BRITISH STANDARD

BS EN 50475:2008

Basic standard for the calculation and the measurement of human exposure to electromagnetic fields from broadcasting service transmitters in the HF bands (3 MHz – 30 MHz)

ICS 13.280; 17.220.20; 33.170

British Standards

National foreword

This British Standard is the UK implementation of EN 50475:2008.

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.

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EUROPEAN STANDARD

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ICS 13.280

English version

Basic standard for the calculation and the measurement of human exposure to electromagnetic fields from broadcasting service transmitters in the HF bands (3 MHz - 30 MHz)

Norme de base pour le calcul et la mesure
de l'exposition humaine
aux champs électromagnétiques
des émetteurs de service de radiodiffusion
dans les bandes HF (3 MHz à 30 MHz)

Grundnorm für die Berechnung und
Messung der Exposition von Personen
gegenüber elektromagnetischen Feldern
von Rundfunksendern in den KW-Bändern
(3 MHz bis 30 MHz)

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

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Foreword

This European Standard was prepared by the Technical Committee CENELEC TC 106X, Electromagnetic fields in the human environment.

The text of the draft was submitted to the formal vote and was approved by CENELEC as EN 50475 on 2008-04-01.

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)	2009-04-01
– latest date by which the national standards conflicting with the EN have to be withdrawn	(dow)	2011-04-01

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1 Scope

This standard applies to short wave broadcast transmitters and installations operating in the frequency range 3 MHz to 30 MHz.

The objective of the standard is to specify, for such a frequency band, basic information allowing the definition of a method for assessment of compliance related to human exposure to radio frequency electromagnetic fields.

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.

EN 50413, *Basic standard on measurement and calculation procedures for human exposure to electric, magnetic and electromagnetic fields (0 Hz – 300 GHz)*

EN 55016 series, *Specification for radio disturbance and immunity measuring apparatus and methods* (CISPR 16 series)

ENV 13005:1999, *Guide to the expression of uncertainty in measurement*

3 Terms and definitions

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

3.1
action values

the magnitude of directly measurable parameters, provided in terms of electric field strength (E), magnetic field strength (H), magnetic flux density (B) and power density (S), at which one or more of the specified measures in 2004/40/EC [2] must be undertaken. Compliance with these values will ensure compliance with the relevant exposure limit values of 2004/40/EC [2]

3.2
antenna

device that serves as a transducer between a guided wave (e.g. coaxial cable) and a free space wave, or vice versa

3.3
basic restriction

restrictions on exposure to time-varying electric, magnetic, and electromagnetic fields that are based directly on established health effects as given in 1999/519/EC [1]

3.4
broadcasting service

radio communication service in which the transmissions are intended for direct reception by the general public. This service may include sound transmissions, television transmissions or other types of transmission

3.5
compliance distance

minimum distance from the antenna to a point of investigation where field level is deemed to be compliant to the limits

3.6
compliance boundary
surface around the antenna outside of which all field levels are deemed to be compliant to the limits

3.7
contact current (IC)
contact current between a person and an object exposed to the field, is expressed in amperes (A). A conductive object in an electric field can be charged by the field

3.8
current density (J)
current density is defined as the current flowing through a unit cross section perpendicular to its direction in a volume conductor such as the human body or part of it, expressed in amperes per square meter (A/m²)

3.9
electric field strength (E)
magnitude of a field vector at a point that represents the force (***F***) on a positive small charge (*q*) divided by the charge

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

Electric field strength is expressed in units of volt per meter (V/m)

3.10
exposure limit values
limits on exposure to electromagnetic fields as given in 2004/40/EC [2] which are based directly on established health effects and biological considerations. Compliance with these limits will ensure that workers exposed to electromagnetic fields are protected against all known adverse health effects

3.11
induced current
current induced inside the body as a result of direct exposure to electromagnetic fields, expressed in the unit ampere (A)

3.12
installation
a particular combination of several types of apparatus and, where applicable, other devices, which are assembled, installed and intended to be used permanently at a predefined location. In this standard, installation includes at least one short wave transmitter

3.13
magnetic field strength (H)
vector quantity obtained at a given point by subtracting the magnetization ***M*** from the magnetic flux density ***B*** divided by the permeability of free space μ_0

$$H = \frac{B}{\mu_0} - M$$

Magnetic field strength is expressed in the unit ampere per metre (A/m)

NOTE In vacuum, the magnetic field strength is at all points equal to the magnetic flux density divided by the permeability of free space: $\boldsymbol{H} = \boldsymbol{B} / \mu_0$

3.14
modulation
process by which a quantity that characterises an oscillation or wave is constrained to follow the values of a characteristic quantity of a signal

NOTE Two modulations, in particular, are used for this standard: AM (Amplitude Modulation) and COFDM (Coded Orthogonal Frequency Division Multiplex); it must also be taken into consideration when carrying out measurements and calculations to determine whether or not the limits are being exceeded by adding the modulation factor to the carrier r.m.s. value.

3.15
reference levels
reference levels of exposure are provided by 1999/519/EC [1] for comparison with measured values of physical quantities; compliance with all reference levels will ensure compliance with basic restrictions. If measured values are higher than reference levels, it does not necessarily follow that the basic restrictions have been exceeded, but a more detailed analysis is necessary to assess compliance with the basic restrictions

3.16
root-mean-square (r.m.s.)
r.m.s. value is obtained by taking the square root of the average of the square of the value of the periodic function taken throughout one period

3.17
shortwave broadcasting
the frequency band between 3 MHz and 30 MHz is called the short wave band. Broadcast transmission in this frequency range is therefore called shortwave broadcasting

3.18
site
area including a short wave installation and with restricted access for public

3.19
specific absorption rate (SAR)
time derivative of the incremental energy (dW) absorbed by (dissipated in) an incremental mass (dm) contained in a volume element (dV) of given mass density (ρ):

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

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

3.20
transmitter
device to generate radio frequency power for the purpose of communication

4 Physical quantities and units

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

Quantity	Symbol	Unit	Dimensions
Current density	J	ampere per square meter	A/m²
Electric field strength	E	volt per meter	V/m
Frequency	f	hertz	Hz
Magnetic field strength	H	ampere per meter	A/m
Specific absorption rate	SAR	watt per kilogram	W/kg
Wavelength	λ	meter	m
Electric conductivity	σ	siemens per meter	S/m
Mass density	ρ	kilogram per cubic meter	kg/m³

5 Applicability of compliance assessment methods

In short wave broadcasting services, horizontally polarized, there are two field regions at the ground level (the far field region does not exist at ground level):

- the reactive near-field region; this region is defined by $r \leq \lambda/4$ where r is the distance from the antenna to the point of investigation;
- the radiating near-field; this region is defined by $r > \lambda/4$ where r is the distance from the antenna to the point of investigation.

This standard describes measurement and calculation methods to define the exposure areas and the next tables (Table 1 and Table 2) will help to select an appropriate method.

Compliance of the results of the assessment with the appropriate reference level or action value will ensure compliance with the relevant limit (basic restriction or exposure limit value). However, it is always possible to test compliance directly with regards to basic restriction or exposure limit values, both expressed in SAR and current density.

5.1 Reference level or action level values

Table 1 – Assessment methods for each antenna region

Assessment methods for each antenna region	
Reactive near field	**Radiating near field**
E **and** H field calculation Induced currents calculation [a] Contact current calculation	H field calculation Induced currents calculation [a]
E **and** H field measurement Induced currents measurement [a] Contact current measurement	H field measurement Induced currents measurement [a]

[a] Compliance of maximum value of E or H field to relevant level, without spatial averaging, gives conformity to induced current.

5.2 SAR and current density

Table 2 – Assessment methods for each antenna region

Assessment methods for each antenna region	
Reactive near field	**Radiating near field**
SAR and current density [a]	SAR and current density

[a] No standardised method of SAR evaluation in reactive near field is available.

SAR and current density evaluation can be based either on calculated or measured field levels.

6 SAR measurement and calculation (local and average SAR)

6.1 Approximate method for SAR calculation for frequencies below body resonance

Outside the reactive near field region, a quasi static approach is appropriate for SAR estimation when the frequency of the wave is below the resonance frequency of a human body (around 70 MHz in free space and 35 MHz when grounded). This approach is particularly applicable in the exposure analysis in the near-field region of large AM-broadcast antennas.

Measurement or calculation techniques permit the determination of the electric field E and the magnetic field H in the near field and far field of a broadcast antenna (frequency range 3 MHz to 30 MHz). For many configurations of broadcast antennas, the safety distance derived from reference levels is overly conservative as the true absorption in the human body is much lower due to near-field or polarisation effects. In principle, SAR-values for a human-body model may be derived by FDTD (Finite-Difference Time-Domain) analysis when the tangential electric and magnetic field components on a closed boundary around the body are known (Huygen’s Principle). However, it is very expensive to assess at several locations the complete field around an appropriate volume of the human model. Hence a practical approach has to implement some simplifications.

In general, the time-varying electric and magnetic fields are vectors and have component values with respect to the three co-ordinate directions. However, at frequencies below resonance where the free-space wavelength of the field is much greater than the dimensions of the human body, a quasi-static calculation may be used for SAR assessment. When the electric and the magnetic field can be regarded as decoupled from each other, the contribution to the SAR is determined by separate field-component terms, each with a coefficient depending only on the incoming wave polarisation and on the shape and conductivity of the body, expressed generally as:

$$\mathrm{SAR} = a \cdot E_x + b \cdot E_y + c \cdot E_z + d \cdot H_x + e \cdot H_y + f \cdot H_z \,.$$

For a general exposure assessment one needs to adopt an *average body model* to obtain representative SAR values, or better a body model which will lead to worst-case SAR values. This is supposed to be fulfilled by the body model of the Visible Human.

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 cryosection images.

The SAR exposure assessment gives more restrictive values compared with limit values than the current density above a frequency range of about 3 MHz to 5 MHz.

6.2 Exposure situation

The energy absorbed by the human body is dependent on the polarisation and the direction of the plane wave incident on the body. Following it is assumed for the model that has three semi-axes, denoted by *a*, *b*, and *c*, with always *a* > *b* > *c*. The coordinate system is such that the greatest semi-axis length *a* is always along the *x*-co-ordinate axis corresponding to the body length; likewise semi-axis *b* is along the *y*-coordinate axis across the body (through the arms in a corresponding human body model), and the shortest semi-axis *c* along the *z*-coordinate axis (from the chest to the back).

The directions of the electric field vector E, the magnetic field vector H, and the propagation vector k of the incident plane wave are always denoted with respect to the *a*-, *b*-, and *c*-axes in that order. Thus, for example, “EHk” denotes E parallel to the *x*-axis, H parallel to the *y*-axis, and k parallel to the *z*-axis. For further details, see references [3] and [4].

The electromagnetic energy absorbed in the body, as expressed by the whole-body SAR, depends on the polarisation of the incoming electromagnetic wave, and, for the standard polarisation described in the previous paragraph, are (see reference [5], Eqq. 7-12):

EkH: $\mathrm{SAR_{wb}} = \mathrm{SE_a} + \mathrm{SH_c}$,

EHk: $\mathrm{SAR_{wb}} = \mathrm{SE_a} + \mathrm{SH_b}$,

kEH: $\mathrm{SAR_{wb}} = \mathrm{SE_b} + \mathrm{SH_c}$,

HEk: $\mathrm{SAR_{wb}} = \mathrm{SE_b} + \mathrm{SH_a}$,

kHE: $\mathrm{SAR_{wb}} = \mathrm{SE_c} + \mathrm{SH_b}$,

HkE: $\mathrm{SAR_{wb}} = \mathrm{SE_c} + \mathrm{SH_a}$,

where the quantities $\mathrm{SE_a}$, $\mathrm{SE_b}$, $\mathrm{SE_c}$, $\mathrm{SH_a}$, $\mathrm{SH_b}$ and $\mathrm{SH_c}$ are quasi-static energy-absorption components which depend only on the semi-axis lengths *a*, *b*, and *c*, the conductivity of the model, and the frequency and effective field strength of the incident electromagnetic wave (see references [4] and [5]). The parameter $\mathrm{SE_a}$, for example, is the energy component absorbed in the body from the incident electric field $\mathrm{E_a}$ polarised along the longest semi-axis *a*, and likewise for the H-field and the other semi-axis directions *b* and *c*. For each wave polarisation above, the contribution to the whole-body SAR is the sum of two independent components, one from the corresponding electric field and the other from the magnetic field, which are regarded as decoupled in the quasi-static case.

This model is only applicable outside the reactive near field region of the antenna.

6.3 Polynomial expansion of “static” component values with frequency

In the quasi-static regime for a plane wave with general polarisation and direction, we have, to a good approximation, (see reference [5]):

$$\mathrm{SAR_{wb}} = \mathrm{SE_x} + \mathrm{SE_y} + \mathrm{SE_z} + \mathrm{SH_x} + \mathrm{SH_y} + \mathrm{SH_z}.$$

The SAR and “static” component values are displayed in Tables A.1 and A.2 for the inhomogeneous Visible Human body model on the ground.

Also tabulated in Table A.3 are the coefficient values of the polynomial expansions of these quasi-static component values as functions of frequency, between 5 MHz and 30 MHz. These permit the determination of the quasi-static values at intermediate frequencies from those plotted. The frequency expansions are of the form (see reference [5], Eq. 21):

$$\mathrm{SE_p} = \sum_{n=0}^{3} \mathrm{a}_{\mathrm{n,E_p}} f^{\mathrm{n}} \qquad \text{and} \qquad \mathrm{SH_p} = \sum_{n=0}^{3} \mathrm{a}_{\mathrm{n,H_p}} f^{\mathrm{n}},$$

where the static components are in units of mW/kg and frequency in MHz. The subscript *p* refers to one of the semi-axis directions of the model, *a*, *b* or *c* corresponding to the usual axes *x*, *y* and *z* chosen for this problem. The expansion coefficients $\mathrm{a}_{\mathrm{n,E_p}}$ and $\mathrm{a}_{\mathrm{n,H_p}}$ are determined by least-squares fitting to the variation of each static component with frequency, and are tabulated in Table A.3 for the body on conducting ground.

The whole-body SAR values plotted and tabulated here are for a plane wave of incident power 1 mW/cm² = 10 W/m² r.m.s., which corresponds to an incident electric field strength of E_{io} = 61,4 V/m r.m.s. and incident magnetic field strength H_{io} = 0,163 A/m r.m.s. The whole-body SAR values for other effective values of incident electric and magnetic field can be determined to a good approximation from the relationship (see reference [5], Eq. 20),

$$SAR_{wb} = \left(\frac{E_x}{E_{io}}\right)^2 SE_a + \left(\frac{E_y}{E_{io}}\right)^2 SE_b + \left(\frac{E_z}{E_{io}}\right)^2 SE_c + \left(\frac{H_x}{H_{io}}\right)^2 SH_a + \left(\frac{H_y}{H_{io}}\right)^2 SH_b + \left(\frac{H_z}{H_{io}}\right)^2 SH_c,$$

where the effective values E_x, E_y, E_z, H_x, H_y and H_z can be measured incident values; or alternatively calculated incident values from some other electromagnetic calculation program. (This could be, for example, a method-of-moments calculation which is suitable for electromagnetic fields radiated from an antenna, and for which the field point can be taken at large distances greater than those permitted by the memory requirements for the mesh of FDTD methods.) The above relation, and the expansions of the static components in terms of frequency, permit the calculation to a good approximation of the whole-body SAR for an incident plane wave, or near-plane wave, of general amplitude and polarisation for frequencies between 5 MHz and 30 MHz for the inhomogeneous Visible Human body model. The static components incorporate the relative permittivity and conductivity values assigned to each tissue type for each of the frequency values 5 MHz, 10 MHz, 20 MHz and 30 MHz (see reference [6], Table 2).

7 Current density (3 MHz – 10 MHz)

At frequencies below 10 MHz there is an additional basic restriction which must be considered, limiting the current density in the central nervous system. The Exposure Limit Value for this is 10 A/m² at 1 MHz and increases in proportion to frequency over the frequency range up to 10 MHz.

State-of-the-art dosimetry may be used to determine the electric field that is needed to produce the value of induced current density in the central nervous system corresponding to the exposure limit value. For example Dimbylow (see reference [8], Table 9 and Figure 6) shows that for a grounded person standing in a vertically polarised electric field the field must exceed 2 000 V/m before the exposure limit is exceeded. For a person who is not grounded, even higher values of electric field would be needed.

An electric field of 2 000 V/m is higher than the electric field that is needed to exceed of any of various SAR exposure limits for vertically polarised electric fields.

This means that for the frequency range covered by this standard the exposure assessment does not need to specifically consider the current density limits, provided the SAR limits are properly considered.

This can be illustrated by referring to dosimetry computations by Findlay, Dimbylow and Mann (reference [9]). The value of vertically polarised electric field needed to produce the Exposure Limit Values for SAR depends on frequency and on whether or not the body is grounded, are given for whole body average SAR, leg SAR and wrist SAR (reference [9], Table 5.3, Table 5.5 and Table 5.8 respectively). These values are all less than 2 000 V/m, and in some cases very much less than 2 000 V/m indicating that these will always be the limiting factor.

Where the electric field is predominantly horizontal it is reasonable to assume that the current density is smaller than if the field is only vertical (which has been demonstrated for whole-body-average SAR) and therefore the maximum electric field corresponding to the exposure limit for current density becomes even larger.

8 Measurement of electric and magnetic field

Measurement of electric and magnetic fields is defined in detail in EN 50413. Measurements made in the reactive near field should be done with specific equipment (for example: small antenna to avoid capacitive coupling, fibre optic connecting cables, etc.).

Frequency selective or broadband measurement equipment, including one or several E-field or H-field probes can be used. The equipment shall be calibrated for the frequencies of the relevant sources to measure.

If an isotropic probe is used then the measurement shall be done using direct acquisitions. If a non-isotropic probe is used, then several directions have to be considered and isotropy has to be evaluated. For instance, if a single dipole antenna is used, then the measurements have to be carried out in three orthogonal directions.

Depending on the particular conditions for the measurement, either broadband or frequency selective equipment can be used. In that last case, the resolution bandwidth of the measurement system shall be 10 kHz or better.

The assessment of uncertainty in the measurement of the electromagnetic fields values shall be based on the general rules provided by the "Guide to the expression of uncertainty in measurement" (ENV 13005). An evaluation of type A as well as type B of the standard uncertainty shall be used.

After scaling post-processing, the expanded uncertainty shall not exceed 30 % of the E or H fields.

9 Calculation of electric and magnetic field

Calculation of electric and magnetic field is defined in details in EN 50413.

10 Contact currents measurement and calculation

10.1 Generalities

Contact currents arise from a person touching a metallic object in the electromagnetic field and could create a risk of shock, or burn from light contact of the fingers with the external object.

It is impossible in a general case to calculate contact currents due the impossibility of defining a generic coupling structure. In a specific case, at a given situation in the site, calculation is possible but measurement is preferred.

With a current clamp, a steady state total current is measured.

10.2 Constraints

If contact current is considered to be important, cautions must be taken:

- during the measure the individual must be isolated from the conductive object;
- the electric circuit of the current meter shall be equivalent to the body impedance at the considered frequency (with a frequency band up to 110 MHz).

If no risk of burn or shock is possible, a clamp current placed around the wrist of the individual can be used to measure the contact current level.

10.3 Equipment

Measurements shall be carried out over the whole frequency band. This can be realised by combining

- an equivalent body impedance equipment, and
- a current clamp.

The methodology is based on the measurement of current flowing through an equipment having the same impedance as a body. It is proposed to use an artificial hand model (see 10.4) connected to the earth through a capacitive metallic plate. Once the equipment is in contact with the object under test, the clamp measures the current going to earth, as in Figure 1:

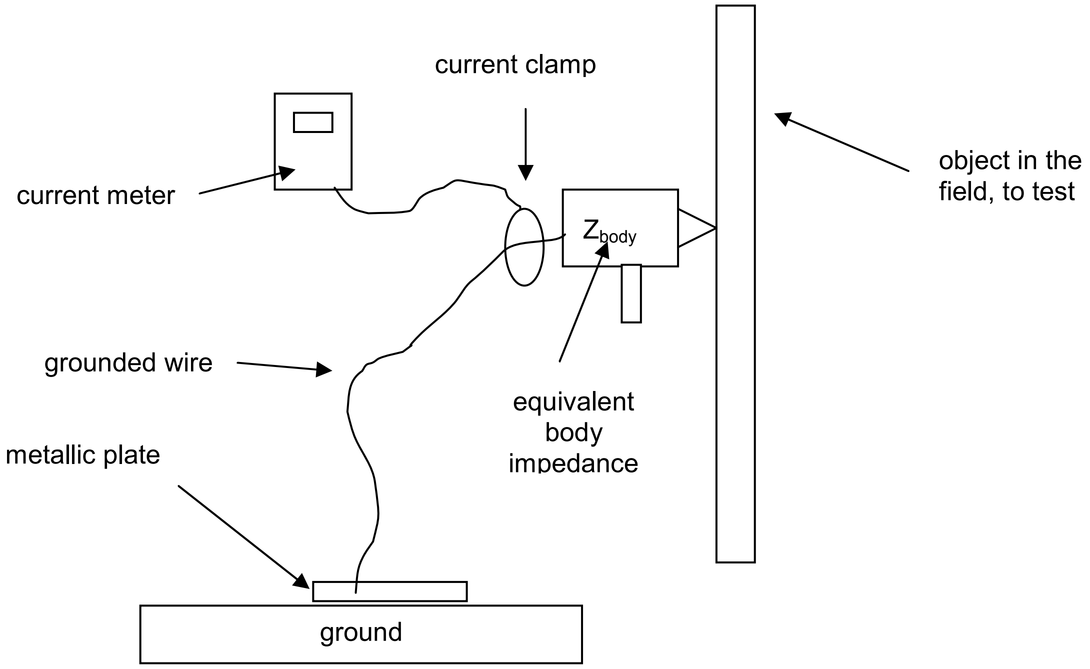


Figure 1 – Contact current measurement

10.4 Equivalent body impedance

The artificial hand of EMC standards (EN 55016) is used as equivalent body impedance.

As described in Figure 2, the artificial hand consists of a metal foil which is connected to one terminal (terminal M) of a circuit consisting of a capacitor of 220 pF in series with a resistance of 510 Ω; the other terminal of the RC element shall be connected to the reference ground of the measuring system.

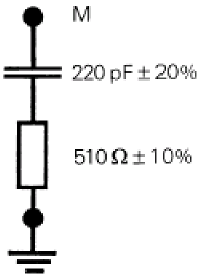


Figure 2 – Equivalent body impedance

11 Induced current calculation and measurement (10 MHz – 30 MHz)

11.1 Induced current calculation

Induced current calculation needs the same tools and methods as SAR calculation. But a standardised approach is not available in the frequency range

Compliance of the maximum value of E or H field to the relevant level, without spatial averaging, gives conformity to induced current.

11.2 Relation between induced current and local SAR

The Induced current reference level has been introduced to respect local SAR in limbs:

- considering that the current I(z) at a given height result from the current density J(z) integrated over a considered surface;
- considering that E is nearly homogeneous on the surface regarding the frequency and taking an averaged conductivity for tissue, I(z) is proportional to E(z):

$$\mathrm{I(z)} \cong \overline{\sigma}\,.\,\overline{\mathrm{E}}_{\mathrm{z}} \sum \mathrm{dS} = \overline{\sigma}\,.\,\overline{\mathrm{E}}_{\mathrm{z}}\,.\,\mathrm{S}\,;$$

- considering a vertical polarization E(z) of the field, SAR is proportional to E²(z):

$$\mathrm{SAR(z)} \cong \frac{\overline{\sigma}}{\rho}\,.\,\overline{\mathrm{E}}_{\mathrm{z}}^{\;2}\,;$$

- SAR(z) is known as below:

$$\mathrm{SAR(z)} \cong \frac{\sigma}{\rho}\,.\left(\frac{\mathrm{I(z)}}{\sigma.\mathrm{S}}\right)^2 = \frac{\mathrm{I}^2\mathrm{(z)}}{\overline{\rho\overline{\sigma}}.\mathrm{S}^2}\,.$$

The relation between SAR and current depends strongly on the conductivity (σ) and the mass density (ρ). This factor (σρ) ranges from 77 kgA/Vm^4 to 2 300 kgA/Vm^4, with an averaged value at 900 kgA/Vm^4. If we are only considering legs, this factor reaches only 1 400 kgA/Vm^4, with an averaged value at 730 kgA/Vm^4.

Regarding the action value for workers with a maximum induced current of 100 mA and a local SAR equal to 20 W/kg, and the reference level for public with a maximum induced current of 45 mA and a local SAR equal to 4 W/kg. This relation gives the following result:

$$SAR(z) \cong \alpha\,.\,I^2(z)$$

where

α = 2 000 V/kgA.

11.3 Induced current measurement

This can be realised by combining

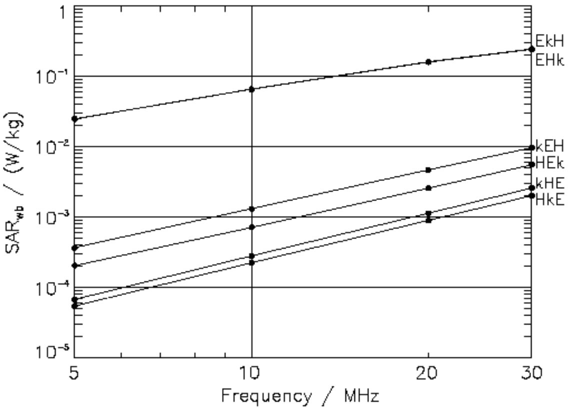
- an equivalent human body impedance, and
- a current clamp.

The measurement should be carried out by a clamp in measuring the current in the equivalent body impedance equipment.

Annex A
(informative)

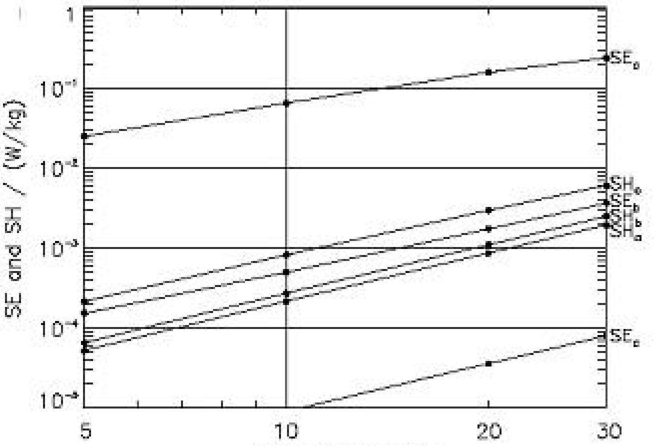
Data for absorption by the Visible Human body model

To permit direct numerical calculation of the body SAR from known calculated or measured field strength, tables are presented of the whole-body SAR values and of the static component values with frequency, and of the polynomial expansion coefficients of the static components with respect to frequency. They are valid outside the reactive near field of the antenna.



Frequency f / MHz

Figure A.1 – Calculated whole-body SAR values for the displayed polarisation for the inhomogeneous Visible Human body model on conducting ground using currently-accepted values for relative permittivity and conductivity at each frequency



Frequency f / MHz

NOTE The incident power is 1 mW/cm² = 10 W/m² r.m.s.

Figure A.2 – Corresponding polarised E- and H-component parts of the whole-body SAR

Table A.1 – Whole-body specific absorption rate for the inhomogeneous Visible Human body model on conducting ground for the different plane-wave polarisation orientations

Frequency *f* / MHz	SAR_{wb} mW/kg					
	EkH	**EHk**	**kEH**	**HEk**	**kHE**	**HkE**
5	24,67	24,60	0,369	0,207	0,068	0,055
10	65,40	65,06	1,317	0,717	0,282	0,225
20	159,53	158,17	4,668	2,593	1,134	0,898
30	242,83	240,19	9,658	5,575	2,587	2,014

NOTE The incident power is 1 mW/cm² = 10 W/m² r.m.s. The simulation of the conducting ground is with electric boundary conditions for the EkH and EHk polarisations where the E-field is along the (longest body dimension) *x*-axis and thus perpendicular to the ground. Magnetic boundary conditions are used for the HEk and HkE polarisations and the open-boundary results already obtained are used for the kEH and kHE polarisations, as electric boundary conditions cannot be used in the calculations for these cases. This means that a mixture of conditions has to be used for the derivation of the quasi-static components given in Table A.2 below.

Table A.2 – "Static" components of the whole-body specific absorption rate for the inhomogeneous Visible Human body model on conducting ground for the different plane-wave polarisation orientations

Frequency *f* / MHz	**SE** mW/kg			**SH** mW/kg		
	SE_a	SE_b	SE_c	SH_a	SH_b	SH_c
5	24,541	0,153 7	0,002 2	0,052 6	0,065 8	0,215 1
10	64,784	0,500 6	0,009 0	0,216 0	0,272 4	0,816 6
20	157,076	1,731 5	0,035 9	0,861 8	1,098 4	2,936 2
30	237,681	3,641 6	0,080 5	1,933 3	2,506 7	6,016 6

NOTE The incident power is 1 mW/cm²= 10 W/m² r.m.s.

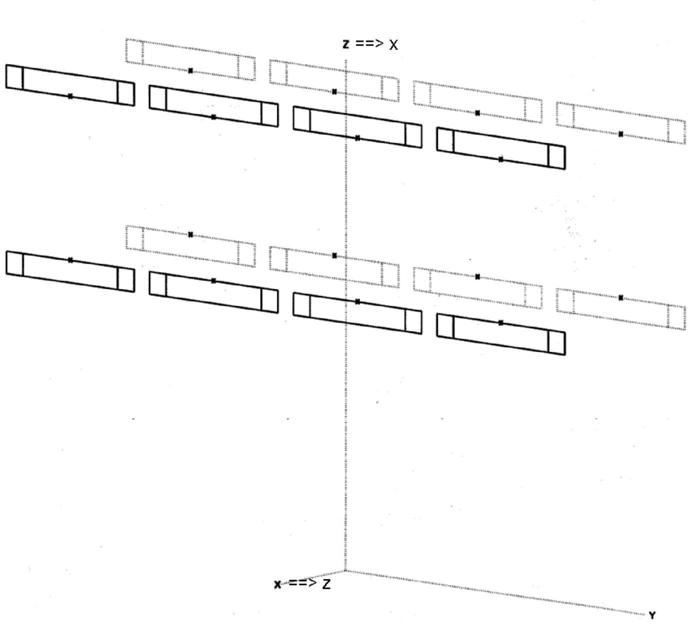
Table A.3 – Polynomial expansion coefficients with respect to frequency for the static components of the whole-body specific absorption rate for the inhomogeneous Visible Human body model on conducting ground

	SE mW/kg			**SH** mW/kg		
	SE_a	**SE_b**	**SE_c**	**SH_a**	**SH_b**	**SH_c**
a_0	$-6,310 \cdot 10^{0}$	$-8,285 \cdot 10^{-3}$	$-2,077 \cdot 10^{-4}$	$-2,562 \cdot 10^{-3}$	$-9,716 \cdot 10^{-3}$	$-2,402 \cdot 10^{-2}$
a_1	$4,955 \cdot 10^{0}$	$1,342 \cdot 10^{-2}$	$4,001 \cdot 10^{-5}$	$4,293 \cdot 10^{-4}$	$2,337 \cdot 10^{-3}$	$9,288 \cdot 10^{-3}$
a_2	$2,703 \cdot 10^{-1}$	$3,815 \cdot 10^{-3}$	$8,793 \cdot 10^{-5}$	$2,146 \cdot 10^{-3}$	$2,525 \cdot 10^{-3}$	$8,007 \cdot 10^{-3}$
a_3	$-5,477 \cdot 10^{-3}$	$-6,909 \cdot 10^{-6}$	$1,538 \cdot 10^{-8}$	$-3,231 \cdot 10^{-7}$	$6,447 \cdot 10^{-6}$	$-5,348 \cdot 10^{-5}$

NOTE The coefficients a_0 to a_3 are the coefficients a_{n,E_p} and a_{n,H_p} of the expansions of the static coefficients (in mW/kg) in frequency (MHz) (see 7.3).

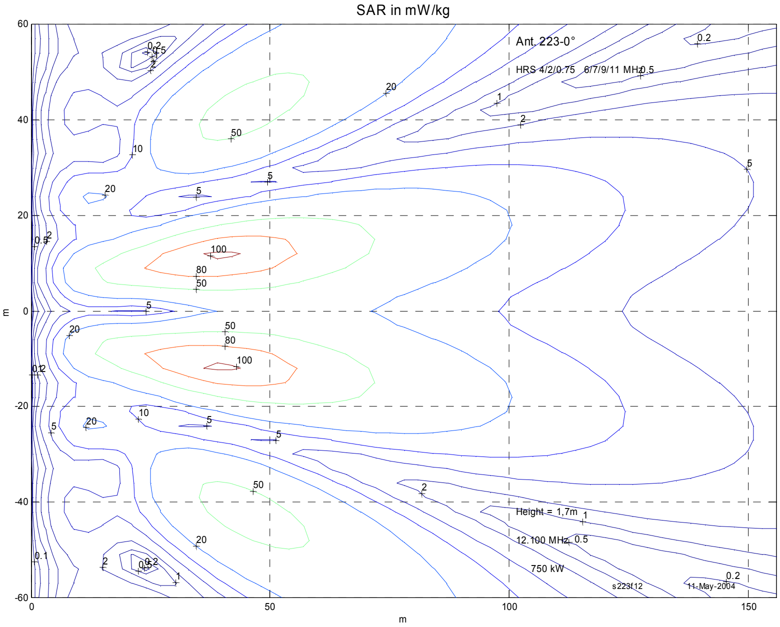
NOTE The orientation of the standing body relative to the horizontal component of the field is not defined, so the largest resulting horizontal field strength $E_Y' = \sqrt{E_Y^2+E_Z^2}$ and $H_Z' = \sqrt{H_Y^2+H_Z^2}$ should be determined and related to the greater component SE_b respectively SH_c.

Application to a representative case:



HRS 4/2/0,75 at 12,1 MHz and 750 kW

Figure A.3 – Model of the antenna considered



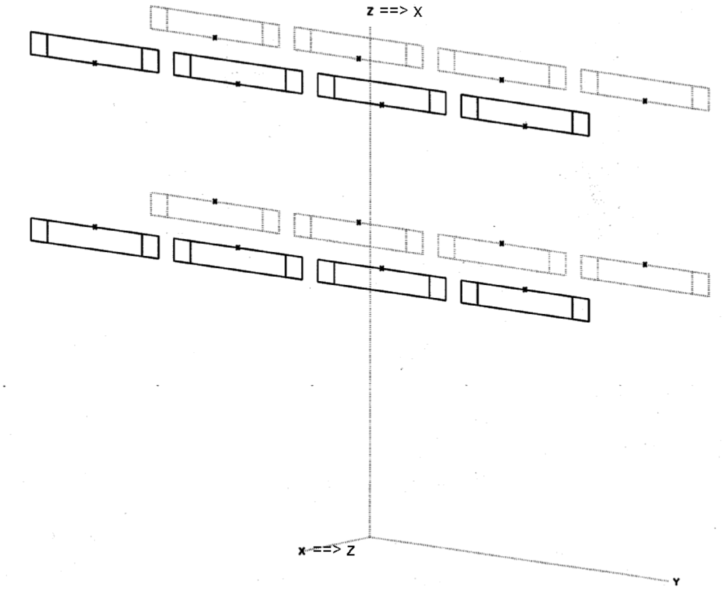
NOTE The calculation was carried out with a transmitted power of 750 kW at a height of 1,7 m. The exposure limits values are 400 mW/kg for 2004/40/EC [2] and basic restrictions are 80 mW/kg for 1999/519/EC [1]. In the case above there is no safety distance for 2004/40/EC [2], but for public it is 57 m.

Figure A.4 – Plot of the SAR calculated on the basis of the model of Visible Human on the basis of calculated field strengths of the electric and magnetic field in front of the studied short wave curtain antenna

Annex B
(informative)

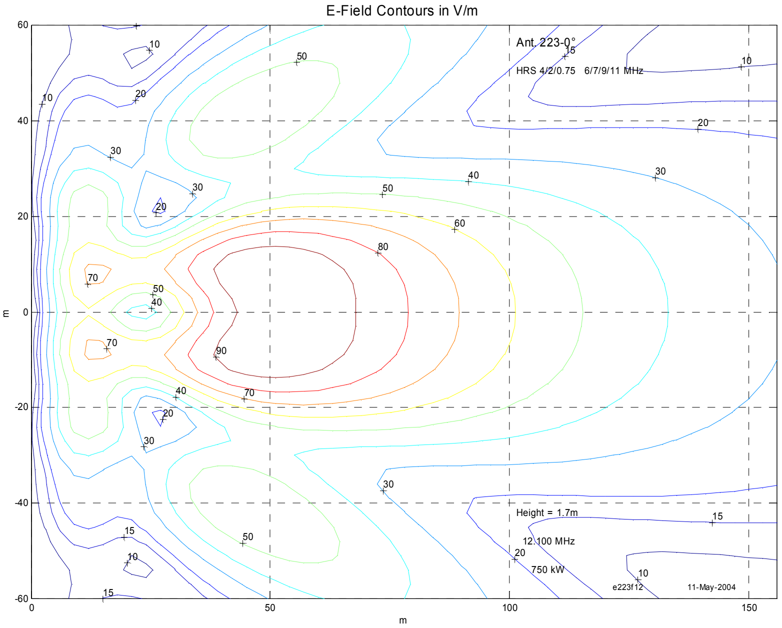
Compliance boundary examples

With the same example, the next paragraphs give an impression of the electric and magnetic field strength in front of a short wave curtain antenna (Figures B.2 and B.3). This is to show that despite higher values than the reference levels in wide areas in this case there is compliance with the basic restrictions, when the whole body SAR is calculated applying the SAR evaluation method corresponding to Annex A.



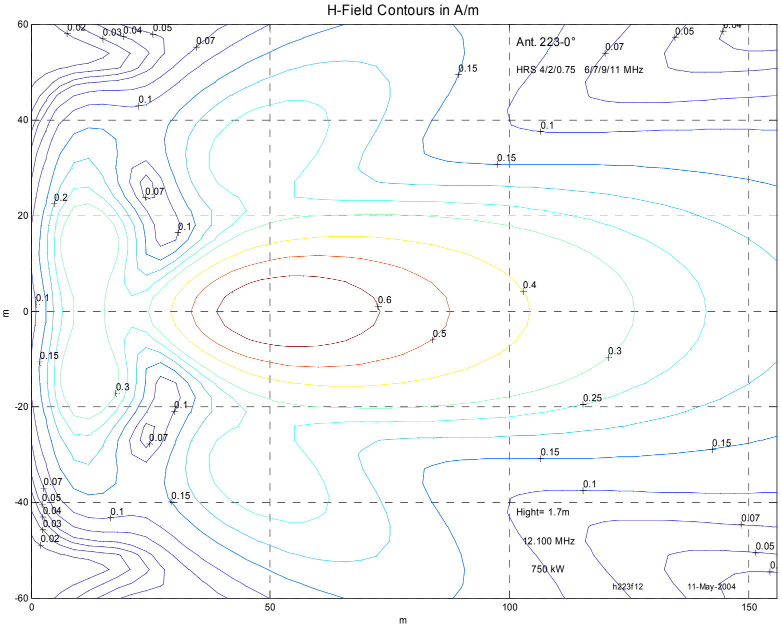
HRS 4/2/0,75 at 12,1 MHz and 750 kW

Figure B.1 – Model of the antenna considered



NOTE The calculation was carried out with a transmitted power of 750 kW at a height of 1,7 m above conductive ground. The actions values are 61 V/m for 2004/40/EC [2] and reference levels are 28 V/m for 1999/519/EC [1], this results in safety distances of 101 m resp. 165 m.

Figure B.2 – Plot of the E-field strength calculated on NEC-2 basis in front of a short wave curtain antenna



NOTE The calculation was carried out with a transmitted power of 750 kW at a height of 1,7 m above conductive ground. The action values are 160 mA/m for 2004/40/EC [2] and the reference levels are 73 mA/m for 1999/519/EC [1], this results in safety distances of 182 m resp. 277 m.

Figure B.3 – Plot of the H-field strength calculated on NEC-2 basis in front of a short wave curtain antenna

Bibliography

[1] *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

[2] *Directive 2004/40/EC of the European Parliament and of the Council of 29 April 2004 on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (Electromagnetic fields),* Official Journal L 159 of 30 April 2004

[3] H. Massoudi, C. H. Durney, C. C. Johnson: *"Long-wavelength analysis of plane wave irradiation of an ellipsoidal model of man",* IEEE Trans. Microwave Theory Tech., Vol. MTT-25, 1977, pp. 41-46

[4] V. Hombach, *"Expositionsanalyse von Kurzwellenantennen", "(Exposure analysis of HF antennas)"*, in: Proceedings of EMV `98, Elektromagnetische Verträglichkeit, 6.Internationale Fachmesse und Kongreß für elektromagnetische Verträglichkeit, 10.-12. Februar 1998, Berlin. Offenbach, ISBN 3-8007-2324-7, pp. 67-74

[5] V. Hombach: *Bestimmung der Exposition von Menschen in der Nähe von Rundfunksendeanlagen*, Abschlußbericht DLV-AC-0073, Technologiezentrum Darmstadt der Deutschen Telekom AG, 1996

[6] J. Cooper, V. Hombach: *Electromagnetic energy absorption in a human body at low MHz frequencies*, Report of T-Systems GmbH, Technologiezentrum Darmstadt, Germany, 2001

[7] Recommendation ITU-R BS.1698 *Evaluating fields from terrestrial broadcasting transmitting systems operating in any frequency band for assessing exposure to non-ionizing radiation*

[8] Dimbylow P, 2005, *Development of the female voxel phantom, NAOMI, and its application to calculation of induced current densities and electric fields from applied low frequency magnetic and electric fields*, Phys Med Biol, vol. 50, pp 1047-1070

[9] Findlay R, Dimbylow P and Mann S, 2006, *Assessing the compliance of emissions from HF broadcast transmitters*, EBU Technical Review, April 2006

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