

INTERNATIONAL STANDARD

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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)

Exposition humaine aux champs radiofréquence produits par les dispositifs de communications sans fils tenus à la main ou portés près du corps – Modèles de corps humain, instrumentation et procédures – Partie 2: Procédure de détermination du débit d'absorption spécifique produit par les appareils de communications sans fil utilisés très près du corps humain (gamme de fréquences de 30 MHz à 6 GHz)



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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

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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- withdrawn,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.

Withdrawn

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).

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 device²

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

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
$\bar{P}_{\text{avg}}$	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: $T (^{\circ}\text{C}) = T (\text{K}) - 273,16$.

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/m³ 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).
- 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:
 - between 300 MHz and 800 MHz, the phantom flat bottom wall may have any shape that encompasses an ellipse with length $0,6 \lambda_0$ and width $0,4 \lambda_0$, 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.

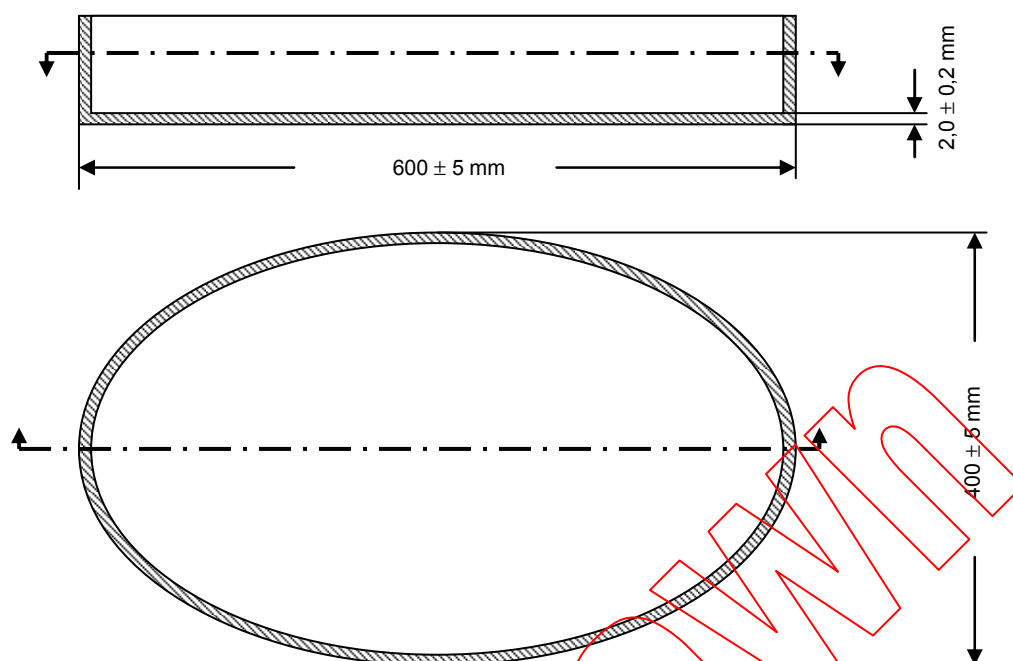


Figure 1 – Dimensions of the elliptical phantom

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:

$$\epsilon_r' \leq 5 \text{ for } f \leq 3 \text{ GHz}$$

$$3 \leq \epsilon_r' \leq 5 \text{ for } f > 3 \text{ GHz [62]}$$

The thickness of the bottom-wall of the flat phantom shall be 2,0 mm with a tolerance of $\pm 0,2$ 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
2 400	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/m³.

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: $\leq \pm 0,2$ 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;
 - $\leq \lambda/3$ for frequencies greater than 2 GHzwhere
 λ is the wavelength in the liquid medium in mm;
- sensitivity: $\leq 0,01$ 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 $\epsilon_r' \leq 5$.

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 $\pm 1,0$ 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 characteristic³

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 test⁴. 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

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.

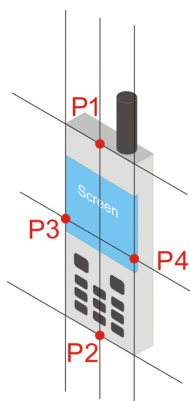


Figure 2 – Definition of reference points

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.

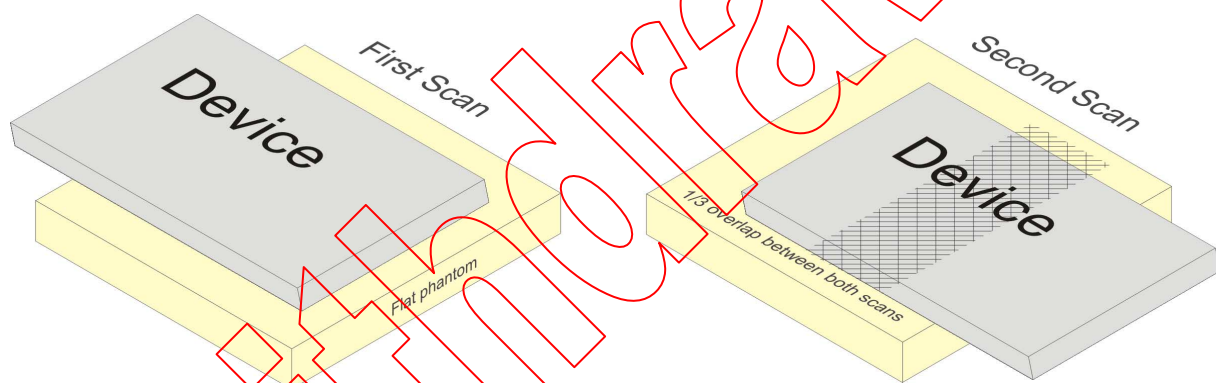


Figure 3 – Measurements by shifting of the device at the phantom

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.

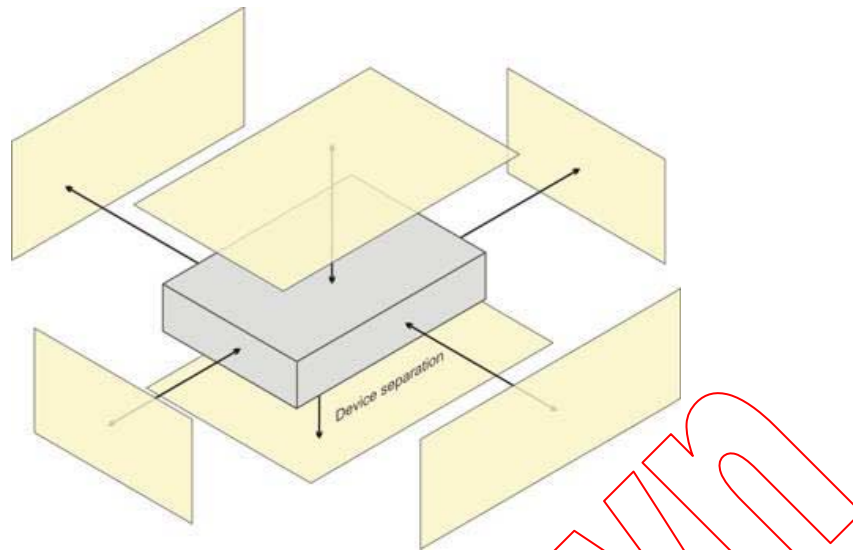


Figure 4 – Test positions for a generic device

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 $\leq 0,005$ and relative permittivity $\leq 1,1$. 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.

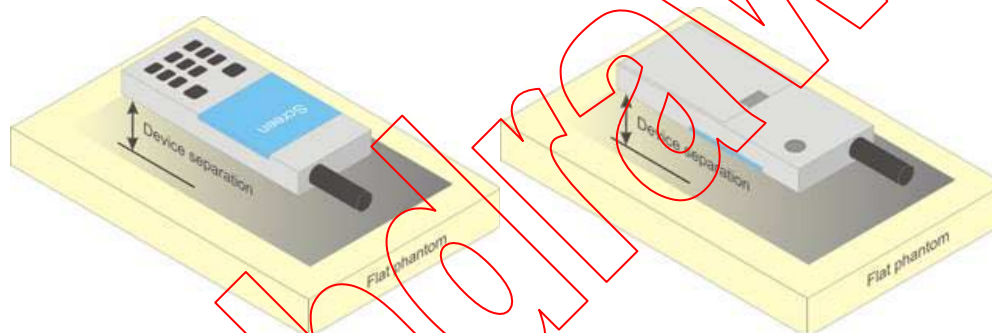


Figure 5 – Test positions for body-worn devices

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.

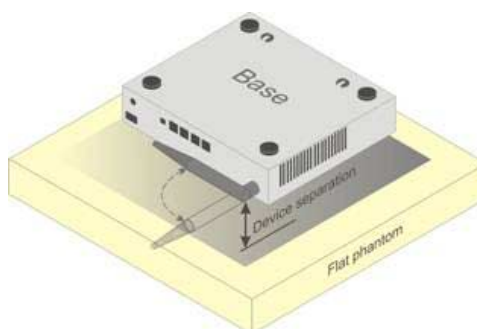


Figure 6 – Device with swivel antenna (example of desktop device)

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.

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.

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.

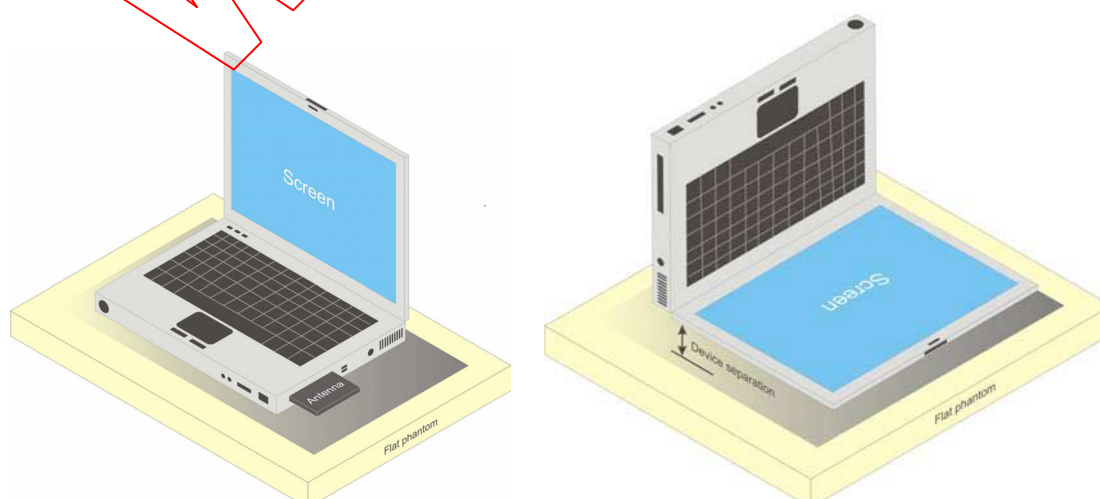
The example in Figure 7b) shows a tablet form factor portable computer for which SAR should be separately assessed with

- d) each surface and
- e) the separation distances

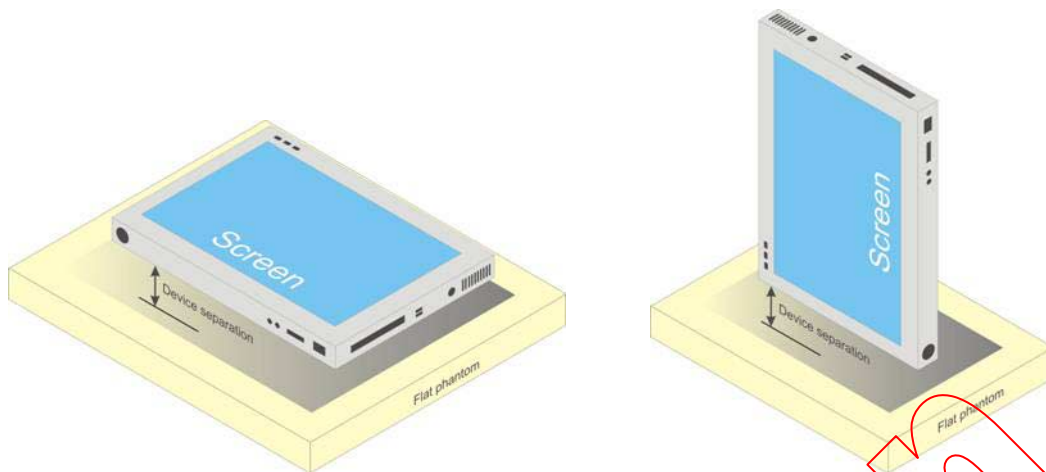
positioned against the flat phantom that correspond to the intended use as specified by the manufacturer. If the intended use is not specified in the user instructions, the device shall be tested directly against the flat phantom in all usable orientations.

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.

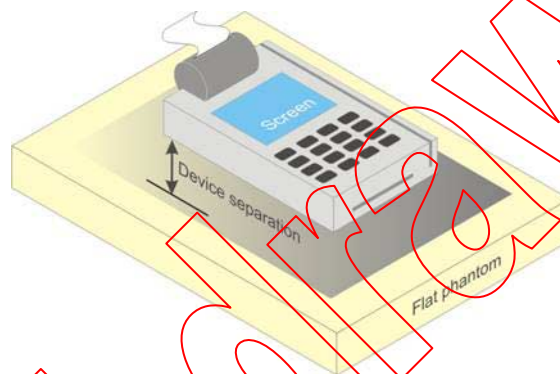
For devices that employ an external antenna with variable positions (e.g. swivel antenna), see 6.1.4.5 and Figure 6.



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.

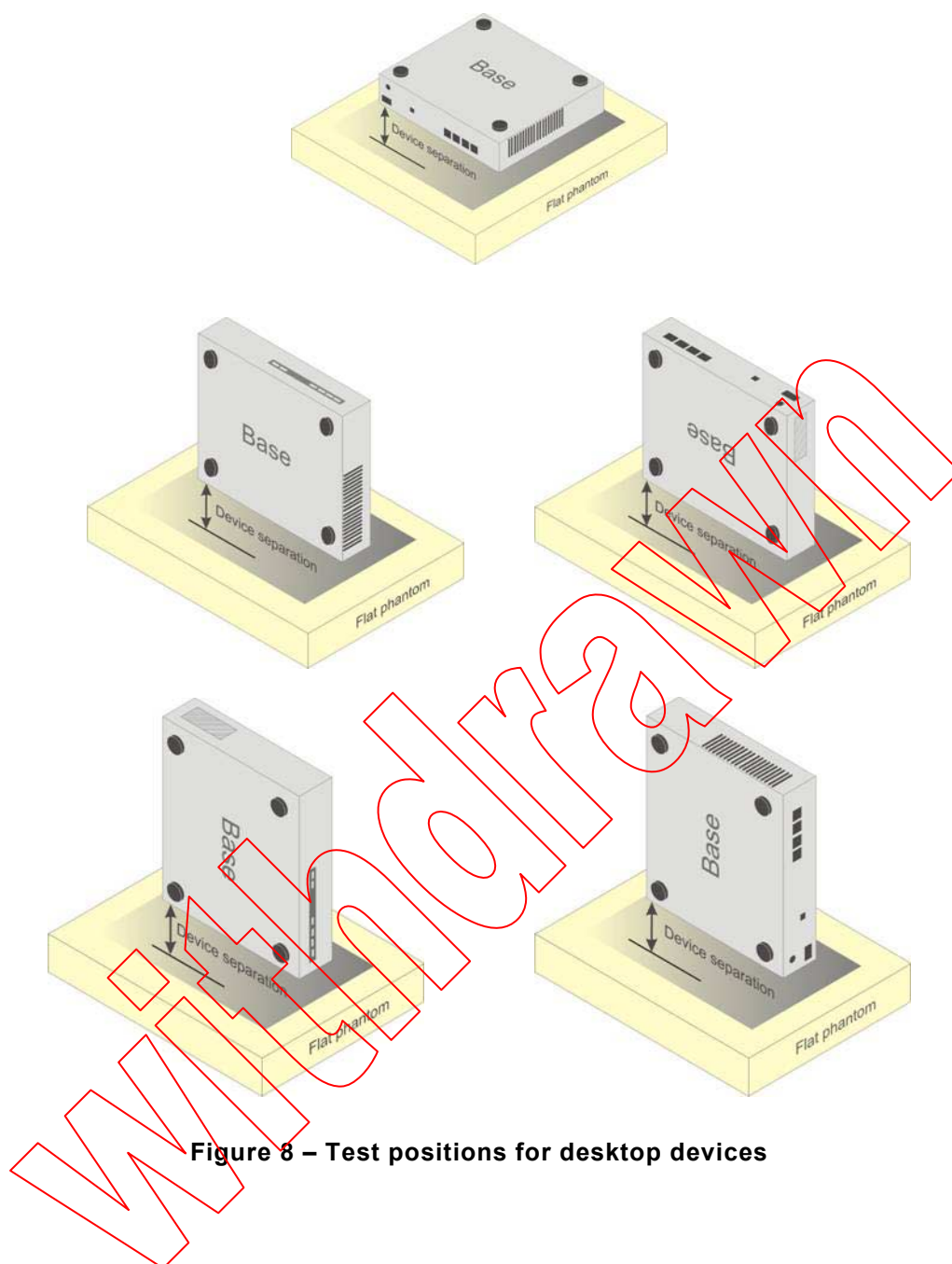
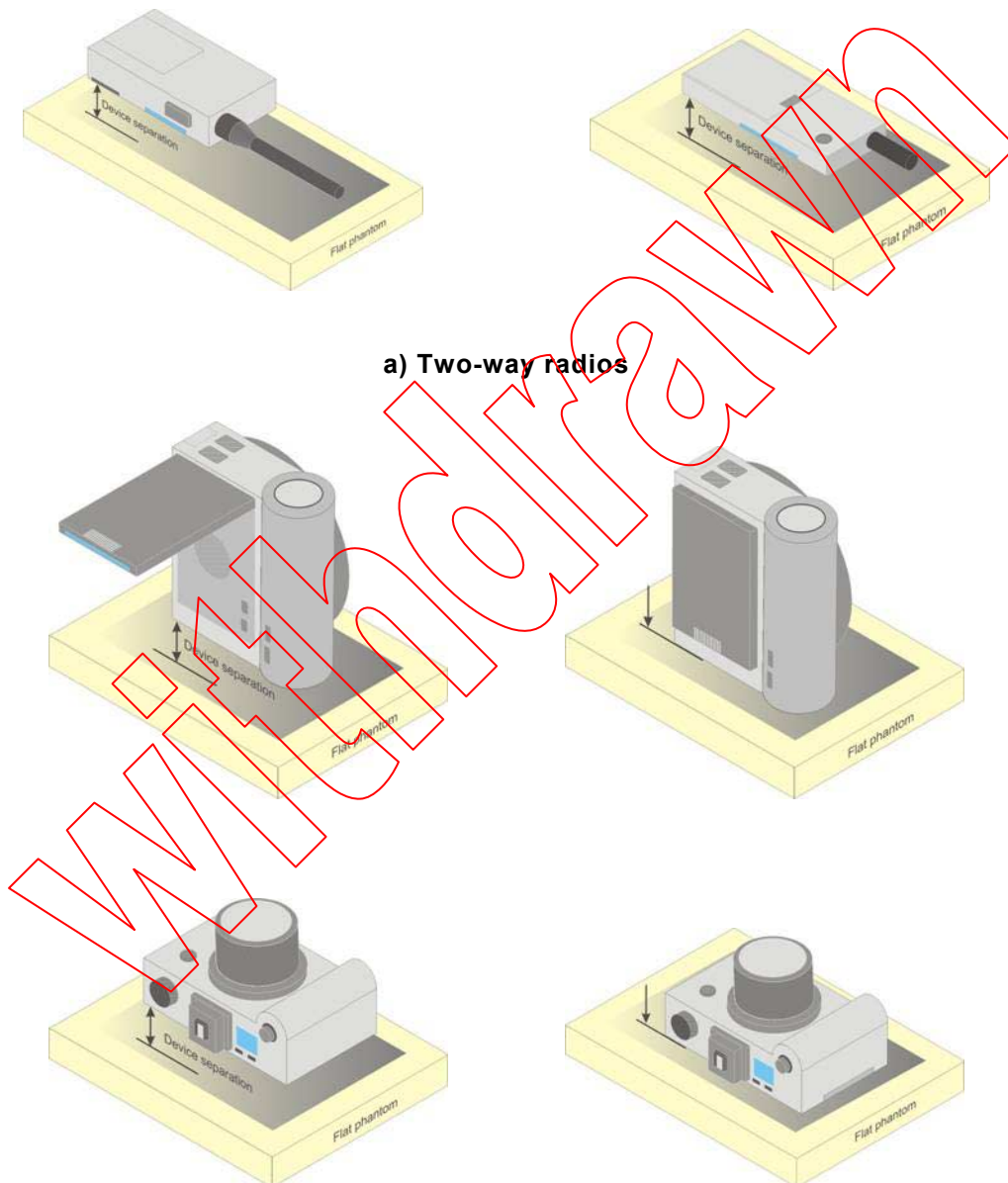


Figure 8 – Test positions for desktop devices

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 mm⁵ 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

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.

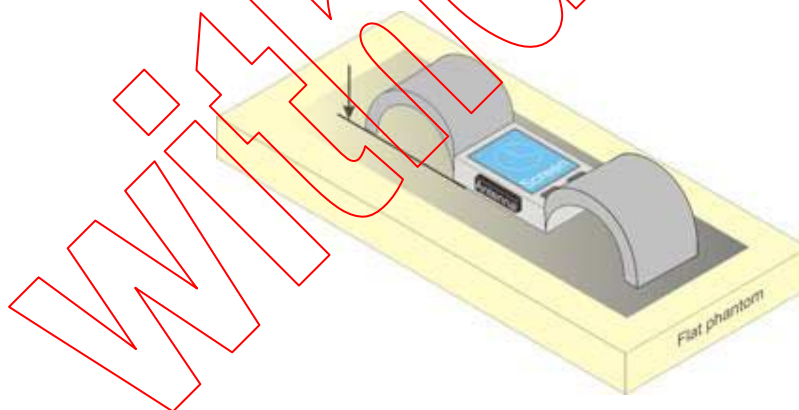


Figure 10 – Test position for limb-worn devices

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).

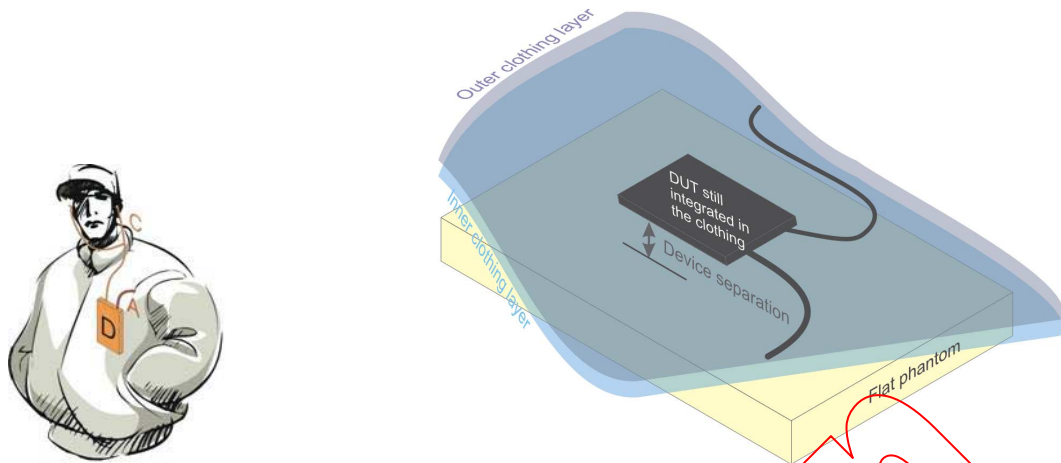


Figure 11 – Test position for clothing-integrated wireless devices

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.

Withdrawn

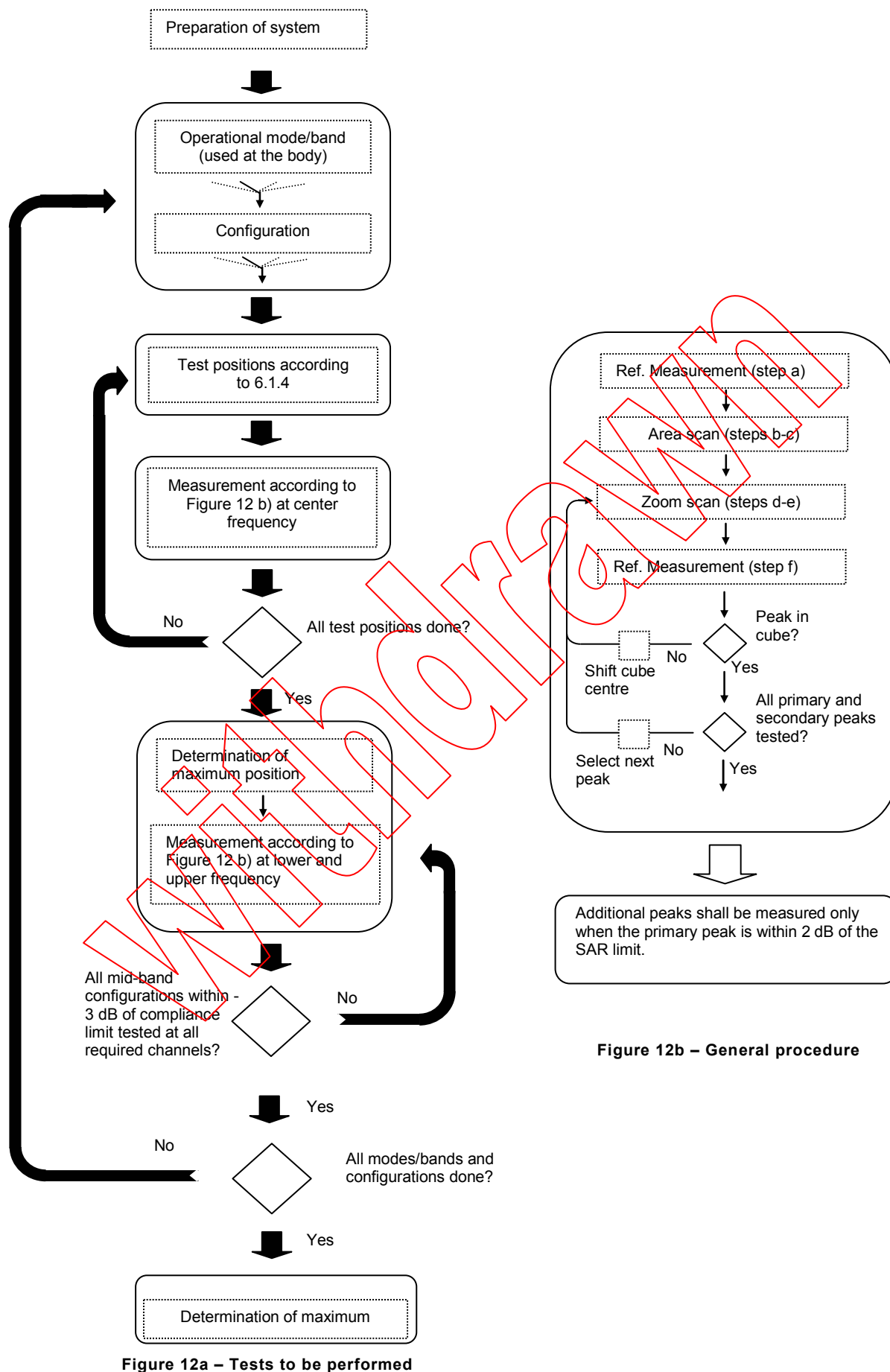


Figure 12 – Block diagram of the tests to be performed

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 $(60/f \text{ [GHz]})$ 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 $\pm 0,5$ 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 dB⁶ of the SAR compliance limit (e.g., 1 W/kg for 1,6 W/kg 1 g limit, or 1,26 W/kg for 2 W/kg, 10 g limit).
- d) Measure the three-dimensional SAR distribution at the local maxima locations identified in step c) (zoom scan procedure). The horizontal grid step shall be $(24 / f \text{ [GHz]})$ mm or less but not more than 8 mm. The minimum zoom scan size is 30 mm by 30 mm by 30 mm for frequencies 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 $(8 \cdot f \text{ [GHz]})$ 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 $(12/f \text{ [GHz]})$ 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 5° . 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.

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.

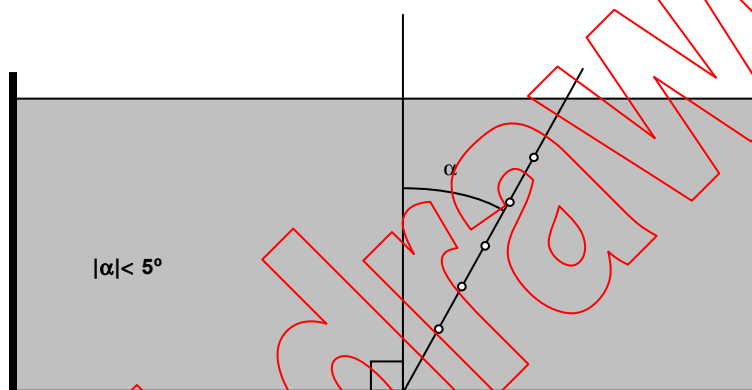


Figure 13 – Orientation of the probe with respect to the normal of the phantom surface

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/m³ 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

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

where

k_p is the coverage factor for a given probability;

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

ν_{eff} is the effective degrees of freedom estimated using the Welch-Satterthwaite

formula:
$$\nu_{\text{eff}} = \frac{u_c^4}{\sum_{i=1}^m \frac{c_i^4 u_i^4}{\nu_i}}.$$

The subscript p refers to the approximate confidence level, e.g., 95 %. Tabulated values of $t_p(\nu_{\text{eff}})$ 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 $\nu_i = 4$ (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 $\nu_{\text{eff}} = \frac{u_c^4}{\sum_{i=1}^m \frac{c_i^4 u_i^4}{\nu_i}}$, the effective degrees of freedom for the combined

standard uncertainty is $\nu_{\text{eff}} = 74$, 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 ($\nu_i = 3$), then $u_c = 15,6$ %, $\nu_{\text{eff}} = 27$, $k = k_p = k_{95} = t = t_{95} = 2,11$, and the expanded uncertainty becomes $U = 2,11 \times 15,6 = 32,9$ %.

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 $\pm 5^\circ$), the isotropy uncertainty is calculated as:

$$SAR_{\text{uncertainty}} [\%] = \sqrt{0,5 \times dev_isotropy_{\text{axial}} [\%]^2 + 0,5 \times dev_isotropy_{\text{hemispherical}} [\%]^2}$$

where

$dev_isotropy_{\text{hemispherical}} [\%]$ is the maximum deviation (%) from the isotropic response assessed for $\Phi: \pm 180^\circ$, $\theta > \pm 60^\circ$;

$dev_isotropy_{\text{axial}} [\%]$ is the maximum deviation (%) from the isotropic response assessed for $\Phi: \pm 180^\circ$, $\theta = 0^\circ$;

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.

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

where

SAR_{eval} is the measured SAR value;

SAR_{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 .

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

where

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

The SAR uncertainty is determined as the maximum of all $\text{SAR}_{\text{mod } X}$ 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:

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

for $(d_{\text{be}} + d_{\text{step}}) < 10 \text{ mm}$ and $f \leq 3 \text{ GHz}$

$$\text{SAR}_{\text{uncertainty}}[\%] = \Delta \text{SAR}_{\text{be}}[\%] \frac{\delta}{\delta - d_{\text{be}}}$$

for $d_{\text{be}} < \delta$ and $f > 3 \text{ GHz}$

where

$SAR_{\text{uncertainty}}$	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. $\delta = 6$ mm at 6 GHz;
ΔSAR_{be}	is the deviation between the measured SAR value at the distance d_{be} from the boundary and the waveguide analytical value or value assessed by temperature probe SAR_{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° , ΔSAR_{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 ΔSAR_{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:

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

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:

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

where

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

$\text{SAR}_{\text{uncertainty_a}}$ 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

$SAR_{\text{uncertainty}_b}$	is the uncertainty for the integration time in percent;
t_{frame}	is the frame duration;
t_{int}	is the integration time;
$slot_{\text{idle}}$	is the number of idle slots in a frame;
$slot_{\text{total}}$	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 $t_{\text{sub-frame}} = 4,6$ ms, with 7 idle slots in an 8-slot sub-frame, while the whole 26-slot frame duration is $t_{\text{frame}} = 120$ ms, including 1 idle sub-frame slot.

$SAR_{\text{uncertainty}_b}$ is an approximation that typically overestimates the uncertainty. Here $slot_{\text{idle}}$ is the number of idle slots in a frame with $slot_{\text{total}}$ being the total number of slots. The frame duration is t_{frame} , with $t_{\text{frame}} < t_{\text{int}}$. 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 $SAR_{\text{uncertainty}_a}$. For US TDMA (IS-136), $t_{\text{frame}} = 20$ ms, with 2 idle slots in a 3-slot frame, and no multiframes. For a probe integration time of 0,2 s, $SAR_{\text{uncertainty}_b}$ gives an uncertainty of 6,67 %, whereas the true uncertainty derived using s_{int} and $SAR_{\text{uncertainty}_a}$ 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.

- 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.
- 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:

$$SAR_{\text{uncertainty}} [\%] = \frac{d_{ss}}{\delta/2} \times 100$$

where

- $SAR_{\text{uncertainty}}$ 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).

$$SAR_{\text{uncertainty}} [\%] = \sqrt{\left(100 \times \left(\frac{(a + d + b/2s)^2}{a^2} - 1\right)\right)^2 + (5|\epsilon_{r\text{shell}} - 4|)^2}$$

for $3 \leq \epsilon_{r\text{shell}} \leq 5$, for $f > 3$ GHz

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

for $f \leq 3$ GHz

where

- $SAR_{\text{uncertainty}}$ 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 \epsilon_{r_{\text{shell}}} - 4 $	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 ($\epsilon_r = 4 \pm 1$) 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 measurement.

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:

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

where

$\text{SAR}_{\text{uncertainty}}$ is the uncertainty in percent;

$\text{SAR}_{\text{w/ holder}}$ is the SAR with device holder in watts per kilogram;

$\text{SAR}_{\text{w/o holder}}$ 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:

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

This uncertainty has an assumed rectangular probability distribution and $\nu_1 = \infty$ 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 $\nu_1 = N - 1$.

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.