

ANNEX

EXPOSURE LIMIT AND ACTION VALUES FOR ELECTROMAGNETIC FIELDS

The following physical quantities shall be used to describe the exposure to electromagnetic fields:

Contact current (I_C) between a person and an object is expressed in amperes (A). A conductive object in an electric field can be charged by the field.

Current density (J) 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 metre (A/m^2).

Electric field strength is a vector quantity (E) that corresponds to the force exerted on a charged particle regardless of its motion in space. It is expressed in volts per metre (V/m).

Magnetic field strength is a vector quantity (H), which, together with the magnetic flux density, specifies a magnetic field at any point in space. It is expressed in amperes per metre (A/m).

Magnetic flux density is a vector quantity (B), resulting in a force that acts on moving charges, expressed in teslas (T). In free space and in biological materials, magnetic flux density and magnetic field strength can be interchanged using the equivalence $1 A/m = 4\pi \cdot 10^{-7} T$.

Power density (S) is the appropriate quantity used for very high frequencies, where the depth of penetration in the body is low. It is the radiant power incident perpendicular to a surface, divided by the area of the surface and is expressed in watts per square metre (W/m^2).

Specific energy absorption (SA) is defined as the energy absorbed per unit mass of biological tissue, expressed in joules per kilogram (J/kg). In this directive it is used for limiting non-thermal effects from pulsed microwave radiation.

Specific energy absorption rate (SAR) averaged over the whole body or over parts of the body, is defined as the rate at which energy is absorbed per unit mass of body tissue and is expressed in watts per kilogram (W/kg). Whole body SAR is a widely accepted measure for relating adverse thermal effects to radio frequency (RF) exposure. Besides the whole body average SAR, local SAR values are necessary to evaluate and limit excessive energy deposition in small parts of the body resulting from special exposure conditions. Examples of such conditions are: a grounded individual exposed to RF in the low MHz range and individuals exposed in the near field of an antenna.

Of these quantities, magnetic flux density, contact current, electric and magnetic field strengths and power density can be measured directly.

A. EXPOSURE LIMIT VALUES

Depending on frequency, the following physical quantities are used to specify the exposure limit values of electromagnetic fields:

- exposure limit values are provided for current density for time-varying fields up to 1 Hz, to prevent effects on the cardiovascular and central nervous system,
- between 1 Hz and 10 MHz exposure limit values are provided on current density to prevent effects on central nervous system functions,
- between 100 kHz and 10 GHz exposure limit values on SAR are provided to prevent whole-body heat stress and excessive localised heating of tissues. In the range 100 kHz to 10 MHz, exposure limit values on both current density and SAR are provided,

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- between 10 GHz and 300 GHz an exposure limit value on power density is provided to prevent excessive tissue heating at or near the body surface.

TABLE 1: EXPOSURE LIMIT VALUES (ARTICLE 3(1)). ALL CONDITIONS TO BE SATISFIED

| Frequency range | Current density for head and trunk J(mA/m ²)(rms) | Whole body average SAR(W/kg) | Localised SAR(head and trunk) (W/kg) | Localised SAR(limbs) (W/kg) | Power density S(W/m ²) |
|--------------------|---|------------------------------|--------------------------------------|-----------------------------|------------------------------------|
| Up to 1 Hz | 40 | — | — | — | — |
| 1 - 4 Hz | 40/f | — | — | — | — |
| 4 - 1 000 Hz | 10 | — | — | — | — |
| 1 000 Hz – 100 kHz | f/100 | — | — | — | — |
| 100 kHz – 10 MHz | f/100 | 0,4 | 10 | 20 | — |
| 10 MHz – 10 GHz | — | 0,4 | 10 | 20 | — |
| 10 – 300 GHz | — | — | — | — | 50 |

Notes:

1. f is the frequency in Hertz.
2. The exposure limit values on the current density are intended to protect against acute exposure effects on central nervous system tissues in the head and trunk of the body. The exposure limit values in the frequency range 1 Hz to 10 MHz are based on established adverse effects on the central nervous system. Such acute effects are essentially instantaneous and there is no scientific justification to modify the exposure limit values for exposure of short duration. However, since the exposure limit values refer to adverse effects on the central nervous system, these exposure limit values may permit higher current densities in body tissues other than the central nervous system under the same exposure conditions.
3. Because of the electrical inhomogeneity of the body, current densities should be calculated as averages over a cross-section of 1 cm perpendicular to the current direction.
4. For frequencies up to 100 kHz, peak current density values can be obtained by multiplying the rms value by $(2)^{1/2}$.
5. For frequencies up to 100 kHz and for pulsed magnetic fields, the maximum current density associated with the pulses can be calculated from the rise/fall times and the maximum rate of change of magnetic flux density. The induced current density can then be compared with the appropriate exposure limit value. For pulses of duration t_p , the equivalent frequency to apply for the exposure limit values should be calculated as $f=1/(2t_p)$.
6. All SAR values are to be averaged over any six-minute period.

7. Localised SAR averaging mass is any 10 g of contiguous tissue; the maximum SAR so obtained should be the value used for estimating exposure. These 10 g of tissue are intended to be a mass of contiguous tissue with nearly homogeneous electrical properties. In specifying a contiguous mass of tissue, it is recognised that this concept can be used in computational dosimetry but may present difficulties for direct physical measurements. A simple geometry such as cubic tissue mass can be used provided that the calculated dosimetric quantities have conservative values relative to the exposure guidelines.
8. For pulsed exposures in the frequency range 0,3 to 10 GHz and for localised exposure of the head, in order to limit and avoid auditory effects caused by thermoelastic expansion, an additional exposure limit value is recommended. This is that the SA should not exceed 10 mJ/kg averaged over 10 g of tissue.
9. Power densities are to be averaged over any 20 cm² of exposed area and any 68/f^{1,05}-minute period (where f is in GHz) to compensate for progressively shorter penetration depth as the frequency increases. Spatial maximum power densities averaged over 1 cm² should not exceed 20 times the value of 50 W/m².
10. With regard to pulsed or transient electromagnetic fields, or generally with regard to simultaneous exposure to multiple frequency fields, appropriate methods of assessment, measurement and/or calculation capable of analysing the characteristics of the waveforms and nature of biological interactions have to be applied, taking account of European harmonised standards developed by CENELEC.

B. ACTION VALUES

The action values referred to in Table 2 are obtained from the exposure limit values according to the rationale used by the International Commission on Non-ionising Radiation Protection (ICNIRP) in its guidelines on limiting exposure to non-ionising radiation (ICNIRP 7/99).

TABLE 2: ACTION VALUES (ARTICLE 3(2)) (UNPERTURBED RMS VALUES)

| Frequency range | Electric field strength, E (V/m) | Magnetic field strength, H (A/m) | Magnetic flux density, B (μT) | Equivalent plane wave power density, S _{eq} (W/m ²) | Contact current, I _c (mA) | Limb induced current, I _L (mA) |
|-----------------|----------------------------------|--------------------------------------|-----------------------------------|--|--------------------------------------|---|
| 0 – 1Hz | – | 1,63x10 ⁵ | 2x10 ⁵ | – | 1,0 | – |
| 1 – 8 Hz | 20000 | 1,63x10 ⁵ /f ² | 2x10 ⁵ /f ² | – | 1,0 | – |
| 8 – 25 Hz | 20000 | 2x10 ⁴ /f | 2,5x10 ⁴ /f | – | 1,0 | – |
| 0,025 – 0,82kHz | 500/f | 20/f | 25/f | – | 1,0 | – |
| 0,82 – 2,5 kHz. | 610 | 24,4 | 30,7 | – | 1,0 | – |
| 2,5 – 65 kHz | 610 | 24,4 | 30,7 | – | 0,4 f | – |

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|----------------|-------------------|-----------------------|----------------------|------|-------|-----|
| 65 – 100 kHz | 610 | 1600/f | 2000/f | – | 0,4 f | – |
| 0,1 – 1 MHz | 610 | 1,6/f | 2/f | – | 40 | – |
| 1 – 10 MHz | 610/f | 1,6/f | 2/f | – | 40 | – |
| 10 – 110 MHz | 61 | 0,16 | 0,2 | 10 | 40 | 100 |
| 110 – 400 MHz | 61 | 0,16 | 0,2 | 10 | – | – |
| 400 – 2000 MHz | 3f ^{1/2} | 0,008f ^{1/2} | 0,01f ^{1/2} | f/40 | – | – |
| 2 – 300 GHz | 137 | 0,36 | 0,45 | 50 | – | – |

Notes:

1. f is the frequency in the units indicated in the frequency range column.
2. For frequencies between 100 kHz and 10 GHz, S_{eq} , E^2 , H^2 , B^2 and I_L^2 are to be averaged over any six-minute period.
3. For frequencies exceeding 10 GHz, S_{eq} , E^2 , H^2 and B^2 are to be averaged over any $68/f^{1.05}$ -minute period (f in GHz).
4. For frequencies up to 100 kHz, peak action values for the field strengths can be obtained by multiplying the rms value by $(2)^{1/2}$. For pulses of duration t_p , the equivalent frequency to apply for the action values should be calculated as $f=1/(2t_p)$.

For frequencies between 100 kHz and 10 MHz, peak action values for the field strengths are calculated by multiplying the relevant rms values by 10^a , where $a = (0,665 \log (f/10^5) + 0,176)$, f in Hz.

For frequencies between 10 MHz and 300 GHz, peak action values are calculated by multiplying the corresponding rms values by 32 for the field strengths and by 1000 for the equivalent plane wave power density.

5. With regard to pulsed or transient electromagnetic fields, or generally with regard to simultaneous exposure to multiple frequency fields, appropriate methods of assessment, measurement and/or calculation capable of analysing the characteristics of the waveforms and nature of biological interactions have to be applied, taking account of harmonised European standards developed by CENELEC.
6. For peak values of pulsed modulated electromagnetic fields, it is also suggested that, for carrier frequencies exceeding 10 MHz, S_{eq} as averaged over the pulse width should not exceed 1 000 times the S_{eq} action values or that the field strength should not exceed 32 times the field strength action values for the carrier frequency.