

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

**Part 1: Procedure to determine the
specific absorption rate (SAR) for
hand-held devices used in close
proximity to the ear (frequency range
of 300 MHz to 3 GHz)**

The European Standard EN 62209-1:2006 has the status of a British Standard

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National foreword

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

Exposition humaine aux champs
radiofréquence produits par les dispositifs
de communications sans fils tenus à la main
ou portés près du corps –
Modèles de corps humain, instrumentation
et procédures
Partie 1: Détermination du débit d'absorption
spécifique (DAS) produit par les appareils
tenus à la main et utilisés près de l'oreille
(plage de fréquence de 300 MHz à 3 GHz)
(CEI 62209-1:2005)

Sicherheit von Personen in hochfrequenten
Feldern von handgehaltenen und
am Körper getragenen schnurlosen
Kommunikationsgeräten –
Körpermodelle, Messgeräte und Verfahren
Teil 1: Verfahren zur Bestimmung der
spezifischen Absorptionsrate (SAR) von
handgehaltenen Geräten, die in enger
Nachbarschaft zum Ohr benutzt werden
(Frequenzbereich von 300 MHz bis 3 GHz)
(IEC 62209-1:2005)

This European Standard was approved by CENELEC on 2006-03-01. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

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CENELEC

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

Central Secretariat: rue de Stassart 35, B - 1050 Brussels

Foreword

The text of the International Standard IEC 62209-1:2005, prepared by IEC TC 106, Methods for the assessment of electric, magnetic and electromagnetic fields associated with human exposure, was submitted to the formal vote and was approved by CENELEC as EN 62209-1 on 2006-03-01 without any modification.

This European Standard supersedes EN 50361:2001.

The following dates were fixed:

- | | | |
|--|-------|------------|
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Endorsement notice

The text of the International Standard IEC 62209-1:2005 was approved by CENELEC as a European Standard without any modification.

CONTENTS

INTRODUCTION.....	6
1 Scope	7
2 Normative references	7
3 Terms and definitions	7
4 Symbols and abbreviated terms	15
4.1 Physical quantities.....	15
4.2 Constants.....	16
4.3 Abbreviations	16
5 Measurement system specifications	16
5.1 General requirements	16
5.2 Phantom specifications (shell and liquid).....	17
5.3 Specifications of the SAR measurement equipment.....	22
5.4 Scanning system specifications.....	22
5.5 Device holder specifications.....	22
5.6 Measurement of liquid dielectric properties.....	23
6 Protocol for SAR assessment.....	23
6.1 Measurement preparation	23
6.2 Tests to be performed.....	29
6.3 Measurement procedure	31
6.4 Post-processing of SAR measurement data.....	32
7 Uncertainty estimation	33
7.1 General considerations	33
7.2 Components contributing to uncertainty.....	34
7.3 Uncertainty estimation	46
8 Measurement report	48
8.1 General.....	48
8.2 Items to be recorded in the test report.....	48
Annex A (normative) Phantom specifications	50
Annex B (normative) Calibration (linearity, isotropy, sensitivity) of the measurement instrumentation and uncertainty estimation.....	56
Annex C (normative) Post-processing techniques and uncertainty estimation	71
Annex D (normative) SAR measurement system validation	76
Annex E (informative) Interlaboratory comparisons	83
Annex F (informative) Definition of a phantom coordinate system and a device under test coordinate system	85
Annex G (informative) Validation dipoles	87
Annex H (informative) Flat phantom	89
Annex I (informative) Recommended recipes for phantom head tissue-equivalent liquids	91
Annex J (informative) Measurement of the dielectric properties of liquids and uncertainty estimation.....	93
Annex ZA (normative) Normative references to international publications with their corresponding European publications.....	108
Bibliography	103

Figure 1 – Picture of the phantom showing ear reference points RE and LE, mouth reference point M, reference line N-F, and central strip.....	18
Figure 2 – Sagittally bisected phantom with extended perimeter (shown placed on its side as used for device SAR tests).....	18
Figure 3 – Cross-sectional view of SAM at the reference plane containing B-M	20
Figure 4 – Side view of the phantom showing relevant markings	21
Figure 5 – Handset vertical and horizontal reference lines and reference points A, B on two example device types	26
Figure 6 – Cheek position of the wireless device on the left side of SAM.....	27
Figure 7 – Tilt position of the wireless device on the left side of SAM	28
Figure 8 – Block diagram of the tests to be performed	30
Figure 9 – Orientation of the probe with respect to the line normal to the surface, shown at two different locations	32
Figure 10 – Orientation and surface of the averaging volume relative to the phantom surface	46
Figure A.1 – Illustration of dimensions in Table A.1	51
Figure A.2 –Close up side view of phantom showing the ear region.....	53
Figure A.3 – Side view of the phantom showing relevant markings	54
Figure B.1 – Experimental set-up for assessment of the sensitivity (conversion factor) using a vertically-oriented rectangular waveguide	60
Figure B.2 – Description of the antenna gain evaluation set-up	62
Figure B.3 – Set-up to assess spherical isotropy deviation in tissue-equivalent liquid	65
Figure B.4 – Alternative set-up to assess spherical isotropy deviation in tissue-equivalent liquid.....	66
Figure B.5 – Experimental set-up for the hemispherical isotropy assessment [11]	67
Figure B.6 – Conventions for dipole position (ξ) and polarization (θ) [11].....	67
Figure B.7 – Measurement of axial isotropy with a reference antenna	69
Figure B.8 – Measurement of hemispherical isotropy with reference antenna	69
Figure C.1 – Methods of three points.....	72
Figure C.2 – Method of the tangential face	72
Figure C.3 – Method of averaging	73
Figure C.4 – Extrude method of averaging.....	73
Figure C.5 – Extrapolation of SAR data to the inner surface of the phantom based on a least-square polynomial fit of the measured data (squares).....	75
Figure D.1 – Set-up for the <i>system check</i>	78
Figure F.1 – Example reference coordinate system for the SAM phantom	85
Figure F.2 – Example coordinate system on the device under test	86
Figure G.1 – Mechanical details of the reference dipole	88
Figure H.1 – Dimensions of the flat phantom set-up used for deriving the minimal dimensions for W and L	89
Figure H.2 – FDTD predicted uncertainty in the 10 g peak spatial-average SAR as a function of the dimensions of the flat phantom compared with an infinite flat phantom	91
Figure J.1 – Slotted line set-up.....	94
Figure J.2 – An open-ended coaxial probe with inner and outer radii a and b , respectively	96
Figure J.3 – TEM line dielectric test set-up [60]	98

Table 1 – Dielectric properties of the tissue-equivalent liquid	21
Table 2 – Reference SAR values in watts per kilogram used for estimating post-processing uncertainties	43
Table 3 – Measurement uncertainty evaluation template for handset SAR test	47
Table A.1 – Head dimensions relevant to phantom shape: SAM dimensions compared to 90th-percentile large male head from Gordon report [18]	52
Table A.2 – Specific guidelines for the design of SAM phantom and CAD file	53
Table B.1 – Uncertainty analysis for transfer calibration using temperature probes	59
Table B.2 – Uncertainty template for calibration using analytical field distribution inside waveguide	61
Table B.3 – Uncertainty template for evaluation of reference antenna gain	63
Table B.4 – Uncertainty template for calibration using reference antenna	64
Table D.1 – Numerical reference SAR values for reference dipole and flat phantom	82
Table G.1 – Mechanical dimensions of the reference dipoles	87
Table H.1 – Parameters used for calculation of reference SAR values in Table D.1	90
Table I.1 – Suggested recipes for achieving target dielectric parameters	92
Table J.1 – Parameters for calculating the dielectric properties of various reference liquids	100
Table J.2 – Dielectric properties of reference liquids at 20 °C	101
Table J.3 – Example uncertainty template and example numerical values for dielectric constant (ϵ_r') and conductivity (σ) measurement	102

INTRODUCTION

The international committees IEC TC 106, CENELEC Technical Committee TC 106x WG1, and IEEE Standards Coordinating Committee 34 (SCC34) worked together informally through common membership to achieve the goal of harmonization, specifically between IEC TC 106 Project Team 62209 for the document "Procedure to Measure the Specific Absorption Rate (SAR) for Hand-Held Mobile Telephones in the Frequency Range of 300 MHz to 3 GHz" and IEEE SCC34 for the IEEE Std 1528 "IEEE Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Head from Wireless Communications Devices: Measurement Techniques" [22]¹.

During the process a primary effort involved was to harmonize these two standards

¹) Numbers in square brackets refer to the bibliography.

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

Part 1: Procedure to determine the specific absorption rate (SAR) for hand-held devices used in close proximity to the ear (frequency range of 300 MHz to 3 GHz)

1 Scope

This International Standard applies to any electromagnetic field (EMF) transmitting device intended to be used with the radiating part of the device in close proximity to the human head and held against the ear, including mobile phones, cordless phones, etc. The frequency range is 300 MHz to 3 GHz.

The objective of this standard is to specify the measurement method for demonstration of compliance with the specific absorption rate (SAR) limits for such devices.

2 Normative references

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

ISO/IEC Guide:1995, *Guide to the Expression of Uncertainty in Measurement*

ISO/IEC 17025:1999, *General requirements for the competence of testing and calibration laboratories*

3 Terms and definitions

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

3.1

attenuation coefficient

numerical factor intended to account for attenuation due to the human head or body tissue between the source and a specified point

3.2

average (temporal) absorbed power

value of the time-averaged rate of energy transfer given by

$$\overline{P}_{\text{avg}} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} P(t) dt$$

where

- t_1 is the start time of the exposure in seconds;
 t_2 is the stop time of the exposure in seconds;
 $t_2 - t_1$ is the exposure duration in seconds;
 $P(t)$ is the instantaneous absorbed power in watts;
 $\overline{P}_{\text{avg}}$ is the average power in watts.

3.3

axial isotropy

the maximum deviation of the SAR when rotating around the major axis of the probe cover/case while the probe is exposed to a reference wave impinging from a direction along the probe major axis

3.4

basic restriction

restrictions on human exposure to time-varying electric, magnetic, and electromagnetic fields that are based directly on established health effects

NOTE Within the frequency range of this standard, the physical quantity used as a basic restriction is the specific absorption rate (SAR).

3.5

boundary effect (probe)

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

3.6

complex permittivity

the ratio of the electric flux density in a medium to the electric field strength at a point. The permittivity of biological tissues is frequency dependent.

$$\epsilon = \frac{|\vec{D}|}{|\vec{E}|} = \epsilon_r \epsilon_0$$

where

- $\vec{D}$ is the electric flux density in coulombs per square metre;
 $\vec{E}$ is electric field in volts per metre;
 ϵ_0 is the permittivity of free space = $8,854 \times 10^{-12}$ farads per metre;
 ϵ_r is the complex relative permittivity: $\epsilon_r = \epsilon'_r - j\epsilon''_r = \epsilon'_r + \frac{\sigma}{j\omega\epsilon_0}$.

NOTE For an isotropic medium, the permittivity is a scalar quantity; for an anisotropic medium, it is a tensor quantity.

3.7

conducted output power

the average power supplied by a transmitter to the transmission line of an antenna during an interval of time sufficiently long compared with the period of the lowest frequency encountered in the modulation evaluated under normal operating conditions

3.8

conductivity

the ratio of the conduction-current density in a medium to the electric field strength

$$\sigma = \frac{|\vec{J}|}{|\vec{E}|}$$

where

$\vec{E}$ is the electric field in volts per metre;

$\vec{J}$ is the current density in amperes per metre squared;

σ is the conductivity of the medium in siemens per metre.

NOTE For an isotropic medium the conductivity is a scalar quantity; for an anisotropic medium it is a tensor quantity in which case the cross product of σ and $\vec{E}$ is implied.

3.9

detection limits

the lower (respectively upper) detection limit defined by the minimum (respectively maximum) quantifiable response of the measuring equipment

3.10

duty factor

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

3.11

electric conductivity

See conductivity.

3.12

electric field

a vector field quantity $\vec{E}$ which exerts on any charged particle at rest a force $\vec{F}$ equal to the product of $\vec{E}$ and the electric charge q of the particle:

$$\vec{F} = q\vec{E}$$

where

$\vec{F}$ is the vector force acting on the particle in newtons;

q is the charge on the particle in coulombs;

$\vec{E}$ is the electric field in volts per metre.

3.13

electric flux density (displacement)

a vector quantity obtained at a given point by adding the electric polarization $\vec{P}$ to the product of the electric field $\vec{E}$ and the dielectric constant ϵ_0 :

$$\vec{D} = \epsilon_0\vec{E} + \vec{P}$$

where

$\vec{D}$ is the electric flux density in coulombs per square metre;

ϵ_0 is the permittivity of free space = $8,854 \times 10^{-12}$ farads per metre;

$\vec{E}$ is the electric field in volts per metre;

$\vec{P}$ is the electric polarization of the medium in coulombs per square metre.

NOTE For purposes of this standard, the electric flux density at all points is equal to the product of the electric field and the dielectric constant:

$$\vec{D} = \epsilon'_r \vec{E}$$

3.14

handset

a hand-held device intended to be operated close to the side of the head, consisting of an acoustic output or earphone and a microphone, and containing a radio transmitter and receiver

3.15

hemispherical isotropy

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

3.16

isotropy

See axial isotropy, hemispherical isotropy, probe isotropy.

3.17

linearity error

the maximum deviation of a measured quantity over the measurement range from the closest reference line defined over a given interval

3.18

loss tangent

the ratio of the imaginary and real parts of the complex relative permittivity of a material:

$$\tan \delta = \frac{\epsilon''_r}{\epsilon'_r} = \frac{\sigma}{\omega \epsilon'_r \epsilon_0}$$

where

$\tan \delta$ is the loss tangent (dimensionless);

ϵ''_r is the imaginary part of the complex relative permittivity;

ϵ'_r is the real part of the complex relative permittivity;

ϵ_0 is the permittivity of free space = $8,854 \times 10^{-12}$ farads per metre;

ω is the angular frequency ($\omega = 2\pi f$) in radians per second;

σ is the conductivity of the medium in siemens per metre.

3.19

magnetic field

a vector quantity obtained at a given point by subtracting the magnetization $\vec{M}$ from the magnetic flux density $\vec{B}$ divided by the magnetic constant (permeability) μ :

$$\vec{H} = \frac{\vec{B}}{\mu} - \vec{M}$$

where

$\vec{H}$ is the magnetic field in amperes per metre;

$\vec{B}$ is the magnetic flux density in teslas;

μ is the magnetic constant (permeability) of the vacuum in henries per metre;

$\vec{M}$ is the magnetization in amperes per metre.

NOTE For the purposes of this standard, $\vec{M} = 0$ at all points.

3.20

magnetic flux density

a vector field quantity $\vec{B}$ which exerts on any charged particle having velocity $\vec{v}$ a force $\vec{F}$ equal to the product of the vector product $\vec{v} \times \vec{B}$ and the electric charge q of the particle:

$$\vec{F} = q\vec{v} \times \vec{B}$$

where

$\vec{F}$ is the vector force acting on the particle in newtons;

q is the charge on the particle in coulombs;

$\vec{v}$ is the velocity of the particle in metres per second;

$\vec{B}$ is the magnetic flux density in teslas.

3.21

magnetic permeability

a scalar or tensor quantity μ the product of which by the magnetic field $\vec{H}$ in a medium is equal to the magnetic flux density $\vec{B}$:

$$\vec{B} = \mu\vec{H}$$

where

$\vec{H}$ is the magnetic field in amperes per metre;

μ is the magnetic constant (permeability) of the vacuum in henries per metre;

$\vec{B}$ is the magnetic flux density in teslas.

NOTE For an isotropic medium, the permeability is a scalar; for an anisotropic medium, it is a tensor.

3.22

measurement range

the interval of operation of the measurement system, which is bounded by the lower and the upper detection limits

3.23

mobile (wireless) device

for this standard only, a wireless communication device which is used when held in proximity of the head against the ear.

NOTE The terms “mobile” and “portable” have specific but generic meanings in IEC 60050 [21] – mobile: capable of operating while being moved (IEV 151-16-46); portable: capable to be carried by one person (IEV 151-16-47). The term “portable” often implies the ability to operate when carried. These definitions are used interchangeably in various wireless regulations and industry specifications, in some cases referring to types of wireless devices and in other cases to intended use.

3.24**multi-band (wireless device)**

a wireless device capable of operating in more than one frequency band

3.25**multi-mode (wireless device)**

a wireless device capable of operating in more than one mode of transmitting signals, e.g., analogue, TDMA and CDMA

3.26**peak spatial-average SAR**

the maximal value of averaged SAR within a specific mass

3.27**penetration depth**

See skin depth.

3.28**permittivity**

See complex permittivity, relative permittivity.

3.29**phantom (head)**

in this context, a simplified representation or a model similar in appearance to the human anatomy and composed of materials with electrical properties similar to the corresponding tissues

3.30**pinna**

auricle

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

3.31**power**

See average (temporal) absorbed power, conducted output power.

3.32**probe isotropy**

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

3.33**relative permittivity**

the ratio of the complex permittivity to the permittivity of free space. The complex relative permittivity,

$$\varepsilon_r = \frac{\varepsilon}{\varepsilon_0}$$

of an isotropic, linear lossy dielectric medium is given by

$$\varepsilon_r = \varepsilon'_r - j\varepsilon''_r = \varepsilon'_r + \frac{\sigma}{j\omega\varepsilon_0} = \varepsilon'_r \left(1 - j \frac{\varepsilon''_r}{\varepsilon'_r} \right) = \varepsilon'_r (1 - j \tan \delta)$$

where

- ϵ_0 is the free-space permittivity ($8,854 \times 10^{-12}$ F/m) or dielectric constant, in farads per metre;
- ϵ is the complex permittivity in farads per metre;
- ϵ_r is the complex relative permittivity;
- ϵ'_r is the real part of the complex relative permittivity, also known as dielectric constant;
- ϵ''_r is the part of the complex relative permittivity (dielectric loss index), which represents dielectric losses;
- σ is the conductivity in siemens per metre;
- ω is the angular frequency in radians per second;
- $\tan \delta$ is the loss tangent.

3.34

response time

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

3.35

scanning system

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

3.36

sensitivity (of a measurement system)

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

3.37

skin depth

the distance from the boundary of a medium to the point at which the field strength or induced current density have been reduced to $1/e$ of their values at the boundary

The skin depth δ of a medium depends on the propagation constant, γ , of the electromagnetic wave, along the propagation direction [56]. The propagation constant depends on the dielectric properties of the material and on the characteristics of the propagating mode.

The skin depth is defined as:

$$\delta = \frac{1}{\operatorname{Re}[\gamma]}$$

where the factor $\gamma = \alpha + j\beta$, α is the attenuation constant and β is the phase constant of the propagating wave, and

$$\gamma^2 = -\omega^2 \mu \epsilon + k_c^2$$

where μ and ϵ are the magnetic permeability and the complex relative permittivity of the medium respectively, and k_c^2 is the transverse propagation constant of the mode. Thus

$$\delta = \frac{1}{\operatorname{Re}\{\sqrt{-\omega^2 \mu \epsilon + k_c^2}\}}.$$

In case of free space propagation $k_c^2 = 0$, then the equation for the skin depth is:

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

where

δ is the skin depth in metres;

ω is the angular frequency in radians per second;

ε'_r is the real part of the complex relative permittivity;

ε_0 is the permittivity of free space in farads per metre;

μ_0 is the permeability of free space in henries per metre;

σ is the conductivity of the medium in siemens per metre.

NOTE In case of TE₁₀ mode propagation in a rectangular waveguide, with largest cross-sectional dimension a :

$$k_c^2 = \left(\frac{\pi}{a} \right)^2$$

3.38

specific absorption rate (SAR)

the time derivative of the incremental electromagnetic energy (dW) absorbed by (dissipated in) an incremental mass (dm) contained in a volume element (dV) of given mass density (ρ)

$$\text{SAR} = \frac{d}{dt} \left(\frac{dW}{dm} \right) = \frac{d}{dt} \left(\frac{dW}{\rho dV} \right)$$

SAR can be obtained using either of the following equations:

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

$$\text{SAR} = c_h \left. \frac{dT}{dt} \right|_{t=0}$$

where

SAR is the specific absorption rate in watts per kilogram;

E is the r.m.s. value of the electric field strength in the tissue in volts per metre;

σ is the conductivity of the tissue in siemens per metre;

ρ is the density of the tissue in kilograms per cubic metre;

c_h is the heat capacity of the tissue in joules per kilogram and kelvin;

$\left. \frac{dT}{dt} \right|_{t=0}$ is the initial time derivative of temperature in the tissue in kelvins per second.

3.39

uncertainty (combined)

standard uncertainty of the result of a measurement when that result is obtained from the values of a number of other quantities, equal to the positive square root of a sum of terms, the terms being the variances and/or covariances of the values of these other quantities weighted according to how the measurement result varies with changes in these quantities

3.40

uncertainty (expanded)

a quantity defining an interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand

3.41

uncertainty (standard)

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

3.42

wavelength

the distance between two points of equivalent phase of two consecutive cycles of a wave in the direction of propagation. The wavelength λ is related to the magnitude of the phase velocity v_p and the frequency f by the equation:

$$\lambda = \frac{v_p}{f}$$

The wavelength λ of an electromagnetic wave is related to the frequency and speed of light in the medium by the expression

$$c = f\lambda$$

where

f is the frequency in hertz;

c is the speed of light in metres per second;

v_p is the magnitude of the phase velocity;

λ is the wavelength in metres.

NOTE In free space the velocity of an electromagnetic wave is equal to the speed of light.

4 Symbols and abbreviated terms

4.1 Physical quantities

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

Symbol	Quantity	Unit	Dimensions
α	Attenuation coefficient	reciprocal metre	1/m
B	Magnetic flux density	tesla	T, Vs/m ²
D	Electric flux density	coulomb per square metre	C/m ²
c_h	Specific heat capacity	joule per kilogram kelvin	J/(kg K)
E	Electric field strength	volt per metre	V/m
f	Frequency	hertz	Hz
H	Magnetic field strength	ampere per metre	A/m

J	Current density	ampere per square metre	A/m ²
$\bar{P}_{\text{avg}}$	Average (temporal) absorbed power	watt	W
SAR	Specific absorption rate	watt per kilogram	W/kg
T	Temperature	kelvin	K
ε	Permittivity	farad per metre	F/m
λ	Wavelength	metre	m
μ	Permeability	henry per metre	H/m
ρ	Mass density	kilogram per cubic metre	kg/m ³
σ	Electric conductivity	siemens per metre	S/m

NOTE In this standard, temperature is quantified in degrees Celsius, as defined by: $T (^\circ\text{C}) = T (\text{K}) - 273,16$.

4.2 Constants

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

4.3 Abbreviations

CAD	= Computer aided design; commonly used file formats are IGES and DXF
DXF	= Digital exchange file
ERP	= Ear reference point
DUT	= Device under test
IGES	= International graphics exchange standard
RF	= Radio frequency
RSS	= Root sum square
SAM	= Specific anthropomorphic mannequin

5 Measurement system specifications

5.1 General requirements

A SAR measurement system is composed of a phantom, electronic measurement instrumentation, a scanning system and a device holder.

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

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

- the ambient temperature shall be in the range of 18 °C to 25 °C and the variation of the liquid temperature shall not exceed ± 2 °C during the test;
- the ambient noise shall be within 0,012 W/kg (3 % of the lower detection limit 0,4 W/kg);
- the wireless device shall not connect to local wireless networks;
- the effects of reflections, secondary RF transmitters, etc., shall be smaller than 3 % of the measured SAR.

Validation of a system according to the protocol defined in Annex D shall be done at least once per year, when a new system is put into operation, or whenever modifications have been made to the system, such as a new software version, different readout electronics or different types of probes. The manufacturer of the measurement equipment should declare conformity of their product with this standard.

5.2 Phantom specifications (shell and liquid)

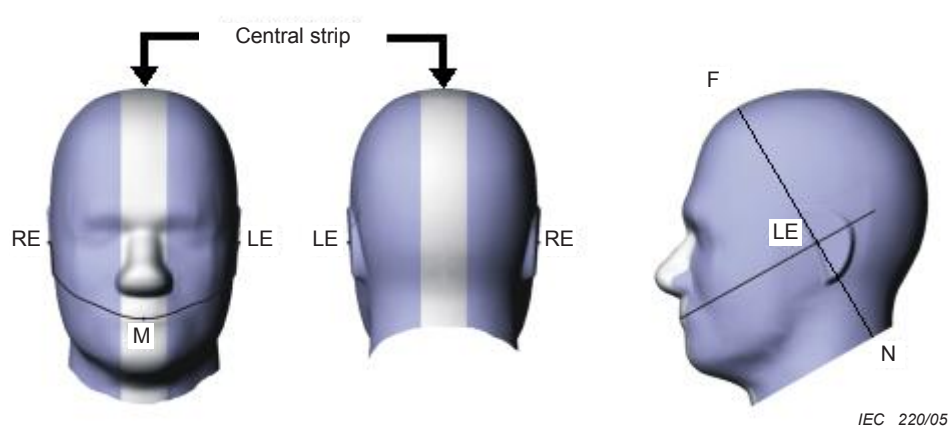
5.2.1 General requirements

Scanning of an E-field probe is carried out within two bisected phantom halves or a full-head phantom with an opening on the top. The physical characteristics of the phantom model (size and shape) for handset testing simulate the head of a user because head shape is a dominant parameter for exposure evaluations. The phantom model shall use materials with dielectric properties similar to those of head tissues. To enable field scanning within, the head material shall consist of a liquid contained in a shell. The shell material shall be as unobtrusive as possible to device radiation, as prescribed below. At least three reference points on the phantom shall be defined by the phantom manufacturer for use in correlating the scanning system with the phantom. These points shall be visible to the user and spaced no less than 10 cm apart. A hand holding the device shall not be modelled (see Annex A).

5.2.2 Standard phantom shape and size

The standard phantom shape is derived from the size and dimensions of the 90th-percentile large adult male head reported in an anthropometric study [18], with the ears adapted to represent the flattened ears of a handset user (see Annex A). Figure 1 shows the realization of these requirements.

The Specific Anthropomorphic Mannequin (SAM) standard phantom as shown in Figure 2 shall be used for the handset SAR measurements of this standard. CAD files for the inner (*SAM_in*) and outer (*SAM_out*) surfaces of the standard phantom are publicly available on CD-ROM in 3D-CAD formats (3D-IGES and DXF). The manufacturer of the phantom shall document conformity of their product with the shape and thickness specifications of this standard.



IEC 220/05

Key

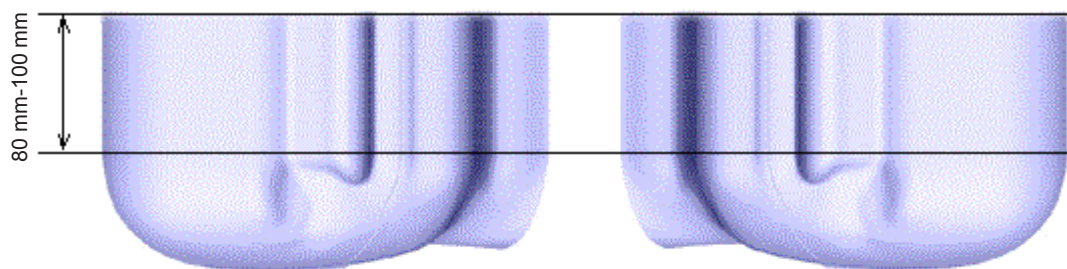
- RE Right ear reference point (ERP)
 LE Left ear reference point (ERP)
 M Mouth reference point
 F Line N-F front endpoint (information only – mark on phantom not required)
 N Line N-F neck endpoint (information only – mark on phantom not required)

NOTE Full-head model is for illustration purposes only—procedures in this standard were derived primarily for the phantom set-up of Figure 2. The central strip region including the nose has a larger thickness tolerance.

Figure 1 – Picture of the phantom showing ear reference points RE and LE, mouth reference point M, reference line N-F, and central strip

5.2.3 Phantom shell

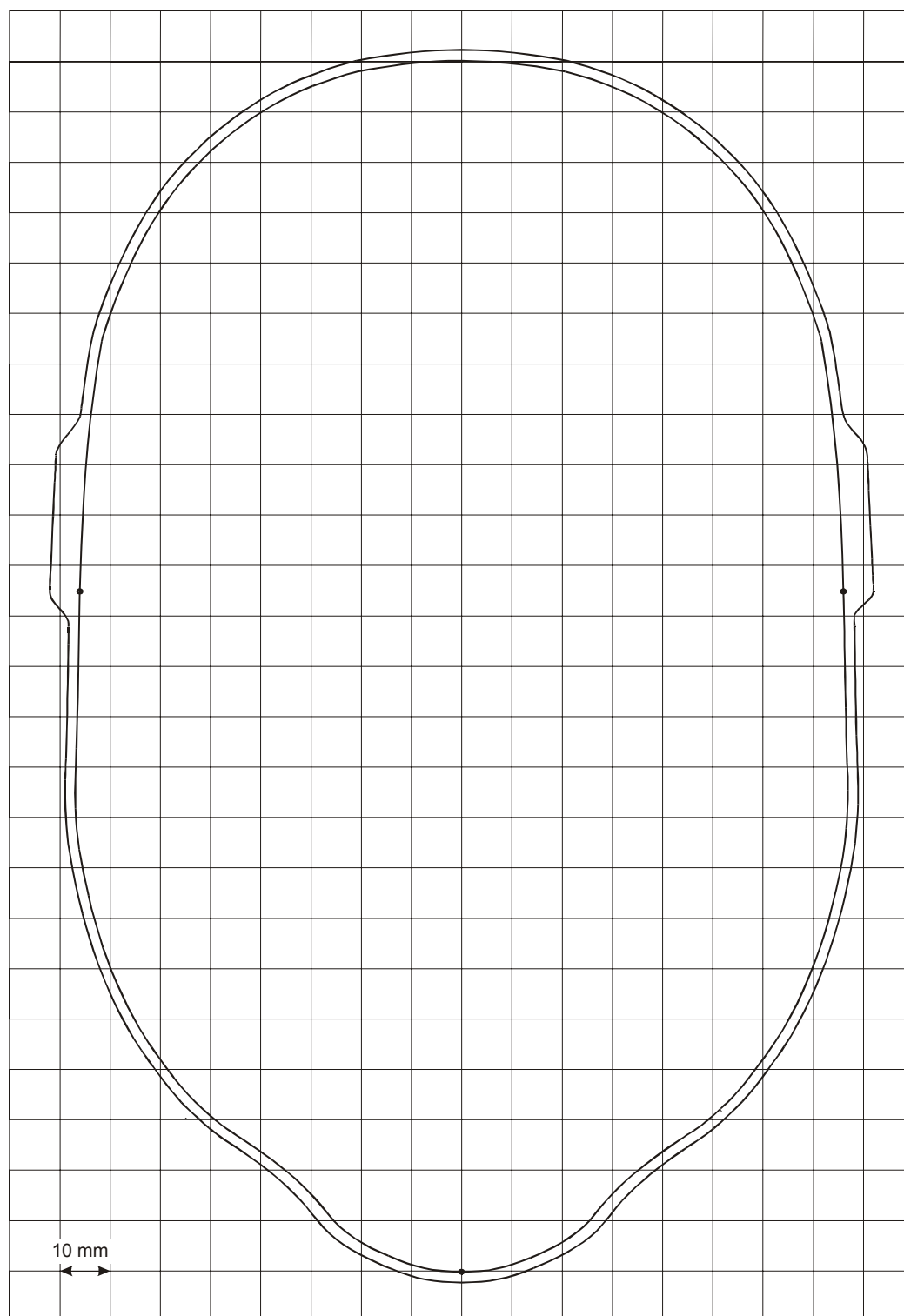
The phantom shell material shall be resistant to all ingredients used in the tissue-equivalent liquid recipes. The shell of the phantom including ear spacers shall be constructed from low permittivity and low loss material, with a relative permittivity ≤ 5 and a loss tangent $\leq 0,05$. The shape of the phantom shall have a tolerance of less than $\pm 0,2$ mm with respect to the CAD file of the SAM phantom. In any area within the projection of the handset, the shell thickness shall be $(2 \pm 0,2)$ mm, except for the ears and the extended perimeter walls (as shown in Figure 2). The low-loss ear spacers (same material as the head shell) shall provide a 6 mm spacing from the tissue-equivalent liquid boundary at the ear reference points (ERPs), within a tolerance of less than $\pm 0,2$ mm. In the central strip region within $\pm 1,0$ cm of the central sagittal plane (Figure 1), the tolerance shall be $\pm 1,0$ mm.



IEC 221/05

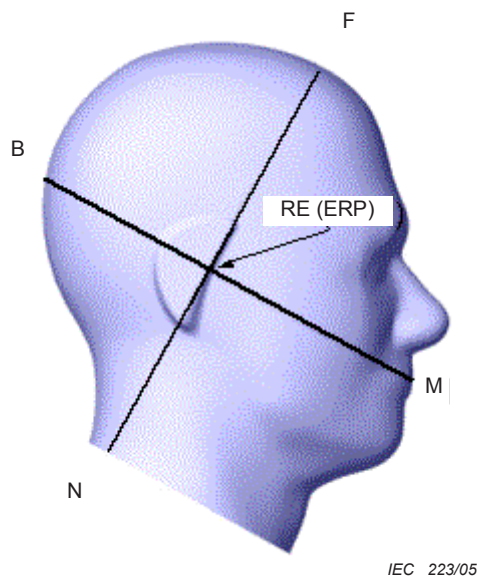
Figure 2 – Sagittally bisected phantom with extended perimeter (shown placed on its side as used for device SAR tests)

In Figure 1 the point “M” is the mouth reference point, “LE” is the left ear reference point (ERP), and “RE” is the right ERP. These points shall be marked on the exterior of the phantom to support reproducible positioning of the wireless device in relation to the phantom. The plane passing through the two ear reference points and M is defined as the reference plane, and contains the line B-M (back-mouth). The CAD file cross section for the reference plane is given in Figure 3. This view is scaled down by a factor of 1,3 from the 26 cm × 18 cm actual size. To facilitate placement of the device, the line N-F (neck-front) shall be a straight line drawn through each ERP, along the front truncated edge of the ear on each side. The projection of both the line B-M and the line N-F shall be indicated on the exterior of the phantom shell, to facilitate device positioning (see Figure 4). The position of the centre of the acoustic output side of the handset shall be located against the ERP of the phantom. All reference point locations are specified in the CAD files.



IEC 222/05

Figure 3 – Cross-sectional view of SAM at the reference plane containing B-M



Key

- B Line B-M back endpoint (information only – mark on phantom not required)
- F Line N-F front endpoint (information only – mark on phantom not required)
- N Line N-F neck endpoint (information only – mark on phantom not required)
- M Mouth reference point
- RE Right ear reference point (ERP)

NOTE Full-head model is for illustration purposes only—procedures in this standard were derived primarily for the phantom set-up of Figure 2.

Figure 4 – Side view of the phantom showing relevant markings

5.2.4 Tissue-equivalent liquid properties

The dielectric properties of the liquid used in the phantom shall be those listed in Table 1. For dielectric properties of head tissue-equivalent liquid at other frequencies within the frequency range, a linear interpolation method shall be used. Examples of recipes for liquids having parameters as defined in Table 1 are given in Annex I.

Table 1 – Dielectric properties of the tissue-equivalent liquid

Frequency MHz	Relative dielectric constant (ϵ_r)	Conductivity (σ) S/m
300	45,3	0,87
450	43,5	0,87
835	41,5	0,90
900	41,5	0,97
1 450	40,5	1,20
1 800	40,0	1,40
1 900	40,0	1,40
1 950	40,0	1,40
2 000	40,0	1,40
2 450	39,2	1,80
3 000	38,5	2,40

5.3 Specifications of the SAR measurement equipment

The measurement equipment shall be calibrated as a complete system. The probe shall be calibrated together with an identical or technically equivalent type of amplifier, measurement device and data acquisition system. The measurement equipment shall be calibrated in each tissue-equivalent liquid at the appropriate operating frequency and temperature, according to the methodology described in Annex B. Calibration of the probe separately from the system is allowed, provided the loading conditions at the probe connector are specified and implemented during measurements.

The minimum detection limit shall be lower than 0,02 W/kg, and the maximum detection limit shall be higher than 100 W/kg. The linearity shall be within $\pm 0,5$ dB over the SAR range from 0,01 W/kg to 100 W/kg. Sensitivity and isotropy shall be determined in the tissue-equivalent liquid. The response time shall be specified. It is recommended that the outside dimension (diameter) of the probe cover/case should not exceed 8 mm in the vicinity of the dipole elements.

5.4 Scanning system specifications

5.4.1 General requirements

The scanning system holding the probe shall be able to scan the whole exposed volume of the phantom in order to evaluate the three-dimensional SAR distribution. The mechanical structure of the scanning system shall not interfere with the SAR measurements. The scanning system shall be correlated with the phantom using at least three reference points on the phantom, with these points defined by the user or system manufacturer.

5.4.2 Technical requirements

5.4.2.1 Accuracy

The accuracy of the probe tip positioning over the measurement area shall be better than $\pm 0,2$ mm.

5.4.2.2 Positioning resolution

The positioning resolution is the increment at which the measurement system is able to perform measurements. The positioning resolution shall be 1 mm or less.

5.5 Device holder specifications

Care shall be taken to avoid significant influence on SAR measurements by any reflection and absorption from the environment (such as floor, device holder, surface of the liquid).

The device holder shall permit the device to be positioned according to the definitions given in 6.1.4 with a tolerance of $\pm 1^\circ$ in the tilt angle. It shall be made of low loss and low permittivity material(s): loss tangent $\leq 0,05$ and relative permittivity ≤ 5 . The positioning uncertainties shall be estimated following the procedures described in 7.2.2.4.2.

To verify that the holder does not perturb SAR, a substitution test should be done by replacing the holder with low relative permittivity and low loss foam blocks, or adhering the handset to the phantom using tape or string, for example (see 7.2.2.4.1).

5.6 Measurement of liquid dielectric properties

The dielectric properties of the tissue-equivalent liquid shall be measured at the relevant temperature and relevant frequency. The dielectric parameters should be evaluated and compared with the values given in Table 1 using linear interpolation. The measured dielectric properties, not the values of Table 1, shall be used in the SAR calculations. This measurement can be performed using the equipment and procedures described in Annex J.

NOTE See 6.1.1 for the allowable variations between the measured and the Table 1 dielectric parameters, as defined for the purposes of this standard.

6 Protocol for SAR assessment

6.1 Measurement preparation

6.1.1 General preparation

The dielectric properties of the tissue-equivalent liquids shall be measured within 24 h before the SAR measurements, unless the laboratory can prove compliance for longer intervals, e.g., weekly measurements. The dielectric properties of the tissue-equivalent liquids shall be measured at the same liquid temperature as that during the SAR measurements within ± 2 °C.

Until verified recipes are available for head tissue-equivalent liquid in the range of 2 GHz to 3 GHz that give both measured dielectric parameters within ± 5 % of the values in Table 1, the following is recommended.

- a) For frequencies above 300 MHz but less than 2 GHz, the measured conductivity and dielectric constant shall be within ± 5 % of the target values in Table 1 (measurement uncertainty of liquid parameters is addressed separately – see 7.2.3),
- b) For frequencies in the range of 2 GHz to 3 GHz, the measured conductivity shall be within ± 5 % of the target values in Table 1. The tolerance of measured relative permittivity can be relaxed to no more than ± 10 %, but shall be as close as possible to the values in Table 1 using available recipes. Effects on the SAR due to the deviation of the dielectric constant from the target values shall be included in the uncertainty estimation.

The phantom shell shall be filled with the tissue-equivalent liquid to a depth of at least 15 cm above the ERP for the horizontal phantom configuration. The liquid shall be carefully stirred before the measurement, and should be free of air bubbles. Care shall be taken to avoid reflections from the liquid surface, which is accomplished with 15 cm depth in the frequency range 300 MHz to 3 GHz. The viscosity of the liquid shall not impede probe movement.

6.1.2 System check

A *system check* according to the procedures of Annex D shall be executed before doing handset SAR measurements. The purpose of the *system check* is to verify that the system operates within its specifications. The *system check* is a test of repeatability 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:

- changes in the liquid parameters, 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.

The *system check* is a complete 1 g or 10 g average SAR measurement. The measured 1 g or 10 g average SAR value is normalized to the target input power of the standard source and compared with the previously recorded target 1 g or 10 g value corresponding to the measurement frequency, the standard source and specific flat phantom. The acceptable tolerance must be determined for each *system check* and shall be within ± 10 % of previously recorded *system check* target values. The *system check* shall be performed at a frequency that is within ± 10 % of the DUT mid-band frequency.

NOTE The terms *system validation* and *system check* are italicised because they refer to specific test protocols described for the purposes of this standard.

6.1.3 Preparation of the wireless device under test

The tested wireless device shall use its internal transmitter. The antenna(s), battery and accessories shall be those specified by the manufacturer. The battery shall be fully charged before each measurement, without external connections or cables.

The device output power and frequency (channel) shall be controlled using an internal test program or by the use of appropriate test equipment (base station simulator with antenna). The wireless device shall be set to transmit at its highest power level for the conditions of use next to the ear. The exposure tests shall be based on the functional and exposure characteristics of the test devices, e.g., operating modes, antenna configurations, etc.

Whenever possible, final commercial product versions shall be tested using all normal operational configurations, e.g., without any cables attached. Cables attached to a product are very likely to alter the transmitter RF current distribution on metallic and conducting portions of the product. Additionally, if tests are performed using prototypes, it shall be verified that the commercial version has exactly the same mechanical and electrical characteristics as the tested prototype. If this cannot be guaranteed, testing shall be repeated by sampling of unmodified commercial product versions.

NOTE If operation of the DUT at the highest time-averaged power level is not possible, the test may be performed at lower power and results then scaled to the maximum output power, provided that the DUT SAR response is linear.

6.1.4 Position of the wireless device in relation to the phantom

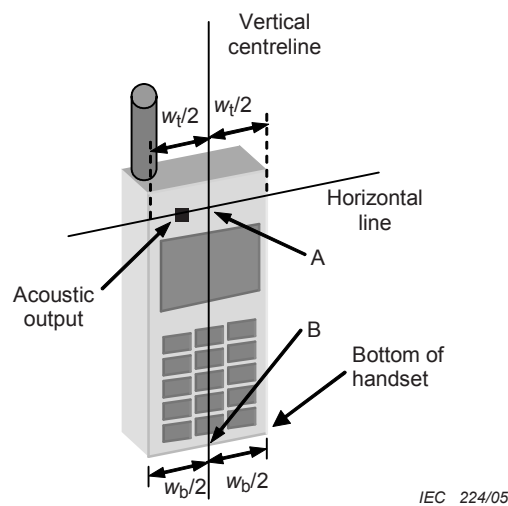
6.1.4.1 General considerations

This standard specifies two handset test positions against the head phantom – the “cheek” position and the “tilt” position. These two test positions are defined in the following subclauses. The handset should be tested in both of these positions on left and right sides of the SAM phantom. If handset construction is such that the handset positioning procedures described in 6.1.4.2 and 6.1.4.3 to represent normal-use conditions cannot be used, e.g., some asymmetric handsets, alternative alignment procedures should be adapted with all details provided in the test report. These alternative procedures should replicate intended use conditions as closely as possible, according to the intent of the procedures described in this clause.

6.1.4.2 Definition of the cheek position

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

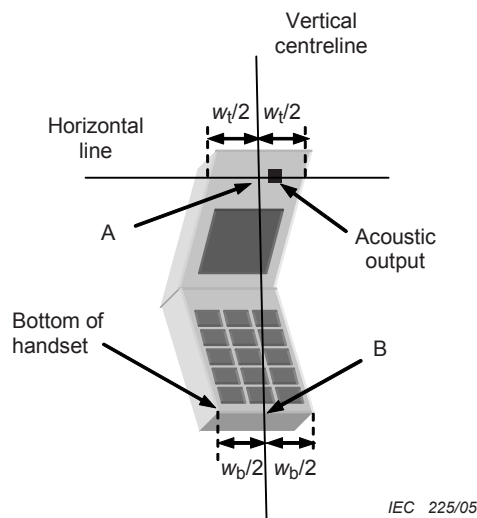
- a) Ready the handset for talk operation, if necessary. For example, for handsets with a cover piece (flip cover), open the cover. If the device can also be used with the cover closed, both configurations shall be tested.
- b) Define two imaginary lines on the handset, the vertical centreline and the horizontal line, for the handset in vertical orientation as shown in Figures 5a and 5b. The vertical centreline passes through two points on the front side of the handset: the midpoint of the width w_t of the handset at the level of the acoustic output (point A in Figures 5a and 5b), and the midpoint of the width w_b of the bottom of the handset (point B). The horizontal line is perpendicular to the vertical centreline and passes through the centre of the acoustic output (see Figures 5a and 5b). The two lines intersect at point A. Note that for many handsets, point A coincides with the centre of the acoustic output. However, the acoustic output may be located elsewhere on the horizontal line. Also note that the vertical centreline is not necessarily parallel to the front face of the handset (see Figure 5b), especially for clam-shell handsets, handsets with flip cover pieces, and other irregularly shaped handsets.
- c) Position the handset close to the surface of the phantom such that point A is on the (virtual) extension of the line passing through points RE and LE on the phantom (see Figure 6). The plane defined by the vertical centreline and the horizontal line of the device must be parallel to the sagittal plane of the phantom.
- d) Translate the handset towards the phantom along the line passing through RE and LE until the handset touches the ear.
- e) Rotate the handset around the (virtual) LE-RE Line until the DUT vertical centreline is in the reference plane.
- f) Rotate the device around its vertical centreline until the plane defined by the DUT vertical centreline and horizontal line is parallel to the N-F Line, then translate the handset towards the phantom along the LE-RE line until DUT point A touches the ear at the ERP.
- g) While keeping point A on the line passing through RE and LE and maintaining the handset in contact with the pinna, rotate the handset about the line N-F until any point on the handset is in contact with a phantom point below the pinna (cheek) (see Figure 6). The physical angles of rotation shall be documented.
- h) While keeping DUT point A in contact with the ERP, rotate the handset around a line perpendicular to the plane defined by the DUT vertical centreline and horizontal line and passing through DUT point A, until the DUT vertical centreline is in the reference plane.
- i) Verify that the cheek position is correct as follows:
 - the N-F line is in the plane defined by the DUT vertical centreline and horizontal line,
 - DUT point A touches the pinna at the ERP, and
 - the DUT vertical centreline is in the reference plane.



Key

- w_t Width of the handset at the level of the acoustic output
- w_b Width of the bottom of the handset
- A Midpoint of the width w_t of the handset at the level of the acoustic output
- B Midpoint of the width w_b of the bottom of the handset

Figure 5a –Typical “fixed” case handset

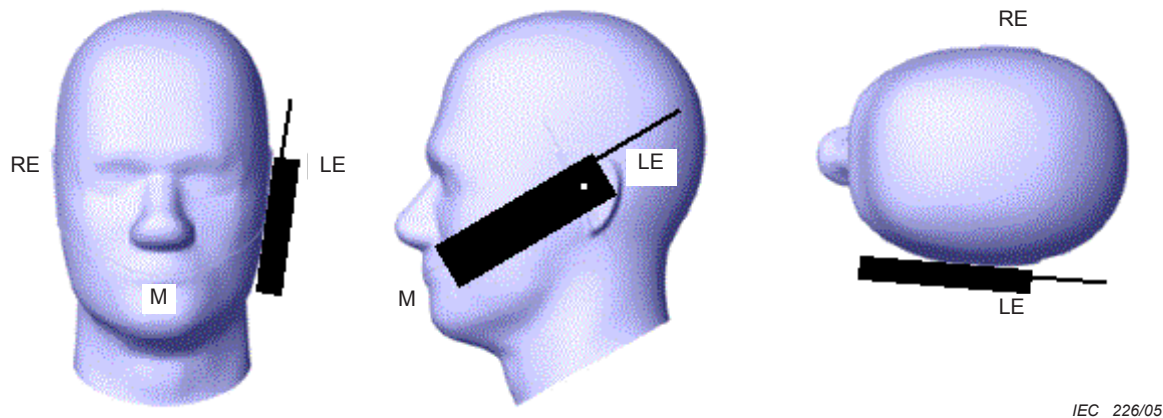


Key

- w_t Width of the handset at the level of the acoustic output
- w_b Width of the bottom of the handset
- A Midpoint of the width w_t of the handset at the level of the acoustic output
- B Midpoint of the width w_b of the bottom of the handset

Figure 5b – Typical “clam-shell” case handset

Figure 5 – Handset vertical and horizontal reference lines and reference points A, B on two example device types



Key

- M Mouth reference point
- LE Left ear reference point (ERP)
- RE Right ear reference point (ERP)

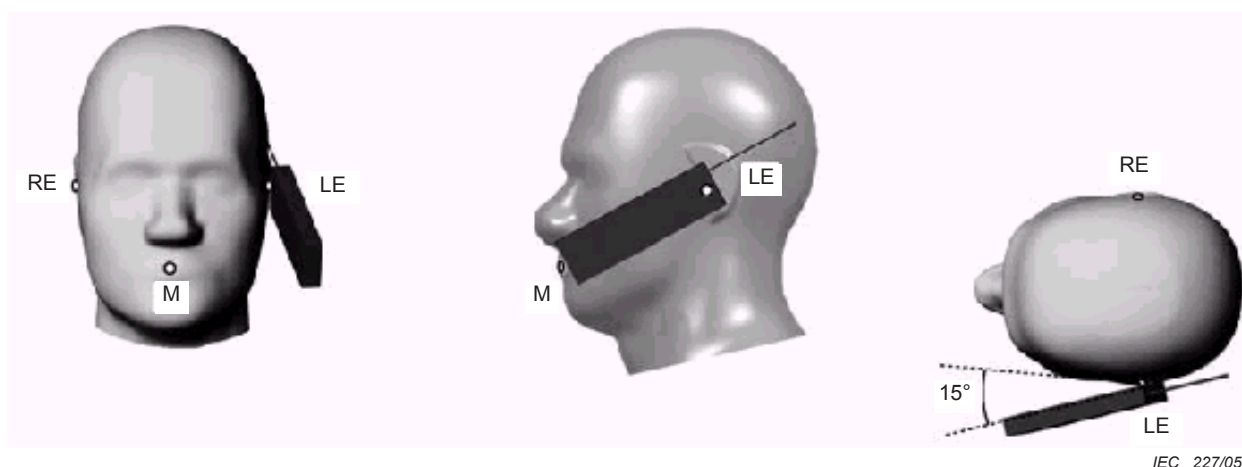
NOTE This device position must be maintained for the phantom test set-up shown in Figure 2.

Figure 6 – Cheek position of the wireless device on the left side of SAM

6.1.4.3 Definition of the tilt position

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

- a) Repeat steps a) to i) of 6.1.4.2 to place the device in the cheek position (see Figure 6).
- b) While maintaining the orientation of the device, retract the device parallel to the reference plane far enough away from the phantom to enable a rotation of the device by 15°.
- c) Rotate the device around the horizontal line by 15° (see Figure 7).
- d) While maintaining the orientation of the handset, move the handset towards the phantom on a line passing through RE and LE until any part of the handset touches the ear. The tilt position is obtained when the contact is on the pinna. If the contact is at any location other than the pinna, e.g., the antenna with the back of the phantom head, the angle of the handset shall be reduced. In this case, the tilt position is obtained if any part of the handset is in contact with the pinna as well as a second part of the handset is in contact with the phantom, e.g., the antenna with the back of the head.

**Key**

M Mouth reference point

LE Left ear reference point (ERP)

RE Right ear reference point (ERP)

NOTE This device position must be maintained for the phantom test set-up shown in Figure 2.

Figure 7 – Tilt position of the wireless device on the left side of SAM**6.1.5 Test frequencies**

A device should be compatible with applicable exposure standards at all channels transmitted by the device. However, testing at every channel is impractical and unnecessary. The purpose of this subclause is to define a practical subset of channels where SAR measurements are to be performed. This subset of channels is chosen so as to give a characterization of compatibility of a handset with any applicable exposure standards.

For each operational mode of the handset, tests should be performed at the channel that is closest to the centre of each transmit frequency band. If the width of the transmit frequency band, ($\Delta f = f_{\text{high}} - f_{\text{low}}$), exceeds 1 % of its centre frequency f_c , then the channels at the lowest and highest frequencies of the transmit band should also be tested. Furthermore, if the width of the transmit band exceeds 10 % of its centre frequency, the following formula should be used to determine the number of channels, N_c , to be tested:

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

where

f_c is the centre frequency of the band in hertz;

f_{high} is the highest frequency in the band in hertz;

f_{low} is the lowest frequency in the band in hertz;

N_c is the number of channels;

Δf is the width of the transmit frequency band in hertz.

NOTE 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. The channels tested should be equally spaced apart in frequency (as much as possible) and should include the channels at the lowest and highest frequencies.

6.2 Tests to be performed

In order to determine the highest value of the peak spatial-average SAR of a handset, all device positions, configurations and operational modes shall be tested for each frequency band according to steps 1 to 3 below. A flowchart of the test process is shown in Figure 8.

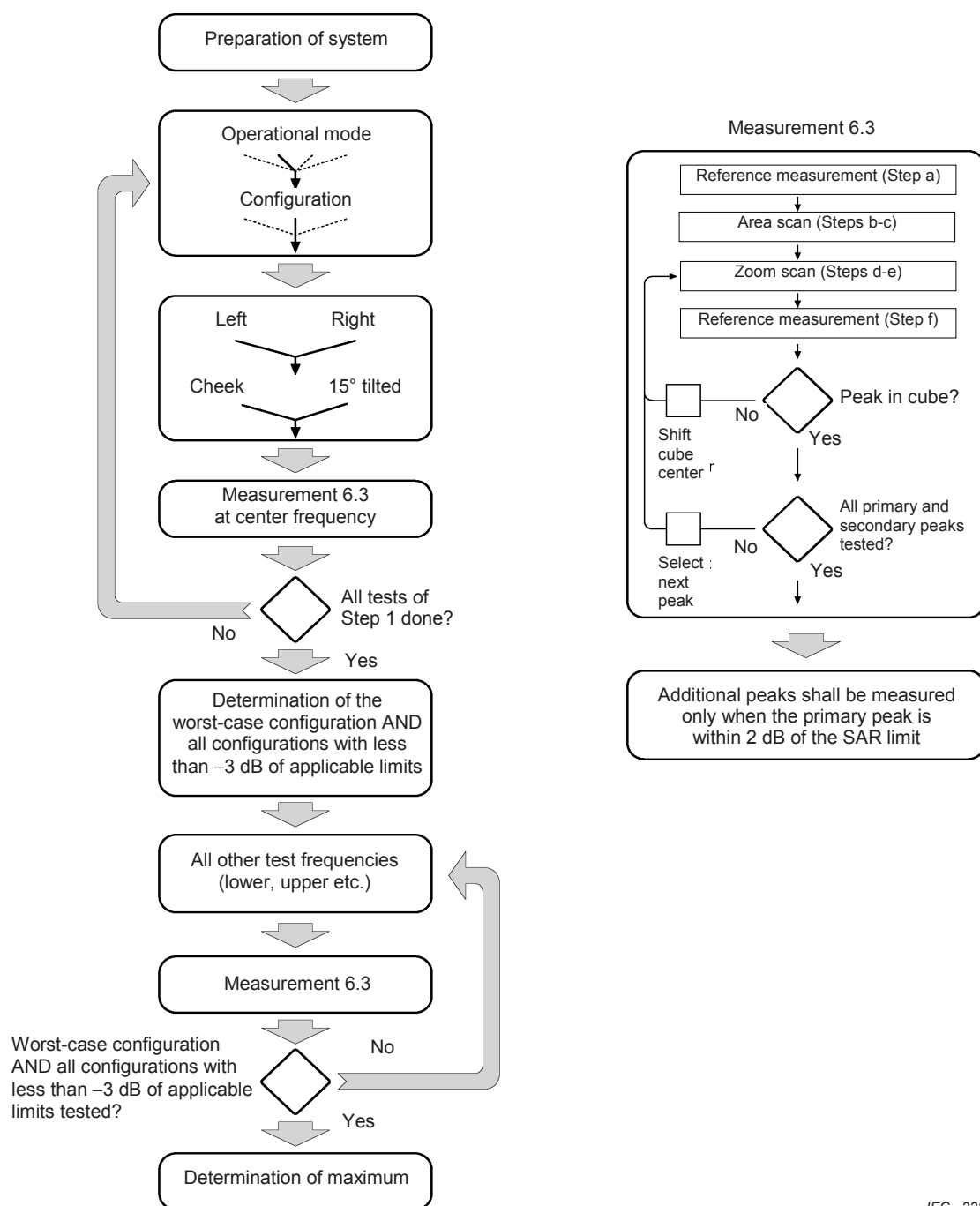
Step 1: The tests described in 6.3 shall be performed at the channel that is closest to the centre of the transmit frequency band (f_c) for:

- a) all device positions (cheek and tilt, for both left and right sides of the SAM phantom, as described in 6.1.4),
- b) all configurations for each device position in a), e.g., antenna extended and retracted, and
- c) all operational modes, e.g., analogue and digital, for each device position in a) and configuration in b) in each frequency band.

If more than three frequencies need to be tested according to 6.1.5 (i.e., $N_c > 3$), then all frequencies, configurations and modes shall be tested for all of the above test conditions.

Step 2: For the condition providing highest peak spatial-average SAR determined in Step 1, perform all tests described in 6.3 at all other test frequencies, i.e., lowest and highest frequencies (see 6.1.5). In addition, for all other conditions (device position, configuration and operational mode) where the peak spatial-average SAR value determined in Step 1 is within 3 dB of the applicable SAR limit, it is recommended that all other test frequencies shall be tested as well.

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



IEC 228/05

Figure 8 – Block diagram of the tests to be performed

6.3 Measurement procedure

The following procedure shall be performed for each of the test conditions (see Figure 8) described in 6.2:

- a) measure the local SAR at a test point within 10 mm or less in the normal direction from the inner surface of the phantom. The test point can be close to the ear;
- b) measure the SAR distribution within the phantom (*area scan* procedure). The SAR distribution is scanned along the inside surface of one side of the phantom head, at least for an area larger than the projection of the handset and antenna. The spatial grid step shall be less than 20 mm. The resolution accuracy can also be tested using the reference functions of 7.2.4. If surface scanning is used, then the distance between the geometrical centre of the probe dipoles and the inner surface of the phantom shall be 8,0 mm or less ($\pm 1,0$ mm). At all measurement points, the angle of the probe with respect to the line normal to the surface is recommended but not required to be less than 30° (see Figure 9);

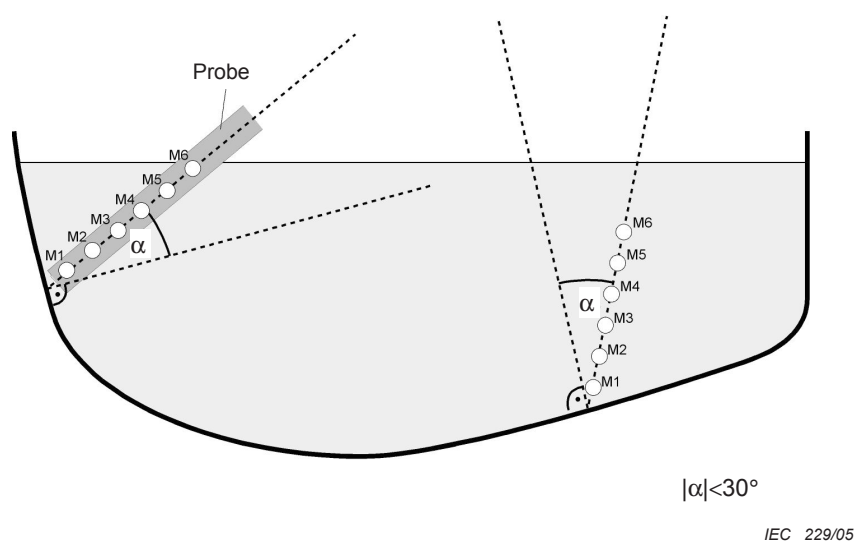
NOTE If the angle is larger than 30° and the measurement distance closer than one probe-tip diameter, the boundary effect may become larger and polarization dependent. This additional uncertainty needs to be analysed and taken into account.

- c) from the scanned SAR distribution, identify the position of the maximum SAR value, as well as the positions of any local maxima with SAR values within 2 dB of the maximum value that are not within the *zoom-scan* volume; Additional peaks shall be measured only when the primary peak is within 2 dB of the SAR limit (i.e., 1 W/kg for a 1,6 W/kg 1 g limit, or 1,26 W/kg for a 2 W/kg 10 g limit). This is consistent with the 2 dB threshold already stated;
- d) measure SAR with a grid step of 8 mm or less in a volume with a minimum size of 30 mm by 30 mm and 30 mm in depth (*zoom scan* procedure). The grid step in the vertical direction shall be 5 mm or less (see C.3.3). Separate grids shall be centred on each of the local SAR maxima found in step c). Uncertainties due to field distortion between the media boundary and the dielectric cover/case of the probe should also be minimized, which is achieved if the distance between the phantom surface and physical tip of the probe is larger than half of the probe tip diameter. Other methods may utilize correction procedures for these boundary effects that enable high precision measurements closer than half the probe diameter [51]. At all measurement points, the angle of the probe with respect to the line normal to the surface is recommended but not required to be less than 30° ;

NOTE If the angle is larger than 30° and the measurement distance closer than one probe diameter, the boundary effect may become larger and polarization dependent. This additional uncertainty needs to be analysed and taken into account.

- e) use interpolation and extrapolation procedures defined described in Annex C to determine the local SAR values at the spatial resolution needed for mass averaging;
- f) the local SAR should be measured at exactly the same location as used in a). The absolute value of the measurement drift, i.e., the difference between the SAR measured in f) and a), shall be recorded in the uncertainty budget (Table 3). It is recommended that the drift be kept within $\pm 5\%$. If this is not possible, even with repeat testing, additional information, e.g., data for local SAR versus time, should be used to demonstrate that the output power applied during the test is appropriate for testing the device. Power reference measurements can be taken after each *zoom scan*, if more than one *zoom scan* is needed. However, the drift should always be recorded as the difference between the device initial state with fully charged battery and all subsequent measurements using that battery.

NOTE The terms *area scan* and *zoom scan* are italicised because they refer to specific test protocols described for the purposes of this standard.

**Key**

M1, ..., M6 Example measurement points used for extrapolation to the surface

α Angle of the probe with respect to the line normal to the surface

Figure 9 – Orientation of the probe with respect to the line normal to the surface, shown at two different locations

6.4 Post-processing of SAR measurement data

6.4.1 Interpolation

If the resolution of measurement grid is not as fine as required to compute the average SAR over a given mass, interpolation shall be carried out between the measurement points. Examples of interpolation schemes are given in Annex C.

6.4.2 Extrapolation

The electric field probes used to measure SAR usually contain three orthogonal dipoles in close proximity and embedded in a protective cover/case. The measurement (calibration) point is situated a few millimetres from the tip of the probe and this offset shall be taken into account when identifying the position of the measured SAR. Examples of extrapolation schemes are given in Annex C.

6.4.3 Definition of the averaging volume

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

If the cube intersects the surface of the phantom, it shall be oriented such that three vertices touch the surface of the shell (C.2.2.1), or one face tangent to the surface at its centre (C.2.2.2). The face of the cube closest to the surface shall be modified to conform to the surface and the added volume shall be subtracted from the opposite face of the cube. Schemes for averaging over a cubical volume are given in Annex C. Descriptions of methods for the estimation of SAR averaged over the mass previously defined are given in Annex C.