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**Measurement procedure for the assessment of specific absorption rate of human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices –
Part 1528: Human models, instrumentation, and procedures
(Frequency range of 4 MHz to 10 GHz)**



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IEC Central Office
3, rue de Varembe
CH-1211 Geneva 20
Switzerland
Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

Institute of Electrical and Electronics Engineers, Inc.
3 Park Avenue
New York, NY 10016-5997
United States of America
stds.ipr@ieee.org
www.ieee.org

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Part 1528: Human models, instrumentation, and procedures
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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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

Part 1528: Human models, instrumentation, and procedures (Frequency range of 4 MHz to 10 GHz)

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International Standard IEC/IEEE 62209-1528 has been prepared by IEC technical committee 106: Methods for the assessment of electric, magnetic and electromagnetic fields associated with human exposure, in cooperation with the International Committee on Electromagnetic Safety of the IEEE Standards Association, under the IEC/IEEE Dual Logo Agreement.

This first edition of IEC/IEEE 62209-1528 cancels and replaces IEC 62209-1:2016, IEC 62209-2:2010, IEC 62209-2:2010/AMD1:2019 and IEEE Std 1528-2013. This edition constitutes a technical revision.

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

- a) extension of the frequency range down to 4 MHz and up to 10 GHz;
- b) testing of devices with proximity sensors;
- c) application specific phantoms;
- d) device holder specifications;
- e) fast SAR testing procedures;
- f) test reduction procedures;
- g) LTE assessment procedure;
- h) revision of validation clause, including validation antennas;
- i) revision of SAR assessment procedure;
- j) time-average SAR measurement procedure;
- k) uncertainty analysis;

This publication is published as an IEC/IEEE Dual Logo standard.

This publication contains attached files in the form of the Fast SAR Wizard described in 7.9.2.2 as well as CAD files for the SAM phantom. These files are available at:

http://www.iec.ch/dyn/www/f?p=103:227:0:::FSP_ORG_ID,FSP_LANG_ID:1303,25.

These files are intended to be used as a complement and do not form an integral part of the publication.

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

FDIS	Report on voting
106/514/FDIS	106/520/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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The IEC Technical Committee and IEEE Technical Committee have 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.

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

INTRODUCTION

The objective of this document is to provide procedures for measuring the human exposure from devices intended to be used at a position near the human head or body. It was developed to provide procedures to evaluate electromagnetic field (EMF) exposures due to radio frequency (RF) transmitting devices used next to the ear, in front of the face, mounted on the body, operating in conjunction with other RF-transmitting and non-transmitting devices or accessories (e.g. belt-clips), or embedded in garments. The types of devices dealt with include but are not limited to mobile telephones, cordless telephones, cordless microphones, and radio transmitters in personal computers. The applicable frequency range is from 4 MHz to 10 GHz. The document defines:

- measurement system requirements (Clause 6),
- SAR measurement protocols (Clause 7),
- SAR measurement uncertainty evaluation (Clause 8), and
- reporting requirements (Clause 9).

At the time this document was developed, two computational and measurement joint IEC/IEEE projects dealing with millimetre-wave power density assessment were under development, covering the frequency range from 6 GHz to 300 GHz. Hence there is an overlap of frequency between this document, which deals with SAR, and the other joint IEC/IEEE projects dealing with power density from 6 GHz to 10 GHz. The IEC/IEEE joint working group was aware of this fact and believed that it would give the flexibility of using whatever metrics suitable for the considered case of compliance assessment.

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

Part 1528: Human models, instrumentation, and procedures (Frequency range of 4 MHz to 10 GHz)

1 Scope

This document specifies protocols and test procedures for the reproducible and repeatable measurement of the conservative exposure peak spatial average SAR (psSAR) induced inside a simplified model of the head and the body by radio-frequency (RF) transmitting devices, with a defined measurement uncertainty. These protocols and procedures apply to a significant majority of the population, including children, during the use of hand-held and body-worn wireless communication devices. These devices include single or multiple transmitters or antennas, and are operated with their radiating structure(s) at distances up to 200 mm from a human head or body. This document is employed to evaluate SAR compliance of different types of wireless communication devices used next to the ear, in front of the face, mounted on the body, operating in conjunction with other RF-transmitting, non-transmitting devices or accessories (e.g. belt-clips), or embedded in garments. The applicable frequency range is from 4 MHz to 10 GHz. Devices operating in the applicable frequency range can be tested using the phantoms and other requirements defined in this document.

The device categories covered include, but are not limited to, mobile telephones, cordless microphones, and radio transmitters in personal, desktop and laptop computers, for multi-band operations using single or multiple antennas, including push-to-talk devices. This document can also be applied for wireless power transfer devices operating above 4 MHz.

This document does not apply to implanted medical devices.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 62209-3:2019, *Measurement procedure for the assessment of specific absorption rate of human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices – Part 3: Vector measurement-based systems (Frequency range of 600 MHz to 6 GHz).*

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

3 Terms and definitions

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

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

- IEC Electropedia: available at <http://www.electropedia.org/>

- ISO Online browsing platform: available at <http://www.iso.org/obp>
- IEEE Dictionary Online: available at <http://dictionary.ieee.org>

3.1

accessory

optional component or attachment that can be used in conjunction with the device under test (DUT)

EXAMPLE 1 Accessories for holding, affixing, or otherwise carrying, wearing or attaching the device, as well as providing a specific use condition on the body of the user (e.g. a belt-clip, wrist-strap or any other body strap, or lanyard for wearing the device using a necklace).

EXAMPLE 2 Electronic accessories for performing specialized tasks or which provide additional features (e.g. GPS modules, outboard printers, MP3 players, cameras or viewing devices).

EXAMPLE 3 Electronic accessories providing audio or video input or output (e.g. headsets, microphones, cameras).

EXAMPLE 4 Accessories providing enhanced RF capability to the device (e.g. original, replacement, or auxiliary antennas).

EXAMPLE 5 Batteries and related DC power components.

EXAMPLE 6 Combinations of accessories, where two or more of the above are combined within one component.

3.2

axial isotropy

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

3.3

basic restriction

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

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

3.4

body-worn device

device containing one or more wireless transmitters or transceivers which is positioned in close proximity to a person's torso or limbs (excluding the head) by means of a carrying accessory to support intended use operations

Note 1 to entry: This document uses the term body-worn synonymously for the term body-mounted, which was employed in earlier versions.

3.5

body-supported device

device containing one or more wireless transmitters or transceivers, with intended use that includes transmitting with any portion of the device being held directly against a user's body

3.6

boundary effect

change in the sensitivity of an electric-field probe when the probe tip is located close (less than one probe-tip diameter) to media boundaries

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

3.7

cable

wire that is necessary for the device functionality in the intended operational configuration

3.8

channel

RF channel

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

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

3.9

conducted power

power delivered by the power amplifier of the device to a matched load

3.10

conservative exposure

estimate of the psSAR, including uncertainties as specified in this document, representative of and slightly higher than that expected to occur in the head or body of a significant majority of the human population during intended use of a wireless transmitting device

3.11

constant-envelope mode

transmission mode where the signal amplitude does not vary with time

3.12

correlated signals

electromagnetic fields, associated to distinct signal waveforms, yielding non-zero time-domain correlation integral at some time instant

Note 1 to entry: Details are specified in IEC TR 62630 [1].

3.13

desktop device

device placed or mounted on a desk, table, or similar supporting structure, with antennas that are intended to be operated at or closer than 200 mm from the human body

3.14

device holder

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

3.15

device under test

DUT

device containing one or more wireless transmitters or transceivers that is tested according to the methods of this document

Note 1 to entry: A device under test may be further categorized as a body-worn, body-supported, desktop, front-of-face, hand-held, limb-worn, clothing-integrated, or generic device.

3.16

duty factor

proportion of time that a transmitter transmits over a specified period

3.17

fast SAR testing

usage of special techniques, methods, or algorithms to decrease the SAR measurement time compared to full SAR testing

Note 1 to entry: Class 1 fast SAR testing uses hardware that complies with all of the requirements of this document for full SAR testing. However, it uses faster testing procedures than those that comply with full SAR testing procedures.

Note 2 to entry: Class 2 fast SAR testing uses hardware and testing procedures that do not comply with the requirements of this document for full SAR testing.

3.18

frequency band

transmitting frequency range associated with a specific wireless operating mode

Note 1 to entry: The frequency band is usually referred to using rounded figures, however the actual frequency allocation can be slightly different; e.g. the GSM 850 MHz band actually uses 824 MHz to 849 MHz and 869 MHz to 894 MHz, and the GSM 900 MHz band actually uses 880 MHz to 915 MHz and 925 MHz to 960 MHz. In other cases, the official 3GPP nomenclature might be used, for instance LTE Band 12 (uplink 699 MHz to 716 MHz; downlink 729 MHz to 746 MHz).

3.19

front-of-face device

hand-held device containing one or more wireless transmitters or transceivers operated in close proximity to the face

Note 1 to entry: Front-of-face device types include PTT devices, two-way radios, and devices equipped with an optical camera.

3.20

full SAR testing

usage of methods, procedures and specific hardware which fully comply with all of the normative requirements in this document, except those specified in 7.9.2

3.21

generic device

device that cannot be categorized as belonging to any of the specific device categories

3.22

hand-held device

portable device which is operated in a user's hand at a distance of over 200 mm from the head or torso during its intended use

3.23

handset

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

Note 1 to entry: For synonymous terms such as "mobile phone", the terms "mobile" and "portable" have specific but generic meanings in IEC 60050 – mobile: capable of operating while being moved (IEC 60050-151:2001, 151-16-46); portable: capable of being carried by one person (IEC 60050 151:2001, 151-16-47). The term "portable" often implies the ability to operate when carried on the user. These definitions are used interchangeably in various wireless regulations and industry specifications, in some cases referring to types of wireless communication devices and in other cases to intended use.

3.24

head-mounted device

device containing one or more wireless transmitters or transceivers that is positioned in close proximity to a person's head or neck by means of an accessory, if necessary, to support its intended use operation

Note 1 to entry: This definition excludes hand-held devices.

3.25

hemispherical isotropy

maximum deviation of the measured SAR when rotating the probe around its major axis with the probe exposed to reference waves impinging from the half space in front of the probe tip, at varying incidence angles relative to the axis of the probe

3.26

host

equipment that needs to be operated with a wireless device or module during testing to provide transmitting functionality according to its intended use

3.27

intended use

use conditions for which a product is intended according to the full range of available functions, in accordance with the specifications, instructions, and information provided by the manufacturer in the user documentation

3.28

limb-worn device

device containing one or more wireless transmitters or transceivers, with intended use that includes being strapped onto the arm or leg of the user while transmitting

Note 1 to entry: Limb-worn device types include wrist-worn, ankle-worn, and forearm-worn devices. Some regulatory jurisdictions specify different requirements for devices worn on limbs away from the wrists or ankles.

3.29

linearity error

maximum deviation of a measured quantity from the expected linear dependency over the measurement range

3.30

measurement drift

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

3.31

measurement uncertainty

3.31.1

uncertainty evaluation

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

3.31.2

uncertainty evaluation

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

3.31.3

standard uncertainty

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

3.31.4

combined uncertainty

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

3.31.5

expanded uncertainty

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

3.32

multi-band

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

3.33

operating mode

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

Note 1 to entry: The operating mode includes all parameters to establish the communication over the wireless network. The specific operating mode parameters include, but are not limited to, communication standard, frequency band, channel, signal modulation, communications protocol, data rate, bandwidth, number and positions of time slots, and number and positions of resource blocks. Some operating modes do not have some of these parameters.

Note 2 to entry: Modern terminals can have multiple operating modes for individual or simultaneous transmission. Examples of operating modes include wireless protocols such as GSM, EDGE, EVDO, GPRS, CDMA, WCDMA, LTE, 5G NR, Bluetooth®¹, and Wi-Fi®². Multiple operating modes can transmit in one or more frequency bands, e.g. a DUT could support both multiple wireless technologies in a frequency band, and also allow multiple wireless transmission modes within a wireless technology, such as GSM, GPRS, EDGE, or WCDMA and HSPA, or 5G NR.

3.34

output power

power at the output of the RF transmitter when the antenna, or a load with the same input impedance as the antenna, is connected to it

3.35

primary peak SAR value

largest interpolated local SAR value determined in an area scan measurement

3.36

secondary peak SAR value

in an area scan measurement, interpolated local SAR maximum that is smaller than the primary peak SAR value

3.37

peak spatial-average SAR

psSAR

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

Note 1 to entry: In this document, the terms psSAR (over 1 g or 10 g) and the terms 1 g SAR and 10 g SAR are used interchangeably.

3.38

penetration depth

depth at which the SAR of an associated incident plane wave, penetrating into a homogeneous lossy medium, is reduced to $1/e^2$ of its value just beneath the surface of the medium

¹ Bluetooth® is a trademark of the Bluetooth Special Interest Group (SIG). This information is given for the convenience of users of this document and does not constitute an endorsement by IEC.

² Wi-Fi® is a trademark of the Wi-Fi Alliance. This information is given for the convenience of users of this document and does not constitute an endorsement by IEC.

Note 1 to entry: For a plane-wave incident normally on a planar half-space, the E-field penetration depth δ is given as:

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

where

ω is the angular frequency;

μ_0 is the magnetic permeability of vacuum, in henry per metre;

ε_0 is the dielectric permittivity of vacuum, in farad per metre;

ε_r' is the relative dielectric permittivity of the lossy medium, unitless;

σ is the electrical conductivity of the lossy medium, in siemens per metre.

3.39

phantom

physical model with an equivalent human anatomy and comprised of a tissue-equivalent medium with dielectric properties specified in this document

3.40

pinna auricle

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

3.41

power control algorithm

protocol of the DUT to set and adjust the maximum output power of the transmitter over a specified averaging period

3.42

production variation

range in output power among DUT production samples when set to transmit at the maximum level

3.43

push-to-talk device

hand-held radio transceiver that enables a user to operate a mechanical switch to toggle between radio transmission and reception (simplex operating mode)

EXAMPLE Two-way radio.

3.44

probe isotropy

property pertaining to the degree to which the response of an electric field probe or magnetic field probe is independent of the polarization and direction of propagation of the incident wave

Note 1 to entry: See also axial isotropy (3.2) and hemispherical isotropy (3.25).

3.45

proximity sensor

capacitive sensor or combination of sensors in the DUT utilized for the detection of user proximity for the purpose of limiting transmitter power in order to ensure compliance with RF exposure limits

3.46

readout electronics

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

3.47

response time

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

3.48

scanning system

automatic positioning system capable of placing the measurement probe at specified positions according to requirements of this document

3.49

sensitivity

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

3.50

separation distance

distance between the device under test and the outside surface of the phantom

Note 1 to entry: The separation distance represents the distance during intended use.

3.51

specific absorption rate

SAR

measure of the rate at which energy is absorbed by the human body when exposed to a radio frequency electromagnetic field

Note 1 to entry: The SAR in the tissue-equivalent medium can be determined by the rate of temperature increase or by E-field measurements, according to the following formulas:

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

$$SAR = c_h \left. \frac{\partial T}{\partial t} \right|_{t=0}$$

where:

SAR is the specific absorption rate in watts per kilogram;

E is the RMS value of the electric field strength in the tissue-equivalent medium in volts per metre;

σ is the electrical conductivity of the tissue-equivalent medium in siemens per metre;

ρ is the mass density of the tissue-equivalent medium in kilograms per cubic metre;

c_h is the specific heat capacity of the tissue-equivalent medium in joules per kilogram per kelvin;

$\left. \frac{\partial T}{\partial t} \right|_{t=0}$ is the initial time derivative of temperature in the tissue-equivalent medium in kelvin per second.

3.52

test configuration

set of DUT parameters applicable to the SAR measurement, consisting of the position of the DUT on the applicable phantom, the DUT use configuration (e.g. antenna position), and operating mode

3.53**time-period averaged SAR****TPAS**

SAR averaged over a specified averaging period when a power control algorithm is applied

3.54**time-averaged SAR**

SAR measured over a sufficiently long integration time to ensure a stable result over the duty factor and other characteristics of the modulated signal

3.55**tune-up specification**

output power tolerance when setting a sample of the DUT to transmit at the maximum output power level

3.56**TX factor**

ratio of the average output power to the peak output power of the DUT over a specified time-averaging period

4 Symbols and abbreviated terms**4.1 Physical quantities**

The International System of Units (SI) is used throughout this document.

Symbol	Quantity	Unit	Dimensions
α	Attenuation coefficient	reciprocal metre	1/m
P	Average (temporal) absorbed power	watt	W
J	Current density	ampere per square metre	A/m ²
σ	Electric conductivity	siemens per metre	S/m
E	Electric field strength	volt per metre	V/m
f	Frequency	hertz	Hz
ρ	Mass density	kilogram per cubic metre	kg/m ³
δ	Penetration depth	metre	m
μ	Permeability	henry per metre	H/m
c_h	Specific heat capacity	joule per kilogram per kelvin	J/(kg K)
ε	Permittivity	farad per metre	F/m
SAR	Specific absorption rate	watt per kilogram	W/kg
T	Temperature	kelvin	K
λ	Wavelength	metre	m

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

4.2 Constants

Symbol	Physical constant	Magnitude
c_0	Speed of light in vacuum	$2,998 \times 10^8 \text{ m/s}$
ε_0	Permittivity of free space	$8,854 \times 10^{-12} \text{ F/m}$
μ_0	Permeability of free space	$4\pi \times 10^{-7} \text{ H/m}$

4.3 Abbreviated terms

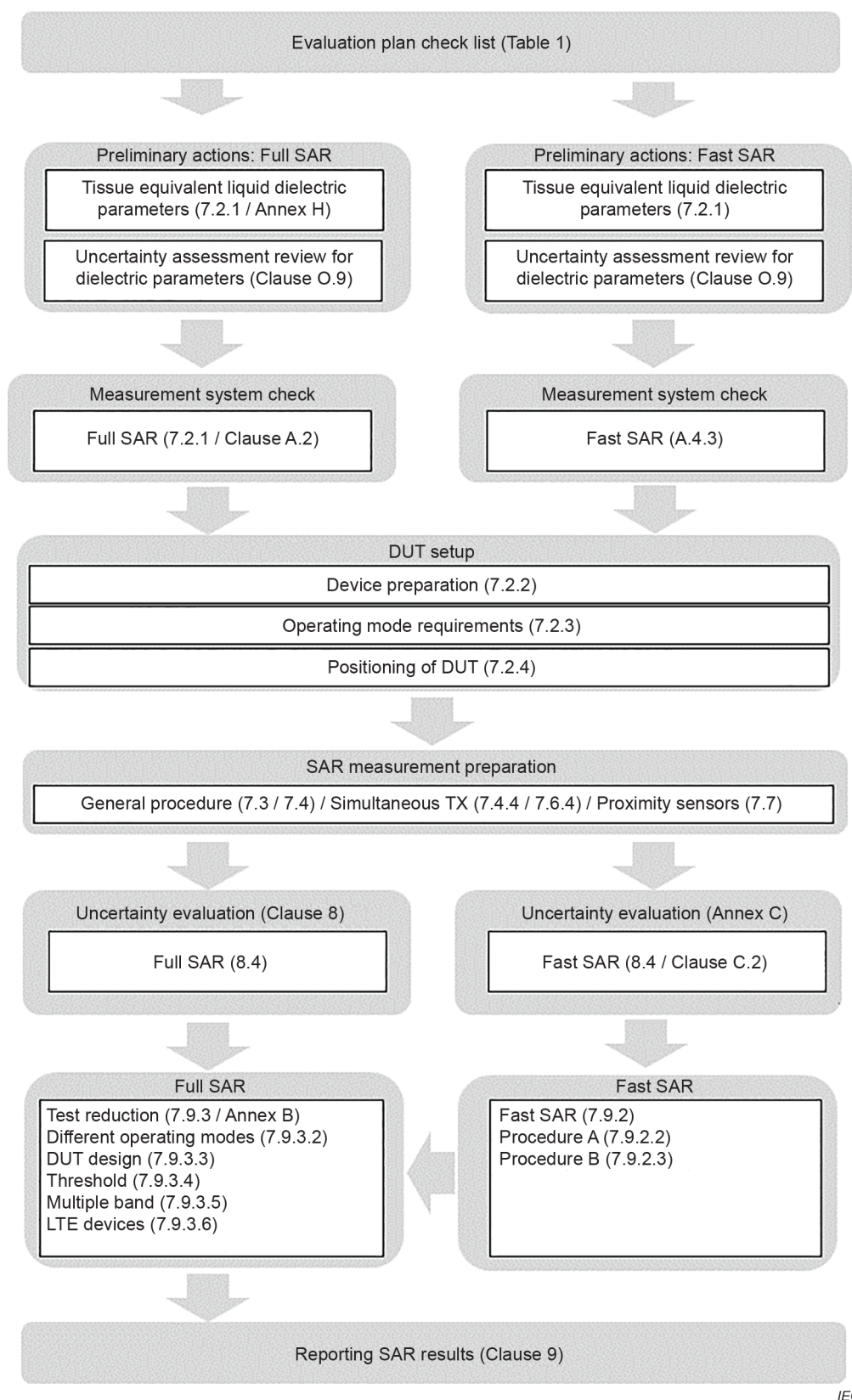
5G NR	Fifth generation new radio
AIPLC	Automatic input power level control
APS	Absolute psSAR
CAD	Computer aided design
CDMA	Code division multiple access
CLA	Confined-loop antenna
CW	Continuous Wave
DCS	Digital Cellular Service
DOE	Design of experiments
DUT	Device under test
EDGE	Enhanced Data rates for GSM Evolution
E-field	Electric field strength
ERP	Ear reference point
FDTD	Finite-difference time-domain
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
H-field	Magnetic field strength
ICES	International Committee on Electromagnetic Safety
ICNIRP	International Commission on Non-Ionizing Radiation Protection
LE	Left ear
LTE	Long Term Evolution
MIMO	Multiple input multiple output
MPR	Maximum power reduction
OFAT	One-factor-at-a-time
OFDM	Orthogonal frequency-division multiplexing
OFDMA	Orthogonal frequency-division multiple access
PCS	Personal Communications Service
PDF	Probability density function
psSAR	Peak spatial-average SAR
PTT	Push-to-talk
RE	Right ear
RF	Radio frequency
RMS	Root mean square
RSS	Root sum square
SAM	Specific anthropomorphic mannequin
SAR	Specific absorption rate
STBC	Space-time block coding
TDMA	Time division multiple access
TX	Transmission
UMTS	Universal Mobile Telecommunications System
VPIFA	Vertical Planar Inverted F-Antenna
WCDMA	Wideband code division multiple access
WiMax	Worldwide Interoperability for Microwave Access
WLAN	Wireless local area network

5 Quick start guide and evaluation plan checklist

The quick start guide shown in Figure 1 and the evaluation plan checklist shown in Table 1 provide a high level overview of the SAR measurement procedures of this document. For the details of each step, refer to the relevant clause specified in Figure 1 and Table 1.

Table 1 – Evaluation plan checklist

Stage	Evaluation steps	Action
Evaluation plan checklist Planning of the measurement configurations	<ul style="list-style-type: none"> – What type of device is being evaluated? – Review of antennas and supported wireless technologies, single or multiple combinations. – What are the test positions applicable? – Working under laboratory conditions and following good laboratory practice and documentation, prepare to conduct the necessary evaluation. 	Complete checklist based on evaluation plan.
Preliminary actions and measurement system check	<ul style="list-style-type: none"> – A liquid dielectric properties measurement shall be performed and recorded. <i>*For array systems, this is typically provided by the manufacturer</i> – System check needs to be performed to verify that the system components are working correctly. 	Should be conducted before starting a project and repeated.
DUT set-up	<p>The protocol for SAR assessment defines all the permutations of operational conditions that should be tested. The essential steps include:</p> <ul style="list-style-type: none"> – Preparing the DUT by establishing a connection to a base station simulator. – Configuring the DUT to operate on the appropriate test frequencies. – Positioning the DUT in relation to the phantom. 	Ensure the DUT is configured in the correct way and radiating appropriately when positioned against the phantom.
Uncertainty evaluation	<ul style="list-style-type: none"> – Guidelines and approximation formulas are provided, enabling the estimation of each individual uncertainty component. – The uncertainty budget shall cover the appropriate frequency range with regards to equipment used in the SAR system. 	Determine uncertainty and complete the uncertainty table.
SAR measurements procedures	<ul style="list-style-type: none"> – This stage is the actual procedure for the measurement of SAR. – The procedure is iterative to ensure that the highest value of the psSAR of a DUT is captured. – This is done by a systematic process looking at all device positions, configurations and operating modes in all frequency bands accordingly. – Measurement systems can incorporate a single probe or array probes. Either fast SAR testing or test reduction techniques may be used. Some accepted techniques may be used to either reduce or accelerate the measurement process. 	Determining highest SAR. Ensure the rationale for test reduction or fast SAR testing is recorded and reported if used.
Reporting SAR results	<ul style="list-style-type: none"> – The final report describes the results of the evaluations, provides enough technical details to allow for repeatability of the evaluations performed, and reports the results by comparison with the relevant limit. – The measurement report shall contain enough details and information for demonstrating compliance to the requirements of this document. 	Prepare the final measurement report along with addressing the requirements.



IEC

Figure 1 – Quick start guide

6 Measurement system specifications

6.1 General requirements for full SAR testing

A SAR measurement system consists of the phantom (a SAM phantom representing the human head, or a flat phantom representing the human body, or both) filled with tissue-equivalent medium, electronic measurement instrumentation, a scanning system, and a DUT holder. Procedures for full SAR testing are described in 7.4. SAR tests performed in accordance with this document shall conform to the following requirements.

- a) SAR shall be measured using a probe that is automatically positioned to measure the internal E-field distribution in the phantom. From the measured E-field values, the SAR distribution and the psSAR value shall be calculated.
- b) The phantom shall be filled with the required tissue-equivalent medium, representing the dielectric properties of tissues in the human head or body.
- c) The tissue-equivalent medium shall be a liquid of low viscosity to allow free movement of the probe within it.
- d) For the tissue-equivalent media, a density ρ of 1000 kg/m³ shall be used.
- e) At least three reference points shall be defined on the phantom by the phantom manufacturer to be used when aligning the scanning system with the phantom. These points shall be visible to the user, enclosing at least 80 % of the phantom top surface and each point shall be at least 20 cm from any other point.
- f) Both the ambient temperature and tissue-equivalent medium temperature shall be in the range of 18 °C to 25 °C, inclusive; see O.9.6 to determine the temperature uncertainty.
- g) Prior to the measurements of tissue-equivalent medium dielectric properties and SAR, the DUT, test equipment, medium, and phantom shall have been kept in the laboratory long enough for their temperatures to have stabilized (i.e. they shall not have been recently moved from another area with a different ambient temperature, such as a refrigerator or storage area).

NOTE Depending on the shape, size, volume, and initial temperature of the medium and the container, 24 hours or more might be required for temperature stabilization.

- h) The temperature of the tissue-equivalent medium during the SAR measurements shall be within 2 °C (or a temperature difference corresponding to a 5 % change in either permittivity or conductivity, if this is smaller) of the temperature at which the dielectric properties were measured. If the temperature change exceeds this tolerance, the dielectric properties shall be re-measured.
- i) The effect of reflections from cables, test equipment, or other reflectors shall be determined by the SAR system check procedure described in Clause A.2, by comparing the SAR measured with and without the reflectors present, or where necessary with the judicious placement of absorbing materials and/or the use of ferrite beads on cables.
- j) SAR measurements of DUTs shall only be performed when the effects of reflections, secondary RF transmitters, etc., result in a psSAR (for 1 g or 10 g mass, whichever is applicable to the test) less than 0,012 W/kg by measuring the psSAR at (approximately) 0,4 W/kg (used to establish the 3 % low detection limit, see 8.4.1.7). When the effect of cables and reflectors is more than 0,012 W/kg, ferrite beads, RF absorbers, and other mitigation techniques shall be applied to reduce the SAR error.

If the preceding limit cannot be achieved, a value higher than 3 % (0,012 W/kg) may be considered in the uncertainty budget in the “RF ambient conditions–reflections” row of the applicable tables in Annex C, provided it can be demonstrated that the SAR contribution due to reflections determined by the system check procedure is less than 10 % of the SAR measured for the DUT.

- k) The requirement on reflections shall be verified at least every year, or whenever the system check shows unexpected results.
- l) During testing, the DUT shall not be connected to any wireless network, except a base station simulator in the laboratory.

- m) System validation according to the protocol specified in Clause A.3 shall be done at least once per year, and additionally when a new measurement system is put into operation, and whenever modifications have been made to the measurement system (such as a new software version, different type or version of readout electronics, or different probes). The transmit sources used for system validation shall be designed and validated to meet the requirements specified in Annex D. Additional transmit sources of dipole and waveguide types at specific frequencies not presently included in Table D.1, Table D.2, Table D.3, Table D.4, Table D.5, Table D.6, Table D.7, Table D.8, Table D.9, and Table D.10 may be used as sources provided they meet the requirements specified in Annex D. In this document, flat phantoms shall be used for system check and system validation.
- n) The measurement system shall be validated as a complete system.
- o) The probe shall be calibrated in a tissue-equivalent medium required for the calibration frequency and temperature range, according to the methodology specified in Annex E. Calibration of the probe separately from the measurement system is allowed, provided that the same electrical interface characteristics specified for the probe and readout electronics are used during measurements. The probe(s) shall be calibrated together with an identical amplifier, measurement device, and data acquisition system.
- p) The lower detection limit shall be at most 0,01 W/kg, and the maximum detection limit shall be at least 100 W/kg.
- q) The probe isotropy shall be less than the expanded uncertainty for the axial isotropy component using the procedures of Table 9 and 8.4.1.5, or $\pm 0,2$ dB (± 5 %), whichever is less, as determined in the tissue-equivalent medium.
- r) The outermost diameter of the probe tip shall not exceed 8 mm in the vicinity of the measurement elements, for frequencies up to and including 2 GHz.
- s) For frequencies above 2 GHz, the probe tip diameter shall not exceed $\lambda/3$, where λ is the wavelength in the medium. The probe tip diameter may be larger if it can be demonstrated that the E-field from any potential field distribution can be measured with an uncertainty of less than ± 15 % ($k = 2$) at the distances from the surface of the phantom as listed in Table 3 and Table 4, or at the distances recommended by the SAR measurement system manufacturer (whichever is less).
- t) The system linearity shall be within $\pm 0,5$ dB over the SAR range from 0,12 W/kg to 100 W/kg.
- u) Where this document explicitly specifies performance characteristics for the measurement system or a part of the measurement system, the manufacturer of the system or sub-system, or the system integrator, shall document the conformity with the provisions of this document.

6.2 Phantom specifications

6.2.1 General

Subclause 6.2 specifies phantoms to be used for psSAR measurements of the DUT. Subclause 6.2.3 defines the head phantom to be used for evaluating exposure in the head, next to the ear. Subclause 6.2.4 defines the flat phantom to be used for evaluating exposure in the torso or other body regions. If the standard head or flat phantoms are not applicable, due to physical constraints of the scanning system or intended use conditions of the DUT, the specific phantoms described in 6.2.5 may be used.

6.2.2 Basic phantom parameters

The phantom shell material shall be resistant to damage or reaction with the chemicals used in the tissue-equivalent medium. The phantom shell shall be made of low-loss and low-permittivity material, having loss tangent $\tan \delta \leq 0,05$ and relative permittivity:

- $\epsilon'_r \leq 5$, for $f \leq 3$ GHz
- $3 \leq \epsilon'_r \leq 5$, for $f > 3$ GHz

Target dielectric properties of the tissue-equivalent medium in the phantom are specified in Table 2 for discrete frequencies ranging between 4 MHz and 10 GHz. For other frequencies within this range, the nominal dielectric properties shall be obtained by linear interpolation between the higher and lower tabulated figures. Example recipes for preparing tissue-equivalent media designed to produce the dielectric properties at some of the frequencies in the 4 MHz to 10 GHz range are provided in Annex F. The rationale for the medium dielectric properties is given in Clause G.5. The liquid temperature specifications are given in 6.1.

NOTE 1 Nominal values are target dielectric properties with a specific tolerance requirement.

To minimize reflections from the upper surface of the tissue-equivalent medium, the depth of the medium should be at least 15 cm. Medium depth of less than 15 cm may be used only if it is demonstrated (e.g. using numerical simulations) that the effect on psSAR is less than 1 % during system validation (see Annex A). If it is more than 1 % but less than 3 %, uncertainty for the highest value from the system validation shall be added to the uncertainty budget.

The dielectric properties shall be measured and compared with the values given in Table 2 using linear interpolation. This measurement can be performed using the equipment and procedures specified in Annex H. The measured dielectric properties, not the values of Table 2, shall be used in the SAR calculations.

NOTE 2 The dielectric properties (permittivity and conductivity) of the medium have been specified to result in conservative exposure (see Clause G.5 for the rationale used to derive the medium dielectric properties).

NOTE 3 See 7.2.1 for the allowable variations between the measured and the target dielectric properties specified in Table 2.

Table 2 – Dielectric properties of the tissue-equivalent medium

Frequency MHz	Real part of the complex relative permittivity, ϵ'_r	Conductivity, σ S/m	Penetration depth (E-field), δ mm
4	55,0	0,75	293,0
13	55,0	0,75	165,5
30	55,0	0,75	112,8
150	52,3	0,76	62,0
300	45,3	0,87	46,1
450	43,5	0,87	43,0
750	41,9	0,89	39,8
835	41,5	0,90	39,0
900	41,5	0,97	36,2
1 450	40,5	1,20	28,6
1 800	40,0	1,40	24,3
1 900	40,0	1,40	24,3
1 950	40,0	1,40	24,3
2 000	40,0	1,40	24,3
2 100	39,8	1,49	22,8
2 450	39,2	1,80	18,7
2 600	39,0	1,96	17,2
3 000	38,5	2,40	14,0
3 500	37,9	2,91	11,4
4 000	37,4	3,43	10,0
4 500	36,8	3,94	9,7

Frequency MHz	Real part of the complex relative permittivity, ϵ_r'	Conductivity, σ S/m	Penetration depth (E-field), δ mm
5 000	36,2	4,45	1,5
5 200	36,0	4,66	8,4
5 400	35,8	4,86	8,1
5 600	35,5	5,07	7,5
5 800	35,3	5,27	7,3
6 000	35,1	5,48	7,0
6 500	34,5	6,07	6,7
7 000	33,9	6,65	6,4
7 500	33,3	7,24	6,1
8 000	32,7	7,84	5,9
8 500	32,1	8,46	5,3
9 000	31,6	9,08	4,8
9 500	31,0	9,71	4,4
10 000	30,4	10,40	4,0

NOTE For convenience, permittivity and conductivity values are linearly interpolated for frequencies that are not a part of the original data from Drossos et al. [2]. They are shown in italics in Table 2. The italicized values are linearly interpolated (below 5800 MHz) or extrapolated (above 5800 MHz) from the non-italicized values that are immediately above and below these values.

6.2.3 Head phantom

The specific anthropomorphic mannequin (SAM) phantom shall be used for evaluating exposure in the head. The rationale for choosing the specific head phantom model (i.e. SAM) for this document is based on the following criteria.

- The psSAR shall provide conservative exposure.
- The test results shall not unnecessarily overestimate the maximum SAR expected in actual users.
- The phantom shall allow stable and repeatable device positioning for psSAR measurements, and be effective for verifying measurement repeatability according to system check procedures, and measurement reproducibility through inter-laboratory comparisons.
- The phantom shall be practical for routine SAR evaluation use.
- The phantom shall support these criteria for contemporary and future wireless device designs, and be unbiased with respect to any particular design or shape.
- Based on the presently available science, literature, and experience, the design of the SAM phantom that meets the above criteria is a function of at least the following parameters:
 - size and shape of the head phantom shell;
 - dielectric properties and material homogeneity of the tissue-equivalent media and the phantom shell;
 - ear pinna size, shape, location, and material properties;
 - exclusion of the hand for measuring SAR in the head (Annex I, 6.3).

6.2.4 Flat phantom

- a) For evaluating exposure in the body, the following requirements apply.
 - 1) The flat phantom shall be used.
 - 2) Its shell shall be constructed in the form of an open-top container with a flat bottom.
 - 3) Any flat phantoms used shall be large enough to allow the measurement of SAR in 1 g and 10 g volumes with an influence from the container shape of less than 1 % (Clause G.4).
- b) The flat phantom shall have the following shape and dimensions (Figure 2).
 - 1) Except as specified in b) 2), the phantom flat bottom wall shall have the shape of an ellipse with a length of 600 mm and a width of 400 mm.
 - 2) For frequencies above 150 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 as follows:
 - i) between 150 MHz and 800 MHz, the phantom flat bottom wall may have any shape that encompasses an ellipse with length of $0,6 \lambda_0$ and width of $0,4 \lambda_0$, where λ_0 is the wavelength in air;
 - ii) between 800 MHz and 10 GHz, the phantom may have any shape flat bottom wall that encompasses an ellipse with length of 225 mm and width of 150 mm.
- c) The thickness of the bottom-wall of the flat phantom shall be 2,0 mm, with a tolerance of $\pm 0,2$ mm. When filled with the required depth of medium, any sagging of the bottom surface of the phantom within the projection of the DUT shall be determined and considered in the uncertainty budget (see 8.4.2.4). If the preceding dimensional requirements are met, the effect of the shape and thickness on the repeatability of SAR measurement results is less than 1 % (see Clause G.4). Effects on the SAR due to the influence of the deviation from the required shell parameters and thickness shall be included in the uncertainty estimation (see 8.4.2.3).

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 the human body. Such coupling to the phantom, while maintaining prescribed distances, is likely to produce conservative exposure. Annex J provides more details about this topic.

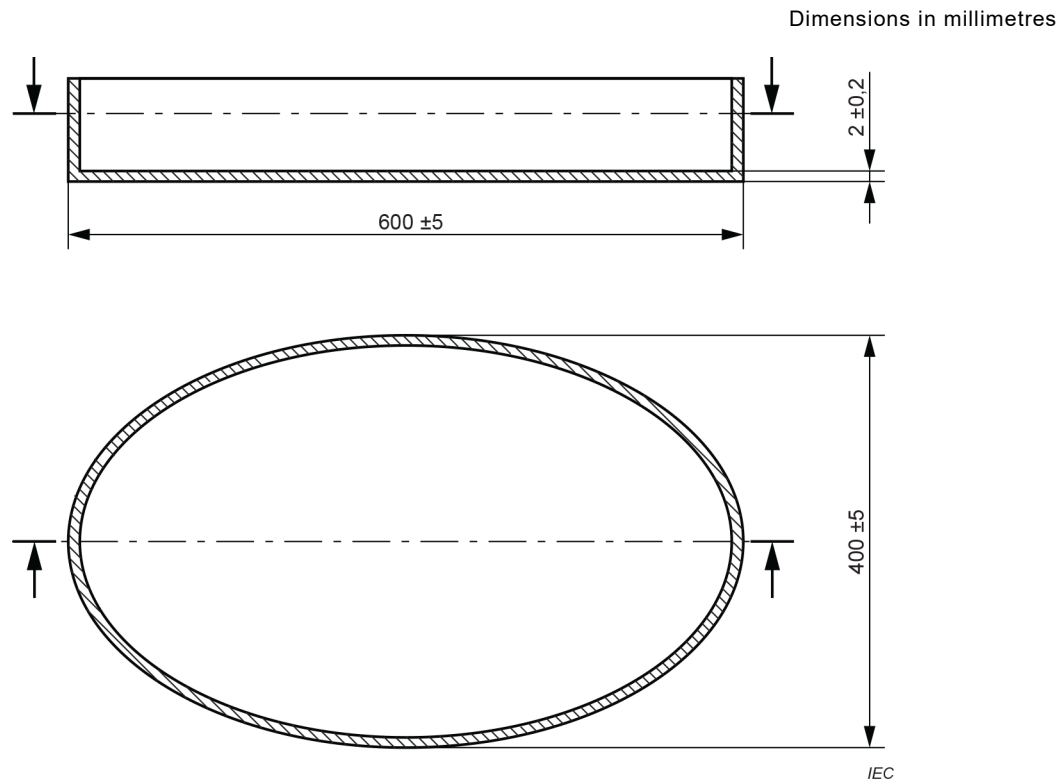


Figure 2 – Dimensions of the elliptical phantom

6.2.5 Device-specific phantoms

Device specific phantoms, alternative to those specified in 6.2.3 or 6.2.4, may be used if the flat phantom or SAM does not support the exposure conditions, or if either of the following applies:

- a) the device is intended for operation on different parts of the body other than the head or torso (e.g. the wrist);
- b) the physical constraints imposed on the scanning system by the phantom do not allow psSAR for the DUT to be determined with the required accuracy.

Examples of alternative device-specific phantoms are specified in Annex K and Annex L. The scientific or technical rationale and specifications of these phantoms are provided in the aforementioned annexes. Alternative device positioning procedures can also be required. These, and the rationale for using alternative specific phantoms, shall be reported.

6.3 Influence of hand on SAR in head

During normal operation, the head and hand are in the near-field of the DUT when used next to the ear, and hence both absorb energy. For extremities such as the hand, a higher SAR limit is allowed (e.g. 4 W/kg averaged over 10 g of tissue in ICNIRP RF exposure guidelines [3] and IEEE Std C95.1-2019 [4]). Numerical and experimental studies have shown that the SAR in the hand at the power levels used by typical DUTs is not expected to exceed those limits (Francavilla et al. [5], Gandhi et al. [6], Jensen and Rahmat-Samii [7], [8], Kuster et al. [9], Watanabe et al. [10]). Furthermore, a practical phantom for SAR measurement in the hand is currently unavailable. Therefore, SAR measurement in the hand is not addressed in this document.

The influence of a hand holding a DUT to the head during SAR measurements was considered in IEEE Std 1528-2013 [11]. Earlier work by Balzano et al. [12] and Kuster et al. [9] reported that the presence of the hand either decreased or had no significant effect on the head SAR; however numerical results by Meyer et al. [13] showed one case with 7 % increase in head SAR due to the hand. These deviations in head SAR were concluded to be within the conservativeness provided by the SAM phantom. Based on these studies, the exclusion of the hand from test procedures would lead to head SAR overestimation in the majority of situations, as confirmed by more recent research results [14], [15], [16] on DUT SAR levels. For these reasons, hand models are not considered in this document.

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

6.4 Scanning system requirements

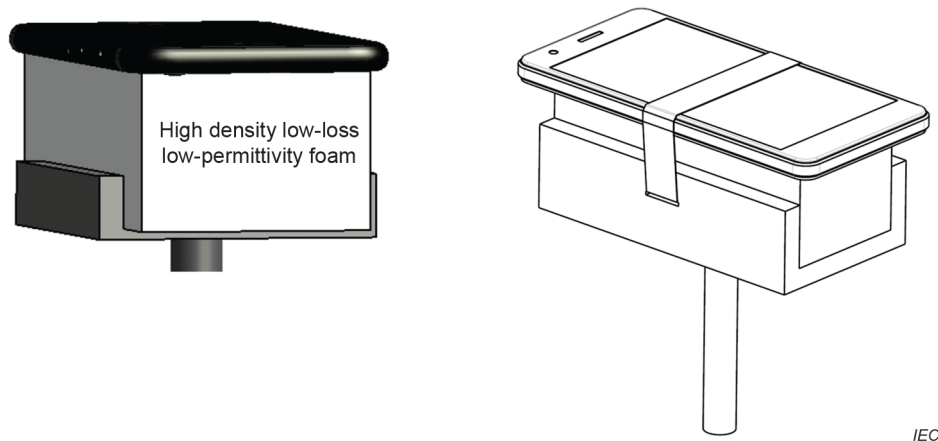
The SAR probe scanning system shall be able to scan the required measurement regions of the phantom that are within the projections of a DUT in order to evaluate the area and zoom scans. The tolerance of the probe tip positioning at a measurement point in the phantom shall be $\leq 0,2$ mm. Accuracy of the probe positioning system in relation to the phantom shall be verified according to the phantom reference points defined by the phantom manufacturer. The mechanical structure of the scanning system shall not interfere with the SAR measurements. The scanning range shall cover at least 90 % of the phantom dimensions in all directions.

6.5 Device holder specifications

The device holder shall permit the DUT to be positioned according to the definitions given in 7.2.4. It shall be made of low loss and low permittivity material(s): loss tangent $\leq 0,05$, and relative permittivity ≤ 5 .

The DUT is preferably mounted on a piece of low relative permittivity ($< 1,2$) and low loss foam before being mounted into the device holder, to avoid any direct contact between the device holder and the DUT (Figure 3). If this is not possible, the device holder shall provide the minimum amount of contact to the DUT to give a secure hold and maintain the required position during the measurement. In cases where a default relative positioning cannot be achieved, e.g. due to the device holder interaction with buttons and sensors on the DUT, then minimal position offsets in a predefined direction should be applied to achieve the required DUT test position. The details shall be provided in the measurement report.

The device holder shall ensure precise and repeatable positioning of the DUT for SAR measurement. The positioning uncertainties shall be estimated following the procedures specified in 8.4.2.5 and 8.4.2.6. If the highest psSAR is determined according to step 3 of the test protocol in 7.3.2, then the device holder uncertainty effect on the reported SAR value is considered to be negligible.



NOTE The DUT may be fixed on top of the foam (left), or held down using a thin strap (right).

Figure 3 – Mounting of the DUT in the device holder using low-permittivity and low-loss foam to avoid changes of DUT performance by the holder material

6.6 Characteristics of the readout electronics

The probe output is processed by the readout electronics and associated instrumentation that combines the voltages from the probe's sensors to provide an output that is proportional to the amplitude-squared of the E-field incident on the sensors. Detector diodes at the dipole feed-point are used to rectify the sensor voltages. The rectified signals are transmitted through resistive (RF-transparent) lines to the readout electronics system. For a continuous-wave signal at low field strength levels, the probe output is proportional to the square of the amplitude of the incident E-field; at higher signal levels (above the diode compression point), the output is not linearly proportional to $|E|^2$, but becomes proportional to $|E|$. This signal compression will lead to an underestimation of the actual SAR at high field strength conditions if it is not compensated correctly through probe calibration. Also, amplifiers in the readout electronics can deviate from an ideal linear response and introduce additional uncertainty. For uncertainties associated with the probe readout electronics, see 8.4.1.6.

7 Protocol for SAR assessment

7.1 General

All measurements should be carried out following good laboratory practice, e.g. in accordance with ISO/IEC 17025 [17], and any other national requirements for device certification. This document does not contain methods to verify the parameters of the DUT operating mode (e.g. modulation, data rate, time slots, resource blocks; see 3.33).

7.2 Measurement preparation

7.2.1 Preparation of tissue-equivalent medium and system check

- a) The measured dielectric properties of the tissue-equivalent media shall be applied in the SAR evaluation. The dielectric properties shall be measured within 24 hours before the SAR measurements, and for every 48 hours of continuous use. However, in the situation where a laboratory documents compliance with Table 2 and the requirements of 6.2.2 using measurement intervals of up to a maximum of one week, less frequent dielectric properties measurements are acceptable. When the test series takes longer than 48 hours, the medium properties shall also be measured at the end of the test series.

- b) Tissue-equivalent media shall yield measured relative permittivity and conductivity values within ± 5 % of the target values at frequencies at which the SAR is measured. When the method of 7.8 is used to correct the measured SAR for the deviations in permittivity and conductivity, the tolerance may be relaxed to a maximum of ± 10 % from the targets. When out-of-tolerance dielectric properties measurements are made during a measurement interval longer than 48 hours, all SAR data measured since the last dielectric properties measurement shall be discarded.
- c) For fast SAR testing systems that are hermetically sealed, the manufacturer shall provide either a procedure for the accurate measurement of the dielectric properties, or documentation of the dielectric properties of the medium (with corresponding medium temperature and ambient temperature) that were measured for the specific phantom when it was manufactured, or during system recalibration.
- d) The temperature of the tissue-equivalent medium shall be measured and recorded at the time of the dielectric properties measurement, and prior to the system check and SAR measurements.
- e) The system check shall be performed at each frequency band to be tested, in order to detect possible drift over short time periods and other measurement errors in the system. A system check according to the procedures of Clause A.2 shall be completed within 24 hours before performing SAR measurements for a DUT.
- f) The system check procedure shall be performed on the same SAR measurement system, with the same SAR probe(s) and same tissue-equivalent medium required by the SAR evaluation of the device for each frequency band tested. To limit power drift during the system check, automatic input power level control may be implemented, as specified in Annex V.

7.2.2 Preparation of the wireless communication DUT

- a) Any radiating element(s), battery, and accessories shall be those specified by the manufacturer, and documented in the measurement report. The battery shall be fully charged before each measurement, and the DUT positioned without external connections or cables that are not required for normal operation.
- b) The RF output power and frequency (channel) shall be controlled by a wireless link to a base station or network simulator for supported operating modes. When a wireless link cannot be established with a base station simulator, test software and internal test codes may be used.

NOTE 1 Some national regulatory agencies might require that verification be undertaken by the device manufacturer for tests performed on prototypes, to ensure that the commercial version has the exact same mechanical and electrical characteristics as the tested prototype.

- c) The DUT shall be set to transmit at the highest time-averaged output power level, within the range of the product's tune-up specifications and production variations.

For testing of wireless power transfer devices, other preparation procedures should be applied, as specified in IEC TR 62905 [18].

NOTE 2 For devices that can monitor and control their transmit power to maintain the time-average SAR below the applicable SAR limit, see 7.6.

7.2.3 DUT operating mode requirements

7.2.3.1 Requirements on DUT output power and signal parameters

The objectives of 7.2.3.1 are as follows.

- To determine that SAR of the DUT is evaluated at its maximum power level, taking into consideration device maximum output power tolerance and production variations.
- To correctly apply probe linearity compensation for time-varying signals, and to ensure that the signal is sampled correctly.

The power requirements are as follows.

- a) The maximum time-averaged power levels of the DUT shall be verified by the device manufacturer, e.g. by conducted power tests with a fully charged battery, to support SAR scaling.
- b) All applicable operating modes shall be considered for testing, although testing of some operating modes might not be required (7.9.3).
- c) A DUT operating in constant-envelope modes shall be tested at the maximum output power of its CW-equivalent (carrier) signal.
- d) A DUT operating in pulsed-envelope modes shall be tested using the same pulse characteristics (duty factor, pulse period). If the DUT is capable of transmitting several modes by varying the pulse characteristics (e.g. transmission in multiple slots) in a wireless technology, the signal with the highest time-average output power per frequency band shall be tested, after considering the maximum output power of the DUT for each mode.
- e) If the pulsed-envelope mode has a long pulse period such that the lowest frequency component of the signal envelope is below the low-pass filter cutoff frequency of the SAR measurement acquisition sub-system, the integration time and/or sample acquisition period shall be chosen to accurately measure the RMS of the signal, e.g. by using an integral number of pulse periods to avoid aliasing.
- f) A DUT in operating modes where the envelope of the signal varies randomly with time (e.g. CDMA, OFDM) shall be tested in the mode resulting in the maximum time-averaged output power transmitted by the device for each wireless technology. The probe shall be calibrated over its dynamic range, and the probe output shall include probe linearity compensation. The linearity compensation in general depends on the operating mode, as reported by Di Nallo and Faraone [19] and by Nadakuduti et.al [20].
- g) If the DUT cannot operate for the duration of the SAR measurement at its highest time-averaged output power level, within the range of the product's tune-up specifications and production variations, the following shall be applied.
 - 1) The DUT may be operated at a lower output power or lower duty factor, and the SAR shall be scaled to the required highest time-averaged output power level. However, the time-average output power shall be within the tolerance range specified for the device.
 - 2) The SAR of the device shall be shown to increase linearly with conducted power.
 - 3) Devices that operate with dual-output amplifiers, where both amplifiers are not required when operating at low power levels, or those that are designed to operate intermittently at very low duty factors, might require additional considerations to ensure SAR can be scaled linearly.

NOTE Some regulatory authorities might impose additional requirements on the maximum time-averaged output power reduction allowed for device SAR testing.

The procedure for power scaling is given in 7.2.3.2.

7.2.3.2 SAR scaling procedure for DUT power or signal variations

SAR scaling is the extrapolation of the SAR of a DUT determined with a tested operating mode (mod_X) to a SAR of the same device in the same exposure test position and frequency channel with a different operating mode (mod_Y). The difference can be in the power level, operating mode, or both. The time-averaged RF output power ratio of mod_X and mod_Y shall both be determined either by measuring the average power, or by numerical integration of the power envelope if the signals are sufficiently well known. SAR scaling is possible if:

- a) the same RF amplifier stage is used for mod_X and mod_Y ;
- b) the same antenna is used for mod_X and mod_Y , and MIMO or other antenna diversity techniques are not applied;
- c) the probe modulation response uncertainty has been evaluated for the modulated signal mod_X (8.4.2.7), and the SAR has been determined for mod_X ;

- d) the time-averaged RF output power ratio (R_p) of mod_X and mod_Y after the RF amplifier stage is known, according to Formula (1):

$$R_p = \frac{P_{\max, modY}}{P_{modX}} \quad (1)$$

where $P_{\max, modY}$ corresponds to the highest time-averaged output power setting. If the two signals differ in operating mode, then the test signal will be set at maximum time-averaged output power: $P_{modX} = P_{\max, modX}$.

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

- e) the RF carrier frequency of mod_X is the same as for mod_Y ;
f) the RF signal bandwidth ratio R_m of mod_X and mod_Y satisfies Formula (2):

$$R_m = \left| \frac{BW_{modY}}{BW_{modX}} - 1 \right| \times 100 \leq 30\% \quad (2)$$

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

If the preceding requirements are fulfilled, a scaling of the SAR from mod_X and mod_Y shall be performed according to Formula (3), and scaling uncertainty shall be determined as specified in 8.4.3.2:

$$SAR_{modY} = R_m \cdot SAR_{modX} \quad (3)$$

When the approach in 7.2.3.2 is used, it shall be stated in the measurement report that points a) through g) are satisfied.

For devices supporting PTT modes or other technology specific TDD operations, the maximum duty factor shall be assessed.

7.2.4 Positioning of the DUT relative to the phantom

7.2.4.1 Test distance and positioning relative to the flat phantom

7.2.4.1.1 General

Subclause 7.2.4.1 describes how the DUT, with or without accessories, shall be positioned, oriented, and configured relative to the phantom for SAR measurement. The specified test position(s) is (are) applicable for device-to-phantom surface separations up to and including 200 mm.

Subclause 7.2.4.1 describes positioning procedures for the following device types:

- devices that are large relative to phantom surface area (7.2.4.1.4);
- devices used with body-worn accessories (7.2.4.1.5);
- devices with hinged or swivel antenna (7.2.4.1.6);
- devices used next to or against the body without an accessory (7.2.4.1.7);
- desktop device (7.2.4.1.8);
- front-of-face device (7.2.4.1.9);
- hand-held usage of the device, not at the head or torso (7.2.4.1.10);
- limb-worn device (7.2.4.1.11);
- clothing-integrated device (7.2.4.1.12);

- generic device (7.2.4.1.13);

NOTE The figures provided in 7.2.4.1 are for illustration purposes only, and are not to scale or representative of the areas that need SAR measurement.

7.2.4.1.2 DUT-to-phantom separation distance

When performing measurements against the flat phantom, the DUT-to-phantom separation distance may be set according to the following hierarchy.

- Regulatory requirement: When there is a national regulatory requirement that specifies the DUT separation distance to the phantom, the DUT shall be positioned according to this requirement.
- “Intended use distance” specified by the manufacturer: When there is no regulatory requirement, the intended use condition or distance specified by the manufacturer shall be used. This information shall be acquired from the user documentation accompanying the DUT.
- Default separation distance: When there is neither a regulatory requirement nor an intended use distance specified by the manufacturer, the DUT shall be measured with each accessible face in direct contact with the surface of the phantom (see also 7.2.4.1.13 generic device).

The stated separation distance may be determined with the carry accessory attached to the DUT, when such condition is tested; see 7.2.4.1.5.

Care should be taken to ensure precise positioning at the applicable separation distances, for example using calibrated gauge blocks or similar means to ensure repeatability.

7.2.4.1.3 DUT reference points

General guidance to identify the orientation of a DUT, or when placed in a carry accessory for positioning to the flat phantom, is as follows. P1, P2, P3, and P4 are defined as the midpoint on each edge of the surface facing the phantom as shown in Figure 4. 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 specified as the distance between the phantom shell and the closest point on the DUT when positioned as specified in the preceding sentences. This general guidance may need to be adapted for specific designs, such as devices or carry accessories with curved surfaces, that require the device to be positioned differently for testing. Clear details of the actual test positions used shall be fully documented in the measurement report.

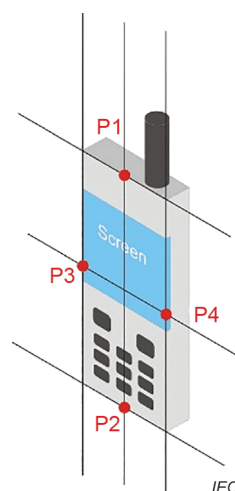


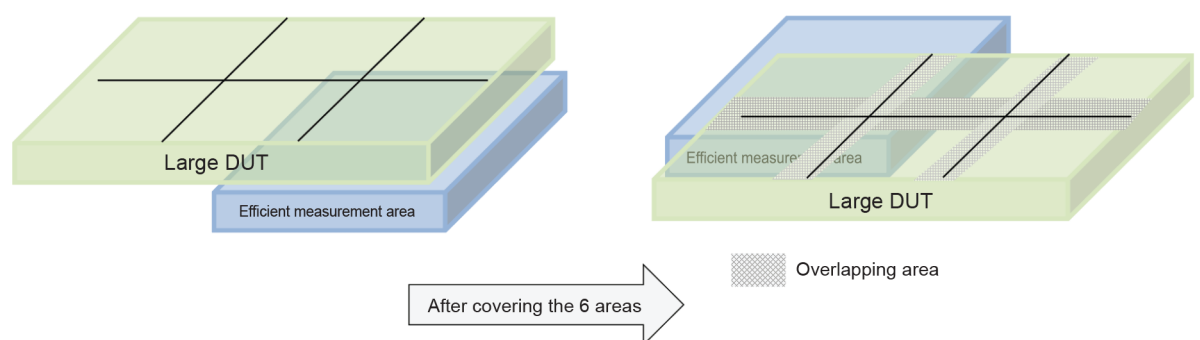
Figure 4 – Designation of DUT reference points

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

If the DUT is larger than the measurable region of the flat phantom specified in 6.2.4, the following applies.

- The DUT shall be shifted such that the SAR distribution of the DUT can be covered by multiple area scans. When the DUT is shifted, the RF coupling between the DUT and phantom could change, resulting in a different SAR distribution compared to that using a larger phantom. A larger phantom, however, might not be representative of the significant majority of exposure situations involving people (see NOTE in 6.2.4).
- To limit differences in the measured SAR due to coupling variations, two successive scans shall have an overlapping area of at least one third the size of the combined area, as shown in Figure 5.
- In the overlapping area, the SAR distribution shall be similar such that the SAR difference at any point relative to the DUT geometry is less than the expanded uncertainty for repeatability. Otherwise, the DUT shall be shifted by a smaller amount such that the SAR difference is within the uncertainty.

Shifting is not needed if the radiating structures are small compared to the DUT and the phantom and/or the first area scan shows that the SAR distribution is entirely captured within the scanning area. In the situation where shifting was omitted, the rationale shall be clearly documented in the measurement report.



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Figure 5 – Measurements performed by shifting a large device over the efficient measurement area of the system including overlapping areas – in this case: six tests performed

7.2.4.1.5 Devices used with body-worn accessories

A device within the scope of this document intended for use with a body-worn accessory approved or specified by the device manufacturer shall be assessed according to the following requirements.

- If the user instructions provided by the manufacturer specify the intended use with a carry accessory (belt-clip, holster, carry-case or similar), the device shall be placed in that carry accessory and positioned in the intended use conditions against the flat phantom.
- For carry accessories constructed from non-conductive materials that are capable of holding the DUT at varying distances to the phantom, the carry accessory providing the closest separation distance is expected to produce the highest SAR; therefore, testing of a carry accessory providing larger separation distances is not necessary unless the carry accessory contains conductive materials.
- If there are multiple carry accessories that hold the DUT at the same distance, at least one carry accessory should be tested. Note that all carry accessories containing conductive materials shall be tested.

- d) For carry accessories that do not contain conductive materials (e.g. no metal parts), it is acceptable to substitute the carry accessory with an air-gap that keeps the DUT at a distance from the phantom surface no greater than the distance provided by the carry accessory.
- e) The device shall be positioned in the intended use configuration with the body-worn accessory where the distance to the outer surface of the phantom is established by the specific accessory (Figure 6).
- f) When evaluating devices that are not supplied with body-worn accessories but users can acquire body-worn accessories on their own, body-worn accessory SAR shall be measured with a separation distance according to the conditions of 7.2.4.1.2.
- g) The surface of the device pointing towards the flat phantom should be positioned at the surface of the phantom according to 7.2.4.1.3; however, not all devices 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 according to the body-worn accessories, shall be documented in the measurement report.
- h) When it is unclear if multiple surfaces can operate in a body-worn accessory facing the user, the DUT shall be tested with all applicable surfaces placed at the most conservative separation distance from the flat phantom. The details of the device position, attached to the accessory, shall be documented in the measurement report. If testing of some (but not all) surfaces is not required, this shall be documented with an associated rationale in the measurement report.

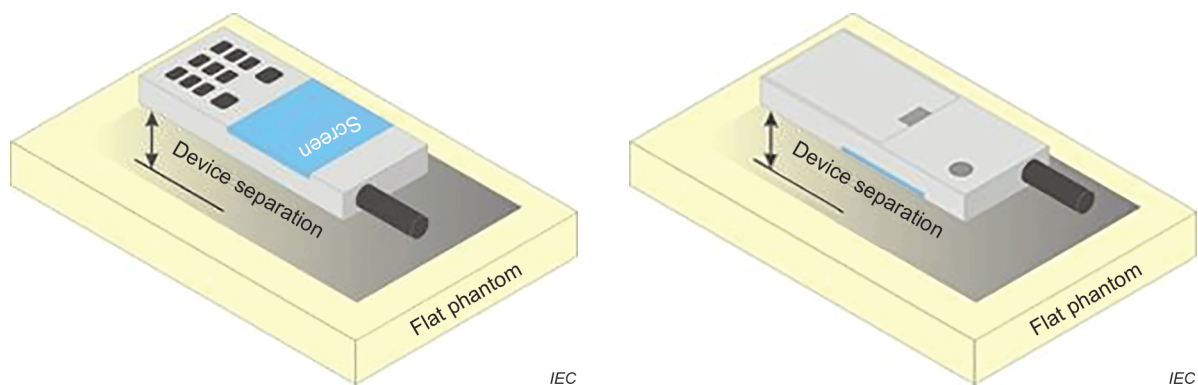


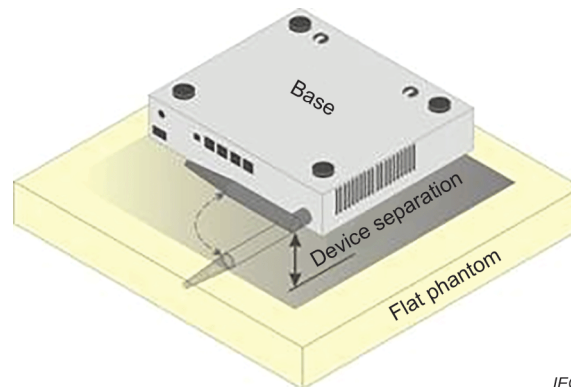
Figure 6 – Test positions for body-worn devices

7.2.4.1.6 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), the following applies.

- a) The DUT shall be positioned in accordance with 7.2.4.1.2 and 7.2.4.1.3.
- b) When it is unclear if certain antenna positions are applicable, tests shall be performed for the antenna positions and polarizations that are expected to be used by the users (Figure 7); for example with the antenna extended and retracted such as to obtain the highest exposure condition.
- c) For antennas that can be rotated through one or two planes, a preliminary investigation across rotation ranges should be made and documented in the measurement report, to determine the highest exposure scenario(s) so that only that position(s) need(s) to be tested.
- d) For devices with multiple detachable antennas, each antenna should be considered separately to determine SAR test requirements; for example, if the antennas are substantially similar (equivalent), certain test reduction considerations may be applied (7.9.3.3).

Subclause 7.2.4.1.6 may be applied in conjunction with test configurations specified in other subclauses, as appropriate for the device.



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Figure 7 – Device with swivel antenna

7.2.4.1.7 Devices used next to or against the body without an accessory

A typical example of a device used next to the body is a wireless enabled laptop or a tablet device containing a peripheral plug-in radio transmitter that can be supported on the user's body. Other devices that fall into this category include tablets of equivalent sizes or larger than a netbook computer (> 20 cm diagonal display), credit card transaction authorization terminals, and point-of-sale and/or inventory terminals. The example in Figure 8 a) shows a tablet form factor portable computer for which SAR should be separately assessed with each surface and edge containing an antenna positioned against the flat phantom in accordance with the conditions of 7.2.4.1.2. Some tablets might limit display orientations so that the edges with antennas are not used next to the user; therefore, such edges might not need testing.

To assess these types of use conditions, the following applies.

- a) The DUT shall be positioned with its base (bottom surface) and applicable edges against the flat phantom. The orientations and other use positions can be host device specific. Therefore, these should be determined according to the transmitter and antenna locations on the host device.

NOTE 1 RF transmitters that can operate in different hosts might require additional consideration.

- b) For antennas incorporated in the display screen of a laptop, notebook or netbook computers, tests shall be performed with the display screen open at a 90° angle as seen in Figure 8 b) (left side), or at a more conservative angle allowing the antennas to be closer to the phantom for assessing the user exposure conditions.
- c) Devices in the scope of 7.2.4.1.7 with a display screen that should be open during normal operation generally do not need to be tested, provided the antenna(s) on the screen is sufficiently far away from the user's body according to the maximum output power of the antenna.
- d) Where a screen mounted antenna is present, the SAR measurement for bystander exposure shall be performed with the screen positioned parallel to the flat phantom as shown in Figure 8 b) (right side).

NOTE 2 A separation distance of 2,5 cm is considered to be conservative for covering a wide range of expected bystander exposure conditions.

- e) Body-supported devices with an external power supply (e.g. AC adapter) supplemental to the battery shall be tested with and without the external power supply attached.
- f) For devices that employ an external antenna with variable positions, the procedures for swivel and detachable antenna should be used; see 7.2.4.1.6 and Figure 7.

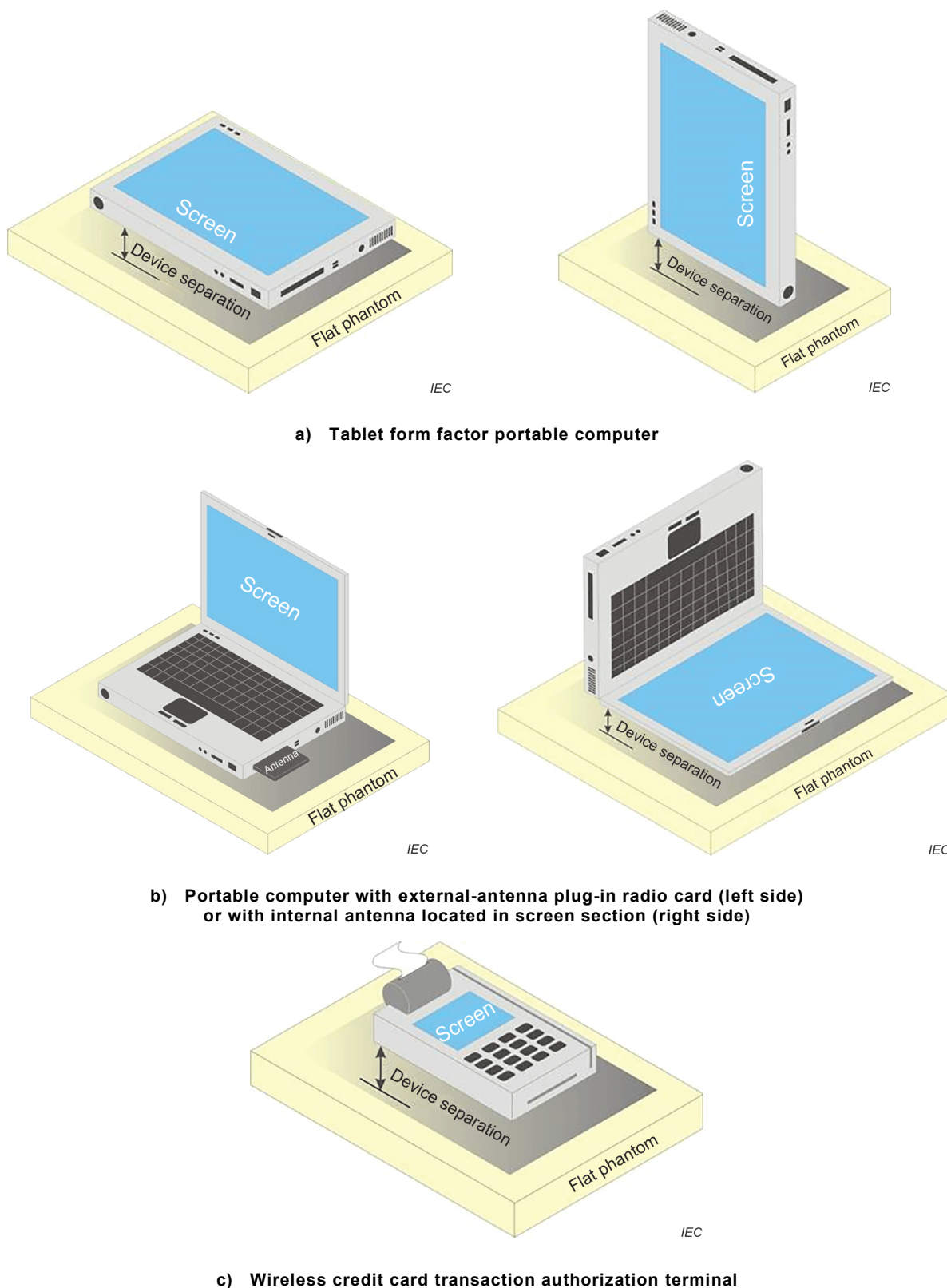


Figure 8 – Test positions for body supported devices

7.2.4.1.8 Desktop device

A typical example of a desktop device is a wireless enabled desktop computer placed on a table or desk at closer than 200 mm to users while being used.

To assess this type of device the following applies.

- The DUT shall be positioned against the flat phantom in accordance with the conditions of 7.2.4.1.2.
- For devices that employ an external antenna with variable positions, tests shall be performed for all antenna positions specified. Figure 7 and Figure 9 illustrate the SAR test positions for desktop device.

Due to the physical design, some device surfaces might not require testing, e.g. the base of a desk standing device.

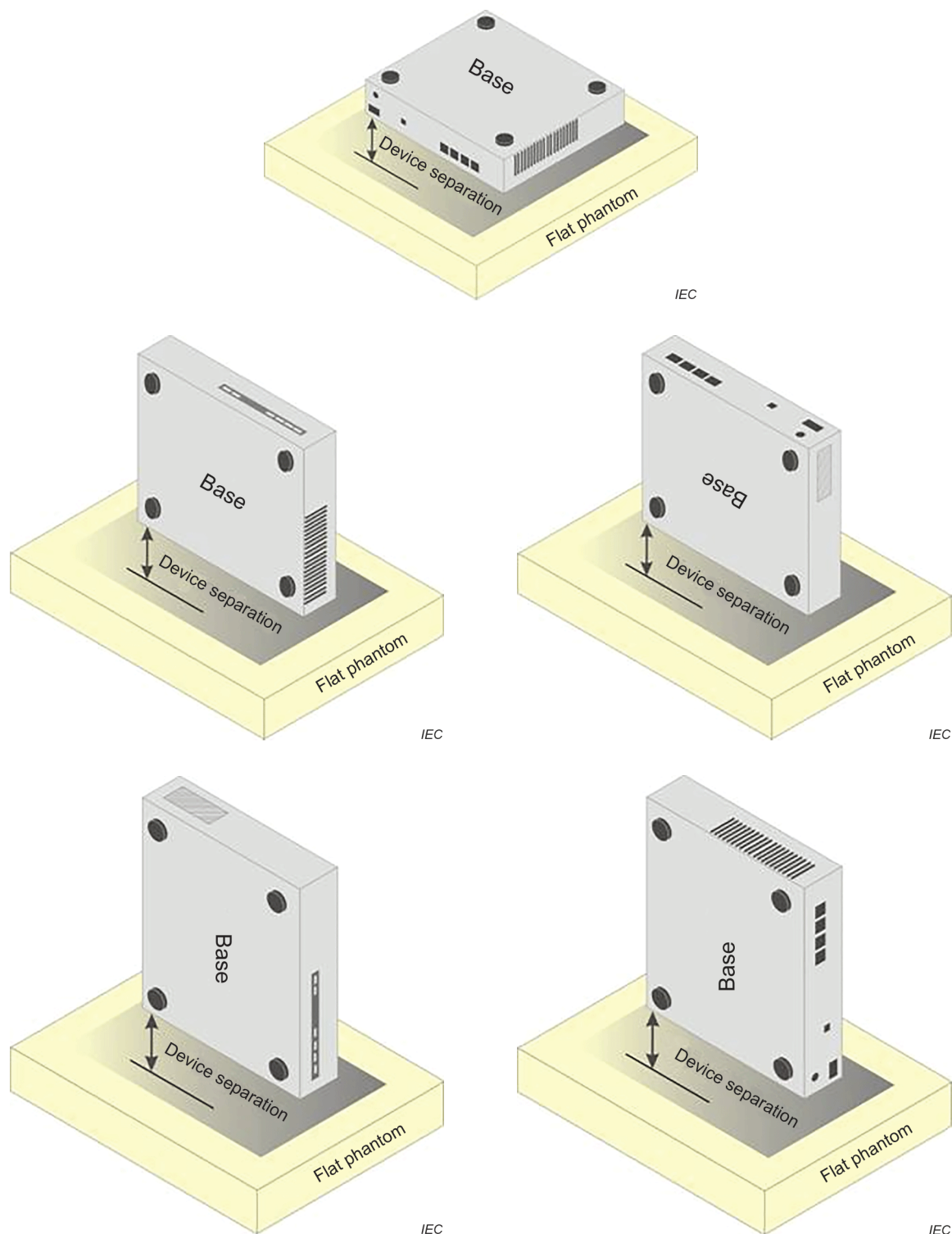


Figure 9 – Test positions for desktop devices

7.2.4.1.9 Front-of-face device

A typical example of a front-of-face device is a two-way radio that is held at a close distance from the face of the user while transmitting. Other devices that fall into this category include wireless-enabled still cameras and video cameras capable of sending data to a network or other device (Figure 10 a)).

To assess this type of device, the following apply:

- The DUT shall be positioned at a test separation distance to the phantom surface in accordance with the conditions of 7.2.4.1.2.
- For a device with intended use that requires contact with the user's face (e.g. device with an optical viewfinder), such a device shall be placed directly against the phantom (Figure 10 a), right side).

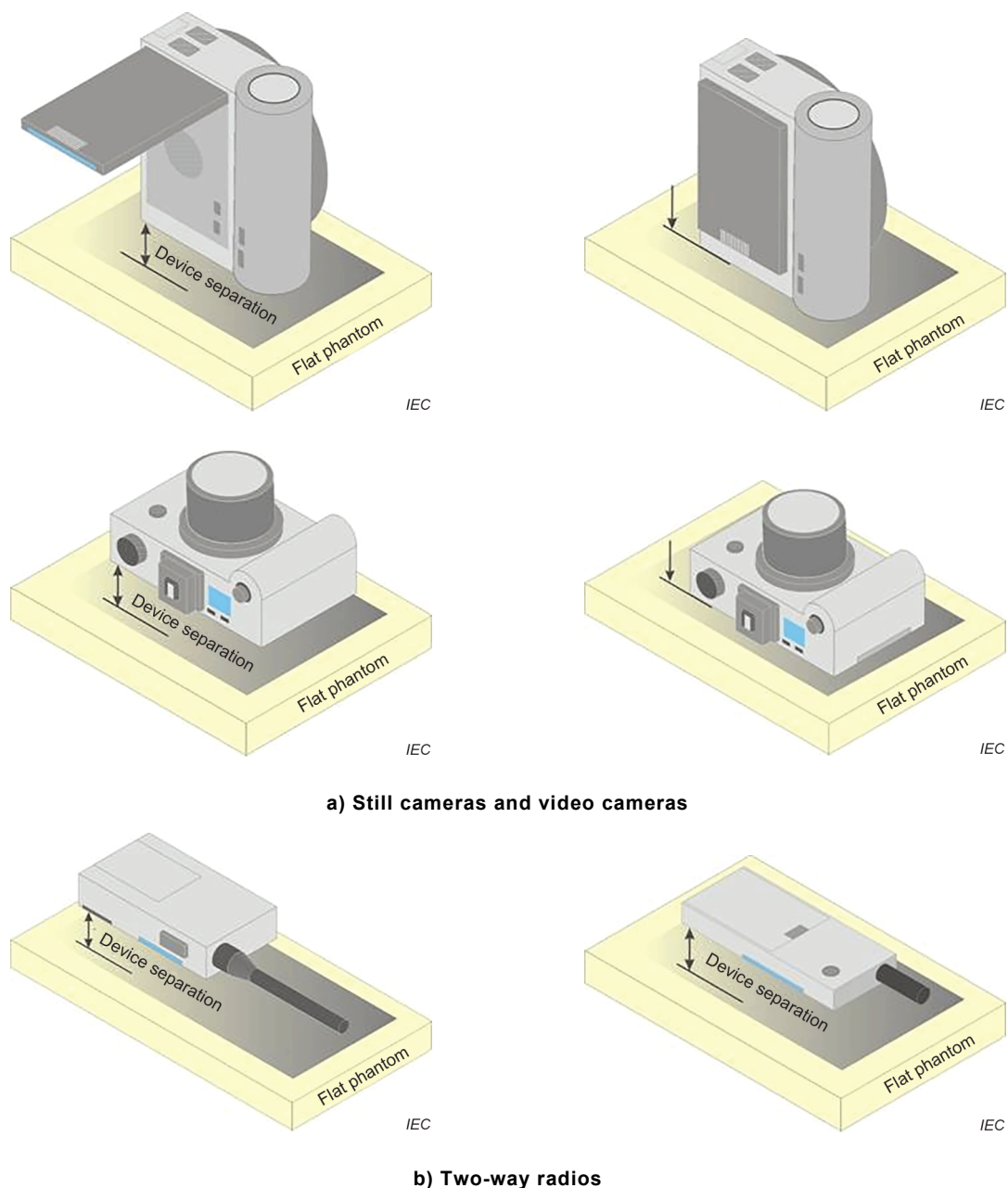


Figure 10 – Test positions for front-of-face devices