C95.1a™

IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz

Amendment 1: Specifies Ceiling Limits for Induced and Contact Current, Clarifies Distinctions between Localized Exposure and Spatial Peak Power Density

IEEE Standards Coordinating Committee 39

Sponsored by the
IEEE International Committee on Electromagnetic Safety

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IEEE International Committee on Electromagnetic Safety

Approved 2 February 2010

IEEE-SA Standards Board

Abstract: Ceiling values for induced and contact current requirements are specified, and distinctions between *localized exposure* and *spatial peak power density* are clarified in this amendment.
Keywords: human exposure RF energy, localized exposure, spatial peak power density, radio frequency (RF) safety levels, RF induced and contact current

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Introduction

This introduction is not part of IEEE Std C95.1a-2010, IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz—Amendment 1: Specifies Ceiling Limits for Induced and Contact Current, Clarifies Distinctions between Localized Exposure and Spatial Peak Power Density.

IEEE Std C95.1-2005 was approved by the IEEE-SA Standards Board on 3 October 2005. During final pre-publication review, questions were raised by the TC95/SC4 Editorial Working Group regarding possible confusion by readers, concerning use of the terms *localized exposure* and *spatial peak power density,* which could not be clarified by simple editorial changes. Moreover, after publication it was discovered that ceiling values for induced and contact currents that appeared in the 1999 edition of IEEE Std C95.1 were inadvertently not included in IEEE Std C95.1-2005. This amendment clarifies the distinctions between localized exposure and spatial peak power density, specifies ceiling values for induced and contact currents, and clarifies other technical issues identified subsequent to publication of IEEE Std C95.1-2005.

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When the IEEE-SA Standards Board approved this amendment on 2 February 2010, it had the following membership:

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IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields, 3 kHz to 300 GHz

Amendment 1: Specifies Ceiling Limits for Induced and Contact Current, Clarifies Distinctions between Localized Exposure and Spatial Peak Power Density

NOTE—The editing instructions contained in this amendment define how to merge the material contained herein into the existing base standard and its amendments to form the comprehensive standard.[1]

The editing instructions are shown in ***bold italic***. Four editing instructions are used: change, delete, insert, and replace. ***Change*** is used to make corrections in existing text or tables. The editing instruction specifies the location of the change and describes what is being changed by using ~~strikethrough~~ (to remove old material) and <u>underscore</u> (to add new material). ***Delete*** removes existing material. ***Insert*** adds new material without disturbing the existing material. Insertions may require renumbering. If so, renumbering instructions are given in the editing instructions. ***Replace*** is used to make changes in figures or equations by removing the existing figure or equation and replacing it with a new one. Editing instructions, change markings, and this NOTE will not be carried over into future editions because the changes will be incorporated into the base standard.

[1]Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.

3. Definitions, acronyms, abbreviations, and letter symbols

3.1 Definitions

Replace 3.1.33 with the following:

3.1.33 localized exposure: Exposure of only a portion of the body. *See also:* **RF hot spot**.

Replace 3.1.58 with the following:

3.1.58 RF hot spot: A highly localized area of relatively more intense RF energy that manifests itself in two principal ways:

1) Near an unpowered conductive object that becomes a source of intense electric or magnetic fields (often referred to as re-radiation) and is surrounded by ambient fields of lower field strength,
2) From reflections and/or narrow beams produced by high-gain radiating antennas or other highly directional sources.

In both cases, there are usually rapid changes in field strength over distances that are small with respect to the exposed object (the body or body part) and wavelength. RF hot spots are normally associated with non-uniform exposure of the body (localized exposure). Such non-uniformity does not necessarily cause, and is not to be confused with, an actual thermal hot spot within the absorbing body.

4. Recommendations

4.1 Basic restrictions (BRs) and maximum permissible exposures (MPEs) for frequencies between 3 kHz and 5 MHz

4.1.3 MPE for the external electric field

Change the heading of 4.1.3.2 as follows:

4.1.3.2 Exposure to ~~Non-uniform~~ non-uniform ~~or localized exposure to~~ sinusoidal electric fields

4.1.4 Contact and induced current limits

4.1.4.1 Sinusoidal current

Change the first sentence of 4.1.4.1 as follows:

Contact and induced current shall be limited as specified in Table 5 <u>and Table 7</u>, subject to the following conditions:

4.2 BRs and MPEs for frequencies between 100 kHz and 3 GHz

4.2.3 Contact and induced current limits, 100 kHz to 110 MHz

Change 4.2.3 as follows:

In the transition region of 100 kHz to 5 MHz, two sets of contact and induced current limits apply. The limits in Table 5 protect against effects associated with electrostimulation and the limits in Table 7 protect against effects associated with tissue heating. Contact and induced current shall both be limited as specified in Table 7, subject to the conditions enumerated in 4.1.4.1, except for a greater averaging time. Figure 1 (upper tier) and Figure 2 (lower tier) provide E-field values below which induced current does not have to be measured. The electric field strength values plotted in Figures 1 and 2 are derived from estimated induced body currents from exposure to uniform electric fields (typically far field exposures) aligned with the axis of the body of a 1.75 m tall individual standing in good conductive contact with ground (Gandhi et al. [R346][7], Tofani et al. [R575]). These assumed exposure conditions will often not be applicable to realistic exposures with the result that substantially higher electric field strengths will be required to produce the induced body or touch current limits specified in this standard. For example, normal footwear can significantly reduce induced body current. In addition, the currents specified in this standard in the 100 kHz to ~~100~~ <u>110</u> MHz frequency range are to be time-averaged over either 6 minutes or 30 minutes <u>for the upper or lower tier, respectively.</u> ~~Moreover, the values for induced current are based on the assumption that all current will flow through one foot to ground, resulting in a conservative indication of field strengths below which induced current measurements are not required.~~

Replace Table 7 of 4.2.3 with the following:

Table 7—RMS induced and contact current limits for continuous sinusoidal waveforms, *f* = 100 kHz to 110 MHz

Condition	Action level [a] (mA)	Persons in controlled environments (mA)
Induced (both feet)	90	200
Induced (each foot)	45	100
Contact (grasp) [b]	—	100
Contact (touch)	16.7	50
NOTE 1—Limits apply to current flowing between the body and a grounded object that may be contacted by the person.		
NOTE 2—The averaging time for determination of compliance is 6 minutes.		
NOTE 3—The ceiling values (temporal peak values as measured with accepted instruments) for induced and contact currents are 500 mA and 220 mA for the upper and the lower tier, respectively.		

[a] MPE for the general public in absence of an RF safety program.

[b] Grasping contact limit pertains to controlled environments where personnel are trained to make grasping contact and to avoid touch contacts with conductive objects that present the possibility of painful contact.

4.4 MPEs for frequencies between 100 kHz and 300 GHz

Change Footnote a in Table 8 and Table 9 as follows:

[a] For exposures that are uniform over the dimensions of the body, such as certain far-field plane-wave exposures, the exposure field strengths and power densities are compared with the MPEs in the Table. For non-uniform exposures, the mean values of the exposure fields, as obtained by spatially averaging the squares of the field strengths or averaging the power densities over an area equivalent to the vertical cross section of the human body (projected area), or a smaller area depending on the frequency ~~(see NOTES to Table and Table 9 below)~~, are compared with the MPEs in the Table. [See NOTE a) in NOTES TO TABLE 8 AND TABLE 9.]

In NOTES TO TABLE 8 AND TABLE 9

Change the last paragraph of NOTE a) as follows:

Frequencies greater than 3 GHz: For frequencies greater than 3 GHz, the MPE is expressed in terms of the incident power density. However, ~~T~~to provide a transition in the frequency range 3 GHz to 6 GHz, compliance with this standard may be demonstrated by evaluation of either incident power density or local SAR. From 3 GHz to 30 GHz, the power density is spatially averaged over any contiguous area corresponding to 100 λ^2, where λ is the free space wavelength of the RF field in centimeters. For frequencies exceeding 30 GHz, the power density is spatially averaged over any contiguous area of 0.01 m^2 (100 cm^2)~~, not to exceed a maximum power density of 1000 W/m² in any one square centimeter as determined by a calculation or a conventional field measurement~~.

Replace NOTE f) with the following:

f) For exposures to pulsed RF fields in the range of 100 kHz to 300 GHz, the peak pulse power densities are limited by the use of normal time averaging, and the limit on peak E field (100 kV/m), with one exception: the total incident energy density during any 100 ms period within the averaging time shall not exceed one-fifth of the total energy density permitted during the entire averaging time for a continuous field (1/5 of 144 J/kg), i.e.,

$$\sum_{0\,\mathrm{s}}^{0.1\,\mathrm{s}} (S_{\mathrm{pk}} \times \tau) \le \frac{MPE_{\mathrm{avg}} \times T_{\mathrm{avg}}}{5} \le 28.8\ \mathrm{J/kg}$$

Change the heading of 4.6 as follows:

4.6 ~~Relaxation of the~~ Spatial peak power density MPEs for localized exposures

Replace 4.6 as follows:

The following spatial peak power density MPEs are allowed for exposures of any part of the body. Compliance with the MPE of Table 8 (upper tier) is determined from spatial averages of the power density and/or the mean squared electric and magnetic field strengths over the area defined in Footnote a of Table 8. The spatial peak value of the mean squared field strength or the power density shall not exceed 20 times the square of the allowed spatially averaged values of the fields and 20 times the allowed power density (Table 8), respectively, at frequencies below 300 MHz, and shall not exceed the equivalent power density of 200 W/m^2 at frequencies between 300 MHz and 3 GHz, 200 $(f/3)^{0.2}$ W/m^2 at frequencies between 3 GHz and 96 GHz (f in GHz), and 400 W/m^2 at frequencies above 96 GHz.

Compliance with Table 9 (lower tier) is determined from spatial averages of power density or the mean squared electric and magnetic field strengths over the area defined in Footnote a of Table 9. The spatial peak value of the mean squared field strength or the power density shall not exceed 20 times the square of the allowed spatially averaged values of the fields or 20 times the allowed power density (Table 9), respectively, at frequencies below 400 MHz, and shall not exceed the equivalent power density of 40 W/m^2 at frequencies between 400 MHz and 3 GHz, $18.56 f^{0.699}$ W/m^2 at frequencies between 3 GHz and 30 GHz (f in GHz), and 200 W/m^2 at frequencies above 30 GHz.

Annex C

(informative)

Rationale

C.2 Basic restrictions (BR) and maximum permissible exposure (MPE)

C.2.3 Basic restrictions: 3 GHz–300 GHz

Change the second paragraph as follows:

For purposes of assessing compliance with the BR and MPE at frequencies between ~~3 GHz–30GHz~~ 3 GHz and 30 GHz, the power density is spatially averaged over any contiguous area corresponding to 100 ~~λ~~λ^2, where ~~λ~~λ is the free space wavelength of the RF field in centimeters. For frequencies greater than 30 GHz, the power density is spatially averaged over any contiguous area of 0.01 m^2 (100 cm^2)~~, not to exceed a maximum power density of 1000W/m^2 in any one square centimeter as determined by a calculation or a conventional field measurement~~.

C.3 Adverse effect levels

C.3.3 Specific absorption rate and temperature

C.3.3.5 Levels associated with uncomfortable or painful sensations

C.3.3.5.1 Thermal stimulation

Change the second paragraph as follows:

Over most of the frequency range in which protection against adverse effects is associated with heating (100 kHz to 300 GHz), exposure under normal circumstances at the MPE for the lower tier cannot even be perceived. For exposures near 100 GHz in the controlled environment, the MPE (100 W/m^2) can only be perceived by individuals who are carefully attending to their skin temperature, and who have been alerted to the onset of the RF exposure. At 30 GHz and below, 100 W/m^2 is imperceptible under any circumstances (Blick et al. [R615]). ~~For the upper tier, since higher power densities up to 1000 W/m^2 over an area up to 0.01 m^2 (100 cm^2) is allowed, perception should be possible under such localized exposure (cf., Blick et al., [R615]), which reports for 10 s exposures at 94 GHz, a perception threshold of 45 W/m^2 over a stimulus area of 327 cm^2.~~ At higher frequencies, the perception threshold is lower. For example, the perception threshold for 10 s exposures at 94 GHz over a stimulus area of 327 cm^2 is 45 W/m^2 (Blick et al. [R615]). Even in the millimeter wavelength range, extended exposures at the MPE are unlikely to elevate skin temperature by as much as 1 °C. RF exposures at lower frequencies (<30 GHz) are much less effective in heating the skin.

C.7 Special considerations

C.7.4 Spatial considerations (peak vs. whole-body average values)

Replace the fifth (last) paragraph with the following:

The time averaging values in Table 8 and Table 9, and the spatial peak power density limits in 4.6, are based on a thermal analysis of tissue heated with RF energy, taking into account diffusion of heat due to thermal conduction and removal of heat due to blood flow, and are intended to limit the temperature increase in tissue exposed to RF energy.

Annex D

(informative)

Practical applications—examples

D.1 Introduction

D.1.1 Characterizing exposure to non-uniform fields

D.1.1.2 Applying the peak power density limits

Replace list item b) with the following:

b) For exposures to pulsed RF fields in the range of 100 kHz to 300 GHz, the peak pulse power densities are limited by the use of normal time averaging, and the limit on peak E field (100 kV/m), with one exception: the total incident energy density during any 100 ms period within the averaging time shall not exceed one-fifth of the total energy density permitted during the entire averaging time for a continuous field (1/5 of 144 J/kg), i.e.,

$$\sum_{0\,\mathrm{s}}^{0.1\,\mathrm{s}} (S_{\mathrm{pk}} \times \tau) \le \frac{MPE_{\mathrm{avg}} \times T_{\mathrm{avg}}}{5} \le 28.8\ \mathrm{J/kg}$$

D.1.1.3 Examples

D.1.1.3.2 Conventional radar

Change the first line of the list in the first paragraph as follows:

pulse width (T_w) 10 <u>µ</u>s

D.1.1.3.3 Non-sinusoidal waveform

Replace the last equation in the third paragraph (beginning with Peak field) as follows:

$$\mathrm{d}E/\mathrm{dt}\ (\mathrm{peak}) = \sqrt{2} \times 1842\ \mathrm{V/m} \times 2 \times \pi \times 10\,000\ \mathrm{Hz} = 163\,676\ \mathrm{kV/m/s}$$

Change the first paragraph in the text beginning with Fourier component as follows:

Fourier component. The B or E field strength of each Fourier component of the square wave is divided by the MPE at each component frequency and summed. This summation must be less than unity to comply with this restriction. In this example, the fundamental frequency component is 10 kHz, the 3rd harmonic is 30 kHz, the 5th is 50 kHz, the 7th is 70 kHz, the 9th is 90 kHz, the 11th is 110 kHz, and the 13th is 130 kHz. ~~Notice that the even harmonics of a square wave function are null. A spectrum analyzer may be employed to measure the field strength of each Fourier comment out to 5 MHz.~~ Because the Fourier components at 110 kHz and 130 kHz fall within the transition region where effects are associated with electrostimulation and heating, the MPEs from Table 2 and Table 8 must be compared for these frequencies and the most restrictive value of each pair used in the summation. (Notice that the even harmonics of a square wave function are null. A spectrum analyzer may be employed to measure the field strength of each Fourier component out to 5 MHz.)

Replace the text under Figure D.2, starting from "Also …" and ending with "is not exceeded," with the following:

The MPEs from Table 2 and Table 8 are

MPE = 490 A/m from 10 kHz to 100 kHz*

MPE = 148 A/m at 110 kHz**

MPE = 125 A/m at 130 kHz**

*Table 2

**Table 8

Therefore, because

$$100/490 + 50/490 + 10/490 + 5/490 + 1/490 + 0.5/148 + 0.1/125 = 0.34 < 1$$

the MPE is not exceeded.

D.4 Measurement requirements

D.4.2 Induced current measurements

Insert a new subclause after D.4.2.1 as follows:

D.4.2.2 Conditions where work practices may be sufficient for compliance

This standard specifies limits for induced and contact currents that also may apply in situations where the user of this standard can determine there would be compliance with the contact current limits by adoption of appropriate work practices. It may be sufficient to ensure compliance with the MPEs for persons in controlled environments for example by use of protective gloves or other safe working practices, including the avoidance of contact with metal objects that may be energized or by use of a grasping contact that avoids touch contact.