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Responsible committee: GEL/106 Human exposure to low frequency and high frequency electromagnetic radiation

Interested committees:

Title: BS EN 62209-3 Amd.1 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)

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- iii) requires additional national guidance or information

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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

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UK Vote

Please indicate whether you consider the UK should submit a negative (with supporting technical reasons) or positive vote on this draft. Please indicate if you are aware of any reason why this draft standard should not be published as a British Standard.

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Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/Figure/ Table/Note	Type of comment	Commend (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	



106/601/CD

COMMITTEE DRAFT (CD)

PROJECT NUMBER:
IEC/IEEE 62209-3 ED2

DATE OF CIRCULATION:
2023-02-10

CLOSING DATE FOR COMMENTS:
2023-04-07

SUPERSEDES DOCUMENTS:
106/577/CD, 106/594A/CC

IEC TC 106 : METHODS FOR THE ASSESSMENT OF ELECTRIC, MAGNETIC AND ELECTROMAGNETIC FIELDS ASSOCIATED WITH HUMAN EXPOSURE

SECRETARIAT:
Germany

SECRETARY:
Mr Alexander Prokop

OF INTEREST TO THE FOLLOWING COMMITTEES:
TC 9, TC 27, TC 29, TC 34, SC 62A, SC 62B, TC 69, TC 77, TC 78, TC 96, TC 100, TC 124, TC 125

PROPOSED HORIZONTAL STANDARD:



Other TC/SCs are requested to indicate their interest, if any, in this CD to the secretary.

FUNCTIONS CONCERNED:

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TITLE:

Measurement procedure for the assessment of specific absorption rate of human exposure to radio frequency fields from hand-held and body-mounted wireless communication devices – Part 3: Vector measurement-based systems (Frequency range of 300 MHz to 6 GHz)

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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 3: Vector measurement-based systems (Frequency range of 300 MHz to 6 GHz)

FOREWORD

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IEC technical committee 106: "Methods for the assessment of electric, magnetic and electromagnetic fields associated with human exposure" and "IEEE International Committee on Electromagnetic Safety (ICES) - technical committee 34 have jointly prepared this IEC/IEEE 62209-3 Ed.2 dual-logo standard.

This second edition cancels and replaces the first edition that was published as an IEC standard in 2019. This edition constitutes a technical revision.

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

- Extension of lower end of frequency range to 300 MHz;
- Updated procedures for SAR measurement of simultaneous transmission, with correlated and uncorrelated signals;
- Considerations for SAR assessments of 5G NR applications;
- Novel procedure for system validation based on Gaussian process interpolation;
- Consolidated annexes describing evaluation of contributing parameters for measurement uncertainty estimation and restructured separately for system manufacturer and for user purposes;
- New annex on frequency-dependency of basic SAR calculation formula;
- Various editorial changes for reorganization, renumbering, and consolidation of some subclauses.

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

FDIS	Report on voting
106/.../FDIS	106/.../RVD

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with the rules given in the ISO/IEC Directives, Part 2, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications/.

This standard contains attached files for the following items. These files are available in the supporting documents folder at:
www.iec.ch/tc106/supportingdocuments.

- four *.IGS files of inner and outer surfaces for the left and right halves extracted from the CAD model of the SAM phantom (see A.1.2);
- GPI-model for system validation (Clause D.4);
- reference antennas described in Annex E;
- analytical functions that are to be used for the evaluation of the reconstruction algorithm uncertainty in Table J.1.

The IEC Technical Committee and IEEE Technical Committee have decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

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

IMPORTANT – The “colour inside” logo on the cover page of this document 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.

400

INTRODUCTION

401 This document specifies the requirements for vector measurement-based systems to measure
402 the specific absorption rate (SAR) of devices that are used in close proximity to the human body
403 or head.

404 Because SAR measurement systems are used for showing compliance with national and
405 international exposure limits, the test procedures have to be standardized. This standardization
406 aims at achieving accurate and reliable results for determining RF exposure compliance.

407 Vector measurement-based systems and the associated protocols can differ from traditional
408 SAR measurement systems and protocols. These systems use field reconstruction methods,
409 allowing the application of indirect measurement approaches in which the SAR is evaluated in
410 three dimensions from a limited number of measurement points that may be located in a limited
411 part of the volume of interest. Such SAR assessment approaches can result in significantly
412 reduced SAR measurement times.

413

414

**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 300 MHz to 6 GHz)**

1 Scope

This part of IEC 62209 specifies measurement protocols and test procedures for the reproducible measurement of peak spatial-average specific absorption rate (psSAR) induced inside a simplified model of a human head or body by radio-frequency (RF) transmitting devices, with a specified measurement uncertainty. Requirements are provided for psSAR assessment using vector measurement-based systems. A vector measurement-based system may be a scanning system or an array system. Such systems determine the psSAR by three-dimensional (3D) field reconstruction within the volume of interest in accordance with the requirements herein for the measurement system, calibration, uncertainty assessment and validation methods. The protocols and procedures apply for the psSAR assessments cover a significant majority of people including children during use of wireless communication devices operated in close proximity to the head or body.

This document is applicable for SAR evaluations of wireless communication devices intended to be used at positions near the human head or body at distances up to and including 200 mm. This document may be 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, combined with other RF-transmitting or non-transmitting devices or accessories (e.g. belt-clip), or embedded in garments. The overall applicable frequency range is from 300 MHz to 6 GHz.

The wireless communication device categories covered include but are not limited to mobile telephones, cordless microphones, auxiliary broadcast devices and radio transmitters in personal computers, desktop and laptop devices, multi-band, multi-antenna, and push-to-talk 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 TR 62630:2010, *Guidance for evaluating exposure from multiple electromagnetic sources*

IEC/IEEE 62209-1528:2020, *Measurement procedure for the assessment of specific absorption rate of human exposure to radio frequency fields from hand-held and body-worn wireless communication devices - Human models, instrumentation and procedures (Frequency range of 4 MHz to 10 GHz)*

IEC/IEEE 62704-1, *Determining the peak spatial-average specific absorption rate (SAR) in the human body from wireless communications devices, 30 MHz to 6 GHz – Part 1: General requirements for using the finite difference time-domain (FDTD) method for SAR calculations*

IEC 62479, *Assessment of the compliance of low-power electronic and electrical equipment with the basic restrictions related to human exposure to electromagnetic fields (10 MHz to 300 GHz)*

ISO/IEC Guide 98-1:2009, *Uncertainty of measurement – Part 1: Introduction to the expression of uncertainty in measurement*

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 terms and definitions given in IEC/IEEE 62209-1528:2020 and the following 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 components or attachments 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 specialised 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

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).

3.3

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.

3.4

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

3.5

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.

3.6

cable

assembly of one or more conductors and/or optical fibres, with a protective covering and possibly filling, insulating and protective material

[Electropedia]

3.7

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 standard, SAR measurements are performed at specific channels; for example, the high, middle, and low channels of the transmission band.

3.8

conservative exposure

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

3.9

constant-envelope mode

transmission mode where the signal amplitude over the channel bandwidth does not vary with time

3.10

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 62630:2010.

3.11

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

3.12

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

3.13

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 can be further categorised as a body-worn, body-supported, desktop, front-of-face, hand-held, limb-worn, clothing-integrated, or generic device.

3.14

duty factor

proportion of time that a transmitter transmits over a specified period

3.15

frequency band

transmitting frequency range associated with a specific wireless operating mode

Note 1 to entry: The frequency band is often 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

564 894 MHz, the GSM 900 MHz band actually uses 880 MHz to 915 MHz and 925 MHz to 960 MHz. In other cases, the
565 official 3GPP nomenclature might be used, for instance LTE Band 12 (uplink 699 MHz to 716 MHz; downlink 729 MHz
566 to 746 MHz).

567 **3.16**

568 **front-of-face device**

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

571 **3.17**

572 **generic device**

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

574 **3.18**

575 **hand-held device**

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

578 **3.19**

579 **handset**

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

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

589 **3.20**

590 **host**

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

593 **3.21**

594 **intended use**

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

598 **3.22**

599 **limb-worn device**

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

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

604 **3.23**

605 **linearity error**

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

608 **3.24**

609 **drift**

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

612 **3.25 measurement uncertainty**

613 **3.25.1**

614 **uncertainty evaluation**

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

617 **3.25.2**

618 **uncertainty evaluation**

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

621 **3.25.3**

622 **standard uncertainty**

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

625 **3.25.4**

626 **combined uncertainty**

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

631 **3.25.5**

632 **expanded uncertainty**

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

636 **3.26**

637 **multi-band <wireless communication device>**

638 wireless communication device, capable of operating in more than one frequency band

3.27

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 handsets, terminals, and devices 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, Wi-Fi®². Multiple operating modes can operate 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.

3.28 power

3.28.1

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

3.28.2

loaded radiated output power

radiated output power when the DUT is placed in a SAR test position against the phantom

Note 1 to entry: Maximum loaded radiated output power within test channels is typically tested using a Total Radiated Power (TRP) measurement system. Alternatively it is calculated by multiplying for each channel the conducted power by transmission coefficient of the antenna in the given test position. Relative maximum loaded output power typically is also measured by SAR measurement systems.

3.29

secondary peak SAR value

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

3.30

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.

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.

3.31

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

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.

3.32

phantom

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

3.33

pinna

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

3.34

production variation

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

3.35

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)

3.36

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

3.37

tune-up specification

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

3.38

probe

Input device of a measuring instrument, generally made as a separate unit and connected to it by means of a flexible cable, which transmits the measurand in a suitable form

3.39

vector probe

probe that measures both the amplitude and phase of an electric field or a magnetic field

3.40

scalar probe

probe that measures only the amplitude of an electric field or a magnetic field

3.41

vector measurement-based system

system consisting of multiple sensors that together provide information about the amplitude distribution or the amplitude and phase distribution of an electric field or a magnetic field to reconstruct SAR over a specified volume (volume of interest)

Note 1 to entry: Throughout this document the term “measurement system” generally refers to vector measurement-based system.

3.42

analysis bandwidth <of a signal analyser>

maximum frequency span of observation for a system capable of spectral analysis

Note 1 to entry: The analysis bandwidth is generally characterized by a specific flatness ($\pm$ a tolerance) of the responses of the system in the specified range of frequencies.

3.43

array system

array measurement system

vector measurement-based system comprised of multiple vector probes or scalar probes that are located at fixed positions on a two-dimensional or three-dimensional regular or irregular grid to obtain the measurement data needed to reconstruct the total electromagnetic field within and outside the scanned region and in the volume of interest

3.44

scanning system

scanning measurement system

vector measurement-based system comprised of one or more vector probes or scalar probes that are physically scanned on a two-dimensional or three-dimensional regular or irregular grid to obtain the measurement data needed to reconstruct the total electromagnetic field within and outside the scanned region and in the volume of interest with an automatic positioning system capable of placing the measurement probe at specified positions

Note 1 to entry: For purposes of this document, the vector measurement and field reconstruction aspects are amended compared to definition **3.48 scanning system** of IEC/IEEE 62209-1528:2020.

3.45

volume of interest

region inside the phantom in which the peak spatial-averaging SAR cubes are induced by the transmitter mounted to the phantom

Note 1 to entry: In the context of this standard, this includes at a minimum the volume as composed of the projection of the device onto the phantom surface with sidewalls normal to this surface having a backside parallel to the surface of the phantom in a distance of at least the side length of the spatial peak SAR 10 g cube, i.e. 21,5 mm.

3.46

specific absorption rate, SAR

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

Note 1 to entry: Annex M describes considerations on frequency dependencies of SAR.

Note 2 to entry: SAR in the tissue-equivalent medium can be determined by the rate of temperature increase or by electric field strength measurements, according to the following formulas:

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

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

where:

SAR is the specific absorption rate in watt per kilogram;

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

c_h is the specific heat capacity of the tissue-equivalent medium in joule 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.

3.47

maximum measurement area (flat phantom)

outer surface of the flat phantom shell aligned with the planar probe array and whose size is equal to the physical size (length times width) of the planar probe array

4 Symbols and abbreviated terms

4.1 Physical quantities

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

Symbol	Quantity	Unit	Dimensions
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	$4\pi \times 10^{-7} \text{ H/m}$

787 **4.3 Abbreviated terms**

4G	Fourth generation wireless technology
5G NR	Fifth generation new radio (3GPP)
CAD	Computer aided design
CDMA	Code division multiple access
CP-OFDM	Cyclic Prefix OFDM
CW	Continuous wave
DC	Dual Connectivity
DFT	Discrete Fourier Transform
DFT-s-OFDM	DFT spread OFDM
DUT	Device under test
EDGE	Enhanced Data rates for GSM Evolution
E-field	Electric field strength
E-UTRA	Evolved UMTS Terrestrial Radio Access
ERP	Ear reference point
FDMA	Frequency division multiple access
FDTD	Finite-difference time-domain
GPRS	General Packet Radio Service
GSM	Global System for Mobile Communications
H-field	Magnetic field strength
LTE	Long Term Evolution
MIMO	Multiple input multiple output
NR	New Radio
OFDM	Orthogonal frequency-division multiplexing
PAPR	Peak to Average Power Ratio
POSIX	Portable Operating System Interface
psSAR	Peak spatial-average SAR
PTT	Push-to-talk
RF	Radio frequency
RMS	Root mean square
RSS	Root sum square
SAM	Specific anthropomorphic mannequin
SAR	Specific absorption rate
TX	Transmission
UL	Uplink
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

788

789

5 Overview of the measurement procedure

The objective of Clause 5 is to give the user of this document a quick overview of the test procedures in this document. The user of the document shall refer to the respective clauses for more details when using the flowchart presented in Figure 1 and the evaluation plan checklist for the device under test (DUT) in Table 1.

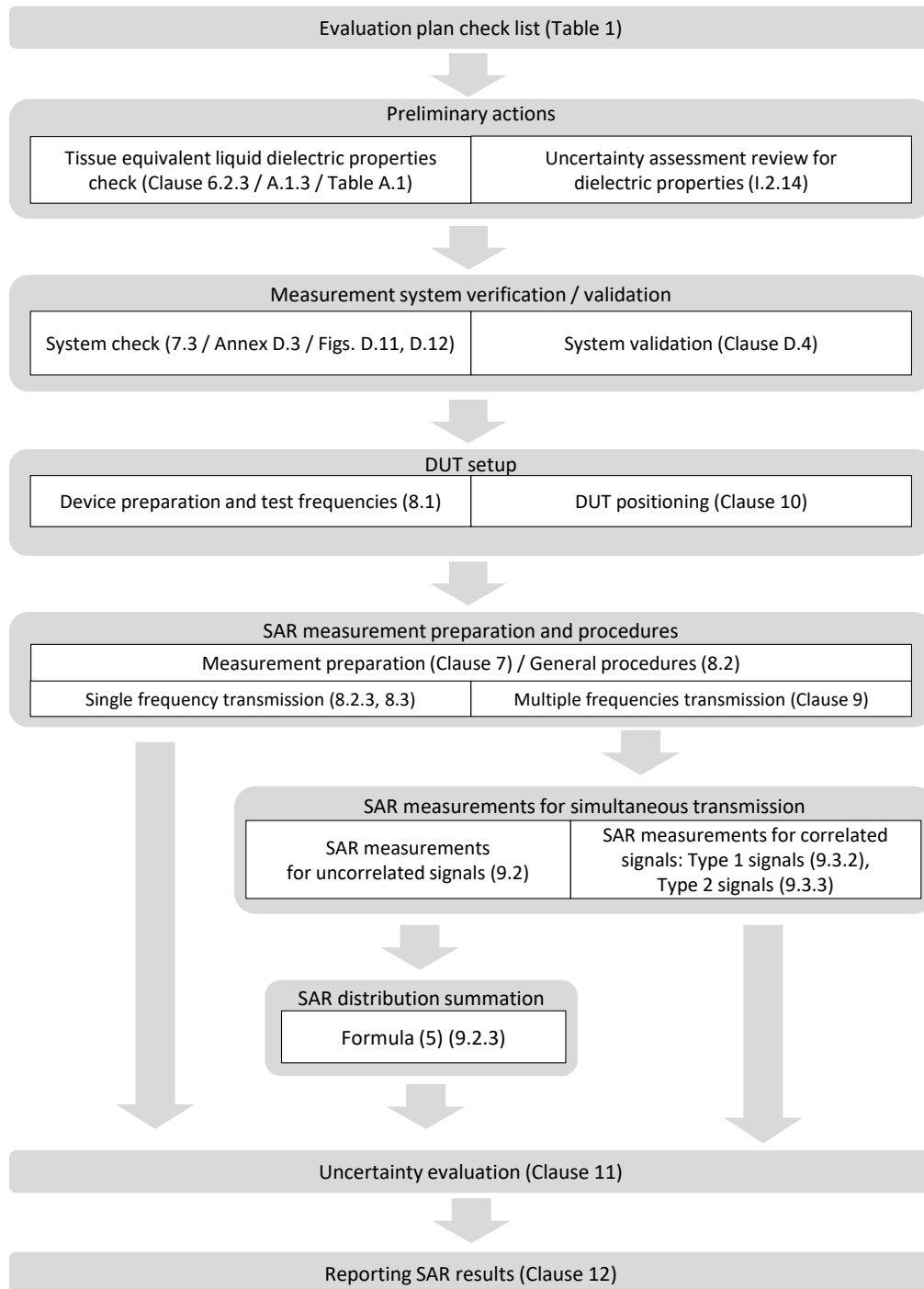


Figure 1 – Evaluation plan checklist

799

Table 1 – Evaluation plan checklist

Stage	Evaluation steps	Action
- Evaluation plan check-list - Planning of the measurement configurations	- What type of device is being evaluated? - Review of antenna(s) contained and wireless technologies supported, singly or in combination. - What are the test positions applicable? - Working under laboratory conditions and following good laboratory practice and documentation, prepare to perform the necessary evaluation. - There should be a check that the measurement system meets the system requirements, including validation, reporting of the reconstruction algorithm and reporting of the measurement uncertainty.	Complete check-list based on evaluation plan (Table 1, Figure 1).
Preliminary actions and measurement system check	- A measurement of the tissue-equivalent medium dielectric properties shall be performed for systems with open phantoms, and the result shall be recorded. - Follow individual system protocol and requirements for sealed phantoms. <i>System check</i> shall be performed to verify that system components are working correctly (Clause D.3).	Perform dielectric measurements of tissue-equivalent medium as well as perform <i>system check</i> before starting a project and repeat according to 7.3
- DUT set-up - Preparation of DUT	- The protocol for SAR assessment specifies all the configurations of operational conditions that should be tested. The essential steps include: - Preparing the DUT by establishing a connection to a network 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.
- SAR measurement procedures - General SAR procedure	- This stage is the actual SAR measurement procedure. - The procedure is sequential 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 test positions, configurations and operating modes in all frequency bands accordingly (8.2.2). - Scanning systems (8.2.3.2) or array systems (8.2.3.3) are used. Specific system or implementation techniques are often used to either reduce or accelerate the measurement process.	Determine highest SAR and ensure the rationale for test reduction is recorded and reported when used.
Measurement uncertainty evaluation	- Guidelines and approximation formulas are provided (Clause 11), 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. - Uncertainty budget templates are provided in Table 3, Table 4, Table 5, and Table 6 (11.3.3).	Evaluate uncertainty contributions and complete the uncertainty analysis.
Reporting SAR results	- The final report describes the results of the evaluations, provides sufficient technical details to allow for repeatability of the evaluations performed and reports the results by comparison with the relevant limit (Clause 12). - The results in the test report can serve as demonstration of compliance with the requirements of this document.	Prepare the final report and consider the requirements listed in Clause 12.

800

801

6 Measurement system specifications

6.1 General requirements

A vector measurement-based system consists of the phantom (a SAM phantom representing the human head and/or a flat phantom representing the human body) filled with tissue-equivalent medium, the electronic measurement instrumentation, one or multiple vector probes and/or scalar probes, a field reconstruction algorithm (Annex C) and DUT holder.

a) The vector measurement-based system may be a scanning system or an array system, and shall meet the following requirements:

- 1) The phantoms are filled with the required homogeneous tissue-equivalent medium (6.2.3 and Annex A, also IEC/IEEE 62209-1528:2020). When scanning probes are used, the tissue-equivalent medium shall be a low-viscosity fluid to allow free movement of the probes in the phantom. For systems using a fixed probe-array specific considerations to ensure long term stability of the tissue-equivalent medium apply (7.2).
- 2) The psSAR shall be assessed from the SAR distribution induced in the volume of interest from the electromagnetic fields produced by the DUT.
- 3) The vector measurement-based system shall reconstruct the SAR in the volume of interest from the measured electric field (E-field) or magnetic field (H-field) components that can include amplitude and phase in frequency or time domain (see Annex C).
- 4) The specified frequency range and bandwidth of the measurement system shall be inclusive of the corresponding operating parameters of the DUT under test.
- 5) The information obtained from the measured fields shall be used to reconstruct the SAR distribution and to determine psSAR with an uncertainty meeting the requirements of this document.
- 6) The manufacturer of the measurement system shall validate and document the field reconstruction algorithms. The measurement system shall meet the validation requirements specified in Annex D and shall have quantified and documented measurement uncertainties.
- 7) The measurement system calibration shall be traceable to national standards and with quantified and documented measurement uncertainties.

b) The tests shall be performed in a laboratory conforming to the following environmental conditions:

- 1) The ambient temperature shall be within the range of 18 °C to 25 °C.
- 2) In open phantom systems where tissue-equivalent medium is in direct contact with air, the tissue-equivalent medium dielectric properties shall be verified regularly following the procedures described in IEC/IEEE 62209-1528.
- 3) In hermetically sealed systems, the measurement system manufacturer shall provide either
 - i) a procedure for the accurate measurement of dielectric properties, or
 - ii) documentation of the dielectric properties and corresponding medium temperature and ambient temperature that were measured for the specific phantom when it was manufactured or during system recalibration.
- 4) In hermetically sealed systems, the measurement system manufacturer shall document and make available the information on the stability of the dielectric properties of the tissue-equivalent medium over a period of time that is equal to or greater than the calibration interval of the SAR measurement system.
- 5) Prior to measuring tissue-equivalent medium dielectric properties and SAR measurements, the DUT, test equipment, tissue equivalent medium and phantom shall have been kept in the laboratory 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).
- 6) The temperature of the tissue-equivalent medium and the ambient environment shall satisfy all of the following requirements:

- i) It shall be ensured that the medium is in thermal equilibrium before the first measurements (guidance shall be provided by the manufacturer).
- ii) For open phantoms, the medium temperature shall not vary by more than 2 °C between the SAR measurement and the dielectric properties measurement.
- iii) For open phantoms, the medium temperature shall not vary by that which will cause a change of 5 % or more in either permittivity or conductivity.
- iv) For sealed phantoms, the ambient temperature shall not vary by more than 2 °C from the temperature during calibration during the measurements
- v) For all phantoms, the temperature shall not vary by more than that which will cause the relative permittivity or conductivity to deviate beyond the acceptable tolerance of the targets.
- vi) Temperature sensitivity uncertainty contributions of the tissue-equivalent medium or ambient temperature shall be determined (I.2.14.5).

NOTE 1 The tissue-equivalent medium might have a large inertia of temperature.

NOTE 2 A larger ambient temperature variation can be tolerated provided the appropriate uncertainty is considered.

7) The effect of reflections from cables, test equipment, or other reflectors shall be determined using the SAR system check procedure with and without reflectors present or where necessary with the judicious placement of absorbing materials and/or the use of ferrite beads on cables.

8) SAR measurements of the DUT shall be performed only 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) of less than 0,012 W/kg by measuring the psSAR at (approximately) 0,4 W/kg (used to establish the preceding 3 % limit) using the SAR system check procedure. 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 requirement cannot be achieved, and 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, then a value higher than 3 % (0,012 W/kg) shall be considered in the uncertainty budget in the “RF ambient conditions” row. If the effects of reflections are demonstrated, the requirement on reflections shall be met at least every year or whenever the system check shows unexpected results.

9) During testing the DUT shall not be connected to any wireless network other than a base station simulator in the lab.

c) In addition, the following system validation requirements apply:

1) *System validation* according to the full protocol specified in Annex D shall be annually performed for each measurement system (i.e. consisting of all parts, including all sensors, the dielectric medium, phantom shell, electronics, algorithms and scanning procedure) by the test laboratory and when a new system is put into operation and whenever hardware or software modifications have been made to the system that can affect the validation results (e.g. updated field reconstruction algorithms, update electronics or updated probe types used in a scanning system). Annex D apply to both scanning systems and array systems. After routine calibration of the system, *system validation* per Annex D is required. The antennas used for *system validation* shall be designed and validated to meet the requirements specified in this document (see Annex E).

NOTE 3 The comprehensive *system validation* is normally performed by the system manufacturer and a random subset selection by the users at the user facilities following Annex D.

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

3) Measurement uncertainties and associated parameters are specified in 11.2.

6.2 Phantom specifications

6.2.1 Head phantom specifications – shell

The SAM phantom shall be used as the head phantom. The rationale for the SAM phantom and the geometrical properties of the SAM phantom are provided in Annex A. The head SAR procedures in this document are applicable with the SAM phantom requirements of IEC/IEEE 62209-1528. For some system configurations, this might not be restricted to a sagittally-bisected horizontal SAM phantom. The phantom container may be open (i.e. the tissue-equivalent medium is in direct contact with air) or hermetically sealed.

6.2.2 Body phantom specifications – shell

The flat phantom for representing a human body shall comply with requirements specified in Annex A. The phantom container may be open (i.e. the tissue-equivalent medium is in direct contact with air) or hermetically sealed.

6.2.3 Tissue-equivalent medium properties

The phantom shall be filled with tissue-equivalent medium with the required dielectric properties. The dielectric properties shall be evaluated and compared with the values given in Table A.1 using linear interpolation. Regardless of the type of system, the measured dielectric properties, not the values of Table A.1, shall be used in the SAR calculations. For an open phantom, the equipment and procedures in Annex H of IEC/IEEE 62209-1528:2020 shall be used.

To minimize reflections from the tissue-equivalent medium surface that is distal from the measurement (phantom) surface in an open phantom, the depth of the medium should be at least 15 cm from the flat phantom inner surface or from the SAM phantom inner surface above the ear reference point. In such case, the uncertainty due to such reflections may be neglected in the uncertainty budget. A medium depth of less than 15 cm may be used if it is demonstrated (e.g. using numerical simulations) that the effect on psSAR is less than 1 % under worst-case conditions. If it is more than 1 % but less than 5 %, detailed evaluation of the maximum uncertainty shall be documented and added to the uncertainty budget. The effect of the medium depth shall not exceed 5 %. Hermetically sealed phantoms shall comply with the requirements in Annex A.

6.3 Measurement system requirements

6.3.1 General

The vector measurement-based system may be a scanning system or an array system. The requirements for scanning systems are provided in 6.3.2, and the requirements for array systems are provided in 6.3.3.

6.3.2 Scanning measurement system specifications

Scanning measurement system uses a single scalar probe or vector probe or an array of probes on a robot to scan the field inside the phantom on a two-dimensional or three-dimensional regular or irregular grid. It uses the measured field points to reconstruct the field according to the requirement of 6.5, in order to assess the psSAR values. The grid resolution may be selected according to system knowledge (e.g. frequency), or according to information gained during the scan process (e.g. peak search).

The scanning measurement system shall comply with the following:

- a) The probe and scanning system and the reconstruction algorithm shall allow the determination of the spatial SAR distribution in the required regions of the phantom with known uncertainty with the phantom in the near-field of a source antenna that is placed

outside the phantom. The requirements on the measurement uncertainty are provided in 11.2.

- b) The measurement system manufacturer shall provide documentation to the user specifying the measurement region and frequency range where the requirements of this document for determination of the psSAR distribution are met. The region should include the entire phantom volume that is exposed by the DUT.

NOTE 1 For example, 7.4.2 of IEC/IEEE 62209-1528:2020 specifies a minimum measurement volume of 30 mm by 30 mm by 30 mm for $f \leq 3$ GHz, and 22 mm by 22 mm by 22 mm for $f > 3$ GHz.

- c) The spatial resolution of the fixed or adaptive measurement grid and the reconstruction algorithm shall allow the fields to be reconstructed with the specified reconstruction uncertainty of Clause 11 within the manufacturer-specified measurement region for all test configurations defined in Annex D.
- d) The accuracy of the probe positioning and orientation at measurement points shall be documented by the system manufacturer and the related uncertainty shall be evaluated according to I.2.10.
- e) All uncertainty contributions as specified in Clause 11 shall be assessed and documented.
- f) The uncertainty budget shall be valid and the maximum measurement uncertainty within the specified tolerance for a measurement system dynamic range covering average SAR values from 0,1 W/kg to 100 W/kg for CW and from 0,1 W/kg to 10 W/kg for all modulations. This requirement applies to the psSAR within the specified measurement region.

NOTE 2 The upper limit of 10 W/kg for modulated signals and 100 W/kg for CW signals takes into account that some modulated signals have a peak-to-average ratio of 10 dB or higher.

- g) The probe shall be calibrated for the applicable use conditions (i.e. complex permittivity of the phantom, frequency, temperature, etc.) according to the requirements of Annex B. It is allowed to calibrate the probe separately from the measurement system, provided that the electrical interface characteristics between the probe and readout electronics are specified and implemented during measurements.
- h) The scanning method shall be documented, including whether it performs two-dimensional or three-dimensional scans within the phantom volume, and the algorithm for determining the measurement grid if it does not measure a fixed grid.
- i) Any boundary-effect corrections shall be documented. The document shall include the method and the verification that the applied corrections are valid for any scanning position (distance to the boundary and orientation of the sensors with respect to the surface) and consistent with the boundary-effect uncertainty. The extent of the measurement region consistent with the boundary-effect uncertainty shall be indicated in the software.
- j) The scan region shall find the primary and all secondary SAR peaks covering the area projected by the DUT onto the phantom.
- k) The linearity for local SAR shall be evaluated in the range of 0,1 W/kg to 100 W/kg (RMS for CW signals).

6.3.3 Array measurement system specifications

Array measurement systems consist of a fixed array of sensors to measure the field inside the phantom. Unlike a scanning system, the sensors in an array system are at fixed locations. It uses the measured field points to reconstruct the field in order to assess the psSAR values.

The array measurement system shall comply with the following items.

- a) The measurement system manufacturer shall provide documentation to the user specifying the measurement region on the phantom surface and frequency range where all the requirements of this document are met for the determination of the psSAR_{10g} distribution and including compliance with the validation acceptance criteria of Annex D.

The measurement regions of the flat phantom and head phantom should be larger than the dimensions of the DUT but the psSAR_{10g} measurement region shall not be smaller than 160 mm × 80 mm.

In case the DUT is larger than the measurement region, the uncertainty shall be determined for each of the configurations being measured.

- b) The measurement system manufacturer shall mark the extent of the measurement region on the flat phantom and document this region as well as the frequency range where the requirements of this document are met. The marking is also required for the head phantoms to identify if the exposure by the DUT is correctly measured when positioned as specified in the test procedure. Markings shall be such that phantom shell requirements of this document are still respected. The measurement and the reconstruction algorithm shall allow the fields to be reconstructed with the specified reconstruction uncertainty of Clause 11 within the manufacturer-specified measurement region per item a) for all test configurations specified in Annex D.
- c) The deviation of the locations of the probes in the array from their specified locations shall be documented and the related uncertainty shall be evaluated according to I.2.10. These positions shall not vary by more than $\pm 0,1$ mm as a function of temperature and pressure.
- d) The spatial resolution of the measurement grid and the reconstruction algorithm shall allow the reconstruction of the fields anywhere to the boundary between the tissue-equivalent medium and the phantom shell within the specified measurement region. The manufacturer shall document the types and spatial distribution of probes in the array. In particular, for each probe in the array, it shall be specified:
 - 1) its location within the phantom;
 - 2) whether it is sensitive to incident magnetic field or electric field;
 - 3) which polarizations of the incident field it is designed to receive;
 - 4) whether they measure amplitude of the field only or amplitude and phase.
- e) All relevant uncertainty contributions as specified in Clause 11 shall be assessed and documented.
- f) The uncertainty budget shall be valid and the maximum measurement uncertainty within the specified tolerance for a measurement system dynamic range covering average SAR values from 0,1 W/kg to 100 W/kg for all modulations. 1 g and 10 g SAR cubes can be located anywhere in the specified measurement region.
- g) The probe-array shall be calibrated at the operating frequency range and temperature range specified for the system in test configurations equivalent to the use conditions (i.e. complex permittivity of the phantom, frequency, temperature, etc.) according to the requirements of Annex B. The probe-array shall be calibrated in the final phantom assembly, with the same or electrically equivalent read-out electronics used for the system and identical type of equipment (amplifiers, filtering, data acquisition, etc.), at the operating frequencies and temperature range, with one of the methods described in Annex B.
- h) The linearity for local SAR shall be evaluated in the range of 0,1 W/kg to 100 W/kg (RMS for CW signals).

6.3.4 Measurement system dynamic range

The required measurement system dynamic range is established by that the lower detection limit shall be at most 0,01 W/kg, and the maximum detection limit shall be at least 100 W/kg. Users shall be alerted if the measured instantaneous SAR exceeds the maximum detection limit of the measurement system.

NOTE The lower detection limit of 0,01 W/kg and the maximum detection limit of 100 W/kg apply to local SAR values as measured using a CW signal without time averaging and without spatial averaging.

– The maximum detection limit of 100 W/kg is established based on the following considerations.

- for the purposes of compliance evaluations, the evaluated time-averaged and peak spatial-averaged SAR are compared to the appropriate regulatory limit. Therefore, the system must be able to accurately measure

- 1057 values that meet or exceed these limits. Examples of such limits for general-population/uncontrolled
1058 exposure are 1.6 W/kg for 1 g psSAR in the head or body [40], 2 W/kg for 10 g psSAR in the head or torso
1059 [36], and 4 W/kg for 10 g psSAR in the extremities [40] or limbs [36].
- 1060 • the psSAR can be several dB below the measured local peak SAR, and
 - 1061 • the time-averaged SAR can be 10 dB or more below the peak value for some measured communication
1062 signals (i.e. peak-to-average power ratios of some signals exceed 10 dB).
- 1063 – The maximum detection limit might need to be higher than 100 W/kg in some cases, such as when measuring
1064 against occupational/controlled exposure limits, or for very sharp SAR distributions where the ratio between the
1065 peak SAR and the spatial-average SAR is high.
 - 1066 – The lower detection limit of 0,01 W/kg is approximately 3 % of the 0,4 W/kg lower limit of the uncertainty
1067 evaluation, where 3 % is the maximum noise tolerance. In other words, it is established as the maximum
1068 acceptable noise level for SAR measurements within the dynamic range covered by the uncertainty budget.

1069

1070 **6.4 Device holder specification**

1071 The device holder shall permit the DUT to be positioned according to the specifications given
1072 in IEC/IEEE 62209-1528. It shall be made of low loss and low permittivity material(s): loss
1073 tangent $\tan \delta \leq 0,05$ and relative permittivity $\epsilon_r \leq 5$.

1074 With array systems using a sealed flat phantom that is oriented upward (open phantoms face
1075 downward to hold the tissue-equivalent medium), a holder might not be needed in certain test
1076 positions. The DUT may for example be disposed over the flat phantom, in direct contact with
1077 the phantom, or using a spacer providing a separation distance.

1078 If spacers are used between the DUT and the phantom to provide the required position or
1079 separation distance, they shall not contain metal and shall be made of low loss and low
1080 permittivity material(s): loss tangent $\tan \delta \leq 0,005$ and relative permittivity $\epsilon_r \leq 1,1$.

1081 When the highest SAR is greater than 75 % of the compliance limit and the DUT has been
1082 measured in contact with the device holder, the highest SAR test condition among all frequency
1083 bands and positions shall be tested again for each single transmitter, without using the holder.
1084 In this case, the DUT position shall be realized by using low-loss foam material and non-
1085 conductive adhesive (e.g. tape or elastic bands). Both the psSAR both with and without holder
1086 conditions shall be reported. If the difference between these values is greater than the
1087 expanded ($k = 2$) uncertainty for measurement repeatability, then all SAR test conditions that
1088 are within the expanded ($k = 2$) uncertainty (see Clause 11) relative to the compliance limit shall
1089 be measured without the holder.

1090 Refer to 6.3 of IEC/IEEE 62209-1528:2020 concerning effects of the hand on the exposure of
1091 the head phantom.

1092

1093 **6.5 Reconstruction algorithm and peak spatial-averaging specifications**

1094 The purpose of the reconstruction algorithm is to determine the distribution of the SAR values
1095 in the volume of interest such that the psSAR can be evaluated with a measurement uncertainty
1096 within ± 30 % using the electric fields and/or magnetic fields measured by the vector
1097 measurement-based system.

1098 NOTE Unlike SAR measurement systems specified in IEC/IEEE 62209-1528, a vector measurement-based system
1099 does not determine the psSAR directly from measurement results at points on a 3D grid covering the peak spatial
1100 averaging volume.

1101 Reconstruction methods are described in Annex C and are applicable to both scanning systems
1102 and array systems.

1103 The following requirements on reconstruction and psSAR shall be met:

- a) The reconstruction algorithm shall determine the SAR distribution in the phantom from the measured electric field and/or magnetic field measured by the sensors.
- b) The SAR distribution shall be determined within the volume of interest containing all SAR peaks (primary and secondary).
- c) The averaging volume shall be in the shape of a cube, except that the front face of the averaging volume shall conform to the phantom shell and the back face shall be equally distorted (Figure 2). The four side walls of the cube shall be parallel to the line normal to the phantom at the centre of the front face of the averaging volume.
- d) The software of the measurement system shall provide error messages to the user if the psSAR is outside the spatial region for which the measurement uncertainty requirements of this document are not met.

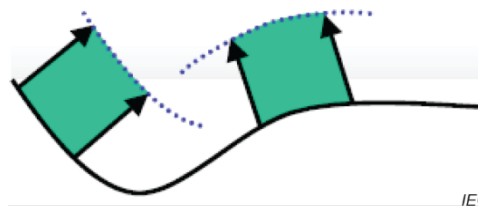


Figure 2 – Illustration of the shape and orientation of the distorted cubic volume for computing psSAR relative to a curved phantom surface

7 Measurement system preparation and laboratory preparation

7.1 General

All measurements should be carried out using good laboratory practice, e.g. in accordance with [1], or any other local and national requirements for device certification. Interlaboratory comparisons can be used to compare the results from several laboratories in order to evaluate the performance of SAR measurement systems (Annex G).

7.2 Preparation of tissue-equivalent medium

The tissue-equivalent medium shall yield relative permittivity ϵ_r and conductivity σ values within $\pm 10\%$ of the target values at the frequencies at which the SAR is measured. The methods of I.3.7 shall be used to correct the measured SAR for the deviations in permittivity and conductivity.

For systems using open phantoms, the dielectric properties of the tissue-equivalent medium shall be measured within 24 h before the SAR measurements and every two days of continuous use. The dielectric properties of the tissue-equivalent medium may be measured less frequently (but not less than once per week) if the laboratory can document compliance with dielectric properties of the tissue-equivalent medium as specified in IEC/IEEE 62209-1528:2020.

If the tissue-equivalent medium is in a hermetically sealed phantom, the test laboratory might not be able to directly measure the dielectric properties of the tissue-equivalent medium. In this case, the manufacturer of the measurement system shall document compliance with dielectric properties of the tissue-equivalent medium during production, as specified in IEC/IEEE 62209-1528:2020, as well as the procedure and measurement interval when it is longer than the validity period of the system calibration.

7.3 System check

A *system check* according to the procedures of Annex D shall be completed before performing SAR measurements for the DUT. The purpose of the *system check* is to verify that the system operates within its specifications. The *system check* is a test of repeatability with a calibrated antenna to ensure that the system works correctly during the compliance test. The *system check* shall be performed in order to detect possible drift over short time periods and other uncertainties in the system, such as:

- unacceptable changes in the parameters of the tissue-equivalent medium, e.g. due to water evaporation or temperature changes;
- component failures;
- component drift;
- operator errors in the set-up or the software parameters;
- adverse conditions in the system, e.g. RF interference;
- adverse conditions in the test environment.

The *system check* procedure shall be performed on the same SAR measurement system, using the same SAR probe, tissue-equivalent medium and software version as the SAR evaluation of the DUT. The measurement shall include each frequency band tested according to the procedures of Annex D.

7.4 Probe calibration

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, (see [33], [34]).

8 Protocol for SAR assessments

8.1 Preparation of the DUT

8.1.1 General

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.

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 for tests performed on prototypes, verification be undertaken by the device manufacturer to ensure the commercial version has the exact same mechanical, electrical, and operating characteristics as the tested prototype.

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.

NOTE 2 For testing of wireless power transfer devices, other preparation procedures should be applied, as specified in [32].

For devices that can monitor and control their transmit power to maintain the time-average SAR below the applicable SAR limit, and devices using proximity or other sensor technologies for exposure mitigation, see IEC/IEEE 62209-1528:2020.

8.1.2 Requirements on power and signal

The objectives of 8.1.2 are:

- 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 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. Conducted power shall be measured at such a location of the power feeding network of the antenna that the measured conducted power is linearly related to the power radiated by the antenna, and hence linearly related to the SAR. Typically this condition is fulfilled if there are no non-linear electronic components between the conducted power measurement point and the antenna radiating element.
- b) All applicable operating modes shall be considered for testing, although testing of some operating modes might not be required.
- 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 cut-off 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.

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, then the SAR shall be scaled to the required highest time-averaged output power level. However, when the DUT is configured in a lower output power level, the time-averaged output power shall be within the tolerance range specified for the device.

2) 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 8.3.

8.1.3 Antenna configuration

For devices that employ one or more external antennas with variable positions (e.g. extended, retracted, or rotated antennas), these shall be positioned in accordance with the user instructions provided by the manufacturer. If no intended antenna position is specified, tests shall be performed with the antenna(s) oriented to obtain the highest exposure condition while maintaining the device in the positions of Clause 10. For antennas that can be extended, testing shall be performed with the antenna fully extended and fully retracted. The antenna configurations shall be documented in the measurement report. All transmit diversity antennas shall be tested for SAR.

8.1.4 Options and accessories

Other accessories that affect the RF output power or RF current distribution of the DUT when used next to the head or body shall be tested according to the intended use conditions specified by the manufacturer. For example, (a) optional antennas, (b) optional battery packs that change the wireless communication device performance or SAR, etc., (c) adapters, hubs, etc., that contain electrically conductive parts, or (d) any other kind of wires that are connected, e.g. to a DUT used next to the body, during intended use. NFC or wireless charging options generally do not require SAR measurement, but their influence on the SAR of other transmitters shall be considered.

8.1.5 Test frequencies for DUT

A DUT shall be compliant with applicable exposure standards at all transmitting frequencies. However, testing at every channel is impractical and unnecessary. The purpose of 8.1.5 is to define a practical subset of channels where SAR measurements are to be performed. This subset of channels is chosen to give a characterization of a DUT for comparison with applicable exposure standards.

Before performing testing using the specific channels required by this document, the maximum output power of the channels shall be verified to determine that the selected channels are producing the highest rated output of the device. The process used to establish the channels for testing purposes shall be documented in the measurement report.

For each operating mode of a wireless technology used by the DUT:

- a) tests shall be performed at the channel producing the highest rated output power, or at the channel producing the highest loaded radiated output power (see 3.28.2) of each test position. If the channel with highest loaded radiated output power maximum of each test position is tested in this step a), then step b) and step c) are not required if the width of the transmit frequency band ($\Delta f = f_{\text{high}} - f_{\text{low}}$) does not exceed 10 % of its centre frequency f_c ;
- b) when the width of the transmit frequency band exceeds 1 % of its centre frequency f_c , the channels at the lowest and highest frequencies of the transmit band shall also be tested.
- c) when the width of the transmit frequency band exceeds 10 % of its centre frequency, the following formula shall be used to determine the number of channels, N_c , to be tested according to Formula (1):

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

where

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

NOTE 1 The function roundup(x) rounds its argument x to the next highest integer. Thus, the number of channels, N_c , will always be an odd number.

NOTE 2 National regulatory agencies might have different requirements on the number and selection criteria of channels to be tested per transmission band, according to frequency allocations and other wireless technology requirements. For example:

$$N_c = \text{round} \left[\sqrt{\frac{100(f_{\text{high}} - f_{\text{low}})}{f_c}} \left(\frac{f_c}{100} \right)^{0.2} \right]$$

The number of channels, N_c , should be equally spaced and shall meet the preceding requirements.

8.2 Measurement procedures

8.2.1 DUT positioning relative to phantom

DUT positioning specifications for SAR measurements using a flat phantom and the SAM head phantom are provided in Clause 10.

8.2.2 Tests to be performed

In order to determine the highest value of the psSAR of a device, all device positions, configurations and operational modes shall be tested for each frequency band according to step 1 through step 4 as follows.

Step 1: The tests shall be performed at the channel that is closest to the centre of the transmit frequency band (f_c) for:

a) the following positions

1) all device positions on the body phantom (if testing of DUT against body phantom is required);

2) all cheek and tilt positions on the left and right head phantoms (if testing of DUT against head phantom is required);

b) all physical configurations of the DUT for each device position per Step 1a),

NOTE Examples of physical configurations are device slide or cover open and closed, or antenna extended and retracted.

c) all operational modes, e.g. modulations and multiplexing modes, for each device position in step 1 a) and configuration(s) of Step 1 b) in each frequency band;

d) all antennas used.

Step 2: For the test condition providing the highest psSAR determined in step 1, perform the tests at all other test frequencies as required by 8.1.5 (e.g. lowest and highest channels). In addition, for each device position, configuration and operating mode where the psSAR value determined in Step 1 a), step to Step 1 d) is greater than or equal to half of the applicable SAR limit, testing of other channels of 8.1.5 is required, as well.

Step 3: When the highest SAR is greater than 75 % of the compliance limit and the DUT has been measured in contact with the device holder, the highest SAR test condition among all frequency bands and positions shall be tested again for each single transmitter, without using the holder. In this case, the DUT position shall be realized by using low-loss foam material and non-conductive adhesive (e.g. tape or elastic bands).

Step 4: Examine all data to determine the highest value of the psSAR found in Step 1 to Step 3 for each operation mode in each frequency band.

8.2.3 Measurements

8.2.3.1 General

Subclause 8.2.3 provides the procedure to be performed for each of the test conditions described in 8.2.2. For scanning systems, the measurement procedure of 8.2.3.2 shall be applied. For array systems, the measurement procedure of 8.2.3.3 shall be applied.

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

Because of the differences in the array systems versus scanning systems, the drift requirements are different.

8.2.3.2 Measurement procedure for scanning systems

If a scanning measurement system is used, the following procedure and requirements shall be applied:

- a) Take a reference measurement with a fully charged battery at a specific location within the phantom.
- b) Measure the electric field or magnetic field within the volume of interest.
- c) If applicable to the method, refine the scanning with higher spatial resolution at the location of interest.
- d) Apply the reconstruction algorithm to reconstruct the field for determining the psSAR distributions.
- e) Apply the averaging algorithm as described in 6.5 to determine the psSAR.
- f) The reference measurement in step a) shall be repeated at the end of each measurement. The relative difference between the first and each subsequent reference measurement should be within 5 %. If the SAR difference exceeds 5 % then the measurements shall be repeated with fully charged battery, or all SAR values shall be increased by the absolute percentage difference between the first and last reference measurement.
- g) Add the upper-bound percentage allowed (i.e. otherwise full re-test needed).

8.2.3.3 Measurement procedure for array systems

If an array system is used, the following procedure and requirements shall be applied:

- a) Measure the electric field or magnetic field over the measurement region.
- b) Apply the reconstruction algorithm to reconstruct the SAR distribution in the volume of interest.
- c) Apply the averaging algorithm as described in 6.5 to determine the psSAR.
- d) If a sequence of different configurations is evaluated without recharging the battery, then the first measurement shall be repeated at the end of each measurement and the relative difference between the first and last measurement shall be within the repeatability tolerance of the system (see 11.2) but not larger than 5 %. If the SAR difference exceeds 5 % then the measurements shall be repeated with fully charged battery, or all SAR values shall be increased by the absolute percentage difference between the first and last measurement.

8.2.4 SAR measurements for simultaneous transmission

Requirements and procedures for SAR measurements of DUTs capable of simultaneous transmission are provided in Clause 9.

8.3 SAR scaling procedure for 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 , 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 (2):

$$R_p = \frac{P_{\max, modY}}{P_{modX}} \quad (2)$$

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 (3):

$$R_m = \left| \frac{BW_{modY}}{BW_{modX}} - 1 \right| \times 100 \leq 30\% \quad (3)$$

- 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 (4), and scaling uncertainty shall be determined as specified in Clause 11:

$$SAR_{modY} = R_m \times SAR_{modX} \quad (4)$$

When the approach in this subclause 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.

9 SAR measurements for simultaneous transmission

9.1 General

DUTs with multiple antennas or multiple transmitters (with single or multiple antennas) transmitting simultaneously require special test considerations. The methods to combine the fields in order to determine the combined SAR distribution differ depending on whether the corresponding RF transmitters emit waveforms that are correlated or uncorrelated in time.

9.2 SAR measurements for uncorrelated signals

9.2.1 General

The simultaneous transmission signals are uncorrelated if they differ in frequency, modulation or both.

Spatial summation of the SAR distributions according to Formula (5) (see 9.2.3) shall be used to determine the combined SAR of the simultaneous transmission signals.

The spatial separation of the SAR distributions impacts the combined SAR. SAR combination can be exempt if the SAR distributions do not overlap, i.e. when the maxima are separated to such an extent that the maximum psSAR values of each distributions will not increase by more than 5 % when the SAR distributions from all the other simultaneous transmission signals would be added according to Formula (5), and if the maximum psSAR value of among all simultaneous transmissions is lower than 95 % of the SAR compliance limit.

9.2.2 SAR measurement procedure

The following procedure shall be applied for SAR testing of uncorrelated simultaneous transmission signals for all applicable simultaneous transmission scenarios:

- a) Determine the uncorrelated transmit signals that are supported and intended to be transmitted simultaneously by the DUT for the evaluated scenario. All the evaluated operating conditions shall be identical or conservative for the intended operation of the DUT while transmitting simultaneously. If the SAR distribution(s) is/are readily measured according to 8.2, it/they can be spatially combined according to step g).
- b) Configure the DUT to transmit the signal(s) determined in step a). The signals may be configured to be transmitted simultaneously, sequentially, or in a combination of both by the DUT.
- c) Switch on the transmit signal(s), using radio communication tester as necessary to establish the transmission.
- d) Position the DUT on the phantom.
- e) Measure the SAR distribution(s).
- f) Repeat steps b) to e) until all transmit signals are measured for the evaluated scenario.
- g) Combine the SAR distributions spatially using Formula (5) of 9.2.3 for the evaluated scenario.

NOTE The DUT possible simultaneous transmissions within a single or multiple wireless operating modes can include for example WWAN (2G, 3G, 4G, and 5G (SA or NSA), WLAN (IEEE Std 802.11, 2.45 GHz or 5 GHz), and WPAN (IEEE Std 802.15).

9.2.3 Procedure for summation of SAR distributions

When two or more signals are uncorrelated (e.g. transmission at different frequencies, modulations, or data streams), the combined SAR_T at each location, r , in the phantom is calculated from simple summation of the SAR values of the N individual transmitters (Formula (5)):

$$SAR_T(r) = \sum_{k=1}^N SAR_k(r) \quad (5)$$

where the subscript T denotes total SAR

Prior to averaging and search of the psSAR, each SAR distribution shall be assessed separately. After field reconstruction and determination of the individual SAR distributions, $SAR_k(r)$, the summation given in Formula (5) is performed. The averaging and search procedures for the peak-spatial average SAR are then performed.

9.3 SAR measurements for correlated signals

9.3.1 General

If multiple antennas are used to transmit signals at the same frequency and using the same modulation, these signals could be correlated. There are two types of correlated signals, as shown in Table 2.

The first type, referred to as type 1, are signals with relative phases unchanged during a relatively long duration compared with symbol duration. These types of signals can be found in MIMO spatial multiplexing techniques and phased array antenna systems where the relative phases of signals fed to the antennas are controlled to form the radiation pattern towards specific directions.

The second type, referred to as type 2, are signals with relative phases changed quickly in a relatively short time period. Such signals can be found in systems utilizing MIMO transmit diversity techniques. The relative phases of signals will be changed from symbols to symbols due to functions such as space-time block codes in MIMO schemes. No specified direction is formed during normal communications.

Table 2 – Two types of correlated signals

Item	Type 1	Type 2
Description	Signals with relative phases unchanged for a long duration compared with symbol duration.	Signals with relative phases that vary quickly over a relatively short period.
Typical use	MIMO spatial multiplexing techniques and phased arrays, where the relative phases of signals fed to the antennas are controlled to achieve optimal antenna patterns. Once the antenna pattern is determined, the relative phases will stay constant for relatively long duration.	MIMO transmit diversity techniques where the relative phases of signals will be changed from symbol to symbol using space time coding.
Applications	Wireless Charging, Location services, NR and LTE using beamforming or spatial multiplexing techniques	NR and LTE using transmit diversity techniques, IEEE Std 802.11n, IEEE Std 802.11ac, WiMAX, HSPA+, etc.

9.3.2 Measurement procedure for Type 1 correlated signals

There are four methods of measuring the SAR from type 1 correlated signals.

- Summation of the field magnitudes from the individual sources, leading to upper bounds on the SAR (see 6.5.2.2 of IEC TR 62630:2010).
- Combination of the magnitudes of the local field components (see 6.5.2.3 of IEC TR 62630:2010).
- Estimation of the magnitude of the vector sum of the individual fields (see 6.5.1 of IEC TR 62630:2010)
- Setting the sources at maximum power levels and sweeping through the possible phase combinations. Sweeping all source phases across their respective ranges allows capturing the maximum realized RMS value over the measurement domain (see 6.5.1 of IEC TR 62630:2010).

NOTE The procedures and advantages of each method are described in IEC TR 62630:2010.

The procedures of c) and d) are preferred as they both give the same accurate result without overestimation. The procedures of a) and b) are alternative methods that may be used and provide an overestimation for the SAR value. Procedure a) gives the highest overestimation.

1495 The manufacturer of the SAR measurement system shall document the method used for SAR
1496 measurement of type 1 correlated signals.

1497 For the procedure of c), the following considerations shall be taken into account to perform the
1498 SAR measurements. In case of N antennas emitting correlated signals and vector (amplitude
1499 and phase) measurements, the following procedure leads to the determination of the psSAR
1500 value for all the possible configurations:

1501 Step 1: Perform N measurements of the electric field phasor $\mathbf{E}_m^{\text{meas}} = \sum_{i=1}^N w_{mi} \mathbf{E}_i$, with $m = 1, \dots, N$.
1502 w_{mi} is the excitations weight of the i -th MIMO antenna used for the m -th measurement.

1503 From one field scan to the other in Step 1, the phase reference undergoes a shift that is
1504 introduced by the change in the illuminating field topologies in an unpredictable manner. As
1505 a result, additional “test” measurements are required in order to align the phase references
1506 of all of the N measurements.

1507 • Step 2: Perform at least one “test” measurement $\mathbf{E}_m^{\text{test}} = \sum_{i=1}^N w_{ti} \mathbf{E}_i$ with excitation weights
1508 different from the ones used in Step 1.

1509 Step 3: Use the fields measured in Step 1 and Step 2 in order to align the phase reference
1510 of the different measurements. This is achieved by introducing a set of phase shifts β_m (with
1511 $m = 2, \dots, N$) on the measured fields $\mathbf{E}_m^{\text{meas}}$ and by minimizing the following cost function
1512 (Formula (6)):

$$f(\beta_2, \dots, \beta_N) = \left\| \sum_{x,y,z} T \mathbf{W}^{-1} \begin{bmatrix} \mathbf{E}_1^{\text{mes}} \\ \mathbf{E}_2^{\text{mes}} e^{j\beta_2} \\ \vdots \\ \mathbf{E}_N^{\text{mes}} e^{j\beta_N} \end{bmatrix} \right\|^2 - \sum_{x,y,z} \left| \mathbf{E}_m^{\text{test}} \right|^2 \quad (6)$$

1513
1514 where

$$\mathbf{W} = \begin{pmatrix} w_{11} & \cdots & w_{1N} \\ \vdots & \ddots & \vdots \\ w_{N1} & \cdots & w_{NN} \end{pmatrix}$$

$$T = [w_{t1} \quad \cdots \quad w_{tN}]$$

1515
1516 T contains the excitation weights of the test measurement $\mathbf{E}_m^{\text{test}}$.

- Step 4: Retrieve the electric field E_i corresponding to each individual antenna of the MIMO system as follows (Formula (7)):

$$\begin{bmatrix} E_1 \\ E_2 \\ \vdots \\ E_N \end{bmatrix} = W^{-1} \begin{bmatrix} E_1^{\text{meas}} \\ E_2^{\text{meas}} \cdot \exp(j\beta_2^{\text{min}}) \\ \vdots \\ E_N^{\text{meas}} \cdot \exp(j\beta_N^{\text{min}}) \end{bmatrix} \quad (7)$$

where $(\beta_2^{\text{min}}, \dots, \beta_N^{\text{min}})$ is the solution giving the minimum of $f(\beta_2, \dots, \beta_N)$.

The phase reference of the first measurement is considered here as a reference for the phase alignment in the formulations of Formula (6) and Formula (7), i.e. $\beta_1 = 0$.

- Step 5: Calculate the total electric field $E_{\text{tot}} = \sum_{i=1}^N w_i E_i$ corresponding to any MIMO excitation scheme.
- Step 6: For each field E_{tot} , compute the corresponding peak spatial-averaged SAR.

9.3.3 Measurement procedure for Type 2 correlated signals

There are two methods of measuring the SAR from type 2 correlated signals:

- Measurement with all signals transmitting simultaneously.
- Sequential measurement of N configurations followed by simultaneous measurement at multiple locations.

Both methods give the same result. The choice of method a) or method b) is based on the capability of the measurement system. The manufacturer of the SAR measurement system shall document the method used for SAR measurement of type 2 correlated signals.

For method a), the procedure is as follows:

- 1) Configure the DUT to transmit the type 2 correlated signal, with all signals on.
- 2) Set the integration time so that the measured value will be stable within the integration time uncertainty (see I.4.4). A longer integration time can be needed compared to the measurement of single signals.
- 3) Measure the SAR as per 8.2.3.

For method b) the assessment of the SAR of such configurations comes down to the determination of the individual SAR ($SAR_i(x, y, z)$) resulting from each antenna of the system, together with the time averaged value $\langle |s_i(t)|^2 \rangle$ of the squared amplitude of the signals that are injected in these antennas.

Considering these observations, the following procedure allows for the assessment of the SAR of type 2 MIMO systems composed of N antennas. The following procedure shall be applied:

- Step 1 – Configuration with slow relative phase variations:
 - a) Set the DUT to operate in a configuration with a stable relative phase distribution.
 - b) Measure at each point (x, y, z) of the measurement domain, the individual local SAR ($SAR_i(x, y, z)$) distributions corresponding to an independent excitation of each antenna of the MIMO device.

- Step 2 - Configuration with fast relative phase variations:
 - a) Set the DUT in the considered type 2 configuration with quick relative phase variations.
 - b) Measure the local instantaneous SAR ($SAR(x_k, y_k, z_k, t)$) at K points (x_k, y_k, z_k) , ($K \geq N$), of the sensor grid, for a duration T that is sufficiently large in order to obtain the convergence of the averaged local SAR $\langle SAR(x_k, y_k, z_k, t) \rangle$.
 - c) Using these averaged SAR values $\langle SAR(x_k, y_k, z_k, t) \rangle$ and the individual SAR of the MIMO antennas ($SAR_i(x, y, z)$) obtained in step 1, calculate the time averaged value $\langle |s_i(t)|^2 \rangle = \alpha_i$ of the squared amplitude of the excitation signals, and this by minimizing the following expression Formula (8):

$$\min_{\alpha_i} \sum_{k=1}^K \left| \langle SAR(x_k, y_k, z_k, t) \rangle - \sum_{i=1}^N \alpha_i SAR_i(x_k, y_k, z_k) \right| \quad (8)$$

From the values of α_i , calculate the SAR value $\langle SAR(x, y, z, t) \rangle$ at every point (x, y, z) of the measurement domain using Formula (9):

$$\langle SAR(x, y, z, t) \rangle = \sum_{i=1}^N \alpha_i SAR_i(x, y, z) \quad (9)$$

10 Position of the DUT in relation to the phantom

10.1 Test distance and positioning relative to the flat phantom

10.1.1 General

Subclause 10.1 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 10.1 describes positioning procedures for the following device types:

- devices that are large relative to phantom surface area (10.1.4)
- devices used with body-worn accessories (10.1.5);
- devices with hinged or swivel antenna (10.1.6);
- devices used next to or against the body without an accessory (10.1.7);
- desktop device (10.1.8);
- front-of-face device (10.1.9);
- hand-held usage of the device, not at the head or torso (10.1.10);
- limb-worn device (10.1.11);
- clothing-integrated device (10.1.12).
- generic device (10.1.13);

NOTE The figures provided in 10.1 are for illustration purposes only, and are not to scale or representative of the areas that need SAR measurement.

10.1.2 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:

- a) 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.
- b) “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.
- c) 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 10.1.13 generic device).

The stated separation distance may be determined with the carry accessory attached to the DUT, when such condition is tested; see 10.1.5.

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.

10.1.3 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 3. 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 on the DUT when positioned as specified in the preceding sentences. This general guidance might 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.

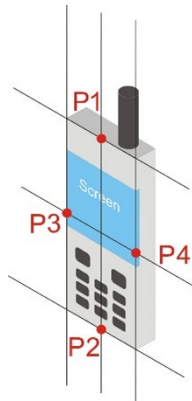


Figure 3 –Designation of DUT reference points

10.1.4 Positions of the DUT in relation to the flat phantom for large DUT

If the DUT is larger than the measurement regions of each phantom specified in 6.2.2, the following applies.

- a) 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 the one 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 of IEC/IEEE 62209-1528:2020).
- b) 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 4.
- c) 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.

Formula (10) and Formula (11) provide the minimum number of tests to perform for a DUT with dimensions greater than or equal to the dimensions of the measurement area, when successive SAR evaluations with one third overlapping section are combined:

$$N_{\text{tests}} = N_{\text{sublength}} \times N_{\text{subwidth}} \quad (10)$$

$$N_{\text{tests}} = \text{roundup} \left[\frac{L'}{L} \times \left(1 + \frac{1}{3} \right) \right] \times \text{roundup} \left[\frac{W'}{W} \times \left(1 + \frac{1}{3} \right) \right] \quad (11)$$

where

L' is the length of the DUT;

W' is the width of the DUT;

L is the length of the measurement area specified by the system manufacturer;

W is the width of the measurement area specified by the system manufacturer;

N_{tests} is the number of tests performed on DUT sub-divisions for a complete SAR evaluation of the DUT;

$N_{\text{sublength}}$ is the number of sub-divisions of the DUT length;

N_{subwidth} is the number of sub-divisions of the DUT width.

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.