



BSI Standards Publication

Measurement procedure for the assessment of specific absorption rate of human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices

Part 1: Devices used next to the ear
(Frequency range of 300 MHz to 6 GHz)

National foreword

This British Standard is the UK implementation of EN 62209-1:2016. It is identical to IEC 62209-1:2016. It supersedes BS EN 62209-1:2006 which is withdrawn.

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English Version

**Measurement procedure for the assessment of specific
absorption rate of human exposure to radio frequency fields from
hand-held and body-mounted wireless communication devices -
Part 1: Devices used next to the ear (Frequency range of 300
MHz to 6 GHz)
(IEC 62209-1:2016)**

Procédure de mesure pour l'évaluation du débit
d'absorption spécifique de l'exposition humaine aux champs
radiofréquences produits par les dispositifs de
communications sans fil tenus à la main ou portés près du
corps - Partie 1: Dispositifs utilisés à proximité de l'oreille
(Plage de fréquences de 300 MHz à 6 GHz)
(IEC 62209-1:2016)

Sicherheit von Personen in hochfrequenten Feldern von
handgehaltenen und am Körper getragenen schnurlosen
Kommunikationsgeräten - Körpermodelle, Messgeräte und -
verfahren - Teil 1: Verfahren zur Bestimmung der
spezifischen Absorptionsrate (SAR) von Geräten, die in
enger Nachbarschaft zum Ohr benutzt werden
(Frequenzbereich von 300 MHz bis 6 GHz)
(IEC 62209-1:2016)

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European foreword

The text of document 106/361/FDIS, future edition 2 of IEC 62209-1 prepared by IEC/TC 106X "Methods for the assessment of electric, magnetic and electromagnetic fields associated with human exposure" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 62209-1:2016.

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- latest date by which the national (dow) 2019-08-10
standards conflicting with the
document have to be withdrawn

This document supersedes EN 62209-1:2006.

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Annex ZA (normative)

Normative references to international publications with their corresponding European publications

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

NOTE 1 When an International Publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

NOTE 2 Up-to-date information on the latest versions of the European Standards listed in this annex is available here: www.cenelec.eu

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
ISO/IEC 17025	2005	General requirements for the competence of testing and calibration laboratories	EN ISO/IEC 17025	2005
ISO/IEC 17043	2010	Conformity assessment - General requirements for proficiency testing	EN ISO/IEC 17043	2010

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

**MEASUREMENT PROCEDURE FOR THE ASSESSMENT OF SPECIFIC
ABSORPTION RATE OF HUMAN EXPOSURE TO RADIO FREQUENCY
FIELDS FROM HAND-HELD AND BODY-MOUNTED WIRELESS
COMMUNICATION DEVICES –****Part 1: Devices used next to the ear
(Frequency range of 300 MHz to 6 GHz)**

FOREWORD

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International Standard IEC 62209-1 has been prepared by IEC technical committee 106: Methods for the assessment of electric, magnetic and electromagnetic fields associated with human exposure.

This second edition cancels and replaces the first edition published in 2005. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

- a) Extension of the frequency range to 300 MHz to 6 GHz.
- b) Fast SAR methods.

- c) Test reduction techniques.
- d) SAR measurements of terminals with multiple antennas and multiple transmitters.
- e) Deviation of dielectric characteristics of the tissue-equivalent liquids is relaxed up to 10 %.
- f) Uncertainty evaluation guidelines for temperature and dielectric parameter deviations of tissue-equivalent liquids.
- g) Addition of the following annexes:
 - Annex K (informative) Measurement uncertainty of specific fast SAR methods and fast SAR examples
 - Annex L (informative) SAR test reduction supporting information
 - Annex M (informative) Applying the head SAR test procedures
 - Annex N (informative) Studies for potential hand effects on head SAR
 - Annex O (informative) Quick start guide.

The text of this standard is based on the following documents:

FDIS	Report on voting
106/361/FDIS	106/365/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.

In this standard, the following print types are used:

- specific test protocols: in *italic* type.

A list of all parts in the IEC 62209 series, published under the general title *Measurement procedure for the assessment of specific absorption rate of human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices*, can be found on the IEC website.

Future standards in this series will carry the new general title as cited above. Titles of existing standards in this series will be updated at the time of the next edition.

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

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

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

INTRODUCTION

IEC TC 106 has the scope to prepare International Standards on measurement and calculation methods used to assess human exposure to electric, magnetic and electromagnetic fields. IEC TC 106 has developed this part of IEC 62209 to provide procedures to evaluate the specific absorption rate (SAR) of human exposures due to electromagnetic field (EMF) transmitting devices when held close to the ear. The types of devices include but are not limited to mobile telephones, cordless telephones, headphones, etc., which are used close to the ear. The IEC TC 106 standards do not deal with the exposure limits. Conformity assessment depends on the policy of national regulatory bodies. While basic restrictions on SAR in the ICNIRP Guidelines [64]¹ go up to 10 GHz, the frequency range for this part of IEC 62209 is limited to an upper end frequency of 6 GHz since current wireless handsets operate below this frequency.

IEC TC 106 and IEEE/ICES TC34² worked together formally through common membership to achieve the goal of harmonization, between IEC TC 106 Maintenance Team 1 for this part of IEC 62209 and IEEE/ICES TC34 for IEEE Std 1528 [66]. During the process a primary effort involved was to harmonize these two standards.

To aid the user of this part of IEC 62209, a quick start guide has been prepared and included as an informative annex (see Annex O). The quick start guide is not a substitute for following the detailed procedure of the standard.

¹ Numbers in square brackets refer to the Bibliography.

² The International Committee on Electromagnetic Safety of the IEEE.

MEASUREMENT PROCEDURE FOR THE ASSESSMENT OF SPECIFIC ABSORPTION RATE OF HUMAN EXPOSURE TO RADIO FREQUENCY FIELDS FROM HAND-HELD AND BODY-MOUNTED WIRELESS COMMUNICATION DEVICES –

Part 1: Devices used next to the ear (Frequency range of 300 MHz to 6 GHz)

1 Scope

This part of IEC 62209 specifies protocols and test procedures for measurement of the peak spatial-average SAR induced inside a simplified model of the head with defined reproducibility. It applies to certain electromagnetic field (EMF) transmitting devices that are positioned next to the ear, where the radiating structures of the device are in close proximity to the human head, such as mobile phones, cordless phones, certain headsets, etc. These protocols and test procedures provide a conservative estimate with limited uncertainty for the peak-spatial SAR that would occur in the head for a significant majority of people during normal use of these devices. The applicable frequency range is from 300 MHz to 6 GHz.

2 Normative references

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

ISO/IEC 17043:2010, *Conformity assessment – General requirements for proficiency testing*

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

axial isotropy

maximum deviation of the SAR measured when rotating around the major axis of the probe while it is exposed to a wave impinging from a direction along its major axis

3.2

conducted power

power delivered by the power amplifier to a matched load

3.3

frequency band

transmitting frequency range associated with a specific wireless operating mode

Note 1 to entry: The frequency band is usually referred to using rounded figures; however the actual frequency allocation may be slightly different, e.g. GSM 850 MHz band actually uses 824 MHz to 849 MHz and 869 MHz to 894 MHz, GSM 900 MHz band actually uses 880 MHz to 915 MHz and 925 MHz to 960 MHz.

3.4

basic restriction

human exposure limits for compliance with time-varying electric, magnetic, and electromagnetic fields measured inside the body that are based on established adverse health effects

Note 1 to entry: Within the frequency range of this Standard, the physical quantity used as a basic restriction is the specific absorption rate (SAR).

3.5

boundary proximity effect

<probe> change in the sensitivity of an electric-field probe when the probe tip is located less than one probe-tip diameter from media boundaries

Note 1 to entry: This effect is caused by distortion of the scattered field at the probe tip due to nearby dielectric phantom surface. This effect can be compensated for known probe orientation with respect to the phantom surface.

3.6

channel

RF channel

specific sub-division of the available frequency range according to the operating parameters of a wireless technology

Note 1 to entry: The number of RF channels and channel bandwidth may vary with individual wireless technologies. For the purpose of this Standard, SAR measurements are performed on specific channels; for example, the high, middle and low channels of the transmission band.

3.7

correlated signals

<in time> electromagnetic fields, associated with distinct signal waveforms, yielding non-zero time-domain correlation integral at some time instant.

Note 1 to entry: For two power-limited field distributions $F_1(r, t)$ and $F_2(r, t)$, said integral is defined as:

$$(F_1 \otimes F_2)(r, t) = \lim_{T \rightarrow \infty} \frac{1}{2T} \int_{-T}^T F_1(r, t)^+ \cdot F_2(r, t + \tau) d\tau \quad (1)$$

where r is the location vector, the superscript $+$ represents the complex conjugate operation and the symbol $\cdot$ represents the inner product operation.

Observe that two fields are uncorrelated at locations where they are geometrically orthogonal. This property does not generally hold at nearby points unless the respective waveforms are uncorrelated [62].

In case of scalar signals, correlated signal waveforms yield a non-zero time-domain correlation integral at some time instant. For two power-limited signals $s_1(t)$, $s_2(t)$, said integral is defined as:

$$(s_1 \otimes s_2)(t) = \lim_{T \rightarrow \infty} \frac{1}{2T} \int_{-T}^T s_1(t)^+ \cdot s_2(t + \tau) d\tau \quad (2)$$

where the superscript $+$ represents the complex conjugate operation.

Note 2 to entry: Two uncorrelated signals would feature a vanishing correlation integral, i.e. the above integral is equal to zero.

Note 3 to entry: Formulas (1) and (2) are originally specified in IEC TR 62630 [62].

3.8

device holder

fixture constructed of low-loss dielectric material that is used to hold the device under test in the required test position during SAR measurement

3.9**device under test DUT**

device that is tested according to the procedures specified in this Standard to determine the specific absorption rate

Note 1 to entry: This note applies to the French language only.

3.10**dielectric constant**

real part of the complex relative permittivity of the lossy material

3.11**duty factor**

ratio of the pulse duration to the pulse period of a periodic pulse train

3.12**fast SAR testing**

<measurements> use of special techniques, methods or algorithms to decrease the measurement time

Note 1 to entry: Fast SAR methods do not fully comply with all of the normative requirements in this Standard. Fast SAR procedures are described in 6.6.

3.13**full SAR testing**

<measurements> use of methods, procedures and specific hardware which fully comply with all of the normative requirements in this Standard, except those specified in 6.6 and 6.7.4

3.14**handset**

<wireless communication device> hand-held device intended to be operated next to the ear, consisting of an acoustic output or earphone and an acoustic input or microphone, and containing a radio transmitter and receiver

Note 1 to entry: The terms "mobile" and "portable" have specific but generic meanings in IEC 60050 [61] – mobile: capable of operating while being moved (IEV 151-16-46); portable: capable to be carried by one person (IEV 151-16-47). The term "portable" often implies the ability to operate when carried on the user. These definitions are used interchangeably in various wireless regulations and industry specifications, in some cases referring to types of wireless devices and in other cases to intended use.

3.15**head mounted device****headset**

device operated next to the side of the head consisting of an acoustic output or earphone and a microphone and containing a radio transmitter and receiver held in position on or around the ear by mechanical support, e.g. around the head. A head mounted device (headset) is designed to be used at the ear but does not protrude into the pinna or the auditory canal. For all practical purposes of this Standard, it is considered as a handset as it contains the same basic components and performs the same basic functions

Note 1 to entry: Where the device under test is a head mounted device (headset), the user shall read the term handset to mean head mounted device throughout this Standard.

Note 2 to entry: A head mounted device that is intended to be used in a way not considered for testing by SAM phantom explained in this Standard is outside the scope of this Standard. (e.g. ear bud).

3.16**hemispherical isotropy**

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

3.17**linearity error**

maximum deviation of a measured quantity from the expected values defined by a reference line over the measurement range

3.18**multi-band**

<wireless device> capable of operating in more than one frequency band

3.19**operating mode**

wireless protocol or standard used by a device to communicate with another terminal or network

Note 1 to entry: Modern terminals may have multiple operating modes incorporated and these may operate individually or multiple modes may be simultaneously active. Examples of operating modes include GSM, EDGE, EVDO, GPRS, CDMA, WCDMA, Bluetooth®, WiFi® and others.³ Each of these modes may have one or more transmission bands associated with it.

3.20**peak spatial-average SAR**

maximum average SAR within a local region based on a specific averaging volume or mass, e.g. any 1 g or 10 g of tissue in the shape of a cube

Note 1 to entry: SAR is expressed in W/kg or equivalently mW/g.

Note 2 to entry: In this Standard, the terms peak spatial-average SAR (over 1 g or 10 g) and the terms 1 g SAR and 10 g SAR are used interchangeably.

3.21**penetration depth**

<for a given frequency> depth at which the electric field (E-field) strength of an incident plane wave, penetrating into a lossy medium, is reduced to $1/e$ of its value just beneath the surface of the lossy medium

Note 1 to entry: For a plane-wave incident normally on a planar half-space, the penetration depth δ is given in Formula (3):

$$\delta = \frac{1}{\omega} \left[\frac{\mu_0 \varepsilon_r' \varepsilon_0}{2} \left(\sqrt{1 + \left(\frac{\sigma}{\omega \varepsilon_r' \varepsilon_0} \right)^2} - 1 \right) \right]^{-\frac{1}{2}} \quad (3)$$

3.22**phantom**

physical model similar in appearance to the human anatomy and comprised of material with electrical properties similar to the corresponding tissues

Note 1 to entry: A phantom representing the human head could be a simple spherical model or a more complex multi-tissue anthropomorphic model.

3.23**pinna auricle**

cartilaginous projecting portion of the outer ear, consisting of the helix, lobule and anti-helix

³ Bluetooth is the trademark of a product supplied by the Bluetooth SIG. WiFi is the trademark of a product supplied by Wi-Fi Alliance. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC of the products named. Equivalent products may be used if they can be shown to lead to the same results.

3.24**push-to-talk device**

hand-held radio transceiver in which a user operates a switch to toggle between radio transmission and reception (simplex operating mode)

EXAMPLE A two-way radio.

3.25**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

3.26**readout electronics**

measurement system component that connects to the E-field probe and provides an analogue-to-digital conversion of the measured values to the post-processor of the measurement system

3.27**response time**

time required by the measuring equipment to reach 90 % of its final value after a step variation of the input signal

3.28**scanning system**

automatic positioning system capable of placing the measurement probe at specified positions

3.29**sensitivity**

<of a measurement system> ratio of the magnitude of the system response (e.g. voltage) to the magnitude of the quantity being measured (e.g. electric field strength squared)

3.30**specific absorption rate****SAR**

The SAR in the tissue-equivalent liquid can be determined by the rate of temperature increase or by E-field measurements, according to Formulas (4) or (5):

$$SAR = \frac{\sigma E^2}{\rho} \quad (4)$$

$$SAR = c_h \left. \frac{dT}{dt} \right|_{t=0} \quad (5)$$

where

SAR is the specific absorption rate in W/kg;

E is the rms value of the electric field strength in the tissue medium in V/m;

σ is the electrical conductivity of the tissue medium in S/m;

ρ is the mass density of the tissue medium in kg/m³;

c_h is the specific heat capacity of the tissue medium in J/(kg K);

$\left. \frac{dT}{dt} \right|_{t=0}$ is the initial time derivative of temperature in the tissue medium in K/s.

3.31 Uncertainty

3.31.1

standard uncertainty

estimated standard deviation of a measurement result, equal to the positive square root of the estimated variance

3.31.2

combined uncertainty

estimated standard deviation of the measurement result obtained by combining the individual standard uncertainties of both Type A and Type B evaluations using the usual "root-sum-squares" method of combining standard deviations which were obtained by taking the positive square root of the estimated variances

3.31.3

expanded uncertainty

quantity defining an interval about the result of a measurement that is expected to encompass a distribution of values within a defined confidence interval that could reasonably be attributed to the measurand

3.32

uncertainty evaluation

<Type A> evaluation of uncertainty by the statistical analysis of a series of observations (measurements)

3.33

uncertainty evaluation

<Type B> evaluation of uncertainty by means other than the statistical analysis of a series of observations (measurements)

4 Symbols and abbreviations

4.1 Physical quantities

The internationally accepted SI units are used throughout the Standard.

Symbol	Quantity	Unit	Dimensions
α	Attenuation coefficient	reciprocal metre	1/m
c_h	Specific heat capacity	joule per kilogram per kelvin	J/(kg K)
E	Electric field strength	volt per metre	V/m
f	Frequency	hertz	Hz
J	Current density	ampere per square metre	A/m ²
P	Average (temporal) absorbed power	watt	W
T	Temperature	kelvin	K
ε	Permittivity	farad per metre	F/m
λ	Wavelength	metre	m
δ	Penetration depth	metre	m
σ	Electric conductivity	siemens per metre	S/m

NOTE In this Standard, temperature is quantified in degrees Celsius, as defined by: $T (^\circ\text{C}) = T (\text{K}) - 273,15$.

4.2 Constants

Symbol	Physical constant	Magnitude
η_0	Intrinsic impedance of free space	$120 \pi \Omega$ or 377Ω
ε_0	Permittivity of free space	$8,854 \times 10^{-12} \text{ F/m}$

4.3 Abbreviations

APS	absolute peak spatial-average SAR
CAD	computer aided design
ERP	ear reference point
DUT	device under test
RF	radio frequency
RMS	root mean square
RSS	root sum square
SAM	specific anthropomorphic mannequin
WLAN	wireless local area network
GSM	global system for mobile communications
GPRS	general packet radio service
EDGE	enhanced data rates for GSM evolution
CW	continuous wave
TDMA	time division multiple access
CDMA	code division multiple access
WCDMA	wideband code division multiple access
OFDM	orthogonal frequency-division multiplexing
DCS	digital cellular service
PCS	personal communications service
UMTS	universal mobile telecommunications system
WiMax	worldwide interoperability for microwave access
PDF	probability density function
SAR	specific absorption rate
psSAR	peak spatial-average SAR
STBC	space-time block code
MIMO	multiple input multiple output
TEM	transverse electric and magnetic
FDTD	finite-difference time-domain

5 Measurement system specifications

5.1 General requirements

A SAR measurement system consists of the SAM phantom (a human head model) filled with tissue-equivalent liquid, electronic measurement instrumentation, a scanning system and a DUT holder.

SAR shall be measured using a miniature probe that is automatically positioned to measure the internal E-field distribution in the SAM phantom representing the human head exposed to electromagnetic fields produced by the DUT. The phantom head is filled with the required tissue-equivalent liquid, representing the electrical properties of tissues in the human head.

This liquid shall be of low viscosity to allow free movement of the probe within it. From the measured E-field values, the SAR distribution and the peak spatial-average SAR value shall be calculated.

The tests shall be performed in a laboratory conforming to the following environmental conditions.

- a) Both the ambient and tissue-equivalent liquid temperatures shall be in the range of 18 °C to 25 °C, inclusive; see 7.2.6.6 to determine the liquid temperature uncertainty.
- b) Prior to tissue-equivalent liquid dielectric properties measurement and SAR measurements, the DUT, test equipment, liquid and phantom shall have been kept in the laboratory long enough for their temperatures to have stabilized (i.e. they shall not have been recently moved from another area with a different ambient temperature, such as a refrigerator or storage area).
- c) The temperature of the liquid during the SAR measurements shall be within 2 °C (or a temperature difference corresponding to a 5 % change in either ϵ' or σ if this is smaller) of that at which the dielectric properties were measured. If the temperature change exceeds this value, the dielectric properties shall be re-measured. See 7.2.6.6 to determine the liquid temperature sensitivity uncertainty.
- d) The effect of reflections from cables, test equipment, or other reflectors shall be determined by the SAR *system check* procedure described in Clause D.2, with and without the reflectors present or where necessary with the judicious placement of absorbing materials and/or the use of ferrite beads on cables.
- e) SAR measurements of test devices shall only be performed when the effects of reflections, secondary RF transmitters, etc., result in a peak spatial-average SAR (for 1 g or 10 g mass, whichever is applicable to the test) less than 0,012 W/kg by measuring the peak spatial-average SAR at (approximately) 0,4 W/kg (used to establish the 3 % low detection limit, see 7.2.9). When the effect of cables and reflectors is more than 0,012 W/kg, ferrite beads, RF absorbers and other mitigation techniques shall be applied to reduce the SAR error. If the preceding limit cannot be achieved, a value higher than 3 % (0,012 W/kg) shall be considered in the uncertainty budget in the "RF ambient conditions – reflections" row of applicable tables, provided it can be demonstrated that the SAR contribution due to reflections determined by the *system check* procedure is less than 10 % of the SAR measured for the test device. The requirement on reflections shall be verified at least every year or whenever the *system check* shows unexpected results.

During testing the DUT shall not be connected to any wireless network except a base station simulator in the lab.

System validation according to the protocol defined in Clause D.3 shall be done at least once per year, additionally when a new system is put into operation and whenever modifications have been made to the system, such as a new software version, different type or version of readout electronics or different probes. The standard sources used for *system validation* shall be designed and validated to meet the requirements specified in Annex D. Additional sources for dipoles and wave guides at specific frequencies not currently included in Tables D.1, D.2, G.1 and G.2 may be used as standard sources provided they meet the requirements specified in D.3.6 and Annex G.

The measurement system shall be validated as a complete system. Calibration of the probe separately from the system is allowed, provided that the electrical interface characteristics between the probe and readout electronics are specified and implemented during measurements. The probe(s) shall be calibrated together with an identical amplifier, measurement device and data acquisition system. The probe shall be calibrated in a tissue-equivalent liquid at the appropriate operating frequency and temperature range, according to the methodology described in Annex B.

The lower detection limit shall be less than or equal to 0,01 W/kg, and the maximum detection limit shall be higher than 100 W/kg. The probe sensitivity and isotropy shall be determined in the tissue-equivalent liquid. The probe response time shall be specified. The outermost

diameter of the probe tip shall not exceed 8 mm in the vicinity of the measurement elements for frequencies up to and including 2 GHz. For frequencies above 2 GHz, the probe tip diameter shall not exceed $\lambda/3$, where λ is the wavelength in the liquid. The probe tip diameter may be larger if it can be shown that specific requirements are met.

A larger probe diameter is acceptable if it can be demonstrated that the E-field from any potential field distribution can be measured with an uncertainty of less than $\pm 15\%$ ($k = 2$) at the distances from the surface of phantom, as listed in Table 1 or at the distances recommended by the dosimetric system manufacturer (whichever is less). The methodology of how to determine this uncertainty is not part of this Standard and shall be developed by the user. Without such an uncertainty methodology this may not be acceptable by national authorities.

Where this Standard explicitly specifies performance characteristics for the measurement system or a part of the measurement system, the manufacturer of the system or of the part, or the system integrator shall document the conformity with the provisions of this Standard.

5.2 Phantom specifications (shell and liquid)

This Standard provides test procedures for a sagittally-bisected SAM phantom oriented horizontally only. For the typical set-up of a sagittally-bisected phantom, each half of the head model is placed on its side, and the DUT is placed underneath. Phantoms that cannot use the procedures in this document are outside the scope of this Standard.

The phantom shall be filled with head tissue-equivalent liquid with the required dielectric properties.

To minimize reflections from the upper surface of the tissue-equivalent liquid, the depth of the liquid should be at least 15 cm, which is approximately the distance between the ears of a typical human head. Liquid depth of less than 15 cm may be used only if it is demonstrated (e.g. using numerical simulations) that the effect on peak spatial-average SAR is less than 1 % under worst-case conditions. If it is more than 1 % but less than 3 %, uncertainty for the worst-case value from the demonstration shall be added to the uncertainty budget.

The dielectric parameters shall be evaluated and compared with the values given in Table A.3 using linear interpolation. This measurement can be performed using the equipment and procedures described in Annex J. The measured dielectric properties, not the values of Table A.3, shall be used in the SAR calculations.

NOTE See 6.2.1 for the allowable variations between the measured and the Table A.3 dielectric parameters, as defined for the purposes of this Standard.

At least three reference points shall be defined on the phantom by the phantom manufacturer for use in aligning the scanning system with the phantom. These points shall be visible to the user, enclosing at least 80 % of the phantom top surface and each point being at least 20 cm apart. Specifications for the phantom and head tissue simulant liquid are given in Annex A.

The rationale for choosing the specific head phantom model (i.e. SAM) described in this Standard is based on the following criteria.

- a) The peak spatial-average SAR shall be a conservative estimate of the actual value expected to occur in the heads of a significant majority of persons, regardless of age, gender and ethnicity, during the intended use of wireless handsets.
- b) The test results shall not unnecessarily overestimate the peak SAR expected in actual users.
- c) The phantom shall allow stable and repeatable device positioning for peak spatial-average SAR measurements and be effective for verifying repeatability and reproducibility demonstrated by inter-laboratory comparisons.
- d) The phantom shall be practical for routine SAR evaluation.

- e) The phantom shall support these criteria for contemporary and future handset designs and be unbiased with respect to any particular handset design or shape.

Based on the currently available science, literature, and experience, the design of a phantom that meets the above criteria, especially item a), i.e. providing a conservative estimate of the actual SAR, is a function of at least the following parameters:

- 1) head size and shape of the SAM phantom shell;
- 2) dielectric parameters and homogeneity of tissue-equivalent liquids and phantom shell;
- 3) ear pinna/auricle size, shape, location and material properties;
- 4) exclusion of the hand for measuring SAR in the head (see Annex N).

5.3 Hand and device holder considerations

During normal operation, the head and hand are in the near-field of the DUT when used next to the ear and hence both absorb energy. For extremities such as the hand, a higher SAR limit is allowed, i.e. 4 W/kg averaged over 10 g of tissue in ICNIRP RF exposure guidelines [64] and IEEE Std C95.1-2005 [65]. Numerical and experimental studies have shown that the SAR in the hand at the power levels used by handsets is not expected to exceed those limits (Francavilla et al. [43], Gandhi et al. [52], Jensen and Rahmat-Samii [69], [70], Kuster et al. [83], Watanabe et al. [149]). Furthermore, a practical phantom for SAR measurement in the hand is currently unavailable. Therefore, SAR measurement in the hand is not addressed in this Standard.

The influence of a hand holding a handset to the head during SAR measurements was considered in IEEE Std 1528-2013 [66]. Earlier work by Balzano et al. [2] and Kuster et al. [83] reported that the presence of the hand either decreased or had no significant effect on the head SAR, although numerical results by Meyer et al. in 2001 [105] showed a case with 7 % increase in head SAR due to the hand. These deviations in head SAR were concluded to be within the conservativeness provided by the SAM phantom. Based on these studies, the exclusion of the hand from test procedures would lead to head SAR overestimation in the majority of situations, as confirmed by more recent research results [4], [5], [77] on handset SAR levels. For these reasons, hand models are not considered in this Standard.

The state of dosimetric research on the effect of the hand on head SAR produced by handsets is described in Annex N. This research shows that there are cases when the SAR produced by handsets in the SAM phantom may increase as well as decrease significantly due to the hand holding the handset, for specific handset designs, operating bands and hand grips. These initial findings have shown that the SAM phantom alone may still overestimate head SAR in a statistically significant number of cases compared to when the hand is present for the measurement. Nevertheless they deserve further investigations, which may potentially warrant future changes in this recommended practice.

5.4 Scanning system requirements

The SAR probe scanning system shall be able to scan the required measurement regions of the SAM phantom that are within the projections of a DUT in order to evaluate the three-dimensional SAR distribution. The tolerance of the probe tip positioning at a measurement point shall be $\leq 0,2$ mm. The positioning resolution shall be ≤ 1 mm. The probe positioning accuracy of the scanning system requires the phantom reference points defined by the phantom manufacturer to be verified.

5.5 Device holder specifications

The device holder shall permit the DUT to be positioned according to the definitions given in 6.2.4. It shall be made of low-loss and low-permittivity material(s): loss tangent $\leq 0,05$ and relative permittivity ≤ 5 .

In coupling the DUT to the phantom, the device holder should provide the minimum amount of contact to the DUT to give a secure hold and maintain the required position during the measurement. The device holder should aid the operator to position the DUT repeatably. In cases where a default relative positioning cannot be achieved, e.g. due to the device holder interaction with buttons and sensors on the DUT, then minimal position offsets in a predefined direction should be applied to achieve the required DUT test position.

The positioning uncertainties shall be estimated following the procedures described in 7.2.5.

To verify that the device holder does not perturb SAR, a substitution test shall be done by supporting the test handset with low relative permittivity and low-loss foam blocks, against a flat phantom (see 7.2.5.2).

5.6 Characteristics of the readout electronics

The probe output is processed by the readout electronics and associated instrumentation that combine the voltages from the probe's sensors to provide an output that is proportional to the amplitude-squared of the E-field incident on the sensors. Detector diodes at the dipole feed point are used to rectify the sensor voltages. The rectified signals are transmitted through resistive (RF-transparent) lines to the readout electronics system. For a continuous-wave signal at low field strength levels, the probe output is proportional to the square of the amplitude of the incident E-field; at higher signal levels (above the diode compression point), the output is not linearly proportional to $|E|^2$, but becomes proportional to $|E|$. This signal compression will lead to an underestimation of the actual SAR at high field strength conditions if it is not compensated correctly through probe calibration. Also amplifiers in the readout electronics can deviate from an ideal linear response and introduce additional uncertainty.

For uncertainties associated with the probe readout electronics, see 7.2.2.6.

6 Protocol for SAR assessment

6.1 General

All measurements should be carried out with good laboratory practice, e.g. in accordance with ISO/IEC 17025 or any other local and national requirements for device certification. This Standard does not contain information needed to configure wireless handsets for specific wireless technologies, including specific settings such as the operating mode or data rate to ensure that the maximum SAR is obtained.

6.2 Measurement preparation

6.2.1 Preparation of tissue-equivalent liquid and system check

The dielectric properties of the tissue-equivalent liquids shall be measured within 24 h before the SAR measurements and every two days of continuous use. Less frequent dielectric measurements are acceptable if the laboratory can document compliance with Table A.3 and the requirements of 5.2 using measurement intervals up to but not greater than one week. If the handset test series takes longer than 48 h, the liquid parameters shall also be measured at the end of the handset test series.

Tissue equivalent liquids shall yield measured relative permittivity and conductivity values within ± 10 % of the target values at frequencies at which the SAR is measured, when 7.2.7.2 is used to correct measured SAR for the deviations in permittivity and conductivity; otherwise, the relative permittivity and conductivity shall be within ± 5 %. If the correction for the deviation of the dielectric parameters (see 7.2.7) is applied, it shall be within ± 10 %.

A *system check* according to the procedures of Annex D shall be completed within 24 h before performing SAR measurements for a DUT. The purpose of the *system check* is to verify that the system operates within its specifications at the test frequencies. The *system check* is a

test of repeatability with a calibrated source to ensure that the system works correctly during the compliance test. The *system check* shall be performed in order to detect possible drift over short time periods and other uncertainties in the system, such as:

- a) unacceptable changes in the liquid parameters, e.g. due to water evaporation or temperature changes;
- b) component failures;
- c) component drift;
- d) operator errors in the set-up or the software parameters;
- e) adverse environmental conditions for the system, e.g. RF interference.

The *system check* procedure shall be performed on the same SAR measurement system, with the same SAR probe(s) and tissue-equivalent liquid as the SAR evaluation of the device for each frequency band tested.

6.2.2 Preparation of the wireless device under test (DUT)

The antenna(s), battery and accessories shall be those specified by the manufacturer, and documented in the measurement report. The battery shall be fully charged before each measurement, without external connections or cables.

For 3G/4G technologies, the RF output power and frequency (channel) shall be controlled by a wireless link to a base station or network simulator. For WLAN, Bluetooth, WiMax, etc., test software and internal test codes are generally used.

If tests are performed using prototypes, it shall be verified that the commercial version has exactly the same mechanical and electrical characteristics as the tested prototype. If this cannot be guaranteed, testing shall be repeated by sampling of unmodified commercial product versions.

The DUT shall be set to transmit at the highest time-averaged maximum output power level for conditions of use next to the ear. The test shall be performed at a maximum power level consistent with tune-up specifications and production variations. The measured SAR shall be scaled to the highest time-averaged maximum output power allowed for product units. The scaling shall be documented in the test report. The maximum time-averaged power levels of the DUT shall be verified, e.g. by conducted power tests with a fully charged battery to support the scaling. Check for the possibility of SAR variations occurring over the course of the SAR measurement.

For certain noise-like digitally modulated signals (see 6.2.3.4) the time-averaged maximum output power may vary in different operating modes according to signal bandwidth, modulation scheme, peak-to-average power ratio and data rate. These conditions require careful selection of device configurations for SAR measurement. When time division duplex (TDD) scheme is used, the uplink and downlink signals are transmitted at the same frequency; typically in random orders with non-periodic duty factors. It is important that these factors are considered for such wireless technologies to ensure SAR is measured correctly. For example, the output power of IEEE Std 802.11 (Wi-Fi/WLAN) devices during SAR measurement is typically set by test software to the maximum level for the corresponding modulation and data rate. The test software also configures the device to transmit with a fixed periodic duty factor to enable the SAR to be measured correctly. The measured SAR may need to be scaled to a higher transmission duty factor corresponding to the maximum exposure expected during actual use. For handsets with Wi-Fi functionality, the lowest order modulation is typically expected to have the lowest peak-to-average power ratio and typically has highest maximum average output power; therefore, when appropriate, the lowest order modulation shall be tested to ensure conservativeness and to avoid SAR measurement errors due to high peak-to-average power ratios. Additional measurement and probe calibration considerations may be required for IEEE Std 802.11ac 160 MHz channels.

6.2.3 Operating modes

6.2.3.1 General

The wireless technologies used by the DUT will determine the operating mode and type of signals (frequency, modulation scheme, output power, etc.) used in the SAR tests. All applicable operating modes intended for device use next to the ear shall be considered for testing. Subclause 6.7.2 provides a test reduction procedure for modes operating in the same technology and frequency band. The signal characteristics of operating modes can be described by 6.2.3.2 to 6.2.3.4. For devices that do not operate with a periodic duty factor, special test software or equipment is generally required to configure the DUT to transmit with a maximum periodic duty factor before conducting the SAR measurement.

6.2.3.2 Constant-envelope operating modes (analogue modulations)

A DUT operating in modes where the envelope of the signal in the time domain is constant, e.g. frequency division multiple access (FDMA) modes, shall be tested with a CW-equivalent (carrier) signal using test codes or a base-station simulator.

6.2.3.3 TDMA (pulse-envelope) operating modes

A DUT operating in TDMA mode may transmit voice and data using different number of slots. Depending on the data rate, data operating modes using higher order modulations may operate at reduced output power to accommodate higher peak-to-average power ratios; for example, EDGE. If data operating modes are operational during voice calls, such as in certain GSM/GPRS/EDGE dual transfer operating mode configurations, the number of time slots and the highest output power for both voice and data shall both be considered in configuring the simultaneous transmission conditions for testing SAR next to the ear.

If it is not feasible to configure the device to operate at its maximum time-averaged output power in multi-slot conditions for voice and/or data due to test equipment limitations, the test shall be performed in single-slot operating mode provided the results are scaled to the maximum number of slots that can be transmitted. Any difference in maximum output power between single slot and multi-slot conditions shall also be accounted for in the scaling. It shall be demonstrated that SAR scaling is either linear or slightly less than linear with respect to output power and the relative SAR distribution is independent of output power. The relationship between SAR and output power shall be documented in the SAR test report according to the power scaling procedure in 6.2.3.5.

6.2.3.4 Digital operating modes with random amplitude and phase modulation

For a DUT in operating modes that employ spread spectrum CDMA, orthogonal frequency-division multiplexing (OFDM) or other modulation schemes where the envelope of the signal varies randomly with time, the output power generally varies because of changing peak-to-average power ratios due to data rate and other technology-specific operating parameters and conditions. The tests shall be performed at a time-averaged maximum output power level supported by the DUT and, when applicable, with a fixed periodic transmission duty factor, for example TDD systems. In some cases, the DUT may not be able to sustain the maximum average power for long durations due to peak-to-average and other design requirements. Care shall be taken to ensure the transmitter is configured to operate at an acceptable time-averaged output power level as allowed by the DUT and to scale the measured SAR to the required highest time-averaged output level. Information on CDMA IS-95, including probe linearity compensation, has been published by Di Nallo and Faraone [25]. Further information for WCDMA, LTE, etc. was recently reported by Nadakuduti et.al [116].

6.2.3.5 SAR scaling procedure for power or signal variations

SAR scaling is the extrapolation of the SAR of a DUT determined with a test signal (mod_x) to a SAR of the same device in the same exposure test position and frequency channel with a different signal (mod_y). The difference can be in the power level, modulation, or both. The time-averaged RF output power ratio of mod_x and mod_y shall be determined either by

measuring the average power for both or by numerical integration of the power envelope if the signals are sufficiently well known. SAR scaling is possible if the following points are satisfied.

- a) The same RF amplifier stage is used for mod_X and mod_Y .
- b) The same antenna is used for mod_X and mod_Y and no MIMO (multiple-input and multiple-output) or other antenna diversity techniques are applied.
- c) The probe modulation response uncertainty has been evaluated for the modulated signal mod_X (see 7.2.2.4) and the SAR has been determined for mod_X .
- d) The time-averaged RF output power ratio (R_p) of mod_X and mod_Y after the RF amplifier stage is known according to Formula (6):

$$R_p = \frac{P_{\max, \text{mod}_Y}}{P_{\text{mod}_X}} \quad (6)$$

where $P_{\max, \text{mod}_Y}$ corresponds to the highest time-averaged output power setting. If the two signals differ in modulation, then the test signal will be set at maximum time-averaged output power: $P_{\text{mod}_X} = P_{\max, \text{mod}_X}$.

The factor R_p shall be determined by experimental means (e.g. measurement using an average power meter).

- e) The RF carrier frequency of mod_X is the same as for mod_Y .
- f) The RF signal bandwidth ratio (R_m) of mod_X and mod_Y satisfies Formula (7):

$$R_m = \left| \frac{BW_{\text{mod}_Y}}{BW_{\text{mod}_X}} - 1 \right| \times 100 \leq 30\% \quad (7)$$

- g) The channel bandwidths of mod_X and mod_Y are each within 5 % of the carrier frequency.

If the above requirements are fulfilled a scaling of the SAR from mod_X to mod_Y shall be performed according to the Formula (8) and the scaling uncertainty as specified in 7.2.11:

$$SAR_{\text{mod}_Y} = R_p \cdot SAR_{\text{mod}_X} \quad (8)$$

If the approach in this subclause is used, it shall be stated in the measurement report that points a) to g) are satisfied.

For handsets supporting push-to-talk modes operated next to the ear, the maximum duty factor shall be deemed to be 0,5 based on 50 % talk and 50 % listen.

6.2.4 Positioning of the DUT in relation to the phantom

6.2.4.1 General

This standard specifies two handset test positions against the head phantom – the "cheek" position and the "tilt" position. These two test positions are defined in 6.2.4.2 and 6.2.4.3, respectively. The DUT shall be tested in both of these positions on the left and right sides of the SAM phantom. In some cases (e.g. asymmetric handsets) the DUT positioning procedures representing intended use conditions (see 6.2.4.2 and 6.2.4.3) cannot be used. In this event, alternative alignment procedures shall be adapted with all details provided in the test report. These alternative procedures shall replicate intended use conditions as closely as possible, according to the intent of the procedures described in 6.2.4.2 and 6.2.4.3.

For other form factors associated with head mounted devices (used at the ear but not protruding into the pinna or the auditory canal), the positions and orientations used for

assessment shall align as closely as possible with those defined for handsets in 6.2.4.2 and 6.2.4.3. Consideration for the intended use orientation shall also be given. See also 6.2.4.6.

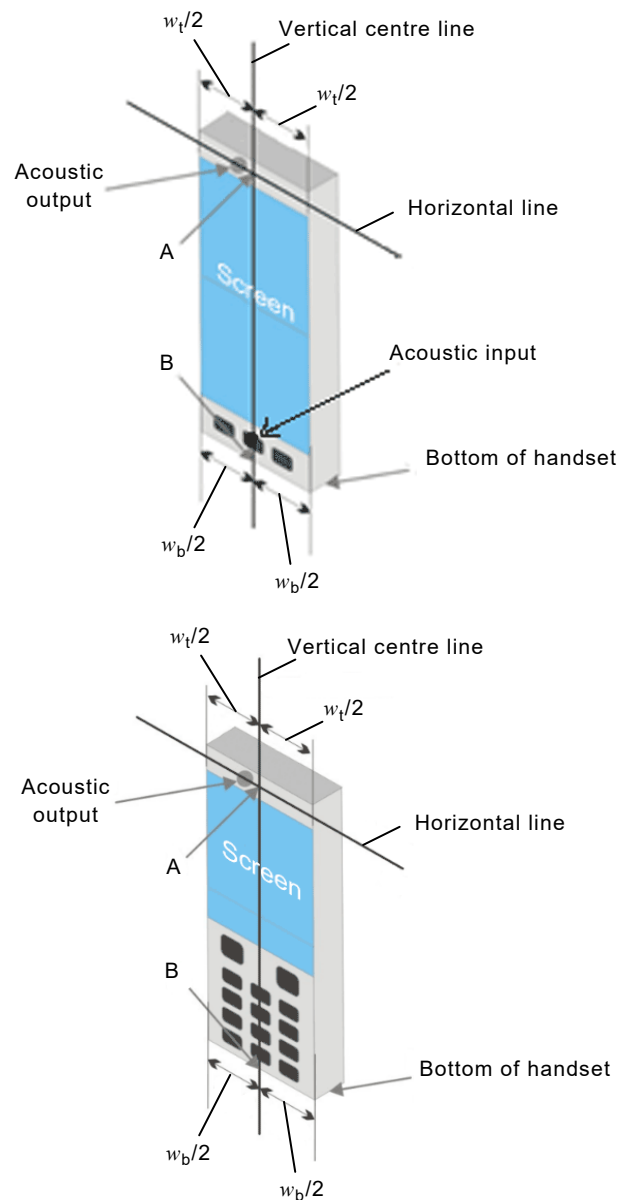
Where the head mounted device contains an acoustic output and acoustic input, then these shall be aligned to the ERP and M reference points, respectively.

Clear details of the actual test positions used shall be fully documented in the test report.

6.2.4.2 Definition of the cheek position

The cheek position is established in points a) to i) as follows.

- a) Configure the DUT for talk operation, if necessary. For example, for a DUT with a flip, swivel or slide cover piece, open the cover if this is consistent with talk operation. If the DUT can also be used with the cover closed, both configurations shall be tested.
- b) Define two imaginary lines on the DUT, the vertical centreline and the horizontal line, for the DUT in vertical orientation as shown in Figure 1. The vertical centreline passes through two points on the front side of the DUT: the midpoint of the width w_t of the handset at the level of the acoustic output (Point A in Figure 1), and the midpoint of the width w_b at the bottom of the handset (Point B). The horizontal line is perpendicular to the vertical centreline and passes through the centre of the acoustic output (see Figure 2). The two lines intersect at Point A. Note that for many handsets, Point A coincides with the centre of the acoustic output. However, the acoustic output may be located elsewhere on the horizontal line. Also note that the vertical centreline is not necessarily parallel to the front face of the DUT, especially for clam-shell handsets, handsets with flip cover pieces, and other irregularly shaped handsets.
- c) Position the DUT close to the surface of the phantom such that Point A is on the (virtual) extension of the line passing through Points RE (right ear) and LE (left ear) on the phantom (see Figure 2a and Figure 2b). The plane defined by the vertical centreline and the horizontal line of the DUT shall be parallel to the sagittal plane of the phantom.
- d) Translate the DUT towards the phantom along the line passing through RE and LE until the handset touches the ear (see Figure 2c).
- e) Rotate the DUT around the (virtual) LE-RE line until the DUT vertical centreline is in the reference plane (see Figure 2d).
- f) Rotate the DUT around its vertical centreline until the plane defined by the DUT vertical centreline and horizontal line is parallel to the N-F line, and then translate the DUT towards the phantom along the LE-RE line until DUT Point A touches the ear at the ERP (ear reference point) (see Figure 2e).
- g) While keeping Point A on the line passing through RE and LE and maintaining the DUT in contact with the pinna, rotate the handset about the line N-F until any point on the DUT is in contact with a phantom point below the pinna (cheek) (see Figure 2f). The physical angles of rotation shall be documented.
- h) While keeping DUT Point A in contact with the ERP, rotate the handset around a line perpendicular to the plane defined by the DUT vertical centreline and horizontal line and passing through DUT Point A, until the DUT vertical centreline is in the reference plane (see Figure 2g).
- i) Verify that the cheek position is correct as follows:
 - the N-F line is in the plane defined by the DUT vertical centreline and horizontal line;
 - DUT Point A touches the pinna at the ERP;
 - the DUT vertical centreline is in the reference plane.



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Key w_t Width of the handset at the level of the acoustic output w_b Width of the bottom of the handsetA Midpoint of the width w_t of the handset at the level of the acoustic outputB Midpoint of the width w_b of the bottom of the handset

Figure 1 – Vertical and horizontal reference lines and reference Points A, B on two example device types: a full touch screen smart phone (top) and a keyboard handset (bottom)



NOTE The reference points for the right ear (RE), left ear (LE), and mouth (M), which establish the Reference Plane for handset positioning, are indicated. This device position shall be maintained for the sagittal phantom test set-up shown in Figure A.4.

Figure 2a – Phone position 1 – cheek position

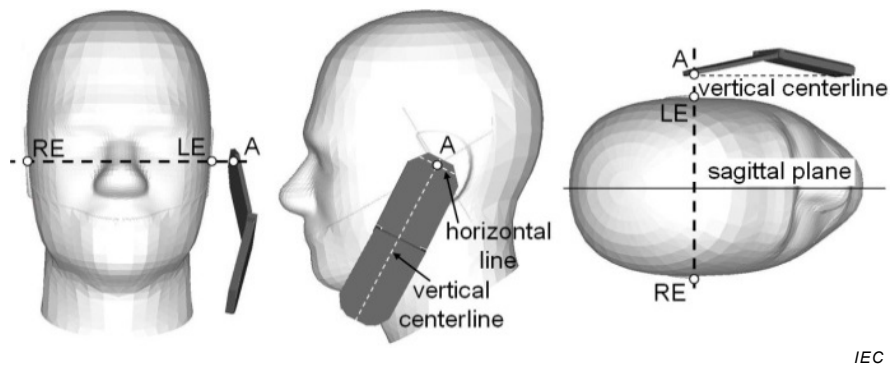
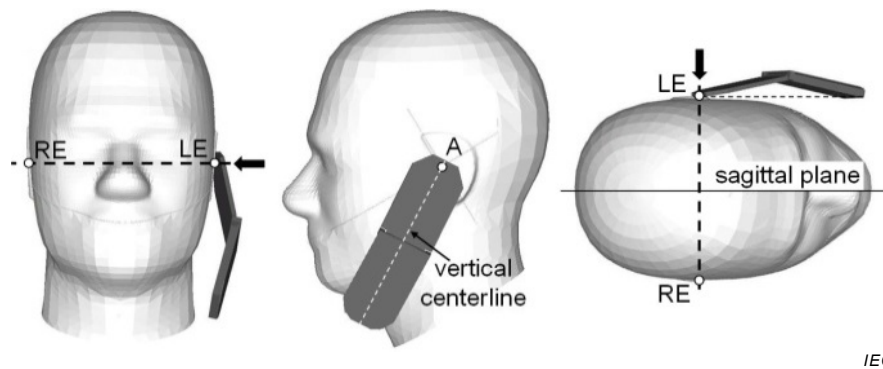
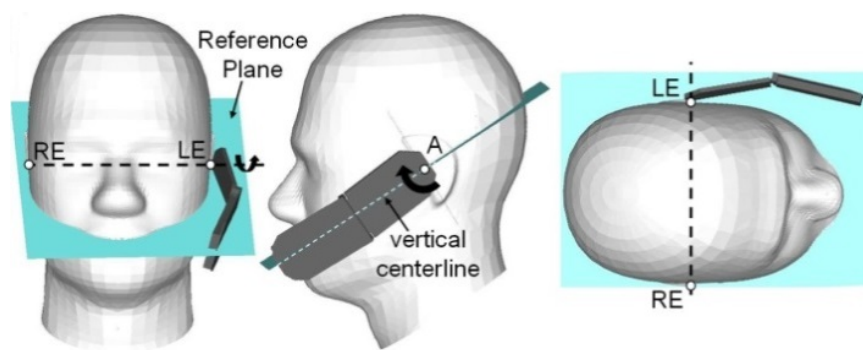


Figure 2b – One possible DUT position against the head after Step c).



NOTE The black arrows show the direction of translation of the DUT for Step d).

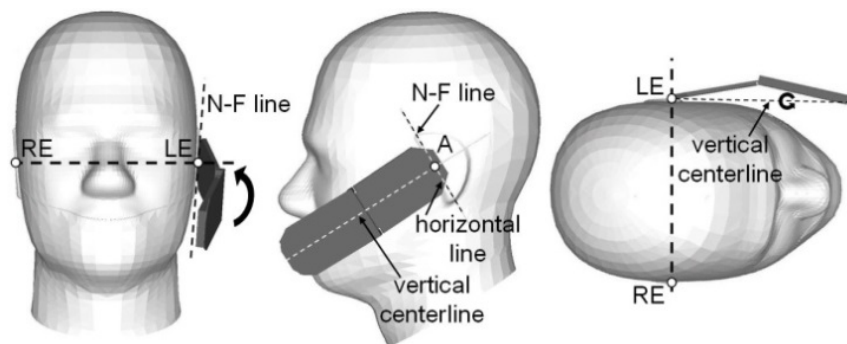
Figure 2c – Handset position of Figure 2b after applying Step d)



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NOTE The curved black arrows show the direction of rotation of the DUT for Step e).

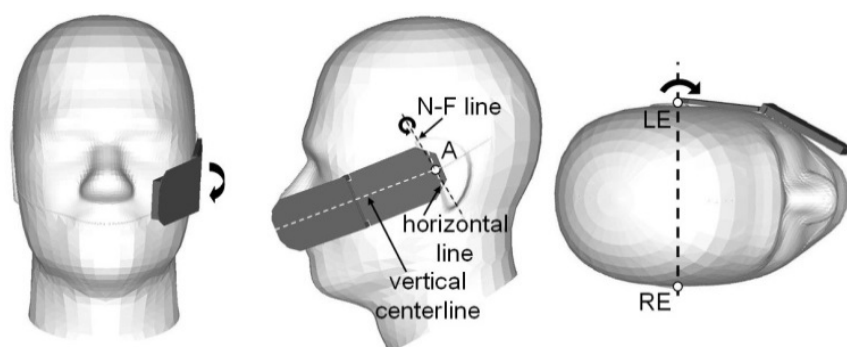
Figure 2d – Handset position of Figure 2c after applying Step e)



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NOTE The curved black arrows show the direction of rotation of the DUT for Step f).

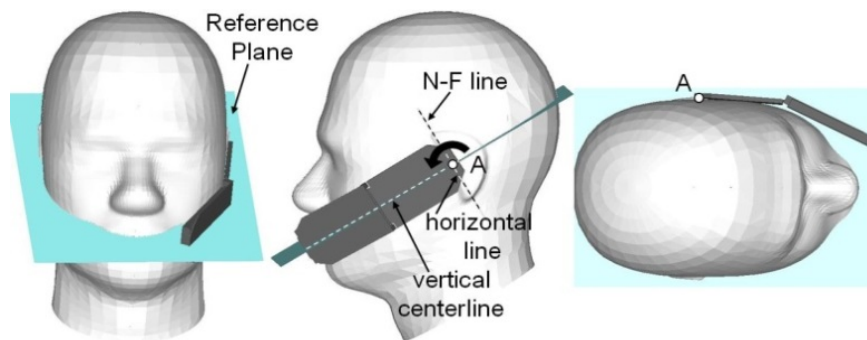
Figure 2e – Handset position of Figure 2d after applying Step f)



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NOTE The curved black arrows show the direction of rotation of the DUT for Step g)

Figure 2f – Handset position of Figure 2e after applying Step g)



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NOTE The curved black arrows show the direction of rotation of the DUT for Step h).

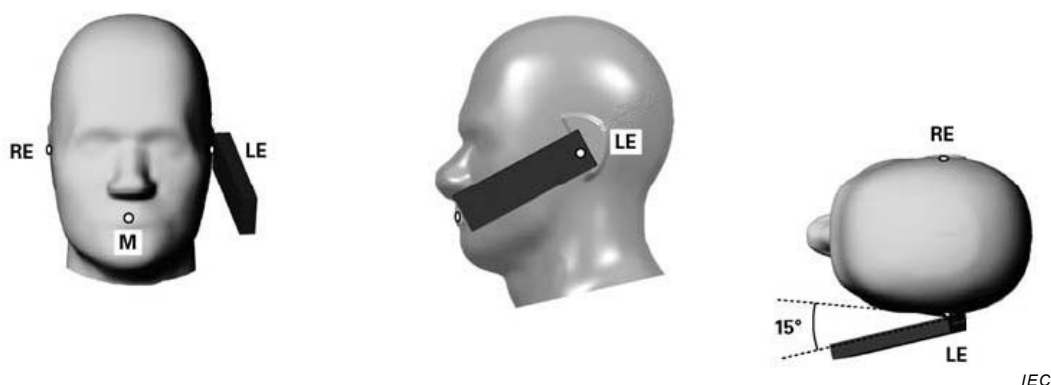
Figure 2g – Handset position of Figure 2f after applying Step h)

Figure 2 – Cheek position of the wireless device on the left side of SAM where the device shall be maintained for the phantom test set-up.

6.2.4.3 Definition of the tilt position

The tilt position is established in points a) to d) as follows.

- Repeat Steps a) to i) of 6.2.4.2 to place the DUT in the cheek position (see Figure 2).
- While maintaining the orientation of the DUT, move the DUT away from the pinna along the line passing through RE and LE far enough to allow a rotation of the handset away from the cheek by 15° .
- Rotate the DUT around the horizontal line by 15° (see Figure 3).
- While maintaining the orientation of the DUT, move the DUT towards the phantom on a line passing through RE and LE until any part of the DUT touches the ear. The tilt position is obtained when the contact is on the pinna. If the contact is at any location other than the pinna, e.g. extended antenna on the back of the phantom head, the angle of the DUT shall be reduced. In this case, the tilt position is obtained if any part of the DUT is in contact with the pinna and a second part of the DUT is in contact with the phantom, e.g. the antenna with the back of the head.



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Key

- M Mouth reference point
- LE Left ear reference point
- RE Right ear reference point

This device position shall be maintained for the phantom test set-up.

Figure 3 – Tilt position of the wireless device on the left side of SAM

6.2.4.4 Antenna

For devices that employ one or more external antennas with variable positions (e.g. antenna extended, retracted, rotated), these shall be positioned in accordance with the user instructions provided by the manufacturer. If no intended antenna position is specified, tests shall be performed with the antenna(s) oriented to obtain the highest exposure condition while still maintaining the device in the cheek and tilt positions of 6.2.4.2 and 6.2.4.3. For antennas that can be extended, testing shall be performed with the antenna fully extended and fully retracted. The antenna configurations shall be documented in the measurement report. Transmit diversity antennas are tested independently for SAR.

6.2.4.5 Options and accessories supplied by the DUT manufacturer

Other accessories that may affect the RF output power or RF current distribution of the DUT when used next to the ear shall be tested according to the intended use conditions specified by the manufacturer. For example, (a) optional antennas, (b) optional battery packs that change the handset performance or SAR, etc., and (c) wires connected during intended use. NFC or wireless charging options generally do not require SAR measurement but their influence on the SAR of other transmitters may need to be considered.

6.2.4.6 DUTs with alternative form factor

For the purpose of this Standard the DUT is considered to be a conventional bar type (rectangular, cuboid) form factor. However the basic principles defined and specified here may be applied to other form factors for other devices covered by the scope of this Standard.

One such device is a wireless headset (e.g. connected by Bluetooth), which can be evaluated in the same manner as any other DUT in this Standard by applying a similar geometry and coordinate mapping from this device to the DUT definition provided in Figure 4.

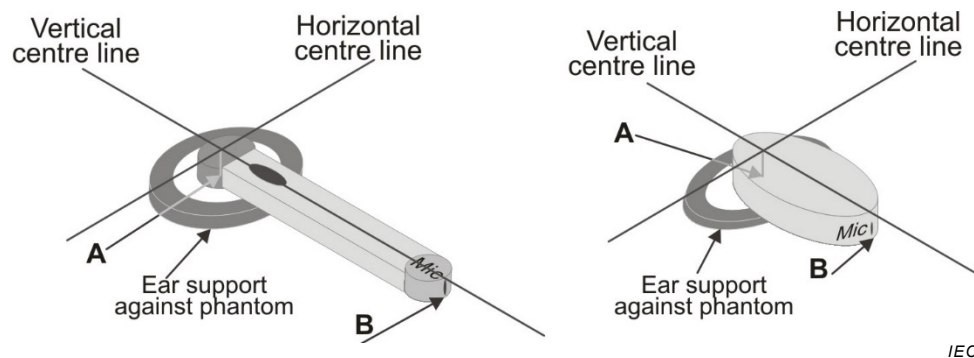


Figure 4 – An alternative form factor DUT and standard coordinate and reference points applied

The basic features of any device that allow for easy mapping to the geometry and coordinate system in use in this Standard include the identification of an acoustic output point that will be defined as point A when at the mid-point of the width of the device and a point B that will be at the bottom of the device, where the primary microphone location is at the end nearest to the mouth.

Other considerations that shall be made here are the operating modes available in such a device and the maximum operating power levels that apply.

All details relating to alternative form factor DUTs shall be fully documented in the measurement report, including diagrams or photographs that would aid the description. Sound engineering practice shall be applied to implement the mapping of an alternate form factor device.

6.2.5 Test frequencies for DUT

A DUT shall be compliant with applicable exposure standards at all transmitting frequencies. However, testing at every channel is impractical and unnecessary. The purpose of 6.2.5 is to define a practical subset of channels where SAR measurements are to be performed. This subset of channels is chosen so as to give a characterization of a DUT with any applicable exposure standards.

NOTE In some cases of Wi-Fi technology and other wide band systems such as WiMAX, the maximum output power of a channel may vary across the frequency band. The required test channels may not include the channel with the highest RF transmit power. For example for Wi-Fi based technologies, the channels operating at the band edge may produce lower power in order to comply with specific out-of-band limits, therefore it may be necessary to perform the testing on the channel adjacent to the band edge channel. For other devices, the maximum output power of different channels may be optimized differently. Therefore before performing testing using the specific channels required by this standard, the maximum output power of the channels needs to be verified to determine whether the chosen channels are indeed producing the highest rated output of the device. The process used to establish the channels for testing purposes shall be documented in the test report.

For each operating mode of a wireless technology used by the DUT, tests shall be performed at the channel closest to the centre of each transmit frequency band. If the width of the transmit frequency band ($\Delta f = f_{\text{high}} - f_{\text{low}}$) exceeds 1 % of its centre frequency f_c , then the channels at the lowest and highest frequencies of the transmit band shall also be tested. Furthermore, if the width of the transmit band exceeds 10 % of its centre frequency, Formula (9) shall be used to determine the number of channels, N_c , to be tested:

$$N_c = 2 \times \text{roundup}[10 \times (f_{\text{high}} - f_{\text{low}})/f_c] + 1 \quad (9)$$

where

- f_c is the centre frequency channel of the transmission band in Hz;
- f_{high} is the highest frequency channel of the transmission band in Hz;
- f_{low} is the lowest frequency channel of the transmission band in Hz;
- N_c is the number of channels.

The function $\text{roundup}(x)$ rounds its argument x to the next highest integer. Thus, the number of channels, N_c , will always be an odd number. The channels tested shall be equally spaced apart in frequency (as much as possible) and shall include the channels at the lowest and highest frequencies. Probe calibrations shall be valid for all test frequencies and liquid dielectric parameters at those frequencies. Substantially large transmission bands may require multiple probe calibration points and different tissue-equivalent liquids to cover the entire frequency band.

NOTE 1 Regulatory agencies may have different requirements on the number of channels to be tested per transmission band, according to frequency allocations and other wireless technology requirements.

NOTE 2 If the test frequency yielding the highest output power does not correspond to the middle channel, the test requirements may vary among different national regulatory authorities.

6.3 Tests to be performed

In order to determine the highest value of the peak spatial-average SAR of a handset, all required device positions, configurations and operating modes shall be tested for each frequency band according to Steps 1 to 3 below. For devices capable of simultaneous transmission, apply the appropriate procedure described in 6.4.3. A flowchart of the test process is shown in Figure 5.

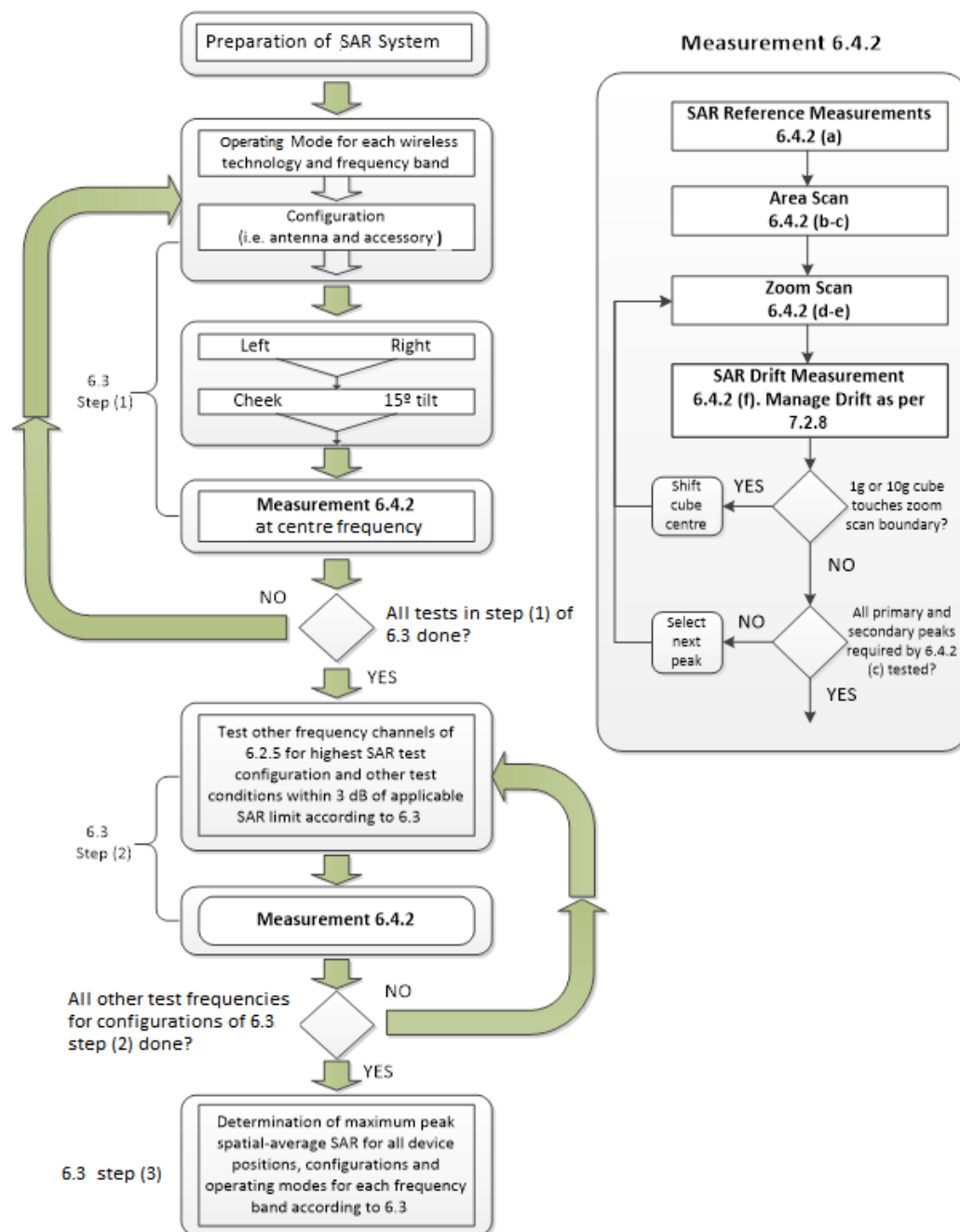
Step 1: The measurement procedure described in 6.4.2 shall be performed at the channel that is closest to the centre of the transmit frequency band (f_c) for each transmit antenna used:

- a) all device test positions (cheek and tilt, for both left and right sides of the SAM phantom, as described in 6.2.4);

- b) all use configurations for each device position in a), e.g. with device slide or cover open and closed or antenna extended and retracted;
- c) all operating modes, e.g. analogue and digital modulation for each device position in a) and configuration in b) in each frequency band.

Step 2: For the condition providing highest peak spatial-average SAR determined in Step 1 for each configuration in a), b) and c), perform all tests described in 6.4.2 at all other test frequency channels, e.g. lowest and highest channels (see 6.2.5). In addition, for each device position, configuration and operating mode where the peak spatial-average SAR value determined in Steps 1 a), b) and c) is greater than or equal to half of the applicable SAR limit, testing of all required channels is required; otherwise, it is not required.

Step 3: Examine all data and determine the reporting requirements for the largest peak spatial-average SAR value measured in Step 1 and Step 2. An example is given in Annex M.



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Figure 5 – Block diagram of the tests to be performed

6.4 Measurement procedure

6.4.1 General

Subclause 6.4 describes the procedure for evaluating the peak spatial-average SAR of the DUT, including the minimum number of drift measurements to be performed. If the drift is high for a particular operating mode and frequency channel, more drift measurements may be necessary, as described in 7.2.8.

6.4.2 General procedure

The following procedure shall be performed for each of the test conditions (see Figure 5) described in 6.3. Table 1 provides the measurement parameters used in the area scan and Table 2 for the zoom scan.

- a) Measure the local SAR at a test point within 10 mm of the inner surface of the phantom where the measured local SAR exceeds the lower detection limit of the measurement system. Preferably, the test point will be above the expected peak SAR location within said distance from the phantom surface. As explained at Step f) below, a comparative measurement will be made by the system at the same point after completion of the SAR measurement.
- b) The area over which the SAR measurement is performed shall cover at least an area larger than the projection of the handset and antenna. For some handsets, the area projected onto the phantom can be large such that the probe may not reach all points. In this case, rotated phantoms may be used and the area may be assessed by multiple overlapping area scans. Measure the two-dimensional SAR distribution within the phantom (area scan procedure). The boundary of the measurement area shall be with respect to the SAM phantom requirements. The measurement resolution and spatial resolution for interpolation shall be chosen to allow identification of the local peak locations to within one-half of the linear dimension of the corresponding side of the zoom-scan volume. The maximum grid spacing shall be 20 mm for frequencies equal to or below 3 GHz and $(60/f \text{ [GHz]})$ mm for frequencies above 3 GHz. The resolution SAR uncertainty of the measurement can be estimated using the functions in 7.2.10. The maximum distance between the geometrical centre of the probe detectors and the inner surface of the phantom shall be ≤ 5 mm for frequencies equal to or below 3 GHz and $\delta \ln(2)/2$ mm for frequencies above 3 GHz, where δ is the plane wave penetration depth and $\ln(x)$ is the natural logarithm [80]. The maximum variation of the sensor-phantom surface distance shall be ± 1 mm for frequencies equal to or below 3 GHz and $\pm 0,5$ mm for frequencies above 3 GHz. At all measurement points, the angle of the probe with respect to the line normal to the surface shall be less than 30° for frequencies equal to or below 3 GHz and 20° for frequencies above 3 GHz (see Figure 6). Table 1 provides the measurement parameters required for the area scan.
- c) From the scanned SAR distribution, identify the position of the maximum SAR value, in addition identify the positions of any local maxima with SAR values within 2 dB of the maximum value that will not be within the zoom scan of other peaks. Additional peaks shall be measured only when the primary peak is within 2 dB of the SAR compliance limit (e.g. 1 W/kg for 1,6 W/kg, 1 g limit; or 1,26 W/kg for 2 W/kg, 10 g limit).
- d) Measure the three-dimensional SAR distribution at the local maxima locations identified in Step c) (zoom scan procedure). The horizontal grid step shall be $(24/f \text{ [GHz]})$ mm or less but not more than 8 mm. The minimum zoom scan size is 30 mm by 30 mm by 30 mm for frequencies equal to or below 3 GHz. For higher frequencies, the minimum zoom scan size can be reduced to 22 mm by 22 mm by 22 mm. A smaller volume zoom scan with tighter spacing between the measurement points is allowed due to steeper decay of the E-field, which may reduce the measurement time. For frequencies above 3 GHz, the grid step in the vertical direction shall not exceed $(8 - f \text{ [GHz]})$ mm, and for frequencies equal to or below 3 GHz if uniform spacing is used the grid step shall not exceed 5 mm. If variable spacing is used in the vertical direction (non-uniform grids or graded grids), the maximum spacing between the two closest measured points to the phantom shell shall not exceed $(12/f \text{ [GHz]})$ mm for frequencies above 3 GHz, and shall not exceed 4 mm for frequencies at or below 3 GHz. Furthermore the spacing between farther adjacent points shall increase by an incremental factor not exceeding 1,5. When graded grids are used, extrapolation routines shall be tested according to 7.2.10.3.2 with the same spacing as used in measurements. The maximum distance between the geometrical centre of the probe detectors and the inner surface of the phantom shall be 5 mm for frequencies equal to or below 3 GHz and $\delta \ln(2)/2$ mm for frequencies above 3 GHz, where δ is the plane wave penetration depth and $\ln(x)$ is the natural logarithm. Separate grids shall be centred on each of the local SAR maxima found in Step c). At all measurement points, the angle of the probe with respect to the line normal to the surface shall be less than 30° for frequencies equal to or below 3 GHz and 20° for frequencies above 3 GHz.

- e) Use the post-processing, i.e. the interpolation and extrapolation procedures defined in 6.5, to determine peak spatial-average SAR values.
- f) Measure the local SAR at exactly the same test point location as in Step a). The SAR drift of the DUT may be estimated by the difference between the two measured single-point SAR values in Steps a) and f). The SAR drift shall be kept within $\pm 5\%$; otherwise, see 7.2.8 for more information on addressing SAR measurement drift.

Commercial handsets should have output power drifts within $\pm 5\%$. Some devices may have significant fluctuations in output power that are not classifiable as undesirable power drift but rather are a characteristic of the normal operating behaviour of the device. In these case, other methods such as power scaling can be performed with the aim of ensuring that an accurate and conservative SAR is obtained.

Uncertainties due to field distortion between the media boundary and the dielectric enclosure of the probe shall also be minimized, which is achieved if the distance between the phantom surface and physical tip of the probe is larger than one probe tip diameter. Compensation methods are typically utilized to apply correction procedures for these boundary effects to enable measurements closer than half the probe diameter [131], especially above 3 GHz.

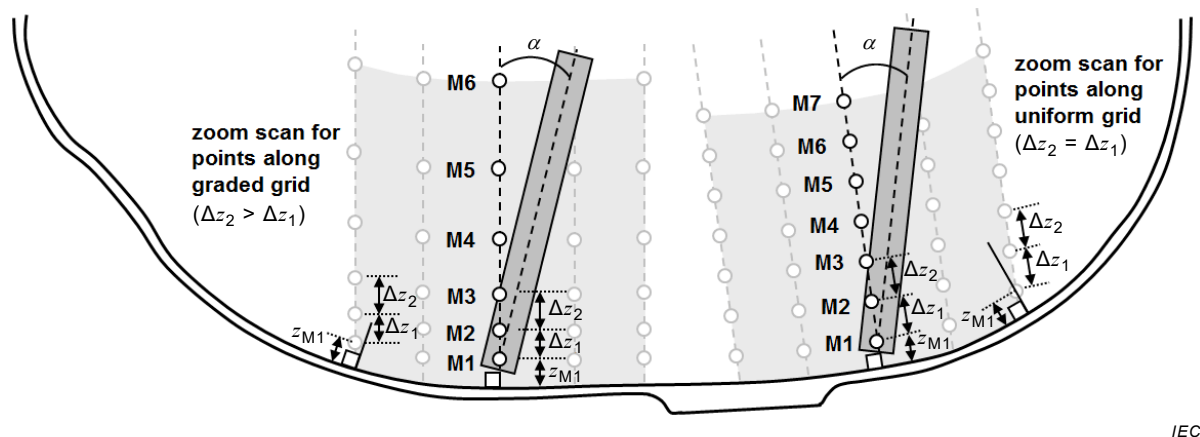
Table 1 – Area scan parameters

Parameter	DUT transmit frequency being tested	
	$f \leq 3 \text{ GHz}$	$3 \text{ GHz} < f \leq 6 \text{ GHz}$
Maximum distance between the measured points (geometric centre of the sensors) and the inner phantom surface (z_{M1} in Figure 6 in mm)	5 ± 1	$\delta \ln(2)/2 \pm 0,5^a$
Maximum spacing between adjacent measured points (see 7.2.10.3.1, in mm) ^b	20 or half of the corresponding zoom scan length, whichever is smaller	$60/f$ or half of the corresponding zoom scan length, whichever is smaller
Maximum angle between the probe axis and the phantom surface normal (α in Figure 6) ^c	30°	20°
Tolerance in the probe angle	1°	1°
^a δ is the penetration depth for a plane-wave incident normally on a planar half-space. ^b See 7.2.10 on how Δx and Δy may be selected for individual area scan requirements. ^c The probe angle with respect to the phantom surface normal is restricted due to the degradation in the measurement accuracy in fields with steep spatial gradients. The measurement accuracy decreases with increasing probe angle and increasing frequency. This is the reason for the tighter probe angle restriction at frequencies above 3 GHz.		

Table 2 – Zoom scan parameters

Parameter	DUT transmit frequency being tested	
	$f \leq 3 \text{ GHz}$	$3 \text{ GHz} < f \leq 6 \text{ GHz}$
Maximum distance between the closest measured points and the phantom surface (z_{M1} in Figure 6 and Table 1, in mm)	5	$\delta \ln(2)/2^a$
Maximum angle between the probe axis and the phantom surface normal (α in Figure 6)	30°	20°
Maximum spacing between measured points in the x - and y -directions (7.2.10.3.2, in mm)	8	$24/f^b$
For uniform grids: Maximum spacing between measured points in the direction normal to the phantom shell (Δz_1 in Figure 6, in mm)	5	$8 - f$

Parameter	DUT transmit frequency being tested	
	$f \leq 3 \text{ GHz}$	$3 \text{ GHz} < f \leq 6 \text{ GHz}$
For graded grids: Maximum spacing between the two closest measured points in the direction normal to the phantom shell (Δz_1 in Figure 6, in mm)	4	$12/f$
For graded grids: Maximum incremental increase in the spacing between measured points in the direction normal to the phantom shell ($R_z = \Delta z_2/\Delta z_1$ in Figure 6)	1,5	1,5
Minimum edge length of the zoom scan volume in the x- and y-directions (L_z in 7.2.10.3.2, in mm)	30	22
Minimum edge length of the zoom scan volume in the direction normal to the phantom shell (L_h in 7.2.10.3.2, in mm)	30	22
Tolerance in the probe angle	1°	1°
^a δ is the penetration depth for a plane-wave incident normally on a planar half-space. ^b This is the maximum spacing allowed, which may not work for all circumstances.		



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NOTE M1 to M7 are example measurement points used for extrapolation to the surface. The maximum of the angle α between the evaluation axis and the surface normal line is given in Table 1 and Table 2. The distance z_{M1} is from the phantom shell to the first measurement point M1, and its maximum value is given in Table 1 and Table 2. The distances Δz_i ($i = 1, 2, 3, \dots$) are the distances from measurement points M_i to M_{i+1} . For uniform grids, Δz_i are equal. For graded grids, $\Delta z_{i+1} > \Delta z_i$. $R_z = \Delta z_{i+1}/\Delta z_i$ is a ratio with a maximum value given in Table 2.

Figure 6 – Orientation of the probe with respect to the line normal to the phantom surface, shown at two different locations

6.4.3 SAR measurements of handsets with multiple antennas or multiple transmitters

6.4.3.1 General

Handsets with multiple antennas or multiple transmitters (with single or multiple antennas) transmitting simultaneously require special test considerations. The methods to combine the fields in order to determine the combined SAR distribution differ depending on whether the corresponding RF transmitters emit waveforms that are correlated or uncorrelated in time. The field summation method and the associated measurement instrumentation requirements for correlated signal waveforms are different from those for uncorrelated signals (see IEC TR 62630) [62].

6.4.3.2 SAR measurements for non-correlated signals

6.4.3.2.1 General requirements

The following procedures are applicable to devices incorporating multiple operating modes that are intended to operate simultaneously using:

- a) multiple frequencies (f_1 , f_2 , etc.) that are separated by more than the valid frequency range of the probe calibration or the tissue equivalent liquid, whichever is the smallest (i.e. when the SAR cannot normally be assessed simultaneously using the same probe and liquid);

The valid frequency range of probe calibration is typically narrow (e.g. ± 50 MHz to ± 100 MHz) for electric field probes in most systems currently in use. Also, since electric field probes used in present systems typically have a DC voltage at the output, the probe cannot distinguish between signals at different frequencies. The valid frequency range of the tissue equivalent liquid refers to the frequency range over which the dielectric parameters are within tolerance of the target values (see Table A.3 and [33]). Due to these limitations, the SAR values shall first be assessed separately then combined arithmetically.

- b) multiple antennas that transmit using different modulations (e.g. a voice call using CDMA and data using Wi-Fi) in the same valid frequency range of both the probe calibration and tissue equivalent liquid.

In the case of multiple antennas transmitting different modulations in the same frequency range, measurements shall be made with both signals transmitting simultaneously. However, this is not necessary if the peak-spatial average values are added as described in Alternative 1 below (6.4.3.2.2, since that method provides a conservative overestimate of the combined SAR). For the case of multiple antennas transmitting correlated signals (e.g. certain MIMO configurations), refer to 6.4.3.3.

In 6.4.3, a test combination is defined as a particular combination of device position (left cheek, right tilt, etc.), configuration (e.g. antenna position) and accessory (battery). Subclauses 6.4.3.2.2 to 6.4.3.2.5 describe alternative evaluation procedures for simultaneous transmission in different frequency bands. The following prerequisites apply for the alternative methods.

- The area scan, zoom scan and peak spatial-average SAR are evaluated separately at each frequency (as per 6.4.2) with the transmission at that frequency turned on and transmission at the other frequencies turned off.
- The SAR data from different frequencies or antennas are combined together only when the test combination is the same for those frequency bands or antennas, and if that test combination is an intended test combination for simultaneous operation (see below).

Different alternative methods may be used for different test combinations. The alternatives are summarized as follows.

- Alternative 1: Summation of peak spatial-average SAR values – simplest but most conservative method to find upper bound; always applicable (6.4.3.2.2).
- Alternative 2: Selection of the highest assessed peak spatial-average SAR value – simple method; applicable under some circumstances (6.4.3.2.3).
- Alternative 3: Calculation of combined volumetric SAR from existing area and/or zoom scans – accurate and fast method; always applicable (6.4.3.2.4).
- Alternative 4: Volumetric scanning – most accurate method; always applicable (6.4.3.2.5).

The DUT measurement is deemed to fully comply with the requirements of this Standard if it meets the requirements of one of these alternative evaluation procedures.

Alternative 1 is the most conservative and computationally simple and it requires no additional SAR measurement. Alternatives 2 and 3 successively reduce the degree of over-estimation,

but require greater computation and test analysis. Alternative 4 provides the least overestimation and requires the most effort.

6.4.3.2.2 Alternative 1: Evaluation by summation of peak spatial-average SAR values

This procedure is applied to determine the upper limit of the combined SAR in a conservative way when the same maximum output power of each transmitter or antenna is used for both standalone and simultaneous transmission. Note that the different peak spatial-average SAR values being summed can be at different spatial locations. This procedure will overestimate the combined SAR in this case. This procedure is always applicable. The following procedures shall be applied using full SAR measurements that comply with all of the normative requirements of this standard. Fast SAR measurements may be used to identify the highest SAR test conditions for each frequency band as described in 6.6.

- a) For a test combination where simultaneous operation is intended, add the peak spatial-average SAR values for each antenna and frequency band where simultaneous operation is intended (see NOTE 1, NOTE 2 and NOTE 3 below).
- b) Check if the maximum summed SAR value is within 3 dB of the applicable SAR limit. If so, ensure that all of the required test frequency channels in 6.2.5 have been measured in all frequency bands and for all antennas at which simultaneous operation is intended and repeat Step a).
- c) The maximum summed SAR value in Steps a) and b) is the combined SAR.

NOTE 1 The SAR value at each frequency band corresponds to the frequency channel tested in that band at which the measured peak spatial-average SAR is the highest. In 6.2.5 the appropriate subset of frequencies to be measured for each frequency band is specified, and procedures for measuring at fewer frequencies than this subset is provided in 6.3. For example, if the SAR has been measured at the lowest, middle and highest channels in a band and the highest SAR is at the lowest frequency channel, the peak-spatial average SAR at the lowest frequency channel is used as the SAR value for that frequency band. If only the SAR at the middle frequency channel has been measured as per the procedures in 6.3, then the peak spatial-average SAR at the middle frequency channel is used as the SAR value for that frequency band.

NOTE 2 An acceptable variation of Step a) is to add the highest peak spatial-average SAR values applicable to all simultaneous transmission combinations regardless of test condition. In other words, the highest peak spatial-average SAR for one frequency band (among all test conditions at that frequency band) is added to the highest peak spatial-average SAR value at the other frequency band (among all test conditions), and so on for the other frequency bands where simultaneous operation is intended. Each of the test combinations that is considered using this method is then evaluated in Steps b) and c). This method is more conservative than the method of Step a).

NOTE 3 Having identified the maximum SAR test configuration, it is acceptable to conduct volumetric scanning on that configuration according to 6.4.3.2.5 to obtain a more accurate estimate of the maximum combined SAR.

6.4.3.2.3 Alternative 2: Evaluation by selection of highest assessed maximum peak spatial-average SAR values

This procedure gives an estimate of the multi-band SAR when the separately measured zoom scan SAR distributions have little or no overlap. The maxima are then separated to such an extent that the maximum peak spatial-average SAR value of each distribution would not increase by more than 5 % when the SAR distributions from all the other simultaneous operating modes are added. This alternative is only applicable if the highest peak spatial-average SAR is less than 70 % of the compliance limit, as calculated from the zoom scans at each frequency. This procedure shall be applied using full SAR measurements that comply with all normative requirements of this Standard.

- a) Measure the peak spatial-average SAR at each frequency separately according to 6.4.2. The area scan shall be performed in the same plane at each frequency. The distance z_{M1} for all area scans shall be less than or equal to the smallest z_{M1} value defined in Table 2 for the frequencies of interest. The probe tip diameter shall comply with the requirements of 5.1 at all of the frequencies of interest and it shall comply with the calibration requirements in this Standard.
- b) The separate area scans shall be interpolated such that the overlapping area has the same grid. The resolution of the interpolated grid shall be 1 mm or better. Find the peak value in each of the area scans. The overlapping area shall contain all SAR peaks.

- c) For all measured area scans, create a new SAR distribution by adding the interpolated area scans spatially, i.e. point-by-point.
- d) If the peak value in the new SAR distribution created in Step c) does not exceed the highest of the separate maximum peak SAR values found in Step b) by more than 5 %, then the multi-band SAR is selected as the highest of the separate peak spatial-average SAR values calculated from the zoom scan, as calculated in Step a).

The uncertainty according to 7.3 shall be assessed, documented and recorded.

6.4.3.2.4 Alternative 3: Evaluation by calculated volumetric SAR data

This procedure uses existing area and zoom scans (or specific 3D scans covering the area scan region) in combination with interpolation and extrapolation for generation of volumetric SAR data and is a rapid way of obtaining the combined SAR. It is always applicable. This procedure shall be applied using full SAR measurements that comply with all of the normative requirements of this Standard.

- a) For a test combination where simultaneous operation is intended, calculate the volumetric SAR distribution over a region corresponding to the area scan for each frequency band where simultaneous operation is intended. Different algorithms to accomplish this have been presented in [9], [80], [101], [102], [103]. The uncertainty of the method used shall be well documented according to the procedures in 7.2.10 and shall be recorded.
- b) Add the volumetric SAR distributions of all frequency bands spatially, using interpolation according to 6.5.1. For each frequency band where simultaneous operation is intended, this step shall be performed for each measured frequency channel according to the requirements of 6.2.5 and the procedures of 6.3 (see NOTE 1 of 6.4.3.2.2).
- c) Use post-processing procedures defined in 6.5 and Annex C to determine the peak spatial-average SAR values from the SAR distributions of Step b).
- d) Check if the maximum peak spatial-average SAR value is within 3 dB of the compliance limit. If so, ensure that all of the required test frequency channels in 6.2.5 have been measured in all frequency bands at which simultaneous operation is intended, and repeat Steps a) to c).

6.4.3.2.5 Alternative 4: Evaluation by volumetric scanning

This procedure is the most accurate way of assessing the combined SAR and is always applicable. As stated above, the SAR data are combined for each test condition (device position, configuration and accessory) where simultaneous transmission is intended. This procedure shall be applied using full SAR measurements that comply with all of the normative requirements of this Standard.

- a) For a test combination where simultaneous operation is intended, ensure that the zoom scan has been measured according to 6.4.2 at all test frequency channels specified in 6.2.5 (see NOTE 1 of 6.4.3.2.2) for each frequency band at which simultaneous operation is intended.
- b) For each frequency band of Step a), select the frequency channel having the highest peak spatial-average SAR.
- c) Determine a volumetric grid that encompasses the zoom scans at the test frequencies determined in Step b) over all of the frequency bands at which simultaneous operation is intended. If the zoom scans at frequencies f_1 , f_2 , etc. are so far apart that the volumetric grid is very large, resulting in very long measurement times, an acceptable variation of this is to identify all zoom scan locations for each frequency channel in Step b) and apply the alternative procedure in Step d).
- d) At each frequency channel determined in Step b), measure the volumetric grid found in Step c). This volumetric grid measurement adheres to all of the requirements of 6.4.2, Steps d) and e) except that the volumetric grid is larger than the zoom scan. If it was decided in Step c) to use zoom scan locations instead of volumetric grid, then at each frequency channel determined in Step b), measure the zoom scan for the other frequencies at exactly the same locations as for each previously measured zoom scan.

Step a). The measurement is conducted with the operating mode at that frequency turned on and the operating modes at the other frequencies turned off.

- e) Add the SAR distributions obtained in Step d) spatially to obtain a summed SAR distribution. Calculate the maximum combined SAR from the summed distribution, using the post-processing procedures (interpolation, extrapolation and averaging) defined in 6.5 to determine the peak spatial-average SAR. When volumetric scans are performed for each frequency, these shall be summed and the maximum peak is determined based on the total distribution. In case only zoom scans are performed in Step d), the zoom scans at each peak location in each frequency band are combined and the highest one is identified to compute peak spatial-average SAR.

The tested device should be fixed on the phantom when the liquids are changed so that the summation of the SAR distributions is as accurate as possible. If the battery of the device needs to be recharged, the charger cable shall be attached to the DUT when it remains positioned on the phantom. The cable shall be attached only during the battery charging between SAR measurements and shall be detached during testing.

6.4.3.2.6 Example calculation of the combined SAR using Alternative 1

Subclause 6.4.3.2.6 describes an example of the application of the summation of peak spatial-average SAR values method (Alternative 1). Subclause 6.4.3.2.6 is for illustrative purposes only. Table 3 shows an example of a wireless handset having two antennas and four operating modes, where 10 g peak spatial-average SAR values from single-band measurements are shown in the third column and third row for the four operating modes and antennas. The cells to the bottom and right of these values show the combined SAR values. Only those cells that are not grey are applicable and evaluated for this example. The four operating modes consist of two voice modes and two data modes, each in two frequency bands. The 10 g peak spatial-average SAR values have all been measured at the centre channel of the respective frequency bands for single-band operation (one operating mode and antenna is transmitting while the other band and antenna are switched off). The SAR values are shown in the third row for Antenna 1 and in the third column for Antenna 2. The combined SAR values are computed using Alternative 1 (i.e. simple summation of the 10 g peak spatial-average SAR values in Row 3 and Column 3). For this example, the handset supports only one voice mode at a time, and one data mode at a time, and it supports simultaneous transmission of voice and data. Therefore, a voice mode is not combined with another voice mode, for example. Also, SAR measurements on the left side of the head are not combined with SAR measurements on the right side. However, it is intended for this example that the two antennas could transmit simultaneously.

Table 3 – Example method to determine the combined SAR value using Alternative 1

Antenna 1 \ Antenna 2			Voice Band 1		Voice Band 2		Data Band 1		Data Band 2	
			Left	Right	Left	Right	Left	Right	Left	Right
Antenna 2			0,285	0,250	0,333	0,315	0,512	0,489	0,593	0,574
Voice Band 1	Left	0,141					0,653		0,734	
	Right	0,120						0,609		0,694
Voice Band 2	Left	0,131					0,643		0,724	
	Right	0,130						0,619		0,704
Data Band 1	Left	0,220	0,505		0,553					
	Right	0,213		0,463		0,528				
Data Band 2	Left	0,225	0,510		0,558					
	Right	0,216		0,466		0,531				

6.4.3.3 SAR measurements for correlated signals

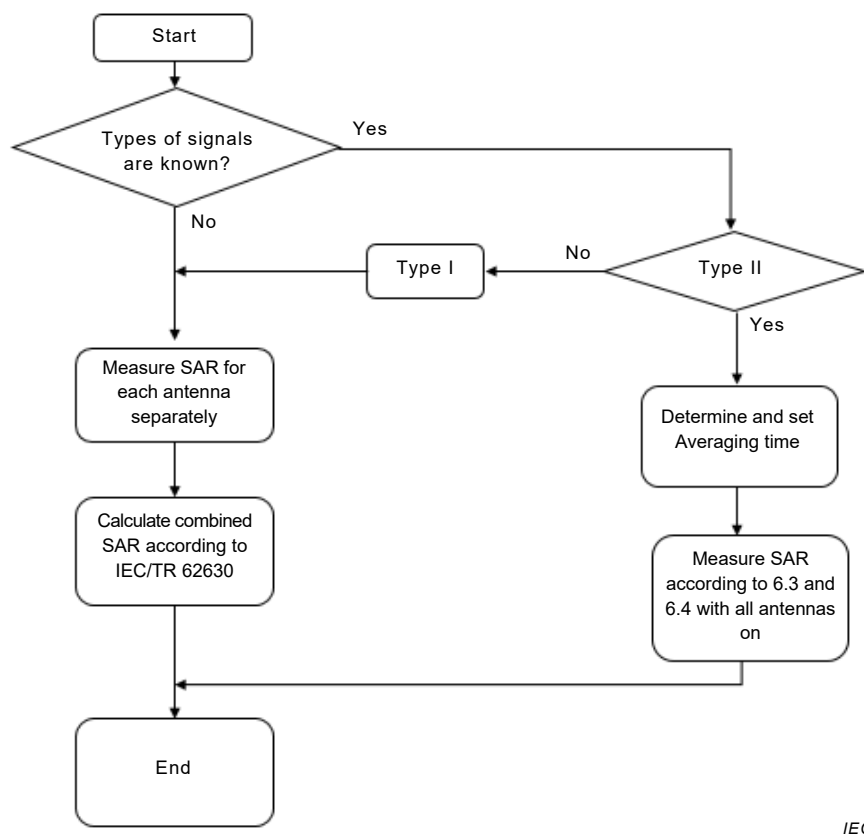
Handsets with multiple antennas transmitting correlated signals simultaneously represent a particular case of devices such as MIMO transmitters with digital beam-forming capabilities and require special test considerations. Signals of such handsets can be classified based on the change of relative phases in a normal communication. In general, there are two types of signals that can be found in the most recent generation of multi-antenna transmitters. The first, referred to as Type 1, are signals with relative phases unchanged for a relatively long duration compared with symbol duration. This type of signals can be found in phased array antenna systems where the relative phases of signals fed to the antennas are controlled to form the radiation pattern of the array antenna toward a certain direction. In different operating environments, the relative phases may change to obtain different desired radiation patterns. Thus, as soon as the transmitting direction is determined and the pattern is formed, the relative phases will be fixed for a certain duration, and will only change when the radiation pattern is configured to another form. In fact, the duration that relative phases are kept unchanged is relatively long compared with the duration of a symbol in normal communication. On the other hand, the second type of signals, referred to herein as Type 2, are signals with relative phases that vary quickly over a relatively short period. Such signals can be found in systems utilizing MIMO techniques. Relative phases of signals will be changed from symbol to symbol due to the function of space-time block code (STBC) in the MIMO schemes. The relative phases of signals are changed from symbol to symbol according to the STBC coding, and beam-forming is not used during normal communication.

As explained in IEC TR 62630 [62], correlated signals can only be transmitted at the same carrier frequency and SAR depends on the relative phase(s) between the signals. Therefore the peak spatial-average SAR cannot be precisely evaluated using scalar E-field probes from one measurement with transmitters set to fixed relative phase condition if those phases are subject to change during the normal operation of the device. Instead, for precise SAR evaluation, repeated measurements corresponding to all phase combinations between the transmitters are needed. This is a rather time-consuming evaluation and may not be practical unless certain SAR systems are used which enable fast SAR scans combined with the software control of DUT to cycle through all possible phase combinations of the signals transmitted simultaneously at their highest time-averaged output powers. In general, it is also possible to accurately evaluate peak spatial-average SAR of each individual transmitter transmitting separately at the highest time-averaged output power using single SAR measurement. However, this requires complex vector E-field measurements (i.e. measurements of magnitude and phase of all three E-field components) and is therefore less practical.

The alternative method that takes advantage of the conventional SAR systems is based on SAR measurements for each transmitter transmitting separately at the highest time-averaged output power and combining the individual SAR results as described in IEC TR 62630 [62]. This approach leads to much faster SAR measurement but provides only an upper bound of the SAR therefore potentially overestimating the results. IEC TR 62630 describes two methods of combining the SAR from individual measurements using the conventional scalar E-field probes. The first method is based on combination of the magnitudes of individual E-field values and the second is based on magnitudes of the individual E-field components. These two methods can be implemented using conventional SAR measurement systems and require only a limited number of SAR scans equal to the number of transmitters. The second approach based on combination of the individual E-field components should be used since it leads to a lesser degree of potential SAR overestimation and many SAR systems readily provide the required input data for post-processing described in [62]. The measurement procedure for different types of correlated signals is described in Figure 7. For the Type 1 signal in the aforementioned classification or unspecified signals, the second approach based on a combination of the individual E-field components should be used, which leads to a lesser degree of potential SAR overestimation and many SAR systems readily provide the required input data for post-processing described in [62]. For the Type 2 signals in the aforementioned classification, using the approach of time-averaged SAR measurements (see NOTE below) requires only the measurement procedure defined in 6.4, with the use of conventional scalar probes.

NOTE Another method is to measure time-averaged SAR in a certain averaging period using conventional SAR scalar measurement systems. This method can be only applicable to the devices generating Type 2 correlated signals. This supposes that the combination of relative phases which yields the maximum SAR does not frequently occur, and even when it does, it occurs for a very short time before being dominated by other combinations which yield lower SAR. Since SAR is determined by the electromagnetic energy absorbed in the exposed tissue-equivalent target material, introducing the time-averaging procedure is suitable for the evaluation of SAR under such rapidly fluctuating electromagnetic fields. To evaluate the time-averaged SAR from such devices, all transmitting antennas are turned on as they are in a normal communication at the same time, and instantaneous SAR values are measured at each measurement point with a sampling-time interval and averaged over a time duration appropriate for capturing the signal characteristics.

This method has the benefit of using a conventional scalar probe and, furthermore, provides measured SAR that is close to actual SAR. It also requires only one time-averaging measurement at each measurement point required by the measurement procedure in 6.4, regardless of the number of transmitting antennas. The averaging time for a multi-antenna system, however, is longer than that for a conventional single transmitting antenna case. Also, when the number of antennas increases, the averaging time would be slightly longer to obtain converged SAR, because the time-fluctuation of the instantaneous SAR increases along with the increase of the number of antennas. The averaging time also depends on the sampling rate of the probes of SAR measurement systems. It is reduced as the sampling rate is increased, and vice versa. For example, for a SAR measurement system with a measurement rate of 1 250 samples per second, the averaging time of 1 s yields that the standard deviation of the instantaneous SAR values due to multiple transmitting antennas is kept under 2 %. In such a case, total measurement uncertainty is evaluated by using the uncertainty budget in Clause 7 with typical values, and the uncertainty for multiple transmitting antennas is at the same level as that of single antenna cases (typically at 8,7 %).



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Figure 7 – Measurement procedure for different types of correlated signals

6.5 Post-processing of SAR measurement data

6.5.1 Interpolation

The resolution of the measurement grid is not as fine as that required by the interpolation requirements for the area and zoom scan to compute the peak spatial-average SAR. Interpolation shall be applied to the measurement points. Examples of interpolation schemes are given in Annex C.

6.5.2 Extrapolation

The electric field probes used to measure SAR usually contain three orthogonal dipoles in close proximity and embedded in a protective cover/case. The measurement (calibration) point is situated a few millimetres from the tip of the probe and this offset shall be taken into account when identifying the position of the measured SAR. Because of probe boundary effect errors and probe sensor offset, SAR is not measured at the surface of the phantom. The measured points closest to the surface are extrapolated to estimate the highest SAR at the phantom surface. Examples of extrapolation schemes are given in Annex C.

6.5.3 Definition of the averaging volume

The averaging volume shall be in the shape of a cube with side dimension that establishes a 1 g or 10 g mass. A density of 1 000 kg/m³ shall be used to represent the head tissue density (actual phantom liquid density shall not be used). The side length of the 1 g cube shall be 10 mm, and the side length of the 10 g cube shall be 21,5 mm. The orientation of the cubical volume is given in Annex C.

6.5.4 Searching for the maxima

The cubical averaging volume shall be shifted throughout the interpolated and extrapolated zoom-scan volume at the inner surface of the phantom in the vicinity of the local maximum SAR, using considerations such as those given in Annex C. The cube with the highest peak spatial-average SAR shall not be at the edge/perimeter of the zoom-scan volume. In case it is, the zoom-scan volume shall be shifted and the measurements shall be repeated.

6.6 Fast SAR testing

6.6.1 General

Measurements using systems that fully comply with the requirements of this Standard are referred to as "full SAR" measurements. The procedures described in 6.6 apply to fast SAR methods that differ from full SAR evaluations. Fast SAR methods use special techniques, methods or algorithms, in order to decrease the measurement time. Fast SAR measurements can be used together with full SAR measurements to reduce the overall measurement time needed to evaluate a wireless device. Since fast SAR methods do not fully comply with all the normative requirements in this Standard, they can be used to assess the relative SAR levels for different test conditions, and full SAR systems are used to assess the absolute SAR levels of selected higher SAR configurations. The special techniques used by fast SAR methods are expected to introduce additional offsets and/or uncertainties which may be dependent on the operating mode (e.g. GSM, WCDMA or frequency, modulation).

NOTE The Fast SAR procedures described in 6.6 allow users of this Standard to save time required for testing. These testing alternatives are not mandatory; the user of this Standard remains free either to apply them properly according to 6.6.1 to 6.6.4 in conjunction with full SAR or to follow the standard full SAR measurement procedure described in 6.3 to 6.5.

For example, a fast SAR system using a fixed measurement resolution will have higher measurement uncertainty at higher frequencies, where the SAR distribution generally has a faster decay in the three coordinate directions (this is the reason why a smaller spacing between measurement points is required at higher frequencies, as described in 6.4.2). For this reason, full SAR measurements shall be used for the highest SAR test condition and other test conditions within a 95 % confidence level of the highest SAR test condition of the SAR limit, as determined by the fast SAR methods (see 6.6.2 or 6.6.4).

Fast SAR methods do not fall in the class of test reduction methods. Fast SAR methods generally aim to decrease the time spent to perform a single measurement (as described below) and test reduction methods aim to reduce the total number of measurements to be performed. In general, fast SAR methods are based on approximations and optimizations that are specific to each implementation. For this reason, the individual method shall be fully validated to determine its applicability for testing different wireless devices, as described in D.4.2. The valid range of frequencies, SAR distributions and SAR levels applicable to the fast