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English version

Basic standard for the measurement of Specific Absorption Rate related to human exposure to electromagnetic fields from mobile phones (300 MHz - 3 GHz)

Norme de base relative à la mesure du Débit d'Absorption Spécifique relatif à l'exposition des personnes aux champs électromagnétiques émis par les téléphones mobiles (300 MHz - 3 GHz)

Grundnorm zur Messung der Spezifischen Absorptionsrate (SAR) in Bezug auf die Sicherheit von Personen in elektromagnetischen Feldern von Mobiltelefonen (300 MHz bis 3 GHz)

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

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CENELEC

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

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Foreword

This European Standard was prepared by the Technical Committee CENELEC TC 211, Electromagnetic fields in the human environment.

The text of the draft was submitted to the Unique Acceptance Procedure and was approved by CENELEC as EN 50361 on 2001-07-03.

The following dates were fixed:

– latest date by which the EN has to be implemented at national level by publication of an identical national standard or by endorsement	(dop)	2002-03-01
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2003-03-01

Annexes designated "normative" are part of the body of the standard.
Annexes designated "informative" are given for information only.
In this standard, annex D is normative and annexes A, B and C are informative.

Contents

1 Scope

This basic standard applies to any electromagnetic field (EM) transmitting devices intended to be used with the radiating part of the equipment in close proximity to the human ear including mobile phones, cordless phones, etc. The frequency range is 300 MHz to 3 GHz.

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

2 Normative references

Council Recommendation 1999/519/EC of 12 July 1999 *on the limitation of exposure of the general public to electromagnetic fields (0 Hz to 300 GHz)* (Official Journal L 197 of 30 July 1999)

International Commission on Non-Ionising Radiation Protection (1998), *Guidelines for limiting exposure in time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz)*. Health Physics 74, 494-522

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

IEC "*Guide to the expression of uncertainty in measurement*", Ed. 1, 1995.

Phantom CAD files, *SAM_in, SAM_out* in 3D-IGES and DXF formats, and reference SAR distributions publicly available on CD-ROM.

3 Physical quantities, units and constants

3.1 Physical quantities

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

Quantity	Symbol	Unit	Dimensions
Current density	J	ampere per square metre	A/m^2
Electric field strength	E	volt per metre	V/m
Electric flux density	D	coulomb per square metre	C/m^2
Electric conductivity	σ	siemens per metre	S/m
Frequency	f	hertz	Hz
Magnetic field strength	H	ampere per metre	A/m
Magnetic flux density	B	tesla (Vs/m^2)	T
Mass density	ρ	kilogram per cubic metre	kg/m^3
Permeability	μ	henry per metre	H/m

Permittivity	ε	farad per metre	F/m
Specific absorption rate	SAR	watt per kilogram	W/kg
Wavelength	λ	metre	m
Temperature	T	kelvin	K
Heat capacity	c_i		J/kg K

NOTE In this standard, temperature is quantified in degrees Celsius, as defined by:

T(°C) = T(K) – 273,16

3.2 Constants

Physical constant		Magnitude
Speed of light in vacuum	c	2,998 x 10^8 m/s
Permittivity of free space	ε_0	8,854 x 10^{-12} F/m
Permeability of free space	μ_0	4π x 10^{-7} H/m
Impedance of free space	Z_0	120π or 377 Ω

4 Definitions

4.1.1
average (temporal) absorbed power (P_{avg})
the time-averaged rate of energy transfer defined by:

$$\bar{P}_{avg} = \frac{1}{t_2 - t_1} \int_{t_1}^{t_2} P(t)dt \qquad (4.1)$$

where t_1 and t_2 are the start and stop time of the exposure. The period t_2 - t_1 is the exposure duration time

4.1.2
averaging time (t_{avg})
the appropriate time over which exposure is averaged for purposes of determining compliance with the limits

4.1.3
basic restriction
the basic restrictions are the restrictions on exposure to time-varying electric, magnetic, and electromagnetic fields that are based directly on established health effects. Concerning the frequency range of this standard, the physical quantity used is the Specific Absorption Rate (SAR)

4.1.4
boundary effect
in this context the boundary effect is the influence of the boundaries between two media of the phantom on the sensitivity of the probe, as well as the influence of the probe on the field distribution and the current density if the probe approaches the boundary between two media

4.1.5
CAD
acronym for Computer Aided Design. Standard formats are IGES and DXF

4.1.6
continuous exposure
exposure for a duration exceeding the averaging time

4.1.7
detection limits
the lower (respectively upper) detection limit is defined by the minimum (respectively maximum) quantifiable response of the measuring equipment

4.1.8
dielectric constant (ε)
see permittivity

4.1.9
duty factor
ratio of the pulse duration to the pulse period of a periodic pulse train. A duty factor of 1 means that the duration of the period is equal to the duration of the pulse

4.1.10
electric conductivity (σ)
the ratio of the conduction-current density in a medium to the electric field strength. Electric conductivity is expressed in units of siemens per metre (S/m)

4.1.11
electric field strength (*E*)
the magnitude of a field vector at a point that represents the force (***F***) on a positive small charge (***q***) divided by the charge

$$E = \frac{F}{q} \quad (4.2)$$

Electric field strength is expressed in units of volts per metre (V/m)

4.1.12
electric flux density (*D*)
the magnitude of a field vector that is equal to the electric field strength (*E*) multiplied by the permittivity (ε)

$$\boldsymbol{D} = \varepsilon \boldsymbol{E} \quad (4.3)$$

Electric flux density is expressed in units of coulomb per square metre (C/m^2)

4.1.13
intrinsic impedance (of free space)
the ratio of the electric field strength to the magnetic field strength of a propagating electromagnetic wave. The intrinsic impedance of a plane wave in free space is 120 π ohms (approximately 377 ohms)

4.1.14
isotropy
deviation of the measured value with regard to various angles of incidence of the measured signal. In this document it is defined for incidences covering a hemisphere centred at the tip of the probe, with an equatorial plane normal to the probe and expanding outside the probe. The axial isotropy is defined by the maximum deviation of the SAR when rotating the probe along its main axis with the probe exposed to a reference wave with normal incidence with regard to the axis of the probe. The hemispherical isotropy is defined by the maximum deviation of the SAR when rotating the probe along its main axis with the probe exposed to a reference wave with varying angles of incidences with regard to the axis of the probe in the half space in front of the probe

4.1.15
linearity
maximum deviation over the measurement range of the measured quantity from the closest linear reference curve defined over a given interval

4.1.16
loss tangent
the loss tangent *tan(δ)* is the ratio of the imaginary part of the complex dielectric constant of a material to its real part

4.1.17
magnetic flux density (*B*)
the magnitude of a field vector that is equal to the magnetic field strength H multiplied by the permeability (μ) of the medium.

$$B = \mu \ H \tag{4.4}$$

Magnetic flux density is expressed in units of tesla (T)

4.1.18
magnetic field strength (*H*)
the magnitude of a field vector in a point that results in a force ($\vec{F}$) on a charge q moving with the velocity $\vec{v}$

$$\vec{F} = q(\vec{v} \times \mu\vec{H}) \tag{4.5}$$

The magnetic field strength is expressed in units of ampere per metre (A/m)

4.1.19
measurement range
the measurement range is the interval of operation of the measurement system, which is bounded by the lower and the upper detection limits

4.1.20
mobile phone
for the purpose of this standard, the term “Mobile Phone” covers any equipment within the scope of this standard

4.1.21
multi-band
a multi-band mobile phone is operating in one single radiocommunication system (mode) in various frequency bands, e.g., GSM 900 and GSM 1 800

4.1.22
multi-mode
a multi-mode mobile phone is operating with various radiocommunication systems, e.g., GSM and DECT

4.1.23
permeability (μ)
the magnetic permeability of a material is defined by the magnetic flux density *B* divided by the magnetic field strength *H*:

$$\mu = \frac{B}{H}, \tag{4.6}$$

where μ is the permeability of the medium expressed in henry per metre (H/m)

4.1.24
permittivity (ε)
the property of a dielectric material, e.g., biological tissue, defined by the electrical flux density *D* divided by the electrical field strength E.

$$\begin{aligned} \varepsilon &= \varepsilon_r . \varepsilon_0 = \frac{D}{E} \\ \varepsilon_r &= \varepsilon_r' - j.\varepsilon_r'' = \left|\varepsilon_r\right| . e^{-j\delta} = \varepsilon_r' + \frac{\sigma}{j\omega\varepsilon_0} \end{aligned} \tag{4.7}$$

where

ε_r	is t the complex relative permittivity
ε'	is t the real part of the relative permittivity
ε''	is t the negative imaginary part of the relative permittivity
δ	is the angle using Euler´s notation of the complex relative permittivity
σ	is the conductivity

The permittivity is expressed in units of farads per metre (F/m)

4.1.25
phantom
in this context a phantom is 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

4.1.26
reference SAR distributions
the reference SAR distributions are derived from calculations of a set of configurations representative of the use of mobile phones. They shall be used for evaluation of uncertainties due to post-processing and mismatching of probe and phantom references

4.1.27
response time
the response time is the time required by the measuring equipment to reach 90 % of its final value after a step variation of the exposure signal

4.1.28
scanning system
the scanning system is the automatic positioning system capable of placing the measurement probe at the specified positions

4.1.29
sensitivity
the sensitivity of the measurement system is the ratio of the magnitude of its response (i.e. voltage) to the magnitude of the quantity measured (i.e. electric field square)

4.1.30
skin depth
the skin depth is defined as 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 boundary values. Skin depth is expressed in meters (m)

4.1.31
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)

$$SAR = \frac{d}{dt}\left(\frac{dW}{dm}\right) = \frac{d}{dt}\left(\frac{dW}{\rho dV}\right) \tag{4.8}$$

SAR is expressed in units of watts per kilogram (W/kg)

NOTE SAR can be calculated by:

$$SAR = \frac{\sigma E_i^{\,2}}{\rho} \tag{4.9}$$

$$SAR = c_i \left.\frac{dT}{dt}\right|_{t=0} \tag{4.10}$$

where

E_i: rms value of the electric field strength in the tissue in V/m

σ: conductivity of body tissue in S/m

ρ: density of body tissue in kg/m^3

c_i: heat capacity of body tissue in J/kg K

$\left.\frac{dT}{dt}\right|_{t=0}$ initial time derivative of temperature in body tissue in K/s

4.1.32
wavelength (λ)
the wavelength (λ) of an electromagnetic wave is related to the frequency (*f*) and speed of light (*c*) by the expression $c = f\ \lambda$. In free space the velocity of an electromagnetic wave is equal to the speed of light

5 Measurement system specifications

The measurement system is composed of the phantom, the SAR measurement equipment, the scanning system and the mobile phone holder.

5.1 General requirements

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 EM fields produced by mobile phones. From the measured E-field values, the SAR distribution and the maximum mass averaged 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 15 °C to 30 °C and the variation shall not exceed ± 2 °C during the test;

- the mobile phone shall not interact with the local mobile networks;
- care shall be taken to avoid significant influence on SAR measurements by ambient EM sources;
- care shall be taken to avoid significant influence on SAR measurements by any reflection from the environment (such as floor, positioner, etc.).

Validation of the system shall be done at least once a year according to the protocol defined in annex D.

5.2 Phantom specifications (shell and liquid)

5.2.1 General requirements

The physical characteristics of the phantom model (size and shape) shall resemble the head and neck of a user since the shape is a dominant parameter for exposure. The phantom shall be made from material with dielectric properties similar to those of head tissues. To enable field scanning within it, the material shall be liquid contained in a head and neck shaped shell model. The shell model acts as a shaped container and shall be as unobtrusive as possible. The hand shall not be modelled (see annex A).

5.2.2 Phantom shape and size

The phantom shape is based on the size and dimensions of the 90 percentile large adult male reported in a 1989 anthropomorphic study and has been adapted to represent the flattened ear of a mobile phone user (see annex A). A physical representation of these requirements is shown in Figure 1.a and Figure 1.b.

Figure 1.a

Figure 1.b

Figure 1 - Picture of the phantom

The Specific Anthropomorphic Mannequin (SAM) shall be used for SAR measurements. CAD files of the inner surface (*SAM_in*) and outer surface (*SAM_out*) of the reference phantom used in this standard are publicly available in 3D-CAD formats including 3D-IGES and DXF on CD-ROM.

5.2.3 Phantom shell

The shell of the phantom shall be made of low loss and low permittivity material: $tan(\delta) \leq 0,05$ and $\varepsilon \leq 5$. The thickness of the phantom is defined in the CAD files and the tolerance shall be $\pm$ 0,2 mm in the area defined in the CAD files (where the phone touches the head).

Reference points on the phantom:

The probe positioning shall be defined in relation to three well defined points on the phantom. These points R1, R2 and R3 shall be used to calibrate the positioning system. Three other points, M for mouth, LE for left ear and/or RE for right ear (maximum acoustic coupling), shall be defined on the phantom(s) (see Figure 2). These points shall be used to allow reproducible positioning of the mobile phone in relation to the phantom.

These points are specified in the CAD files.

5.2.4 Liquid material properties

The dielectric properties of the liquid material required to fill the phantom shell shall be:

$$\varepsilon_r = 46{,}52 - 0{,}006\ f(\mathrm{MHz}) + 1{,}59\mathrm{x}10^{-6}\ f(\mathrm{MHz})^2 - 1{,}40\mathrm{x}10^{-10}\ f(\mathrm{MHz})^3 \qquad (5.1)$$

$$\sigma\ (\mathrm{S/m}) = 0{,}805\,4 + 0{,}000\,15\ f(\mathrm{MHz}) + 4{,}12\mathrm{x}10^{-8}\ f(\mathrm{MHz})^2 + 2{,}87\mathrm{x}10^{-11}\ f(\mathrm{MHz})^3 \qquad (5.2)$$

Table 1 - Dielectric properties of the liquid material

Frequency (MHz)	ε_r	σ (S/m)
300	45	0,85
450	44	0,88
900	42	0,99
1 450	41	1,20
1 800	40	1,38
2 450	39	1,84
3 000	39	2,40

The measured dielectric properties of the liquid shall be used in SAR calculations rather than the theoretical values defined in Equation 5.1 and Equation 5.2 and shown in Table 1. Examples of recipes for liquids defined in Table 1 used at mobile communication frequencies are proposed in annex A.

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 the 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 defined in annex B.

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 ± 0,5 dB over the SAR range from 0,02 to 100 W/kg. The isotropy shall be within ± 1 dB. Sensitivity, linearity and isotropy shall be determined in the tissue equivalent liquid. The response time shall be specified.

In order to meet these requirements, it is recommended that the length of the individual sensing elements in the E-field probe shall not exceed 5 mm and that the outside dimension of the protective cover shall not exceed 8 mm.

If the measured signal is a pulsed signal, e.g., a TDMA frame, the integration and averaging time of the SAR measurement equipment (based on rms-detection) shall be able to yield results reproducible to within ± 5 %.

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.

5.4.2 Technical requirements

Accuracy:

The accuracy of the probe tip positioning over the measurement area shall be less than ± 0,2 mm.

Sampling resolution:

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

5.5 Mobile phone holder specifications

The mobile phone holder shall permit the phone to be positioned according to the definitions given in 6.1.4 with a tolerance of ± 1° in the tilt angle. It shall be made of low loss and low permittivity material(s): $\tan(\delta) \leq 0{,}05$ and $\varepsilon_r \leq 5$.

5.6 Other equipment

5.6.1 Measurement of liquid dielectric properties

The dielectric properties of the tissue equivalent liquid shall be measured at the relevant frequency and temperature. This measurement can be performed using the equipment and procedure described in annex A.

6 Protocol for SAR assessment

6.1 Measurement preparation

6.1.1 General preparation

The dielectric properties of the tissue equivalent materials shall be measured prior to the SAR measurements and at the same temperature with a tolerance of ± 2° C. The measured values shall comply with the values defined at the specific frequencies in 5.2.4. with a tolerance of ± 5 % for relative permittivity and conductivity. The measurement procedures are described in annex A.

The phantom shell shall be filled with the tissue equivalent liquid. The depth of the tissue equivalent liquid inside the phantom and at the vertical position of the ear canal shall be at least 15 cm. The liquid shall be carefully stirred before the measurement and it shall be free of air bubbles.

The coordinate system of the scanning system shall be aligned to the coordinate system of the phantom with a tolerance of ± 0,2 mm.

6.1.2 Simplified performance checking

A simplified performance check and a noise level check according to 7.2.1.7 shall be made before the measurements if any of the above parameters are changed.

The purpose of the simplified performance check is to verify that the system operates within its specifications. The simplified performance check is a simple test of repeatability to make sure that the system works correctly during the compliance test. The simplified performance check shall be performed in order to detect possible drift over short time periods and other errors in the system, such as:

- changes in the liquid parameters, e.g., due to water evaporation or temperature change,
- component failures,
- component drift,
- operator errors in the set-up or the software parameters,
- adverse conditions in the system, e.g., RF interference.

The simplified performance check shall be carried out according to annex D. It shall be a measurement of the 10 g averaged SAR using a simplified set-up with a dipole source. The components and procedures in the simplified performance check are the same as those used for the compliance tests. The simplified performance check shall be performed prior to compliance tests and the result shall be within ± 10 % of the target value. The target value shall be determined in the system itself, e.g., after the system validation check. The simplified performance check shall be performed at a central frequency of each transmitting band of the mobile phone.

6.1.3 Preparation of the mobile phone under test

The tested mobile phone 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 and there shall be no external connections.

The output power and frequency (channel) shall be controlled using an internal test program or by the use of appropriate test equipment (base station simulator). The mobile phone shall be set to transmit at its highest output peak power level allowed by the system. If a wireless link is used, an antenna shall be connected to the output of the base station emulator. The antenna shall be placed at least 50 cm from the phone. The signal emitted by the emulator at antenna feed point shall be lower than the output level of the phone by at least 30 dB.

6.1.4 Position of the mobile phone in relation to the phantom

The mobile phone shall be tested in the “cheek” and “tilted” positions on left and right sides of the phantom.

Definition of the “cheek” position:

a) position the device with the vertical centre line of the body of the device and the horizontal line crossing the centre of the ear piece in a plane parallel to the sagittal plane of the phantom ("initial position" see Figure 2). While maintaining the device in this plane, align the vertical centre line with the reference plane containing the three ear and mouth reference points (M, RE and LE) and align the centre of the ear piece with the line RE-LE;

b) translate the mobile phone box towards the phantom with the ear piece aligned with the line LE-RE until the phone touches the ear. While maintaining the device in the reference plane and maintaining the phone contact with the ear, move the bottom of the box until any point on the front side is in contact with the cheek of the phantom or until contact with the ear is lost.

Definition of the "tilted" position:

a) position the device in the "cheek" position described above;

b) while maintaining the device in the reference plane described above and pivoting against the ear, move it outward away from the mouth by an angle of 15 degrees or until contact with the ear is lost.

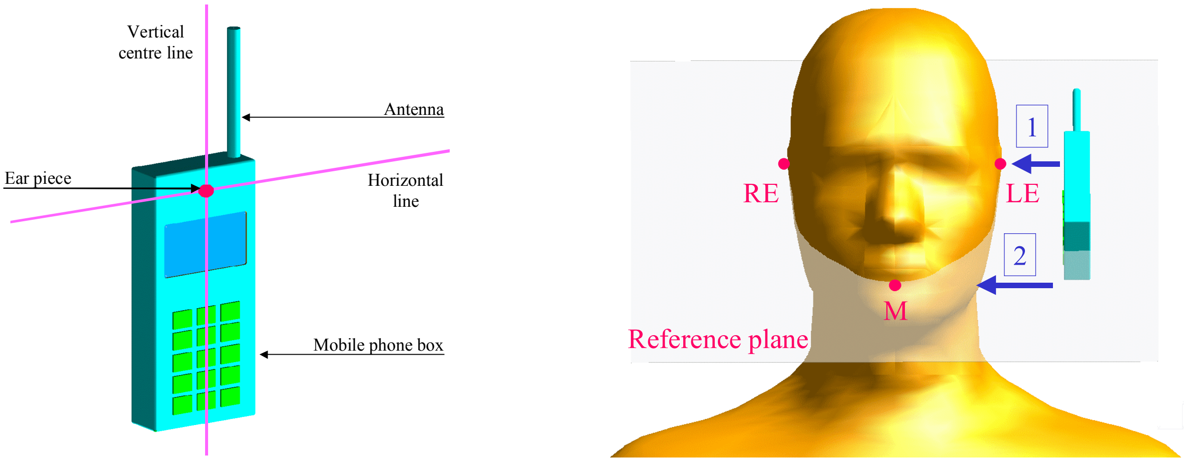


Figure 2 - Definition of the reference lines and points, on the phone and on the phantom and initial position

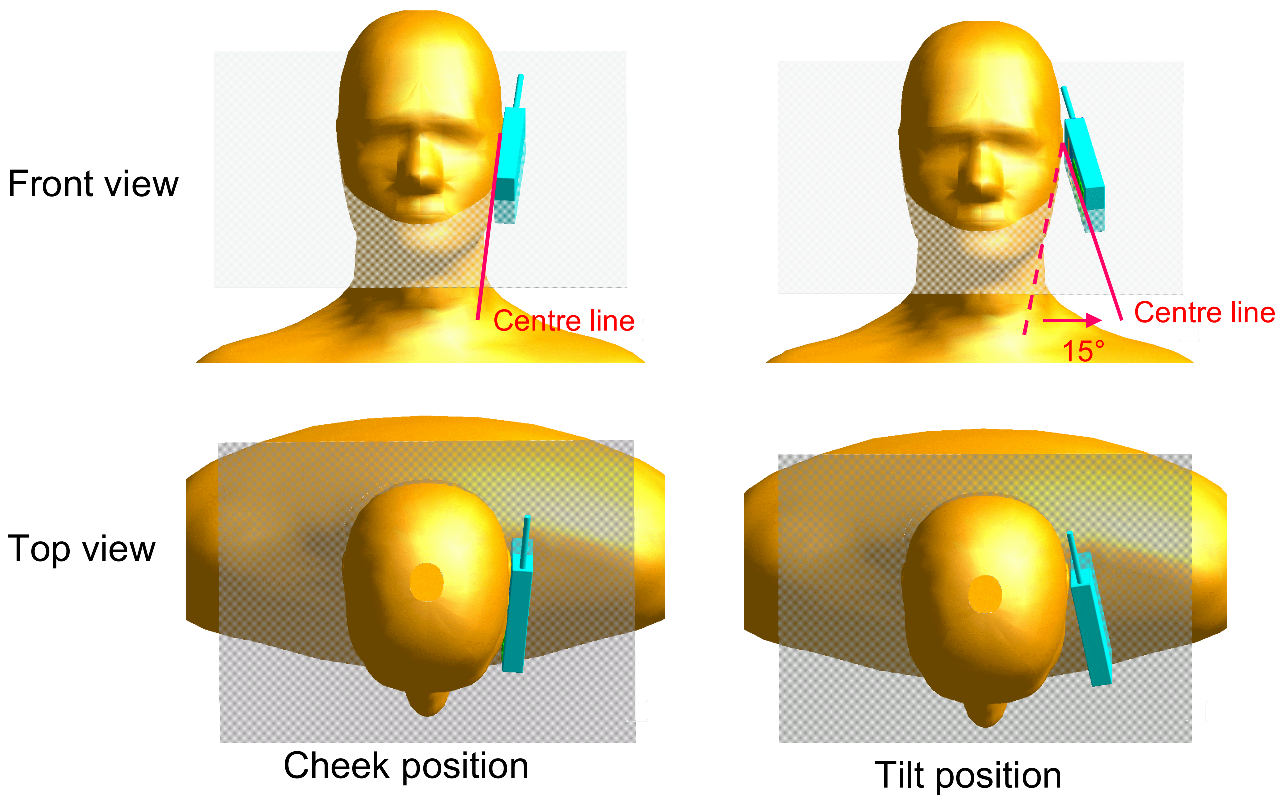


Figure 3 - "Cheek" and "tilt" positions of the mobile phone on the left side

6.2 Tests to be performed

Tests shall be performed with both phone positions described in 6.1.4., on the left and right sides of the head and using the centre frequency of each operating band. Then the configuration giving rise to the maximum mass-averaged SAR shall be used to test the low-end and the high-end frequencies of the transmitting band. If the mobile phone has a retractable antenna, all of the tests described above shall be performed both with the antenna extended and with it retracted. When considering multi-mode and multi-band mobile phones, all of the above tests shall be performed in each transmitting mode/band with the corresponding maximum peak power level.

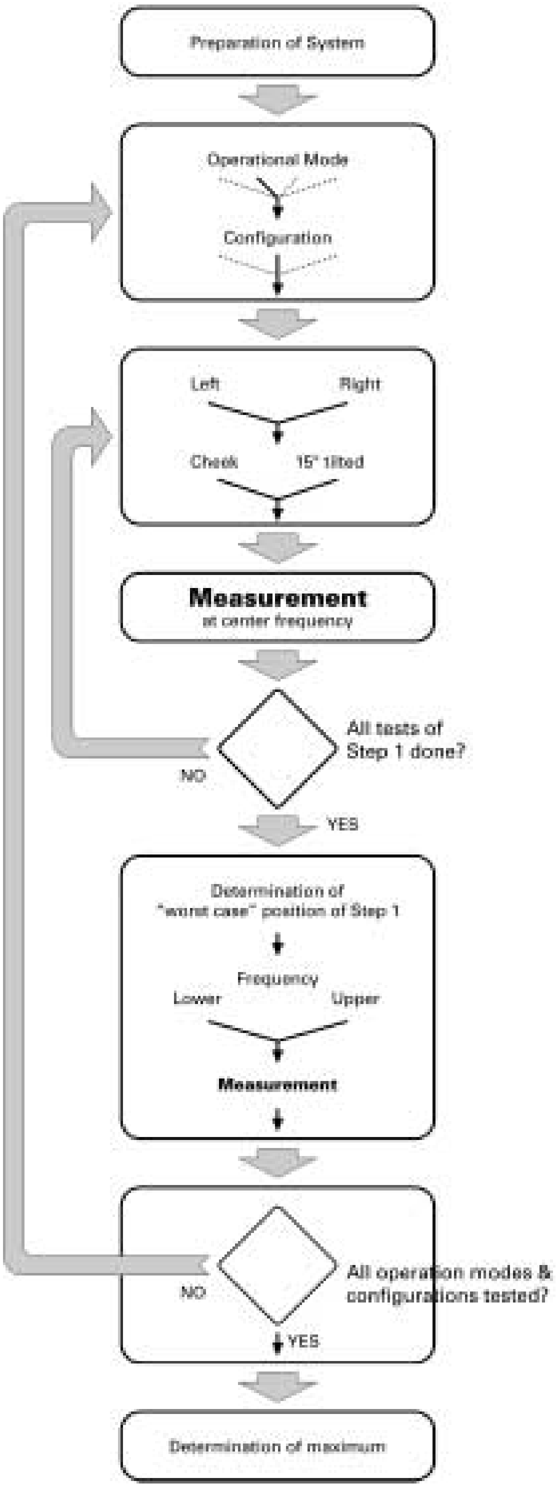


Figure 4 - Block diagram of the tests to be performed

6.3 Measurement procedure

The following procedure shall be performed for each of the test conditions described in 6.2:

a) measure the local SAR at a test point within 10 mm of the inner surface of the phantom. The test point shall also be close to the ear;

b) verify that the measured SAR at the point used in item 1 is stable after 3 minutes within ± 5 % in order to ensure that there is no drift due to the mobile phone electronics;

c) measure the SAR distribution within the phantom. The spatial grid step shall be less than 20 mm. If surface scanning is used, then the distance between the geometrical centre of the probe detectors and the inner surface of the phantom shall be constant within ± 0,5 mm and less than 8 mm. If volume scanning is performed, then the scanning volume shall be as close as possible to the inner surface of the phantom (less than 8 mm), the grid step shall be 5 mm or less, the grid shall extend to a depth of 25 mm and then go directly to item 6;

d) 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 of more than 50 % of the maximum value;

e) measure SAR with a grid step less than 5 mm in a volume with a minimum size of 30 mm by 30 mm and 25 mm in depth. Separate grids shall be centred on each of the local SAR maxima;

f) use interpolation and extrapolation procedures defined in annex C to determine the local SAR values at the spatial resolution needed for mass averaging;

g) repeat the SAR measurement at the initial test point used in item 1. If the two results differ by more than ± 5 % from the final value obtained in item 2, the measurements shall be repeated with a fully charged battery or the actual drift shall be included in the uncertainty evaluation.

6.4 Post-processing

6.4.1 Interpolation

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

6.4.2 Extrapolation

The electric field probes used generally contain three orthogonal dipoles in close proximity and these dipoles are embedded in a protective tube. The measurement point is situated a few millimetres from the tip of the probe and this offset should be taken account of when identifying the position of the measured SAR. Examples of extrapolation schemes are given in annex C.

6.4.3 Definition of averaging volume

The averaging volume shall be in the shape of a cube and the side dimension of a 10 g mass would depend on the density of the liquid representing the tissues. A density of 1 000 kg/m^3 shall be used to represent the head tissue density and not the phantom liquid density, in order to be consistent with the definition of the liquid dielectric properties.

If the cube intersects the surface of the phantom, it shall be oriented so that 3 vertices touch the surface of the shell or the centre of a face is at a tangent to the surface. 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 cubic volume are given in annex C. Descriptions of methods for the estimation of SAR averaged over the volume previously defined are given in annex C.

6.4.4 Searching for the maxima

The cubic volumes shall be moved on the inner surface of the phantom, in the vicinity of the local maximum SAR, according to the rules given in annex C.

The cube with the highest local maximum SAR shall not be at the edge of the scanning volume. If this is found to be the case, the scanning volume shall be shifted and the measurements shall be repeated.

7 Uncertainty assessment

7.1 General requirements

The assessment of uncertainty in the measurement of the SAR values produced by mobile phones shall be based on the general rules provided by the IEC “Guide to the expression of uncertainty in measurement”, Ed. 1, 1995.

Type A as well as *Type B* evaluation of the standard uncertainty shall be used.

When a *Type A* analysis is performed, the standard uncertainty u_i shall be derived from the estimate from statistical observations. When *Type B* analysis is performed, u_i comes from the upper a_+ and lower a_- limits of the quantity in question, depending on the distribution law defining $a = (a_+ - a_-)/2$, then:

- Rectangular law: $u_i = a/\sqrt{3}$
- Triangular law: $u_i = a/\sqrt{6}$
- Normal law: $u_i = a/k$ where k is a coverage factor
- U-shaped (asymmetric): $u_i = a/\sqrt{2}$

7.2 Components contributing to uncertainty

7.2.1 Contribution of the measurement system

7.2.1.1 Calibration of the measurement equipment

A protocol for the evaluation of sensitivity (or calibration) is given in annex B including an approach to uncertainty assessment. The uncertainty in the sensitivity shall be evaluated with assuming a normal probability distribution.

7.2.1.2 Probe isotropy

The isotropy of the probe shall be measured according to the protocol defined in annex B. The uncertainty due to isotropy shall be evaluated with a rectangular probability distribution.

$$Total\ Isotropy\ Error = \sqrt{(1-c_i).[Axial\ isotropy]^2 + c_i.[Hemispherical\ isotropy]^2}$$

If the probe orientation is essentially normal to the surface (within ± 30°) during the measurement, then c_i = 0,5 otherwise c_i = 1.

7.2.1.3 Probe linearity

The probe linearity shall be assessed according to the protocol defined in annex B. A correction shall then be performed to establish linearity. The uncertainty is considered after this correction. The uncertainty due to linearity shall be evaluated assuming it has a rectangular probability distribution.

7.2.1.4 Detection limits

Detection limits shall be evaluated according to the protocol defined in annex B. Errors may be introduced if local measurements are outside these limits. If a measurement is below the lower detection limit, then the value of the detection limit shall be used. If the measurement is higher than the upper detection limit then the measurement shall be considered invalid.

The uncertainty due to the detection limits shall be assessed for the range 0,4 W/kg and 10 W/kg assuming a maximal duty factor of 0,1. Specific uncertainty estimation shall be made if local SAR measurements are found to be outside this range and smaller duty factors. The uncertainty due to detection limits shall be evaluated assuming it has a rectangular probability distribution.

7.2.1.5 Boundary effect

7.2.1.5.1 Definition

Measurements made with probes of finite dimensions in close vicinity to media interfaces result in errors due to boundary effects (see annex B). These effects depend on the probe size and can be quantified as a function of the distance from the surface using the wave guide calibration set-up or plane wave exposure (see annex B). Having been quantified, the effects can be compensated for in order to minimise any errors introduced.

7.2.1.5.2 Evaluation

Assuming a linear model and minimal skin depth, as would represent the worst-case, the maximum error in the integration arising from this effect can be determined as:

$$\text{Error [\%]} = \text{[Uncertainty of the boundary effect at } d_{be} \text{ in \%]} \frac{d_{be} + d_{step}}{sd/2}$$

where

d_{be} is the distance between the surface and the closest measurement point used for the cube averaging process

d_{step} is the separation between the first and second closest points, assuming that the boundary effect at that location is negligible

sd is the minimum skin depth, i.e., sd = 14 mm at 3 GHz.

If the uncertainty of the boundary effect compensation cannot be determined, then the boundary effect shall be used in the above formula.

7.2.1.6 Measurement device

The uncertainty contributed by the measurement device, e.g., voltmeter, shall be assessed with reference to its calibration certificates. The uncertainty due to the measurement device shall be evaluated assuming a normal probability distribution.

7.2.1.7 Response time

Response time shall be evaluated according to the protocol defined in annex B. The uncertainty arising from the response time shall be neglected if the probe is stationary for a time period greater than twice the response time before the measured SAR is logged.

7.2.1.8 Noise

7.2.1.8.1 Definition

This is the signal detected by the measurement system even if the phone is not transmitting. The sources of these signals include RF noise, ELF noise (lighting systems, the scanning system, grounding of the laboratory power supply, etc.), electrostatic effects (movement of the probe, people walking, etc.) and other effects (light detecting effects, temperature, etc.)

7.2.1.8.2 Evaluation

The noise level shall be determined by three different coarse scans with the RF source switched off. None of the evaluated points shall exceed 0,02 W/kg. This test shall be repeated periodically (preferably every second month). Within this constraint, the uncertainty due to noise shall be neglected.

7.2.1.9 Integration time

The integration time may introduce additional error if the mobile phone is not emitting a continuous wave (CW) signal. This uncertainty depends on the signal characteristics and must be evaluated prior to any SAR measurements. If a non-CW signal is used, then the uncertainty introduced must be taken into account in the global uncertainty assessment. The uncertainty due to integration time shall be evaluated assuming it has a rectangular probability distribution.

Example of evaluation for a GSM signal :

For an integration time of t_{int}, if 2 pulses are missed, this induces the following uncertainty:

$$u = 2.\frac{4,6x10^{-3}}{t_{\text{int}}}$$

7.2.2 Contribution of mechanical constraints

7.2.2.1 Scanning system

The mechanical constraints of the scanning system introduce uncertainty to the SAR measurements through the accuracy and repeatability of positioning. These parameters shall be assessed with reference to the scanning system's specifications. The uncertainty contribution d_{ss} to the averaged SAR value (rectangular distribution) is then calculated based on the minimum skin depth *sd*, i.e., *sd* = 14 mm at 3 GHz and first-order approximation:

$$\text{Error SAR [\%]} = 100\frac{d_{ss}}{sd/2}$$

7.2.2.2 Phantom shell

The shape and the thickness of the phantom shell shall be specified. The uncertainty contribution d_{ph} to the averaged SAR value (rectangular distribution) is then calculated based on the minimum skin depth *sd*, i.e., *sd* = 14 mm at 3 GHz and first-order approximation:

$$\text{Error SAR [\%]} = 100\frac{d_{ph}}{sd/2}$$

7.2.2.3 Matching between probe and phantom references

Before each scan the alignment between position of the probe and the phantom shall be verified using the three reference points R1, R2 and R3 described in 5.2.3. The uncertainty is calculated by the maximum mis-alignment at all three points d_{mis} and the uncertainty contribution to the averaged SAR value (rectangular distribution) is then calculated based on the minimum skin depth *sd*, i.e., *sd* = 14 mm at 3 GHz and first-order approximation:

$$\text{Error SAR [\%]} = 100\frac{d_{mis}}{sd/2}$$

7.2.2.4 Positioning of the phone

7.2.2.4.1 Definition

This is the uncertainty in the spatial peak SAR that occurs as a result of uncertainty in the positioning of the phone with respect to the phantom. It only depends on the positioner and can be determined from the positioner specification.

7.2.2.4.2 Evaluation

Three devices that provide significantly different SAR distributions shall be used for this test. The tests shall be conducted on the left head side for both positions. Three people shall perform 4 evaluations of spatial peak SAR each at both positions whereby the device shall be de-mounted and newly positioned before each tests. A statistical analysis shall be provided for each device at each position (i.e., at least 12 tests at each position for each device). The mobile phone positioning uncertainty is the largest standard deviation determined by this evaluation. The uncertainty due to the phone positioning shall be evaluated assuming it has a normal probability distribution.

7.2.3 Contribution of physical parameters

7.2.3.1 Liquid density

The electromagnetic parameters of the tissue equivalent liquids have been evaluated assuming they have a density of 1 000 kg/m^3. This density shall be used for SAR evaluation and the uncertainty introduced by the assumption shall be considered negligible.

7.2.3.2 Liquid conductivity

The uncertainty due to the liquid conductivity arises from two different sources. The first source of error is the deviation of the liquid conductivity from its target value (max. ± 5 %) and the second source of error arises from the measurement procedures used to assess conductivity. The uncertainty shall be assessed using a rectangular probability For 10 g averaging, the maximum weighting coefficient for SAR is 0,5.

7.2.3.3 Liquid permittivity

The uncertainty due to the liquid permittivity arises from two different sources. The first source of error is the deviation of the liquid conductivity from its target value (max. ± 5 %) and the second source of error arises from the measurement procedures used to assess permittivity. The uncertainty shall be assessed using a rectangular probability. For 10 g averaging, the maximum weighting coefficient for SAR is 0,5.

7.2.3.4 Drifts in output power of the phone, probe, temperature and humidity

The drifts due to the electronics of the phone and the measurement equipment, as well as temperature and humidity, are controlled by the first and last step of the measurement process defined in 6.3 and the resulting error is less than ± 5 %. The uncertainty shall be evaluated assuming a rectangular probability distribution.

7.2.3.5 Perturbation of the environment

The perturbation of the environment results from various contributing factors:

- reflection of waves in the laboratory,
- influence of the EM properties of the phantom shell and the mobile phone holder,
- background level of EM fields.

The error is usually of ± 3 % and the uncertainty shall be evaluated assuming a rectangular probability distribution.

7.2.4 Contribution of post-processing

This is the uncertainty caused by the implemented extrapolation, integration and averaging procedure assuming the local SAR are accurately measured at their correct positions.

7.2.4.1 Extrapolation and interpolation algorithms

The uncertainty due to the extrapolation and interpolation algorithms shall be evaluated assuming a rectangular probability distribution. The relative uncertainty is evaluated using the following formula (see annex C):

$$U_{extra/\mathrm{int}erpol}\% \quad = 100.\frac{\left|SAR_{extrap/\mathrm{int}erp} - SAR_{ref}\right|}{SAR_{ref}}$$

Four sets of 3D reference data, publicly available on CD-ROM, shall be used. These data sets represent the SAR, estimated by numerical methods, induced by two numerical models of mobile phone next to the phantom and two analytical functions (see annex C).

Using these data sets, the « unknown data » have to be calculated using the « known data » with the interpolation and extrapolation process. In this way, the estimated SAR averaged over 10 g in a given cube shall be compared to the target value given by the reference data.

7.2.4.2 Maximum SAR evaluation

The uncertainty due to these shall be evaluated assuming a rectangular probability distribution. The relative uncertainty shall be evaluated using the following formula (see annex C):

$$U_{\max finding}\% \quad = 100.\frac{SAR_{\max estimated} - SAR_{\max ref}}{SAR_{\max ref}}$$

Four sets of 3D reference data, publicly available on CD-ROM, shall be used. These data sets represent the SAR induced by two numerical models of mobile phone next to the phantom and two analytical functions (see annex C).

The reference data sets include target values for their maximum mass averaged SAR and these shall be compared with the maximum mass averaged SAR yielded by the averaging and maximum finding schemes under evaluation.

7.3 Uncertainty assessment

7.3.1 Combined and expanded uncertainties

The contributions of each component of uncertainty shall be registered with their name, probability distribution, sensitivity coefficient and uncertainty value. The results shall be recorded in a table of the following form (see Table 2). The combined uncertainty shall then be evaluated according to the following formula:

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

where c_i is the weighting coefficient.

The expanded uncertainty shall be evaluated using a confidence interval of 95 %.

Table 2

ERROR SOURCES	Description (subclause)	Uncertainty value (%)	Probability distribution	Divisor	c_i	Standard uncertainty (%)
Measurement equipment						
Calibration	7.2.1		Normal	1 or k	1	
Isotropy	7.2.1		Rectangular	$\sqrt{3}$	1	
Linearity	7.2.1		Rectangular	$\sqrt{3}$	1	
Detection limits	7.2.1		Rectangular	$\sqrt{3}$	1	
Boundary effect	7.2.1		Rectangular	$\sqrt{3}$	1	
Measurement device	7.2.1		Normal	1 or k	1	
Response time	7.2.1		Normal	1	1	
Noise	7.2.1		Normal	1	1	
Integration time	7.2.1		Normal	1	1	
Mechanical constraints						
Scanning system	7.2.2		Rectangular	$\sqrt{3}$	1	
Phantom shell	7.2.2		Rectangular	$\sqrt{3}$	1	
Matching between probe and phantom	7.2.2		Rectangular	$\sqrt{3}$	1	
Positioning of the phone	7.2.2		Normal	1 or k	1	
Physical parameters						
Liquid conductivity (deviation from target)	7.2.3	5 %	Rectangular	$\sqrt{3}$	0,5	
Liquid conductivity (measurement error)	7.2.3		Rectangular	$\sqrt{3}$	0,5	
Liquid permittivity (deviation from target)	7.2.3	5 %	Rectangular	$\sqrt{3}$	0,5	
Liquid permittivity (measurement error)	7.2.3		Rectangular	$\sqrt{3}$	0,5	
Drifts in output power of the phone, probe, temperature and humidity	7.2.3	5 %	Rectangular	$\sqrt{3}$	1	
Perturbation by the environment	7.2.3	3 %	Rectangular	$\sqrt{3}$	1	
Post-processing						
SAR interpolation and extrapolation	7.2.4		Rectangular	$\sqrt{3}$	1	
Maximum SAR evaluation	7.2.4		Rectangular	$\sqrt{3}$	1	
Combined standard uncertainty			$u_c = \sqrt{\sum_{i=1}^{m} c_i^2 \cdot u_i^2}$			
Expanded uncertainty (confidence interval of 95 %)			**Normal**			$u_e = 1{,}96\ u_c$

7.3.2 Maximum expanded uncertainty

The expanded uncertainty with a confidence interval of 95 % shall not exceed 30 % for SAR values averaged over 10 g in the range from 0,4 to 10 W/kg.

8 Measurement report

8.1 General

The results of each test, calculation or measurement carried out shall be reported accurately, clearly, unambiguously and objectively, and in accordance with any specific instructions in the required method(s).

The results shall be recorded, usually in a test report, and shall include all the information necessary for the interpretation of the test or calibration results and all information required by the method used.

All of the information needed for performing repeatable tests, calculations, or measurements giving results within the required calibration and uncertainty limits shall be recorded, see 8.2.

Further guidelines on the test report can be found in 5.10 of ISO/IEC 17025.

8.2 Items to be recorded in the test report

8.2.1 General introduction

- Referring to EUT
- Requirements
- Standards used

8.2.2 Measurement system

- Measurement system
- Positioner
- Description of interpolation/extrapolation scheme

8.2.3 Uncertainty assessment

Report of Table 2 presented in 7.3.1.

8.2.4 Results

- Description of the device / Serial number, e.g., IMEI (International Mobile Equipment Identity)
- Testing condition (temperature, etc.)
- Liquid used and its characteristics
- Results of system validation check
- Results of each test performed (graphical representation of the coarse scan with respect to the phone and ear position and the spatial peak SAR value)

8.2.5 Statement about compliance

- SAR values over the testing positions, bands, modes and antenna configurations
- Reference to a basic restriction recommendation and a statement of compliance, or otherwise

Annex A
(informative)

Phantom specifications

A.1 Rationale for the phantom shape

Phantom-body-parts are essential components of electromagnetic dosimetry. While it is desirable that they emulate the anatomical details of the body part they represent, it is not always necessary or practical for them to do so. It is therefore important to define and standardise the relevant features, dimensions and material properties that affect SAR measurement.

The back ear protrusion has a direct effect on determining the closeness of the mobile phone and antenna to the head and is an important parameter for determining SAR. The shape of the ear is a factor in positioning the mobile phone and shall be designed to enable correct and reproducible positions.

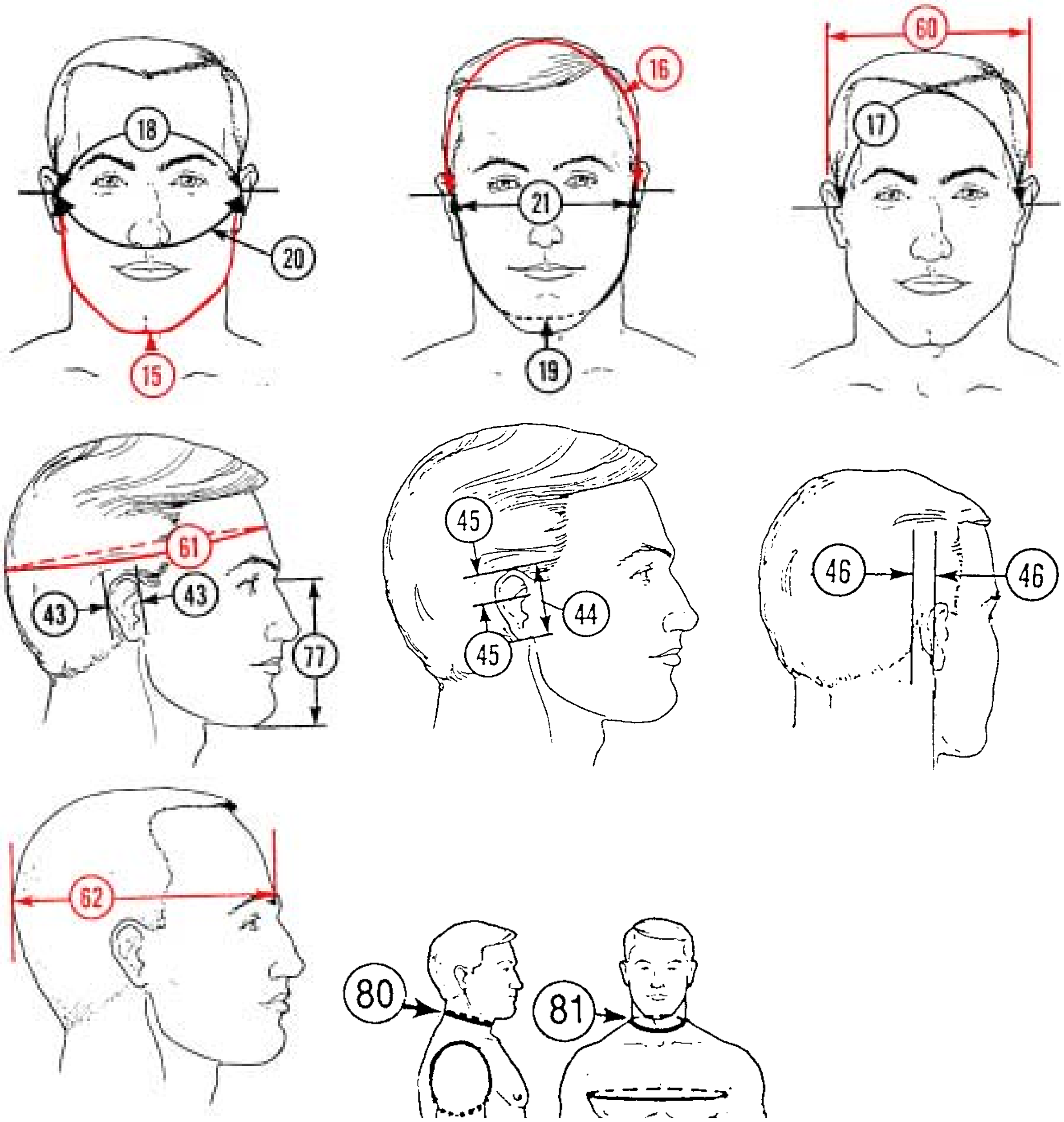
Dosimetric studies suggest that larger heads (adult, male user) couple more energy and constitute a worse case exposure scenario compared to smaller heads (women and children) [1].

The statistical breakdown of anatomical shapes and sizes can be obtained from anthropometric studies of human population to guide the specification of a realistic phantom shape. A 1988 anthropometric study of U.S. army personnel provides data based on a sample of mixed age, race, and ethnic identity [2]. The shape of the head is defined by a number of lines and curves as illustrated in Figure A.1.

The dimensions of relevance to mobile phone dosimetry are highlighted in Table A.1. A 90th percentile large (adult male) head dimension shall be used to ensure that well over 90 % of all users have smaller heads and would therefore sustain a lower exposure.

Table A.1 - Head dimensions relevant to phantom shape: large 90 percentile male head

	Anatomy	Mean	Std Dev	90th percentile
15	Bitragion Chin Arc	32,58	1,34	34,31
16	Bitragion Coronal Arc	35,33	1,29	36,97
17	Birtagion Crinion Arc	32,64	1,16	34,15
18	Bitragion Frontal Arc	30,43	1,06	31,82
19	Bitragion Submandibular Arc	30,42	1,45	32,32
20	Bitragion Subnasale Arc	29,20	1,11	30,63
21	Bizygomatic Breadth	14,05	0,56	14,78
43	Ear Breadth	3,77	0,27	4,11
44	Ear Length	6,47	0,43	7,03
45	Ear Length above Tragion	3,19	0,25	3,50
46	Ear Protrusion	2,42	0,36	2,88
60	Head Breadth	15,17	0,54	15,86
61	Head Circumference	56,77	1,54	58,73
62	Head Length	19,71	0,71	20,60
77	Menton-Sellion Length	12,19	0,65	13,04
80	Neck Circumference	37,96	1,97	40,53
81	Neck Circumference Base	40,84	2,05	43,49



NOTE Dimensions of Figure A.1 in cm.

Figure A.1 - Illustration of dimensions in Table A.1

The ear protrusion has been adjusted to simulate the pressure of the phone on the ear.

Considering a 10 g mass averaging, a 6 mm thick loss-less spacer including the 2 mm shell is considered to model the external ear (pinna).

With respect to modelling the hand, there are practical difficulties in specifying a unique hand holding position that is applicable to all mobile phones. Moreover, dosimetric studies suggest that not modelling the hand constitute a worse case scenario for SAR in the head [3]. For these reasons, in this standard the mobile phone is not held by a hand.

A.2 Tissue equivalent liquids

As a primary study, a simple analytical model of a half-space layered tissue model exposed to a plane wave was utilised to investigate the impact of impedance matching, standing waves, etc. on the spatial peak SAR. The tissue layers were varied in composition and thickness, representing the anatomical variation of the exposed head region covering the user group including adults and children (< 10 % > 90 % percentile). Based on the worst case tissue layer composition with respect to absorption at each frequency, head tissue equivalent dielectric parameters for homogeneous modelling were derived resulting in the same spatial peak absorption (see Table A.2). The validity of this approach for near field exposures was demonstrated by replacing the plane wave by half wave dipole and quarter wave monopole sources in the closest proximity of the layered structures, as well as by comparison with results based on MRI based non-homogeneous human head models of adults and children from the literature [4] [5].

Table A.2 - Dielectric properties of the equivalent liquid for a 10 g and 1 g averaging and corresponding harmonized value

Frequency (MHz)	ε_r	σ 1 g (S/m)	σ 10 g (S/m)	σ harmonised (S/m)
300	**45**	0,87	0,70	**0,85**
450	**44**	0,87	0,75	**0,88**
900	**42**	0,97	0,85	**0,99**
1 450	**41**	1,20	1,10	**1,20**
1 800	**40**	1,40	1,40	**1,38**
2 450	**39**	1,70	1,80	**1,84**
3 000	**39**	2,10	2,40	**2,40**

NOTE Harmonised values have been agreed on considering the highest sigma that would produce the highest SAR, in order to use the same liquid for a 1 g and a 10 g averaging, as defined in other exposure guidelines, and using a 3rd order polynomial interpolation function.

A.3 Preparation of tissue equivalent material

The following recipes are provided in percentage by weight.

300 MHz

saccharose	55,74 %
de-ionised water	37,24 %
NaCl salt	5,86 %
hydroxyethyl cellulose (HEC)	0,97 %
bactericide	0,19 %

900 MHz

1,2-propanediol	64,81 %
de-ionised water	34,40 %
NaCl salt	0,79 %

1 800 MHz – 1 900 MHz

2-(2-butoxyethoxy) ethanol	44,92 %	(or diethylene glycol monobutyl ether)
de-ionised water	54,90 %	
NaCl salt	0,18 %	

A.4 Measurement of the dielectric properties of liquids and uncertainty estimation

This subclause deals with measurement of the dielectric properties of tissue equivalent material as part of the SAR characterisation procedure.

A.4.1 Measurement techniques

The dielectric properties are experimentally determined by measuring the permittivity ε' and the conductivity σ. The dielectric parameters ε' and σ vary with temperature and frequency. The measurement of the dielectric properties of tissue equivalent materials can be carried out using one of several well-established techniques.

The following or equivalent instrumentation is required:

a) vector network analyser and S-parameter test set;

b) sample holder;

c) special methodology and application software to translate measurements to dielectric properties of the samples.

Two types of sample holders suitable for liquid materials are described

A.4.2 Slotted line

A terminated coaxial slotted line, provided with a moving probe can be used as sample holder. The network analyser provides the RF source at the input of the slotted line and enables the magnitude and phase of the signal transmitted in the sample to be recorded, through the moving probe, as a function position along the slotted line.

The special methodology should specify the network analyser calibration and settings for the required frequency range, the starting measurement position, step size along the slot and total number of subsequent measurements. The special software should interpret the measurements to yield the dielectric properties of the sample.

General precautions (prior to performing measurement) :

Ensure that the slotted line it is clean, inside and out, use compressed air if necessary.

Ensure that the probe is clean and undamaged.

Devise a procedure for filling the slotted line completely with liquid sample without trapping air bubbles. One way of achieving this is to use a large syringe fitted with a flexible tube. Trapped air can be easily removed prior to filling the line slowly with the tube at the bottom of the line.

Ensure that the scale graduation allows for the first measurement point accurately located and for the step-size required by the methodology.

Record the temperature of the sample and note that the dielectric properties are applicable at this temperature.

It is essential that the person carrying out the testing is acquainted with the nature of the measurement and what to expect at each stage. It is a good practice to measure a reference liquid prior to measuring the sample to ensure that the set-up is operational.

Advantage :

High accuracy (± 2 %) is achievable provided the experimental procedure is sufficiently rigorous.

Disadvantage :

Sample handling intricate.

No commercially available methodology and software package.

A.4.3 Contact probe

Contact probes are open-ended transmission line sections terminated by an impedance matched loss-less window and a ground plane. Measurements are made by placing a probe in contact with a sample and measuring its reflection coefficient using a network analyser or equivalent instrumentation. Liquid samples are placed in an appropriate size non-metallic container.

Special methodology and software specify the probe dimensions, sample volume, network analyser calibration and settings for the required frequency range and interpret the measurements to yield the dielectric properties of the sample as a function of frequency.

To use this technique, acquire a probe/software package for your network analyser, follow the procedure to obtain the dielectric properties of the sample.

General precautions (prior to performing measurement) :

Ensure that the probe is clean and undamaged.

Ensure that there are no air bubbles trapped under the probe. If a glass container is used, visual inspection is sufficient.

Record the temperature of the sample and note that the dielectric properties are applicable at this temperature.

It is essential that the person carrying out the testing t be acquainted with the nature of the measurement and what to expect at each stage. It is good practice to measure a reference liquid (other than that used in he system calibration) prior to measuring the sample to ensure that the set-up is operational.

Advantages :

Minimal sample handling

Sample temperature regulation possible

High accuracy (it is ± 3 % in ε' and ± 8 % in σ) is achievable provided the theoretical implementation and experimental procedure are sufficiently rigorous.

Packages comprising probe and software are commercially available with network analysers.

Disadvantage :

Calibration and measurement procedures are not independent of each other.

At least one reference liquid of known dielectric properties is required for the purpose of calibration. To avoid this becoming a source of systematic error, the choice of reference liquid should be confined to de-ionised water at a well-defined temperature.

A.4.4 TEM-line

The method is based on the measurement of complex transmission coefficient of a TEM-line filed with the liquid. Transmission measurement is done using VNA, recording the magnitude and phase of scattering coefficient S_{21}. The complex permittivity of the liquid is calculated from the magnitude and phase of S_{21} by numerical solution of the equation of transmission coefficient derived by signal flow graph technique.

$$S_{21} = \frac{\left(1-\Gamma^2\right)\exp\left(-\mathrm{j}kd\right)}{1\text{-}\Gamma^2\exp\left(-\mathrm{j}2kd\right)},$$

$$\Gamma = \frac{1-\sqrt{\varepsilon_r}}{1+\sqrt{\varepsilon_r}},$$

$$k = \frac{2\pi f}{c_0}\sqrt{\varepsilon_r},$$

where Γ is the reflection coefficient at liquid surfaces, k the propagation factor in the liquid, d the length of the sample, f the frequency and εr = εr´–jεr´´ the relative complex permittivity of the sample.

The transmission sensor is a strip-line consisting of a circular centre conductor, two planar ground conductors, one transparent plastic wall and a temperature sensor. The length d is adjusted for certain frequency range so that (1) the effect of multiple reflections inside the sensor is small, and (2) the total attenuation of the sensor does not exceed the dynamic range of VNA. The dimensions of the centre and ground conductors D, b are chosen so that (1) the impedance of empty sensor is 50 Ω, and (2) the structure does not support spurious wave modes at the desired measurement frequency range.

Advantages :

- high accuracy (95 % confidence level, $U(\varepsilon) = \pm 1{,}4\ \%$ and $U(\sigma) = \pm 2{,}0\ \%$),
- the method has proven to be less sensitive to the uncertainty of VNA measurements than the conventional methods discussed above,
- the measurement can be automated and performed over a wide frequency range,
- the structure is open such that the liquid is completely visible after insertion in the sensor, and the bubbles can be totally removed,
- the structure is simple and easy to manufacture,
- the measurement volume/sample volume ratio is large,
- cut-off frequency of wave-guide modes is high, and temperature of the liquid can be continuously monitored during the measurement.

Disadvantage :

No commercially available methodology and software package.

The proposed rationale for the calculation of the liquid parameters is as follows:

As a primary study, a simple analytical model of an half-space layered tissue model exposed to a plane wave was utilised to investigate the impact of impedance matching. standing waves, etc. on the spatial peak SAR. The tissue layers were varied in composition and thickness, representing the anatomical variation of the exposed head region covering the user group including adults and children (< 10 %, > 90 % percentile). Based on the worst case tissue layer composition with respect to absorption at each frequency, head tissue equivalent dielectric parameters for homogeneous modelling were derived resulting in the same spatial peak absorption. The validity of this approach for near field exposures was demonstrated by replacing the plane wave by half wave dipole and quarter wave monopole sources in the closest proximity of the layered structures, as well as by comparison with results based on MRI based non-homogeneous human head models of adults and children from the literature.

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[1] Schönborg p76

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[3] Kuster et al., 1997

[4] Drossos et al, *The Dependence of Electromagnetic Energy Absorption Upon Human Head Tissue Composition in the Frequency Range of 300 - 3000 MHz*, accepted for publication in the special issue of IEEE MTT, Nov. 2000.

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Annex B
(informative)

Calibration of the measurement equipment (linearity, isotropy, sensitivity) and uncertainty assessment

B.1 Introduction

The measurement equipment is composed of the probe, amplifiers and the measurement device. Currently available probes are based on Schottky diode detectors. The measured signal, the output of the probe, is a voltage proportional to E or E^2 depending on the level of RF exposure.

Most isotropic probes consist of three small sensors with orthogonal directivity patterns and detector diodes in the sensor gap. The total electrical field can then be evaluated as the root sum square of the three E-field components. In the square-law region of the diode characteristic, the sensor output voltage is proportional to the mean square of the corresponding field component. Beyond that range the output voltage is compressed and therefore requires linearisation of the dynamic range. Manufacturing tolerances between the sensors and diodes will produce different sensitivities for each sensor.

The total field shall be evaluated according to:

$$|E|^2 = \sum_{i=1}^{3} |E_i|^2 = \sum_{i=1}^{3} \frac{V_i}{K_i}$$

where K_i is the absolute sensitivity of the dipole sensors in the media.

B.2 Assessment of the sensitivity of the dipole sensors

The sensitivity factors can be determined by either applying “two step” procedures or by using a “single step” procedure.

B.2.1 Two step procedures

The total field shall be evaluated according to:

$$|E|^2 = \sum_{i=1}^{3} |E_i|^2 = \sum_{i=1}^{3} \frac{f_i(V_i)}{\eta_i \gamma_i}$$

where $f_i(V_i)$ is the linearisation function of the rectified sensor signal V_i, η_i absolute sensitivities of the dipole sensors [μ V/(V/m)^2] in free space and γ_i the ratio of the sensitivity of the probe sensors in media to their sensitivity in free space.

The separation of the probe sensitivity in two factors (η_i and γ_i) allows partial use of the standardised procedures and provides additional validation of the probe performance and calibration set-up. This calibration is only valid sufficiently far away from any media boundaries. At very close distances, the sensitivity may change. This effect is referred to as a boundary effect and must be assessed separately as well as the isotropy.

B.2.1.1 Sensitivity in free space (1st step)

The most accurate set-ups used for the generation of well defined standard fields in free space are waveguides. The reasons are as follows:

- waveguide set-ups require moderate power and less space than far-field calibration set-ups,
- generation of the most accurate fields traceable to power readings is possible,
- the error produced by the field disturbance due to the probe insertion is negligible for small near-field probes when the waveguide's dimensions are considerably larger than those of the probe,
- the set-ups allow easy access for orienting the probe axis normal or parallel to the field polarisation inside the set-up,
- in addition, cross validation of the general field strengths is possible by using a set of waveguides with overlapping frequency ranges.

At higher frequencies, the field disturbance in the waveguide due to the presence of the probe becomes significant and free space standard field methods must be used for calibration. At lower frequencies (< 750 MHz) waveguides become too large and are not easily available, so that TEM cells can be employed instead. However, the field inside the cell is less well defined, i.e., there is rather large deviation from the predicted homogeneous field distribution [1]. For example, in the commercial TEM cell ifi110 the field varies by ± 6 % when moving along the central axis from the septum to the outer wall. Comparisons between probe response in the TEM cell and within the waveguides however allow calibration of a specific measurement location inside the TEM cell.

The probe is generally inserted through the small holes in the walls of each set-up and positioned at the centre where the field is mostly homogeneous over the probe dimensions. Each sensor is evaluated with respect to the field component parallel to the sensor 1). As long as the resistive line is not loading the dipole-diode sensor and the probe is small compared to the wavelength, the sensitivity will be independent of the frequency. This gives an additional validation of the calibration set-ups and checks for eventual field disturbance by the probe. The effect on the incident power is negligible, if high quality waveguide couplers and matched sources are used. An additional error source in the waveguide set-ups is from reflections from the terminating load, which can result in a standing wave pattern within the set-up. The reflections can be kept below 1 % if high quality waveguide loads are used. Furthermore, the error can be compensated by performing supplementary measurements with a $\lambda/4$ shifted load and averaging the two readings.

B.2.1.2 Sensitivity in media (2nd step)

The sensitivity in media is determined by generating locally known field values inside the media. The two methods can be used:

- transfer calibration with temperature probe,
- calibration with analytical fields.

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1) The care must be taken that each sensor has the maximal coupling with the incident field, e.g., for probes having sensors aligned to the probe coordinate system, both polarisations of the incident field with respect to the probe axis has to be used.

B.2.1.2.1 Transfer calibration with temperature probes

In lossy liquids the specific absorption rate (*SAR*) is related both to the electric field (*E*) and the temperature gradient (*dT/dt*) in the liquid. Hence, based on the relation:

$$SAR = \sigma \frac{E^2}{\rho} = c \left. \frac{dT}{dt} \right|_{t=0}$$

The electric field in lossy liquid can be measured indirectly by measuring the temperature gradient in the liquid. Non-disturbing temperature probes (optical probes or thermistor probes with resistive lines) with high spatial resolution (< 1-2 mm) and fast reaction time (< 1 s) are available and can be easily calibrated with high precision [2]. The set-up and the exciting source have no influence on the calibration; only the relative positioning uncertainties of the standard temperature probe and the E-field probe to be calibrated must be considered. However, several problems limit the available accuracy of probe calibrations with temperature probes:

- the temperature gradient is not directly measurable but must be evaluated from temperature measurements at different time steps. Special precaution is necessary to avoid measurement errors caused by temperature gradients due to energy equalising effects or convection currents in the liquid. Such effects cannot be completely avoided, as the measured field itself destroys the thermal equilibrium in the liquid. With a careful set-up these errors can be kept small;
- the measured volume around the temperature probe is not well defined. It is difficult to calculate the energy transfer from a surrounding gradient temperature field into the probe. These effects must be considered, since temperature probes are calibrated in liquid with homogeneous temperatures;
- the calibration depends on the assessment of the specific density, the heat capacity and the conductivity of the medium. While the specific density and heat capacity can be measured accurately with standardised procedures (~ ± 2 % for c; much better for ρ) , there is no standard for the measurement of the conductivity. Depending on the method and liquid, the error can well exceed ± 5 %;
- temperature rise measurements are not very sensitive and therefore are often performed at a higher power level than the E-field measurements. The non-linearities in the system (e.g., power measurements, different components, etc.) must be considered.

Considering these problems, the possible accuracy of the calibration of E-field probes with temperature gradient measurements in a carefully designed set-up is about ± 10 % (standard uncertainty) [3]. Recently, a set-up which is a combination of the waveguide techniques and the thermal measurements was presented in [4]. The estimated standard uncertainty of the set-up is ± 5 % when the same liquid is used for the calibration and for actual measurements and ± 7-9 % when not, which is in good agreement with the estimates given in [3].

When performing an uncertainty analysis of the transfer calibration using a temperature probe, at least the parameters included in Table B.1 should be considered.

Table B.1 - Uncertainty analysis for transfer calibration using temperature probes

ERROR SOURCES	**Description (Subclause)**	**Uncertainty value (%)**	**Probability distribution**	**Divisor**	c_i	**Standard uncertainty (%)**
Positioning errors						
- E-field probe			normal	1 or k	1	
- temperature probe			normal	1 or k	1	
Liquid parameters					0	
- conductivity			rectangular	$\sqrt{3}$	1	
- specific heat			normal	1 or k	1	
E-field probe linearity			rectangular	$\sqrt{3}$	1	
Temp. probe accuracy			normal	1	1	
Combined standard uncertainty						
Expanded uncertainty (confidence interval of 95 %)						

B.2.1.2.2 Calibration with analytical fields (waveguides)

In this method a technical set-up is used in which the field can be calculated analytically from measurements of other physical magnitudes (e.g., input power). This corresponds to the standard field method for probe calibration in air; however, there is no standard defined for fields in lossy liquids.

When using calculated fields in lossy liquids for probe calibration, several points must be considered in the assessment of the uncertainty:

- the set-up must enable accurate determination of the incident power;
- the accuracy of the calculated field strength will depend on the assessment of the dielectric parameters of the liquid;
- due to the small wavelength in liquids with high permittivity, even small set-ups might be above the resonant cut-off frequencies. The field distribution in the set-up must be carefully checked for conformity with the theoretical field distribution.

Rectangular waveguides are self-contained systems in which the cross-sectional field distributions are not dependent on reflections. This can be utilised to generate an analytically known field inside tissue simulating liquids, e.g., the set-up presented in [5]. In this set-up (see Figure B.1), the upper part of a standing open waveguide is filled with liquid. A dielectric slab at a distance > λ from the feeding coupler provides an impedance match (> 10 dB return loss) between air and liquid. The symmetry of the construction and high losses in the liquid ensure that the field distribution inside the tissue simulating liquid follows the TE_{10} pattern, although higher modes could theoretically exist. In [5] this was carefully validated through means of a complete volume scan in the liquid, which showed a deviation from the theoretical TE_{10} pattern of only < ± 1-2 %.

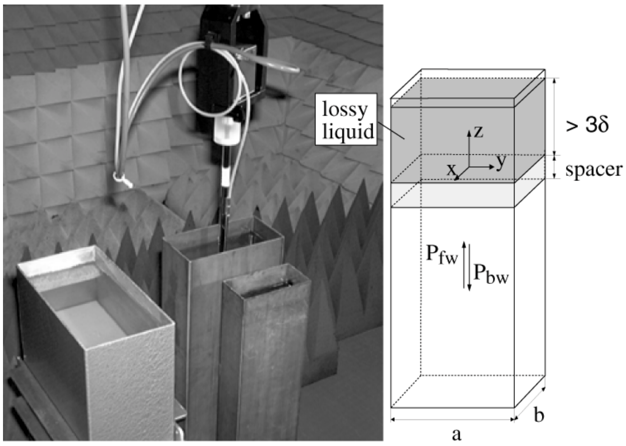

Figure B.1 - Experimental set-up for assessment of the conversion factor when using a vertically rectangular waveguide

Inside the liquid, the field nearly propagates as a TEM wave, because of the low cut-off frequency. The medium depth (> 3 skin depths) was chosen so that the reflections at the upper surface of the liquid are negligible. The power absorbed in the liquid is assessed by measuring forward and reflected power inside the waveguide:

$$SAR^{V} = \frac{4(P_{fw} - P_{bw})}{ab\delta} \cos^{2}\left(\pi \frac{y}{a}\right) e^{-(2z/\delta)}$$

where *ab* is the cross-sectional area of the waveguide, P_{fw} and P_{bw} the forward and backward powers inside the waveguide and δ the skin depth inside the lossy liquid.

This technique provides excellent accuracy, with a standard uncertainty of < ± 3,6 % depending on the frequency and media. The calibration itself is reduced to power measurements traceable to a standard calibration procedure. The practical limitation given by the waveguide size to the frequency band between 800 and 2 500 MHz is not severe in the context of compliance testing, since most of the operational frequencies for mobile communications systems are covered. For frequencies below 800 MHz, transfer calibration with temperature probes remains the most practical way to achieve calibration with decent precision.

When performing an uncertainty analysis of the calibration with analytical fields, at least the parameters included in Table B.2 should be considered.

Table B.2 - Uncertainty Analysis for the technique using the analytical field distribution inside waveguides

ERROR SOURCES	Description (subclause)	Uncertainty value (%)	Probability distribution	Divisor	c_i	Standard uncertainty (%)
Incident power			rectangular	$\sqrt{3}$		
Mismatch uncertainty			rectangular	$\sqrt{3}$	1	
Exp. Fitting error (95 % confidence)			normal	1 or k	1	
Liquid permittivity			rectangular	$\sqrt{3}$	0	
Probe positioning			normal	1 or k	1	
Filed homogeneity			rectangular	$\sqrt{3}$	1	
Combined standard uncertainty						
Expanded uncertainty (confidence interval of 95 %)						

B.2.2 Single step procedure

Reference antennas are small antennas designed for operating with the appropriate tissue equivalent liquid. Examples of antennas developed at 900 and 1 800 MHz have been described in [6] [7].

At least two identical antennas are necessary to evaluate the gain in the main lobe of the reference antennas.

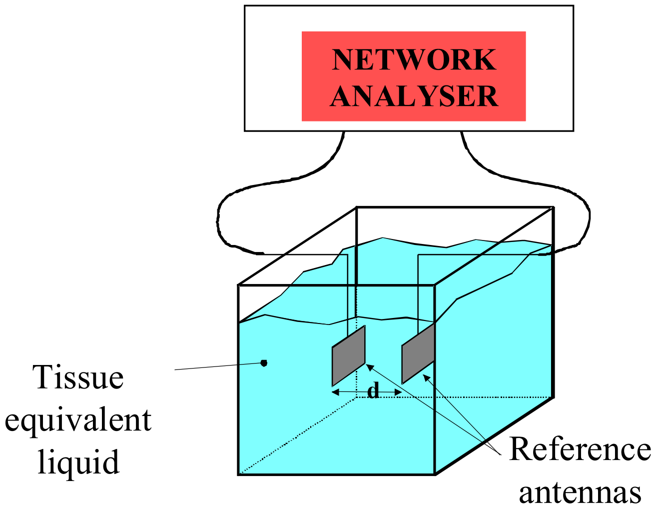

Figure B.2 - Description of the set-up

The gain evaluation is performed according to the following protocol:

a) position the antennas in the liquid so that their normal axis are aligned and at a well defined distance *d*, such that $d \geq 2D^2/\lambda_l$, *D* is the largest dimension of the reference antenna and λ_l is the wavelength in the liquid. The antennas shall be at a minimum distance of 10 cm from the walls of the liquid container;

b) measure the return loss ρ_1 and ρ_2 at input port of each antenna;

c) measure the S_{21} the two antennas at the same ports;

d) the gain is $G = \left|S_{21}(d\ )\right|.e^{\alpha.d}.\left(\dfrac{4.\pi.d}{\lambda_l}\right).\dfrac{1}{\sqrt{\left(1-\left|\rho_1\right|^2\right)\left(1-\left|\rho_2\right|^2\right)}}$

where the attenuation is $\alpha = \dfrac{2\pi f}{c}.\left[\left(\varepsilon_r^{'2} + \varepsilon_r^{''2}\right)\right]^{1/4}.\sin\left[\dfrac{1}{2}\arctan\left(\dfrac{\varepsilon_r^{''}}{\varepsilon_r^{'}}\right)\right]$

When performing an uncertainty analysis of the evaluation of reference antenna gain, at least the parameters included in Table B.3 should be considered.

Table B.3 - Uncertainty analysis for the evaluation of reference antenna gain

ERROR SOURCES	**Description (subclause)**	**Uncertainty value (%)**	**Probability distribution**	**Divisor**	c_i	**Standard uncertainty (%)**
Incident power			rectangular	$\sqrt{3}$	1	
Reflection coefficients			rectangular	$\sqrt{3}$	1	
Distance			rectangular	$\sqrt{3}$	1	
Liquid permittivity			rectangular	$\sqrt{3}$	1	
Combined standard uncertainty						
Expanded uncertainty (confidence interval of 95 %)						

The following protocol shall be used for evaluating the sensitivity coefficients of the probe:

a) position one antenna in the tissue equivalent liquid. The antenna shall be at a minimum distance of 10 cm from the walls of the liquid container;

b) connect a power source to the input port of the reference antenna. P_{in} is the input power and ρ is the return loss of the antenna. The electric field E_{th} is :

$$\mathrm{E_{th}} = \left[\left(\frac{P_{in}\left(1-\left|\rho\right|^2\right)Ge^{2\alpha d}}{4\pi d^2}\right) * \left(\frac{120\pi}{2\sqrt{\varepsilon_r}}\right)\right]^{1/2}$$

at a distance *d* from the antenna where $d \geq 2D^2/\lambda_l$ and *D* is the largest dimension of the reference antenna and λ_l is the wavelength in the liquid. It is recommended to connect a bi-directional coupler to control the input power. Tune the input power so that E_{th} ~ 30 V.m^{-1};

c) position the probe in the liquid so that the centre of the detectors is at a distance **d** from the antenna;

d) orient the probe in order to fit the direction of the dipole with the polarisation of the reference antenna;

e) measure the voltage signal at the port of the probe related to the exposed dipole V_{1mes};

f) the sensitivity coefficient K_1 for this dipole is $K_1 = \dfrac{V_{1mes}}{E_{th}^2}$;

g) repeat steps 4 to 6 for the other 2 dipoles and evaluate K_2 and K_3.

Using the sensitivity coefficients of the probe, it comes:

$$\mathrm{SAR} = \frac{\sigma}{\rho_l}\left(\frac{V_1}{K_1} + \frac{V_2}{K_2} + \frac{V_3}{K_3}\right)$$ where ρ_l is the density (1 000 kg.m^{-3}).

When performing an uncertainty analysis of the calibration with reference antennas, at least the parameters included in Table B.4 should be considered.

Table B.4 - Uncertainty analysis for the technique using reference antennas

ERROR SOURCES	**Description (subclause)**	**Uncertainty value (%)**	**Probability distribution**	**Divisor**	c_i	**Standard uncertainty (%)**
Incident power			rectangular	$\sqrt{3}$	1	
Reflection coefficients			rectangular	$\sqrt{3}$	1	
Antenna gain			normal	1 or k	1	
Liquid permittivity			rectangular	$\sqrt{3}$	0	
Probe positioning			rectangular	$\sqrt{3}$	1	
Combined standard uncertainty						
Expanded uncertainty (confidence interval of 95 %)						

B.3 Isotropy

Axial isotropy

The probe shall be exposed to a reference wave with normal incidence with regard to the axis of the probe. The axial isotropy is determined by rotating the probe along its main axis from 0° to 360° with a step of less than 15°.

Hemispherical isotropy

The probe shall be exposed to a reference wave with varying angles of incidences. The hemispherical isotropy shall be determined by rotating either the probe or the polarisation of the reference wave. The angles of incidence shall vary from 90° (axial) to 0° (normal) with a step of less than 30°. For each incidence, the probe shall be rotated with a range of 360° and a step less than 15°.

The following two protocols can be used:

- dipole with flat phantom,
- reference antenna.

B.3.1 Isotropy with dipole and flat phantom

The set-up consists of a thin plastic box filled with tissue simulating liquid exposed to a half-wave resonant dipole operating at test frequency.

The following protocol shall be used for evaluating the spherical isotropy of the probe:

a) mount the dipole antenna on a turntable and position it parallel to the flat phantom (see Figure B.3). The antenna shall be positioned at a maximum distance of e=λ/10 from the adjacent wall of the liquid container;

b) insert the probe vertically in the liquid so that the centre of the three probe sensors is positioned in the extension of the dipole axis;

c) the horizontal placement of the probe shall be, whenever possible, at the maximum of the standing wave near the back side of the box, at a distance *d* from the phantom/liquid interface, where the E-field is partially homogeneous and the H-field is at a minimum. The Measurement can also be conducted in a gradient field. (The maximum of the E-field can be assessed by performing a line scan in the x-direction),

d) the dipole shall be turned around its axis form at least 0° to 90° with incremental steps of less than 30°,

e) at each step the probe is rotated on its axis from 0° to 360° by the robot and measurement data is recorded with steps less than 15°,

f) the deviation from spherical isotropy is then expressed as the maximal SAR deviation from the average values among all measured probe positions (± xx dB).

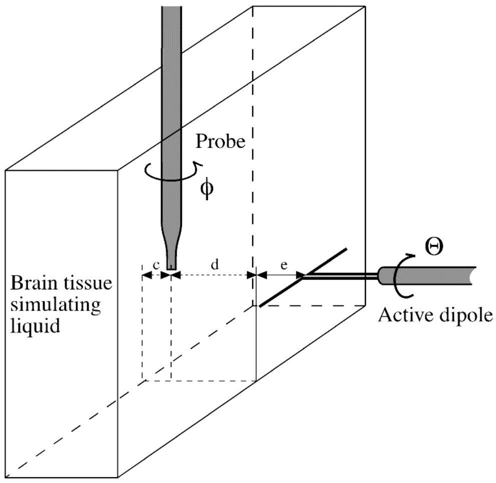

Figure B.3 - Set-up used to assess the deviation from spherical isotropy in tissue-simulating liquid

B.3.2 Isotropy with reference antennas

The following protocol shall be used for evaluating the isotropy of the probe:

a) position one antenna in the tissue equivalent liquid. The antenna shall be at a minimum distance of 10 cm from the walls of the liquid container;

b) position the probe in the liquid so that the centre of the detectors is at a distance *d* from the antenna where $d \geq 2D^2 / \lambda_{gel}$ and *D* is the largest dimension of the reference antenna and λ_{gel} is the wavelength in the liquid. It is recommended that the SAR value is between 0,5 and 1 W/kg at this position;

c) orient the probe axis so that its main axis is orthogonal to the direction of the radiation from the antenna (see Figure B.4);

d) rotate the probe along its main axis from 0° to 360° with a step of less than 15°. Record the SAR values. The axial isotropy is defined by the SAR deviation from the rms value;

e) modify the incidence of the reference signal by rotating the reference antenna or the probe axis (see Figure B.5.) from 0° to 90° with a step of 15° or 30°;

f) for each incidence, rotate the probe along its main axis from 0° to 360° with a step of less than 15°. Record the SAR values;

g) the hemispherical isotropy is defined by the SAR deviation from the rms value among non normal exposure of the probe.

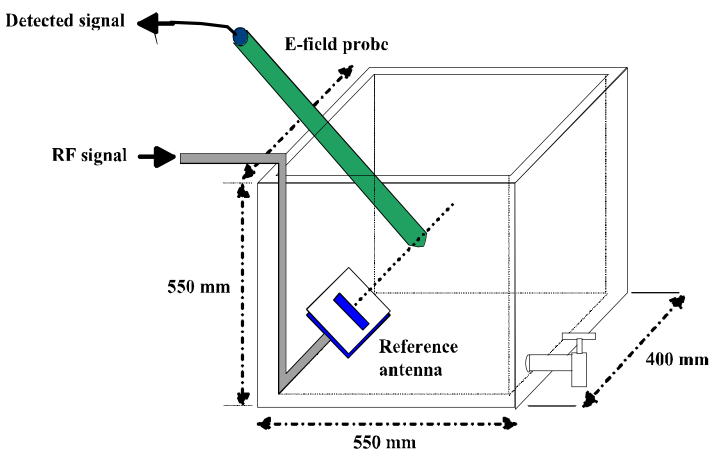

Figure B.4 - Measurement of axial isotropy with reference antenna

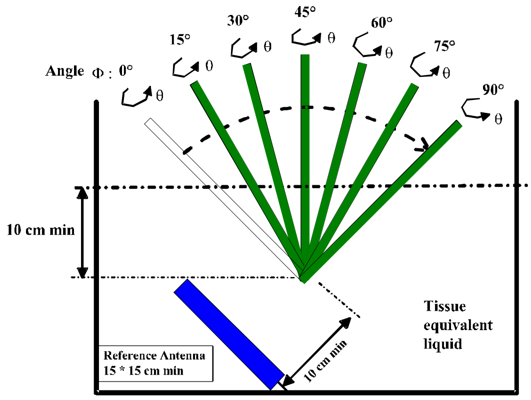

Figure B.5 - Measurement of hemispherical isotropy with reference antenna

B.4 Linearity

Since the non linear response of the probe depends only on the characteristics of the diode, the evaluation of the linearising functions may be done either in free space or in the tissue equivalent liquid. This is performed by a power sweep covering the requested detection range. Small TEM cells, waveguides or reference antennas can be used, since high field strengths can be produced with medium power amplifiers.

The linearity is defined by the maximum deviation over the measurement range of the measured quantity from the closest linear reference curve defined over the interval 0,02 W/kg – 100 W/kg. The evaluation can be performed by using one of the set-ups described in B.2. or D.1. The power shall be increased by steps not larger than 1 dB over the interval 0,01 and 100 W/kg.

B.5 Lower detection limit

The lower detection limit is related to the noise level, offset and asymmetry of the measurement system. Saturation and other non-linearity effects define the upper detection limit. The lower and upper limit can be assessed with various set-ups, e.g., set-up of B.2, D.1, etc. It is defined as the level from which the response deviates from linearity by more than 0,5 dB (also see B.4). In actual operational conditions of the measurement system, the lower detection limit may be impaired by the background EM environment.

B.6 Boundary effects

In the closest vicinity to the inner surface of the shell, the sensitivity deviates from the one defined by normal calibration conditions. This deviation shall be evaluated by using a field distribution inside a flat phantom which approximately corresponds to that of a plane wave exposure. To determine this effect, a set-up similar to the one described in D.1 can be used, whereby the boundary effect is defined as the deviation between the SAR measured data and the expected exponential decay in the liquid when the probe is oriented normal to the interface. This effect can be largely compensated as described in [8] [9]. The uncertainty of the procedure must be evaluated according to 7.2.1.5.

B.7 Response time

The probe shall be exposed to a reference wave. The response time is the time required by the measurement equipment to reach 90 % of its final value after a step variation or switch on/off of the power source. The step shall be defined to provide at least 0,4 W/kg local SAR.

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Annex C
(informative)

Post-processing techniques and uncertainty assessment

C.1 Extrapolation and interpolation schemes

C.1.1 Introduction

The local SAR inside the phantom is measured using small dipole sensing elements inside a probe body. It is generally assumed that the underlying E-field measurements are associated with the geometric centre of the dipoles, so it is necessary to account for the fact that dipoles are a few millimetres from the physical tip of the probe when defining the measurement positions.

The probe tip must not be in contact with the phantom surface in order to minimise measurement errors, but the highest local SAR will occur at the surface of the phantom. These highest local SAR are essential to determine the peak spatially averaged SAR so they must be obtained from measurements at a distance from the shell through extrapolation.

The accurate assessment of the maximum SAR averaged over 10 grams requires a very fine resolution in the three dimensional scanned data array. Since the measurements have to be performed over a limited time, e.g., due to the duration of the battery life, the measured data have to be interpolated to provide an array of sufficient resolution.

This annex describes some extrapolation and interpolation process, it also describes the way to evaluate the uncertainty associated with these extrapolation and interpolation schemes.

C.1.2 Interpolation schemes

Interpolation could be performed using many mathematical techniques such as statistics [1], basis function fitting [2], Fourier analysis [3] Wavelet [4] or Polynomial and Splines [5]. Computational mathematics books [6] describe how to implement some of these methods.

C.1.3 Extrapolation schemes

Extrapolation could be performed using Splines, biharmonic Splines, Wavelets, polynomials or rational functions. Computational mathematics books describe how to implement some of these methods.

Since the accuracy of the extrapolation depends on the distance and on the field distribution being extrapolated, the uncertainty associated with the extrapolation has to be estimated carefully.

C.1.4 Extrapolation and interpolation uncertainty assessment

The methodology used to analyse the accuracy is a sensitive issue because it is highly correlated to the uncertainty evaluation [7]. The relative uncertainty associated with the data process shall be:

$$\frac{\Delta SAR_{over10g}}{SAR_{over10g}} = \frac{\left| SAR_{extrap/\mathrm{int}erp} - SAR_{ref} \right|}{SAR_{ref}}$$

Assessment of the SAR_{ref} and the $SAR_{extrap/interp}$ over 10 g :

Four sets (publicly available on the CD-ROM attached with this standard) of 3D reference data shall be used. Two sets represent the SAR, estimated by numerical methods, induced by two numerical mobile phones next to the phantom and two analytical functions defined hereafter:

$$f_1(x,y,z) = A\frac{a^2}{a^2+x'^2}\cdot\cos^2\left(\frac{\Pi}{2}\cdot\frac{y'}{3a}\right)\cdot e^{-\frac{z}{a}}\cdot\left(3-e^{-\frac{2z}{a}}\right)$$

$$f_2(x,y,z) = A\frac{a^2}{\frac{a^2}{4}+x'^2+y'^2}\cdot\left(e^{-\frac{2z}{a}}+\frac{a^2}{2(a+2z)^2}\right)$$

$$\begin{aligned} x' &= x+2\text{ mm}\\ y' &= y+3\text{ mm}\\ a &= 20\,\text{mm}\\ A &= 1\text{ W/kg}\end{aligned}$$

The « unknown data » have to be calculated using the « known data » with the interpolation and extrapolation process. In this way, the estimated SAR averaged over 10 grams in a given cube shall be compared to the target value given by the reference data.

The relative uncertainty is evaluated using the following formula.

$$U_{extra/\text{int}erpol}\% \;= 100.\frac{\left|SAR_{extrap/\text{int}erp} - SAR_{ref}\right|}{SAR_{ref}}$$

C.2 Averaging scheme and maximum finding

C.2.1 Introduction

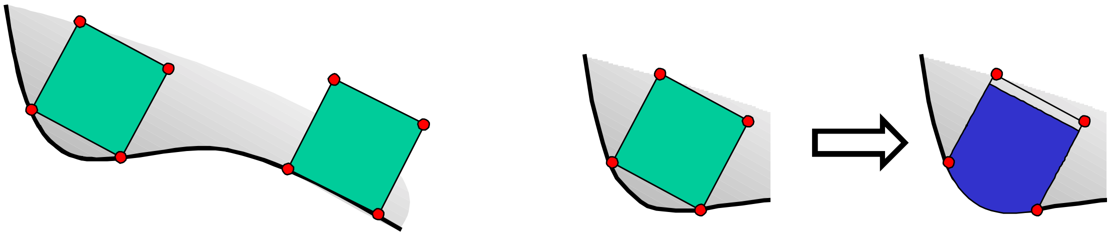
According to ICNIRP Guidelines [8] the averaging volume shall be chosen as 10 g of contiguous tissue. However a cube may be used [9].

The cubic volumes over which the SAR measurements are averaged after extrapolation and interpolation have to be close to the phantom surface in order to include the highest values of local SAR. The cube should therefore be rotated until it is co-incident with the surface.

Two methods are proposed for orientation of the cube. Then the way to choose the points for averaging will be investigated before a method for the evaluation of uncertainty is described.

C.2.2 Choice of the cube

C.2.2.1 Method of the 3 points

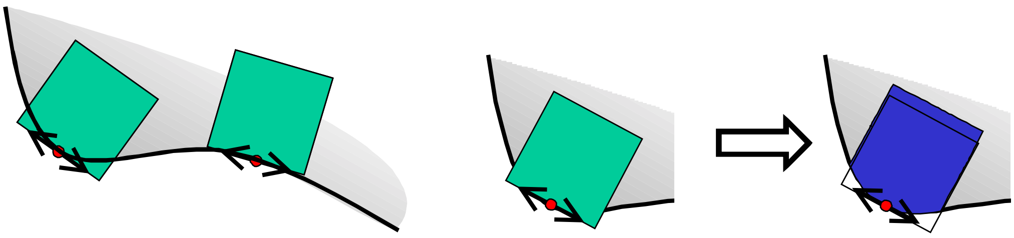


The cube face may be fitted to the phantom surface by orienting it such that three of its vertices are co-incident with the surface. The positions of the remaining five vertices of the cube can then be identified.

The space between the cube and the phantom surface must be included in the averaging volume as it is likely to be a region of high localised SAR. This may be accomplished by adapting the surface of the cube to conform to concave inner surface of the phantom. Adapting the opposite surface of the cube to reduce the cube depth may then be use to correct the cube volume and restore a 10 g averaging mass.

The three locating points should be scanned over the phantom surface in order to evaluate the maximum SAR occurring over any 10 g cube.

C.2.2.2 Method of the tangential face

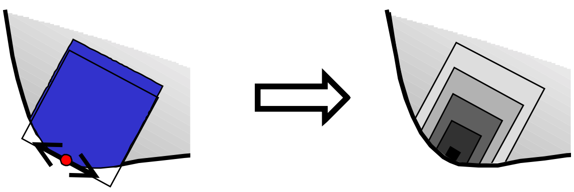


Another method is to choose a point on the phantom surface and define this to be co-incident with the centre of one cube face. Two tangential vectors are then evaluated and these can be used to arrange the surface of the cube at a tangent to the phantom surface. The remaining faces of the cube are then located before the cube is rotated about a vector normal to the phantom surface in order to evaluate the maximum mass averaged SAR.

As with the previous method, the surface of the cube in contact with the phantom shell must be made conformal in order to fully include the region of highest localised SAR. The opposite face of the cube is then either extended or contracted in order to maintain a 10 g averaging mass.

The cube should be scanned and rotated at points over the surface of the phantom in order to return the maximum SAR over any 10 g cube.

C.2.2.3 Method of averaging

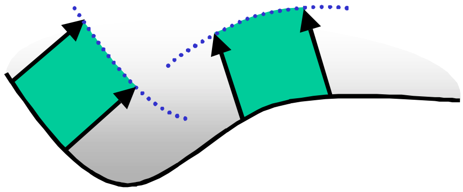


The main objective is to obtain an averaging mass of 10 g. To achieve this, SAR points may be added layer by layer to make the cube grow until its mass exceeds 10 g. Then, the corresponding absorbed power may be deduced by linear interpolation.

NOTE Most of the time, the averaging cube is described in a staircased form due to the grid on which the measurement points have been interpolated. Though an interpolation could be done especially for the cube, such a method would be time consuming as the interpolation would be different for each averaging cube.

C.2.3 Extrude method of averaging

The scanning of the volume may be done parallel to the surface of the phantom. In this method, the easiest way to average is to make an extrusion of the surface of the phantom at a depth of 215 mm. This ensures that the volume which is extruded is close to a cube in shape, and conforms to the surface.



The method of averaging is intrinsically simple since the cube essentially conforms to the measurement grid, or at least conforms to the extrapolated and interpolated data grid. The maximum mass averaged SAR is found by moving the averaging cube over a selected region, e.g., a region with a local SAR above some criterion.

C.2.4 Averaging scheme and maximum finding uncertainty assessment

The peak localised SAR will occur at the inner surface the phantom, so the highest spatially averaged SAR should occur in a cubic tissue volume at the surface of the phantom. It therefore follows that high resolution measurement scans should be centred on the peak localised SAR determined from a scan of the interior surface of the phantom. This scanned surface should extend laterally at least twice the linear dimension of the tissue cube used for mass averaging. Computer controlled algorithms should be used to determine the highest SAR according to the local SAR gradients in the mass averaging cube.

To verify the accuracy of this maximum finding process and evaluate the related uncertainty, four sets (publicly available on the CD-ROM attached with this standard) of 3D reference data have to be used. These data sets represent the SAR induced by two numerical mobile phones next to the phantom and two analytical functions defined hereafter:

$$f_1(x,y,z) = A\frac{a^2}{a^2 + x'^2} \cdot \cos^2\left(\frac{\Pi}{2} \cdot \frac{y'}{3a}\right) \cdot e^{-\frac{z}{a}} \cdot \left(3 - e^{-\frac{2z}{a}}\right)$$

$$f_2(x,y,z) = A\frac{a^2}{\frac{a^2}{4} + x'^2 + y'^2} \cdot \left(e^{-\frac{2z}{a}} + \frac{a^2}{2(a+2z)^2}\right)$$

$$x' = x + 2 \text{ mm}$$

$$y' = y + 3 \text{ mm}$$

$$a = 20 \text{ mm}$$

$$A = 1 \text{ W/kg}$$

The reference data have been collected with a millimetric spatial resolution to avoid the need for any extrapolation or interpolation processes. The reference data sets include target values for their maximum mass averaged SAR and these shall be compared with the maximum mass averaged SAR yielded by the averaging and maximum finding schemes under evaluation.

The relative uncertainty shall be evaluated using:

$$U_{\max finding}\% \quad = 100.\frac{\left|SAR_{\max estimated} - SAR_{\max ref}\right|}{SAR_{\max ref}}$$

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Annex D
(normative)

Measurement system validation

D.1 Simplified performance checking

D.1.1 Phantom set-up

The set-up uses a flat phantom with a dipole antenna held at a specified distance. The following phantom specifications are necessary to guarantee a high repeatability in the measurement:

- the phantom must be at least 0,6 times the wavelength in air, in both length and width. This gives a maximum difference below 1 % for the 10 g averaged SAR with respect to an infinitely large flat phantom,
- the depth of liquid in the phantom shell must be greater than three penetration depths or larger than 15 cm. This guarantees negligible errors due to standing waves at the liquid surface,
- the phantom shell shall be made of low permittivity and low loss material with permittivity less than 5 and loss tangent less than 0,05. The thickness of the bottom of the phantom shall be less than 6,5 mm, although the sides may be thicker,
- the thickness should be uniform with the precision of ± 0,2 mm. When filled with liquid of the appropriate depth, the sagging of the bottom surface of the liquid should be less than 0,5 % of the box length,
- the same liquids that are required for compliance testing with the anthropomorphic phantom shall be used, see 5.2.4,
- the flat phantom shall be mounted in a structure made of a rigid material of low dielectric constant and low conductivity. Metallic parts must be avoided in the vicinity of the structure.

D.1.2 Dipole source

The dipole shall be positioned and centred below the phantom, parallel to the longest side of the phantom. A low loss and low dielectric constant spacer on the dipole may be used to guarantee the correct distance between the dipole top surface and the phantom bottom surface. The distance between the liquid surface and the dipole centre is specified within ± 0,1 mm for each test frequency. The dipole shall have < - 20 dB return loss in the set-up to reduce the uncertainty in the power reading.

For the dipoles described below, the distance d is given by:

- dipoles for 300 MHz to 1 000 MHz: d = 15 mm ± 0,1 mm
- dipoles for 1 000 MHz to 3 000 MHz: d = 10 mm ± 0,1 mm

The definition of *d* is the distance from the liquid surface to the dipole's central axis at location of the feedpoint. The dipole arms shall be parallel to the flat phantom surface with a precision better than ± 2 degrees (see Figure D.1).

D.1.3 Dipole input power measurement

The uncertainty of the input power to the dipole must be as small as possible. This requires a sophisticated set-up with directional couplers and power monitoring during the system check. The recommended set-up is described below in Figure D.1.

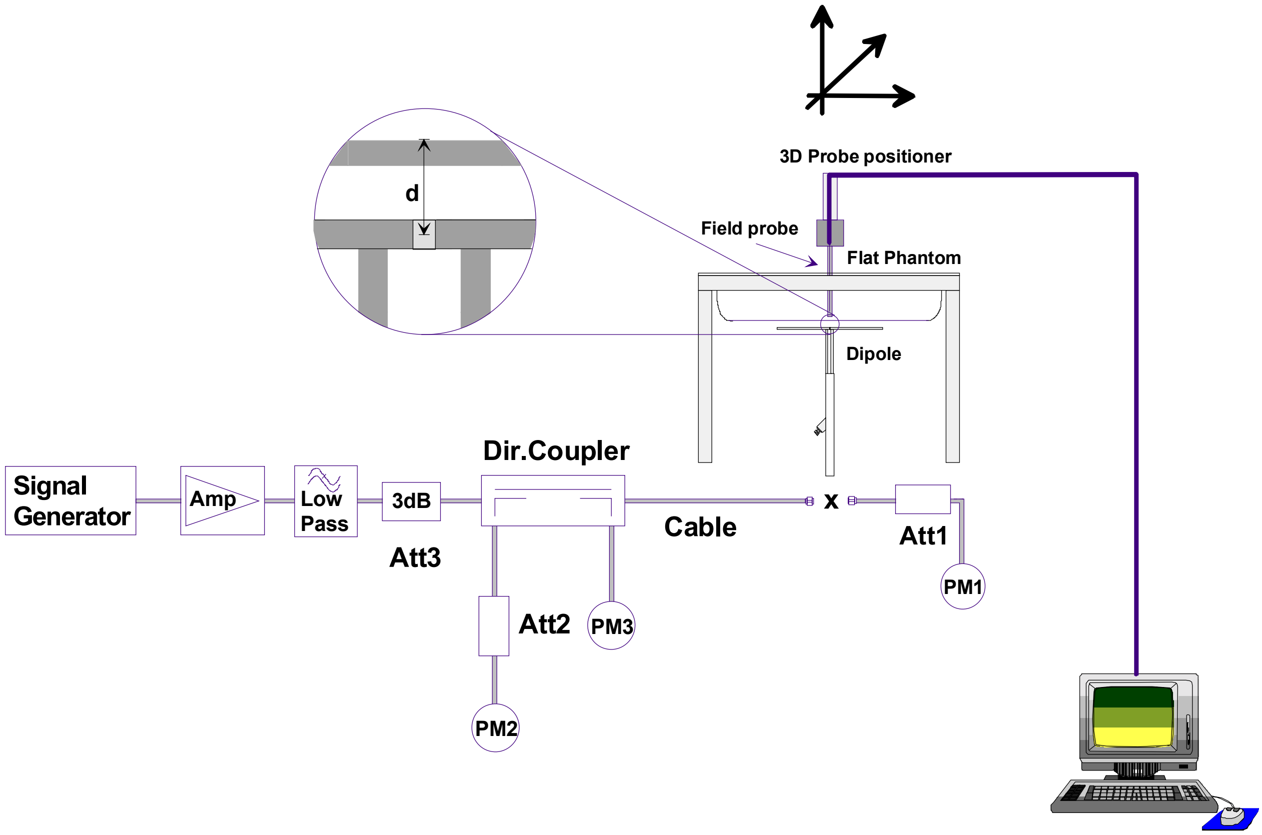

Figure D.1 - Simplified performance checking set-up

First the power meter PM1 is connected to the cable and it measures the forward power at the location of the dipole connector (X). The signal generator is adjusted for the desired forward power at the dipole connector (taking into account the (Att1) value) and the power meter PM2 is read at that level. Then after connecting the cable to the dipole, the signal generator is readjusted for the same reading at the power meter PM2. If the signal generator does not allow a setting in 0,01 dB steps, the remaining difference at PM2 must be taken into consideration. PM3 records the reflected power from the dipole and ensures that the value is not changed from the previous value. The reflected power should be 20 dB below the forwarded power. The requirements for the components are:

- the signal generator and amplifier should be stable (after warm-up). The forward power to the dipole should be high enough to avoid the influence of measurement noise. If the signal generator can deliver 15 dBm or more, an amplifier is generally not necessary. Some high power amplifiers should not be operated at a level far below their maximum output power level, e.g., a 100 W power amplifier operated at 250 mW output can be quite noisy. An attenuator between the signal generator and amplifier is recommended to protect the amplifier input;
- the low pass filter after the amplifier reduces the effect of harmonics and noise from the amplifier. For most amplifiers in normal operation the filter is not necessary;
- the attenuator after the amplifier improves the source matching and the accuracy of the power sensor. (See power meter manual.) It can also be used to make the amplifier operate at its optimal output level for noise and stability. In a set-up without directional coupler, this attenuator should be at least 10 dB;

- the directional coupler (recommended - 20 dB) is used to monitor the forward power and adjust the signal generator output for constant forward power. A medium quality coupler is sufficient because the loads (dipole and power head) are both well matched. (If the set-up is used for more reflective loads, a high quality coupler with respect to directivity and output matching is necessary to avoid additional errors.);
- the power meters PM2 and PM3 should have a low drift and a resolution of 0,01 dBm, but otherwise its accuracy has no impact on the power setting (Calibration is not required.);
- the power meter PM1 and attenuator Att1 must be high quality components. They should be calibrated, preferably together. The attenuator (- 10 dB) improves the accuracy of the power reading. (Some higher power heads come with a built-in calibrated attenuator.) The exact attenuation of the attenuator at the test frequency must be known; many attenuators are up to 0,2 dB off from the specified value;
- use the same power level for the power set-up with power meter PM1 as for the actual measurement to avoid linearity and range switching errors in the power meters PM2 and PM3. If the system check is performed at various power levels, do the power setting procedure at each level;
- the dipole must be connected directly to the cable at location “X”. If the power meter has a different connector system, use high quality adaptors.

D.1.4 System check procedure

The system check includes all measurement procedures used also for compliance tests. The 10 g averaged SAR value is normalised to the target input power of the dipole and compared to the target 10 g value. The acceptable tolerance must be determined for each system. It is evaluated from the uncertainty of all involved system components and the uncertainty of the dipole input power.

D.2 System validation

D.2.1 Purpose

The system validation tests the system against known SAR values of selected standard phones. This set-up utilises the same standard human head like anthropomorphic phantom filled with brain simulating mixtures as defined in 5.2. The target SAR-values are defined by inter-laboratory comparison and are available from the institutes specified in D.2.3.

If the differences and discrepancies between the measured data and target data are > 15 % then the calibrations, measurement uncertainty calculations, positions, power etc must be checked and the measurements repeated. System checking must be performed at least once a year.

D.2.2 Phantom set-up

The anthropomorphic phantom is described in 5.2. The phantom shall have a mounting structure made of a rugged material of low dielectric constant and low conductivity. Metallic parts will be avoided in the vicinity of the structure.

The phantom shall be irradiated using a standard cellular phone that is working in the required frequency range. The phone shall be mounted according to the requested test positions in 6.1.4.

D.2.3 Reference mobile phones

Reference phones shall be available in three institutes accepted by national committees. Each phone is checked individually by the manufacturer for the validation process so that the output power of each phone is in the range of ± 0,3 dB of the desired value and that the radiated power also is in that range measured in an anechoic chamber. The institutes also provide the software to control the phones frequency and output power. Before and after each measurement the output power is checked.

D.2.4 Power set-up

The power set-up is based on the precision of measuring the output power of the reference phone. The phone battery has to be fully charged and checked in the beginning and at the end of each measurement. The phone output power shall be adjusted via test software for maximum power output. All efforts shall be expended to ascertain an accurate measurement of output power. This feature will be considered when selecting the standard phone used in the test.

D.2.5 Comparison procedure

For comparison purposes the SAR values of the reference phones will be reported both as two-dimensional scan plots and as the maximum SAR values in a tabular form.

In general, the system protocols utilised during the validation process are very similar to the protocols described in clause 6.

If the differences and discrepancies between the measured data can be attributed to differences of the calibration and measurement uncertainty; the validation is successful. If not, all sources of errors will be investigated . A recommended course of action can be developed as follows:

- improve calibration and repeat part/parts or all measurement,
- improve part/parts of the test set-up and repeat part/parts or all measurement, and/or
- improve measurement protocol.

D.2.6 Uncertainty calculations

The acceptable tolerance shall be well below the uncertainty evaluation in clause 7 taking into account the relevant components in the validation system used.