BS EN 62209-2:2010

BSI Standards Publication

Human exposure to radio frequency fields from hand-held and bodymounted wireless communication devices — Human models, instrumentation, and procedures

Part 2: Procedure to determine the specific absorption rate (SAR) for wireless communication devices used in close proximity to the human body (frequency range of 30 MHz to 6 GHz) (IEC 62209-2:2010)

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National foreword

This British Standard is the UK implementation of EN 62209-2:2010.
It is identical to IEC 62209-2:2010, incorporating corrigendum June 2010.

The start and finish of text introduced or altered by corrigendum is indicated in the text by tags. Text altered by IEC corrigendum June 2010 is indicated in the text by [AC1⟩ ⟨AC1].

The UK participation in its preparation was entrusted to Technical Committee GEL/106, Human exposure to low frequency and high frequency electromagnetic radiation.

A list of organizations represented on this committee can be obtained on request to its secretary.

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EUROPEAN STANDARD
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EN 62209-2

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English version

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

(IEC 62209-2:2010)

Exposition humaine aux champs radio fréquence produits par les dispositifs de communications sans fils tenus à la main ou portés près du corps - Modèles du corps humain, instrumentation et procédures - Partie 2: Procédure pour la détermination du débit d'absorption spécifique produit par les dispositifs de communications sans fils utilisés très près du corps humain (gamme de fréquence de 30 MHz à 6 GHz)
(CEI 62209-2:2010)

Sicherheit von Personen in hochfrequenten Feldern von handgehaltenen und am Körper getragenen schnurlosen Kommunikationsgeräten – Körpermodelle, Messgeräte und Verfahren – Teil 2: Verfahren zur Bestimmung der spezifischen Absorptionsrate (SAR) von schnurlosen Kommunikationsgeräten, die in enger Nachbarschaft zum menschlichen Körper verwendet werden (Frequenzbereich von 30 MHz bis 6 GHz)
(IEC 62209-2:2010)

This European Standard was approved by CENELEC on 2010-06-01. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

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This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CENELEC member into its own language and notified to the Central Secretariat has the same status as the official versions.

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European Committee for Electrotechnical Standardization
Comité Européen de Normalisation Electrotechnique
Europäisches Komitee für Elektrotechnische Normung

Management Centre: Avenue Marnix 17, B - 1000 Brussels

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Foreword

The text of document 106/195/FDIS, future edition 1 of IEC 62209-1, prepared by IEC TC 106, Methods for the assessment of electric, magnetic and electromagnetic fields associated with human exposure, was submitted to the IEC-CENELEC parallel vote and was approved by CENELEC as EN 62209-2 on 2010-06-01.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN and CENELEC shall not be held responsible for identifying any or all such patent rights.

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2011-03-01
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2013-06-01

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 62209-2:2010 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

[30]	IEC 62311:2007	NOTE	Harmonized as EN 62311:2008 (modified).
[31]	IEC 62479	NOTE	Harmonized as EN 62479.
[34]	ISO 10012:2003	NOTE	Harmonized as EN ISO 10012:2003 (not modified).

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

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

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

Publication	Year	Title	EN/HD	Year
IEC 62209-1	2005	Human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices - Human models, instrumentation, and procedures - Part 1: Procedure to determine the specific absorption rate (SAR) for hand-held devices used in close proximity to the ear (frequency range of 300 MHz to 3 GHz)	EN 62209-1	2006
ISO/IEC 17025	2005	General requirements for the competence of testing and calibration laboratories	EN ISO/IEC 17025	2005

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

HUMAN EXPOSURE TO RADIO FREQUENCY FIELDS FROM HAND-HELD AND BODY-MOUNTED WIRELESS COMMUNICATION DEVICES – HUMAN MODELS, INSTRUMENTATION, AND PROCEDURES –

Part 2: Procedure to determine the specific absorption rate (SAR) for wireless communication devices used in close proximity to the human body (frequency range of 30 MHz to 6 GHz)

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as "IEC Publication(s)"). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
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International Standard IEC 62209-2 has been prepared by IEC technical committee 106: Methods for the assessment of electric, magnetic and electromagnetic fields associated with human exposure.

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

FDIS	Report on voting
106/195/FDIS	106/200/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.

The French version of this standard has not been voted upon.

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

A list of all parts of the IEC 62209 series, published under the general title *Human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices – Human models, instrumentation, and procedures*, can be found on the IEC website.

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

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

The contents of the corrigendum of June 2010 have been included in this copy.

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

The IEC work item “Evaluation of the Human Exposure to Radio Fields from Hand-Held and Body-Mounted Wireless Communication Devices in the Frequency range 30 MHz to 6 GHz (Human Models, Instrumentation, Procedures),” has the objective to measure the human exposure from devices intended to be used at a position near the human body. This standard was developed to provide procedures to evaluate exposures due to any electromagnetic field (EMF) transmitting device when held in the hand or in front of the face, mounted on the body, combined with other transmitters within a product, or embedded in garments. The types of devices dealt with include but are not limited to mobile telephones, cordless telephones, cordless microphones, auxiliary broadcast devices and radio transmitters in personal computers. For transmitters used in close proximity to the human ear, specific absorption rate (SAR) measurements should be performed using the procedures of IEC 62209-1:2005.

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. The task includes assessment methods for the exposure produced by specific sources. It applies to basic restrictions and reference levels. Although the establishment of exposure limits is not within the scope of TC 106, the results of assessments performed in accordance with TC 106 standards can be compared with the basic restrictions of relevant standards and guidelines. Conformity assessment depends on the policy of national regulatory bodies.

A Category D liaison in IEC involves organizations that can make an effective technical contribution and participate at the working group level or specific project level of the IEC technical committees or subcommittees. Obvious goals are standards harmonization and minimizing duplication of effort. The work of IEC technical committee 106 (TC 106) and IEEE International Committee on Electromagnetic Safety (ICES SCC39), technical committee 34 (TC 34), is an example where two international committees worked together informally through common membership to achieve the goal of harmonization, specifically between IEC Project Team 62209 (PT 62209) on the “Procedure to Measure the Specific Absorption Rate (SAR) for Hand-Held Mobile Telephones” and IEEE/SCC39-ICES/TC34 on IEEE Std 1528-2003 “IEEE Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Head from Wireless Communications Devices: Measurement Techniques” [32].[1]

IEEE/SCC39-ICES/TC34 has a similar project. Because the project is more advanced in IEC, a Category D liaison was sought in order to avoid divergence of standards and duplication of work. Thus, rather than developing two separate standards (IEC and IEEE), the IEEE committee felt it would be more efficient to develop a single IEC standard with direct input from the members of IEEE/SCC39-ICES/TC34, many of whom are also members of PT 62209 or are from the same organizations that send delegates to participate in the work of PT 62209. The Category D liaison is limited only to this project (Part 2 of IEC 62209 series).

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[1] Figures in square brackets refer to the Bibliography.

HUMAN EXPOSURE TO RADIO FREQUENCY FIELDS FROM HAND-HELD AND BODY-MOUNTED WIRELESS COMMUNICATION DEVICES – HUMAN MODELS, INSTRUMENTATION, AND PROCEDURES –

Part 2: Procedure to determine the specific absorption rate (SAR) for wireless communication devices used in close proximity to the human body (frequency range of 30 MHz to 6 GHz)

1 Scope

This part of IEC 62209 series is applicable to any wireless communication device capable of transmitting electromagnetic fields (EMF) intended to be used at a position near the human body, in the manner described by the manufacturer, with the radiating part(s) of the device at distances up to and including 200 mm from a human body, i.e. when held in the hand or in front of the face, mounted on the body, combined with other transmitting or non-transmitting devices or accessories (e.g. belt-clip, camera or Bluetooth add-on), or embedded in garments. For transmitters used in close proximity to the human ear, the procedures of IEC 62209-1:2005 are applicable.

This standard is applicable for radio frequency exposure in the frequency range of 30 MHz to 6 GHz, and may be used to measure simultaneous exposures from multiple radio sources used in close proximity to human body. Definitions and evaluation procedures are provided for the following general categories of device types: body-mounted, body-supported, desktop, front-of-face, hand-held, laptop, limb-mounted, multi-band, push-to-talk, clothing-integrated. The types of devices considered include but are not limited to mobile telephones, cordless microphones, auxiliary broadcast devices and radio transmitters in personal computers.

This International Standard gives guidelines for a reproducible and conservative measurement methodology for determining the compliance of wireless devices with the SAR limits.

Because studies suggest that exclusion of features to represent a hand in human models constitutes a conservative case scenario for SAR in the trunk and the head, a representation of a hand is not included if the device is intended to be used next to the head or supported on or near the torso [73], [80]. This standard does not apply for exposures from transmitting or non-transmitting implanted medical devices. This standard does not apply for exposure from devices at distances greater than 200 mm away from the human body.

IEC 62209-2 makes cross-reference to IEC 62209-1:2005 where complete clauses or subclauses apply, along with any changes specified.

2 Normative references

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

IEC 62209-1:2005, *Human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices – Human models, instrumentation, and procedures – Part 1: Procedure to determine the specific absorption rate (SAR) for hand-held devices used in close proximity to the ear (frequency range of 300 MHz to 3 GHz)*

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 terms and definitions given in the IEC 62209-1:2005, as well the following apply.

3.1
accessory
optional component that can be used in conjunction with a transmitting device

EXAMPLES

Accessories for mobile phones, wireless transmitting devices, wireless receiving devices or wireless transceiving devices, or two-way radios include the following:

a) accessories for holding, affixing, or otherwise carrying, wearing or attaching the device, as well as providing spacing from the body (e.g. a belt-clip, wrist-strap or any other body strap, or lanyard for wearing the device as necklace);

b) electronic accessories for performing tasks or which provide features (e.g., GPS modules, outboard printers, MP3 players, cameras or viewing devices);

c) electronic accessories providing audio or video input or output (e.g., headsets, microphones, cameras);

d) accessories providing enhanced RF capability to the device (e.g., replacement or auxiliary antennas);

e) batteries and related d.c. power components;

f) combinations of accessories, where two or more of the above are combined within one component (e.g., belt clip with built-in Bluetooth and “pigtail” audio cable to device).

3.2
body-mounted device[2]
body-worn device
portable device containing a wireless transmitter or transceiver which is positioned in close proximity to a person’s torso or limbs (excluding the head) by means of a carry accessory during its intended use or operation of its radio functions

3.3
body-supported device
a device whose intended use includes transmitting with any portion of the device being held directly against a user’s body

NOTE This differs from a body-mounted device in that it is not attached to a user’s body by means of a carry accessory

3.4
cable
wire that is necessary for the functionality in the intended operational configuration

3.5
conservative exposure
estimate of the peak spatial-average SAR, including uncertainties as defined in this standard, representative of and slightly higher than expected to occur in the bodies of a significant majority of persons during intended use of hand-held devices

NOTE Conservative estimate does not mean the absolute maximum SAR value that could possibly occur under every conceivable combination of body size, body shape, wireless device orientation, and spacing relative to the body. In order to ensure that the results are not overly restrictive, and thereby unnecessarily inhibit the

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[2] Both terms are used. Colloquially the term “body-worn” is preferred over “body-mounted”.

advancement of new mobile communications technologies, SAR overestimates should be as small as possible. For example, overestimates of the order of 20 % have been reported for head exposures [78], [79], and were deemed reasonable. Achieving an optimal compromise between over- or underestimate conditions is a complex task, which is why the conductivity of the tissue-equivalent liquid is not selected to be arbitrarily large, for example.

3.6
desktop device

a device placed or mounted on a desk, table, or similar supporting structure, and the antenna of which is intended to be operated closer than 200 mm from the human body

3.7
device under test
DUT

a device that contains one or more wireless transmitters or transceivers that is subject to this standard

NOTE A device under test may be further categorised as a body-worn, body-supported, desktop, front-of-face, hand-held, limb-worn, clothing-integrated or as a generic device.

3.8
duty factor

operational time averaging factor

the proportion of time that a transmitter transmits over a specified period

3.9
front-of-face device

hand-held device operated in close proximity to the face

EXAMPLE Front-of-face device types include push-to-talk devices, two-way radios, devices equipped with a camera.

3.10
generic device

a device that cannot be categorized as any of the specific device types

3.11
hand-held device

a portable device which is located in a user’s hand during its intended use

3.12
host

any equipment which has complete user functionality when not connected to the radio equipment part and to which the radio equipment part provides additional functionality and to which connection is necessary for the radio equipment part to offer functionality

3.13
intended use

intended purpose

use for which a product, process or service is intended according to the specifications, instructions and information provided by the manufacturer. Also, use of a device for the full range of available functions, in accordance with the specifications, instructions and information provided by the manufacturer

NOTE 1 User guide instructions may include the intended use operating position and orientation.

NOTE 2 Intended use, i.e. the way a manufacturer specifies that a device should be used may not encompass all possible use conditions.

3.14
laptop device

portable computer

a portable device containing one or more wireless transceivers, that can sit on the user's lap and is not intended for hand-held use

NOTE Laptop device types include laptop (notebook) computers, typically comprised of separate keyboard and display sections connected by hinge, and tablet computers, which typically have a one-section construction where the display section also serves as input interface using a stylus or virtual keyboard.

3.15
limb-mounted device

a device whose intended use includes being strapped to the arm or leg of the user while transmitting (except in idle mode)

EXAMPLE Limb-mounted device types include wrist-mounted, ankle-mounted, and forearm-mounted devices.

3.16
measurement drift

continuous or incremental change over time in indication, due to changes in metrological properties of a measuring instrument

3.17
multi-band transmission

operation mode for transmitting on several radio frequency bands simultaneously

3.18
output power

power at the output of the RF transmitter when the antenna, or a load with the same impedance at the test frequency and in the considered test position, is connected to it

3.19
peak SAR value, primary

largest SAR value determined in an area scan measurement

3.20
peak SAR value, secondary

other local SAR maxima determined in an area scan measurement that are smaller than the primary peak SAR value

3.21
separation distance

distance between the DUT and the outside surface of the phantom, representing the distance during intended use

3.22
two-way radio

push-to-talk (PTT) device

a hand-held radio transceiver in which a switch is used to toggle between radio transmission and reception

4 Symbols and abbreviated terms

4.1 Physical quantities

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

Symbol	Quantity	Unit	Unit symbol
E	Electric field strength	volt per metre	V/m
f	Frequency	Hertz	Hz
H	Magnetic field strength	ampere per metre	A/m
J	Current density	ampere per square metre	A/m^2
$\overline{P}_{avg}$	Average (temporal) absorbed power	watt	W
SAR	Specific absorption rate	watt per kilogram	W/kg
T	Temperature	kelvin	K
ε	Permittivity	farad per metre	F/m
λ	Wavelength	metre	m
μ	Permeability	henry per metre	H/m
ρ	Mass density	kilogram per cubic metre	kg/m^3
σ	Electric conductivity	siemens per metre	S/m

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

4.2 Constants

Symbol	Physical constant	Magnitude
c	Speed of light in vacuum	$2{,}998 \times 10^8$ m/s
η	Impedance of free space	120π or 377 Ω
ε_0	Permittivity of free space	$8{,}854 \times 10^{-12}$ F/m
μ_0	Permeability of free space	$4\pi \times 10^{-7}$ H/m

4.3 Abbreviations

CDMA	code division multiple access
CW	continuous wave
DOE	design of experiments
DUT	device under test
E-field	electric field
EMC	electromagnetic compatibility
FDTD	finite-difference time-domain
FDMA	frequency division multiple access
GPRS	general packet radio service
GSM	global system for mobile communication
MIMO	multiple input multiple output
MOD	modulation
OFAT	one-factor-at- a-time
PTT	push-to-talk
RF	radio frequency

RMS	root mean square
RSS	root sum square
SAR	specific absorption rate
TDMA	time division multiple access

5 Measurement system specifications

5.1 General requirements

A SAR measurement system consists of a human body model (phantom), electronic measurement instrumentation, a scanning system and a device holder.

The test shall be performed using a miniature probe that is automatically positioned to measure the internal *E*-field distribution in a phantom representing the human body exposed to the electromagnetic fields produced by wireless devices. From the measured *E*-field values, the SAR distribution and the peak spatial-average SAR value shall be calculated.

The test shall be performed in a laboratory conforming to the following environmental conditions:

- both the ambient and liquid temperatures shall both be in the range of 18 °C to 25 °C; see 7.2.4.4 to determine the liquid temperature uncertainty;
- 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 should not have been recently moved from another area with a different ambient temperature, such as a refrigerator or outdoors);
- the variation of the liquid temperature during the test shall not deviate from the liquid temperature during dielectric property measurement by more than ± 2 °C or that which would result in a SAR deviation within ± 5 %, whichever is smaller; see 7.2.4.4 to determine the liquid temperature uncertainty;
- the ambient noise (e.g., noise of measurement system, noise due to the robot motors, other RF transmitters, etc.) shall not induce a 1 g SAR greater than 0,012 W/kg (3 % of the lower measurement value of 0,4 W/kg that can be determined with the uncertainties of Table 5), as measured according to 7.2.4.5 with the RF transmitter of the DUT turned off;
- during testing the DUT shall not connect to any wireless network; the connection to a base station simulator is acceptable;
- the effects of scatterers (e.g., floor, robot, other devices, etc.) other than the transmitter and the phantom shall be smaller than 3 % of the measured SAR, as measured according to 7.2.4.5 with the RF transmitter of the DUT turned on. If the effect of the scatterers is larger than 3 %, additional uncertainty shall be added (7.2.4.5).

System validation according to the protocol defined in Annex B shall be done at least once per year, including 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 types of probes. The standard sources used for system validation (e.g. a half-wave dipole, patch antenna, open-ended waveguide) shall be designed and validated according to the protocol in Annex B. Additional sources (e.g. dipoles at specific frequencies not presently included in Tables B.1, D.1, and D.2) may be used as standard sources provided they meet the requirements specified in Annex B.

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

5.2 Phantom specifications – shell and liquid

5.2.1 General requirements

The physical characteristics of the standard flat phantom are intended to simulate a human body. The flat phantom is an open-top container with a thin dielectric shell and filled with a tissue-equivalent liquid. The dielectric properties (permittivity and conductivity) of the liquid are specified in 5.2.3, and have been formulated to obtain a conservative assessment of the SAR induced in the user [6] (see Annex A for the rationale used to derive liquid parameters).

5.2.2 Phantom material, shape and size

The phantom shell shall be constructed in the form of an open-top container with a flat bottom. In this standard, flat phantoms shall be used for system validation, system check and for measurements of SAR for DUTs using positions specified in 6.1.4.

Any flat phantoms used shall be large enough to allow the measurement of SAR in 1 g and 10 g volumes (liquid density of 1 000 kg/m^3 is used) with an influence from shape of less than 1 % (see Annex A).

NOTE Use of a flat phantom as a standard phantom for SAR evaluations of body-worn and body-supported devices is intended to represent maximum coupling between the DUT and phantom compared to a significant majority of exposure situations involving people. Such coupling to the boundary while maintaining prescribed distances is likely to produce a conservative estimation of SAR. Annex H provides more details about this topic.

The flat phantom shall have the following shape and dimensions:

a) Except as specified in item b), the shape of the phantom shall be an ellipse with length 600 mm ± 5 mm and width 400 mm ± 5 mm (see Figure 1).

[AC1⟩ b) For frequencies above 300 MHz and for separation distances less than or equal to 25 mm from the outer surface of the bottom of the phantom shell, phantoms with other shapes and smaller dimensions are allowed [5] as follows: ⟨AC1]

- between 300 MHz and 800 MHz, the phantom flat bottom wall may have any shape that encompasses an ellipse with length 0,6 λ_0 and width 0,4 λ_0, where λ_0 is the wavelength in air.
- between 800 MHz and 6 GHz, the phantom may have any shape flat bottom wall that encompasses an ellipse with length 225 mm and width 150 mm.

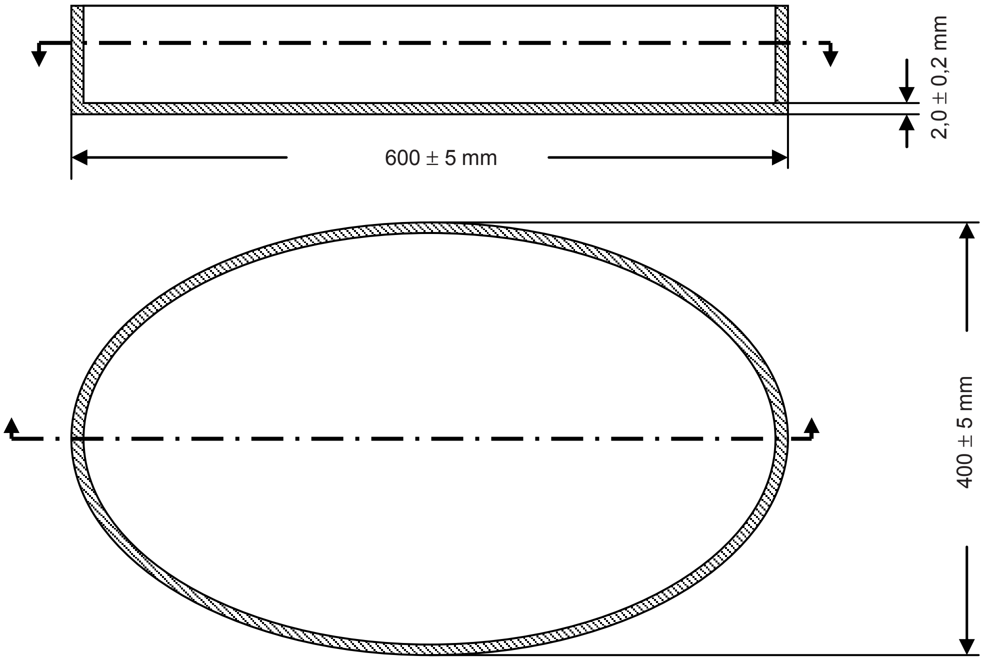

Figure 1 – Dimensions of the elliptical phantom

The phantom shall be filled with tissue-equivalent liquid to a depth of at least 150 mm. For the frequency range 3 GHz to 6 GHz, a liquid depth of 150 mm is also recommended, but it can be reduced provided that the reflections from the top liquid surface do not change the peak spatial average SAR values by more than 1 %. When filled with liquid, the sagging of the outer surface at the centre of the bottom wall shall be less than 2 mm.

The phantom shell shall be made of low-loss and low-permittivity material, having loss tangent $\tan\delta \leq 0{,}05$ and relative permittivity:

$\varepsilon_r' \leq 5$ for $f \leq 3$ GHz

$3 \leq \varepsilon_r' \leq 5$ for $f > 3$ GHz [62]

The thickness of the bottom-wall of the flat phantom shall be 2,0 mm with a tolerance of ± 0,2 mm.

If the above requirements are met, the effect of the shape and thickness on the repeatability of SAR measurement results is less than 1 %. Effects on the SAR due to the influence of the deviation from the shell parameters and thickness shall be included in the uncertainty estimation.

The phantom shell material shall be resistant to damage or reaction with tissue-equivalent liquid chemicals.

5.2.3 Tissue-equivalent liquid material properties

Nominal dielectric values of the tissue-equivalent liquid in the phantom are specified in Table 1, for discrete frequencies ranging between 30 MHz and 6 GHz. For other frequencies within this range, the nominal dielectric values shall be obtained by linear interpolation between the higher and lower tabulated figures. Example recipes for preparing tissue-equivalent liquids designed to produce the dielectric properties at some of the frequencies in the 30 MHz to 6 GHz range are provided in Annex E. The rationale for the liquid equivalent material properties is given in Annex A.

The liquid temperature specifications are given in 5.1.

Table 1 – Dielectric properties of the tissue-equivalent liquid material

Frequency MHz	**Real part of the complex relative permittivity,** ε_r'	**Conductivity,** σ S/m
30	55,0	0,75
150	52,3	0,76
300	45,3	0,87
450	43,5	0,87
750	*41,9*	*0,89*
835	41,5	0,90
900	41,5	0,97
1 450	40,5	1,20
1 800	40,0	1,40
1 900	40,0	1,40
1 950	40,0	1,40
2 000	40,0	1,40
2 100	39,8	1,49
2 450	39,2	1,80
2 600	*39,0*	*1,96*
3 000	38,5	2,40
3 500	37,9	2,91
4 000	37,4	3,43
4 500	36,8	3,94
5 000	36,2	4,45
5 200	36,0	4,66
5 400	35,8	4,86
5 600	35,5	5,07
5 800	35,3	5,27
6 000	35,1	5,48

NOTE For convenience, permittivity and conductivity values at some frequencies that are not part of the original data from Drossos et al. [16] or the extension of FCC data [17] are provided (these values are shown in italics in Table 1). The italicized values were linearly interpolated between the non-italicized values that are immediately above and below these values, except the values at 6 000 MHz which were linearly extrapolated from the values at 3 000 MHz and 5 800 MHz.

For the purpose of SAR evaluations, the tissue-equivalent liquids shall be assumed to have a density of 1 000 kg/m^3.

5.3 Measurement instrumentation system specifications

5.3.1 General requirements

The requirements of the scanning system and probes are given in 5.3.2 and 5.3.3 respectively. The probe calibration and DUT holder requirements are defined in 5.3.4 and 5.3.5 respectively.

5.3.2 Scanning system

The minimum requirements for the scanning system are:

- positional accuracy: ≤ ± 0,2 mm;
- minimum resolution (step size): ≤ 1 mm;
- scanning range: ≥ 90 % of the phantom dimensions in all directions.

5.3.3 Probes

Accurate measurements require that the probe tip has sufficiently small size to be able to effectively resolve the distribution of the fields induced in the phantom. The probe should only minimally distort the field distribution, which can be achieved if the probe diameter is smaller than one third of the wavelength in the liquid. Furthermore, accurate measurements are needed as close as possible to the surface of the phantom in order to keep the extrapolation error as low as possible. Clause M.1 gives a rationale for the probe requirements.

The minimum requirements of the preceding paragraph are achieved if the probe fulfils the following specifications:

- probe tip diameter:
  - ≤ 8 mm, for frequencies up to and including 2 GHz;
  - ≤ $\lambda/3$ for frequencies greater than 2 GHz

    where

    λ is the wavelength in the liquid medium in mm;
- sensitivity: ≤ 0,01 W/kg.

5.3.4 Probe calibration

The probe shall be calibrated together with associated readout electronics and the calibration so obtained shall be valid for any other identical or technically equivalent type of readout electronics. The probe shall be calibrated in each tissue-equivalent liquid at the appropriate operating frequency and temperature range according to the methodology described in Annex B of IEC 62209-1:2005.

5.3.5 Specifications for fixture(s) to hold the DUT in the test position

The device holder shall be made of low loss and low permittivity material(s):

- loss tangent $\tan\delta \leq 0{,}05$,
- relative permittivity $\varepsilon_r' \leq 5$.

The device holder shall ensure precise and repeatable positioning of the DUT. The positioning uncertainty shall be assessed according to methods of 7.2.3.4.3.

6 Protocol for SAR evaluation

6.1 Measurement preparation

6.1.1 General preparation

The dielectric properties of the tissue-equivalent liquids shall be measured within 24 h before the SAR measurements, or less frequently if the laboratory can document compliance with the recommendations of 5.2.3 using measurement intervals up to but not greater than one week. The measured conductivity and relative permittivity shall be within 10 % of the target values. The measured SAR results shall be corrected using the procedures of Annex F. If the correction ΔSAR has a negative sign, the measured SAR results shall not be corrected.

The measurement procedures for the dielectric parameters in Annex I should be used. Methods to determine the effect on the SAR due to permittivity and conductivity deviations are described in Annex F.

6.1.2 System check

A system check according to the procedures of Annex B shall be completed before performing SAR measurements for a DUT.

6.1.3 Preparation of the device under test

6.1.3.1 General

The DUT shall use its internal, integrated or connected transmitter. The antenna(s) and accessories used shall be specified in the measurement report.

The RF output power and frequency (channel) shall be controlled using an internal test program or by a wireless link to a base station or network simulator.

The DUT shall be set to transmit at its highest time-averaged RF output power level that is defined by the transmission mode and/or the operating requirements of the DUT. If this is not possible or practical, the test may be performed at any lower power level and then scaled to the highest power level numerically if the scaling factor is known and documented in the measurement report. Annex L describes an example scaling procedure.

If the normal mode of operation includes transmission in bursts without a fixed duty factor the tests shall be performed using a fixed controlled duty factor and the SAR results shall then be scaled to the maximum intended duty factor for that mode and documented in the measurement report. If the maximum intended duty factor is not well identified or if a fixed controlled duty factor is difficult to generate, then an available mode of operation shall be used and appropriate scaling shall be chosen and documented in the measurement report.

The exposure tests shall be based on the characteristics of the DUT, i.e. operating modes, operating bands, antenna configurations, etc. Where multiple operating modes are available they shall all be tested, unless some modes can clearly be shown to utilise a lower time-averaged output power than others at the same frequency. For example, if a DUT has multiple transmit slots, the mode using the highest number of slots shall be used, and the modes using fewer slots at the same frequency do not need to be tested (assuming that the time-average output power during the slot is the same for all modes). Where some modes are to be excluded from testing, there shall be a clear explanation of the relationship of the operating modes with respect to their power level, duty factor, operating frequency and antenna used, see 6.2 and Annex C for further details. Testing in idle mode is not necessary where this has a lower time-average output power than during active transmission.

In general, the DUT shall be tested using its available operational configurations as detailed in the user instructions. There shall be no cables attached to the DUT, unless the cables are necessary for the functionality in the intended operational configuration (e.g., a headset cable for hands-free use or a data cable for data transmission). Attaching cables to the DUT can alter the RF current distribution on the surface of the DUT. Cables that are not necessary for the functionality in the intended operational configuration shall be positioned perpendicular to the phantom surface so that the impact on the measured SAR is minimized. Cables that are necessary for the functionality in the intended operational configuration shall be positioned to produce conservative SAR results. The cable positioning shall be documented in the measurement report.

If an operational mode is capable of simultaneous multiple transmission (e.g., GSM and Bluetooth transmitting together), this operational mode shall also be tested (see 6.3.2 for procedures).

Where a DUT is only intended to be operated with an external power source, the manufacturer-supplied cabling should be used to connect to a suitable power source. Where a battery is the intended power source, the battery shall be fully charged before the measurements and there shall be no external power supply. A single charge of the battery may be used for a sequence of measurements as long as the drift is assessed as described in 6.1.3.2 and SAR values are corrected according to guidelines included in this document.

6.1.3.2 Multiple SAR measurements using a single charge of the battery

6.1.3.2.1 General requirements

There are three conditions which shall be met when multiple SAR measurements are made using a single charge of the battery:

a) measured SAR values shall be corrected by a factor greater than or equal to the magnitude of the drift;

NOTE No correction to a measured SAR value is to be made when the drift is upwards i.e. an apparent increase in E-field (or power); only downward drift shall be corrected.

b) the cumulative drift (i.e. the magnitude of the drift after the second, third, fourth, etc. measurement in the sequence) shall be less than or equal to ± 1,0 dB;

c) the results of measurements for which the cumulative drift is greater than 1,0 dB shall be discarded (i.e. repeated where appropriate).

The magnitude of the drift can be assessed in three different ways as detailed below.

6.1.3.2.2 Method 1 – drift assessment by measurement of the battery's discharge characteristic[3]

This method of drift assessment uses the measured discharge characteristic of the battery for the same frequency and mode of operation as used in the SAR test[4]. The discharge characteristic can be measured either as a conducted power measurement using the DUT's external RF connector (if available) or as a SAR measurement using a liquid-filled flat phantom. For both types of measurement, the power out of the DUT (set to transmit the required frequency and mode) shall be continuously monitored until the magnitude of the drift exceeds 1,0 dB (26 %).

For a conducted power measurement, a direct power reading is made. Conducted power measurements are made on the DUT at the antenna port using equipment capable of measuring RF power prior to DUT placement for SAR test. If a conducted power measurement

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[3] The method used to measure the discharge characteristic of the battery unavoidably includes variations in the SAR measurement system components.

[4] To avoid numerous repetitions of the measurement of the battery's discharge characteristic of the battery for each possible frequency and mode, a single measurement can be made using the frequency and mode with the highest time-averaged output power. This would ensure a conservative approach to drift correction.

is performed, the power shall be measured immediately before and immediately after the SAR measurement.

For a radiated E-field measurement, the single-point SAR value at a fixed reference point within the liquid-filled flat phantom is continuously measured - the result being converted to SAR after completion of the measurement. The reference point shall be chosen so that the single-point SAR value exceeds the lower detection limit of the SAR system. A secondary measurement shall be made by the system at the user defined point immediately after the SAR measurement.

The resulting curve of power or SAR reduction against time shall be used to correct for the drift in the multiple measurements. Correction shall be carried out by noting the time duration from the start of the multiple test sequence to the end of each successive test and reading the corresponding drop in power or SAR for that time period from the curve.

6.1.3.2.3 Method 2 – drift assessment by calculation of the cumulative drift

In this method, the recorded drift for each of the individual SAR measurements is added to the cumulative drift recorded for all of the preceding measurements in the sequence e.g. if, in a 3-test sequence, the initial test has a drift of 0,4 dB, the second test has 0,25 dB and the third test has 0,31 dB, then the drifts to be compensated are:

for the initial test:	0,4 dB
for the second test:	0,65 dB (i.e. 0,4 dB + 0,25 dB)
for the third test:	0,96 dB (i.e. 0,4 dB + 0,25 dB + 0,31 dB).

The magnitude of the drift for each individual SAR measurement shall be evaluated by measuring the radiated E-field strength (or single-point SAR) value at a fixed reference point inside the liquid-filled phantom, as described in 6.1.3.2.2, before and after each SAR measurement. If the radiated E-field strength method is not sensitive, as an alternative the conducted power from the external coaxial connector on the DUT shall be measured before and after each SAR measurement. If the DUT continues to transmit between the successive SAR measurements, the time delay between these separate SAR measurements should be minimised and should not exceed 5 min.

When the cumulative drift after the second, third, fourth, etc. measurement exceeds 1,0 dB, the last individual SAR measurement shall be discarded, and the SAR values of the previous measurements in the sequence shall be corrected for the relevant magnitude of drift.

6.1.3.2.4 Method 3 – Drift assessment by calculation of the cumulative drift

This method is only applicable if the DUT is not moved during the sequence of multiple tests.

This method of drift assessment is similar to that of 6.1.3.2.3, but in this case, the cumulative drift is calculated by re-setting the DUT, after each successive test, to the frequency and mode of the transmission used in the initial test and recording the conducted power level or the radiated E-field (or SAR value) relative to the level recorded before the start of the initial test.

When the cumulative drift is equal to, or exceeds 1,0 dB, the last individual SAR measurement shall be discarded, and the SAR values of the previous measurements in the sequence shall be corrected for the relevant magnitude of drift.

6.1.4 Position of the device under test in relation to the phantom

6.1.4.1 General considerations and requirements

This subclause describes positioning procedures for the following device types:

- generic device (6.1.4.3);
- body-worn device (6.1.4.4);
- device with hinged or swivel antenna (6.1.4.5);
- body-supported device (6.1.4.6);
- desktop device (6.1.4.7);
- front-of-face device (6.1.4.8);
- hand-held only device (6.1.4.9);
- limb-worn device (6.1.4.10);
- clothing-integrated device (6.1.4.11).

This subclause describes how the DUT, with or without accessories, shall be positioned, oriented and configured with respect to the phantom. The specified test position(s) is (are) applicable for device-to-phantom surface separations up to and including 200 mm.

NOTE The figures provided in this subclause are for illustration purposes only and are not to scale or representative of the required scanned area.

If the manufacturer has specified several intended device operation positions and orientations, each of these shall be tested and testing shall be limited to these positions. If no intended use positions are specified or there are no instructions, the test procedures for the generic device shall be used.

In all cases, the DUT shall be tested against a flat phantom. The DUT shall be positioned below the phantom in such a way that the peak spatial-average SAR can be measured. For larger devices or where the maximum is recorded at the edge of the scanning area, a larger phantom with dimensions that are at least 20 % larger than the projection of the DUT (including cables, if any) may be needed, or shifting of the DUT and re-measurement may be necessary so that the maximum is fully captured within the scanning area (see 6.1.4.2).

The DUT shall be oriented in accordance with the manufacturer's intended use, if specified. General guidance for the orientation of a DUT or carry accessory parallel to the flat phantom is as follows. This guidance shall be followed as long as it is consistent with the manufacturer's intended use. P1, P2, P3, and P4 are defined as the midpoint of each edge of the surface as shown in Figure 2. Line P1-P2 and Line P3-P4 shall be parallel to the phantom surface such that the distance between P1 and the phantom surface is equal to the distance between P2 and the phantom surface. Similarly, the distance between P3 and the phantom surface shall be equal to the distance between P4 and the phantom surface. The separation distance is defined as the distance between the phantom shell and the closest point of the DUT when positioned as described above. The closest point in practice could be then P1 and P2, P3 and P4, or the point defined by the separation distance between the phantom shell and the closest point of the DUT when positioned as described above.

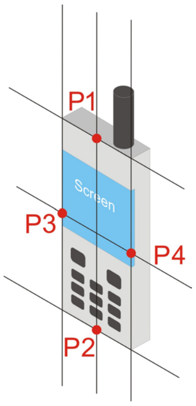


Figure 2 – Definition of reference points

6.1.4.2 Positioning for devices that are large relative to phantom surface area

If the DUT is larger than the minimum elliptical phantom defined in Figure 1 and associated text, the DUT shall be shifted such that multiple area scans can be made of the whole DUT. When the phantom is shifted over the considered surface of the DUT, the coupling between the DUT and phantom may change and will then be different from that seen with a larger phantom covering the whole DUT.

To limit differences in the measured SAR due to coupling variations, the scanned areas of the DUT of two successive tests should intersect by at least one third in the direction of the shifting as shown in Figure 3.

It should be verified that the maximum single-point SAR deviation between the two intersecting scanned areas shall be less than the expanded uncertainty for repeatability per Table 7. Otherwise, the resulting uncertainty shall be assessed and documented according to the procedures and techniques presented in Clause 7. There is no need for shifting if the radiating structures are small compared to both the DUT and the phantom and/or the first area scan shows that the SAR distribution is entirely captured within the scanning area. The motivations for omitting shifting shall be clearly stated in the measurement report.

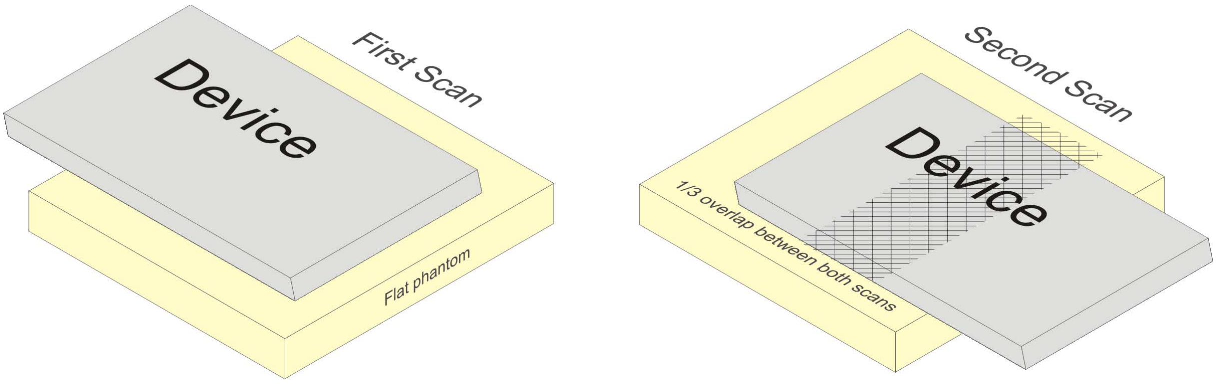


Figure 3 – Measurements by shifting of the device at the phantom

6.1.4.3 Generic device

For a device that can not be categorized as any of the other specific device types in 6.1.4.1, it shall be considered to be a generic device; i.e. represented by a closed box incorporating at least one internal RF transmitter and antenna.

The SAR evaluation shall be performed for all surfaces of the DUT that are accessible during intended use, as indicated in Figure 4. The separation distance in testing shall correspond to the intended use distance as specified in the user instructions provided by the manufacturer. If the intended use is not specified, all surfaces of the DUT shall be tested directly against the flat phantom.

The surface of the generic device (or the surface of the carry accessory holding the DUT) pointing towards the flat phantom shall be parallel to the surface of the phantom.

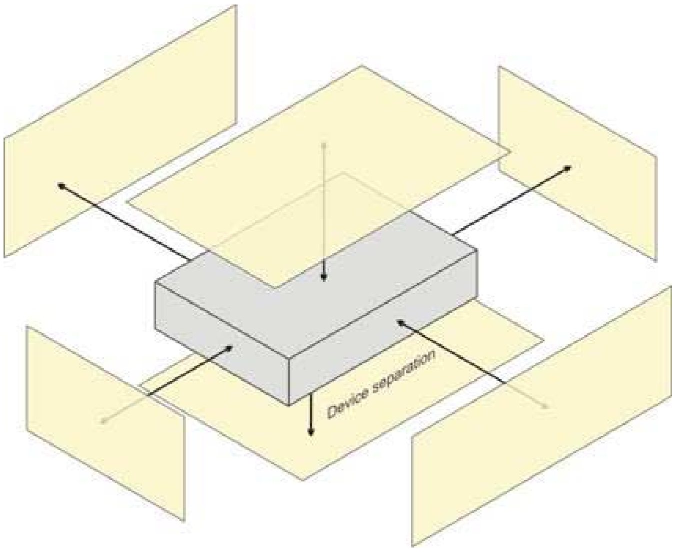


Figure 4 – Test positions for a generic device

The generic device principle may be applied to all devices. Where a transmitter is added to the host device so that the host and transmitter operate as a single device it should be addressed according to subclauses 6.1.4.4 to 6.1.4.11 as applicable. Where the antenna or the attached RF transmitter is external to the host and the positioning of the antenna or attached RF transmitter is independent of positioning of the host, e.g. transmitter is attached by a cable, it shall be assessed using the generic device procedures.

For DUTs with multiple antennas, the same principles are applicable, and all the relevant combinations of antenna positions shall be tested. Annex C provides more insight on the way to reduce the number of combinations tested.

6.1.4.4 Body-worn device

A typical example of a body-worn device is a mobile phone, wireless enabled PDA or other battery operated wireless device with the ability to transmit while mounted on a person's body using a carry accessory approved by the wireless device manufacturer.

If the user instructions provided by the manufacturer specify intended use with a carry accessory (belt-clip, holster, carry-case or similar), the device shall be placed as intended in that carry accessory and the carry accessory shall be placed in the intended orientation against the flat phantom.

For carry accessories constructed from non conductive materials that are capable of holding the DUT at varying minimum distances to the phantom, the carry accessory providing the closest separation distance is expected to produce the highest SAR; therefore, testing of the carry accessories providing larger separation distances is not necessary. For carry accessories that do not contain conductive materials (e.g. metal), it is acceptable to substitute the carry accessory with an air-gap or a spacer that keeps the DUT at a distance from the phantom surface no greater than the distance provided by the carry accessory. The spacer shall be made of a low loss and low permittivity material with a loss tangent ≤ 0,005 and relative permittivity ≤ 1,1. Accessories that do not contain RF transmitters and have been proven to increase the peak SAR by less than 5 %, such as hands-free kits, do not need SAR tests separate from the SAR tests attached to a main DUT configuration. Annex G provides other information and rationale about hands-free kit testing.

NOTE In this context, hands-free kit means only non-transmitting earpiece(s) and/or headset accessory connected to a mobile device via a cable or wire, but not devices such as a Bluetooth earpiece and/or headset, i.e. an "un-wired hands-free kit."

If the user instructions provided by the manufacturer specify an intended use with an appropriate accessory at a certain separation distance to the body, the device shall be positioned as intended at the distance to the outer surface of the phantom that corresponds to the specified distance (Figure 5). When evaluating device SAR without a specific carry accessory, the separation distance shall not exceed 25 mm. The surface of the device pointing towards the flat phantom should be parallel to the surface of the phantom. However, all devices do not have a flat surface. Therefore the details of the device position, e.g. the definition of the distance and the physical relationship between the device and the phantom (see 6.1.4.1), shall be documented in the measurement report according to the manufacturer instructions.

EXAMPLE A separation distance 15 mm is commonly used for body-worn mobile phones, to represent a spacing provided by intended accessories.

If the intended use is not specified in the user instructions, the device shall be tested with all its surfaces directly against the flat phantom. The details of the device position, especially contact points to the surface of the phantom, shall be documented in the measurement report. If testing for one or more surfaces is omitted, this shall be documented with an associated rationale in the measurement report.

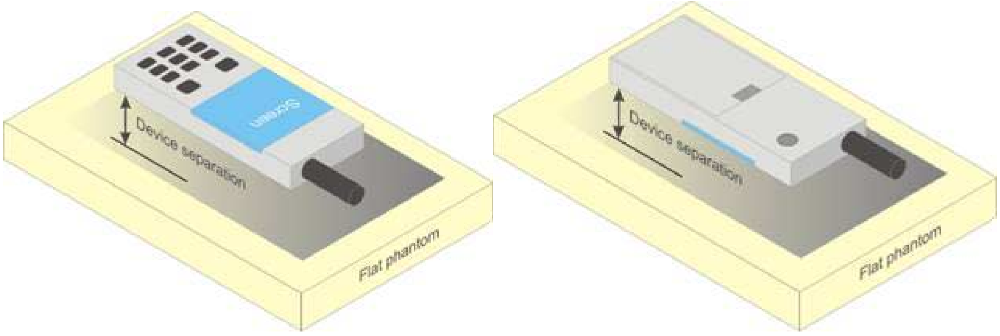


Figure 5 – Test positions for body-worn devices

6.1.4.5 Devices with hinged or swivel antenna(s)

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. For a device with only one antenna, if no intended antenna position is specified, tests shall be performed if applicable in both the horizontal and vertical positions relative to the phantom, and with the antenna oriented away from the body of the DUT (Figure 6) and/or with the antenna extended and retracted such as to obtain the highest exposure condition. For antennas that may be rotated through one or two planes, an evaluation should be made and documented in the measurement report to the highest exposure scenario and only that position(s) need(s) to be tested. For devices with multiple detachable antennas see provisions of 6.2.2.

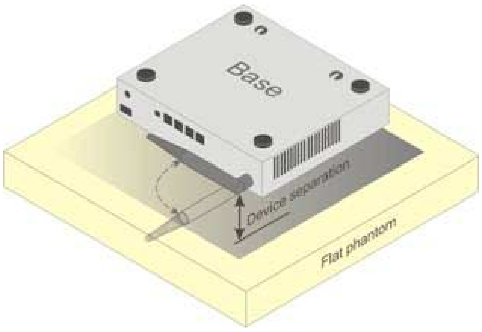


Figure 6 – Device with swivel antenna (example of desktop device)

6.1.4.6 Body-supported device

A typical example of a body supported device is a wireless enabled laptop device that among other orientations may be supported on the thighs of a sitting user. To represent this orientation, the device shall be positioned with its base against the flat phantom. Other orientations may be specified by the manufacturer in the user instructions. If the intended use is not specified, the device shall be tested directly against the flat phantom in all usable orientations.

AC1 The screen portion of the device shall be in an open position at a 90° angle as seen in Figure 7a (left side), or at an operating angle specified for intended use by the manufacturer in the operating instructions. Where a body supported device has an integral screen required for normal operation, then the screen-side will not need to be tested if the antenna(s) integrated in it ordinarily remain(s) 200 mm from the body. Where a screen mounted antenna is present, the measurement shall be performed with the screen against the flat phantom as shown in Figure 7a) (right side), if operating the screen against the body is consistent with the intended use. AC1

Other devices that fall into this category include tablet type portable computers and credit card transaction authorisation terminals, point-of-sale and/or inventory terminals. Where these devices may be torso or limb-supported, the same principles for body-supported devices are applied.

The example in Figure 7b) shows a tablet form factor portable computer for which SAR should be separately assessed with

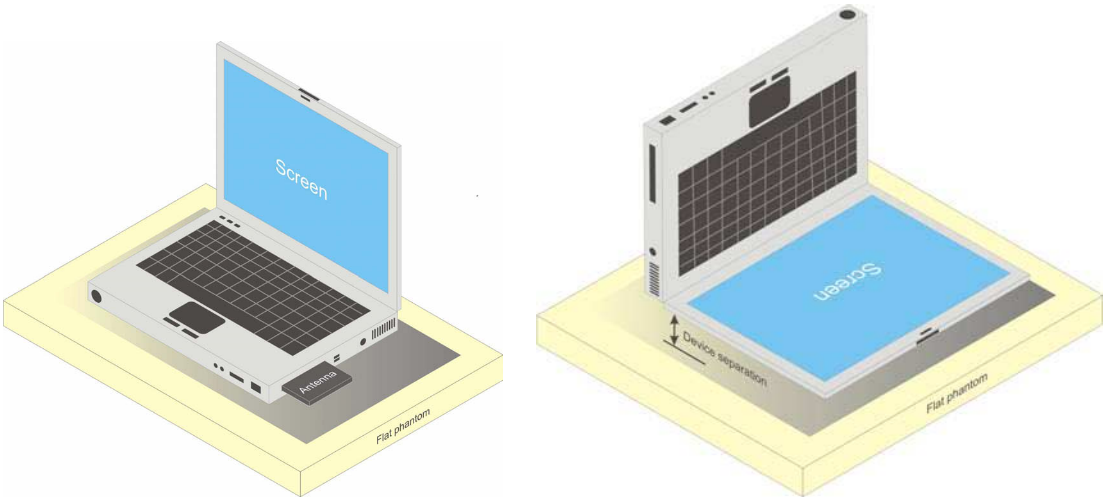
d) each surface and

e) the separation distances

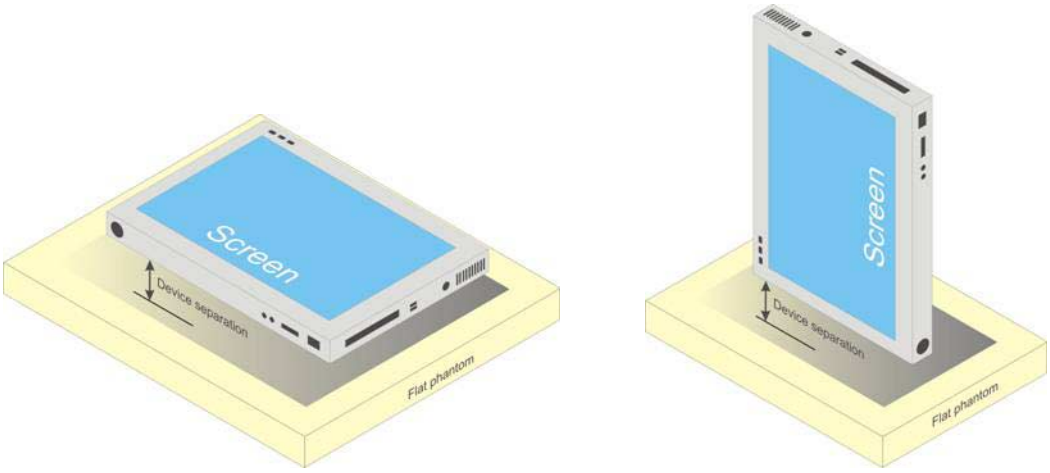
positioned against the flat phantom that correspond to the intended use as specified by the manufacturer. If the intended use is not specified in the user instructions, the device shall be tested directly against the flat phantom in all usable orientations.

Some body-supported devices may allow testing with an external power supply (e.g. a.c. adapter) supplemental to the battery, but it shall be verified and documented in the measurement report that SAR is still conservative.

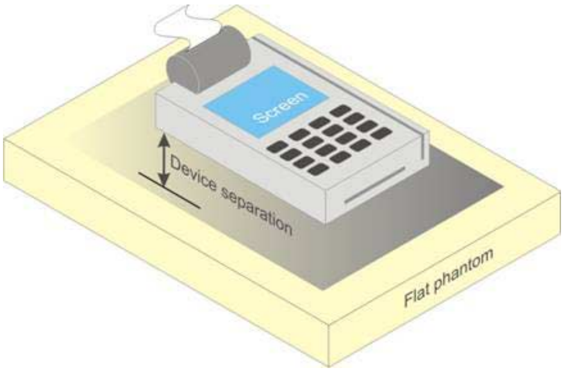
For devices that employ an external antenna with variable positions (e.g. swivel antenna), see 6.1.4.5 and Figure 6.



a) Portable computer with external antenna plug-in-radio-card (left side) or with internal antenna located in screen section (right side)



b) Tablet form factor portable computer



c) Wireless credit card transaction authorisation terminal

Figure 7 – Test positions for body supported devices

6.1.4.7 Desktop device

A typical example of a desktop device is a wireless enabled desktop computer placed on a table or desk when used.

The DUT shall be positioned at the distance and in the orientation to the phantom that corresponds to the intended use as specified by the manufacturer in the user instructions. For devices that employ an external antenna with variable positions, tests shall be performed for all antenna positions specified. Figures 6 and 8 show positions for desktop device SAR tests. If the intended use is not specified, the device shall be tested directly against the flat phantom.

Due to the physical design, some device surfaces may not be required for testing, e.g. the base of a desk standing device.

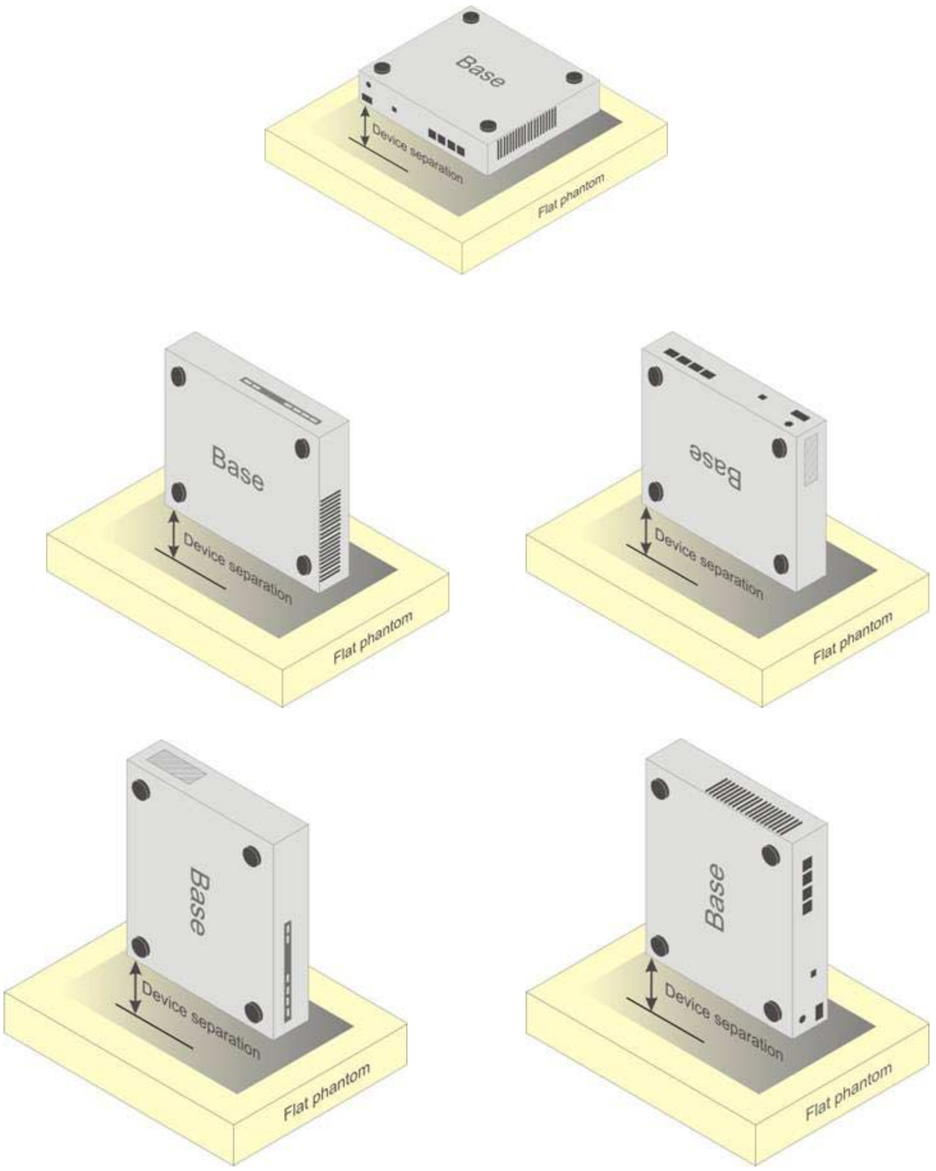
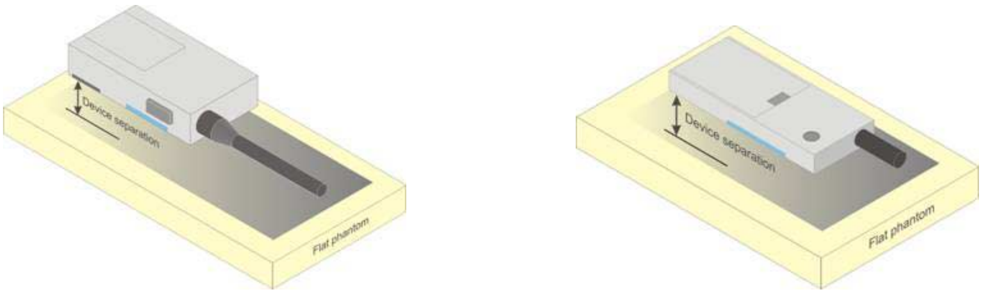


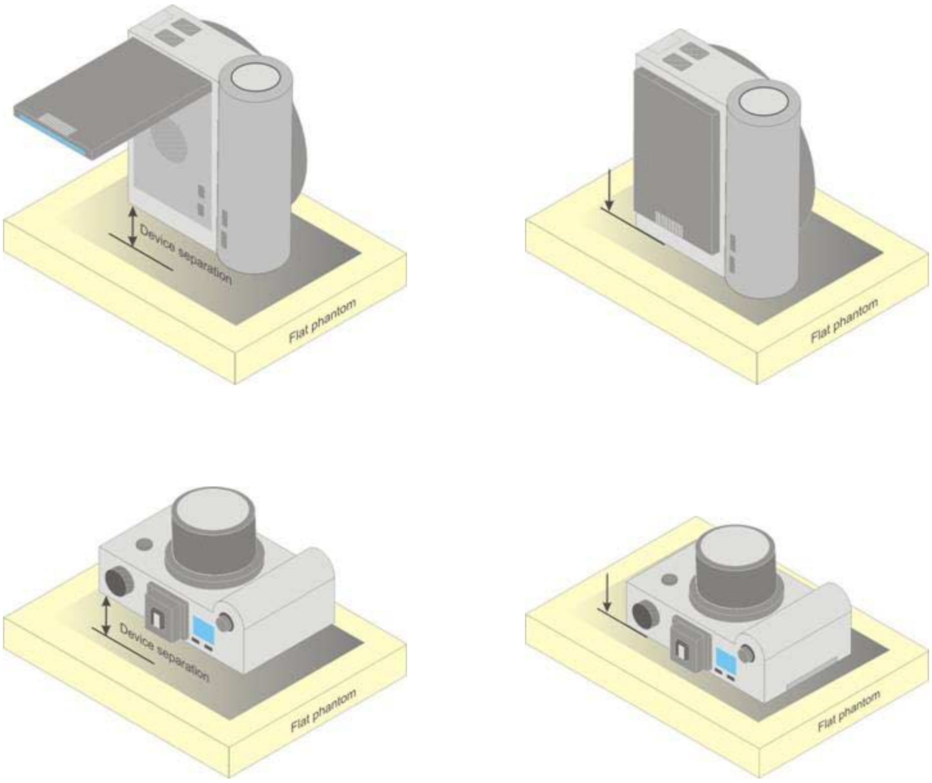
Figure 8 – Test positions for desktop devices

6.1.4.8 Front-of-face device

A typical example of a front-of-face device is a two-way radio that is held at a distance from the face of the user when transmitting. In these cases the device under test shall be positioned at the distance to the phantom surface that corresponds to the intended use as specified by the manufacturer in the user instructions (Figure 9a). If the intended use is not specified, a separation distance of 25 mm[5] between the phantom surface and the device shall be used.



a) Two-way radios



b) Still cameras and video cameras

Figure 9 – Test positions for front-of-face devices

Other devices that fall into this category include wireless-enabled still cameras and video cameras that can send data to a network or other device (Figure 9b). In the case of a device

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[5] This distance corresponds to the 95 % percentile of the nose protrusion distance obtained in the anthropomorphic survey of Gordon et al. [27].

whose intended use requires a separation distance from the user (e.g., device with a viewing screen), this shall be positioned at the distance to the phantom surface that corresponds to the intended use as specified by the manufacturer in the user instructions (Figure 9b, left side). If the intended use is not specified, a separation distance of 25 mm between the phantom surface and the device shall be used.

For a device whose intended use requires the user's face to be in contact with the device (e.g., device with an optical viewfinder), this shall be placed directly against the phantom (Figure 9b, right side).

6.1.4.9 Hand-held usage of the device, not at the head or torso

Additional studies remain needed for devising a representative method for evaluating SAR in the hand of hand-held devices. Future versions of this standard are intended to contain a test method based on scientific data and rationale. Annex J presents the currently available test procedure.

6.1.4.10 Limb-worn device

A limb-worn device is a unit whose intended use includes being strapped to the arm or leg of the user while transmitting (except in idle mode). It is similar to a body-worn device. Therefore, the test positions of 6.1.4.4 also apply. The strap shall be opened so that it is divided into two parts as shown in Figure 10. The device shall be positioned directly against the phantom surface with the strap straightened as much as possible and the back of the device towards the phantom.

If the strap cannot normally be opened to allow placing in direct contact with the phantom surface, it may be necessary to break the strap of the device but ensuring to not damage the antenna.

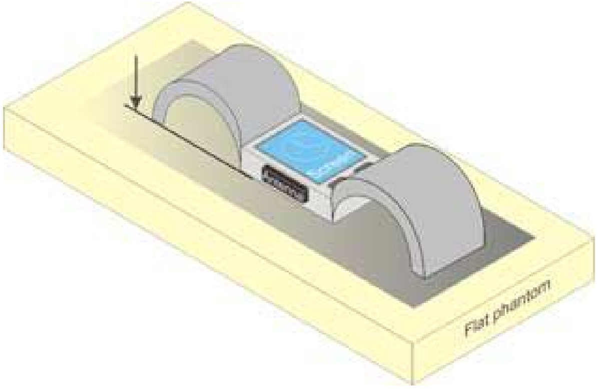

Figure 10 – Test position for limb-worn devices

6.1.4.11 Clothing-integrated device

A typical example of a clothing-integrated device is a wireless device (mobile phone) integrated into a jacket to provide voice communications through an embedded speaker and microphone. This category also includes headgear with integrated wireless devices.

All wireless or RF transmitting components shall be placed in the orientation and at the separation distance to the phantom surface that correspond to intended use of the device when it is integrated into the clothing (Figure 11).

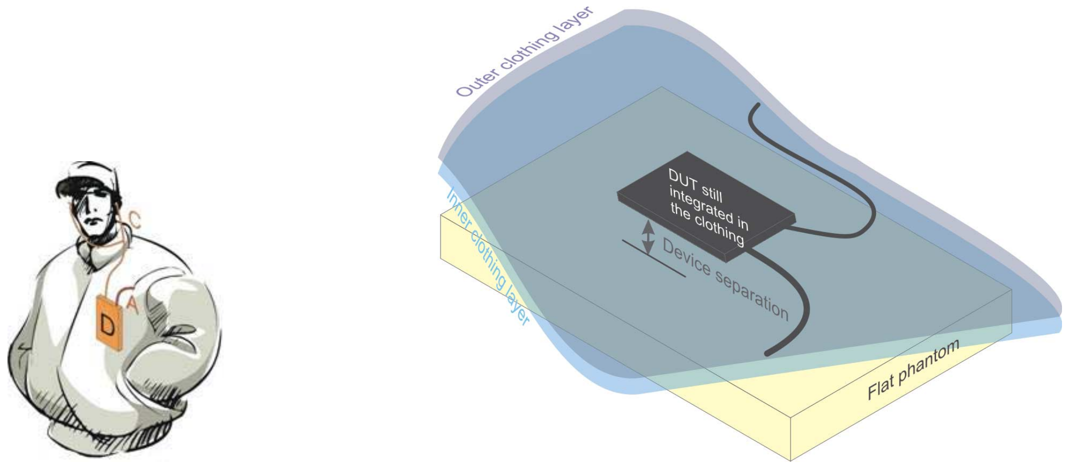

Figure 11 – Test position for clothing-integrated wireless devices

6.1.5 Test frequencies

The procedures of IEC 62209-1:2005 shall be used.

6.2 Tests to be performed

6.2.1 General requirements

The test procedure encompasses two main steps:

a) The selection of the test conditions to be measured using the test reduction techniques discussed in 6.2.2, and

b) the SAR evaluation of these test conditions using the general test procedure discussed in 6.2.3; optionally, fast SAR evaluation methods conforming to the requirements set forth in 6.2.4 may be employed.

In order to determine the highest value of the peak spatial-average SAR of a DUT according to the above steps, device positions, configurations and operational modes shall be tested for each frequency band as follows:

c) Identify all possible test conditions of the device (frequencies, frequency bands, operational modes, accessories, device positions, etc.).

d) Select test conditions to be measured applying test reduction (6.2.2) methods (optional)

    i) Exclude unnecessary test conditions based on physical rationale (6.2.2.2) or analysis of SAR data (6.2.2.3);

    ii) Perform a search (6.2.2.4) to choose the test conditions to be tested (optional).

e) Test the selected test conditions using 6.2.3.

In all cases where test reductions (6.2.2) have been exercised or applied, the relevant device-accessory combinations or device orientations that are excluded and the rationale for test reduction shall be clearly documented in the measurement report.

6.2.2 Test reductions

6.2.2.1 General requirements

In all cases where test reductions have been exercised or applied, the relevant device-accessory combinations or device orientations that are excluded and the rationale for test reductions shall be clearly documented in the measurement report. For more information on test reduction see Annex C and Annex K.

6.2.2.2 Test reductions based on physical rationale

Justification may be made to exclude SAR testing of certain device-accessory combinations if through sound scientific or engineering rationale it is shown that there is no increase in SAR with respect to a reference configuration. Two common cases where the use of physical rationale is deemed acceptable are:

- body-worn accessories that do not contain conductive materials (e.g. metal), where only the one that positions the device closer to the body is tested, and
- accessories that are similar (with identical metal content) except for the colour, which has no impact on SAR, where only one such device is tested.

6.2.2.3 Test reductions based on analysis of SAR data

Analysis of SAR data, e.g., statistical analysis based on a design of experiments (DOE) approach, may be used to develop scientific or engineering rationales for the test reduction of certain SAR tests. For example, if devices are available with optional faceplates with paint coatings of varying metal content, statistical analysis of SAR data may be used to justify excluding the testing of faceplates with less than a certain amount of metal content. Care shall be made to limit the application of the test reduction to products that are sufficiently similar to the original product for which the test reduction was determined.

6.2.2.4 Search for highest SAR test conditions

A device may operate in different transmission modes and may be usable with several antenna options, battery options and other accessories, and the number of possible combinations can be very large. Methods are therefore needed to streamline the measurement process, so that the highest SAR test conditions can be quickly identified. For example, a device with two antenna configurations (antenna extended and retracted), four battery types, four types of carry accessories and four types of audio accessories, testing all possible combinations would result in at least $2^7 = 128$ tests per frequency band and device position. It is unnecessary to test all possible combinations; statistical techniques can be used to show trends from a smaller set of data and determine which device-accessory combinations result in higher SAR values. Using a design of experiments (DOE) is the preferred statistical method of achieving this. A DOE is a structured, organized method for analyzing the influence of factors and the interactions between factors on the output of a process. The DOE approach is extensively covered in the literature [62]. Other methods of searching for high SAR test conditions are given in Annex C (C.4).

6.2.3 General test procedure

In order to determine the highest value of the peak spatial-average SAR of a handset, the applicable test conditions shall be tested for each frequency band according to steps 1 to 3 below. A flowchart of the test process is shown in Figure 12.

Step 1: The tests described in either 6.2.4 or 6.3.1 below shall be performed at the usable channel that is closest to the centre of the transmit frequency band covered by the transmitter and antenna for the device positions described in 6.1, all configurations for each device position, and all operational modes for each device position and configuration, in each frequency band.

Step 2: For the condition providing highest peak spatial-average SAR determined in Step 1, perform the tests described in 6.3.1 at all other test frequencies identified in 6.1.5. In addition, for all other conditions (device position, configuration and operational mode) where the peak spatial-average SAR value determined in Step 1 is within 3 dB of the applicable SAR compliance limit, all other test frequencies shall be tested as described in 6.3.1 as well.

Step 3: Examine all the data to determine the highest value of the peak spatial-average SAR found in Steps 1 to 2.

Step 4: For devices capable of simultaneous transmission from multiple separate antennas, apply the appropriate procedure described in 6.3.2.

6.2.4 Fast SAR evaluations

Full SAR testing (see 6.3) is not required for the purpose of identifying the highest SAR test conditions. Faster methods for determining the SAR can be used. The uncertainty of any fast SAR method shall be determined and documented following the procedures and techniques as presented in Clause 7. Several methods for fast SAR assessments are described in [47]. Annex C provides more information on fast SAR evaluations.

The uncertainty of any fast SAR method shall be determined and documented following the procedures and techniques as presented in Clause 7, as much as possible. However, Clause 7 may not be sufficient to determine the complete uncertainty budget for any fast SAR method. Indeed, some of these techniques use specific hardware and certain uncertainty contributions are hardware dependent. When a particular uncertainty contribution reported in Clause 7 is not applicable for some specific fast SAR technique, this shall be clearly justified (e. g. probe positioning uncertainty in 7.2.3.1 is irrelevant for a system using a fixed probe-array). Moreover, technology-specific uncertainty contributions shall also be assessed and reported, following explicit scientific or engineering rationales. In all cases, the configuration resulting in the highest SAR value needs to be repeated by the standardized measurement method.

In addition, all other test configurations having a SAR result higher than the applicable compliance limit reduced by the uncertainty of the faster SAR evaluation method (k = 2, see 7.1.2) need to be repeated by the standardized measurement method.

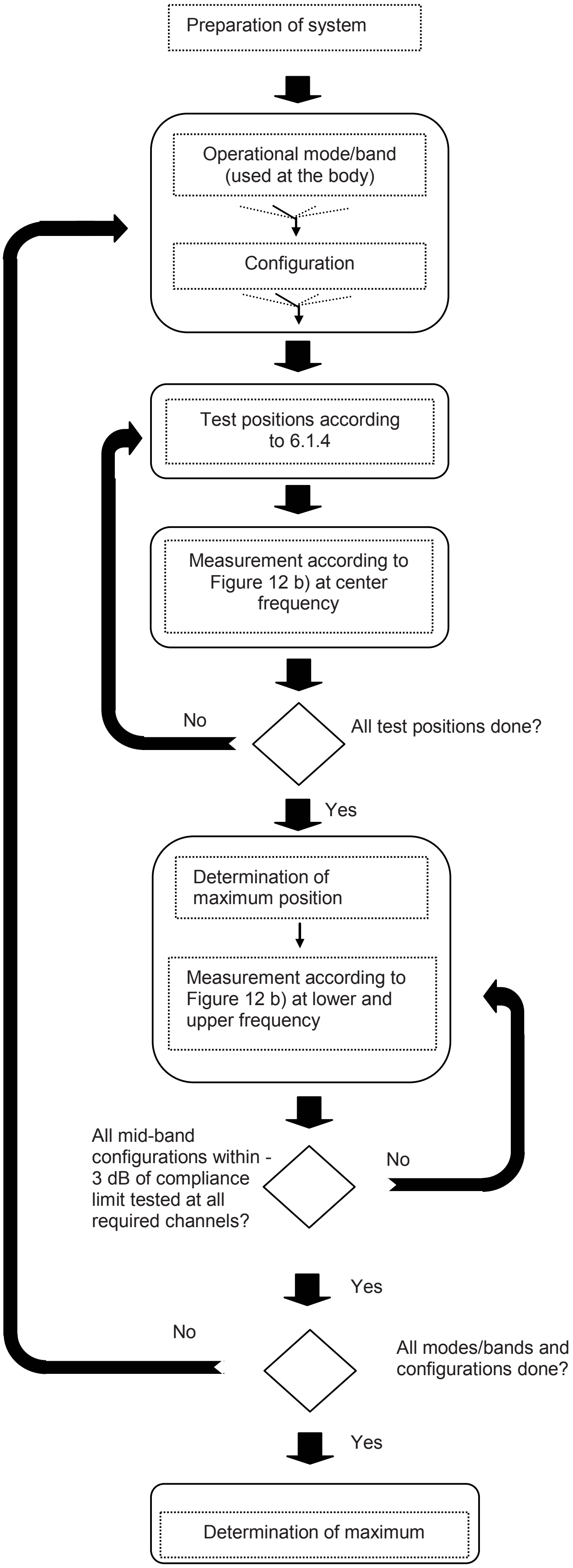

Figure 12a – Tests to be performed

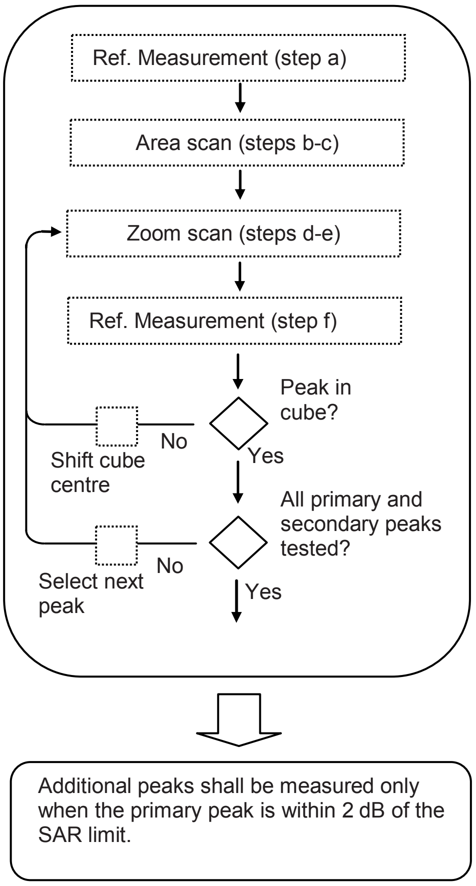

Figure 12b – General procedure

Figure 12 – Block diagram of the tests to be performed

6.3 Measurement procedure

6.3.1 General procedure

The following procedure shall be performed for each of the test conditions (see Figure 12) described in 6.2.

a) Measure the local SAR at a test point within 8 mm of the phantom inner surface that is closest to the DUT. Alternatively, measure the SAR drift as described in 7.2.2.10.

b) Measure the two-dimensional SAR distribution within the phantom (area scan procedure). The boundary of the measurement area shall not be closer than 20 mm from the phantom side walls. The distance between the measurement points should enable the detection of the location of local maximum with an accuracy of better than half the linear dimension of the tissue cube after interpolation. A maximum grid spacing of 20 mm for frequencies below 3 GHz and (60/*f* [GHz]) mm for frequencies of 3 GHz and greater is recommended. The resolution can also be tested using the functions in 7.2.5.2. The maximum distance between the geometrical centre of the probe detectors and the inner surface of the phantom shall be 5 mm for frequencies below 3 GHz and $\delta\,ln(2)/2$ mm for frequencies of 3 GHz and greater, where δ is the plane wave skin depth and $ln(x)$ is the natural logarithm. The maximum variation of the sensor-phantom surface distance shall be ± 1 mm for frequencies below 3 GHz and ± 0,5 mm for frequencies of 3 GHz and greater. At all measurement points the angle of the probe with respect to the line normal to the surface should be less than 5° (see Figure 13 and Annex M). If this cannot be achieved for a measurement distance to the phantom inner surface shorter than the probe diameter, additional uncertainty evaluation is needed.

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[6] 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* [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 below 3 GHz. For higher frequencies, the minimum zoom scan size can be reduced to 22 mm by 22 mm by 22 mm. The grid step in the vertical direction shall be (8-*f* [GHz]) mm or less but not more than 5 mm, if uniform spacing is used (Annex C.3.3 of IEC 62209-1:2005). If variable spacing is used in the vertical direction, the maximum spacing between the two closest measured points to the phantom shell shall be (12/*f* [GHz]) mm or less but not more than 4 mm, and the spacing between farther points shall increase by an incremental factor not exceeding 1,5. When variable spacing is used, extrapolation routines shall be tested 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 below 3 GHz and $\delta\,ln(2)/2$ mm for frequencies of 3 GHz and greater, where δ is the plane wave skin depth and $ln(x)$ is the natural logarithm. Separate grids shall be centred on each of the local SAR maxima found in step c). Uncertainties due to field distortion between the media boundary and the dielectric enclosure of the probe should also be minimized, which is achieved if the distance between the phantom surface and physical tip of the probe is larger than probe tip diameter. Other methods may utilize correction procedures for these boundary effects that enable high precision measurements closer than half the probe diameter [2], [66]. For all measurement points, the angle of the probe with respect to the flat phantom surface shall be less than 5º. If this can not be achieved an additional uncertainty evaluation is needed following 7.2.2.6.

e) Use post processing (e.g. interpolation and extrapolation) procedures defined in 6.4 to determine the local SAR values at the spatial resolution needed for mass averaging.

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[6] This limit is given by the required minimum spacing between the measurement points and the uncertainty of the interpolation schemes.

f) The local SAR should be measured at the same location as in Step a). SAR drift is assessed and reported in the uncertainty budget (Table 5) as described in 7.2.2.10.

   In the event that the evaluation of measurement drift exceeds the 5 % tolerance, it is required that SAR be reassessed following guidelines contained within this standard.

   If the drift is larger than 5 %, then the measurement drift shall be considered a bias, not an uncertainty. A correction shall be applied to the measured SAR value. It is not necessary to record the drift in the uncertainty budget (i.e. u_i = 0 %). The uncertainty budget reported in a measurement report should correspond to the highest SAR value reported (after correction, if applicable). Alternatively, the uncertainty budget reported should cover all measurements, i.e., it should report a conservative value.

   Alternatively, measure the SAR drift again as described in 7.2.2.10.

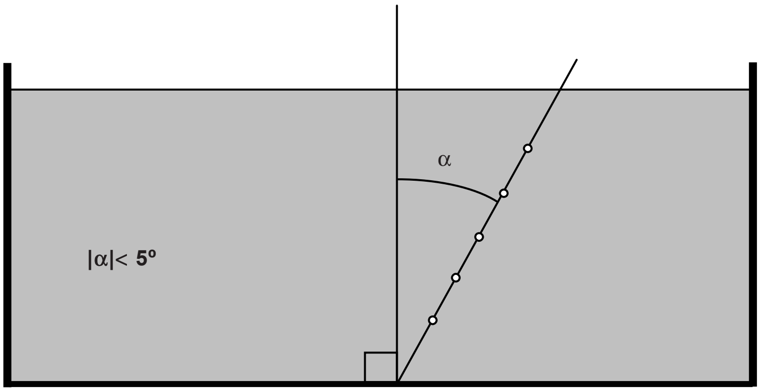


Figure 13 – Orientation of the probe with respect to the normal of the phantom surface

6.3.2 Procedures for testing of DUTs with simultaneous multi-band transmission

6.3.2.1 General requirements

The following procedures are applicable to devices incorporating multiple transmission modes that are intended to operate simultaneously at 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 can not normally be assessed simultaneously using the same probe and liquid). The valid frequency range of probe calibration (5.3.4) is typically narrow (e.g., ± 50 MHz) for electric field probes in most systems currently in use. Also, since electric field probes used in present systems typically have a d.c. 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 5.2). Due to these limitations, the multiple transmission modes must first be assessed separately, then combined arithmetically.

Some secondary transmitters (i.e. lower power transmitters) can be eliminated from evaluation if their power levels fall below a threshold level. Annex K details procedures for establishing these threshold levels, dependent on frequency and separation distance.

Subclauses 6.3.2.2 to 6.3.2.5 describe alternative evaluation procedures. The following prerequisites apply for the alternative methods:

a) The area scan, zoom scan and peak spatial-average SAR are evaluated separately at each frequency (as per 6.3.1) with the transmission mode at that frequency turned on and the modes at the other frequencies turned off.

b) The SAR data are combined for each test condition (device position, channel, configuration and accessory) where two or more modes are intended to operate simultaneously (as per 6.2).

The alternatives are summarized as follows:

1) summation of peak spatial-averaged SAR values – simplest but most conservative method to find upper bound (6.3.2.2);
2) selection of highest assessed maximum SAR values – accurate estimate when separate maxima are far apart and do not effect each other by more than 5 % (6.3.2.3);
3) calculation of multi-band SAR from existing area and zoom scans – accurate and fast method, always applicable (6.3.2.4);
4) volumetric scanning – most accurate, always applicable (6.3.2.5).

Alternative (1), being the most conservative, is identified as the reference method. The DUT is deemed to fully comply with the requirements of this standard if it meets the requirements when using one of these alternative evaluation procedures.

6.3.2.2 Alternative 1: Evaluation by summation of peak spatial-averaged SAR values

This procedure gives the easiest and most conservative method to determine the upper limit of the multi-band SAR. Note that the peak-spatial averaged SAR values for different modes may be at different spatial locations. This method will overestimate the multi-band SAR in this case.

1) For each test condition where simultaneous operation is intended, add the peak spatial-average SAR values at each frequency, f_1, f_2, etc (see Note below).
2) If the maximum summed SAR value is within -3 dB of the compliance limit, additional measurements at lower and upper frequencies shall be conducted for this test condition. These additional values shall be used to determine the maximum SAR.
3) The maximum summed SAR value in step 1 or 2 is the multi-band SAR.

NOTE An acceptable variation of step 1 is to add the highest peak spatial-average SAR values regardless of test condition. In other words, add the highest peak spatial-average SAR at the frequency f_1 (among all test conditions at that frequency) to the highest peak spatial-average SAR value at the frequency f_2 (among all test conditions), and so on for any other frequencies. Steps 2 and 3 must still be followed using this method. This method is more conservative than the method of step 1.

6.3.2.3 Alternative 2: Evaluation by selection of highest assessed maximum SAR values

This procedure gives an accurate estimate of the multi-band SAR when the separately measured SAR zoom scan distributions have little or no overlap. The maxima are then separated to such extent that they differ in level by less than 5 % from the resulting maximum peak SAR value if the SAR distributions are added spatially.

1) Measure the maximum mass-averaged SAR at each frequency separately according to 6.3.1.
2) For all identical test conditions, analyse to what extent the SAR distributions overlap by adding the area scans spatially, i.e. point-by-point.
3) If the resulting maximum peak SAR value of the added distribution is less than 5 % from the highest of the separate maximum peak SAR values, then the multi-band SAR is equal to the higher of the two separate mass-averaged SAR values.

6.3.2.4 Alternative 3: Evaluation by calculated volumetric SAR data

This procedure uses existing area and zoom scans in combination with interpolation and extrapolation for generation of volumetric SAR data and is a rapid way of obtaining the multi-band SAR. It is always applicable.

1) At each frequency, calculate the volumetric SAR distribution over the region projected by the area scan. Different algorithms to accomplish this have been presented (e.g., [4], [9], [43], [54], [55], [56], [57]). The uncertainty of the method used must be well documented and shall be recorded.
2) Add the volumetric SAR distributions of all frequencies spatially, using interpolation according to 6.4.1 if necessary.
3) Use post processing procedures defined in 6.4 to determine the peak spatial-average SAR from the SAR distribution of step 2.

6.3.2.5 Alternative 4: Evaluation by volumetric scanning

This procedure is the most accurate way of assessing the multi-band SAR and is always applicable. As stated above, the SAR data are combined for each test condition (device position, channel, configuration and accessory) where two or more modes are intended to operate simultaneously (as per 6.2).

1) Determine a volumetric grid that encompasses the zoom scans at all frequencies f_1, f_2, etc. measured previously (see Note).
2) At each frequency, measure the volumetric zoom scan found in step 1. This zoom scan measurement adheres to all of the requirements of 6.3.1 except for the size of the volume. The measurement is conducted with the transmission mode at that frequency turned on and the modes at the other frequencies turned off.
3) Add the SAR distributions obtained in step 2 spatially to obtain a summed SAR distribution. Calculate the maximum multi-band SAR from the summed distribution, using the post-processing procedures defined in 6.4 to determine the peak spatial-averaged 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. It is suggested that if the battery of the device needs to be recharged, the charger cable is attached to the DUT when it remains positioned on the phantom.

NOTE The encompassing volume in step 1 can be large (e.g., if the zoom scans at frequencies f_1, f_2, etc. are far apart), resulting in long measurement times in step 2. An acceptable variation of step 1 is to choose zoom scan volumes for each frequency that correspond to the previously-measured zoom scans at the other frequencies. For step 2, this will result in SAR measurements at frequency f_1 using separate zoom scans from frequencies f_2, f_3, etc., then SAR measurements at frequency f_2 using the zoom scans from frequencies f_1, f_3, etc., and so on.

6.4 Post-processing

6.4.1 Interpolation

If the measurement grid is not as fine as required to compute the averaged SAR over a given mass, interpolation shall be carried out between the measurement points. Examples of interpolation schemes are given in Annex C of IEC 62209-1:2005 and uncertainty is evaluated according to Clause 7.

6.4.2 Probe offset extrapolation

The electric field probes used generally contain three orthogonal dipoles in close proximity and these dipoles are embedded in a protective tube. The measurement 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. Examples of extrapolation schemes are given in Annex C of IEC 62209-1:2005 and uncertainty is evaluated according to Clause 7.

6.4.3 Definition of averaging volume

The averaging volume shall be in the shape of a cube and the side dimension of a 1 g or 10 g mass. A density of 1 000 kg/m^3 shall be used to represent the body tissue density (do not use the phantom liquid density), in order to be consistent with the definition of the liquid dielectric properties, i.e. the side length of the 1 g cube shall be 10 mm, the side length of the 10 g cube 21,5 mm.

When filled with liquid the outer bottom surface of the phantom may deviate from an ideal plane surface. Schemes for averaging over a cubic volume with regard to a curved shell are given in Annex C of IEC 62209-1:2005.

6.4.4 Searching for the maxima

The cubic volumes shall be moved on the inner surface of the phantom, in the vicinity of the local maximum SAR, using the rules given in Annex C of IEC 62209-1:2005. The cube with the highest local maximum SAR shall not be at the edge of the scanning volume. If this is found to be the case, the scanning volume shall be shifted and the measurements shall be repeated.

7 Uncertainty estimation

7.1 General considerations

7.1.1 Concept of uncertainty estimation

The concept of uncertainty estimation in the measurement of the SAR values produced by wireless devices is based on the general rules provided by the ISO/IEC Guide 98-3:2008. Nevertheless, uncertainty estimation for complex measurements remains a difficult task and requires high-level and specialized engineering knowledge. In order to facilitate this task, guidelines and approximation formulas are provided in this clause, enabling the estimation of each individual uncertainty component. The uncertainty templates in Table 5, Table 6, and Table 7 are intended to address generic system uncertainty covering the entire frequency range of 30 MHz to 6 GHz and for any device under test. However, actual uncertainty component values and quantities generally will not remain the same throughout the frequency range of 30 MHz to 6 GHz, and uncertainties for partial frequency ranges must necessarily be adjusted accordingly. Use of standard template and standard uncertainty component values has the disadvantage that uncertainty may be overestimated in some cases, but advantages include usage of approximations and formulae as provided in this clause.

Manufacturers of SAR measurement systems shall specify the operational frequency of coverage in which the system has been designed to measure e.g., 450 MHz to 1 900 MHz. This will make it easier to determine variables to the quantities used within Table 5 which shall be updated with regards to fixed values for specific frequencies e.g., probe isotropy, boundary effect, probe positioner etc. In the event that measurements extend beyond the frequency scope as specified by a system manufacturer the onus will be on the user to determine quantities and the influence associated with uncertainty, and update the table accordingly. Where a series of values have been used to cover a broad frequency range (3 GHz to 6 GHz), additional documentation may be required detailing the estimation of each quantity, influence and methodology. Where a system employs a value of zero for a fixed quantity within the uncertainty table, strong technical justification shall be provided by either the system manufacturer or user.

7.1.2 Type A and type B evaluations

Both type A and type B evaluations of the standard uncertainty shall be used. When a Type A analysis is performed, the standard uncertainty u_i shall be derived using the estimated standard deviation from statistical observations. When a type B analysis is performed, u_i comes from the upper a_+ and lower a_- limits of the quantity in question, depending on the probability distribution function defining $a = (a_+ - a_-)/2$, then:

- rectangular distribution: $u_i = a/\sqrt{3}$
- triangular distribution: $u_i = a/\sqrt{6}$

- normal distribution: $u_i = a/k$
- U-shaped (asymmetric) distribution: $u_i = a/\sqrt{2}$

where

a is the half-length of the interval set by limits of the influence quantity;

k is a coverage factor;

u_i is the standard uncertainty.

For n repeat measurements of the same specific device or quantity in the same test set-up, the standard deviation of the mean (= $s/\sqrt{n}$) can be used for the standard uncertainty, where s is the standard deviation obtained from a larger set of previous readings for the same test conditions. Predetermined standard deviations based on a larger number of repeat tests can be used to estimate uncertainty components in cases where the system, method, configuration and conditions, etc., are representative of the specific device test. Predetermination does not include the contributions of the particular DUT. For a specific device, the value of n used for the standard deviation of the mean is the number of tests with the specific device, not the tests used in the predetermination.

7.1.3 Degrees of freedom and coverage factor

When the degrees of freedom are less than 30, a coverage factor of two is not the appropriate multiplier to be used to achieve a 95 % confidence level. A simple but only approximately correct method is to use t in place of the coverage factor k, where t is the Student's-t factor. Standard deviations of t-distributions are narrower than normal (Gaussian) distributions, but the curves approach the Gaussian shape for large numbers of degrees of freedom. The degrees of freedom for most standard uncertainties based on type B evaluations can be assumed to be infinite. Then the effective degrees of freedom of the combined standard uncertainty, u_c, will most strongly depend on the degrees of freedom of the type A contributions and their magnitude relative to the type B contributions.

The coverage factor (k_p) for small sample populations should be determined as

$$k_p = t_p(\nu_{eff}),$$

where

k_p is the coverage factor for a given probability;

$t_p(\nu_{eff})$ is the t-distribution;

ν_{eff} is the effective degrees of freedom estimated using the Welch-Satterthwaite formula: $\nu_{eff} = \dfrac{u_c^4}{\sum_{i=1}^{m} \dfrac{c_i^4 u_i^4}{\nu_i}}$.

The subscript p refers to the approximate confidence level, e.g., 95 %. Tabulated values of $t_p(\nu_{eff})$ are available, for example in [61].

EXAMPLE Assume that the combined standard uncertainty calculated from all the influence quantities in Table 5 with an assumed positioning uncertainty of 7 % is u_c = 14,5 %. Assume also that the number of samples or tests is equal to 5, so ν_i = 4 (number of samples or tests equal to 5), and the degrees of freedom for all of the other components are $\nu_i = \infty$. From the equation $\nu_{eff} = \dfrac{u_c^4}{\sum_{i=1}^{m} \dfrac{c_i^4 u_i^4}{\nu_i}}$, the effective degrees of freedom for the combined standard uncertainty is ν_{eff} = 74, so k = 2 does apply in this case, and the expanded uncertainty is U = 29 %. If the standard uncertainty for positioning variations goes to 9 % and the number of tests is reduced to 4 (ν_i = 3), then u_c = 15,6 %, ν_{eff} = 27, $k = k_p = k_{95} = t = t_{95}$ = 2,11, and the expanded uncertainty becomes U = 2,11 × 15,6 = 32,9 %.

7.2 Components contributing to uncertainty

7.2.1 General

Each component contributing to uncertainty that is frequency-dependent shall be evaluated in the frequency band where SAR assessment is performed. For frequency spread operational modes, the uncertainty contribution is the highest value found within the considered bandwidth.

7.2.2 Contribution of the measurement system (probe and associated electronics)

7.2.2.1 Probe calibration uncertainty

The calibration uncertainty of an E-field probe is estimated with the procedures described in Annex B of IEC 62209-1:2005 for temperature and waveguide calibration techniques. The uncertainty in the sensitivity shall be estimated assuming a normal probability distribution.

7.2.2.2 Probe isotropy uncertainty

E-field probe isotropy is a measure of the deviation in probe response to arbitrary field polarization. In general, fields emitted by a DUT are of arbitrary polarization. However, the fields induced in the tissue-equivalent liquid have a predominant polarization component parallel to the surface, due to the physics of the absorption mechanism [74]. When the probe orientation is essentially normal to the phantom surface during the measurement (within ± 5°), the isotropy uncertainty is calculated as:

$$\mathrm{SAR}_{\mathrm{uncertainty}}[\%] = \sqrt{0{,}5 \times \mathit{dev\_isotropy}_{\mathrm{axial}}\,[\%]^2 + 0{,}5 \times \mathit{dev\_isotropy}_{\mathrm{hemispherical}}\,[\%]^2}$$

where

$\mathit{dev\_isotropy}_{\mathrm{hemispherical}}$ [%]	is the maximum deviation (%) from the isotropic response assessed for Φ: ± 180°, $\theta > \pm 60°$;
$\mathit{dev\_isotropy}_{\mathrm{axial}}$ *[%]*	is the maximum deviation (%) from the isotropic response assessed for Φ: ± 180°, $\theta = 0°$;

Φ is the rotation around probe axis;

θ is the rotation around the normal of the probe axis.

The uncertainty posed by the isotropy deviation can be rather high and depends on manufacturing details, i.e. it needs to be assessed for each probe individually.

This deviation is assessed with the method described in Annex B of IEC 62209-1:2005.

A rectangular probability distribution has been assumed for probe isotropy uncertainty in Table 5.

7.2.2.3 Probe linearity uncertainty

Diode detectors are generally non-linear with amplitude and non-symmetric with respect to the response to time-varying fields, i.e. its response is non-linear with respect to field strength and modulation. The uncertainty with respect to true mean power detector needs to be determined by the procedure described in the following:

The setup can be equivalent with one described in IEC 62209-1:2005, Annex B. Since the effects are only functions of the sensor element (diode, sensor, line) and not functions of the surrounding media, the deviation from mean power response can be determined in any medium including air.

An uncertainty factor shall be assessed for CW signals. Uncertainty shall also be assessed for pulsed signals at 10 % duty factor and 11 Hz pulse repetition rate, and 4 % duty factor with a repetition rate of 1 000 Hz at the lowest and highest applicable frequency used in TDMA systems.

For modulations other than CW (including CDMA) and TDMA, the deviation from linearity shall be assessed separately.

E-field sensor linearity uncertainty is assessed using the procedures described in Annex B of IEC 62209-1:2005 according to the square of the measured E-field strength magnitude. The maximum deviation from the mean power response is assessed for the equivalent mean power SAR range from 0,01 W/kg to 100 W/kg in steps of 3 dB or less. The range is expected to occur in the cubical volume for testing compliance in the range of 0,4 W/kg to 10 W/kg.

$$\mathrm{SAR}_{\mathrm{uncertainty}}[\%]=\left|100\left(\frac{\mathrm{SAR}_{\mathrm{eval}}}{\mathrm{SAR}_{\mathrm{ref}}}-1\right)\right|_{\max} \text{ for } 0{,}01\,\frac{\mathrm{W}}{\mathrm{kg}}\leq \mathrm{SAR}_{\mathrm{ref}}^{\mathrm{rms}}\leq 100\,\frac{\mathrm{W}}{\mathrm{kg}}\,;\text{modulation}(\text{CW, pulsed, system modulation})$$

where

$\mathrm{SAR}_{\mathrm{eval}}$	is the measured SAR value;
$\mathrm{SAR}_{\mathrm{ref}}$	is the reference SAR value as determined by average power meters.

The uncertainty posed by the non-linear response can be rather high and depends on the various probe components, i.e. it needs to be determined for each probe individually. If the uncertainty has not been established for the particular probe an uncertainty of 200 % shall be used. A rectangular probability distribution has been assumed for probe linearity uncertainty in Table 5.

7.2.2.4 Probe modulation response uncertainty

The response to modulated signals of probes based on diode-detectors can be complex since the diodes are greatly non-linear elements. The diode response theories were reported in [40] and [50]. The linearization parameters for a particular modulation can be determined by two methods: 1) numerically determined based on the modulation envelope and the electrical characteristics of the diode and the other sensor elements (must be determined experimentally) or 2) by relative experimental calibration, i.e., power-sweep at that particular modulation. These parameters must be determined for each sensor separately. For constant envelope pulsed signals (GSM, GMSK, Bluetooth, DECT), the parameters of the compensation function are reduced to one parameter for some probes, namely the crest factor.

The uncertainty can be determined by using any source (e.g., waveguide or dipole) with a setup equal to or equivalent to the setup described in Figure B.1. The signal generation setup shall simulate the modulation for which the uncertainty is determined according to the specification of the communication system standard. The power should be increased for probe sensor voltage equivalent to smaller than 100 mW/kg to the equivalent of larger than 10 W/kg for the investigated sensor in 5 dB steps. At each power level, the SAR should be measured with the modulated signal and with CW at the same mean power (verification that the power meter is a true mean power detector and the amplifier is sufficient linear for the entire dynamic of the signal is required). This procedure must be repeated for each field sensor.

The equation below can be used to derive the modulation uncertainty for the particular modulation X.

$$\text{SAR\_mod } X_{\text{uncertainty}}[\%] = \underset{i=\{x,y,z\}}{\text{MAX}} \left(\underset{P_i = P_0}{\overset{P_0 + 20\text{ dB}}{\text{MAX}}} \left(100 \times \left| \frac{\text{SAR}\,(P_i)_{\text{mod}\,X_i}}{\text{SAR}\,(P_i)_{CW_i}} - 1 \right| \right) \right)$$

where

SAR_mod $X_{\text{uncertainty}}$	is the uncertainty for the particular modulation X in percent;
SAR$(P_i)_{\text{mod } X\text{i}}$	is the SAR measured with the modulated signal at a mean power;
SAR$(P_i)_{\text{Cw}i}$	is the SAR measured with CW at the same mean power.

The SAR uncertainty is determined as the maximum of all SAR_mod*X* at each step for all three sensors. A rectangular probability distribution has been assumed for probe modulation response uncertainty in Table 5.

7.2.2.5 Probe sensitivity and detection limits

Field-probe sensitivity and system detection limit uncertainties may arise when the measured field strength is too close to the detection limit of the probe and associated system instrumentation. The setup to be used is described in IEC 62209-1:2005, Annex B. This uncertainty should be assessed with a CW signal and a pulsed signal corresponding to the minimum duty factor allowed or specified for the SAR test system. The CW and pulsed signals should produce approximately 0,1 W/kg, 2,0 W/kg, and 10,0 W/kg of time-averaged SAR for this evaluation. For example, at 10 % duty factor 10 W/kg would correspond to the maximum peak SAR of 100 W/kg specified by the protocols in this standard. The SAR level of 0,1 W/kg is chosen to provide a sufficient signal-to-noise ratio for this evaluation, which corresponds to 1,0 W/kg at 10 % duty factor. This level is also chosen because SAR levels less than 0,1 W/kg typically have negligible contribution to the peak spatial-average SAR. This range of SAR levels should cover the peak-to-average power ratio and signalling requirements of the typical DUTs operating in FDMA, TDMA, and CDMA modes. For devices that operate at less than 10 % duty factors, such as the DECT system, the evaluation shall be modified accordingly to cover that operating range. The uncertainty due to detection limits shall be evaluated assuming it has a rectangular probability distribution.

7.2.2.6 Boundary effect uncertainty

In some cases, the probe may need to be used to measure closer than the radius r_p of the probe tip, in order to reduce interpolation and extrapolation uncertainties. Then boundary effect uncertainty should be assessed preferably using the waveguide system described in IEC 62209-1:2005, Annex B. Alternatively, the temperature method could be used. The method below is valid assuming the angle between the probe axis and the surface normal line is smaller than 5°. Since the boundary effect is a characteristic of a specific probe, it should be determined during the probe calibration (i.e. according to r_p value of the probe). If algorithms are applied to compensate for the boundary effect, then the SAR uncertainty should be determined with the same evaluation hardware and software as is used for performing the SAR measurements. The boundary effect uncertainty can be estimated according to the following uncertainty approximation formula based on linear and exponential extrapolations between the surface and $d_\text{be} + d_\text{step}$ along lines that are approximately normal to the surface:

$$\text{SAR}_{\text{uncertainty}}[\%] = \Delta\text{SAR}_{\text{be}}[\%]\,\frac{\left(d_{\text{be}} + d_{\text{step}}\right)^2}{2d_{\text{step}}}\,\frac{\left(\mathrm{e}^{-d_{\text{be}}/(\delta/2)}\right)}{\delta/2}$$

for (d_be + d_step) < 10 mm and $f \leq 3$ GHz

$$\text{SAR}_{\text{uncertainty}}[\%] = \Delta\text{SAR}_{\text{be}}[\%]\,\frac{\delta}{\delta - d_{\text{be}}} \qquad \text{for } d_{\text{be}} < \delta \text{ and } f > 3\text{ GHz}$$

where

$\mathrm{SAR}_{\mathrm{uncertainty}}$	is the uncertainty in percent of the probe boundary effect;
d_{be}	is the distance between the surface and the closest measurement point used in the averaging process in millimetres;
d_{step}	is the separation distance between first and second measurement points from the surface, in millimetres, provided that boundary effect uncertainties at the second measurement point are negligible;
δ	is the minimum penetration depth in millimetres of the tissue-equivalent liquids (see Table 1), i.e. δ = 6 mm at 6 GHz;
ΔSAR_{be}	is the deviation between the measured SAR value at the distance $\mathrm{dB_e}$ from the boundary and the waveguide analytical value or value assessed by temperature probe $\mathrm{SAR}_{\mathrm{ref}}$.

If the probe diameter exceeds one third of the wavelength (in the medium), the boundary effect is large (>> 1 dB) and accurate measurements are difficult to obtain. The condition that the boundary effect is negligible at the second measurement point might be violated as well. In these cases, a default uncertainty for the boundary effect of 50 % shall be used (Annex M).

In case the angle between probe axis and normal vector of the surface is larger than 5°, $\Delta\mathrm{SAR}_{\mathrm{be}}$ shall be assessed by the following steps using the setup defined in B.3 for the test frequency:

Step 1: Perform an area scan and move to the interpolated maximum (all measurements in steps 2 to 8 are taken on a line normal to the surface that includes this interpolated maximum).

Step 2: Perform a z-scan in which all points correspond to the grid points in the z-direction of the volume scan. These values will represent the reference values. The reference values shall be compared to the numerical values and shall be documented and not deviate more than the uncertainty for the system validation.

Step 3: Rotate the inclination of the probe angle by 10° (the maximum angle of 5° plus 5°).

Step 4: Rotate the axial rotation to 0°.

Step 5: Perform a z-scan and assess the deviation in comparison to the reference values for the first measurement point.

Step 6: Rotate the probe around the axis in 15° steps until the rotation is less than 360° and repeat steps 4 to 6.

Step 7: Rotate the inclination of the probe angle by 5° until the rotation is less than the maximum inclination achieved during the measurements and repeat steps 4 to 7.

Step 8: Report all values. The maximum deviation recorded in Step 5 is the maximum boundary uncertainty $\Delta\mathrm{SAR}_{\mathrm{be}}$ to be used in the above equations.

A rectangular probability distribution has been assumed for the boundary effect uncertainty in Table 5.

7.2.2.7 Uncertainty of readout electronics

The uncertainty components of the field probe readout electronics include amplification, linearity, loading of the probe and evaluation algorithm uncertainties, etc. The expected ranges of these uncertainty components can be generally assessed by using simulated terminations in place of the field probes and the use of manufacturer specifications for the electronic components. The root sum squared value of the uncertainty components shall then be used to get the overall readout electronics uncertainty. A normal probability distribution has been assumed for the readout electronics uncertainty in Table 5.

7.2.2.8 Response time

The probe shall be exposed to a well-defined electric field producing at least 2 W/kg near the surface of phantom and the tissue-equivalent liquid. The signal response time is evaluated as the time required by the measurement equipment (probe and readout electronics) to reach 90 % of the expected final value after a step variation or switch on/off of the power source. The SAR uncertainty resulting from this response time may be neglected if the probe is spatially stationary for a period of time greater than twice the response time before a SAR value is measured. In this case, enter a zero in column *c* of Table 5. If the probe is not spatially stationary for twice the response time or more, enter the actual uncertainty of the response time in column *c* of Table 5. A rectangular probability distribution has been assumed for the response time uncertainty in Table 5.

7.2.2.9 Integration time

Probe integration-time uncertainties may arise when test devices do not emit a continuous signal, such as the digital modulations used in some DUTs. When the integration time and discrete sampling intervals used in the probe electronics are not synchronized with the modulation characteristics of the measured signal, the RF energy at each measurement location may not be fully or correctly captured. This uncertainty shall be evaluated according to the signal characteristics of the test device prior to the SAR measurement.

For signals with amplitude or pulse modulation components and a periodicity greater than 1 % of the probe integration time, additional SAR uncertainties shall be considered when the probe integration time is not an exact multiple of the longest periodicity *T*. The uncertainty should be assessed according to the maximum uncertainty expected for unsynchronized probe integration time with an assumed rectangular probability distribution. For a signal with an envelope $s(t)$, the average signal read by the probe during the integration time t_{int} starting from time t_0 is given by $s_{\text{int}}(t_0, t_{\text{int}})$ in:

$$s_{\text{int}}(t_0, t_{\text{int}}) = \frac{1}{t_{\text{int}}} \int_{t_0}^{t_0+t_{\text{int}}} s(t)dt \qquad 0 \le t_0 \le T$$

s_{int} assumes that the filtering of the probe does not alter the signal envelope $s(t)$. If t_0 is not synchronized with the longest period T of $s(t)$, the probe integration-time uncertainty can be defined as shown in:

$$\text{SAR}_{\text{uncertainty}\_a}\,[\%] = 100 \times \frac{\max\left(s_{\text{int}}(t_0, t_{\text{int}})\right) - \min\left(s_{\text{int}}(t_0, t_{\text{int}})\right)}{2 \times s_{\text{int}}(0, T)}$$

where

$\text{SAR}_{\text{uncertainty\_a}}$ is the uncertainty for the integration time in percent;
max (s_{int} (t_0,t_{int})) are the maximum of any interval (t_0, t_{int}) between $0 \le t_0 \le T$;
min (s_{int} (t_0,t_{int})) are the minimum of any interval (t_0, t_{int}) between $0 \le t_0 \le T$.

$\text{SAR}_{\text{uncertainty\_a}}$ can be used to derive the probe integration-time uncertainty of any signal. A simple alternative formula for the uncertainty for a TDMA signal is provided in:

$$\text{SAR}_{\text{uncertainty\_b}}\,[\%] = 100 \times \sum_{\text{all sub-frames}} \frac{t_{\text{frame}}}{t_{\text{int}}} \frac{\text{slot}_{\text{idle}}}{\text{slot}_{\text{total}}} \quad \text{for } t_{\text{int}} > t_{\text{frame}},$$

where

$\mathrm{SAR}_{\mathrm{uncertainty\_b}}$	is the uncertainty for the integration time in percent;
t_{frame}	is the frame duration;
t_{int}	is the integration time;
$slot_{\mathrm{idle}}$	is the number of idle slots in a frame;
$slot_{\mathrm{total}}$	is the total number of slots in a frame.

In the above equation, it is implied that a TDMA signal may be comprised of multiple frame layers. For example, the basic sub-frame for GSM systems has a duration $t_{\mathrm{sub\text{-}frame}}$ = 4,6 ms, with 7 idle slots in an 8-slot sub-frame, while the whole 26-slot frame duration is t_{frame} = 120 ms, including 1 idle sub-frame slot.

$\mathrm{SAR}_{\mathrm{uncertainty\_b}}$ is an approximation that typically overestimates the uncertainty. Here $\mathrm{slot}_{\mathrm{idle}}$ is the number of idle slots in a frame with $slot_{\mathrm{total}}$ being the total number of slots. The frame duration is t_{frame}, with $t_{\mathrm{frame}} < t_{\mathrm{int}}$. The total probe integration-time uncertainty is the sum of the uncertainties for all sub-frames in the frame structure that have idle slots. For example, for a probe integration time of 0,2 s, the uncertainty is estimated to be s_{int} and $\mathrm{SAR}_{\mathrm{uncertainty\_a}}$. For US TDMA (IS-136), t_{frame} = 20 ms, with 2 idle slots in a 3-slot frame, and no multiframes. For a probe integration time of 0,2 s, $\mathrm{SAR}_{\mathrm{uncertainty\_b}}$ gives an uncertainty of 6,67 %, whereas the true uncertainty derived using s_{int} and $\mathrm{SAR}_{\mathrm{uncertainty\_a}}$ is 0 % (the integration time is an exact multiple of the frame time). GPRS is the same as GSM, except that the number of idle slots can be 6, 5, …, where 7 idle slots is the worst case.

Enter this value in the uncertainty table, whereby a rectangular distribution can be assumed. FDMA and CDMA devices are tested with continuous or CW-equivalent signals; therefore, an uncertainty value of zero should be entered.

7.2.2.10 Measured SAR drift

If the measured SAR drift is within 5 %, then it can be treated either as an uncertainty (i.e. random error) or a bias. If treated as an uncertainty, the drift shall be recorded in the uncertainty table. If treated as a bias, a correction shall be applied to the measured SAR value (6.3.1); in this case, it is not necessary to record the drift in the uncertainty budget (i.e. u_{i} = 0 %).

Measured SAR drift is dynamic to the device under test during the evaluation for SAR and derived as a method to ensure stable power is applied to the device throughout the measurement process. This means that uncertainty shall be established. A standard uncertainty value of 5 % is included in Table 5 to cover the measured SAR drift. The 5 % tolerance can be updated to reflect a different value by utilizing one of two methods.

a) As the preferred method, dynamic SAR (single point) measurements shall be made by the SAR measurement system within the tissue at a user defined point prior to the area scan being conducted. A secondary measurement shall be made by the system at the user defined point after completion of the SAR value. The difference between the measured SAR values can then be dynamically applied to Table 5 for measurement uncertainty.

b) Alternatively and if the preferred method in a) is not sensitive enough, conducted measurements can be made on the device at the antenna port using equipment capable of measuring RF power prior to device placement for SAR test. The user shall repeat the conducted RF power measurement after the SAR test has completed. The difference between the conducted RF power measurements can be assessed and used as an updated tolerance in Table 5.

A rectangular probability distribution has been assumed for the measured SAR drift uncertainty in Table 5 (labelled Drift of Output Power).

7.2.3 Contribution of mechanical constraints

7.2.3.1 Scanning system

The mechanical restrictions of the field probe positioner can introduce deviations in the accuracy and repeatability of probe positioning which add to the uncertainty of the measured SAR. The uncertainty may be estimated with respect to the specifications of the probe positioner relative to the position required by the actual measurement location defined by the geometrical centre of the field probe sensors and is expressed as maximum deviation d_{ss}. By assuming a rectangular probability distribution, the peak spatial-average SAR uncertainty contributions due to mechanical restrictions of the probe positioner, d_{ss}, may be calculated using a first-order uncertainty approximation:

$$\mathrm{SAR}_{\mathrm{uncertainty}}[\%] = \frac{d_{\mathrm{ss}}}{\delta/2} \times 100$$

where

$\mathrm{SAR}_{\mathrm{uncertainty}}$	is the uncertainty in percent;
d_{ss}	is the maximum position uncertainty between the calculated position of the centre of the probe sensors and the actual position with respect to a reference point defined by the system manufacturer;
δ	is the minimum penetration depth in millimetre of the tissue-equivalent liquid for the frequency range studied, e.g., $\delta \approx 6$ mm at 6 GHz.

If the manufacturer of the positioner does not specify the mechanical restrictions of the probe positioner, this shall be evaluated to determine the contribution to SAR measurement uncertainty. This can be simply performed by evaluating the relative accuracy of movement in the area of the coarse scan and converting differences in positions specified by the software to that actually achieved into an uncertainty. The SAR uncertainty shall be entered in column *c* of Table 5 using an assumed rectangular distribution.

7.2.3.2 Phantom shell uncertainty

The uncertainty as a function of the tolerance of the phantom shell is assessed according to a conservatively strong dependence on distance, i.e. dependence on the square of the distance and assuming a distance of a = 5 mm between the body tissue-equivalent liquid and the location of the equivalent filament current density (the equivalent current density does not correspond to the closest current source but to the current density approximating the local H-field distributions).

$$\mathrm{SAR}_{\mathrm{uncertainty}}[\%] = \sqrt{\left(100 \times \left(\frac{(a+d+b/2s)^2}{a^2} - 1\right)\right)^2 + \left(5\left|\varepsilon_{r_{\mathrm{shell}}} - 4\right|\right)^2}$$

for $3 \le \varepsilon_{r_{\mathrm{shell}}} \le 5$, for $f > 3$ GHz

$$\mathrm{SAR}_{\mathrm{uncertainty}}[\%] = 100 \times \left(\frac{(a+d+b/2s)^2}{a^2} - 1\right)$$

for $f \le 3$ GHz

where

$\mathrm{SAR}_{\mathrm{uncertainty}}$	is the uncertainty in percent;
a	is the distance between the body tissue-equivalent liquid and the position of the equivalent filament current density;
b	is the maximum extension of the device including antenna and accessories under test; alternatively b is the distance between the

	centre of the phantom and the centre of the evaluated cube of the zoom scan;
d	is the maximum tolerance of the shell thickness and phantom shape;
s	is the maximum sagging of the shell in % per distance;
$5\times\lvert\varepsilon_{r_{\text{shell}}} - 4\rvert$	is the absolute value of the actual permittivity of the shell minus the norm permittivity of 4 multiplied with the uncertainty of 5 % assessed when the permittivity deviates by 1.

Beside distance tolerance and sagging, the uncertainty due to the tolerance of the relative permittivity ($\varepsilon_r = 4 \pm 1$) of the shell shall also be considered, which is ± 5 %.

Enter the uncertainty value (rectangular distribution) in the corresponding row of the uncertainty table.

7.2.3.3 Probe position with respect to phantom shell surface

The uncertainty of the probe positioner with respect to the phantom shell d_{ph} shall be estimated. By assuming a rectangular probability distribution, the peak spatial-average SAR uncertainty contribution is calculated using a first-order error approximation:

$$\text{SAR}_{\text{uncertainty}}[\%] = \frac{d_{\text{ph}}}{\delta/2}\times 100$$

where

$\text{SAR}_{\text{uncertainty}}$	is the uncertainty in percent;
d_{ph}	is the maximum uncertainty for determining the distance between probe tip and phantom shell, i.e. the uncertainty of determining the phantom location with respect to the probe tip;
δ	is the minimum penetration depth in millimetres of the tissue-equivalent liquid for the frequency range studied.

The SAR uncertainty shall be entered in column *c* of Table 5 in the uncertainty table, assuming a rectangular distribution.

7.2.3.4 Device positioning and holders uncertainties

7.2.3.4.1 General

A device holder is used to maintain the test position of a DUT against the phantom during a SAR measurement. Because a device holder may influence the characteristics of a DUT, the SAR uncertainty due to device holder perturbation shall be estimated using the procedures in 7.2.3.4.2. Procedures for SAR uncertainties due to positioning variations resulting from mechanical tolerances of the device holder are discussed in 7.2.3.4.3. Both subclauses include procedures for device-specific and predetermined uncertainties. If predetermined uncertainties are used, in most cases multiple repeats of device-specific tests can be done to reduce the predetermined standard deviations further.

7.2.3.4.2 Device holder perturbation uncertainty

7.2.3.4.2.1 General

The device holder shall be made of low-loss dielectric material with a relative permittivity of less than 5 and loss tangent of less than 0,05 (these material parameters can be determined for example using the coaxial contact probe method). Nevertheless, some holders may still affect the source, so the uncertainty resulting from the holder (i.e. the deviation from a set-up without the holder) should be estimated. The uncertainty for a specific test device should be estimated according to the method described in 7.2.3.4.2.2, which is a type B method. The method described in 7.2.3.4.2.3 provides a type A method to assess the uncertainty for a group of DUTs having similar SAR characteristics and tested with the same device holder.

The SAR uncertainty to be used in Table 5 is:

$$\mathrm{SAR}_{\mathrm{uncertainty}}\,[\%] = \left(\frac{\mathrm{SAR}_{\mathrm{w/\ holder}} - \mathrm{SAR}_{\mathrm{w/o\ holder}}}{\mathrm{SAR}_{\mathrm{w/o\ holder}}} \right) \times 100$$

where

$\mathrm{SAR}_{\mathrm{uncertainty}}$	is the uncertainty in percent;
$\mathrm{SAR}_{\mathrm{w/\ holder}}$	is the SAR with device holder in watts per kilogram;
$\mathrm{SAR}_{\mathrm{w/o\ holder}}$	is the SAR without device holder in watts per kilogram.

7.2.3.4.2.2 Device holder perturbation uncertainty for a specific test device: type B

The uncertainty for a specific DUT operating in a specific configuration shall be estimated by performing the following two tests using a flat phantom:

a) evaluation of the peak spatial-averaged SAR ($\mathrm{SAR}_{\mathrm{w/\ holder}}$) by placing the device in the holder in the same way it would be held when tested against the body, then positioning the DUT in direct contact with a flat phantom (horizontal and vertical centre line of the DUT parallel to the bottom of the flat phantom);

b) evaluation of the peak spatial-average SAR ($\mathrm{SAR}_{\mathrm{w/o\ holder}}$) by placing the device in the same position but held in place using foamed polystyrene or equivalent low-loss and non-reflective material (permittivity no greater than 1,2 and loss tangent no greater than 10^{-5}).

This uncertainty has an assumed rectangular probability distribution and $\nu_i = \infty$ degrees of freedom.

7.2.3.4.2.3 Device holder perturbation uncertainty for specific types of devices: type A

A type A uncertainty analysis can be applied for a group of DUTs having similar shapes and SAR distributions. The uncertainty arising from this analysis can apply to other DUTs having similar SAR characteristics and tested with the same device holder, such that the specific tests described in 7.2.3.4.2.2 can be avoided. The effect of the device holder for *N* different models of DUTs in the different configurations shall be estimated by performing the tests of 7.2.3.4.2.2 for each model (*N* shall be at least 6), where for each configuration.

The corresponding uncertainty for Table 5 shall be estimated by using the root-mean-square of the individual uncertainties, with degrees of freedom of $\nu_i = N - 1$.

7.2.3.4.3 Evaluation of device positioning uncertainty with respect to phantom

7.2.3.4.3.1 General

The DUT test positions established by a single test operator using a device holder may deviate from the exact positions described in 6.1. SAR uncertainties due to device positioning deviations may vary by DUT design and the procedures used by a specific holder or test operator, and these effects are usually inseparable. The procedures of 7.2.3.4.3.2 may be used to evaluate an individual DUT design. Subclause 7.2.3.4.3.3 describes the procedures that may apply for evaluating a specific series or group of DUT designs that have the same shape and substantially equivalent dimensions and were tested using the same device holder. Unless these requirements are satisfied, the procedures in 7.2.3.4.3.2 should be used to evaluate each individual device. If a predetermined standard deviation for a specific device holder derived from testing a specific group of DUTs is applicable, an individual device may not require 7.2.3.4.3.2 repeat testing.

7.2.3.4.3.2 Positioning uncertainty of a specific DUT in a specific device holder

The positioning uncertainty of a specific DUT tested in a specific device holder is assessed by repeat measurements of the 1 g or 10 g SAR. This positioning uncertainty should be evaluated using the antenna position, frequency channel, and device position for the operational mode (see 6.3) that produced the highest SAR among all frequency bands. In addition to the original SAR measurement, the DUT should be repositioned and the tests repeated at least four times. This minimum of five tests should be sufficient to establish a reasonable value for the degrees of freedom. If the positioning uncertainty of an individual device is suspected to be large, more tests may need to be performed to reduce the impact on the total measurement uncertainty. Increasing the number of tests will increase the effective degrees of freedom ($v_{eff)}$ and decrease the coverage factor. The average SAR for the total number of measurements (N) is used to determine the SAR uncertainty according to the standard deviation and degrees of freedom ($v_i = N - 1$) of the number of tests performed.

7.2.3.4.3.3 Positioning uncertainty of specific types of DUTs in a specific device holder

The positioning uncertainty for a specific group of DUT with predominantly the same shape and substantially equivalent dimensions tested with a specific device holder may be assessed using the following procedures. The tests should include at least six devices, each evaluated according to the procedures of 7.2.3.4.3.2 (5 tests each). When a DUT has the same shape, and substantially equivalent dimensions and SAR distribution characteristics, so as to satisfy the requirements of the specific group of devices tested using a specific holder, the device positioning uncertainty for this selected group of devices may be used in lieu of performing the tests described in 7.2.3.4.3.2 for that particular DUT (predetermination). The SAR uncertainty is reported in the corresponding row and column of Table 5 according to the mean power of the uncertainties determined for each device from the procedures in 7.2.3.4.3.2. The degrees of freedom (v_i) are determined according to the number of tests (N) performed for the M devices included in the specific group of DUTs, with $v_i = (N \times M) - 1$.

7.2.4 Contribution of physical parameters

7.2.4.1 General

Details of dielectric parameter test methods are given in Annex J of IEC 62209-1:2005, and uncertainty estimation methods are given in Annex J.7 of IEC 62209-1:2005. Annex I provides parameters for the frequency band 30 MHz to 6 GHz.

NOTE In accordance with usual metrological practices, the measurement uncertainty for each of the dielectric parameters is recommended to be less than or equal to the allowable variations from the target values of the measured dielectric parameters.

7.2.4.2 Liquid density

The tissue-equivalent liquids are assumed to have a density of 1 000 kg/m^3. This density value shall be used for SAR evaluations without any uncertainty associated with it.

7.2.4.3 Liquid permittivity and conductivity

The uncertainty due to the liquid permittivity and conductivity arises from two different sources. The first source of uncertainty is from the use of the SAR correction for dielectric parameters within an allowable variation of ± 10 % from the Table 1 target value (see Annex F). The second source of uncertainty arises from the measurement procedures used to assess permittivity and conductivity which is described in this section.

The dielectric property measurement procedures use vector network analyzers. Network analyzers require calibration in order to account for and remove inherent losses and reflections. The uncertainty budget for dielectric measurement derives from inaccuracies in the calibration data, analyzer drift, and random errors. Other possible sources of errors are the tolerances on the sample holder hardware and deviations from the optimal dimensions for the specified frequencies. This applies regardless of the type of sample holder and the nature of the scattering parameters being measured.

Uncertainties due to the straight-line fit in the slotted-line method can be evaluated using a least-squares analysis.

Table 2 – Example uncertainty template and example numerical values for relative permittivity (ε'_r) and conductivity (σ) measurement; separate tables may be needed for each ε'_r and σ

		a		*b*	*c*	*d* $u_i = (a/b) \times (c)$	*e*
	Uncertainty component	**Tolerance (± %)**	**Probability distribution**	**Divisor**	c_i	**Standard uncertainty (± %)**	v_i **or** v_{eff}
1	Repeatability of ε'_r or σ (*N* repeats)	5,2	N	1	1	5,20	4
2	Deviation from reference liquid target ε'_r or σ	3,0	R	√3	1	1,73	4
3	Network analyzer-drift, linearity, etc.	0,5	R	√3	1	0,29	∞
4	Test-port cable variations	0,5	U	√2	1	0,35	∞
5	Combined standard uncertainty					5,50	5

NOTE Row headings 1 to 5 and column headings *a* to *d* are for reference.

An example uncertainty template is shown in Table 2. All influence quantities may or may not apply to a specific test setup or procedure, and other components not listed may be relevant in some test setups. Other possible influence quantities not included in Table 2 may need to be considered, such as sample-to-probe air gaps/bubbles, frequency interpolations, sensor dimensional/positioning considerations, numerical analysis/data extraction artifacts, coaxial probe finite flange effects, etc. Table 2 also includes example numeric values. Depending on the test setup, actual uncertainty estimates may and should differ from the values shown here. Measurement of well-characterized reference materials can be used to estimate the dielectric property measurement uncertainty ([83], [84], [85], [86]) as described in the following procedure.

a) Configure and calibrate the network analyzer in a frequency span large enough around the center frequency of interest, for example 835 MHz ± 100 MHz at five or more frequencies within the device transmission band.

b) Measure a reference material at least *n* times to obtain the average and standard deviation for the relative permittivity and conductivity at each device centre band and nearby frequencies.

c) For each of the test runs from step b) perform steps d) to h).

d) Calculate the repeatability as the sample standard deviation divided by the mean value. For the permittivity, this is given as:

$$\text{Repeatability (\%)} = 100 \times \frac{1}{\overline{\varepsilon'_r}} \sqrt{\frac{1}{N} \sum_{i=1}^{N} (\varepsilon'_{r,i} - \overline{\varepsilon'_r})}$$

where the mean value is

$$\overline{\varepsilon'_r} = \frac{1}{N}\sum_{i=1}^{N}\varepsilon'_{r,i}$$

Do the same for the conductivity.

e) Enter the repeatability in row 1, column *a* of Table 2. The degrees of freedom $v_i = N - 1$ is entered in column *e*. Determine the deviation of the dielectric parameters from the target values, $\varepsilon_{r,\mathrm{ref}}$ and σ_{ref}. For the permittivity, this is given as:

$$\text{Deviation (\%)} = 100 \times \left| \frac{\overline{\varepsilon'_r} - \varepsilon'_{r\,\mathrm{ref}}}{\varepsilon'_{r\,\mathrm{ref}}} \right|$$

Enter the deviation in row 2, column *a* of Table 2. The degrees of freedom $v_\mathrm{i} = N - 1$ is entered in column *e*. Do the same for conductivity.

f) Estimate the type B uncertainties for the other components of Table 2 (and other relevant components if needed) in the frequency range under consideration.

g) Determine the combined standard uncertainty as the root-sum-squared of the uncertainty components from steps c), d) and e). Enter this value in row 5 column *d* of Table 2.

h) For relative permittivity, choose the frequency that gives the largest value for the combined standard uncertainty in step f). Enter this uncertainty and the corresponding degrees of freedom v_i into the appropriate row of Tables 5, 6 and 7. Do the same for conductivity.

Insert two completed versions of Table 2 (one each for permittivity and conductivity) into the measurement report, along with rationale for which influence quantities were used or omitted. The versions of Table 2 correspond to the largest values for the combined standard uncertainty found in steps f) and g).

In Tables 5, 6, and 7, the sensitivity coefficients c_i in columns *f* and *g* for the liquid conductivity and liquid permittivity measurement uncertainties are needed. These sensitivity coefficients are c_σ for conductivity and c_ε for permittivity. They are calculated using equations (F.1) to (F.5). The largest sensitivity coefficients over the frequency range 300 MHz to 6 GHz were found to be c_σ= 0,78 (at 300 MHz) and c_ε= 0,23 (at 2 000 MHz) for 1 g averaging, and c_σ= 0,71 (at 300 MHz) and c_ε= 0,26 (at 5 500 MHz) for 10 g averaging. These maximum values are entered into Tables 5, 6 and 7. Alternatively, maximum values for specific tested frequency ranges can be entered.

7.2.4.4 Liquid temperature

The standard requires that SAR measurements are conducted within 18 ºC and 25 ºC, as well as within ± 2 ºC of the temperature at which the dielectric parameters were measured. The following evaluation shall be conducted for each recipe to determine the uncertainty caused by the temperature tolerance.

Measurements of the dielectric parameters at liquid temperatures T_low = 18 °C ± 1 ºC and T_high = 25 °C ± 1 ºC should be performed and the equations

$$\varepsilon\text{\_temp\_liqud}_{\mathrm{uncertainty}}[\%] = 100 \times \left| \frac{2 \times \left[\varepsilon_r(T_\mathrm{high}) - \varepsilon_r(T_\mathrm{low})\right]}{\varepsilon_r(T_\mathrm{high}) + \varepsilon_r(T_\mathrm{low})} \times \frac{2\ ^\mathrm{o}\mathrm{C}}{T_\mathrm{high} - T_\mathrm{low}} \right|$$

$$\sigma\text{\_temp\_liquid}_{\mathrm{uncertainty}}[\%] = 100 \times \left| \frac{2 \times \left[\sigma(T_\mathrm{high}) - \sigma(T_\mathrm{low})\right]}{\sigma(T_\mathrm{high}) + \sigma(T_\mathrm{low})} \times \frac{2\ ^\mathrm{o}\mathrm{C}}{T_\mathrm{high} - T_\mathrm{low}} \right|.$$

where

ε_temp_liquid$_{\mathrm{uncertainty}}$	is the temperature uncertainty for the liquid permittivity in percent;

σ_temp_liquid$_{\text{uncertainty}}$	is the temperature uncertainty for the liquid conductivity in percent;
$\varepsilon_r(T_{\text{high}})$	is the relative permittivity at temperature T_{high};
$\varepsilon_r(T_{\text{low}})$	is the relative permittivity at temperature T_{low};
$\sigma(T_{\text{high}})$	is the conductivity at temperature T_{high};
$\sigma(T_{\text{low}})$	is the conductivity at temperature T_{low};
T_{high}	is the highest temperature in °C at which the dielectric parameters were measured;
T_{low}	is the lowest temperature in °C at which the dielectric parameters were measured.

These equations can be used to derive the temperature uncertainty for the particular liquid. The uncertainty of T_{low} and T_{high} should be less than 0,1 ºC.

The values of ε_temp_liquid$_{\text{uncertainty}}$ and σ_temp_liquid$_{\text{uncertainty}}$ are entered into column *c* of the appropriate rows in Tables 5, 6, and 7. Calculated values for some recipes are provided in Annex I. A rectangular probability distribution has been assumed for the liquid temperature uncertainty in Tables 5, 6, and 7. The sensitivity coefficients for the liquid temperature uncertainty are c_σ for conductivity and c_ε for permittivity. They are calculated using the procedure described in 7.2.4.3.

7.2.4.5 Perturbation of the environment

Measurement uncertainties may occur when unwanted RF ambient signals are present during a SAR test. The ambient RF level is evaluated by performing SAR measurements using the same equipment setup as used for testing the DUT, but with the RF power switched off. RF ambient noise may not be checked before each SAR test if the laboratory can demonstrate that any RF sources that can influence the peak 1 g SAR measurement by not more than 0,012 W/kg.

Subclause 5.1 requires the SAR uncertainty due to RF ambient noise and the effects of RF scatterers each to be less than 3 % of the lower detection limit of the system. The test configurations described in Annex B are used to assess the effects of reflections from nearby objects at a test site. In addition, the RF ambient noise should be determined by performing SAR measurements with all local RF sources switched off. The effects of RF reflections and ambient fields should result in a peak 1 g SAR less than 0,012 W/kg, which corresponds to 3 % of 0,4 W/kg, to provide a sufficient signal-to-noise ratio for meeting the 100 mW/kg low dynamic range specified in this recommended practice. The SAR uncertainty shall be entered in the corresponding row of Table 5 for ambient field effects, (see e.g. [32]), and a rectangular probability distribution can be assumed.

When SAR measurements are performed in a controlled environment, such as an anechoic chamber, RF ambient effects should be assessed at least once a year. When SAR measurements are not performed in a controlled environment, RF ambient effects shall be assessed periodically, for example every 4 months, or when RF ambient conditions changes ensuring that any nearby high output non-periodic sources, for example walkie-talkies, that any nearby high output non-periodic sources, for example walkie-talkies, are present in the non controlled environment during the SAR measurements. In the case of non controlled environment, the laboratory shall declare in the measurement report the RF ambient conformity and the date of ambient noise check.

The rationale for the non-controlled environment RF check evaluation is that there is no reason to assess this uncertainty contribution before any SAR measurement if it can be demonstrated that RF sources are sufficiently far from the SAR measurement system location, even if the measurement system is placed in a non controlled environment, given the near field nature of the SAR measurement. The rationale on calibration intervals described in ISO 10012:2003 is recommended to assess the periodicity of evaluating RF ambient effects on SAR measurements.

7.2.5 Contribution of post-processing

7.2.5.1 General

This clause describes the estimation of the uncertainty resulting from the post-processing of the discrete measured data to determine the 1 g and 10 g peak spatial-average SAR, i.e. the combined uncertainty of interpolation, extrapolation, averaging and maximum finding algorithms. These algorithms may add uncertainty due to general assumptions about field behaviour, and therefore may not perfectly predict the electric field distribution in the tissue-equivalent liquid for a specific DUT. The algorithm uncertainty is a function of the resolution chosen for the measurement and the post-processing methods used in the area and zoom scans.

The actual SAR distribution at the peak location is strongly dependent on the operating frequency and design of the DUT, test position, and proximity to the tissue-equivalent liquid. SAR distributions can have a rather flat gradient when a low frequency source is a large distance away, or can have a very steep gradient when a small high frequency source such as a helix antenna is placed next to the tissue. In some cases, the maximum SAR is not at the surface of the phantom due to cancellation of magnetic fields at the surface.

The analytical SAR distribution functions presented below are intended to simulate these conditions and have been developed for the purpose of this uncertainty estimation. These reference functions are used to create artificial or “dummy” SAR data sets for testing the system software post-processing subroutines. Computed reference function values at coarse and fine grid spacings, the same as are used in measurements, are input to the SAR system software. SAR values at grid points corresponding to the area- and zoom-scan measurement grids are computed according to the three SAR distributions given in 7.2.5.2 and processed by the system interpolation, extrapolation, and integration algorithms as if they were actually measured. The resulting 1 g and 10 g SAR values are compared with reference SAR values listed in 7.2.5.2. Procedures for evaluating the SAR uncertainty of the area and zoom- scan post-processing algorithms are described in 7.2.5.3. The test functions assume a planar tissue-equivalent liquid and phantom interface. This uncertainty concept assumes that there are no errors in location of the grid points calculated with the analytical distribution functions, and probe positioning and measurement uncertainties are not included.

The post-processing uncertainty shall be estimated using a rectangular probability.

7.2.5.2 Evaluation test functions

Three analytical functions, f_1, f_2 and f_3, [82] are used to represent the possible range of SAR distributions expected for DUTs tested according to the procedures of this document. For the 30 MHz – 3 000 MHz frequency range, function f_1 is based on the evaluation of SAR footprints of actual wireless devices [18]. Two parameter sets are given for f_1 such that SAR distributions with single and double maxima can be evaluated. The function f_2 is used to account for exposure conditions with *H*-field cancellation at the phantom/tissue-equivalent liquid surface. For the frequency range above 3 GHz, f_3 is added to account for the much stronger attenuation. Since noise may effect the extrapolation at these frequencies, a noise term is included. The distribution functions are defined for the phantom surface at $z = 0$, and the half-space tissue-equivalent liquid is defined for all $z > 0$.

$$f_1(x,y,z) = A_1 e^{-\left(\frac{(x'+x_\mathrm{d}/2)^2}{2\sigma^2_\mathrm{xpeak}}\right)} e^{-y'^2 \big/ 2\sigma^2_\mathrm{ypeak}} e^{-z/a} + A_2 e^{-\left(\frac{(x'-x_\mathrm{d}/2)^2}{2\sigma^2_\mathrm{xsec}}\right)} e^{-y'^2 \big/ 2\sigma^2_\mathrm{ysec}} e^{-z/a}$$

where

$$\sigma_\mathrm{xpeak} = \begin{cases} \sigma_\mathrm{xpp}, x' \geq -x_\mathrm{d}/2 \\ \sigma_\mathrm{xpn}, x' < -x_\mathrm{d}/2 \end{cases}, \qquad \sigma_\mathrm{ypeak} = \begin{cases} \sigma_\mathrm{ypp}, y' \geq 0 \\ \sigma_\mathrm{ypn}, y' < 0 \end{cases},$$

$$\sigma_{\text{xsec}} = \begin{cases} \sigma_{\text{xsp}}, x' \geq x_{\text{d}} / 2 \\ \sigma_{\text{xsn}}, x' < x_{\text{d}} / 2 \end{cases}, \qquad \sigma_{\text{ysec}} = \begin{cases} \sigma_{\text{ysp}}, y' \geq 0 \\ \sigma_{\text{ysn}}, y' < 0 \end{cases}$$

$$f_2(x, y, z) = A\, e^{-\frac{z}{a}} \frac{a^2}{a^2 + x'^2} \left(3 - e^{-\frac{2z}{a}} \right) cos^2 \left(\frac{\pi}{2} \frac{y'}{3a} \right)$$

$$f_3(x, y, z) = A \left(e^{\frac{-(x'^2 + \frac{y'^2}{2})}{(a/4)^2}} \right) \left(e^{-\frac{8z}{a}} \right) + 0{,}4 \times \left[\frac{N_{\text{rms}}}{A} \times rnd(\zeta) \right]$$

where

x, y and z are the spatial coordinates (in mm);

$x' = x + d$ (in mm);

$y' = y + d$ (in mm);

x_{d} = separation distance between SAR maxima, for two peaks case; see Table 3.

d = offset parameter (in mm);

a = 20 mm;

A = 1 W/kg;

N_{rms} is the amplitude of the system noise in W/kg in the liquid in the absence of an RF signal. This parameter is system dependent and corresponds to the noise measured inside the liquid in the absence of an RF signal according to 7.2.4.5. For the evaluation of the reference function f_3, a value of 0,1 W/kg should be used for N_{rms};

$rnd(\zeta)$ is a function which returns normally distributed random numbers with a standard deviation of 1. Appropriate functions are available in typical math applications. The variable ζ is an arbitrary seed. The function $rnd(\zeta)$ shall be evaluated for each point of the measurement grid.

The above parameters a and A do not have any particular physical meaning other than for generation of the appropriate SAR distributions.

The parameters for function f_1 have been selected on the evaluations of different handsets at 1 950 MHz. They are given in Table 3.

Table 3 – Parameters for reference function f_1

No of peaks	A_1 W/kg	A_2 W/kg	a mm	x_{d} mm	σ_{xpp} mm	σ_{ypp} mm	σ_{xsp} mm	σ_{ysp} mm	σ_{xpn} mm	σ_{ypn} mm	σ_{xsn} mm	σ_{ysn} mm
1	1,2	0,0	11,9	n. a.	19,6	15,5	n. a.	n. a.	21,9	17,2	n.a.	n.a.
2	1,2	1,0	11,9	60,47	22,6	19,7	19,4	19,6	22,0	15,5	17,9	24,2

A value of d = 2,5 mm, for example, provides a lateral shift of the SAR distribution so that the peak location is not aligned with a measurement grid having a 5 mm increment. This offset is used to test the software peak search subroutines and uncertainty.

The reference SAR values of the distribution functions f_1, f_2, and f_3 for 1 g and 10 g cubes aligned with the (x, y, z) coordinate axes are given in Table 4. When function f_1 is considered, the maximum deviation from reference values obtained considering one peak and two peaks cases, shall be used for post-processing uncertainty computations. The reference values are used in the following subclauses for testing other data-processing functions.

Table 4 – Reference SAR values in watts per kilogram used for estimating post-processing uncertainties

	Reference SAR value W/kg		
Function	**1 g cube**	**10 g cube**	**Peak case**
f_1	0,791	0,494	One peak
f_1	0,796	0,503	Two peaks, cube centred on the primary peak
f_1	0,686	0,438	Two peaks, cube centred on the secondary peak
f_2	1,796	1,375	
f_3	0,157	0,026 8	

7.2.5.3 Data-processing algorithm uncertainty evaluations

7.2.5.3.1 Evaluation of the coarse area scan

A precondition for peak spatial-average SAR evaluation with a given uncertainty is that the location of the maximum exposure can be determined from the area scan data with such a precision that the peak spatial-average SAR is entirely enclosed in the zoom-scan volume. In other words, the area-scan interpolation algorithms should be capable of locating peak SAR locations with an accuracy of $\pm L_z/2$ mm or better, where L_z is the side length of the zoom-scan volume. If this precondition is satisfied, which is tested with the procedures of this subclause, then the evaluation of the *area scan* does not contribute to the uncertainty budget.

The reference function values calculated at the usual area-scan grid points are input to the system software. The interpolation algorithm treats these data points as if they were measured to complete the area scan and determine the peak SAR location (x_{eval}, y_{eval}). This is compared with the actual peak location defined by the analytical functions at (x_{ref}, y_{ref}) = (-2,5, -2,5) mm, when d = 2,5 mm. The subscripts “eval” and “ref” refer to evaluated and reference, respectively. In other words, the following inequalities shall be satisfied:

$$\left|x_{\mathrm{ref}} - x_{\mathrm{eval}}\right| \le L_{\mathrm{z}}/2 \quad \mathrm{mm}$$

$$\left|y_{\mathrm{ref}} - y_{\mathrm{eval}}\right| \le L_{\mathrm{z}}/2 \quad \mathrm{mm}$$

The ability of the two-dimensional area scan to accurately locate the SAR peak is dependent on the spatial resolution (Δx, Δy) of the area-scan grid, the spatial resolution (Δx_{i}, Δy_{i}) of the interpolated values, and the type of interpolation functions [$g_{\mathrm{i(}}(x)$, $g_{\mathrm{i}}(y)$] used. It is also dependent on the location of the evaluation grid with respect to the actual peak location (x_{ref}, y_{ref}) and the number of evaluation points used (N_{x}, N_{y}).

The following procedure should be used to assess the uncertainty of the interpolation algorithms used in the area scan for determining the peak SAR location:

a) Choose the measurement resolution (Δx, Δy), and number of evaluation (corresponding to measurement) points (N_{x}, N_{y}). The centre of the area scan should be set to (x_0, y_0) = (0, 0).

b) SAR values are computed using the functions f_1, f_2 and f_3,at the area-scan evaluation grid points within the ranges:

$$x_0 - \Delta x \times [(N_x - 1)/2] \le x \le x_0 + \Delta x \times [(N_x - 1)/2],$$

$$y_0 - \Delta y \times [(N_y - 1)/2] \le y \le y_0 + \Delta y \times [(N_y - 1)/2],$$

where N_x and N_y are assumed to be odd integers. A value of $z = 0$ is assumed since the peak location is independent of z for these three functions.

c) The SAR values computed by the three distribution functions are interpolated by the SAR measurement system with a spatial resolution of (Δx_i, Δy_i) according to the interpolation functions [$g_i(x)$, $g_i(y)$] used by the system to determine the peak SAR location (x_{eval}, y_{eval}). If the measurement system does not allow SAR values to be imported to perform the evaluation, the same algorithm should be implemented independently by other means to determine the interpolation and peak search uncertainties.

d) The peak SAR location determined by the interpolation algorithms should satisfy the requirements of the inequalities

$$\left|x_{\text{ref}} - x_{\text{eval}}\right| \le L_z/2 \quad \text{mm}$$

$$\left|y_{\text{ref}} - y_{\text{eval}}\right| \le L_z/2 \quad \text{mm}.$$

Otherwise, the data-processing and measurement systems should use a finer grid resolution and/or a larger number of interpolation points to repeat the evaluation starting at step b).

e) The centre of the area scan (x_0, y_0) should be shifted in 1 mm steps within the range $0 < x_0 \le \Delta x/2$ and $0 < y_0 \le \Delta y/2$ to repeat the evaluation starting at step b) for each of the shifted (x_0, y_0) in these ranges.

7.2.5.3.2 Evaluation of the zoom scan

The zoom scan is evaluated by comparing the highest 1 g or 10 g SAR values with the reference SAR values in 7.2.5.2. From the area scan procedure in 7.2.5.3.1, the true peak location (x_{ref}, y_{ref}) will be displaced from the estimated peak location (x_{eval}, y_{eval}) by an amount given by inequalities:

$$\left|x_{\text{ref}} - x_{\text{eval}}\right| \le L_z/2 \quad \text{mm}$$

$$\left|y_{\text{ref}} - y_{\text{eval}}\right| \le L_z/2 \quad \text{mm}$$

This displacement is accounted for in the reference functions f_1, f_2, and f_3, defined in 7.2.5.2 by incorporating the distance d. Since this displacement will vary in practice, the value of d should be varied over the range:

$$|d| \le (L_z - L_c)/2$$

where L_c is the cube side length (10 mm for 1 g, 21,5 mm for 10 g). For each distance d, the largest uncertainty produced by any of the three functions is recorded. The root-mean-square of the largest uncertainty values for several distances d is entered as the uncertainty due to extrapolation, interpolation and integration.

NOTE Although the requirement for the area scan is that the local peak SAR is located within $|d| \le L_z/2$, a smaller range of $|d| \le (L_z - L_c)/2$ is used here to ensure that the 1 g or 10 g cube can be computed on the first attempt. For values of $(L_z - L_c)/2 < |d| \le L_z/2$, the measurement software should alert that the 1 g or 10 g cube is not captured and the measurement should be re-attempted. This will not affect the uncertainty, so it is not necessary to consider this case here.

a) Choose a displacement d for the evaluation of the functions f_1, f_2 and f_3. d should vary from $-(L_z - L_c)/2$ to $+(L_z - L_c)/2$ in small increments (e.g., 1 mm steps). It should also vary separately in the x and y directions.

b) SAR values are computed according to the functions f_1, f_2 and f_3, at the evaluation grid points that correspond to measured zoom-scan volume points. The centre of the zoom-scan volume should be positioned at

$$(x, y, z) = (0, 0, L_h/2 + z_d)$$

where

L_h is the height of the zoom-scan volume, and

z_d is the measurement point closest to the inner surface.

c) The computed SAR values are extrapolated to the phantom surface at $z = 0$ by the system software to obtain the additional points in the zoom scan volume that cannot be measured due to probe constraints. Both the computed and extrapolated data points are then interpolated to a finer resolution by the system software, which subsequently applies the integration algorithms as well as the search algorithm for finding the peak spatial-average SAR within the zoom scan volume to determine the highest 1 g or 10 g SAR. Other procedures are possible. If the system does not allow SAR values to be imported to perform the evaluation, the same algorithm should be implemented independently by other means to test the extrapolation, interpolation and integration algorithms.

d) The 1 g and 10 g SAR values determined by the system or data processing software ($\mathrm{SAR}_{\mathrm{eval}}$) are compared to the reference SAR values given in 7.2.5.2. The standard deviation caused by the random noise ($\mathrm{SAR}_{\mathrm{stdev}}$ (N_{rms})) is determined by evaluating f_3 at least 100 times, and with each of the 100 or more evaluations using different random noise parameters. The SAR uncertainty for distribution functions f_1 and f_2 is calculated using equation:

$$\mathrm{SAR}_{\mathrm{uncertainty}}[\%] = 100 \times \left| \frac{\mathrm{SAR}_{\mathrm{eval}} - \mathrm{SAR}_{\mathrm{ref}}}{\mathrm{SAR}_{\mathrm{ref}}} \right|$$

The SAR uncertainty for distribution function f_3 is calculated using equation:

$$\mathrm{SAR}_{\mathrm{uncertainty}}[\%] = 100 \times \left| \frac{\mathrm{SAR}_{\mathrm{eval}} - \mathrm{SAR}_{\mathrm{ref}}}{\mathrm{SAR}_{\mathrm{ref}}} \right| + 100\sqrt{3} \times \left| \frac{\mathrm{SAR}_{\mathrm{stdev}}(N_{\mathrm{rms}})}{\mathrm{SAR}_{\mathrm{stdev}}} \right|$$

e) The highest SAR uncertainty estimated by either of the three distribution functions is recorded.

f) Repeat steps b) to d) for other displacement values d.

g) Compute the root-mean-squared value of the uncertainties calculated in step d) for each displacement d above. This value should be entered as the uncertainty due to extrapolation, interpolation and integration in the corresponding row and column of Table 5 assuming rectangular probability distribution.

h) Record the following parameters used to estimate the zoom scan uncertainty:

- the dimension of the grid used to sample the reference functions both in terms of number of points and sample steps in the three dimensions;
- the number of interpolation points included between two test points, or the interpolation resolution in the three directions, for the reference functions;
- the dimension d_{be} of the extrapolation region, i.e. the distance between the probe sensor position at the first measurement point and the phantom surface (measurement point is behind the probe tip);
- the interpolation, extrapolation and averaging algorithms used.

The computational conditions (such as the number of grid points, the grid increments, and the number of interpolation points in the three directions) shall be the same for all the functions.

7.2.6 Standard source offset and tolerance

For system validation, the mechanical and electrical tolerances of the standard source affect the resulting peak spatial SAR values, e.g., different feedpoint impedance and current distribution as function of distance, phantom shell, liquid, etc. The real physical construction also deviates from the numerical model upon which the target values are based. The resulting offset and uncertainty can be determined by type A or type B evaluations. Type A would involve evaluations with different liquids, probes and phantoms. For type B evaluations, all parameters need to be assessed experimentally or numerically.

7.3 Uncertainty estimation

7.3.1 Combined and expanded uncertainties

The contributions of each component of uncertainty shall be recorded with description, probability distribution, sensitivity coefficient and uncertainty value. A recommended tabular form is shown in Table 5. The combined standard uncertainty u_c shall be estimated according to the following formula:

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

where

c_i is the sensitivity coefficient;
u_c is the combined standard uncertainty;
u_i is the standard uncertainty.

The expanded uncertainty *U* shall be estimated using a confidence interval of 95 %.

7.3.2 Maximum expanded uncertainty

The expanded uncertainty with a confidence interval of 95 % shall not exceed 30 % for peak spatial-average SAR values in the range from 0,4 W/kg to 10 W/kg. If the uncertainty is greater than 30 %, reported data need to take into account the percentage difference between the actual uncertainty and the 30 % target value – e.g. see method of IEC 62311 [30].

Table 5 – Measurement uncertainty evaluation template for DUT SAR test

A	*b*	*c*	*D*	*e* = *f*(*d*,*k*)	*f*	*g*	*h* = *c* × *f* / *e*	*i* = *c* × *g* / *e*	*k*
Source of Uncertainty	**Description**	**Tolerance/ Uncertainty value ± %**	**Probability Distribution**	**Div.**	**c_i (1 g)**	**c_i (10 g)**	**Standard uncertainty ± %, (1 g)**	**Standard uncertainty ± %, (10 g)**	**ν_i or ν_{eff}**
Measurement system									
Probe calibration	7.2.2.1		N	1	1	1			∞
Isotropy	7.2.2.2		R	√3	1	1			∞
Linearity	7.2.2.3		R	√3	1	1			∞
Probe modulation response	7.2.2.4		R	√3	1	1			∞
Detection limits	7.2.2.5		R	√3	1	1			∞
Boundary effect	7.2.2.6		R	√3	1	1			∞
Readout electronics	7.2.2.7		N	1	1	1			∞
Response time	7.2.2.8		R	√3	1	1			∞
Integration time	7.2.2.9		R	√3	1	1			∞
RF ambient conditions – noise	7.2.4.5		R	√3	1	1			∞
RF ambient conditions – reflections	7.2.4.5		R	√3	1	1			∞
Probe positioner mech. restrictions	7.2.3.1		R	√3	1	1			∞
Probe positioning with respect to phantom shell	7.2.3.3		R	√3	1	1			∞
Post-processing	7.2.5		R	√3	1	1			∞
Test sample related									
Device holder uncertainty	7.2.3.4.2		N	1	1	1			*M*-1
Test sample positioning	7.2.3.4.3		N	1	1	1			*M*-1
Power scaling	L.3		R	√3	1	1			∞
Drift of output power (measured SAR drift)	7.2.2.10		R	√3	1	1			∞
Phantom and set-up									
Phantom uncertainty (shape and thickness tolerances)	7.2.3.2		R	√3	1	1			∞
Algorithm for correcting SAR for deviations in permittivity and conductivity	7.2.4.3	1,9	N	1	1	0,84	1,9	1,6	∞
Liquid conductivity (meas.)	7.2.4.3		N	1	0,78	0,71			*M*-1
Liquid permittivity (meas.)	7.2.4.3		N	1	0,23	0,26			*M*
Liquid permittivity – temperature uncertainty	7.2.4.4		R	√3	0,78	0,71			∞
Liquid conductivity – temperature uncertainty	7.2.4.4		R	√3	0,23	0,26			∞
Combined standard uncertainty	7.3.1		RSS						

A	*b*	*c*	*D*	*e* = *f*(*d*,*k*)	*f*	*g*	*h* = *c* × *f* / *e*	*i* = *c* × *g* / *e*	*k*
Source of Uncertainty	**Description**	**Tolerance/ Uncertainty value ± %**	**Probability Distribution**	**Div.**	c_i **(1 g)**	c_i **(10 g)**	**Standard uncertainty ± %, (1 g)**	**Standard uncertainty ± %, (10 g)**	v_i **or** v_{eff}
Expanded uncertainty (95 % conf. interval)	7.3.2								

Table 6 – Measurement uncertainty evaluation template for system validation

A	*b*	*c*	*D*	$e = f(d,k)$	*f*	*g*	$h = c \times f / e$	$i = c \times g / e$	*k*
Source of Uncertainty	**Description**	**Tolerance/ Uncertainty value ± %**	**Probability distribution**	**Div.**	c_i **(1 g)**	c_i **(10 g)**	**Standard uncertainty ± %, (1 g)**	**Standard uncertainty ± %, (10 g)**	v_i **or** v_{eff}
Measurement system									
Probe calibration	7.2.2.1		N	1	1	1			∞
Isotropy	7.2.2.2		R	√3	1	1			∞
Linearity	7.2.2.3		R	√3	1	1			∞
Modulation response	7.2.2.4		R	√3	1	1			∞
Detection limits	7.2.2.5		R	√3	1	1			∞
Boundary effect	7.2.2.6		R	√3	1	1			∞
Readout electronics	7.2.2.7		N	1	1	1			∞
Response time	7.2.2.8		R	√3	1	1			∞
Integration time	7.2.2.9		R	√3	1	1			∞
RF ambient conditions - noise	7.2.4.5		R	√3	1	1			∞
RF ambient conditions - reflections	7.2.4.5		R	√3	1	1			∞
Probe positioner mech. restrictions	7.2.3.1		R	√3	1	1			∞
Probe positioning with respect to phantom shell	7.2.3.3		R	√3	1	1			∞
Post-processing	7.2.5		R	√3	1	1			∞
Field source									
Deviation of the experimental source from numerical source	7.2.6		N	1	1	1			∞
Source to liquid distance	7.2.3.4.3		R	√3	1	1			∞
Drift of output power (measured SAR drift)	7.2.2.10		R	√3	1	1			∞
Phantom and set-up									
Phantom uncertainty (shape and thickness tolerances)	7.2.3.2		R	√3	1	1			∞
Algorithm for correcting SAR for deviations in permittivity and conductivity	7.2.4.3		N	1	1	0,84			∞
Liquid conductivity (meas.)	7.2.4.3		N	1	0,78	0,21			*M*
Liquid permittivity (meas.)	7.2.4.3		N	1	0,23	0,26			*M*
Liquid conductivity – temperature uncertainty	7.2.4.4		R	√3	0,78	0,71			∞
Liquid permittivity – temperature uncertainty	7.2.4.4		R	√3	0,23	0,26			∞
Combined standard uncertainty	7.3.1		RSS						

A	*b*	*c*	*D*	*e* = *f*(*d*,*k*)	*f*	*g*	*h* = *c* × *f* / *e*	*i* = *c* × *g* / *e*	*k*
Source of Uncertainty	**Description**	**Tolerance/ Uncertainty value ± %**	**Probability distribution**	**Div.**	**c_i (1 g)**	**c_i (10 g)**	**Standard uncertainty ± %, (1 g)**	**Standard uncertainty ± %, (10 g)**	**v_i or v_{eff}**
Expanded uncertainty (95 % conf. interval)	7.3.2								

Table 7 – Measurement uncertainty evaluation template for system repeatability

A	*b*	*c*	*D*	$e = f(d,k)$	*f*	*g*	$h = c \times f / e$	$i = c \times g / e$	*k*
Source of Uncertainty	**Description**	**Tolerance/ Uncertainty value ± %**	**Probability distribution**	**Div.**	c_i **(1 g)**	c_i **(10 g)**	**Standard uncertainty ± %, (1 g)**	**Standard uncertainty ± %, (10 g)**	ν_i **or** ν_{eff}
Measurement system									
Modulation response	7.2.2.4		R	√3	0	0			∞
Detection limits	7.2.2.5		R	√3	0	0			∞
Boundary effect	7.2.2.6		R	√3	0	0			∞
Readout electronics	7.2.2.7		N	1	0	0			∞
Response time	7.2.2.8		R	√3	0	0			∞
Integration time	7.2.2.9		R	√3	0	0			∞
RF ambient conditions – noise	7.2.4.5		R	√3	0	0			∞
RF ambient conditions – reflections	7.2.4.5		R	√3	0	0			∞
Probe positioner mech. restrictions	7.2.3.1		R	√3	1	1			∞
Probe positioning with respect to phantom shell	7.2.3.3		R	√3	1	1			∞
Post-processing	7.2.5		R	√3	0	0			∞
Field source									
Deviation between experimental sources	7.2.6		N	1	1	1			∞
Source to liquid distance	7.2.3.4.3		R	√3	1	1			∞
Drift of output power (measured SAR drift)	7.2.2.10		R	√3	1	1			∞
Phantom and set-up									
Phantom uncertainty (shape and thickness tolerances)	7.2.3.2		R	√3	1	1			∞
Algorithm for correcting SAR for deviations in permittivity and conductivity	7.2.4.3		N	1	1	0,84			∞
Liquid conductivity (meas.)	7.2.4.3		N	1	0,78	0,71			*M*
Liquid permittivity (meas.)	7.2.4.3		N	1	0,23	0,26			*M*
Liquid conductivity – temperature uncertainty	7.2.4.4		R	√3	0,78	0,71			∞
Liquid permittivity – temperature uncertainty	7.2.4.4		R	√3	0,23	0,26			∞
Combined standard uncertainty	7.3.1		RSS						
Expanded uncertainty (95 % confidence interval)	7.3.2								

Notes for Tables 5 to 7

NOTE 1 Column headings *a-k* are given for reference.

NOTE 2 Abbreviations used in Table 5:

N, R, U – normal, rectangular, U-shaped probability distributions

Div. – divisor used to get standard uncertainty

NOTE 3 The uncertainty components indicated in this table are based on the test procedures and protocols developed for this document. When test protocols and procedures vary, different uncertainty components may apply, e.g., parameters defined for testing other phantom configurations and device positions.

NOTE 4 The divisor is a function of the probability distribution and degrees of freedom (ν_i and ν_{eff}).

NOTE 5 c_i is the sensitivity coefficient that should be applied to convert the variability of the uncertainty component into a variability of SAR.

NOTE 6 See 7.1.3 for discussions on degrees of freedom (ν_i) for standard uncertainty and effective degrees of freedom (ν_{eff}) for the expanded uncertainty.

NOTE 7 *M* in the ν_i column is number of tests.

NOTE 8 Some of the uncertainty influence quantities may be estimated from performance specifications provided by the equipment manufacturers; the uncertainty of certain other components that vary from test to test may need to be estimated for each measurement.

NOTE 9 All influence quantities in this template are applicable for system validation testing except the three items in the Test Sample Related group are replaced by a Dipole group containing two influence quantities described as: dipole axis to liquid distance, input power and SAR drift.

NOTE 10 As stated in the ISO/IEC Guide 99:2007, repeatability condition of measurement is here defined as the "*condition of measurement, out of a set of conditions that includes the same measurement procedure, same operators, same measuring system, same operating conditions and same location, and replicate measurements on the same or similar objects over a short period of time*," thus implicitly emphasizing that a key aspect is that repeatability must include conditions and components for testing ONLY within one specific test lab. In this context, the dipole used for system repeatability tests is not part of the measuring system.

8 Measurement report

8.1 General

All test results shall be recorded in a measurement report and shall include all the information necessary for the interpretation of the DUT configurations tested, calibration performed and all information required by the method and instrumentation used.

This clause states the minimum requirements required to be included in the measurement report, further guidelines on the required content of the measurement report can be found in 5.10 of ISO/IEC 17025:2005. A test report compliant with ISO/IEC 17025 and including as a minimum the items listed below will demonstrate compliance with this standard.

8.2 Items to be recorded in the measurement report

All of the information needed for performing repeatable tests, calculations, or measurements giving results within the required calibration and uncertainty limits shall be recorded. The measurement report shall include:

a) General introduction
   1) Identification of the test laboratory
   2) Identification of the DUT including hardware and software revision numbers, serial number, e.g., IMEI (international mobile equipment identity)

   3) Compliance requirements, e.g., test standards, guidelines, recommendations, etc.
   4) Exposure limits applicable, e.g., ICNIRP, IEEE/ICES, etc.
   5) A list of any accreditations provided by National or International bodies to perform testing at the standards listed above. This shall include the date of expiry

b) Measurement system
   1) Measurement system main component description e.g., positioner, probe, liquid, etc.
   2) Calibration data for relevant components
   3) Description of interpolation/extrapolation scheme used
   4) Liquids used and characteristics
   5) Results of system check

c) Uncertainty estimation
   1) To include measurement uncertainty value from Table 5
   2) Any other relevant items

d) Device and test details
   1) Description of the form factor of the DUT and a brief description of its intended function
   2) Description of the positions and orientations to be tested and rationale for any test reductions including, when appropriate according to 6.1.4.2, justifications of the definition of the distances based on the physical relationship between the device and the phantom
   3) Description of the available and tested antenna(s) and accessories, including batteries
   4) Description of the available and tested operating modes, power levels and frequency bands and rationale for any test reductions
   5) Testing environmental condition, e.g., temperature
   6) Results of all tests performed (peak spatial-average SAR value for each test, and graphical representation of the coarse scans with respect to the device for the maximum SAR value of each mode) and details on scaling of the results

e) Report summary
   1) Tabulated SAR values over the testing positions, bands, modes and configurations
   2) Reference to exposure limits and a statement of compliance, or otherwise

Annex A
(informative)

Phantom rationale

A.1 Rationale for the phantom characteristics

Phantoms that represent the human anatomy are essential components of electromagnetic exposure evaluation. It is neither always necessary nor practical for the phantoms to emulate the anatomical details, however it is important to define and standardise the relevant features, dimensions and material properties that affect SAR measurement. The statistical breakdown of anatomical shapes and sizes can be obtained from anthropometric studies of human population to guide the specification of a realistic phantom shape.

The shape and size of the flat phantom are important for accurate and representative SAR measurements. The part of the body exposed to the RF emissions of the body-worn devices is not always well defined and may vary with the product model design and usage.

The flat phantom should not be excessively large compared with the size of a human torso. Large phantoms are also more difficult to construct, and SAR measurement systems may not be capable of performing measurements in phantoms that are very large or very deep.

A flat phantom represents a simple engineering structure for which the SAR can easily and unambiguously be measured and calculated. It is an open-top thin dielectric shell with bottom wall which is filled with a tissue-equivalent liquid. The physical characteristics of the standard flat phantom are intended to simulate a human body.

A flat-bottomed phantom provides maximal surface area contact with the device under test and therefore generally gives a conservative estimate of SAR in a real person. In addition, a flat-bottomed phantom will accommodate devices of various sizes. Flat phantoms should be large enough to allow complete coupling of the RF radiating antenna and to allow scanning of 1 g and 10 g volumes.

The use of a flat phantom as a standard phantom for SAR evaluations of body-worn devices is intended to represent maximum coupling of variations and distortions which may be caused by irregularity of the tissue boundary among the population. Such coupling to the boundary while maintaining prescribed distances will likely produce a conservative estimation of SAR.

The compositions of the tissue-equivalent liquid specified in this standard have been designed to produce a conservative estimate of SAR in an equivalent human body assuming homogeneous composition of the body tissues (see also Annex H).

If the intended use of the device is within 200 mm of the torso or in front of the face then the hand may be ignored [73], [80]. The flat phantom may be used to simulate the hand if the intended use of the device is in the hand at more than 200 mm from the torso or the head. Estimation in the hand SAR using a flat phantom is addressed in Annex J.

A.2 Rationale for the phantom shell requirements

In order to prevent any influence on the phantom shape on the measured SAR, resonance effects must be eliminated. At low frequencies (30 MHz to 300 MHz), the freespace wavelength λ ranges from 1 m to 10 m, and resonances are likely to occur if the phantom dimensions are in the order of magnitude of $\lambda/2$. Reproducible measurements can only be warranted if the shape and size of the phantom are stringently specified.

For all frequencies above 300 MHz, size- and shape-dependent effects can be avoided by specifying minimum phantom dimensions and limiting the distance between the phantom and the device to less than 25 mm [2].

The phantom shell must be made of low loss and low permittivity material: $\tan(\delta) \leq 0{,}05$ and relative permittivity $\varepsilon_r' < 5$ for $f \leq 3$ GHz and $\varepsilon_r' = 4 \pm 1$ for $f > 3$ GHz. These values on the relative permittivity are based on a study by Onishi and Uebayashi [62]. The thickness of the bottom of the flat phantom must be 2,0 mm at the location where the device is positioned, with a tolerance of ± 0,2 mm. This minimal thickness results in a conservative estimate of SAR compared to measurements on thicker phantoms. Smaller thicknesses are not recommended due to problems with mechanical strength when holding the liquid.

The effect of the shape and thickness on SAR is assumed to be less than 1 % if the above requirements are met, and therefore the effect can be neglected [2].

When filled with the required depth of liquid as given in 5.2.2, any sagging of the lower surface of the bottom side of the phantom container must be less than 2 mm. This ensures that the surface area contact of the device under test to the phantom liquid is maximized.

A.3 Rationale for tissue-equivalent liquids

The dielectric properties (permittivity and conductivity) of the liquid as specified in 5.2.3 have been formulated to obtain a conservative assessment of the SAR, irrespective of the body characteristics of the user of the device for the comparable exposure conditions [6].

The electrical parameters of the tissue simulant liquids for head SAR measurements ("head tissue-equivalent liquid") were proposed by Drossos et al. [16]. The values for parameters were derived for 10 frequencies in the frequency range of 300 MHz to 3 000 MHz using an analytical model of an infinite half-space of layered tissues exposed to a plane wave. This approach allows to study the effect of impedance matching and standing waves to the peak spatial-averaged SAR. The tissue layers were varied in composition and thickness to represent the anatomical variation of the exposed head region, covering the user group including adults and children (between the 10th and 90th percentile). Based on the worst-case tissue layer compositions of the head with respect to absorption at each frequency, head tissue-equivalent liquid dielectric parameters for homogeneous modelling were derived resulting in the same or slightly higher spatial peak absorption. The dielectric properties of the tissues used to model the human head were computed by the 4-term-Cole–Cole formula, which is a simple extrapolation of the short time results. The validity of this approach for near-field exposure of the head was demonstrated using flat layered and anatomically representative child and adult head models based on magnetic resonance imaging (MRI) by Kainz et al.[39] and Beard et al. [1].

The study of Drossos et al. [16] was extended for general body tissue composition [6]. It was found that standing wave effects due to reflections in the subcutaneous adipose tissue lead to a significant increase of SAR in comparison to the findings of Drossos et al. [16]. This increase cannot be compensated by modifying the dielectric parameters of the tissue-equivalent liquids. A comprehensive analysis of the coupling mechanism shows that the standing wave effects need only to be considered in the Fresnel zone and the far-field zone of the DUT [7]. At close distances, a conservative exposure estimate can be achieved using the parameters for head tissue-equivalent liquids as proposed by Drossos et al. [16]. Therefore, the liquid parameters defined in IEC 62209-1:2005 have been retained for the measurements of hand-held and body-mounted devices.

The frequency range of the tissue-equivalent liquids has been extended to 5,8 GHz considering the Cole-Cole dispersion characteristics of body tissues with high water content and the producibility of the liquids within the required tolerances. The permittivity and conductivity in the frequency range 3 GHz to 5,8 GHz were linearly interpolated, and also linearly extrapolated to 6 GHz.

For the frequency band 30 MHz to 150 MHz muscle tissue parameters are published in [22]. However, the high permittivity values are difficult to realize in practice. Since decreasing the permittivity leads to higher SAR lower permittivity values were chosen for the body simulant liquid, leaving conductivity values roughly unchanged.

For 150 MHz, conductivity and permittivity equal to those recommended for head tissue simulant in [17] were chosen. FDTD simulations showed that the tissue simulant electrical parameters proposed in Table 1 provide an overestimation for SAR regarding equipment for body-worn use at 30 MHz and 150 MHz.

Further information on the distance range within which these liquids yield a conservative exposure estimate is given in Annex H.

SAR is strongly dependent on the dielectric parameters of the tissue-equivalent material, as shown in Annex F. Therefore, it is important that these parameters are accurately measured before use in a phantom for SAR measurement.

Any combination of materials can be used for the tissue-equivalent material provided it has the required dielectric parameters within the specified tolerances at the frequency of interest. The application of the proposed body tissue-equivalent material electrical parameters leads to a conservative estimation of 1 g and 10 g volume averaged SAR under the conditions described in this annex.

Annex B
(normative)

SAR measurement system verification

B.1 General

This clause provides procedures for the following:

a) system check;

b) system validation.

The objectives and applications of these different levels of validation procedures are as follows.

The system check provides a fast and reliable test method that can be performed daily or before every SAR measurement. The objective here is to ascertain that the set-up components are still within laboratory calibration limits, including drift effects. This test requires a flat phantom and a standard source, e.g., a half-wave dipole or open-ended waveguide.

System validation provides a means of system-level validation. The test set-up consists of a flat phantom and a reference dipole (see Annex D) or open-ended waveguide source. Therefore, system validation does not include uncertainty due to the use of anthropomorphic phantoms, nor does it include the uncertainty due to device positioning variability. This test is performed annually (e.g., after probe calibration), before measurements related to interlaboratory comparison (Annex E of IEC 62209-1:2005), and every time modifications have been made to the system, such as a new software version, different readout electronics, or different types of probes.

NOTE Interlaboratory comparisons provide laboratory qualification using a reference DUT (E.3 of IEC 62209-1:2005) and a standard anthropomorphic phantom. This qualification method includes the data scatter due to the human-like phantom and due to device positioning effects. This test is used to compare the accuracy and precision performance of various laboratories.

B.2 System check

B.2.1 Purpose

The purpose of the system check is to verify that the system operates within its specifications. The system check is a check of repeatability to make sure that the system works correctly at the time of the compliance test. The system check detects possible short-term drift and uncertainties in the system, such as:

a) changes in the liquid parameters (e.g., due to water evaporation or temperature change),

b) test system component failures,

c) test system component drift,

d) operator errors in the set-up or software parameters,

e) other possible adverse conditions in the system configuration, e.g., RF interference.

The system check is a complete 1 g or 10 g averaged SAR measurement in a simplified set-up with a standard source (see B.2.3). The instrumentation and procedures in the system check are the same as those used for the compliance tests. The system check shall be performed using the same liquid as in the compliance test and at a chosen fixed frequency that is within ± 10 % or ± 100 MHz of the compliance test mid-band frequency, whichever is greater. System checks shall be performed daily or before every SAR measurement and the results shall always be within the tolerance specified in B.2.5. The target values are 1 g or 10 g averaged SAR values measured on systems having current system validation and calibration status, and using the system check setup as shown in Figure B.1. These target values should be determined using a standard source.

System performance should be checked using the system check procedures to ensure that the system operates within specifications and tolerance ranges. This procedure should be done prior to a full-compliance SAR evaluation.

B.2.2 Phantom set-up

A flat phantom shall be used with the recommended tissue-equivalent liquid for the system check and system validation purposes (see Clause 5). The shape, dimensions and other specifications of the flat phantom are given in 5.2.2.

For dipole sources, the feedpoint shall be placed at the centre of the ellipse or rectangle, and the dipole arms shall be aligned with the major axis (see Annex D for dipole specifications). For waveguide sources, the longer side of the waveguide shall be aligned with the major axis. The material shall be resistant to damage or reaction with tissue-equivalent liquid chemicals.

B.2.3 Standard source

The phantom shall be irradiated using a standard source for the required frequency (e.g., a half-wave dipole, or patch antenna or open-ended waveguide). The reference dipoles source used for system validation (see Annex D) can also but are not required to be used for the system check. A standard source shall be selected which has good positioning repeatability, mechanical stability, and impedance matching. In the following positioning instructions, a half-wave dipole is assumed as an example of a standard source.

A half-wave dipole shall be positioned below the bottom of the phantom and centred with its axis parallel to the longest dimension of the phantom. The distance between the liquid-filled phantom inner surface and the dipole centre, s, (see Figure B.1 and Table D.1) shall be specified for each test frequency. A low loss (loss tangent $< 0,5$) and low relative permittivity (relative permittivity < 5) spacer shall be used to establish the correct distance between the top surface of the dipole and the bottom surface of the phantom. The dipole shall have a return loss less than – 20 dB at the resonant frequency (as measured in the set-up) to reduce the uncertainty in the power measurement. The acceptable tolerance of the distance s shall be within ± 0,2 mm.

B.2.4 Standard source input power measurement

The uncertainty of the power to the source shall be as low as possible. This requires the use of a test set-up with directional couplers and power meters during the system check. The recommended set-up is shown in Figure B.1 (which uses a half-wave dipole as an example of a standard source).

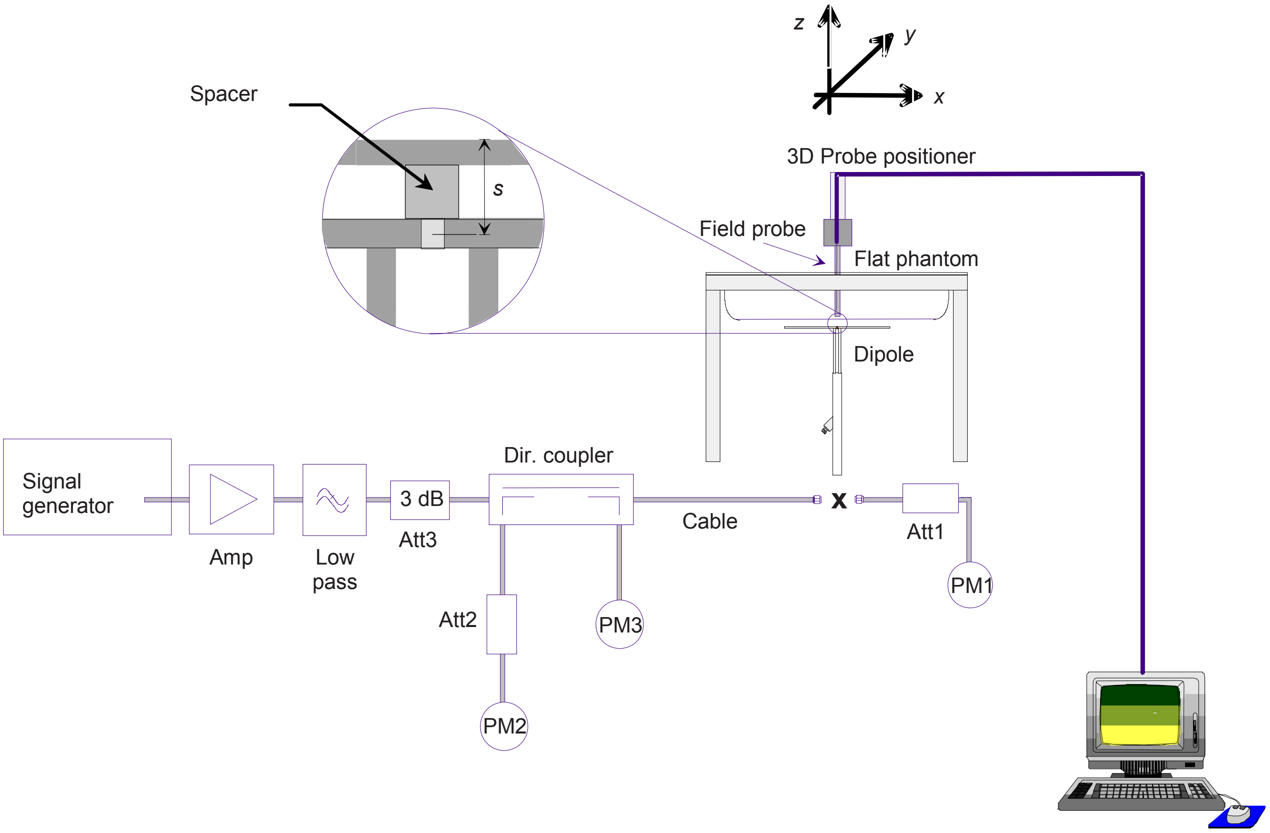


Figure B.1 – Set-up for the system check

First the power meter PM1 (including attenuator Att1) is connected to the cable to measure the forward power at the position of the dipole standard source connector (X). The signal generator is adjusted for the desired forward power at the dipole source connector (taking into account the attenuation of Att1) as read by power meter PM1. After connecting the cable to the dipole source, the signal generator is readjusted for the same reading at power meter PM2. If the signal generator does not allow adjustment in 0,01 dB steps, the remaining difference at PM2 shall be taken into consideration. The matching of the dipole source should be checked using a network analyser (in regular intervals) to ensure that the reflected power is at least 20 dB below the forward power.

The component and instrumentation requirements are as follows:

a) The signal generator and amplifier shall be stable (after warm-up). The forward power to the dipole source shall be high enough to produce a SAR value exceeding the lower detection limit of the probe system (see B.5 of IEC 62209-1:2005). If the signal generator can deliver 15 dBm or more, an amplifier is generally not necessary. Some high power amplifiers shall not be operated at a level far below their maximum output power, e.g., a 100 W power amplifier operated at 250 mW output power can be quite noisy. An attenuator between the signal generator and amplifier is recommended to protect the amplifier input.

b) The low pass filter inserted after the amplifier reduces the effect of harmonics and noise from the amplifier. For most amplifiers in normal operation, the filter is not necessary.

c) The attenuator after the amplifier improves the source matching and the accuracy of the power sensor (consult the power meter manual).

d) The directional coupler (recommended - 20 dB coupling coefficient) is used to monitor the forward power and adjust the signal generator output for constant forward power. A medium-quality coupler is sufficient because the loads (dipole and power head) are both well matched.

e) The power meters PM2 and PM3 shall have low drift and a resolution of 0,01 dBm, but otherwise the accuracy has negligible impact on the power setting (absolute calibration is not required).

f) The power meter PM1 and attenuator Att1 shall be high-quality components. These shall be calibrated, preferably together. The attenuator (– 10 dB) improves the accuracy of the power reading (some high-power heads come with a built-in calibrated attenuator). The exact loss factor of the attenuator at the test frequency shall be known; many attenuators vary up to 0,2 dB from the specified value.

g) Use the same power level for PM1 test as used for the actual measurement to avoid linearity and range switching uncertainties in the power meters PM2 and PM3. If the power level is changed, the power level setting procedure shall be repeated.

h) The dipole source shall be connected directly to the cable at position “X”. If the power meter has a different connector type, use high-quality adapters.

i) It is recommended to periodically check the insertion loss of the cables (especially the cable that connects the directional coupler to the dipole antenna) to ensure that they are of good quality. The insertion loss should be low (e.g., within 1 dB; this depends on cable length and frequency) and stable across frequency. Do not assume that a cable that works well at a lower frequency (e.g., 900 MHz) will work well at a higher frequency (e.g., 5 GHz). Higher quality cables may be needed for higher frequency operation. During the system check, movement of the cable should be avoided, as this may affect the cable loss.

B.2.5 System check procedure

The system check is a complete 1 g and/or 10 g averaged SAR measurement. The measured 1 g and/or 10 g averaged SAR value is normalized to the target input power of the standard source and compared with the previously recorded target 1 g and/or 10 g value corresponding to the measurement frequency, the standard source and phantom type. If the validation dipoles are used for system check as the standard source then the difference from the target values should be within the uncertainty of the system repeatability, but not larger than ± 10 %. If another standard source is used, then the target value and its uncertainty shall be assessed and documented.

B.3 System validation

B.3.1 Purpose

The system validation procedure tests the system against reference SAR values, and the performance of probe, readout electronics and software. It is a validation of the system with respect to the reference SAR values in Table B.1. This set-up utilizes a flat phantom and a reference dipole source. Thus, this validation procedure does not include uncertainty due to device positioning variability.

System validation is performed annually, when a new system is put into operation, or whenever modifications have been made to the system, such as a new software version, different readout electronics, or different types of probes. System validation shall be done with a calibrated probe.

The objective of this clause is to provide a methodology for SAR measurement system validation. Since SAR measurement equipment, calibration techniques, phantoms, and tissue-equivalent liquids can vary widely between various laboratories, a validation methodology is needed to ascertain that uniform results are obtained within reasonable measurement uncertainties. Numerically calculated reference SAR values for use in system validation are listed in Table B.1.

NOTE The system validation procedure is neither an alternative to probe calibration nor to the uncertainty estimation of Clause 7. The probe and the readout electronics shall be calibrated regularly according to the procedures given in Annex B of IEC 62209-1:2005. Probe hemispherical isotropy is not considered in the protocol for system validation.

B.3.2 Phantom set-up

The flat phantom set-up described for the system check (see Figure B.1) is also used for the system validation tests. The system validation shall be performed using tissue-equivalent liquids having dielectric properties as defined in Table 1.

B.3.3 Reference sources

B.3.3.1 Reference dipole source

The phantom shall be irradiated using a reference dipole specified in Annex D for the required frequency. The reference dipole shall be positioned below the bottom of the phantom and centred with its axis parallel to the longest side of the phantom. A low loss and low relative permittivity spacer can be used to establish the correct distance between the top surface of the reference dipole and the bottom surface of the phantom. The distance between the liquid-filled phantom bottom surface and the reference dipole centre (designated *s*) is specified within 0,2 mm for each test frequency. The reference dipole shall have a return loss better than - 20 dB (measured in the set-up) at the resonant frequency to reduce the uncertainty in the power measurement.

For the reference dipoles described in Annex D, the spacing distance *s* is given by:

a) s = 15 mm ± 0,2 mm for 300 MHz $\leq f \leq$ 1 000 MHz;

b) s = 10 mm ± 0,2 mm for 1 000 MHz $< f \leq$ 3 000 MHz;

c) s = 10 mm ± 0,2 mm for 3 000 MHz $< f \leq$ 6 000 MHz.

The reference dipole arms shall be parallel to the flat surface of the phantom within a tolerance of ± 2° or less (see Figure B.1).

Computation of the reference values for frequencies > 5 000 MHz requires specific consideration of the build structure of the small dipoles (both internal and external) and numerical values may therefore only be specific to dipoles from one manufacturing source. Also, the structure of the distance spacer used shall also be modelled as it can affect the numerical values obtained.

B.3.3.2 Reference waveguide sources

The reference SAR values for waveguide sources given in Table B.2 are, at present, only defined for frequencies > 5 000 MHz. This is due to the difficulties of handling the larger waveguides needed for lower frequencies. Above 5 000 MHz, the reference SAR values calculated for waveguides are less dependent on constructional nuances than for dipoles. Two procedures have been advanced for using either open-ended or matched-window waveguides resulting in the two sets of reference values given in Table B.2.

B.3.3.3 Reference open-ended waveguide source

The purpose of this subclause is to provide a procedure for using a full-band rectangular waveguide as a source for system validation and system check. The procedure is applicable for frequencies above 5 GHz, where the use of dipole sources may require very detailed consideration of spacer and internal structure to enable accurate computation of reference values. Waveguide sources provide a more readily modelable source geometry for which reference values will be less dependent on manufacturing implementation details.

Reference waveguide sources have been studied for the two cases of open-ended waveguides spaced away from the flat-phantom [52] and waveguides with a matching window placed directly against the phantom [70]. Different waveguide dimensions were used for each study, so the reference values (given in Table B.2) are different for each case. Choice of method will depend on equipment availability. A waveguide with a matching window is needed for SAR probe calibration, and use of this procedure [70] offers easier source positioning and requires less waveguide components. The open-ended procedure has the advantages of not requiring a matching window and the ability to tune the waveguide to minimise reflected power.

The procedure using a matching-window is described here but full details enabling the use of the open-ended waveguide have been published [52], where the reference values listed in Table B.2 are given.

The matched-waveguide source described in [70] uses a rectangular waveguide (WR 137 also known as WG13) with internal dimensions of 40 mm × 20 mm. A 4,3 mm thick matching window is implemented in the form of a detachable flange containing a low-loss ceramic material of relative permittivity, $K = 6$. The flange dimensions are those for an IEC-designated PDR58 flange i.e. 81 mm by 62 mm in overall extent.

Reference values for this source geometry have been computed at frequencies of 5 200 MHz and 5 800 MHz by different groups using different FDTD codes [51],[70] and the values are listed in Table B.2.

The proposed validation reference values include data for the centreline decay in a box phantom when following the procedures above. The equations given in Table B.2 have been fitted to the computationally-derived FDTD data [52] and can be used to represent reference value centreline profiles.

Centreline scans (above the centre of the waveguide matching window) should be made in steps of 0,2 mm starting with the probe in direct contact with the bottom of the phantom box. The SAR values should be normalised to 0,25 W feed input power and post-processed to apply boundary corrections for comparison with the reference profiles. Separate consideration should be given to the shape and magnitude of the measured data in relation to the reference values. It should be demonstrated that the shape of the profile matches the reference profiles to confirm the absence of interfering influences and the applicability of any boundary correction scheme applied.

With the feed-input to the waveguide set-up as in Figure B.1 (but with waveguide instead of dipole source), and with 3D scan data collected according to the criteria of Clause 5, SAR values normalised to a net input power of 0,25 W should be compared with the reference values in Table B.2.

Full-band rectangular waveguides can be used as well-characterized broadband irradiators for SAR system validations for frequencies in excess of 3 GHz. Commercially available waveguides are broadband with simultaneous bandwidths larger than 1 GHz to 2 GHz.

B.3.4 Reference dipole input power measurement

The input power measurement set-up described for the system check (see B.2.4) is also used for system validation tests.

B.3.5 System validation procedure

System validation is used for verifying the accuracy of the complete measurement system and accuracy of the software and control algorithms. Device positioning uncertainties are not considered. The system validation procedure consists of five steps. Step a) is the most important part of the system validation procedure and shall be done every time. Steps b) to e) (recommended) offer a means for quick and simple validations of the performance of probe, readout electronics, and software. These additional tests shall be done any time system components have been modified (e.g., new software release, new readout electronics, new probe type) but need only to be performed for the same system version by each laboratory (e.g., by the calibration laboratory or by the SAR measurement system end-user laboratory). The system validation procedure is as follows:

a) SAR evaluation: A complete 1 g and/or 10 g averaged SAR measurement is performed using a standard source of Annex D. The input power of the standard source is adjusted to produce a 1 g and/or 10 g averaged SAR value falling in the range of 0,4 W/kg to 10 W/kg. The 1 g and/or 10 g averaged SAR is measured at frequencies in Table B.1 within the range to be used in compliance tests. The results are normalized to 1 W forward input power and compared with the reference SAR value shown in columns 3 and 4 of Table B.1. The difference between the measured values and the target values given in Table B.1 or Table B.2 should be less than the expanded uncertainty for the system validation using the procedures of Table 6.

b) Extrapolation routine: Local SAR values are measured along a vertical axis directly above the centre of the standard source (i.e., dipole feed-point or centre line of waveguide) using the same test grid-point spacing as used for handset SAR evaluations. The measured values are extrapolated to the phantom surface and compared to the appropriate target value (column 5 of Table B.1 or column 4 of Table B.2, with $d = 0$). If the dipole source is used, this measurement is repeated along another vertical axis with a 2 cm transverse offset (y direction of Figure B.1) from the standard dipole feed-point. SAR values are extrapolated to the phantom surface and compared with the numerical values given in column 6 of Table B.1. The difference between the extrapolated values and the target values should be less than the expanded uncertainty for system validation using the procedures of Table 6.

c) Probe linearity: The measurements in step a) are repeated using different input power levels. The power levels selected for each frequency are selected to produce 1 g and/or 10 g averaged SAR values of approximately 10 W/kg, 2 W/kg, 0,4 W/kg, 0,08 W/kg and 0,01 W/kg. The measured SAR values are normalized to 1 W forward input power and compared with the 1 W normalized values from step a). The difference between these values should be less than the expanded uncertainty for the linearity component using the procedures of Table 6 and 7.2.2.3.

d) Modulation response: The measurements in step a) are repeated with pulse-modulated signals having a duty factor of 0,1 and pulse repetition rate of 10 Hz. The power is adjusted to produce a 1 g and/or 10 g averaged SAR of approximately 8 W/kg with a CW signal or a peak power of approximately 80 W/kg. The measured SAR values are normalized to 1 W forward input power and duty factor of 1, and compared with the 1 W normalized values from step a). The difference between these values should be less than the expanded uncertainty for system validation using the procedures of Table 6.

e) Probe axial isotropy: The center point of the probe's sensors is placed directly above the centre of the standard source at a measurement distance of 5 mm to 10 mm from the phantom inner surface. The probe (or standard source) is rotated around its axis at least 180° in steps no larger than 15°. The maximum and minimum SAR readings are recorded. The difference between these values should be less than the expanded uncertainty for the axial isotropy component using the procedures of Table 6 and 7.2.2.2.

B.3.6 Reference SAR values

In the system validation test, the reference dipole constructed for the frequency f_i (described in Annex D) shall produce the numerical reference peak spatial-average SAR values shown in columns 3 and 4 of Table B.1, within the uncertainty for system validation (see Table 6 Note 10). Columns 5 and 6 of Table B.1 are used to validate the system extrapolation routines, as described in B.3.5. The reference SAR values have been calculated using the FDTD numerical-computation method with the parameters of the flat phantom of Table D.2. The values for frequencies between 300 MHz and 6 000 MHz have been experimentally verified. The values above 3 GHz depend on the dipole spacer and detailed construction of the dipoles and may vary by as much as ±10 %. The reasons are that the dipole dimensions are short with respect to arm diameter and spacer dimensions, i.e., the numerical reference values are not generic and need to be determined for a particular configuration. The dielectric properties used for the liquid are defined in Table 1, and the dimensions of the reference dipoles are shown in Table D.1. Different reference SAR value may apply for dipoles whose mechanical dimensions depart from those of the reference dipoles given in Annex D.

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

1	2	3	4	5	6
Frequency MHz	**Phantom shell thickness** mm	**1 g SAR** W/kg	**10 g SAR** W/kg	**Local SAR at surface (above feedpoint)** W/kg	**Local SAR at surface (*y* = 2 cm offset from feedpoint)** W/kg
300	6,3	3,02	2,04	4,40	2,10
300	2,0	2,85	1,94	4,14	2,00
450	6,3	4,92	3,28	7,20	3,20
450	2,0	4,58	3,06	6,75	2,98
750	2,0	8,49	5,55	12,6	4,59
835	2,0	9,56	6,22	14,1	4,90
900	2,0	10,9	6,99	16,4	5,40
1 450	2,0	29,0	16,0	50,2	6,50
1 800	2,0	38,4	20,1	69,5	6,80
1 900	2,0	39,7	20,5	72,1	6,60
1 950	2,0	40,5	20,9	72,7	6,60
2 000	2,0	41,1	21,1	74,6	6,50
2 450	2,0	52,4	24,0	104	7,70
2 585	2,0	55,9	24,4	119	7,90
2 600	2,0	55,3	24,6	113	8,29
3 000	2,0	63,8	25,7	140	9,50
3 500	2,0	67,1	25,0	169	12,1
3 700	2,0	67,4	24,2	178	12,7
5 000	2,0	77,9	22,1	305	15,1
5 200	2,0	76,5	21,6	310	15,9
5 500	2,0	83,3	23,4	349	18,1
5 800	2,0	78,0	21,9	341	20,3

NOTE 1 The mechanical dimensions of the reference dipoles given in Annex D shall be used. The values above 3 GHz depend on the dipole spacer and detailed construction of the dipoles and may vary by as much as ± 10 %. The reasons are that the dipole dimensions are short with respect to arm diameter and spacer dimensions, i.e. the numerical reference values are not generic and need to be determined for a particular configuration.

NOTE 2 The phantom dimensions given in 5.2.2 shall be used. The values above 3 GHz depend on the dipole spacer and may vary by as much as ± 10 %

NOTE 3 Should the dipole forward power result in measured SAR values that are above the dynamic range of the probe, lower powers should be used so as not to introduce additional measurement uncertainty or damage the probe.

Table B.2 shows the reference SAR values for the system validation test using the standard waveguide sources described in Annex D. The reference SAR values of Table B.2 were calculated using the finite-difference time-domain method [53]. The waveguide used in the simulations was modeled as a perfect electric conductor with dimensions as specified in Annex D. The phantom used in the simulations has a height of 216 mm, a width of 152 mm, a depth of 80 mm, a shell thickness of 2 mm and a shell relative permittivity of 2,56. The dielectric parameters of the liquid are as defined in Table 1.

Table B.2 – Numerical reference SAR values for reference matched waveguides in contact with flat phantom (from reference [53])

Frequency (MHz)	**1g SAR (W/kg/W)**	**10g SAR (W/kg/W)**	**Point SAR as a function of distance, *d* (mm) into the phantom along its centre-line**
5 200	159,0	56,9	548,4 exp(-2d/6,25)
5 800	181,2	61,5	682,0 exp(-2d/5,57)

NOTE 1 All SAR values are normalized to 1 W forward power.

NOTE 2 The 1 g and 10 g reference SAR values are only valid for the system validation procedure, using standard waveguides having dimensions as defined in Annex D.

NOTE 3 Should the forward power result in measured SAR values that are above the dynamic range of the probe, lower powers should be used so as not to introduce additional measurement uncertainty or damage the probe.

Annex C
(informative)

Fast SAR testing

C.1 General

This annex specifies a possible approach for fast SAR assessment techniques which all aim at reducing the measurement time, to identify the highest SAR test conditions. Fast SAR techniques can be classified into three classes which are subsequently considered in the following subclauses.

C.2 Fast SAR methods based on specific measurement procedures and post-processing techniques

A first class of fast SAR techniques is based on a modified measurement procedure and post-processing algorithms. In practice, these methods require a special software but use a measurement system satisfying the specifications of Clause 5. For this type of approach, the idea is generally to decrease the time used for mechanical probe movements by significantly reducing the number of measurement points, and applying appropriate interpolation and extrapolation schemes [4], [9], [42], [43], [54], [55], [58]. In particular, some of the methods, e.g., [9], [43], [54], only necessitate a coarse area-scan and use extrapolation of all the volumetric data.

By definition, contributions of mechanical constraints to the uncertainty budget (7.2.3) will remain unchanged when using such techniques. However, the post-processing uncertainty contribution (7.2.5) may be different. In particular, the uncertainties in peak SAR location and mass-averaged SAR calculation have to be determined. However, since the zoom-scan step is omitted in most of the available techniques, 7.2.5.3.1 and 7.2.5.3.2 have to be considered in a different way. For some of the methods, e.g. [9], physical parameters (7.2.4) can also have an impact on the uncertainty budget, if the extrapolated SAR values depend on the dielectric parameters of the tissue-equivalent liquids in a specific way.

C.3 Fast SAR methods based on specific SAR assessment systems

The second class of fast SAR techniques includes a broad range of techniques but using SAR assessment systems generally meeting the Clause 5 specifications.

Among the existing and known techniques, most of them also focus on reducing probe movements, especially by using several probes or a probe array [8], [11], [36], [45], [57]. Probes of various types may be used (e.g. probes measuring only two tangential field components, thermal probes…), as well as different types of phantoms (solid, filled with gel…). Some of the systems, e.g. in [8], also use specific probe technologies and electronics allowing the assessment of the phase of the electric field in a given plane. Different types of dedicated post-processing algorithms [8], [45] can then be used to reconstruct the volumetric data inside the phantom.

Concerning the uncertainty budget, the contributions due to measurement procedures and post-processing methods for such specific assessment systems can be treated as in C.2. However, Clause 7 may not be sufficient to determine the complete uncertainty budget for any fast SAR method. Indeed, since this class of techniques use specific hardware, certain uncertainty contributions are hardware-dependent. An appropriate uncertainty budget shall hence be assessed, following explicit scientific or engineering rationales.

C.4 Fast SAR methods based on theoretical search for the highest SAR test conditions

C.4.1 General

A device may be usable with several antenna options, battery options and other accessories, and the number of possible combinations can be very large. Three traditional methods of experimentation are given below. These methods have drawbacks compared to the design of experiments (DOE) approach described in 6.2.2.

C.4.2 One-Factor-At-A-Time (OFAT) search

With this method, the experimenter starts with a baseline test condition and successively varies one factor at a time while holding all other factors constant. For example, this could be achieved by first varying antenna configurations, then battery types, then carry accessory types, then audio accessory types. At the end of each step, the factor giving the highest SAR is selected for the next steps. The main drawback of this approach is that it does not consider any interactions between the different accessory types (e.g., the interaction of the battery and the antenna on SAR that is not explained by the influences of each factor independently). If interactions exist, the OFAT approach may not find the optimum (i.e. highest SAR) solution.

C.4.3 Analysis of unstructured data

A common source of unstructured data is historical data. This data typically was collected without any specific objective in mind, or it may have been collected for different purposes than the current experimental objective. This data may be useful in spotting trends, but it may be very difficult to have high confidence in the findings.

For this reason, any findings from the analysis of unstructured data should be verified (e.g., using a DOE).

C.4.4 Best Educated Guess (BEG)

The BEG approach is the use of technical or theoretical knowledge of the DUT to determine how the experimentation should be proceeded. The drawback to this approach is that if the initial best guess does not produce the desired results, the experimenter has to take another guess. This can continue without any guarantee of success. For this reason, this approach is not appropriate for SAR compliance evaluation.

Annex D
(informative)

Standard sources and phantoms for system validation

D.1 Dipoles

A flat phantom should be irradiated using a reference dipole for the required frequency. The reference dipoles are defined for the specific dielectric parameters and thickness of the phantom shell as indicated in Table D.1. The reference dipole should be positioned below the bottom of the phantom and centred with its axis parallel to the longest dimension of the phantom. A low loss and low relative permittivity spacer can be used to establish the correct distance between the top surface of the reference dipole and the bottom surface of the phantom. The spacer should not change the measured 1 g and 10 g averaged SAR values more than 1 %. The distance between the liquid-filled phantom bottom surface and the reference dipole centre (designated *s*) is specified within 0,2 mm for each test frequency. The reference dipole should have a return loss of better than –20 dB (measured in the test system) at the test frequency to reduce the uncertainty in the power measurement. To meet this requirement, it is acceptable to fine-tune the reference dipoles using low-loss dielectric or metal tuning elements at the ends of the dipole. See Figure D.1 and Table D.1 for the mechanical dimensions of the dipole.

At frequencies above 3 GHz, the influence of the spacer on the dipole impedance can be significant, i.e., the spacer is not independent but shall be considered as an integral part of dipole. Hence, the same spacer, for which the dipole was optimized, shall always be used. The effect of the position change of the spacer with respect to the feedpoint need to be assessed and considered in the uncertainty budget of the dipole (7.2.6).

D.2 Target SAR values

D.2.1 Target SAR values below 3 GHz

The mechanical dimensions of the dipoles shall be met with a tolerance of better than ± 2 %. The target values are provided in Table B.1. It is important to demonstrate by numerical means that this spacer does not change the measured 1 g and 10 g averaged SAR values more than 1 %.

D.2.2 Target SAR values above 3 GHz

The target values above 3 GHz cannot be universally given as for below 3 GHz due to the greater effect from the spacer, phantom bottom and mechanical tolerances. Thus, the target values may be different from one dipole to another. It is important that for each dipole used for system validation a fully documented analysis is provided based on numerical simulations. This shall include a sensitivity analysis of the mechanical tolerances, feedpoint modelling and phantom properties.

Table D.1 – Mechanical dimensions of the reference dipoles

Frequency MHz	**Phantom shell thickness** mm	***L*** mm	***h*** mm	***d*₁** mm	***d*₂** mm
300	6,3	396,0	250,0	6,35	
300	2,0	420,0	250,0	6,35	
450	6,3	270,0	166,7	6,35	
450	2,0	290,0	166,7	6,35	
750	2,0	176,0	100,0	6,35	
835	2,0	161,0	89,8	3,6	
900	2,0	149,0	83,3	3,6	
1 450	2,0	89,1	51,7	3,6	
1 800	2,0	72,0	41,7	3,6	
1 900	2,0	68,0	39,5	3,6	
1 950	2,0	66,3	38,5	3,6	
2 000	2,0	64,5	37,5	3,6	
2 450	2,0	51,5	30,4	3,6	
2 585	2,0	49,1	29,0	3,6	
2 600	2,0	48,5	28,8	3,6	
3 000	2,0	41,5	25,0	3,6	
3 500	2,0	37,0	26,4	3,6	
3 700	2,0	34,7	26,4	3,6	
5 000	2,0	20,6	40,3	3,6	2,1
6 000	2,0	20,6	40,3	3,6	2,1

NOTE 1 The tolerance on *L*, *h* and *d* should be within ± 2 %.

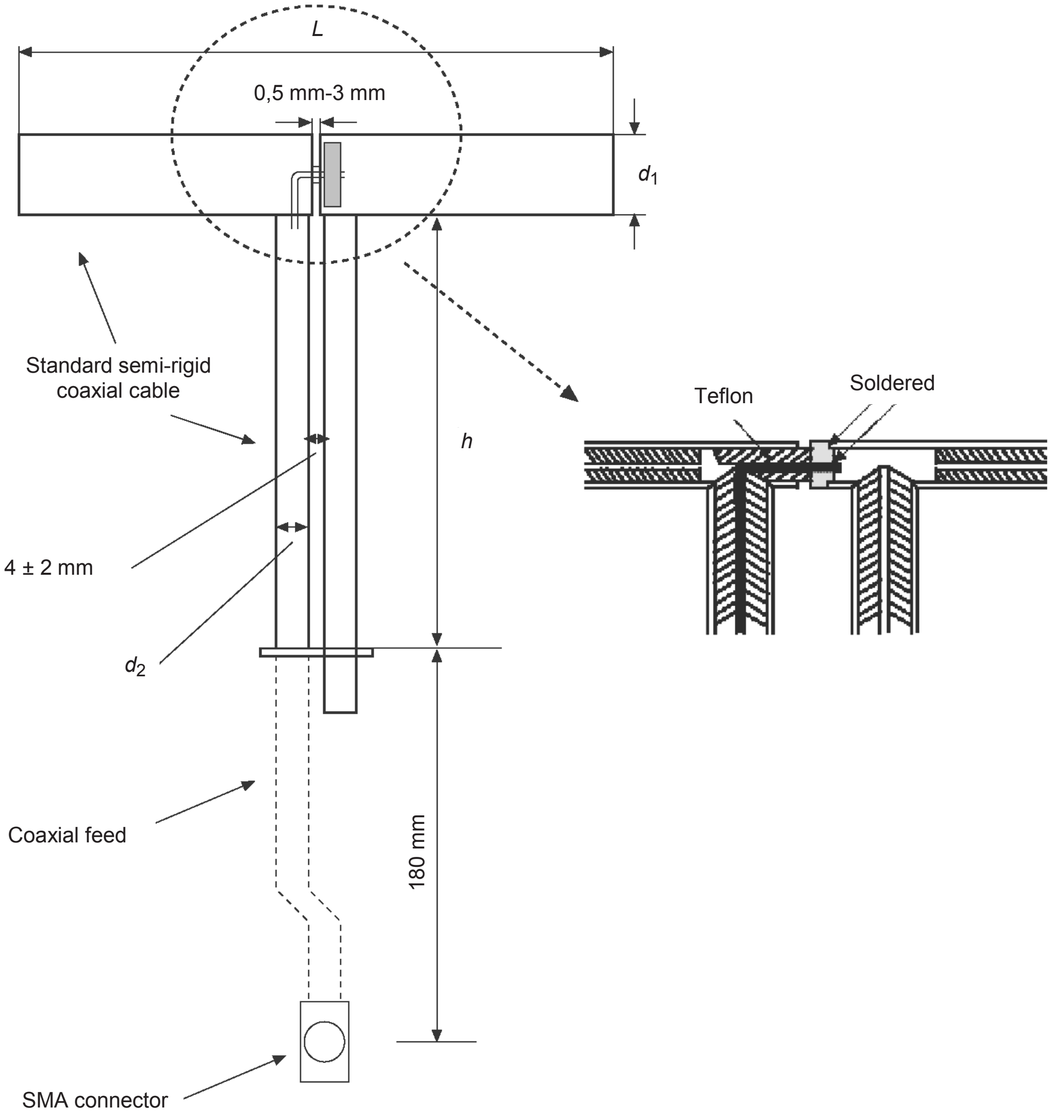
NOTE 2 The values for 5 000 MHz to 6 000 MHz are valid for a phantom shell thickness of 2 mm. The return loss shall be more than 20 dB (better than -20 dB).

For the reference dipoles described in this annex, the spacing distance *s* is given by:

a) s = 15 mm ± 0,2 mm for 300 MHz $\leq f \leq$ 1 000 MHz,

b) s = 10 mm ± 0,2 mm for 1 000 MHz $< f \leq$ 6 000 MHz.

The reference dipole arms shall be parallel to the flat surface of the phantom within a tolerance of ± 2° or less (see Figure D.2). This can be assured by carefully positioning the empty phantom and the reference dipole to horizontal level using a spirit level.



Key

L	length of the dipole
d_1	diameter of the dipole arms
d_2	diameter of the stub
h	length of the balun choke section

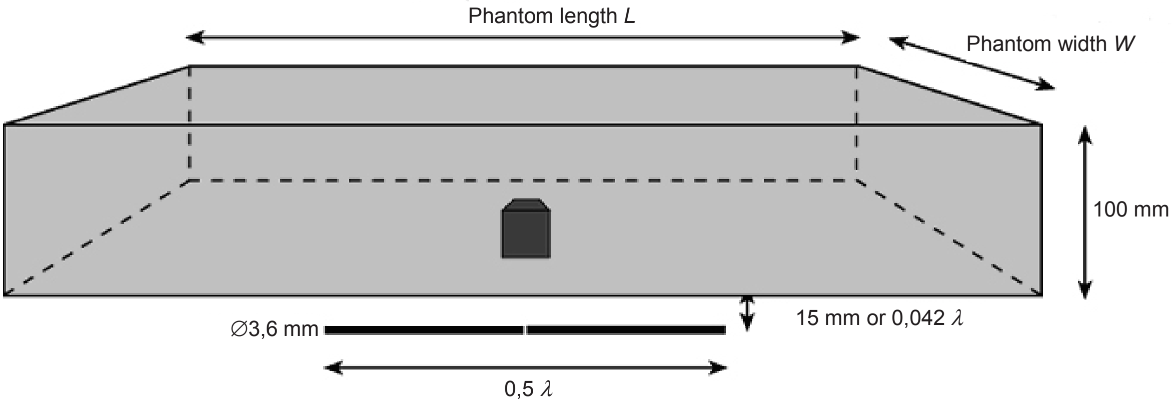
Figure D.1 – Mechanical details of the reference dipole

D.3 Flat Phantom

The influence of the dimensions of the flat phantom (see Figure D.2) on the absorbed energy in a 10 g cube inside the liquid-only phantom (without box) was assessed numerically using a commercial FDTD code. The phantom was illuminated with a matched dipole antenna at a distance of 15 mm (0,042 λ at 840 MHz). The dimensions of the phantom (W and L) were varied between 0,4 λ and 3 λ. The power absorbed in the cube was alternately normalized to a feedpoint current of 1 A or a feedpoint power of 1 W. Although deviations occur in the absorbed power in the cube when normalized either to the feedpoint power or the feedpoint current, the minimum dimensions necessary to keep the uncertainty below one percent were determined for both methods of normalization. The above conditions are met for dimensions of the flat phantom larger than 0,6 λ in length and larger than 0,4 λ in width, as shown by Figure D.3. The influence of the width of the phantom is not very large. However, the width should not be less than 0,4 λ to keep the deviation of the absorbed power within the limit of 1 %. The dimensions of the phantom set-up can be scaled in terms of the free-space wavelength. The dependence on the liquid properties is not very critical as long as it is relatively lossy.

The effects resulting in differences depend on perturbations of the dipole current magnitude and spatial distribution. Since the dipole dimensions are large compared with the SAR averaging volumes, the perturbations will increase with volume size. Although the depth used in this study was 100 mm, instead of the 150 mm required for the flat phantom in this annex, it is 2,57 times the penetration depth at 840 MHz, and therefore the power reflection at the liquid surface is negligible (less than 1 %).

NOTE Because of its larger size, a 10 g averaging cube will be more sensitive to dimension changes, i.e. the uncertainty associated with the 1 g average will be smaller than that of the 10 g average.



Key

λ free-space wavelength

NOTE A 10 g cube is shown at the bottom centre of the flat phantom.

Figure D.2 – Dimensions of the flat phantom set-up used for deriving the minimal dimensions for *W* and *L*

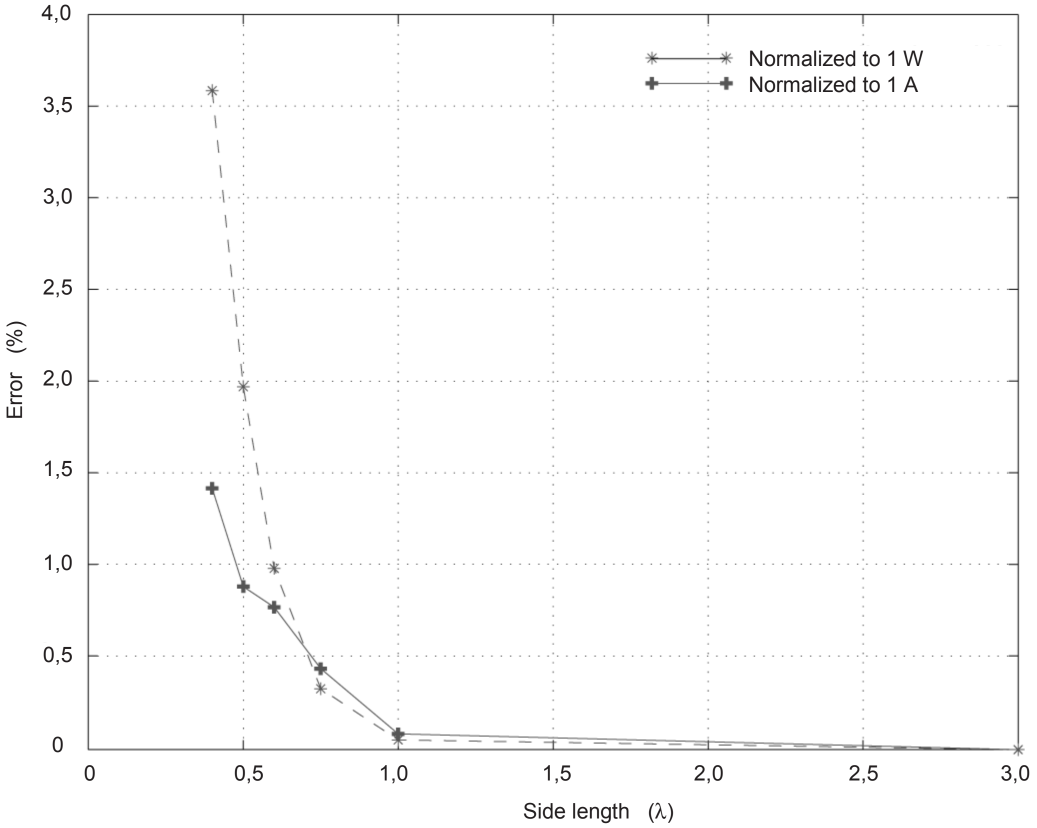


Figure D.3 – FDTD predicted uncertainty in the 10 g peak spatial-average SAR as a function of the dimensions of the flat phantom compared with an infinite flat phantom

Table D.2 – Parameters used for calculation of reference SAR values in Table B.1

Frequency MHz	**Phantom shell thickness** mm	**Phantom shell permittivity**	**Phantom dimensions used for FDTD models** mm **x, y, z**	**Reference dipole distance *s* from the liquid** mm
300	6,3	3,7	1 000, 800, 170	15
450	6,3	3,7	700, 600, 170	15
750	2,0	3,7	700, 600, 170	15
835	2,0	3,7	360, 300, 150	15
900	2,0	3,7	360, 300, 150	15
1 450	2,0	3,7	240, 200, 150	10
1 800	2,0	3,7	220, 160, 150	10
1 900	2,0	3,7	220, 160, 150	10
1 950	2,0	3,7	220, 160, 150	10
2 000	2,0	3,7	160, 140, 150	10
2 450	2,0	3,7	180, 120, 150	10
2 585	2,0	3,7	180, 120, 150	10
2 600	2,0	3,7	180, 120, 150	10
3 000	2,0	3,7	220, 160, 150	10
3 500	2,0	3,7	174,110,150	10
3 700	2,0	3,7	174,110,150	10
5 000	2,0	3,7	90, 80, 35	10

Frequency MHz	Phantom shell thickness mm	Phantom shell permittivity	Phantom dimensions used for FDTD models mm x, y, z	Reference dipole distance *s* from the liquid mm
6 000	2,0	3,7	90, 80, 35	10
NOTE This table represents parameters used for the numerical FDTD modelling.				

D.4 Mechanical dimensions of standard waveguide source

The standard waveguide source of Figure D.4 with mechanical dimensions given in Table D.3 (corresponding to WR159 or UK WG-13) will produce the SAR values given in Table B.2 when the system validation test of B.3 is followed. If waveguides are used that have different parameters than those given in Table D.3, or if waveguides are used at frequencies other than those listed in Table D.3, the reference SAR values for those sources should be documented and independently verified (e.g., by comparison of numerical simulations with measurements).

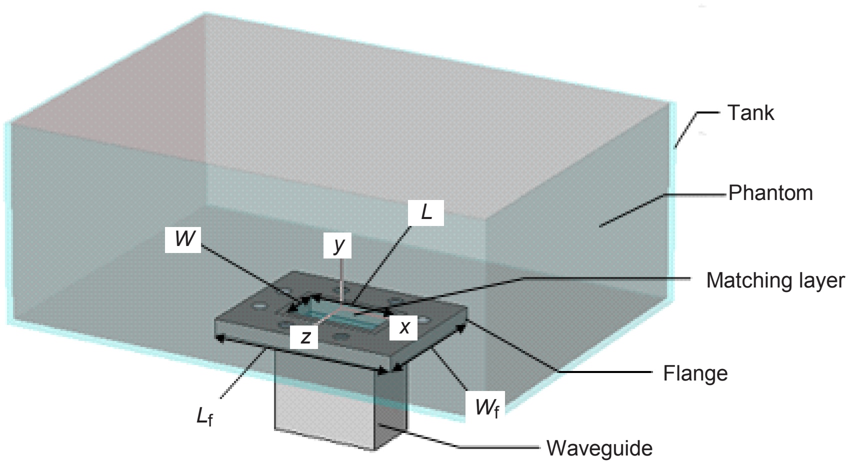


Figure D.4 – Standard waveguide source

Table D.3 – Mechanical dimensions of the standard waveguide

Frequency MHz	Phantom shell thickness mm	*L* mm	*W* mm	L_f mm	W_f mm	*t* mm	ε_r
5 200	2	40,39	20,19	81,03	61,98	5,3	6
5 800	2	40,39	20,19	81,03	61,98	4,3	6

NOTE *L* and *W* are the inner length and width of the waveguide, and *t* and ε_r are the thickness and relative permittivity of the matching layer. L_f and W_f are the outer length and width of the flange. The matching layer is a lossless dielectric slab that fills the cross-sectional $L \times W$ area of the waveguide. The waveguide and matching layer are in direct contact with the phantom shell.

Annex E
(informative)

Example recipes for phantom tissue-equivalent liquids

E.1 General

The dielectric properties of the liquid material used in the phantom shall be those listed in Table 1. For dielectric properties of tissue-equivalent liquid at other frequencies within the frequency range, a linear interpolation method shall be used. Table E.1 suggests examples of recipes for liquids having parameters as defined in Table 1.

More examples of recipes are given in Annex I of IEC 62209-1:2005.

WARNING

To ensure personnel safety, the users shall follow the instructions provided in the material safety data sheet (MSDS) for any material, and/or any local regulations.

E.2 Ingredients

The following ingredients are used for producing the tissue-equivalent liquids:

a) Sucrose (Sugar) (> 98 % pure)

b) Sodium Chloride (Salt) (> 99 % pure)

c) De-ionised water (16 MΩ cm resistivity minimum)

d) Hydroxyethyl Cellulose (HEC)

e) Bactericide

f) Diethylene Glycol Butyl Ether (DGBE) (> 99 % pure)

g) Diethylene Glycol monohexylether

h) Polyethylene glycol mono [4-(1,1,3,3-tetramethylbutyl) phenyl ether]. This is available as (Triton X-100). The quality of the Triton X-100 shall be ultra pure to match the composition of salt.

i) Diacetin

j) 1,2-Propanediol

k) Polyoxyethylene (20) sorbitan monolaurate (Tween 20)

l) Emulsifiers

m) Mineral Oil

NOTE 1 Viscosity of HEC-based tissue-equivalent liquids should be low enough not to affect E-field probe movement.

NOTE 2 Add salt to water first to make a saline solution, then add the Triton X-100.

NOTE 3 Actual results and mixture percentages may vary from those shown depending on grade and type of components used.

NOTE 4 The formulas containing Triton X-100 are under review and verification.

E.3 Tissue-equivalent liquid formulas (permittivity/conductivity)

Table E.1 – Suggested recipes for achieving target dielectric parameters

Frequency (MHz)	**30**	**50**		**144**		**450**		**835**	**900**	
Recipe source number	3	3	2	2	3	2	4	2	2	4
Ingredients (% by weight)										
Deionised water	48,30	48,30	53,53	55,12	48,30	48,53	56	50,36	50,31	56
Tween			44,70	43,31		49,51		48,39	48,34	
Oxidised mineral oil							44			44
Diethylenglycol monohexylether										
Triton X-100										
Diacetin	50,00	50,00			50,00					
DGBE										
NaCl	1,60	1,60	1,77	1,57	1,60	1,96		1,25	1,35	
Additives and salt	0,10	0,10			0,10					
Measured dielectric parameters										
ε_r'	54,2	53,1	54,54	52,81	51,0	43,29	42,3	41,6	41,0	40,6
σ (S/m)	0,75	0,75	0,76	0,76	0,77	0,88	0,84	0,90	0,98	0,98
Temp. (°C)			21	21		21	20	21	21	20
ε_temp_liquid$_{\text{uncertainty}}$ (%)	0,8	0,1			0,1	0,1		0,04	0,04	
σ_temp_liquid$_{\text{uncertainty}}$ (%)	2,8	2,8			2,6	4,2		1,6	1,6	
Target values (from Table 1)										
ε_r'	55,0	54,5		52,4		43,5		41,5	41,5	
σ (S/m)	0,75	0,75		0,76		0,87		0,90	0,97	

Table E.1 *(continued)*

Frequency (MHz)	**1 800**		**2 450**	**4 000**	**5 000**	**5 200**	**5 800**	**6 000**
Recipe source number	2	4	4	4	4	1	1	4
Ingredients (% by weight)								
Deionised water	54,23	56	56	56	56	65,53	65,53	56
Tween	45,27							
Oxidised mineral oil		44	44	44	44			44
Diethylenglycol monohexylether						17,24	17,24	
Triton X-100						17,24	17,24	
Diacetin								
DGBE								
NaCl	0,50							
Additives and salt								
Measured dielectric parameters								
ε_r'	40,2	38,9	37,9	35,8	34	36,8	35,2	32,2
σ (S/m)	1,41	1,42	1,83	3,18	4,29	4,60	5,29	5,44
Temp. (°C)	21	20	20	20	20	22	22	20
$\varepsilon\_temp\_liquid_{uncertainty}$ (%)	0,4					1,7	1,8	
$\sigma\_temp\_liquid_{uncertainty}$ (%)	2,3					2,7	2,6	
Target values (from Table 1)								
ε_r'	40,0		39,2	37,4	36,2	36,0	35,3	35,3
σ (S/m)	1,40		1,8	3,43	4,45	4,66	5,07	5,27

NOTE 1 Multiple columns under a single frequency indicate optional recipes.

NOTE 2 Recipe number, reference:, 1 [verified by different labs], 2 [20], 3 [64], 4 [65].

NOTE 3 The values of $\varepsilon\_temp\_liquid_{uncertainty}$ and $\sigma\_temp\_liquid_{uncertainty}$ are liquid temperature uncertainties described in 7.2.4.4, based on measurements of the applicable liquid recipes given above. These are not part of the original publications but have been subsequently developed by the project team.

Annex F
(normative)

SAR correction for deviations of complex permittivity from targets

F.1 General

In this standard, dielectric parameters of the tissue-equivalent liquid used for SAR measurement are chosen so as to give an SAR value that is conservative with respect to the exposure in a person. Deviations of the dielectric parameters from the target values can lead to measurement uncertainty. One way to reduce measurement uncertainty is to keep the dielectric parameters of the tissue-equivalent liquids within a tight tolerance of the targets (e.g., within ± 5 %). However, it can be difficult to find suitable and stable liquid recipes whose dielectric parameters are close to the targets, particularly at frequencies above 2 GHz. There are three solutions to this problem:

a) change the target dielectric parameters to match those of available liquid recipes;

b) widen the tolerance (without correcting the SAR for the deviation in dielectric parameters);

c) allow a wider tolerance, and correct the SAR for the deviation of the measured dielectric parameters from the target values.

The third solution is the best because changing the targets may restrict the standard to particular liquid recipes, and simply widening the tolerance increases the measurement uncertainty.

The methodology used to determine the SAR correction is described in [13] and [14]. The methodology was conducted over a frequency range of 30 MHz to 6 000 MHz. The methodology was also studied for permittivity and conductivity ranges of ± 20 % from the target values in Table 1, but ranges of ± 10 % have been chosen for this standard, as described in 6.1.1. Given that the change in dielectric parameters influences the conversion factor of the probe, this influence will be small if a ± 10 % range is used (see [13]).

F.2 SAR correction formula

From [13] and [14], a linear relationship was found between the percent change in SAR (denoted ΔSAR) and the percent change in the permittivity and conductivity from the target values in Table 1 (denoted $\Delta\varepsilon_r$ and $\Delta\sigma$, respectively). This linear relationship agrees with the results of Kuster and Balzano [48] and Bit-Babik et al. [2]. The relationship is given by:

$$\Delta \mathrm{SAR} = c_\varepsilon\, \Delta\varepsilon_r + c_\sigma\, \Delta\sigma \tag{F.1}$$

where

$c_\varepsilon = \partial(\Delta\mathrm{SAR})/\partial(\Delta\varepsilon)$ is the coefficients representing the sensitivity of SAR to permittivity where SAR is normalized to output power;

$c_\sigma = \partial(\Delta\mathrm{SAR})/\partial(\Delta\sigma)$ is the coefficients representing the sensitivity of SAR to conductivity, where SAR is normalized to output power.

The values of c_ε and c_σ have a simple relationship with frequency that can be described using polynomial equations. For the 1 g averaged SAR c_ε and c_σ are given by

$$c_\varepsilon = -7{,}854\times10^{-4} f^3 + 9{,}402\times10^{-3} f^2 - 2{,}742\times10^{-2} f - 0{,}202\,6 \tag{F.2}$$

$$c_{\sigma} = 9{,}804 \times 10^{-3} f^{3} - 8{,}661 \times 10^{-2} f^{2} + 2{,}981 \times 10^{-2} f + 0{,}782\,9 \qquad \text{(F.3)}$$

where

f is the frequency in GHz.

For the 10 g averaged SAR, the variables c_{ε} and c_{σ} are given by:

$$c_{\varepsilon} = 3{,}456 \times 10^{-3} f^{3} - 3{,}531 \times 10^{-2} f^{2} + 7{,}675 \times 10^{-2} f - 0{,}186\,0 \qquad \text{(F.4)}$$

$$c_{\sigma} = 4{,}479 \times 10^{-3} f^{3} - 1{,}586 \times 10^{-2} f^{2} - 0{,}197\,2 f + 0{,}771\,7 \qquad \text{(F.5)}$$

where

f is the frequency in GHz.

F.3 Uncertainty of the correction formula

The mean power uncertainty of equations in Clause F.2, defined in [13] as the RMS error between the SAR deviation predicted by the formulas and the simulated deviation over 440 analyzed cases, is shown in Table F.1 for the peak 1 g average SAR and the peak 10 g average SAR. Table F.1 shows how the mean power error increases as the maximum allowable value of $\Delta\varepsilon_r$ and $\Delta\sigma$ increases. It has also been shown in [13] that these corrections are valid for realistic wireless handset models.

Table F.1 – Root-mean-squared error of Equations (F.1) to (F.3) as a function of the maximum change in permittivity or conductivity [13]

Max. change in ε_r **or** σ	**RMS uncertainty for SAR$_{1g}$** %	**RMS uncertainty for SAR$_{10g}$** %
± 5 %	1,2	0,97
± 10 %	1,9	1,6

Using this approach, the measurement uncertainty is lower, due to the fact that this correction eliminates the need for uncertainty items that account for the deviation of the dielectric parameters from the targets. Instead, there is an uncertainty item which accounts for the error of the correction formula. The value of this uncertainty item is given in Table F.1. For ± 10 % deviation in permittivity and conductivity, enter 1,9 % and 1,6 % in the uncertainty budget for 1 g and 10 g average SAR, respectively. These uncertainty values should be entered into the appropriate rows of Tables 5, 6 and 7 where a normal probability distribution is assumed.

Annex G
(informative)

Hands-free kit testing

G.1 Concept

This annex is based on [3], which should be referred to for further details.

The following annex describes a procedure suitable for assessing the SAR in the head from a wired personal hands-free headset. It is noted that other procedures following the same core principles will also be suitable.

An experimental setup designed in accordance with the principles set out in IEC 62209-1:2005 and in this standard should be used. An isotropic miniature E-field probe should be used to perform electric field measurements in the liquid head tissue following recognized standard procedures.

For correct comparison the configurations shown in Figures G.1 and G.2 should be used.

Although this standard adopts the flat phantom, hands-free kit testing using the flat phantom has not been established. In addition, no exact shape and size of the phantom with torso is provided. This annex only provides how to make an informed assessment of hands-free kits.

Figure G.1 – Configuration of a wired personal hands-free headset

Figure G.2 – Configuration without a wired personal hands-free headset

The simulant head tissue at the appropriate operating frequency should be used as defined in IEC 62209-1:2005.

The two conditions to be tested are:

- the head region of the fibreglass model is filled with the tissue simulant;
- the whole phantom is filled.

In both setups, the phone should be placed next to the ear, and then at the waist with the earpiece connected to the phone via leads and taped at the ear. Scanning shall be focused in a 32 mm × 32 mm area at the ear. This area was chosen to find SAR changes close to the ear. The maximum SAR in the head should also be measured.

The human phantoms used for measurements involving a hands-free accessory should include the torso, i.e. measurements shall not be performed on the head phantom alone.

This has significant impact on the results because the RF energy coupled into the leads of hands-free accessories is strongly attenuated by the body.

G.2 Example results

For the phantom partially filled with tissue simulant and the phone speaker centred at the phantom ear. The peak 1 g avg. SAR of 1,2 W/kg was located below the ear. The maximum 1 g average SAR at the ear position was about 0,4 W/kg. There was no significant change in the results of this measurement when the torso was also filled with tissue simulant as the phone interacts mainly with the head. When, the earpiece accessory was measured. The earpiece was centred at the phantom ear canal and the phone at the belt (see Figure G.1). In this case (with the torso empty) the peak 1 g average SAR measured at the ear (32 mm × 32 mm) was 0,05 W/kg, showing an 87 % (9 dB) reduction compared to the level from the phone at the ear position. The same configuration as in the second case, but with the phantom torso completely filled with tissue simulant, gave a peak 1 g average SAR of 0,02 W/kg near the ear, or a 95 % (13 dB) reduction from the case of phone at the ear.

G.3 Discussion

From these measurements it is clear that: 1) the SAR near the ear where the earpiece was located is low compared to the peak SAR produced by the phone; 2) the global peak SAR is not located near the ear with the earpiece accessory; 3) the presence of the torso attenuates the field from the earpiece accessory, resulting in a lower SAR compared to that measured without the torso. It should be noted that in the situations mentioned above, coupling between the phone and earpiece accessory was very strong as shown by the additional measurement of global maximum SAR in the head from the earpiece without the presence of the torso (the same configuration as described above for the second set of measurements). These measurements gave a peak 1 g average SAR of 0,9 W/kg. Again, it should be noted that the location of this peak is not near the earpiece, but it is shifted down to the cheek where the corresponding current on the earpiece wire is stronger. This is close to the results of computations with best coupling between the wire and RF source, which indicated that the presence of the torso leads to a strong decrease of the global maximum SAR in the head even when the wire is strongly coupled to the RF source (handset).

The experimental measurements have also shown that SAR from the earpiece accessories near the ear is always lower than when the phone is near the head. It should be noted that if the primary RF source is removed from the ear, the secondary radiator (earpiece) produces a much lower exposure at that location.

Though attenuation effect of the body may vary depending on the position of the wire relative to the body, if a large part of the hands-free accessory wire is close to the user’s body, SAR measured in the ear region may be more than 10 dB lower than SAR measured from the handset alone when placed near the head.

Annex H
(informative)

Skin enhancement factor

NOTE The Project Team is conscious that the scope is to develop a measurement standard. It is beyond the scope of the IEC to decide on exposure limits. The current metric for basic restrictions between 100 kHz and 10 GHz is SAR. In order to get clarification on the question raised in this annex project team 62209 asked ICNIRP and IEEE ICES for technical comments and advice.

H.1 Background

In the course of the development of this measurement standard, several studies ([6], [7], [71]) indicated that the measurements in homogeneous phantom may result in localised SAR values lower than the maximum values in a heterogeneous and anatomically realistic body model at 1 900 MHz. Since then, a number of research projects and simulations were undertaken within the IEC Technical Committee 106 to verify these results. Simulations were undertaken with homogeneous phantoms and layered models simulating skin fat and muscle. Christ's findings were confirmed in simulations for the metric SAR.

The exposure standard of IEEE ICES C95.1 and the recommendations by ICNIRP are designed to protect against established adverse heath effects. ICNIRP states in [10], page 17: *"Established biological and health effects in the frequency range 10 MHz to a few GHz are consistent with responses to a body temperature rise of more than 1 °C."* Nevertheless, simulations for temperature result in different distributions compared to SAR distributions (see Figure H.1), with the temperature rise distribution being much smoother than the corresponding SAR distribution. This result indicates that local SAR enhancements do not typically produce equivalent temperature rise enhancement due to the different nature of the underlying physics: wave phenomena for SAR and diffusion phenomena for temperature.

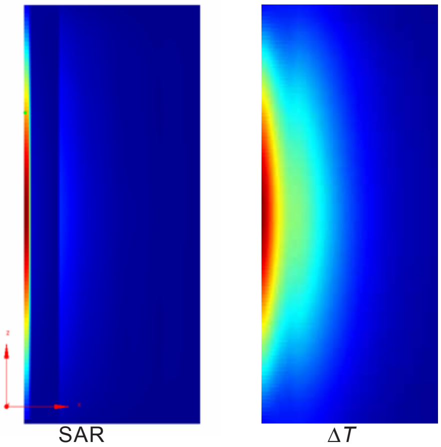


Figure H.1 – SAR and temperature increase (ΔT) distributions simulated for a three-layer (skin, fat, muscle) planar torso model

H.2 Rationale

The reasons for the higher localized SAR values in heterogeneous tissue are standing wave effects which can occur under far-field-like exposure conditions if a tissue layer with low water content, such as fat, bone or breast tissue, is enclosed between two tissues with high water content, e. g., muscle, skin, most inner organs, etc. The most typical structure consists of a fat layer between skin and muscle. Incident waves which pass the skin experience almost no attenuation in the subsequent fat tissue layer. If the thickness of the fat layer corresponds to approximately $\lambda/4$, the phase of the wave reflected at the muscle layer will lead to a standing wave with its maximum in the skin layer. This will lead to a significant increase of the local SAR in the skin. Even if the SAR is averaged over a cubical volume, which in this case will obtain a comparatively large amount of fat tissue, the SAR measured in the same volume of homogeneous tissue-equivalent liquid will not yield a conservative exposure estimate. A detailed discussion and quantification of this effect can be found in [6], [7].

H.3 Simulations

The project team investigated the existing literature in respect to age, sex and race on:

- statistical distribution of epidermis plus dermis thickness;
- statistical distribution of the fat layer thickness;
- thickness given by mean and standard deviation.

Skin anatomy and physiology undergo modifications throughout the whole lifespan. Diller [12] assumes that the skin thickness of children is 72 % of adult skin thickness.

Body-worn device positions according to a report of Carnegie Mellon University [26] were chosen. This report from Carnegie Mellon University identified regions of the human body where radios can be carried without negative impact on the person regarding his or her movement. Dynamic wearability is confined to body positions such as:

- arm – triceps;
- forearm;
- upper chest;
- back – subscapular;
- back – above pelvis;
- ankle;
- leg – calf;
- thigh – front;
- waist – lateral.

The thickness of the body tissue varies with individuals. The various thicknesses have a probability distribution. The SAR for a given skin and fat tissue (t_s, t_f) is weighted according to $p(t_s)\ p(t_f)$ by thickness probability.

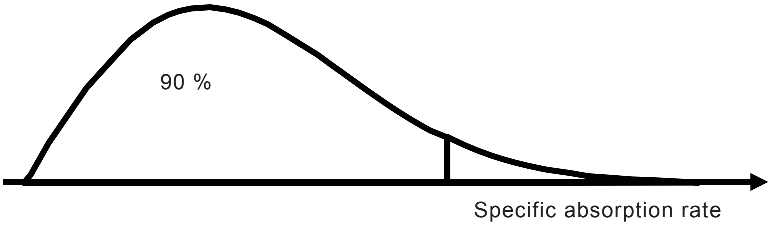


Figure H.2 –Statistical approach to protect 90 % of the population

Simulations were done for the different wearability areas with the data from the literature study on the skin and fat thicknesses of the human body [81]. Antennas with electric length of

0,5 λ, 0,47 λ, 0,35 λ, 0,23 λ, 0,10 λ and 0,05 λ were analysed at frequencies between 30 MHz and 6 GHz.

The increased SAR also varied with the distance of the antenna from the body. This distance depends on the frequency.

H.4 Recommendation

The results of all simulations for the different thicknesses of the skin, different thicknesses of the fat layers, different dielectric parameters, different antennas and different distances from the body were analysed. From all the simulations, adopting a statistical coverage factor protective of 90 % of the population (Figure H.2), skin enhancement factors can be derived as shown in Table H.1 and Figure H.3.

Table H.1 – Spatial-average SAR correction factors

Frequency band	Device to phantom distance	Skin enhancement factor[a]
300 MHz to 800 MHz	0 mm to 200 mm	1,0
800 MHz to 1 000 MHz	0 mm to 40 mm	1,0
	40 mm to 45 mm	linearly interpolate between 1,0 and 1,1
	45 mm to 200 mm	1,1
1 700 MHz to 3 000 MHz	0 mm to 20 mm	1,0
	20 mm to 35 mm	linearly interpolate between 1,0 and 1,5
	35 mm to 200 mm	1,5
5 000 MHz to 6 000 MHz	0 mm to 200 mm	1,0

[a] For all other frequencies and distances, use linear interpolation.

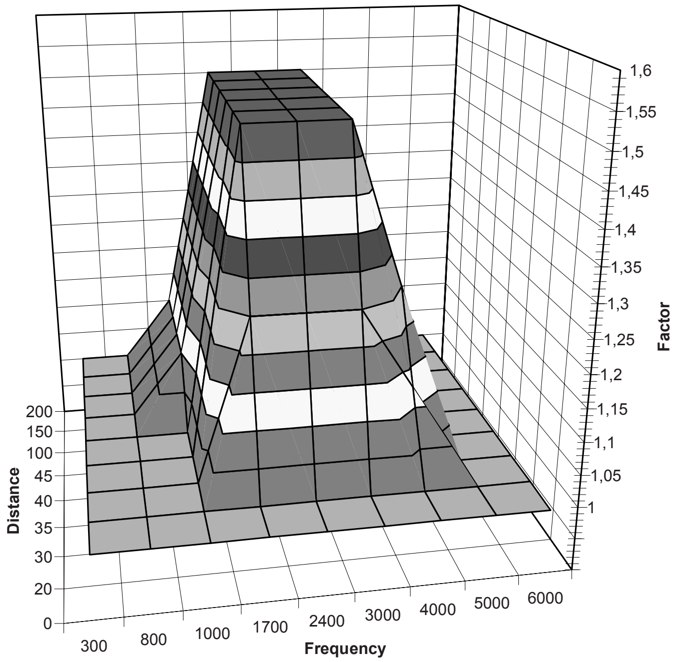


Figure H.3 – Spatial-average SAR skin enhancement factors

The project team asked the International Commission for Non-Ionizing Radiation Protection and the International Committee for Electrical Safety for advice whether this factor is necessary for the evaluation of the exposure. The International Committee for Electrical Safety came to a very clear consensus:

a) It is not necessary to apply a scaling factor to limit the skin SAR.

b) The measurement of SAR in a homogenous phantom without a scaling factor is adequate to protect the public.

The International Commission for Non-Ionizing Radiation Protection responded that this issue will be considered in the general revision of the RF guidelines.

In order to quantify the possible SAR underestimation and to specify the conditions under which this underestimation will occur, this annex is retained as an informative part to this standard.

Annex I
(informative)

Tissue-equivalent liquid dielectric property measurements and measurement uncertainty estimation

Annex J of IEC 62209-1:2005 applies for the measurement of the dielectric properties of liquids and uncertainty estimation. For the frequency range 30 MHz to 6 GHz the Table I.1 and Table I.2 shall be used instead of Table J.1 and Table J.2 of IEC 62209-1:2005.

Table I.1 – Parameters for calculating the dielectric properties of various reference liquids

Reference Liquid	Temperature °C	Reference	Model	ε_s	ε_∞	τ (ps)	β
DI water	20	[29]	Debye	80,21	5,6	9,36	1
DI water	25	[29]	Debye	78,36	5,2	8,27	1
DMS	20	[28][a]	Debye	47,13	7,13	21,27	1
DMS	25	[28][a]	Debye	46,48	6,63	19,18	1
DMS	25	[29]	Cole-Davidson	47,0	3,9	21,1	0,878
Ethanediol	20	[23][b]	Cole-Davidson	41,5	3,8	157,18	0,82
Ethanediol	20	[23][c]	Cole-Davidson	41,9	5,02	161,4	0,88
Methanol	20	[23]	Debye	33,90	4,70	53,20	1
Methanol	20	[20]	Debye	33,7	4,8	53,8	1
Methanol	20	[28][a]	Debye	33,64	5,68	56,6	1
Methanol	25	[28][a]	Debye	32,67	5,58	50,8	1

[a] Data derived from measurements to 5 GHz only.

[b] Recipe valid from 130 MHz – 20 GHz.

[c] Recipe valid from 30 MHz – 5 GHz.

Table I.2 – Dielectric properties of reference liquids at 20 °C

Frequency	**Methanol [21]**		**DMS [28]**		**DI water [37]**		**Ethanediol [51]**	
MHz	ε_r'	σ	ε_r'	σ	ε_r'	σ	ε_r'	σ
30	33,64	0,000 50	47,13	0,000 27	80,2	0,000 22	41,87	0,001 6
150	33,56	0,012	47,11	0,006 7	80,2	0,005 5	40,89	0,038
300	33,33	0,049	47,07	0,027	80,19	0,02	39,21	0,14
450	32,94	0,11	46,99	0,060	80,16	0,05	36,78	0,29
750	31,95	0,29	46,73	0,17	80,07	0,14	30,73	0,66
835	31,37	0,35	46,64	0,20	80,03	0,17	29,53	0,76
900	31,04	0,41	46,56	0,24	80,00	0,20	28,38	0,83
1 450	27,77	0,92	45,68	0,60	79,67	0,51	20,63	1,36
1 800	25,51	1,27	44,94	0,91	79,38	0,78	17,38	1,61
1 900	24,88	1,37	44,71	1,01	79,29	0,87	16,64	1,66
2 000	24,25	1,47	44,46	1,11	79,19	0,96	15,96	1,72
2 450	21,57	1,89	43,25	1,61	78,69	1,44	13,53	1,92
2 600	21,11	2,07	42,82	1,79	78,51	1,61	12,88	1,94
3 000	18,76	2,33	41,59	2,31	77,96	2,13	11,53	2,11
4 000	15,17	3,12	38,24	3,70	76,30	3,70	9,36	2,34
5 000	12,40	3,58	34,78	5,14	74,27	5,62	8,12	2,51
6 000	10,51	3,89	31,48[a]	6,52[a]	71,95	7,81	7,33	2,64

[a] Data derived from measurements to 5 GHz only.

Annex J
(informative)

Testing compliance for the exposure of the hand

J.1 Purpose

This annex will inform the user of this standard of the status of development of SAR measurement protocols for hand-held devices as defined in 3.11.

With respect to modelling the hand, there are practical difficulties in specifying a unique hand holding position that is applicable to all devices. Moreover, dosimetric studies suggest that, excluding the hand in modelling constitutes a conservative case scenario for SAR in the head [26]. For these reasons, in this standard the device under test is not held in a hand model during SAR evaluations within 200 mm from the head and torso. For the exclusive exposure of the hand at larger distances than 200 mm from the head or torso, see Clause J.3.

J.2 General

The hand includes a large number of bones, ligaments, muscles, nerves and blood vessels.

It is assumed that SAR within the hand induced by a hand-held wireless device would be lower than the SAR induced in the homogeneous flat phantom approximating wet tissue, but the research data supporting this assumption is not yet available.

A typical example of a hand-held device is a wireless enabled PDA with integrated RF module that is intended to be held in the hand at a distance larger than 200 mm from the head and body during use. This procedure is not applicable for devices which are intended to being hand-held to enable use at the ear (see IEC 62209-1:2005) or worn on the body when transmitting.

J.3 Procedure

The device shall be placed directly against the flat phantom as shown in Figure J.1, for those sides of the device that are in contact with the hand during intended use.

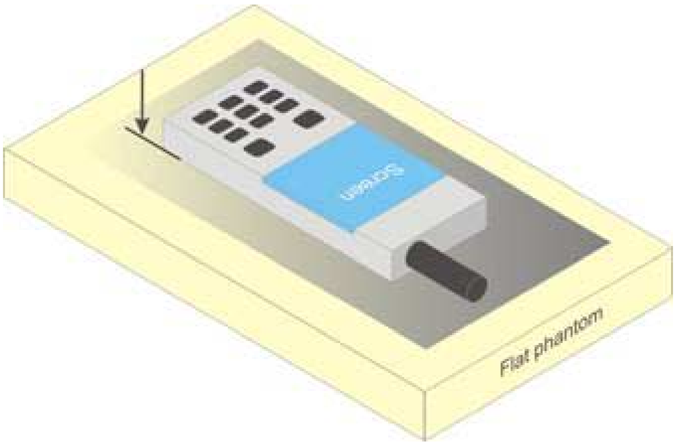


Figure J.1 – Test position for hand-held devices, not used at the head or torso

J.4 Rationale for measurement evaluation of hand-held devices

The measurement methods described in 6.1.4.9 use the same phantom and tissue simulant for SAR measurement that we assume to be conservative. Developing the SAR measurement methods for hands is a demanding task and will require more time and resources. For these reasons, it will be reviewed by future amendments of this standard.

Annex K
(informative)

Test reduction

K.1 General

TC 106 has the mandate to prepare international standards on measurement and calculation methods to assess human exposure to electric, magnetic and electromagnetic fields. The task includes assessment methods for the exposure produced by specific sources. It applies to basic restrictions and reference levels. However, the establishment of exposure limits is not in the scope of TC 106.

It is noted that this differs from typical IEC radiated disturbance EMC standards which do establish limits.

This standard provides a reproducible and conservative measurement methodology to measure the SAR of hand-held and body-mounted wireless communication devices, which can be used to determine compliance of such equipment with the human exposure basic restrictions. Clearly, there is a point where the power generated by wireless devices is at such a level that it is incapable of exceeding the basic restriction. Measurements following the procedure of this standard might then not be necessary.

K.2 Test reduction procedure

K.2.1 General

There may be DUTs that generate power at such a level that it is incapable of exceeding the basic restriction of the respective exposure guideline. That level can be determined by a variety of techniques which do not require the actual exposure level measurements. Determining this level would speed up the process without compromising technical accuracy. IEC 62479 proposes techniques for such purposes and may be applied.

K.2.2 Example 1

The maximum power level, $P_{\mathrm{max,m}}$, that can be transmitted by a device before the SAR averaged over a mass, m, exceeds a given limit, SAR_{lim}, can be defined. Any device transmitting at power levels below $P_{\mathrm{max,m}}$ can then be excluded from SAR testing. The lowest possible value for $P_{\mathrm{max,m}}$ is:

$$P_{\mathrm{max,m}} = \mathrm{SAR}_{\mathrm{lim}} \times m$$

For example, an exposure limit of $\mathrm{SAR}_{\mathrm{lim}}$ = 2 W/kg and an averaging mass of m = 10 g give a total transmitting power of $P_{\mathrm{max,m}}$ = 20 mW that would conservatively meet this exposure limit. For an exposure limit of $\mathrm{SAR}_{\mathrm{lim}}$ = 1,6 W/kg and an averaging mass of m = 1 g, a total transmitting power of $P_{\mathrm{max,m}}$ = 1,6 mW would conservatively meet the exposure limit. This assessment is based on the unrealistic assumption that all of the conducted power is radiated by the antenna and then absorbed in the body (i.e. none of the power is transmitted for communication) and all of the absorbed power is concentrated in the averaging mass. IEC 62479 gives less restrictive power thresholds that may be applied in certain cases.

K.2.3 Example 2

Simultaneous multi-band transmission means that the device can transmit multiple transmission modes at the same time, e.g., a Wideband Code Division Multiple Access (W-

CDMA) transmission at 2 GHz and a Wireless Local Area Network (WLAN) transmission at 2,45 GHz. The time-averaged output power of a secondary transmitter (i.e. the lower power transmitter, e.g. Bluetooth, WLAN) may be much lower than that of the primary transmitter (i.e. the higher power transmitter, e.g., W-CDMA). In some cases, the secondary transmitter can be excluded from SAR testing when used alone (e.g., using Example 1). However, when the primary and secondary transmitters are used together, the SAR limit may still be exceeded. A means of determining the threshold power for the secondary transmitter that allows it to be excluded from SAR testing is needed.

One way of determining the threshold power level available to the secondary transmitter ($P_{\text{available}}$) is to calculate it from the measured peak spatial-average SAR of the primary transmitter (SAR_1) according to the equation:

$$P_{\text{available}} = P_{\text{th,m}} \times (\text{SAR}_{\text{lim}} - \text{SAR}_1) / \text{SAR}_{\text{lim}}$$

where $P_{\text{th},m}$ is the threshold exclusion power level taken from Annex B of IEC 62479[7] for the frequency of the secondary transmitter at the separation distance used in the testing.

If the output power of the secondary transmitter is less than $P_{\text{available}}$, SAR measurement for the secondary transmitter is not necessary.

The above formula can be easily generalized to the case where more than two transmitters are communicating simultaneously. If there are N simultaneous transmitters and the peak spatial-average SAR of the first N – 1 transmitters are known (SAR_{i}), then the threshold power level available to the Nth transmitter can be found from

$$P_{\text{available}} = P_{\text{max,m}} \times (\text{SAR}_{\text{lim}} - \sum_{i=1}^{\text{N}-1} \text{SAR}_{\text{i}}) / \text{SAR}_{\text{lim}}$$

Alternatively, $P_{\text{th,m}}$ can be replaced by $P_{\text{max,m}}$, which is an easier approach but leads to more restrictive power threshold.

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[7] To be published.

Annex L
(normative)

Power scaling procedure

L.1 Procedure

Power scaling is the extrapolation of the SAR of a DUT determined with a test signal (modX) to a SAR of the same device with a modulation (modY). Power scaling based on numerical or experimental methods for different modulation signals is possible if:

- the same RF amplifier stage is used for modX and modY;
- the same antenna is used for modX and modY and no MIMO techniques are applied;
- the SAR probe has been calibrated for the modulation signal modX and the SAR has been determined for modX;
- the time-averaged RF output power ratio R_p of modX and modY after the RF amplifier stage modulations is known:

$$R_\mathrm{p} = \left(\frac{Pmax_\mathrm{modY}}{Pmax_\mathrm{modX}} \right)$$

- the RF carrier frequency of modX is the same as for modY;
- the IF signal bandwidth ratio (R_m) of modX and modY :

$$\left| \frac{BW_\mathrm{modX}}{BW_\mathrm{modY}} - 1 \right| \leq 30 \ \%$$

- the bandwidth of modX and modY $< 5\ \% \times f_\mathrm{c}$.

If the above mentioned requirements are fulfilled a scaling of the SAR from modX to modY can be performed according to the following formula:

$$\mathrm{SAR}_\mathrm{modY} = R_\mathrm{p} \times \mathrm{SAR}_\mathrm{modX}$$

The factor R_p may be determined by numerical (calculation of P_avg including amplifier characteristic and modulation signal) or experimental means (e.g. measurement of the average power). In both cases the effect of the antenna impedance on the amplifier stage adds uncertainty.

If the approach of Annex L is used, a justification shall be given in the measurement report.

L.2 Usage pattern

For push-to-talk devices, the maximum duty factor shall be deemed to be 0,5 operated in front of the face or body-worn.

L.3 Power Scaling Uncertainty

Uncertainties of the power scaling are associated with non-linearities of the signal and RF amplifier stages, the modulation signal bandwidth and antenna impedance.

The power scaling uncertainty is evaluated by determination of the SAR of modY at the peak SAR location ($x_{p,}$ $y_{p,}$ z_p) using the following procedure:

- perform a 2-D SAR scan with modX according to Clause 6.
- move the probe the maximum location of the 2-D scan.
- take the SAR reading with modX.
- switch the device to modY (without moving the device).
- take the SAR reading with modY.
- calculate the ratio of the measured and scaled SAR_{modY}

$$\text{SAR}_{\text{scaling uncertainty}} = \left| \left(\frac{\text{SAR}(x_p, y_p, z_p)_{\text{modY}}}{\text{SAR}(x_p, y_p, z_p)_{\text{modX}} \times R_p} - 1 \right) \times 100 \ \% \right|$$

- $\text{SAR}_{\text{scaling uncertainty}}$ > 5 %: do not use the scaling and perform the full SAR assessment for modY.

Annex M
(informative)

Rationale for probe parameters

M.1 Probe outer tip dimensions

In general, dosimetric probes are constructed and protected using materials (low loss and low dielectric parameters) that substantially differ from the tissue-simulating liquid (high loss and high dielectric material). This results in local distortion of the field and scattered fields. In order to keep these effects small, i.e., below resonance and independent of the field characteristics, the probe tip diameter should be small with respect to a wavelength. In general, the smaller the probe tip diameter, the fewer disturbances occur. It is recommended to keep the probe tip diameter within one-third of a wavelength in the medium, as shown in Table M.1. At frequencies at or below 2 GHz, the maximum probe tip diameter is 8 mm.

Table M.1 – Minimum probe requirements as a function of frequency and parameters of the tissue equivalent liquid

1	2	3	4	5	6	7	8
Frequency MHz	**Relative permittivity**	**Conduc-tivity** S/m	**Wavelength in the medium (λ)** mm	**Plane wave Skin Depth (δ)** mm	**Maximum Diameter** mm	**50 % Distance for M1 ($z_{50\,\%} = \delta\, ln(2)/2$)** mm	**Min. distance for M1 (z_{M1})** mm
300	45,3	0,87	148,6	46,1	8,0	16,0	5,0
450	43,5	0,87	101,1	42,9	8,0	14,9	5,0
750	41,9	0,89	61,8	39,8	8,0	13,8	5,0
835	41,5	0,9	55,8	38,9	8,0	13,5	5,0
900	41,5	0,97	51,7	36,1	8,0	12,5	5,0
1 450	40,5	1,20	32,5	28,6	8,0	9,9	5,0
1 800	40,0	1,40	26,4	24,3	8,0	8,4	5,0
2 000	40,0	1,40	23,7	24,2	8,0	8,4	5,0
2 450	39,2	1,80	19,6	18,7	6,5	6,5	5,0
2 600	39,0	1,96	18,5	17,2	6,2	5,9	5,0
3 000	38,5	2,40	16,1	13,9	5,4	4,8	5,0
4 000	37,4	3,43	12,3	9,6	4,1	3,3	3,3
5 000	36,2	4,45	10,0	7,3	3,3	2,5	2,5
5 200	36,0	4,66	9,6	7,0	3,2	2,4	2,4
5 400	35,8	4,86	9,3	6,7	3,1	2,3	2,3
5 600	35,5	5,07	9,0	6,4	3,0	2,2	2,2
5 800	35,3	5,27	8,7	6,1	2,9	2,1	2,1
6 000	35,1	5,48	8,4	5,9	2,8	2,0	2,0

M.2 Probe sensor displacement

The induced field distribution is a function of skin depth δ and incident *H*-field distribution, i.e., the field can attenuate even faster than the skin depth with respect to the normal distance from the phantom boundary. Due to this strong attenuation, extrapolation becomes very sensitive to uncertainties of the measured points, i.e., local field distortions, boundary effects, noise, etc. In order to keep the uncertainties within reasonable boundaries, the closest measurement point M1 must be measured at a distance $z_{50\ \%} = \delta\ \ln(2)/2$ within which the SAR is more than 50 % of the SAR at the surface. These distances are provided in column 7 of Table M.1, assuming plane wave attenuation. The attenuation is typically stronger for antennas close to the phantom surface than it is for plane waves [43], especially at lower frequencies such that the minimal distance up to 3 GHz was defined as z_{M1} = 5 mm. However, at frequencies above 3 GHz, z_{M1} can be set to $z_{50\ \%}$, as the skin depth is similar to that of a plane wave at higher frequencies [15]. As accurate results cannot be measured when the probe has direct contact with the phantom, the distance corresponds to the sensor displacement plus the minimal probe tip distance to the phantom surface.

M.3 Probe inclination with respect to surface

At higher frequencies, probes tend to be larger with respect to the wavelengths and measurements very close to the surface become more imperative. To achieve results with acceptable uncertainty, the probe must be positioned normal to the surface, i.e., for deviations larger than 20°, special precautions and considerations are required to ensure acceptable uncertainty. Deviations less than 5º are technically preferable.

M.4 Extrapolation and integration uncertainty

The gradient normal to the surface grows sharply at higher frequencies. The number of measurements inside the zoom scan volume, which is above the noise floor of the probe, decreases and may significantly affect the extrapolation and integration. A strategy to overcome this problem is to use graded meshes. Nevertheless, the uncertainty can sharply increase when the probe is not sensitive enough. In Table M.2, the error is determined by adding white noise to the functions f_1, f_2 and f_3, the amplitude of which is defined in dB of the values at the surface. Table M.2 enables the determination of the assessment error with respect to the noise floor of the system. The values are the standard deviation after 4 000 iterations.

For example, the evaluation with a noise (N_{rms}) of 25 mW/kg will result in an uncertainty of 5 % for graded meshes (closest measurement point 1,5 mm, grading 1,5, 7 × 7 × 5) and 30 % for homogenous grid (closest measurement point 4 mm, grid 11 × 11 × 7).

Table M.2 – Extrapolation and integration uncertainty of the 10 g peak spatial average SAR (*k*=2) for homogeneous and graded meshes

	Homogeneous grid					**Graded grid**				
S/N	$f1_{1peak}$	$f1_{2p,prim}$	$f1_{2p,sec}$	$f2$	$f3$	$f1_{1peak}$	$f1_{2p,prim}$	$f1_{2p,sec}$	$f2$	$f3$
30 dB	0,1 %	0,0 %	0,1 %	0,1 %	17 %	0,0 %	0,1 %	0,0 %	0,0 %	1,3 %
20 dB	0,1 %	0,1 %	0,1 %	0,2 %	18 %	0,1 %	0,1 %	0,1 %	0,0 %	1,9 %
13 dB	0,6 %	0,6 %	0,6 %	0,4 %	27 %	0,5 %	0,5 %	0,5 %	0,3 %	8,7 %
10 dB	2,8 %	2,7 %	2,7 %	1,8 %	69 %	2,3 %	2,4 %	2,2 %	1,4 %	39 %

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