

INTERNATIONAL STANDARD

NORME INTERNATIONALE



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

**Détermination des champs de radiofréquences et du DAS aux environs des
stations de base utilisées pour les communications radio dans le but d'évaluer
l'exposition humaine**



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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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

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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 standard is based on the following documents:

FDIS	Report on voting
106/221/FDIS	106/228/RVD

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

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

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

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Withdrawn

INTRODUCTION

This standard addresses the evaluation of RF field strength or specific absorption rate levels in the vicinity of non-broadcast RF radiocommunication sources (i.e. RBS) intentionally radiating in the frequency range 300 MHz to 6 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 standard defines how a suitably qualified surveyor shall select between the described evaluation methods in order to prepare specific or generic evaluation plans and how to validate their implementation. When using this standard to establish RBS compliance, the full set of limiting conditions needs to be defined. These may include for example limits on human exposure to RF fields; the likelihood that people may have access to a specific location; specific decision rules for interpretation of uncertainty. This standard does not define such limits or the associated requirements for a safety programme. Further, this standard recognises that national regulators (or the test client) may establish rules (termed “assessment schemes”) on how to interpret uncertainty when establishing compliance. However, this standard does provide guidance on how to apply the described evaluation methods consistent with such rules. Additional guidance can be found in Technical Report IEC 62669 [54]¹⁾ which includes a set of worked case studies giving practical examples of the application of this standard.

Clause 2, Clause 3 and Clause 4 address normative references, definitions and abbreviations respectively.

Clause 5, with Annex A, Annex B and Annex C, defines how to select the evaluation methods to be used and how to plan the evaluation task. The standard describes the alternative methods that may be included in the evaluation plan and defines a ranking to be applied in the event of dispute where the higher ranking evaluation takes precedence. Lower ranking evaluations are of course valid within their applicability and may be more practical to implement.

Clause 6 describes the evaluation methods to determine a measurand (SAR or RF field strength) value at a specified point. These cover both laboratory and *in situ* measurement methods for SAR and electric field strength and computation methods for SAR, power flux density, electric field strength and magnetic field strength. Annex C describes how the evaluation methods may be employed for specific purposes. Annex F and Annex G provide information on implementation of computation methods and Annex H with included referenced spread sheets provides computation validation information.

Clause 7 and Annex O address the estimation of uncertainty or the determination that the evaluated value meets a specified confidence level. Annex L and Annex M describe how to address uncertainty when determining compliance with limit values in accordance with relevant national regulatory requirements.

Clause 8 describes reporting requirements for the evaluation.

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

¹⁾ Numerals in square brackets refer to the Bibliography.

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

1 Scope

This International Standard 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 standard:

- a) considers RBS which transmit on one or more antennas using one or more frequencies in the range 300 MHz to 6 GHz;
- b) 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;
- c) describes how surveyors with a sufficient level of expertise shall establish their specific evaluation procedures appropriate for their evaluation purpose;
- d) considers the evaluation purposes, namely:
 - 1) product conformity: to establish that a RBS conforms to a defined set of limit conditions under its intended use;
 - 2) compliance boundary: to establish the compliance boundary or boundaries for a RBS in relation to a defined set of limit conditions;
 - 3) to evaluate RF field strength or SAR values at one or more evaluation locations, namely:
 - i) evaluation location(s) at arbitrary locations outside the control boundary to provide information for interested parties;
 - ii) evaluation location(s) at the control boundary to confirm validity of control boundary;
 - iii) evaluation location(s) within the control boundary with the specific conditions relevant to investigate an alleged over-exposure incident;
- e) 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;
- f) provides informative guidance on how to evaluate ambient RF field strength levels in the vicinity of a RBS from RF sources other than the RBS under evaluation and at frequencies within and outside the range 300 MHz to 6 GHz;
- g) provides short descriptions of the informative example case studies to aid the surveyor given in the companion Technical Report IEC 62669 [54].

2 Normative references

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

IEC 60215, *Safety requirements for radio transmitting equipment*

IEC 62209-1:2005, *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 62209-2:2010, *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)*

ISO/IEC 17025:2005, *General requirements for the competence of testing and calibration laboratories*

3 Terms and definitions

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

3.1 ambient fields

background electromagnetic fields in the frequency range from 100 kHz to 300 GHz other than the emissions from the EUT in the frequency range 300 MHz to 6 GHz

3.2 antenna factor

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

3.3 assessment

determination of a decision based on measurand value (e.g. comparison with a relevant limit)

3.4 assessment configuration

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

3.5 average (temporal) transmitted power

rate of radiated energy transfer expressed in W given by

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

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 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.

3.6 average (temporal) absorbed power

ohmic power dissipated in a volume V given by

$$P_A = \int_V \sigma [E(x, y, z)]^2 dV$$

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

3.7 axial isotropy, probe

maximum deviation of the SAR , E^2 or H^2 when rotating around the major axis of the probe enclosure/case while the probe is exposed to a reference wave impinging from a direction along the probe major axis

3.8 basic restriction

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

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

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

surface of arbitrary shape defining a volume outside of which there is an applicable confidence that the applicable limit condition is not exceeded

3.11 control boundary

set of locations which together define where human access to a compliance boundary is controlled either via warnings or physical controls

3.12 detection limits

lower detection limit defined by the minimum quantifiable response of the measuring equipment; upper detection limit defined by the maximum quantifiable response of the measuring equipment

3.13 directivity (of an antenna, in a given direction)

D

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 If no direction is specified, the direction of maximum radiation intensity from the given antenna is implied.

NOTE 2 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 The ratio may also be expressed in decibels.

3.14

duty factor

the ratio of (1) the sum of pulse durations to (2) a stated averaging time. For repetitive phenomena, the averaging time is the pulse repetition period

IEC 60050-531:1974, 531-18-15, [67]²⁾

3.15

dynamic range

quotient of the signal from the maximum measurable indication of a quantity by the signal from the minimum measurable value of that quantity

NOTE In some cases the dynamic range may be expressed as an interval of the above-mentioned corresponding values.

IEC 60050-394:2007, 394-40-17, [71]

3.16

equivalent isotropic radiated power (in a given direction)

EIRP

the product of the radiofrequency power supplied to an antenna and the absolute gain of the antenna in a given direction

IEC 60050-712:1992, 712-02-51, [68] modified

3.17

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:

$$F = Q E$$

IEC 60050-121:1998, 121-11-18, [70]

3.18

evaluation

process of determining a value of a measurand

3.19

evaluation configuration

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

3.20

evaluation plan

document defining the specific methodology to be employed for an evaluation case, prepared in advance of the performance of the evaluation, including all methods to be used and which evaluation locations will be investigated using each defined method

3.21

evaluation location

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

NOTE In the case of spatial averaging, this is the reference location defined in the averaging scheme.

²⁾ Numerals in square brackets refer to the Bibliography.

3.22

exposure, partial-body

localised exposure of part of the body, producing a corresponding localised SAR, as distinct from a whole-body exposure

3.23

exposure, whole-body

exposure averaged over the whole body

3.24

exposure quotient

EQ

evaluated exposure parameter related to the relevant compliance limit expressed as the power fraction of the related limit at a given frequency

NOTE The exposure quotient may also be expressed as a percentage, i.e. $EQ \% = EQ (\text{dimensionless}) \times 100 \%$.

3.25

field strength (of a radio transmitter)

the magnitude of the electromagnetic field created at a given point by a radio transmitting system operating at a specified characteristic frequency with specified installation and modulation conditions

IEC 60050-705:1995, 705-08-31, [69]

3.26

frequency response

curve, representing the variations, with respect to frequency, of the indicated level of the measurand as a measuring instrument responds to a constant stimulus level

3.27

gain (of an antenna, in a given direction)

G

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 If no direction is specified, the direction of maximum radiation intensity from the given antenna is implied.

NOTE 2 The ratio may also be expressed in decibels.

3.28

intended use

reasonably foreseeable use of a 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

3.29

linearity error

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

IEC 60050-394:2007, 394-40-31, [71]

3.30

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 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 The rotation of the magnetic field strength is the total current density J_t :

$$\text{rot } H = J_t$$

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

IEC 60050-121:1998, 121-11-56, [70]

3.31

measurement drift (power drift)

gradual deviation over time from a reproducible reading of the measured value

3.32

peak spatial-average SAR

maximal value of averaged SAR within a specific mass

3.33

planar array (antenna)

array in which corresponding points of the radiating elements lie in a plane

IEC 60050-712:1992, 712-01-07, [68]

3.34

power flux density

radiant flux density

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

IEC 60050-705:1995, 705-02-03, [69]

3.35

plane wave equivalent

term associated with any electromagnetic wave with a power density equal in magnitude to the power flux density of a plane wave

3.36

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

3.37

radiocommunication base station

radio base station

RBS

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

NOTE 1 Examples of RBS include roof-top, standalone masts, access point installations, cordless base station etc. that are not normally used in close proximity (i.e. within 20 cm) to the human body.

NOTE 2 Examples of wireless telecommunications networks include those used in cellular communication, wireless local area networks, public safety networks and point-to-point communication and point-to-multipoint communication according to ITU-R F.592-3 [1].

NOTE 3 Radar, TV and radio broadcast services are excluded.

NOTE 4 Fixed implies that the RBS does not move in relation to its intended RF coverage area.

3.38 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)

$$SAR = \frac{d}{dt} \left(\frac{dW}{dm} \right) = \frac{d}{dt} \left(\frac{dW}{\rho dV} \right)$$

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;
- 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.

3.39 source-environment plane

conceptual map of the regions around an antenna in terms of source region and environment complexity (cluttered to non-cluttered)

NOTE Evaluation locations (for all sources) are mapped onto the source-environment plane with the source regions on the x axis and the complexities of the environment (scatterer/absorber) on the y axis.

3.40 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 or SAR

NOTE 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.

3.41 surveyor

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

4 Symbols and abbreviated terms

4.1 Physical quantities

The internationally accepted SI units are used throughout the standard.

Symbol	Quantity	Unit	Dimensions
α	Attenuation coefficient	reciprocal metre	m^{-1}
B	Magnetic flux density	tesla	$\text{T}, \text{V s m}^{-2}$
D	Electric flux density	coulomb per square metre	C m^{-2}
c_h	Specific heat capacity	joule per kilogram per kelvin	$\text{J kg}^{-1} \text{K}^{-1}$
E	Electric field strength	volt per metre	V m^{-1}
f	Frequency	hertz	Hz
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}
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 standard, temperature is quantified in degrees Celsius, as defined by: $T(^{\circ}\text{C}) = T(\text{K}) - 273,16$.

NOTE 2 Annex D defines various symbols and variables used in this standard.

4.2 Constants

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

4.3 Abbreviations

AMPS	Advanced Mobile Phone System
BCCH	broadcast control channel
CDMA	code division multiple access

CPICH	common pilot channel
DECT	Digital Enhanced Cordless Telecommunications
DPCH	dedicated physical channel
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 <i>Groupe Spécial Mobile</i>)
HPBW	half power beamwidth
LTE	Long Term Evolution
MoM	method of moments
NMT	Nordic Mobile Telephone
OFDM	orthogonal frequency division multiplexing
PML	perfectly matched layer
RBS	radiocommunication base station
RF	radio frequency
r.m.s.	root mean square
r.s.s.	root sum square
TDD	time division duplex
TDMA	time division multiple access
TETRA	Terrestrial Trunked Radio
UMTS	Universal Mobile Telecommunications System
USDC	United States Digital Cellular
WCDMA	wideband code division multiple access
Wi-Fi ³⁾	Wireless Fidelity
WiMAX	Worldwide Interoperability for Microwave Access

5 Developing the evaluation plan

5.1 Overview

This clause defines the evaluation plan which shall be the basis for the assessment. Detailed guidance is provided in the annexes:

- Annex A provides a thorough step-by-step approach to developing the evaluation plan;
- Annex B presents the source-environment plane and describes how to establish where evaluation points lie within the source-environment plane;
- Annex C provides guidance on the application of the evaluation methods to the specific evaluation purposes.

³⁾ Wi-Fi is a trademark of the Wi-Fi Alliance. The term "Wi-Fi" suggests *Wireless Fidelity*, resembling the long-established audio-equipment term *High Fidelity* or "Hi-Fi". *Wireless Fidelity* has been used in an informal way, even by the Wi-Fi Alliance itself, but officially the term does not mean anything. See (<http://en.wikipedia.org/wiki/Wi-Fi>).

Generic evaluation plans may be developed to cover the purposes and types of work which are commonly performed.

5.2 Key tasks

The following tasks shall be performed:

a) Establish the key evaluation parameters according to the following steps:

- Categorise the evaluation purpose (see A.2.1).
- Categorise the RBS under evaluation (see A.2.2). Note that this standard may be used to evaluate the RF field strength / SAR from low power RBS. IEC 62479 may be applied first to determine if any such evaluation is required in order to comply with the relevant limit.
- Determine the availability of key information (see A.2.3).
- Determine if the evaluation parameters can be controlled (e.g. by setting transmit power) (see A.2.4).
- Establish the evaluation points in relation to the source-environment plane (see A.2.5 and Annex B).

b) Establish if ambient fields need to be considered.

Where the evaluation purpose is to evaluate the combined field from all sources at a given location, ambient fields shall be evaluated (see Annex K):

- Reasonable endeavours shall be applied to identify all RF emissions between 100 kHz and 300 GHz.
- The ambient fields identified from fixed, permanent RF sources shall be considered. Such 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.

c) Select the evaluation method(s) according to the following steps:

- Establish the appropriate measurand (see A.3.2).
- Select computation or measurement approach (see A.3.3) and either
 - select measurement method (see A.3.4), or
 - select computation method (see A.3.5).
- Review the additional considerations (see A.3.6).

d) Review the checklist for completing the evaluation plan (see Table 1).

Table 1 provides a checklist summarising the main aspects which shall be considered when developing a specific evaluation plan.

Table 1 – Checklist for the evaluation plan

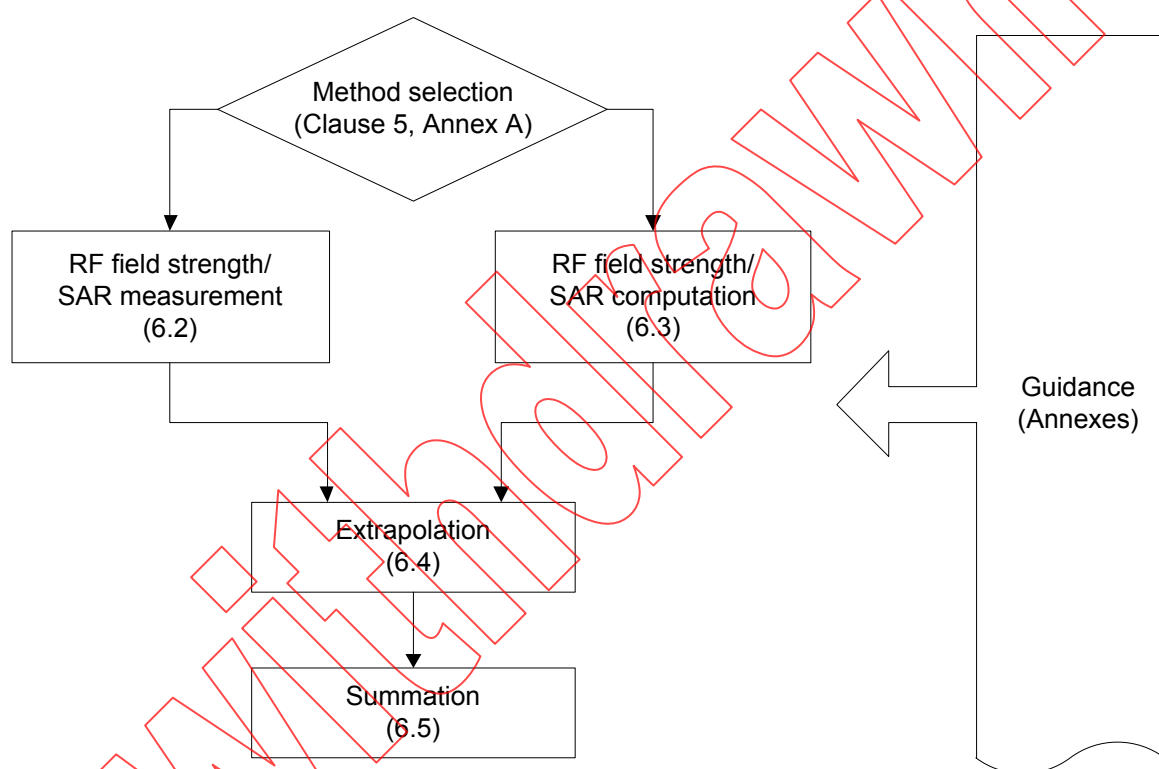
Criteria	Evaluation plan activity	Reference	Check
1) General considerations on safe and practical working on site	Where the evaluation is to be performed on site: - Develop a check sheet to be used on site. - Identify permissions required to work (access) - Consider the safety of the public and people performing the measurements. Ensure that a risk assessment is performed to identify potential hazards and to establish appropriate safety protocols to mitigate them. The procedures and guidance given in IEC 60215 shall be observed where appropriate.	IEC 60215	☐
2) Identify parameters relevant to the evaluation	Record all parameters needed for the evaluation and any actions needed to establish/verify their values. Clearly establish the evaluation configuration and assessment configuration.	Clause 6 and Annex D	☐
3) Evaluation method	Ensure that the selected evaluation method(s) is/are clearly defined together with the reasoning for their selection and clear traceability of their applicability.	Clause 6; Annex D; Annex F; Annex G; Annex I; Annex J; Annex K; Annex N; Annex P; IEC 62669 [54]	☐
4) Evaluation locations	Define the specific evaluation locations required or give sufficient guidance on how these can be established on site. Ensure that it is clear which evaluation methods are used for each evaluation point.	Clause 6; Annex A; Annex B; Annex C ; Annex K	☐
5) Measurement equipment	Identify measurement equipment to be used, its calibration requirements and compile relevant documentation.	Clause 6; Annex E; Annex N	☐
6) Computations	Establish that the computational resources are available. Establish that the appropriate validation work has been completed for the implementation.	Clause 6 and Annex F Clause 6 and Annex H	☐
7) Uncertainty	For any RF field strength or SAR value reported, define where it lies on the uncertainty probability density function e.g. best estimate, upper 95 %, etc. Consider location on source-environment plane if this affects the uncertainty of the evaluation.	Clause 6; Clause 7; Annex O; Annex P Annex B	☐
8) Limit evaluations	If comparison with a limit is required: - Define the relevant limit - Define the assessment scheme to be applied. - Define applicable assessment configuration as well as evaluation configuration.	Annex M Clause 3; Annex D; Annex L	☐
9) Reporting	Establish format for the evaluation report appropriate for the evaluation purpose considering guidance in Clause 8; and, Annex P.	Clause 8 and Annex P	☐

6 Evaluation methods

6.1 Overview

This clause describes alternative evaluation methods to measure or compute RF field strength or SAR. Each method description defines the applicability constraints within which it may be employed, the information required to implement the method and how to characterise the uncertainty of the evaluation.

Figure 1 provides an overview of the evaluation methods. The evaluation method selection is made when developing the evaluation plan (see Clause 5 and Annex A) as an iterative process also considering this Clause 6. For additional information, clarification or justification, the evaluation methods refer to annexes and external references.



IEC 1024/11

Figure 1 – Overview of evaluation methods

The evaluation plan may employ a combination of methods to complete the evaluation.

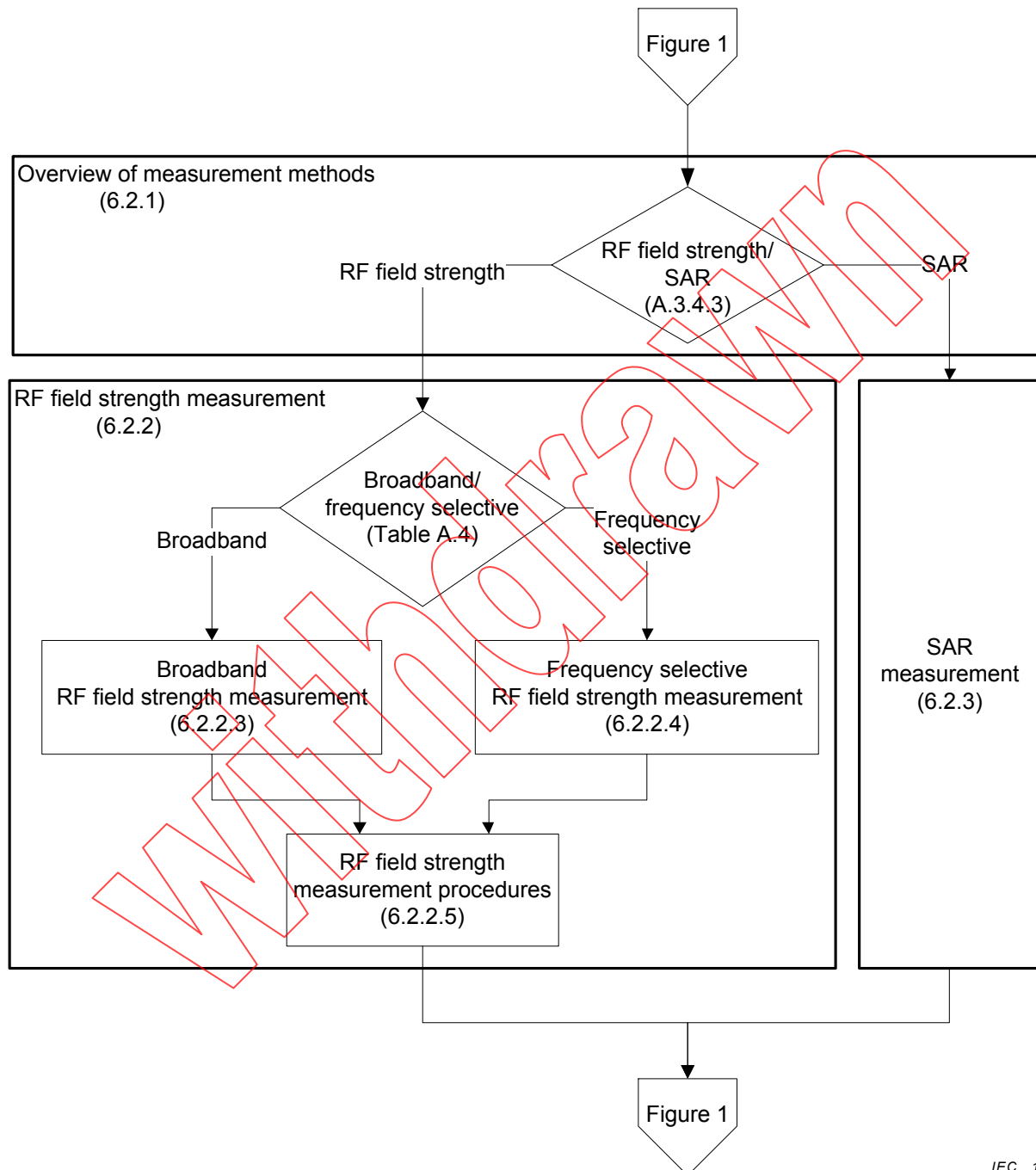
Extrapolation (see 6.4) is required if the evaluation is performed with RBS parameters (e.g. power output) that do not directly represent the RBS configuration required to be assessed. For example, if the radiated power from the RBS varies over an extended time, extrapolation of the evaluated result is performed to obtain an estimate of the maximum possible RF field strength or SAR (see Annex N and Annex J) as required to establish compliance boundaries around antennas (see Annex C).

Summation, (see 6.5), is required when contributions from multiple sources or frequencies are to be combined.

6.2 Measurement methods

6.2.1 Overview of measurement methods

Figure 2, an expansion of the RF field strength / SAR measurement block from Figure 1, presents an overview of the measurement methods.



IEC 1025/11

Figure 2 – Overview of RF field strength measurement methods

The peak spatial-average SAR measurement methods described in this standard are performed in a suitable test facility and are generally best suited for product compliance evaluations at up to 0,4 m from the surface of the RBS antenna. The described field strength measurement methods may be used for laboratory or *in situ* evaluations (see Annex A).

6.2.2 RF field strength measurement

6.2.2.1 Applicability of RF field strength measurement

RF field strength measurement is applicable in all source-environment plane regions (see Table A.1 and Annex B).

Frequency-selective measurement is recommended anywhere that there is more than a single signal on one frequency present (see Table A.5).

NOTE Provided the measurement equipment is calibrated at the evaluation frequencies, the RF field strength measurement methods described here may be employed with care also to evaluate RF field strength at frequencies below 300 MHz.

6.2.2.2 General requirements

At least the following checks shall be performed:

- The measurement equipment shall meet the requirements of Annex E.
- Determine as many of the known characteristics of the sources of the RF fields as possible and estimate their likely propagation characteristics.
- Estimate the expected RF field strength using the basic computation methods in 6.3.2.
- 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, may affect (especially broadband) instruments.

- Establish if the reading may be measurement equipment noise.
- Determine the optimum measurement equipment settings.

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

- 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.
- 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:

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

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 i^{th} 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 i^{th} 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 flux density at the measurement point;
- S_i is the plane wave equivalent power flux density measured by the i^{th} measurement antenna or isotropic probe at the measurement point.

NOTE 3 For broadband measurement equipment, the above summation may 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.

- i) Consider the location of the source and RF propagation path during surveys to minimise the influence of the body on the measurement (see O.4.13). For handheld measurements, the uncertainty due to the scattering of the RF field by the surveyor's body shall be minimised by:
 - holding the probe or antenna away from the surveyor's body (it is recommended that a separation of at least 50 cm 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 in the direct line of propagation.
- 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) (see O.4.12) 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 2 and Table 3 (see 6.2.2.6);
 - 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 (see O.4.11) 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 e.g. [2]

6.2.2.3 Broadband RF field strength measurement

6.2.2.3.1 Applicability of broadband RF field strength 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 6.2.2.4) is required.

Broadband measurement results may be extrapolated to estimate the maximum possible RF field strength. However, 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.

6.2.2.3.2 Broadband RF field strength 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 (see 6.2.2.2) over the required frequency range and fulfils the requirements in Annex E.

The frequency response of the probe shall either be flat over the required frequency range (Table E.1) or shall be the inverse of the relevant frequency dependent compliance limit to provide a direct read-out expressed in terms of the relevant exposure quotient (see 6.2.2.3.3.2).

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 6.2.2.5.1), tripod procedure (see 6.2.2.5.2) or automated spatial sweeping procedure (see 6.2.2.5.3).

If required, spatial averaging of the field can be performed (see 6.2.2.5.4).

Investigate temporal variations in the field to ensure a stable indication of the RF field strength (see Annex J) or to fulfil related averaging time requirements for compliance determination (see 6.2.2.5.5).

6.2.2.3.3 Interpreting measurements over multiple frequency bands

6.2.2.3.3.1 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 compliance limit for the frequencies present shall be used to determine the combined exposure quotient expressed as a fraction/percentage of the relevant compliance limit.

6.2.2.3.3.2 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 quotient for example as a percentage of the applicable limit.

6.2.2.4 Frequency-selective RF field strength measurement

6.2.2.4.1 Applicability of frequency-selective RF field strength 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;

NOTE For example, frequency-selective RF field strength measurement is used for the purpose of demonstrating compliance with a limit or exceedance of a limit without the potential overestimation associated with a broadband evaluation.

- for measurements in low RF field strength environments (e.g. public areas) where the higher sensitivity of spectrum analysers/receivers compared with broadband probes makes this method especially suitable.

6.2.2.4.2 Frequency-selective RF field strength measurement method

When using frequency-selective instrumentation, ensure the instrumentation covers the frequency range of the signals to be evaluated (see Annex N). 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/polarisations. 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 N 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 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 relevant limit (see 6.2.2.5.5). Annex J 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 6.2.2.5.1); tripod RF field strength measurement procedure (see 6.2.2.5.2); or automated spatial-sweep measurement procedure (see 6.2.2.5.3). Additionally, spatial averaging of the field can be performed (see 6.2.2.5.4) (see Table A.1).

To obtain an estimate of the maximum possible level (see 6.4 and Annex J) extrapolation of the result shall be performed if required. 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.

6.2.2.5 RF field strength measurement procedures

6.2.2.5.1 Handheld instrument RF field strength measurements

6.2.2.5.1.1 Determining the RF field strength 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 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.

6.2.2.5.1.2 Sweeping a volume to determine a RF field strength of interest and/or its location

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

- determine the locations with the RF field strength of interest that has been identified in the evaluation plan;

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

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

NOTE 2 In the case of an uncluttered environment, the maximum RF field strength 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 (see 6.2.2.2). In general, measurements up to a height of 2 m above the floor or walkway are sufficient. The measurement antenna / isotropic probe shall be moved vertically and horizontally throughout the region under test while observing the instrument display. In addition, see 6.2.2.4.2 if a non-isotropic measurement antenna/probe is used. 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). The measurement antenna / isotropic probe shall be swept slowly over the region in order not to miss any maxima.

When using frequency-selective instruments:

- 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 Annex N.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 may be necessary to separate the frequencies into various groups (bands) to identify the levels of emissions from these individual bands.

6.2.2.5.2 RF field strength measurements using tripod-supported instrument/antenna

The measurement equipment and general methodology specified in 6.2.2.5.1 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 6.2.2.5.1) 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 may be limited by the dimensions of the measurement antenna / isotropic probe.

6.2.2.5.3 RF field strength measurements using automated spatial positioning equipment

Laboratory-based measurements of the RF field strength shall be performed with automated (or semi-automatic) spatial positioning equipment. The measurement antenna / isotropic probe is mounted on the positioner and automatically swept over a line, area or volume to capture/store RF field strength readings. These values can be processed for example to

obtain the maximum reading and spatially-averaged values over the scanned line/surface/volume.

The positioner shall be constructed in a manner that minimises reflections and perturbation of the field over the frequency range of interest. The scattering effect of the positioner shall be quantified and included in the uncertainty calculation.

6.2.2.5.4 Spatial averaging

6.2.2.5.4.1 Applicability of spatial averaging

Spatial averaging applicability depends on the relevant limit as described in A.3.2.

In a non-plane wave RF field, comparing the maximum RF field strength evaluated at a single point with the compliance 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. Annex I provides further information and guidance on spatial averaging schemes.

In cases of doubt or to resolve disputes, the reference spatial averaging method is the spatial average over nine points (see Figure I.1).

Where partial body exposure is relevant, (e.g. to establish compliance with a relevant peak spatial-average SAR limit or to compare with a relevant point RF field strength limit) then the maximum RF field strength at any of the measurement points may also need to be considered (see Annex A.3.2).

6.2.2.5.4.2 Spatial averaging measurement method

For each evaluation location, perform measurements as described in 6.2.2.5.1; 6.2.2.5.2; or, 6.2.2.5.3 at measurement points according to the spatial averaging scheme (see Annex I).

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

$$\bar{E} = \sqrt{\frac{\sum_{i=1}^{N_p} E_i^2}{N_p}} \quad \text{or} \quad \bar{H} = \sqrt{\frac{\sum_{i=1}^{N_p} H_i^2}{N_p}} \quad \text{or} \quad \bar{S} = \frac{\sum_{i=1}^{N_p} S_i}{N_p} \quad (2)$$

where:

$\bar{E}$ 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 i^{th} measurement point;

$\bar{H}$ 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 i^{th} measurement point;

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

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

S_i is the plane wave equivalent power flux density at the i^{th} measurement point.

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

6.2.2.5.5 Time averaging measurement procedure

6.2.2.5.5.1 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 due to push-to-talk 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 relevant 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.

NOTE 1 Depending on the relevant exposure standard; the instantaneous RF field strength may exceed the relevant limit value provided that its time-averaged value is below the relevant limit (see Annex A.3.2).

NOTE 2 The time-averaged RF field strength can provide a valid result at the time of measurement but may not be indicative of the field conditions at other periods.

NOTE 3 Data on the RF field strength variation over the measurement time can help establish whether such variations can be treated as a measurement uncertainty influence quantity or whether a time averaging measurement method is required for the evaluation (see Annex J).

6.2.2.5.5.2 Time averaging 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) may 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 6.2.2.5.1.2) to establish the location of spatial-peak field strength.
- d) Perform the evaluation.

NOTE 2 Such measurements may be performed with portable data logging devices adapted to the averaging time of the relevant compliance standard / exposure guideline. 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).

6.2.2.6 RF field strength measurement uncertainty

The sources of uncertainty identified in Table 2 or Table 3 shall be considered in three categories: measurement equipment; measurement methodology; and, source and environment.

- The measurement equipment uncertainty shall be in accordance with Annex E.
- The measurement methodology uncertainty shall be quantified.
- Source and environment factors (e.g. rain, open windows, environmental clutter) may be difficult to quantify but shall at least be described in the report (see Clause 8).

It is recommended that the expanded uncertainty of the measurement equipment and the methodology combined (i.e. excluding all source and environment influence factors) does not exceed 4 dB.

It is recommended that, where practical, the uncertainty of the source and environment factors is quantified.

See also other uncertainty considerations in Clause 7, Annex J, Annex L, and Annex O.

Table 2 – Sample template for estimating the expanded uncertainty of a RF field strength measurement that used a frequency-selective instrument

Source of uncertainty (influence quantity)	Unit	Prob. distrib. type	Uncertainty or semi span <i>a</i>	Divisor <i>d</i>	Sens. coeff. <i>c</i>	Standard uncertainty <i>u = a/d</i>	Corr. fact <i>t</i>	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.		$\sqrt{3}$	1			
Combined linearity deviation of the meter/cable/antenna	dB	rect.		$\sqrt{3}$	1			
Isotropy of the antenna	dB	rect.		$\sqrt{3}$	1			
Combined temperature and humidity response of meter/cable/antenna	dB	rect.		$\sqrt{3}$	1			
Mismatch between antenna and meter / spectrum analyser	dB	U		$\sqrt{2}$	1			
Methodology								
Probe position in high field gradients	dB	rect.		$\sqrt{3}$	1			
Field scattering from surveyor's body	dB	rect.		$\sqrt{3}$	1			
Mutual coupling between measurement antenna or isotropic probe and object	dB	rect.		$\sqrt{3}$	1			
Meter reading error of fluctuating signals	dB	triang.		$\sqrt{6}$	1			
Source and environment								
Variation in the power of the RF source from the nominal level	dB	rect.		$\sqrt{3}$	1			
Field reflections from movable large objects near the source during measurement	dB	rect.		$\sqrt{3}$	1			
Scattering from nearby objects and the ground	dB	rect.		$\sqrt{3}$	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, see Annex O.2.	
NOTE 2 See Annex O for guidance on the variables in this Table.	

Table 3 – Sample template for estimating the expanded uncertainty of a 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	$c^2 u^2$
Measurement equipment								
Calibration of field probe	dB	normal		1,96	1			
Frequency response of field probe	dB	rect.		$\sqrt{3}$	1			
Isotropy of the field probe	dB	rect.		$\sqrt{3}$	1			
Temperature response of the field probe	dB	rect.		$\sqrt{3}$	1			
Linearity deviation of the field probe	dB	rect.		$\sqrt{3}$	1			
Methodology								
Meter reading error of fluctuating signals	dB	triang.		$\sqrt{6}$	1			
Field reflections from surveyor's body	dB	rect.		$\sqrt{3}$	1			
Probe position in high field gradients	dB	rect.		$\sqrt{3}$	1			
Mutual coupling between measurement antenna or isotropic probe and object	dB	rect.		$\sqrt{3}$	1			
Source and environment								
Variation in the power of the RF source from the nominal level	dB	rect.		$\sqrt{3}$	1			
Scattering from nearby objects and the ground	dB	rect.		$\sqrt{3}$	1			
Field reflections from movable large objects near the source	dB	rect.		$\sqrt{3}$	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, see Annex Q.2.		
NOTE 2 See Annex O for guidance on the variables in this Table.		

6.2.3 SAR measurement method

6.2.3.1 Overview of SAR measurement method

The maximum peak spatial-average SAR (normally averaged over 1 g or 10 g of tissue) can be evaluated by measurements of induced electric fields in an equivalent body model (e.g. flat phantom) exposed to RF electromagnetic fields. Other IEC standards specify SAR measurement methods and procedures for radiocommunication terminals used at the ear (IEC 62209-1) and held near the face or to the body (IEC 62209-2). The methods below are based on, and make reference to IEC 62209-1 and IEC 62209-2.

6.2.3.2 SAR measurement applicability

The SAR measurement procedures described here are applicable for small stand alone equipment/devices and multi-element single-column 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 may be performed in the whole frequency range covered by this standard.

6.2.3.3 SAR measurement requirements

6.2.3.3.1 General requirements

The SAR measurement system is composed of a flat body 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 are given in IEC 62209-2:2010 (Clause 5) and IEC 62209-1:2005 (Annex B). Other tissue simulating materials (e.g. gel) and electric field strength measurement systems (e.g. grid of fixed probes) may be used provided the general requirements of IEC 62209-1 and IEC 62209-2 are satisfied.

6.2.3.3.2 Phantom selection

The methods described in this standard use two phantoms (See Figure 3):

- For maximum peak spatial-average SAR measurements, the elliptical phantom specified in IEC 62209-2:2010 may be used if the broadside of the EUT can be circumscribed by the ellipse.
- Otherwise the flat box-shaped whole-body phantom [50],[72] shall be used.

- This has lateral dimensions of 1,54 m × 0,339 m.
- The phantom shell thickness shall be up to 2 mm as specified in IEC 62209-2:2010, however, external strengthening fins of a maximum height (thickness) of 3 mm may be used provided that the effect on the local spatial peak 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 local spatial peak 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 62209-2:2010. 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.

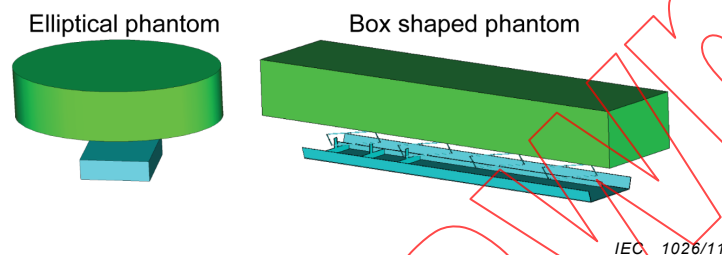


Figure 3 – Positioning of the EUT relative to the relevant phantom

6.2.3.3.3 EUT configuration for SAR measurement

If the EUT is a 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 if 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.

6.2.3.3.4 Measurement requirements

If the purpose of the evaluation is to establish product conformity, establish the compliance boundary or confirm the control boundary then the maximum SAR configuration shall be the assessment configuration (see 3.4). The following requirements shall be addressed:

- Maximum peak spatial-average SAR and whole-body SAR shall be considered.
- The measurement should 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 6.4 and Annex L) and documented in the test report.
- 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.
- If the EUT is capable of simultaneous multiple transmission (e.g. GSM 900 and GSM 1800), this mode shall also be evaluated.
- 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 imply that the antenna's main lobe direction shall be orthogonal to the phantom surface.

- f) During the measurements the centre of the EUT/antenna shall be placed below the centre of the relevant (see 6.2.3.3) phantom (see Figure 3). To avoid that an antenna element is positioned close to an edge of the phantom, small adjustments of the positioning may be made. The EUT positioning shall be documented in the test report.
- g) To establish the validity of a control boundary, if the user instructions provided by the manufacturer or site safety instructions/signage specify a minimum separation distance (or several separation distances) between the device/antenna and the body of a person, the test shall be performed at a separation distance (or separation distances) between the device/antenna and the tissue simulating liquid that corresponds to the specified minimum separation distance(s). In the absence of any such instructions/signage, the measurement shall be performed at 5 mm.
- h) To establish the compliance boundary, testing shall be performed at different separation distances between 5 mm and 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 evaluation see Annex C.3.

Control boundaries and compliance boundaries for different power levels may be obtained by linear scaling of a SAR versus separation distance curve (see Annex C.3).

6.2.3.4 SAR measurement description

6.2.3.4.1 General method

The SAR evaluation protocol is described below. The applicable parts (see NOTE) of the following subclauses of IEC 62209-2:2010 shall be applied:

- 6.1.1 General preparation;
- 6.1.2 System check;
- 6.1.4. Position of the device under test in relation to the phantom;
- 6.1.5 Test frequencies;
- 6.2.4 Fast SAR evaluations;
- 6.3 Measurement procedure;
- 6.4 Post-processing.

NOTE 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 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. Parts of the fast SAR evaluations, measurement procedure, and post-processing are only applicable for localized SAR assessments (evident from its context).

6.2.3.4.2 Maximum peak spatial-average SAR measurement description

For each of the measurement configurations required in 6.2.3.3, the maximum peak spatial-average SAR shall be evaluated in four steps:

- a) Use the measurement procedures specified in IEC 62209-2:2010 subclause 6.3 to determine an initial measured peak spatial-average SAR, $SAR_m(d)$, using the relevant phantom (see 6.2.3.3.2).
- 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:

$$CF_1(d) = \begin{cases} 1 & d < 200 \text{ mm} \\ \frac{d}{200} & 200 \text{ mm} \leq d < 400 \text{ mm} \\ 2 & 400 \text{ mm} \leq d \leq 1\,000 \text{ mm} \end{cases} \quad (3)$$

NOTE 1 For EUT distances above 200 mm, the maximum peak SAR in an actual human body may 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 [73] using the following formula:

$$CF_2(d) = \begin{cases} 2 & d \leq \frac{\lambda}{4} \quad \text{AND } N_e > 1 \\ -\frac{4d}{7\lambda} + \frac{15}{7} & \frac{\lambda}{4} < d < 2\lambda \quad \text{AND } N_e > 1 \\ 1 & d \geq 2\lambda \quad \text{OR } N_e = 1 \end{cases} \quad (4)$$

NOTE 2 For example, $CF_2(d)$ has a value of 1 for single element antennas.

NOTE 3 In the interpolation function in equation (4), 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

$$SAR_{psa}(d) = SAR_m(d) \times CF_1(d) \times CF_2(d) \quad (5)$$

where

d is the EUT distance (mm) measured from the liquid surface

N_e is the number of elements in the antenna array

$SAR_m(d)$ 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

6.2.3.4.3 Whole-body SAR measurement description

For each of the measurement configurations required in 6.2.3.3, the whole-body SAR measurement is performed in two steps:

- a) First determine the average (temporal) absorbed power, P_A , in the phantom at a given separation distance from the antenna by measuring the electric field strength in the volume defined by the area of the phantom and bounded by the planes $z = 0$ to $z = 0,09$ m (where $z = 0$ is the shell-liquid interface) [50],[72]. The measurement procedures in subclause 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 $(60/f_{\text{GHz}})$ mm for frequencies of 3 GHz and greater.
 - The grid step in the vertical direction for a uniform spacing shall be $(8 - f_{\text{GHz}})$ mm or less but not more than 5 mm (IEC 62209-2:2010).
 - 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 $(12/f_{\text{GHz}})$ mm or less but not more than 4 mm. The spacing between farther points shall increase by a factor not exceeding 1,5 (IEC 62209-2:2010). 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. [75]), provided that
 - the procedure has been thoroughly verified with volumetric measurements, and

- the uncertainty has been quantified.

b) The second step is to evaluate the whole body SAR, SAR_{wb} , using the following formula:

$$SAR_{wb}(d) = \frac{P_A(d) \times 1,8}{M} \quad (6)$$

where:

$P_A(d)$ 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 determining a compliance boundary or confirming a control boundary it is recommended that for adults M should be 46 kg ([50],[72]), and for children M should be 12,5 kg (corresponding to the 3rd percentile body weight data for a 4-year old girl [74]).

NOTE The multiplicative correction factor of 1,8 (2,5 dB) accounts for the tissue layering effect ([50], [72]).

6.2.3.5 SAR measurement uncertainty

Measurement uncertainty shall be estimated using the specifications in Clause 7 of IEC 62209-2:2010. For whole-body SAR measurements the uncertainty estimation shall be made in terms of absorbed power. The SAR measurement procedure has been designed to produce results which are located on the conservative side of the probability distribution.

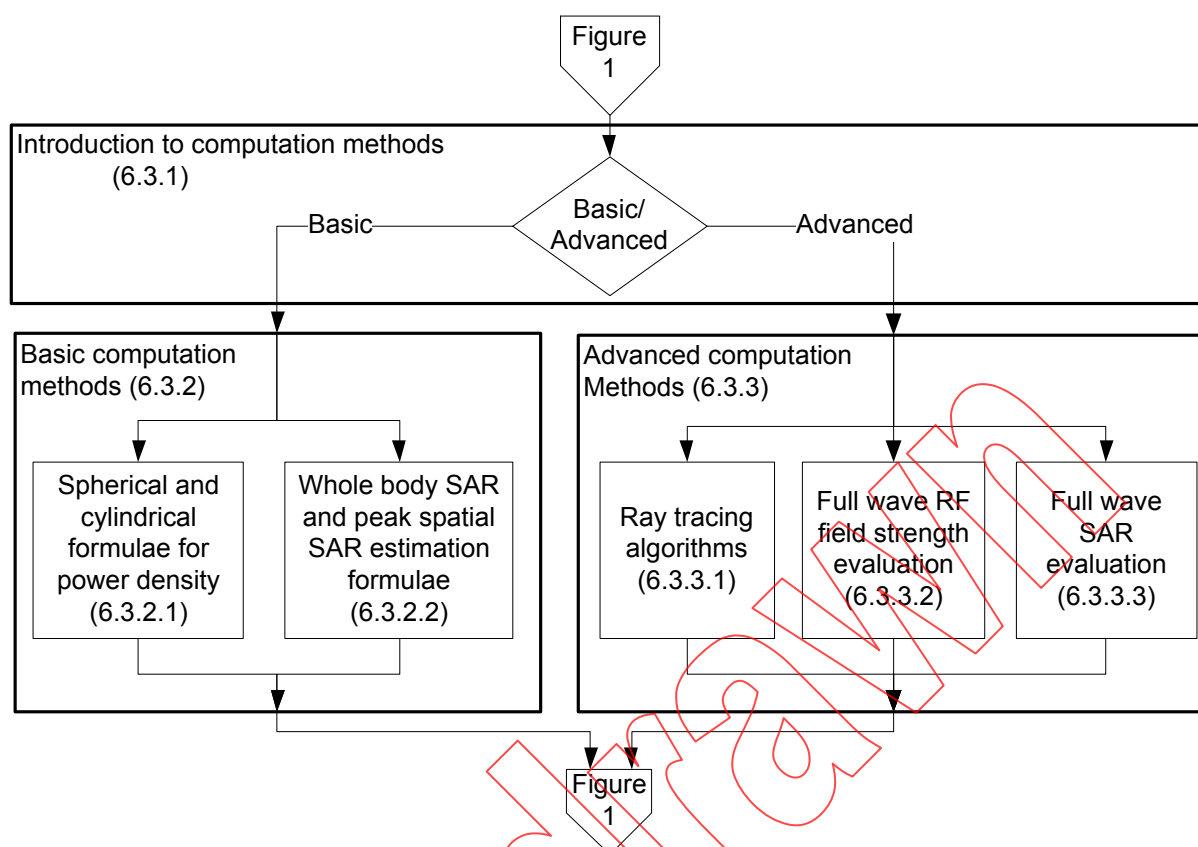
6.3 Computation methods

6.3.1 Overview and general requirements

Computing RF field strength and SAR can be less labour intensive than measurements and can play a useful role in the RF field evaluations at RBS sites. Figure 4, an expansion of the RF field strength / SAR computation block from Figure 1, presents an overview of computation methods described in this standard.

When considering which computation method to select, the simplest applicable method should be used that gives the required level of precision for the required measurand. A more comprehensive (advanced) evaluation method will usually take much longer to perform; however, the results obtained can be more precise and may take precedence when compared to the results of a quick and easy evaluation - see the evaluation ranking Table A.7. Table A.6 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 H. These results have been obtained from computational codes that have been verified extensively against canonical problems as well as measurements in the published literature. These reference results have been produced by experienced users of computational techniques. For methods or cases not covered in Annex H, validation shall be completed against measured data.



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Figure 4 – Overview of computation methods

Table 4 provides a summary of applicable computation methods (basic and advanced) in the source-environment plane (see Figure B.1).

**Table 4 – Applicability of computation methods
for source-environment regions of Figure B.1**

	Applicable methods ^a		
	Source Region I	Source Region II	Source Region III
Environment Region M	1. Full wave – Field strength (see 6.3.3.2) 2. Full wave – SAR (see 6.3.3.3)	1. Ray tracing algorithm (see 6.3.3.1) 2. Full wave – Field strength (see 6.3.3.2) 3. Full wave – SAR (see 6.3.3.3)	1. Ray tracing algorithm (see 6.3.3.1) 2. Full wave – Field strength (see 6.3.3.2) 3. Full wave – SAR (see 6.3.3.3)
Environment Region 1	1. Full wave – Field strength (see 6.3.3.2) 2. Full wave – SAR (see 6.3.3.3)	1. Cyl.-spherical formula (see 6.3.2.1) 2. Ray tracing algorithm (see 6.3.3.1) 3. Full wave – Field strength (see 6.3.3.2) 4. Full wave – SAR (see 6.3.3.3)	1. Cyl.-spherical formula (see 6.3.2.1) 2. Ray tracing algorithm (see 6.3.3.1) 3. Full wave – Field strength (see 6.3.3.2) 4. Full wave – SAR (see 6.3.3.3)
Environment Region 0	1. SAR estimation formulae (see 6.3.2.2) 2. Full wave – Field strength (see 6.3.3.2) 3. Full wave – SAR (see 6.3.3.3)	1. SAR estimation formulae (see 6.3.2.2) 2. Cyl.-spherical formula (see 6.3.2.1) 3. Ray tracing algorithm (see 6.3.3.1) 4. Full wave – field strength (see 6.3.3.2) 5. Full wave – SAR (see 6.3.3.3)	1. SAR estimation formulae (see 6.3.2.2) 2. Cyl.-spherical formula (see 6.3.2.1) 3. Ray tracing algorithm (see 6.3.3.1) 4. Full wave – field strength (see 6.3.3.2) 5. Full wave – SAR (see 6.3.3.3)
^a Methods are listed in order of recommendation for the specific source-environment plane geometry under consideration.			

- **Basic computations (see 6.3.2):** The basic computation formulae presented in 6.3.2 are conservative formulae for the estimation of RF field strength, power density or SAR. The formulae are easy to implement and may be adequate for RF field strength and SAR evaluation. No uncertainty estimations are required when using these formulae but there is clear guidance on where and when these formulae are applicable. The basic computation formulae can only be employed in limited applications as defined in 6.3.2.
- **Advanced computations (see 6.3.3):** 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 a RBS antenna. The advanced computation techniques are presented in 6.3.3, 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.

6.3.2 Basic computation methods

6.3.2.1 Spherical and cylindrical formulae for power density

6.3.2.1.1 Overview of spherical and cylindrical formulae

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 [3], [4] which gradually converts to spherical in the far-field. Simple formulae can be used to predict the fields radiated by these linear arrays.

This subclause discusses the conditions under which these estimation formulae can be applied.

6.3.2.1.2 Applicability of spherical formulae

The far-field spherical formulae 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:

$$S = \frac{\bar{P}_{\text{avg}} \cdot G_{\theta,\phi}}{4 \cdot \pi \cdot r^2} \quad (7)$$

The associated r.m.s. electric field strength E and magnetic field strength H can be evaluated as follows:

$$E = \frac{\sqrt{30 \cdot \bar{P}_{\text{avg}} \cdot G_{\theta,\phi}}}{r} \quad (8)$$

$$H = \frac{E}{\eta_0} \quad (9)$$

The far-field spherical formulae shall only be used considering the following limitations:

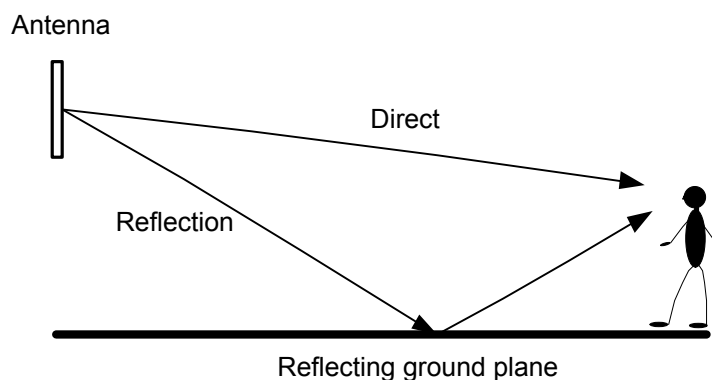
- $r \geq \frac{2L^2}{\lambda}$, where L is the maximum dimension of the antenna.
- For the estimate of S , E or H to be conservative, $\bar{P}_{\text{avg}}$ and $G_{\theta,\phi}$ values shall be the upper bounds of the uncertainty.
- Reflecting surfaces/objects, a ground plane and mounting structures 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 5), use the equation:

$$S = (1 + |\Gamma|)^2 \cdot \frac{\bar{P}_{\text{avg}} \cdot G_{\theta,\phi}}{4 \cdot \pi \cdot r^2} \quad (10)$$

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 [46] ground reflection conditions.

See Annex D for definition of variables.



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Figure 5 – Reflection due to the presence of a ground plane



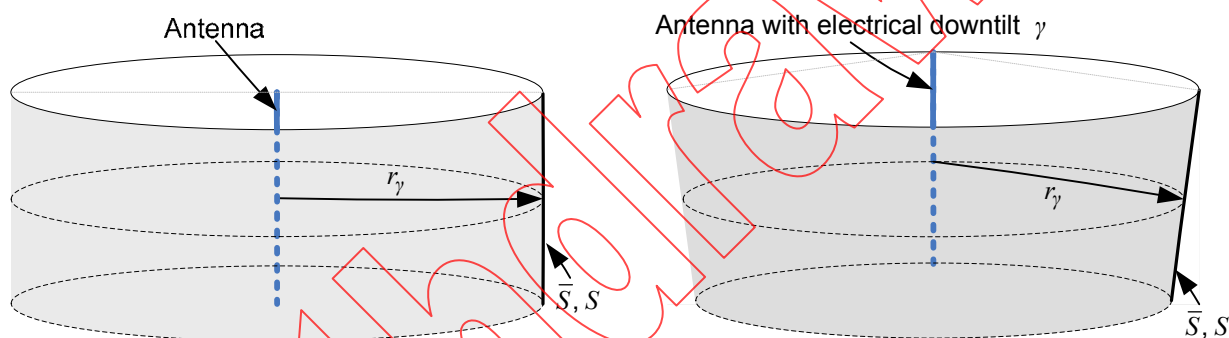
The adjusted spherical formulae presented in F.2 [53] can be employed inside parts of source regions I and II (spatial-peak and spatial-average field strength) but evaluations are limited to the zones detailed in Figure F.2. The advantage in using the adjusted spherical formulae is to obtain conservative but realistic RF field strength evaluations much closer to the antenna than with the classical far-field formulae referenced above.

Another set of relatively basic adjusted spherical formulae that can be used in source region II (radiating near-field) is presented in [51], [52] which details the limitations of the technique.

6.3.2.1.3 Applicability of cylindrical formulae

The cylindrical formulae presented in F.2 can be used to calculate

- the spatial-peak power flux density, S , in those parts of all source regions (see Annex B) limited to the enclosed cylinder of the antenna array (see Figure 6); and,
- the power flux density spatially-averaged over the length of the antenna, $\bar{S}$, within those parts of source region III limited to the enclosed cylinder of the antenna array (see Figure 6).



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Figure 6 – Enclosed cylinder around collinear arrays, with and without electrical downtilt

Limitations for applying the cylindrical formulae:

- The electrical tilt angle, γ , of the linear array shall be less than or equal to 10° . The cylindrical formulae 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.

6.3.2.1.4 Procedures to follow when applying the spherical and cylindrical formulae

The following procedure shall be followed when performing an evaluation using the spherical or cylindrical formulae:

- a) Ensure that the evaluation will be valid considering the restrictions and limitations of the different methods.
- b) Implement the formulae presented above, in Annex F or in the relevant referenced technical papers.

NOTE A basic spreadsheet or mathematics modelling package implementation would be sufficient.

- c) Validate the implementation by comparing example results to known or published results. For the adjusted spherical formulae and cylindrical formulae given in Annex F, validation shall be performed by comparing against results presented in H.1.

- d) Establish input parameters (see 6.3.2.1.5).
- e) Perform the field evaluation(s) using the formulae.
- f) Report on the evaluation using the guidelines presented in Clause 8 (also see Clause 7, Annex L, and, Annex M).

6.3.2.1.5 Input requirements

To apply the far-field spherical formulae the following information is required:

- $\bar{P}_{\text{avg}}$, $G_{\theta,\phi}$, η_0 , and r (see 4.2, Annex D and Annex F.2.1);

In addition, the adjusted spherical formulae require the following information:

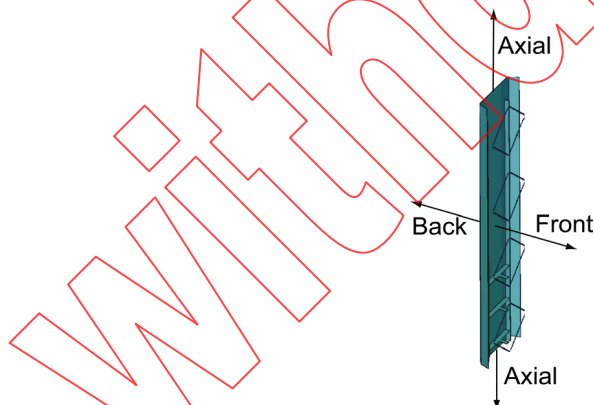
- G , $G_{\text{side lobe}}$, $\phi_{3\text{dB}}$, $\theta_{3\text{dB}}$, γ , and λ (see Annex D)

To apply the cylindrical formulae L and r_γ (see Annex F.2) are also required.

6.3.2.2 Whole body SAR and peak spatial-average SAR estimation formulae

6.3.2.2.1 Applicability

The formulae in this subclause 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 formulae are given for three main directions: front (main beam), axial, and back according to Figure 7.



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Figure 7 – Directions for which SAR estimation expressions are given

Table 4 summarizes recommended and permitted applications for the SAR estimation formulae ([49], [50]) in terms of the source-environment plane regions. Further constraints on the applicability of the estimation formulae are summarized in Table 5.

Table 5 – Applicability of SAR estimation formulae

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	Phantom to antenna separation distance, d greater than 20 cm. Formulae applicable for adult RF exposure evaluation
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. 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 6.5.

6.3.2.2.2 Using the SAR estimation formulae

The following procedure shall be followed when employing the SAR estimation formulae:

- Ensure that the evaluation will be valid considering the restrictions and limitations of the method.
- Implement the formulae presented in F.3.
- Validate the implementation against the results presented in H.2.
- Establish input parameters (see 6.3.2.2.3).
- Perform the SAR evaluation(s) using the validated implementation.
- Report on the evaluation using the guidelines presented in Clause 8 (also see Clause 7, Annex L, and Annex M).

6.3.2.2.3 Input parameters

To apply the SAR estimation formulae the following information is required:

- Frequency bands for all transmitters;
- $\bar{P}_{\text{avg}}$, N_e , $\phi_{3\text{dB}}$, $\theta_{3\text{dB}}$, G , (see Annex D);
- L , the physical antenna array length for each band measured in metres.

6.3.2.2.4 SAR estimation formulae uncertainty

The SAR estimation formulae 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.

6.3.3 Advanced computation methods

6.3.3.1 Ray tracing algorithms

6.3.3.1.1 Applicability of ray tracing algorithms

Various ray tracing algorithms have been developed (e.g. [3] [4], [5], [6], [7], [8], [9]) and implemented in commercial computer codes, for the evaluation of RF field strength in all directions around RBS antennas. The specific application of ray tracing for RBS antennas usually involves obtaining the electric field strength at an observation point using a vector sum of a number of small “patches” of the antenna treated as separate sources. This is also known as the synthetic model. These ray tracing algorithms are suited to evaluations in the far-field (source region III) and radiating near-field (source region II). Table 4 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 is commonly used for:

- Evaluation of RF field strength 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 & 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, for example as done in US FCC OET Bulletin 65 [46], 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 is commonly used for:

- Evaluation of RF field strength 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 is commonly used for:

- Evaluation of RF field strengths 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 build 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.

6.3.3.1.2 Input requirements for ray tracing algorithms

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.

6.3.3.1.3 Description of ray tracing algorithms

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. The methodology is widely understood and can be employed to evaluate multiple sources and different frequencies. Technical details for implementing ray tracing algorithms can be found in e.g. [3], [4], [5], [6], [7], [8], and [9].

Figure 8 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 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.

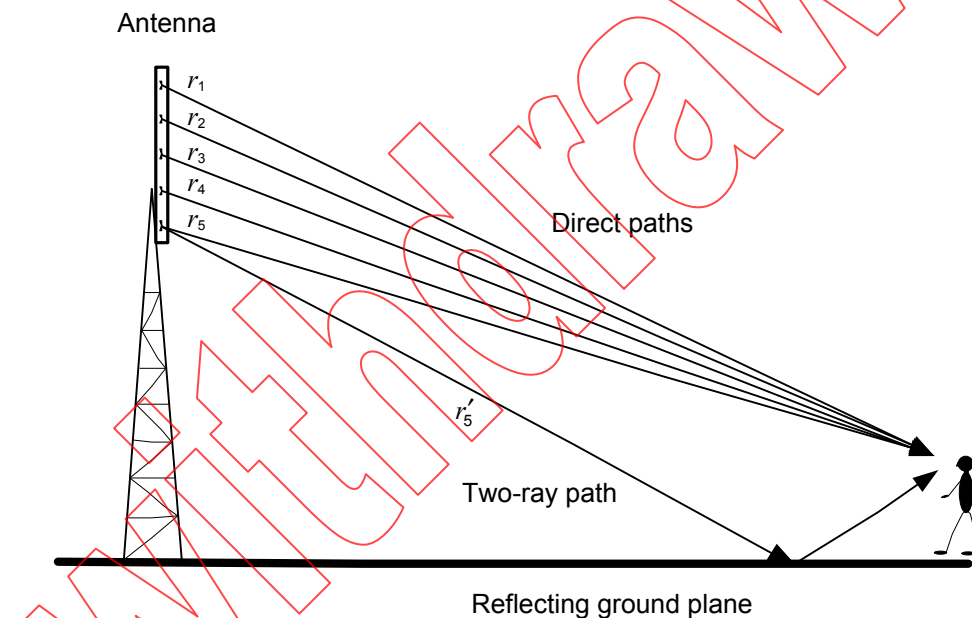


Figure 8 – Ray tracing (synthetic model) geometry and parameters

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:

- Ensure that the evaluation will be valid considering the restrictions and limitations of the method.
- Select commercial code or implement algorithms.
- Validate using pre-calculated examples (see Annex H.3).
- Establish input parameters (see 6.3.3.1.2).
- Perform evaluation (apply ray tracing algorithm).
- Perform uncertainty analysis (see 6.3.3.1.4).

- g) Apply uncertainty for result interpretation (see Clause 7; Annex L; and, Annex M);
- h) Report on evaluation (see Clause 8).

6.3.3.1.4 Ray tracing uncertainty parameters

Uncertainty factors for ray tracing fall into three categories namely transmitter system, modelling technique and environmental uncertainties. Table 6 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.

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Table 6 – Sample template for estimating the expanded uncertainty of a ray tracing RF field strength computation

Source of uncertainty	Unit	Prob. distrib. type	Uncertainty or semi span a	Divisor d	Sens. coeff. c	Standard uncertainty $u = a/d$	Corr. fact t	$c^2 u^2$
System								
Variation in the power of the RF transmitter from its nominal level	dB	rect.		$\sqrt{3}$	1			
Cable/connector losses	dB	normal		1,96	1			
Mismatch between antenna and its feed	dB	U		$\sqrt{2}$	1			
Antenna radiation pattern data (see NOTE 2)	dB	normal		1,96	1			
Antenna positioning, mounting & support structure	dB	rect.		$\sqrt{3}$	1			
Technique Uncertainties								
Inherent uncertainties associated with the approximate numerical model used to represent the antenna.	dB	rect.		$\sqrt{3}$	1			
Null-filling of antenna patterns (if applied)	dB	Depends on algorithm			1			
Environmental Uncertainties								
Scattering from nearby objects and the ground	dB	rect.		$\sqrt{3}$	1			
Uncertainty in using electric field strength evaluations to estimate magnetic field strength, or vice versa	dB	rect.		$\sqrt{3}$	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, see Annex O.2.								
NOTE 2 The normalized radiation pattern uncertainty can be different inside the HPBW (very small); outside the main beam (larger); and in the side lobes.								
NOTE 3 See Annex O for guidance on the variables in this Table.								

6.3.3.2 Full wave RF field strength computation

6.3.3.2.1 Full wave RF field strength computation applicability

Full wave analysis techniques (i.e. 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 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 (~ radiating near-field) and source region III (~ 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 4 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 (~ 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 (~ 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.

6.3.3.2.2 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 analyzed 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 ($\lambda/20$ 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.

6.3.3.2.3 Full wave RF field strength computation description

The main methods to use with full wave analysis are the Method of Moments (MoM) ([15], [35], [10], [11], [48]) the finite element method (FEM) ([12], [13], [14], [15], [48]) and the finite

difference time domain (FDTD) ([10], [16], [17], [18], [19], [48]) method. 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. Method specific information about full wave field evaluation can be found in Annex G.

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 Annex H.4).
- d) Prepare detailed antenna models and verify against measurements for evaluations in source region I.
- e) Perform field evaluation for each antenna (see Annex G).
- f) Study convergence for each antenna (see Annex G).
- g) Validate converged results against antenna specifications (each antenna).
- h) Perform field calculation for all antennas (see Annex G).
- i) Perform uncertainty analysis (see 6.3.3.2.4).
- j) Use uncertainty analysis for result interpretation (see Clause 7; Annex L; and, Annex M).
- k) Report of evaluation (see Clause 8).

6.3.3.2.4 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 7 is an uncertainty estimation template listing uncertainty parameters that shall be considered when using full wave RF field strength analysis - also see Annex O.5.