BRITISH STANDARD

BS EN 62311:2008

Assessment of electronic and electrical equipment related to human exposure restrictions for electromagnetic fields (0 Hz – 300 GHz)

ICS 13.280; 97.030

British Standards

National foreword

This British Standard is the UK implementation of EN 62311:2008. It was derived by CENELEC from IEC 62311:2007. It supersedes BS EN 50392:2004 which is withdrawn.

The CENELEC common modifications have been implemented at the appropriate places in the text and are indicated by tags (e.g. [C) (C]).

The UK participation in its preparation was entrusted to Technical Committee GEL/106, Human exposure to low frequency and high frequency electromagnetic radiation.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Compliance with a British Standard cannot confer immunity from legal obligations.

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Assessment of electronic and electrical equipment related to human exposure restrictions for electromagnetic fields (0 Hz - 300 GHz)

(IEC 62311:2007, modified)

Evaluation des équipements
électroniques et électriques
en relation avec les restrictions
d'exposition humaine
aux champs électromagnétiques
(0 Hz - 300 GHz)
(CEI 62311:2007, modifiée)

Bewertung von elektrischen
und elektronischen Einrichtungen
in Bezug auf Begrenzungen
der Exposition von Personen
in elektromagnetischen Feldern
(0 Hz - 300 GHz)
(IEC 62311:2007, modifiziert)

This European Standard was approved by CENELEC on 2007-12-04. CENELEC members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration.

Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Central Secretariat or to any CENELEC member.

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
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Foreword

The text of document 106/129/FDIS, future edition 1 of IEC 62311, prepared by IEC TC 106, Methods for the assessment of electric, magnetic and electromagnetic fields associated with human exposure, was submitted to the IEC-CENELEC parallel vote.

A draft amendment, prepared by the Technical Committee CENELEC TC 106X, Electromagnetic fields in the human environment, was submitted to the Unique Acceptance Procedure.

The combined texts of IEC 62311:2007 and the draft amendment prAA were approved by CENELEC as EN 62311 on 2007-12-04.

This European Standard supersedes EN 50392:2004.

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)	2009-01-01
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2011-01-01

Annex ZA has been added by CENELEC.

Endorsement notice

The text of the International Standard IEC 62311:2007 was approved by CENELEC as a European Standard with agreed common modifications.

CONTENTS

ASSESSMENT OF ELECTRONIC AND ELECTRICAL EQUIPMENT RELATED TO HUMAN EXPOSURE RESTRICTIONS FOR ELECTROMAGNETIC FIELDS (0 Hz – 300 GHz)

1 Scope and object

This International Standard applies to electronic and electrical equipment for which no dedicated product- or product family standard regarding human exposure to electromagnetic fields applies.

The frequency range covered is 0 Hz to 300 GHz.

The object of this generic standard is to provide assessment methods and criteria to evaluate such equipment against basic restrictions or reference levels on exposure of the general public related to electric, magnetic and electromagnetic fields and induced and contact current.

NOTE This standard is intended to cover both intentional and non-intentional radiators. If the equipment complies with the requirements in another relevant standard, e.g. EN 50371 covering low power equipment, then the requirements of this standard (IEC 62311) are considered to be met and the application of this standard to that equipment is not necessary. See also Clause 7.2.

2 Normative references

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

IEC 60050-161, *International Electrotechnical Vocabulary – Chapter 161: Electromagnetic compatibility*

Ⓒ 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 199 of 30 July 1999 Ⓒ

3 Terms and definitions

For the purposes of this document, the terms and definitions contained in IEC 60050-161 as well as the following terms and definitions apply.

3.1
averaging time
t_{avg}
appropriate time over which exposure is averaged for purposes of determining compliance

3.2
basic restriction
maximum exposure level that should not be exceeded under any conditions

NOTE Examples of basic restrictions can be found in Annex II of the Council Recommendation 1999/519/EC [6][1], ICNIRP Guidelines [1] IEEE Std C95.6™ [2] and IEEE Std C95.1™ [3].

[1] Figures in square brackets refer to the Bibliography.

3.3
contact current
current flowing into the body resulting from contact with a conductive object in an electromagnetic field. This is the localised current flow into the body (usually the hand, for a light brushing contact)

3.4
[C> induced current density <C]
J
current per unit cross-sectional area flowing inside the human body as a result of exposure to electromagnetic fields

3.5
duty factor
duty cycle
ratio of pulse duration to the pulse period of a periodic pulse train. Also, a measure of the temporal transmission characteristic of an intermittently transmitting RF source such as a paging antenna by dividing average transmission duration by the average period for transmissions. A duty factor of 1,0 corresponds to continuous operation

3.6
electric field strength
E
magnitude of a field vector at a point that represents the force (F) on an infinitely small charge (q) divided by the charge

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

3.7
equipment under test
EUT
an electrical or electronic apparatus that is tested for compliance with exposure limits

3.8
exposure
exposure occurs whenever and wherever a person is subjected to electric, magnetic or electromagnetic fields or to contact current other than those originating from physiological processes in the body and other natural phenomena

3.9
exposure level
value of the quantity used to assess exposure

NOTE This may be an induced current density, SAR, power density, electric or magnetic field strength, a limb current or a contact current.

3.10
exposure limit
value of an electric, magnetic or electromagnetic field derived from the basic restrictions using worst-case assumption about exposure. If the exposure limit is not exceeded, then the basic restrictions will never be exceeded

3.11
exposure, direct effect of
result of a direct interaction in the exposed human body from exposure to electromagnetic fields

3.12
exposure, indirect effect of
result of a secondary interaction between the exposed human body and an electromagnetic field, often used to describe a contact current, shock or burn arising from contact with a conductive object

3.13
exposure, partial-body
localised exposure of part of the body, producing a corresponding localised SAR or induced current density, as distinct from a whole-body exposure

3.14
exposure, whole-body
exposure of the whole body (or the torso when induced current density is considered)

3.15
induced current
current induced inside the body as a result of exposure to electromagnetic fields

3.16
limb current
current flowing in an arm or a leg, either as a result of a contact current or else induced by an external field

3.17
magnetic field strength
H
magnitude of a field vector in a point that results in a force (F) on a charge (q) moving with velocity (v)

$$F = q(v \times \mu H)$$

(or magnetic flux density divided by permeability of the medium, see 3.18 “magnetic flux density”)

3.18
magnetic flux density
B
magnitude of a field vector that is equal to the magnetic field H multiplied by the permeability (μ) of the medium

$$B = \mu H$$

3.19
multiple frequency fields
superposition of two or more electromagnetic fields of differing frequency.

NOTE These may be from different sources within a device, e.g., the magnetron and the transformer of a microwave oven, or they may be harmonics in the field of a nominally single frequency source such as a transformer

3.20
power density
S
power per unit area normal to the direction of electromagnetic wave propagation. For plane waves the power density (S), electric field strength (E) and magnetic field strength (H) are related by the impedance of free space, i.e., 377 Ω

$$S = \frac{E^2}{377} = 377\ H^2 = EH$$

NOTE 1 Although many survey instruments indicate power density units, the actual quantities measured are E or H or the square of those quantities.

E and H are expressed in units of V/m and A/m, respectively, and S in the unit of W/m^2.

NOTE 2 It should be noted that the value of 377 Ω is only valid for free space, far field measurement conditions.

3.21
power density, average (temporal)
instantaneous power density integrated over a source repetition period. This averaging is not to be confused with the measurement averaging time

3.22
power density, plane-wave equivalent
commonly used term associated with any electromagnetic wave, equal in magnitude to the power density of a plane wave having the same electric (E) or magnetic (H) field strength as the measured field

3.23
reference levels
levels of field strength or power density derived from the basic restrictions using worst-case assumptions about exposure. If the reference levels are met, then the basic restrictions will be complied with, but if the reference levels are exceeded, that does not necessarily mean that the basic restrictions will not be met

3.24
root-mean-square
r.m.s.
the effective value or the value associated with joule heating, of a periodic electromagnetic wave. The r.m.s. value is obtained by taking the square root of the mean of the squared value of a function

$$F = \sqrt{\frac{1}{T}\int_{\frac{-T}{2}}^{\frac{T}{2}}\left(F(t)\cdot F(t)^{*}\,dt\right)} \quad \text{(expression in time domain)}$$

$$X = \sqrt{\sum_{1}^{n}\left(X_{\mathrm{n}}\right)^2} \quad \text{(expression in frequency domain)}$$

NOTE Although many survey instruments in the high frequency range indicate r.m.s., the actual quantity measured is root-sum-square (rss) (equivalent field strength).

3.25
root-sum-square
rss
the value rss is obtained from three individual r.m.s. field strength values, measured in three orthogonal directions, combined disregarding the phases.

$$X = \sqrt{X_{\mathrm{x}}^2 + X_{\mathrm{y}}^2 + X_{\mathrm{z}}^2}$$

3.26
specific absorption
SA
energy absorbed per unit mass of biological tissue, expressed in joule per kilogram (J/kg); specific energy absorption is the time integral of specific energy absorption rate

3.27
specific absorption rate
SAR
power absorbed by (dissipated in) an incremental mass contained in a volume element of biological tissue when exposure to an electromagnetic field occurs. *SAR* is expressed in the unit watt per kilogram (W/kg). *SAR* is used as a measure of whole-body exposure as well as localised exposure

3.28 exposure assessment
for purposes of this standard the term exposure assessment means conformity assessment with respect to applicable exposure limit(s).

[C⟩4 Compliance criteria

The electronic and electrotechnical apparatus shall comply with the basic restriction as specified in Annex II of Council Recommendation 1999/519/EC.

NOTE 1 The time averaging in the EU-Recommendation applies.

The reference levels in the Council Recommendation 1999/519/EC on public exposure to electromagnetic fields are derived from the basic restrictions using worst-case assumptions about exposure. If the reference levels are met, then the basic restrictions will be complied with, but if the reference levels are exceeded, that does not necessarily mean that the basic restrictions will not be met. In some situations, it will be necessary to show compliance with the basic restrictions directly, but it may also be possible to derive compliance criteria that allow a simple measurement or calculation to demonstrate compliance with the basic restriction. Often these compliance criteria can be derived using realistic assumptions about conditions under which exposures from a device may occur, rather than the conservative assumptions that underly the reference levels.

NOTE 2 The limit is the basic restriction.

If the technology in the apparatus is not capable of producing an E-field, H-field or contact current, at the normal user position, at levels higher than 1/2 the limit values then the apparatus is deemed to comply with the requirements in this standard in respect of that E-field, H-field or contact current without further assessment. ⟨C]

5 Assessment methods

One or more of the examples of assessment methods in 7.2 may be used.

The assessments should be made according to an existing basic standard. If the assessment method in the basic standard is not fully applicable then deviations are allowed as long as

- a description of the assessment method used is given in the assessment report;
- an evaluation of the total uncertainty is given in the assessment report.

For transmitters intended for use with external antennas at least one typical combination of transmitter and antenna shall be assessed. The technical specification (under far field conditions) of this antenna shall be documented in detail such that the boundary where the basic restrictions are met can be identified, e.g., by documented radiation patterns.

For non-radio transmitting apparatus, the compliance assessment to emissions of E or H field has to be made according to the highest internal frequency used within the apparatus under analysis or at which the apparatus operates with the following criteria:

– if the highest internal frequency of the apparatus is less than 100 MHz, the assessments shall only be made up to 1 GHz;
– if the highest internal frequency of the apparatus is between 100 MHz and 400 MHz, the assessment shall only be made up to 2 GHz;
– if the highest internal frequency of the apparatus is between 400 MHz and 1 GHz, the assessment shall only be made up to 5 GHz.

If the highest internal frequency of the apparatus is above 1 GHz, the measurement shall be made up to 5 times the highest frequency.

6 Evaluation of compliance to limits

The apparatus is deemed to fulfill the requirements of this standard if the measured values are less than or equal to the limit and if the actual assessment uncertainty is less than the maximum measurement uncertainty specified for the applied assessment method(s). The assessment uncertainty of assessment method shall be determined by calculating the expanded uncertainty using a confidence interval of 95 %.

Generally, a relative uncertainty of 30 % is used for a number of EMF assessment methods. Therefore this level of relative uncertainty is used as a default maximum in this generic standard.

If the relative uncertainty is less than 30 %, then the measured value L_{m} shall be compared directly with the applicable limit L_{lim} for evaluation of compliance.

If the relative uncertainty is larger than 30 %, then the actual uncertainty shall be included in the evaluation of compliance with the limit as follows.

If the actual assessment uncertainty is larger than the specified maximum allowed uncertainty value and if it is also larger than the maximum default uncertainty value of 30 %, then a penalty value shall be added to the assessment result before comparison with the limit. Conversely, one can also reduce the applicable limit L_{lim} with the same penalty value, and compare the actual measured L_{m} value with the reduced limit. The right-hand side of Equation 1 shows how the limit L_{lim} is reduced in case the actual relative uncertainty is larger then 30 %.

NOTE The uncertainty of EMF assessment methods is generally given in %. If the uncertainty is stated in non-linear units e.g. in dBs, then this value shall be converted into percentage (%) first.

Equation 1 shall be used to determine whether the measured value L_{m} complies with reduced limit if the actual measurement uncertainty of the applicable assessment method is 30 % or more.

$$L_{\mathrm{m}} \leq \left(\frac{1}{0{,}7 + \frac{U(L_{\mathrm{m}})}{L_{\mathrm{m}}}} \right) L_{\mathrm{lim}} \qquad (1)$$

where

L_{m} is the measured value;
L_{lim} is the exposure limit;
$U(L_{\mathrm{m}})$ is the absolute expanded uncertainty.

EXAMPLE:

Suppose the relative uncertainty of a certain EMF assessment method is 55 %. Then

$$\frac{U(L_{\mathrm{m}})}{L_{\mathrm{m}}} = 0{,}55$$

Using Equation (1), the acceptance criterion for the measured value is then:

$$L_{\mathrm{m}} \leq \left(\frac{1}{0{,}7 + \frac{U(L_{\mathrm{m}})}{L_{\mathrm{m}}}} \right) L_{\mathrm{lim}} = \left(\frac{1}{0{,}7 + 0{,}55} \right) L_{\mathrm{lim}} = \frac{1}{1{,}25} L_{\mathrm{lim}} = 0{,}8\ L_{\mathrm{lim}}$$

The uncertainty penalty (the amount of reduction of the limit) is then:

$$U_{\mathrm{pen}} = L_{\mathrm{lim}} - 0{,}8\, L_{\mathrm{lim}} = 0{,}2\ \ L_{\mathrm{lim}}$$

The uncertainty values specified for each EMF assessment method are the maximum allowed uncertainties. If the uncertainty value is not specified, then a default value of 30 % shall be used.

NOTE Guidance on the uncertainty can be found in ANSI NCSL Z540-2 [8]: US guide to the expression of uncertainty in measurement and in the ISO/IEC Guide on Measurement Uncertainty [9].

7 Applicability of compliance assessment methods

7.1 General

An analysis can be made to investigate which parts emit EMF. A description of the several parts of an equipment is recommended in order to determine what parts are emitting EMF. Table 1 gives the characteristics and parameters of the equipment to be considered. Table 2 gives a list of possible assessment methods.

Table 1 – Characteristics and parameters of the equipment to be considered

Information needed	Further detailed description of the information needed
Frequency	Frequency of emissions
Waveform	Waveform and other information such as duty factor for establishment of peak- and/or average emission
Multiple frequency sources	Does the equipment produce fields at more than one frequency or fields with a high harmonic content? Are the emissions simultaneous?
Emission of electric fields	Voltage differences and any coupling parts e.g., metallic surfaces charged at a voltage potential
Emission of magnetic fields	Current flow and any coupling parts e.g., coils, transducers or loops
Emission of electromagnetic fields	Generation or transmission of high frequency signals and any radiating parts e.g., antennas, loops, transducers and external cables
Contact currents	Possibility of touching conducting surfaces when either the surface or the person is exposed to electromagnetic fields?
Whole body exposure	Fields produced by equipment extend over region occupied by the whole body
Partial body exposure	Fields produced by equipment extend over only part of region occupied by the body, or over region occupied by limbs
Duration/time variation	Duty cycle of emissions, on/off time of power used or emitted by equipment. Variation of power use or emissions during production process
Homogeneity	Extent to which the strength of the fields varies over the body or region of the body that is exposed. Shall be measured without the presence of a body
Far/near field	Are exposures in near field? (see Annex A) Propagating near field? Far field?
Pulsed/transient fields	Are the emissions pulse-modulated or true pulses? Are there occasional or periodic transients in the field?
Information needed	**Further detailed description of the information needed**
Physical size	Is the equipment so small that any significant exposure will be to part of the body? In relation to the wavelength (operating frequency) Is it so big that different parts will contribute to exposures “independently”?
Power	What is the emitted power? What is the power consumption? If there is an antenna system, what is the effective radiated power?
Distance (source to user)	What is the spatial relationship between the equipment and the operator or user when it is used normally? The distance used for the assessment shall be specified by the manufacturer and be consistent with the intended usage of the equipment
Intended usage	How is the equipment commonly used? Conditions of intended usage producing the highest emission or absorption? Operating conditions? How does the intended usage affect the spatial relationship between the equipment and the user? Can the usage affect the emission characteristics of the equipment? Can the equipment be part of a system?
Interaction sources/user	Do the emitted fields change if the equipment is close to the body? Does the equipment couple to the body during use?

Table 2 – List of possible assessment methods

Assessment methods	Applicability area and limitations	Reference
Far field calculation	Electromagnetic fields far from source. Very small microwave equipment not used close to body, or large lower-frequency transmitters at greater distances. That region of the field of an antenna where the angular field distribution is essentially independent of the distance from the antenna. In this region (also called the free space region), the field has a predominantly plane-wave character, i.e., locally uniform distribution of electric field strength and magnetic field strength in planes transverse to the direction of propagation	See Annex A
Near field calculation	Electromagnetic fields very close to the source. There can be an interaction between the radiated fields from the source and the user	See Annex A
Simulation with/without a phantom	Evaluation of measurement results inside the phantom representing a body	See Annex B
Numerical modelling	Calculation only	See Annex C
Body/limb current	Measurement or calculation	See Annex C or D
SAR	Calculation and measurements; 100 kHz – 10 GHz. For modelling	See Annex E See Annex C
E and H measurement	Near or far field. Direct measurement for comparison with reference levels or as input for more detailed assessment	See Annex F
Source modelling	Prediction of exposures from calculation of emissions at a specific distance	See Annex G
Direct measurement of physical properties: Contact current		See Annex D, E or F
The physical characteristics and intended use of the equipment may have an impact on the choice of assessment method. E.g., radiators of EMF intended for use in close proximity to the body shall be assessed differently from transmitters intended for fixed installations in buildings.		

7.2 Generic procedure for assessment of equipment

The following generic procedure for assessment of equipment involves a decision tree drawing on information from Tables 1 and 2.

(1) The equipment should be characterised to determine the nature of EMF emissions (see 8.1) and also the intended usage conditions.

An assessment shall be performed: Fields and body currents should be determined at the typical user position under normal operating conditions giving the highest emission – see note – e.g., based on limited pre-tests, but consistent with the normal operating conditions as specified by the manufacturer.

NOTE For practical reasons it is acceptable to perform the assessment with the equipment being operated with the maximum settings (e.g., maximum rated load, maximum rated power consumption, maximum speed or other), consistent with the intended use as specified by the manufacturer. The equipment is operated for a sufficient period to ensure that the conditions of operation are typical of those during normal use.

(2) By measurement or calculation (see 8.1). If these quantities are below the relevant reference levels, taking into account waveform/frequency content (8.1), and any allowed time and spatial averaging then the equipment is deemed to meet the requirements in this standard. If not, then go to paragraph (3).

(3) Measured emission values should be compared with any product-specific compliance criteria (e.g., kind of emission, operating frequency (range), limits) that can be derived for the equipment (Clause 5). If the emission values are below the product-specific compliance criteria then the equipment is deemed to meet the requirements in this standard. If no product-specific compliance criteria (by e.g., the manufacturer) have been specified for an E-field, H-field or contact current which is to be assessed, or if compliance criteria have been specified but not met, then go to paragraph (4).

NOTE The technology of some products may allow assumptions about human exposure from the equipment to be made e.g., always magnetic field, always partial body exposure etc. From these assumptions it may be possible to derive compliance criteria for that product or product type, e.g., "if the magnetic field strength is below", or "if the power is below".

(4) Further assessment involving more detailed measurement, calculation and source/ exposure modelling should be undertaken (see 8.2) to allow comparison of exposure levels with all relevant basic restrictions on exposure. If the exposures are below the basic restrictions then the equipment is deemed to meet the requirements in this standard. If not, then the equipment is deemed not to comply with the requirements in this standard.

This process is summarized in the flowchart in Figure 1.

The decision “low power / inherently compliant” shall be based on an assessment where the emissions are specified in a performance standard e.g. a transmitter performance standard and where the output power is limited to a level that can not exceed the basic restriction. It can also be any other product standard giving the same limitation on the emission level as e.g. EN 50371. Some products use a technology or input powers that have the consequence that the emissions cannot exceed the basic restrictions, e.g. non-radiotransmitter products like wrist-watches, ADSL modems, computers, telecommunications equipment and hi-fi systems. This shall also be taken into account when the assessment is made.

The choice of assessment method in stages (3) and (4) above is optional, but it must be suitable for the exposure quantity to be assessed and for the frequency of emission. Where more than one equally valid assessment method exists for a particular exposure quantity, then it is acceptable to use only one assessment method for that particular quantity. Where only one assessment method is chosen, this should be clearly stated and the reasons given for the choice.

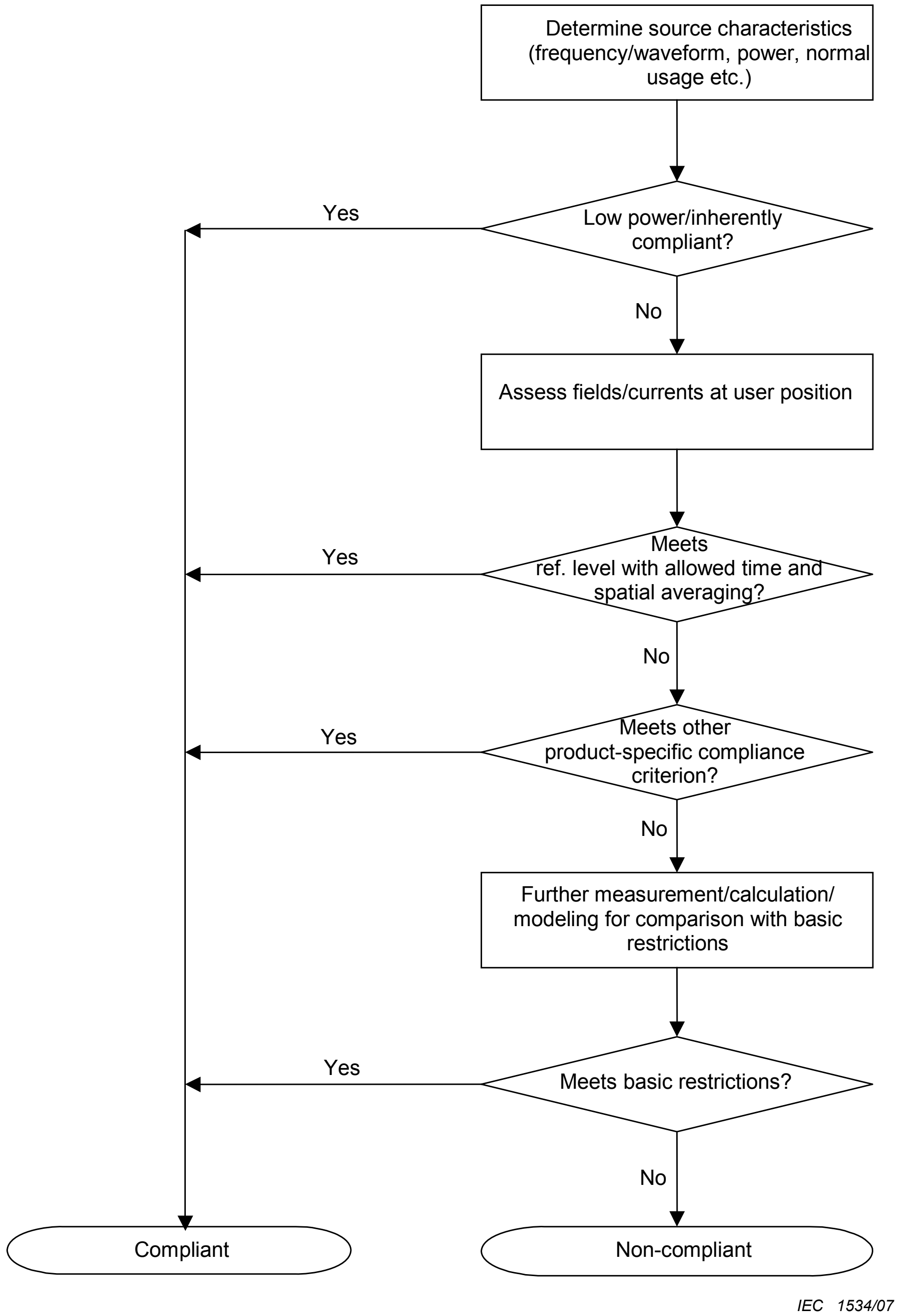


Figure 1 – Assessment flowchart

8 Sources with multiple frequencies

8.1 Introduction

Based on the technical characteristics of the products, the examples below gives guidance on which procedure is the most appropriate. Not all the procedures would normally be applicable to a product. If the sources are independent (phase non-coherent source) the possibility that these exposures will be additive in their effects must be considered. To take effects from unstable signals in the low frequency range into account, the measurement time shall be sufficiently long. Calculations based on such additivity should be performed separately for each effect; thus separate evaluations should be made for thermal and electrical stimulation effects on the body.

In situations where sources are not independent (phase coherent sources) or the frequencies are harmonics of only one source the phase information is relevant. As examples there are two separate summation regimes for simultaneous exposure to fields for ICNIRP and IEEE. For other limits the same principles may be used.

For ICNIRP there are two separate summation regimes of different frequencies: 1 Hz – 10 MHz for stimulation effects and 100 kHz – 300 GHz for thermal effects. Additivity should be examined separately for the effects of thermal and electrical stimulation, and the basic restriction should be met.

For IEEE there are two separate summation regimes of different frequencies: 0 Hz – 5 MHz for stimulation effects and 3 kHz – 300 GHz for thermal effects.

8.2 Frequency range from 1 Hz – 10 MHz (ICNIRP-based)

8.2.1 Frequency domain assessment

For investigation in the frequency domain, it is most realistic to include relative phase. This can be achieved by using a waveform capture approach with *post hoc* Fourier analysis. This procedure is applicable if there is only line spectra in the signal, for example for magnetic fields having a fundamental frequency and some harmonics.

In this frequency range the underlying basic restriction is induced current density or in situ electric field. The basic-restriction-based summations may or may not include consideration of phase. The most conservative is to neglect phase information.

Therefore, as a worst case assumption, multiple current densities/in situ electric fields at different frequencies or measured field values should be evaluated according to the following formulas:

$$\sum_{i=1\,\text{Hz}}^{10\,\text{MHz}} \frac{J_i}{J_{\text{L},i}} \leq 1$$

where

J_i is the current density at frequency i;

$J_{\text{L},i}$ is the current density basic restriction at frequency i.

When electric and magnetic field strengths are measured, the exposures should be summed according to these formulas:

$$\sum_{i=1\,\text{Hz}}^{1\,\text{MHz}} \frac{E_i}{E_{\text{L},i}} + \sum_{i>1\,\text{MHz}}^{10\,\text{MHz}} \frac{E_i}{a} \leq 1$$

and $$\sum_{j=1\text{Hz}}^{65\text{ kHz}} \frac{H_j}{H_{\text{L},j}} + \sum_{j>65\text{ kHz}}^{10\text{ MHz}} \frac{H_j}{b} \le 1$$

where

E_i is the electric field strength at frequency i;

$E_{\text{L},i}$ is the electric field strength reference level at frequency i;

H_j is the magnetic field strength at frequency j;

$H_{\text{L},j}$ is the magnetic field strength reference level at frequency j;

a is 87 V/m;

b is 5 A/m (6,25 μT).

For contact current, the following requirements should be applied:

$$\sum_{k=10\text{MHz}}^{110\text{ MHz}} \left(\frac{I_k}{I_{\text{L},k}}\right)^2 \le 1, \sum_{n=1\text{Hz}}^{10\text{MHz}} \frac{I_n}{I_{\text{C},n}} \le 1, \sum_{n=100\text{ kHz}}^{100\text{MHz}} \left(\frac{I_n}{I_{\text{C},n}}\right)^2 \le 1$$

where

I_k is the limb current at frequency k;

$I_{\text{L},k}$ is the reference revel for limb current at frequency k ;

I_n is the contact current component at frequency n;

$I_{\text{C},n}$ is the reference level for contact current at frequency n.

Most values and formulas presented above are based on ICNIRP Guidelines [1].

NOTE 1 The values a and b are only examples.

The pure summation always results in an overestimation of the exposure and for broadband fields consisting of higher frequency harmonic components or noise, the limitation based on summation formula is very conservative because the components do not have the same phase.

NOTE 2 Further guidance on the summation of relative phases can be found in the ICNIRP statement "Guidance on determining compliance of exposure to pulsed and complex non-sinusoidal waveforms below 100 kHz with ICNIRP guidelines" [7].

Nevertheless, using most measurement equipment, the relative phases are not measured (for example if a spectrum analyser is used), but an r.m.s. summation of frequency components can be undertaken. This will usually give a more realistic outcome than neglecting phase information completely. Examples for the r.m.s. evaluation are:

$$H = \sqrt{\sum_{n=1}^{n=k} \left(\frac{H_n}{H_{\text{L},n}}\right)^2} \quad \text{and} \quad E = \sqrt{\sum_{n=1}^{n=k} \left(\frac{E_n}{E_{\text{L},n}}\right)^2}$$

where

H_n, E_n is the magnitude of the n^{th} Fourier component of the exposure waveform in the same quantity as $H_{\text{L},n}, E_{\text{l}n;}$

$H_{\text{L},n}, E_{\text{L}n}$ is the maximum permissible exposure value of the E-field or H-field with a single sinusoidal waveform at frequency f_{n};

K is the maximum frequency to be considered.

8.2.2 Time domain assessment

In general for all kinds of signals (e.g., broadband, non-sinusoidal) a physical measurement system (time domain assessment), which incorporates a "weighting circuit", is applicable. The measurement will be done in the time domain, but the measured signal will be frequency depended evaluated. Typical examples for broadband sources are electric motors and power staplers.

For comparison with the given exposure levels, the weighting circuit should have a frequency response (transfer function A), which matches the frequency response of the exposure standard (function V) so that the weighting and summation of spectral components happens in the time-domain.

NOTE 1 Further guidance on the restriction of weighted field values can be found in the ICNIRP statement "Guidance on determining compliance of exposure to pulsed and complex non-sinusoidal waveforms below 100 kHz with ICNIRP guidelines" [7]. This approach is based on the restriction of the weighted peak value of a broadband field. The weighting function has been derived from the reference levels as a function of frequency. The weighted peak restriction can be applied for periodic non-sinusoidal waveforms where the mutual phases of harmonic components do not vary significantly.

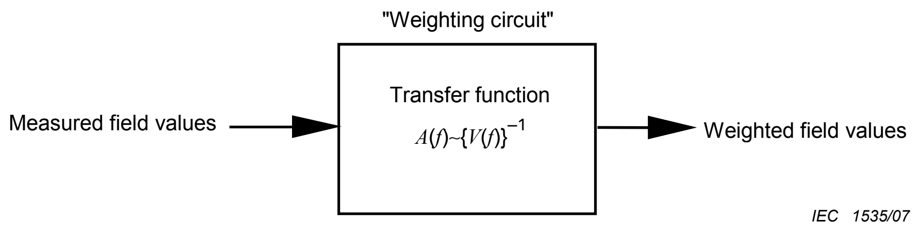


Figure 2 – Schematic of "weighting circuit"

EXAMPLE: Deduction of the transfer function A from the dependency on frequency f of the limits

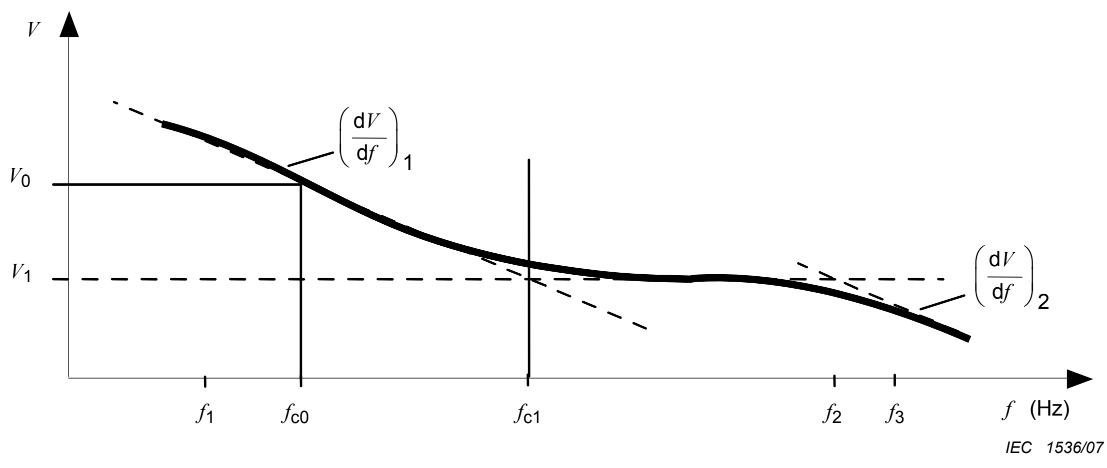


Figure 3 – Dependency on frequency of the reference levels V plotted with smoothing edges

with $V(f_{C0}) = V_0$, $V(f_{C1}) = V_1$ and the gradients $\left(\frac{dV}{df}\right)_n$

The transfer function A in Figure 3 is the on V_0 normalized inverse of the reference level V. The normalization shall be done at the frequency f_{C0} which is the scaling frequency of the equipment (e.g. 50 Hz or 60 Hz).

The transfer function A shown in Figure 4 shall have the following characteristics (shown in double logarithmic scale) and shall be realized with a first order filter:

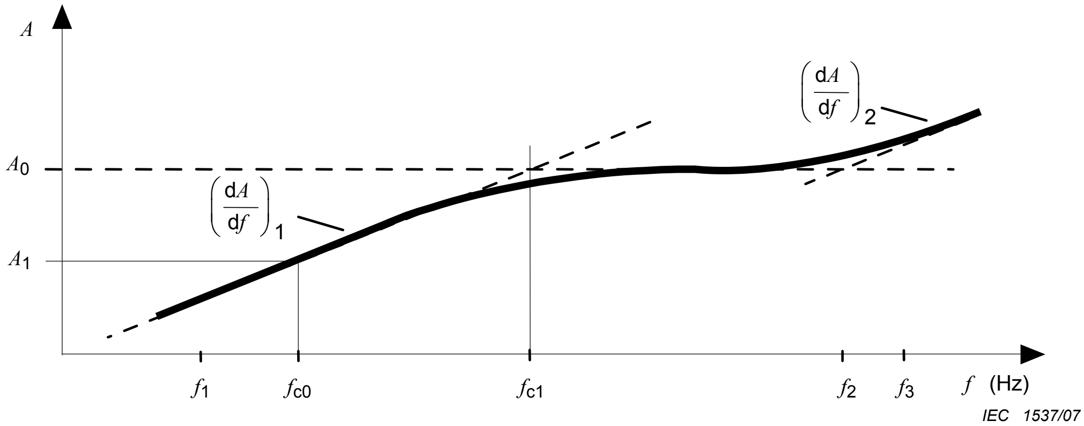


Figure 4 – Transfer function A

$$A(f) = \frac{V(f_{C0})}{V(f)}$$

For the transfer function the following shall be suitable:

$$A(f_{C0}) = A_0 = \frac{V(f_{C0})}{V_0} = 1, \qquad A(f_{C1}) = A_1 = \frac{V(f_{C0})}{V_1},$$

and for the gradients

$$\left(\frac{\mathrm{d}A}{\mathrm{d}f}\right)_n = \left[\left(\frac{\mathrm{d}V}{\mathrm{d}f}\right)_n\right]^{-1}$$

Examples for measurement of the magnetic flux density (for other quantities similar procedures are applicable):

The reference level $B_{RL}(f)$ based on ICNIRP can be used to calculate the transfer function as follows:

$$V(f) := B_{RL}(f)$$

(f_1 = 10 Hz) $\leq f \leq$ (f_{C1} = 800 Hz):

$$A(f) = \frac{B_{RL}(f_{C0} = 50\ \text{Hz})}{B_{RL}(f)} = \frac{\frac{5\,000}{50}\ \mu\text{T}}{\frac{5\,000}{f}\ \mu\text{T s}} = \frac{f}{50\ \text{Hz}}$$

(f_{C1} = 800 Hz) $\leq f \leq$ (f_2 = 150 kHz):

$$A(f) = \frac{B_{RL}(f_{C0} = 50\ \text{Hz})}{B_{RL}(f)} = \frac{\frac{5\,000}{50}\ \mu\text{T}}{6{,}25\ \mu\text{T}} = 16$$

$(f_2 = 150 \text{ kHz}) \le f \le (f_{n=3} = 400 \text{ kHz})$: $$A(f) = \frac{B_{\text{RL}}(f_{C0} = 50 \text{ Hz})}{B_{\text{RL}}(f)} = \frac{\frac{5\,000}{50}\,\mu\text{T}}{\frac{920\,000}{f}\,\mu\text{Ts}} = \frac{f}{9{,}2 \text{ kHz}}$$

The actual measured value of the magnetic flux density B shall be compared with the maximum permissible exposure value $B_{\text{RL}}(f)$ at frequency f_{C0} (A_0 = 1):

$$\frac{B}{B_{\text{RL}}} \le 1$$

where

B is the actual measured value with proper normalisation with transfer function (see Figure 2);

B_{RL} is the maximum permissible exposure value at frequency f_{C0} in the same quantity as B. If B is a r.m.s. value, it should be r.m.s., otherwise peak.

NOTE 2 For measurement of short duration fields (< 1s) an instrument with peak-hold function is recommended. The automatic range selection if any should be switched off.

8.3 Frequency range from 100 kHz – 300 GHz (ICNIRP-based)

In this frequency range, the exposure standard is based on the avoidance of thermal effects. The basic restrictions are on SAR and power density, and summation of these quantities should follow the formula

$$\sum_{i = 100 \text{ kHz}}^{10 \text{ GHz}} \frac{SAR_i}{SAR_{\text{L}}} + \sum_{i > 10 \text{ GHz}}^{300 \text{ GHz}} \frac{S_i}{S_{\text{L}}} \le 1$$

where SARs can be for the whole body or part of body. Partial-body SARs should be summed together; whole body SARs should be summed together. Partial body should not be summed with total body.

where

SAR_i is the SAR caused by exposure at frequency i;

SAR_{L} is the SAR basic restriction;

S_i is the power density at frequency i;

S_{L} is the power density basic restriction.

Exposure field strengths can be compared to the reference levels on an rss basis:

$$\sum_{i = 100 \text{ kHz}}^{1 \text{ MHz}} \left(\frac{E_i}{c}\right)^2 + \sum_{i > 1 \text{ MHz}}^{300 \text{ GHz}} \left(\frac{E_i}{E_{\text{L},i}}\right)^2 \le 1$$

and $$\sum_{i = 100 \text{ kHz}}^{1 \text{ MHz}} \left(\frac{H_i}{d}\right)^2 + \sum_{i > 1 \text{ MHz}}^{300 \text{ GHz}} \left(\frac{H_i}{H_{\text{L},i}}\right)^2 \le 1$$

where

E_i is the electric field strength at frequency i;

$E_{\text{L},i}$ is the electric field reference level;

H_i is the magnetic field strength at frequency i;

$H_{L,i}$ is the magnetic field reference level ;

c is 87/f½ V/m (f in MHz);

d is 0,73/f A/m (f in MHz).

The summation formula for limb current is:

$$\sum_{k=10\text{ MHz}}^{110\text{ MHz}} \left(\frac{I_k}{I_{L,k}} \right) \leq 1$$

where

I_k is the limb current component at frequency k;

$I_{L,k}$ is the reference level for limb current, 45 mA.

All values and formulas above are based on the ICNIRP Guidelines [1].

NOTE The values c and d are only examples.

Under this thermal summation regime, the relative phases of the spectral components can be neglected.

8.4 Frequency range from 0 kHz – 5 MHz (IEEE-based)

8.4.1 Frequency domain assessment

The summation is carried out from the lowest frequency of the exposure waveform, to a maximum frequency of 5 MHz. Note that N_i and ME_i must measure the same quantity, as well as be in the same units.

For instance, if N_i is the magnitude of a flux density waveform, then ME_i must also be a measure of flux density. Alternatively, both N_i and ME_i could be measures of the time derivative of the field, the induced *in situ* electric field, or induced current density.

$$\sum_{i=0\text{ Hz}}^{5\text{ MHz}} \frac{N_i}{ME_i} \leq 1$$

where

N_i is the magnitude of the i^{th} Fourier component of the exposure waveform in the same quantity as ME;

ME_i is the maximum permissible exposure or the basic *in situ* field restriction with a single sinusoidal waveform at a frequency f_i.

NOTE The Formula is based on the IEEE Std C95.6™-2002. For further explanation refer to the mentioned document.

8.4.2 Time domain assessment

The time domain valuation in 8.2.2 can also be applied for IEEE. In this case, the transfer function for the IEEE reference level $B_{RL}(f)$ has to be calculated as follows:

(f_1 = 10 Hz) ≤ f ≤ (f_{C1} = 20 Hz):
$$A(f) = \frac{B_{RL}(f_{C0} = 60\text{ Hz})}{B_{RL}(f)} = \frac{0{,}904\ \mu\text{T}}{\frac{18{,}1}{f}\ \mu\text{Ts}} = \frac{f}{20\text{ Hz}}$$

(f_{C1} = 20 Hz) ≤ f ≤ (f_2 = 759 Hz):
$$A(f) = \frac{B_{RL}(f_{C0} = 60\text{ Hz})}{B_{RL}(f)} = \frac{0{,}904\ \mu\text{T}}{0{,}904\ \mu\text{T}} = 1$$

(f_2 = 759 Hz) ≤ f ≤ (f_3 = 3,35 kHz):
$$A(f) = \frac{B_{RL}(f_{C0} = 60\text{ Hz})}{B_{RL}(f)} = \frac{0{,}904\ \mu\text{T}}{\frac{687}{f}\ \mu\text{Ts}} = \frac{f}{759\text{ Hz}}$$

(f_3 = 3,35 kHz) ≤ f ≤ (f_4 = 100 kHz):
$$A(f) = \frac{B_{RL}(f_{C0} = 60\text{ Hz})}{B_{RL}(f)} = \frac{0{,}904\ \mu\text{T}}{0{,}205\ \mu\text{Ts}} = 4{,}41$$

(f_4 = 100 kHz) ≤ f ≤ ($f_{n=5}$ = 400 kHz):
$$A(f) = \frac{B_{RL}(f_{C0} = 60\text{ Hz})}{B_{RL}(f)} = \frac{0{,}904\ \mu\text{T}}{\frac{20{,}5}{f}\ \text{Ts}} = \frac{f}{22{,}68\text{ kHz}}$$

NOTE All frequencies f used above are in Hz.

8.5 Frequency range from 3 kHz – 300 GHz (IEEE-based)

When multiple sources are introduced into an environment, it becomes necessary to address the sources interdependently, since each source will contribute some percentage of the ME toward the total exposure at a fixed location. The sum of the ratios of the exposure from each source (expressed as a plane-wave equivalent power density) to the corresponding ME for the frequency of each source is evaluated. The exposure complies with the ME if the sum of the ratios is less than unity, i.e.,

$$\sum_{i=1}^{n} \frac{S_{E_i}(duty\,factor)}{MPE_{E_i}} < 1$$

and

$$\sum_{i=1}^{n} \frac{S_{H_i}(duty\,factor)}{MPE_{H_i}} < 1$$

NOTE The corresponding MEs must be expressed in terms of power density in the above summation or in terms of the field strength squared.

NOTE The formula is based on the IEEE Std C95.1™-2005 [3]. For further explanation refer to the mentioned document.

9 Assessment report

9.1 General

The results of each assessment, 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 an assessment report, and shall include all the information necessary for the interpretation of the assessment, test or calibration results and all information required by the used method.

All the information needed for performing repeatable assessments, tests, calculations, or measurements shall be recorded.

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

9.2 Items to be recorded in the assessment report

9.2.1 Assessment method

The assessment method selected shall be recorded including the rationale (see Clause 5) for the choice.

9.2.2 Presentation of the results

The presentation of the results shall include the following:

- description of the equipment / Serial number if applicable;
- testing conditions (temperature, etc.) if applicable;
- operating conditions;
- results of validation check on assessment method;
- measurement uncertainty;
- results of each assessment performed;

9.2.3 Equipment using external antennas

The technical specification of an external antenna shall be documented in detail such that the boundary where the basic restrictions are met can be identified e.g., by documented radiation patterns. The characteristics of the transmitter shall also be documented (e.g., output power, frequency, modulation etc.).

10 Information to be supplied with the equipment

The manufacturer shall provide all necessary information with the product with regard to the safe use. If documentation for repair and maintenance is prepared, the document shall also include special precautions if needed during repair/maintenance.

Annex A
(informative)

Field calculation

A.1 Purpose

This annex contains the background on “electromagnetic field calculation" including the justification of the boundaries between field regions and some supporting information for the formulas used in the calculation methods.

A.2 Far-field region

The field calculation does not take into account the antenna size, which is assumed to be a point source. An ideal isotropic antenna is used as a reference to compare the performance of practical antennas: P watts is radiated, from a point, uniformly over the surface of sphere of radius r.

The Pointing vector gives the power density: $S = E \times H = \frac{E^2}{\eta} = \frac{P}{4\pi r^2}$

In free space:

$$E = \eta_0 H = \frac{\sqrt{30 P G(\theta,\phi)}}{r}$$

where

G is the antenna gain relative to an isotropic antenna;

θ, ϕ are elevation and azimuth angles to point of investigation;

r is the distance from observation point to the antenna;

η_0 is the characteristic impedance of free space.

A.3 Radiating near-field region

Real antennas have finite dimensions (not a point source).

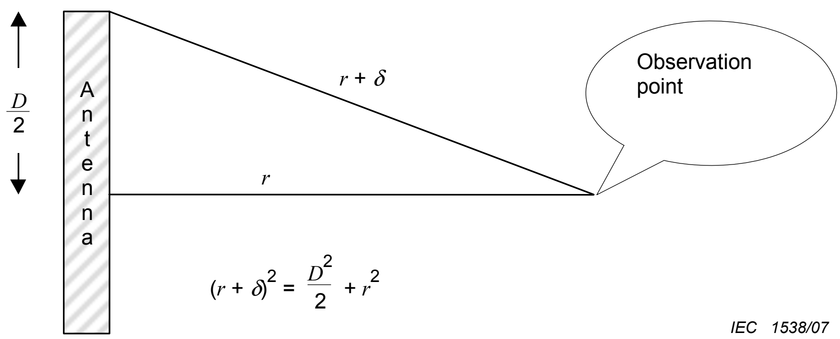


Figure A.1 – Geometry of antenna with largest linear dimension *D*

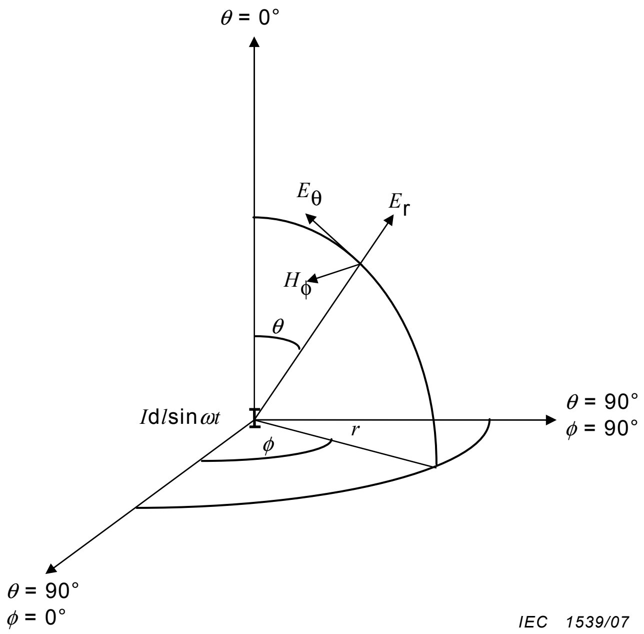
The phase difference between the signals from the end of the antenna and those from the centre is a function of the path difference δ (see Figure A.1. When δ is greater than the Rayleigh criterion of $\lambda/16$ this phase difference will significantly modify the signal level at the point of investigation. Thus, when $r \le \frac{2D^2}{\lambda}$ free space conditions from a point source no longer apply. If r becomes very small the reactive near-field conditions are significant, see Figure A.3 below.

This requires that the boundary for the radiating near-field region be defined by: $\frac{\lambda}{4} < r \le \frac{2D^2}{\lambda}$.

If the antenna is very short, $2D^2/\lambda$ may be less than $\lambda/4$, in which case the radiating near field region will be inside the reactive near field region.

A.4 Reactive near field region

Electromagnetic field equations for complicated antenna systems can be derived from fields produced by an oscillating current $I \sin\omega t$ in a short linear element (see Figure A.2):



$H_\phi = \psi(1 - \alpha)$
$E_\theta = \eta\psi\,(1 - \alpha + \alpha^2)$
$E_r = 2\eta_0\psi\cot(\theta)(\alpha - \alpha^2)$

where $\Psi = \frac{\mathrm{IdIsin}\theta}{2\lambda\,\mathrm{r}}\mathrm{e}^{-j\omega\left(t-\frac{r}{c}\right)}$ and $\alpha = \frac{\mathrm{j}}{\beta\mathrm{r}}$

H_ϕ = magnetic field
E_θ = electric field
E_r = radial electric field
I = elemental current, A
dl = element length, m
ω = 2πf, rads/s (f = frequency, Hz)
β = $2\pi/\lambda$, m^{-1}

Figure A.2 – Current element *I*d*l*sin(ωt) at the origin of spherical coordinate system

α represents induction and α^2 represents electrostatic near-fields of the reactive near field terms. The energy represented by these terms circulates (ebbs/flows) around the source, i.e., it does not propagate outwards towards infinity.

To determine the difference between the non-radiative and radiative components the following analysis can be performed.

For H^2 values only, summing the real and imaginary components and dividing by the radiated component gives:

$$\left\|\frac{\psi(1-\alpha)}{\psi}\right\|^2 = \|1-\alpha\|^2 = \left\|1-j(\frac{\lambda}{2\pi\ r})\right\|^2 = 1+\frac{\lambda^2}{4\pi^2 r^2}$$

For E^2 values only when $\theta \Rightarrow 90°$ (i.e., antenna centre element bore sight) $E_r \Rightarrow 0$, taking real and imaginary components of E_θ dividing by radiated components we get:

$$\left\|\frac{\eta\psi(1-\alpha+\alpha^2)}{\eta\psi}\right\|^2 = \left\|1-\alpha+\alpha^2\right\|^2 = \left\|1-\frac{\lambda^2}{4\pi^2 r^2}-\mathrm{j}(\frac{\lambda}{2\pi\ r})\right\|^2 = 1-\frac{\lambda^2}{4\pi^2 r^2}+\frac{\lambda^4}{16\pi^4 r^4}$$

For $E \times H$ values: When $\theta \Rightarrow 90°$ (i.e., antenna centre element bore sight) $E_r \Rightarrow 0$, taking real and imaginary components of E_θ and H_ϕ dividing by radiated components we get

$$\left\|\frac{\eta\psi^2(1-\alpha)(1-\alpha+\alpha^2)}{\eta\psi^2}\right\| = \left\|1-2\alpha+2\alpha^2-\alpha^3\right\| = \left\|1-\frac{\lambda^2}{2\pi^2 r^2}-j(\frac{\lambda}{\pi}+\frac{\lambda^3}{8\pi^3 r^3})\right\| = \sqrt{1+\frac{\lambda^6}{64\pi^6 r^6}}$$

As can be seen, η and ψ terms cancel in the above ratios, thus there are no time or impedance terms present.

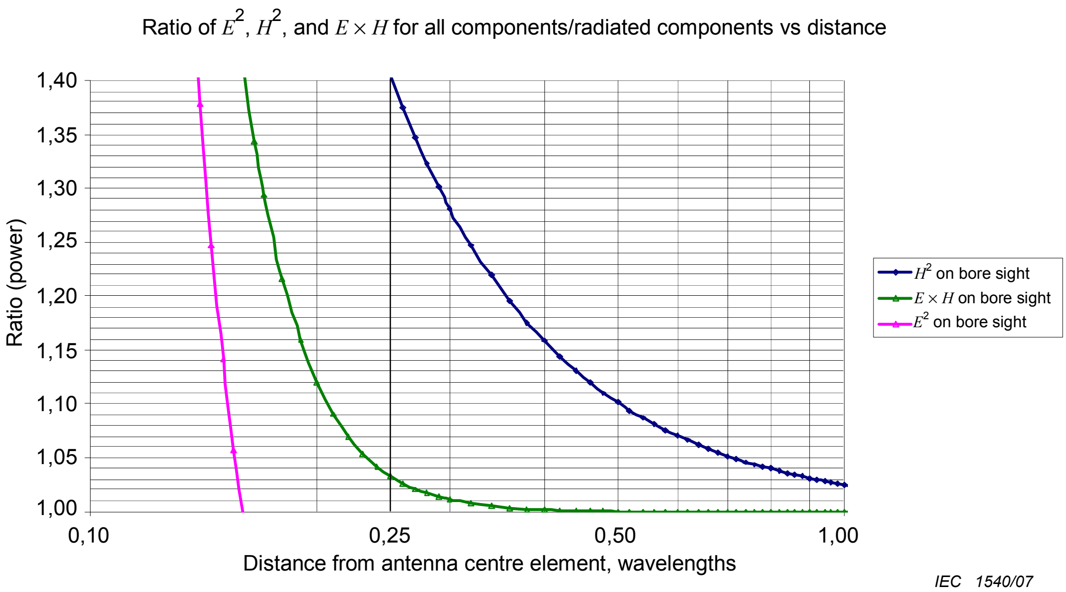


Figure A.3 – Ratio of E^2, H^2, and $E \times H$ field components

A.4.1 Typical antenna examples

Figure A.4 below shows three example antenna ratios for $E \times H$ between all field terms and radiated terms. The graphs were produced using a model based on a vector summation of the infinitesimal element wave equations. The 7 dipole array antenna and 12 dipole array antenna were modelled using the approximation of one infinitesimal increment per dipole. The single dipole antenna was divided into 15 equally spaced infinitesimal increments

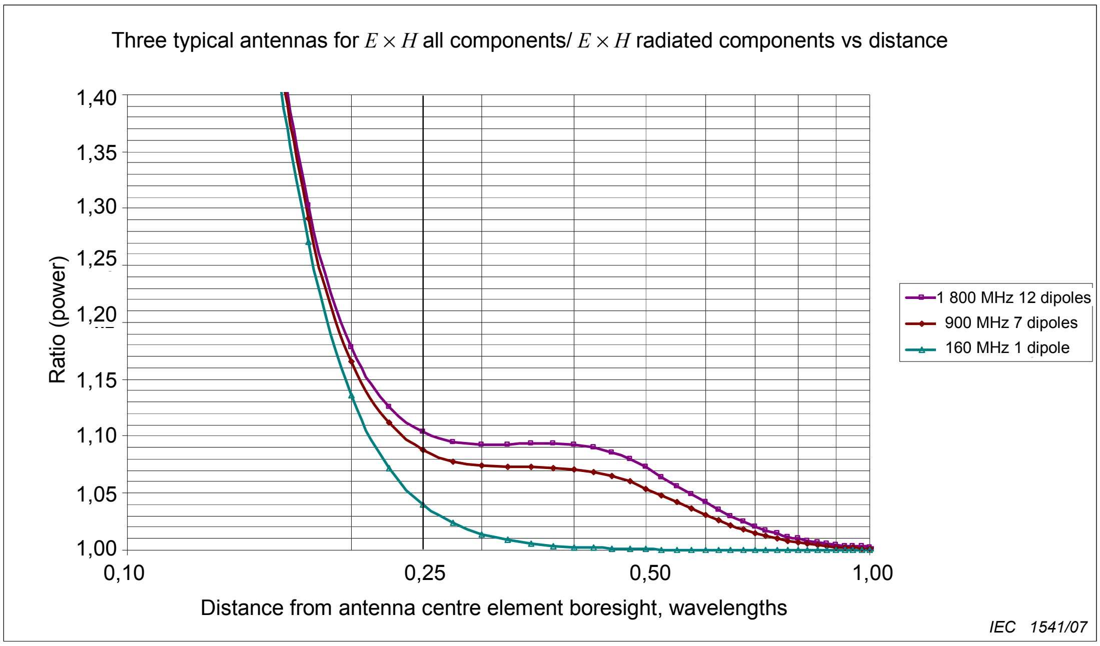


Figure A.4 – Ratio of $E \times H$ field components for three typical antennas

A.4.2 Discussion

From Figure A.4 it can be seen the ratio remains at 1,1 or less at distances greater than $\lambda/4$. Thus if a minimum calculation distance of $\lambda/4$ is used, the effective maximum difference between all field components and radiated field components would be 10 % or less, for the three example antennas.

A.4.3 Conclusion

The bore sight ratio of all components divided by radiated components for $E \times H$ is $\sqrt{1+\frac{\lambda^6}{64\pi^6 r^6}}$ at close distances to the antenna, giving the result that at a distance of $\lambda/2\pi$ from the antenna the power ratio is 1,41. Unlike the single dipole antenna case, for a multiple dipole antenna, as the distance from the antenna increases from $\lambda/2\pi$ other off centre dipoles contribute to the ratio (the radial E field), but as can be seen from Figure A.4 these increases are marginal.

It is recommended to use a distance of $\lambda/4$ as the boundary between the radiated near field and reactive near field for RF exposure compliance assessment.

NOTE This is especially the case when compared with the uncertainty of evaluating *SAR*.

A.5 Example of calculations within field regions at 900 MHz (see Figure A.5)

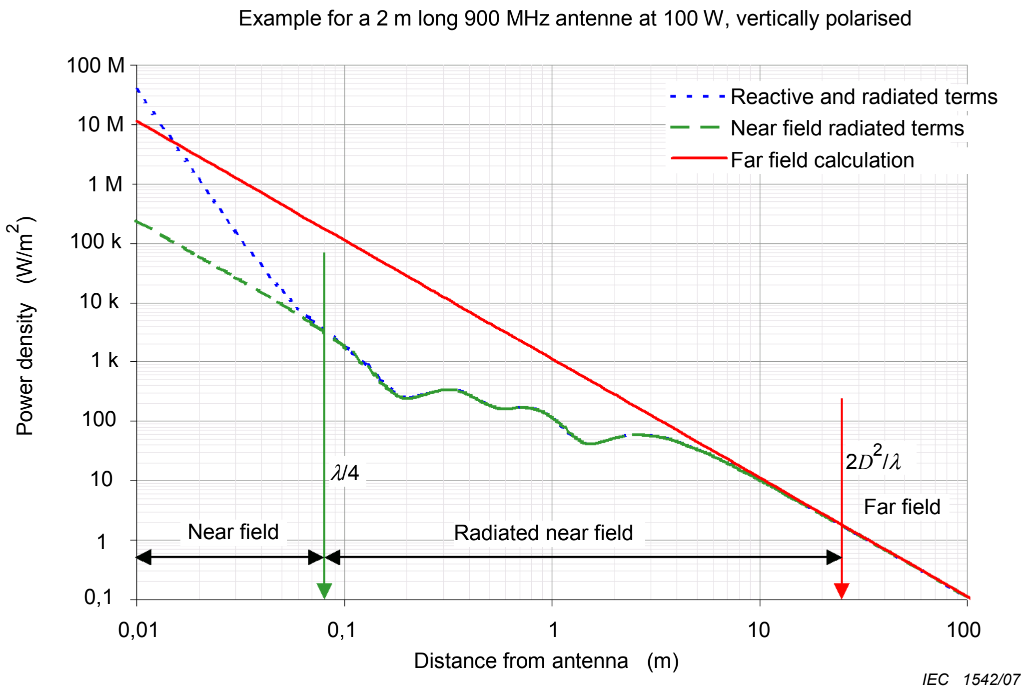


Figure A.5 – Far-field = straight line, radiated near-field = lower line & all near-fields = other line

Annex B
(informative)

SAR compliance assessment

B.1 Whole body *SAR*

B.1.1 Introduction

The current version of this standard does not include specifications for whole-body *SAR* measurements. Such measurements are for further study and will be described in later revisions of this standard.

Whole-body *SAR* measurements are not required for transmitters that have maximum output power levels too low to result in exposure levels that can reach the whole-body *SAR* compliance limits under any conditions. This section specifies whole-body *SAR* exclusion criteria.

SAR compliance can also be assessed by modelling, see Annex C.

B.1.2 Whole-body *SAR* implicit compliance

If the maximum radiated r.m.s. power emitted by EUT is less than the values specified in Table B.1, the maximum exposure will not exceed the whole-body averaged *SAR* compliance limits under any conditions and thus whole-body *SAR* measurements are not necessary.

Table B.1 – Determining whole-body *SAR* implicit compliance levels

Exposure category	Maximum radiated r.m.s. power W
General public	$P_{max} = SAR_{Wblimit} \times 12{,}5$
Occupational	$P_{max} = SAR_{Wblimit} \times 42$

- *Rationale for the whole-body SAR implicit compliance power levels*

The whole-body *SAR* implicit compliance levels have been derived based on the following assumptions:

a) all of the power emitted from the antenna is absorbed in the body (worst-case assumption);

b) the body masses for a 4-year-old child and a 16-year-old worker have been taken as 12,5 kg and 42 kg, respectively. This is the 3rd percentile body weight data for girls and women (conservative approach) (see Body weight data from the U.S. National Center for Health statistics [2]).

B.2 Localised *SAR*

This clause describes the procedure for measurements of the maximum localised *SAR* in a phantom model that simulates a person exposed to radio frequency fields emitted by an antenna. The measurement protocol described here shall be used to verify that equipment under test (EUT) is in compliance with the localised *SAR* limits at a specified distance.

[2] http://www.cdc.gov/nchs/about/major/nhanes/growthcharts/charts.htm

It can also be used to determine the compliance distance for a certain output power level or to determine the maximum output power level to meet a compliance distance requirement.

Since the available information about localised *SAR* measurement methodologies is limited, the procedure is valid only for the following conditions:

a) the separation between the phantom and the outer surface of the radiating structure shall be 40 cm or less;

b) the size of the radiating structure surface shall be less than 60 cm by 30 cm;

c) the frequency shall be in the range from 30 MHz to 3 000 MHz.

If these conditions are not met, assessments of field strength or power density in air shall be performed.

Since the recommended *SAR* limits for the limbs are five times higher than for the head and trunk, measurements of *SAR* in the limbs are not considered. The size of the phantom described in this section has been chosen to correspond to the trunk of an adult man. The phantom is shaped like a box in order to simplify the measurements and the manufacturing of the phantom. The absorption by a box shaped phantom is at least as high as in an anatomically shaped body model.

The same tissue-simulating liquids specified for *SAR* measurements of handheld mobile phones (see IEC 62209-1 [1] [3)]) have also been selected for this standard. The rationale for this is that dielectric parameters of the skin and muscle tissues, which are normally most exposed, are close to those specified for head tissue. This also means that the measurement results are relevant also for head exposure, and that only one set of tissue recipes are needed for *SAR* testing of mobile, portable or fixed EUTs.

Reference [2] indicates that the homogeneous phantom model specified in this standard may give localised *SAR* values lower than the maximum values in a heterogeneous and anatomically realistic body model. Further studies are needed to verify these results and possibly develop a phantom that provides more accurate estimates of the true maximum localised *SAR*.

B.3 Reference documents

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

[2] GEDDES, LA and BAKER, LE., ICRP 66 (1994), International Commission for Radiological Protection, 1994. The Specific Resistance of Biological Material – A Compendium of Data for the Biomedical Engineer. *Medical and Biological Engineering*, 1967, Vol. 5, pp 271-293.

[3)] Figures in square brackets in this annex refer to the reference documents in Clause B.3

Annex C
(informative)

Information for numerical modelling

C.1 Introduction

This annex provides some information for numerical modelling purposes.

In Clauses C.2 through C.4 an overview of body models as well as numerical source models are shown.

Numerical calculation methods are listed in Clauses C.5 and C.6 which can be used for various calculations for compliance demonstration with reference and basic limits (like induced current density, power densities, *SAR* or fields) in combination with the introduced body and source models.

Examples for such calculation are given in the remaining clauses of Annex C.

Comparisons have been made between different models and methods, with varying degrees of correlation [1], [2][4)].

C.2 Anatomical models

During the drafting of this document, a number of anatomical models were identified. References to these, or the institution responsible for them, do not indicate that they are any more suitable or more accurate than other models are. The parameters and voxel size of the model can contribute significant uncertainties, which is why most models are scaled to match the ICRP Standard Man [3].

C.2.1 The Visible Human Project

The Visible Man data set is the first result of the Visible Human Project of the National Library of Medicine, 8600 Rockville Pike, Bethesda, Maryland, USA. It is a digital image data set of a complete human male and consists of computed tomographic and magnetic resonance scans as well as cyrosection images.

C.2.2 "MEET Man"

This is a processed version of the Visible Man data set to obtain a volume data set in voxel representation, which has then been segmented and classified into 40 different tissue types. This work was done by the Institute of Biomedical Engineering, University of Karlsruhe, Kaiserstrasse 12, D-76128 Karlsruhe, Germany.

C.2.3 "Hugo"

This anatomical 3D volume and surface data set is also based on the Visible Man information. The data is currently categorised into 40 types of tissue. The data is created in different forms, including a voxel set, useful for dosimetry. ViewTec, Schaffhauserstrasse 466, CH-8052 Zürich, Switzerland.

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4) Figures in square brackets in this annex refer to the reference documents in Clause C.8.

C.2.4 "Norman"

This model is a 3D array of voxels, each of which contains information on its discrete tissue type (or air). It is based on medical imaging data and has been categorised into 37 different tissue types and scaled to match the ICRP 66 Standard Man. This work was done by the National Radiological Protection Board (NRPB), Chilton, Didcot, Oxfordshire, UK.

C.2.5 University of Utah

This anatomically based voxel model of the human body was obtained from MRI scans of a male volunteer. It is categorised into 31 Tissue types and is scaled to match the ICRP 66 Standard Man.

C.2.6 University of Victoria

This is a voxel-based model categorised with up to 128 different tissues. This work has been done by The Applied Electromagnetics Group, Department of Electrical and Computer Engineering, University of Victoria, Victoria, B.C., Canada, V8W 3P6.

C.2.7 Brooks Air force Base

3-dimensional anatomical model produced from images from the Visible Human Project (National Library of Medicine Brooks Air Force Base, Texas).

Voxels are color coded for over 40 tissue types and assigned dielectric values.

C.2.8 Average Japanese male and female human models

These are the anatomically based voxel human models, which are obtained from MRI scans of Japanese male and female volunteers [4]. The volunteers have been selected in order to represent the average size of the Japanese people. Both models are segmented in 2 mm voxels and classified into 51 different tissue types.

This wok has been done by CRL (Communication Research Laboratory), the name of which has now been changed to NICT (National Institute of Information and Communications Technology), 4-2-1, Nukui-Kitamachi, Koganei, Tokyo 184-8795, Japan. These models are publicly available (See http://www.nict.go.jp).

C.2.9 Korean human model

This is based on magnetic resonance imaging (MRI) and partially computerized tomography (CT) scans of a male volunteer who meets well the national standard body [5, 6, 7]. The resolution of the head including the neck is 1 mm × 1 mm × 1 mm and that of the rest part of the body is 3 mm × 3 mm × 3 mm. It is classified into 29 different tissue types. Radio Technology Research Group, ETRI (Electronics and Telecommunications Research Institute), 161 Gajeong-dong, Yuseong-Gu, Daejeon, 305-350, Korea.

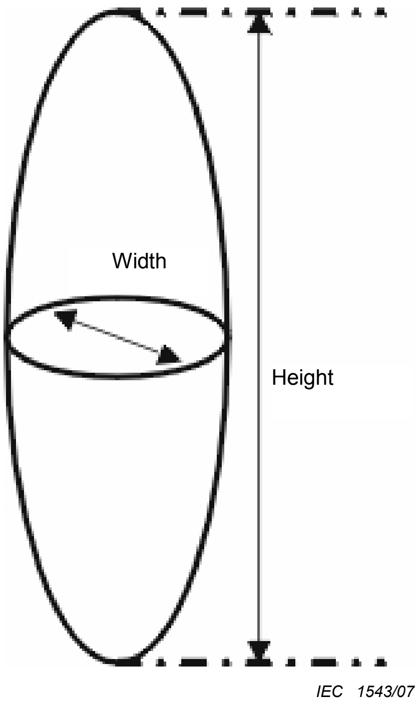
C.3 Simpler, homogeneous body models

In order to model the induced current density or other parameters such as power density, *SAR* and influence of fields, a simplified body shape of uniform conductivity can also be used. Suitable body models are prolate spheroids and homogeneous human bodies. Simple disks and cuboids are also often used as methods to validate a calculation as the geometry and the exposure situation is easier to model and to compare against known results or theory.

The dielectric properties of such a model are often the whole body average at the frequencies being investigated, but could, instead, be representative of particular body parts or tissue types which were being investigated. The results are highly dependant on the size of the model and these models tend to overestimate the current density when in the near field.

C.3.1 Spheroids

For different usages of the model, some dimensions are given as examples. They can be changed according to the specific exposure situation. Their height × width is given in mm (millimeters). See Figure C.1.



Torso: 600 mm × 300 mm

Head: 300 mm × 200 mm

Head+torso: 1 000 mm × 350 mm or 1 800 mm × 400 mm, 1 800 mm × 80 mm, 1 200 × 60 mm

Figure C.1 – Numerical model of a homogenous ellipsoid

The position of the model, e.g., height from the ground, should be according to the equivalent position of a human body for the exposure situation being assessed.

C.3.2 Cuboids

As body model, a homogeneous cuboid, see Figure C.2 with edge length d_x = d_y = 0,4 m, d_z = 1,8 m is given as an example for the usage for calculations. For different usages of the model the dimensions can be changed according the specific exposure situation.

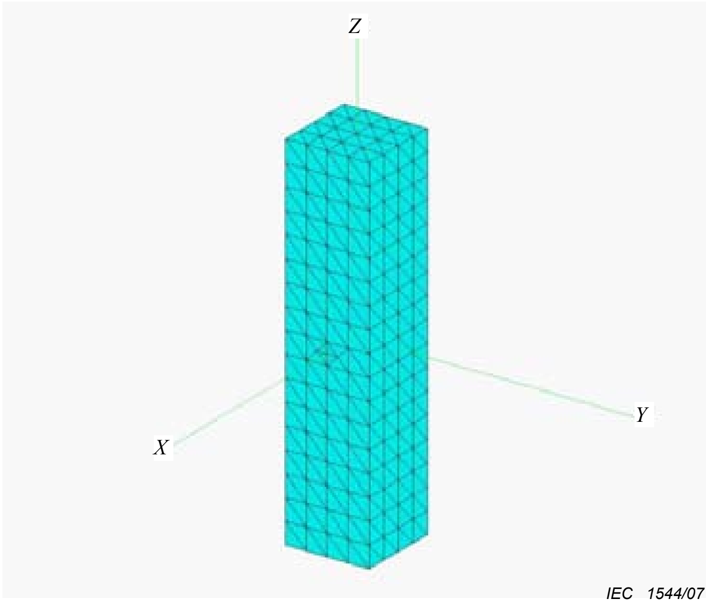


Figure C.2 – Numerical model of a homogenous cuboid

C.3.3 Homogenous human body models

More sophisticated are models reflecting more the real shape of a human body or a part of a human body, for example the homogenous body model in Figure C.3.a and Figure C.3.b (based on German Standard DIN 33 402, Part 2, 1986[5])

For different usages of the model, some dimensions (unit: mm) are given as examples. The dimension of the bottom part (600 mm) represents the half of axis of an ellipse.

All dimensions can be changed according to the specific exposure situation, i.e., dimension of the bottom part from 600 mm to 150 mm or 200 mm.

The position of the model, e.g. height from the ground, should be according to the equivalent position of a human body for the exposure situation being assessed.

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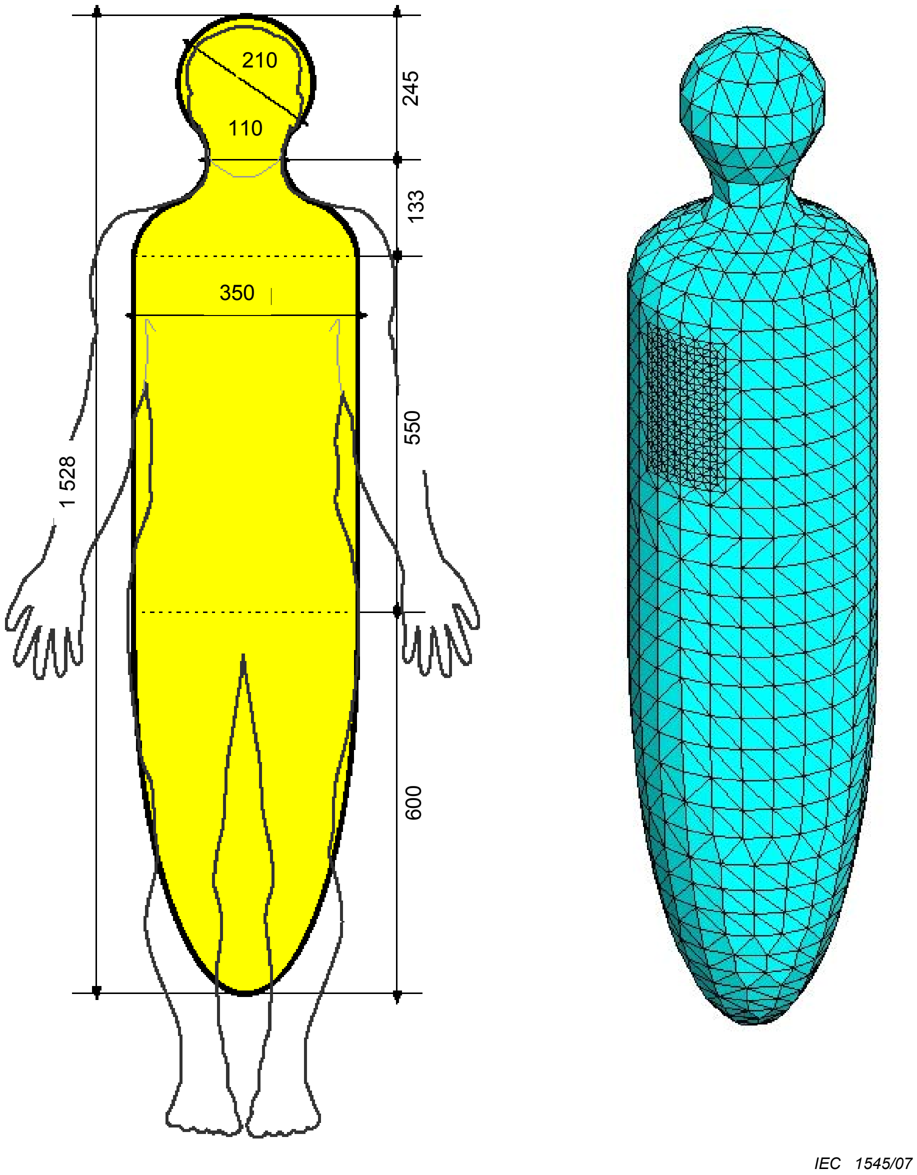
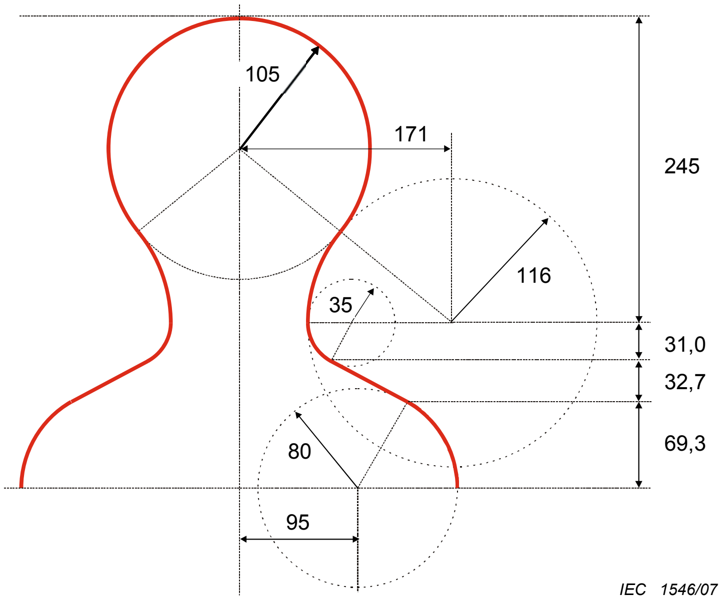
[5] DIN 33 402, Teil 2, *Körpermaße des Menschen, Werte*



Dimensions in millimeters

Figure C.3a — Description of the whole body



Dimensions in millimeters

Figure C.3b — Details of the construction of the head and shoulders

Figure C.3 – Numerical model of a homogenous human body

C.4 Electrical properties of tissue

There have been several investigations into the electrical characteristics of various tissue types [9, 10, 11]. In most cases, these were published for specific frequencies or ranges of frequencies. It has been shown that these properties vary with frequency and values have been interpolated between frequencies and tissue types when modelling. It is also possible that further interpolation and/or averaging of property values is required to match the exact tissue characterisation of particular anatomical models.

Gabriel, *et al.*, made an extensive evaluation of this in published papers and reports during 1995/1996. The work included new measurements, a comparison of existing literature and an algorithm to calculate the properties across a wide range of frequencies [12, 13, 14, 15]. This is generally accepted to be the most comprehensive work on the subject, at the date of issue of this standard. A significant proportion of current modelling work uses these values as a basis, supplementing them with information from previous work where appropriate. The uncertainties grow larger at the ends of the frequency range and this has to be taken into consideration. Further information can be found in the referenced document.

Work continues in this field, however, and this may produce new results in the future.

It must be noted that some tissue types are anisotropic (i.e., have different properties in different directions). It is not always possible to model this effect, however, and so an average (or similar) value is used in the model.

The tables of values provided here were obtained from calculations made by the Electromagnetic Wave Research Institute of the Italian National Research Council [16], based on the algorithms provided in the Gabriel report to the Brooks AFB. These tables are example values, which may be used or interpolated for numerical modelling purposes. More precise values, at specific frequencies, may also be obtained from the quoted references or work of a similar nature.

Table C.1 – Conductivity of tissue types

	Conductivity (S/m)									
Frequency	**10 Hz**	**100 Hz**	**1 kHz**	**10 kHz**	**100 kHz**	**1 MHz**	**10 MHz**	**100 MHz**	**1 GHz**	**10 GHz**
Tissue type										
Air	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Aorta	0,25	0,28	0,31	0,31	0,32	0,33	0,34	0,46	0,73	9,13
Bladder	0,20	0,21	0,21	0,21	0,22	0,24	0,27	0,29	0,40	3,78
Blood	0,70	0,70	0,70	0,70	0,70	0,82	1,10	1,23	1,58	13,13
Bone (cancellous)	0,08	0,08	0,08	0,08	0,08	0,09	0,12	0,17	0,36	3,86
Bone (cortical)	0,02	0,02	0,02	0,02	0,02	0,02	0,04	0,06	0,16	2,14
Bone (marrow)	0,00	0,00	0,00	0,00	0,00	0,00	0,01	0,02	0,04	0,58
Brain (grey matter)	0,03	0,09	0,10	0,11	0,13	0,16	0,29	0,56	0,99	10,31
Brain (white matter)	0,03	0,06	0,06	0,07	0,08	0,10	0,16	0,32	0,62	7,30
Breast fat	0,02	0,02	0,02	0,02	0,03	0,03	0,03	0,03	0,05	0,74
Cartilage	0,16	0,17	0,17	0,18	0,18	0,23	0,37	0,47	0,83	9,02
Cerebellum	0,05	0,11	0,12	0,13	0,15	0,19	0,38	0,79	1,31	9,77
Cerebro spinal fluid	2,00	2,00	2,00	2,00	2,00	2,00	2,00	2,11	2,46	15,38
Cervix	0,30	0,41	0,52	0,54	0,55	0,56	0,63	0,74	0,99	10,05
Colon	0,01	0,12	0,23	0,24	0,25	0,31	0,49	0,68	1,13	11,49
Cornea	0,41	0,42	0,42	0,44	0,50	0,66	0,87	1,04	1,44	11,33
Duodenum	0,51	0,52	0,52	0,53	0,54	0,58	0,78	0,90	1,23	13,31
Dura	0,50	0,50	0,50	0,50	0,50	0,50	0,54	0,74	0,99	8,58
Eye sclera	0,50	0,50	0,50	0,51	0,52	0,62	0,80	0,90	1,21	11,31
Fat	0,01	0,02	0,02	0,02	0,02	0,03	0,03	0,04	0,05	0,59
Gall bladder	0,90	0,90	0,90	0,90	0,90	0,90	0,90	1,01	1,29	12,53
Gall bladder bile	1,40	1,40	1,40	1,40	1,40	1,40	1,40	1,54	1,88	15,36
Heart	0,05	0,09	0,11	0,15	0,22	0,33	0,50	0,73	1,28	11,84
Kidney	0,05	0,10	0,11	0,14	0,17	0,28	0,51	0,81	1,45	11,57
Lens	0,26	0,26	0,26	0,27	0,28	0,30	0,43	0,56	0,83	8,53
Liver	0,03	0,04	0,04	0,05	0,08	0,19	0,32	0,49	0,90	9,39
Lung (deflated)	0,20	0,21	0,22	0,24	0,27	0,33	0,44	0,56	0,90	10,12
Lung (inflated)	0,04	0,07	0,08	0,09	0,11	0,14	0,23	0,31	0,47	4,21
Mucous membrane	0,00	0,00	0,00	0,00	0,07	0,22	0,37	0,52	0,88	8,95
Muscle	0,20	0,27	0,32	0,34	0,36	0,50	0,62	0,71	0,98	10,63
Nerve	0,02	0,03	0,03	0,04	0,08	0,13	0,22	0,34	0,60	6,03
Oesophagus	0,51	0,52	0,52	0,53	0,54	0,58	0,78	0,90	1,23	13,31
Ovary	0,31	0,32	0,32	0,33	0,34	0,36	0,46	0,75	1,34	9,82

Table C.1 *(continued)*

	Conductivity (S/m)									
Frequency	**10 Hz**	**100 Hz**	**1 kHz**	**10 kHz**	**100 kHz**	**1 MHz**	**10 MHz**	**100 MHz**	**1 GHz**	**10 GHz**
Tissue type										
Pancreas	0,05	0,10	0,11	0,14	0,17	0,28	0,51	0,81	1,45	11,57
Prostate	0,41	0,42	0,42	0,43	0,44	0,56	0,78	0,91	1,25	12,38
Skin (dry)	0,00	0,00	0,00	0,00	0,00	0,01	0,20	0,49	0,90	8,01
Skin (wet)	0,00	0,00	0,00	0,00	0,07	0,22	0,37	0,52	0,88	8,95
Small intestine	0,51	0,52	0,53	0,56	0,59	0,86	1,34	1,66	2,22	12,69
Spinal cord	0,02	0,03	0,03	0,04	0,08	0,13	0,22	0,34	0,60	6,03
Spleen	0,04	0,10	0,10	0,11	0,12	0,18	0,51	0,80	1,32	11,38
Stomach	0,51	0,52	0,52	0,53	0,54	0,58	0,78	0,90	1,23	13,31
Tendon	0,25	0,30	0,38	0,39	0,39	0,39	0,41	0,49	0,76	10,34
Testis	0,41	0,42	0,42	0,43	0,44	0,56	0,78	0,91	1,25	12,38
Thymus	0,51	0,52	0,52	0,53	0,54	0,60	0,72	0,79	1,08	12,13
Thyroid	0,51	0,52	0,52	0,53	0,54	0,60	0,72	0,79	1,08	12,13
Tongue	0,26	0,27	0,27	0,28	0,29	0,39	0,57	0,67	0,98	11,08
Trachea	0,30	0,30	0,30	0,31	0,34	0,37	0,46	0,55	0,80	8,54
Uterus	0,20	0,29	0,49	0,51	0,53	0,56	0,75	0,94	1,31	12,49
Vacuum	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
Vitreous humor	1,50	1,50	1,50	1,50	1,50	1,50	1,50	1,50	1,67	15,13

Table C.2 – Relative permittivity of tissue types

Frequency / Tissue type	100 kHz	1 MHz	10 MHz	100 MHz	1 GHz	10 GHz
Air	1	1	1,0	1,0	1,0	1,0
Aorta	930	218	109,5	59,8	44,6	32,7
Bladder	1 231	343	51,5	22,7	18,9	14,0
Blood	5 120	3 026	280,0	76,8	61,1	45,1
Bone (cancellous)	472	249	70,8	27,6	20,6	12,7
Bone (cortical)	228	145	36,8	15,3	12,4	8,1
Bone (marrow)	111	40	19,3	6,5	5,5	4,6
Brain (grey matter)	3 222	860	319,7	80,1	52,3	38,1
Brain (white matter)	2 108	480	175,7	56,8	38,6	28,4
Breast fat	71	24	7,9	5,7	5,4	3,9
Cartilage	2 572	1 391	179,3	55,8	42,3	25,6
Cerebellum	3 515	1 141	464,7	89,8	48,9	34,6
Cerebro spinal fluid	109	109	108,6	88,9	68,4	52,4
Cervix	1 751	448	179,7	60,3	49,6	37,7
Colon	3 722	1 679	271,5	81,8	57,5	41,9
Cornea	10 567	2 878	259,4	76,0	54,8	40,3
Duodenum	2 861	1 678	246,4	77,9	64,8	48,9
Dura	326	253	194,9	60,5	44,2	33,0
Eye sclera	4 745	2 178	208,3	67,9	55,0	41,5
Fat	93	27	13,8	6,1	5,4	4,6
Gall bladder	107	100	98,8	79,0	59,0	47,2
Gall bladder bile	120	120	119,5	95,0	70,0	55,9
Heart	9 846	1 967	293,5	90,8	59,3	42,2
Kidney	7 652	2 251	371,2	98,1	57,9	40,3
Lens	1 704	829	212,5	55,8	41,8	30,7
Liver	7 499	1 536	223,1	69,0	46,4	32,5
Lung (deflated)	5 145	1 171	180,3	67,1	51,1	38,0
Lung (inflated)	2 581	733	123,7	31,6	21,8	16,1
Mucous membrane	15 357	1 833	221,8	66,0	45,7	33,5
Muscle	8 089	1 836	170,7	66,0	54,8	42,8
Nerve	5 133	926	155,1	47,3	32,3	23,8
Oesophagus	2 861	1 678	246,4	77,9	64,8	48,9
Ovary	1 942	678	293,6	87,2	49,8	32,8
Pancreas	7 652	2 251	371,2	98,1	57,9	40,3
Prostate	5 717	2 683	246,9	75,6	60,3	45,2
Skin (dry)	1 119	991	361,7	72,9	40,9	31,3
Skin (wet)	15 357	1 833	221,8	66,0	45,7	33,5
Small intestine	13 847	5 676	488,5	96,5	58,9	42,0
Spinal cord	5 133	926	155,1	47,3	32,3	23,8
Spleen	4 222	2 290	440,5	90,7	56,6	40,6
Stomach	2 861	1 678	246,4	77,9	64,8	48,9
Tendon	472	160	103,2	53,9	45,6	29,3
Testis	5 717	2 683	246,9	75,6	60,3	45,2
Thymus	3 301	1 433	162,7	68,8	59,5	45,2
Thyroid	3 301	1 433	162,7	68,8	59,5	45,2
Tongue	4 746	2 178	208,3	67,9	55,0	41,5
Trachea	3 735	775	146,1	53,0	41,8	31,1
Uterus	3 411	1 168	321,6	80,0	60,8	45,3
Vacuum	1	1	1,0	1,0	1,0	1,0
Vitreous humor	98	84	70,0	69,1	68,9	57,9

C.5 Numerical source models

The following list of simple numerical source models represents the approximated non-uniform magnetic field distribution of the interested EUT (equipment under test). Not all simple source models are listed below, however, it gives an overview:

– straight wire;
– circular coil;
– rectangular coil;
– magnetic elementary dipole.

In this standard, the circular coil and straight wires (Y and Z directions) are used for the simple numerical sources. Furthermore, to simulate the exact non-uniform magnetic field distribution, the equivalent source model is applied.

C.5.1 Straight wire (Y and Z direction)

Figure C.4 shows the single straight wire in the Y and Z directions, which has a length of L and carries the current of I_Q. For example, if the length L of the straight wire (Z direction, lay on the Z axis and centred on origin point) is able to approximate to infinite length ($L \approx \infty$), the magnetic field value (H_x and H_y, $H_z = 0$) at a point (x, y, z: constant) can be calculated by Ampere's Law, according to the following equation [17].

$$H_x = \frac{-I_Q}{2\pi} \frac{y}{\left(x^2 + y^2\right)}$$

$$H_y = \frac{I_Q}{2\pi} \frac{x}{\left(x^2 + y^2\right)}$$

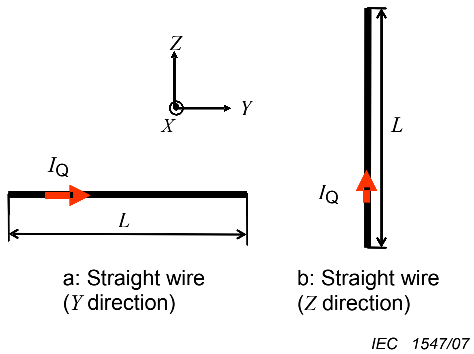


Figure C.4 – Schematic of straight wire

C.5.2 Circular coil

The following Figure C.5 shows the circular coil, which has a radius of r_{Coil} and is located on the YZ-plane (centred on the origin point) and carries the current I_{Q}. The magnetic field value (radial H_{r} and vertical H_{x}) at a point (x, y, z) around this circular coil, can be calculated by the following equation [17]:

$$H_{\text{r}} = \frac{I_{\text{Q}} k x}{4\pi\, r \sqrt{r_{\text{coil}} r}} \left(-K(k) \right) + \frac{r_{\text{coil}}^2 + r^2 + x^2}{\left(r_{\text{coil}} - r \right)^2 + x^2} E(k)$$

$$H_{\text{x}} = \frac{I_{\text{Q}} k}{4\pi\, r \sqrt{r_{\text{coil}} r}} \left(K(k) \right) + \frac{r_{\text{coil}}^2 + r^2 + x^2}{\left(r_{\text{coil}} - r \right)^2 + x^2} E(k)$$

with

$$k = \sqrt{\frac{4 r_{\text{coil}} r}{\left(r_{\text{coil}} + r \right)^2 + x^2}}$$

$$r = \sqrt{y^2 + z^2}$$

$$K(k) = \int_0^{\pi/2} \frac{1}{\sqrt{\left(1 - \kappa^2 \sin^2 \theta \right)}} \text{d}\theta$$

$$E(k) = \int_0^{\pi/2} \sqrt{\left(1 - \kappa^2 \sin^2 \theta \right)}\, \text{d}\theta$$

where K and E are elliptical integrals at the 1st and 2nd orders.

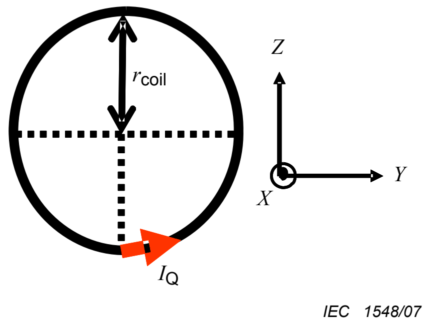


Figure C.5 – Schematic of circular coil

C.5.3 Equivalent source model

Applying the unique theorem of field theory and the Huygens principle, a distribution of fictive (equivalent) sources (e.g., magnetic elementary dipoles) can be found on (or inside) the surface of a volume to represent the real sources inside. This equivalent source model, allows the reproduction of complicated non-uniform magnetic field distributions around an equipment under test (EUT) with full generality (i.e., supports three-dimensional vector fields). Figure C.6 shows a block diagram of the method proposed:

First, the magnetic flux density (magnitude and phase) is measured on a surface (e.g., a cylinder) around the EUT at the frequency of interest, e.g., by using the “3D-scan” automatically measurement system [18, 19], which measures the magnetic field vectors with high accuracy.

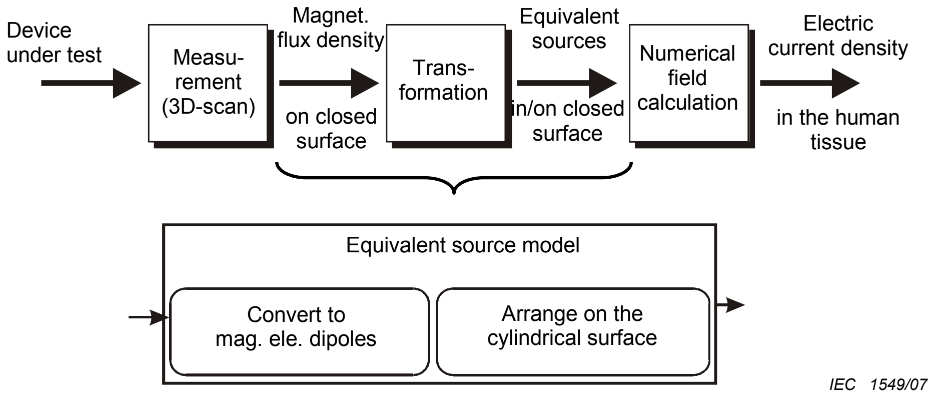


Figure C.6 – Block diagram of the method

In a second step, a numerical field transformation based on equation (C.1) is carried out. The N magnetic elementary dipoles are e.g., located on the surface of the cylinder, on which the magnetic field data have been collected. Consequently, this yields the unknown magnetic elementary dipole moments $\vec{m}_i$ instead of the measured magnetic fields $\vec{H}_{\text{measure}}(\vec{r})$. In the following linear equations, $\vec{r}$ is the observation point while $\vec{r}_0$, $\vec{r}_{0,\,i}$ represent the positions of the magnetic dipole moments.

$$\vec{H}_{\text{measure}}(\vec{r}) = \left\{ -\,grad\left(\frac{\vec{m}_i\left(\vec{r}-\vec{r}_{0,i}\right)}{4\pi\mu_0\left|\vec{r}-\vec{r}_{0,i}\right|^3} \right) \right\} \quad \text{with} \quad \vec{H}_{\text{d}}(\vec{r}) = -grad\left(\frac{\vec{m}\left(\vec{r}-\vec{r}_0\right)}{4\pi\mu_0\left|\vec{r}-\vec{r}_0\right|^3} \right) \qquad \text{(C.1)}$$

Calculating this linear equation numerical, the unknown magnetic dipole moments $\vec{m}_i$ will be solved. These dipole moments (equivalent source model) conduct the same three-dimensional magnetic field vectors around the DUT (outside the measured cylinder) with full generality. The detail of the numerical field transformation is described in the reference [20].

Finally, the equivalent source model is used within a numerical calculation, which determines for instance the induced electric current density inside the human body.

C.6 Numerical modelling methods

Any numerical method and any field calculation software package that is suitable for the models in Clause C.3 can be used for compliance demonstration with reference and basic limits.

Generally applied methods are:

- BEM (boundary element method);
- FDFD (finite difference frequency domain);
- FDTD (finite difference time domain);
- FEM (finite element method);
- FIT (finite integration technique);
- MoM (method of moments);
- SPFD (scalar potential finite difference);
- IP (impedance method).

If using RF software codes, the application of a frequency scaling method [21] is possible for induced electric current density calculation. For any magnetic source, the calculation can be carried out at a higher frequency f' (≤500 kHz to guarantee the quasi-stationary character of the field). For this calculation, the electric conductivity $\sigma(f)$ of tissue must be taken into account for the frequency f (not f'). This calculation yields the electric field strength E' at the frequency f'. Now, by scaling the electric field strength due to

$$\vec{E}(\vec{r}) = f/f' \cdot \vec{E}'(\vec{r}) \tag{C.2}$$

the values for the frequency of interest (f) can be determined. Finally, the electric current density can be evaluated by applying Ohm's law:

$$J(\vec{r}) = \sigma(r) \cdot E(\vec{r}) \tag{C.3}$$

For validation purposes of the methods, the calculation example in C.7.1 can be used.

C.7 Calculation examples

C.7.1 Current density calculation with cuboid and current loop

The situation depicted in Figure C.7 shall be considered. As body model, a homogeneous cuboid with edge length $d_x = d_y$ = 0,4 m, d_z = 1,8 m and an electric conductivity σ = 0,1 S/m shall be investigated at a frequency f = 50 Hz.

NOTE The application of the frequency scaling method [21] is possible.

As field source, a square loop with a current I = 1,0 A and an edge length of 50 mm shall be considered with a distance of 10 mm in front of the cuboid (see Figure C.7).

With the software tool to be used for the test procedure, the electric current density induced in the body model shall be calculated.

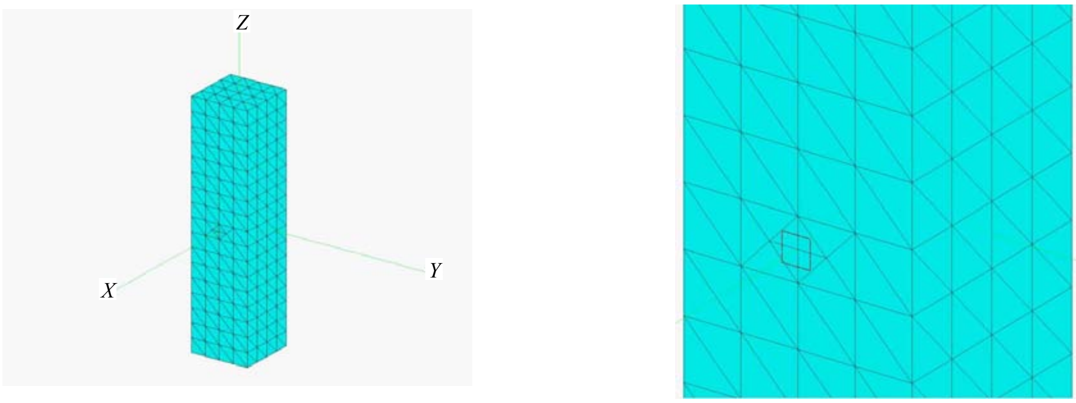


Figure C.7 – Test situation for validation – Current loop in front of a cuboid

The magnetic field source shall yield a maximum in situ electric field or electric current density inside the tissue in the range of

$$J_{\text{max}} = 0{,}1\ \frac{S}{m} \cdot 62{,}8 \frac{\mu\text{V}}{\text{m}} = 6{,}28\ \frac{\mu\text{A}}{\text{m}^2} \pm 10\ \% \qquad \text{(C.4)}$$

The value of J from formula C.4 represents the average of the calculation results of equations C.2 to C.4 derived with different calculation methods.

The factor of ±10 % includes all deviations of the approaches in the different software packages used (e.g., the minimum distance to the surface of the cuboid, for which a field calculation is possible).

References:

As references, the results determined by means of different software packages are given:

IP (impedance method, [22]):

$$J_{\text{max}} = 0{,}1\ \frac{S}{m} \cdot 63{,}8 \frac{\mu\text{V}}{\text{m}} = 6{,}38\ \mu\text{A/m}^2\,, \qquad \text{(C.5)}$$

FDTD (finite difference time domain method, [23]):

$$J_{\text{max}} = 0{,}1 \frac{S}{m} \cdot 63{,}2 \frac{\mu\text{V}}{\text{m}} = 6{,}32\ \mu\text{A/m}^2 \qquad \text{(C.6)}$$

SPFD (scalar potential finite difference method) [24]:

$$J_{\text{max}} = 0{,}1 \frac{S}{m} \cdot 61{,}3 \frac{\mu\text{V}}{\text{m}} = 6{,}13\ \mu\text{A/m}^2\,. \qquad \text{(C.7)}$$

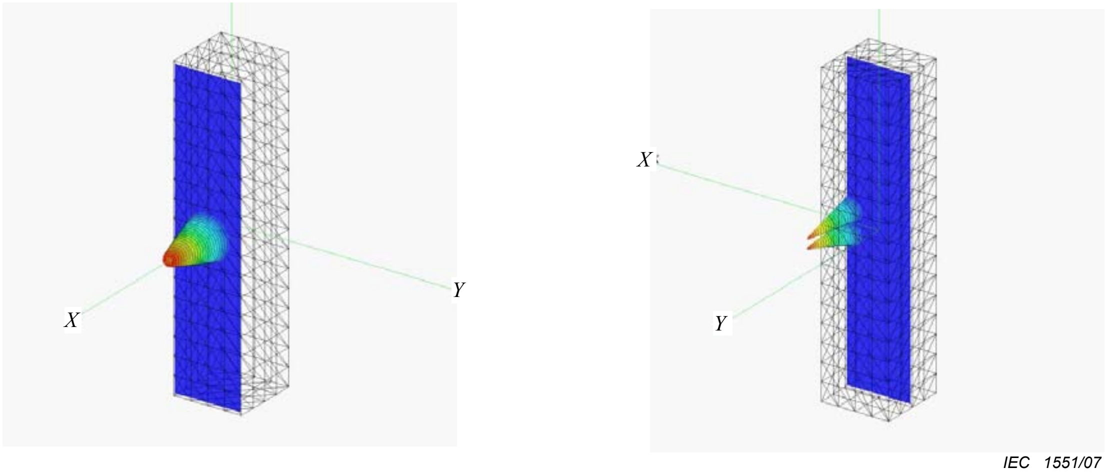


Figure C.8 – Distribution of the electric current density *J* in the planes x = + 0,20 m (left) and y = 0,0 m (right)

Additionally, the distribution of the electric current density J is given for the planes x = + 0,2 m (Figure C.8, left) and y = 0,0 m (Figure C.8, right). The colour scaling used is a logarithmic one, normalised on each maximum value and performing a dynamic range of 30 dB.

NOTE The FDTD-based software package EMPIRE [23] has been used.

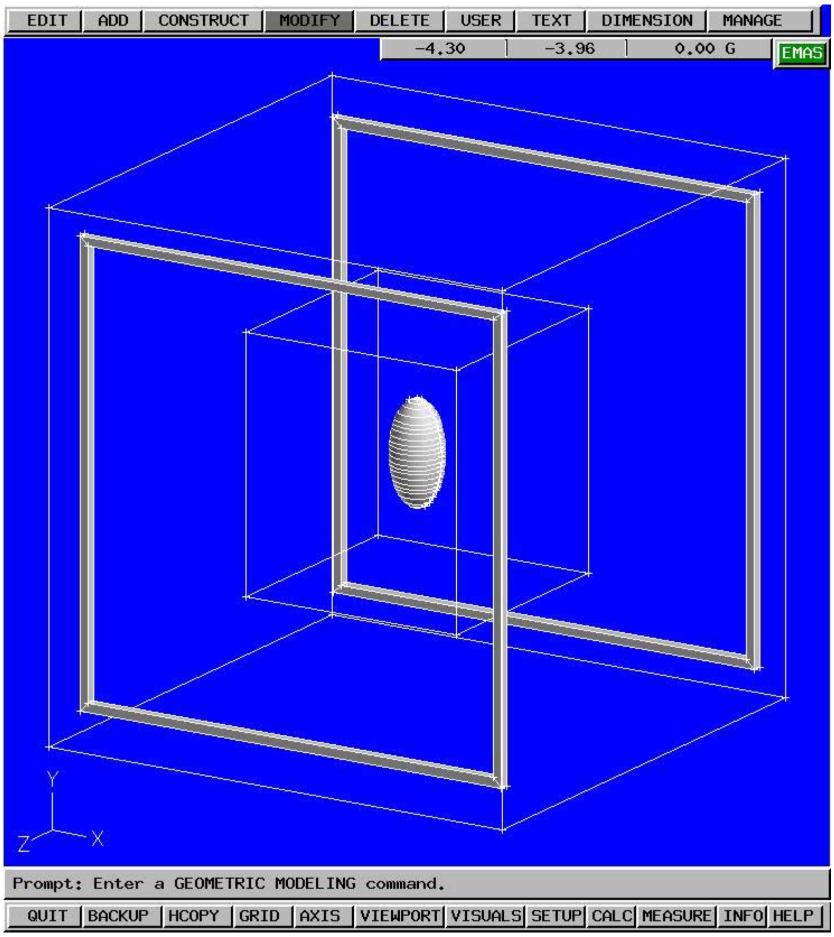
C.7.2 Induced current densities for different sizes of prolate spheroid

Here is an evaluation of induced current in three different size prolate spheroid solids: 60 cm by 30 cm, 120 cm by 60 cm and 160 cm by 80 cm, all full width and height dimensions. The modelling was performed using commercially available FEM software.

The uniform field was simulated using coils that were large in relation to the prolate spheroids under consideration. Results are shown for both the generated magnetic field and the resultant induced current density, using 0,2 S/m conductivity (see Figures C.10, C.11 and C.12). The values are not specific to any one piece of equipment or any particular Guidelines. The ratio between the results shows how the modelling can be made using one size of spheroid and converted to another size using a multiplying factor. Table C.3 provides a summary of results.

C.7.2.1 Uniform magnetic field source

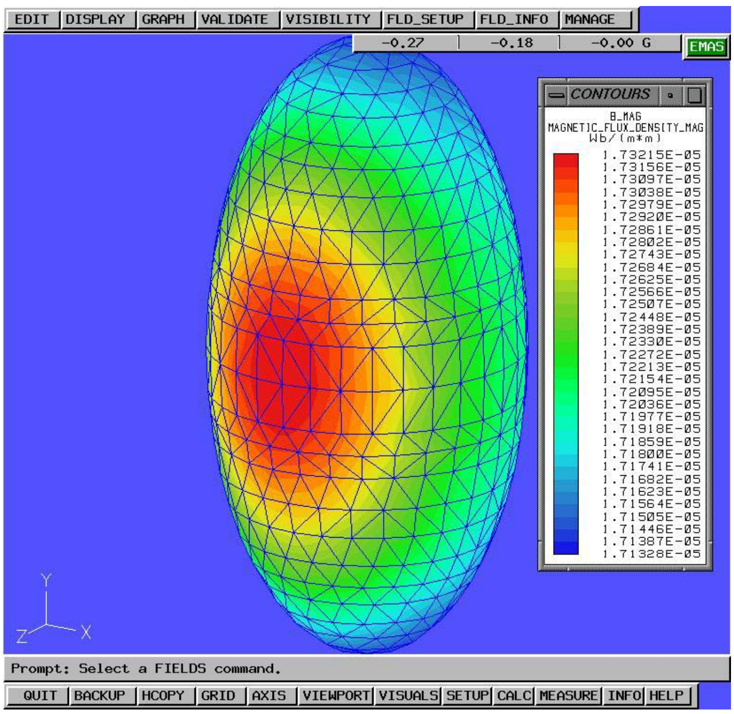
A very large set of Helmholtz coils, 5 m^2, were used to provide a uniform magnetic field at 58 kHz frequency. The degree of uniformity of the magnetic field was to within 1 % or less. Figure C.9 shows this geometry of the Helmholtz coils and prolate spheroid.



IEC 1552/07

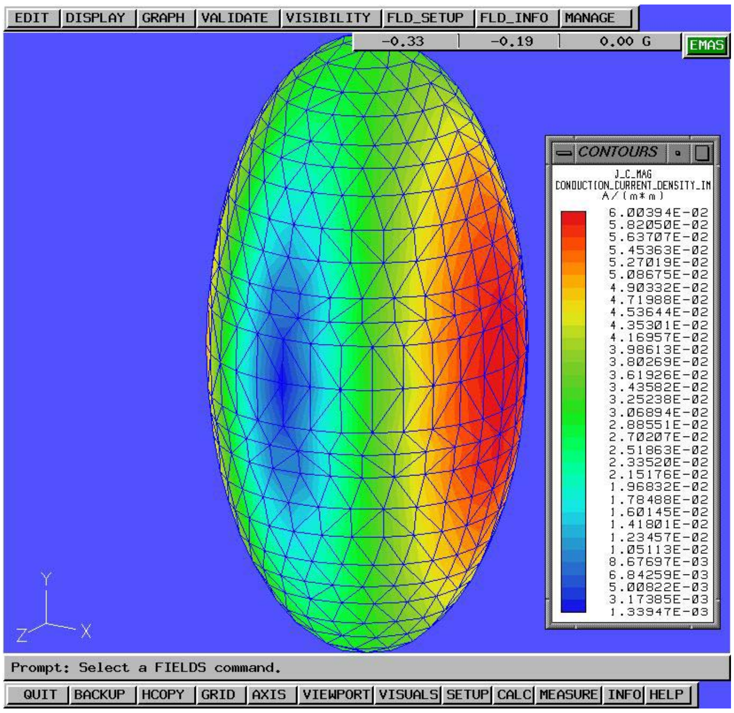
Figure C.9 – Helmholtz coils and prolate spheroid

C.7.2.2 Modelling results for a 60 cm by 30 cm prolate spheroid



IEC 1553/07

Figure C.10a – Magnetic field

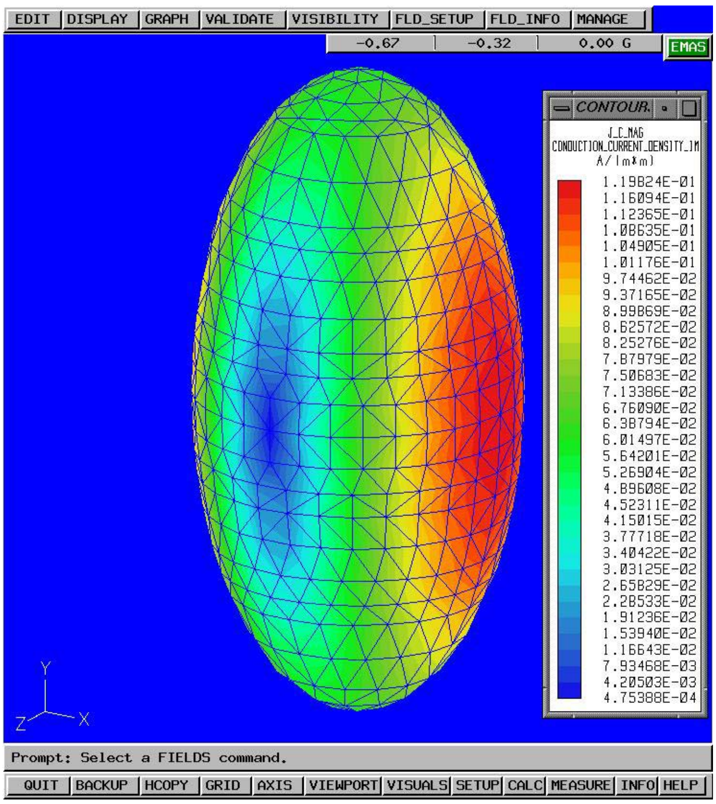


IEC 1554/07

Figure C.10b – Induced current density

Figure C.10 – Modelling results for a 60 cm by 30 cm prolate spheroid

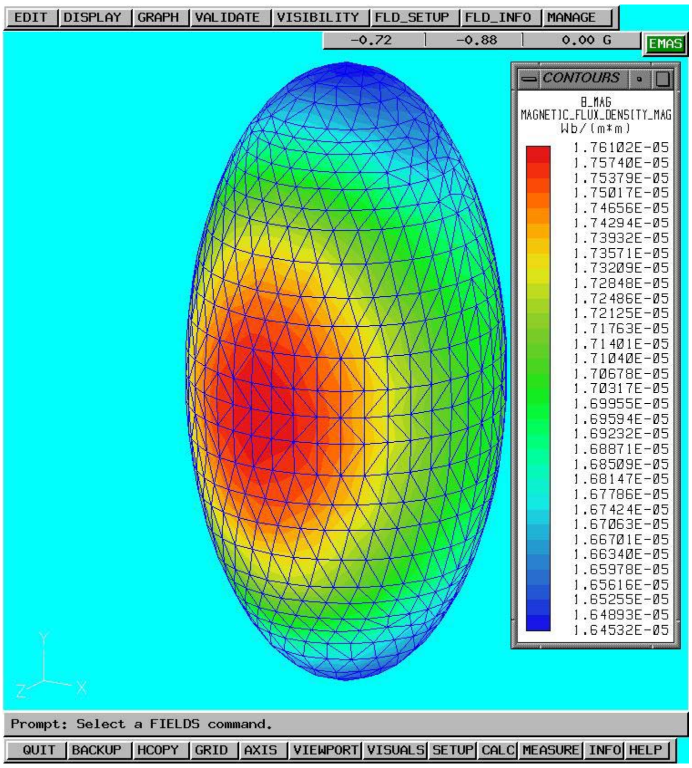
C.7.2.3 Modelling results for a 120 cm by 60 cm prolate spheroid



IEC 1555/07

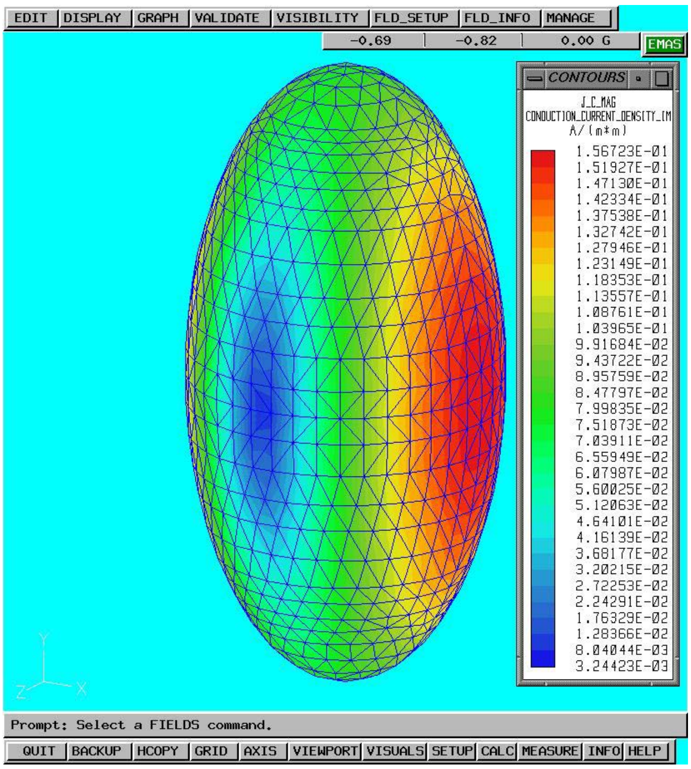
Figure C.11 – Induced current density

C.7.2.4 Modelling results for a 160 cm by 80 cm prolate spheroid



IEC 1556/07

Figure C.12a – Magnetic field



IEC 1557/07

Figure C.12b – Induced current density

Figure C.12 – Modelling results for a 160 cm by 80 cm prolate spheroid

C.7.2.5 Summary of results

Table C.3 – Summary of results

Prolate spheroid size	Maximum magnetic field (used in the model)	Maximum induced current density	Ratio vs. 60 cm by 30 cm
60 cm by 30 cm	17,3 µT	60,0 mAm^{-2}	1,0
120 cm by 60 cm	17,5 µT	119,8 mAm^{-2}	2,0
160 cm by 80 cm	17,6 µT	156,7 mAm^{-2}	2,6

C.7.3 Induced current densities for the human body and head

C.7.3.1 Uniform magnetic field

Figure C.13 shows a uniform magnetic field of B_{eff}=100 µT at $f = 50$ Hz applied to a homogeneous body model (Figure C.3) with $\sigma = 0{,}37 \frac{\mathrm{S}}{\mathrm{m}}$. The example is calculated using the method of moments [25].

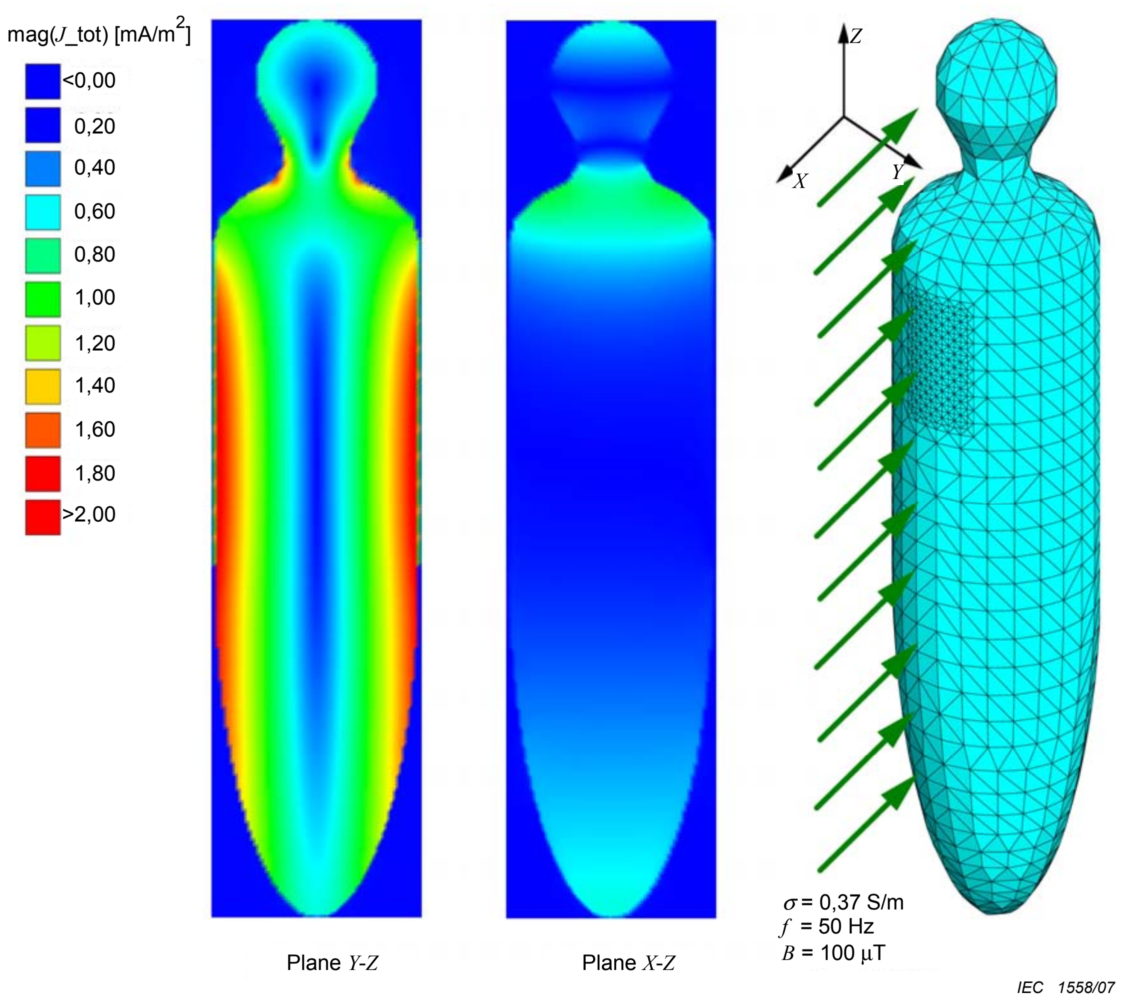


Figure C.13 – Distribution of induced electric current density

C.7.3.2 Non-uniform magnetic fields and calculation of the coupling factor k

Circular current loops were used as sources to calculate the coupling factors. Therefore the current loops of different diameter were positioned in a *worst-case* manner towards the numerical models. This is illustrated in Figure C.14.

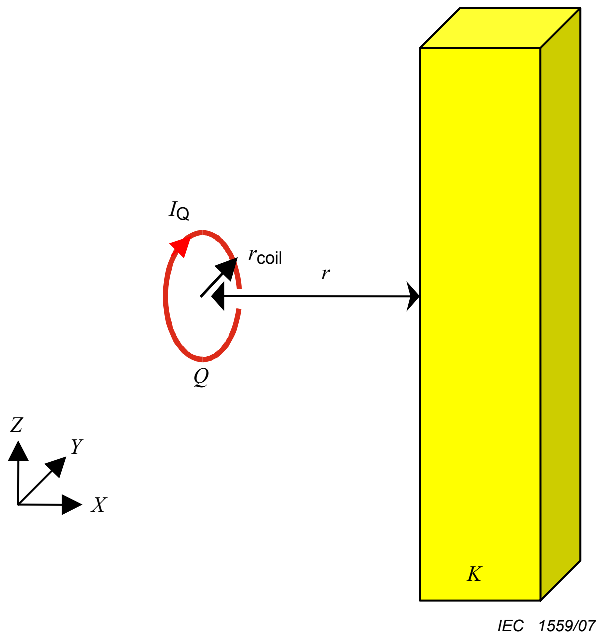


Figure C.14 – Schematic position of source Q against model K

The coupling factor k gives the relation between the maximum induced electric current density $J_{max}(r)$ inside the numerical body model and the maximum magnetic flux density measured at the same position. The source current I_Q can be chosen arbitrarily but should be equal for the calculation of J_{max} and $B_{max,sensor}$. The evaluation of the coupling factor k depends therefore on the sensor used.

For an arbitrary sensor area of A_{Sensor} the averaged magnetic flux density ($B_{max, Sensor}$) through it has to be calculated.

Sensor areas of A_{Sensor} with 3 cm^2 and 100 cm^2 are taken.

The position of the source coil in relation to the sensor and the body model is illustrated in Figure C.15.

For simplification reasons, a 2 D representation was taken to show the location of the coil, distance r and the location of the sensor to the corresponding area of the body model.

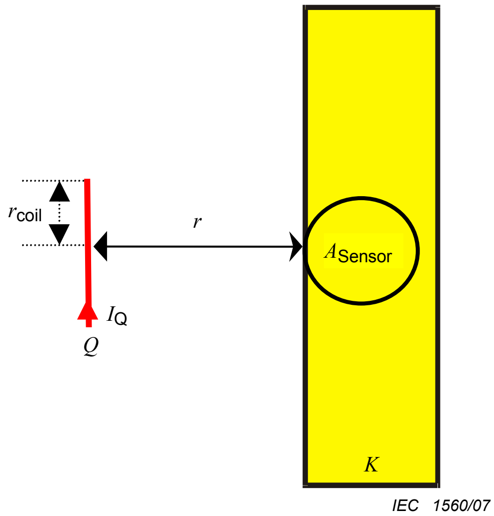


Figure C.15 – Position of source *Q*, sensor and model *K*

Since the frequency f and the conductivity σ are linearly connected to the factor k it can be calculated as follows:

$$k(r,f,\sigma) = \frac{J_{\text{max}}(r,f,\sigma)}{B_{\text{max,Sensor}}(r,A_{\text{Sensor}})} \tag{C.8}$$

For the conductivity of the numerical homogenous hand model an average of σ = 0,1 S/m was evaluated.

For the conductivity of the homogenous body model σ = 0,2 S/m may be chosen. However, the non-uniformity of the fields and their very modest penetration into the body makes it possible to use σ = 0,1 S/m as well.

For the determination of the coupling factor k in this annex, the method of moments (MoM) [20] as numerical technique was used.

EXAMPLE 1

For a circular coil with radius r_{Coil} = 20 mm in a distance r = 10 cm and a source current I_Q = 100 A, one gets for the body model (σ = 0,1 S/m and f = 50 Hz) the induced electric current density J_{max} = 14,956 μA/m^2. The averaged magnetic flux density for a 100 cm^2 sensor is calculated to $B_{\text{max, sensor=100cm}^2}$ = 5,4683 μT. The coupling factor k therefore calculates to

$$k(r = 10\text{ cm}, f = 50\text{ Hz}, \sigma = 0{,}1\tfrac{\text{S}}{\text{m}}) = \frac{14{,}956\,\frac{\mu\text{A}}{\text{m}^2}}{5{,}4683\,\mu\text{T}} = 2{,}735\,\frac{\text{A/m}^2}{\text{T}}\,. \tag{C.9}$$

EXAMPLE 2

For a circular coil with radius r_{Coil} = 20 mm in a distance r = 10 cm and a source current I_Q = 100A, one gets for a human head model (sphere with r_{sphere} = 10,5 cm, σ = 0,15 S/m and f = 60 Hz) the induced electric current density J_{max} = 19,17 μA/m^2. The averaged magnetic flux density for a 100 cm^2 sensor is calculated to $B_{\text{max,sensor=100cm}^2}$ = 5,46835 μT. The coupling factor k therefore calculates to

$$k(r = 10\text{ cm}, f = 60\text{ Hz}, \sigma = 0{,}15\,\tfrac{\text{S}}{\text{m}}) = \frac{19{,}17\,\frac{\mu\text{A}}{\text{m}^2}}{5{,}46835\ \mu\text{T}} = 3{,}505627\,\frac{\text{A/m}^2}{\text{T}} \quad \text{and}$$

$$\frac{k(r = 10\text{ cm}, f = 60\text{ Hz}, \sigma = 0{,}15\,\tfrac{\text{S}}{\text{m}})}{\sigma = 0{,}15\,\tfrac{\text{S}}{\text{m}}} = \frac{3{,}505627\,\frac{\text{A/m}^2}{\text{T}}}{0{,}15\,\frac{\text{S}}{\text{m}}} = 23{,}370847\,\frac{\text{V/m}}{\text{T}} \tag{C.10}$$

Normally the result of the numerical calculation is the electric field strength E_i in the body model. The calculation of the *in situ* electric field strength E_i (as used in IEEE Standard C95.6) can be carried out by simply dividing the factor k through the corresponding conductivity σ used for the evaluation of k.

The *in situ* electric field strength $E_{i,\text{max}}$ therefore calculates to

$$E_{i,\text{max}} = \frac{k(r = 10\text{ cm}, f = 60\text{ Hz}, \sigma = 0{,}15\,\tfrac{\text{S}}{\text{m}})}{\sigma = 0{,}15\,\tfrac{\text{S}}{\text{m}}} \cdot B_{\text{max,Sensor}}(r = 10\text{ cm}, A_{\text{Sensor}} = 100\text{ cm}^2)$$

$$= 23{,}370847\,\frac{\text{V/m}}{\text{T}} \cdot 5{,}46835\ \mu\text{T} = 127{,}8\ \mu\text{V/m}$$

C.7.3.3 Compliance demonstration by k factor usage

The usage of k factor for compliance demonstration with basic restrictions is done in 3 steps:

a) determination of the equivalent (source) coil size;

b) determination of k factor;

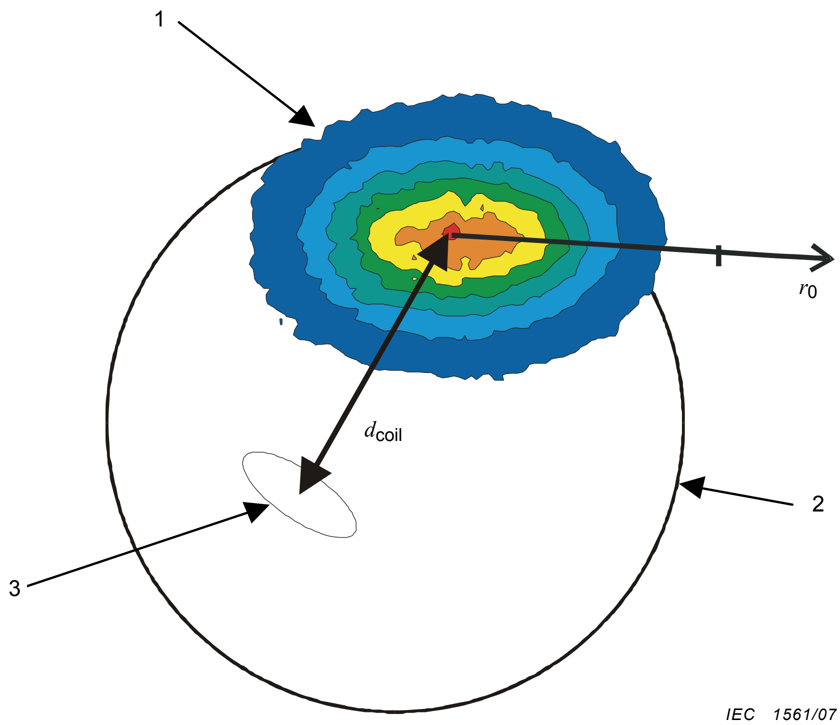
c) compliance demonstration with basic restrictions.

- **Step 1: Determination of the equivalent (source) coil size**

In this step, the equivalent (source) coil size for the device under test will be determined.

Measurement of the magnetic flux density B (r_0) tangentially to the surface along the line of the lowest gradient starting at the hot spot r_0 = 0. The measured shall stop at r_0 = X where the flux density decreases to 10 % of the maximum value of the hot spot. The distance between the measurement points is sufficient in the range of 0,5 cm to 1 cm.

The sensor size used for the measurement can be, for example, 3 cm^2, but it can also be done with other small sensors.



1 Measurement on a tangential plane around the hot spot

2 Model of a household appliance as a sphere

3 Coil as an equivalent field source

Figure C.16 – Hot spot

$$\frac{B(r_0 = X)}{B(r_0 = 0)} = 0{,}1 \tag{C.11}$$

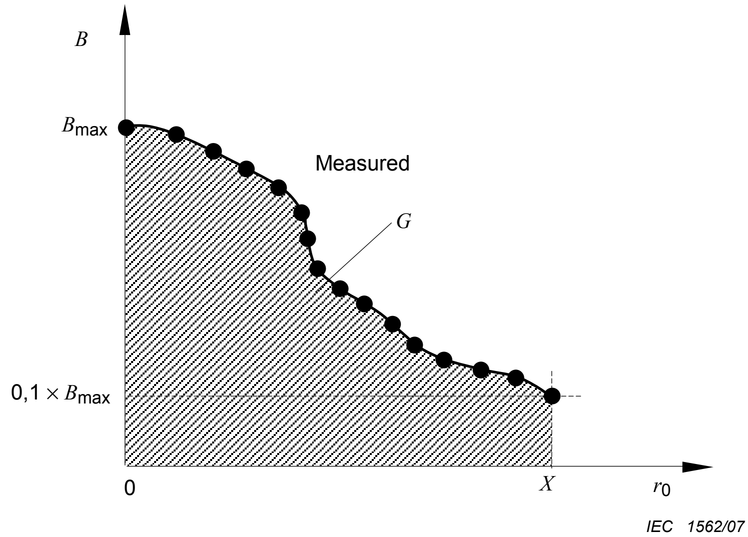


Figure C.17 – Gradient of flux density and area *G*

The measurement results are used to determine the diameter of an equivalent coil which gives a similar area G. For further calculation it is assumed that the equivalent coil is located under the hot spot in a distance d_{coil}, which has to be estimated knowing, from the construction of the equipment, where the field source is located.

NOTE The procedure is applicable only for concentrated sources. The field distribution from the hot spot with B_{max} to 0,1 B_{max} must be continuous.

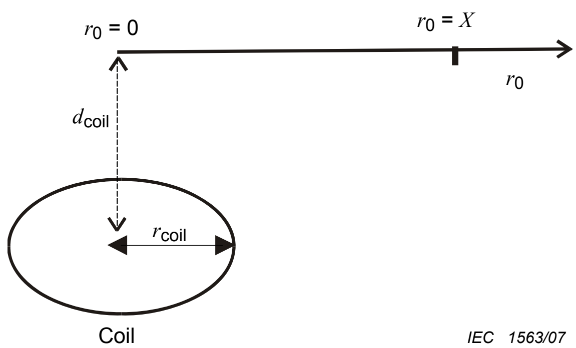


Figure C.18 – Equivalent coil

An integration of the normalised measured flux density along the axis results in a single value G that can be used to determine the radius r_{coil} of the equivalent coil (see Table C.4). Linear interpolation can be used to obtain other values of radius r_{coil}. For the determination of the radius r_{coil}, the distance d_{coil} shall be at least r_{coil}.

NOTE 1 The distance d_{coil} is estimated from the distance of the field source inside the equipment under the hot spot to the surface of the housing. For a small equipment it is approximately half of the equipment diameter. For a larger equipment it is the distance from a motor, for example, to the surface. This parameter is not very critical, because it leads to a different coil radius, but in Table C.4 the distance r already takes the d_{coil} into account. Therefore the result is not very different.

$$G(r_{\text{coil}}, d_{\text{coil}}) = \int_{r_0=0}^{r_0=X} \frac{B(r_0)}{B(r_0=0)}\, dr_0 \qquad \text{(C.12)}$$

Table C.4 – Values G[m] of different coils with radius r_{coil} and distance d_{coil}

Distance d_{coil} (mm)	Radius r_{coil} (mm)					
	10	20	30	50	70	100
10	0,013 54					
15	0,015 62					
20	0,018 48	0,027 03				
25	0,021 68	0,028 80				
30	0,025 11	0,031 17	0,040 51			
35	0,028 61	0,033 90	0,042 17			
40	0,032 22	0,036 89	0,044 29			
50	0,039 55	0,043 34	0,049 41	0,067 50		
70	0,054 48	0,057 18	0,061 64	0,075 35	0,094 44	
100	0,077 11	0,079 05	0,082 19	0,092 13	0,106 44	0,134 93
200	0,153 17	0,154 15	0,155 73	0,160 85	0,168 45	0,184 20
300	0,229 53	0,230 12	0,231 19	0,234 61	0,239 71	0,250 54

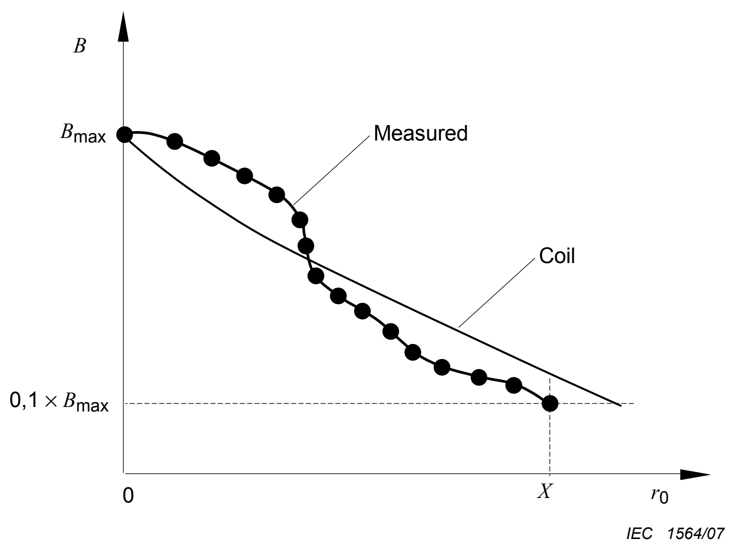


Figure C.19 – Gradients of flux density and coil

- **Step 2: Determination of *k* factor**

The parameter coil radius r_{coil} is used to determine the coupling factor $k(r,\ r_{coil},\ f,\ \sigma)$ (see C.7.3.2) between the equivalent source (coil) and the body in the distance r. It shows the relation between the flux density caused by the source and the current density generated in the body.

$$r = r_1 + d_{coil} \tag{C.13}$$

where

r_1 is the measuring distance (operator distance);

d_{coil} is the inside distance from the equivalent coil to the equipment surface.

$$k(r, r_{coil}, f, \sigma) = \frac{J_{max}(r, r_{coil}, f, \sigma)}{B_{max,Sensor}(r, r_{coil}, A_{Sensor})} \tag{C.14}$$

where

J_{max} is the highest current density in the body;

A_{Sensor} is the measuring area of the sensor.

In Table C.5, the factors at 50 Hz and 0,1 S/m with A_{Sensor} = 100 cm^2 for the whole body are listed. The factor depends on the distance r between coil and body as well as of the selected body model (see Clause C.3), the electric conductivity σ of the homogeneous model of the body and the size of the sensor.

NOTE In case of inhomogeneous fields a value of σ = 0,1 S/m makes sense due to the fact that the highest field values occur on the surface of the body.

Table C.5 – Coupling factor k $\left[\frac{A/m^2}{T}\right]$ at 50 Hz for the whole body

Distance r cm	Radius r_{coil} mm					
	10	**20**	**30**	**50**	**70**	**100**
1	21,354	15,326	8,929	5,060	3,760	3,523
5	4,172	3,937	3,696	3,180	2,858	2,546
10	2,791	2,735	2,696	2,660	2,534	2,411
20	2,456	2,374	2,369	2,404	2,398	2,488
30	2,801	2,735	2,714	2,778	2,687	2,744
40	3,070	2,969	2,933	3,042	2,865	2,916
50	3,271	3,137	3,086	3,251	2,989	3,040
60	3,437	3,271	3,206	3,429	3,079	3,134
70	3,588	3,388	3,311	3,595	3,156	3,216
100	3,940	3,659	3,601	4,022	3,570	3,604
NOTE The factors k are determined by applying the coil as a source with the appropriate numerical model for the human body as described in Clause C.8. It is applicable only for the region close to the source and not for homogenous fields.						

Factors k for other frequencies f and conductivity's σ can be calculated from the values in Table C.5 by

$$k^*(r, r_{\text{coil}}) = \frac{f}{50\,\text{Hz}} \cdot \frac{\sigma}{0{,}1\,\frac{\text{S}}{\text{m}}} \cdot k \qquad \text{(C.15)}$$

- **Step 3: Compliance demonstration with basic restrictions**

The coupling factor k shows the relation between the flux density caused by the source and the current density generated in the body at the same position (see Figure C.16). So it is possible to calculate from a measured magnetic field strength B_{mess} to corresponding current density J for compliance demonstration with the basic restriction when given as current density.

$$J = K \cdot B_{\text{mess}} \qquad \text{(C.16)}$$

The current density can be compared with the ICNIRP basic restriction.

Additionally a relationship to IEEE values can be derived with

$$E = J / \sigma \qquad \text{(C.17)}$$

NOTE B_{mess} is measured in a distance of r_1 between the surface of the equipment and the normal position of the operator (see Figure C.20). To choose the right factor k from table C.5, the distance r has to be calculated with (C.13).

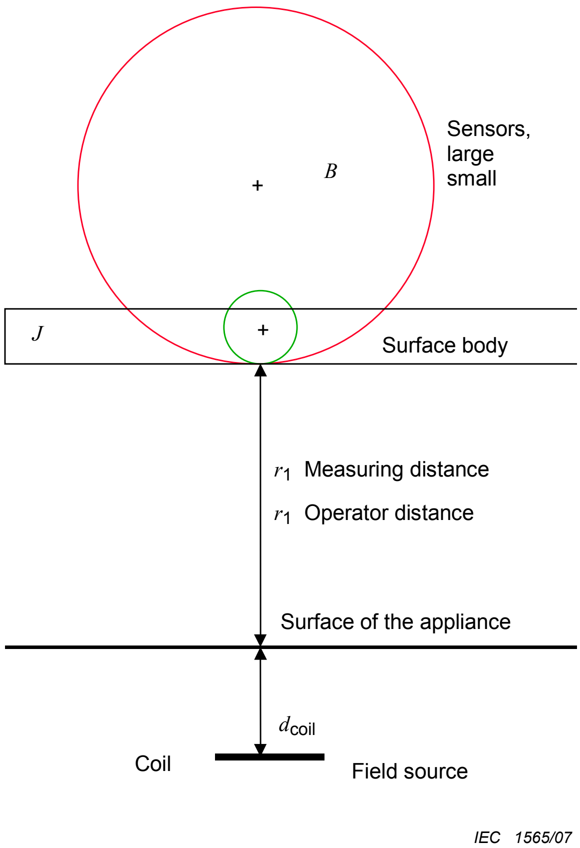


Figure C.20 – Measurement distance and related distances

C.8 Reference documents

[1] DIMBYLOW, PJ. Induced Current Densities from Low-Frequency Magnetic Fields in a 2 mm Resolution, Anatomically Realistic Model of the Body. *Phys. Med. Biol.*, 1998, Vol. 43, pp. 221-230.

[2] STUCHLY, MA. and GANDHI, OP. *Inter-Laboratory Comparison of Numerical Dosimetry for Human Exposure to 60 Hz Electric and Magnetic Fields.* Publication data to be advised.

[3] ICRP 66 (1994), International Commission for Radiological Protection, 1994.

[4] WATANABE, S., NAGAOKA, T., SAKURAI, K., WATANBE, S., KUNIEDA, E., TAKI, M. and YAMANAKA, Y.. *Development of voxel male and female whole-body models and dosimetry*. XXVIIth General Assembly of the International Union of Radio Science, KB.O5, Maastricht, the Netherlands, 17-24 August, 2002.

[5] LEE, AK., CHOI, HD., CHO, KY., CHOI, WY. and CHUNG, MS. Effects of the outer shape of a head on SAR evaluation of a mobile phone. *BEMS 22th Annual Meeting Abstract Book*, June 11-16, 2000, pp 130-131.

[6] LEE, AK. and PACK, JK. Study of the tissue volume for spatial-peak mass-averaged SAR evaluation. *IEEE Trans. on EM*C, May, 2002, vol.44, no.2, pp 404-408.

[7] LEE, AK., CHOI, HD, LEE, HS. and PACK, J.K. Human head size and SAR characteristics for handset exposure. *ETRI Jour.,* Apr. 2002, vol. 24, no. 2, pp 176-179.

[8] FOSTER KR. and SCHWAN HP. Dielectric Properties of Tissues. In: *Handbook of Biological Effects of Electromagnetic Fields*, Second Edition, Ed. E. Polk and E. Postow, CRC Press, Boca Raton, Fla., USA, 1995

[9] DURNEY, CH., MASSOUDI, H. and ISKANDER MF. *Radio frequency Radiation Dosimetry Handbook.,* 4th Ed. USAF/SAM, Brooks AFB, TX, USA, 1986

[10] STUCHLY MA. and STUCHLY SS. Dielectric Properties of Biological Substances – Tabulated. *Journal of Microwave Power*, 1980, Volume 15(1), pp 19-26.

[11] GABRIEL, C., GABRIEL, S. and COURTHOUT, E. The Dielectric Properties of Biological Tissues: I. Literature survey. *Phys. Med. Biol*. 1996, 41 (11), pp 2231-2250.

[12] GABRIEL, S., LAU, RW. and GABRIEL C. The Dielectric Properties of Biological Tissues: II. Measurement in the frequency range 10 Hz to 20 GHz. *Phys. Med. Biol*. 1996, 41 (11), pp 2251-2269.

[13] GABRIEL, S., LAU, RW. and GABRIEL C. The Dielectric Properties of Biological Tissues: III. Parametric models for the dielectric spectrum of tissues. *Phys. Med. Biol*., 1996, 41 (11), pp 2271-2293.

[14] GABRIEL, C. and GABRIEL, S. *Compilation of the Dielectric Properties of Body Tissues at RF and Microwave Frequencies*. Report AL/OE-TR-1996-0037, Armstrong Laboratory, Radiofrequency Radiation Division, Brooks Air Force Base, Texas 78235, USA, 1996; (Internet Site: http://www.brooks.af.mil; http://www.brooks.af.mil/AFRL/HED/hedr/reports/dielectric/Title/Title.html)

[15] The Electromagnetic Wave Research Institute of the Italian National Research Council, Via Panciatichi 64, 50127 Florence, Italy (Internet Site: http://www.iroe.fi.cnr.it ; http://sparc10.iroe.fi.cnr.it/tisspro

[16] JACKSON, John David *Classical Electrodynamics.* Third Edition. John Wiley Sons, Inc., 1998.

[17] NISHIZAWA, S., LANDSTORFER, F. and HASHIMOTO, O. Experimental study on equivalent magnetic source in ELF range. *IEICE*, B, , 2003, Vol.J86-B, No.7, pp1251-1254.

[18] KAMPET, U. and HILLER, W. Measurement of magnetic flux densities in the space around household appliances. In: *Proceedings of NIR 99, Nichtionisierende Strahlung, 31. Jahrestagung des Fachverbandes für Strahlenschutz*, Köln, 1999, vol. II, pp. 885-891.

[19] NISHIZAWA, S., RUOSS, H.–O., LANDSTORFER, F. and HASHIMOTO, O. Numerical study on an equivalent source model for inhomogeneous magnetic field dosimetry in the low frequency range. IEEE Transaction on Biomedical Engineering. *IEEE transactions on biomedical engineering*, April 2004, Vol 51, No. 4.

[20] FURSE C.M. and GANDHI, OP. Calculation of electric fields and currents induced in a millimeter-resolution human model at 60 Hz using the FDTD method. *Bioelectromagnetics*, 1998, vol. 19, pp. 293-299.

[21] ORCUTT, N. and GANDHI, OP. A 3-D Impedance Method to Calculate Power Deposition in Biological Bodies Subjected to Time Varying Magnetic Fields. *IEEE Transactions on Biomedical Engineering*, August 1988, Vol. 35, No. 8.

[22] Programm EMPIRE, http://www.imst.de/

[23] DAWSON, TW., CAPUTA, K. and STUCHLY, MA. Numerical evaluation of 60 Hz magnetic induction in the human body in complex occupational environments. *Physics in Medicine & Biology*, April 1999, Vol. 44 (4), pp. 1025-1040.

[24] JAKOBUS, U. Erweiterte Momentenmethode zur Behandlung kompliziert aufgebauter und elektrisch grosser elektromagnetischer Steuprobleme. Fortschrittsberichte VDI, Reihe 21, Nr.171, VDI Verlag, Duesseldorf, 1995

Annex D
(informative)

Measurements of physical properties and body currents

D.1 Measurement of body current

Measurement equipment for body current may be carried out in two categories:

- measurement equipment for body to ground current;
- measurement equipment for contact current.

It should be noted that both of these approaches may involve measurement of the RF current in a person. Where exposure of people going about their normal working and domestic tasks is being investigated, then the use of such techniques should not involve any additional exposure of people – it is a quantification of exposures already taking place. However, when new and/or novel exposures are investigated, and if for example a third party is making measurements in areas and situations that are not routinely encountered, then preliminary measurements with a non-contact current measurement system should be used to determine that no hazard exists. Only then should the approaches below be used to determine more accurately the true body currents.

This approach is justified for radiofrequency body currents because exposure standards allow exposures to such currents to be time-averaged. A very brief (instantaneous) exposure of a person to a level beyond the time-averaged value is permissible as long as the averaged exposure meets the relevant limit.

At frequencies where time-averaging of body current is not permitted, investigations for purposes of compliance with exposure standards should not involve the potential exposure of people as part of the measurement process.

In these cases, and in cases where time-averaged RF body currents might be expected to approach or exceed the relevant limit, the impedance of the body should be simulated by an array of electrical components or a physical phantom with impedance equal to or less than that of the human body at the relevant frequency.

D.2 Measurement of induced radiofrequency body currents

Body currents are induced currents resulting from exposure of the body to RF fields in the absence of contact with objects other than the ground. The two principal techniques used for measuring body currents include clamp-on type (solenoidal) current transformers for measuring current flowing in the limbs, and parallel plate systems that permit the measurement of currents flowing to ground through the feet.

Clamp-on current transformer instruments have been developed that can be worn. The meter unit is mounted either directly on the transformer or connected through a fibre-optic link to provide a display of the current flowing in a limb around which the current transformer is clamped. Current sensing in these units may be accomplished using either narrowband techniques, e.g., spectrum analysers or tuned receivers which offer the advantage of being able to determine the frequency distribution of the induced current in multi-source environments, or broadband techniques using diode detection or thermal conversion.

Instruments have been designed to provide true r.m.s. indications in the presence of multiple frequencies and/or amplitude-modulated waveforms.

The upper frequency response of current transformers is usually limited to about 100 MHz, however air cored transformers (as opposed to ferrite-cored), have been used to extend the upper frequency response of these instruments. Whilst air-cored transformers are lighter and therefore useful for longer-term measurements, they are significantly less sensitive than ferrite-cored devices.

An alternative to the clamp-on device is the parallel plate system. In this instrument, the body current flows through the feet to a conductive top plate, through some form of current sensor mounted between the plates, and thereby to ground. The current flowing between the top and bottom plates may be determined by measuring the RF voltage drop across a low impedance resistor. Alternatively, a small aperture RF current transformer or a vacuum thermocouple may be used to measure the current flowing through the conductor between the two plates.

Instruments with a flat frequency response between 3 kHz and 100 MHz are available. There are several issues that should be considered when selecting an instrument for measuring induced current.

Firstly, stand-on meters are subject to the influence of electric-field induced displacement currents from fields terminating on the top plate. Investigations have shown that apparent errors arising in the absence of a person are not material to the operation of the meters when a person is present.

Secondly, the sum of both ankle currents measured with clamp-on type meters tends to be slightly greater than the corresponding value indicated with plate type meters. The magnitude of this effect, which is a function of the RF frequency and meter geometry, is not likely to be material. Nonetheless, the more accurate method of assessing limb currents is the current transformer. The precise method of measurement may depend upon the requirements of protection guidelines against which compliance assessments are made.

Thirdly, the ability to measure induced currents in limbs under realistic grounding conditions such as found in practice need to be considered. In particular, the differing degree of electrical contact between the ground and bottom plate of the parallel plate system and the actual ground surface may affect the apparent current flowing to ground.

Measurements can be made using antennas designed to be equivalent to a person. This enables a standardised approach to be used and permits current measurements to be made without the need for people to be exposed to potentially hazardous currents and fields.

D.3 Measurement of contact current

The current measurement device has to be inserted between the hand of the person and the conductive object. The measurement technique may consist of a metallic probe (definite contact area) to be held by hand at one end of the probe while the other end is touched to the conductive object. A clamp-on current sensor (current transformer) as described in Clause D.2 can be used to measure the contact current, which is flowing into the hand in contact with the conductive object.

In the case where excessively high currents are expected, an electrical network of resistors and capacitors can simulate the body’s equivalent impedance.

Alternative methods are:

- measurement of the potential difference (voltage drop) across a non-inductive resistor (resistance range of 5 Ω – 10 Ω) connected in series between the object and the metallic probe holding in hand;
- a thermocouple millimetre placed directly in series.

The wiring connections and the current meter must be set up in such way that interference and errors due to "pick-up" are minimised.

D.4 Measurement of touch voltage

The touch voltage (no-load-voltage) is measured by means of a suitable voltmeter or oscilloscope for the frequency range under consideration. The measurement equipment are connected between the conductive object charged by field induced voltage and reference potential (ground). The input impedance of the voltmeter must not be smaller than 10 kΩ.

D.5 Reference documents

[1] DIMBYLOW, PJ. Induced Current Densities from Low-Frequency Magnetic Fields in a 2 mm Resolution, Anatomically Realistic Model of the Body. *Phys. Med. Biol.*, 1998, Vol. 43, pp. 221-230.

[2] STUCHLY MA. and GANDHI OP. *Inter-Laboratory Comparison of Numerical Dosimetry for Human Exposure to 60 Hz Electric and Magnetic Fields.* Publication data to be advised.

[3] ICRP 66 (1994), International Commission for Radiological Protection, 1994

[4] GEDDES, LA. and BAKER, LE. The Specific Resistance of Biological Material – A Compendium of Data for the Biomedical Engineer. *Medical and Biological Engineering*, 1967, Vol. 5 pp 271-293.

[5] FOSTER, KR. and SCHWAN, HP. Dielectric Properties of Tissues. In: *Handbook of Biological Effects of Electromagnetic Fields*, Second Edition, Ed. E. Polk and E. Postow, CRC Press, Boca Raton, Fla., USA, 1995.

[6] DURNEY, CH., MASSOUDI, H. and ISKANDER MF. *Radiofrequency Radiation Dosimetry Handbook.,* 4th Ed. USAF/SAM, Brooks AFB, TX, USA, 1986

[7] STUCHLY MA. and STUCHLY SS. Dielectric Properties of Biological Substances – Tabulated. *Journal of Microwave Power*, 1980, Volume 15(1), pp 19-26.

[8] GABRIEL, C., GABRIEL, S. and COURTHOUT, E. The Dielectric Properties of Biological Tissues: I. Literature survey. *Phys. Med. Biol*. 1996, 41 (11), pp 2231-2250.

[9] GABRIEL, S., LAU, RW. and GABRIEL C. The Dielectric Properties of Biological Tissues: II. Measurement in the frequency range 10 Hz to 20 GHz. *Phys. Med. Biol.* 1996, 41 (11), pp 2251-2269.

[10] GABRIEL, S., LAU, RW. and GABRIEL C. The Dielectric Properties of Biological Tissues: III. Parametric models for the dielectric spectrum of tissues. *Phys. Med. Biol.*, 1996, 41 (11), pp 2271-2293.

[11] GABRIEL, C. and GABRIEL, S. *Compilation of the Dielectric Properties of Body Tissues at RF and Microwave Frequencies*. Report AL/OE-TR-1996-0037, Armstrong Laboratory, Radiofrequency Radiation Division, Brooks Air Force Base, Texas 78235, USA, 1996; (Internet Site: http://www.brooks.af.mil; http://www.brooks.af.mil/AFRL/HED/hedr/reports/dielectric/Title/Title.html)

[12] The Electromagnetic Wave Research Institute of the Italian National Research Council, Via Panciatichi 64, 50127 Florence, Italy (Internet Site: http://www.iroe.fi.cnr.it ; http://sparc10.iroe.fi.cnr.it/tisspro

The web site for tissue properties from The Electromagnetic Wave Research Institute of the Italian National Research Council is now

http://niremf.ifac.cnr.it/tissprop/

although http://sparc10.iroe.fi.cnr.it/tissprop) still functions at the moment

The USA FCC has created a web site for tissue properties, also based on Gabriel/BrooksAFB. It is located at:

http://www.fcc.gov/cgi-bin/dielec.sh

The “The International EMF Dosimetry Handbook” project is hosted at

http://www.emfdosimetry.org/

Here there is access to:

(1) Radiofrequency Radiation Dosimetry Handbook V4

(2) The Gabriel Report for BrooksAFB

(3) Ongoing development of the next version of the Dosimetry Handbook

Annex E
(informative)

Specific absorption rate (*SAR*)

E.1 Specific absorption rate (*SAR*) measurement procedures

E.1.1 Electric field measurement procedures

The *SAR* is also proportional to the squared r.m.s. electric field strength *E* (V/m) inside the exposed tissue:

$$SAR = \sigma E^2/\rho$$

where σ(S/m) is the electrical conductivity and ρ (kg/m^3) is the mass density of the tissue material at the position of interest. Using an isotropic electric field probe, the local *SAR* inside an irradiated body model can be determined. By moving the probe and repeating the electric field measurements in the whole body or in a part of the body, the *SAR* distribution and the whole-body or partial-body averaged *SAR* values can be determined. A single electric field measurement takes only a few seconds, which means that three-dimensional *SAR* distributions can be determined with high spatial resolution and with a reasonable measurement time (typically less than an hour). In Annex B, procedures for evaluations of local peak *SAR* for handheld radio transmitters and radio base stations are defined.

E.1.2 Temperature measurement procedures

The *SAR* is proportional to initial rate of temperature rise d*T*/d*t* (K/s) in the tissue of an exposed object:

$$SAR = c\Delta T/\Delta t$$

where *c* is the specific heat capacity of the tissue material (J/kgK). Using certain temperature probes, the local *SAR* inside an irradiated body model can be determined. One or more probes are used to determine the temperature rise, ΔT, during a short exposure time, Δt (typically less than 30 s to prevent heat transfer). The initial rate of temperature rise is approximated by $\Delta T/\Delta t$, and the local *SAR* value is calculated for each measurement position. By repeating the temperature measurements in the whole body or in a part of the body, the *SAR* distribution and the whole-body or partial-body averaged *SAR* values can be determined.

Three-dimensional *SAR*-distribution measurements are very time consuming due to the large number of measurement points. To achieve a reasonable measurement time the number of points has to be limited. This means that it is very difficult to measure strongly non-uniform *SAR* distributions accurately. The accuracy of temperature measurements may also be affected by thermal conduction and convection during measurements, or between measurements.

E.1.3 Calorimetric measurement procedures

The whole-body average *SAR* can be determined using calorimetric methods. In a normal calorimetric measurement, a full-size or scaled body model at thermal equilibrium is irradiated for a period of time. A calorimeter is then used to measure the heat flow from the body, until the model is at thermal equilibrium again. The obtained total absorbed energy is then divided by the exposure time and the mass of the body model, which gives the whole-body *SAR*. The calorimetric twin-well technique uses two calorimeters and two identical body models. One of the models is irradiated, and the other one is used as a thermal reference. This means that the measurement can be performed under less well-controlled thermal conditions than a normal calorimetric measurement.

Calorimetric measurements give rather accurate determinations of whole-body *SAR*, but do not give any information about the internal *SAR* distribution. To get accurate results a sufficient amount of energy deposition is required. The total time of a measurement, which is determined by the time to reach thermal equilibrium after exposure, may be up to several hours. Partial-body *SAR* can be measured by using partial-body phantoms and small calorimeters.

Annex F
(informative)

Measurement of E and H field

F.1 Measurement of external electromagnetic fields

F.1.1 General considerations

The measurement of external fields with regard to human exposure assessment will depend upon the objective. In the first instance it may be that the measurements are simply to assess compliance with external field strength reference level values contained in exposure guidelines. For some guidelines additional information may be required to enable calculation of the spatial averaging of inhomogeneous field distributions. In other cases detailed field distribution data may be needed to provide input to other analytical or computational techniques for assessing compliance with the basic quantities underpinning particular guidelines. The approaches used and the spatial resolution of instrumentation used to carry out these tasks may differ substantively.

Prior to making measurements, one should estimate the expected field strength and determine the type of instrument required. Additional approaches and equations for calculating field strength in various situations are given in Annex A. The measurement procedures to be used may differ, depending on the source and propagation information available.

If the information is adequate, then the surveyor, after making estimates of expected field strengths and selecting an instrument, may proceed with the survey. The surveyor should use a high-power probe with the range switch set on the most sensitive scale. The high-intensity field areas, e.g., the main beam of a directional antenna, should be approached from a distance to avoid probe burnout. The surveyor then gradually proceeds to move progressively closer to the regions of higher field strength. Extreme care should be exercised to avoid overexposure of the surveyor and survey instrument. The field measurements have to be performed at the normal user position.

On the other hand, if the information is not well defined (for example, reports of strong, intermittent interference), then it may be difficult to make a hazard survey without first conducting an empirical hazard assessment. A survey for potentially hazardous fields of unknown frequency, modulation, distribution within an area, etc. may require use of several instruments.

When performing a measurement, the overall measurement uncertainty shall be predicted and evaluated. All possible sources of uncertainty including the instrumentation specifications and the specific situation parameters shall be taken into account.

F.1.2 Equivalent field strength

F.1.2.1 Electric field strength

The electric component of the electromagnetic field can be easily measured using suitable antennas, e.g., bi-conical, log-periodic etc. However, for exposure assessment, small elementary dipoles are generally used as sensors in order to minimally perturb the field and to ensure a good spatial resolution. Directional probes contain only one dipole, whereas isotropic probes contain three orthogonal dipoles.

If a single dipole is used, three measurements should be performed in three orthogonal directions to obtain the different components of the field. The total E-field would be given by the following formula:

$$E = \sqrt{E_x^2 + E_y^2 + E_z^2}$$

F.1.2.2 Magnetic field strength

The magnetic component of the electromagnetic field is usually measured with loop sensors, as the current induced in the loop is proportional to the magnetic field strength crossing the loop. Here again, for exposure assessment, small loops are generally used as sensors in order to disturb as little as possible the field and to ensure a good spatial resolution. Directional probes (one loop) are widely used, but many isotropic probes exist with three orthogonal loops.

If a single loop is used, three measurements should be performed in three orthogonal planes to obtain the different components of the field. The total H-field would be given by the following formula:

$$H = \sqrt{H_x^2 + H_y^2 + H_z^2}$$

F.1.2.3 Broadband measurements

If several frequencies (and varying modulations) are present in the frequency range to be observed, either the peak value or the r.m.s. values (irrespective of signal shape) can be measured directly with appropriate broadband measuring equipment.

In case all existing spectral frequencies correspond to the same level, a broadband probe with a flat frequency response can be used.

However if several frequencies are present for which different reference levels have to be taken into account, it is possible to use broadband probes which intentionally and automatically weight the individual measured frequency contributions according to the respective reference levels.

In case of low frequency signals, a second possibility can be used to measure electromagnetic fields consisting of several spectral frequencies with possibly different signal shapes, which is called the time domain method, as described in 8.2.2. Thereby the signal is weighted in the time domain using hardware filters.

For all of the three methods it has to be ensured that the bandwidth of the instrument and the probe are sufficiently wide to record all potential occurring spectral frequencies.

Depending on the probe used, also the contribution of the three axes X, Y and Z can be evaluated separately. A commonly used probe size is 100 cm^2.

F.1.2.4 Narrowband measurements

If several frequencies (and varying modulations) are present in the frequency range to be observed, and if the derived levels are the same for each of these frequencies, then the peak values and/or the r.m.s. values at each frequency can be measured directly with frequency-selective measurement equipment. In this case, it should be noted that peak values for the individual (independent from each other) frequencies should be added linearly, in order to determine the total peak value, whereas r.m.s. values for the individual frequencies should be added geometrically, in order to determine the total r.m.s. value.

In case it is relevant to measure the contribution of just one spectral signal out of a multi-frequency environment, it is possible to use selective measurement equipment with a possibility to measure in a kind of a zero-span mode, such as is generally known from common spectrum analyzers.

The result can be directly a r.m.s. or a peak value.

NOTE Measurement of peak value is not recommended because the limits are expressed in r.m.s. and because of problems with reproducibility.

If the derived levels are not the same for all the frequency components to be evaluated, then a sufficiently narrow bandwidth should be chosen, to ensure that the influence of the change in the derived value within the frequency range covered by the instrument is negligible.

If measurements are carried out in the time domain (using a transient recorder) and the frequency spectrum is calculated by Fourier transformation, then an adequate frequency resolution must be ensured in order to facilitate the evaluation of limiting values (this is not applicable when frequencies are independent of each other).

Annex G
(informative)

Source modelling

G.1 Numerical modelling

G.1.1 Description of available methods

Analytical procedures can only be used to calculate the electromagnetic properties for a few special cases and geometries. To solve general problems, numerical techniques have to be applied. The most common numerical procedures to calculate the electromagnetic fields from a transmitting source or the internal fields and the specific absorption rate in biological bodies, are listed below. A brief description is also given for some of these methods. The most appropriate numerical technique for a certain problem depends on the frequency range considered, the geometrical structures to be modelled, and the type of exposure situation (near-field or far-field). References [1-7] contain further information about these techniques and their application.

Numerical modelling methods:

– physical optics (PO);
– physical theory of diffraction (PTD);
– geometrical optics (GO);
– geometrical theory of diffraction (GTD);
– uniform theory of diffraction (UTD);
– method of equivalent currents (MEC);
– method of moments (MoM);
– multiple multipole method (MMP);
– finite-difference time-domain method (FDTD);
– finite element method (FEM);
– impedance method;
– fast Fourier transform/conjugate gradient method (FFT/CG)

G.1.1.1 Method of moments (MoM)

The method of moments is a technique which has been extensively used to solve electromagnetic problems and to make *SAR* calculations in block models of biological bodies. In MoM, the electric fields inside a biological body are calculated by means of a Green's function solution of Maxwell's integral equations.

G.1.1.2 Fast Fourier transform/conjugate gradient method (FFT/CG)

The FFT/CG method is a further development of the method of moments. Iterative algorithms based on FFT and the gradient procedure are used to solve linear equations derived from the method of moments.

G.1.1.3 Finite-difference time-domain method (FDTD)

FDTD is a numerical method to solve Maxwell's differential curl equations in the time domain. It can be used to calculate internal and external electromagnetic fields and *SAR* distribution in biological bodies for both near-field or far-field exposures. In FDTD, both time and space are discretised, and a biological body is modelled by assigning the permittivity and conductivity values to the space cells it occupies. The computer memory required is proportional to the number of space cells. FDTD is considered the most promising *SAR* calculation method, but for accurate calculations very powerful computers are needed.

G.1.1.4 Multiple multipole method (MMP)

MMP is based on analytical solutions to field equations, which have a multipole at one point in space, and is used in conjunction with the generalized multipole technique (GMP). The MMP procedure is especially suitable for the simulation of so-called "lossy scattering" bodies, which are near to radiation sources, i.e., within the immediate near-field.

G.1.1.5 Impedance method

The impedance method has been successfully used to solve dosimetric problems where quasi-static approximations can be made. For calculations of *SAR* in human bodies, this method has proven to be very effective at frequencies up to 40 MHz. In the impedance method, the biological body is modelled by a three-dimensional network of complex impedances.

G.2 Field strength calculations

Most of the methods listed above can be used to calculate field strength levels from electromagnetic radiators. The accuracy of the results depends very much on how well the radiator (for example antenna) is modelled. If objects near the radiator, between the radiator and the prediction point, or close to the point of field strength prediction may affect the field strength levels significantly, such objects should also be modelled.

Which of these methods is most appropriate for a particular problem depends e.g. on the frequency, the exposure conditions, the size of the exposed object, the required accuracy and the maximum tolerable calculation time. Each method requires experience in biophysics and numerical analysis.

To use any of these models, a three-dimensional geometric numerical model of the exposed body, or part of the body, is required. The electrical properties at the exposure frequency should be known for the different parts of the body. Depending on the required accuracy, models with different complexity may be used.

Three-dimensional information concerning transmitting antenna geometry and detailed information concerning transmitting antenna feeding arrangement are also required. Transmitting antenna feeding arrangement may be really complex in the case of FM or TV broadcasting antennas or GSM base station transmitting panel and it has essential influence on the accuracy of the transmitting antenna model.

G.3 Specific absorption rate calculations

Due to the difficulty of measuring the whole-body averaged or local peak *SAR* in many exposure situations, in numerical calculations several of the numerical techniques mentioned above can be used for estimation of the specific absorption rate distribution in a biological body exposed to either near-field or far-field electromagnetic radiation, for example the finite-difference time-domain method (FDTD), the method of moments and the multiple multipole method (MMP).

Which of these methods is most appropriate for a particular problem depends e.g. on the frequency, the exposure conditions, the size of the exposed object, the required accuracy and the maximum tolerable calculation time. Each method requires experience in biophysics and numerical analysis.

To use any of these models, a three-dimensional geometric numerical model of the exposed body, or part of the body, is required. The electrical properties at the exposure frequency should be known for the different parts of the body. Depending on the required accuracy, models with different complexity may be used. In some situations, simple shapes like spheres and cylinders are appropriate to model the body. The dielectric properties of human tissues are given in the literature [8]. Using magnetic resonance (MR) images of a human body, very complex and accurate numerical body models can be developed. MR models with several different tissue types and a spatial resolution of less than a few millimetres have been used for FDTD calculations of the *SAR* distribution in humans exposed to electromagnetic fields from handheld radio transmitters [9], [10].

Three-dimensional information concerning transmitting antenna geometry and detailed information concerning transmitting antenna feeding arrangement are also required. Transmitting antenna feeding arrangement may be really complex in the case of FM or TV broadcasting antennas or GSM base station transmitting panel and it has essential influence on the accuracy of the transmitting antenna model.

G.4 References

[1] BALANIS, C.A. *Advanced Engineering Electromagnetics*. John Wiley & Sons, New York.

[2] UFIMTSEV, P.Y. *Method of waves in the Physical Theory of Diffraction* (In Russian), Izd. Vo. Sov. Radio, pp. 1-243, 1962. (Translation prepared by the U.S. Air Force Technology Division, Wright-Patterson AFB, Ohio.)

[3] HARRINGTON, R.F. *Field Computation by Moment Methods*, Mcmillan, New York, 1968.

[4] Kunz, K.S. and Luebbers, R.J. *The Finite Difference Time Domain Method for Electromagnetics.* CRC Press, Boca Raton, FL, 1993.

[5] MORGAN, M.A. (Editor), *Finite Element and Finite Difference Methods in Electromagnetic Scattering.* Eisevier Science Publishing, New York, 1990.

[6] GANDHI, O.P. (Editor). *Biological Effects and Medical Applications of Electromagnetic Energy.* Prentice Hall, Englewood Cliffs, N.J., 1990.

[7] KUSTER, N. Multiple Multipole Method for Simulating EM Problems Involving Biological Bodies. *IEEE Trans. Biomed. Eng.* , July 1993, vol. 40, no. 7.

[8] FOSTER, K.R. and SCHWAN, H.P. *Dielectric properties of tissues and biological materials: A critical review.* Critical Reviews in Biomedical Engineering, vol. 17 , 1989.

[9] DIMBYLOW P .J. and MANN, S.M. SAR calculations in an anatomically realistic model of the head for mobile communication transceivers at 900 MHz and 1.8 GHz. *Phys. Med. Biol.*, 1994 vol. 39.

[10] HOMBACH, V., MEIER, K., KUHN, E. and KUSTER, N. The dependence of human head modeling on EM absorption. *IEEE Transactions on Microwave Theory and Techniques*, 1996.

Bibliography

[1] ICNIRP Guidelines. Guidelines for Limiting Exposure to Time-Varying Electric, Magnetic, and Electromagnetic Fields (up to 300 GHz). *Health Physics* 74(4): 494 - 522, 1998.

[2] IEEE Std C95.6™ *IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0–3 kHz.* 2002.

[3] IEEE Std C95.1™ *IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz.* 2005.

[4] IEC 61786:1998, *Measurement of low-frequency magnetic and electric fields with regard to exposure of human beings – Special requirements for instruments and guidance for measurements*

[5] ISO/IEC 17025:2005, *General requirements for the competence of testing and calibration laboratories*

NOTE Harmonized as EN ISO/IEC 17025:2005 (not modified).

[6] *European 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)*

[7] ICNIRP, Guidance on determining compliance of exposure to pulsed and complex non-sinusoidal waveforms below 100 kHz with ICNIRP guidelines. *Health Physics*, 2003, vol 84, No 3, pp. 383-387

[8] ANSI NCSL Z540-2: US guide to the expression of uncertainty in measurement.

[9] BIPM, IEC, IFCC, ISO, IUPAC, IUPAP and OIML, 1995, *Guide to the expression of uncertainty in measurement*

Annex ZA
(normative)

Normative references to international publications with their corresponding European publications

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

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

Publication	Year	Title	EN/HD	Year
IEC 60050-161	–[1]	International Electrotechnical Vocabulary (IEV) - Chapter 161: Electromagnetic compatibility	–	–

[1] Undated reference.

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