{m}} = \max\begin{cases} 2+\sqrt{\dfrac{EIRP\cdot A_{\mathrm{sl}}}{10\pi}} \\ 2+\sqrt{\dfrac{EIRP}{10\pi}}\sin(\alpha+1{,}129\theta_{\mathrm{bw}}) \end{cases} \qquad D_{\mathrm{m}} = \sqrt{\frac{EIRP}{10\pi}} \tag{6.3}$$

where:

f is the frequency of operation of the RBS in MHz;

A_{sl} is the side lobe suppression value in linear scale;

α is the downtilt in radians (both electric and mechanic);

θ_{bw} is the vertical half power beamwidth in radians.

6.2.5 Assessment area selection

The domain of investigation (DI) represents the volume where an exposure evaluation and assessment shall be conducted. The DI is the part of the assessment domain boundary (ADB) of the equipment under test, where the people may have access. Access in this context refers to any part of the body being within the ADB under normal conditions. Outside the ADB, the exposure ratio from the product installation shall be less than 0,05.

NOTE Outside the ADB the product is not a relevant source, and an evaluation is not needed.

If the compliance boundary is available, the length D_{ad} (in metres) of the ADB in the main beam direction shall be 5 times the compliance distance. Alternatively:

- for a single band antenna the simplified expression provided in Equation (6.4) can be used. It is based on the free-space formula (Equation (B.21) in B.4.2.1.1.2) and provides a conservative estimation of the ADB in the shape of a box (Figure 9).

$$D_{\mathrm{ad}} = \sqrt{\frac{EIRP}{0{,}05S_{\mathrm{lim}}4\pi}} = 1{,}3\cdot\sqrt{\frac{EIRP}{S_{\mathrm{lim}}}}, \tag{6.4}$$

  where S_{lim} is the relevant power density exposure limit (W/m^2).

- for multiband antennas having more than one active band, the ADB can be calculated using

$$D_{\mathrm{ad}} = 1{,}3 \cdot \sqrt{\sum_i \frac{EIRP_i}{S_{\mathrm{lim},i}}}, \tag{6.5}$$

where $EIRP_i$ is the $EIRP$ of the product in band i and $S_{\mathrm{lim},i}$ is the relevant power density exposure limit (W/m^2) for band i.

The dimensions of the ADB, if determined using Equation (6.4) or (6.5), are largely overestimated in the vertical direction of the antenna. Therefore, the following rules shall be applied:

- Access regions placed H_{b} metres or more below the antenna mounting height (measured from the centre point of the antenna) shall not be considered as part of the ADB, where H_{b} is given by[3]

  $$H_{\mathrm{b}} = \max\left(D_{\mathrm{ad}} \tan \alpha, 3{,}5\right) \tag{6.6}$$

  Here, α is the antenna downtilt (mechanical and electrical) in radians. If α is not known it can be assumed to equal π/15 radians (12 degrees), which is a realistic maximum downtilt chosen to obtain a conservative result. The number 3,5 m was also chosen to correspond to a realistic maximum H_{b} for an antenna with no downtilt.
- General public access regions placed 3,5 m or more above the antenna mounting height (measured from the centre point of the antenna) shall not be considered as part of the ADB.

The equations above are applicable for down-tilted antennas. If the antenna is tilted upwards the values shall be swapped. In addition, for rooftop or wall installations, regions within the building on which the antenna is mounted shall be excluded from the ADB if the antenna main beam is pointing away from the building[4].

Based on observations of the product installation and environment, as well as on experience gained by RF exposure evaluations of similar sites, the DI can be restricted to the points of maximum exposure.

If the general public has no access to the ADB, there is no DI and the product installation is compliant for general public access.

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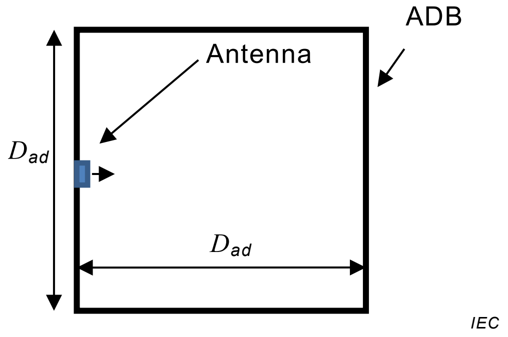
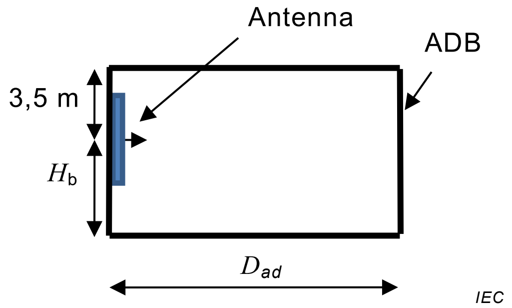
3 The first term in brackets corresponds to the height of the ADB given by the main beam for down-tilted antennas. The second term takes into consideration that for small tilt angles, the ADB in the vertical direction might be given by the antenna side lobe (or by the extension of the main lobe in the vertical plane). Since the maximum side lobe amplitude and direction might be difficult to estimate, a minimum height of 3,5 m is conservatively chosen.

4 Transmission in these directions corresponds to the side lobe of the antenna. In addition, the attenuation in the walls and roof can reduce the power density by 10 dB to 20 dB or more.



a) Top view



b) Side view

The ADB is oriented according to the antenna direction.

Figure 9 – Square-shaped assessment domain boundary (ADB) with size D_{ad}

6.2.6 Measurements

6.2.6.1 General

RF field strength measurements by means of both frequency selective or broadband equipment can be used to evaluate the product installation. The measurement system(s) and the post processing shall at least cover the frequency range from 100 kHz to 6 GHz and up to 300 GHz if required. Measurement equipment shall be chosen and operated according to B.3.1.2.

6.2.6.2 Determination of the total exposure ratio (TER)

The total level of exposure shall be calculated by summing the exposure ratios. This involves the extrapolated field strength E_i in each band used by the product and the relevant ambient sources (see 6.2.6.5). Where the general exposure evaluation has reported maximum field strength within the points of the DI, the following formula shall apply:

$$TER = \sum_{i=1}^{N} ER_i \ , \tag{6.7}$$

where ER_i is the exposure ratio for the band i.

6.2.6.3 General TER measurements

General TER evaluation consists of measurement of the total field strength over the entire frequency range of the product and relevant sources. Broadband equipment is suitable for this type of measurement. Frequency selective instruments can be used provided that the field strength is integrated over the entire bandwidth.

During general exposure evaluation, measurements shall be taken according to B.3.1.2.5 over the whole DI. Good practice is to move the probe slowly through the site of investigation, since probes are generally sensitive to fast movements.

The RBS installation is assessed to be compliant without further investigation if the maximum measured TER is lower than 0,05[5]. If the measurement equipment does not have a shaped frequency response, the lowest electric field strength or power density exposure limit values in the frequency range used by the entire RBS installation shall be used to calculate TER.

5 In this case the 0,05 threshold is related to additional nearby sources.

Otherwise, a comprehensive *TER* measurement shall be performed according to 6.2.6.4.

6.2.6.4 Comprehensive *TER* measurement

The comprehensive *TER* measurement shall be performed at the location(s) of maximum *TER* found in the general *TER* evaluation. It is conducted in order to obtain a conservative estimate of the *TER* when the product is transmitting at maximum power.

The comprehensive measurement shall be performed using broadband or frequency selective measurement equipment that is in compliance with the requirements and the measurement procedures specified in B.3.1.2.

For comprehensive measurements, the extrapolation procedure as described in B.5 shall be applied and spatial averaging shall follow 6.4. Where the *ER* of the product obtained with comprehensive measurements is less than 0,05 no further evaluation is required, and the site is assessed to be compliant.

6.2.6.5 Exposure contribution of ambient sources

Ambient sources shall be identified according to the description in 7.2.

For evaluations where the extrapolation of the field strength to the maximum power has been obtained by means of broadband measurements, the contribution from ambient sources is implicitly evaluated. No additional measurements need to be performed.

For evaluations using a frequency selective device, exposure ratios of greater than or equal to 0,05 shall be considered as relevant sources. Sources with lower *ER* can be excluded.

If the operating bands of nearby ambient sources are known, the *ER* contribution of each source can be determined. This can be done using frequency selective equipment by integrating the field strength over the corresponding band. When this information is not directly available, it can be retrieved by inspection of the significant spectrum peaks measured by the frequency selective device.

For time variant signals, the field strength from relevant source contributions shall be scaled to maximum power (see B.5). If the extrapolation factors are unknown the power density for each of the relevant bands shall be measured. Such measurement should occur during high-traffic hours, using a max-hold trace for a time until the equipment reading stabilizes (typically 1 min or less). However, additional uncertainty associated with not actually scaling to maximum power should be appropriately accounted for in the uncertainty evaluation (see Clause 9).

6.2.7 Computations

Various computational methods can be used to evaluate the level of exposure within the DI (see B.4). An overview of the applicability of the methods is provided in Table 7.

The transmitted power of the RBS shall be conservatively assumed equal to the maximum power (theoretical or actual, see B.5). Ambient sources with a computed *ER* larger than 0,05 within the DI shall be included in the evaluation.

The effect of environmental reflectors and scatterers shall be considered where relevant, see B.3.1.2.6. In areas with environmental reflectors a modified free space approach may be applied. In this case the *ER* can be overestimated by using the *ER* estimated in free space multiplied by a factor. Alternatively, the effect of reflecting objects shall be included in the uncertainty budget.

Reflections can be modelled using calculation tools, such as Ray Tracing (see B.4.4.1). If not possible, a generic multiplicative factor of 2,56 (for power density) or 1,6 (for E-field) can be used as recommended in [15] for ground reflections. Other site-specific power density multiplication factors can be used where more detailed information is available. In general, an accurate estimation of these reflection factors requires information on site topography including material parameters of near-by structures, frequency, transmission bandwidth, and field polarization.

A reflecting structure may be excluded from the RF exposure computations if one or more of the following conditions apply:

- The reflecting structure is not within line of sight from both the point of investigation and the radio source.
- The geometry of the reflector, point of investigation and radio source is such that the reflected ray is directed away from the point of investigation.
- The maximum projected dimension of the reflecting structure in the direction of the point of investigation is less than $L_{\mathrm{max}}$where

$$L_{\mathrm{max}} = \sqrt{\frac{d}{\lambda}}$$

where

d is the distance from the radio source to the structure;

λ is the wavelength of the considered radio source.

6.2.8 Uncertainty

Uncertainty analysis shall be performed according to Clause 9.

The target expanded uncertainty is 4 dB or below, which is considered industry best practice. The expanded uncertainty for the RF exposure evaluation used for the product installation compliance assessment shall not exceed 6 dB.

6.2.9 Reporting

Reporting shall be performed according to Clause 10. The RF exposure evaluation report used for product installation compliance shall contain at least the following.

- Description of the product:
  - name, reference (e.g. serial number), technologies;
  - maximum transmitted power for each transmit frequency band of the base station as installed;
  - antenna characteristics (gain, horizontal and vertical beamwidth) for each transmit frequency band, total $EIRP$, and a detailed description of the configuration of the base station in its operational environment, including antenna system (feeders, connectors, combiners, etc.). If the product installation compliance has been assessed using the simplified evaluation process as defined in 6.2.4, then all parameters used to define the installation class in Table 2 shall be included.
- Description of installation configuration for the product, including installation height, etc.
- Implementation of the simplified evaluation method (rationale, outcome) if applicable.
- If the simplified evaluation is not applicable, additional technical information required for repeatability and for documentation of the validity of the method are required. This shall include a description of the evaluation method and the exposure metrics (TER, S, E or H), the rationale for the choice (see 7.2), as well as:
  - description of the domain of investigation, relevant sources and scatters;

  - spatial averaging method used;
  - for measurements:
    - probe(s) and measurement instrument(s) used, including characteristics and calibration details,
    - testing conditions (temperature, etc.);
  - for calculations:
    - name and version of the simulation tool (if applicable),
    - calculation and simulation parameters used;
  - validity of measurement and/or calculation results.
  - uncertainty analysis.
- Description of general public access restrictions, if any, and guidelines on how to comply with workers limits during installation, maintenance and repair of the product.

The documentation may cover several base stations with similar technical specifications and environmental conditions.

6.3 Evaluation processes for in-situ RF exposure assessment

6.3.1 General requirements, source determination and site analysis

The objectives of in-situ measurements are:

- to determine if the RF exposure levels are in compliance with applicable exposure limits and regulations, e.g. in the vicinity of an operating RBS installation, or
- to obtain the RF exposure data, typically required for communication purposes.

The procedure described in Figure 10 shall be used to evaluate in-situ RF exposure assessment based on measurement methods, uncertainty, and reporting specified in 6.3.2 to 6.3.4.

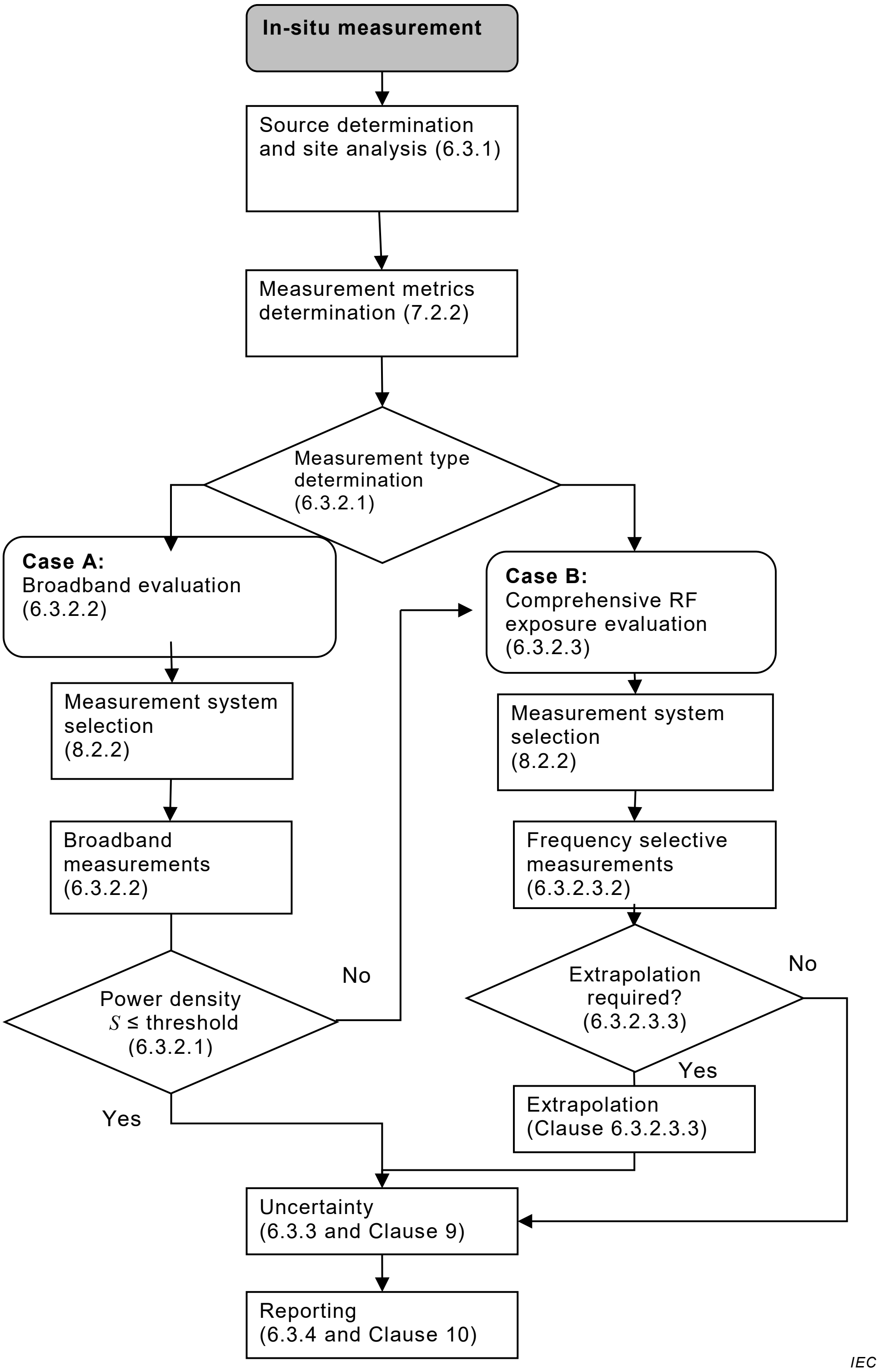


Figure 10 – Alternative routes to evaluate in-situ RF exposure

The in-situ RF exposure evaluation or assessment shall be performed at one location or area, known as the measurement area.

The process shall start by identifying all relevant fixed and permanently emitting RF source installations in the surrounding area according to 7.2. The measurement system(s) and the post processing shall cover the RF emissions from the product and all relevant ambient sources between at least 100 kHz and 300 GHz as determined by the site analysis.

Then, the measurement metrics applicable on the measurement area shall be determined according to the distance from the source antenna, see 7.2.3).

NOTE In a complex field local minima and maxima occur within a relatively small area. Factors such as shadowing, reflection and diffraction, together with the radiation pattern characteristics of transmitting antennas, can be involved. The effects of fast fading, however, can be estimated and accounted for by spatial sampling and averaging (described in 6.4.).

6.3.2 Measurement procedures

6.3.2.1 Measurement type selection

The second step is to choose between two evaluation approaches, known as Case A and Case B as indicated in Figure 10. Case A provides a set of results covering all sources and frequencies at one measurement area. Case B provides separate sets of field values for each source, frequency or frequency sub-band present in the measurement area.

The choice of the measurement type depends on the objective of the in-situ evaluation.

- If the objective is to provide a global evaluation of RF exposure level from all sources together “as observed” (i.e. no extrapolation, no signal spectrum differentiation) then the evaluation shall start with Case A evaluation. However, if the power density assessment based on Case A is above applicable RF exposure limits (i.e. the threshold defined under Case A in Figure 10 is the applicable exposure limits) or if it is necessary or desired to investigate the contribution from each RF source, the Case A evaluation shall be complemented by a Case B evaluation.
- If the objective is to provide a detailed evaluation of RF exposure levels (i.e. combining the contributions of all RF sources, spectrum differentiation above a certain threshold), the evaluation shall start using Case A. If the power density level is above 10 mW/m^2 (i.e. threshold defined under Case A in Figure 10), the Case A evaluation shall be complemented by a Case B evaluation. However, if there are pre-existing national requirements, a different threshold between 5 mW/m^2 and 100 mW/m^2 may be used. Further, some national requirements may specify one method or another.
- If the objective is to provide a comprehensive evaluation of RF exposure, i.e. investigating every contribution from RF sources using a frequency selective analysis, then a Case B evaluation shall be conducted. It is recommended that a Case B evaluation is preceded by a Case A evaluation.

6.3.2.2 Case A (broadband evaluation)

Case A corresponds to an exposure evaluation on one measurement area using broadband equipment in compliance with 8.2.2 and B.3.1.2.3 and consistent with the purpose (6.1.1).

The measurement system(s) shall cover the frequency range of the RF emissions from the product and all relevant ambient sources between at least 100 kHz and 300 GHz as determined by the site analysis. Additional requirements are defined in B.3.1.2.2.

A Case A evaluation shall start by performing a slow scan over the measurement area at a height of 1,5 m above ground in order to find the location of the maximum exposure. At this location, if spatial averaging is applicable, measurements at different heights shall be performed in order to assess the spatial averaged value as described in 6.4.1. If time averaging is required, it shall be implemented as defined in 6.4.2.

Broadband measurements may be used to provide instantaneous environmental field-strength information or to indicate if it is necessary to perform a comprehensive exposure evaluation (Case B).

Broadband measurement in case of global or detailed RF exposure evaluation (Case A) shall not be used for extrapolation. Without the ability to discriminate frequency, such extrapolation could result in a large overestimation of the maximum exposure.

6.3.2.3 Case B (comprehensive exposure evaluation)

6.3.2.3.1 General

Case B corresponds to a comprehensive exposure evaluation with a frequency selective instrument, including identification of relevant sources, and extrapolation of exposure to maximum traffic load if required.

6.3.2.3.2 Measurement protocol

The operator shall use frequency selective measurement equipment as specified in 8.2.2 and B.3.1.2.4. Case B measurements shall be performed at a given location, e.g. the location of maximum exposure of a measurement area identified in Case A (see 6.3.2.2). The total exposure taking into account multiple frequencies shall be performed according to B.6.

The evaluation shall begin with a comprehensive frequency scan at the measurement location covering at least 100 kHz to 6 GHz, unless pre-evaluation of operating sources/ frequencies has been conducted and documented in the report. The scan results or pre-evaluation shall be used to identify for each technology the significant frequencies for which spatially averaged (see 6.4) or sweeping (see B.3.1.2.5.2) measurements, shall be conducted. In order to be able to accurately measure total exposure levels down to 1 % of the power density reference levels, sources shall be considered as significant when the exposure level is above 0,01 % (-40 dB) of the lowest power density reference level in the assessed frequency range. If no significant source is measured, the two highest sources shall be reported.

Frequency selective measurements shall be conducted at all points required for the implementation of spatial averaging or sweeping method. Depending on the objective of the in-situ evaluation or assessment, either the raw measurement results or the extrapolated measurement result, according to 6.3.2.3.3, shall be provided.

The total exposure shall be assessed using the summation formulas defined in B.6.

6.3.2.3.3 Extrapolation of the exposure at the network maximum traffic load

For the case where the aim is to evaluate the maximum exposure conditions taking into account traffic and transmitted power variations, then the evaluation result data shall be extrapolated. When extrapolation is performed it shall apply only to significant sources (see 6.3.2.3.2). The result shall be extrapolated from measurement of time independent channel(s) as defined in B.5 and Annex F.

6.3.3 Uncertainty

Uncertainty analysis shall be performed according to Clause 9.

The target expanded uncertainty is 4 dB or below, which is considered industry best practice. The expanded uncertainty for RF exposure evaluation used in in-situ RF exposure assessment shall not exceed 6 dB.

6.3.4 Reporting

Reporting shall be performed according to Clause 10. The in-situ RF exposure evaluation or assessment report shall contain at least:

- description of the measurement site, including the relevant RF sources and the points where measurements have been performed;
- environmental conditions, time and date, name of entity responsible for the measurement;
- measurement protocol used, including spatial averaging, time averaging, etc.;
- probe(s) and measurement instrument(s) used, including characteristics and calibration details and probe correction factors;

- measurement results and all information necessary for the interpretation of the in-situ RF exposure evaluation or assessment (e.g. instantaneous, extrapolation, etc.)
  - if extrapolation is used, description of the extrapolation method and rationale for the extrapolation factor(s);
- uncertainty analysis.

6.4 Averaging procedures

6.4.1 Spatial averaging

Where spatial averaging is required (e.g. 6.3 related to in-situ RF exposure assessment), it shall be performed according to the specifications defined in B.3.1.4 and with a minimum of three measurement points as defined in Figure B.10. However, depending on the location and accuracy required, the number of measurement points to be averaged may be increased using B.3.1.4.4.2 specifications.

Where localized, partial-body exposure, or the applicable RF exposure limits (for example in the near-field) are relevant, the maximum RF field strength or power density shall also be considered (see Table 3).

6.4.2 Time averaging

Time averaging is applicable where the RF field strength varies over time. Factors that contribute to time variation include changing propagation conditions, variations of the transmitter power due to traffic load, variations due to power control, or transmitter duty cycle.

Where time averaging is applicable, it shall be implemented as defined in B.3.1.

The relevant exposure standard may specify the appropriate time over which exposure is to be averaged.

7 Determining the evaluation method

7.1 Overview

Once the purpose of the evaluation has been determined, the next step is to determine the evaluation method including the evaluation points, ambient fields and other details. The evaluation method shall be selected considering the exposure metrics (see 7.2.3) and the applicability of the evaluation methods (see Clause 8 and Table 3). More than one evaluation method may be valid.

If specific evaluation methods are specified in Clause 6, these shall be used. Otherwise, the process in 7.2 shall be followed. When defining the assessment configuration, the specific national (e.g. regulatory and legislative) requirements shall be taken into account.

Evaluation method determination examples can be found in the worked case study examples of IEC TR 62269 [1].

7.2 Process to determine the evaluation method

7.2.1 General

Prior to conducting an evaluation, the surveyor shall determine the evaluation configuration following the tasks described below.

a) Establish the evaluation points in relation to the source-environment plane (see 7.2.2).
b) Establish the appropriate exposure metric (see 7.2.3).
c) Select computation or measurement approach (see Annex A).

d) Establish if ambient fields need to be considered.

Where the evaluation purpose is to determine the combined field from all sources at a given location, ambient fields shall be evaluated (see B.3.1.2.6). The surveyor shall identify all fixed permanently installed RF sources operating between 100 kHz and 6 GHz and reasonable endeavours shall be applied to identify all RF emissions between 100 kHz and 300 GHz. The evaluation shall be performed according to the specifications in 6.2.6.5 or 6.3.2.

e) Ambient sources can be identified through visual inspection, consultation of available user database, information from the site owner, as well as broadband or frequency-selective measurements.

f) Additional considerations to consider can be found in A.5.

Based on the determined evaluation configuration and guidance provided in Clause 8 and Annex B, the evaluation method is chosen.

7.2.2 Establishing the evaluation points in relation to the source-environment plane

7.2.2.1 General

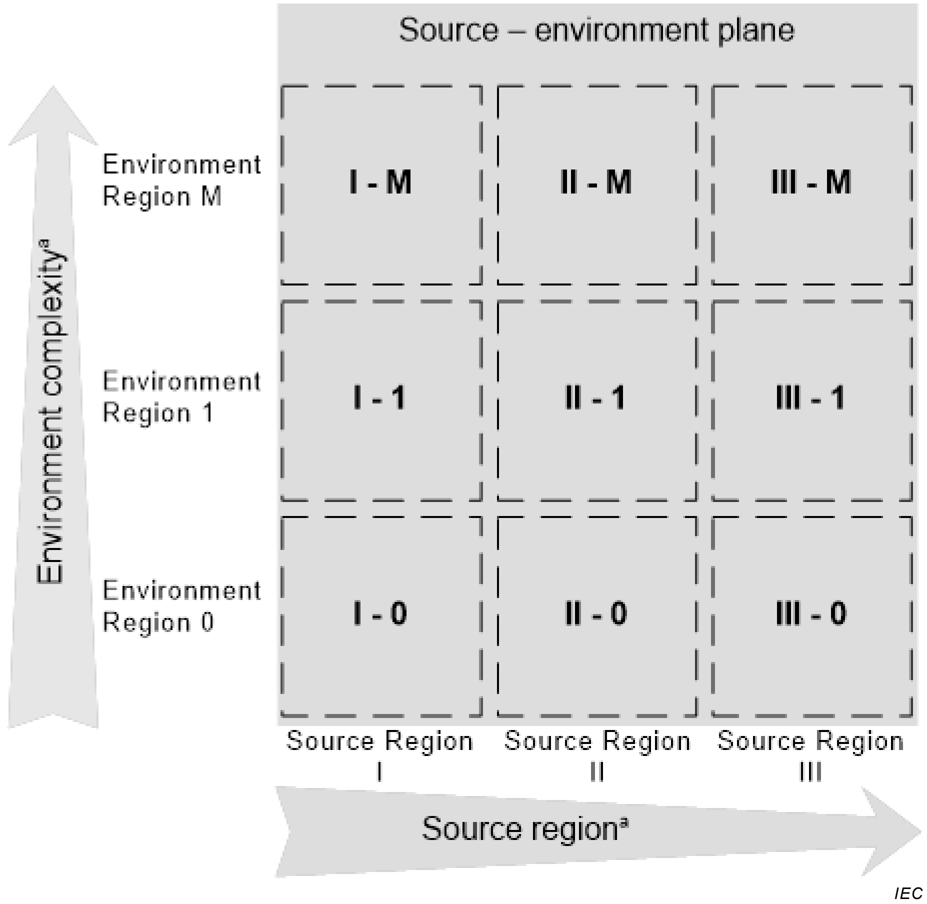
The source-environment plane defines the evaluation regions to be considered in the evaluation point selection based on environmental complexity and distance from the source.

7.2.2.2 Source-environment plane definition

The source-environment plane is a tool to categorize the regions around an antenna based on environmental complexity and distance from the antenna. Influenced by both the scattering environment and the distance separating the antenna from the evaluation point, the source-environment classification impacts the evaluation method.

For more detail on the environmental regions see Annex A.

The source-environment plane consists of nine evaluation regions. The "x-axis" represents increasing distance from a source located at the coordinate-system origin. The "y-axis" represents increasing scattering effects contributing to total fields at observation points (see Figure 11).



[a] In this document, if a * replaces the environment region character, this means any environment region (i.e. 0, 1 or M) applies. If a * replaces the source region character it means any source region (i.e. I, II or III) applies.

Figure 11 – Source-environment plane concept

7.2.2.3 Definitions of source regions

Source region I constitutes the reactive near-field of the source, see A.1.3.

Source region II constitutes the radiating near-field of the source, see A.1.3.

Source region III constitutes the far-field of the source, see A.1.3.

7.2.2.4 Definitions of environment regions

The environment regions are based on the proximity to, or effects from, scattering objects; such scattering objects may be in the vicinity of the source, in the vicinity of the evaluation point or may otherwise affect the RF field strength between the antenna and the evaluation point.

In environment region 0 there is no obstruction between the source antenna and the evaluation point. Also the levels from any reflections are small enough not to affect materially the evaluated level, within the uncertainty of the evaluation.

In environment region 1 there is no obstruction between the source antenna and the evaluation point and there is just one clearly dominant reflector, e.g. the ground. Other reflectors meet the environment region 0 criteria.

In environment region M there is obstruction between the source antenna and the evaluation point and/or there are two or more reflectors.

Examples are provided in A.1.2.

7.2.2.5 Establish where evaluation points are on the source-environment plane

Determine in which source-environment plane regions (see A.1) the evaluation points lie.

7.2.3 Exposure metric selection

Table 3 gives the exposure metrics (field strength, power density, *SAR*) validity and class based on where the evaluation point lies in the source-environment plane (see 7.2.2) and the relevant limit.

Table 3 – Exposure metrics validity for evaluation points in each source region

Exposure metric class	Exposure metrics validity (Measured/computed)[a]		
	Source region I	Source region II	Source region III
1	Localized and whole-body *SAR* and power density[b, c]		
2	Electric field strength and magnetic field strength[c, d]	Electric field strength or magnetic field strength / Plane wave equivalent power density[c, e]	

[a] The exposure metric can be expressed as a value or exposure ratio.

[b] Some international safety standards and guidelines state *SAR* or power density depending on the used frequency range as the basic restriction, thereby giving these highest priority in the applicable frequency range.

[c] Where the applicable exposure limits include a time averaging period, a relevant time-averaged evaluation has a higher validity than a non-time-averaged evaluation.

[d] The reactive power components are not negligible in source region I, so both electric field strength and magnetic field strength need to be evaluated (see A.1).

[e] The validity of spatial averaging depends on the relevant limit according to two cases:

Case i) The applicable exposure limits include different spatial-peak and spatially-averaged RF field strength limits (both conditions to be met): In this case, the spatially-averaged RF field strength is more appropriate than the spatial-peak RF field strength when comparing with the spatially-averaged limit. The spatially-averaged RF field strength shall not be compared with the spatial-peak limit.

Case ii) The applicable exposure limits include a single limit addressing both spatial-peak and spatially-averaged evaluations: In this case, the spatial-peak RF field strength is more appropriate than the spatially-averaged RF field strength.

8 Evaluation methods

8.1 Overview

Clause 8 provides an overview of the evaluation methods to measure or compute RF field strength, power density, or *SAR*. The details are defined in corresponding annexes. Each method description includes the applicability and constraints within which it may be employed, the information required to implement the method, and advice relating to the uncertainty of the evaluation.

The evaluation method is selected according to Clause 7. For additional information, clarification or justification of the evaluation methods, refer to annexes and external references.

8.2 Measurement methods

8.2.1 General

The relevant measurement methods are displayed below in Figure 12. This process is an expansion of the measurement block from Figure 1.

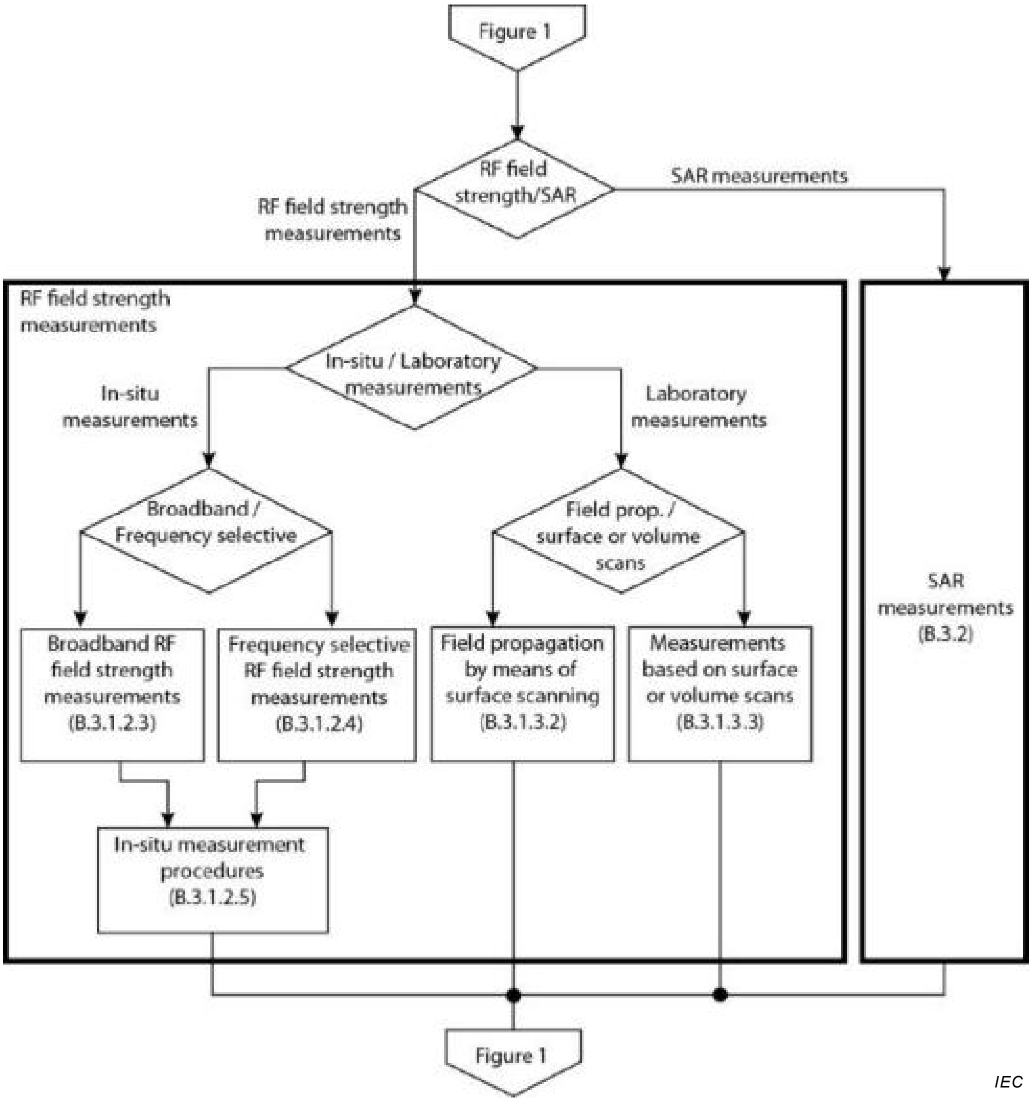


Figure 12 – Flow chart of the measurement methods

8.2.2 RF field strength measurements

RF field strength measurement is applicable in all source-environment plane regions (see 7.2 and Table 3). Frequency-selective measurement is recommended anywhere when there is more than one signal or frequency present.

Field strength measurements shall be performed according to the requirements defined in B.3, in particular the requirements listed in Table 4.

Table 4 – Requirements for RF field strength measurements

Normative subclause	Title
B.3.1.2	In-situ RF exposure measurements
B.3.1.3	Laboratory based field strength measurements
B.3.1.4	Spatial averaging
B.3.1.5	Time averaging
B.3.1.6	RF field strength measurement uncertainty

8.2.3 *SAR* measurements

The *SAR* measurement procedures are generally applicable for small stand-alone equipment/devices and multi-element base station antennas shorter than or equal to 1,5 m. The distance between the phantom and the outer surface of the radiating structure (antenna) shall not exceed 1 000 mm. *SAR* measurements are applicable in the frequency range 300 MHz to 6 GHz.

If the maximum RF transmitted power of the product is less than the values specified in Table 5, it is not necessary to perform whole-body *SAR* measurement.

Table 5 – Whole-body *SAR* exclusions based on RF power levels

Exposure condition	Maximum transmitted RF power (W)
General public exposure.	General public whole-body *SAR* limit [W/kg] × 12,5 [kg]
General public exposure. Lowest part of the product antenna installed 2,2 m or more above level realistically accessible by the general public. Access denied to children due to antenna installation height.	General public whole-body *SAR* limit [W/kg] × 46 [kg]
Workers exposure.	Occupational whole-body *SAR* limit [W/kg] × 46 [kg]
NOTE 1 The product installation point is measured from the lowest part of the antenna above an area realistically accessible to the general public. The height of 2,2 m is derived from class E10 (see Table 2 in 6.2.4). NOTE 2 The whole-body *SAR* exclusion power levels have been derived based on the following assumptions: (1) all of the power emitted from the antenna is absorbed in the body, (2) children below the age of 4 do not have access to the antenna at a distance of less than 20 cm and (3) the body masses for a 4-year-old child (12,5 kg) and a 16-year-old worker (46 kg) have been derived from body weight statistics published by WHO [16] and US National Center for Health [17] (see B.3.2.3.4).	

SAR measurements (local or whole-body) shall be performed using the measurement equipment defined in B.3.2. More specifically for local *SAR* measurements, the protocol defined in B.3.2.3.3 shall be used. For whole-body *SAR* measurements, the protocol defined in B.3.2.3.4 shall be used.

SAR measurements shall be performed according to the requirements defined in B.3.2, in particular the requirements listed in Table 6.

Table 6 – Requirements for *SAR* measurements.

Normative subclause	Title
B.3.2.2	*SAR* measurement requirements
B.3.2.3	*SAR* measurement description
B.3.2.4	*SAR* measurement uncertainty

8.3 Computation methods

The relevant computation methods for RF field strength, power density and *SAR* evaluation are displayed in Figure 13. This process is an expansion of Figure 1, dividing the evaluation methods into one of two categories, based on their complexity.

When considering which computation method to select, the simplest applicable method should be used provided that it delivers the required level of precision. A more comprehensive (advanced) evaluation method will usually take longer to perform, but yield a more accurate result; as such, an advanced computation may take precedence when compared to the results of a basic evaluation – see the exposure metric class in 7.2 and the evaluation method ranking in Table A.12. Table A.10 provides further guidance on how to select the appropriate computation method.

Each computation method shall be validated before it is used. As a minimum, the described computation methods shall be verified against the results presented in Annex B. For methods or cases not covered in Annex B, validation shall be completed against measured data.

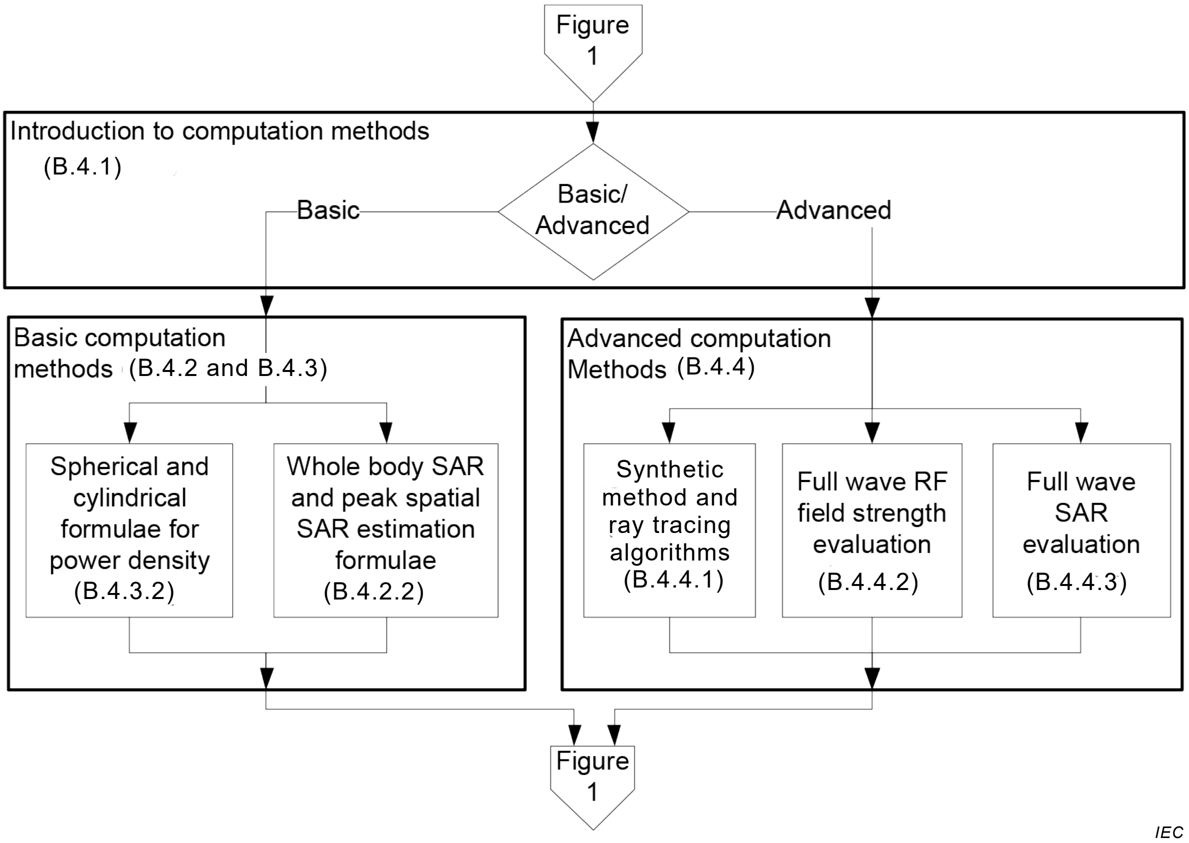


Figure 13 – Flow chart of the relevant computation methods

Table 7 provides a summary of applicable computation methods (basic and advanced) in the source-environment plane (see Annex A).

Table 7 – Applicability of computation methods for source-environment regions of Figure 10

	Applicable methods[a] (see B.4.4.1 B.4.4.2, B.4.4.3)	
	Source region I	**Source regions II and III**
Environment region M	1. Full wave – Field strength 2. Full wave – *SAR*	1. Synthetic model and ray tracing algorithms 2. Full wave – Field strength 3. Full wave – *SAR*
Environment region 1	1. Full wave – Field strength 2. Full wave – *SAR*	1. Spherical or/and cylindrical formulas (see B.4.3.2) 2. Synthetic model and ray tracing algorithms 3. Full wave – Field strength 4. Full wave – *SAR*
Environment region 0	1. *SAR* estimation formulas (see B.4.2.2) 2. Full wave – Field strength 3. Full wave – *SAR*	1. *SAR* estimation formulas (see B.4.2.2) 2. Spherical or/and cylindrical formulas (see B.4.3.2) 3. Synthetic model and ray tracing algorithms 4. Full wave – Field strength 5. Full wave – *SAR*

[a] Methods are listed in order of recommendation based on practicability of implementation. However, as a general principle, methods based on basic restrictions always take precedence over reference level based methods in case of dispute.

RF exposure computation shall be performed according to the requirements defined in B.4, in particular the requirements listed in Table 8.

Table 8 – Requirements for computation methods

Normative subclause	Title
B.4.2	Formulas
B.4.3	Basic algorithms
B.4.4	Advanced computation methods

9 Uncertainty

Uncertainty shall be estimated for every reported measured and calculated RF field strength, power density or *SAR* evaluation. It shall take into account specific requirements defined in Annex B for each evaluation method. Annex E provides general information and additional guidance on how to estimate uncertainty can be found in JCGM 100:2008 [18].

The total combined uncertainty is based on a mathematical model which defines how the influence quantities are added, see E.3. A simple multiplicative model, expressed as a linear series of dB variation terms, is generally appropriate as provided in Table B.7 and Table B.8. Alternatively, the total combined uncertainty can be determined by combining uncertainties expressed in percent for *SAR* assessments. The use of mixed dB and linear units shall be avoided when determining the combined uncertainty.

Carobbi [19] has examined the issue of conversion between linear and log units in addition to its effect on the uncertainty evaluation from a mathematical point of view. The approach used in [19] may be applicable to each particular case of uncertainty evaluation by using logarithmic expression. The chosen unit may affect the uncertainty evaluation results, and it may cause an overestimation or underestimation of the uncertainty.

The expanded uncertainty for the evaluation should be below the target values specified for each method in 6.2.8, 6.3.3 and Annex B which represent industry best practice and shall not exceed the maximum values specified in 6.2.8, 6.3.3 and Annex B. Where there is a requirement for the assessment to be conducted at maximum operating power or a set power level, variations due to product transmit power control should not be considered when evaluating the expanded uncertainty.

Where the extrapolation factor is known, additional uncertainty is not required (see Annex B and for information about RF power variations for different technologies see Annex F).

Where an extrapolation factor is unknown, additional uncertainty for scaling to maximum power shall be appropriately accounted for in the uncertainty evaluation.

10 Reporting

10.1 General requirements

The results of each evaluation or assessment carried out, and all information necessary for their interpretation shall be reported accurately, clearly, unambiguously and objectively.

All the information needed for performing repeatable evaluations or assessment giving results within the required calibration and uncertainty limits shall be recorded. More detailed requirements are provided in Clause 6 for each type of evaluation.

Further guidelines on the evaluation or assessment report can be found in ISO/IEC 17025 [20].

10.2 Report format

The format shall be designed both to accommodate each type of evaluation or assessment carried out and to minimize the possibility of misunderstanding or misuse. Example reports are presented as case studies in IEC TR 62669 [1].

The report itself should have but is not limited to the following:

a) a title;
b) the name and address of the laboratory or entity performing the evaluation or assessment, and the address where the measurements/computations were carried out, if different from the laboratory;
c) unique identification of the report (such as the serial number), and on each page an identification to ensure that the page is recognized as a part of the test report, and a clear identification of the end of the test report;
d) the name and address of the client;
e) a description of the item(s) evaluated;
f) the date(s) of performance of the evaluation;
g) the regions or locations at which the evaluation or assessment was conducted;
h) where relevant, conditions that may influence evaluated data:
    - for exterior or interior surveys, a description/photograph of the environment, illustrating the proximity of antennas to absorbing, scattering, or re-radiating structures located above, in front, or beneath the surface; weather conditions, and unusual or uncontrollable human movement in the survey area;

i) the evaluation methods employed (either explicitly described or by referencing the document describing the evaluation method);

j) the evaluation results with, where appropriate, the units of measurement – for example, for spectrum surveys, plots, or tabulations of RF field strength versus frequency;

k) measurement equipment and/or simulation software used:
   - lists of instrumentation;
   - measurement antenna/probe used (its height, orientation information, antenna factor/ gain, type, and frequency range);
   - cable loss between the measurement antenna/probe and associated equipment, unless it is included in the antenna factor/gain;
   - all gains or losses of measurement system components – amplifiers, attenuators, power splitters, filters, etc.;
   - any internal attenuator setting;
   - frequency or frequencies being measured;
   - bandwidth used for the evaluation;
   - detector functions selected and characteristics – for example, time constants, channel decoding;
   - post detector filter characteristics such as bandwidth;
   - type of output – for example, log, linear, and characteristics (for example, range);
   - signal and noise levels measured;
   - confirmation of traceable calibration;

l) the name(s), function(s) and signature(s) or equivalent identification of person(s) performing the evaluation and authorizing the evaluation report;

m) where relevant, a statement to the effect that the results relate only to the items tested;

n) where relevant, a statement to the effect that the evaluation takes into consideration the intended use of the RBS;

o) uncertainty analysis;

p) opinions and interpretations.

10.3 Opinions and interpretations

When opinions and interpretations are included, the report shall record the basis upon which these have been made. Opinions and interpretations shall be clearly marked as such in the evaluation or assessment report.

Opinions and interpretations included in the report may comprise, but not be limited to, the following:

- where appropriate, an opinion on the statement of compliance/exceedance of the results with limit requirements;
- fulfilment of contractual requirements;
- recommendations on how to use the results;
- guidance to be used for improvements.

Annex A
(informative)

Source environment plane and guidance on the evaluation method selection

NOTE Annex A provides complementary information for the implementation of Clause 7.

A.1 Guidance on the source-environment plane

A.1.1 General

In order to facilitate the understanding of the source-environment plane and of the source-region boundaries defined in Clause 7, examples are provided in A.1.2 and A.1.3 for different types of antennas and antenna installations.

A.1.2 Source-environment plane example

An example of the application of the source-environment plane applied to a typical tower installation is depicted below in Figure A.1. The side view of a narrow vertical beamwidth antenna mounted on a tower or on a wall is shown.

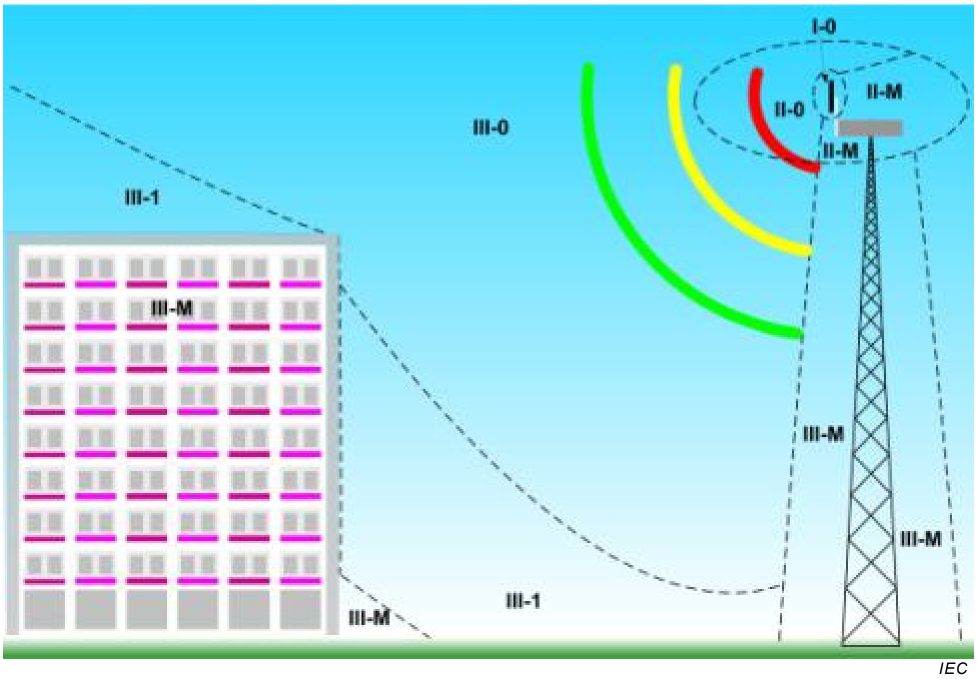


Figure A.1 – Example source-environment plane regions near a radio base station antenna on a tower which has a narrow vertical (elevation plane) beamwidth (not to scale)

Depending on frequency and dimensions, the source regions progress from region I to III. In Figure A.1, the environment regions are classified as follows:

- In most of the main beam (coloured radials), reflections are not relevant, so environment region 0 applies.
- Outside the main beam, there is a single reflector (off the face of the building) making environment region 1 applicable.
- Along the rooftop, there is a significant reflector (the roof-top itself) making environment region 1 applicable.

- The environment where the beam has penetrated the building and there are multiple reflectors from internal walls and other structures is designated environment region M.
- The areas below and behind the antenna where the antenna is obscured (by the tower structure and/or headframe) and these elements reflect/reradiate RF fields are both designated environment region M.

In line-of-sight to the antenna and above the antenna there is an area where roof-top reflections are not relevant and so environment region 0 applies.

Another example is shown in Figure A.2 for a roof-top installation.

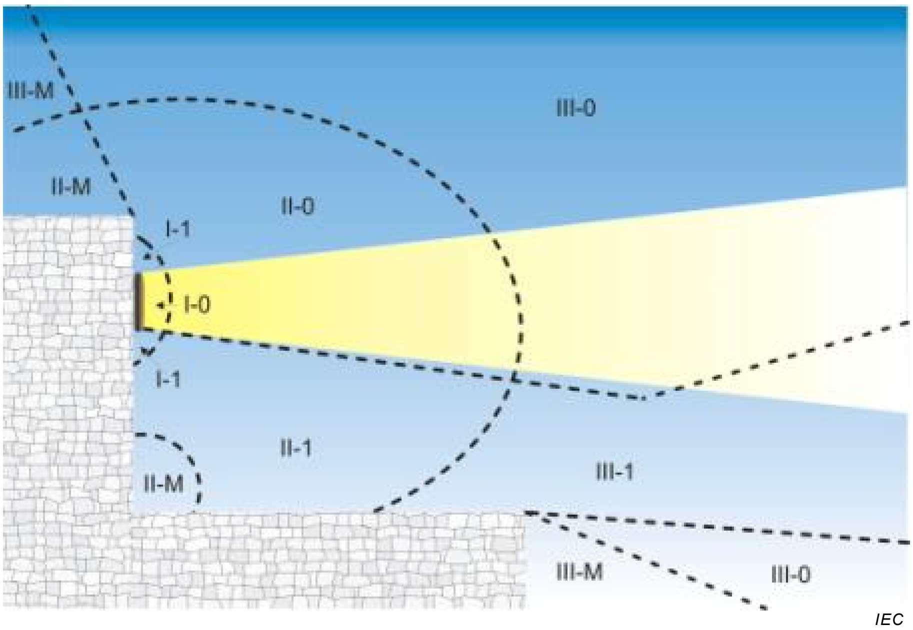


Figure A.2 – Example source-environment plane regions near a roof-top antenna which has a narrow vertical (elevation plane) beamwidth (not to scale)

A.1.3 Source regions

A.1.3.1 General

The space surrounding an antenna is conventionally divided into two principal regions: one near the antenna called the near-field region and one at a larger distance called the far-field region. The near-field region is usually subdivided into the reactive and the radiating near-field regions. Typically, the far-field region is defined as that region of the field of the antenna where the angular field distribution is essentially independent of the distance from a specified point in the antenna region. The reactive near-field region is defined as that portion of the near-field region immediately surrounding the antenna, wherein the reactive field predominates [21].

Antenna field regions are often described in textbooks in terms of:

- reactive/radiating near-field boundary. This can be defined in a number of ways: where the reactive and radiating fields have the same magnitude is one approach, another is where the radiating fields dominate by a defined amount;
- far-field, which can be defined based on how far from the antenna it is possible to accurately evaluate the directivity as would be observed from a long way away from the antenna.

A.1.3.2 Source definition and antenna geometry

A.1.3.2 defines the source regions which should be used. The antenna type, antenna geometry and evaluation point are all factors which influence the source region. Boundary definitions for leaky feeders, reflectors and default source region are also presented.

Prior to categorizing the evaluation source regions, some fundamental antenna geometry variables need to be defined. Figure A.3 presents the geometry of an antenna configuration.

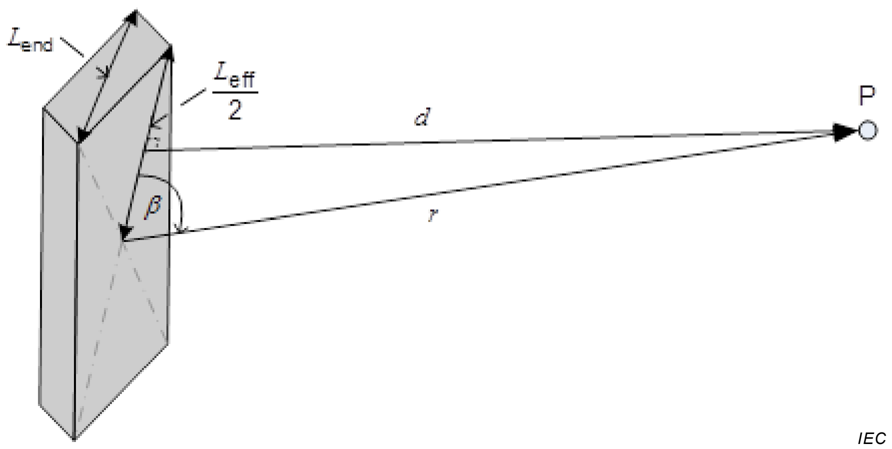


Figure A.3 – Geometry of an antenna with largest linear dimension L_{eff} and largest end dimension L_{end}

In Annex A, the following variables are used:

- r is the distance from the centre point on the major axis of the antenna (the origin) to a point P, specifically:
- r_{III} is the minimum distance from the antenna centre point to the boundary between source region II and source region III;
- d is the minimum distance from the surface of the antenna to a point P, specifically:
- d_I is the minimum distance from the surface of the antenna to the boundary between source region I and source region II;
- d_{III} is the minimum distance from the surface of the antenna to the boundary between source region II and source region III;;
- d_{end} defines a surface according to Table A.4 considering L_{end};
- d_r defines a surface according to Table A.4 considering L_{eff};
- λ is the wavelength measured in metres;
- β is the angle between the main axis (along the largest linear dimension) of the antenna and the line from the origin of the antenna to a point (e.g. on the source region II to source region III boundary);
- L_{end} is the maximum end dimension measured in metres orthogonal to the front face (the chassis depth) of the antenna;
- L_{eff} is the maximum dimension measured in metres between two points on the front face of the antenna.

Table A.1 defines the source regions.

Table A.1 – Definition of source regions

<table>
<tr><th>Source region I

$0 \le d < d_{\mathrm{I}}$</th><th>Source region II

$d_{\mathrm{I}} \le d < d_{\mathrm{III}}$ or

$d \ge d_{\mathrm{I}}$ and $r < r_{\mathrm{III}}$</th><th>Source region III

$d_{\mathrm{III}} \le d < \infty$</th></tr>
<tr><td>In region I, reactive power components are not negligible. The power density oscillates and, depending on the evaluation location, lower values might be obtained closer to the antenna in contrast to higher values further away.</td><td>Antenna pattern according to the specifications of the manufacturer is not yet valid.</td><td>Far-field conditions</td></tr>
<tr><td colspan="3">Where distances d_{I}, d_{III} and r_{III} are defined in Table A.2, Table A.3, Table A.4, Table A.5, according to antenna classification:
• Default source region boundaries – see Table A.2.
• Antennas with maximum dimension less than 2,5 λ – see Table A.3.
• Linear/planar antenna arrays of small elements aligned linearly, normally along a vertical axis, and with more elements on the vertical axis than horizontally and with the maximum dimension greater than 2,5 λ – see Table A.4.
• Equiphase radiating apertures (e.g. parabolic dish antenna) with maximum dimension >> λ – see Table A.5.
• Leaky feeders – see Table A.6.

NOTE Some evaluation methods described in this document specify additional constraints defining where the method can be employed. The evaluation zones can therefore differ from the source regions.</td></tr>
</table>

The default source region boundaries (see Table A.2) should be used when there is any doubt as to the classification of the source antenna. For common antenna classifications (antennas and leaky feeders), Table A.3, Table A.4, Table A.5, and Table A.6 provide examples of source region boundaries.

NOTE Where similar regions are defined in Annex B, the definitions in Annex B apply.

Table A.2 – Default source region boundaries

<table>
<tr><th>Source region I to source region II boundary[a]</th><th>Source region II to source region III boundary[a]</th></tr>
<tr><td>$d_{\mathrm{I}} = \max\begin{pmatrix}\lambda \\ L_{\mathrm{eff}} \\ \dfrac{L_{\mathrm{eff}}^2}{4\lambda}\end{pmatrix}$</td><td>$d_{\mathrm{III}} = \max\begin{pmatrix}5\lambda \\ 5L_{\mathrm{eff}} \\ \dfrac{0{,}6L_{\mathrm{eff}}^2}{\lambda}\end{pmatrix}$</td></tr>
<tr><td colspan="2">NOTE The distance limits of the default source regions are smaller than those proposed in textbooks covering exact descriptions of antennas. The textbook distance limits were reduced based on not noticeably influencing the uncertainty of the RF field strength evaluation [15].

[a] These distance limits of the regions are applicable generally. Antennas exist for which these limits are conservative, for example for source region I, λ or less can be sufficient even if L_{eff} or $L_{\mathrm{eff}}^2/(4\lambda)$ are larger. However, unless these cases are included in Annex A, sustainable proof is required.</td></tr>
</table>

Table A.3 – Source region boundaries for antennas with maximum dimension less than 2,5 λ

Source region I to source region II boundary[a]	Source region II to source region III boundary
$d_{\mathrm{I}} = \lambda$	In [22], the source region II to source region III boundary surface is a sphere radius r_{III}, centred at the middle of the antenna: $$r_{\mathrm{III}} = \begin{cases} 1{,}6\lambda & L_{\mathrm{eff}} < 0{,}3\lambda \\ 5L_{\mathrm{eff}} & 0{,}3\lambda \le L_{\mathrm{eff}} < 2{,}5\lambda \end{cases}$$
[a] Measurements of either E or H are acceptable at distances down to $\lambda/4$ from the surface of the antenna by considering (a) the increase in uncertainty (see A.1.3.3.1) and (b) that lower power density values may be obtained closer to the antenna in contrast to higher values further away.	

Table A.4 – Source region boundaries for linear/planar antenna arrays with a maximum dimension greater than or equal to 2,5 λ

Source region I to source region II boundary[a]	Source region II to source region III boundary
$d_{\mathrm{I}} = \lambda$	The source region II to source region III boundary is specified by an examination of two surfaces surrounding the antenna evaluated from functions of L_{eff} and L_{end}: A large surface described by r, centred on the middle of the antenna: $$r = \frac{2{L_{\mathrm{eff}}}^2}{\lambda}\sin^2\beta + \frac{L_{\mathrm{eff}}}{2}\left\|\cos\beta\right\| - \frac{\lambda}{32}$$ from which the corresponding distance, d_{r} to the surface of the antenna can be determined: $$d_{\mathrm{r}} = r\left\|\sin\beta\right\|$$ A smaller surface described by d_{end}, considering the end dimensions of the antenna: $$d_{\mathrm{end}} = \begin{cases} 1{,}6\lambda & L_{\mathrm{end}} < 0{,}3\lambda \\ 5L_{\mathrm{end}} & 0{,}3\lambda \le L_{\mathrm{end}} < 2{,}5\lambda \\ \dfrac{2{L_{\mathrm{end}}}^2}{\lambda} & L_{\mathrm{end}} \ge 2{,}5\lambda \end{cases}$$ $$d_{\mathrm{III}} = \max\begin{pmatrix} d_{\mathrm{r}} \\ d_{\mathrm{end}} \end{pmatrix}$$
[a] Measurements of either E or H are acceptable at distances down to $\lambda/4$ from the surface of the antenna by considering (a) the increase in uncertainty (see A.1.3.3.1) and (b) that lower power density values can be obtained closer to the antenna in contrast to higher values further away.	

Table A.5 – Source region boundaries for equiphase radiation aperture (e.g. dish) antennas with maximum reflector dimension much greater than a wavelength

Source region I to source region II boundary	Source region II to source region III boundary
Within the main beam before the first null is reached: $$d_{\mathrm{I}} = \frac{L_{\mathrm{eff}}^{2}}{4\lambda}$$ Outside the main beam and after the first null is reached[a]: $$d_{\mathrm{I}} = \max\begin{pmatrix}\lambda \\ L_{\mathrm{eff}}\end{pmatrix}$$	$$d_{\mathrm{III}} = \frac{0{,}6\ L_{\mathrm{eff}}^{2}}{\lambda}$$
[a] Outside the main beam and after the first null is reached, measurements of either E or H are acceptable at distances down to $\lambda/4$ from the surface of the antenna by considering (a) the increase in uncertainty (see A.1.3.3.1) and (b) that lower power density values can be obtained closer to the antenna in contrast to higher values further away.	

Table A.6 – Source region boundaries for leaky feeders

Source region I to source region II boundary	Source region II to source region III boundary
$$d_{\mathrm{I}} = \frac{\lambda}{4}$$	d_{III} is not usefully definable since leaky feeder lengths are typically tens to hundreds of metres, thus much greater than the evaluation point distance from the radiating structure
NOTE Leaky feeders are also known as (intentionally) radiating cables.	

A.1.3.3 Boundary between source regions for RBS antennas with small elements, e.g. dipoles/slots/loops

A.1.3.3.1 Boundary between source region I and source region II

Various criteria can be used for determining the source region boundaries for RBS antennas with small elements. The boundary between source regions I and II is directly related to the influence of the reactive near-field. In turn, the reactive near-field region is a function of the antenna geometry.

Considering the region within which the maximum RF field strength can be found, λ is the appropriate value for d_{I}.

Considering the requirement to measure both electric field strength and magnetic field strength (or SAR), the following apply.

a) For dipole type antennas, prevalent in many RBS antenna designs, an analysis was performed in IEC 62311 based on the analytical expressions for fields radiated by a short linear element. By calculating the ratio of the total power density to the radiated power density for a few simple array antennas, as well as for a single dipole element, it was found that the effective maximum difference between the total and the radiated power density would be 10 %, 0,4 dB, or less for distances larger than a quarter of a wavelength.

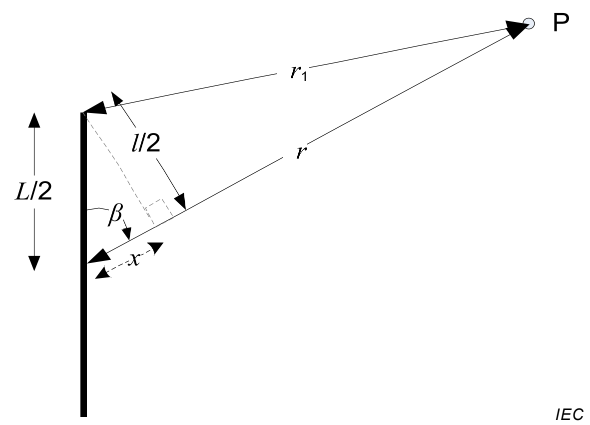
b) In [23], [24] the measurement error is stated to be less than 1 dB for a distance of a quarter of a wavelength.

c) In [25], localized and whole-body SAR is given as a function of distance for a number of scenarios with different RBS antennas showing the gradual transition between different field regions.

Provided the increased uncertainty is considered, measurement of either electric field strength or magnetic field strength at distances larger than or equal to $\lambda/4$ from the surface of the antenna is acceptable.

A.1.3.3.2 Boundary between source region II and source region III for maximum antenna dimension $L \geq 2{,}5\ \lambda$ and elements in a linear configuration

The criteria for determining the source region II and III boundaries for RBS antennas with small elements is discussed here. A commonly used requirement for when far-field conditions can be said to apply is when the maximum phase error (phase difference between fields emanating from the centre and the edge of the antenna) is smaller than $\pi/8$ [26]. Translated to distance this corresponds to a path difference of $\lambda/16$ between the observation point and the current sources in the extremities of the antenna array.



Key

L antenna array total length

l array projected area at observation point P

Figure A.4 – Maximum path difference for an antenna with largest linear dimension L

Consider the general configuration of Figure A.4 with an antenna of length L and an evaluation at point P. The path length represented by x is constant for all $r > x$ and helps define the far-field directivity. The $\lambda/16$ constraint therefore applies to the difference in path lengths between paths $r\text{-}x$ and r_1.

From geometry and [27],

$$x = \frac{L}{2}\left|\cos\beta\right| \quad \text{and} \quad r_1^{\,2} = r^2 + \frac{L}{4}^2 - rL\left|\cos\beta\right|$$

For constraint $r_1 - (r\text{-}x) = \lambda/16$:

$$r = \frac{2L^2}{\lambda}\sin^2\beta - \frac{\lambda}{32} + \frac{L}{2}\left|\cos\beta\right| \qquad \text{(A.1)}$$

For the special case of β = 90°(main beam), and ignoring the $\frac{\lambda}{32}$ term, this simplifies to the often quoted $r = \frac{2L^2}{\lambda}$. However, note that for other values of β, Equation (A.1) gives smaller far-field distances, e.g. see Table A.7.

Table A.7 – Far-field distance r measured in metres as a function of angle β

β	10°	30°	60°	90°	120°	150°	170°
r	1,8 m	7,5 m	20,5 m	26,7 m	20,5 m	7,5 m	1,8 m
NOTE This is for the case where L = 2 m and λ = 0,3 m (i.e. 1 GHz).							

A.1.3.4 Source regions for equiphase radiating aperture (e.g. parabolic dish) antennas

A.1.3.4 describes the criteria for determining the source region boundaries for equiphase radiating apertures. This class of antennas includes parabolic dish antennas where, when observed in the main beam, a significant cross-sectional area of reflector is reflecting the radiated energy from the feed source into a narrow beam.

Within the main beam, apply the criteria when the oscillation of the power density stops for increasing distance as shown by ETSI TR 102 457 [11], and as used in FCC OET Bulletin 65 [15]. Additional discussion is provided in [28].

Outside the main beam and after the first null is reached, the “equiphase” conditions do not apply and so the source regions can be based on Table A.2.

A.2 Select between computation or measurement approaches

Table A.8 provides guidance on selecting between computation and measurement methodologies based on a number of practical considerations.

Table A.8 – Guidance on selecting between computation and measurement approaches

Computation (B.4)		Measurement (B.3)
Unable to access area to be evaluated. For example, due to safety considerations or due to not having right of access by building / land owner.	←	
	→	Insufficient information available to perform computation.
Requirement is to present a comprehensive field visualization.	←	
	→	Requirement is to cover specific limited routes/locations e.g. access route, nominated locations.
	→	Client requires measurement.
Client requires computation.	←	
Requirement includes an evaluation in locations where, or at times when, the RBS is not radiating (e.g. prior to construction).	←	
	→	Requirement is for a physical demonstration to interested people.
NOTE The scales symbol is used to imply application of balance in determining the method. The arrow presents which column is suggested considering the applicability of the cases described in the cells.		

If measurement is selected then the next step is A.3. Otherwise, if computation is selected then the next step is A.4.

A.3 Select measurement method

A.3.1 Selection stages

Determine the measurement method in the following stages:

a) determine if *SAR*, RF field strength or power density measurement is appropriate (see A.3.2);

b) select either broadband or frequency-selective measurement approach (see A.3.3);

c) determine which measurement procedures are applicable (see A.3.4).

A.3.2 Selecting between field strength and *SAR* measurement approaches

For any in-situ measurement, and in environment regions *-1 and *-M (* means I or II or III, see 7.2.2.2), RF field strength measurement is applicable.

For laboratory measurements in source-environment plane regions I-0 and II-0 (see 7.2.2.2), either RF field strength measurement (see B.3.1) or *SAR* measurement (see B.3.2) may be selected. *SAR* measurement is recommended for region I-0 and where the key consideration is in obtaining the most accurate results for example, to determine the smallest volume that needs to be enclosed within a compliance boundary. RF field strength measurement may be selected where it is simpler to implement.

NOTE Generally, the spatial-peak RF field strength relates closely to the local *SAR* [29].

A.3.3 Selecting between broadband and frequency-selective measurement

Determine if broadband or frequency-selective measurement is appropriate according to Table A.9.

Table A.9 – Guidance on selecting between broadband and frequency-selective measurement

Broadband **(see B.3.1.2.3)**		**Frequency-selective** **(see B.3.1.2.4)**
<u>Indication of total field:</u> A broadband measurement can provide a simple means to indicate the total field and may require care in certain circumstances to ensure that the results are correctly interpreted and presented: • no frequency discrimination required; • precise knowledge/control of evaluation parameters; • as indicative evaluation – for example, an initial scan to find the peak field using a broadband probe can be followed by a more detailed measurement using a frequency-selective instrument.	↔	<u>Indication of total field:</u> Frequency-selective measurement is required when frequency discrimination is required, for example: • to evaluate constant part of transmitted signal for extrapolation (see F.4); • to evaluate frequency weighting for exposure ratio.
<u>Comparison with a limit:</u> Where the field strengths are significantly below the relevant limit. Where the RBS is the single dominant source and either as an "as observed" evaluation without extrapolation is required; or, the output power of the RBS is controlled during the measurement.	↔	<u>Comparison with a limit:</u> Identifying and evaluating single and multi-frequency signals for comparison with a limit. Where extrapolation is required from a constant level part of the signal in the presence of other signals.
	→	<u>Limit exceedance:</u> In case of any doubt, or when the purpose is to confirm that a limit has been exceeded, the frequency-selective method is recommended.
	→	<u>Signal discrimination:</u> A frequency-selective method is essential for evaluating individual frequency bands or signal types. This includes identifying ambient fields for either inclusion or exclusion from final processing and reporting of results.
	→	<u>Low level fields</u>: Identifying and measuring signals in low RF field strength environments (e.g. public areas).

NOTE 1 The term "frequency-selective" is used rather than "narrow band" to imply the ability to discriminate between frequencies. The term "broadband" is used when a wide spectrum range is measured simultaneously without frequency discrimination. An instrument which can indicate the RF field strength from a logical channel (e.g. using a channel decoder) is also deemed to be "frequency-selective".

NOTE 2 The scales symbol is used to imply application of balance in determining the method. The arrow presents which column is suggested considering the applicability of the cases described in the cells.

A.3.4 Selecting RF field strength measurement procedures

Select appropriate measurement procedures according to Table A.10.

Table A.10 – Guidance on selecting RF field strength measurement procedures

Measurement procedure	Guidance on selection
Handheld – Fixed point of interest (see B.3.1.2.5.1)	Convenient and time efficient method to identify fields at specific points of interest.
Handheld – Sweeping a volume to determine a RF field strength value of interest and/or its location (see B.3.1.2.5.2)	Convenient and time efficient method to identify location where a specific RF field strength level is observed. For example, this procedure is useful for establishing a control boundary. Convenient and time efficient method to identify spatial-peak RF field strength in a volume. For example this procedure is useful in public areas to demonstrate low field strengths, or to establish locations where more precise evaluation is required when comparing with a limit value.
Tripod – (see B.3.1.2.5.3)	Where one or more of the following are important: • measurements at fixed or nominated points in space are required; • monitoring of fields over long time periods; • minimizing influence of body during measurement;
Automated scanning – (see B.3.1.3.2.2.1)	Where the RF field strength is being evaluated in laboratory conditions.
Spatial averaging – (see 6.4.1 and B.3.1.4)	Where a spatially-averaged value is required to establish the representative average RF field strength over the area of a human body in complex field conditions (environment regions 1 and M).
Time averaging – (see 6.4.2 and B.3.1.5)	To establish time-averaged field strength. For example, for information purposes, or to establish value for more representative comparison with limit value defined as an average over time.

A.4 Select computation method

Select appropriate computation procedures according to Table A.11.

Table A.11 – Guidance on selecting computation methods

Basic computation methods **(see B.4.3)**		**Advanced computation methods** **(see B.4.4)**
Where the main requirement is simplicity of evaluation. Minimal source or environment information required/available.	↔	Where the main requirement is to obtain the most accurate results for example to determine the smallest volume that needs to be enclosed within a compliance boundary. Where the required significant source and environment information is available.
↓		↓
Basic – Cylindrical-spherical formulas (see B.4.3.2) Simple field – better suited to source regions II and III. Select the cylindrical-spherical formulas for a quick and simple power density evaluation. The calculations are easy to perform without the complexity/expense of advanced calculations, but at the expense of accuracy, i.e. the simple cylindrical-spherical formulas will usually result in quick but over-conservative power density evaluations.		**Advanced – Synthetic model and ray tracing (see B.4.4.1)** Advanced field – Well suited for accurate power density evaluations in source regions II and III. The algorithm is relatively easy to implement and verify, alternatively, commercial software packages exist. When an implementation / software package is available, this method can be very powerful in producing quick, accurate and visually informative power density evaluations for simple or complex RBS sites.
Basic – *SAR* estimation formulas (see B.4.2.2) Simple *SAR* – better suited to source regions I and II. Select the *SAR* estimation method for quick and simple *SAR* evaluation. The *SAR* estimation method is faster than the more advanced methods at the price of being somewhat more conservative. When it comes to establishing compliance boundaries, the method will probably produce boundaries enclosing a smaller volume compared with techniques based on power density evaluations.		**Advanced – Full wave RF field strength (see B.4.4.2)** Advanced field – Well suited for very accurate power density evaluations in source regions I and II. Very complex and time consuming to implement and verify these algorithms, but a good number of commercial software packages are available. Even with these software packages available, the user should be proficient with the use of such packages and the time in setting up and verifying accurate antenna models should not be underestimated. However, the power density results obtained with such an evaluation will be very accurate in both source regions I and II.
		Advanced – Full wave *SAR* (see B.4.4.3) Advanced *SAR* – Well suited for very accurate *SAR* evaluations in source regions I and II. Very complex and time consuming to implement and verify these algorithms but a good number of commercial software packages are available. Even with these software packages available, the user should be proficient with the use of such packages and the time in setting up and verifying accurate antenna AND human phantom models should not be underestimated. However, the *SAR* results obtained will be the most accurate and authoritative evaluation possible for source regions I and II.
NOTE The scales symbol is used to imply application of balance in determining basic or advanced approach based on the top row. The twin-headed arrow presents which column is suggested based on the most applicable cell description. Having determined basic or advanced approach, the relevant advanced/basic down arrow indicates the set of methods described in this document. The description that best matches the specific task required guides the selection of the specific method.		

A.5 Additional considerations

A.5.1 Simplicity

Generally, select the simplest evaluation method which satisfies the evaluation purpose. For example, a simple peak RF field strength evaluation, which is conservative, may be used with care to demonstrate compliance.

NOTE Compared to simple evaluations, more complex evaluations are likely to be able to assess compliance with an applicable exposure limit closer to the RBS antenna. For example, a *SAR* evaluation might confirm the smallest volumes around an antenna wherein limits can be exceeded.

A.5.2 Evaluation method ranking

Where the results of one evaluation are being compared with a second evaluation, the highest ranking evaluation method should take precedence subject to both being applicable for the specific evaluation purpose and conditions.

The highest ranking evaluation method with valid applicability is the reference method for that exposure metric.

Table A.12 ranks the evaluation methods included in this document.

Table A.12 – Guidance on specific evaluation method ranking

Evaluation exposure metric (see 7.2.3)	Evaluation method ranking (1 is highest rank)				
	1	2	3	4	5
SAR **(whole-body & localized)**	Measurement (localized)	Full wave	*SAR* estimation formulas		
Power density; electric field strength; magnetic field strength	Frequency-selective measurement	Broadband measurement[a]	Full wave	Ray tracing	Spherical / cylindrical formulas

[a] Under very limited evaluation conditions where all relevant information is known to enable accurate interpretation/extrapolation (see B.5), broadband measurements are suitable. Otherwise, broadband measurements can result in a systematic overestimation of the RF field strength and are ranked 6.

A.5.3 Applying multiple methods for RF exposure evaluation

More than one valid evaluation method may be used sequentially or simultaneously to evaluate RF exposure near to a RBS antenna. Provided there is a valid demonstration that the applicable exposure limit value is not exceeded (see Annex D) by any means not contradicted by a higher ranking evaluation, the one providing the smallest compliance boundary around the antenna may be used.

NOTE For example, a *SAR* measurement around a micro cell antenna or a *SAR* modelling around a larger base station antenna is likely to provide the smallest compliance boundary.

Annex B
(normative)

Evaluation methods

B.1 Overview

Annex B defines the evaluation methods that shall be used to measure or compute RF field strength, power density or SAR as required in Clauses 6, 7 and 8. Each method description includes the applicability constraints within which it may be employed, the information required to implement the method and how to characterize the uncertainty of the evaluation.

B.2 Evaluation parameters

B.2.1 Overview

Coordinate systems relative to the RBS antenna and the main evaluation parameters used within this document are defined in B.2.2 to B.2.4.

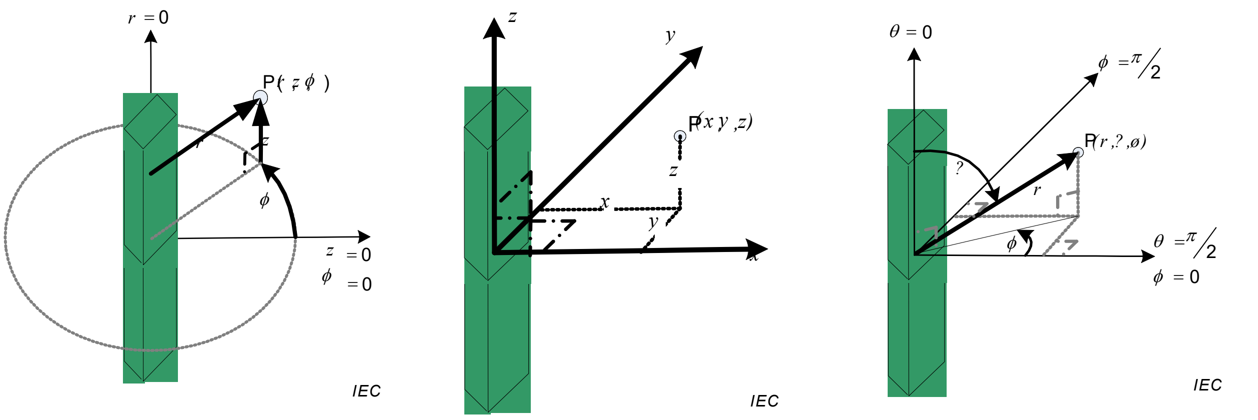
B.2.2 Coordinate systems

According to the evaluation method, coordinates for RBS antennas may be defined in cylindrical, Cartesian or spherical coordinates according to Figure B.1.

The reference axes are defined by:

- x – the direction in front of the antenna; or $\theta = \pi / 2, \quad \phi = 0$ radians in the spherical coordinate system; or, z = 0 m, $\phi = 0$ radians in the cylindrical coordinate system. The front of the antenna shall be defined, for instance, as the line orthogonal to the plane in which the elements are configured or by the centre of the symmetrical horizontal beam pattern.
- y – the direction to the left of the antenna looking out from the front of the antenna along the x-axis, or $\theta = \pi / 2, \quad \phi = \pi / 2$ radians in the spherical coordinate system.
- z – the direction "up" (often orthogonal to the centre of the main beam), or θ = 0 radians in the spherical coordinate system.

The origin of the coordinate system shall be defined, for instance, by the centre of the back panel in case of panel antennas, and the centre of the antenna in case of omnidirectional antennas.



a) Cylindrical: P$(r,\ z,\ \phi)$ $-\pi \le \phi \le \pi$ b) Cartesian: P$(x,\ y,\ z)$ c) Spherical: P$(r,\ \theta,\ \phi)$ $-\pi \le \phi \le \pi$ and $0 \le \theta \le \pi$

Figure B.1 – Cylindrical, cartesian and spherical coordinates relative to the RBS antenna

B.2.3 Reference points

Where there is a clearly defined antenna (e.g. desktop unit with external antenna or where the RBS antenna has exposed radiating elements), the reference point is either the centre of the antenna or any characteristic point (e.g. bottom of the radome) and shall be defined and recorded in the report. The report shall also clarify if the antenna contains passive elements, reflectors and/or active elements.

For EUT with built in antennas (e.g. desktop box with internal antenna) where there is no external indication of antenna position, the surface of the enclosure shall be used as the reference point.

B.2.4 Variables

Table B.1 defines the dimension variables.

Table B.1 – Dimension variables

Variable	Default Unit	Description
d_{xx}	m	Distance between points identified by the subscript xx
r_{xx}	m	Radius from point of origin, where subscript xx is used to identify the end point.
L_{xx}	m	Dimension of an antenna, phantom or other object, where subscript xx is used to define the specific case.

Table B.2 defines the variables relating to the RF power.

Table B.2 – RF power variables

Variable	Unit	Description	Notes
$\overline{P}_{\text{avg}}$	W	Average (temporal) transmitted power	This is time-averaged conducted power applied to the antenna input connector minus the reflected power from the antenna input connector and minus the power dissipated as heat within the antenna. In the absence of additional information, assume no power is dissipated in the antenna and no power reflected.
$\overline{P}_{\text{net}}$	W	Net average (temporal) power transferred into the antenna port.	This is the time-average conducted forward power minus the reflected power at the antenna input connector. In the absence of additional information, assume no power is reflected.

The value of the power ($\overline{P}_{\text{avg}}$ or $\overline{P}_{\text{net}}$) to be used in an evaluation depends on the method and purpose.

- Maximum RBS RF power for each frequency band (theoretical or actual as defined in B.5) shall be used when the objective of the evaluation is to assess compliance with applicable exposure limits, either directly by computation or in developing extrapolation factors for measurements. This shall be the maximum conducted power anticipated under operating conditions time-averaged over relevant averaging period. A lower maximum value may be used if there is justification based on a detailed knowledge of the constraints on specific system parameters.
- Practical evaluation based on RBS RF power (for each frequency band) defines a practical evaluation condition to be used to extrapolate exposure metric values to the assessment configuration, for example with maximum RBS RF power. There shall be a known relationship between the reference RBS RF power and the required assessment configuration.

NOTE Depending on the technology (see Annex F), there is some part of the signal that remains substantially constant in amplitude e.g. for GSM, the BCCH; For UMTS, a pilot channel.

The RBS RF power may be established:

- by using manufacturer's data, in which case the uncertainty shall be as stated by the manufacturer; or
- by direct measurement, in which case the uncertainty shall be the uncertainty of the measurement combined with the manufacturer's uncertainty if extrapolated to other operating configurations and environmental conditions.

Table B.3 defines the antenna variables that can be obtained from manufacturer's documentation. If N_{e} is not available, it can be determined from the antenna size and wavelength according to B.4.2.2.5.

Table B.3 – Antenna variables

Variable	Unit	Description
D	Linear ratio	Peak directivity of the antenna at the frequency under evaluation.
$D_{\theta,\phi}$	Linear ratio	Directivity of antenna in direction specified in spherical coordinates at the frequency under evaluation.
G	Linear ratio	Peak antenna gain at the frequency under evaluation.
$G_{\theta,\phi}$	Linear ratio	Antenna gain in direction specified in spherical coordinates at the frequency under evaluation.
$D_{\text{side lobe}}$	Linear ratio	Gain of the maximum side lobe in the vertical gain pattern at the frequency under evaluation.
$\phi_{3\text{dB}}$	Radians	Azimuth HPBW at the frequency under evaluation.
$\theta_{3\text{dB}}$	Radians	Vertical HPBW at the frequency under evaluation.
γ	Radians	Electrical downtilt angle of the antenna main beam from x-y plane at the frequency of evaluation. Down is positive and up is negative.
N_{e}	Integer number	The number of antenna elements at the frequency of evaluation.

Table B.4 defines the exposure metric variables.

Table B.4 – Exposure metric variables

Variable	Unit	Description	Notes
S	W m^{-2}	Plane wave equivalent power density value over the longer period of either the modulation or the pulse waveforms	Time averaging to address modulation and pulses or to be consistent with relevant $\overline{P}_{\text{avg}}$ or $\overline{P}_{\text{net}}$
$\overline{S}_{\text{avg}}$	W m^{-2}	Time-averaged plane wave equivalent power density	Time averaging e.g. as defined by relevant regulation or international exposure standard
$\overline{S}$	W m^{-2}	Spatially-averaged plane wave equivalent power density	Spatial averaging defined by spatial averaging scheme
E	V m^{-1}	R.M.S. electric field strength over the longer period of either the modulation or the pulse waveforms	Time averaging to address modulation and pulses or to be consistent with relevant $\overline{P}_{\text{avg}}$ or $\overline{P}_{\text{net}}$
E_{avg}	V m^{-1}	Time-averaged r.m.s. electric field strength	Time averaging e.g. as defined by relevant regulation or international exposure standard
$\overline{E}$	V m^{-1}	Spatially-averaged r.m.s. electric field strength	Spatial averaging defined by spatial averaging scheme
H	A m^{-1}	R.M.S. magnetic field strength over the longer period of either the modulation or the pulse waveforms	Time averaging to address modulation and pulses or to be consistent with relevant $\overline{P}_{\text{avg}}$ or $\overline{P}_{\text{net}}$
H_{avg}	A m^{-1}	Time-averaged r.m.s. magnetic field strength	Time averaging e.g. as defined by relevant regulation or international exposure standard
$\overline{H}$	A m^{-1}	Spatially-averaged r.m.s magnetic field strength	Spatial averaging defined by spatial averaging scheme
SAR_{wb}	W kg^{-1}	Specific absorption rate averaged over the whole body	Time averaging to address modulation and pulses or to be consistent with relevant $\overline{P}_{\text{avg}}$ or $\overline{P}_{\text{net}}$
SAR_{10g}	W kg^{-1}	Peak spatial-average specific absorption rate in 10 g	Time averaging to address modulation and pulses or to be consistent with relevant $\overline{P}_{\text{avg}}$ or $\overline{P}_{\text{net}}$
SAR_{1g}	W kg^{-1}	Peak spatial-average specific absorption rate in 1 g	Time averaging to address modulation and pulses or to be consistent with relevant $\overline{P}_{\text{avg}}$ or $\overline{P}_{\text{net}}$

B.3 Measurement methods

B.3.1 RF field strength measurements

B.3.1.1 Applicability of RF field strength measurements

RF field strength measurement is applicable in all source-environment plane regions (see Annex A).

Frequency-selective measurement is recommended anywhere that there is more than a single signal on one frequency present (see Table A.9).

B.3.1.2 In-situ RF exposure measurements

B.3.1.2.1 General requirements

The following checks shall be performed:

a) The measurement equipment shall meet the requirements of B.3.1.2.2.

b) Determine as many of the known characteristics of the sources of the RF fields as possible and estimate their likely propagation characteristics.

c) Estimate the expected RF field strength using the basic computation methods in B.4.2.1.

d) Ensure out-of-band and/or strong ambient signals do not create spurious responses in the measurement equipment.

NOTE 1 Co-band sources located adjacent to the EUT, or low frequency fields from high-tension power lines, can affect (especially broadband) instruments.

e) Establish if the reading may be measurement equipment noise.

f) Determine the optimum measurement equipment settings.

NOTE 2 See Annex F, the measurement equipment manufacturers' specifications, and measurement equipment manufacturers' guidelines.

g) Where a shaped frequency response broadband instrument is used, ensure that its summation algorithm and frequency calibration are consistent with the requirements of the relevant standard.

h) If more than one measurement antenna or isotropic probe is required to cover a specified frequency range, then the RF field strength shall be determined using:

$$E = \sqrt{\sum_{i=1}^{N} E_i^2} \quad \text{or} \quad H = \sqrt{\sum_{i=1}^{N} H_i^2} \quad \text{or} \quad S = \sum_{i=1}^{N} S_i \tag{B.1}$$

where:

E is the electric field strength at the measurement point;

E_i is the r.m.s. value of the electric field strength measured by the ith measurement antenna or isotropic probe at the measurement point;

H is the magnetic field strength at the measurement point;

H_i is the r.m.s. value of the magnetic field strength measured by the ith measurement antenna or isotropic probe at the measurement point;

N is the number of measurement antennas and isotropic probes;

S is the plane wave equivalent power density at the measurement point;

S_i is the plane wave equivalent power density measured by the ith measurement antenna or isotropic probe at the measurement point.

NOTE 3 For broadband measurement equipment, the above summation can result in a systematic overestimation of the RF field strength if the measurements have overlapping frequencies. This can be avoided by using frequency-selective measurements.

NOTE 4 Depending on whether the same or different exposure limit applies to the measurement results in the frequency range, the results can need to be normalized to the applicable limits before combining to determine compliance.

i) Consider the location of the source and RF propagation path during surveys to minimize the influence of the body on the measurement. Refer to the manufacturer's specifications for the minimum distance between the measurement probe tip and the body of the "operator" as well as any reflecting object. For handheld measurements, the uncertainty due to the scattering of the RF field by the surveyor's body shall be minimized by:

- holding the probe or antenna away from the surveyor's body (a separation of at least 50 cm should be maintained between the measurement antenna or isotropic probe and the surveyor's body);
- pointing the probe towards the source;
- ensuring that the surveyor's body is not along the direct line of propagation between the source and the measurement probe (either in front of or behind).

j) The uncertainty due to mutual coupling between measurement antenna or isotropic probe and physical objects (e.g. walls, floor, ceiling, furniture and other objects) shall be considered:

- measurements at separation distances of 20 cm or closer are acceptable dependent on the measurement frequency and measurement equipment but at separation distances of less than 50 cm, this influence on the measurement uncertainty shall be included in Table B.7 and Table B.8 (see B.3.1.6);
- where the size of the receiving elements of the measurement antenna or isotropic probe do not exceed a dimension of 0,4 m, and where a separation distance of 50 cm or greater is maintained, this influence on measurement uncertainty need not be considered.

k) The uncertainty due to high gradients in the RF field strength (e.g. quasi-static near-field) in proximity to RF radiators or re-radiators shall be considered if the minimum separation distance between the measurement antenna or isotropic probe and RF radiators or re-radiators is less than three times the largest dimension of the measurement antenna or isotropic probe.

For additional information see, for example, [30].

B.3.1.2.2 In-situ measurement equipment requirements

Equipment used for in-situ measurement shall be calibrated at a sufficient number of frequencies to achieve the declared uncertainty of the equipment over the measurement frequency range. This may be achieved as a whole system or by calibration of all the individual parts of the system. For signals with high crest factors or combinations of several signals, additional calibration may be necessary to assess uncertainty.

Where specific demodulation capabilities are used, measurement equipment shall also be calibrated for the parameters of interest (e.g. for WCDMA the CPICH signal and signal-to-noise ratio, see Annex F).

Table B.5 summarizes the performance requirements for a broadband measurement system for RF exposure evaluation.

Table B.5 – Broadband measurement system requirements

Frequency response	Minimum detection level	Dynamic range	Linearity	Probe isotropy[a]
900 MHz to 3 GHz ± 1,5 dB	< 2 mW/m^2 (i.e. 1 V/m or 0,003 A/m)	> 40 dB	± 1,5 dB	< 2,5 dB for isotropic probe
< 900 MHz and > 3 GHz ± 3 dB for the frequencies to be measured				

[a] Probes and measurement antennas with isotropic response are recommended. Single-axis (e.g. dipole) and directional measurement antennas are permitted provided that the measurements are post processed to obtain the total field strength (equivalent to a measurement with an isotropic probe / measurement antenna).

Table B.6 summarizes the performance requirements for the frequency-selective measurement system for RF exposure evaluation.

Table B.6 – Frequency-selective measurement system requirements

Frequency response	Minimum detection level	Dynamic range	Linearity	Probe isotropy [a]
900 MHz to 3 GHz ± 1,5 dB	< 0,01 mW/ m^2 (i.e. 0,06 V/m)	> 60 dB	± 1,5 dB	< 900 MHz: < 2 dB
< 900 MHz and > 3 GHz ± 3 dB for the frequencies to be measured	Signal-to-noise ratio of at least 10 dB in the measurement bandwidth			from 900 MHz to 3 GHz: < 3 dB > 3 GHz: < 5 dB

[a] Probes and measurement antennas with isotropic response are recommended. Single-axis (e.g. dipole) and directional measurement antennas are permitted provided that the measurements are post processed to obtain the total field strength (equivalent to a measurement with an isotropic probe / measurement antenna).

B.3.1.2.3 Broadband in-situ measurements

B.3.1.2.3.1 Applicability of broadband in-situ measurements

Broadband measurements give the sum of all signals over the frequency range of the probe without distinguishing the contribution of different frequencies (whether from the EUT or from ambient sources). These may give an instantaneous or time-averaged field strength value.

The method gives an informative environmental field strength reading as observed at the time of measurement and is adequate for monitoring the RF field.

A broadband measurement is suitable for determining overall levels in the environment and may be helpful in determining if a more comprehensive measurement using the frequency-selective method (see B.3.1.2.4.2) is required.

Extrapolation of broadband measurement results is not recommended. Such extrapolation can result in a vast overestimation depending on the characteristics of the probe and the characteristics of the EUT/ambient signals. Therefore frequency-selective measurements are recommended where accurate extrapolation is required.

B.3.1.2.3.2 Broadband in-situ measurement method

Select an isotropic broadband survey instrument that has a measurement range adequate to measure the RF field strength estimated during the pre-evaluation checks over the required frequency range (see 6.3) and fulfils the requirements in B.3.1.2.2.

The frequency response of the probe shall either be flat over the required frequency range (Table B.5) or shall be the inverse of the relevant frequency dependent exposure limit to provide a direct read-out expressed in terms of the relevant exposure ratio (see B.3.1.2.3.3.2).

To evaluate the highest RF field strength or the RF field strength at discrete points in a region, perform a search using the handheld sweep method (see B.3.1.2.5.2) or tripod procedure (see B.3.1.2.5.3).

If required, spatial averaging of the field can be performed (see 6.4.1 and B.3.1.4).

Investigate temporal variations in the field to ensure a stable indication of the RF field strength or to fulfil averaging time requirements required by the applicable exposure limits used for compliance assessment (see B.3.1.5.3).

B.3.1.2.3.3 Interpreting measurements over multiple frequency bands

B.3.1.2.3.3.1 Flat frequency response probe

If signals are being radiated over multiple frequency bands (e.g. 900 MHz and 1 800 MHz) and the probe is capable of operating accurately over the aggregate signal band then the lowest applicable exposure limit for the frequencies present shall be used to determine the combined exposure ratio expressed as a fraction/percentage of the relevant exposure limit.

B.3.1.2.3.3.2 Shaped frequency response probe

The measurement instrument sums the individual measurement levels at the frequencies of the various sources and presents the result in the form of an exposure ratio, for example as a percentage of the applicable limit.

B.3.1.2.4 Frequency-selective in-situ measurements

B.3.1.2.4.1 Applicability of frequency-selective in-situ measurements

These techniques employ spectrum analysis or channel decoding to isolate and identify the RBS source and ambient frequencies. The method shall be used:

- to discriminate signals at different frequencies;
- when ambient fields are comparable to, or may exceed, the level of the RBS source;
- when information is needed to enable the precise extrapolation from the evaluation configuration to the assessment configuration;
- in case of in-situ RF exposure assessment, when the power density level is above a given threshold, for example 100 mW/m^2 (as described in 6.3.2).

B.3.1.2.4.2 Frequency-selective in-situ measurement method

When using frequency-selective instrumentation, ensure the instrumentation covers the frequency range of the signals to be evaluated (see Annex F). Measurement over a wide range of frequencies may in some cases require more than one measurement antenna.

The RF field strength measurement shall consider contributions from all directions/polarizations. An isotropic antenna is best suited to this. Other antennas may be used in accordance with the following provisions.

- Single-axis (e.g. dipole) can be used to obtain the total RF field strength by positioning the probe in three orthogonal directions and summing the individual measured results.
- A directional measurement antenna or probe can be used to separate contributions from different directions (not source region I). These contributions shall be summed to determine the total field strength. However this value will be an overestimation of the true level.
- A directional antenna may be used for the handheld sweep method provided it is oriented to read the maximum RF field strength value.

Correlation between results obtained using isotropic and non-isotropic antennas may be influenced by the presence of strong multi-path signals.

Perform an initial broad spectrum scan to identify signals of interest for subsequent analysis.

For signals of interest (e.g. high level), increase the measurement resolution by centring on the signal frequency and performing a specific measurement of each signal.

Each of the relevant frequency bands to be investigated shall be analysed to determine the optimum settings for the selective meter. The resolution bandwidth setting shall take into account the RBS signal types and, when appropriate, ambient fields. Annex F provides technology-specific information useful for determining selective meter settings.

Additional processing is required for the measurement of signals that change level with time, for example as a function of the number of users accessing the communications system. Temporal variations in the field shall be investigated to ensure a stable indication of the RF field strength or to fulfil related averaging time requirements for determining compliance with the applicable exposure limit. B.3.1.5.3 provides additional guidance on evaluating time varying signals.

To evaluate the highest RF field strength or the RF field strength at discrete points in a region, perform a search using a handheld RF field strength measurement procedure (see B.3.1.2.5.2) or tripod RF field strength measurement procedure (see B.3.1.2.5.3). Additionally, spatial averaging of the field can be performed (see 6.4.1 and B.3.1.4).

To obtain an estimate of the maximum possible level, extrapolation of the result shall be performed if required (see B.5). This post-processing is required to determine a time-independent maximum possible RF field strength that in turn can be used to establish compliance boundaries around antennas.

B.3.1.2.5 In-situ measurement procedures

B.3.1.2.5.1 Determining the RF field strength or power density at fixed points of interest

Measurements shall be made using a measurement antenna or isotropic probe with its antenna factor calibrated as a function of frequency. If a non-isotropic measurement antenna is used, it shall be oriented to read the maximum value (when performing a search for a maximum RF field strength or power density value and/or its location). In the case of single axis probe / measurement antenna, it shall be rotated to obtain the three orthogonal components of the field and the measurement result summed (r.s.s.) to obtain the total RF field strength or power density.

B.3.1.2.5.2 Sweeping a volume to determine a RF field strength or power density of interest and/or its location

The handheld sweep method shall be used in-situ to:

- determine the locations with the RF field strength or power density of interest (see 6.3);

  NOTE 1 The handheld sweep method can be used to determine locations for subsequent investigation using spatial averaging techniques

- determine the maximum RF field strength or power density in a region without requiring information about location.

  NOTE 2 In the case of an uncluttered environment, the maximum RF field strength or power density from a single source is likely to be found in the main beam of the antenna.

The measurement antenna / isotropic probe shall be moved smoothly throughout the region avoiding proximity to objects. Measurements shall be performed at and around a height of 1,5 m above the floor or walkway. The measurement antenna / isotropic probe shall be moved vertically (up to 2 m) and horizontally throughout the region under test while observing the instrument display in order not to miss any maxima. Careful sweeping is necessary around the location where the value of interest is expected.

When searching for the spatial-peak field strength in a region, the displayed/recorded signal trace shall be set to capture the maximum level (i.e. maximum hold).

When using frequency-selective instruments, choose spectrum analyser settings so as to ensure accurate evaluation of the signal, in particular:

- the r.m.s. detector shall be selected;
- the number of sweeps per second of the spectrum analyser shall not be too high and the frequency span shall be sufficiently small to ensure an accurate evaluation of the r.m.s. value of the signal (see F.3).

Where there is more than one frequency of interest, a scan shall be made of the entire frequency range of interest to identify frequency peaks and their respective levels.

NOTE 3 It can be necessary to separate the frequencies into various groups (bands) to identify the levels of emissions from these individual bands.

B.3.1.2.5.3 In-situ measurements using tripod-supported instrument/antenna

The measurement equipment and general methodology specified in B.3.1.2.4 are applicable to the tripod method; however, influences of the surveyor's body are reduced. A support/mounting system that is non- or minimally perturbing (e.g. wooden tripod) to the field shall be used to hold the measurement antenna / isotropic probe in position during measurements.

A scan of the region under investigation using the handheld sweep method (see B.3.1.2.5.2) shall be performed to determine the locations of significant RF field strength levels and limit the size of the investigative volume. Select an area/volume around these locations and divide it into a suitable measurement grid to enable a finer investigation of the field. The resolution of such a grid shall be suitable to distinguish all field gradients and capture all field peaks.

NOTE The smallest step size can be limited by the dimensions of the measurement antenna / isotropic probe.

B.3.1.2.6 Guidance on determining ambient field levels

B.3.1.2.6.1 Overview

This clause provides guidance on how to evaluate the level of RF ambient fields in locations where people may also be exposed to RF fields from the RBS(s) under evaluation. The ambient fields from individual sources or from frequency bands may be expressed as an exposure ratio or as RF field strength according to the specific evaluation purpose.

The ambient field is the appropriate summation (see B.6) of all RF ambient fields from sources other than the RBS(s) under evaluation.

B.3.1.2.6.2 Ambient radio source identification

Reasonable endeavours shall be employed to identify all RF emissions likely to affect the RF exposure evaluation (see 6.3). The ambient fields identified for fixed permanent RF sources shall be considered:

- Such sources can be identified through visual inspection, consultation of user database (public / site owner) as well as broadband or frequency-selective measurement.
- 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 they are not significant in many cases for evaluating human exposure to RF fields. Very high power sources (e.g. RADAR, over-the-horizon communications) need to be considered only if they target the same region as the EUT.

Categorize the RF sources as either being "collocated" or "remote" from the RBS. Collocated RF sources are those located on the same antenna support, for example mast, roof-top or within the same transmitter compound or room as the RBS. All other sources are "remote".

In frequency bands other than the operating band of the RBS, the combined RF field shall be evaluated (see B.6).

When evaluating the exposure ratio from the EUT combined with the ambient fields then it is acceptable to reduce the number of signals requiring precise evaluation by specifying appropriate significance criteria.

NOTE For example, if the RF field from an adjacent RBS or from all signals in the FM broadcast band contributes less than say 5 % of the combined exposure ratio, then improving the precision of the ambient RF field strength evaluation will not significantly reduce the uncertainty of the combined exposure ratio evaluation.

B.3.1.2.6.3 Selecting ambient field evaluation locations

B.3.1.2.6.3.1 Collocated sources

The ambient field level from these sources is likely to vary considerably over the evaluation area near the RBS. The ambient field shall be evaluated at all locations where the RBS fields are evaluated.

B.3.1.2.6.3.2 Remote sources

For RF fields from sources located at some distance from the RBS, it is expected that there will be little variation in RF field strength over the evaluation area arising from the source antenna directivity or the small changes in distance from the source from the nearest to furthest evaluation location. There are, however, likely to be significant variations in RF field strength as a result of propagation affects, e.g. scattering and fading.

For the set of radio sources to be considered, choose a point in the clear above the clutter as near as possible to the area of evaluation (e.g. on roof-top and/or in area of evaluation away from local clutter), or for calculation purposes at a point above the area of evaluation where free space propagation can be assumed.

This location may be used for evaluation of the ambient field if it is representative for all radio sources based on the following (see B.3.1.2.6.4):

- the distance from the ambient evaluation location to any RBS evaluation location is less than 40 times the distance to the ambient source, see B.3.1.2.6.4.2.1;
- the ambient source is not highly directional.

For any radio sources not completely covered by this “master” evaluation location, select additional evaluation locations such that criteria in B.3.1.2.6.3 are met, for example:

- between the source and the area of evaluation, or
- additional evaluation locations in the clear, including the nearest point on the area of evaluation to the source.

B.3.1.2.6.3.3 Description

Evaluate the RF field strength for each ambient RBS source according to the evaluation protocol established in 6.3.

For other RF sources, evaluate the RF field strength according to the appropriate international standards, e.g. IEC 62311.

B.3.1.2.6.4 Proof of non-collocated source evaluation location selection criteria

B.3.1.2.6.4.1 Principles

A minimum number of evaluation locations when establishing worst-case exposure ratios for those ambient radio sources generally well removed from the evaluation location.

The RF field strength determined at an evaluation location is deemed to represent conservatively the maximum exposure ratio for a radio source over an area defined by a circle of radius δr provided

- the selected evaluation location is substantially in the clear of the local clutter;
- the variation of the exposure ratio is less than 5 % due to the difference in path length;
- change in directivity of the radio source antenna based on free-space propagation can be ignored in the area containing the evaluation points.

B.3.1.2.6.4.2 Establish criteria for separation of source evaluation locations considering distance to radio source

B.3.1.2.6.4.2.1 Consider change of RF field strength with distance

Given free-space propagation, what is the minimum ratio of distance between two evaluation locations and a radio source that results in a 5 % change in exposure ratio?

The power density, S, from the remote source is defined by:

$$S = \frac{A}{r^2} \tag{B.2}$$

where:

r is the distance to the remote source;

A is a constant (subject to change in directivity not being significant).

NOTE The value of A depends on the unit for r, e.g. m or km.

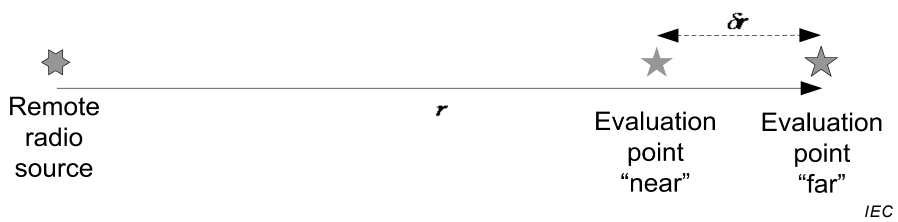


Figure B.2 – Evaluation locations

Consider Figure B.2, moving a small distance δr towards the source (most critical condition) then the power density S will increase by δS such that:

$$S + \delta S = \frac{A}{(r - \delta r)^2} \tag{B.3}$$

For a 5 % increase in S over distance δr :

$$\frac{S + \delta S}{S} = 1{,}05 \tag{B.4}$$

Using Equations (B.2) and (B.3) in Equation (B.4):

$$\frac{r^2}{(r-\delta r)^2} = 1{,}05 \tag{B.5}$$

The ratio X required is defined as

$$X = \frac{r}{\delta r} \tag{B.6}$$

Substituting for X in Equation (B.5) and solving gives X = 41,49.

For a real (and probably cluttered) environment, the power flux S decays with a power factor in Equation (B.2) greater than 2. For two evaluation locations oriented in any other direction, S changes more slowly with δr. Therefore, a factor of 40 is appropriate for simplicity – i.e. provided the radio source is at a distance 40 times the distance between evaluation points, a single evaluation is all that is required.

B.3.1.2.6.4.2.2 Variation of RF field strength due to remote source antenna directivity

Now consider Figure B.3 for two evaluation locations at constant r but varying direction ϕ relative to the radio source.

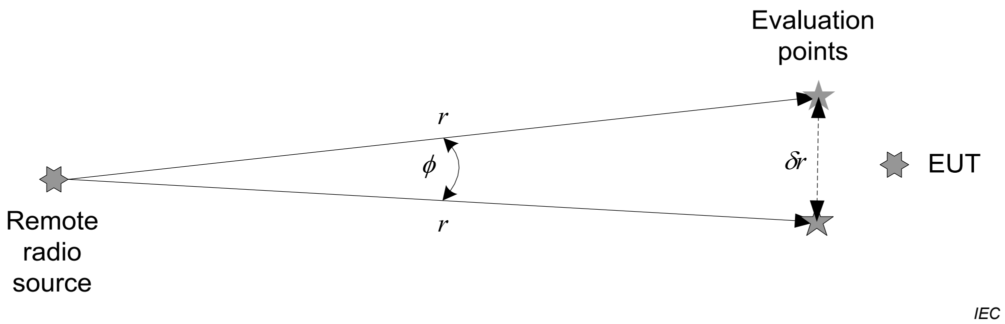


Figure B.3 – Relationship of separation of remote radio source and evaluation area to separation of evaluation points

For a source at a distance 40 times the separation between two evaluation locations:

$$r = 40 \cdot \delta r \tag{B.7}$$

and

$$\phi = 2 \cdot \tan^{-1} \frac{(\delta r / 2)}{40 \cdot \delta r} = 1{,}4° \tag{B.8}$$

This is small enough to be disregarded except for highly directional (horizontal pattern) antenna sources deployed at the higher microwave frequencies. In those cases, the clutter variation is likely to be dominant and the maximum gain condition applicable for the area of evaluation should be used.

EXAMPLE 1

In an area of evaluation 15 m by 20 m, the maximum distance, d, between any two points:

$$d = \sqrt{15^2 + 20^2} = 25 \text{ m}$$

For a radio source to be evaluated based on a single evaluation location, it shall be a distance of at least r from the area of evaluation where:

$$r = 40 \times 25 = 1\,000 \text{ m}$$

EXAMPLE 2

For a selected evaluation location 2 km from the nearest ambient radio source under investigation, an evaluation is valid for the parts of an area under evaluation extending to a distance d from the evaluation location:

$$d = \frac{2\,000}{40} = 50 \text{ m}$$

B.3.1.2.7 Personal RF monitors (informative)

Personal RF monitors are generally defined as small portable handheld or body worn units that can be used by workers as safety devices to identify potentially hazardous RF sources in their workplace.

These units enable workers to move freely through areas of varying and unknown RF field strengths with the expectation that the device will provide some form of warning before the RF exposure to the user exceeds the applicable threshold.

A variety of personal RF monitors are available around the world that caters for a variety of frequency windows, exposure standards, detector polarities, field characteristics, and accuracy specifications.

Personal RF monitors should not be used for RF exposure compliance assessment as defined in Clause 6 interaction between the user's body and relative position of the unit affects the indicated exposure level.

Personal RF monitors can trigger the need for further investigations to be carried out by a trained surveyor using calibrated RF survey equipment.

B.3.1.3 Laboratory based field strength measurements

B.3.1.3.1 General

Laboratory based field strength measurements can be obtained either by surface or volume scanning. The methods used are to measure directly or indirectly the E-field or H-field strength, deduce the field distribution for a given input power and frequency.

B.3.1.3.2 Field propagation by means of surface scanning

B.3.1.3.2.1 General

Measurements of electric field amplitude, phase and polarization are made at points on a surface surrounding the EUT to establish the parameters to model a set of isotropic sources on that surface that will produce at the point of investigation the same field as the EUT. The scanned surface shall contain all the relevant energy that is radiated from the EUT. The parameters of this set of isotropic-radiators are then used to calculate the field at the points of investigation.

A summary of the main steps is given in Figure B.4.

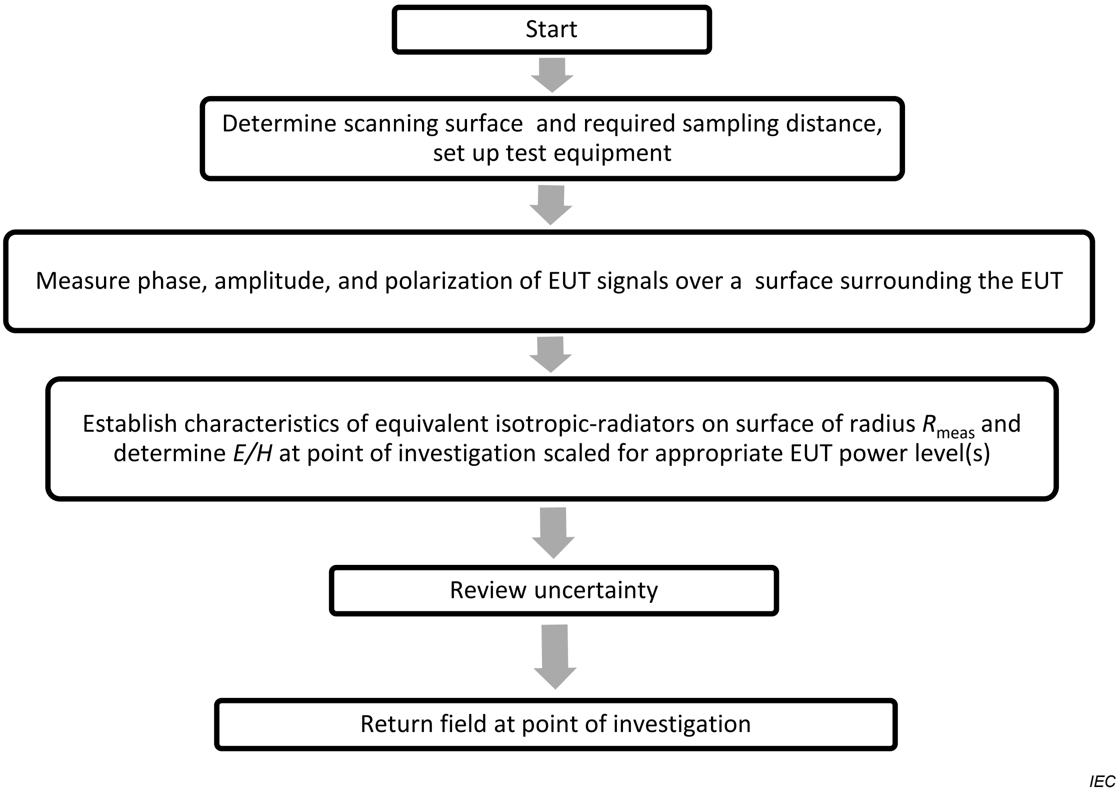


Figure B.4 – Outline of the surface scanning methodology

Methods to perform surface scanning could be, but are not limited to, far-field, compact range, and planar, cylindrical or spherical near-field as long as the methodology is accurately defined and the uncertainty is quantified. For simplicity, the specifications below are given assuming a spherical measurement surface. Generalizations to other measurement surfaces are possible.

B.3.1.3.2.2 Measurement equipment

B.3.1.3.2.2.1 General description

The surface scanning consists of an EUT mounted on an azimuthal positioner and the probe(s) mounted on a support structure at distance R_{meas} from the EUT. This method requires the ability to measure the phase of the signal. Detection shall consist of either one probe moved mechanically along the structure or one probe array switched electronically in order to perform an angular elevation scan of the electromagnetic fields. Alternatively, the EUT may be moved to different elevation angles by means of an additional elevation positioner.

The near-field antenna measurement system shall be configured according to Figure B.5.

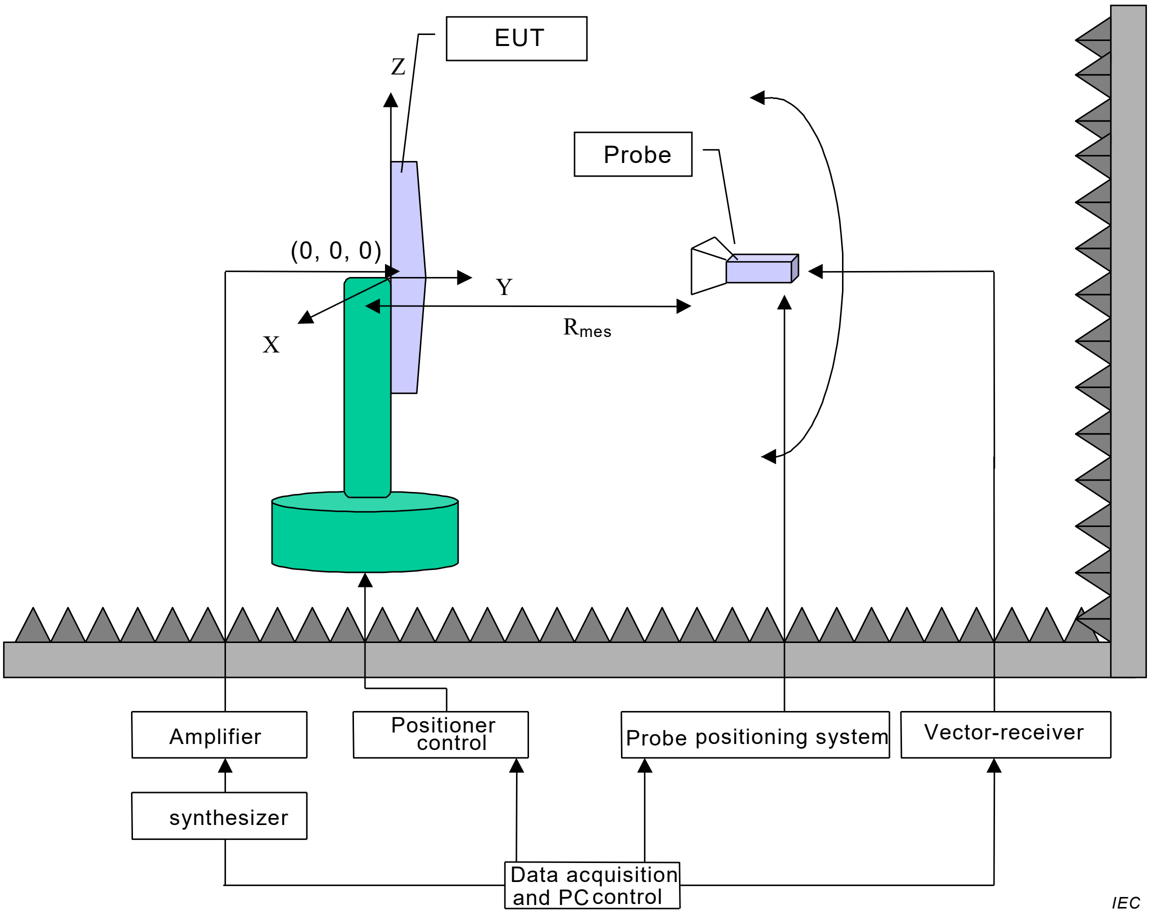


Figure B.5 – Block diagram of the near-field antenna measurement system

The following equipment is required:

- anechoic chamber;
- electric probe(s) (antenna(s));
- support structure for probe(s);
- supporting structure;
- vector-receiver;
- synthesizer and amplifier(s);
- probe positioning system or probe array controller system;
- EUT positioning system.

A computer controls the measurement equipment located in the anechoic chamber. The computer shall be placed so as not to influence the measurements.

The test shall be performed using probe antennas providing electric field measurements. The probe antennas shall be accurately positioned to measure the electric field distribution in a spherical surface around the EUT.

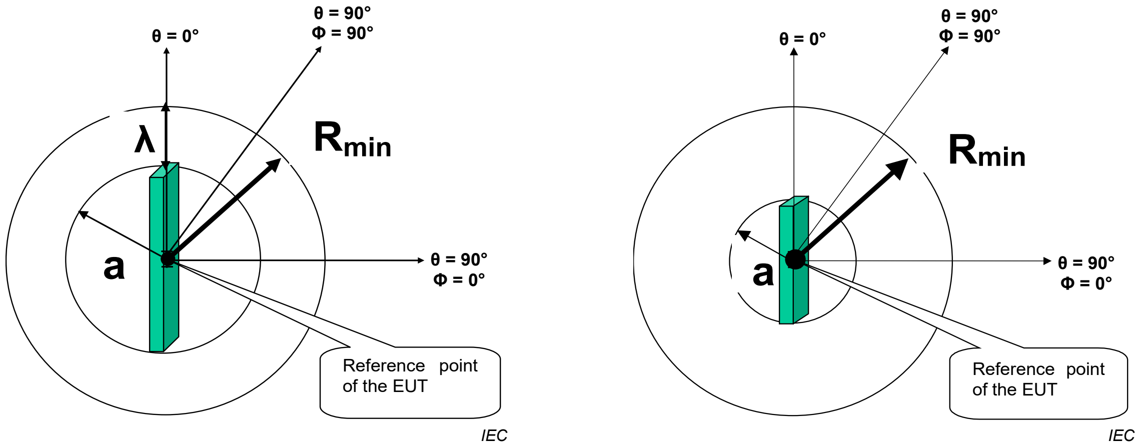
The measurement shall be carried out with a minimum of reflections from the environment in order to simulate free space conditions.

B.3.1.3.2.2.2 Positioning, orientation, and sampling requirements of the scanning equipment

The measurement system shall be able to scan a spherical surface of radius R_{meas} with radial and angular position accuracies of $\lambda/72$ degrees and 0,5°, respectively.

The distance between the EUT reference point at the origin of rotation and the measurement probe(s) shall be the greater of:

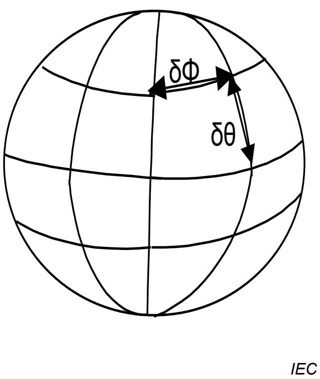
- R_{min} in order to minimize the impact of the non-radiating near-fields where R_{min} depends upon the maximum dimension of the EUT and the wavelength λ according to Figure B.6; and
- the distance required to ensure that the probes and measurement equipment are operating within their calibrated level range for the power specifications of the EUT.



When a > λ, R_{min} = a+ λ When a ≤ λ, R_{min} = 2λ

Figure B.6 – Minimum radius constraint where *a* denotes the minimum radius of a sphere, centred at the reference point, that will encompass the EUT

The sampling criterion requires a maximum angular spacing of the measurement points of $\lambda/2$ over the sphere circumscribing the EUT with radius R_{meas}. The angles $\delta\phi$ (azimuth) and $\delta\theta$ (elevation) between adjacent measurements shall comply with the constraints of Figure B.7.



$$\delta\phi \le \frac{\lambda}{2R_{\text{meas}}}$$

$$\delta\theta \le \frac{\lambda}{2R_{\text{meas}}}$$

Figure B.7 – Maximum angular sampling spacing constraint

B.3.1.3.2.2.3 Measurement probe

The probe or probe array shall be designed and dimensioned such as not to disturb the electromagnetic fields generated by the EUT.

The probe(s) gain shall be calibrated with a measurement uncertainty less than ±0,5 dB.

The probe shall be able to provide orthogonal polarization with cross-polar isolation better than 30 dB. Alternatively, a second scan with a probe rotated by 90° could detect the cross-polar values.

B.3.1.3.2.2.4 Supporting structure

The antenna shall be mounted on a dielectric holder fixed on the positioning system. The holder shall be made of low conductivity and low relative permittivity material(s): tan (δ) ≤ 0,05 and $\varepsilon_r \leq 5$.

Alternatively, the antenna may be mounted on a metallic mast, if this is the normal operating situation of the antenna. If the mounting situation differs from a free-space equivalent, this shall be documented in the measurement results.

The antenna shall be mounted so that the reference point (0, 0, 0) is in the centre of the sphere.

B.3.1.3.2.2.5 Vector-receiver

The dynamic range shall be more than 90 dB. To minimize external interference, a phase locked loop (PLL) system is preferred. The receiver shall be able to measure the magnitude and phase for every detection point.

B.3.1.3.2.2.6 Anechoic chamber

The level of perturbation due to reflections and/or noise shall not exceed −30 dB of the incident field where measurements are made.

If no PLL-system is used, the shielding level of the anechoic chamber enclosure should be better than 50 dB at the measurement frequencies.

Ambient temperature shall be in the range of 10° C to 30° C and shall not vary by more than ±5° C during the test.

B.3.1.3.2.3 Measurement protocol

B.3.1.3.2.3.1 Calibration of the test facility

Four calibrations of the near-field spherical test facility shall be performed:

- polarization calibration;
- amplitude and phase calibration (uniformity between probes);
- gain calibration;
- electrical noise evaluation.

The measurement equipment shall be calibrated as a complete system at the appropriate frequencies.

B.3.1.3.2.3.2 Test to be performed

The test shall be performed at the fixed power level matched to the detection range of the measurement equipment. Results for the desired transmitted power shall be obtained by post-processing.

For multi-mode and multi-band EUTs, all the previous tests shall be performed in each operating transmitting band.

The EUT shall be fed with frequencies comparable to normal configurations. A signal generator capable of providing the same signal transmitted by the BS may replace the transmitter providing the input power to the EUT.

B.3.1.3.2.3.3 Measurement procedure

B.3.1.3.2.3.3.1 Basic test configuration

The basic test configuration corresponds to an initial angle $\phi = \phi_0$ (azimuth). The angular scan θ (elevation) shall start at one of the edges of the circular path and be incremented by a value $\delta\theta$. The angular scan in elevation shall be performed along the whole circular path. At each $\theta_i = \theta_{i\text{-}1} + \delta\theta$ position of the probe(s), the received or emitted signal shall be recorded. The basic test configuration will be repeated for each azimuthal increment $\delta\phi$.

B.3.1.3.2.3.3.2 Pre-test procedure

Check if the detection probe(s) can accept the power levels radiated during the measurements. Calibrate the electric and/or magnetic probe(s) in gain. Alternatively, confirm that the absolute values of the electromagnetic fields can be derived from the measurement data over the whole sphere.

Measurements shall be made for a minimum of three frequencies:

F_c: centre frequency

F_{min}: lower band edge frequency

F_{max}: upper band edge frequency

Determine values of $\delta\phi$, ϕ_{max}, $\delta\theta$, θ_{min}, θ_{max}, R_{meas} where:

$\delta\phi$ is the azimuthal increment;

ϕ_{max} is the maximum azimuthal angle value from the reference*;

$\delta\theta$ is the elevation increment;

θ_{min} is the lower edge angle of the circular elevation path;

θ_{max} is the upper edge angle of the circular elevation path;

R_{meas} is the radius of the scan in elevation.

Confirm that the total contribution of interference's and reflected signals is less than −30 dB below the incident signal.

B.3.1.3.2.3.3.3 Test procedure

- Confirm proper operation of the probe(s), measurement system and instrumentation.
- Mount the EUT in the measurement configuration.
- Configure the EUT for optimum output power, at the desired frequency and for the desired operating modes.
- Position (or configure) the probe(s) at the initial measurement location.
- Perform an initial elevation scan at the reference azimuth position and store the data.
- Measure and acquire the electromagnetic fields distribution.
- The EUT or the probe(s) are moved incrementally in azimuth with $\Delta\phi$ angle step around a vertical axis that corresponds also to a symmetry axis for the sphere to be scanned.
- Repeat the electromagnetic fields measurement until $\phi_i = \phi_{max}$ (with $\phi_i = \phi_{i\text{-}1} + \delta\phi$, with $i_{min} = 1$).
- After measurements, perform again a final elevation scan at the reference azimuth position and compare the data with the initial elevation scan. Verify that the final values at

the maximum levels are within 5 % of the initial values (influence of the drift due to surrounding equipment and environment).

- If the drift is greater than 5 %, repeat the measurements.

B.3.1.3.2.4 Post-processing

B.3.1.3.2.4.1 General

The electromagnetic field values shall be obtained by applying a post-processing technique on the set of measured near-field data.

B.3.1.3.2.4.2 Determining electromagnetic field values outside or inside the scanned surface

The measured tangential electromagnetic field shall be mapped on a spherical vector-wave expansion consisting of a sum of TE and TM wave functions. The number of modes to consider in the expansion shall be at least $N = \frac{2\pi}{\lambda} a + 10$. Modes of higher order are evanescent and will have no significant contribution for distances larger than R_{min}. The expansion will not converge for distances smaller than R_{min}. Therefore, a zone of exclusion exists in the vicinity of the antenna where the expansion cannot be performed. This corresponds to the region with significant contributions from reactive field components.

B.3.1.3.2.4.3 Scaling measurements to a given input power

The measured electric and magnetic fields, denoted E_{o} and H_{o}, respectively, are obtained for a given input power P_{o}. As the fields are proportional to the square root of the input power, the field strength levels at the desired transmitted power P shall be obtained as:

$$E = \sqrt{\frac{P}{P_{\mathrm{o}}}} E_{\mathrm{o}} \qquad H = \sqrt{\frac{P}{P_{\mathrm{o}}}} H_{\mathrm{o}}$$

B.3.1.3.3 Measurements based on surface or volume scans

B.3.1.3.3.1 General

Direct measurements of electric and magnetic fields are made at points of investigation within a volume or at a surface surrounding the EUT. A summary of the main steps is given in Figure B.8.

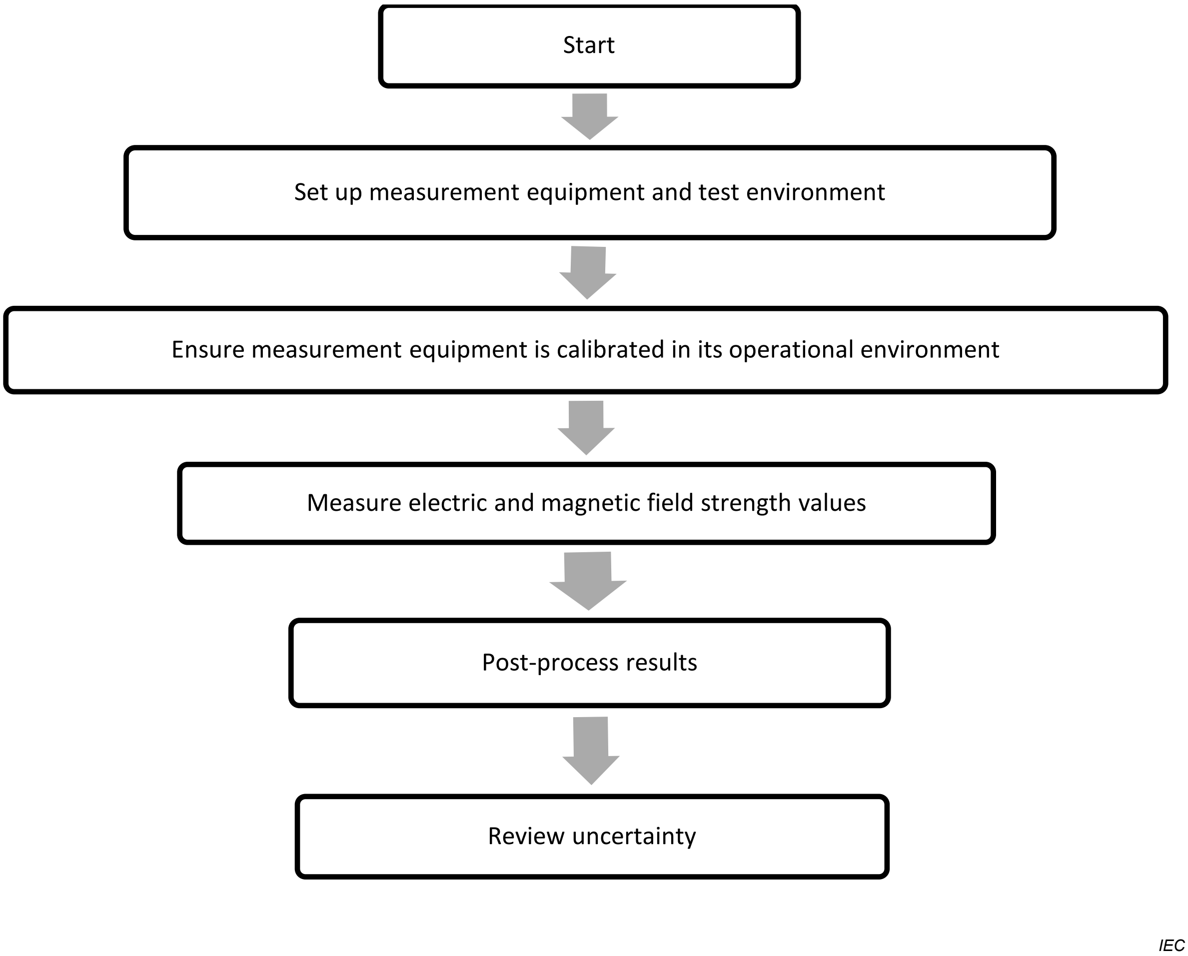


Figure B.8 – Outline of the volume/surface scanning methodology

B.3.1.3.3.2 Measurement equipment and test environment

B.3.1.3.3.2.1 General description

The volume/surface scanning equipment consists of an isotropic probe and a structure to hold the EUT and the probe allowing a 3D movement relative to each other.

The following equipment may be required:

- anechoic chamber or suitable test site;
- electric and/or magnetic isotropic probe;
- supporting structure for isotropic probe;
- supporting structure for the EUT;
- synthesizer and amplifier(s);
- isotropic probe positioning system or probe array controller system;
- EUT positioning system;
- receiver or other measurement device.

A computer may be used to control the measurement equipment. The test equipment shall be placed so as not to influence the measurements. A typical near-field EUT measurement system configuration is shown in Figure B.9.

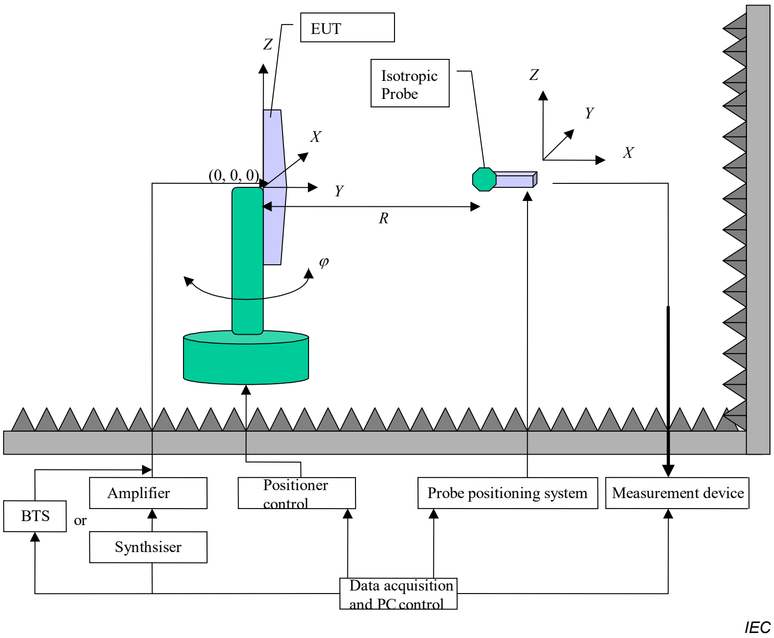


Figure B.9 – Block diagram of typical near-field EUT measurement system

B.3.1.3.3.2.2 Scanning equipment

The positioning system holding the EUT and the isotropic probe shall be able to scan a specified volume/surface of the test environment. The sampling of the specified volume/surface is achieved through the relative displacements, translation and rotation, between the structure supporting the probe and the EUT. The measurements shall be carried out as a set of scans on cylindrical, spherical or planar surfaces.

The accuracy of the probe tip positioning over the measurement area shall be less than ±0,5 cm.

The resolution at which the measurement system is able to sample the field strengths shall be $\lambda/10$ or less.

Cylindrical, Cartesian or spherical coordinate systems may be used as illustrated in Figure B.1. The reference axes are defined by:

- x – the distance in front of the antenna, or θ = 90°, ϕ = 0° in the spherical co-ordinate system;
- y – the distance on the side of the antenna, or ϕ, the azimuth angle in the cylindrical co-ordinate system;
- z – the height along the antenna axis, or θ = 0° in the spherical co-ordinate system.

The origin of the co-ordinate system shall be defined, for instance by the centre of the back panel in case of panel antennas, and the centre of the antenna in case of omni-directional antennas.

B.3.1.3.3.2.3 Measurement equipment

The measurement equipment shall be composed of the isotropic probe and the measurement device.

The isotropic probe shall be designed and dimensioned such as not to disturb the electromagnetic fields generated by the EUT.

The measurement equipment shall have a measurement range compatible with the RF power levels used in the test and the resulting fields at the points of observation.

Where an E-field measurement equipment is used, the lower detection limit shall be lower than 3 V/m and the upper detection limit shall be higher than 200 V/m.

Where a H-field measurement equipment is used, the lower detection limit shall be lower than 0,03 A/m and the upper detection limit shall be higher than 0,6 A/m.

The linearity of E-field and H-field measurement equipment shall be within ±1 dB within the measurement range and the isotropy of measurement target value of ±1 dB below 1 GHz, and ±3 dB above 1 GHz.

B.3.1.3.3.2.4 Supporting structure for the EUT

The antenna shall be mounted on a dielectric holder fixed on the positioning system. The holder shall be made of low conductivity and low relative permittivity material(s): $\tan(\delta) \leq 0{,}05$ and $\varepsilon_r \leq 5$.

Alternatively the antenna may be mounted at a metallic support, if this is the normal operating situation of the antenna. If the mounting situation differs from a free-space equivalent, this shall be documented in the measurement results.

B.3.1.3.3.2.5 Input power specifications

The EUT shall be fed with frequencies comparable to normal configurations. An RF source, e.g. a generator or a synthesizer and amplifier, capable of providing the same signals transmitted by the BS may replace the transmitter providing the input power to the EUT. Power scaling is conducted in a post-processing step.

Enough power shall be available to generate a field level in the detection range of the measurement equipment at the largest measurement distance.

The power chain is typically composed of a signal synthesizer with a power amplifier, a directional coupler connected to a power meter, and a cable to the antenna.

The test signal source / base station system shall be operated according to the manufacturer's instructions in order to ensure the RF power output stability throughout the test campaign. Typically this may require the signal source / base station system to be operational at the required output power for one hour prior to commencement of measurements in order to reach thermal equilibrium.

The power chain shall be carefully evaluated in order to estimate accurately the input power fed into the antenna.

B.3.1.3.3.2.6 Test site

The test site shall be evaluated in order to minimize the level of perturbation due to reflections or ambient noise, which shall not exceed –25 dB of the incident field at any point of observation.

Ambient temperature shall be in the range of 10° C to 30° C and shall not vary by more than ±5° C during the test.

B.3.1.3.3.3 Measurement protocol

B.3.1.3.3.3.1 Calibration of the test facility

The measurement system shall be calibrated as a whole system at appropriate frequencies.

B.3.1.3.3.3.2 Simplified performance checking

The measurement system shall be validated by performing a scan of a calibrated reference antenna, e.g. a half-wave dipole. The measurements shall be compared in the far-field to the reference field given by the far-field formula:

$$E = \frac{\sqrt{30 \times P \times G}}{R} \qquad H = \frac{E}{\eta_0} = \frac{\sqrt{P \times G}}{69 \times R}$$

where

P is the input power of the reference antenna, in watts;

G is the gain in the main beam of the reference antenna;

R is the distance between the probe and the reference antenna, in metres;

η_0 is the free space impedance.

The tolerable error on the performance checking shall be below ±1 dB.

B.3.1.3.3.3.3 General requirements for scanning sampling

Different coordinate systems may be used for scanning sampling (see Figure B.1).

The angular orientation of the antenna in relation to the measurement point shall be established within 2 % of the nominal −3 dB beamwidth of the antenna under test, in E and H planes as appropriate.

For Cartesian scans, at distances shorter than 3λ from any part of the antenna, the sampling step shall be shorter than $\lambda/2$. At distances larger than 3λ, the sampling step shall be shorter than λ.

For cylindrical scans, at distances shorter than 3λ from any part of the antenna, the sampling step shall be shorter than $\lambda/2$ in the ρ, Z and φ directions. At distances larger than 3λ, the sampling step shall be shorter than λ in the Z and ρ directions. In azimuth, the maximum angular separation between two adjacent sampling points, $\Delta\Phi_{\text{max}}$, shall be

$$\Delta\Phi_{\text{max}} = \frac{180}{kP + 10'}$$

Where k and P denote the wavenumber and the smallest radius of a circular cylinder (with axis along z) enclosing the EUT, respectively.

For spherical scans, at distances shorter than 3λ from any part of the antenna, the sampling step shall be shorter than $\lambda/2$. At distances larger than 3λ, the sampling step shall be shorter than λ in the R direction. In elevation, the maximum angular separation between two adjacent sampling points, $\Delta\Theta_{\text{max}}$ shall be

$$\Delta\Theta_{\text{max}} = \frac{180}{kR + 10'}$$

where R denotes the smallest radius of a cylinder (with axis along y enclosing the EUT. The maximum angular separation in azimuth is defined as for cylindrical scans.

B.3.1.3.3.3.4 Measurement procedure

- Mount the EUT in the measurement configuration.
- Configure the EUT for optimum output power, at the desired frequency and for the desired operating modes.
- Perform an initial E-field or H-field measurement at the reference position P_r close to the antenna (but at a distance larger than $\lambda/2$) and store the data for the power drift check.
- Perform 3D scanning around the EUT, according to the general requirements to acquire the electromagnetic fields distribution.
- As a final step in the test, repeat the E-field or H-field measurement at the reference position P_r. If the field value deviates more than 5 % from the initial values then the power chain shall be checked, and the test repeated.

B.3.1.3.3.4 Post-processing

B.3.1.3.3.4.1 Interpolation of measurements

Evaluation of the E or H field at points of investigation shall be done by direct measurement and/or by interpolation between measurement points.

B.3.1.3.3.4.2 Scaling measurements to a given input power

The measured electric and magnetic fields, denoted E_o and H_o, respectively, are obtained for a given input power P_o. As the fields are proportional to the square root of the input power, the field strength levels at the desired transmitted power P shall be obtained as:

$$E = \sqrt{\frac{P}{P_o}} E_o \qquad H = \sqrt{\frac{P}{P_o}} H_o$$

B.3.1.4 Spatial averaging

B.3.1.4.1 Applicability of spatial averaging

Spatial averaging applicability depends on the relevant RF exposure limit as described in 6.4.1.

In a non-plane wave RF field, comparing the maximum RF field strength evaluated at a single point with the RF exposure limit may overestimate the whole-body RF absorption. Spatially averaging the RF field strength in regions that a body occupies provides a better representation of the whole-body human exposure.

In cases of doubt or to resolve disputes, the reference spatial averaging method is the spatial average over nine points (see Figure B.10).

The orientation of the plane used for reference method shall be based on the foreseeable exposure conditions at the evaluation location. For example, when evaluating exposure of pedestrians from a single source, the plane of the spatial averaging scheme should be vertical, including the evaluation location and oriented perpendicular to the direction of the source.

Where localized or partial-body exposure is relevant for the applicable RF exposure limits, the maximum RF field strength or power density at any of the measurement points shall also be considered (see Table 3).

B.3.1.4.2 Spatial averaging measurement method

For each evaluation location, perform measurements as described in Figure B.10, at measurement points according to the spatial averaging scheme (see B.3.1.4.4.2).

The spatially-averaged value of the RF field strength at each evaluation location is determined using:

$$\overline{E} = \sqrt{\frac{\sum_{i=1}^{N_\mathrm{p}} E_i^{\,2}}{N_\mathrm{p}}} \quad \text{or} \quad \overline{H} = \sqrt{\frac{\sum_{i=1}^{N_\mathrm{p}} H_i^{\,2}}{N_\mathrm{p}}} \quad \text{or} \quad \overline{S} = \frac{\sum_{i=1}^{N_\mathrm{p}} S_i}{N_\mathrm{p}} \tag{B.9}$$

where:

$\overline{E}$ is the spatially-averaged electric field strength at the evaluation location;

E_i is the r.m.s. value of the electric field strength at the ith measurement point;

$\overline{H}$ is the spatially-averaged magnetic field strength at the evaluation location;

H_i is the r.m.s. value of the magnetic field strength at the ith measurement point;

N_p is the total number of measurement points for each evaluation location;

$\overline{S}$ is the spatially-averaged plane wave equivalent power density at the evaluation location;

S_i is the plane wave equivalent power density at the ith measurement point.

For a frequency-selective measurement, the above formula shall be evaluated separately for each frequency band.

B.3.1.4.3 Error related to spatial averaging

E.11 contains informative direction on the error related to spatial averaging. Determination of error, statistical parameters, characterization of different averaging schemes and environment are all discussed.

B.3.1.4.4 Guidance on spatial averaging schemes

B.3.1.4.4.1 General

The applicable exposure limit may be the spatially-averaged RF field strength over the entire body of the exposed individual, but with the important condition that the peak spatial-average *SAR* is not exceeded, e.g. [12], [31]. Whilst the exposure ratio for the spatially-averaged field will correspond more accurately with the whole-body average *SAR* exposure ratio, it may not ensure compliance with peak spatial-average *SAR* limits. Evaluating the maximum RF field strength at a point may ensure compliance with both the whole-body average and peak spatial-average *SAR* limits.

NOTE In IEEE [31] and ARPANSA [32], additional limits on the spatial-peak field strength or power density are given to minimize the risk of exposure above peak spatial-average *SAR* limits.

When defining the assessment configuration (see Clause 7) the specific national (e.g. regulatory and legislative) requirements shall be taken into account.

B.3.1.4.4.2 Spatial averaging schemes

Spatial averaging means the root mean square of the field over a vertical line or cross-sectional area that represents the volume occupied by a body. The spatial distribution of the field at the position of a body will depend on propagation conditions including reflections from objects in the environment ([33], [34]). Selection of the spatial averaging scheme may be influenced by multiple sources. This may require multiple points, across more than one axis.

In some situations the spatial distribution will be dominated by the direct field from the antenna (e.g. source-environment region *-0) or in combination with a ground reflected wave (e.g. in open areas). Ideally, the spatially-averaged field value should be determined from many evaluation points to obtain information on the variation in field strength.

In a cluttered environment, the distribution is influenced by multiple reflections and diffraction and may create a highly non-uniform field distribution. A theoretical analysis in [33], based on the statistics of small scale fading (random variations of the field around a local mean), provides some guidance on determining the uncertainty in the estimation of the spatial-average field from a limited set of spatial measurements.

The reference and examples of alternative, spatial averaging schemes are shown in Figure B.10, for averaging above a walkway or other foot support and Figure B.11 for averaging around a point of spatial-peak field. The RF field strength is evaluated for each measurement/computation point and the spatially-averaged RF field strength determined using Equation (B.9) in B.3.1.4.2 with equal weighting for all measurement/computation points.

The schemes shown in Figure B.10 are useful for evaluating RF field strength for determining human exposure in typical positions of the body (e.g. floor standing). In some circumstances where, for example, exposures occur whilst at elevated heights (e.g. on a ladder or other support structure), exposure evaluation shall be done for a realistic position of the body and foot support which provides maximum exposure (e.g. position the evaluation location in the main beam of the transmitting antenna).

Information about the spatial averaging scheme(s) employed shall be provided in the report (see Clause 10).

It is recognized that national regulatory agencies may define alternative averaging schemes.

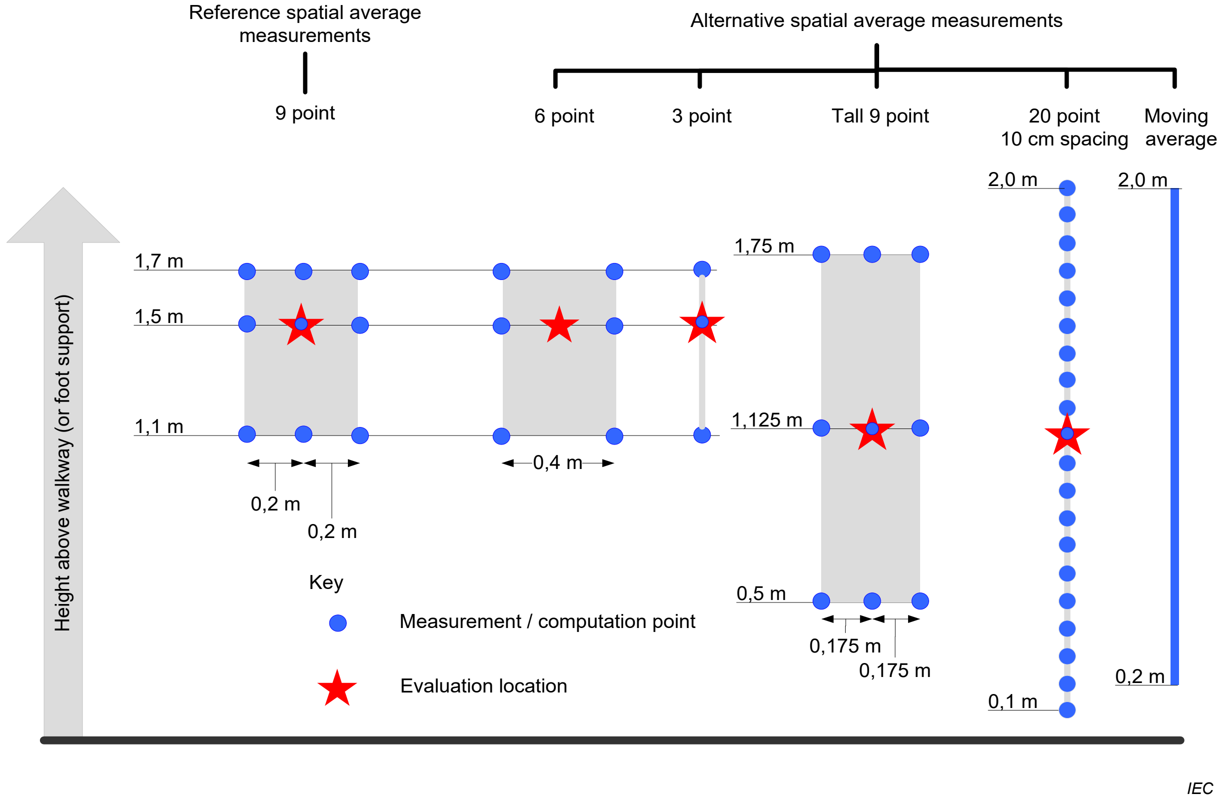


Figure B.10 – Spatial averaging schemes relative to foot support level and in the vertical plane oriented to offer maximum area in the direction of the source being evaluated

B.3.1.4.4.3 Averaging around the spatial-peak field point

The method is shown in Figure B.11. The spatially-averaged RF field strength is determined by first scanning between 0,5 m and 1,75 m above ground to find the spatial-peak field strength in the region. The peak and two additional measurements at points one wavelength vertically above and below it are combined to determine the spatially-averaged RF field strength. This method is not specific to a typical or "standard" height adult human and it weights the result towards the spatial-peak field strength value.

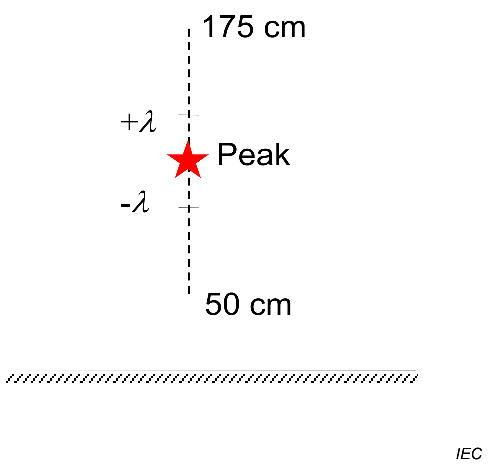


Figure B.11 – Spatial averaging relative to spatial-peak field strength point height

B.3.1.5 Time averaging

B.3.1.5.1 Applicability of time averaging

Time averaging is applicable where the RF field strength varies over time, for example as a result of changing propagation conditions or variations of the transmitter power due to traffic variations or power control or duty cycle or due to transmitter operation.

The relevant exposure standard may specify the applicable time averaging period. Time averaging over periods different to the relevant exposure standard may provide useful information but shall not be used for comparison with the applicable exposure limits.

Time averaging can be employed for push-to-talk (PTT) systems, where the RBS transmits only when the operator keys up the transmitter during simplex communication. Duty cycle data may be considered as a subsequent correction if required for the evaluation purpose.

B.3.1.5.2 Time averaging measurement method

The following steps shall be performed:

a) Determine when to perform the measurement. For example, this may be related to the time of day to ensure evaluation during highest RF field strength conditions – i.e. under maximum traffic.

NOTE 1 Data logging over an extended period (day/week) can be useful in determining when to perform the time-averaged evaluation.

b) Specify the averaging time, for example, according to the relevant exposure standard.

c) Specify the evaluation location; for example, use the sweep method (see B.3.1.2.5.2) to establish the location of spatial-peak field strength.

d) Perform the evaluation.

NOTE 2 Such measurements can be performed with portable data logging devices adapted to the averaging time related to the applicable exposure limits. These can provide a “sliding” average (i.e. the instantaneous value of the average over a period of time ending at the present time and starting at the appropriate averaging time before the present).

B.3.1.5.3 Guidance on addressing time variation of signals in measurement

The following shall be considered when interpreting measurement data or defining the time at which the measurement is performed.

- In operation and depending on the technology, the RBS output power is likely to vary in time. Typically, the radiated power varies according to overall traffic carried – often with a dependency on time of day, whether it is a working day or vacation, etc. There may be short-term variations in output power as traffic changes minute by minute and power control operates on shorter timescales. These variations can introduce uncertainty into sequential measurements performed at different locations. Long-term variations in RF field strength depend on traffic and are not determined during short-term measurement activities.
- If the evaluation purpose is to measure the highest field strength, then short-term measurements should be made at times when communications traffic is heaviest, for example during a weekday evening rush hour when there is maximum human activity in the area around the RBS. However, measurements of a stable reference signal may be made at any time. The spectrum analyser should be set to capture the maximum signal (i.e. maximum hold mode) for comparison with an instantaneous value.
- At evaluation locations removed from the RF source, changes in propagation path may introduce fading.

Since measurements are normally made at different locations in a time sequence, the field variations in time and space tend to mix in the measurement result. This mixing is generally acceptable for spatially-time-averaged measurements. However, one of the following approaches may be employed to separate the spatial and temporal variations:

a) Repeat measurements at evaluation locations and examine the difference between repetitions as a function of time.
b) Fix a measurement antenna / isotropic probe at one location and observe how the readings change in time to isolate the temporal variation and handle as an influence factor (combined RBS output power and propagation path time variations) in the uncertainty analysis.
c) Use a fixed measurement antenna / isotropic probe as a reference to correct the readings of a second measurement antenna / isotropic probe at the evaluation points.
d) Measure a stable reference signal from the EUT (see Annex F) and use communications traffic data to determine the combined RF field strength for all signals as a function of time. Stable reference signal measurements may be made at any time. However, even the reference signal is subject to fluctuation due to changes in the propagation path.
e) Measure a stable reference signal from the EUT (see Annex F) over time to isolate the uncertainty influence factor of changes in propagation path over time from changes in RBS output power.

B.3.1.6 RF field strength measurement uncertainty

B.3.1.6.1 In-situ RF measurement uncertainty

The sources of uncertainty identified in Table B.7 or Table B.8 shall be considered in three categories

1) measurement equipment,
2) measurement methodology, and
3) source and environment.

The measurement equipment uncertainty shall be in accordance with performance requirements in Table B.5 and Table B.6. A description of relevant influence quantities and how the corresponding uncertainty may be assessed is given in E.7.

The measurement methodology uncertainty shall be quantified.

See uncertainty requirements in 6.3 and Clause 9.

Where practical, the uncertainty of the source and environment factors (e.g. rain, open windows, environmental clutter) should be quantified. If source and environment factors are difficult to quantify, they shall at least be described in the report (see Clause 10).

Table B.7 – Sample template for estimating the expanded uncertainty of an in-situ RF field strength measurement that used a frequency-selective instrument

Source of uncertainty (influence quantity)	Unit	Prob. distrib. type	Uncertainty or semi span a	Divisor d	Sens. coeff. c	Standard uncertainty $u = a/d$	Corr. fact. t	c^2u^2
Measurement equipment								
Calibration of the meter (or spectrum analyser)	dB	normal		1,96	1			
Calibration of the antenna factor	dB	normal		1,96	1			
Calibration of the cable loss	dB	normal		1,96	1			
Combined frequency response of the meter/cable/antenna	dB	rect.		√3	1			
Combined linearity deviation of the meter/cable/antenna	dB	rect.		√3	1			
Isotropy of the antenna	dB	rect.		√3	1			
Combined temperature and humidity response of meter/cable/antenna	dB	rect.		√3	1			
Mismatch between antenna and meter/ spectrum analyser	dB	U		√2	1			
Methodology								
Probe position in high field gradients	dB	rect.		√3	1			
Field scattering from surveyor's body	dB	rect.		√3	1			
Mutual coupling between measurement antenna or isotropic probe and object	dB	rect.		√3	1			
Meter reading error of fluctuating signals	dB	triang.		√6	1			
Source and environment								
Variation in the power of the RF source from the nominal level	dB	rect.		√3	1			
Field reflections from movable large objects near the source during measurement	dB	rect.		√3	1			
Scattering from nearby objects and the ground	dB	rect.		√3	1			
Combined correction factor, $t_c = \sum_{i=1}^{N} t_i$								N/A
Combined standard uncertainty, $u_c = \sqrt{\sum_{i=1}^{N} (c_i^2\, u_i^2)}$								
Coverage factor for required (e.g. 95 %) confidence interval, k								
Expanded uncertainty, $U = k \times u_c$								
NOTE 1 The value of divisor d for normal probability distribution is for 95 % confidence. NOTE 2 See Annex E for guidance on the variables in this table. NOTE 3 This table is under the assumption that the logarithmic expression of the measured quantities can be similarly treated to that of the linear expression in view of statistical properties.								

Table B.8 – Sample template for estimating the expanded uncertainty of an in-situ RF field strength measurement that used a broadband instrument

Source of uncertainty (influence quantity)	Unit	Prob. distrib. type	Uncertainty or semi span a	Divisor d	Sens. coeff. c	Standard uncertainty $u = a/d$	Corr. fact t	c^2u^2
Measurement equipment								
Calibration of field probe	dB	normal		1,96	1			
Frequency response of field probe	dB	rect.		√3	1			
Isotropy of the field probe	dB	rect.		√3	1			
Temperature response of the field probe	dB	rect.		√3	1			
Linearity deviation of the field probe	dB	rect.		√3	1			
Methodology								
Meter reading error of fluctuating signals	dB	triang.		√6	1			
Field reflections from surveyor's body	dB	rect.		√3	1			
Probe position in high field gradients	dB	rect.		√3	1			
Mutual coupling between measurement antenna or isotropic probe and object	dB	rect.		√3	1			
Source and environment								
Variation in the power of the RF source from the nominal level	dB	rect.		√3	1			
Scattering from nearby objects and the ground	dB	rect.		√3	1			
Field reflections from movable large objects near the source	dB	rect.		√3	1			
Combined correction factor, $t_c = \sum_{i=1}^{N} t_i$								N/A
Combined standard uncertainty, $u_c = \sqrt{\sum_{i=1}^{N} (c_i^2\, u_i^2)}$								
Coverage factor for required (e.g. 95 %) confidence interval, k								
Expanded uncertainty, $U = k \times u_c$								

NOTE 1 The value of divisor d for normal probability distribution is for 95 % confidence.

NOTE 2 See Annex E for guidance on the variables in this table.

NOTE 3 This table is under the assumption that the logarithmic expression of the measured quantities can be similarly treated to that of the linear expression in view of statistical properties.

B.3.1.6.2 Laboratory measurement uncertainty

B.3.1.6.2.1 Uncertainty for field propagation

The sources of uncertainty identified in Table B.9 shall be considered in four categories: measurement equipment, mechanical constraints, physical parameters, and post-processing. A description of relevant influence quantities and how the corresponding uncertainty may be assessed is given in Annex E.

After post-processing, the expanded uncertainty shall not exceed 30 %.

Table B.9 – Sample template for estimating the expanded uncertainty of a laboratory-based RF field strength measurement using the surface scanning method

Source of uncertainty (influence quantity)	**Unit**	**Prob. distrib. type**	**Uncertainty or semi span** a	**Divisor** d	**Sens. coeff.** c	**Standard uncertainty** $u = a/d$	**Corr. fact.** t	c^2u^2
Measurement equipment								
Calibration of field probe	%	normal		1,96	1			
Isotropy of field probe	%	rect.		√3	1			
Linearity deviation of the field probe	%	rect.		√3	1			
Measurement device	%	normal		1,96	1			
Noise	%	normal		1,96	1			
Integration time	%	normal		1,96	1			
Power chain	%	normal		1,96	1			
Mechanical constraints								
Positioning system	%	rect.		√3	1			
Matching between probe and EUT	%	rect.		√3	1			
Physical parameters								
Drifts in output power of the EUT, temperature and humidity	%	rect.		√3	1			
Perturbation by the environment	%	rect.		√3	1			
Post-processing								
Contribution of post-processing	%	rect.		√3	1			
Combined correction factor, $t_c = \sum_{i=1}^{N} t_i$								N/A
Combined standard uncertainty, $u_c = \sqrt{\sum_{i=1}^{N} (c_i^2\ u_i^2)}$								
Coverage factor for required (e.g. 95 %) confidence interval, k								
Expanded uncertainty, $U = k \times u_c$								
NOTE 1 The value of divisor d for normal probability distribution is for 95 % confidence. NOTE 2 See Annex E for guidance on the variables in this table.								

B.3.1.6.2.2 Uncertainty for surface or volume scans

The sources of uncertainty identified in Table B.10 shall be considered in three categories: measurement equipment, mechanical constraints, and physical parameters. A description of relevant influence quantities and how the corresponding uncertainty may be assessed is given in Annex E.

After post-processing, the expanded uncertainty shall not exceed 30 %.

Table B.10 – Sample template for estimating the expanded uncertainty of a laboratory-based RF field strength measurement using the volume scanning method

Source of uncertainty (influence quantity)	Unit	Prob. distrib. type	Uncertainty or semi span a	Divisor d	Sens. coeff. c	Standard uncertainty $u = a/d$	Corr. fact. t	c^2u^2
Measurement equipment								
Calibration of field probe	%	normal		1,96	1			
Isotropy of field probe	%	rect.		√3	1			
Linearity deviation of the field probe	%	rect.		√3	1			
Fields out of measurement range	%	rect.		√3	1			
Measurement device	%	normal		1,96	1			
Noise	%	normal		1,96	1			
Integration time	%	normal		1,96	1			
Power chain	%	normal		1,96	1			
Mechanical constraints								
Positioning system	%	rect.		√3	1			
Matching between probe and EUT	%	rect.		√3	1			
Physical parameters								
Drifts in output power of the EUT, temperature and humidity	%	rect.		√3	1			
Perturbation by the environment	%	rect.		√3	1			
Post-processing								
Contribution of post-processing	%	rect.		√3	1			
Combined correction factor, $t_c = \sum_{i=1}^{N} t_i$								N/A
Combined standard uncertainty, $u_c = \sqrt{\sum_{i=1}^{N} (c_i^2\, u_i^2)}$								
Coverage factor for required (e.g. 95 %) confidence interval, k								
Expanded uncertainty, $U = k \times u_c$								

NOTE 1 The value of divisor d for normal probability distribution is for 95 % confidence.

NOTE 2 See Annex E for guidance on the variables in this table.

B.3.2 *SAR* measurements

B.3.2.1 Overview of *SAR* measurements

The methods described in B.3.2.2 to B.3.2.4 are applicable for both maximum peak spatial-average *SAR* and whole-body average *SAR*. They are based on and make reference to IEC 62209-1 and IEC 62209-2.

B.3.2.2 *SAR* measurement requirements

B.3.2.2.1 General requirements

The *SAR* measurement system is composed of a flat phantom shell filled with tissue simulating liquid, a device holder, an electric field probe, a probe scanning system and electronic measurement instrumentation. General specifications and requirements on all of these components as well as on the measurement environment as defined in IEC 62209-2 and IEC 62209-1 shall be used. Other tissue simulating materials (e.g. gel) and electric field strength measurement systems (e.g. grid of fixed probes) may be used provided that the applicable requirements of IEC 62209-1 and IEC 62209-2 are satisfied.

B.3.2.2.2 Phantom selection

Three different phantoms may be used for *SAR* measurements (see Figure B.12):

- a flat elliptical phantom as specified in IEC 62209-2;
- a flat box-shaped phantom with lateral dimensions 1,54 m × 0,339 m [35], [29]. In the following this phantom is referred to as the large box-shaped phantom;
- a flat box-shaped phantom with lateral dimensions 0,96 m × 0,233 m [36]. In the following this phantom is referred to as the small box-shaped phantom.

For maximum peak spatial-average *SAR* measurements, all three phantoms specified above may be used if the broadside of the EUT can be circumscribed by the lateral dimensions of the phantoms.

For whole-body *SAR* measurements related to occupational exposure, the large box-shaped phantom shall be the preferred choice. Also the small box-shaped phantom and the elliptical phantom may be used to determine the absorbed power if the broadside of the EUT can be circumscribed by the lateral dimensions of the phantoms and the uncertainty introduced, compared with using the preferred phantom, is assessed. The absorbed power shall for this case be normalized with the mass of an adult according to 8.2.3 and B.3.2.3.4.

When general public exposure is considered, it is necessary to distinguish between two possible exposure configurations.

- For products that may be placed arbitrarily in homes, offices and other places, the exposure evaluations shall be conducted assuming potential exposure of all members of the general public, including children. The small box-shaped phantom shall then be the preferred alternative, but measurements in a small volume of the large phantom may also be used if the obtained measurement results are corrected as specified in B.3.2.3.4. Also the flat elliptical phantom may be used to determine the absorbed power if the broadside of the EUT can be circumscribed by the ellipse and the uncertainty introduced (compared with using the preferred phantom) is assessed. The absorbed power shall for this case be normalized with the mass of a child according to 8.2.3 and B.3.2.3.4.
- For products which are installed in ways that will prevent children from entering the immediate vicinity of the transmitting antenna(s), the evaluations may be conducted assuming adult exposure. For this case the large box-shaped phantom shall be the preferred choice. Also the small box-shaped phantom and the elliptical phantom may be used to determine the absorbed power if the broadside of the EUT can be circumscribed by the lateral dimensions of the phantoms and the uncertainty introduced (compared with

using the preferred phantom) is assessed. The absorbed power shall be normalized with the mass of an adult according to 8.2.3 and B.3.2.3.4.

The phantom shell thickness shall be up to 2 mm as specified in IEC 62209-2; however, external strengthening fins of a maximum height (thickness) of 3 mm may be used provided that the effect on the localized *SAR* is less than 5 %. When the phantom is filled with tissue simulating liquid at the required depth, the sagging shall be less than 2 mm from true flat.

NOTE The effect of strengthening fins on localized *SAR* is something that is verified by the phantom manufacturer. One way to do this is to compare the result obtained with results obtained using the elliptical flat phantom in IEC 62209-2. Another way is to use simulations using generic dipole sources to assess the effect in the near-field and the plane wave incidence to address effects for far-field exposure.

The depth of the tissue simulating liquid during the measurements shall be at least 0,15 m from the shell-liquid interface.

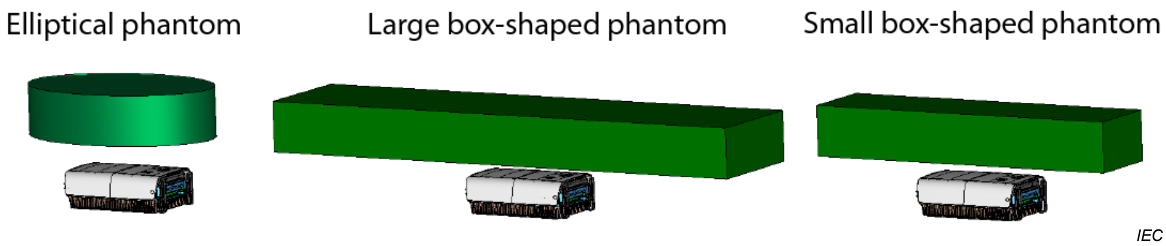


Figure B.12 – Positioning of the EUT relative to the relevant phantom

B.3.2.2.3 EUT configuration for *SAR* measurement

- If the EUT is an RBS with integrated antenna(s), it shall use its internal transmitter, the normal power supply, and the original antenna(s). The RBS shall be configured according to the specifications provided by the manufacturer, and the output power and frequency (channel) shall be controlled using an internal test program or by appropriate external equipment. A continuous wave (CW) signal may be used provided that the average power is adjusted to produce a conservative result.
- If the RBS is intended for use with external antenna(s), the same requirements apply, but the RBS may be replaced with any transmitter providing the same antenna input power and frequency as the RBS under evaluation.

B.3.2.2.4 Measurement requirements

The following requirements shall be addressed.

a) Maximum peak spatial-average *SAR* and whole-body *SAR* shall be considered.
b) The measurement shall be performed at the highest output power level, as specified by the manufacturer or the network operator. Alternatively, the measurement may be performed at a known lower power level and the result scaled to the highest power level numerically (see 6.1.5.3) and documented in the test report.
c) The RF transmission characteristics of the EUT shall be taken into account, i.e. operating modes, operating bands and antenna configurations. Where there are multiple modes, bands or antenna configurations, they shall all be evaluated, at the corresponding specified power levels. The *SAR* probe calibration and *SAR* scaling shall take into account the peak-to-average power ratio of the measured RF signal of the EUT according to IEC 62209-1.
d) If the EUT is capable of simultaneous transmission of multiple bands and technologies (e.g. WCDMA 2 100 MHz and LTE 2 600 MHz), all bands and technologies shall be evaluated and combined using the formulas defined in B.6 and taking IEC 62209-2 into consideration.
e) To determine the maximum *SAR*, the evaluation shall be performed with the antenna, or the side of the device where the antenna is located, facing the phantom. The antenna or device shall be positioned so as to obtain the highest possible *SAR*, which for many situations implies that the antenna's main lobe direction shall be orthogonal to the

phantom surface. If the measurement is conducted in the reactive near-field region, additional test positions may need to be considered due to differences in RF coupling.

f) During the measurements, the centre of the EUT/antenna shall be placed below the centre of the relevant phantom (see Figure B.12). If an EUT/antenna with electrical tilt is measured, it shall be aligned to make the main beam expose the centre of the phantom. For whole-body exposure, it may be necessary to align the phantom with the antenna in the same relationship/orientation as in the actual installation to account for proper RF coupling.

g) For localized *SAR* measurements, small adjustments of the EUT position may be made in order to avoid that an antenna element is positioned close to an edge of the phantom. The EUT positioning shall be documented in the test report.

h) To establish the compliance boundary, testing shall be performed at different separation distances up to 1 000 mm from the tissue simulating liquid to determine the compliance distance, i.e. the distance at which the *SAR* value is below the appropriate *SAR* limit for the assessment configuration. Measurements in a number of positions may be needed. For guidance on compliance boundary assessment, see 6.1.2.

Compliance boundaries for different power levels may be obtained by linear scaling of a *SAR* versus separation distance curve (see 6.1.5.3).

B.3.2.3 *SAR* measurement description

B.3.2.3.1 General method

The *SAR* assessment protocol described below is applicable to both localized (see B.3.2.3.3) and whole-body (see B.3.2.3.4) *SAR*.

- Step 1: For each transmitter and transmit band used by the EUT, measure the lower, centre and upper frequency at zero distance between the EUT and the phantom shell. If the EUT can be configured to transmit in the entire transmit band, separate measurements for low, mid and high frequencies are not required.

  When *SAR* assessment is performed on multiple surfaces of the EUT, these measurements shall be made on all surfaces required in 6.1.4 of IEC 62209-2:2010 at the centre frequency (default) or the frequency with highest transmitted power (if measured). Measurements on the remaining two frequencies are performed only on the surface with highest *SAR* among all measured surfaces.

- Step 2: For each transmitter and transmit band used by the EUT, the frequency that provides the highest *SAR* value shall be used to measure the *SAR* at additional separation distances until the *SAR* is below the exposure limit; the maximum separation distance to be used for tests shall take into account all combined transmitters and transmit bands (see B.6).

- Step 3: Establish the separation distance SD at which exposure to all combined transmitter and transmit bands is below the exposure limit (see B.6).

- Step 4: Position the EUT at the separation distance SD and measure *SAR* for lower, centre and upper frequency of each band in order to verify that the combined *SAR* is below the exposure limit based on IEC 62209-2. If necessary, repeat at larger separation distances until the measured value is below the applicable *SAR* limits.

When implementing the *SAR* assessment protocol the following subclauses of IEC 62209-2:2010 shall be applied:

- 6.1.1 General preparation;
- 6.1.4. Position of the device under test in relation to the phantom;
- 6.2.4 Fast *SAR* evaluations;
- 6.3 Measurement procedure;
- 6.4 Post-processing.

IEC 62209-2 specifies localized *SAR* measurement procedures for wireless communication devices used in close proximity to the human body. Therefore the IEC 62209-2:2010 subclauses listed above are not relevant in their entirety for the localized and whole-body *SAR* measurements relating to radio base stations. General specifications concerning measurement preparation are applicable for both localized and whole-body *SAR* measurements with one exception. It is only for localized *SAR* that a correction of the measured result is required due to deviations of complex permittivity from the target values. Whole-body *SAR* has been found to be less sensitive to this deviation [37], and as a consequence, the effect shall instead be included in the uncertainty budget (see E.9.5). Parts of the fast *SAR* evaluations, measurement procedure, and post-processing are only applicable for localized *SAR* assessments (evident from its context).

B.3.2.3.2 System check and system validation

System check shall be performed using reference dipoles according to 6.1.2 and B.2 of IEC 62209-2:2010, taking into account the numerical reference *SAR* values defined in columns 3, 4, 5 and 6 of Table B.11, which is extracted from IEC 62209-2:2010, Table B.1.

The system check shall be performed using the same liquid as in the compliance test and at a chosen fixed frequency that is within ±10 % or ±100 MHz of the compliance test mid-band frequency, whichever is greater.

System validation shall be performed using reference dipoles according to B.3 of IEC 62209-2:2010, taking into account the numerical reference *SAR* values defined in columns 3, 4, and 7 of Table B.11. The difference between the measured values and the target values given in Table B.11 shall be less than the expanded uncertainty for the system validation using the template defined in Table B.15 for whole-body *SAR* system validation.

Table B.11 – Numerical reference *SAR* values for reference dipoles and flat phantom – All values are normalized to a forward power of 1 W

1	2	3	4	5	6	7
Frequency MHz	**Phantom shell thickness** mm	**1 g *SAR*** W/kg	**10 g *SAR*** W/kg	**Local *SAR* at surface (above feedpoint)** W/kg	**Local *SAR* at surface (y = 2 cm offset from feedpoint)** W/kg	**Whole-body *SAR*[a,b]** W/kg
300	2,0	2,85	1,94	4,14	2,00	0,073 / 0,021 / 0,073
450	2,0	4,58	3,06	6,75	2,98	0,073 / 0,021 / 0,074
750	2,0	8,49	5,55	12,6	4,59	0,070 / 0,020 / 0,070
835	2,0	9,56	6,22	14,1	4,90	0,069 / 0,019 / 0,068
900	2,0	10,9	6,99	16,4	5,40	0,068 / 0,019 / 0,068
1 450	2,0	29,0	16,0	50,2	6,50	0,068 / 0,019 / 0,068
1 800	2,0	38,4	20,1	69,5	6,80	0,064 / 0,017 / 0,064
1 900	2,0	39,7	20,5	72,1	6,60	0,062 / 0,017 / 0,062
1 950	2,0	40,5	20,9	72,7	6,60	0,062 / 0,017 / 0,062
2 000	2,0	41,1	21,1	74,6	6,50	0,061 / 0,017 / 0,061
2 450	2,0	52,4	24,0	104	7,70	0,055 / 0,015 / 0,055
2 585	2,0	55,9	24,4	119	7,90	0,052 / 0,014 / 0,052
2 600	2,0	55,3	24,6	113	8,29	0,052 / 0,014 / 0,052
3 000	2,0	63,8	25,7	140	9,50	0,046 / 0,013 / 0,046
3 500	2,0	67,1	25,0	169	12,1	0,039 / 0,011 / 0,040
3 700	2,0	67,4	24,2	178	12,7	0,038 / 0,010 / 0,038
5 000	2,0	77,9	22,1	305	15,1	0,028 / 0,008 / 0,028
5 200	2,0	76,5	21,6	310	15,9	0,027 / 0,007 / 0,027
5 500	2,0	83,3	23,4	349	18,1	0,025 / 0,007 / 0,025
5 800	2,0	78,0	21,9	341	20,3	0,024 / 0,007 / 0,024

The mechanical dimensions of the reference dipoles given in IEC 62209-2 shall be used. The values above 3 GHz depend on the dipole spacer and detailed construction of the dipoles and can vary by as much as ±10 %. The reasons are that the dipole dimensions are short with respect to arm diameter and spacer dimensions, i.e. the numerical reference values are not generic and need to be determined for a particular configuration.

The phantom dimensions given in B.3.2.2.2 shall be used. The values above 3 GHz depend on the dipole spacer and can vary by as much as ±10 %.

If the dipole forward power results in measured *SAR* values that are above the dynamic range of the probe, lower powers can be used so as not to introduce additional measurement uncertainty or damage the probe.

[a] Values are given as follows: small box-shaped phantom / large box-shaped phantom / elliptical phantom.

[b] Whole-body *SAR* numerical reference values defined in column 7 were obtained with the dipole oriented along the longest dimension of the phantoms. For the small box-shaped phantom and the elliptical phantom, a mass of 12,5 kg was used, whereas for the large box-shaped phantom a mass of 46 kg was used.

B.3.2.3.3 Maximum peak spatial-average *SAR* measurement description

For each of the measurement configurations required in B.3.2.2.3, the maximum peak spatial-average *SAR* shall be evaluated in four steps.

a) Use the measurement procedures specified in IEC 62209-2:2010, 6.3 to determine an initial measured peak spatial-average *SAR*, $SAR_{\mathrm{m}}(d)$, using the relevant phantom (see B.3.2.2.2). If location of the maximum peak spatial average *SAR* ends up within 50 mm from any phantom side wall, the EUT position shall be slightly adjusted, provided that the

SAR distribution does not change (e.g. due to RF coupling), and the measurements repeated.

b) Determine the correction factor, $CF_1(d)$, to be applied to take into account a possible increase in maximum peak spatial-average SAR due to a tissue layering effect using the following formula, see IEC 62209-2 and [38]:

$$CF_1(d) = \begin{cases} 1 & d < 200\,\text{mm} \\ \dfrac{d}{200} & 200\,\text{mm} \le d < 400\,\text{mm} \\ 2 & 400\,\text{mm} \le d \le 1\,000\,\text{mm} \end{cases} \quad \text{(B.10)}$$

NOTE 1 For EUT distances above 200 mm, the maximum peak SAR in an actual human body can exceed the maximum SAR obtained from measurements in the specified flat phantom. At 400 mm distance or above, the real SAR can be up to a factor of 2 higher than the phantom SAR. The correction factor $CF_1(d)$ has been introduced to account for this effect.

c) Determine the correction factor, $CF_2(d)$, to account for a possible increase in maximum peak spatial-average SAR for small phantom-antenna separations related to effects of varying antenna element load conditions using the following formula:

$$CF_2(d) = \begin{cases} 2 & d \le \dfrac{\lambda}{4} \quad \text{AND } N_e > 1 \\ -\dfrac{4d}{7\lambda} + \dfrac{15}{7} & \dfrac{\lambda}{4} < d < 2\lambda \quad \text{AND } N_e > 1 \\ 1 & d \ge 2\lambda \quad \text{OR } N_e = 1 \end{cases} \quad \text{(B.11)}$$

where

N_e is the number of elements in the antenna array.

NOTE 2 For example, $CF_2(d)$ has a value of 1 for single element antennas.

In the interpolation function in Equation (B.11), d and λ shall both be measured in the same units (e.g. mm or m).

d) Determine maximum peak spatial-average SAR using the following formula

$$SAR_{psa}(d) = SAR_m(d) \times CF_1(d) \times CF_2(d) \quad \text{(B.12)}$$

where

d is the EUT distance (mm) measured from the liquid surface;

$SAR_m(d)$ is the uncorrected measured peak spatial-average SAR averaged over either 1 g (SAR_{1g}) or 10 g (SAR_{10g})

$SAR_{psa}(d)$ is the evaluated maximum peak spatial-average SAR over either 1 g (SAR_{1g}) or 10 g (SAR_{10g}) according to the averaging used in step a) for the measurement configuration.

B.3.2.3.4 Whole-body SAR measurement description

For each of the measurement configurations required in B.3.2.2.3, the whole-body SAR measurement is performed in two steps.

a) For a given separation distance from the antenna, determine the absorbed power, P_A, by measuring the electric field strength in the relevant measurement volume defined by the considered exposure configuration and used phantom, see Table B.12 and Figure B.13. The measurement procedures in 6.3 of IEC 62209-2:2010 shall be applied whenever applicable using the following grid spacing:

- The maximum horizontal grid spacing shall be 20 mm for frequencies below 3 GHz and ($60/f$ GHz) mm for frequencies of 3 GHz and greater.
- The grid step in the vertical direction for a uniform spacing shall be ($8 - f$ GHz) mm or less but not more than 5 mm (IEC 62209-2).
- If a variable spacing is used in the vertical direction, the maximum spacing between the two closest measured points to the phantom shell shall be ($12/f$ GHz) mm or less but not more than 4 mm. The spacing between farther points shall increase by a factor not exceeding 1,5 (IEC 62209-2). When variable spacing is used, extrapolation routines shall be tested with the same spacing as used in measurements.

To reduce the time needed to perform whole-body SAR measurements, procedures based on measurements in one or more planes may be used in combination with various techniques for numerical field propagation (e.g. [39]), provided that

1) the procedure has been thoroughly verified, and
2) the uncertainty has been quantified.

b) Evaluate the whole-body SAR, SAR_{wb}, using the following formula:

$$SAR_{\mathrm{wb}}(d) = \frac{P_{\mathrm{A}}(d) \times CF_3(d) \times CF_4(f)}{M} \tag{B.13}$$

where:

$P_{\mathrm{A}}(d)$ is the average temporal absorbed power (watts) in the phantom measured at a distance d, the EUT distance (mm) measured from the liquid surface;

M is the mass of the body measured in kilograms. For the assessment of workers exposure or general public exposure when the lowest part of the EUT antenna is installed at 2,2 m or more above level realistically accessible by the general public, a mass of 46 kg representing adults ([35], [29]) shall be used. For the assessment of general public exposure when the lowest part of the EUT antenna is installed less than 2,2 m above level realistically accessible by the general public, a mass of 12,5 kg representing the third percentile body weight data for a four-year old girl [17] shall be used. This weight is slightly smaller than the WHO data [16] for a fifth percentile four-year-old child and leads to a conservative whole-body SAR for the general public;

$CF_3(d)$ is a correction factor to account for a possible increase in whole-body SAR due to a tissue layering effect [35] [29] defined by:

$$CF_3(d) = \begin{cases} 1 + \dfrac{0{,}8d}{400} & d < 400\ \mathrm{mm} \\ 1{,}8 & d \geq 400\ \mathrm{mm} \end{cases}; \tag{B.14}$$

$CF_4(f)$ is a correction factor to compensate for a possible bias in the obtained general public whole-body SAR when assessed using the large box-shaped phantom for child exposure configurations according to Table B.13. For frequencies between the data points provided in Table B.13, a linear interpolation shall be used. For other exposure configurations and phantom type combinations, $CF_4(f) = 1$.

Table B.12 – Phantom liquid volume and measurement volume used for whole-body *SAR* measurements [35], [29]

Exposure configuration	Phantom type	Phantom liquid volume m³ $\Delta X \times \Delta Y \times \Delta Z$ **or** $\pi ab\ \Delta Z$	Measurement volume m³ $\Delta X_m \times \Delta Y_m \times \Delta Z_m$ **or** $\pi ab\ \Delta Z_m$
Occupational and general public (adults only)	Large box-shaped phantom (preferred choice)	1,54 × 0,339 × ≥0,15	1,54 × 0,339 × 0,09
	Small box-shaped phantom	0,96 × 0,233 × ≥0,15	0,96 × 0,233 × 0,09
	Elliptical phantom	0,19 × ≥0,15	0,19 × 0,09
General public (including children)	Small box-shaped phantom (preferred choice)	0,96 × 0,233 × ≥0,15	0,96 × 0,233 × 0,06
	Large box-shaped phantom	1,54 × 0,339 × ≥0,15	0,96 × 0,233 × 0,06
	Elliptical phantom	0,19 × ≥0,15	0,19 × 0,06

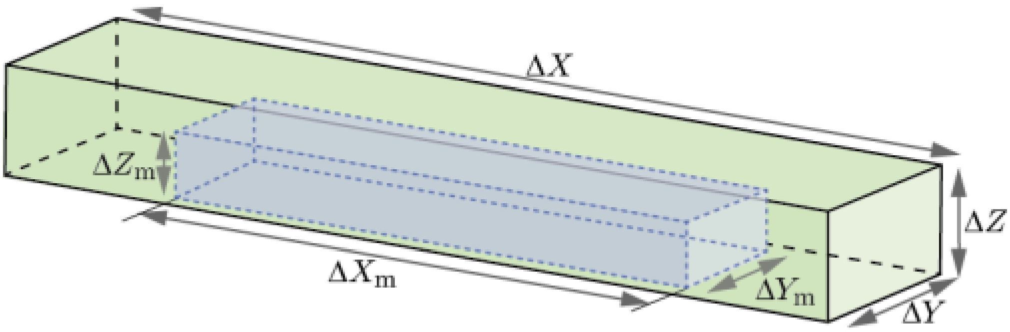
NOTE 1 Where a = 300 mm is the semi-major axis of the elliptical measurement area.

NOTE 2 Where b = 200 mm is the semi-minor axis of the elliptical measurement area.

NOTE 3 See also Figure B.13.

Table B.13 – Correction factor to compensate for a possible bias in the obtained general public whole-body *SAR* when assessed using the large box-shaped phantom for child exposure configurations [36]

Frequency MHz	300	450	900	1 800	2 600	3 500	6 000
$CF_4(f)$	2,4	2,3	1,5	1,3	1,2	1,2	1,2



For general public (including children) exposure assessments using the large box-shaped phantom, the smaller measurement volume shall be centred at the bottom of the phantom.

NOTE See also Table B.12.

Figure B.13 – Phantom liquid volume and measurement volume used for whole-body *SAR* measurements with the box-shaped phantoms

B.3.2.4 *SAR* measurement uncertainty

SAR measurement uncertainty shall be estimated using the specifications in Clause 7 of IEC 62209-2:2010. For whole-body *SAR*, the templates defined in Table B.14 and Table B.15 shall be used. The uncertainty associated with many of the influence quantities listed in IEC 62209-2 and the way it is assessed is applicable also for *SAR* measurements using the box-shaped phantoms. For some influence quantities, such as those related to the box phantom, the description in IEC 62209-2 is not applicable. Details on how to assess the uncertainty for these influence quantities is given in E.9. The *SAR* measurement procedure has been designed to produce results which are located on the conservative side of the probability distribution.

The expanded uncertainty with a confidence interval of 95 % shall not exceed 30 % for peak spatial-average and whole-body *SAR*. If the uncertainty is larger than 30 % the difference shall be added to the evaluation result before comparison with the applicable exposure limit according to the procedure in IEC 62311.

Table B.14 – Measurement uncertainty evaluation template for EUT whole-body *SAR* test

Source of uncertainty	Description	Prob. distrib. type	Uncertainty or semi span, a (± %)	Div. d	Sens. coeff. c	Standard uncertainty $u = a \times c/d$	v_i
Probe calibration	IEC 62209-2	N		1,96	1		∞
Isotropy	IEC 62209-2	R		√3	1		∞
Linearity	IEC 62209-2	R		√3	1		∞
Probe modulation resp.	IEC 62209-2	R		√3	1		∞
Detection limits	IEC 62209-2	R		√3	1		∞
Boundary effect	IEC 62209-2	R		√3	1		∞
Readout electronics	IEC 62209-2	N		1,96	1		∞
Response time	IEC 62209-2	R		√3	1		∞
Integration time	IEC 62209-2	R		√3	1		∞
RF ambient conditions – noise	IEC 62209-2	R		√3	1		∞
RF ambient conditions – reflections	IEC 62209-2	R		√3	1		∞
Probe positioner mech. restrictions	IEC 62209-2	R		√3	1		∞
Probe positioning with respect to phantom shell	IEC 62209-2	R		√3	1		∞
Post-processing	E.9.2	R		√3	1		∞
Device holder uncertainty	E.9.3	N		1,96	1		$M - 1$
Test sample positioning	E.9.4	R		1,96	1		∞
Power scaling	IEC 62209-2	R		√3	1		∞
Measurement drift	IEC 62209-2	R		√3	1		∞
Phantom shell uncertainty	E.9.5	R		√3	1		∞
Target liquid permittivity and conductivity	E.9.6	N	2.0	1,96	1	2.0	∞
Liquid permittivity (meas.)	E.9.7	N		1,96	0,34		$M - 1$
Liquid conductivity (meas.)	E.9.7	N		1,96	0,25		$M - 1$

Source of uncertainty	Description	Prob. distrib. type	Uncertainty or semi span, a (± %)	Div. d	Sens. coeff. c	Standard uncertainty $u = a \times c/d$	v_i
Liquid permittivity – temperature uncertainty	E.9.8	R		√3	0,34		∞
Liquid conductivity – temperature uncertainty	E.9.8	R		√3	0,25		∞
Combined standard uncertainty, $u_c = \sqrt{\sum_{i=1}^{N} (c_i^2\ u_i^2)}$							
Coverage factor for required (e.g. 95 %) confidence interval, k							
Expanded uncertainty, $U = k \times u_c$							
NOTE 1 The value of divisor d for normal probability distribution is for 95 % confidence. NOTE 2 See Annex E for guidance on the variables in this table.							

Table B.15 – Measurement uncertainty evaluation template for whole-body *SAR* system validation

Source of uncertainty	Description	Prob. distrib. type	Uncertainty or semi span, a (± %)	Div. d	Sens. coeff. c	Standard uncertainty $u = a \times c/d$	v_i
Probe calibration	IEC 62209-2	N		1,96	1		∞
Isotropy	IEC 62209-2	R		√3	1		∞
Linearity	IEC 62209-2	R		√3	1		∞
Probe modulation resp.	IEC 62209-2	R		√3	1		∞
Detection limits	IEC 62209-2	R		√3	1		∞
Boundary effect	IEC 62209-2	R		√3	1		∞
Readout electronics	IEC 62209-2	N		1,96	1		∞
Response time	IEC 62209-2	R		√3	1		∞
Integration time	IEC 62209-2	R		√3	1		∞
RF ambient conditions – noise	IEC 62209-2	R		√3	1		∞
RF ambient conditions – reflections	IEC 62209-2	R		√3	1		∞
Probe positioner mech. restrictions	IEC 62209-2	R		√3	1		∞
Probe positioning with respect to phantom shell	IEC 62209-2	R		√3	1		∞
Post-processing	E.9.2	R		√3	1		∞
Deviation of the experimental source from numerical source	IEC 62209-2	N		1,96	1		∞
Source to liquid distance	E.9.4	R		1,96	1		∞
Measurement drift	IEC 62209-2	R		√3	1		∞

Source of uncertainty	Description	Prob. distrib. type	Uncertainty or semi span, a (± %)	Div. d	Sens. coeff. c	Standard uncertainty $u = a \times c/d$	v_i
Phantom shell uncertainty	E.9.5	R		√3	1		∞
Target liquid permittivity and conductivity	E.9.6	N	2,0	1,96	1	2,0	∞
Liquid permittivity (meas.)	E.9.7	N		1,96	0,34		$M - 1$
Liquid conductivity (meas.)	E.9.7	N		1,96	0,25		$M - 1$
Liquid permittivity – temperature uncertainty	E.9.8	R		√3	0,34		∞
Liquid conductivity – temperature uncertainty	E.9.8	R		√3	0,25		∞
Combined standard uncertainty, $u_c = \sqrt{\sum_{i=1}^{N}(c_i^2\ u_i^2)}$							
Coverage factor for required (e.g. 95 %) confidence interval, k							
Expanded uncertainty, $U = k \times u_c$							
NOTE 1 The value of divisor d for normal probability distribution is for 95 % confidence.							
NOTE 2 See Annex E for guidance on the variables in this table.							

B.4 Computation methods

B.4.1 Overview and general requirements

The overview and general requirements of computational methods are defined in 8.3 and include the following.

- **Basic computations:** The basic computation formulas presented in B.4.2 are conservative formulas for the estimation of RF field strength, power density or *SAR*. The formulas are easy to implement and may be adequate for RF field strength and *SAR* evaluation. No uncertainty estimations are required when using these formulas but there is clear guidance on where and when these formulas are applicable. The basic computation formulas can only be employed in limited applications as defined in B.4.2.
- **Advanced computations:** For some scenarios more accurate evaluation may be required, for example field evaluation in the near-field of an antenna or *SAR* evaluations to the side of an RBS antenna. The advanced computation techniques are presented in B.4.4, with specific guidance on how these methods shall be employed (typically, but not necessarily, using commercially available software). If an advanced method is selected, a full uncertainty analysis shall be performed. The subclauses on uncertainty related to each advanced computation method present the minimum uncertainty parameters that shall be considered.

B.4.2 Formulas

B.4.2.1 Field strength estimation formulas

B.4.2.1.1 Spherical and cylindrical formulas for power density

B.4.2.1.1.1 Overview of spherical and cylindrical formulas

For the sector or omnidirectional linear array configurations with arbitrary polarizations widely employed in wireless communications infrastructure, the fields in the near-field of the RBS antenna have a cylindrical character [40], [41] which gradually converts to spherical in the far-field. Simple formulas can be used to predict the fields radiated by these linear arrays. These estimation formulas are applicable under the conditions defined in B.4.2.1.1.2 and B.4.2.1.1.3.

B.4.2.1.1.2 Applicability of spherical formulas

The far-field spherical formulas can be used to evaluate the spatial-peak and spatially-averaged RF field strengths. The spatially-averaged and spatial-peak equivalent power densities can be evaluated as follows:

$$S = \frac{\overline{P}_{\text{net}} G_{\theta,\phi}}{4\pi r^2} \tag{B.15}$$

The associated r.m.s. electric field strength E and magnetic field strength H can be evaluated as follows:

$$E = \frac{\sqrt{30 P_{\text{net}} G_{\theta,\phi}}}{r} \tag{B.16}$$

$$H = \frac{E}{\eta_0} \tag{B.17}$$

The far-field spherical formulas shall only be used considering the following limitations:

- For the estimate of S, E or H to be conservative, $\overline{P}_{\text{net}}$ and $G_{\theta,\phi}$ values shall be the upper bounds of the uncertainty.
- Reflecting surfaces/objects, a ground plane and mounting structures are not allowed in the general direction of the evaluation point if the above equations are to be used.

If a reflecting ground plane is present (e.g. see Figure B.14), use Equation (B.18):

$$S = (1 + |\Gamma|)^2 \frac{\overline{P}_{\text{net}} G_{\theta,\phi}}{4\pi r^2} \tag{B.18}$$

with reflection coefficient $|\Gamma| = 1$ for the theoretical highest field strength scenario of a perfectly conducting ground plane (e.g. flat metallic roof) or with reflection coefficient $|\Gamma| = 0{,}6$ for typical [15] ground reflection conditions. Use of the far-field spherical formulas in the near-field region will overestimate the field strength levels.

See B.2.4 for definition of variables.

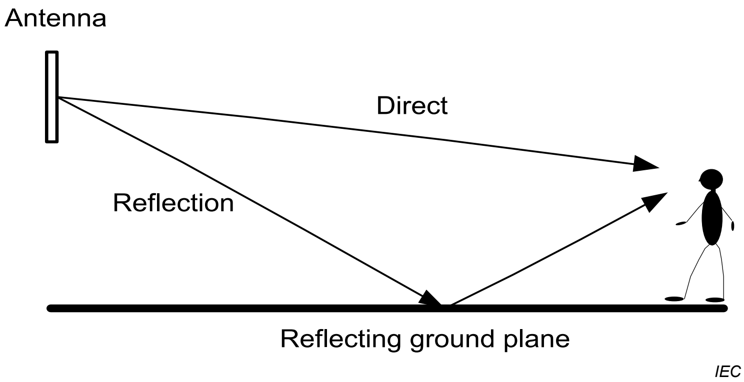


Figure B.14 – Reflection due to the presence of a ground plane

The adjusted spherical formulas presented in B.4.3.2 [42] can be employed inside parts of source regions I and II (spatial-peak and spatial-average field strength) but evaluations are limited to the zones detailed in Figure B.19. The advantage in using the adjusted spherical formulas is to obtain conservative but realistic RF field strength evaluations much closer to the antenna than with the classical far-field formulas referenced above.

Another set of relatively basic adjusted spherical formulas that can be used in source region II (radiating near-field) is presented in [43], [44] which detail the limitations of the technique.

B.4.2.1.1.3 Applicability of cylindrical formulas

B.4.2.1.1.3.1 General

The cylindrical formula can be used to evaluate the spatial-peak and spatially-averaged power density S, in the enclosed cylinder of an antenna array (see Figure B.15).

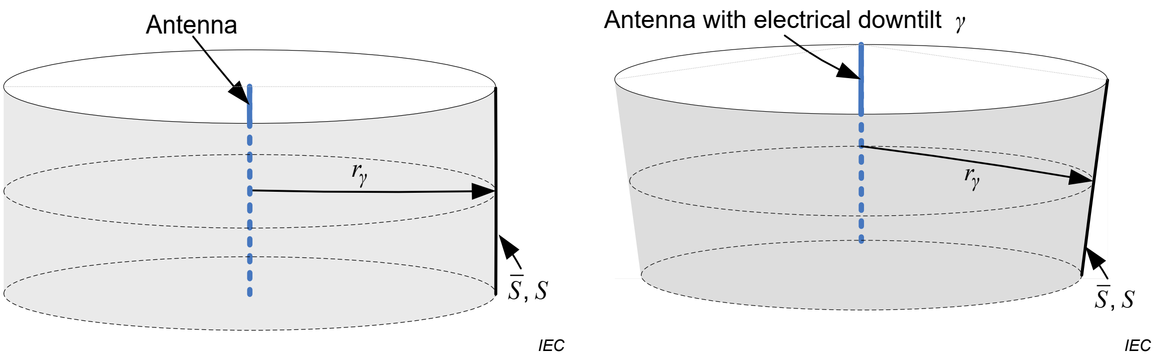


Figure B.15 – Enclosed cylinder around collinear arrays, with and without electrical downtilt

Limitations for applying the cylindrical formulas:

- The electrical tilt angle, γ, of the linear array shall be less than or equal to 10°. The cylindrical formulas do not take into account the formation of grating lobes near end-fire, whose power content typically becomes significant for electrical tilt angles greater than 10°.
- The presence of reflecting surfaces/objects, reflecting ground planes and mounting structures (mast, tower, wall, etc.) in the general direction of the evaluation point is not allowed.

B.4.2.1.1.3.2 Spatial-average cylindrical formulas

a) Omnidirectional arrays

$$\bar{S}(r) = \frac{\bar{P}_{\mathrm{avg}}}{2\pi r L} \tag{B.19}$$

b) Sector-coverage arrays

$$\bar{S}(r) = \frac{\bar{P}_{\mathrm{avg}}}{\phi_{\mathrm{3dB}} r L} \tag{B.20}$$

For array antennas with electrical tilt, the formulas in B.4.3.3 shall be applied.

B.4.2.1.1.3.3 Spatial-peak cylindrical formulas

a) Omnidirectional arrays

$$\bar{S}(r) = \frac{\bar{P}_{\mathrm{avg}}}{\pi r L} \tag{B.21}$$

b) Sector-coverage arrays

$$\bar{S}(r) = \frac{2\bar{P}_{\mathrm{avg}}}{\phi_{\mathrm{3dB}} r L} \tag{B.22}$$

For array antennas with electrical tilt, the formulas in B.4.3.3 shall be applied.

B.4.2.1.1.3.4 Procedure to follow when applying spherical and cylindrical formulas

The following procedure shall be followed when performing an evaluation using the spherical or cylindrical formulas.

a) Ensure that the evaluation will be valid considering the restrictions and limitations of the different methods.
b) Implement Formulas (B.15) to (B.22).
c) Validate the implementation by comparing example results to known or published results.
d) Establish input parameters (see B.4.2.1.1.4).
e) Perform the field evaluation(s) using the formulas.
f) Report on the evaluation using the guidelines presented in Clause 10.

B.4.2.1.1.4 Input requirements

To apply the far-field spherical formulas, the following information is required:

$\bar{P}_{\mathrm{net}}$, $G_{\theta,\phi}$, η_0, and r (see Equation (B.18) and B.4.2.1.1).

To apply the cylindrical formulas, $\bar{P}_{\mathrm{avg}}$, L, ϕ_{3dB} and r (see B.4.2.1.1) are required.

B.4.2.1.2 Formulas to estimate conservatively the RF field strength from leaky RF cables

Figure B.16 shows the geometry of a typical leaky RF cable, consisting of a coaxial cable whose metallic sheath or braid features regularly spaced slots that leak out a small fraction of the RF energy guided inside the cable. Therefore, the guided wave attenuation consists of two components: the conventional field attenuation due to ohmic and dielectric losses in the cable materials, and the guided field attenuation due to energy loss in the form of leaked radiation.

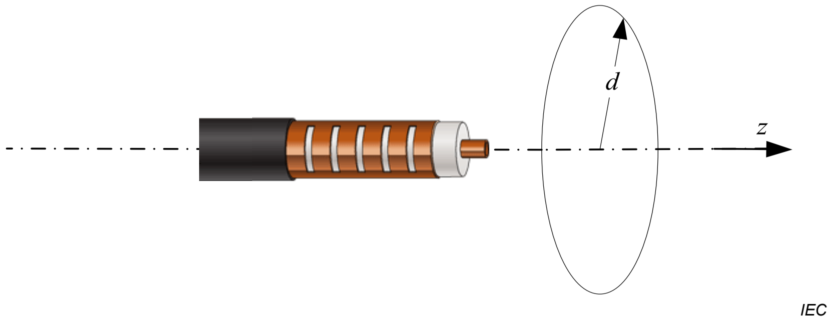


Figure B.16 – Leaky feeder geometry

Because of the aforementioned characteristics, leaky feeders are radiating transmission lines frequently employed to provide coverage in tunnels or indoors, characterized by a frequency dependent attenuation coefficient, α :

$$\alpha = \alpha_{\mathrm{d}} + \alpha_{\mathrm{r}} \tag{B.23}$$

where

α_{d} is the attenuation coefficient due to dissipation loss along the transmission line (dB/m);

α_{r} is the attenuation coefficient due to radiation loss along the transmission line (dB/m).

Neglecting dissipative attenuation and assuming that all guided field attenuation is due to RF leakage, i.e. $\alpha = \alpha_{\mathrm{r}}$, allows overestimating the relative fraction of radiated RF power, which leads to a conservative RF field strength evaluation. Under this hypothesis, the travelling power decay versus distance along the transmission line (assuming that the cable is fed at $z = 0$) is:

$$P(z) = \overline{P}_{\mathrm{net}} \cdot 10^{-z\left(\frac{\alpha}{10}\right)} = \overline{P}_{\mathrm{net}} \cdot e^{-\alpha z\left[\frac{\ln(10)}{10}\right]} = \overline{P}_{\mathrm{net}} \cdot e^{-z\left[\frac{\alpha}{4{,}343}\right]} \tag{B.24}$$

Therefore the radiated power per unit length P_{r} is:

$$P_{\mathrm{r}}(z) = \left.\frac{P(z) - P(z+\Delta z)}{\Delta z}\right|_{\Delta z \to 0} = -\frac{\partial}{\partial z} P(z) = \overline{P}_{\mathrm{net}} \left(\frac{\alpha}{4{,}343}\right) \cdot e^{-z\left(\frac{\alpha}{4{,}343}\right)} \ \mathrm{W\ m^{-1}} \tag{B.25}$$

Since the waves emitted from leaky cables generally feature conical character, it is possible to produce a conservative estimate of the emission levels at a radial distance d by introducing a cylindrical-type decay as follows:

$$S(d,z) = \frac{P_{\mathrm{r}}(z)}{2 \cdot \pi \cdot d} = \left(\frac{\alpha}{4{,}343}\right) \cdot \frac{\overline{P}_{\mathrm{net}}}{2 \cdot \pi \cdot d} e^{-z\left(\frac{\alpha}{4{,}343}\right)} \ \mathrm{W\ m^{-2}} \tag{B.26}$$

The power density estimate can be made even more conservative by taking its peak, at z = 0:

$$S(d) = \frac{\overline{P}_{\mathrm{net}} \cdot \alpha}{8{,}646 \cdot \pi \cdot d} \ \mathrm{W\ m^{-2}} \tag{B.27}$$

where

$S(d)$ is the power density (W m^{-2}) at radial distance d (m) from the centre of the leaky feeder at the feed connector;

$S(d,z)$ is the power density (W m^{-2}) at radial distance d (m) from the centre of the leaky feeder at a distance z (m) from the feed connector;

α is the frequency dependent attenuation coefficient (dB/m);

$\overline{P}_{\text{net}}$ is the net average (temporal) power (W) transferred into the leaky feeder.

Equation (B.27) can be considered a conservative estimate of the exposure on a person disposed parallel to the cable axis. Since cables normally run horizontally in tunnels or offices, the formula would provide a very conservative evaluation when applied at the closest radial distance where any portion of the exposed person's body may be relative to the cable longitudinal axis.

B.4.2.2 Whole-body *SAR* and peak spatial-average *SAR* estimation formulas

B.4.2.2.1 Applicability

The formulas in B.4.2.2.2 and B.4.2.2.3 can be used to estimate the peak spatial-average *SAR* and whole-body *SAR* for RBS antennas where the driven elements of the antenna lie on the same vertical axis. Estimation formulas are given for three main directions: front (main beam), axial, and back according to Figure B.17.

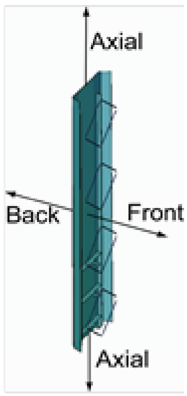


Figure B.17 – Directions for which *SAR* estimation expressions are given

Table 7 summarizes recommended and permitted applications for the *SAR* estimation formulas ([12], [35]) in terms of the source-environment plane regions. Further constraints on the applicability of the estimation formulas are summarized in Table B.16.

Table B.16 – Applicability of *SAR* estimation formulas

Directions of validity	Antenna types	Frequency range MHz	Estimation value provided	Additional restrictions
Front	Directional (vertically polarized and cross-polarized) and omnidirectional RBS antennas	300 to 5 000	Upper bounds of localized and whole-body *SAR* within the main beam of the antenna	For localized *SAR*, the phantom to antenna separation distance, *d*, shall be larger than 20 cm. For whole-body *SAR*, the phantom to antenna separation distance, *d*, shall be larger tha $\lambda/(2\pi)$ [35].
Back	Directional (vertically polarized and cross-polarized) RBS antennas	700 to 2 700	Upper bound of localized *SAR* in a plane behind the antenna oriented perpendicular to the back direction	N/A
Axial	Directional (vertically polarized and cross-polarized) and omnidirectional RBS antennas	700 to 2 700	Upper bound of localized *SAR* in a plane above (or below) the antenna oriented perpendicular to the axial direction	N/A
NOTE The frequency range is limited based on completed validation [12], [35]. Extension of the applicable frequency range and directions of validity requires further study.				

The method may be employed for multiple sources (multiple antennas operating at the same or different frequencies), see B.6.

B.4.2.2.2 *SAR* estimation formulas applicable to the front (main beam) direction

The whole-body *SAR* and peak spatial-averaged *SAR* (1 g or 10 g) shall be evaluated using the following formulas [35], which takes whole-body mass of 46 kg for adults and 12,5 kg for children, see 8.2.3 and [17], [16]:

$$SAR_{\text{wb}}^{\text{a,ch}} = C(f) \cdot \frac{H_{\text{eff}}}{\widetilde{A}^{\text{a,ch}} \cdot \widetilde{B}^{\text{a,ch}}} \cdot \frac{\overline{P}_{\text{avg}}}{\phi_{\text{3dB}} \cdot L \cdot d} \cdot \left[1 + \left(\frac{4 \cdot \pi \cdot d}{\phi_{\text{3dB}} \cdot D \cdot L} \right)^2 \right]^{-1/2} \tag{B.28}$$

$$SAR_{\text{10g}} = 25 \cdot SAR_{\text{wb}}^{\text{a}} \cdot \frac{\widetilde{B}}{H_{\text{eff}}} \cdot \frac{1}{R_{\text{wb/10g}}} \tag{B.29}$$

$$SAR_{\text{1g}} = 20 \cdot SAR_{\text{wb}}^{\text{a}} \cdot \frac{\widetilde{B}}{H_{\text{eff}}} \cdot \frac{1}{R_{\text{wb/1g}}} \tag{B.30}$$

where

$SAR_{\text{wb}}^{\text{a,ch}}$ denotes the whole-body *SAR* evaluated for adults, $SAR_{\text{wb}}^{\text{a}}$, or children, $SAR_{\text{wb}}^{\text{ch}}$;

$\widetilde{A}^{\text{a,ch}}$ equals $\widetilde{A}^{\text{a}}$ = 0,089 m for adults and $\widetilde{A}^{\text{ch}}$ = 0,06 m for children;

$\widetilde{B}^{\text{a,ch}}$ equals $\widetilde{B}^{\text{a}}$ = 1,54 m for adults and $\widetilde{B}^{\text{ch}}$ = 0,96 m for children;

d is the closest distance measured in metres from the antenna element to the evaluation point. If the distance to the antenna elements is not known, d may be taken conservatively as the distance to the antenna radome;

H_{eff} is the effective height of the body measured in metres;

L is the physical antenna array length measured in metres. The individual antenna lengths for each band shall be used for antennas covering more than one band;

$$R_{\text{wb/10g}} = \begin{cases} 1{,}5 & 300\ \text{MHz} < f \leq 2{,}5\ \text{GHz} \\ 1 & 2{,}5\ \text{GHz} < f < 5\ \text{GHz} \end{cases}$$

$$R_{\text{wb/1g}} = \begin{cases} 0{,}6 & 300\ \text{MHz} < f \leq 2{,}5\ \text{GHz} \\ 0{,}3 & 2{,}5\ \text{GHz} < f < 5\ \text{GHz} \end{cases}$$

H_{eff} shall be evaluated using

$$H_{\text{eff}} = \begin{cases} L & H_{\text{beam}} < L \text{ AND } H_{\text{beam}} < \tilde{B} \\ H_{\text{beam}} & L \leq H_{\text{beam}} < \tilde{B} \\ \tilde{B} & \tilde{B} \leq H_{\text{beam}} \\ \tilde{B} & \tilde{B} \leq L \end{cases}$$

where

$$H_{\text{beam}} = 2 \cdot d \cdot \tan(\theta_{\text{3dB}} / 2)$$

$C(f)$ shall be evaluated using Table B.17. The distance dependence behaviour is included to describe the effect of tissue layering according to B.3.2.3.3.

Table B.17 – Definition of $C(f)$

f MHz	$C(f,d)$ 10^{-4} m³/kg	
300 to 900	$\left(3{,}5 + \frac{f - 300}{600}\right)\left(1 + \frac{0{,}8d}{400}\right)$	for 200mm ≤ d ≤ 400mm
	$6{,}3 + \left(\frac{f - 300}{600}\right)1{,}8$	for d > 400mm
900 to 5 000	$4{,}5\left(1 + \frac{0{,}8d}{400}\right)$	for d ≤ 400mm
	8,1	for d > 400mm

B.4.2.2.3 *SAR* estimation formulas applicable to the axial and back directions

Peak spatial-average *SAR* (1 g or 10 g) values shall be evaluated using the following formulas [12]:

$$SAR_{\text{1g,10g}}(d, \overline{P}_{\text{avg}}, N_{\text{e}}) = \begin{cases} \tilde{C}^{\text{A,B}}_{\text{1g,10g}} \dfrac{\overline{P}_{\text{avg}}}{N_{\text{e}}} & d < 0{,}01\ \text{m} \\ \tilde{D}^{\text{A,B}}_{\text{1g,10g}} \dfrac{\overline{P}_{\text{avg}}}{N_{\text{e}} \cdot d} & d \geq 0{,}01\ \text{m} \end{cases} \quad \text{(B.31)}$$

where

the suffixes ^{A} and ^{B} denote axial and back directions, respectively.

$\tilde{C}^{A}_{1g} = 10\ \text{kg}^{-1}$

$\tilde{D}^{A}_{1g} = 0{,}1\ \text{m}\cdot\text{kg}^{-1}$

$\tilde{C}^{B}_{1g} = 1\ \text{kg}^{-1}$

$\tilde{D}^{B}_{1g} = 0{,}01\ \text{m}\cdot\text{kg}^{-1}$

$\tilde{C}^{A}_{10g} = 5\ \text{kg}^{-1}$

$\tilde{D}^{A}_{10g} = 0{,}05\ \text{m}\cdot\text{kg}^{-1}$

$\tilde{C}^{B}_{10g} = 0{,}5\ \text{kg}^{-1}$

$\tilde{D}^{B}_{10g} = 0{,}005\ \text{m}\cdot\text{kg}^{-1}$

d is:

- in the back direction, the distance measured in metres from the antenna back plate to the evaluation point;
- in the axial direction, the smallest distance measured in metres from the nearest antenna element to the evaluation point. For a conservative evaluation the distance from the antenna radome may be used in the axial direction.

NOTE For comparison with full wave-simulations, d is the closest distance between the phantom and either the back plate for the back direction evaluation or the nearest antenna element for the axial direction evaluation.

N_e is the number of antenna elements at the frequency of evaluation.

B.4.2.2.4 Using the *SAR* estimation formulas

The following procedure shall be followed when employing the *SAR* estimation formulas.

a) Ensure that the evaluation will be valid considering the restrictions and limitations of the method.
b) Implement the formulas presented in B.4.2.2.
c) Validate the implementation against the results presented in B.4.2.2.7.
d) Establish input parameters (see B.4.2.2.5).
e) Perform the *SAR* evaluation(s) using the validated implementation.
f) Report on the evaluation using the guidelines presented in Clause 10.

B.4.2.2.5 Input parameters for *SAR* estimation formulas

To apply the *SAR* estimation formulas, the following information is required:

- frequency bands for all transmitters;
- $\overline{P}_{avg}$, N_e, ϕ_{3dB}, θ_{3dB}, D, (see B.2.4);
- L, the physical antenna array length for each band measured in metres.

If the number of antenna elements is not known the following estimation shall be used [45]:

$$N_e = L/(0{,}85\lambda),$$

rounded to the nearest integer. If the antenna directivity is not known, the antenna gain may be used as a substitute provided that $\overline{P}_{\text{avg}}$ is replaced by $\overline{P}_{\text{net}}$. If $\overline{P}_{\text{avg}}$ is not known it may be replaced with $\overline{P}_{\text{net}}$.

B.4.2.2.6 *SAR* estimation formulas uncertainty

The *SAR* estimation formulas will give a conservative estimate (≥ 95 % confidence level) of localized and whole-body *SAR* provided that the input parameters are chosen within their range so as to maximize the estimated value.

B.4.2.2.7 Validation of *SAR* estimation formulas

The correctness of an implementation of these formulas shall be verified for the front, back and axial directions as defined in Figure B.17 using the input parameters in Table B.18. If the obtained results agree with the reference results in Table B.19, then the implementation has passed the validation.

Table B.18 – Input parameters for *SAR* estimation formulas validation

Transmitter parameters		Antenna parameters				
Frequency	RF power	Array length	Gain	Horizontal HPBW	Vertical HPBW	Number of elements
2 140 MHz	1 W	1,3 m	18 dBi	65°	6,5°	10

Table B.19 – SAR_{10g} and SAR_{wb} estimation formula reference results for Table B.18 parameters and a body mass of 46 kg

Direction (Figure 7)	*SAR* results W/kg/W phantom-to-antenna separation (m)								
	0,001 m	0,01 m	0,1 m	0,2 m	1 m	5 m	10 m	15 m	20 m
SAR_{10g} Front	N/A	N/A	N/A	0,40	0,10	0,017	0,006 1	0,003	0,001 8
SAR_{10g} Axial	0,5	0,5	0,05	0,025	0,005	0,001	N/A	N/A	N/A
SAR_{10g} Back	0,05	0,05	0,005	0,002 5	N/A	N/A	N/A	N/A	N/A
SAR_{wb} Front	N/A	N/A	N/A	0,020	0,005 2	0,000 86	0,000 31	0,000 18	0,000 11
NOTE The provided whole-body *SAR* results correspond to adult exposure (m = 46 kg), see 8.2.3.									

B.4.3 Basic algorithms

B.4.3.1 Overview

B.4.3 describes the basic algorithm for power density calculation.

The coordinate system is defined according to Figure B.18.

The reference frame relative to an array antenna axis employed in the analytical prediction formulas for the spatially-averaged power density, $\overline{S}$, and the spatial-peak power density, S, are illustrated in Figure B.18.

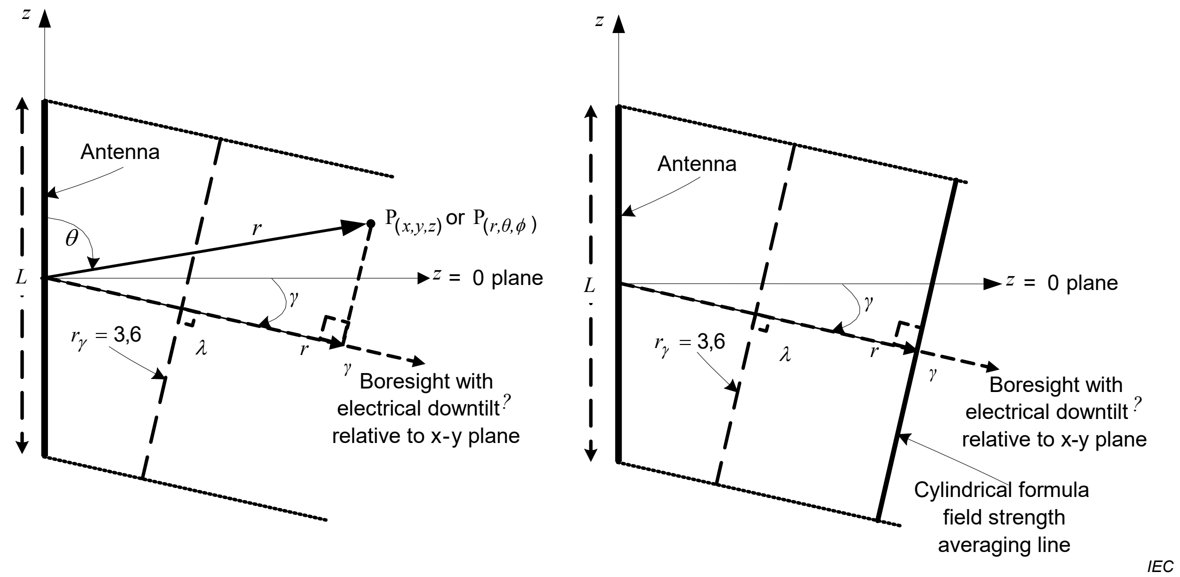


Figure B.18 – Reference frame employed for cylindrical formulas for field strength computation at a point P (left), and on a line perpendicular to boresight (right)

B.4.3.2 Spherical and cylindrical formulas

B.4.3.2.1 General

Spherical formulas with different constants and cylindrical formulas can be employed for RF field strength evaluations in three zones of computation (see Figure B.19 and Table B.20) around a typical linear antenna. Reference [42] details how these formulas were derived and how the computed values relate to the confidence level (see Figure E.2) in the different zones of computation.

NOTE The uncertainty of the computation is dependent on the exact location in relation to the antenna. For better accuracy, in [42] four zones of computation are defined with statistical analysis of extensive computational data providing uncertainty information as tables of offsets. These can be employed to determine the values of S at specific locations corrected for the required confidence level.

The spherical and cylindrical formulas use the variables defined in Clause 4, B.2.4 and as follows (see Figure B.18):

D is the peak antenna directivity, measured as a linear ratio, at the frequency under evaluation. If the directivity is not known, the antenna gain may be used as a substitute;

G is the peak antenna gain, measured as a linear ratio, at the frequency under evaluation;

$G_{\text{side lobe}}$ is the gain, measured as a linear ratio, of the maximum side lobe in the vertical gain pattern at the frequency under evaluation;

L is the physical antenna array length measured in metres. The individual antenna lengths for each band shall be used for antennas covering more than one band;

r is the radius measured in metres taken from the centre of the antenna;

r_γ is the radius measured in metres along boresight of the antenna (see Figure B.18);

γ is the electrical downtilt angle measured in radians of the antenna main beam from the x-y plane (i.e. z = 0) at the frequency of evaluation and where down is positive and up is negative;

λ is the wavelength measured in metres for each band;

θ is the angle measured in radians between the positive z-axis and the line formed between the origin and the point of interest;

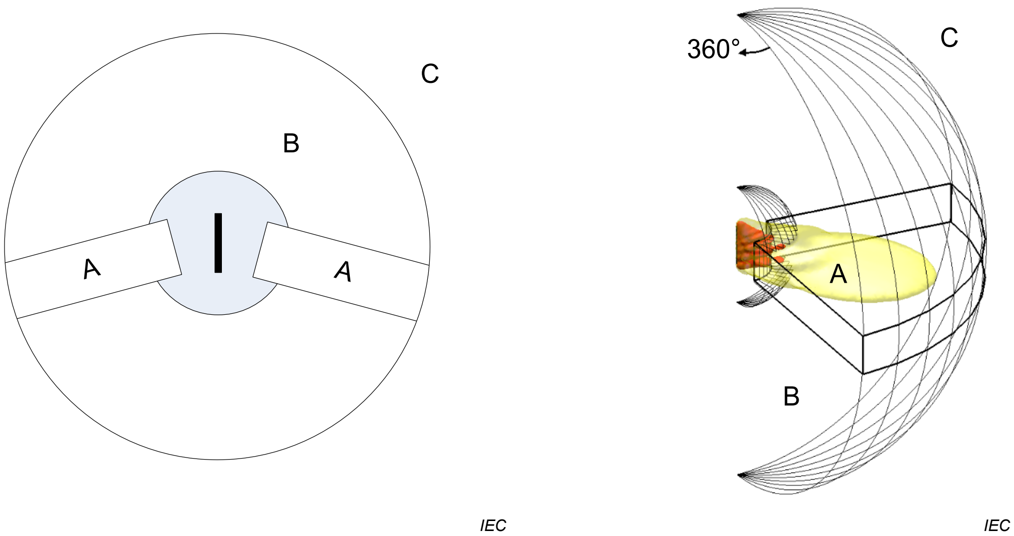
θ_{3dB} is the vertical HPBW measured in radians at the frequency under evaluation;

ϕ is the azimuth angle measured in radians between the positive x-axis and the line from the origin to the point of interest projected onto the x-y plane (i.e. where z = 0) and $-\pi < \phi \leq \pi$ and the maximum azimuth gain of the antenna is at $\phi = 0$ radians;

ϕ_{3dB} is the azimuth HPBW measured in radians at the frequency under evaluation.

B.4.3.2.2 Zone boundaries

Table B.20 gives the formulas for calculating the zone boundaries applicable to the adjusted spherical and cylindrical formulas respectively (see Figure B.19 for visual representation of zones). These are consistent with the uncertainty analysis described in [42]. In Figure B.19, the three-dimensional view shows pie-slice sections of the same three zones, which are symmetrically equivalent around the z-axis. For antennas employing a mechanical downtilt, the zone boundaries would be rotated accordingly. The angular variables in B.4.3.3 to B.4.3.5 are defined in the coordinate system of the antenna, see Figure B.18.



a) Two-dimensional view b) Three-dimensional view

Figure B.19 – Views illustrating the three valid zones for field strength computation around an antenna

Table B.20 – Definition of boundaries for selecting the zone of computation

	Point of interest in zone:		
	A	**B**	**C**
Method of calculation	**Peak/Average** **Cylindrical formulas**	**Peak/Average** **Adjusted spherical formulas**	**Peak/Average** **Classical spherical formulas**
Boundary restrictions	$3{,}6\lambda \le r_\gamma \le \max\begin{bmatrix} \dfrac{2L^2}{\lambda} \\ L/2+2{,}5\lambda \end{bmatrix}$ Applicable in boresight within height of antenna[a]. Sector arrays: $-\pi/2 \le \phi \le \pi/2$ Omnidirectional arrays: $-\pi \le \phi \le \pi$	$L/2+2{,}5\lambda \le r \le \dfrac{2L^2}{\lambda}$ Applicable off-boresight above and below height of the antenna[a].	$r \ge \max\begin{bmatrix} \dfrac{2L^2}{\lambda} \\ L/2+2{,}5\lambda \end{bmatrix}$

[a] In the case of electrical downtilt, the condition “in boresight within height of antenna” is defined by: $-\frac{L}{2} - r_\gamma \cdot \sin(\gamma) \le z \le \frac{L}{2} - r_\gamma \cdot \sin(\gamma)$, where z is defined by Figure B.1 case a) and case b).

B.4.3.3 Description: cylindrical estimation formulas

B.4.3.3.1 Spatial-average cylindrical formulas

The formulas for estimating the spatially-averaged plane wave equivalent power density $\overline{S}$ applicable in zone A (see Figure B.19) are described in [41]:

a) Omnidirectional arrays

$$\overline{S}(r_\gamma) = \frac{\overline{P}_{\mathrm{avg}}}{2 \cdot \pi \cdot r_\gamma \cdot L \cdot \cos^2(\gamma) \cdot \sqrt{1+(r_\gamma / r_0)^2}}, \quad r_0 = \frac{1}{2} D \cdot L \cdot \cos^2 \gamma \tag{B.32}$$

b) Sector-coverage arrays

$$\overline{S}(r_\gamma, \phi) = \frac{\overline{P}_{\mathrm{avg}} \cdot 2^{-(2\phi/\phi_{3\mathrm{dB}})^2}}{\phi_{3\mathrm{dB}} \cdot r_\gamma \cdot L \cdot \cos^2(\gamma) \cdot \sqrt{1+(r_\gamma / r_0)^2}}, \quad r_0 = \frac{\phi_{3\mathrm{dB}}}{12} D \cdot L \cdot \cos^2 \gamma \tag{B.33}$$

NOTE 1 Formulas (B.32) and (B.33) compute the plane wave equivalent power density spatially-averaged over the specified antenna length L and therefore this does not necessarily relate to the spatial averaging schemes in 6.4.1 and B.3.1.4.

NOTE 2 The average cylindrical formulas provide values of S representing the best estimate confidence level for the “technique uncertainty”. From [42], the corresponding upper 95 % confidence level is between +0,3 dB and +7,5 dB (depending on ϕ) above the S determined by Formulas (B.32) and (B.33) for the range of antennas evaluated in the reported study.

B.4.3.3.2 Spatial-peak cylindrical formulas

The formulas for estimating the spatial-peak plane wave equivalent power density S defined in [41] and applicable in zone A (see Figure B.19) are:

a) Omnidirectional arrays

$$S(r_\gamma) = \frac{\overline{P}_{\text{avg}}}{\pi \cdot r_\gamma \cdot L \cdot \cos^2(\gamma) \cdot \sqrt{1 + \left(2 r_\gamma / r_0\right)^2}}, \quad r_0 = \frac{1}{2} D \cdot L \cdot \cos^2 \gamma \qquad \text{(B.34)}$$

b) Sector-coverage arrays

$$S(r_\gamma, \phi) = \frac{2 \cdot \overline{P}_{\text{avg}} \cdot 2^{-(2\phi/\phi_{\text{3dB}})^2}}{\phi_{\text{3dB}} \cdot r_\gamma \cdot L \cdot \cos^2(\gamma) \cdot \sqrt{1 + \left(2 r_\gamma / r_0\right)^2}}, \quad r_0 = \frac{\phi_{\text{3dB}}}{12} \cdot D \cdot L \cdot \cos^2 \gamma \qquad \text{(B.35)}$$

NOTE The peak cylindrical formulas provide values of S representing the best estimate confidence level for the “technique uncertainty”. From [42], the corresponding upper 95 % confidence level is between +0,6 dB and +7,2 dB (depending on ϕ) above the S determined by Equations (B.34) and (B.35) for the range of antennas evaluated in the reported study.

B.4.3.4 Description: spherical estimation formulas

B.4.3.4.1 Adjusted spherical formulas

The formulas for estimating both the spatially-averaged plane wave equivalent power density $\overline{S}$ and spatial-peak S plane wave equivalent power density applicable in zone B (see Figure B.19) are:

a) Omnidirectional arrays

$$S(r,\theta) \approx \overline{S}(r,\theta) = \frac{1{,}2 \cdot \overline{P}_{\text{net}} \cdot G_\theta}{4 \cdot \pi \cdot r^2}, \quad G_\theta = 1{,}26 \cdot G_{\substack{\text{side}\\\text{lobe}}} + G \cdot 2^{-\left(\frac{\theta - \gamma - \pi/2}{\theta_{\text{3dB}}}\right)^2} \qquad \text{(B.36)}$$

b) Sector-coverage arrays

$$S(r,\theta,\phi) \approx \overline{S}(r,\theta,\phi) = \frac{1{,}2 \cdot \overline{P}_{\text{net}} \cdot G_{\theta,\phi}}{4 \cdot \pi \cdot r^2}, \quad G_{\theta,\phi} = 1{,}26 \cdot G_{\substack{\text{side}\\\text{lobe}}} + G \cdot 2^{-\left(\frac{\theta - \gamma - \pi/2}{\theta_{\text{3dB}}}\right)^2 - \left(\frac{1{,}9 \cdot \phi}{\phi_{\text{3dB}}}\right)^2} \qquad \text{(B.37)}$$

NOTE 1 The adjusted spherical formulas as derived in [42] provide values of S representing the best estimate confidence level for the “technique uncertainty” considering the complete computation zone B (see Figure B.19). From [42] the corresponding upper 95 % confidence level is up to +5,8 dB on the S determined by Equations (B.36) and (B.37) depending on r, θ and ϕ for the range of antennas evaluated in the reported study.

NOTE 2 $G_{\theta,\phi}$ and G_θ represent models for the gain variation as function of the angular variables θ and ϕ.

B.4.3.4.2 Classical spherical formula

The classical spherical formula [see Equation (B.18)] is applicable in zone C (see Figure B.19) for estimating both the spatially-averaged plane wave equivalent power density $\overline{S}$ and spatial-peak plane wave equivalent power density S.

NOTE The classical spherical formula provides a value of S representing the best estimate confidence level for the “technique uncertainty”. The upper 95 % confidence level is +3,5 dB on the S determined by the simplified equation in [42] that fully defines the method to determine the three-dimensional gain pattern and the associated uncertainties used for the range of antennas evaluated in the reported study.

B.4.3.5 Validation of cylindrical and spherical algorithms

B.4.3.5.1 General

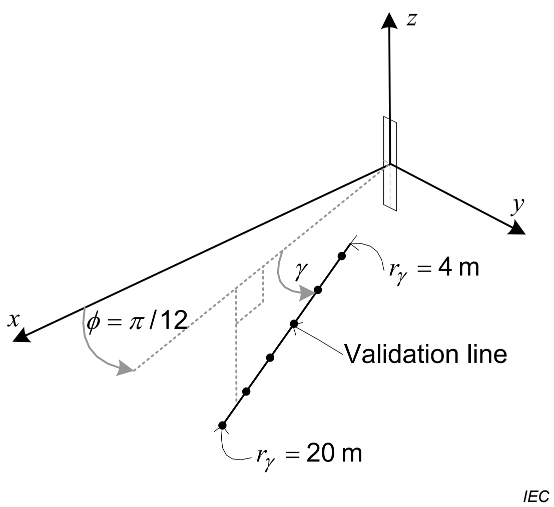
The power density of the RF fields transmitted by omnidirectional and sector-coverage RBS antennas can be determined using the cylindrical and spherical formulas presented in B.4.3.2. The input parameters for the validation are listed in Table B.21. The correct implementation of the formulas shall be verified by checking that the results produced by the implementation correlate within 1 % with the reference results in Figure B.20 and Figure B.21.

Table B.21 – Input parameters for cylinder and spherical formulas validation

Antenna type	Freq.	RF power	Array length	Vertical HPBW	Horizontal HPBW	Electrical downtilt	Gain and directivity	Maximum side lobe gain
Omni	925 MHz	80 W	2,158 m	8°	N/A	5°	11 dBi	-9 dBi
Sector	925 MHz	80 W	2,158 m	8°	84°	5°	17 dBi	-3,6 dBi

B.4.3.5.2 Validation of cylindrical formulas

For each of the implemented cylindrical formulas, determine $\bar{S}$ and S at positions every 2 m from r_γ = 4 m to r_γ = 20 m along the validation line in the main vertical beam (see Figure B.20) for the omnidirectional and sector-coverage antennas described in Table B.21 and where $\phi = \pi / 12$ radians.

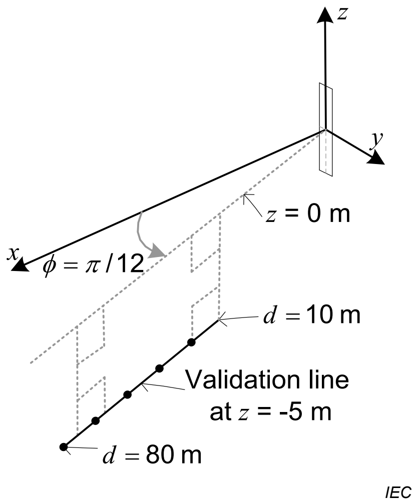


Position	Omnidirectional		Sector-coverage	
r_γ (m)	$\bar{S}$ (W/m²)	S (W/m²)	$\bar{S}$ (W/m²)	S (W/m²)
4	1,43	2,56	5,58	9,96
6	0,905	1,48	3,54	5,74
8	0,639	0,958	2,49	3,70
10	0,478	0,665	1,86	2,56
12	0,370	0,485	1,43	1,86
15	0,265	0,325	1,02	1,25
20	0,166	0,190	0,639	0,727

Figure B.20 – Cylindrical formulas reference results

B.4.3.5.3 Validation of spherical formulas

Using each of the implemented spherical formulas, at positions described in Figure B.21 determine S for the omnidirectional and sector-coverage antennas described in Table B.21 at positions every 10 m from d = 10 m to d = 80 m along the validation line (Figure B.21), 5 m below the centre of the antenna and where $\phi = \pi / 12$ radians.



Zone	Position	Adjusted spherical		Simple spherical	
		Omni	Sector	Omni	Sector
	d (m)	S (mW/m²)	S (mW/m²)	S (mW/m²)	S (mW/m²)
B[a]	10	14,7	52,0	6,41	22,2
	20	96,3	353	7,37	26,5
C[a]	30	85,1	313	37,4	136
	40	57,1	210	41,1	150
	50	38,4	141	31,4	114
	60	26,8	98,6	22,3	81,1
	70	19,6	72,0	15,9	57,8
	80	14,8	54,5	11,6	42,1

[a] The values of S are given for reference regardless of the applicability of the formulas when considering the Table B.20 criteria.

Figure B.21 – Spherical formulas reference results

B.4.4 Advanced computation methods

B.4.4.1 Synthetic model and ray tracing algorithms

B.4.4.1.1 Applicability of synthetic model and ray tracing algorithms

The synthetic model is used to calculate the electric field strength at an observation point using a vector sum of a number of small “patches” of the EUT antenna treated as separate sources [46]. The synthetic model can be used alone for free space exposure evaluation or together with the ray tracing algorithms to take into account the environment (e.g. ground, walls).

This model is applicable in the radiating near-field and far-field regions.

The electric field strength at a point of investigation may be obtained by a vector sum of n small patches of the antenna, treated as separate sources:

$$E = \sum_n \alpha_n \frac{\sqrt{30 \times P_n \times G_n}}{r_n} e^{j(\gamma_n + \frac{2\pi r_n}{\lambda})}$$

where:

- r_n is the distance between the observation point and reference point of patch n;
- P_n is the input power to patch n;
- γ_n is the relative phase of applied voltage at antenna patch n;
- G_n is the gain of patch n towards the point of investigation relative to an isotropic antenna;
- α_n is the weighting coefficient.

The patch gain G_n may be determined according to references given in [46].

Various ray tracing algorithms have been developed (e.g. [40] to [47]) and implemented in commercial computer codes, for the evaluation of RF field strength or power density in all directions around RBS antennas.

These ray tracing algorithms are suited to evaluations in the far-field (source region III) and radiating near-field (source region II). Table 7 summarizes recommended and permitted applications for ray tracing methods. Typical implementations involve one, two or multi-rays. Applicability of each of these is discussed below.

a) Ray tracing – one-ray
   - Commonly used for evaluation of RF field strength or power density in the far-field or radiating near-field of one or more sources with no or negligible environmental reflectors (source-environment plane regions III-0 and II-0), for example towers, masts and poles.
   - Can also be used in more complex environments but a more comprehensive uncertainty analysis is then required.
   - Alternatively, the method can be enhanced by employing a factor to account for average ground reflection (6.2.7), for example as done in US FCC OET Bulletin 65 [15], where the factor is 1,6 for RF field strength (2,56 for power density) (source-environment plane II-1 and III-1).

b) Ray tracing – two-ray
   - Commonly used for evaluation of RF field strength or power density in the far-field or radiating near-field (source-environment plane II-1 and III-1) of one or more sources with one environmental reflector, for example roof-top reflection or ground reflection in open and semi-built up areas.
   - Can also be used in more complex environments but a more comprehensive uncertainty analysis is then required.

c) Ray tracing – multi-ray
   - Commonly used for evaluation of RF field strengths or power density in the far-field or radiating near-field of one or more sources with more than one environmental reflector (source-environment plane regions II-M and III-M), for example complex roof-tops, or complex built-up areas.
   - This method would theoretically provide more accurate results than the one-ray or two-ray techniques, but for this to be the case very detailed and accurate information is required on the multiple environmental objects. In practice, one-ray or two-ray methods with appropriate uncertainty analysis taking possible multiple environmental reflectors into account would suffice.

B.4.4.1.2 Input requirements for synthetic model and ray tracing algorithms

The input requirements for synthetic model are listed below:

r_n distance between the observation point and reference point of patch n;

P_n input power to patch n;

γ_n relative phase of applied voltage at antenna patch n;

G_n gain of patch n towards the point of investigation relative to an isotropic antenna;

α_n weighting coefficient.

The input data requirements for ray tracing techniques are listed below:

- transmitter power;
- RF transmission system losses;
- antenna gain;
- antenna aperture;
- antenna pattern;
- antenna mounting height, position and orientation;
- environmental clutter data (ground, buildings);
- topography.

If one or more of the input data values are unknown, ray tracing may still be used but the uncertainty estimation shall then include additional sources of uncertainty relating to the estimated data values.

B.4.4.1.3 Description of synthetic model and ray tracing algorithms

Synthetic model and ray tracing algorithms employ a simple approach which uses antenna pattern synthesis and spherical free-space wave propagation to calculate approximate field values in the radiating near-field as well as the far-field of antennas (source-environment plane regions II-* and III-*). The antenna parameters (gain, horizontal and vertical far-field radiation pattern cuts) are typically obtained from manufacturers' published data. Technical details for implementing ray tracing algorithms can be found in, for example, [40] to [47]

Figure B.22 shows the typical geometry and parameters to apply ray tracing with the synthetic model where r_1 to r_5 represent the direct path from (e.g. [40] to [47]) the centre of the five individual radiating elements in the array to the point of interest and r_5' represents the two-ray path from the lowest element of the array reflecting from the ground to the point of interest.

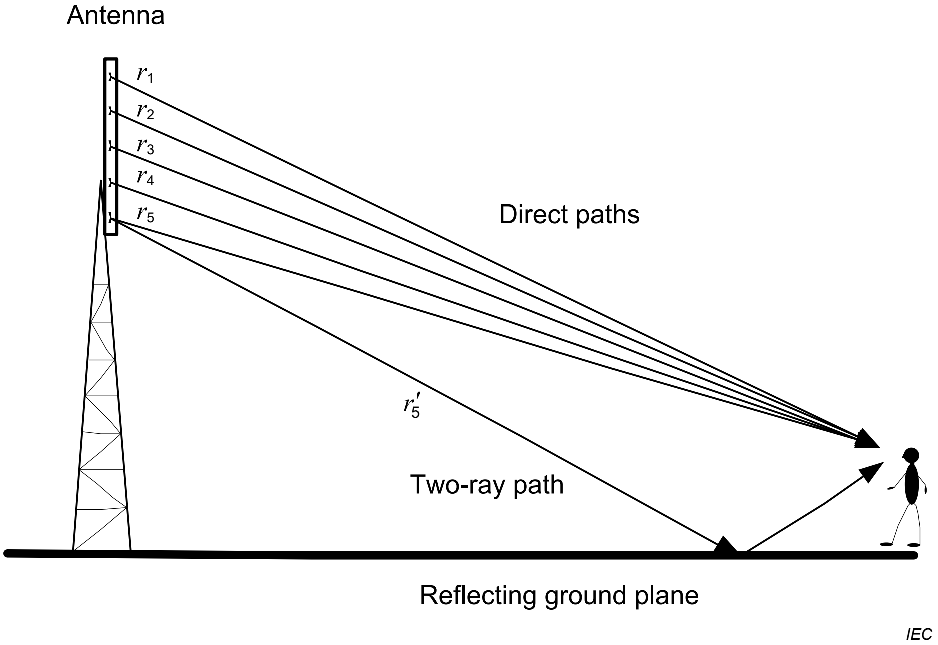


Figure B.22 – Synthetic model and ray tracing algorithms geometry and parameters

Ray tracing algorithms typically overestimate the RF field strength due to absorption of RF energy in the ground, building walls and other man-made structures that are not taken into account with basic implementations. This overestimation shall form part of the uncertainty analysis.

The following procedure shall be followed when employing ray tracing algorithms.

a) Ensure that the evaluation will be valid considering the restrictions and limitations of the method.
b) Select commercial code or implement algorithms.
c) Validate using pre-calculated examples (see B.4.4.1.5).
d) Establish input parameters (see B.4.4.1.2).
e) Perform evaluation (apply ray tracing algorithm).
f) Perform uncertainty analysis (see B.4.4.1.4).

g) Apply uncertainty for result interpretation (see Clause 9 and Annex E).

h) Report on evaluation (see Clause 10).

B.4.4.1.4 Synthetic model and ray tracing uncertainty parameters

Uncertainty factors for ray tracing fall into three categories, namely transmitter system, modelling technique and environmental uncertainties. Table B.22 identifies the main uncertainty factors for these three categories. The surveyor shall work through these to make sure that he understands and tests for each applicable source of uncertainty.

Table B.22 – Sample template for estimating the expanded uncertainty of a synthetic model and ray tracing RF field strength computation

Source of uncertainty	Unit	Prob. distrib. type	Uncertainty or semi span a	Divisor d [a]	Sens. coeff. c	Standard uncertainty $u = a/d$	Corr. fact. t	c^2u^2
System								
Variation in the power of the RF transmitter from its nominal level	dB	rect.		√3	1			
Cable/connector losses	dB	normal		1,96	1			
Mismatch between antenna and its feed	dB	U		√2	1			
Antenna radiation pattern data[b]	dB	normal		1,96	1			
Antenna positioning, mounting and support structure	dB	rect.		√3	1			
Technique uncertainties								
Inherent uncertainties associated with the approximate numerical model used to represent the antenna.	dB	rect.		√3	1			
Null-filling of antenna patterns (if applied)	dB	Depends on algorithm			1			
Environmental uncertainties								
Scattering from nearby objects and the ground	dB	rect.		√3	1			
Uncertainty in using electric field strength evaluations to estimate magnetic field strength, or vice versa	dB	rect.		√3	1			
Combined correction factor, $t_\mathrm{c} = \sum_{i=1}^{N} t_i$								N/A
Combined standard uncertainty, $u_\mathrm{c} = \sqrt{\sum_{i=1}^{N}(c_i^2\ u_i^2)}$								
Coverage factor for required (e.g. 95 %) confidence interval, k								
Expanded uncertainty, $U = k \times u_\mathrm{c}$								

NOTE 1 See Annex E for guidance on the variables in this table.

NOTE 2 This table is under the assumption that the logarithmic expression of the measured quantities can be similarly treated to that of the linear expression in view of statistical properties.

[a] The value of divisor d for normal probability distribution is for 95 % confidence.

[b] The normalized radiation pattern uncertainty can be different inside the HPBW (very small); outside the main beam (larger); and in the side lobes.

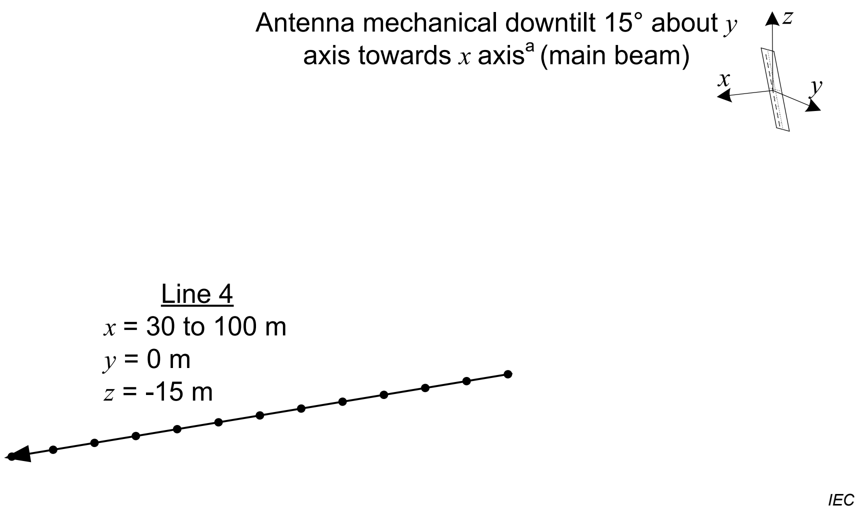
B.4.4.1.5 Validation of synthetic model and ray tracing algorithms

B.4.4.1.5 provides an example for validating the correct implementation of a synthetic model and ray tracing algorithm using the generic panel RBS antenna. The example antenna has nine dipole radiators and operates at 900 MHz. It is highly recommended that several examples are checked to make sure the radiating near-field power density error does not exceed ±3 dB.

a) The antenna parameters for the synthetic model and ray tracing algorithms validation are given in Figure B.24. A point-source array model or aperture field representation shall be extracted using these patterns.
b) The power density values shall be determined for a frequency of 900 MHz and $\overline{P}_{\mathrm{avg}}$ of 80 W along line 1, line 2 and line 3 (see Figure B.26) in the radiating near-field of the antenna, and on line 4 (see Figure B.23) in the far-field.
c) The determined power density values shall be compared with the reference power density values Table B.23.

NOTE The results obtained with the synthetic model and ray tracing algorithms are compared to results obtained from a full wave simulation. The results compare very well on lines 1, 2 and 4. The ray tracing algorithm ignores polarization of the electric fields and for this reason the results very close to the antenna, on line 3, differ slightly more when compared to the full wave solution. This is however expected and within the uncertainty range of a typical ray tracing algorithm.

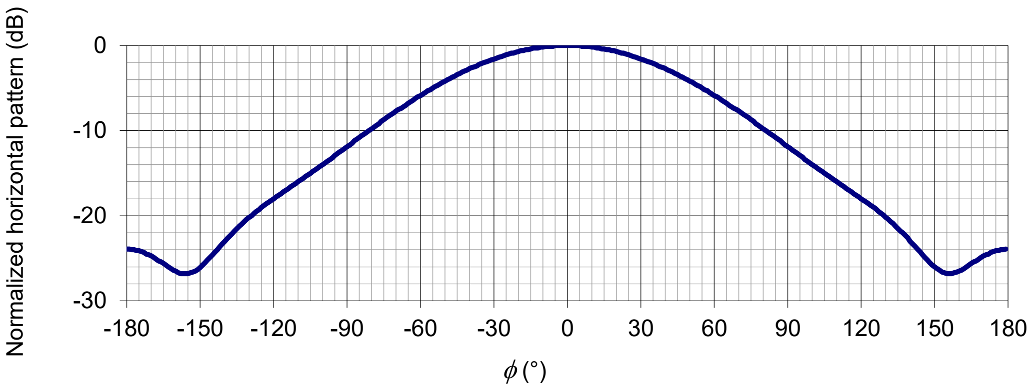
If the maximum deviation from the reference results is within ±3 dB, the simulation package has passed the example validation.



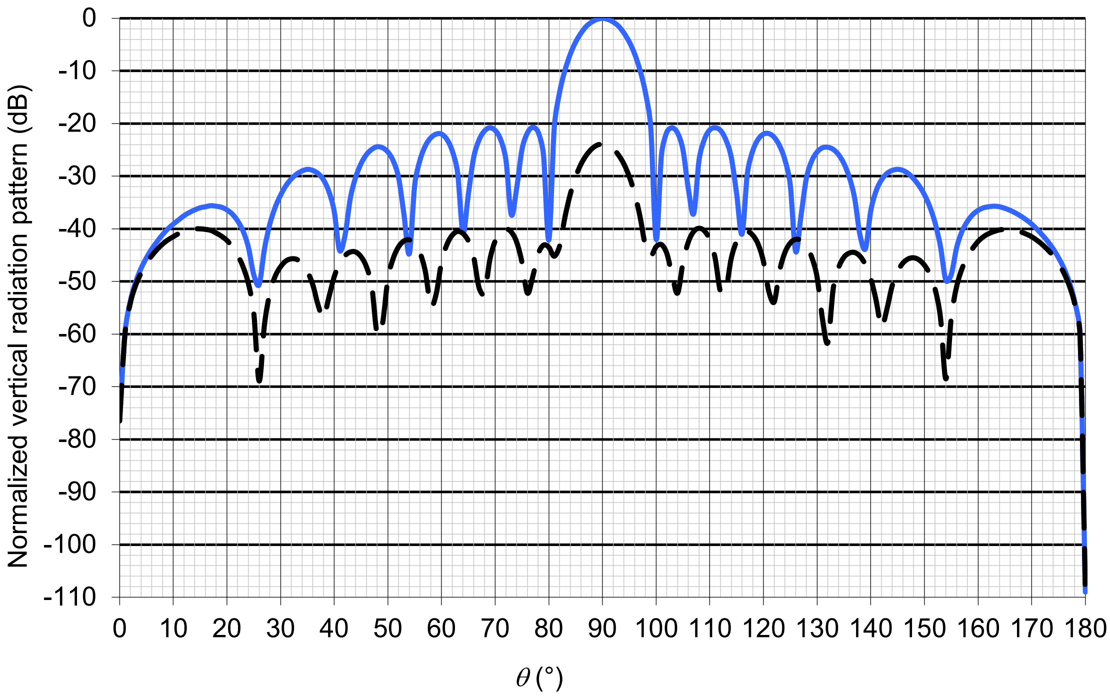
NOTE Line 4 represents a mast antenna configuration, where the power density is calculated 15 m below the antenna, and the antenna is tilted downwards by 15°.

[a] The coordinate system origin (x = 0, y = 0, z = 0) is at the centre of the middle feed segment.

Figure B.23 – Line 4 far-field positions for synthetic model and ray tracing validation example



a) Normalized horizontal radiation pattern (dB) for θ equal to 90°



b) Normalized vertical radiation pattern (dB) for ϕ equal to 0° and ϕ equal to 180°

Gain = 17,0 dBi and radome length = 2,25 m.

Spherical coordinates θ and ϕ are defined by Figure B.1.

Figure H.4 .xls

NOTE The embedded file, Figure B.24.xls, includes the normalized horizontal radiation pattern (dB) in 1° steps for ϕ = -180° to 179° where θ = 90° and the normalized vertical radiation pattern (dB) in 1° steps for θ = 0° to 180° where ϕ = 0° and ϕ =180°.

Figure B.24 – Antenna parameters for synthetic model and ray tracing algorithms validation example

Table B.23 – Synthetic model and ray tracing power density reference results

Power density along Figure B.26 line 1		Power density along Figure B.26 line 2		Power density along Figure B.26 line 3		Power density along Figure B.23 line 4	
Position x (m)	S (W/m^2)	**Position** y (m)	S (W/m^2)	**Position** z (m)	S (W/m^2)	**Position** x (m)	S (mW/m^2)
0,5	72,8	0	41,7	0	385	30	2,33
1	41,7	0,2	39,6	0,2	261	40	48,5
1,5	25,5	0,4	34,2	0,4	205	50	105
2	13,1	0,6	27,1	0,6	152	60	80,7
2,5	11,1	0,8	19,8	0,8	80,1	70	45,2
3	11	1	13,3	1	179	80	22,6
3,5	10,7	1,2	8,75	1,2	7,32	90	10,7
4	9,92	1,4	5,76	1,4	1,12	100	4,99

B.4.4.2 Full wave RF field strength computation

B.4.4.2.1 Full wave RF field strength computation applicability

Full wave analysis techniques (e.g. methods requiring Maxwell's equations to be solved anywhere) are essentially used when high accuracy is desired for the evaluation of RF fields, for example for RBS RF field strength, power density or SAR evaluation in source region I (the reactive near-field of the antenna(s)) where ray tracing methods cannot be employed with sufficient accuracy. An accurate and realistic numerical model of the antenna shall be created for a full wave field analysis. Multiple antennas (sources) at multiple frequencies can be modelled.

Full wave methods can also be employed in the source region II (generally radiating near-field) and source region III (generally far-field) but the increase in effort to create an accurate model together with the increase in required computational resources may not warrant the small increase in accuracy obtained in these regions, compared to ray tracing techniques. Table 7 summarizes recommended (1) and permitted (2 to 4) applications for full wave field evaluations. If any of the full wave techniques are used for analysis in the source region I (generally reactive near-field) with one or more reflectors present inside source region I, then geometrical details of the reflector/reflectors are required to be included in the model.

Full wave analysis in source regions II and III (generally radiating near-field or far-field regions) are permitted. For these scenarios the antennas, and possibly one ground plane, can be included in the full wave analysis. For more environmental reflectors (environment region M), an extended uncertainty analysis is required to take these reflections into account.

B.4.4.2.2 Full wave RF field strength computation requirements

Computational resources needed to carry out full wave analysis vary greatly with the complexity and size of the structure to be analysed as well as with the analysis method that is chosen. To be able to model an antenna and evaluate the RF field strength at least the following data is required:

- transmitter power;
- RF transmission system losses;
- detailed description of the antenna geometry;

NOTE 1 However, the model can be simplified to reduce the computational cost, e.g. omit unnecessary detail which will not influence the results such as the feed network, or approximate an uneven metal plane with variations much smaller than a wavelength with an even plane. Detail such as screws and joints can be omitted and holes much smaller than the wavelength (λ_0/20 of the highest frequency), e.g. screw holes, can be closed. Additionally, dielectric radome structures can typically be omitted in base station antenna simulations.

- antenna element excitation;
- antenna mounting height, position and orientation.

Additionally, for verification purposes the following manufacturer data are required:

- antenna gain;
- antenna pattern.

Environment clutter data (ground, buildings) and topography data is required, or shall be accounted for, in the uncertainty analysis/reporting.

NOTE 2 Environment data is not a requirement for product conformity assessments if it is assumed that the antenna is transmitting in free space.

B.4.4.2.3 Full wave RF field strength computation description

The main methods to use with full wave analysis are the Method of Moments (MoM) [48], [49], [50], [51], [52], the finite element method (FEM) [50], [52], [53], [56] and the finite difference time domain (FDTD) method [48], [52], [54], [55],. These methods are complex and difficult to implement. Nonetheless, various commercial software packages (as well as numerous in-house research codes) are available that can be used for full wave field analysis. Other techniques are also available and used in commercial software packages, which are closely related to the three methods mentioned above.

Each of the three main methods has strengths and weaknesses of its own.

When performing full wave field analysis, either with a commercial package or an in-house implementation of any of the three techniques, the following procedure shall be followed.

a) Ensure that the evaluation will be valid considering the restrictions and limitations of the method.
b) Select commercial code or implement method.
c) Validate 3D code against reference results (see B.4.4.2.6).

   NOTE This applies only to the code developer.
d) Prepare detailed antenna models and verify against measurements for evaluations in source region I.
e) Perform field evaluation for each antenna.
f) Study convergence for each antenna.
g) Validate converged results against antenna specifications (each antenna).
h) Perform field calculation for all antennas.
i) Perform uncertainty analysis (see B.4.4.2.5).
j) Use uncertainty analysis for result interpretation (see Clause 9 and Annex E).
k) Report of evaluation (see Clause 10).

B.4.4.2.4 Implementation of full wave field evaluation

B.4.4.2.4.1 Method of moments (MoM)

MoM is used to numerically solve integral equation formulations of Maxwell’s equations. In principle, the radiated electromagnetic fields are obtained by following a two-step procedure.

a) First, structures which are represented with a mesh are replaced by equivalent currents. A matrix is derived which represents the effect of each element/segment on each other segment/element and the surface currents are solved.

b) Secondly, these currents are integrated to obtain the electric and magnetic fields at the points of interest.

Metallic structures can be modelled accurately and efficiently using MoM. Fine structures with arbitrary orientations can also be treated easily. Another advantage is that only the radiating antenna needs to be discretized, i.e. the memory requirements and the solution time do not depend on the distance between the source and the field point. For the same reason, there is no uncertainty component rising from the truncation of the computational domain as is the case for the methods FDTD and FEM. MoM is however not the most efficient method for inhomogeneous dielectric mediums but when hybridized with FEM it can be an effective solution. Since the typical RBS antenna's structure is physically quite large compared to the wavelength, and with a lot of detail, these simulations can get quite memory- and time-consuming when the frequency is high, e.g. GSM-1800 or UMTS; however, this is a general CEM problem for these calculations.

When using MoM the following principles shall be considered.

- The edge length of the elements of the model should be small enough to give accurate results and big enough to ensure that realistic computational resources can be used. To determine if the edge lengths of the elements are small enough, convergence tests should be done, which is an iterative process where the mesh size is varied and the results are compared until the optimal mesh size is determined. Start with edge lengths of, for example, $\lambda_0/5$, $\lambda_0/8$ and $\lambda_0/10$ (with λ_0 the wavelength in free space) and repeat until the results differ by less than 10 %. The edge length of the elements should also be small enough to create a mesh which resembles the geometry. This is sometimes called geometric convergence.
- When meshing a detailed model of an antenna the mesh elements can be differing lengths: finer (e.g. $\lambda_0/15$) where the highest current variations are, for example close to feed pins, and coarse (e.g. $\lambda_0/8$) elsewhere, to reduce the runtime.
- In certain cases there will be other limits on the size of the mesh elements; for example, if two metal plates are close to each other there are limitations on the maximum edge length of the elements. Another example is the limitations on the radius vs. segment length of a wire element.
- Accurate information concerning the excitation of each radiating element is required for accurate full wave modelling of an antenna.

B.4.4.2.4.2 Finite difference time domain (FDTD)

In FDTD, Maxwell's time-dependent curl equations are solved directly by approximating the differential equations with finite difference equivalents over a structured grid. A method called finite integration technique (FIT) is closely related to FDTD and the instructions given here for FDTD also apply for FIT analysis as well.

The computational lattice of FDTD consists of rectangular cells. The difference with MoM is that the computational lattice has to be extended to all the regions where electric field values are desired to be calculated. This means that the amount of memory in the computer can become a limiting factor for evaluating fields several metres away from the antenna. In traditional FDTD the computational mesh is rectangular in shape, which means that curved surfaces and arbitrarily oriented objects are difficult to model accurately. Furthermore, absorbing boundary conditions have to be applied at the lattice boundaries to simulate open space conditions.

When FDTD method is used for field evaluation purposes, the following items shall be taken into account.

- Lattice cell size requirements

  Local side length of the cell should not exceed one tenth of the wavelength in that material. Otherwise, wave propagation is not accurately simulated.

Local side length of the cell should be small enough to be able to describe the geometry of the analysed structure. The source region shall be accurately modelled. One weakness of FDTD is that arbitrarily oriented thin sheets usually require a very dense lattice. When sophisticated techniques for modelling fine details (such as conformal meshes and thin wire approximations) are used, it is important to be aware of their limitations.

- Effectiveness of absorbing boundary conditions

  No ideal absorbing boundary exists and therefore there is always some reflection from the boundary. Typically, absorbing boundary conditions are based on approximate factorization of the wave equation, on extrapolation of field values, or on lossy material layers at the boundary. To be able to estimate the expanded uncertainty of the field strength evaluation, the size of the error due to reflections from the lattice boundary shall be quantified. Usually, this means that the simulation has to be repeated with variable lattice sizes and/or absorbing boundary condition parameters.

  To minimize the error due to reflections from lattice boundaries a useful rule of thumb is that reflected wave component is small where incoming wave power density is small. Therefore it is good to extend the computational lattice especially in the directions where the antenna radiates most.

- Accurate information concerning the excitation of each radiating element is required for accurate full wave modelling of an antenna.

B.4.4.2.4.3 Finite element method (FEM)

In FEM, the solution for field quantities is approximated with the sum of basis functions that differ from zero in elements of finite size. The elements are chosen to conform to the physical structure to be simulated, which enables easy and accurate modelling of interface and boundary conditions. The mesh is usually created using tetrahedral elements, which also allows for accurate geometrical representations of arbitrary structures.

Like FDTD, FEM is also based on volume discretization, which means that it has the same disadvantage of having to discretize all the regions where field values are to be calculated. However, when the points where field values are to be calculated are outside a minimum domain (with appropriate absorbing boundary conditions) circumscribing the radiating structure, near to near-field transformations similar to those used in method of moments can be advantageously employed for those points. The field evaluated on a surface surrounding the radiating structure can be used as a secondary source to evaluate the field outside this surface via integral equations.

When FEM is used for field evaluation purposes, the following items shall be taken into account.

- Mesh size and/or polynomial order of the basis functions

  Although adaptive meshing can automatically cope with the accuracy of the solution with a minimum of number of degrees of freedom, it is recommended that the maximum size of the element (side length of the element) is limited to ensure the accuracy of the field solution. The maximum size of the element in a media should be lower than a fifth or a tenth of wavelength in that medium depending on the polynomial order of the basis functions, second order or first order. For higher order polynomials, the size of the mesh can be relaxed.

- Mesh truncation of radiating structures

  In FEM, different techniques to truncate the mesh domain and simulate outgoing waves exist. Very rigorous and thus accurate techniques are those coupling FEM with MoM on an arbitrary surface or coupling FEM with spherical harmonics on a sphere. The surface can be placed close to the radiating surface, minimizing the size of the problem to be solved. A simpler technique like Silver-Muller first order absorbing boundary condition can also be used provided that the truncation surface is far enough away such that the incident wave is close to normal incidence. This distance may depend on the radiating structure; a minimum distance of a half wavelength is required. The popular PML (perfectly matched layer) introduced for FDTD has been derived for FEM with the same performance and requirements.

- Accurate information concerning the excitation of each radiating element is required for accurate full wave modelling of an antenna.

B.4.4.2.5 Full wave RF field strength computation uncertainty

Various parameters shall be taken into account when estimating the expanded uncertainty associated with a full wave field solution. Table B.24 is an uncertainty estimation template listing uncertainty parameters that shall be considered when using full wave RF field strength analysis.

Table B.24 – Sample template for estimating the expanded uncertainty of a full wave RF field strength computation

Source of uncertainty (influence quantity)	Unit	Prob. distrib. type	Uncertainty or semi span a	Divisor d [a]	Sens. coeff. c	Standard uncertainty $u = a/d$	Corr. fact. t	c^2u^2
System								
Variation in the power of the RF transmitter from its nominal level	dB	rect.		√3	1			
Cable/connector losses	dB	normal		1,96	1			
Mismatch between antenna and its feed	dB	U		√2	1			
Antenna model	dB	normal		1,96	1			
Technique uncertainties								
Including computational assumptions, limitations, interpolation and extrapolation	dB	normal		1,96	1			
Environmental uncertainties								
Scattering from nearby objects and the ground	dB	rect.		√3	1			
Using electric field strength evaluations to estimate magnetic field strength, or vice versa	dB	rect.		√3	1			
Combined correction factor, $t_c = \sum_{i=1}^{N} t_i$								N/A
Combined standard uncertainty, $u_c = \sqrt{\sum_{i=1}^{N} (c_i^2 \, u_i^2)}$								
Coverage factor for required (e.g. 95 %) confidence interval, k								
Expanded uncertainty, $U = k \times u_c$								

NOTE 1 Numerical rounding errors are usually negligible compared to the other listed influence quantities.

NOTE 2 A conservative alternative approach to estimating the standard uncertainty for antenna mismatch is to assume a perfect match.

NOTE 3 See Annex E for guidance on the variables in this table.

NOTE 4 This table is under the assumption that the logarithmic expression of the measured quantities can be similarly treated to that of the linear expression in view of statistical properties.

[a] The value of divisor d for normal probability distribution is for 95 % confidence.

B.4.4.2.6 Validation of full wave field analyses

B.4.4.2.6.1 General

B.4.4.2.6 describes how to validate the correct implementation of full wave field analyses. Before a newly implemented code or commercially available code is used for determining the field strengths from RBS antennas, it shall be validated for the antenna structure to be analysed.

– If the elements of the antenna include dipoles, then validation 1 (see B.4.4.2.6.2) shall be performed.
– If the elements of the antenna include slot feeding structure, then validation 2 (see B.4.4.2.6.3) shall be performed.

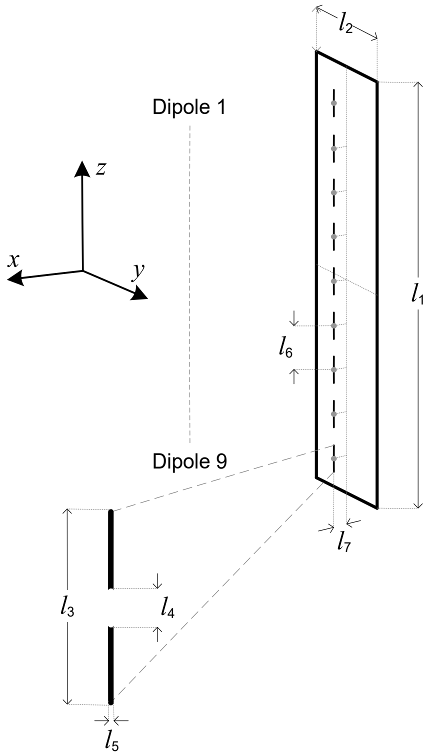
Additionally, if the code also is to be used for full wave *SAR* evaluations, validation using B.4.4.3.6 shall be performed.

NOTE The mesh size is not explicitly given for the validation examples because the optimal mesh size will differ for different simulation packages. It is the user's responsibility to verify the chosen mesh size, by doing convergence tests.

B.4.4.2.6.2 Validation 1: Antenna with dipole radiators

Validation 1 shall use the following procedure.

a) Implement the simple panel RBS antenna, representative of a real RBS antenna, with dipole radiators and excitation parameters as presented in Figure B.25.
b) The electric field strength values shall be determined along line 1, line 2 and line 3 (see Figure B.26) in the near-field of the antenna for a frequency of 900 MHz and $\overline{P}_{\text{avg}}$ of 80 W.
c) The determined power density values shall be compared with the reference power density values in Table B.25. If the maximum deviation from the reference results is less than 10 %, then the simulation package has passed the validation.



Dimensions

l_1 Reflector length = 2,25 m

l_2 Reflector width = 0,3 m

l_3 Length of a dipole = 0,158 m

l_4 Separation of feed segments = 0,02 m

l_5 Dipole thickness = 0,001 m

l_6 Spacing between the dipole centres = 0,25 m

l_7 Spacing between the dipoles and the reflector = 0,04 m

Excitation parameters

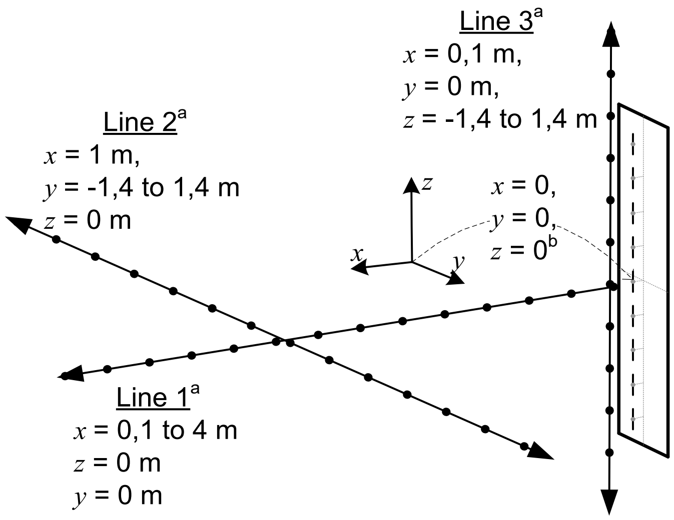
Feed segment	**Amplitude (relative to maximum)**	**Phase (°)**
1 and 9	0,582 8	0
2 and 8	0,609 7	0
3 and 7	0,809 0	0
4 and 6	0,949 4	0
5	1,000 0	0

IEC

NOTE 1 The coordinate system origin (x = 0, y = 0, z = 0) is at the centre of the middle feed segment.

NOTE 2 The dipole array is in the centre of the reflector plate if viewed directly from the front.

Figure B.25 – Generic 900 MHz RBS antenna with nine dipole radiators



[a] Line 1 is along the x-axis in the main beam direction; Line 2 is parallel to the y-axis; Line 3 is parallel to the z-axis (i.e. parallel to the antenna).

[b] The coordinate system origin (x = 0, y = 0, z = 0) is at the centre of the middle feed segment.

Figure B.26 – Line 1, 2 and 3 near-field positions for full wave and ray tracing validation

Table B.25 – Validation 1 full wave field reference results

Power density along Figure B.26 line 1		Power density along Figure B.26 line 2		Power density along Figure B.26 line 3	
Position x (m)	S (W/m^2)	Position y (m)	S (W/m^2)	Position z (m)	S (W/m^2)
0,5	65,8	0	39,4	0	338
1	39,4	± 0,2	37,6	± 0,2	272
1,5	25	± 0,4	32,8	± 0,4	163
2	13,4	± 0,6	26,3	± 0,6	111
2,5	10,7	± 0,8	19,6	± 0,8	105
3	10,4	± 1	13,6	± 1	129
3,5	10,1	± 1,2	9,16	± 1,2	3,77
4	9,44	± 1,4	6,22	± 1,4	0,173

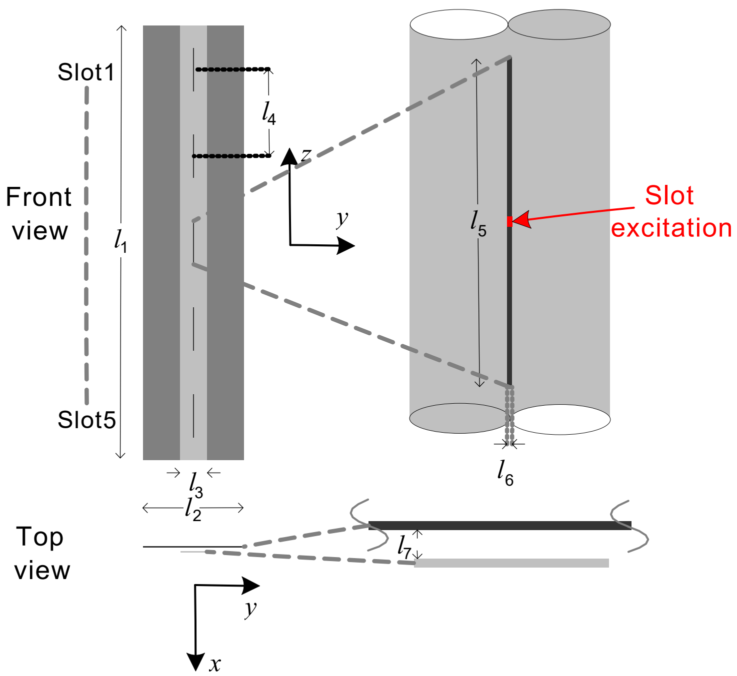
B.4.4.2.6.3 Validation 2: Antenna with slot elements

Validation 2 shall use the following procedure.

a) Implement the antenna array of five slot radiators as shown in Figure B.27. The antenna is excited with voltage sources in the centres of slots according to the excitation parameters specified in Figure B.27, at a frequency of 1 800 MHz and with $\overline{P}_{\text{avg}}$ equal to 40 W.

b) The electric field strength values shall be determined along line 1, line 2 and line 3 (see Figure B.26) in the near-field of the antenna.

c) The determined power density values shall be compared with the reference power density values in Table B.26. If the maximum deviation from the reference results is less than 10 %, then the simulation package and surveyor have passed the validation.



Dimensions

l_1, reflector/front plate length = 0,66 m

l_2, reflector width = 0,155 m

l_3, front plate width = 0,04 m

l_4, slot centre spacing = 0,32 m

l_5, slot length = 0,067 m

l_6, slot width = 0,002 m

l_7, slot to reflector spacing = 0,007 5 m

Excitation parameters

Feed segment	Amplitude (relative to maximum)	Phase (°)
1 and 5	0,791 7	0
2 and 4	0,878 2	0
3	1	0

IEC

NOTE 1 The slots are in the centre of the front plate

Figure B.27 – Generic 1 800 MHz RBS antenna with five slot radiators

Table B.26 – Validation 2 full wave field reference results

Power density along Figure B.26 line 1		Power density along Figure B.26 line 2		Power density along Figure B.26 line 3	
Position x (m)	S (W/m^2)	Position y (m)	S (W/m^2)	Position z (m)	S (W/m^2)
0,5	146	0	90	± 0	688
1	90	± 0,2	79,7	± 0,2	477
1,5	50,6	± 0,4	57,1	± 0,4	20
2	31,1	± 0,6	35,5	± 0,6	1,31
2,5	20,8	± 0,8	20,6	± 0,8	0,406
3	14,8	± 1	11,8	± 1	0,193
3,5	11	± 1,2	6,86	± 1,2	0,113
4	8,54	± 1,4	4,1	± 1,4	0,073 9

B.4.4.3 Full wave *SAR* computation

B.4.4.3.1 Applicability of full wave methods for *SAR* evaluation

The strength of full wave techniques is that in addition to field evaluation they can also be used to evaluate *SAR* and therefore enable a comparison to be made with the relevant *SAR* limit. B.4.4.2.1 gives information on different methods and their applicability for electromagnetic field evaluation in the near-field region of an antenna. All of the issues discussed in B.4.4.2.1 shall be considered when performing full wave *SAR* analysis because it relates to the accurate numerical modelling of the antenna(s) which would serve as the source(s) for full wave *SAR* calculations. There are additional points to consider for numerical *SAR* evaluations. These points are described in this subclause in general. Table 7 (see 8.3) summarizes the applications for full wave *SAR* evaluations.

B.4.4.3.2 Full wave *SAR* computation methods requirements

In addition to the items listed in B.4.4.2.2, it is necessary to have a phantom or human body model with data on tissue dielectric parameters (permittivity and conductivity applicable to the frequency under investigation) and mass density. Any phantom can be employed for the evaluation, however a full uncertainty analysis (see B.4.3.5) shall be performed.

B.4.4.3.3 Full wave *SAR* computation methods description

The most commonly used method for full wave *SAR* evaluation is the finite difference time domain (FDTD) method ([48], [54], [55]). This method can be used for modelling the source (RBS antenna) as discussed in B.4.4.2.4.2 and is ideal for modelling of the inhomogeneous human body. Both the finite element method (FEM) ([53] to [56], [52]) and method of moments (MoM) ([48], [49], [50], [51], [52]), as well as hybrids of these techniques have been used successfully for full wave *SAR* analysis. Various commercial software packages (and in-house research codes) are available that can be used for full wave *SAR* analysis.

When performing full wave *SAR* analysis, either with a commercial package or an in-house implementation of any of the three techniques, the following procedure shall be followed.

a) Ensure that the evaluation will be valid considering the restrictions and limitations of the method.
b) Select commercial code or implement method.
c) Complete source antenna validation.
d) Validate 3D code against reference results (see B.4.4.3.6).

NOTE This applies only to the code developer.

e) Prepare detailed antenna models and verify against measurements for evaluations in source region I.
f) Prepare full model with selected phantom.
g) Perform *SAR* calculations.
h) Study convergence for *SAR* results.
i) Perform uncertainty analysis (see B.4.4.3.5).
j) Use uncertainty analysis for result interpretation (see Clause 9 and Annex E).
k) Report on evaluation (see Clause 10).

B.4.4.3.4 Implementation of full wave *SAR* evaluation

B.4.4.3.4.1 General

SAR evaluations involve modelling of the RBS antenna as well as the human phantom. B.4.4.3.4 will focus on the additional requirements for modelling the human phantom.

It shall be noted that a human phantom is large compared to the wavelength at the frequencies considered in this document. For this reason all *SAR* evaluation simulations will be memory- and time-consuming, especially in the upper frequency band (e.g. at UMTS). The simplest phantom geometry should be used that will still lead to sufficiently accurate results. Parts of the phantom which will not influence the results may be omitted. Symmetry may be used to reduce the computational resource requirements when applicable.

B.4.4.3.4.2 Method of moments (MoM) and hybrid methods

When performing *SAR* calculations using the MoM, the following guidelines shall be adhered to.

- The mesh size of the phantoms shall be smaller on the face and in places where the geometry is detailed.
- Inhomogeneous dielectric regions can be very resource consuming when simulated with MoM. Hybrid FEM/MoM solutions can be a good alternative for inhomogeneous dielectric regions.
- The edge length of the dielectric triangles used to model the phantom shall be small enough to give accurate results and large enough to give a realistic runtime. Suggested mesh sizes for specific situations will differ depending on the simulation package. Convergence tests shall be done with the phantom model to ascertain accurate results.

When deciding on the mesh size of the phantom, the following principles shall be followed.

– To determine if the surface elements of the phantom in a MoM simulation is fine enough, start with three varying edge lengths, e.g. $\lambda_0/5$, $\lambda_0/8$ and $\lambda_0/10$, and do convergence tests with $\lambda_0$the wavelength in free-space.
– The dielectric triangles on the surface of the phantom can be meshed as a fraction of λ_0, but any dielectric triangles within the phantom have to be meshed as a fraction of the appropriate λ_r, with λ_r the wavelength in the phantom material.
– The tetrahedra of phantoms to be used in hybrid FEM/MoM solutions can be meshed with bigger mesh sizes (up to $\lambda_r/4$). Do convergence tests to determine the optimal mesh size.
– To save computational cost, the phantoms of FEM/MoM hybrid solutions can be enclosed in an air box, which can be meshed coarser (a fraction of λ_0 instead of λ_r). This will result in fewer surface elements and therefore in smaller computational requirements.

B.4.4.3.4.3 Finite difference time domain (FDTD)

When FDTD method is used for *SAR* evaluation purposes, the following shall be taken into consideration.

- When evaluating the whole-body average *SAR* the local side length of lattice cell shall be smaller or equal to one tenth of the wavelength in the phantom material (λ_r).
- When evaluating the maximum localized *SAR* (1 g or 10 g), the local side length of lattice cells in the averaging volume (giving the maximum *SAR*) is recommended to be smaller or equal to one fifteenth of the wavelength in the phantom material (λ_r).
- The local side length of the lattice cells in the phantom could be smaller on places of high importance, for example where the geometry is detailed or where the highest field strengths are likely to occur, and larger on places of less importance.

B.4.4.3.4.4 Finite element method (FEM)

When performing *SAR* calculations with FEM, the following guidelines shall be adhered to.

- The edge length of the tetrahedra used to model the phantom shall be small enough to give accurate results and big enough to give a realistic runtime. Suggested mesh sizes for specific situations will differ depending on the simulation package. Convergence tests shall be done with the phantom model to ascertain accurate results.
- The mesh size of the phantoms shall be smaller on the face and on places where the geometry is detailed.

When deciding on the mesh size of the phantom, the following principle shall be observed.

– The tetrahedra of phantoms to be used in FEM solutions can be meshed with mesh sizes of $\lambda_r/4$, $\lambda_r/5$ and $\lambda_r/8$, with λ_r the wavelength in the phantom material. Perform convergence tests to determine the optimal mesh size.

B.4.4.3.5 Full wave *SAR* computation uncertainty

For full wave *SAR* computation, the uncertainty analysis consists of the uncertainties associated with the source (antenna) modelling as well as the uncertainty parameters associated with the phantom and phantom simulations. Table B.27 presents a list of parameters that shall be recorded, considering information from E.6, E.8, [57] and [58]. Separate *SAR* uncertainty estimation tables are required for SAR_{wb}, SAR_{10g} (limbs or head/trunk), SAR_{1g} (limbs or head/trunk).

When employing the heterogeneous virtual man phantom [59], the corresponding uncertainty information ([60] to [61], and [29]) can be used to estimate the expanded uncertainty. If a different phantom is selected, the relevant uncertainty *a* values shall be determined for that specific phantom.

Table B.27 – Sample template for estimating the expanded uncertainty of a full wave *SAR* computation

Source of uncertainty (influence quantity)	Unit	Prob. distrib. type	Uncertainty or semi span a [a]	Divisor d	Sens. coeff. c	Standard uncertainty $u = a/d$	Corr. fact t	c^2u^2
System								
Variation in the power of the RF transmitter from its nominal level	dB	rect.		√3	1			
RF transmission system losses	dB	normal		1,96	1			
Mismatch between antenna and its feed	dB	U		√2	1			
Antenna model	dB	normal		1,96	1			
Technique uncertainties								
Analysis technique	dB	normal		1,96	1			
Model resolution (errors associated with finite discretization)	dB	normal		1,96	1			
Interpolations / Extrapolation	dB				1			
Steady state (FDTD)	dB	rect.		√3	1			
For FDTD/FEM: Efficiency of absorbing boundary condition	dB	rect.		√3	1			
For FDTD: Inaccuracy related to truncation of the simulation time	dB	rect.		√3	1			
Environmental uncertainties								
RF propagation – multiple reflections, scatterers and clutter losses	dB	rect.		√3	1			
Uncertainties associated with phantom								
Phantom position and posture	dB				1			
Phantom rotation	dB				1			
Phantom shape and size	dB				1			
Electrical material parameter estimations	dB				1			
Correction factor for homogeneous phantom (if applicable)	dB				1			
Uncertainties associated with *SAR* calculations								
Whole-body and local peak *SAR* algorithm uncertainties. This could be particularly large for local peak *SAR* calculations	dB				1			
Errors due to finite discretization of the human phantom model	dB				1			

Source of uncertainty (influence quantity)	Unit	Prob. distrib. type	Uncertainty or semi span a [a]	Divisor d	Sens. coeff. c	Standard uncertainty $u = a/d$	Corr. fact t	c^2u^2
In the reactive near-field, the errors introduced in the antenna element power division due to the presence of the phantom and the effect thereof on the re-active feed network [62].	dB				1			
Combined correction factor, $t_c = \sum_{i=1}^{N} t_i$								N/A
Combined standard uncertainty, $u_c = \sqrt{\sum_{i=1}^{N} (c_i^2\ u_i^2)}$								
Coverage factor for required (e.g. 95 %) confidence interval, k								
Expanded uncertainty, $U = k \times u_c$								

NOTE 1 Numerical rounding errors are negligible compared to any of the other uncertainties listed above.

NOTE 2 A conservative alternative approach to estimating the standard uncertainty for antenna mismatch is to assume a perfect match.

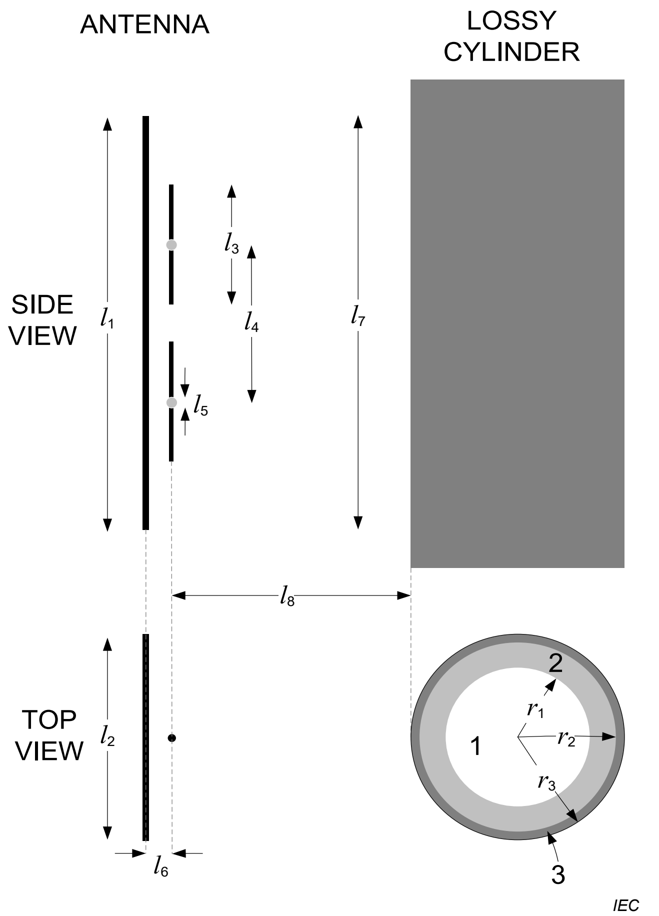
NOTE 3 See Annex E for guidance on the variables in this table.

NOTE 4 This table is under the assumption that the logarithmic expression of the measured quantities can be similarly treated to that of the linear expression in view of statistical properties.

[a] The value of divisor d for normal probability distribution is for 95 % confidence.

B.4.4.3.6 Validation of *SAR* analysis

Figure B.28 shows the validation example consisting of a simplified RBS antenna placed in front of a lossy, circular cylinder with three material layers.



Dimensions

l_1, reflector length = 0,6 m

l_2, reflector width = 0,3 m

l_3, dipole length = 0,158 m

l_4, dipole separation = 0,25 m

l_5, antenna feed separation = 0,02 m

l_6, dipole/reflector separation = 0,04 m

l_7, lossy cylinder height = 0,7 m

l_8, dipole/cylinder separation = 0,4 m

r_1, cylinder outer layer 1 radius = 0,138 m

r_2, cylinder outer layer 2 radius = 0,148 m

r_3, cylinder outer radius = 0,15 m

Cylinder material parameters			
Layer	ε_r	σ (S/m)	ρ (kg/m^3)
1	55,0	0,94	1 041
2	11,3	0,11	916
3	41,4	0,87	1 100

Antenna excitation parameters:

Amplitude (V) (relative) = 1 for both dipoles

Phase (°) (relative) = 0 for both dipoles

NOTE 1 The dipole array is located in the centre of the reflector plate if viewed directly from the front.

Figure B.28 – RBS antenna placed in front of a multi-layered lossy cylinder

The antenna elements are excited by means of a voltage gap (electric field) on each feed segment. Excitation parameters for the dipole array are specified in Figure B.28. The *SAR* shall be evaluated for a $\overline{P}_{\mathrm{avg}}$ of 20 W at a frequency of 900 MHz.

Table B.28 presents the validation reference results for whole-body *SAR* and localized *SAR* (averaged over 10 g of tissue in the shape of a cube).

Table B.28 – Validation reference *SAR* results for computation method

Metric	Validation reference *SAR* results for computation method
Whole-body *SAR*	0,092 W/kg
Localized *SAR*	1,6 W/kg

If the whole-body *SAR* results are within 3 % of the validation reference results and if the localized *SAR* results are within 15 % of the validation reference results, then the simulation package and surveyor have passed the validation.

B.5 Extrapolation from the evaluated *SAR* / RF field strength to the required assessment condition

B.5.1 Extrapolation method

Extrapolation is applicable to exposure evaluation results when the evaluation has been performed according to 6.1, 6.2 or 6.3 at RF power levels lower than the maximum RF transmitted power. For RF exposure evaluation related to product compliance, it can be used for example to extrapolate *SAR* values to a range of RF transmit power levels. For RF exposure evaluation related to in-situ RF exposure assessment, extrapolation can be used, for example, to determine the maximum power density or field strength values from the measurement of technology-specific pilot channels.

The extrapolation shall be performed in the following steps.

a) Establish the values of the parameters which define the RBS configuration as evaluated (the evaluation configuration) and the RBS configuration to be assessed (the assessment configuration). If required, consider relevant criteria to define the potential maximum RF field strength case (see B.5.2 and B.5.3). Identify the relevant parameters that affect the RF field strength, power density or *SAR* including peak-to-average power ratio, see B.3.2.2.4.

b) Establish the case-specific extrapolation factor F_{ext} using all relevant parameters defined in Annex F. Extrapolation may be made to theoretical maximum or actual[6] maximum (95th percentile) exposure conditions.

c) Determine the RF field strength, power density or *SAR* for the assessment configuration by applying the extrapolation factor F_{ext} to the evaluated RF field strength / *SAR* as follows:

$$E_{\text{asmt}} = E_{\text{eval}} \times \sqrt{F_{\text{ext}}} \tag{B.38}$$

$$H_{\text{asmt}} = H_{\text{eval}} \times \sqrt{F_{\text{ext}}} \tag{B.39}$$

$$S_{\text{asmt}} = S_{\text{eval}} \times F_{\text{ext}} \tag{B.40}$$

$$SAR_{\text{asmt}} = SAR_{\text{eval}} \times F_{\text{ext}} \tag{B.41}$$

where:

E_{asmt} is the assessment electric field strength ($\text{V}\cdot\text{m}^{-1}$);

E_{eval} is the evaluated electric field strength ($\text{V}\cdot\text{m}^{-1}$);

H_{asmt} is the assessment magnetic field strength ($\text{A}\cdot\text{m}^{-1}$);

H_{eval} is the evaluated magnetic field strength ($\text{A}\cdot\text{m}^{-1}$);

S_{asmt} is the assessment power density ($\text{W}\cdot\text{m}^{-2}$);

S_{eval} is the evaluated power density ($\text{W}\cdot\text{m}^{-2}$)

SAR_{asmt} is the assessment *SAR* ($\text{W}\cdot\text{kg}^{-1}$);

SAR_{eval} is the evaluated *SAR* ($\text{W}\cdot\text{kg}^{-1}$).

---

6 Knowledge on the actual maximum transmitted power can, for example, be obtained from network based measurements via the Operations Support System (OSS), normally used by operators to monitor, control and analyse the performance of their networks. Statistics gathered for both single cells as well as for all sites within a very large geographical area can be used to define the actual maximum transmitted power for the corresponding configurations.

EXAMPLE Depending on the specific technology, the measured RF field strength of a stable part of the transmitted signal (e.g. a “control channel”) can be used to determine the corresponding RF field strength for the RBS in the relevant evaluation condition. For example, such extrapolation can be used to estimate the RF field strength if the RBS were to transmit at its maximum output power (i.e. operating at full capacity with all transmit channels engaged at the respective maximum power settings) if that were the requirement for a compliance decision.

B.5.2 Extrapolation to maximum RF field strength using broadband measurements

Only under the following measurement conditions can broadband measurements be accurately extrapolated to determine the maximum RF field strength:

- the EUT parameters at the time of measurement are known (especially the transmitted power);
- there are no significant ambient signals (see B.3.1.2.6); and
- the EUT transmissions are in a single (known) frequency band.

In all other conditions, the extrapolation is not recommended and in any case, the following assumptions are required resulting in an overestimation of the maximum field strength.

a) The EUT (and any relevant ambient signals) are operating at the lowest transmit power – for example, only the time invariant component of the signals is present (see Annex F).
b) Apply the highest extrapolation factor of all active systems in the vicinity of the measurement location.
c) When evaluating the exposure ratio, if the relevant limit is frequency dependent, apply the lowest limit value for the frequency range of the measured RF fields.

The extent of the overestimation shall be considered and reported.

B.5.3 Extrapolation to maximum RF field strength for frequency and code selective measurements

To extrapolate time variant signals to the maximum possible output power conditions, a time invariant component of the signal (e.g. the pilot channel or control channel, see Annex F) shall be evaluated. The ratio between maximum possible signal and the time invariant component of the signal shall be determined based on knowledge of the technology and the specific RBS configuration. This ratio shall be used to determine the extrapolation factor. Examples for some common technologies (e.g. TDMA [GSM, TETRA], WCDMA [UMTS] and OFDM [LTE]) are provided in Annex F.

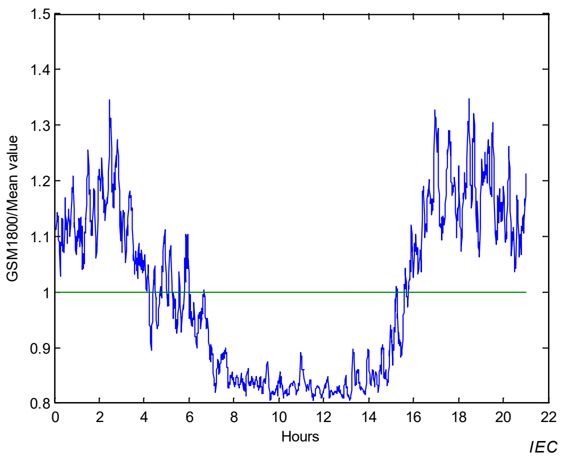
If it is not possible to isolate the RF field strength from the time invariant part of the signal (e.g. pilot channels – see Annex F), then an approach which overestimates the maximum RF field strength shall apply. It shall be based on the established ratio and assume that the evaluated levels (E_{eval}, H_{eval}, and S_{eval}) are only derived from the invariant part of the signal. The uncertainty due to the measurement and the extrapolation shall be estimated and reported.

EXAMPLE Consider the case of a GSM RBS capable of transmitting simultaneously at 10 W on each of four frequencies including the time invariant component (BCCH), i.e. $F_{\mathrm{ext}} = 4$. Consider the case where at the time of measurement the average (temporal) transmitted power $\overline{P}_{\mathrm{avg}}$ was equivalent to 25 W. If the electric field strength of the BCCH can be discriminated then $E_{\mathrm{eval}} = E_{\mathrm{BCCH}}$ and E_{asmt} can be accurately determined from $E_{\mathrm{asmt}} = E_{\mathrm{eval}} \times\sqrt{4}$. If it was not possible to discriminate the electric field strength from the BCCH $E_{\mathrm{eval}} = \sqrt{\frac{25}{10}} E_{\mathrm{BCCH}}$, an extrapolation based on from $E_{\mathrm{asmt}} = E_{\mathrm{eval}} \times\sqrt{4}$ overestimates E_{asmt} by a factor of $\sqrt{\frac{25}{10}}$. The extent of the overestimate is therefore dependent on the ratio $\sqrt{\frac{E_{\mathrm{eval}}}{E_{\mathrm{BCCH}}}}$. Estimation of the overestimate uncertainty depends on knowledge of the probability distribution in time of $\overline{P}_{\mathrm{avg}}$ between, in this case, 10 W and 40 W, i.e. +0 dB to +6 dB assuming no other ambient RF fields.

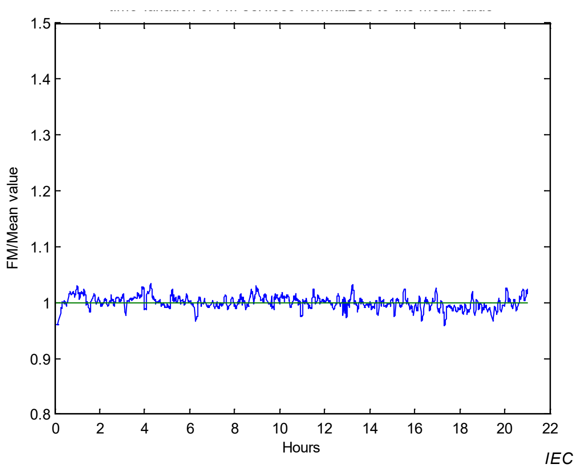
B.5.4 Influence of traffic in real operating network

In many cases this extrapolation can significantly overestimate the actual exposure: Due to different access technique, such as Erlang law, adaptive power control and discontinuous transmission (DTX), the real maximum is well below the theoretical maximum.

The wireless systems are based on different radio access techniques involving communication techniques such as time division multiple access (TDMA), discontinuous transmission (DTX), code division multiple access (CDMA) and adaptive power control (APC), therefore the power emitted by these systems is variable. In case of RF exposure evaluation used for compliance assessment, the measurements or the simulations shall be performed to evaluate the maximum output power level condition (see B.5.1). Nevertheless, these systems rarely if ever transmit at the maximum power. Figure B.29 shows the results for 24 hour measurements at a fixed location using a spectrum analyser and a tri-axes isotropic probe for all the RF services (FM, GSM, etc.).



a) GSM1800 services



b) FM Services

Figure B.29 – Time variation over 24 h of the exposure induced by GSM 1800 MHz (left) and FM (right) both normalized to mean

Figure B.29 shows the time variation of EMF associated with GSM 1 800 MHz and FM (normalized to the mean value over 24 hours). As can be seen, the FM is quite stable but the GSM is variable. Measurements started at 15:00 hrs, the figure shows (as expected) a night exposure smaller than the day exposure, but as can be seen for GSM the difference is below 30 %. The difference between minimum and maximum is less than 2, which is considerably below the theoretical variations (for instance, the ratio is 6 with a mean value of 6 transmitters associated with a "pilot channel"). This is consistent with advanced analysis involving Erlang law, power control and discontinuous transmission.

B.6 Summation of multiple RF fields

B.6.1 Applicability

Summation of RF fields for a combined RF field strength, power density or *SAR* value is required under the following circumstances:

- when the RBS emits RF fields on multiple carrier frequencies and/or on multiple frequency bands;
- when evaluating RF fields from multiple sources.

IEC TR 62630 [63] provides guidance on how to sum these fields depending on whether they are correlated or uncorrelated in time. Correlation in time is relevant since the field summation method and the associated measurement instrumentation depend significantly on field correlation. In particular, fields at distinct frequencies are necessarily uncorrelated in time, as happens in many practical instances featuring sources that operate in different bands (e.g. GSM and Wi-Fi).

B.6.2 Uncorrelated fields

For uncorrelated signals, under the hypotheses made in [63] which are generally met for common wireless communication systems, SAR and power density can be summed algebraically at any point in space according to the following formulas in the case of N field sources producing individual SAR distributions $[SAR_k(x,y,z)]$ or power density distributions $[S_k(x,y,z)]$:

$$SAR_{\mathrm{T}}(x,y,z) = \sum_{k=1}^{N} SAR_k(x,y,z) \tag{B.42}$$

$$S_{\mathrm{T}}(x,y,z) = \sum_{k=1}^{N} S_k(x,y,z) \tag{B.43}$$

NOTE When frequency-dependent power density limits, $S_{\mathrm{lim}}(f)$, apply, as required by some international exposure guidelines, the power density summation can be expressed in terms of exposure ratios:

$$ER_{\mathrm{T}}(x,y,z) = \sum_{k=1}^{N} ER_k(x,y,z) = \sum_{k=1}^{N} \frac{S_k(x,y,z)}{S_{\mathrm{lim}}(f_k)} \tag{B.44}$$

where f_k are the field frequencies and the subscript $_{\mathrm{T}}$ is used to indicate total.

It follows that scalar field probes (e.g. miniature diode-detector dipoles), which are already extensively employed in RF field strength measurements, are also suitable to perform uncorrelated fields summation.

B.6.3 Correlated fields

Correlated fields feature necessarily overlapping frequency bands [63]. The summation of multiple correlated fields involves the vector-sum of the individual fields:

$$\left|e(x,y,z)\right|^2_{\mathrm{r.m.s.}} = \left|\sum_{k=1}^{N} e_k(x,y,z)\right|^2_{\mathrm{r.m.s.}} = \sum_{w=x,y,z} \left|\sum_{k=1}^{N} e_k{}^{w}(x,y,z)\right|^2_{\mathrm{r.m.s.}} \tag{B.45}$$

where $e_k = \hat{x}e_k^x + \hat{y}e_k^y + \hat{z}e_k^z,\ k = 1 \ldots N$ and the caret-symbol indicates a unit vector.

This rigorous approach may increase measurement complexity significantly since vector sensors capable of measuring magnitude and phase of each field component would be required. For this reason, it is desirable to allow the use of widely-available scalar field sensors when summing multiple correlated fields and, therefore, two conservative approaches allowing the use of scalar sensors are introduced in [63].

B.6.4 Ambient fields

The above considerations on field summation apply to known field sources as well as unknown ones producing ambient fields. For ambient fields, often only a little information is available and frequently the ambient fields they produce are at a very low level, with occasional exceptions for example near broadcast stations. Therefore, these fields should be treated as uncorrelated in time relative to other fields.

Annex C
(informative)

Rationale supporting simplified product installation criteria

C.1 General

The product installation classes defined in Table 2 provide simplified criteria to identify when an EUT installation is deemed to comply with ICNIRP exposure limits [12] without further RF exposure assessment in addition to the product compliance results provided by the manufacturer in accordance with the requirements defined in 6.1.

In order to be consistent with IEC 62209-2, the classes defined in Table 2 are also based on the assumption that, when conducting product installation compliance assessments as defined in this document according to 6.2, ambient sources need to be considered only if the EUT has a product compliance boundary larger than 200 mm.

NOTE The scope of IEC 62209-2 corresponds to equipment "intended to be used at a position near the human body, in the manner described by the manufacturer, with the radiating part(s) of the device at distances up to and including 200 mm from a human body". For products within the scope of IEC 62209-2, RF exposure assessment is conducted without considering ambient sources.

C.2 Class E2

For EUT having an *EIRP* equal to 2 W or below, compliance with the exposure limits is generally obtained at zero distance or within a few centimetres. Therefore, it is not required to investigate the contributions of ambient fields and the EUT can be installed according to the manufacturer's instructions based on product compliance results obtained in accordance with 6.1.

As an example, *SAR* measurements using the methodology in this standard for a low power BS with single patch antenna element (G = 5 dBi, *EIRP* = 2 W, f = 2 100 MHz) is provided in Figure C.1. The uncertainty of the measurements is less than 30 % and the *ER* is well below 1.

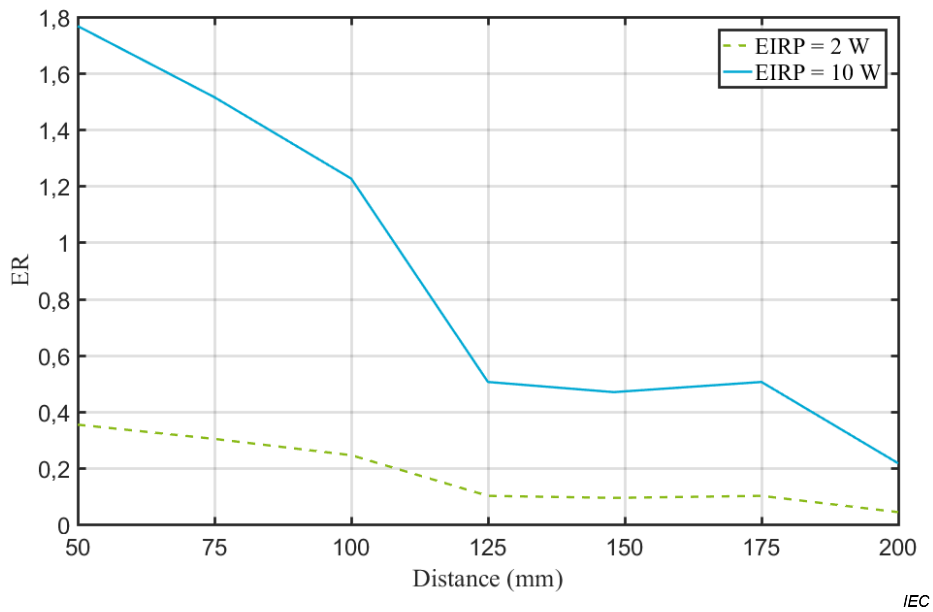


Figure C.1 – Measured *ER* as a function of distance for a low power BS (G = 5 dBi, f = 2 100 MHz) transmitting with an *EIRP* of 2 W (class E2) and 10 W (class E10)

C.3 Class E10

For EUT having an *EIRP* equal to 10 W or below, product compliance distance in the main lobe is typically below 20 cm (see, for example, [36] and Figure C.1. Product installation compliance can be ensured by a requirement on minimum installation height above the public walkway in order to make sure that the general public cannot enter the compliance boundary.

An example of generic assessment is provided in Figure C.2. Assuming a 2 m tall person standing beneath the antenna, the minimum installation height has been assessed using the localized *SAR* estimation formulas for the axial direction in B.4.2.2.3 for a range of transmitted power values between 2 W and 5 W. According to Table 3, localized *SAR* evaluation is the preferred approach for this type of near-field exposure configuration. The following two examples correspond to equipment having an *EIRP* below 10 W and classify as E10:

- EUT transmitted power of 2 W (3 dBW) with an antenna gain below 7 dBi;
- EUT transmitted power of 5 W (7 dBW) with an antenna gain below 3 dBi.

The minimum installation height will vary for different combinations of conducted power and number of antenna elements (related to antenna gain) that are relevant for *SAR* evaluation. Figure C.2 shows that the minimum installation height of 2,2 m defined in Table 2 is conservative.

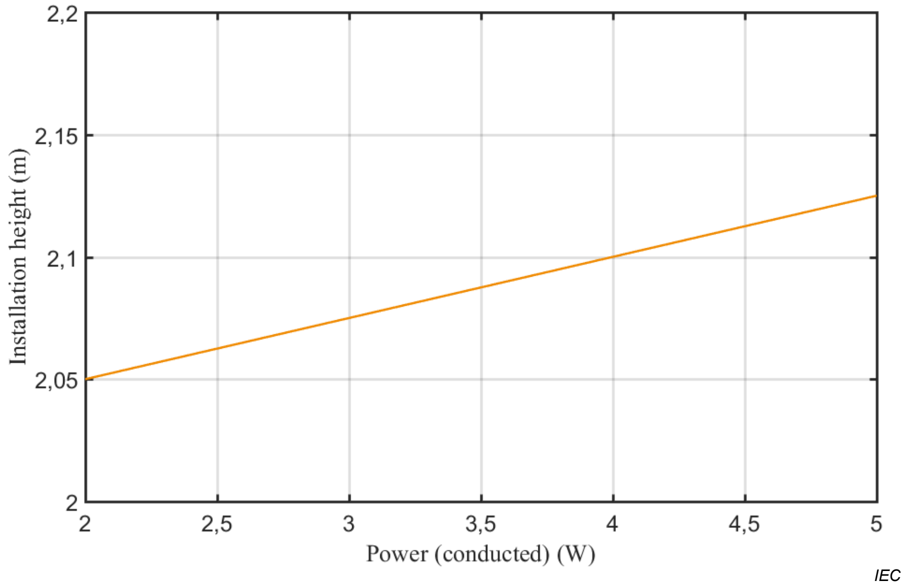


Figure C.2 – Minimum installation height as a function of transmitting power corresponding to class E10

Due to the small compliance distance (below 20 cm), it is not required to investigate the contributions of ambient fields and the EUT can be installed according to the manufacturer's instructions based on product compliance results obtained in accordance with 6.1.

C.4 Class E100

For EUT having an *EIRP* equal to 100 W or below, as shown in Figure C.3, the product compliance distance in the main lobe is typically below 1 m if the frequency is 1 500 MHz or above and 2 m for frequencies down to 400 MHz using Equation (B.16).

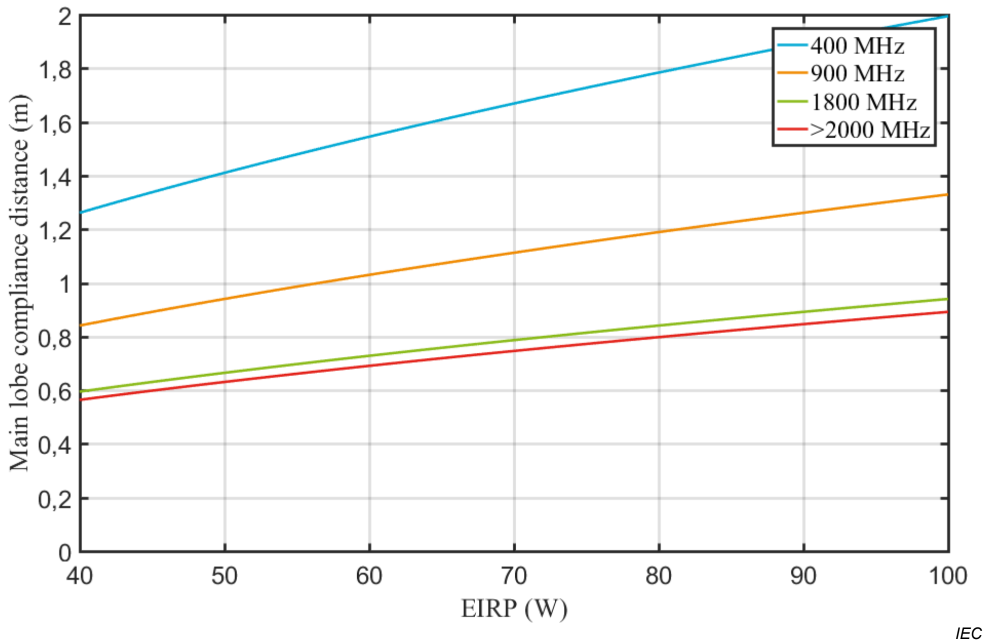


Figure C.3 – Compliance distance in the main lobe as a function of *EIRP* established according to the far-field formula corresponding to class E100

An example of generic assessment is provided in Figure C.4. Assuming a 2 m tall person standing beneath the antenna, the minimum installation height has been assessed using the localized *SAR* estimation formulae in B.4.2.2.3 for a range of transmitted power values between 10 W and 18 W. According to Table 3, localized *SAR* evaluation is the preferred approach for this type of near-field exposure configuration. The following two examples correspond to equipment having an *EIRP* below 100 W and classify as E100:

- EUT transmitted power of 10 W (10 dBW) with an antenna gain below 10 dBi;
- EUT transmitted power of 16 W (12 dBW) with an antenna gain below 8 dBi.

The minimum installation height will vary for different combinations of conductive power and number of antenna elements (related to antenna gain) that are relevant for *SAR* evaluation. Figure C.4 shows that the minimum installation height of 2,5 m defined in Table 2 is conservative.

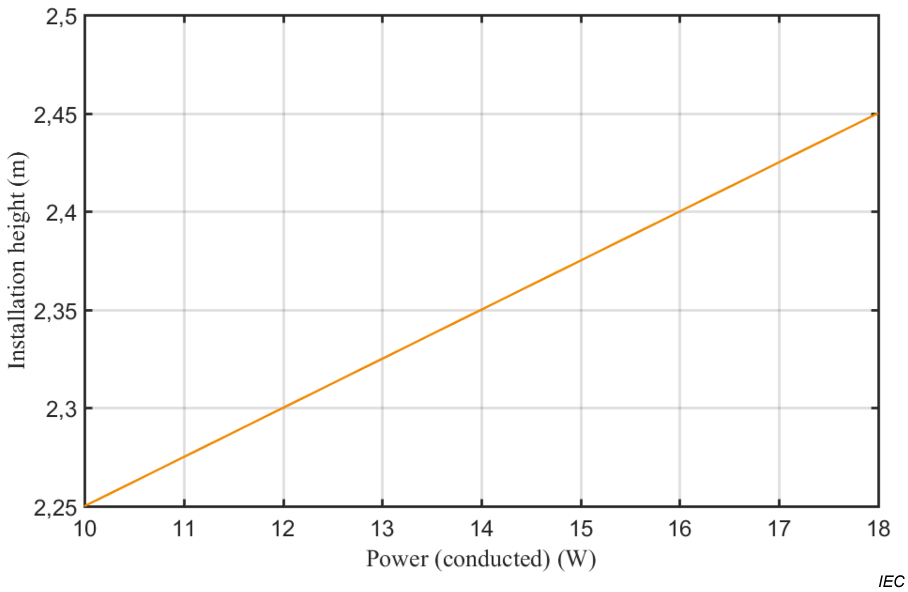
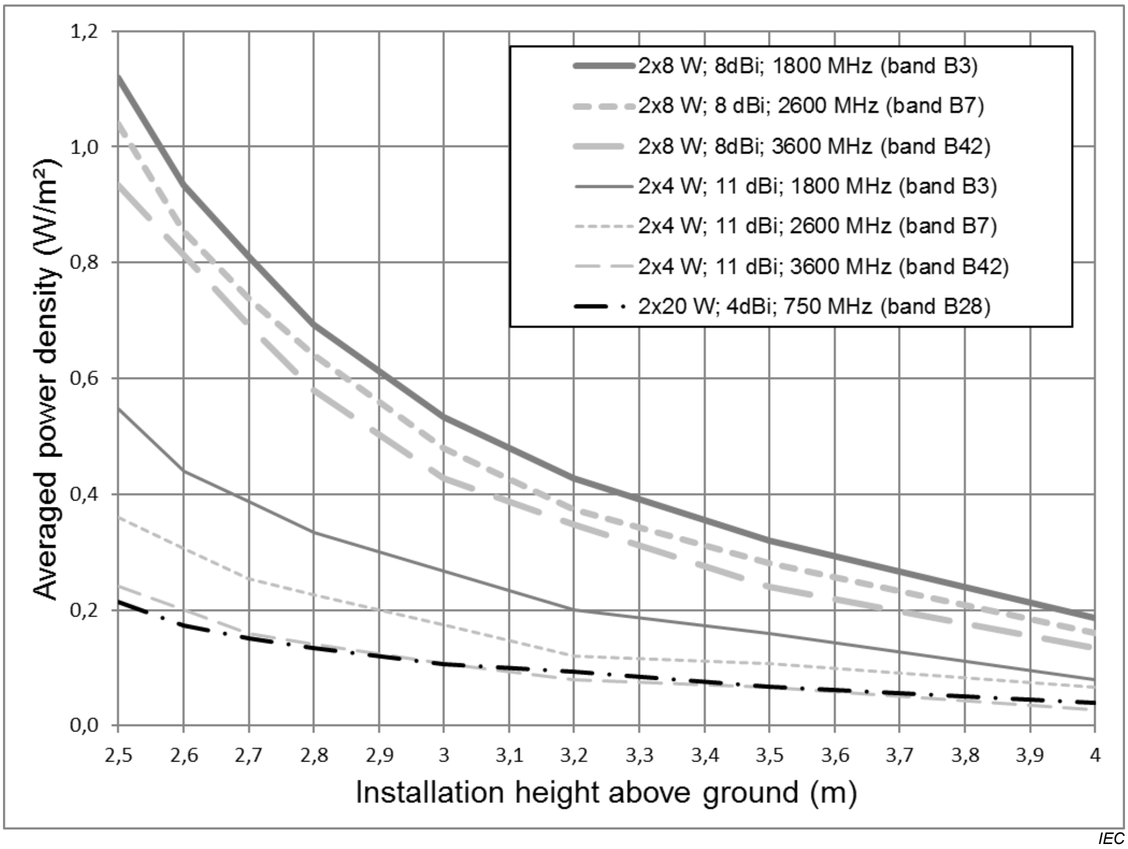


Figure C.4 – Minimum installation height as a function of transmitting power corresponding to class E100

Class E100 EUT can have compliance boundaries (D_m) larger than 200 mm. Therefore, it is necessary to consider effects of possible ambient sources. Taking the approach defined in 6.2.6.5, the ER of the EUT at a distance of 5 D_m is below 0,05 assuming far-field propagation. Therefore, its contribution on pre-existing sources at distances larger than 5 D_m is not significant. For further simplification, according to Figure C.4, D_m can be assumed to be 2 m (general case) or 1 m if the all EUT transmit frequencies are equal to or above 1 500 MHz.

Other generic assessment results are provided in Figure C.5. In this study, the averaged power density at ground level is calculated using the synthetic model methods for seven typical configurations of equipment with 100 W $EIRP$ and transmit frequencies between 700 MHz and 3 600 MHz. The installation height is varying from 2,5 m to 4 m. All configurations correspond to the upper $EIRP$ values of E100 class and the corresponding RF exposure levels are well below ICNIRP limits.



NOTE The Bxx values correspond to the 3GPP bands defined in [9], [10].

Figure C.5 – Averaged power density at ground level for various installation configurations of equipment with 100 W $EIRP$ (class E100)

C.5 Class E+

For EUT having an $EIRP$ above 100 W, there is a large range of product compliance distances in the main lobe and minimum installation heights as shown in Figure C.6 and Figure C.7, which are based on Equations (6.1), (6.2) and (6.3) defined in 6.2.4.

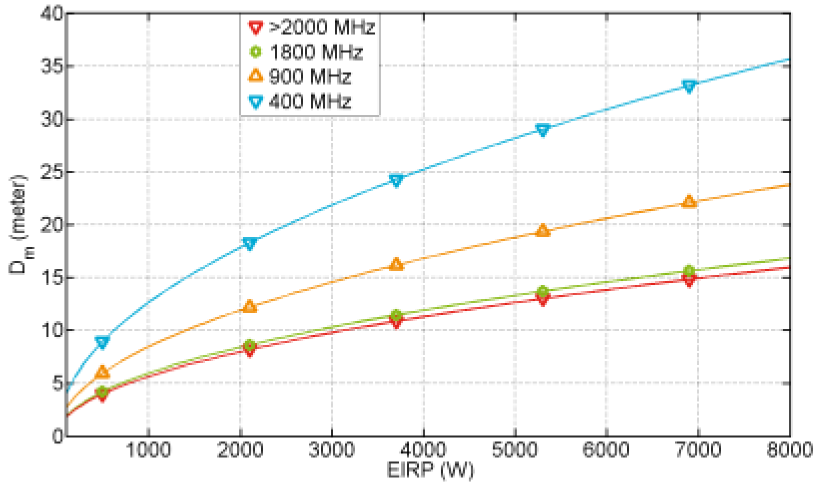


Figure C.6 – Compliance distance in the main lobe as a function of *EIRP* established according to the far-field formula corresponding to class E+

The results of Figure C.7 are based on a conservative choice of antenna parameters: π/12 half-power beamwidth (θ_{bw}), π/12 antenna downtilt (α, electrical and mechanical) and side lobe suppression (A_{sl}) of 0,05. H_m will decrease by decreasing θ_{bw} , α and the side lobe suppression.

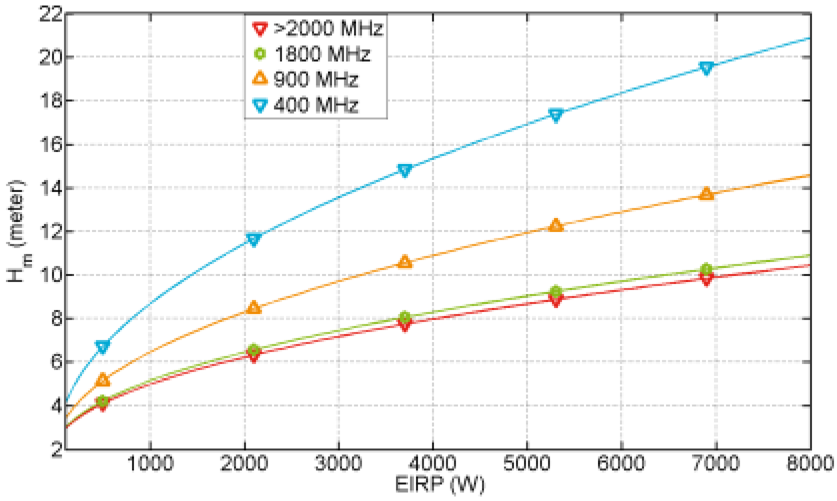


Figure C.7 – Minimum installation height as a function of transmitting power corresponding to class E+

Class E+ EUT can have compliance boundaries (D_m) larger than 200 mm. Therefore, it is necessary to consider effects of possible ambient sources. Taking the approach defined in 6.2.6.5, the ER of the EUT at a distance of 5 D_m is below 0,05 assuming far-field propagation.

Annex D
(informative)

Guidance on comparing evaluated parameters with a limit value

D.1 Overview

The comparison of an evaluated *SAR* or RF field strength against a limit value using a given assessment scheme is discussed in Annex D.

A common purpose of the assessment is to compare the evaluated RF field strength, power density or *SAR*, known as the exposure metric, with a limit value. An evaluation provides an RF field strength, power density or *SAR* value coupled with uncertainty information; the latter provides an understanding of the probabilities for the real value being above or below the evaluated value.

Assessment schemes define how to interpret the results of an evaluation as being above or below a given limit value. For more information, see E.4.

D.2 Information required to compare evaluated value against limit value

Depending on the specific case, certain information is required to make a valid comparison between the evaluated value and a limit value. The required information includes the following:

a) evaluated value;
b) evaluation and assessment configurations;
c) uncertainty information:
    1) the confidence level of the evaluated value (e.g. “best estimate”, “upper 95 %”),
    2) the offset to the confidence level required by the assessment scheme;
d) assessment scheme to be applied (E.4):
    1) limit value,
    2) comparator offset,
    3) reference exposure metric confidence level,
    4) target uncertainty,
    5) comparator confidence level.

D.3 Performing a limit comparison at a given confidence level

The confidence level may be specified either as confidence that the true level is below the limit or above the limit. This circumstance is known as an “outcome” based assessment scheme.

In the absence of a specific assessment scheme process (see Annex E), this procedure shall apply for:

– establishing a compliance boundary with given confidence;
– evaluating a field strength / *SAR* to establish if the true value is below the limit value with given confidence;
– evaluating a field strength / *SAR* to establish if the true value is above the limit value with given confidence.

The following steps apply.

a) Extrapolation: Use the evaluation configuration and assessment configuration information to establish the extrapolation factor (see B.5.1). Apply the factor to the evaluated value.
b) Uncertainty evaluation: Establish the confidence level of the extrapolated value. Express the expanded uncertainty in single sided confidence form. Select either
   - confidence that the true value is below the exposure metric, or
   - confidence that the true value is above the exposure metric according to the assessment scheme.
c) Normalize confidence level:
   - If the confidence level required for the compliance boundary is the same as that of the extrapolated value, normalization is not required.
   - Otherwise, additional uncertainty analysis is required to establish the comparator offset value; for example, if it is required that there is 97,5 % confidence that the true value at the boundary is below the limit value, then the upper 95 % extrapolated value is required. If the extrapolated value is a "best estimate", then the difference between the best estimate and upper 95 % is the comparator offset to be added to the extrapolated value.
d) Compare with limit: The normalized extrapolated value is then compared to the limit value.

NOTE If the evaluation method only provides a "conservative" exposure metric value and it is not possible to determine a "best estimate" value, then normalization is not possible. In such a case, if the extrapolated value is below the relevant limit then there is confidence (approximately equal to the conservativeness) that the true value is also below the limit. However, if the measured value is above the limit, it is unclear whether the true value is likely to be above or below the limit. For more information see D.4.

D.4 Performing a limit comparison using a process based assessment scheme

The following procedure applies for process based assessment schemes (see E.4).

a) Extrapolation: Use the evaluation configuration and assessment configuration information to establish the extrapolation factor (see B.5.1). Apply the factor to the evaluated value to give the extrapolated value.
b) Uncertainty evaluation: Establish the confidence level of the extrapolated value. Express the expanded uncertainty in single sided confidence form. Select either
   - confidence that the true value is below the exposure metric, or
   - confidence that the true value is above the exposure metric according to assessment scheme.
c) Normalize extrapolated value to the reference exposure metric confidence level defined by the assessment scheme:
   - If the exposure metric value is expressed at the same confidence level (e.g. best estimate or 50 %) as required by the assessment scheme, then no additional offset is required.
   - If the exposure metric is expressed at a different confidence level, then a normalization offset is required to be added or subtracted. It shall be equal to the difference between the exposure metric value and the value at the reference confidence level. This approach yields a normalized extrapolated value.
d) Establish the constraint offset: The assessment scheme (see Annex E) may require a further offset depending on a range of considerations for example, depending on the uncertainty of the evaluation.
e) Compare with limit: The normalized extrapolated value with constraint offset is then compared to the limit value.

Guidance on uncertainty and assessment schemes is provided in Clause 9 and E.4.

Annex E
(informative)

Uncertainty

E.1 Background

Annex E provides a background on uncertainty and the elements that contribute to the uncertainty associated with RF evaluations. No matter how carefully performed every measurement or calculation of RF field strength, power density or *SAR*, a certain amount of random error will exist. With careful analysis, the bounds of this error can be statistically quantified and presented as an uncertainty estimate. Providing uncertainty estimates for an evaluation gives a measure of its quality and engenders confidence in its reliability.

Annex E also specifies a target uncertainty value to improve the quality of the exposure evaluation taking into account the uncertainty of the measurement equipment and variability of the RF field (e.g. fast fading).

Providing uncertainty estimates is particularly important when determining compliance with exposure limits. Uncertainty estimates should be performed in accordance with the recommendations of JCGM 100:2008 [18].

Some additional material that may assist in understanding and implementing uncertainty estimates are [64] to [65]. This is not a complete list and it is recommended other sources are investigated as applicable.

Whenever a continuous physical quantity is measured or calculated, the result of the evaluation will differ from the true value by an amount termed an “error”. In general, the actual error value is unknown but it may be assumed it comes from a probability distribution characterized by parameters (e.g. the standard deviation of a normal distribution) which may be known or estimated. JCGM 100:2008 defines the term “uncertainty” as “the parameter associated with the result that characterizes the dispersion of values that could reasonably be attributed to the exposure metric.”

Uncertainty analysis of RF evaluations serves to “qualify” the validity of the evaluation and is necessary for determining the degree of confidence with which a limit has been complied with, or whether an observed change in a quantity (e.g. over time or as a consequence of some engineering change) is truly significant. Uncertainty estimates also allow the meaningful comparison of results from different methodologies and help to identify and therefore minimize sources of error.

NOTE For example, a cautious motorist can travel slightly slower than the prevailing speed limit in order to account for an uncertain error in his speedometer. Conversely, when adjudicating on speeding infringements, it is common practice to allow slightly higher speeds than the allowable limit in order to account for an overestimation of the motorist’s speed from a police radar or speed camera.

E.2 Requirement to estimate uncertainty

Where an evaluation method is designed to provide only a “conservative” value, the sources of uncertainty shall be recorded and evaluated to the extent required to demonstrate that the relevant uncertainty constraints have been met.

Otherwise, uncertainty shall be estimated for every measured and calculated RF field strength, power density or *SAR* evaluation performed sufficient to provide the relevant data according to the relevant assessment scheme (see E.4.3).

NOTE Typically for measurements, the uncertainty estimate will specify the best (i.e. most likely) estimate of the exposure metric value, as well as the upper and lower uncertainty bounds for a 95 % confidence interval (CI) of the evaluation e.g. ±3 dB.

E.3 How to estimate uncertainty

In general, the estimation of uncertainty will entail the following four tasks:

- identification of all of the sources of uncertainty (i.e. influence quantities) that may reasonably be expected to cause significant variation or uncertainty in the evaluation;
- for each source of uncertainty, an estimation of the probability distribution type and parameter;
- specification of how the sources of uncertainty are combined to provide a total uncertainty value (i.e. a mathematical model which defines how the influence quantities are combined or added);
- determination of the best estimate of the evaluation and expanded uncertainty for a 95 % confidence interval (CI).

NOTE Depending upon the assessment scheme (see E.4) employed, the best estimate can not be the appropriate comparator value.

There are many good published references on how to estimate uncertainty, including JCGM 100:2008 [18].

E.4 Guidance on uncertainty and assessment schemes

E.4.1 General

E.4 provides guidance on how assessment schemes affect the interpretation of the results of an evaluation as being above or below a given limit value.

Important concepts such as comparator offset, reference exposure metric confidence level, and target uncertainty are explained.

The assessment scheme may be specified by regulation, inferred from regulatory statements, or specified by the customer requesting the evaluation. For circumstances where the assessment scheme is not specified, the best estimate method is recommended as a default process based assessment scheme (see A.3.4 and Figure E.1).

E.4.2 Overview of assessment schemes

Evaluations include a unique value (exposure metric) for the RF field strength / *SAR* along with an uncertainty distribution. This uncertainty distribution provides information on the probability of the true value being above or below the exposure metric value. It is the assessment scheme which defines the rules and constraints to be applied to the exposure metric and uncertainty distribution; the application of these rules allows for a determination to be made as to whether the RF field strength / *SAR* levels are deemed to be above or below a given limit value.

The assessment schemes may be characterized as either “process” or “outcome” based. The detailed evaluation procedures and constraints that define each type of scheme are subtly different, as explained below.

- An “outcome” based assessment scheme aims to provide a given confidence that the ‘true value’ is below the limit. In this case the uncertainty for the evaluation can be used to determine the offset (see Figure E.2), which relate to that given confidence, required to add/subtract from the exposure metric before comparison with the limit.

- A “process” based assessment defines the decision process. In this case, the requirement is to specify conditions for the evaluated value (e.g. best estimate, target uncertainty) with further rules for an offset to be applied before comparing with the limit value.

NOTE Some evaluation methods can only provide a “conservative” value of the exposure metric. In this case, and provided any constraints in the methodology are met, there is a (defined) high confidence that the true value of the *SAR*/field parameter is lower than the exposure metric.

The assessment scheme used should consider a range of factors; these include the following.

a) Assessment configuration: This is the specification of the RBS parameters to be used when evaluating compliance. These parameters may include transmit power, antenna gain, distance/orientation from antenna, etc. They may be stated or derived in association with the actual parameters used in the extrapolation component of the evaluation method (see B.5.1 and Annex F).

b) Limit value: the constraint which defines the RF field strength, power density or *SAR* value against which the comparison is to be made.

c) Comparator offset: a factor used to increase or decrease the evaluated value before comparison with the limit value. This may be a constrained fixed value or a determined value. The latter may be influenced by process or the comparison between the uncertainty and target values.

d) Reference exposure metric confidence level: This process based constraint defines the required confidence of the exposure metric value to be used prior to application of any comparator offset; e.g. upper 95 %, best estimate.

e) Target uncertainty: This is an example process based constraint which specifies a decision level (e.g. ±4 dB uncertainties at 95 % confidence) for the evaluation uncertainty. The estimated evaluation uncertainty may be compared with this decision level. The process-based decision rules will then dictate the operations based on the result; for example, “allow use of best estimate else apply comparator offset”.

f) Comparator confidence level: This is the main outcome based constraint. It specifies the required confidence of the comparator value to be used in comparison with the limit value. Examples are:

   1) 95 % confidence that limit value not exceeded;

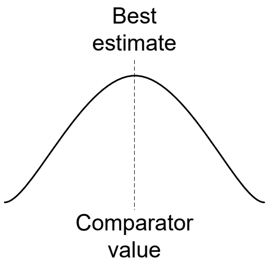
   2) 95 % confidence that limit value is exceeded;

   3) 50 % confidence that limit is or is not exceeded.

E.4.3 Examples of assessment schemes

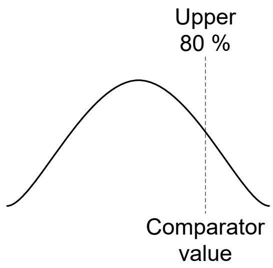
E.4.3.1 Examples of general assessment schemes

Assessment schemes can be defined by a number of factors. In E.4.3, target uncertainty assessment schemes, process flow and target values are explained. Assessment of compliance against a limit, and confidence that the limit is exceeded, are both discussed with accompanying examples. Figure E.1 presents a number of examples of general assessment schemes. These are illustrated in process based form since the definition is related to the exposure metric. Guidance also clarifies the circumstance where the assessment scheme may be expressed using an outcome based constraint.



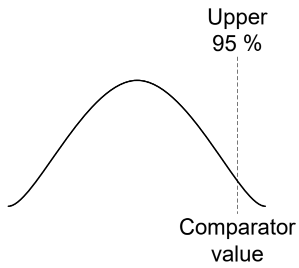
Example a. Surveyor uses the best estimate value to compare with the limit.

Equivalent to constraining comparator level to be 50 % confident that true value is above or below comparator value



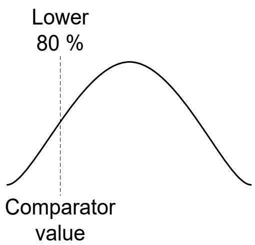
Example b. Surveyor uses upper 80 % CI value to compare with the limit.

Equivalent to constraining comparator level to be 90 % confident that true value is below comparator value.



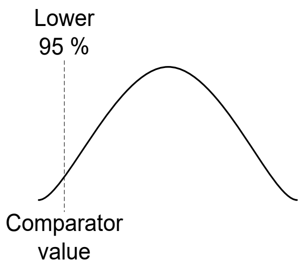
Example c. Surveyor uses upper 95 % CI value to compare with the limit.

Equivalent to constraining comparator level to be 97,5 % confident that true value is below comparator value.



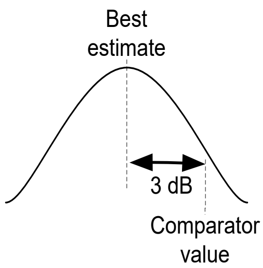
Example d. Surveyor uses lower 80 % CI value to compare with the limit.

Equivalent to constraining comparator level to be 90 % confident that true value exceeds comparator value.



Example e. Surveyor uses lower 95 % CI value to compare with the limit.

Equivalent to constraining comparator level to be 97,5 % confident that true value exceeds comparator value.



Example f. Surveyor adds arbitrary 3 dB to best estimate value to compare with the limit.

Confidence that true value exceeds comparator depends on the evaluation uncertainty.

Figure E.1 – Examples of general assessment schemes

E.4.3.2 Example target uncertainty based assessment scheme

E.4.3.2.1 Target uncertainty assessment scheme principles

Target uncertainty describes the maximum range for uncertainty for a given evaluation type. The accuracy of an evaluation may be questioned when the target uncertainty cannot be achieved.

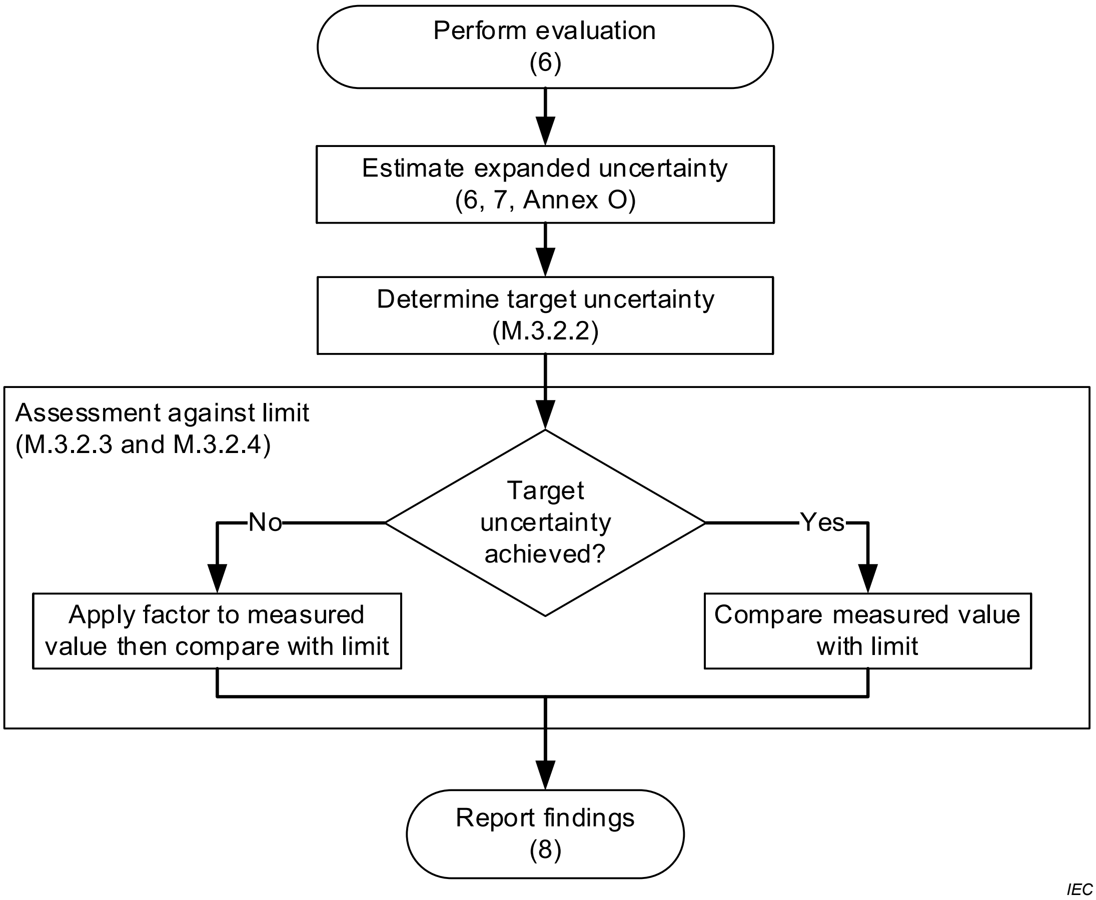
The following principles relating to assessment schemes and the associated target uncertainty apply.

– Where the expanded uncertainty of the evaluation is within a defined “target uncertainty”, then the exposure metric shall be compared with the relevant limit.

– Where the expanded uncertainty of the evaluation is outside of a defined “target uncertainty”, then the measured value is subject to a comparator offset and the corrected value compared with the relevant limit.

Figure E.2 presents an overview of the target uncertainty scheme process.

NOTE Generic standard IEC 62311 describes an alternative target based assessment scheme using a linear uncertainty model.



NOTE Numbers in parentheses refer to (sub)clauses of this document.

Figure E.2 – Target uncertainty scheme overview

E.4.3.2.2 Determining the target uncertainty

Target uncertainty varies based on the exposure metric parameter and evaluation purpose. Table E.1 provides recommended target uncertainty values according to the evaluation purpose and the exposure metric parameter.

Table E.1 – Determining target uncertainty

Evaluation purpose (see Clause 6)	**Exposure metric parameter**	**Target uncertainty[a,b]**
Establishing with confidence that a limit is not exceeded, or Information on maximum value (e.g. compliance boundary assessment)	SAR	+1,2 dB
	S	+4 dB
	E or H	+4 dB
Establishing with confidence that a limit is exceeded, or Information on minimum value (e.g. potential overexposure investigation)	SAR	-1,5 dB
	S	-4 dB
	E or H	-4 dB

NOTE This table is under the assumption that the logarithmic expression of the measured quantities can be similarly treated to that of the linear expression in view of statistical properties.

[a] The target uncertainty constraint can be specified in one direction depending on the evaluation purpose.

[b] The values here are representative values based on the experience of the members of the project team developing this document.

E.4.3.2.3 Assessment of compliance with an exposure limit

E.4.3.2.3.1 Overview

The intent of assessments of compliance with an exposure limit is to arrive at a determination of whether the evaluation is equal to or below the specified limit. This method is explained by way of a practical example for two target uncertainty values.

E.4.3.2.3.2 Method

When conducting an RF evaluation (measured or computed) to assess compliance with a specified limit the expanded uncertainty shall be determined. To estimate the expanded uncertainty the following steps shall be followed:

a) Determine the applicable target uncertainty.

b) Compare the expanded uncertainty to the target (maximum) value and recommended value.

c) If the expanded uncertainty is compliant then compare the evaluation comparator level to the specified limit. The evaluation indicates the limit is not exceeded if the evaluation comparator level is equal to or less than the specified limit.

E.4.4 Assessment schemes and compliance probabilities

E.4.4.1 Assessment scheme uncertainty and compliance probabilities overview

This clause and indeed this document detail a number of potential assessment schemes. The surveyor may have the flexibility to choose which assessment scheme to apply or they may be constrained by regulation. In either case, it is useful to understand the consequences of the assessment scheme and measurement uncertainty on the compliance probability, in particular where an initial on-the-limit determination by the surveyor is re-evaluated by an auditor.

The combination of uncertainties and assessment schemes in both surveyor (e.g. operator) and auditor (e.g. regulator) RF evaluations creates the possibility of the following important compliance verification events.

a) Non-compliance determination: auditor finds that RF field strength, power density or SAR at surveyor's compliance boundary is non-compliant with the relevant exposure limit.

b) Compliance error: auditor decides that RF field strength, power density or SAR at the surveyor's compliance boundary is compliant with the relevant exposure limit when it really is not.

c) Non-compliance error: auditor decides that the RF field strength, power density or SAR at the surveyor's compliance boundary is non-compliant with the relevant exposure limit when it really is compliant.

E.4.4.2 Monte Carlo simulation of target uncertainty based assessment scheme

An effective mechanism for quantifying statistical probability is known as Monte Carlo simulation. The probabilities for the three compliance verification events of E.4.4.1 can be easily and robustly calculated using a Monte Carlo approach. Random outcomes for both surveyor (e.g. operator's) and auditor's (e.g. regulator's) RF field strength, power density or SAR evaluations are generated from the probability distributions of their uncertainties. Then they can be tested for the three events above in accordance with the example assessment schemes used by surveyor and auditor. This process is repeated for a large number of trials (e.g. 10 000) allowing an estimate of event probabilities by simply dividing the number of event occurrences by the total number of trials.Table E.2, Table E.3 and Table E.4 show the consequences of two independent evaluations of the same limit situation. In each case the surveyor has determined a location where he finds the level to be just compliant with the limit. The level is evaluated by the auditor at the same location and the probabilities of the compliance verification events tabulated for various evaluation uncertainties by the surveyor and the auditor respectively.

Table E.2 shows the results of a Monte Carlo simulation of 10 000 trials where both the surveyor and the auditor apply the best estimate assessment scheme.

Table E.2 – Monte Carlo simulation of 10 000 trials, both surveyor and auditor using best estimate

Expanded uncertainty of surveyor's evaluations for 95 % CI	Probability of non-compliance determination			Probability of compliance error			Probability of non-compliance error		
	Expanded uncertainty of auditor's evaluations for 95 % CI								
	1 dB	**3 dB**	**5 dB**	**1 dB**	**3 dB**	**5 dB**	**1 dB**	**3 dB**	**5 dB**
1 dB	50 %	50 %	50 %	12 %	19 %	23 %	13 %	20 %	21 %
	0 dB	0 dB	0 dB						
3 dB	50 %	50 %	50 %	5 %	12 %	16 %	5 %	12 %	16 %
	0 dB	0 dB	0 dB						
5 dB	50 %	50 %	50 %	3 %	9 %	13 %	3 %	9 %	13 %
	0 dB	0 dB	0 dB						
	Probability of auditor deciding non-compliance. NOTE dB numbers indicate the penalty factor applied to compliance boundary.			Probability that the auditor decides that the surveyor's compliance boundary is compliant with the relevant exposure limit when it really is not.			Probability that the auditor decides that the surveyor's compliance boundary is non-compliant with the relevant exposure limit when it really is compliant.		

Table E.3 shows the results of a Monte Carlo simulation of 10 000 trials where both the surveyor and the auditor use a target uncertainty assessment scheme (see E.4.3.2) with a target uncertainty of 4 dB. The surveyor assesses compliance with the limit (see E.4.3.2.3) whilst the auditor assesses exceedance of limit.

Table E.3 – Monte Carlo simulation of 10 000 trials, both surveyor and auditor using target uncertainty of 4 dB

Expanded uncertainty of surveyor's evaluations for 95 % CI	Probability of non-compliance determination			Probability of compliance error			Probability of non-compliance error		
	Expanded uncertainty of auditor's evaluations for 95 % CI								
	1 dB	**3 dB**	**5 dB**	**1 dB**	**3 dB**	**5 dB**	**1 dB**	**3 dB**	**5 dB**
1 dB	50 %	50 %	35 %	13 %	20 %	30 %	12 %	20 %	15 %
	0 dB	0 dB	0 dB						
3 dB	50 %	50 %	36 %	5 %	12 %	23 %	5 %	12 %	10 %
	0 dB	0 dB	0 dB						
5 dB	34 %	36 %	29 %	3 %	7 %	15 %	3 %	9 %	9 %
	1 dB	1 dB	1 dB						
	Probability of auditor deciding non-compliance. NOTE dB numbers indicate the penalty factor applied to compliance boundary.			Probability that the auditor decides that the surveyor's compliance boundary is compliant with the relevant exposure limit when it really is not.			Probability that the auditor decides that the surveyor's compliance boundary is non-compliant with the relevant exposure limit when it really is compliant.		

Table E.4 shows the results of a Monte Carlo simulation of 10 000 trials where the surveyor uses the upper 95 % CI value Figure E.1 example c, and auditor uses the lower 95 % CI value Figure E.1 example e.

Table E.4 – Monte Carlo simulation of 10 000 trials surveyor uses upper 95 % CI vs. auditor uses lower 95 % CI

Expanded uncertainty of surveyor's evaluations for 95 % CI	Probability of non-compliance determination			Probability of compliance error			Probability of non-compliance error		
	Expanded uncertainty of auditor's evaluations for 95 % CI								
	1 dB	**3 dB**	**5 dB**	**1 dB**	**3 dB**	**5 dB**	**1 dB**	**3 dB**	**5 dB**
1 dB	0 %	1 %	1 %	2 %	3 %	3 %	0 %	1 %	1 %
	1 dB	1 dB	1 dB						
3 dB	0 %	0 %	0 %	2 %	3 %	2 %	0 %	0 %	0 %
	3 dB	3 dB	3 dB						
5 dB	1 %	1 %	0 %	1 %	2 %	2 %	0 %	0 %	0 %
	5 dB	5 dB	5 dB						
	Probability of auditor deciding non-compliance. NOTE dB numbers indicate the penalty factor applied to compliance boundary.			Probability that the auditor decides that the surveyor's compliance boundary is compliant with the relevant exposure limit when it really is not.			Probability that the auditor decides that the surveyor's compliance boundary is non-compliant with the relevant exposure limit when it really is compliant.		

E.4.4.3 Compliance error probability simulation

A range of example simulations for assessment schemes used by a surveyor and auditor are provided in spreadsheets in the supplementary file "IEC 62232 Compliance error probabilities.xls":

IEC 62232
Compliance error prol

For various evaluation options used by the operator and auditor, this spreadsheet calculates the probability that:

a) the auditor will find that RF field strength, power density or *SAR* level at the surveyor's compliance boundary is non-compliant with the relevant exposure limit;

b) the auditor commits a compliance error – i.e. the auditor decides that the RF field strength, power density or *SAR* levels at the operator's compliance boundary is compliant with the relevant exposure limit when it really is not;

c) the auditor commits a non-compliance error – i.e. the auditor decides that the RF field strength, power density or *SAR* level at the operator's compliance boundary is non-compliant with the relevant exposure limit when it really is compliant.

The probabilities for the three events listed above will depend on how the surveyor uses their evaluations to determine a compliance boundary and how the auditor uses their evaluations to assess compliance. They will also vary according to the quality of the surveyor and auditor evaluations which can be quantified by the expanded uncertainties of their evaluations.

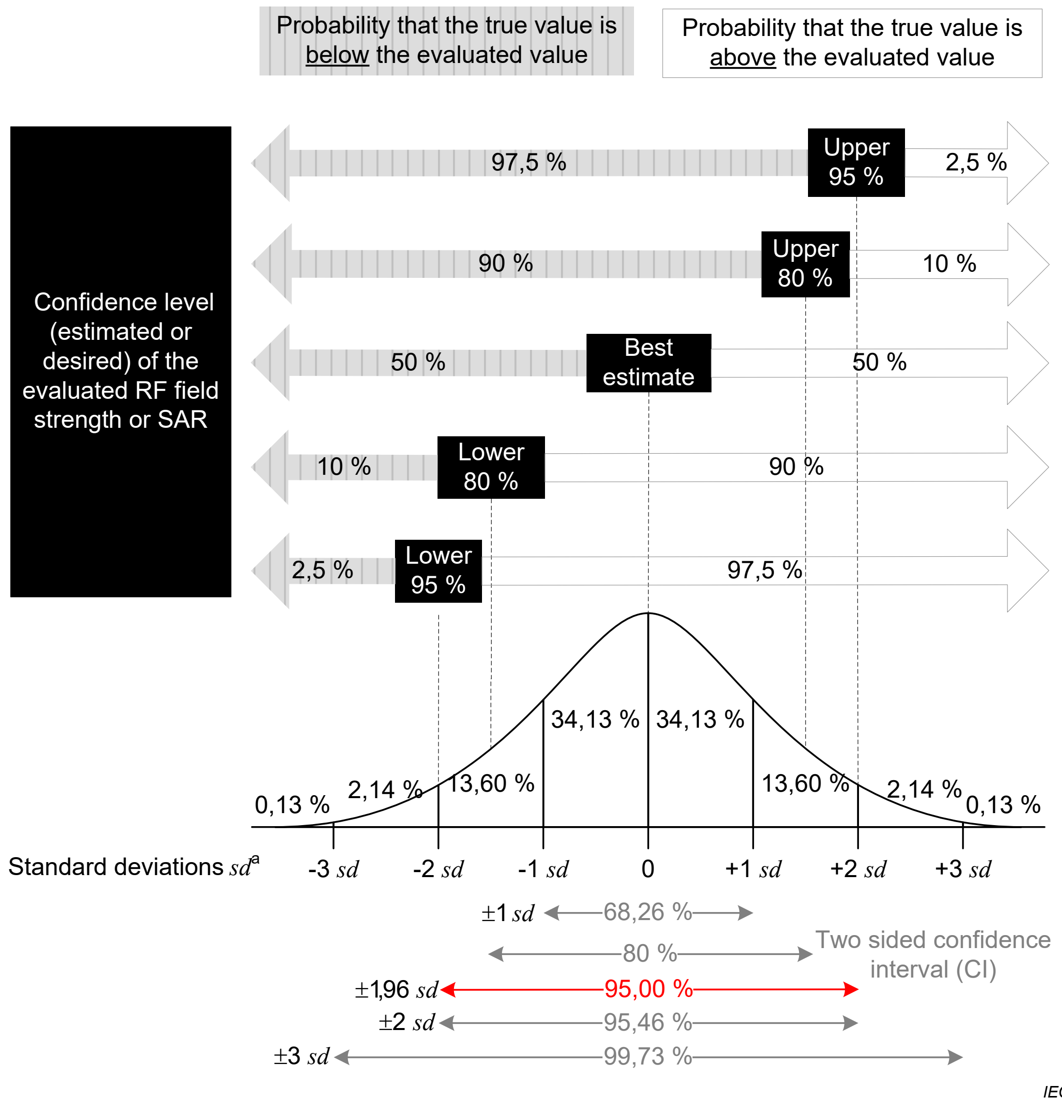
E.5 Guidance on uncertainty

E.5.1 Overview

In E.5 the specific instance of measurement uncertainty and confidence intervals is discussed; with a graphic of probability of true value being above or below the elevated value.

E.5.2 Measurement uncertainty and confidence levels

Figure E.3 illustrates the probability of the true value either being above or below the evaluated value depending on the confidence level for the exposure metric assuming the uncertainty is normally distributed.



[a] To apply this in an assessment scheme (see E.4, the x-axis can be expressed in dB or % depending on the selected uncertainty model and the specific evaluation.

Figure E.3 – Probability of the true value being above (respectively below) the evaluated value depending on the confidence level assuming a normal distribution

Similar diagrams to Figure E.3 can be prepared for different uncertainty distributions. Depending on the evaluation method, the evaluated RF field strength / *SAR* value may be for example:

a) the best estimate – i.e. with equal probability of the real value being above or below the evaluated value;

b) upper 95 % or upper 80 % an overestimate – i.e. with greater probability of the real value being below the evaluated value than above it;

c) lower 95 % or lower 80 % an underestimate – i.e. with greater probability of the real value being above the evaluated value than below it.

EXAMPLE Consider the case where the “Best estimate” RF field strength is measured to be 2 W/m^2 with an expanded uncertainty U (for a 95 % two sided confidence interval) estimated to be 3 dB (i.e. on Figure E.3 -1,96 sd corresponds to -3 dB and +1,96 sd corresponds to +3 dB). This means that there is an equal probability that the true value is above or below 2 W/m^2. Using Figure E.3 the corresponding “Upper 95 %” value will be 3 dB above 2 W/m^2, i.e. 4 W/m^2 – meaning that there is a 97,5 % probability that the true value is below 4 W/m^2. The corresponding “Lower 95 %” value will be 3 dB below 2 W/m^2, i.e. 1 W/m^2 – meaning that there is a 97,5 % probability that the true value is above 1 W/m^2.

E.6 Applying uncertainty for compliance assessments

There are many ways to use uncertainty when determining or checking compliance of an evaluated RF field strength, power density or *SAR* within the relevant limit. Commonly, two approaches are used to deal with uncertainty (see Figure E.3); they are:

– shared risk approach, where the best estimate value is compared to the relevant limit and the expanded uncertainty shall not exceed a defined maximum value; and,

– conservative approach, where the upper 95 % confidence value is compared to the relevant limit.

In both cases, the expanded uncertainty is commonly estimated for a confidence interval of 95 %.

To understand the likelihood of agreement between the decisions of two independent compliance determinations, it is necessary to consider how uncertainty is addressed for each determination.

NOTE For example, a surveyor might use the 95 % CI upper bound of his evaluation when setting a compliance boundary, and conversely a second surveyor, auditing the original evaluation, might use the lower 95 % CI bound when checking compliance at the surveyor's boundary. Alternatively, the surveyor and auditor may both simply apply the best estimates of their evaluations.

This document recognizes that the specification of the assessment scheme is a matter that rests with the relevant regulatory authority or client. However, in choosing an appropriate assessment scheme, it is recommended that due consideration is given to the following questions.

a) What is the probability of a non-compliance determination, i.e. an auditor finds that the RF field strength, power density or *SAR* at the surveyor's compliance boundary is non-compliant with the relevant limit?

b) What is the probability of a compliance error, i.e. an auditor decides that a surveyor's compliance boundary is compliant with the relevant limit when it really is not?

c) What is the probability of a non-compliance error, i.e. an auditor decides that the surveyor's compliance boundary is non-compliant with the relevant limit when it really is compliant?

d) What is the penalty factor to be applied when comparing the evaluation with the relevant exposure limit?

More information on uncertainty and assessment schemes is provided in Clause 9 and E.4, which provides guidance on the application of assessment schemes for determining compliance within a limit.

E.7 Example influence quantities for field measurements

E.7.1 General

The uncertainty effect of the following influence quantities should normally be made insignificant by selection of appropriate instrumentation and good measurement technique:

- lead pick-up;
- direct pick-up;
- coupling into probes;

- static charge fields;
- out of band responses;
- zero drift;
- detector modulation response.

If, however, any of these influence quantities is suspected to cause significant uncertainty and/or correction, then its influence should be estimated and combined with the influence quantities in E.7.2 to E.7.23.

E.7.2 Calibration uncertainty of measurement antenna or field probe

The calibration of an E or H measurement antenna or field probe is affected by the uncertainty in the reference field level used for the calibration. This is usually specified in the calibration report as an uncertainty, U, for a 95 % two sided confidence interval where d in this case is 1,96 (≈ 2).

The standard uncertainty u for calibration can be determined by dividing U by the divisor d.

It is important to note that calibrations are generally performed under specified standard conditions. For example, these conditions might be:

- the calibration was performed at discrete (spot) frequencies ranging from 10 MHz to 8 000 MHz;
- the calibration was performed at a particular field intensity;
- the ambient temperature was 20,5 °C;
- the meter reading was taken at the average point of the probe's isotropic response;
- the reference field was an unmodulated continuous wave (CW).

This information sets a benchmark reference when considering the added uncertainties and corrections for other sources of variation such as frequency response, probe linearity with field intensity, temperature response, probe isotropy, and response to field modulations.

E.7.3 Frequency response of the measurement antenna or field probe

For electric field and magnetic field probes, calibration reports typically provide a correction factor at discrete calibration frequencies which shall be multiplied by the field meter reading to obtain the best estimate of the field level, F. When interpreting calibration charts, it is important to know whether the calibration factors apply to the field level (i.e. E or H) or to the square of the field (E^2, H^2 or S_{eq}).

In the example calibration chart shown in Figure E.4, the calibration report indicates a correction factor of 0,88 for E at the frequency of 2 450 MHz. In this case, the true electric field strength reading is the meter reading multiplied by 0,88 (calibration factor for this example).

For estimates of E^2 or S_{eq}, the meter reading shall be multiplied by the square of the calibration factor (i.e. $0{,}88^2$ in this example) to obtain the true reading.

In most cases, the measurement frequency will not exactly coincide with one of the calibration frequencies. Recommended practices are provided below for three such scenarios, with reference to Figure E.4 as an example.

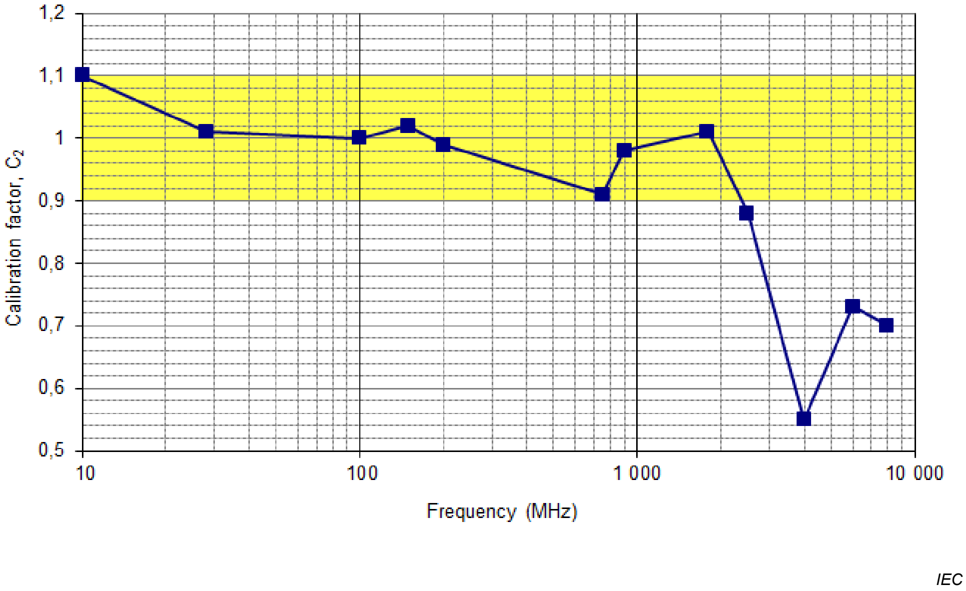


Figure E.4 – Plot of the calibration factors for E (not E^2) provided from an example calibration report for an electric field probe

In Figure E.4, the yellow zone depicts the extent of calibration factors that are within ±10 % of 1.

a) Scenario 1 – The measurement frequency does not coincide with any of the calibration frequencies provided in the calibration report.

Determine the linear correction factor from linear interpolation between the two nearest spot frequency calibration factors. For example, a correction factor of 0,74 would be applied at 3 000 MHz in the Figure E.4 example. It can be generally assumed that the added uncertainty due to interpolation between the calibration points will be negligible compared to other uncertainties and may be ignored so long as there is no more than a fourfold difference between the frequencies of the calibration points used for the interpolation.

b) Scenario 2 – The measurements entail a broadband measurement of multiple frequencies.

- Apply a correction factor that is midway between the extremes of the correction factors, a_+ and a_-, in the measurement frequency range. For example, broadband measurements between 100 MHz and 3 000 MHz would require a correction factor of $(a_+ + a_-)/2$ = (1,02 + 0,74)/2 = 0,88.

- The standard uncertainty in this case can be calculated by modelling the variability as a rectangular distribution which spans between the extreme values of the calibration factors. The standard uncertainty for a rectangular distribution is calculated as $(a_+ - a_-)/(2\sqrt{3})$. For the 100 MHz to 3 000 MHz broadband measurement example, the standard uncertainty would therefore be calculated as (1,02 – 0,74)/(2√3) = 0,081 dB.

c) Scenario 3 – The calibration factor(s) for E or H at the measurement frequency or frequency range is within 10 % of 1 (i.e. 0,9 to 1,1).

For convenience, the correction factor in this case may be set to 1 and the standard uncertainty is calculated from a rectangular distribution with a half width, a, of 0,87 dB. The standard uncertainty is then calculated as $a/\sqrt{3}$ = 0,87/√3 = 0,50 dB. This approach leads to higher estimated uncertainties than the methods indicated above, but reduces the effort required in adjusting calibration factors for each measurement. In the example shown in Figure E.4, the yellow zone depicts the extent of calibration factors that are within ±10 % of 1.

NOTE Scenario 3 is only applicable if the correction factor is changing at random. This is not always the case. If a correction factor increases or decreases gradually, then a systematic error is introduced by the proposed method.

E.7.4 Isotropy of the measurement antenna or field probe

The responses of RF probes typically vary for different orientations of the probe with respect to the electric field or magnetic field. This variation is generally larger when the probe is attached directly to the field meter, except for measurements where the meter body has little field scattering influence on the probe, for example when the field is much higher at the probe head than at the meter.

Such variation can be effectively nullified by rotating the probe and recording the average response, as is the practice when the probes are calibrated in a laboratory. Where this is not practical, a standard uncertainty shall be applied. The expanded uncertainty range for probe isotropy is normally provided in the manufacturer's specification sheet for the instrument. If the confidence interval is not specified for the uncertainty, it may generally be assumed that d = 1,96 (≈ 2).

E.7.5 Frequency response of the spectrum analyser

It is the uncertainty over a specified frequency and represents overall system performance resulting from the flatness characteristics and interactions of individual components including attenuator flatness and mixer conversion loss. Frequency response uncertainty is usually specified for relative and absolute measurements. Relative uncertainty describes the amplitude extremes relative to a midpoint value between the extremes. Absolute uncertainty describes the amplitude uncertainty relative to an internal amplitude reference signal. A rectangular distribution can be assumed for the probability distribution with $d = \sqrt{3}$.

E.7.6 Temperature response of a broadband field probe

The electric field probe or magnetic field probe response can vary with changes in temperature. Field probes are normally calibrated at room temperature (20 °C), and hence if the temperature response is known an appropriate correction can be applied for other operating temperatures.

If a temperature correction is not applied, then a standard uncertainty for temperature variation shall be added to the combined estimate. The uncertainty range for temperature response is normally provided in the manufacturer's specification sheet for the instrument. Unless specified otherwise, a 95 % confidence interval may be assumed for the uncertainty range with d = 1,96 (≈ 2).

E.7.7 Linearity deviation of a broadband field probe

Ideally, the response of a field probe should be linear with respect to the measured E^2 or H^2 level. However, probes normally exhibit a linearity deviation which varies with the level of the measured field and which is usually greatest at the low and high extremes of the measurement range of the probe. Thus, for instance, the standard uncertainty for linearity deviation may be higher for low level environmental measurements than it would be for RF exposure measurements used for compliance assessment.

The expanded uncertainty range for linearity deviation is normally provided in the manufacturer's specification sheet for the instrument. Unless specified otherwise, a 95 % confidence interval may be assumed for the uncertainty range with d = 1,96 (≈ 2).

E.7.8 Mismatch uncertainty

When a spectrum analyser is connected to a measurement antenna through a transmission line, the voltages and current on the line can be described in terms of reflection coefficients, incident and reflected waves. Since usually only the magnitudes of the reflection coefficients will be known, the worst-case maximum and minimum mismatch uncertainty, a_M (dB) associated with power transfer is obtained from:

$$a_{\mathrm{M}} = 20\log_{10}(1 \pm |\Gamma_{\mathrm{A}}||\Gamma_{\mathrm{SA}}|) \quad \text{(E.1)}$$

where $|\Gamma_{\mathrm{A}}|$ and $|\Gamma_{\mathrm{SA}}|$ are the magnitudes of the reflection coefficients for the measurement antenna and the spectrum analyser. Mismatch uncertainty is asymmetric about the measured result, however, the difference it makes to the total combined uncertainty is often insignificant and it is acceptable to use the larger of the two limits. The U-shaped probability distribution function is appropriate so d is $\sqrt{2}$ and the mismatch standard uncertainty, u_{M}, is given by:

$$u_{\mathrm{M}} = \frac{a_{\mathrm{M}}}{\sqrt{2}} \quad \text{(E.2)}$$

E.7.9 Deviation of the experimental source from numerical source

For system validation, the mechanical and electrical tolerances of the standard source affect the resulting whole-body SAR values, e.g. different feedpoint impedance and current distribution as function of distance, phantom shell, liquid, etc. The real physical construction also deviates from the numerical model upon which the target values are based. The resulting offset and uncertainty can be determined by type A or type B evaluations. Type A would involve evaluations with different liquids, probes and phantoms. For type B evaluations, all parameters need to be assessed experimentally or numerically.

E.7.10 Meter fluctuation uncertainty for time varying signals

In many cases, the measured signal is continuously varying, for example due to active power control, channel occupancy, fading or intermittent data transfer on a communications link.

When taking measurements for instantaneous E and H limits, the recommended practice is to use the maximum-hold function of the meter (if available).

When taking measurements for time-averaged E and H limits, it should be standard practice to record the average reading, rather than the peak reading. This may be achieved on some instruments by using a time averaging function built into the meter which will lead to negligible uncertainty. If due to time constraints this approach is not practical, then the meter reading will entail a significant uncertainty. This uncertainty could be reliably estimated by comparing repeated measures against an instrument time averaged measure of the signal, i.e. a type A estimate.

E.7.11 Uncertainty due to power variation in the RF source

There are some RF sources which can vary substantially in average radiated power from one period (e.g. six minutes) to the next. If the source power is known at the time of measurement, then the measurements should be scaled by a factor to reflect the reasonable maximum operational power. The variation shall be assumed to be a rectangular distribution.

E.7.12 Uncertainty due to field gradients

E.7.12.1 General

RF fields can vary rapidly with location relative to the source. Such situations occur for example in the ‘near-field’ of a radiator or re-radiator where the magnitude of the field can vary inversely with the cube of the distance ($1/d^3$) from the radiator. In high field gradients (e.g. close to the source or re-radiating conductors) this can lead to a significant uncertainty in the measurement if the location of the field probe is uncertain. Separation distances have been computed for a range of probe dimensions to limit the measurement uncertainty to ±10 % (separation distances to achieve a lower uncertainty of ±5 % are provided if this is a requirement).

In high field gradients, the variation shall be assumed to be a *rectangular distribution.* For a range of ±10 % in E or H, the standard uncertainty is consequently calculated as $0{,}87/\sqrt{3}$ = 0,5 dB.

E.7.12.2 Uncertainty due to field gradients when using dipoles

The error (δ) in measurement of non-uniform near-field electric fields using a dipole antenna can be expressed as:

$$L \leq 2R_0\sqrt{1-\frac{1}{\sqrt{\delta+1}}} \tag{E.3}$$

Where L is the total length of the dipole and R_0 the distance from the centre of the dipole to the source of the near-field. The error is positive, and is the difference between the average electric field strength over its total length and the electric field strength at the centre of the dipole when this difference is normalized to the field at the centre.

EXAMPLE 1 For an error (δ) equal to 0,1 (10 % for E or 21 % for E^2), then the separation distance R_0 should not be less than 2,3 times the total dipole length (L).

EXAMPLE 2 For an error (δ) equal to 0,05 (5 % for E or 10 % for E^2) R_0 should not be less than 3,2 times the total dipole length (L).

Table E.5 gives guidance on minimum separation distances for some selected dipole dimensions to ensure that the uncertainty does not exceed 5 % or 10 % in a measurement of electric field strength. The variation shall be assumed to be a symmetric rectangular distribution. For example, for a range of ±10 % in electric field strength, the standard uncertainty is consequently calculated as $0{,}87/\sqrt{3}$ = 0,5 dB.

Table E.5 – Guidance on minimum separation distances for some dipole lengths to ensure that the uncertainty does not exceed 5 % or 10 % in a measurement of *E*

Dipole total length	Minimum separation distance	
	For u < 10 % (E)	For u < 5 % (E)
40 mm	92 mm	128 mm
67 mm	154 mm	214 mm
133 mm	306 mm	426 mm
400 mm	920 mm	1 280 mm

E.7.12.3 Uncertainty due to field gradients when using loop antennas

Guidance on the estimation of uncertainty in a magnetic field strength (H) measurement due to non-uniform near-fields is given in [64] and [66]. Table 4 and 5 in [64] give uncertainty estimations for single-axis and three-axis loop antennas.

When using a three-axis loop at a separation distance (measured from the centre of the loop) equal to two times its diameter, the uncertainty in the measurement of H can range from -10,8 % to +7,6 % (and slightly less for a single loop). This is equivalent to -22,7 % to +15,8 % in H^2. The uncertainty in H can be reduced to just under ±5 % (or ±10 % in H^2) if the separation distance is increased to three times the diameter of the loop.

Table E.6 gives guidance on minimum separation distances for some selected loop dimensions to ensure that the uncertainty does not exceed 5 % or 10 % in an H measurement. The variation shall be assumed to be a symmetric rectangular distribution. For example, a range of ±10 % in electric field strength or magnetic field strength, the standard uncertainty is consequently calculated as $0{,}87/\sqrt{3}$ = 0,5 dB.

Table E.6 – Guidance on minimum separation distances for some loop diameters to ensure that the uncertainty does not exceed 5 % or 10 % in a measurement of *H*

Loop diameter	Minimum separation distance	
	For u < 10 % (H)	For u < 5 % (H)
40 mm	80 mm	120 mm
67 mm	133 mm	201 mm
133 mm	267 mm	399 mm
400 mm	800 mm	1 200 mm

E.7.13 Mutual coupling between measurement antenna or isotropic probe and object

Mutual coupling between a dipole and object (floor, wall, furniture, etc.) can alter the impedance of the dipole and therefore change the relationship (e.g. antenna factor) between the electric field strength (E) along the probe and voltage at its terminals. This can lead to an error in the measurement of the field because the antenna factor established during calibration is no longer valid. Guidance provided in [64] for dipole like antennas indicates that worst-case measurement errors, over the frequency range of 300 MHz to 3 000 MHz, can be kept below 10 % (21 % for RF field strength squared), under the following worst-case conditions.

a) The detector (load) impedance is low, with respect to the antenna's source impedance, i.e. the detector draws a relatively high RF current from the receiving antenna. In contrast, a low capacitance, high-impedance diode detector will reduce the probe loading errors by about a factor of two.
b) The perturbing object (passive re-radiator) may have a scattering cross section, i.e. its size can be much greater than several wavelengths at the frequency being measured. Small scatterers will introduce lower measurement errors.
c) The dipole total electrical length is less than or equal to 0,4 wavelengths tip-to-tip.
d) The distance between the probe and the perturbing object is greater than 200 mm at 300 MHz (0,2 wavelengths), and greater than 20 mm (0,2 wavelengths) at 3 000 MHz.

Table E.7 summarizes the conditions for some selected dipole dimensions.

Table E.7 – Example minimum separation conditions for selected dipole lengths for 10 % uncertainty in *E*

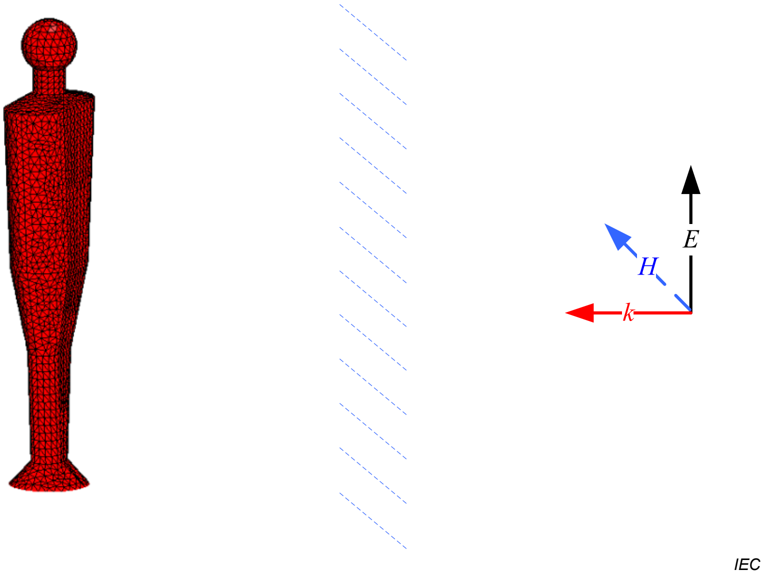
Frequency (MHz)	Minimum separation distance (0,2 λ)	Dipole total length (0,4 λ)
3 000	20 mm	40 mm
1 800	33 mm	67 mm
900	67 mm	133 mm
300	200 mm	400 mm

A separation of 200 mm is required for a dipole that is 400 mm in length. A 20 mm separation distance is suitable for dipoles with a maximum tip-to-tip length not more than 40 mm when used over the frequency range 300 MHz to 3 GHz. In general, arbitrary sized dipoles can be used so long as the criteria for total dipole dimension and separation distance are observed to ensure the measurement uncertainty is not greater than 10 % in E or 21 % in E^2. The variation shall be assumed to be a symmetric rectangular distribution. For an example, a range of ±10 % in E, the standard uncertainty is consequently calculated as $0{,}87/\sqrt{3}$ = 0,5 dB.

E.7.14 Uncertainty due to field scattering from the surveyor's body

Scattered fields from the surveyor's body can be a substantial source of uncertainty. When a person points a field probe towards a high frequency (> 300 MHz) RF source, a portion of the incident RF wave is reflected from the front of their body and combines with the incident wave to form a standing wave due to constructive and destructive interference. The perturbation due to these reflected fields is greatly affected by the distance of the measuring probe from the reflective front body surface. At lower frequencies, the scattered fields from a standing surveyor resemble the re-radiation from a monopole antenna. The influence of scattered fields is more prominent in the measurement of far-fields which are away from higher field gradients encountered near the source and which entail whole-body exposure and reflections from the surveyor.

The level of field perturbation in front of a surveyor due to reflections from the body has been estimated by numerical calculation as indicated in the model setup shown in Figure E.5. The estimated range of variation is shown in Table E.8 for frequencies ranging from 300 kHz to 10 GHz. This variation is represented by an asymmetric rectangular distribution based on the upper (a_+) and lower (a_-) bounds indicated in Table E.9, and has been interpolated for particular types of radio services in Table E.9. Note that the perturbation effect of the body is large for mobile telephony and satellite/microwave services, and hence surveyors should take particular care to avoid body reflections when measuring these services if they wish to avoid large uncertainties. This can be achieved by standing off to the side of the main lobe of high gain antennas like microwave dishes, or by mounting the RF meter and probe on a non-conducting tripod.



NOTE Represents an adult of average height and girth standing on a perfectly conducting ground and exposed to a vertically polarized plane wave propagating in direction k.

Figure E.5 – Computational model used for the variational analysis of reflected RF fields from the front of a surveyor

The man model consisted of a homogeneous glossy material with dielectric values equivalent to 2/3 muscle at the exposure frequency. The model was analysed by method of moments using the surface equivalence principle (SEP). The dots in the diagram indicate the range of measurement points (0,7 m to 1 m in front of the centre of the body, and 0,8 m to 1,8 m above ground).

Table E.8 – Standard estimates of dB variation for the perturbations in front of a surveyor due to body reflected fields as described in Figure E.5

Frequency (MHz)	dB variation due to body reflected fields	
	E	*H*
0,3	-1,4 to +1,1	-0,2 to 0,0
1	-1,4 to +1,1	-0,2 to 0,0
3	-1,4 to +1,1	-0,2 to 0,0
10	-1,2 to +1,2	0,0 to 0,1
30	-0,8 to +1,6	0,9 to 2,7
100	-0,18 to +2,2	-2,6 to 0,7
300	-1,4 to +2,0	-2,8 to 1,4
1 000	-5,7 to +3,4	-6,0 to 3,7
3 000	-6,1 to 3,5	-6,1 to 3,5
10 000	-5,0 to 3,2	-5,0 to 3,2

Table E.9 – Standard uncertainty (u) estimates for E and H due to body reflections from the surveyor for common radio services derived from estimates provided in Table E.8

Radio service	dB variation due to body reflected fields					
	E			*H*		
	a_+	a_-	u	a_+	a_-	u
MF AM radio	-1,4	+1,1	0,7	-0,2	+0,0	0,1
HF radio	-1,4	+1,6	0,9	-0,2	+0,1	0,1
VHF FM radio	-0,2	+2,2	0,7	-2,6	+0,7	1,0
VHF TV	-1,4	+2,2	1,0	-2,8	+1,4	1,2
UHF TV	-2,5	+2,5	1,4	-3,0	+2,5	1,6
800 MHz and 900 MHz mobile telephony	-5,7	+3,4	2,6	-6,0	+3,7	2,8
1 800 MHz and 2 100 MHz mobile telephony	-6,0	+3,4	2,7	-6,0	+3,5	2,7
Microwave and satellite links	-5,5	+3,2	2,5	-5,5	+3,2	2,5

E.7.15 Measurement device

The uncertainty contribution due to the measurement device (e.g. vector receiver) shall be assessed with reference to its calibration certificates assuming a normal probability distribution.

E.7.16 Fields out of measurement range

Errors may be introduced if local measurements are outside the measurement range of the measurement device. If an E-field or H-field level is below the lower detection limit, then the value of the measurement device detection limit shall be used. If the E-field or H-field level is above the upper measurement device limit, then the measurements shall be considered invalid. The uncertainty due to detection limits shall be evaluated assuming a rectangular probability distribution.

E.7.17 Noise

This is the signal detected by the measurement system even if the antenna is not transmitting. The sources of these signals include RF noise, ELF noise (lighting systems, the scanning system, grounding of the laboratory power supply, etc.), electrostatic effects (movement of the probe, people walking, etc.) and other effects (light detecting effects, temperature, etc.).

The noise level shall be determined by three different coarse scans with the RF source switched off or with an absorbing load connected to the output of the transmitter. None of the evaluated points shall exceed −25 dB of the lowest incident field being measured. Within this constraint, the uncertainty due to noise shall be neglected.

E.7.18 Integration time

The integration time shall not introduce additional error if the EUT emits a continuous wave (CW) signal. This uncertainty depends on the signal characteristics and must be evaluated prior to any electromagnetic field measurements. If a non-CW signal is used, then the uncertainty introduced shall be taken into account in the global uncertainty evaluation. The uncertainty due to integration time shall be evaluated assuming it has a normal probability distribution.

E.7.19 Power chain

The mismatch in the power chain leads to an uncertainty in the evaluation of the emitted power from the power measured by the power meter. The power chain uncertainty shall be assessed assuming a normal probability distribution.

E.7.20 Positioning system

The mechanical constraints of the positioning system introduce uncertainty to the electromagnetic field measurements through the accuracy and repeatability of positioning. The uncertainty shall be assessed with reference to the positioning system's specifications assuming a rectangular probability distribution.

E.7.21 Matching between probe and the EUT

Before each scan the alignment between position of the probe and the EUT shall be verified using three reference points.

E.7.22 Drifts in output power of the EUT, probe, temperature, and humidity

The drift due to electronics of the EUT and the measurement equipment, as well as temperature and humidity, are controlled by the first and last step of the measurement process defined in the measurement procedure and the resulting error shall be less than ±5 %. The uncertainty shall be evaluated assuming a rectangular probability distribution.

E.7.23 Perturbation by the environment

The perturbation of the environment results from various contributing factors:

- reflections in the laboratory;
- influence of the EUT and isotropic probe positioner;
- influence of cables and equipment;
- background level of electromagnetic fields.

The uncertainty shall be assessed assuming a rectangular probability distribution.

E.8 Example influence quantities for RF field strength computations by ray tracing or full wave methods

E.8.1 General

The influence quantities for calculated evaluations of fields differ from those for measurements, and may vary depending on how the calculated evaluation is performed. The minimal list of influence quantities defined in E.8.2 to E.8.4 should be considered.

E.8.2 System

E.8.2.1 Transmitter power

Transmitter power output may vary over time depending on load and signal modulation. An estimate of the uncertainty due to variation may be obtained by monitoring output over a sufficient length of time, using manufacturers' or historical data, or information obtained from similar transmitter installations.

The type of distribution that adequately models power variation will depend on the quality of the information available to the surveyor. If insufficiently characterized, the surveyor may choose a uniform distribution based on best estimate of maximum and minimum variation. In other cases, a triangular or normal distribution may be suitable.

E.8.2.2 System losses

Estimation of the "losses" incurred by the signal between the output of the RF amplifier and the input ports(s) of the antenna are subject to uncertainty. Two major components of uncertainty are:

- transmission line and connector/component losses;
- antenna mismatch to the transmission line feeder.

Losses in the form of attenuation can be considered to be normally distributed while mismatch "loss" is modelled by a U-shaped distribution.

E.8.2.3 Antenna

The model of the antenna is an important source of uncertainty in ray tracing and full wave analysis. In full wave analysis, the physical antenna can be modelled to give good agreement with measured field patterns, both in the near- and far-field. The uncertainty in the evaluated RF field strength will depend on the degree of alignment between the model and physical antenna and in particular, accuracy in modelling feed structures. To estimate the uncertainty in the antenna model, computed field patterns should be compared with measured data and/or data obtained using other computational methods that have been verified.

In ray tracing analysis, antenna gain is an important source of uncertainty for calculations using the spherical equation or near-field calculations based on synthetic apertures. In many cases, it is possible to obtain manufacturer's specification data of the far-field gain for the horizontal radiation pattern (HRP) and vertical radiation pattern (VRP) of the antenna.

Unless reliably indicated otherwise, it may be assumed that these data (and other antenna gain data obtained from a trustworthy source) are normally distributed and will have a standard uncertainty of 1,5 dB (if the nulls in an antenna pattern are deliberately filled in to provide conservative estimates, then the standard uncertainty shall be altered accordingly to account for the asymmetric variability introduced by this approach).

If the gain is estimated by antenna pattern synthesis from the HRP and VRP in directions away from these planes, then an additional standard uncertainty shall be estimated for the uncertainty in the approximation introduced by the antenna pattern synthesis technique. The characteristics of this uncertainty will depend on how the antenna pattern synthesis is formulated.

If the antenna gain varies across the frequency spectrum of the source, then it is acceptable to calculate the emissions at the mid-range of the transmission spectrum, with an added uncertainty estimate for the effect of varying antenna gain across the transmission spectrum.

For smart/adaptive antenna arrays, additional constraints shall be considered such as the antenna pattern of the individual narrow beams, number of beams operational at a given time, overall envelope antenna pattern formed as the peak gain varies with target direction.

E.8.2.4 Modelling of antenna structures and supports

Reflections from structures and supporting elements may contribute to the total field at evaluation locations. In some cases, computational modelling tools may not be able to include the effects of structures and supports. A contribution to uncertainty shall be included to account for the effect on field patterns due to the interaction between the antenna and positioning, mounting and support structures. The rectangular distribution can be assumed unless there is information to suggest otherwise.

E.8.3 Technique uncertainties

Uncertainty in the general accuracy of the modelling technique can be difficult to estimate, but shall nonetheless be considered. Depending on the particular computational method adopted, contributions to uncertainty can include:

- model resolution;
- boundary conditions;
- convergence criteria;
- interpolations/extrapolations;
- null-filling of antenna patterns.

A set of computational tools are described in E.4 and these include the spherical and cylindrical formulas, ray tracing and full wave field. The approach taken towards validating and estimating the uncertainty will depend on the type of computational tool that is being used, and recommended approaches are provided in Annex B and [42].

E.8.4 Environmental uncertainties

The presence of a scattering object near a RF field strength calculation point may introduce some uncertainty in the estimate if it has not been explicitly included in the calculation model. This uncertainty may be considered negligible if the scattering object is at least twice as far from the source as the calculation point. Otherwise, an uncertainty estimate should be provided if the scattering object has not been included in the calculation model.

In scattering environments, the relationship between the field components, E and H, will be complex and not well approximated by the free space impedance. If both components of the field are not explicitly included in the calculation model, then inferring one component (e.g. H) from the evaluation of the other (e.g. E) may introduce some additional uncertainty. An estimate of uncertainty should be provided where one component is inferred from the evaluation of the other.

The rectangular distribution can be assumed unless there is information to suggest otherwise.

E.9 Influence quantities for *SAR* measurements

E.9.1 General

Influence quantities for maximum peak spatial-average *SAR* measurements are described in IEC 62209-2. The uncertainty associated with many of these influence quantities and the way it is assessed is applicable also for whole-body average *SAR* measurements. A description of how to assess the uncertainty for a number of influence quantities for which the description in IEC 62209-2 is not applicable is given in E.9.2 to E.9.8.

E.9.2 Post-processing

E.9.2 describes the estimation of the uncertainty resulting from the post-processing of the discrete measured data to determine whole-body *SAR* including uncertainty due to the interpolation and extrapolation schemes used. For procedures based on measurements in one or more planes used in combination with various techniques for numerical field propagation, other types of algorithm-related contributions are also included in this influence quantity. The uncertainty is a function of the resolution chosen for the measurement and the post-processing methods used.

The post-processing uncertainty is assessed using numerical simulations. The approach is based on generating two sets of electric field strength data. One set of data is determined at the spatial measurement grid points inside the phantom for the used measurement resolution. These data are provided as input to the post-processing algorithm to obtain a whole-body *SAR* value corresponding to a measurement result. The second data set consists of a full volume grid used to determine a reference whole-body *SAR* result. The resolution of this grid shall be chosen to obtain converged results.

The evaluation shall include at least five devices, operating in the frequency bands of interest, and evaluations shall be made for at least four phantom-antenna separation distances of relevance for the measurements conducted. The maximum obtained deviation in whole-body *SAR* defines a rectangular uncertainty distribution. An infinite number of degrees of freedom ($v_\mathrm{i} = \infty$) may be assumed for this uncertainty.

E.9.3 Device holder

E.9.3.1 General

Although the device holder is made of a low-loss material, it may affect the transmitting source. As a consequence, the uncertainty shall be assessed[7]. Either a type A or a type B method may be used.

The *SAR* uncertainty associated with this influence quantity is:

$$u_{SAR}[\%] = \left(\frac{SAR_{\mathrm{w/holder}} - SAR_{\mathrm{w/o\ holder}}}{SAR_{\mathrm{w/o\ holder}}} \right) \times 100$$

where

u_{SAR} is the uncertainty in percent;

($SAR_{\mathrm{w/holder}}$) is the *SAR* with device holder in watts per kilogram;

($SAR_{\mathrm{w/o\ holder}}$) is the *SAR* without device holder in watts per kilogram.

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7 For RBS products employing sector coverage antennas mounted on large ground planes, the impact of the device holder on the source may be very small, resulting in a negligible uncertainty.

E.9.3.2 Device holder perturbation uncertainty for a specific test device: type B

The uncertainty for a specific EUT operating in a specific configuration shall be estimated by performing the following two tests using a flat box-shaped phantom:

a) evaluation of whole-body *SAR* ($SAR_{\text{w/holder}}$) by placing the EUT in the holder in the same way it would be held during *SAR* measurements, then positioning the EUT in direct contact with a flat phantom (horizontal and vertical centre line of the DUT parallel to the bottom of the flat phantom);
b) evaluation of whole-body *SAR* ($SAR_{\text{w/o holder}}$) by placing the device in the same position but held in place using foamed polystyrene or equivalent low-loss and non-reflective material (permittivity no greater than 1,2 and loss tangent no greater than 10^{-5}).

This uncertainty has an assumed rectangular probability distribution and $v_{\text{i}} = \infty$ degrees of freedom.

E.9.3.3 Device holder perturbation uncertainty for specific types of devices: type A

A type A uncertainty analysis can be applied for a group of EUTs having similar shapes and *SAR* distributions. The uncertainty arising from this analysis can apply to other EUTs having similar *SAR* characteristics and tested with the same device holder, such that the specific type B tests described above can be avoided. The effect of the device holder for M different EUT models shall be estimated by performing the tests of E.9.3.2 for each model ($M \geq 6$).

The corresponding uncertainty shall be estimated by using the root-mean-square of the individual uncertainties, with $M - 1$ degrees of freedom of (i.e. $v_{\text{i}} = M - 1$).

E.9.4 Test sample positioning

E.9.4.1 General

The EUT test positions established by a single test operator using a device holder may deviate from the exact position. *SAR* uncertainties due to device positioning deviations (different for maximum peak spatial-average and whole-body average *SAR*) may vary by EUT and holder designs and the procedures used by the test operator. These effects are usually inseparable.

The positioning uncertainty may be assessed using measurements. Whole-body *SAR* measurements are very time-consuming, however, and simulations are recommended. The approach is based on first assessing the range of possible deviation from the true position and then assessing the impact on maximum peak spatial-average and whole-body average *SAR*.

An example of a positioning device is given in Figure E.6 illustrating three different positioning errors.

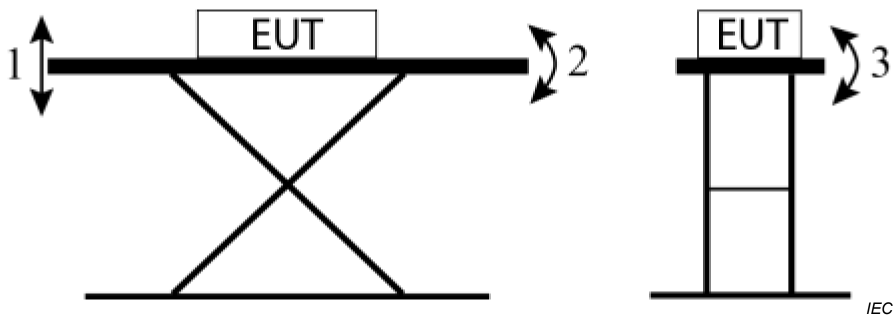


Figure E.6 – Positioning device and different positioning errors

The positioning errors in this example consist of a vertical and two rotational misalignments.

The procedures of E.9.4.2 may be used to evaluate an individual EUT design. E.9.4.3 describes the procedures that may apply for evaluating a specific series or group of EUT designs that have the same shape and substantially equivalent dimensions and were tested using the same device holder. Unless these requirements are satisfied, the procedures in E.9.4.2 should be used to evaluate each individual device. If a predetermined standard deviation for a specific device holder derived from testing a specific group of EUTs is applicable, an individual device may not require repeat testing.

E.9.4.2 Positioning uncertainty of a specific EUT in a specific device holder

The first step is to identify possible positioning errors and then estimate the range of possible deviations from the true position. The uncertainty is evaluated using simulations / measurements spanning the range of possible positioning errors and comparing obtained maximum peak spatial-average and whole-body average *SAR* results against the true position results. The position errors can in general not be assumed to be independent. Evaluations shall be made at the EUT transmit frequency for at least four phantom-antenna separation distances of relevance for the measurements conducted.

The maximum obtained deviations in maximum peak spatial-average and whole-body average *SAR* define corresponding assumed rectangular uncertainty distributions. An infinite number of degrees of freedom ($v_\mathrm{i} = \infty$) may be assumed for this uncertainty.

E.9.4.3 Positioning uncertainty of specific types of EUTs in a specific device holder

The positioning uncertainty for a specific group of EUTs with predominantly the same shape and substantially equivalent dimensions tested with a specific device holder may be assessed using the following procedures. The tests should include at least five devices, operating in the frequency bands of interest, each evaluated according to the procedures of E.9.4.2.

The maximum obtained deviations in maximum peak spatial-average and whole-body average *SAR* define corresponding assumed rectangular uncertainty distributions. An infinite number of degrees of freedom ($v_\mathrm{i} = \infty$) may be assumed for this uncertainty.

E.9.5 Phantom shell uncertainty

The uncertainty due to the phantom shell tolerances is assessed conservatively according to 7.2.3.2 in IEC 62209-2:2010 for both maximum peak spatial-average and whole-body average *SAR*.

E.9.6 *SAR* correction / target liquid permittivity and conductivity

According to IEC 62209-2, the measured conductivity and relative permittivity shall be within 10 % of the target values and the measured maximum peak spatial-average *SAR* results shall be corrected for the deviation of the measured dielectric parameters from the target values using specific procedures. This approach and corresponding uncertainty is applicable also here for maximum peak spatial-average *SAR*.

Whole-body *SAR* has been found to be less sensitive to deviations in the tissue liquid dielectric parameters from their nominal values [37]. As a consequence, a correction algorithm for measured whole-body *SAR* results is not required. The uncertainty corresponding to the allowed 10 % deviation in liquid material parameters from their target values shall be estimated. In [37], the r.m.s. uncertainty for a 10% maximum deviation from the target values was found to be 2 %.

E.9.7 Liquid permittivity and conductivity measurements

This uncertainty is due to the measurement procedures used to assess the tissue simulating liquid permittivity and conductivity. The uncertainty shall be assessed according to 7.2.4.3 in IEC 62209-2:2010. The largest sensitivity coefficients c_ε for permittivity an c_σ for conductivity, obtained over the frequency range 300 MHz to 6 GHz, are given in Table E.10 for both maximum peak spatial-average and whole-body average *SAR*. Alternatively, maximum values for a specific tested frequency range may be used.

Table E.10 – Maximum sensitivity coefficients for liquid permittivity and conductivity over the frequency range 300 MHz to 6 GHz

Sensitivity coefficients	1 g maximum peak spatial-average *SAR*	10 g maximum peak spatial-average *SAR*	Whole-body average *SAR*
c_{ε}	0,23	0,26	0,34
c_{σ}	0,78	0,71	0,25

E.9.8 Liquid temperature

The uncertainty caused by liquid temperature variations within the specified tolerance shall be determined according to 7.2.4.4 in IEC 62209-2:2010. The largest sensitivity coefficients over the frequency range 300 MHz to 6 GHz are given in Table E.10 for both maximum peak spatial-average and whole-body average *SAR*. Alternatively, maximum values for a specific tested frequency range may be used.

E.10 Influence quantities for *SAR* calculations

Validation and influence quantities for *SAR* estimation formulas are contained in Annex B. Validation and influence quantities for full wave *SAR* calculations are contained in [29], [60], [61] and [62].

E.11 Spatial averaging

E.11.1 General

To assess exposure, electric and magnetic field measurements or equivalent plane wave power density evaluations can be performed. Due to diffractions and reflections, the radiofrequency signal is, at a given location, the sum of various waves having different phases and amplitudes.

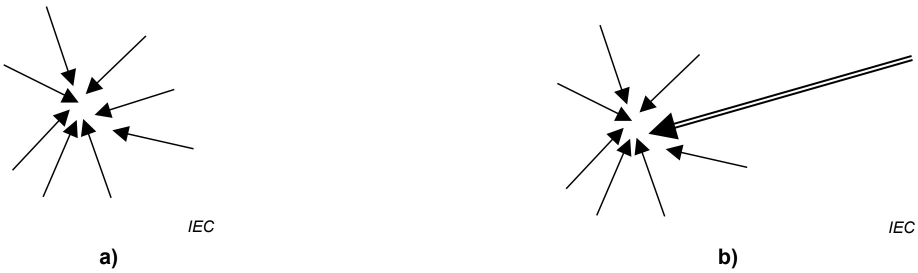


Figure E.7 – Physical model of Rayleigh (a) and Rice (b) small-scale fading variations

As a consequence, the radiofrequency signal is affected by spatial variations known as small-scale fading, which depend on the environment and the signal spectral bandwidth, and are more severe in case of narrowband signals. Examples of this are Rayleigh and Rice fading, as shown in Figure E.7.

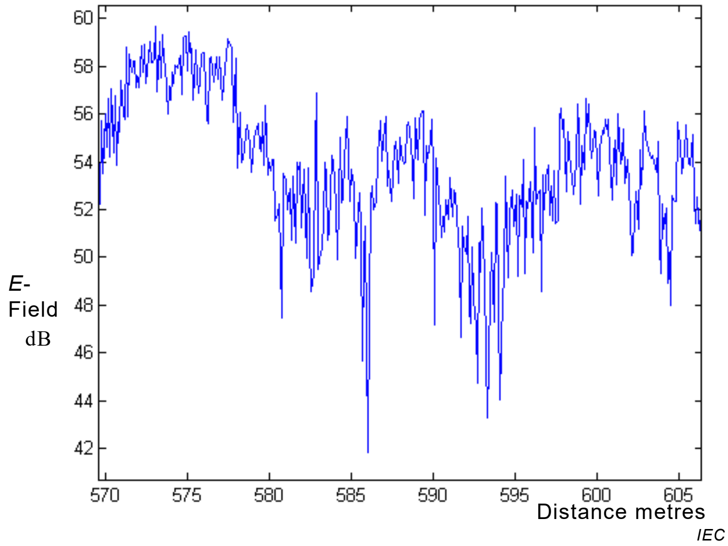


Figure E.8 – Example of E field strength variations in line of sight of an antenna operating at 2,2 GHz

The electric field emitted by a base station can be described with spatial variations at different scales. These variations are due on the one hand to the distance to the base station and on the other hand to shadowing and small-scale (multipath) spatial fading. Small-scale fading entails random variations around a local mean. These small-scale variations are due to the incoherent summation of a number of multipath signals incident at the measurement point, as shown in Figure E.8.

The small-scale fading statistical properties of spatial variations of narrowband signals such as GSM can be characterized through parameters. Based on this a methodology can be developed to control uncertainties for average power density estimation in Rayleigh, Rician-k, and Nakagami-m environments [33].

E.11.2 Small-scale fading variations

We consider the exposure assessment in a volume corresponding to a human body with spatial variations at this local scale that are only due to small-scale fading. Small-scale fading entails random variations around a local mean with a periodicity of about half a wavelength. The variations of electric field are usually modelled by a Rayleigh distribution for non-line of sight, by a Rician-k distribution for line of sight or by a Nakagami-m distribution for both. Due to the small-scale fading variations an averaging process of electric field measurements is used to obtain a reliable and repeatable exposure assessment.

E.11.3 Error on the estimation of local average power density

E.11.3.1 Definition of the error on estimated average power density

Let $\hat{\mu}$ be the estimation of the average power density μ and let $F_{\hat{\mu}}$ be the cumulative distribution function of $\hat{\mu}$. Let $p(\gamma)$ (with $\gamma \geq 1$) denote the probability to have the error on average power estimation less than $10\log_{10}(\gamma)$ dB: $p(\gamma) = F_{\hat{\mu}}(\gamma\mu) - F_{\hat{\mu}}(\mu/\gamma)$.

Then, we define the error εx % in dB at x % in the following way: $\varepsilon x\ \% = 10\log_{10}[p^{-1}(x\ \%)]$, where p^{-1} denotes the inverse function of p.

E.11.3.2 Determination of significant statistical parameters

Let us consider that we have collected N independent samples of electric field strength. Average electric field is given by the quadratic mean of these values. Therefore, we have to consider the arithmetic mean $\hat{\mu}$ of power density $(s_i)1 \leq i \leq N$ that is the realization of a random variable s (which represents individual spot-location measurement) with mean μ and standard deviation σ.

The N points have to be independent. We take into account a fading correlation distance of 0,8 wavelength. Assuming N is high enough, we can consider according to the central limit theorem, that $\hat{\mu}$ is a normal variable with mean μ and standard deviation σ/N. We can show that, for the computation of εx %, the significant parameter concerning small-scale fading is the coefficient of variation η of power density, $\eta = \sigma/\mu$. However, for low values of N, εx % will depend on the distribution of $(s_i)1 \leq I \leq N$. If we suppose that electric field values follow a Rayleigh, a Rice-k or a Nakagami-m distribution, we can show again that fundamental environment parameter is the coefficient of variation of power density.

E.11.4 Error on the estimation of local average power density

Figure E.9 represents the error on the estimation of local average power density for each small-scale fading model. We notice that the Gaussian approximation of the central limit theorem (dotted line) is valid only for high values of N or for low values of η. We also see that Nakagami-m model is close to Rician-k model, although the Nakagami-m model is able to describe more severe fading. At this stage, it would be interesting to estimate the distribution of parameter η in real environments.

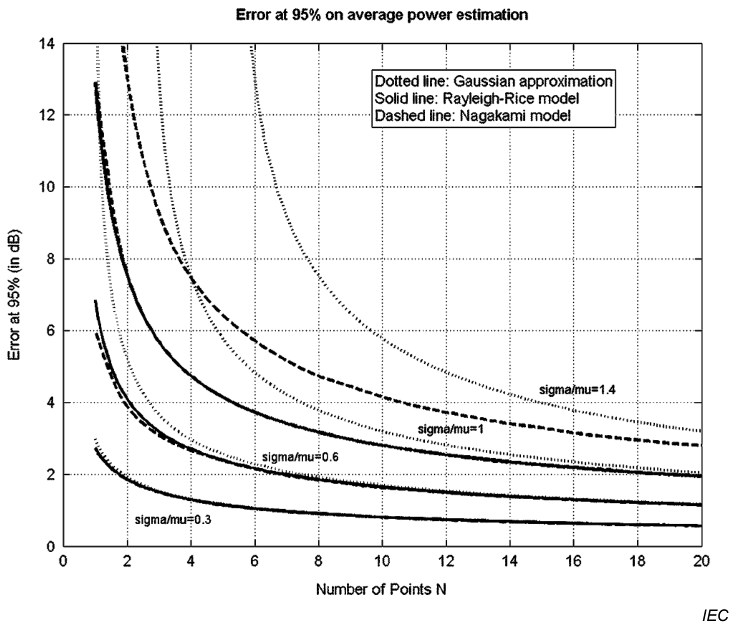


Figure E.9 – Error at 95% on average power estimation

E.11.5 Characterization of environment statistical properties

Measurements of electric field strength were carried out on a nine-point grid, which matches human body dimensions. Measurements were achieved in 234 locations (indoor as well as outdoor) distributed in 77 sites. To limit time variations, only BCCH (broadcast channels) are taken into account and measurements are averaged over 50 time samples.

In every measurement location and for every selected BCCH, the parameter η is estimated. We compute the empirical expectation of $\varepsilon_{95\ \%}$ according to the distribution of $\hat{\eta}$ provided by measurements. We obtain the values in Table E.11, which are derived from [33].

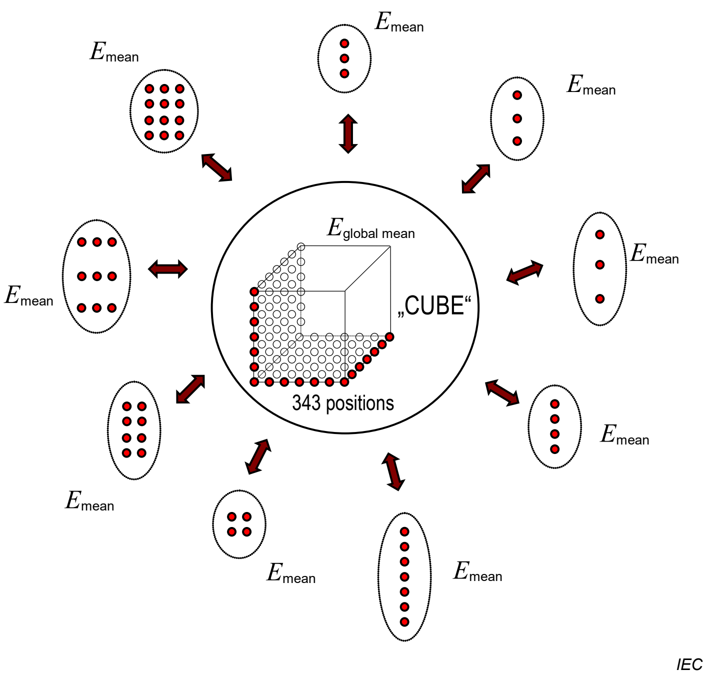
Table E.11 – Uncertainty at 95 % for different fading models

N	1	3	6	9
$\varepsilon_{95\ \%}$ (dB) for one-sided Gaussian (η = 1,4)	24,2	9,4	5,7	4,5
$\varepsilon_{95\ \%}$ (dB) for Rayleigh (η = 1)	12,9	5,7	3,8	3,0
$\varepsilon_{95\ \%}$ (dB) for Rice 1 (η = 0,6)	6,9	3,2	2,2	1,8
$\varepsilon_{95\ \%}$ (dB) for Rice 2 (η = 0,3)	2,8	1,5	1,1	0,9
$\varepsilon_{95\ \%}$ (dB) averaged	10,7	3,5	2,3	1,8

E.11.6 Characterization of different averaging schemes

E.11.6.1 General

Several measurement campaigns in the GSM 900, DCS 1800 and UMTS frequency band as well as a Radio Channel and a TV Channel delivered a large database which was evaluated regarding the application of different averaging procedures [67]. Eleven scenarios were measured and delivered the database for further analysis. The investigation of the electromagnetic field distribution in the vicinity of mobile communication base stations was carried out through measurements performed on a three-dimensional geometrical figure consisting of 343 measurement positions, see Figure E.10. By arranging the measurement positions within this figure with a grid step of 15 cm (and for some frequency bands also 7,5 cm) in all three orthogonal directions information regarding the global mean electric field value were gained. The variation in time was eliminated by measuring with a reference antenna and normalizing the measured values; in this way, only the spatial variation was considered. One-dimensional and two-dimensional templates were created and the impact of reducing the number of measurement points regarding the global mean value was investigated.



NOTE The E_{mean} was compared with the $E_{\text{global mean}}$.

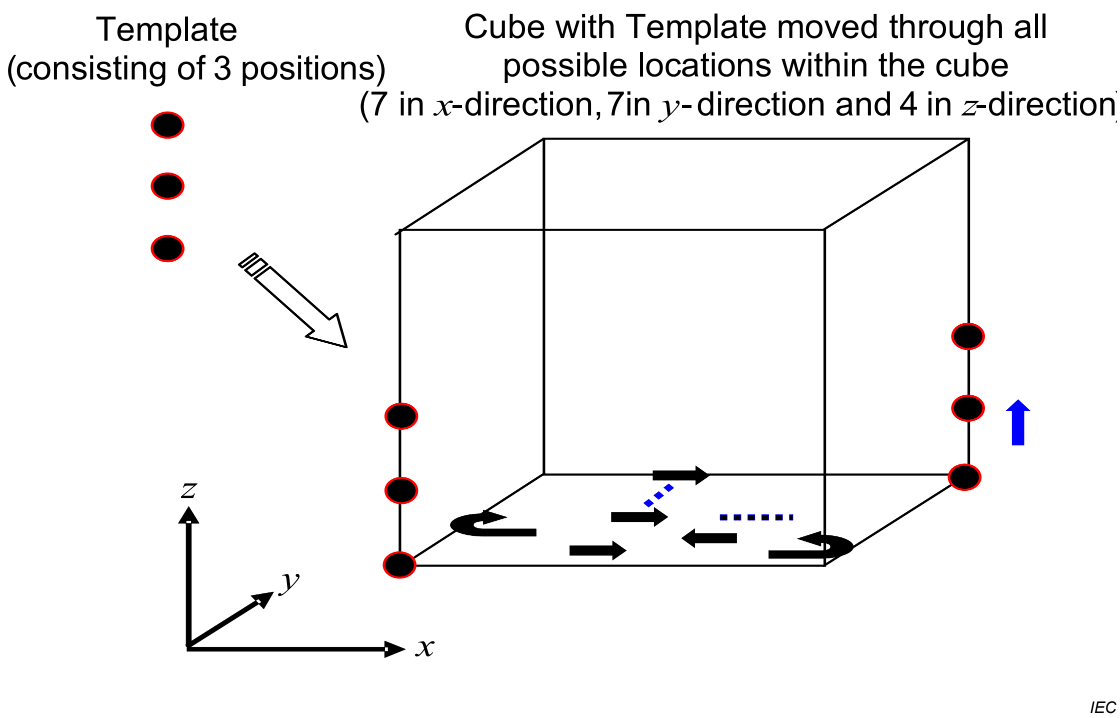
Figure E.10 – 343 measurement positions building a cube (centre) and different templates consisting of a different number of positions

The investigations of different templates were done by comparing the electromagnetic field strength global mean value built by all measurement values ($E_{\text{global mean}}$) with the field strength mean value (E_{mean}) derived by the positions building a template (3 to 12) and deriving their deviation. This can mathematically be described with Equation (E.1):

$$Deviation = \frac{\overline{E_{\mathrm{template}}} - \overline{E_{\mathrm{global}}}}{\overline{E_{\mathrm{global}}}} = \frac{\dfrac{\sum_{i=1}^{n_i} E_i}{n_i} - \dfrac{\sum_{j=1}^{n_j} E_j}{n_j}}{\dfrac{\sum_{j=1}^{n_j} E_j}{n_j}} \tag{E.1}$$

where n_i is the number of positions building a template (3 to 12) and n_j is 343.

Each template was moved through the CUBE by changing its location within the CUBE (Figure E.11). In this way each possible location delivered a mean value which was compared to the global mean value of the whole CUBE by deriving the deviation (see Equation (E.1)).



NOTE For each possible location within the CUBE, the mean value (E_{mean}) was built and compared to the global mean value ($E_{\mathrm{global\ mean}}$).

Figure E.11 – Moving a template (Line 3) through the CUBE

Those deviations might allow conclusions to establish which templates best describe the global mean value. Therefore mathematical and statistical evaluations were used to evaluate the nine different templates. With the help of the correlation factor the correlation of the mean values built by templates can be compared to the global mean value. With Equation (E.2) the correlation coefficient was derived.

$$r = r_{xy} = \frac{s_{xy}}{s_x \times s_y} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \times \sum_{i=1}^{n}(y_i - \bar{y})^2}} \tag{E.2}$$

For determining the correlation coefficient, all nine templates for cubes measured in the GSM 900 and DCS 1800 frequency band in several scenarios were taken as basis.

For example, the Line 7 template consisting of seven consecutive positions can have 49 different locations within a cube (7 in x-direction and 7 in y-direction), this gives a total of 49 mean values (E_{mean}). The correlation coefficient could therefore be derived with the mean values (corresponding to x_i in Equation (E.2)) delivered by templates moved through a cube and the global mean values (corresponding to y_i in Equation (E.2)) which were evaluated for four cubes in the GSM 900 frequency band and for two cubes in the DCS 1800 frequency band.

The correlation coefficients are displayed in Table E.12 The red highlighted fields are showing the templates with lower correlation and the green highlighted fields are displaying the templates with the highest correlation coefficients.

Table E.12 – Correlation coefficients for GSM 900 and DCS 1800

Line 3 **Line 3 middle** **Line 3 big**	**Line 3** **Line 3 middle** **Line 3 big**
0,946 2 0,95 0,956 8	0,873 9 0,894 1 0,894 5
Line 4 **Line 7** **Area 4**	**Line 4** **Line 7** **Area 4**
0,966 9 0,981 3 0,934 5	0,905 1 0,931 2 0,855 0
Area 8 **Area 9** **Area 12**	**Area 8** **Area 9** **Area 12**
0,974 6 0,982 9 0,978 3	0,932 8 0,932 5 0,947 3

It can be seen that templates with a higher number of positions comprising a bigger area deliver slightly higher values and might therefore be better suited.

A Chi–Square Test was applied before to determine if the standard deviation of the mean values of the examined templates regarding the respective global mean field values can be assessed. Out of 99 tests (9 templates in 11 measured cubes allows 99 tests) 66 were valid, demonstrating that the local mean values were in most cases normal distributed; results are displayed in Table E.13 In addition, these results are displayed graphically for the GSM 900, DCS 1800 and UMTS frequency bands in Figure E.12.

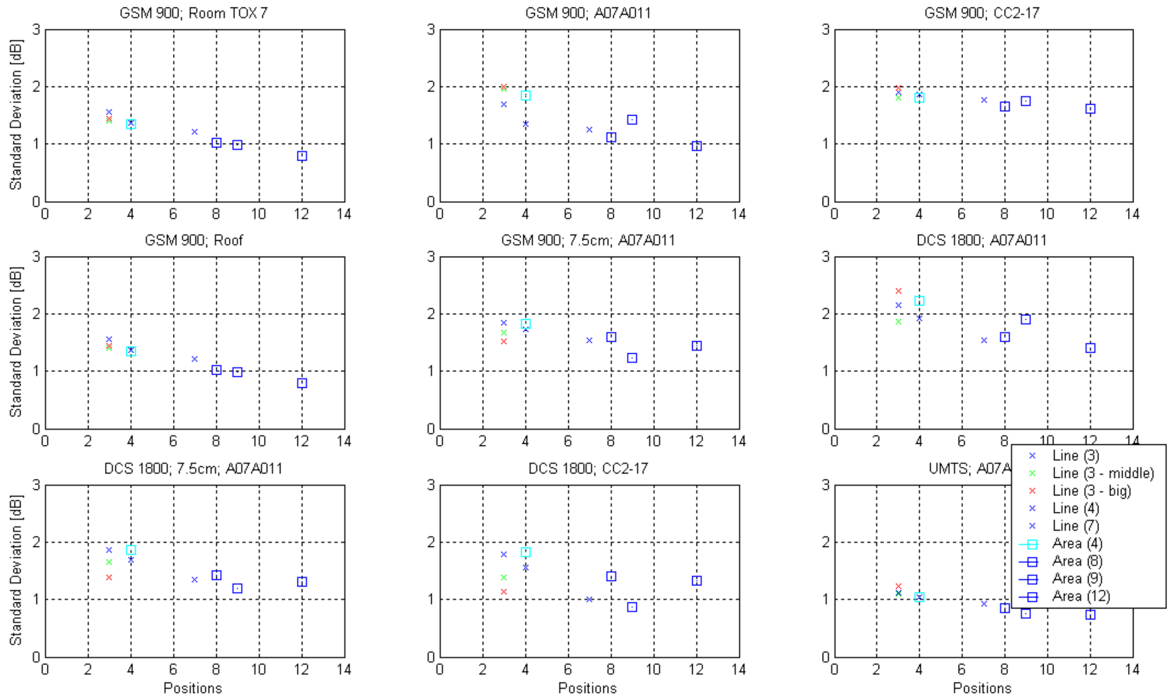


Figure E.12 – Standard deviations for GSM 900, DCS 1800 and UMTS

It was shown that even templates with a very small number of positions (e.g. Line 3 template) do not show much higher standard deviations than templates consisting of more measurement positions, e.g. a Line 7 template. The variations of the standard deviations normalized to the global mean are shown in Figure E.12. These results show the impact of the type of averaging procedure selected.

Table E.13 – Variations of the standard deviations for the GSM 900, DCS 1800 and UMTS frequency band

Templates	Standard deviations
Line (3)	1,12 to 2,15
Line (3m)	1,10 to 1,95
Line (3b)	1,14 to 2,39
Line (4)	1,04 to 1,93
Line(7)	0,94 to 1,76
Area (4)	1,04 to 2,23
Area (8)	0,84 to 1,66
Area (9)	0,76 to 1,90
Area (12)	0,73 to 1,61
m means one position left out	
b means two positions left out	

E.11.6.2 Example of uncertainty assessment

Table E.14 gives an estimation example at GSM frequencies of the total expanded uncertainty

Table E.14 – Examples of total uncertainty calculation

Measurement equipment	1,2 dB (32 %)	0,8 dB (20 %)	1,14 dB (30 %)	1,14 dB (30 %)	1,14 dB (30 %)
Physical parameters	1 dB (26 %)	1 dB (26 %)	1 dB (26 %)	1 dB (26 %)	0 dB (0 %)
Post-processing	3,5 dB (124 %)	3,5 dB (124 %)	2,8 dB (90 %)	3,5 dB (124 %)	3,5 dB (124 %)
Total in % $u_c = \sqrt{\sum_{i=1}^{m} \cdot u_i^2}$	131 %	128 %	100 %	128 %	128 %
Total in dB $u_c = \sqrt{\sum_{i=1}^{m} \cdot u_i^2}$	3,6 dB	3,6 dB	3 dB	3,6 dB	3,6 dB

E.12 Influence of human body on probe measurements of the electrical field strength

E.12.1 Simulations of the influence of human body on probe measurements based on the Method of Moments (Surface Equivalence Principle)

E.12.1.1 Background

The simulations described here determine the influence of the presence of the operator during the measurements on the measurement results of an omnidirectional probe. Nevertheless, the results given can be seen only as a guideline for the determination of the required distance between the operator and a probe during measurement. A detailed error analysis shall be carried out. The scenario modelled is simplified since no additional reflections by the environment are taken into account.

E.12.1.2 Simulation parameters

The simulation of the human body uses the Method of Moments according to the Surface Equivalence Principle. The incident plane wave produces a frequency-independent electrical field strength (see Figure E.13), when the human body is not present. In comparison the presence of the body produces a ripple in the measured field strength values according to Figure E.14.

The parameters are given below:

- Human body model (max. triangle edge length = 0,045 m).
- Relative permittivity: 57, conductivity: 1 S/m.
- Incident plane wave.
- Electrical probe at distances 0,5 m / 1 m / 2 m / 3 m / 10 m in front of the human body.
- Frequencies: 1 MHz to 2,2 GHz, 20 frequency points.

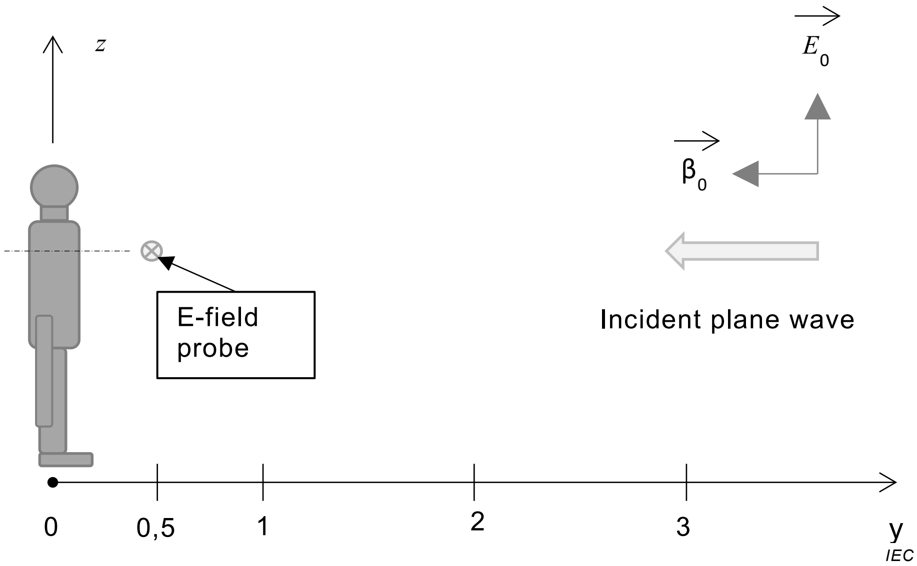


Figure E.13 – Simulation arrangement

E.12.1.3 Results of electrical probe simulations

The results of simulations are displayed in Figure E.14 and the maximum simulated error is provided in Table E.16.

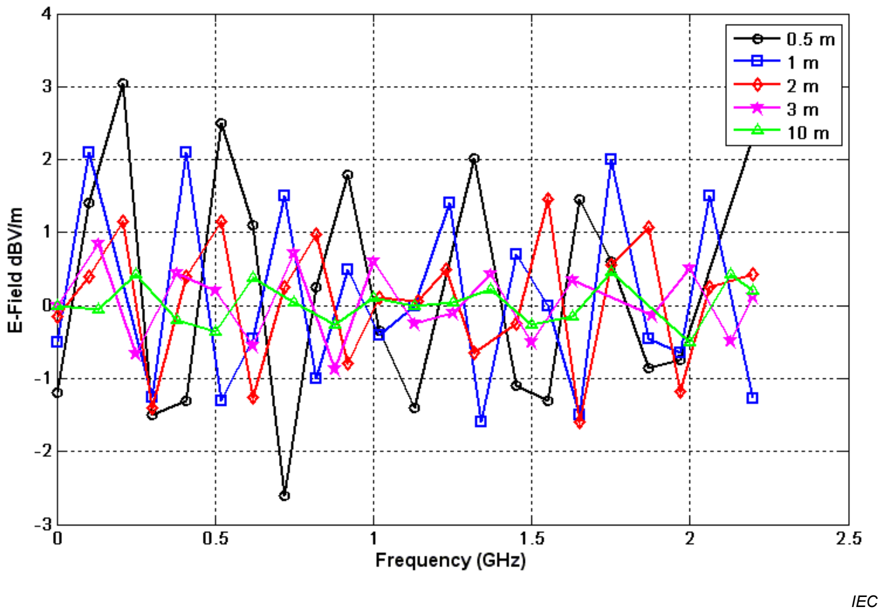


Figure E.14 – Body influence

Table E.15 – Maximum simulated error due to the influence of a human body on the measurement values of an omni-directional probe

Distance probe – human body	Maximum simulated error in measurement values
0,5 m	-2,5 to +3 dB
1 m	-1,5 to +2 dB
2 m	±1,5 dB
3 m	±1,0 dB
10 m	±0,5 dB

E.12.2 Comparison with measurements

To compare the simulation with measurements, the following arrangement was selected (see Figure E.15):

- omnidirectional low gain probe,
- distance probe–antenna 4 m,
- measurements of the influence of a person behind the probe.

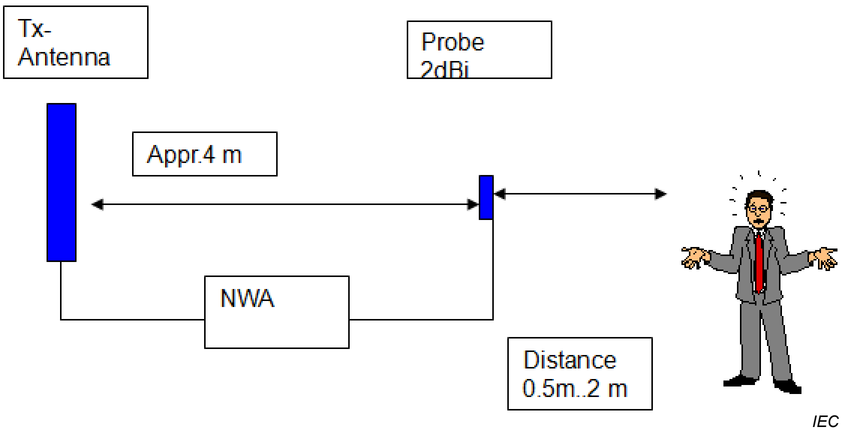


Figure E.15 – Simulation arrangement

The measured maximum changes of the path loss (within the frequency range 824 MHz to 960 MHz and 1 701 MHz to 2 170 MHz) are presented in Table E.16.

Table E.16 – Measured influence of a human body on omni-directional probe measurements

Distance	Max. difference 824 MHz to 960 MHz	Max. difference 1 700 MHz to 2 170 MHz
0,5 m	±1,7 dB	±1,8 dB
1 m	±1,4 dB	±1,5 dB
2 m	±1 dB	±0,8 dB

E.12.3 Conclusions

The measurements and calculations show good agreement. For a frequency range 100 MHz to 2,5 GHz at a distance of 2 m, a human body will influence the indicated field value from an omnidirectional probe by about 1 dB to 1,5 dB. It can be expected that for higher frequencies the influence will be similar. It shall be clearly stated that the results can be considered as valid for a non-reflective or low reflective free space environment. In a multiple reflection environment, that means fading environment, the influence of a body can be higher due to cancellation of local maximums.

Annex F
(informative)

Technology-specific guidance

F.1 Overview to guidance on specific technologies

Annex F provides data on specific technologies and additional guidance on how to apply the evaluation methods when considering these technologies.

F.2 Summary of technology-specific information

Information provided in Table F.1 summarizes the key features of the major mobile and wireless communications technologies in operation around the world. In some countries, the national spectrum assignment/management agency may introduce variations and these should be taken into account when planning and performing RF field strength, power density or SAR evaluations.

Table F.1 – Technology specific information

Technology	Frequency band (MHz)	Downlink freq. (base–mobile) (MHz)	Uplink freq. (mobile–base) (MHz)	Modulation type	Multiple access	Channel bandwidth (kHz)	Tx unit power (W)[a]	Downlink Tx power control range	No. of timeslots (TDMA)	Relevant technology standard references
AMPS	824 to 894	869 to 894	824 to 849	FM	FDMA	30	< ≈ 50		N/A	
C-450	450 to 465			FM	FDMA	20 / 10			N/A	
CDMA IS-95	824 to 894	869 to 894	824 to 849	QPSK	CDMA	1 250			N/A	
CDMA2000	Multiple	Multiple	Multiple	QPSK	CDMA	1 250			N/A	See 3rd Generation Partnership Project 2 (3GPP2), C.S0057
CDPD	824 to 894			FH / Packet GMSK		30				
DECT	1 880 to 1 980[b] 2 010 to 2 025 2 400 ISM	n/a (TDD)	n/a (TDD)	GFSK B·T = 0,5	TDMA	1 728	0,25 Pk 0,01 av. per channel Typical 0,01 to 0,06 for RBS		24	ETSI EN 300 175-1, EN 300 175-2
GSM 900[c]	876 to 960	921 to 960	876 to 915	GMSK	FDMA / TDMA	200	0,1 to 20	≈ 30 dB (BCCH 0 dB)	8	
GSM 1800	1 710 to 1 880	1 805 to 1 880	1 710 to 1 795							
GSM / PCS1900	1 850 to 1 990	1 930 to 1 990	1 850 to 1 910							
LTE	Multiple	Multiple	Multiple	QPSK, 16QAM, 64QAM	OFDM	Multiple	Multiple		N/A	3GPP TS 36.104, TR36.942
NAMPS	824 to 894			FM	FDMA	10			N/A	
NMT-450	450 to 470			FM	FDMA	25			N/A	
NMT-900	890 to 960			FM	FDMA	12,5			N/A	

Technology	Frequency band (MHz)	Downlink freq. (base–mobile) (MHz)	Uplink freq. (mobile–base) (MHz)	Modulation type	Multiple access	Channel bandwidth (kHz)	Tx unit power (W)[a]	Downlink Tx power control range	No. of timeslots (TDMA)	Relevant technology standard references
PHS	1 884 to 1 920	1 884 to 1 920	1 884 to 1 920	Multiple	TDMA	300	4		8	Association of Radio Industries and Businesses (ARIB) in Japan – RCR STD-28
TACS: JTACS	832 to 925					25				
ETACS	872 to 960	917 to 960	872 to 915	FM	FDMA				N/A	
NTACS	843 to 925					12,5				
TETRA	Below 1 000	390 to 400 420 to 430 460 to 470 851 to 867 915 to 921	380 to 390 410 to 420 450 to 460 806 to 822 870 to 876	π/4 DQPSK	TDMA	25	4			ETSI TS 100 392-15
TETRAPOL				GMSK	FDMA	10				www.tetrapol.com
UMTS (W-CDMA)	Multiple	Multiple	Multiple	QPSK	CDMA	5 000	20		N/A	3GPP TS 25.104,
USDC	824 to 894	869 to 894	824 to 849	π/4 DQPSK	TDMA	30			6	
Wi-Fi	2 400 to 2 483,5 5 150 to 5 850	n/a (TDD)	n/a (TDD)	Multiple	OFDM		0,25 typical 1 max. (subject to national regulation)			IEEE 802.11 series, IEEE 802.11b and IEEE 802.11g at 2,45 GHz, IEEE 802.11a (ETSI HyperLAN) at 5 GHz
WiMax	Multiple	n/a (TDD, FDD)	n/a (TDD, FDD)	Multiple	OFDM	Multiple	20 (RBS) 0,5 (CPE) 0,2(mob)		128, 256, 1 024, 2 048 OFDM sub-carriers	IEEE 802.16-2004, IEEE 802.16e

Technology	**Frequency band** (MHz)	**Downlink freq. (base–mobile)** (MHz)	**Uplink freq. (mobile–base)** (MHz)	**Modulation type**	**Multiple access**	**Channel bandwidth** (kHz)	**Tx unit power** (W)[a]	**Downlink Tx power control range**	**No. of timeslots (TDMA)**	**Relevant technology standard references**
XGP (Next generation PHS)	2 545 to 2 625	2 545 to 2 625	2545 to 2 625	Multiple	Multiple	Multiple	10(BS) 0,2(MS)		8	Association of Radio Industries and Businesses (ARIB) in Japan – RCR STD-T95

[a] For systems not using continuous power transmission like TDMA in GSM, peak and average power can be indicated.

[b] In Europe – Frequency Band: possible 1 880 MHz to 1 980 MHz, 2 010 MHz to 2 025 MHz or 2,4 GHz ISM, typical allocation (Europe): 1 880 MHz to 1 900 MHz.

[c] Includes GSM-R, E-GSM and primary GSM bands.

F.3 Guidance on spectrum analyser settings

F.3.1 Overview of spectrum analyser settings

F.3 provides guidance on the spectrum analyser settings required to measure signals from different technologies. Accurate measurements with a spectrum analyser require the settings of parameters such as:

- detection mode;
- resolution bandwidth (RBW) and SPAN (or f_{start} and f_{stop});
- video bandwidth (VBW).

This annex is not intended to be a substitute for specific equipment guidance and/or specialist training.

F.3.2 Detection algorithms

Spectrum analysers usually offer different detection modes. This is due to the fact that the spectral trace is divided into N – 1 buckets of size $\delta f = \dfrac{f_{\text{stop}} - f_{\text{start}}}{N-1}$ because of sampling process. Let's denote:

$$f_k = f_{\text{start}} + k\delta f \quad \text{with } 0 \le k \le N-1 \tag{F.1}$$

- In “sample” mode, the sample v_k corresponds to the voltage at frequency f_k.
- In “peak” mode, the sample v_k corresponds to the maximum voltage found between frequency $f_k - \delta f$ and f_k.
- In “average” mode, the sample v_k corresponds to the average voltage between frequency $f_k - \delta f$ and f_k.
- For true r.m.s. mode, m voltage samples u_i within the interval $f_k - \delta f$ to f_k are taken. v_k is the root mean square of these u_i:

$$v_k = \sqrt{\frac{1}{m} \cdot \sum_{1}^{m} u_i^2} \tag{F.2}$$

The sweep time should be long enough to have m samples.

With the reference resistance R, the power, p_k, is determined as follows:

$$p_k = \frac{v_k^2}{R} \tag{F.3}$$

In peak mode this calculation leads to a correct power p_k when measuring CW amplitude. However, it leads to a bias when measuring noise-like signals such as UMTS signals and does not allow channel power processing because samples are not equally spaced in frequency and the signal shape is not taken into account.

F.3.3 Resolution bandwidth and channel power processing

F.3.3.1 Measurement at a single frequency

For narrowband signals, the RBW parameter should be chosen according to channel bandwidth and carrier spacing. An RBW higher than carrier spacing would prevent frequency selectivity analysis whereas an RBW lower than channel bandwidth would require additional processing. For GSM, the carrier spacing is equal to 200 kHz. Figure F.1 presents the frequency occupancy of a GMSK modulation with a parameter BT = 0,3. The dotted line represents the power integrated with an ideal (i.e. rectangular) filter of variable bandwidth. The solid line represents the power integrated with a real filter with variable bandwidth. The dashed line represents the power integration of an adjacent channel (spaced 200 kHz from the target channel) with a real filter.

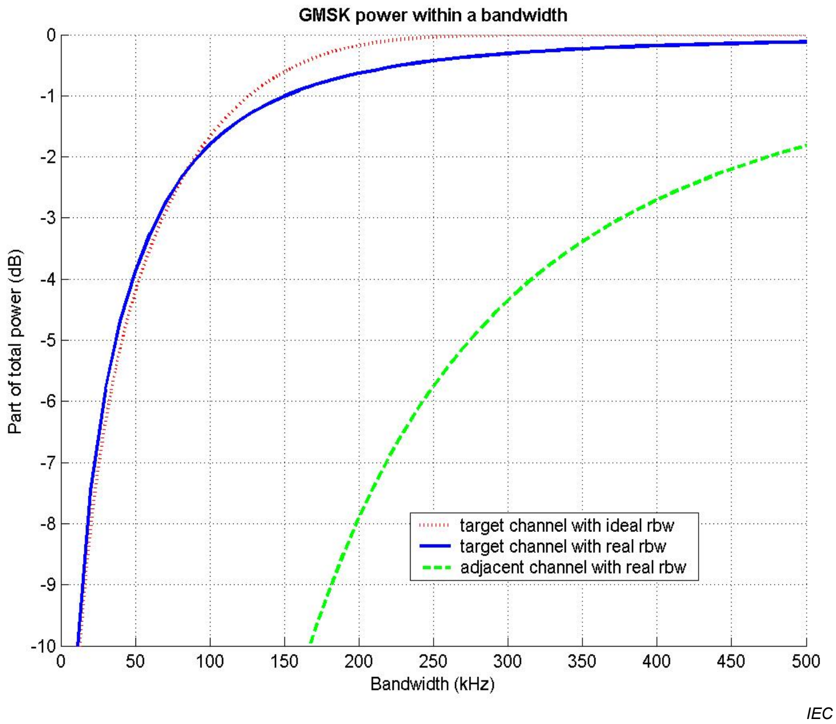


Figure F.1 – Spectral occupancy for GMSK

The real filter shape is obtained using the trace of a pure sine wave signal measured with an RBW equal to 300 kHz. Other filter bandwidths are obtained by extrapolation from this trace, assuming that the shape remains the same. The GMSK signal is given by a signal generator output measured with an RBW equal to 1 kHz and VBW equal to 10 kHz.

On the one hand, an RBW of 300 kHz would include the whole power of the target channel in the case of a perfect filter, but it would result in a loss of 0,3 dB with the real filter that we have used, with a rejection of -4,3 dB of the power of an adjacent channel. On the other hand, an RBW of 100 kHz would entail a loss of 1,8 dB. With an RBW of 200 kHz, the loss for target channel is 0,6 dB and the rejection of an adjacent channel is -7,9 dB.

Figure F.2 presents the frequency occupancy of a UMTS (CDMA) signal. The real filter shape is obtained using the trace of a pure sine wave signal measured with the RBW equal to 5 MHz. Other filter bandwidths are obtained by an extrapolation from this trace, assuming that the shape remains the same. The UMTS signal is given by a signal generator output measured with the RBW equal to 1 kHz and VBW equal to 10 kHz.

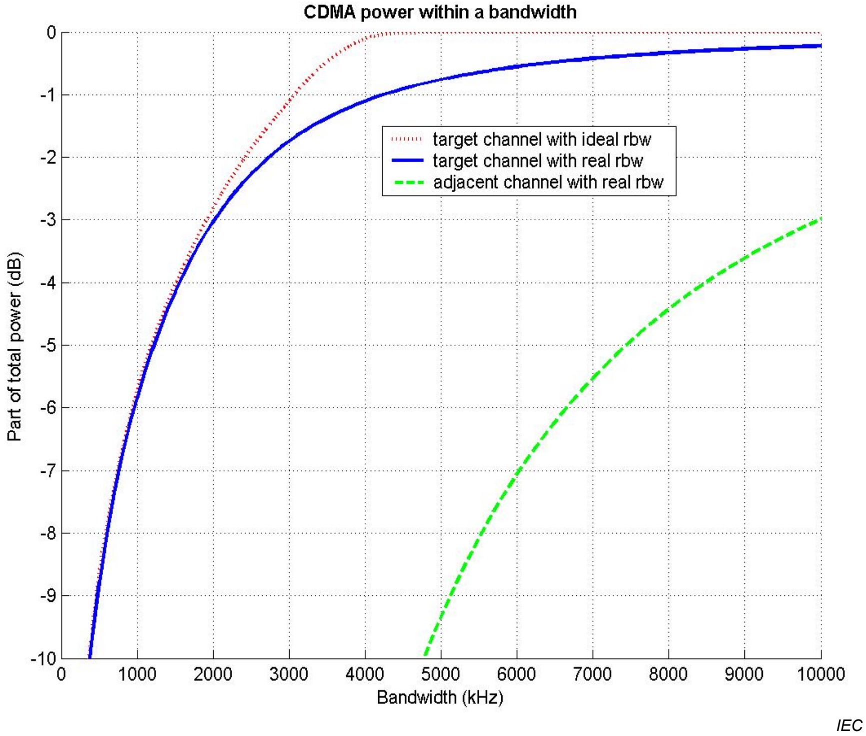


Figure F.2 – Spectral occupancy for CDMA

An RBW of 3 MHz results in a loss of 1,7 dB, and an RBW of 5 MHz results in a loss of 0,8 dB, with a rejection of about -9,3 dB of an adjacent channel. Moreover, as the CDMA signal is a noise-like signal, VBW averaging in log scale may lead to a biased measurement. If the ratio VBW/RBW is high enough (usually 3 or 10), the averaging effect of the VBW filter does not significantly affect power detection accuracy. However, when an appropriate VBW filter is not available, it is important to perform measurements in a linear scale or to use channel power method with a lower RBW.

Finally, if the detection mode "sample" is used, it is important to choose f_{start}, f_{stop} and N so that f_k corresponds to channel carrier frequencies. In this manner, RBW filters will be centred on carrier frequencies. This precaution allows the use of a corrective factor when an appropriate RBW is not available and shall limit inaccuracy in measurements.

NOTE All these results depend on the shape of the RBW filter that is used.

F.3.3.2 Measurement over a bandwidth and channel power processing

For wideband signals or for unknown signals, additional processing is required to establish the channel power. Several samples need to be summed to evaluate the power within a channel or within a whole frequency band. To reduce the effect of filter imperfections, an overlap criterion on RBW has to be verified (see the recommendations of the spectrum analyser manufacturer). Channel power over $\lfloor f_{k1}, f_{k2} \rfloor$ has to be determined in linear scale. Total power p (in dBm) is given by the following relation:

$$p = 10 \cdot \log_{10}\left(\alpha \frac{\delta f}{RBW} \sum_{k_1}^{k_2} 10^{\frac{p_k}{10}} \right) \qquad \text{(F.4)}$$

where α is a fitting parameter to correct RBW imperfections.

$$\alpha = \frac{RBW}{B_{\mathrm{n}}} \tag{F.5}$$

with B_{n} the equivalent noise bandwidth of the filter.

Thus, channel power process simulates the use of a sharp RBW filter of wanted bandwidth.

Finally, spectral contributions whose level is around the measuring equipment's noise level should not be considered in channel power processing. This amounts to a threshold zeroing.

NOTE Measuring equipment with a high noise level will reduce the overall system sensitivity. Moreover, built-in channel power does not allow noise to be removed.

F.3.4 Integration per service

F.3.4.1 Broadband emulation or integration per service

The power channel measurement is not only useful for wideband signals, it can also be used to emulate in post-processing an integrated RF field strength over a frequency band or service, e.g. the whole GSM band. In this case, spectral contributions whose level is around the equipment noise level should not be considered in channel power processing. This amounts to a threshold zeroing.

NOTE Measuring equipment with a high noise level will reduce the overall system sensitivity. Moreover, built-in channel power does not allow noise to be removed.

F.3.4.2 Example of settings

Table F.2 shows the settings for a spectrum analyser with 401 points in a trace, i.e. the SPAN is divided in 400 intervals. The purpose is to perform channel power processing to achieve an integration per service. The presented parameters may have to be modified according to the spectrum analyser used (because of the number of points in a trace, the overlap criterion for channel power, etc.). For the GSM and DCS bands, the RBW filters are centred on the carrier frequencies and an extrapolation processing is also possible instead of a channel power processing. Table F.2 provides further examples.

Table F.2 – Example of spectrum analyser settings for an integration per service

Band	f_{start} (MHz)	f_{stop} (MHz)	RBW (MHz)	VBW (MHz)	Post-processing
FM	80	120	0,3	3	Channel power + denoising
TV	174	230	0,3	3	Channel power + denoising
TV	470,2	670,2	1	3	Channel power + denoising
TV	670,2	870,2	1	3	Channel power + denoising
GSM	925	965	0,3	3	Channel power + denoising or extrapolation
DAB	1 452	1 492	0,3	3	Channel power + denoising
DCS	1 800	1 880	0,3	3	Channel power + denoising or extrapolation
DECT	1 880	1 900	0,1	1	Channel power + denoising
UMTS	2 100	2 180	0,3	3	Channel power + denoising

F.4 Constant power components

F.4.1 TDMA/FDMA technology

TDMA mobile phone technology (e.g. GSM or TETRA) and FDMA mobile phone technology (e.g. TETRAPOL, TACS) utilize a time invariant RBS radio channel that operates at constant full power and can be used as a stable reference.

For example, in the GSM system this constant power channel is known as the Broadcast Control Channel (BCCH). Additional radio channels are utilized as traffic requirements demand. These signals are subject to significant amplitude variation and may be frequency hopping. This requires assumptions to be made to quantify their contribution to the overall RF field. Table F.3 lists constant power components for various technologies.

Table F.3 – Example constant power components for specific TDMA/FDMA technologies

Technology	Constant power component
AMPS/TACS	Control Channel
GSM	BCCH
TETRA	MCCH
TETRAPOL	MCCH

If the traffic channels each operate at a maximum power equal to the constant power component, then a conservative maximum transmit power, P_{max}, can be determined by multiplying the power of the constant power component, P_{const}, by the total number of radio channels (control and traffic) that feed into the antenna, N_{c}.

If P_{max} represents the required assessment configuration, and the RF field strength, power density or SAR of the constant power component has been evaluated, extrapolation is conducted according to B.5.1, and if there are no other parameters relevant, the extrapolation factor, F_{ext}, can be determined as:

$$F_{\text{ext}} = \frac{P_{\text{asmt}}}{P_{\text{eval}}} = \frac{P_{\text{max}}}{P_{\text{const}}} = N_{\text{c}} \qquad \text{(F.6)}$$

If the evaluated RF field strength from the constant component of the signal is E_{const} then the extrapolated maximum RF field strength E_{max} is:

$$E_{\text{max}} = E_{\text{const}}\sqrt{N_{\text{c}}} \qquad \text{(F.7)}$$

F.4.2 WCDMA/UMTS technology

WCDMA/UMTS mobile phone systems use spread spectrum technology employing a constant power control/pilot channel (embedded in the carrier) which has a fixed power relationship to the maximum allocated power. Instruments are available that enable the constant power reference channel (e.g. Common Pilot Channel (CPICH) in UMTS/WCDMA) to be decoded and measured allowing a calculation of maximum RF field strength to be made.

If the ratio of the maximum allocated power to the power in the control channel is β and the measured RF field strength from the control channel is E_{CPICH} then the extrapolated RF field strength is:

$$E_{\text{max}} = E_{\text{CPICH}}\sqrt{\beta} \tag{F.8}$$

If there are M detected and extrapolated CPICH channels, the total extrapolated field, E_{ext} for one carrier frequency can then be expressed as the quadratic sum of all M detected and extrapolated CPICH channels:

$$E_{\text{ext}} = \sqrt{\sum\nolimits_{i=1}^{M}(E_{\text{max}}^{2})_i} \tag{F.9}$$

NOTE The parameters β and M are set by the telecommunications operator. A typical value for β is 10 (i.e. 10 % of total power allocated to CPICH).

F.4.3 OFDM technology

Orthogonal Frequency Division Multiplexing (OFDM) technology has been developed to enhance the capacity related to the total data throughput, see 3GPP TS 36.104 [10], and [68], [69], [70], [71]. It can be implemented using frequency domain duplex (FDD) or time domain duplex (TDD). More detail is provided in F.7 and F.8.

F.5 WCDMA measurement and calibration using a code domain analyser

F.5.1 WCDMA measurements – General

This subsection presents a method for measuring WCDMA (UMTS) signals, see 3GPP TS 25.104, and for the calibration of measurement equipment. Calibration addresses both the absolute (E_c) and the relative (E_c/I_o) level of the CPICH power. Figure F.3 shows the channel allocation for a WCDMA signal. I_o denotes the total received power over 5 MHz. The procedure focuses on both the generator and the WCDMA decoder.

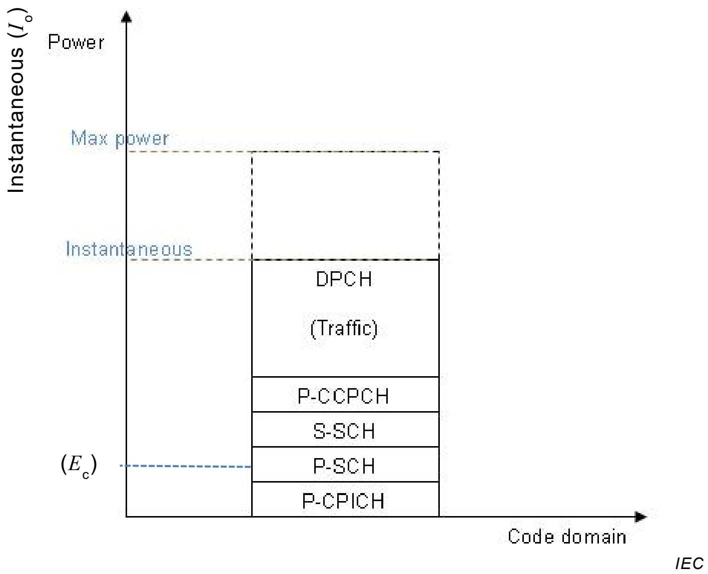


Figure F.3 – Channel allocation for a WCDMA signal

F.5.2 Requirements for the code domain analyser

It is recommended that a code domain analyser is used to perform WCDMA measurement since other WCDMA RBS can operate at the same frequency sharing the same bandwidth. The WCDMA decoder should satisfy the requirements listed in Table F.4.

Table F.4 – WCDMA decoder requirements

WCDMA scanner	
Type	UMTS Scanning and decoding Detection of scrambling codes (SC)
Measuring parameters	The decoder shall measure at least two of the following parameters: • I_o (total received power over 5 MHz centred on the carrier frequency in dBm) • E_c (CPICH absolute power in dBm for one scrambling code) • E_c/I_o (in dB)
Detection mode	r.m.s. and sample
Frequency band	2 110 MHz to 2 170 MHz or as required for national frequency allocation
Number of detected SC	At least 4 per carrier frequency
Scanning mode	Automatic scanning of all scrambling codes per carrier frequency
Dynamic	≥ 66 dB for I_o (power dynamic) ≥ 20 dB for E_c/I_o(decoding dynamic)
Precision	±2 dB
Multi-path (rake fingers)	Sum of all fingers

F.5.3 Calibration

F.5.3.1 Signal types used for calibration

To detect the Primary Pilot Channel (P-CPICH) component of a UMTS signal, at least the synchronization channels named the Primary Synchronization CHannel (P-SCH), the Secondary Synchronization CHannel (S-SCH) and the Primary Common Control Physical CHannel (P-CCPCH) shall be present, too. Further channels may be added for signalling and traffic. The signal configurations described in Table F.5 shall be used.

Table F.5 – Signal configurations

Signal name	**Channel power (dB) in reference to the signal total emitted power, P_{total}**				**Other channels (signalling and traffic)**
	P-CPICH	S-SCH	P-SCH	P-CCPCH	
CP-3.2	-3,2	-3,2	-3,2	-3,2	None
CP-0.5	-0,5	-10,5	-10,5	-10	None
CP-10	-10	-13	-13	-10	DPCH = -0,97 dB
CP-20	-20	-20	-20	-20	DPCH = -0,092 dB

NOTE 1 S-SCH and P-SCH are interleaved within the P-CCPCH.

NOTE 2 All the given values are referenced to the total signal power noted P_{total}.

F.5.3.2 Source (generator) calibration

The configurations listed in Table F.6 shall be used.

Table F.6 – WCDMA generator setting for power linearity

Signal	Total emitted power P_{total} (dBm)	Frequency (GHz)
CP-10	-20	2,14
CP-10	-40	2,14
CP-10	-80	2,14

The total received power shall be measured using a precision thermal power meter or a spectrum analyser directly linked to the generator. In the case of a spectrum analyser, a channel power over 5 MHz should be used. The spectrum analyser or the power meter shall be calibrated with an uncertainty of within ±0,5 dB.

The total deviation between the total emitted power (P_{total}) and the total received power over 5 MHz (I_o) centred on the carrier frequency should not exceed ±1 dB in the calibration power range.

F.5.3.3 WCDMA decoder calibration

The calibration of the WCDMA decoder needs a calibrated source generator and two different approaches can be used to calibrate such a decoder:

- use one single source for the calibration of all the WCDMA devices [72];
- use two or more different generators for performing individual calibration [73].

To verify the frequency response, linearity and influence of traffic channels on the WCDMA decoder, the measurements of P-CPICH channel power are performed under the conditions given in Table F.7:

Table F.7 – WCDMA generator setting for decoder calibration

Signal type	Frequency (GHz)	P_{total} (dBm)	P-CPICH target (dB)	Calibration type
CP-3.2	2,11	-20	-3,2	Frequency response
CP-3.2	2,17	-20	-3,2	Frequency response
CP-3.2	2,14	-10	-3,2	Linearity
CP-3.2	2,14	-30	-3,2	Linearity
CP-3.2	2,14	-40	-3,2	Linearity
CP-3.2	2,14	-50	-3,2	Linearity
CP-0.5	2,14	-20	-0,5	Traffic
CP-10	2,14	-20	-10	Traffic
CP-20	2,14	-20	-20	Traffic

The P-CPICH power is compared to the expected target P-CPICH value, resulting in a calibration factor which shall not exceed 2 dB in all the configurations.

The frequency response of the reflection coefficient is measured with an SWR bridge at the input of the equipment to be calibrated under the conditions in Table F.8.

Table F.8 – WCDMA generator setting for reflection coefficient measurement

Signal type	Frequency (GHz)	P_{total} (dBm)
CP-3.2	2,11	-20
CP-3.2	2,14	-20
CP-3.2	2,17	-20

These measurements are needed to estimate the uncertainty of the measurements.

F.6 Wi-Fi measurements

F.6.1 General

The Wi-Fi signal is a spread-frequency signal emitted with random backoff. Therefore measurement has to be carried out carefully since the signal is noise-like and not permanent. Moreover, most spectrum analysers are not able to record the entire trace. Figure F.4 shows an example of Wi-Fi frames.

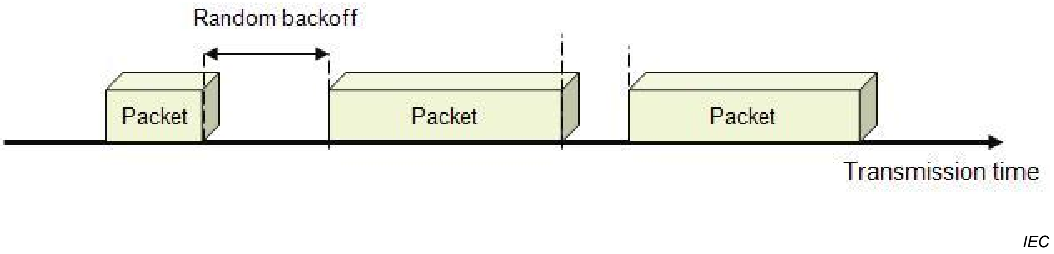


Figure F.4 – Example of Wi-Fi frames

The evaluation of the relevant RF field strength from a Wi-Fi system implies the knowledge of the real emitted power by the EUT. In most commercial IEEE 802.11 devices, the access to the medium is done by a CSMA/CA (Carrier Sense Multiple Access) protocol completed by a random waiting time before retrial, known as back-off time. Even if the maximum output power is constant and known and no power control is performed, the random backoff time makes it impossible to retrieve the emitted power shape over the time for most existing spectrum analysers.

Wi-Fi (802.11) has advanced through several new generations (802.11 a/b/g/n/ac) that are mostly based on OFDM and include MIMO and beamforming.

F.6.2 Integration time for reproducible measurements

The random duration of the backoff time, integrated within the inter-packet delay, makes a deterministic calculation of the channel occupation impossible. Moreover, a sequence of random inter-packet delays will introduce a needed minimum integration time on the random duty cycle or channel occupation. A set of random backoff time values will converge after a minimum observation time has elapsed. Figure F.5 shows how the indicated channel occupation varies with integration time.

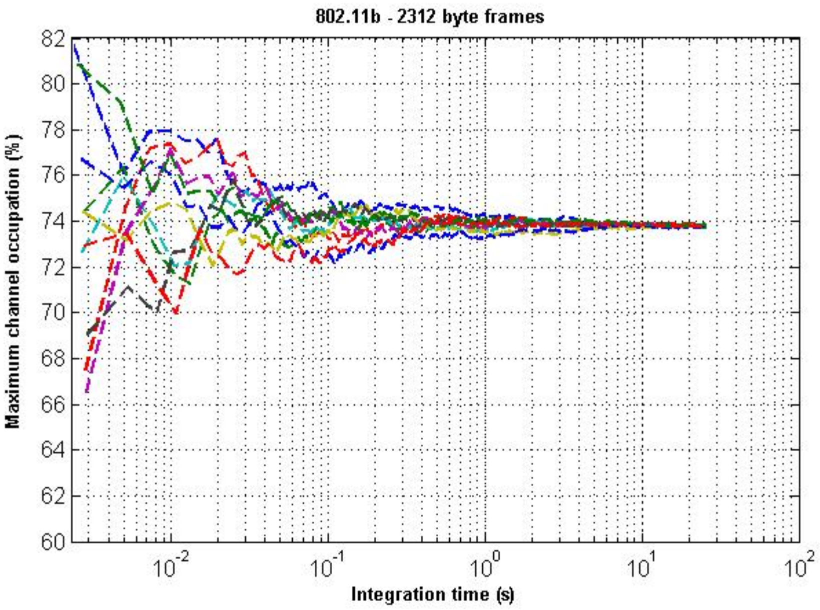


Figure F.5 – Channel occupation versus the integration time for IEEE 802.11b standard

F.6.3 Channel occupation

The packet transmission is done by encapsulating the IP packets into the MAC layer frames. These IP packets carry the application data and transport details from the upper layers and their size is not deterministic. Moreover, the size of the IP packets is usually not known *a priori* unless a controlled traffic generator is used. Our interest is to calculate the emission time over a full observation time. Operating at a fixed maximum throughput, the length of the packets sent into the MAC layer will be an important parameter to be determined. This length will provide the variable time in which the channel is occupied. Figure F.6 shows how channel occupation varies with nominal throughput rate.

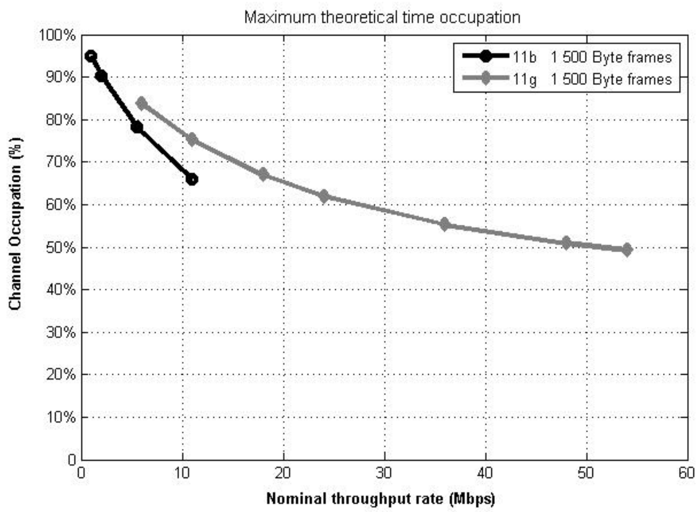


Figure F.6 – Channel occupation versus nominal throughput rate for IEEE 802.11b/g standards

F.6.4 Some considerations

A spectrum analyser is not able to plot the entire trace of a Wi-Fi signal even using the channel power process because of the insufficient resolution bandwidth. The definition of the analyser parameters can enhance the plotting. However, due to the random separation between emissions, or packets, and the minimum sweeping time of the analyser, the plotted trace will have discontinuities while performing a measurement. Yet, the resolution bandwidth of the conventional equipment is an inverse function of the sweep time. An agreement between the 22 MHz minimum needed resolution bandwidth and the minimum sweep time to integrate the full emitted power is not possible. Figure F.7 shows a snapshot of a Wi-Fi spectrum trace.

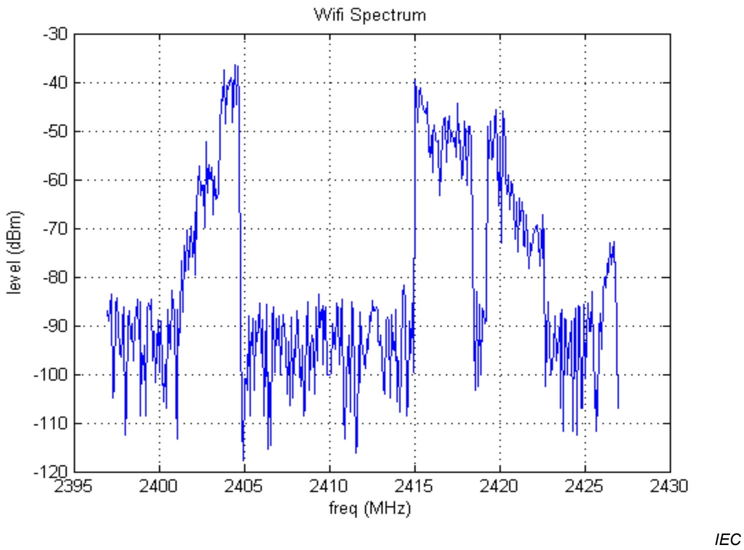


Figure F.7 – Wi-Fi spectrum trace snapshot

F.6.5 Scalability by channel occupation

The maximum output power can be measured either with a sensitive power meter or taking as reference the maximum-hold power trace. This trace would be escalated by the occupation factor in order to get close to the real emitted power.

F.6.6 Influence of the application layers

In ad-hoc networks the traffic can be raised up to the maximum by streaming data packets from one computer to another using the UDP protocol. The reason is that UDP offers a higher channel occupation than TCP by eliminating the error control and acknowledgement delays from the transport layer.

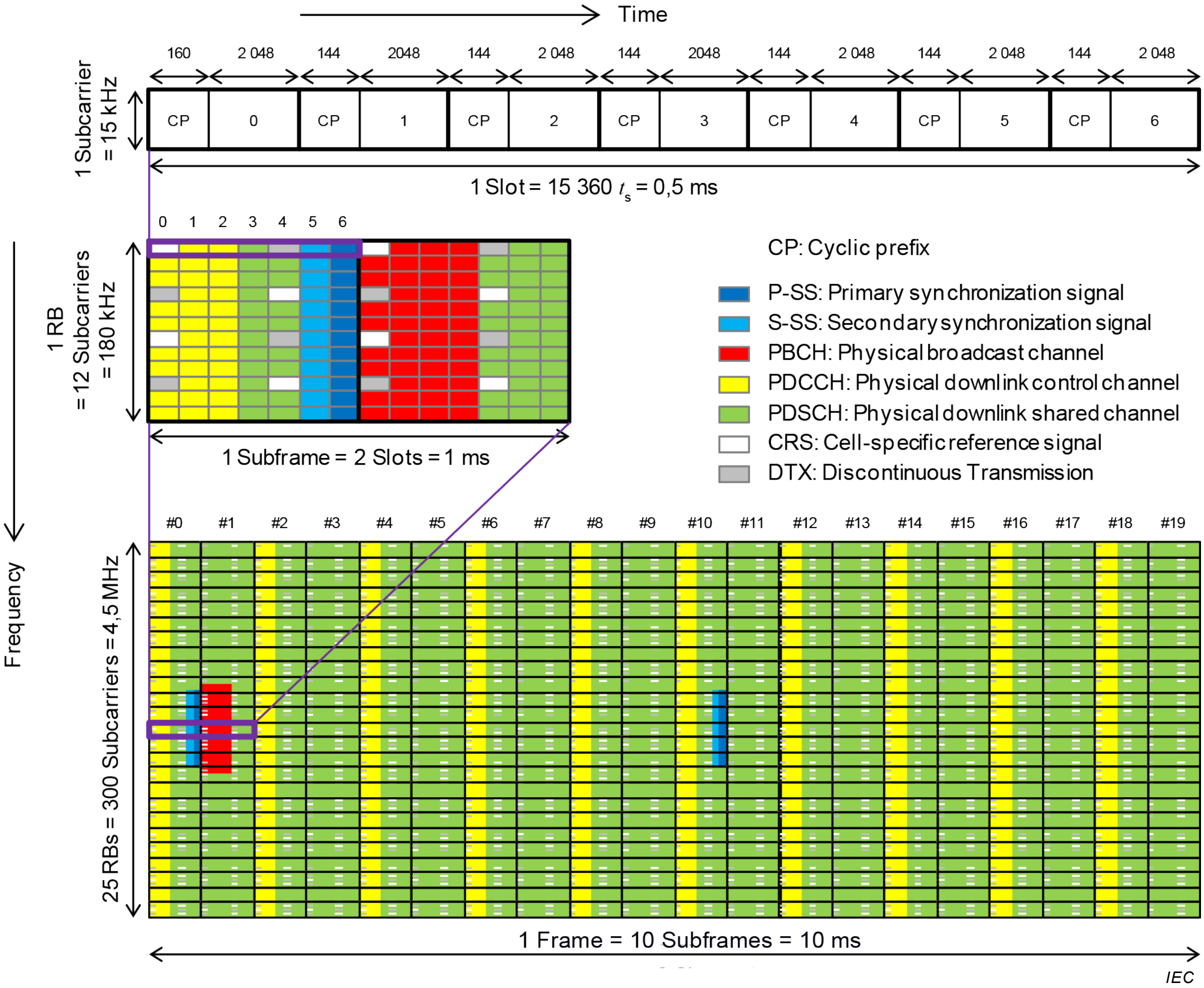
F.7 LTE measurements for Frequency Division Duplexing (FDD)

F.7.1 Overview

LTE mobile phone systems use Orthogonal Frequency Division Multiplexing (OFDM) technology defined in 3GPP TS 36.104 to enhance the capacity related to the total data throughput [68], [69], [70], [71]. Figure F.8 shows the frame structure for the LTE downlink signal. F.7 is based on 3GPP Release 8 specifications. Most recent release may be used where relevant.

The frame in Figure F.8 is composed of resource elements (REs) consisting of one subcarrier in the frequency domain and one OFDM symbol in the time domain. The OFDM spacing between the individual subcarriers in LTE is 15 kHz. There is no frequency guard band between the subcarriers. The OFDM symbol consists of effective data and a guard period called the cyclic prefix (CP) used in the time domain to prevent multipath interference. The LTE slot and subframe are 0,5 ms and 1 ms long in the downlink frame. In LTE, a normal and an extended CP length is possible resulting in seven or six OFDM symbols per slot, respectively. A resource block (RB) consists of 12 subcarriers, with a total bandwidth of 180 kHz, and is transmitted for the duration of one LTE slot. Transmission bandwidth configurations between six and 100 RBs are possible, corresponding to a channel bandwidth between 1,4 MHz and 20 MHz, as shown in Table F.9.

As for other land mobile radio systems, the total transmission power of an LTE base station depends on the amount of communication traffic, and the power level will reach the designed maximum power when the amount of communication traffic is at maximum. Two types of evaluation methods for LTE exposure levels based on measurement are given in F.7.2 and F.7.3. F.7.2 describes evaluation methods for assessing the maximum exposure level using two kinds of measurements and extrapolations. F.7.3 describes an evaluation method for assessing the instantaneous exposure level.



NOTE Different time intervals are defined as multiples of a basic time unit t_s = 1/30 720 000 s.

Figure F.8 – Frame structure of transmission signal for LTE downlink

F.7.2 Maximum LTE exposure evaluation

F.7.2.1 General

F.7.2 describes two evaluation methods based on extrapolation to assess the maximum exposure level from an LTE base station. F.7.2.2 describes an evaluation method using a dedicated decoder. F.7.2.3 describes an evaluation method using a spectrum analyser. Both methods may be used, but in environments with strong selective fading or when evaluating each exposure level from multiple base stations accurately the method using a dedicated decoder is recommended.

To evaluate the exposure level for maximum traffic conditions by extrapolation, it is important that the transmitted power of the received signal or channel is not dependent on the amount of traffic. The reference signal (RS), the Primary Synchronization Signal (P-SS), the Secondary Synchronization Signal (S-SS), and the Physical Broadcast Channel (PBCH) can be used as the received signal in the extrapolation-based evaluation method, because the power levels are constant. The RS is well suited for this because the locations of the LTE Reference Signals (RSs) are uniformly distributed over the occupied radio bandwidth to reduce effects of frequency selective fading.The RS represents the cell-specific reference signal (CRS), which is one type of reference signal.

F.7.2.2 Method using a dedicated decoder

In this method, the field strength corresponding to the RS[8] of an LTE cell is measured. If multiple antennas are used for transmission by the same cell (MIMO), the RS should be determined for each antenna (or antenna port). This type of measurement requires dedicated LTE decoders or LTE analysers.

The measurements require that the system bandwidth and centre frequency of the target LTE carrier is set. The maximum electric field strength (V/m), E_{max}, is:

$$E_{\text{max}} = \sqrt{N_{\text{RS}}} \cdot E_{\text{RS}} \tag{F.10}$$

where:

E_{RS} is the field level (V/m) of the RS;

N_{RS} is the extrapolation factor for the RS, which is the ratio of the maximum transmission power to transmission power corresponding to the RS.

In the case of a MIMO antenna system, operated with large-delay cyclic delay diversity (CDD) or Tx diversity, Equation (F.10) above may be modified as:

$$E_{\text{max}} = \sqrt{\frac{N_{\text{RS}}}{F_{\text{B}}}} \cdot \sqrt{\sum_i E_{\text{RS},\,i}^2}\ , \tag{F.11}$$

where $E_{\text{RS},\,i}$ denotes the electric field strength (V/m) from branch i of the MIMO antenna and the sum is taken over all branches.

Here it is assumed that the transmitted fields associated with each branch may be treated as uncorrelated, see F.7.4. F_{B} denotes the power boosting factor for the RS. This value may be obtained from the operator.

Considering the frame structure for the LTE downlink described in F.7.1, N_{RS} corresponds to the number of subcarriers for the system bandwidth of the target base station. The theoretical extrapolation factor, N_{RS}, for each system bandwidth is shown in Table F.9, when all subcarriers are at the same power level.

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8 The RS field strength is measured as the linear average over the field strength contributions of all resource elements that carry the RS within the operating bandwidth. Thus, the measured value corresponds to the average power transmitted for one subcarrier.

Table F.9 – Theoretical extrapolation factor, N_{RS}, based on frame structure given in 3GPP TS 36.104 [10]

Channel bandwidth (MHz)	**Number of resource blocks**	**Transmission bandwidth** (MHz)	N_{RS} **= extrapolation factor for RS (linear/dB)**
1,4	6	1,08	72 / 18,57
3	15	2,7	180 / 22,55
5	25	4,5	300 / 24,77
10	50	9,0	600 / 27,78
15	75	13,5	900 / 29,54
20	100	18,0	1 200 / 30,79

F.7.2.3 Method using a basic spectrum analyser

A basic spectrum analyser (SA) is less expensive and more commonly available compared with a dedicated LTE decoder. However, when using a basic SA, the powers of the RSs cannot be accurately detected since they are transmitted on single resource elements spread in frequency and time.

To overcome this issue and to avoid requirements on access to prior knowledge regarding band occupation or service characteristics, the PBCH power can be measured. The PBCH is transmitted with the same characteristics regardless of the configuration or service bandwidth and spans a bandwidth of six RBs (approximately 1 MHz) over the centre frequency of the LTE signal.

Note that the signal from each LTE base station cannot be identified using this method due to frequency spectrum overlapping.

The PBCH power should be measured using the following SA configuration.

- The centre frequency of the spectrum analyser should be equal to the centre frequency of the LTE signal.
- The frequency span should be set to zero (scope mode) in order to measure the received time signal for the downlink emission frequency.
- A resolution bandwidth (RBW) of 1 MHz should be set to integrate the signal over the PBCH spectral spread.
- The sweep time should be set equal to approximately the product of the number of display points of the SA and the symbol duration (approximately 70 µs) in order to obtain an integration time close to the symbol duration of each pixel on the screen of the SA, e.g. a sweep time of approximately 70 ms for an SA with 1 000 display points (or equivalent ratio for instruments with lower display resolution).
- The detector should be set to root-mean-square (r.m.s.).
- The trace type should be set to maximum hold using a minimum sweep time of 20 s.

In order to use the r.m.s. detector, the maximum power shall be effectively allocated to the PBCH channel.

The measured peak power, P_{PBCH}, corresponds to the received PBCH signal power over the bandwidth of six RBs (72 subcarriers).The electric field strength of the PBCH signal, E_{PBCH}, is determined from P_{PBCH}. The maximum electric field strength, E_{max}, of the LTE signal at each measurement location is given by

$$E_{max} = \sqrt{N_{PBCH}} \cdot E_{PBCH} , \qquad (F.12)$$

where N_{PBCH} is the extrapolation factor for the PBCH, which is the ratio of the maximum transmission power to the transmission power corresponding to the PBCH over six RBs. N_{PBCH} can be provided by the network operator or can be calculated theoretically according to

$$N_{\text{PBCH}} = \frac{N_{\text{RS}}}{72}, \tag{F.13}$$

where N_{RS} denotes the number of subcarriers in the used transmission bandwidth, see Table F.9.

Figure F.9 shows measurement examples of an LTE downlink signal using the spectrum analyser with a zero span, 550 sampling points, a sweep time of 39 ms (70 µs × 550), and the resolution bandwidth of 1 MHz. Figure F.9 a) and b) show the results for low and medium traffic level environments with a single sweep, respectively. Figure F.9 c) shows the received signal after the sweep of 20 s regardless of the amount of traffic.

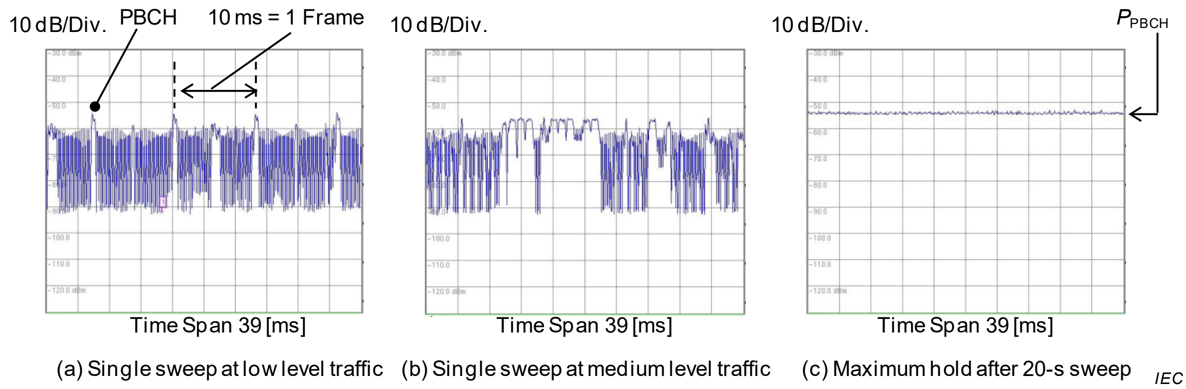


Figure F.9 – Examples of received waves from LTE downlink signals using a spectrum analyser using zero span mode

F.7.3 Instantaneous LTE exposure evaluation

For the appropriate settings of measurements of momentary or instantaneous LTE exposure, an SA and suitable antenna probes are needed.

The SA settings have a huge influence on the measurement results and it is very important to specify these to determine the optimal settings to perform RF exposure evaluation of LTE signals. The following optimal settings to perform exposure evaluation for LTE are proposed in [74]: r.m.s detector, resolution bandwidth (RBW) = 1 MHz, sweep time = 20 s, and appropriate selection of the frequency span, e.g. 50 MHz. These settings were determined and tested in the laboratory and in-situ [74].

F.7.4 MIMO multiplexing of LTE base station

LTE introduces Multiple Input Multiple Output (MIMO) multiplexing to increase the system capacity and data throughput. When conducting an exposure evaluation, the multiple RF sources shall be considered. If four-layer MIMO multiplexing is employed, the number of RF sources is equal to four on the same RF frequency band. IEC TR 62630 describes a method for combining multiple RF sources [63]. The combination method depends heavily on the correlation between the RF sources. There are some options for LTE regarding the MIMO transmission mode, i.e. Tx diversity, large-delay CDD, and closed-loop spatial multiplexing. In [76], no correlation between the fields associated with different MIMO branches employed in large-delay CDD or Tx diversity was observed. In this transmission mode, the simple power sum method is applicable as the combination method to evaluate the total field strength as described in IEC TR 62630 [63]. On the other hand, if a correlation between the signals from

MIMO branches is found, applying the first or second conservative method given in IEC TR 62630 [63] should be considered to evaluate the total field strength. See also F.8.

F.8 LTE measurements for Time Division Duplexing (TDD)

F.8.1 General

In 3GPP TS 36.211 [71], there are two types of frame structure for LTE. The frame structure type 1 is applicable to FDD, and the frame structure type 2 is applicable to TDD. In general, the exposure evaluation methods recommended are applicable to the TDD case because of similar frame structure.

F.8.2 Definitions and transmission modes

F.8.2.1 General

RF exposure evaluation of TD-LTE BS using a smart antenna (MIMO antenna) is more complex than with the TD-SCDMA system. The TD-LTE system includes antenna beam forming that can follow the users, while TD-SCDMA system includes only fixed beam. TD-LTE also has multiple transmission modes compared to TD-SCDMA. So, the protocols used with TD-LTE need to be more advanced than TD-SCDMA.

In TD-LTE, the UE is configured by higher layer to decode PDCCH using different RNTI, such as SI-TNTI, P-RNTI, RA-RNTI, C-RNTI, SPS C-RNTI and temporary C-RNTI. The RNTI used by scrambling initialization of PDSCH is the same as the corresponding PDCCH. The various RNTI are used for different access and transmission procedure.

In TD-LTE Release 9, the UE is semi-statically configured to receive PDSCH data transmissions according to one of eight transmission modes, i.e. TM1 to TM8, as follows:

F.8.2.2 Transmission mode 1

The scheme of PDSCH is single-antenna port transmission, using port 0. DCI format 1A of PDCCH can be used for common and UE specific, or format 1 for UE specific search space.

F.8.2.3 Transmission mode 2

The scheme of PDSCH is diversity transmission. DCI format 1A of PDCCH can be used for common and UE specific, or format 1 for UE specific search space.

For diversity scheme, the layer mapping shall be done according to different antenna ports and pre-coding for diversity is used in combination with layer mapping.

F.8.2.4 Transmission mode 3

The scheme of PDSCH includes diversity and large delay CDD transmission. For diversity scheme, DCI format 1A of PDCCH can be used for common and UE specific search space. For diversity or large delay CDD scheme, DCI format 2A of PDCCH can be used for UE specific search space.

For large delay CDD scheme, the layer mapping and pre-coding are different depending on the antenna ports.

F.8.2.5 Transmission mode 4

The scheme of PDSCH includes diversity and closed-loop spatial multiplexing transmission. For diversity scheme, DCI format 1A of PDCCH can be used for common and UE specific search space. For diversity or closed-loop spatial multiplexing scheme, DCI format 2 of PDCCH can be used for UE specific search space.

For closed-loop spatial multiplexing scheme, the layer mapping is the same as that of large delay CDD, but different for pre-coding.

F.8.2.6 Transmission mode 5

The scheme of PDSCH includes diversity and multi-user MIMO transmission. For diversity, DCI format 1A of PDCCH can be used for common and UE specific search space. For multi-user MIMO, DCI format 1D of PDCCH can be used for UE specific search space, and the UE may assume that an eNodeB transmission on the PDSCH would be performed on single layer.

F.8.2.7 Transmission mode 6

The scheme of PDSCH includes diversity and closed-loop spatial multiplexing using a single transmission layer. For diversity, DCI format 1A of PDCCH can be used for common and UE specific search space. For closed-loop spatial multiplexing using a single transmission layer, DCI format 1B of PDCCH can be used for UE specific search space.

F.8.2.8 Transmission mode 7

The scheme of PDSCH includes diversity and single-antenna port using port 0 or 5. For diversity or single-antenna port using port 0, DCI format 1A of PDCCH can be used for common and UE specific search space. For single-antenna port using port 5, DCI format 1 of PDCCH can be used for UE specific search space.

F.8.2.9 Transmission mode 8

The scheme of PDSCH includes diversity, single-antenna port using port 0 or 7 or 8, dual layer transmission. For diversity or single-antenna port using port 0, DCI format 1A of PDCCH can be used for common and UE specific search space. For single-antenna port using port 7 or 8 and dual layer transmission, DCI format 2B of PDCCH can be used for UE specific search space.

For the dual layer transmission scheme of the PDSCH, the UE may assume that an eNodeB transmission on the PDSCH would be performed with two transmission layers on antenna ports 7 and 8.

Within a transmission mode, there are different transmission schemes which can be adopted depending on different wireless environment.

F.8.3 TDD frame structure

The frame structure is shown in Figure F.10. Type 2 is applicable to TDD. Each radio frame of length $T_\mathrm{f} = 307\,200\, T_\mathrm{s} = 10\,\mathrm{ms}$ consists of two half-frames of length $153\,600\, T_\mathrm{s} = 5\,\mathrm{ms}$ each. Each half-frame consists of five subframes of length $30\,720\, T_\mathrm{s} = 1\,\mathrm{ms}$.

The supported uplink-downlink configurations are listed in Figure F.11 where, for each subframe in a radio frame, “D” denotes the subframe is reserved for downlink transmissions, “U” denotes the subframe is reserved for uplink transmissions and “S” denotes a special subframe with the three fields DwPTS, GP and UpPTS. The length of DwPTS and UpPTS is given by Table F.10 subject to the total length of DwPTS, GP and UpPTS being equal to $30\,720\, T_\mathrm{s} = 1\,\mathrm{ms}$ .Each subframe i is defined as two slots, $2i$ and $2i+1$ of length $T_\mathrm{slot} = 15\,360\, T_\mathrm{s} = 0{,}5\,\mathrm{ms}$ in each subframe.

Uplink-downlink configurations with both 5 ms and 10 ms downlink-to-uplink switch-point periodicity are supported. In case of 5 ms downlink-to-uplink switch-point periodicity, the special subframe exists in both half-frames. In case of 10 ms downlink-to-uplink switch-point periodicity, the special subframe exists in the first half-frame only.

Subframes 0 and 5 and DwPTS are always reserved for downlink transmission. UpPTS and the subframe immediately following the special subframe are always reserved for uplink transmission.

In case multiple cells are aggregated, the UE may assume the same uplink-downlink configuration across all the cells and that the guard period of the special subframe in the different cells has an overlap of at least 1 456 T_s.

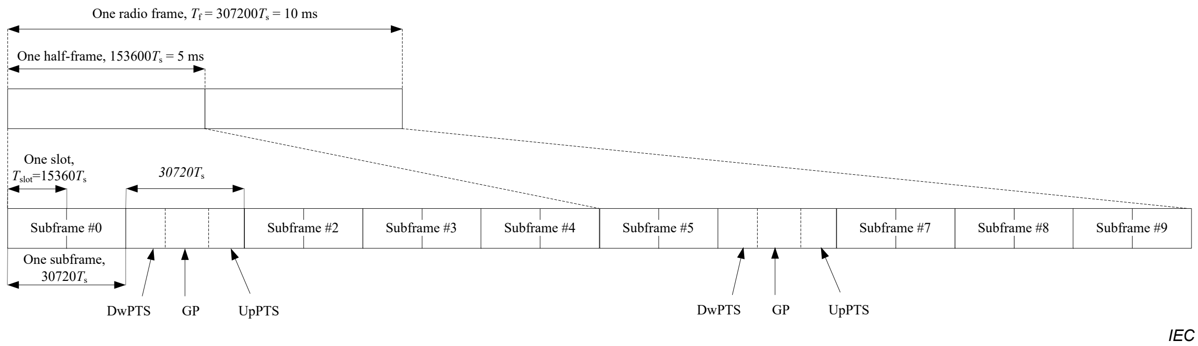


Figure F.10 – Frame structure type 2 (for 5 ms switch-point periodicity)

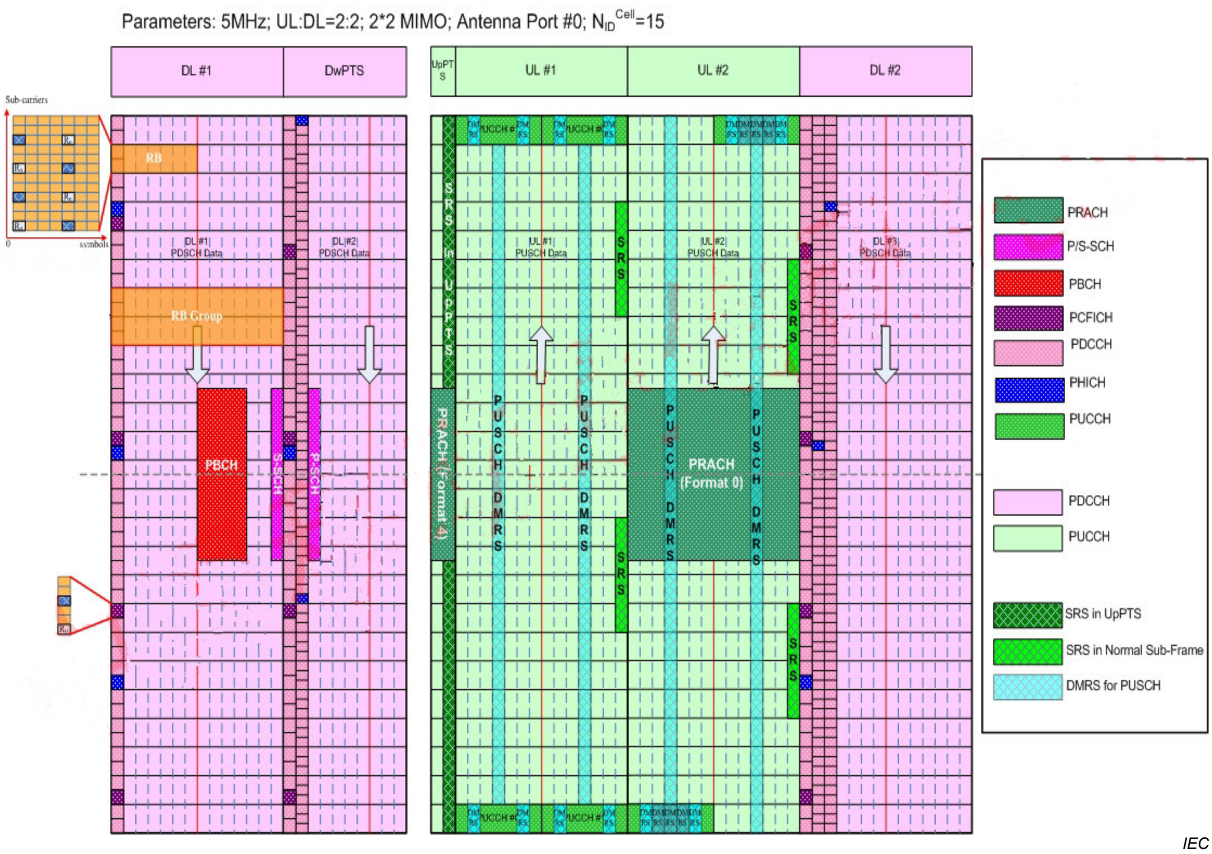


Figure F.11 – Frame structure of transmission signal for TDD LTE

Table F.10 – Configuration of special subframe (lengths of DwPTS/GP/UpPTS)

<table>
<tr><th rowspan="3">Special subframe configuration</th><th colspan="3">Normal cyclic prefix in downlink</th><th colspan="3">Extended cyclic prefix in downlink</th></tr>
<tr><th rowspan="2">DwPTS</th><th colspan="2">UpPTS</th><th rowspan="2">DwPTS</th><th colspan="2">UpPTS</th></tr>
<tr><th>Normal cyclic prefix in uplink</th><th>Extended cyclic prefix in uplink</th><th>Normal cyclic prefix in uplink</th><th>Extended cyclic prefix in uplink</th></tr>
<tr><td>0</td><td>$6592 \cdot T_s$</td><td rowspan="5">$2192 \cdot T_s$</td><td rowspan="5">$2560 \cdot T_s$</td><td>$7680 \cdot T_s$</td><td rowspan="4">$2192 \cdot T_s$</td><td rowspan="4">$2560 \cdot T_s$</td></tr>
<tr><td>1</td><td>$19760 \cdot T_s$</td><td>$20480 \cdot T_s$</td></tr>
<tr><td>2</td><td>$21952 \cdot T_s$</td><td>$23040 \cdot T_s$</td></tr>
<tr><td>3</td><td>$24144 \cdot T_s$</td><td>$25600 \cdot T_s$</td></tr>
<tr><td>4</td><td>$26336 \cdot T_s$</td><td>$7680 \cdot T_s$</td><td rowspan="3">$4384 \cdot T_s$</td><td rowspan="3">$5120 \cdot T_s$</td></tr>
<tr><td>5</td><td>$6592 \cdot T_s$</td><td rowspan="4">$4384 \cdot T_s$</td><td rowspan="4">$5120 \cdot T_s$</td><td>$20480 \cdot T_s$</td></tr>
<tr><td>6</td><td>$19760 \cdot T_s$</td><td>$23040 \cdot T_s$</td></tr>
<tr><td>7</td><td>$21952 \cdot T_s$</td><td>-</td><td>-</td><td>-</td></tr>
<tr><td>8</td><td>$24144 \cdot T_s$</td><td>-</td><td>-</td><td>-</td></tr>
</table>

Table F.11 – Uplink-downlink configurations

Uplink-downlink configuration	Downlink-to-uplink switch-point periodicity	Subframe number									
		0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
0	5 ms	D	S	U	U	U	D	S	U	U	U
1	5 ms	D	S	U	U	D	D	S	U	U	D
2	5 ms	D	S	U	D	D	D	S	U	D	D
3	10 ms	D	S	U	U	U	D	D	D	D	D
4	10 ms	D	S	U	U	D	D	D	D	D	D
5	10 ms	D	S	U	D	D	D	D	D	D	D
6	5 ms	D	S	U	U	U	D	S	U	U	D

F.8.4 Maximum LTE exposure evaluation

F.8.4.1 Method using an LTE signal analyser

In this method, the field strength corresponding to the RS of an LTE cell is measured. If multiple antennas are used for transmission by the same cell (MIMO), the RS should be determined for each antenna (or antenna port). This type of measurement requires dedicated LTE decoders or LTE analysers.

NOTE The RS field strength is measured as the linear average over the field strength contributions of all resource elements that carry the RS within the operating bandwidth. Thus, the measured value corresponds to the average power transmitted for one subcarrier.

In case of TDD with traditional antenna, the maximum electric field strength (V/m), E_{max}, can also be expressed as:

$$E_{max} = \sqrt{\frac{N_{RS}}{F_B}} \cdot E_{RS} \tag{F.14}$$

In case of TDD with smart antenna, the maximum electric field strength (V/m), E_{max}, can also be expressed as:

$$E_{\text{max}} = \sqrt{\frac{N_{\text{RS}} \cdot D}{F_{\text{B}}}} \cdot E_{\text{RS}} \tag{F.15}$$

where:

E_{RS} is the field level (V/m) of the RS per RE;

N_{RS} is the extrapolation factor for the RS, which is the ratio of the maximum transmission power to transmission power corresponding to the RS per RE;

F_{B} is the boosting factor for the RS;

D is the beam forming gain of smart antenna.

The RS power should be measured using the following SA configuration.

- The centre frequency of the spectrum analyser should be equal to the centre frequency of the LTE signal.
- The bandwidth setting depends on the BTS under test signal.
- The antenna setting depends on the BTS under test signal.

Considering the frame structure for the LTE downlink described in F.8.3, N_{RS} corresponds to the number of subcarriers for the system bandwidth of the target base station. The theoretical extrapolation factor, N_{RS}, for each system bandwidth is shown in Table F.9, when all subcarriers are at the same power level. RS power per resource element measurement example is shown in Figure F.12.

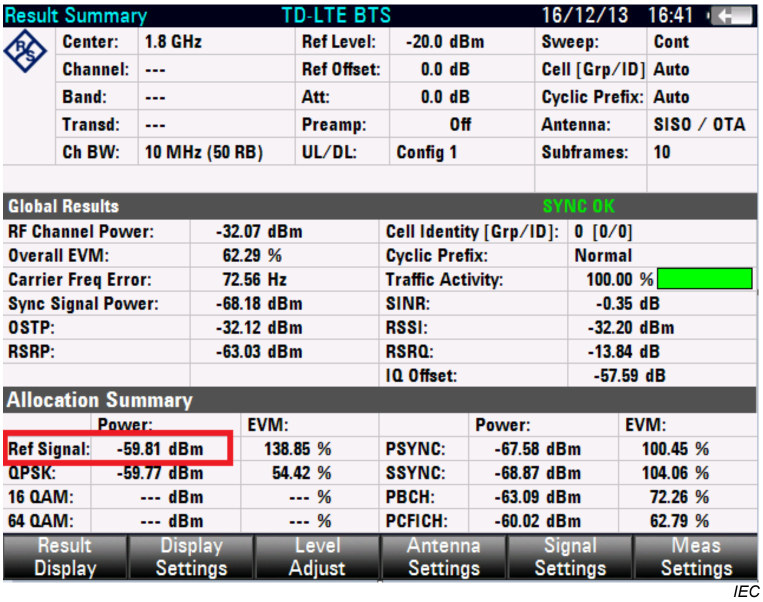


Figure F.12 – PBCH measurement example

F.8.4.2 Method using a basic spectrum analyser

A basic spectrum analyser (SA) is less expensive and more commonly available compared with a dedicated LTE decoder. However, when using a basic SA, the powers of the RSs cannot be accurately detected since they are transmitted on single resource elements spread in frequency and time.

LTE signal measurement should be based on F.7.2.3. It is difficult to directly detect the power of the RSs, however the PBCH can be measured using a spectrum analyser and extrapolation factor for the PBCH as stated in F.7.2.3. It is well known that a spectrum analyser cannot distinguish uplink signals from downlink signals in TDD mode. The spectrum analyser cannot distinguish PBCH signal from PRACH; therefore, in general, the SA method for FDD case cannot be applied to TDD case. However if we are located close to base station and away from mobile terminals, the signals from mobile terminals can be neglected. In this case, the SA method can be applied to TDD case.

Note that when we detect PBCH in TDD with a spectrum analyser, we should guarantee there are no mobile terminals nearby in order to avoid interference of PBCH signal from downlink by PRACH from uplink.

The PBCH power should be measured using the following SA configuration.

- The centre frequency of the spectrum analyser should be equal to the centre frequency of the LTE signal.

The maximum electric field strength, E_{max}, of the LTE signal at each measurement location is given by

$$E_{\text{max}} = \sqrt{N_{\text{PBCH}}} \times E_{\text{PBCH}}\,, \tag{F.16}$$

where N_{PBCH} is the extrapolation factor for the PBCH, which is the ratio of the maximum transmission power to the transmission power corresponding to the PBCH over six RBs.

To overcome this issue and to avoid requirements on access to prior knowledge regarding band occupation or service characteristics, the PBCH power can be measured. The PBCH is transmitted with the same characteristics regardless of the configuration or service bandwidth and spans a bandwidth of six RBs (approximately 1 MHz) over the centre frequency of the LTE signal.

Please note that the signal from each LTE base station cannot be identified using this method due to frequency spectrum overlapping.

The PaBCH power should be measured using the following SA configuration.

- The centre frequency of the spectrum analyser should be equal to the centre frequency of the LTE signal.
- The frequency span should be set to zero (scope mode) in order to measure the received time signal for the downlink emission frequency.
- A resolution bandwidth (RBW) of 1 MHz should be set to integrate the signal over the PBCH spectral spread.
- The detector should be set to root-mean-square (r.m.s.).
- The trace type should be set to maximum hold using a minimum sweep time of 20 s.

In order to use the r.m.s. detector, the maximum power shall be effectively allocated to the PBCH channel.

The measured peak power, P_{PBCH}, corresponds to the received PBCH signal power over the bandwidth of six RBs (72 subcarriers). The electric field strength of the PBCH signal, E_{PBCH}, is determined from P_{PBCH}. The maximum electric field strength, E_{max}, of the LTE signal at each measurement location is given by:

$$E_{\text{max}} = \sqrt{N_{\text{PBCH}}} \times E_{\text{PBCH}} \tag{F.17}$$

where N_{PBCH} is the extrapolation factor for the PBCH, which is the ratio of the maximum transmission power to the transmission power corresponding to the PBCH over six RBs.

N_{PBCH} can be provided by the network operator or can be calculated theoretically according to:

$$N_{\text{PBCH}} = \frac{N_{\text{RS}}}{72} \tag{F.18}$$

where N_{RS} denotes the number of subcarriers in the used transmission bandwidth, see Table F.9.

Figure F.13 shows measurement examples of PBCH power with spectrum analyser using zero span.

Figure F.13 – PBCH measurement example spectrum analyser using zero span mode

F.9 Establishing compliance boundaries using numerical simulations of MIMO array antennas emitting correlated wave-forms

F.9.1 General

To enhance system performance and service capabilities, multiple input multiple output (MIMO) transmission schemes, employed together with multiple antennas at the transmitter and receiver, may be used. When assessing exposure from multiple electromagnetic sources the different contributions have to be combined. In this context it is important to first determine whether the fields in the point of investigation shall be regarded as correlated or uncorrelated.

The compliance boundaries of MIMO array antennas with densely packed columns emitting correlated waveforms, see Figure F.14, can be evaluated using calculation methods and the requirements defined in 6.1. Both the case when all excited ports correspond to the same nominal polarization (denoted Co-pol case) and the case when the excited ports correspond to orthogonal nominal polarizations (denoted X-pol case) are considered.

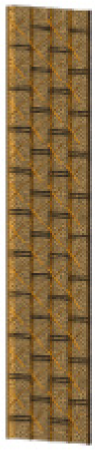


Figure F.14 – MIMO array antenna with densely packed columns

Complementary information on the technical background can be found in [63], [75] and [76].

F.9.2 Field combining near radio base stations for correlated exposure with the purpose of establishing compliance boundaries

As mentioned in B.6, accurate field combination of correlated fields involves a vector-summation of the individual field components which need to be known to both amplitude and phase.

For array antennas it is well known that beams may be formed towards a target receiver by changing the excitation coefficients. The resulting increase of the received power may be used to enhance the performance of the communication channel. Beam-forming can either be performed by selecting the excitation vector from a set of pre-defined vectors, also known as codebook-based beam-forming, or by applying an arbitrary excitation at the transmitter side.

Usually, the RF exposure is to be time-averaged over several minutes before being compared with applicable exposure limits. Depending on the traffic and radio conditions, the excitation coefficients will in most cases vary over a much shorter time frame, which makes a straightforward application of the true vector sum unpractical to work with. Instead, a conservative approach may be adopted where the exposure is maximized for every evaluation point according to the field combining method considered. Even though this resulting field distribution in the vicinity of the antenna is not physically realizable for any single array excitation, the approach is justified by the objective to determine a conservative compliance boundary. The approach has the advantage that knowledge of the exact excitations is not needed, which simplifies the exposure evaluation.

For the case when the amplitude distribution of the excitation is fixed and known but the phase may vary arbitrarily, a conservative approach based on the summation of field strength magnitudes was presented in [63]. Using this method, the combined electric field strength can be written as

$$E_{\text{rms}}(r) \leq \sum_{n=1}^{N} \left| w_n \left| E_n(r) \right|_{\text{rms'}} \right| \text{ (Magnitude method)} \tag{F.19}$$

Where w_n denotes the complex excitation coefficients associated with port n and N denotes the total number of ports. In the following this method is referred to as the Magnitude method. For the case where the excitations may vary in both amplitude and phase for a fixed transmitted power, it is possible to analytically determine an optimal set of weight coefficients per evaluation point which will maximize the combined field strength. The combined electric field strength can then be obtained as:

$$E_{\text{rms}}(r) = \left| \sum_{n=1}^{N} w_n^{\text{opt}} E_n(r) \right|_{\text{rms}}, \quad \text{(Optimal Weights method)} \tag{F.20}$$

where the optimal set of weights $w^{\text{opt}} = \left(w_1^{\text{opt}},\ldots,w_N^{\text{opt}}\right)$ is to be determined as the eigenvector corresponding to the largest eigenvalue of the $N \times N$ matrix P with elements:

$$P_{mn}(r) = E_m^*(r) \times E_n^*(r) \qquad m = 1\ldots N,\ \ n = 1\ldots.N \tag{F.21}$$

In the following, this approach is denoted as the Optimal Weights method.

F.9.3 Numerical simulations of MIMO array antennas with densely packed columns

For the considered antenna type, the distance between the array columns can be quite small, typically around 0,5 wavelengths. As a consequence, it becomes important to consider effects of mutual coupling between the antenna elements in the numerical simulations. At the same time it is desirable to obtain field distributions for each port separately to be able to apply the field combination methods outlined above. To satisfy both these requirements an embedded pattern approach may be used where each port is excited and simulated separately with the other ports terminated in matched loads.

In situations where both the amplitude and the phase of the excitation may vary, the Optimal Weights method may be used to provide an upper bound of the combined field strengths levels for both Co-pol and X-pol configurations.

For situations where the excitation amplitudes are fixed but the phases may vary, different approaches are applicable for Co-pol and X-pol configurations. For Co-pol configurations, a straightforward application of the conservative Magnitude method has been found to produce only a minor over-estimation of the compliance boundary dimensions compared with a best estimate method.

A similar application of the Magnitude method for the X-pol case leads to a significant overestimation of the front compliance distance. The reason is that fields associated with ports of different antenna polarization are essentially uncorrelated in this direction. Instead, the following approach may be used, which has been found to produce conservative and accurate results compared with a best estimate method.

- Columns/ports corresponding to one of the nominal polarizations (e.g. +45°) are simulated and the corresponding field strengths in the vicinity of the base station antenna are calculated.
- The power per port, compared with the case when all ports are excited, is doubled. Here it is assumed that the number of +45° ports equals the number of −45° ports.
- The fields are combined using the Magnitude method.

F.9.4 Numerical simulations of large MIMO array antennas

For an array antenna with N ports, the approach described in F.9.3 implies that field strength results from N separate embedded element simulations are required. For large antenna arrays, this procedure becomes very costly in terms of computational resources.

In large array antennas, many of the elements are surrounded by other elements and therefore sense a similar electromagnetic environment. For these antenna arrays an approximate approach may be used whereby the total transmitted field is constructed by summing the spatially shifted field distribution of a centrally located element [78]. Optionally, to better consider effects of the edge and corner elements, the centre element solution may for elements located on the outer rim of the array be replaced by the corresponding field distributions for an edge and a corner element as applicable.

In [78], it was found that for arrays with 5×5 elements or more, the approximate solution based on the spatially shifted field distribution of a centrally located element resulted in a relative error magnitude in terms of front compliance distance of less than 5 %. The improvement in evaluation time, compared with the rigorous embedded element simulation approach described in F.9.3, is proportional to the number of ports in the array.

F.10 Smart antennas

F.10.1 Overview

Smart antenna systems can be deployed in telecommunications (e.g. TD-SCDMA) networks to reduce interference. Smart antennas produce a number of simultaneous narrow beamwidths directed to individual users to optimize communications. The power fed to the antenna is therefore split between users and the instantaneous directivity adjusted; i.e. smart antennas have different directivity for each individual communications channel. Therefore, if the RF field strength is evaluated in one fixed position near the base station, the measured value will vary significantly from time to time.

For a compliance evaluation, the requirement is to define the set of conservative RBS parameters for an RBS under normal use, i.e. non-fault conditions. This requires a detailed analysis specific to the employed technology and with due consideration for any site-specific factors.

F.10.2 Deterministic conservative approach

The gain per user may be several decibels higher than the equivalent average gain over all channels. A very conservative case can be derived from the maximum gain in any direction and the total radiated power. This would be equivalent to having all communications channels operating at maximum power and all the individual directed beams aligned towards the evaluation point. This is not usually a realistic case, but it may be simple to apply.

F.10.3 Statistical conservative approach

In developing a robust statistical model, at least the following aspects should be considered.

a) Antenna design: What is the narrow beam pattern? When swept over full range of directions, what is the overall envelope antenna pattern?
b) Antenna steering: Is the narrow beam continuously steered or is it selected from a (few) fixed orientations? Is the narrow beam adjusted in ϕ alone or in both θ and ϕ.
c) Technical limitation: Are there any design constraints that limit the fraction of available power directed to a single narrow beamwidth? What fraction of the available power can be directed to a single user?
d) Geographic distribution of users in relation to antenna: Are there any factors that slue the geographic distribution of users from “random”? For example, if an RBS is located 1 000 m from a conference centre within the coverage area of the cell, it may be anticipated that there will be a significant concentration of users over a limited range of bearings.
e) RF field strength modelling: Select a suitable computation model from B.4 and respect any constraints on applicability (see Table 7). Consider that when approaching closer to an antenna with very narrow beamwidth, a person may obstruct more than one beam at a time.

In general, a statistical model defines:

- the computation or measurement methods from Clause 8 to either establish the conservative RF field strength / SAR or a reference (e.g. “average”) RF field strength / SAR;
- a function defining a factor to reduce the deterministic conservative case or to modify the reference RF field strength / SAR;

- the applicability constraints considering all relevant aspects and at least a) to d) above and any assumptions that apply;
- the level of conservativeness, and allows for that level to be parametrically expressed in the corresponding analytical formulation.

In the case study associated with the example approach (see F.10.4), the computed deterministic conservative power density is 0,5 W m^{-2} and the statistical conservative power density is 0,23 W m^{-2} for a level of conservativeness of 97,6 %.

F.10.4 Example approaches

F.10.4.1 Overview

Figure F.15 presents a plan view of a smart antenna with N_u independently steerable (in ϕ only) narrow beams each of beamwidth NB_{3dB} combining to provide coverage over a sector beamwidth of $SMRT_{3dB}$. Each beam is directed to a single user within the coverage area. The example approaches evaluate the RF field strength at the evaluation point according to deterministic conservative, long term time-average and statistical conservative methods.

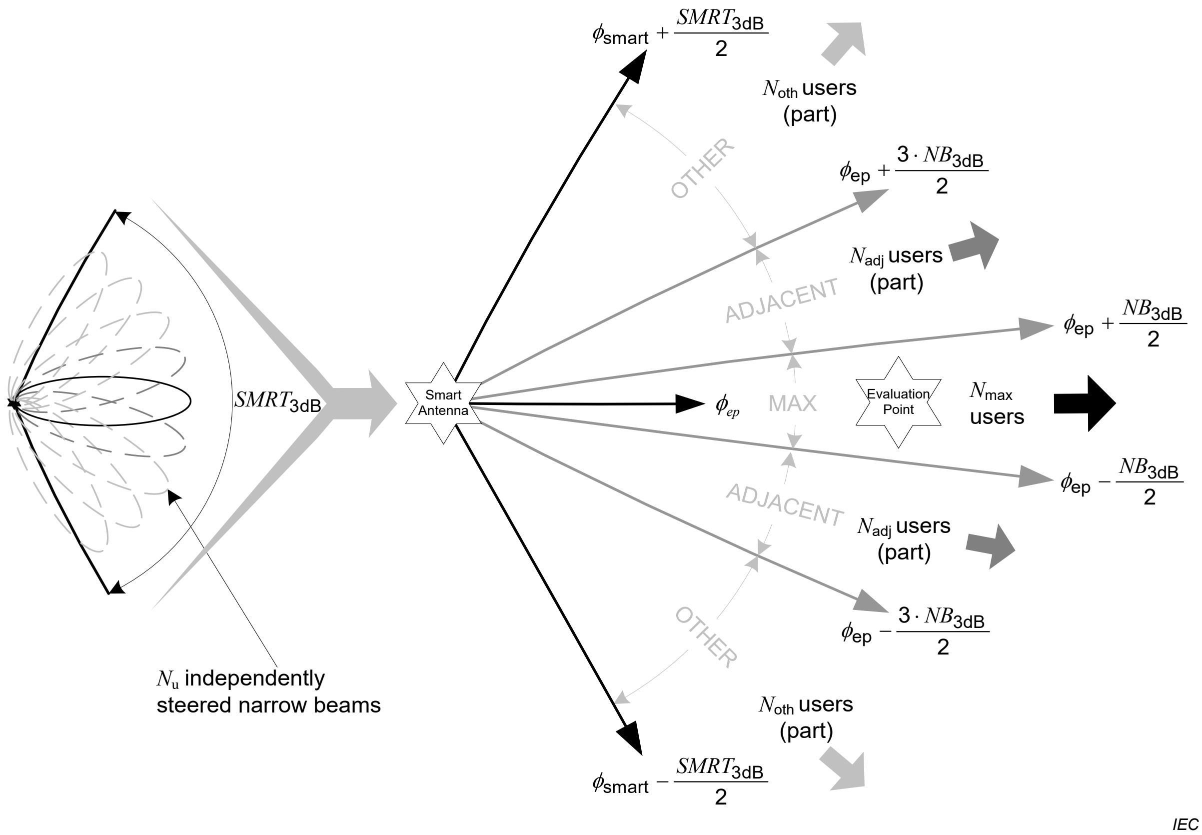


Figure F.15 – Plan view representation of statistical conservative model

The following definitions are used (see Figure F.15):

G_u	is the maximum gain of the narrow beam directed to a user;
$D_{\phi side}$	is the maximum horizontal directivity of the side lobes of the narrow beam;
$D_{\theta ep}$	is the vertical directivity of the narrow beam directed to the evaluation point;
$SMRT_{3dB}$	is -3 dB horizontal beamwidth(°) of the smart antenna;
NB_{3dB}	is -3 dB horizontal beamwidth(°) of the narrow beam directed to each user;
ϕ_{ep}	is the bearing (° East of North) to the evaluation point;

ϕ_{smart} is the boresight bearing (° East of North) of the smart antenna if $SMRT_{3\text{dB}} < 360°$;

$\overline{P}_{\text{u}}$ is the maximum value of the average (temporal) transmitted power (W) for each user;

N_{u} is the maximum number of simultaneous users;

$\overline{P}_{\text{avg}}$ is the maximum value of the average (temporal) transmitted power (W) for the smart antenna and $\overline{P}_{\text{avg}} = \overline{P}_{\text{u}} \cdot N_{\text{u}}$;

NOTE 1 In the case where a different transmit power level is available to each user, the definition of $\overline{P}_{\text{u}}$ implies that $\overline{P}_{\text{avg}} \le \overline{P}_{\text{u}} \cdot N_{\text{u}}$ ensuring the conservativeness of the computed power density.

N_{max} is the statistically defined maximum number of users in a single narrow beamwidth $\phi_{3\text{dBu}}$ (see Figure F.15 "MAX") centred on the evaluation point bearing ϕ_{ep}, i.e. within bearing range $\phi_{\text{ep}} - \frac{NB_{3\text{dB}}}{2} \le \phi \le \phi_{\text{ep}} + \frac{NB_{3\text{dB}}}{2}$;

N_{adj} is the statistically defined (considering N_{max}) maximum number of users in the two bearing ranges (see Figure F.15 "ADJACENT") $\phi_{\text{ep}} - \frac{3 \cdot NB_{3\text{dB}}}{2} \le \phi < \phi_{\text{ep}} - \frac{NB_{3\text{dB}}}{2}$ and $\frac{NB_{3\text{dB}}}{2} < \phi \le \phi_{\text{ep}} + \frac{3 \cdot NB_{3\text{dB}}}{2}$;

N_{oth} is the number of remaining users (after considering the statistically defined N_{max} and N_{adj}) in bearing ranges (see Figure F.15 "OTHER") $\phi_{\text{smart}} - \frac{SMRT_{3\text{dB}}}{2} \le \phi < \phi_{\text{ep}} - \frac{3 \cdot NB_{3\text{dB}}}{2}$ and $\phi_{\text{ep}} + \frac{3 \cdot NB_{3\text{dB}}}{2} < \phi \le \phi_{\text{smart}} + \frac{SMRT_{3\text{dB}}}{2}$;

δ_{max} is the factor modifying the effective gain in the direction of the evaluation point of the set of narrow beams serving users in a "MAX" bearing range centred on ϕ_{ep} (see Figure F.15) considering the distribution of users (see N_{max}) within the bearing range;

δ_{adj} is the factor modifying the effective gain in the direction of the evaluation point of the set of narrow beams serving users in the two "ADJACENT" bearing ranges (see Figure F.15) considering the distribution of users (see N_{adj}) within the bearing ranges;

δ_{oth} is the factor modifying the effective gain in the direction of the evaluation point of the remaining set of narrow beams serving users in the two "OTHER" bearing ranges (see Figure F.15) considering the distribution of users (see N_{oth}) within the bearing ranges.

Assume that the RF fields transmitted to each user are non-correlated and may be summed to find the total power density (see B.6.2).

NOTE 2 The validity of this assumption is technology dependent.

F.10.4.2 Deterministic conservative power density model

Considering Figure F.15, this model assumes that all N_{u} users are in the same direction as the evaluation point and that all the transmitted power is directed towards the evaluation point, i.e. $N_{\text{max}} = N_{\text{u}}$. The deterministic conservative power density can be determined using the evaluation methods in this document according to their validity. However, as an example, Equation (F.22) uses the simple spherical model, see Equation (B.18):

$$S_{\mathrm{det}} = \frac{\overline{P}_{\mathrm{avg}} \cdot G_{\mathrm{u}} \cdot D_{\theta \mathrm{ep}}}{4 \cdot \pi \cdot r^2} \qquad \text{(F.22)}$$

NOTE Where a single reflector is present, a factor of $(1+|\Gamma|)^2$ is appropriate (see Equation (B.21)).

F.10.4.3 Long term time-average power density model

Considering that over a long time period each narrow beam is effectively covering the full smart antenna beam width, the effective gain of each of the narrow beams is therefore reduced by the ratio of these two beam widths such that the long-term (e.g. over several days) time-averaged power density S_{avg} can be expressed as:

$$S_{\mathrm{avg}} = S_{\mathrm{det}} \cdot \frac{NB_{3\mathrm{dB}}}{SMRT_{3\mathrm{dB}}} \qquad \text{(F.23)}$$

This value is significant only in that it establishes a possible basis for estimating the long term overall environmental RF exposure level from the RBS.

F.10.4.4 Statistical conservative power density model

F.10.4.4.1 Overview

The deterministic conservative approach described above ensures that for 100 % of the time that the cell is fully loaded, the computed field strength / SAR can never be exceeded.

A statistical approach may be used to define a more realistic conservative power density value. This is based on defining a very small but acceptable probability that, over the (limited) time that the cell is fully loaded, the statistical conservative value may be exceeded.

NOTE For example, consider the case where a) the fully loaded situation (maximum power to all users on cell edge, all frequencies/timeslots in use, maximum data rate, etc.) occurs for say 5 % of the time and b) the defined acceptable probability for exceedance is 2,5 %. The probability that the computed value is exceeded is 2,5/100 × 5/100 = 12,5/10 000 or 0,125 %. This means that over time, there is 99,875 % probability that the real value is below the statistically conservative value compared with 100 % probability for the deterministic conservative approach.

In the statistical conservative case, it is still necessary to account for all the transmitted power, but not necessarily with all the users in a single narrow beamwidth as in the deterministic conservative case.

The example approach breaks the problem into three parts.

a) To establish the deterministic conservative power density (S_{u}) from a single narrow beam supporting one user considering the maximum gain modified by the vertical directivity to the evaluation point.
b) To establish appropriate factor(s) ($\delta_{\mathrm{max}}, \delta_{\mathrm{adj}}, \delta_{\mathrm{oth}}$) to modify the horizontal gain of the narrow beams considering that some of the transmitted power is targeted at users at bearings other than the evaluation point.
c) To establish a statistical model defining the number of users ($N_{\mathrm{max}}, N_{\mathrm{adj}}, N_{\mathrm{oth}}$) in appropriate bearing ranges considering the field computation model constraints and the level of conservativeness. This effectively defines the transmitted power distribution over the smart antenna beamwidth.

The statistical conservative power density S_{sta} is expressed as:

$$S_{\mathrm{sta}} = S_{\mathrm{u}} \cdot \left(\delta_{\mathrm{max}} \cdot N_{\mathrm{max}} + \delta_{\mathrm{adj}} \cdot N_{\mathrm{adj}} + \delta_{\mathrm{oth}} \cdot N_{\mathrm{oth}}\right) \qquad \text{(F.24)}$$

In Equation (F.24), the subscripts relate to the “MAX”, “ADJACENT” and “OTHER” bearing ranges shown in Figure F.15.

F.10.4.4.2 Establishing the single user conservative power density

In principle, any of the evaluation methods described in Clause 8 may be applied to determine S_{u} depending on the criteria in Clause 7 and Annex A and due consideration of their applicability to source-environment plane regions within which the evaluation point(s) lie. For simplicity, the spherical model (see B.4.2.1.1.2) is used with the horizontal gain at maximum and the vertical directivity appropriate for the evaluation point. For a single user, for evaluation points in the source-environment plane region III-0, the conservative power density S_{u} can be expressed as:

$$S_{\text{u}} = \frac{\overline{P}_{\text{u}} \cdot G_{\text{u}} \cdot D_{\theta\text{ep}}}{4 \cdot \pi \cdot r^2} \tag{F.25}$$

NOTE It may be possible to extend this method to source-environment plane region III-1 with the application of a factor $(1 + |\Gamma|)^2$ to the final computed value of S_{u} [see Equation (B.21)].

F.10.4.4.3 Determining horizontal gain modification factors

In Figure F.15, the users are distributed in a number of bearing ranges within the overall beamwidth of the smart antenna. These bearing ranges are defined (see Figure F.15) as:

- “MAX”, characterized by the -3 dB beamwidth of a single narrow beam;
- “ADJACENT”, characterized by being the two beamwidths immediately adjacent to “MAX”;
- “OTHER”, characterized by any bearings within the overall beamwidth of the smart antenna other than “MAX” and “ADJACENT”.

Within the “MAX” bearing range, the N_{max} users will be on bearings such that the narrow beams directed at them will have a gain of between G_{u} and $G_{\text{u}} - 3\ \text{dB}$ as observed from the evaluation point. It may be possible to define a statistical model to the distribution in ϕ of users within $\pm NB_{3\text{dB}}/2$ of the bearing to the evaluation point and then establish a rationale for setting $0{,}5 < \delta_{\text{max}} \leq 1$. However a deterministic conservative approach is to set $\delta_{\text{max}} = 1$, i.e. assume maximum gain in direction of evaluation point for all of the N_{max} users.

Within the “ADJACENT” bearing ranges, the N_{adj} users will be on bearings such that the narrow beams directed at them have horizontal gains, as observed from the evaluation point, distributed over the beam pattern from $G_{\text{u}} - 3\ \text{dB}$ to $G_{\text{u}} - x\ \text{dB}$, where x depends on the directivity at $\pm 3NB_{3\text{dB}}/2$ from the centre of the narrow beam. Again, it may be possible to apply a statistical model to define this distribution. However, a deterministic conservative approach is to set $\delta_{\text{adj}} = 1/2$, i.e. assume gain is $G_{\text{u}} - 3\ \text{dB}$ in the direction of evaluation point for all of the N_{adj} users.

Within the “OTHER” bearing ranges, the remaining N_{oth} users will be on bearings such that when the narrow beams are directed at them, the evaluation point is more than $\pm 3NB_{3\text{dB}}/2$ from the centre of their respective beams. A deterministic conservative approach is to assume the gain is determined by the horizontal side lobe directivity. For example, if the highest gain horizontal side lobe $D_{\phi\text{side}}$ is $G_{\text{u}} - 12\ \text{dB}$, then $\delta_{\text{oth}} = 0{,}063$.

F.10.4.4.4 Determining N

The probability of any individual user being in a target beamwidth depends on the relevant part of the array beamwidth that is covered by the target beamwidth. The probability, PR_{max}, of any individual user being in the “MAX” beamwidth centred on ϕ_{ep} the evaluation point is:

$$PR_{\mathrm{max}} = \frac{NB_{\mathrm{3dB}}}{SMRT_{\mathrm{3dB}}} \tag{F.26}$$

To determine the probability of any individual user being in the two "ADJACENT" bearing sectors, PR_{adj}, the denominator is reduced to account for the concurrent condition covered by Equation (F.26), i.e.:

$$PR_{\mathrm{adj}} = \frac{2 \cdot NB_{\mathrm{3dB}}}{SMRT_{\mathrm{3dB}} - NB_{\mathrm{3dB}}} \tag{F.27}$$

The binomial cumulative probability function [79] establishes the probability of less than k users out of N being within the target narrow beam(s).

$$F(k, PR_{***}, N_{***}) = \sum_{i=0}^{k} \binom{N_{***}}{i} (PR_{***})^{i} (1 - PR_{***})^{(N_{***} - i)} \tag{F.28}$$

where

PR_{***} is the probability of any individual user being in a specified beamwidth (e.g. PR_{max}, PR_{adj});

k is the assumed maximum number of users in the target beamwidth (determined iteratively by specifying the minimum value for $F(k, PR_{***}, N_{***})$;

N_{***} is the number of users in the specified beamwidth (e.g. N_{max}, N_{adj}).

Equation (F.28) is applied twice, first to establish N_{max} and then to establish N_{adj}. Finally N_{oth} is established. The process is described in the following steps:

a) For the specific values of PR_{***} determine the relevant N_{***}:
   - first application for N_{max}, use Equation (F.26) to determine PR_{***}, and set $N_{***} = N_{\mathrm{u}}$;
   - second application for N_{adj}, use Equation (F.27) to determine PR_{***}, and set $N_{***} = N_{\mathrm{u}} - N_{\mathrm{max}}$.

b) Plot the binomial cumulative probability function $F(k, PR_{***}, N_{***})$ for $k = 1 \text{ to } N_{***}$.

c) Assign a minimum value for $F(k, PR_{***}, N_{***})$ (e.g. 0,97 or 97 %).

d) Find the nearest integer value of k to assure this minimum value:
   - on first application, assign $N_{\mathrm{max}} = k$ then go back to step a),
   - on second application, assign $N_{\mathrm{adj}} = k$.

e) Determine N_{oth}:

$$N_{\mathrm{oth}} = N_{\mathrm{u}} - N_{\mathrm{max}} - N_{\mathrm{adj}} \tag{F.29}$$

F.10.4.4.5 Determining S_{sta}

The statistical conservative power density is then computed using Equation (F.24) and the parameter values derived in F.10.4.4.

The above statistical model is intended for use for evaluation points within the bearing range where there is at least 1,5 narrow beamwidths between the evaluation point bearing and the −3 dB points on the overall smart antenna pattern, i.e. the following condition is true:

$$\phi_{\mathrm{smart}} - \frac{SMRT_{\mathrm{3dB}}}{2} + \frac{3 \cdot NB_{\mathrm{3dB}}}{2} \le \phi_{\mathrm{ep}} \le \phi_{\mathrm{smart}} + \frac{SMRT_{\mathrm{3dB}}}{2} - \frac{3 \cdot NB_{\mathrm{3dB}}}{2} \tag{F.30}$$

A similar statistical approach can be applied for evaluation points nearer the edge of the smart antenna pattern, but the PR_{***} values may not be according to Equations (F.26) and (F.27).

This method only considers beam steering antennas where the narrow beam is adjusted in ϕ alone (see Figure B.1).

The binomial cumulative distribution function may not be adequately conservative where there are site-specific factors that significantly slue the uniform geographic distribution of users within the service area – for example, if there is a conference centre with a high concentration of users in a small bearing range near the edge of the coverage area.

F.10.4.5 Power flux density evaluation for TD-LTE

F.10.4.5.1 Overview

A statistical method may be used to define a more realistic power flux density value of TD-LTE with smart antenna systems. The method is based on analysis of all kinds of transmission mode (TM) and transmission scheme (TS) used in TD-LTE with smart antenna systems, and the antenna parameters such as diversity gain, spatial multiplexing gain and beam-forming gain are taken into account.

In TD-LTE R9 with smart antenna systems, different TSs have different antenna gain mode and shows different application ratios in real networks depending on operational environment. In the statistical method, the application ratios of different TSs are the factors to modify the TS, i.e. it is still necessary to account for all the transmitted power, but not necessarily with all the power in a single TS. Besides that, it is not necessary to have all users in a single narrow beam-width as in TD-SCDMA systems (see F.10.4.4).

The method breaks the problem into three parts:

a) To establish the weight factor of a single traffic channel beam-width's power flux density.

   By the previous method of TD-SCDMA statistical conservative power density model (see F.10.4.4.4), to establish δ_{max}, δ_{adj}, δ_{oth} and N_{max}, N_{adj}, N_{oth}, and then to calculate the weight factor in Formula (F.24), i.e. $\delta_{\mathrm{max}} \cdot N_{\mathrm{max}} + \delta_{\mathrm{adj}} \cdot N_{\mathrm{adj}} + \delta_{\mathrm{oth}} \cdot N_{\mathrm{oth}}$. This step's requirements are the same as parts b) and c) in TD-SCDMA systems in F.10.4.4.

b) To establish the statistical power flux density from a single beam with the factor of TS application ratios for traffic channel (S_{uT}), and as well as deterministic power flux density for control channel (S_{uB}).

c) To combine traffic channel and control channel.

The statistical power flux density of TD-LTE with smart antenna system S_{staLTE} is expressed as:

$$S_{\mathrm{staLTE}} = R_{\mathrm{T}} \cdot S_{\mathrm{uT}} \cdot \left(\delta_{\mathrm{max}} \cdot N_{\mathrm{max}} + \delta_{\mathrm{adj}} \cdot N_{\mathrm{adj}} + \delta_{\mathrm{oth}} \cdot N_{\mathrm{oth}}\right) + R_{\mathrm{B}} \cdot S_{\mathrm{uB}} \tag{F.31}$$

In Equation (F.31), the subscripts relate to the "MAX", "ADJACENT" AND "OTHER" bearing ranges shown in Figure F.15. R_{T} and R_{B} are the temporal ratio of traffic channel and control channel of the subframe, respectively, and generally R_{T} is 10 to 13 (of 14) and R_{B} is 1 to 4 (of 14) accordingly, such that R_{T} + R_{B} = 1.

F.10.4.5.2 Determining power density of traffic channel

F.10.4.5.2.1 Traffic channel power flux density distribution

In TD-LTE R9 with smart antenna system, out of TM1 to TM8, typical TMs for traffic channel are TM2, TM3 and TM8 and they are also practically used TMs in real networks for outdoor environment. TM2 is diversity, TM3 is diversity and spatial multiplexing, and TM8 is diversity and beam-forming, so TS2 accounts for diversity gain, TS3 accounts for spatial multiplex gain and TS8 accounts for beam-forming gain. So the traffic channel power flux density can be divided into three parts as Equation (F.32):

$$S_{\mathrm{uT}} = S_{\mathrm{Diversity}} \cdot \rho_{\mathrm{Div}} + S_{\mathrm{Space}} \cdot \rho_{\mathrm{Spa}} + S_{\mathrm{Beamforming}} \cdot \rho_{\mathrm{Bmfm}} \qquad \text{(F.32)}$$

where

$S_{\mathrm{Diversity}}$, S_{Space}, and $S_{\mathrm{Beamforming}}$	are the maximum power flux density components of TS2, TS3 and TS8 of the TD-LTE with smart antenna systems, respectively;
ρ_{Div}, ρ_{Spa}, and ρ_{Bmfm}	are the ratios of TS2, TS3 and TS8 of the TD-LTE with smart antenna systems, respectively.

In Equation (F.32), the three parts stand for the real power flux density components of TS2, TS3 and TS8 of the TD-LTE with smart antenna systems successively.

In principle, any of the evaluation methods described in Clause 8 may be applied to determine $S_{\mathrm{Diversity}}$, S_{Space}, and $S_{\mathrm{Beamforming}}$ depending on the criteria in Clause 7 and Annex A and due consideration of their applicability to source-environment plane regions within which the evaluation point(s) lie. For simplicity, the spherical model (see B.4.2.1.1.2) is used with the horizontal gain at maximum and the vertical directivity appropriate for the evaluation point. For a single user, for evaluation points in the source-environment plane region III-0, the conservative power flux density $S_{\mathrm{Diversity}}$, S_{Space}, and $S_{\mathrm{Beamforming}}$ can be expressed as:

$$S_{\mathrm{Diversity}} = \frac{\overline{P}_{\mathrm{uT}} \cdot G_{\mathrm{uDiv}} \cdot D_{\theta\mathrm{ep}}}{4 \cdot \pi \cdot r^2} \qquad \text{(F.33)}$$

$$S_{\mathrm{Space}} = \frac{\overline{P}_{\mathrm{uT}} \cdot G_{\mathrm{uSpa}} \cdot D_{\theta\mathrm{ep}}}{4 \cdot \pi \cdot r^2} \qquad \text{(F.34)}$$

$$S_{\mathrm{Beamforming}} = \frac{\overline{P}_{\mathrm{uT}} \cdot G_{\mathrm{uBmfm}} \cdot D_{\theta\mathrm{ep}}}{4 \cdot \pi \cdot r^2} \qquad \text{(F.35)}$$

where

$\overline{P}_{\mathrm{uT}}$	is the maximum value of the average (temporal) transmitted traffic channel power (W) for each user;
G_{uDiv}, G_{uSpa} and G_{uBmfm}	are the values of the diversity gain, spatial multiplexing gain and the beam-forming gain of the smart antenna, respectively.

NOTE It may be possible to extend this method to source-environment plane region III-1 with the application of a factor $(1 + |\Gamma|)^2$ to the final computed value of $S_{\mathrm{Diversity}}$, S_{Space}, and $S_{\mathrm{Beamforming}}$ (see B.4.2.1.1.2).

So the S_{uT} can be expressed as:

$$
\begin{aligned}
S_{\text{uT}} &= S_{\text{Diversity}} \cdot \rho_{\text{Div}} + S_{\text{Space}} \cdot \rho_{\text{Spa}} + S_{\text{Beamforming}} \cdot \rho_{\text{Bmfm}} \\
&= \frac{\overline{P}_{\text{uT}} \cdot G_{\text{uDiv}} \cdot D_{\theta\text{ep}}}{4 \cdot \pi \cdot r^2} \cdot \rho_{\text{Div}} + \frac{\overline{P}_{\text{uT}} \cdot G_{\text{uSpa}} \cdot D_{\theta\text{ep}}}{4 \cdot \pi \cdot r^2} \cdot \rho_{\text{Spa}} + \frac{\overline{P}_{\text{uT}} \cdot G_{\text{uBmfm}} \cdot D_{\theta\text{ep}}}{4 \cdot \pi \cdot r^2} \cdot \rho_{\text{Bmfm}} \\
&= \frac{\overline{P}_{\text{uT}} \cdot D_{\theta\text{ep}}}{4 \cdot \pi \cdot r^2} \left(G_{\text{uDiv}} \cdot \rho_{\text{Div}} + G_{\text{uSpa}} \cdot \rho_{\text{Spa}} + G_{\text{uBmfm}} \cdot \rho_{\text{Bmfm}} \right)
\end{aligned} \quad \text{(F.36)}
$$

F.10.4.5.2.2 Ratios of the three types of TS's

In an operational network, these three transmission schemes can be measured on site to determine the ratios of TS2, TS3, TS8.

F.10.4.5.2.3 Control channel power flux density distribution

For the control channel, just as in Equations (F.33) to (F.35), the deterministic power flux density S_{uB} can be expressed as:

$$
S_{\text{uB}} = \frac{\overline{P}_{\text{uB}} \cdot G_{\text{uB}} \cdot D_{\theta\text{ep}}}{4 \cdot \pi \cdot r^2} \quad \text{(F.37)}
$$

where

$\overline{P}_{\text{uB}}$ is the maximum value of the average (temporal) transmitted control channel power (W);

G_{uB} is the gain of the control channel of the smart antenna.

F.10.4.5.3 Summary

The total power flux density can be expressed as:

$$
\begin{aligned}
S_{\text{staLTE}} &= R_{\text{T}} \cdot S_{\text{uT}} \cdot \left(\delta_{\max} \cdot N_{\max} + \delta_{\text{adj}} \cdot N_{\text{adj}} + \delta_{\text{oth}} \cdot N_{\text{oth}} \right) + R_{\text{B}} \cdot S_{\text{uB}} \\
&= R_{\text{T}} \cdot \frac{\overline{P}_{\text{uT}} \cdot D_{\theta\text{ep}}}{4 \cdot \pi \cdot r^2} \left(G_{\text{uDiv}} \cdot \rho_{\text{Div}} + G_{\text{uSpa}} \cdot \rho_{\text{Spa}} + G_{\text{uBmfm}} \cdot \rho_{\text{Bmfm}} \right) \cdot \left(\delta_{\max} \cdot N_{\max} + \delta_{\text{adj}} \cdot N_{\text{adj}} + \delta_{\text{oth}} \cdot N_{\text{oth}} \right) + R_{\text{B}} \cdot \frac{\overline{P}_{\text{uB}} \cdot G_{\text{uB}} \cdot D_{\theta\text{ep}}}{4 \cdot \pi \cdot r^2}
\end{aligned} \quad \text{(F.38)}
$$

F.10.4.6 Example smart antenna

F.10.4.6.1 Problem definition

Problem: What is the deterministic conservative, long term time-average and statistical conservative (to 97,5 %) power density 20 m from the smart antenna in the boresight of the main beam?

This specific case is for a communications system serving up to 24 simultaneous users (with one carrier); a smart antenna with 120° sector beamwidth and 15° beamwidth for each user with gain 22 dBi and maximum vertical beamwidth side lobes less than -12 dB; 16 W maximum power at antenna feed point (after considering feeder losses and accounting for modulation and TDMA on-off cycle as applicable), i.e. G_{u} is 158,5 (22 dBi); $SMRT_{3\text{dB}}$ is 120°; $NB_{3\text{dB}}$ is 15°; $\overline{P}_{\text{u}}$ is $\frac{16}{24}$ W; N_{u} is 24; $\overline{P}_{\text{avg}}$ is 16 W; r is 20 m; $D_{\phi\text{side}} = 0{,}063$ (-12 dB). The evaluation is in the main beam so $D_{\theta\text{ep}} = 1$.

F.10.4.6.2 Establish the deterministic conservative power density

From Equation (F.22):

$$S_{det} = \frac{16 \times 158{,}5}{4 \times \pi \times 20^2} = 0{,}50 \text{ W m}^{-2}$$

F.10.4.6.3 Establish the long term time-averaged power density

From Equation (F.23):

$$S_{avg} = 0{,}5 \times \frac{15}{120} = 0{,}063 \text{ W m}^{-2}$$

F.10.4.6.4 Establish the statistical conservative power density

- Step 1: Determine S_u

  Apply the simple spherical model – from Equation (F.25):

$$S_u = \frac{\overline{P}_u \cdot G_u \cdot D_{\theta ep}}{4 \cdot \pi \cdot r^2} = \frac{(16/24) \times 158{,}5 \times 1}{4 \times \pi \times 20^2} = 0{,}021 \text{ W m}^{-2}$$

- Step 2: Determine δ

  Apply the deterministic conservative approach so that: $\delta_{max} = 1$, $\delta_{adj} = 0{,}5$, $\delta_{oth} = 0{,}063$.

- Step 3: Determine N_{max}

  From Equation (F.26): $PR_{max} = \dfrac{NB_{3dB}}{SMRT_{3dB}} = \dfrac{15}{120} = 0{,}125$

  From F.10.4.4.4,step a): N_{max}

  Figure F.16 plots the relevant binomial cumulative probability function.

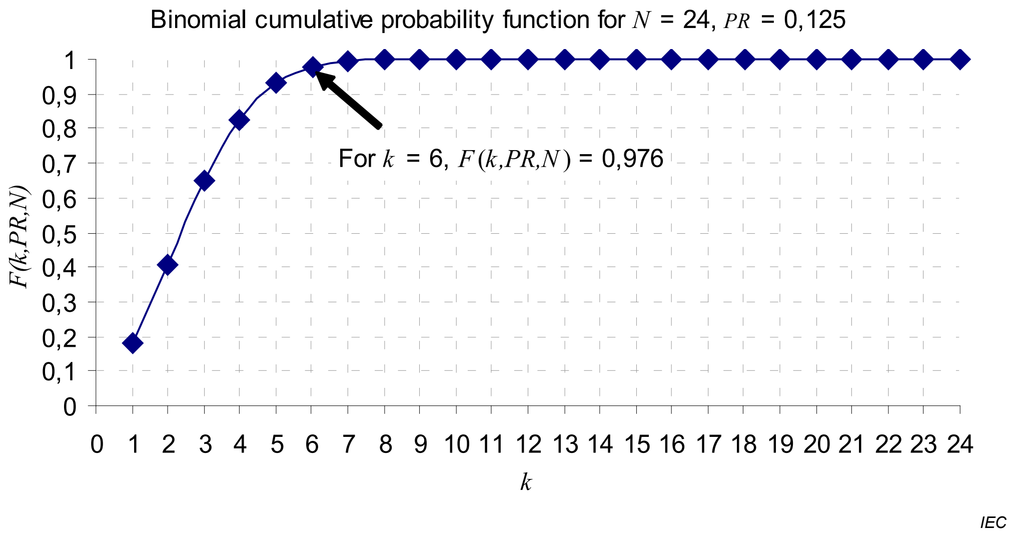


Figure F.16 – Binomial cumulative probability function for N = 24, PR = 0,125

From Figure F.16, the 97,5 % constraint is met for k = 6. Therefore, set $N_{max} = 6$.

- Step 4: Determine N_{adj}

  From Equation (F.27): $PR_{adj} = \dfrac{2 \cdot NB_{3dB}}{SMRT_{3dB} - NB_{3dB}} = \dfrac{2 \times 15}{120 - 15} = \dfrac{2}{7}$

  From F.10.4.4.4, step a): $N_{***} = N_u - N_{max} = 18$

  Figure F.17 plots the relevant binomial cumulative probability function.

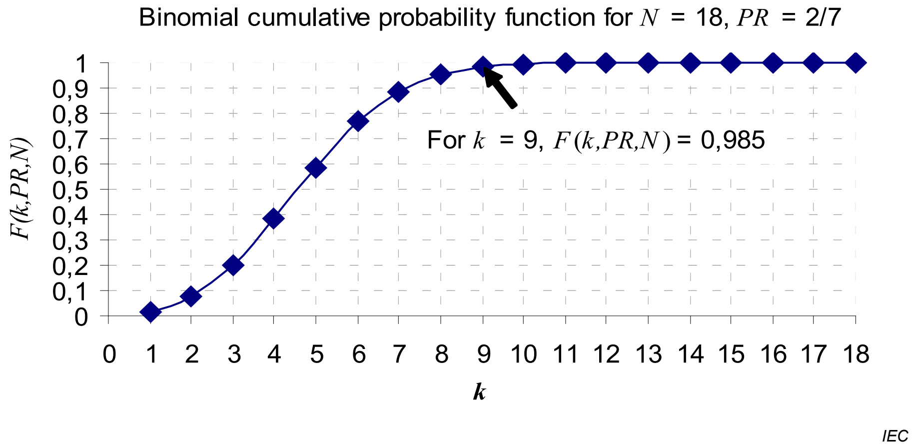


Figure F.17 – Binomial cumulative probability function for N = 18, PR = 2/7

From Figure F.17, the 97,5 % constraint is met for k = 9. Therefore, set $N_{adj} = 9$.

- Step 5: Determine N_{oth}

  From Equation (F.29): $N_{oth} = N_u - N_{max} - N_{adj} = 24 - 6 - 9 = 9$

- Step 6: Determine S_{sta}

  From Equation (F.24) and using the parameter values derived in the previous steps:

$$S_{sta} = S_u \cdot \left(\delta_{max} \cdot N_{max} + \delta_{adj} \cdot N_{adj} + \delta_{oth} \cdot N_{oth}\right)$$

$$S_{sta} = 0{,}021 \times \left[(1 \times 6) + (0.5 \times 9) + (0.063 \times 9)\right] = 0{,}23 \text{ W m}^{-2}$$

F.10.5 Smart antenna (TD-LTE)

In TD-LTE, multiple MIMO is used for more data throughput. A smart antenna is one mode of MIMO in TD-LTE. In trying to measure the electromagnetic field strength radiated from smart antenna in LTE, the same problem is found as the previous experience in TD-SCDMA. Although, in most cases, the antenna radiation is the same in different angles or directions in terms of long-term average, in fact the distribution of users in a cell is not even and is always moving. So, if a person probes the EM field strength in one fixed position near the base station, the measured value may vary significantly with time. Therefore, it cannot be derived directly from a multiplication factor applied to single antenna compliance boundary.

Evaluating the time averaged value in all directions and then using such an average value to determine the compliance boundary may not be applicable. For example, the assessment results would be different depending on the number and position of active users during the measurement. The unrealistic assumption that all users are at the same angle at the same time will result in an overly conservative compliance boundary. Statistical approaches should be considered in this case.

F.11 Establishing compliance boundary for systems using dish antennas

F.11.1 General

Dish antennas are generally deployed for radio-relays or point-to-point communication systems, which typically operate at frequencies from 1,4 GHz up to 86 GHz and beyond. They are characterized by high directivity, typically above 30 dBi, and low radiation outside the main beam. The objective of F.11 is to provide simple formulas to assess the compliance boundary in front of a dish antenna.

F.11.2 Overview

Microwave links are installed in towers, masts, on rooftops or in similar locations. The main design criterion consists in having the two locations in line of sight, so there is no possibility that some building be "crossed" by the radio signal, since, in such case, an attenuation would be produced and the connection would not work properly.

Outdoor units and antennas are normally required to be inaccessible by the general public to prevent intentional or unintentional damage to the equipment or to the radio link. This establishes a special condition for these systems: unavailability of the radio path for the general public.

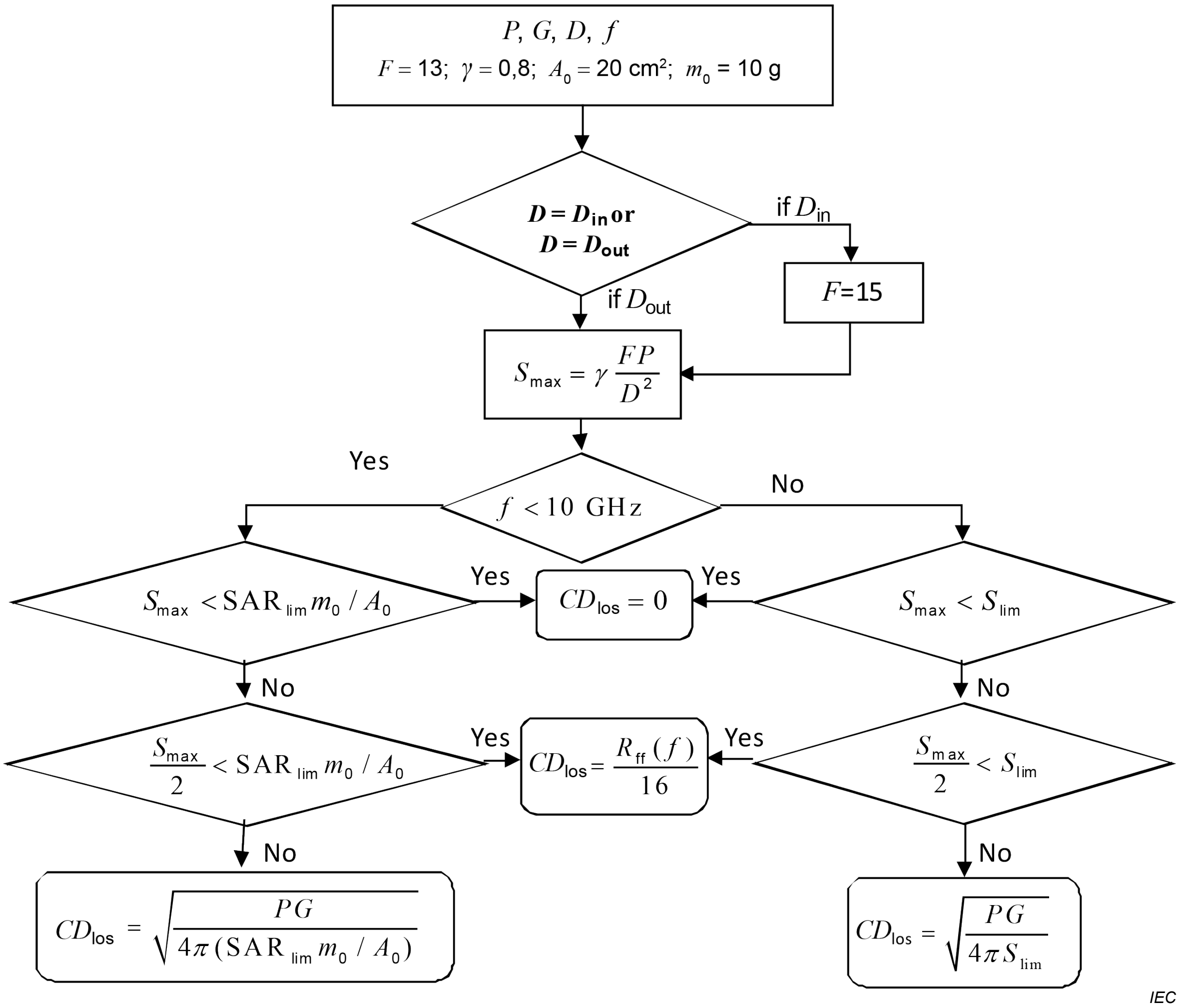
The basics of antenna physical parameters relevant for the RF exposure evaluation of dish antennas can be found in ETSI TR 102457 [11]. This technical report also reviews far-field analysis principles as well as near-field evaluation based on simulation methods and measurements calibration. It includes measurement and calculation results on real systems that have been used to establish the evaluation method described in F.11.3 and to provide an estimation of its accuracy.

In order to assess human exposure to RF from dish antennas, the maximum power density from these antennas can be derived from the following parameters: transmitted power, frequency, antenna diameter, aperture efficiency and antenna gain. The compliance boundary parameters are described in Figure 6.

F.11.3 Compliance boundary of a dish antenna

As described in [11], the compliance boundary of a dish antenna (or parabolic antenna) can be evaluated according to the flowchart presented in Figure F.18, which applies to both general public and occupational exposure situations. The compliance boundary parameters are based on the following assumptions:

- Compliance touch means that exposure limits are not exceeded while touching the radome of the equipment under test.
- The coefficient γ (0,8) relates to the 1 dB attenuation due to spatial averaging in a plane perpendicular to the antenna main direction at frequencies between 10 GHz and 300 GHz.
- The compliance boundary, if not zero, is a cylinder defined by the line of sight axis and the diameter D_{out} up to the compliance distance CD_{los} (see Figure 7).



Key

γ	factor used for spatial averaging
λ	wavelength (m)
A_0	reference area 20 cm^2 used for spatial averaging
CD_{los}	compliance distance in the line of sight
D	diameter of the antenna (m), can be equal to D_{in} (inner diameter) or D_{out} (outer diameter)
G	antenna gain
m_0	reference mass 10 g for spatial averaging
P	power transmitted to the antenna
r	distance between the point of investigation and the antenna
R_{ff}	far-field distance defined as $R_{ff} = \frac{2D^2}{\lambda}$ (see A.1.3)
S	power density (W/m^2) at distance r (m) from the antenna
S_{lim}	applicable limit for power density (W.m^{-2})
S_{max}	maximum power density spatially averaged over 20 cm^2
SAR_{lim}	applicable limit for local SAR for m_0

Figure F.18 – Flowchart for the assessment of EMF compliance boundary in the line of sight of dish antennas (from [11])

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