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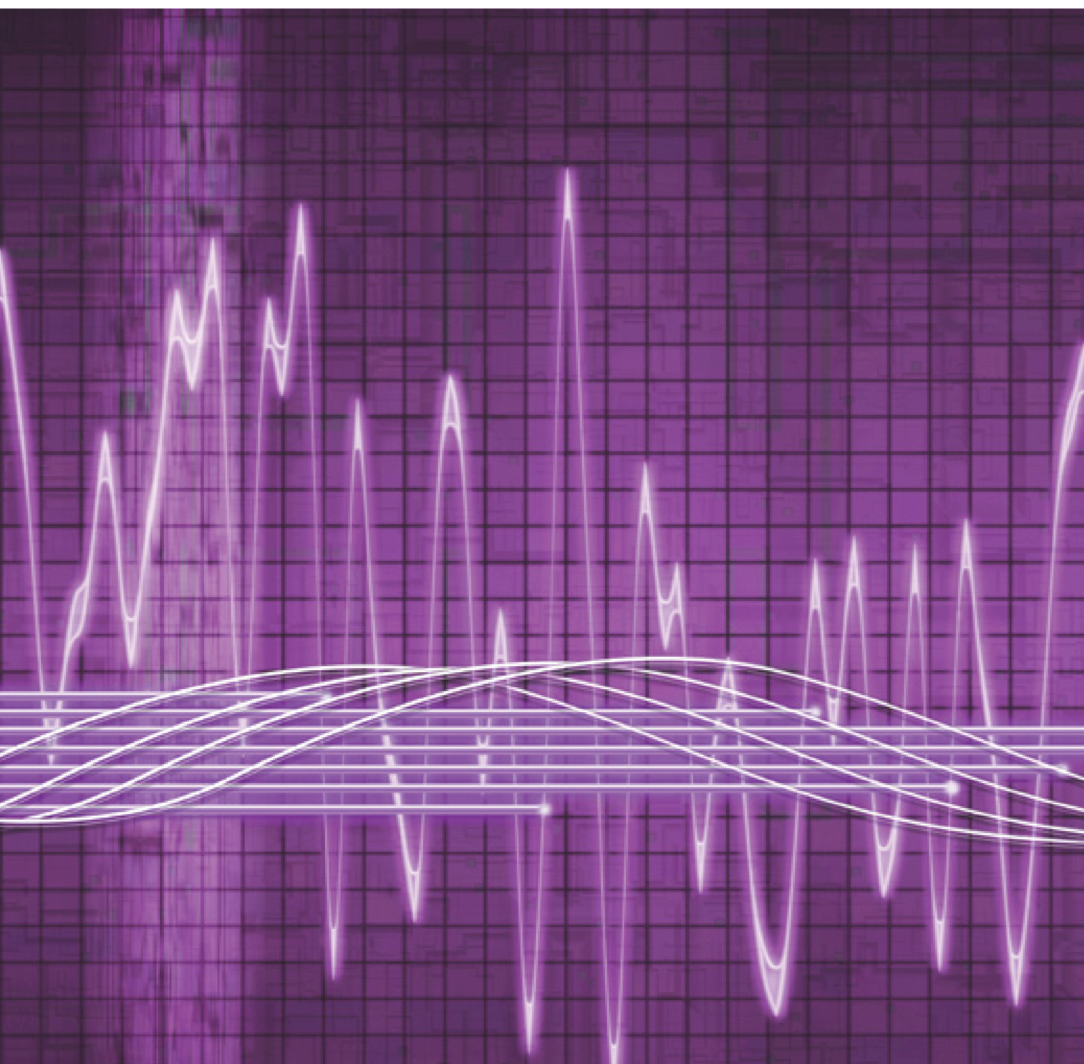
Limits of Human Exposure to Radiofrequency Electromagnetic Energy in the Frequency Range from 3 kHz to 300 GHz

Safety Code 6 (2009)



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Errata

Section 2.3, page 19

“For frequencies between 3 kHz and 100 kHz, the averaging time for induced and contact currents shall be 1 second (Section 2.1.2). For frequencies greater than 100 kHz and up to 15 000 MHz, time averaging provisions in this code take into account that the basic restrictions are designed to limit temperature increases in tissues. Temperature increases in living tissue due to RF energy absorption follow a well-defined pattern with a time constant of approximately 6 minutes (thermal time constant), where ~~67%~~ **63%** of the steady state temperature increase occurs within 6 min. Time averaging permits exposures to be greater than the limits outlined in Sections 2.1 and 2.2 over short periods of time, provided that the total absorbed energy in any 6 min period does not exceed the energy absorbed from a constant (time invariant) exposure at the limits outlined in Sections 2.1 and 2.2. Since time averaging is based on absorbed energy considerations, the electric and magnetic field intensities shall be squared before time averaging is applied, while the power density and SAR are applied directly.”

Limits of Human Exposure to Radiofrequency Electromagnetic Energy in the Frequency Range from 3 kHz to 300 GHz

Consumer and Clinical Radiation Protection Bureau
Environmental and Radiation Health Sciences Directorate
Healthy Environments and Consumer Safety Branch
Health Canada

Safety Code 6 (2009)

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Preface

This document is one of a series of safety codes prepared by the Consumer and Clinical Radiation Protection Bureau, Health Canada. These safety codes specify the requirements for the safe use of, or exposure to, radiation emitting devices. This revision replaces the previous version of Safety Code 6 (99–EHD–237) published in 1999.

The purpose of this code is to establish safety limits for human exposure to radiofrequency (RF) electromagnetic energy in the frequency range from 3 kHz to 300 GHz. The safety limits in this code apply to all individuals working at, or visiting, federally regulated sites. These guidelines may also be adopted by the provinces, industry or other interested parties. The Department of National Defence shall conform to the requirements of this safety code, except in such cases where it considers such compliance to have a detrimental effect on its activities in support of training and operations of the Canadian Forces. This code has been adopted as the scientific basis for the equipment certification specifications outlined in Industry Canada's regulatory compliance documents[1–3], that govern the use of wireless devices in Canada, such as cell phones, cell towers (base stations) and broadcast antennae. Safety Code 6 does not apply to the deliberate exposure for treatment of patients by, or under the direction of, medical practitioners. Safety Code 6 is not intended for use as a product performance specification document, as the limits in this safety code are for controlling human exposure and are independent of the source of RF energy.

In a field where technology is advancing rapidly and where unexpected and unique problems may occur, this code cannot cover all possible situations. Consequently, the specifications in this code may require interpretation under special circumstances. This interpretation should be done in consultation with scientific staff at the Consumer and Clinical Radiation Protection Bureau, Health Canada.

The safety limits in this code are based on an ongoing review of published scientific studies on the health impacts of radiofrequency electromagnetic energy. This code is periodically revised to reflect new knowledge in the scientific literature and the exposure limits may be modified, if deemed necessary.

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1. Introduction

Electromagnetic radiation is emitted by many natural and man-made sources and is a fundamental aspect of our lives. We are warmed by electromagnetic radiation emitted from the sun and our eyes can detect the visible light portion of the electromagnetic spectrum. Radiofrequency (RF) energy is a portion of the electromagnetic spectrum with frequencies ranging from 3 kHz to 300 GHz, below that of visible light and above that of extremely low frequency (ELF) electromagnetic energy. RF energy is produced by many man-made sources including cellular (mobile) phones and base stations, television and radio broadcasting facilities, radar, medical equipment, microwave ovens, RF induction heaters as well as a diverse assortment of other electronic devices within our living and working environments.

It has long been recognized that sufficiently intense RF energy can cause heating of materials with finite conductivity, including biological tissues. A number of well established biological effects and adverse health effects from acute exposure to intense RF energy have been documented[(4–9)]. For the most part, these effects relate to localized heating or stimulation of excitable tissue from intense RF energy exposure. The specific biological responses to RF energy are generally related to the rate of energy absorbed. The rate and distribution of RF energy absorption depends strongly on the frequency, intensity and orientation of the incident fields as well as the body size and its constitutive properties (dielectric constant and conductivity). At frequencies between 100 kHz and 6 GHz, RF energy absorption is commonly described in terms of the specific absorption rate (SAR), which is a measure of the rate of energy deposition per unit mass of body tissue and is usually expressed in units of watts per kilogram (W/kg). Based on a large amount of historical knowledge, national and international exposure limits have been established to protect the general public against adverse effects associated with acute RF energy exposures[(8–9)].

The exposure limits specified in Safety Code 6 have been established based upon a thorough evaluation of the scientific literature related to the thermal and possible non-thermal effects of RF energy on biological systems. Health Canada scientists consider all peer-reviewed scientific studies, on an ongoing basis, and employ a weight-of-evidence approach when evaluating the possible health risks of RF energy. This approach takes into account both the quantity of studies on a particular endpoint (whether adverse or no effect), but more importantly, the quality of those studies. Poorly conducted studies (e.g. incomplete dosimetry or inadequate control samples) receive relatively little weight, while properly conducted studies (e.g. all controls included, appropriate statistics, complete dosimetry) receive more weight. The exposure limits in Safety Code 6 are based upon the lowest exposure level at which scientifically-established human health hazards occur. Safety factors have been incorporated into these limits to add an additional level of protection for the general public and personnel working near RF sources. The scientific approach used to establish the exposure limits in Safety Code 6 is comparable to that employed by other science-based international standards bodies[(8–12)]. As such, the basic restrictions in Safety Code 6 are similar to those adopted by most other nations, since all recognized standard-setting bodies use the same scientific data. It must be stressed that Safety Code 6 is based upon scientifically-established health hazards and should be distinguished from some municipal and/or national guidelines that are based on socio-political considerations.

In the following sections, the maximum exposure levels for persons in both controlled and uncontrolled environments are specified. These levels shall not be exceeded.

1.1 Purposes of the Code

The purposes of this code are to:

(a) specify maximum levels of human exposure to RF energy at frequencies between 3 kHz and 300 GHz, to prevent adverse human health effects;

(b) specify maximum allowable RF contact and induced body currents to prevent the physical perception of internal currents resulting from RF energy in uncontrolled environments, and to prevent RF shock or burns to personnel in controlled environments;

(c) provide guidance for evaluating RF exposure levels, to ensure that personnel in controlled and uncontrolled environments are not exposed at levels greater than the limits specified in this code.

2. Maximum Exposure Limits

The scientific literature with respect to possible biological effects of RF energy has been monitored by Health Canada scientists on an ongoing basis since the last version of Safety Code 6 was published in 1999. During this time, a significant number of new studies have evaluated the potential for acute and chronic RF energy exposures to elicit possible effects on a wide range of biological endpoints including: human cancers (epidemiology); rodent lifetime mortality; tumor initiation, promotion and co-promotion; mutagenicity and DNA damage; EEG activity; memory, behaviour and cognitive functions; gene and protein expression; cardiovascular function; immune response; reproductive outcomes; and perceived electromagnetic hypersensitivity (EHS) among others. Numerous authoritative reviews have summarized this literature(13–30).

Despite the advent of thousands of additional research studies on RF energy and health, the predominant adverse health effects associated with RF energy exposures in the frequency range from 3 kHz to 300 GHz still relate to the occurrence of tissue heating and excitable tissue stimulation from short-term (acute) exposures. At present, there is no scientific basis for the premise of chronic and/or cumulative health risks from RF energy at levels below the limits outlined in Safety Code 6. Proposed effects from RF energy exposures in the frequency range between 100 kHz and 300 GHz, at levels below the threshold to produce thermal effects, have been reviewed. At present, these effects have not been scientifically established, nor are their implications for human health sufficiently well understood. Additionally, a lack of evidence of causality, biological plausibility and reproducibility greatly weaken the support for the hypothesis for such effects. Thus, these proposed outcomes do not provide a credible foundation for making science-based recommendations for limiting human exposures to low-intensity RF energy.

For frequencies from 3 to 100 kHz, the predominant health effect to be avoided is the unintentional stimulation of excitable tissues, since the threshold for electrostimulation in this frequency range will typically be lower than that for the onset of thermal effects. Experimental studies have demonstrated that exogenous electric and magnetic field exposures can induce *in situ* electric fields and currents within biological tissue that can lead to nerve and muscle depolarization(5, 8–9, 31–32). Limits for maximum external electric and magnetic field strengths have been established in Safety Code 6 to avoid *in situ* electric field strengths greater than that of the minimum excitation threshold for excitable tissues.

For frequencies from 100 kHz to 300 GHz, tissue heating is the predominant health effect to be avoided. Other proposed non-thermal effects have not been conclusively documented to occur at levels below the threshold where thermal effects arise. Studies in animals, including non-human primates, have consistently demonstrated a threshold effect for the occurrence of behavioural changes and alterations in core-body temperature of ~1.0 ^{o}C, at a whole-body average SAR of ~4 W/kg(7–9). This forms the scientific basis for the whole-body average SAR limits in Safety Code 6. To ensure that thermal effects are avoided, a safety factor of 10 has been incorporated for exposures in controlled environments, resulting in a whole-body-averaged SAR limit of 0.4 W/kg. A safety margin of 50 has been incorporated for exposures in uncontrolled environments to protect the general public, resulting in a whole-body average SAR limit of 0.08 W/kg.

Peak (spatial-average) SAR limits have also been established in Safety Code 6 to avoid excessive thermal effects (hot-spots) in localized human tissues. The peak SAR limits reflect the highly non-homogenous nature of typical RF energy exposures and the differing thermoregulatory properties of various body tissues. The peak SAR limits pertain to discrete tissue volumes (1 or 10 g), where thermoregulation can efficiently dissipate heat and avoid changes (>1^{o}C) in core body temperature. As such, the peak SAR limits for exposures in controlled environments are 20 W/kg for the limbs and 8 W/kg for the head, neck and trunk. For exposures in uncontrolled environments, the peak SAR limits are 4.0 W/kg for the limbs and 1.6 W/kg for the head, neck and trunk. There are also limits in Safety Code 6 for the avoidance of painful shocks or burns from contact currents.

The basic restrictions which shall not be exceeded are given in terms of the currents in the body, either by induction or contact with energized metallic objects, or in terms of the rate at which RF electromagnetic energy is absorbed in the body (i.e. SAR). In practice, direct measurements of SAR are only feasible under laboratory conditions. Therefore, recommended maximum exposure levels in terms of unperturbed electric and magnetic field strength as well as power density are given in addition to the SAR limits. These maximum field intensities are at levels that ensure that the SAR or induced body current will be no greater than that of the basic restrictions. Additional factors such as temporal variations in intensity and spatial distribution of the exposure fields are accounted for by provisions for time and spatial averaging. Exposure to RF energy in excess of the limits given in this safety code, when time and spatially-averaged, may cause adverse health effects.

For the purpose of this code, controlled environments are defined as those where all of the following conditions are satisfied:

(a) the RF field intensities in the controlled area have been adequately characterized by means of measurements, calculations or modeling (such as with the use of FDTD [finite difference time domain] software),

(b) the exposure is incurred by persons who are aware of the potential for RF exposure and are cognizant of the intensity of the RF energy in their environment and,

(c) the exposure is incurred by persons who are aware of the potential health risks associated with RF energy exposures and whom can control their risk using mitigation strategies.

All situations that do not meet the specifications above are considered to be uncontrolled environments. Uncontrolled environments are defined as areas where either insufficient assessment of RF energy has been conducted or where persons who are allowed access to these areas have not received proper RF awareness training and have no means to assess or, if required, mitigate their exposure to RF energy.

To determine whether the maximum exposure levels are exceeded, full consideration shall be given to such factors as:

(a) nature of exposure environment (controlled or uncontrolled);

(b) duration of exposure and/or time-averaging (including ON/OFF times of the RF source, direction of the beam, duty factors, sweep times, etc...);

(c) spatial characteristics of exposure (i.e. whole body or parts thereof);

(d) uniformity of the exposure field (i.e. spatial averaging).

In certain circumstances, higher exposure levels may be permitted for short durations. If this is the case, the field strengths and power densities should be averaged over any one tenth-hour period (0.1 h or 6 min). Graphs are provided in Appendix I for easy identification of maximum exposure levels at various frequencies.

SI units are used throughout this document unless specified otherwise.

2.1 Basic Restrictions

2.1.1 Specific Absorption Rate (SAR) Limits

The specific absorption rate (SAR) is a measure of the rate at which electromagnetic energy is absorbed in the body. At frequencies between 100 kHz and 6 GHz, SAR limits take precedence over field strength and power density limits and shall not be exceeded.

The SAR should be determined for situations where exposures occur at a distance of 0.2 m or less from the source. In cases where SAR determination is feasible, the values in Table 1 shall not be exceeded. For conditions where SAR determination is impractical, field strength or power density measurements shall be carried out and the limits outlined in Section 2.2 shall be respected.

Table 1. SAR Exposure Limits for Controlled and Uncontrolled Environments.

Condition	SAR Limit (W/kg)	
	Controlled Environment	Uncontrolled Environment
The SAR averaged over the whole body mass.	0.4	0.08
The spatial peak SAR for the head, neck and trunk, averaged over any one gram (g) of tissue*.	8	1.6
The spatial peak SAR in the limbs as averaged over any 10 g of tissue*.	20	4

* Defined as a tissue volume in the shape of a cube. A 10 g mass of tissue represents a volume of approximately 10 cm^3, while 1 g of tissue represents a volume of approximately 1 cm^3.

Note: Although not a requirement of the code, it is suggested that whenever possible, the organ-averaged SAR for the eye should not exceed 0.4 W/kg in the controlled environment and 0.2 W/kg in the uncontrolled environment.

2.1.2 Induced and Contact Current Limits

Limits for induced and contact currents are intended to reduce the potential for RF shock or burns as follows:

(a) For free standing individuals (standing upright, no contact with metallic objects), current induced in the human body by electromagnetic energy in the frequency bands listed in Column 1 of Tables 2 and 3, shall not exceed the values specified in Column 2 of:

(i) Table 2 for Controlled Environments.

(ii) Table 3 for Uncontrolled Environments.

An evaluation for compliance with the limits of induced currents should be made with an appropriate instrument. Measurements should be made with a person or a human equivalent antenna standing upright.

Note: Induced current through both feet can be measured by using a clamp-on current probe or a low profile platform consisting of two parallel conductive plates isolated from each other and one located above the other. If the latter is used, the platform should be placed on the surface where the person stands, and a person or a human equivalent antenna is placed on the upper plate of the platform. A voltage drop on a low-inductance resistor connected between the plates provides a measure of the induced current.

(b) No object, with which an individual may come into contact by hand grip, shall be energized by electromagnetic energy in the frequency bands listed in Column 1 of Tables 2 and 3, to such an extent that the maximum current flow through a human body, exiting through the feet, exceeds the values specified in Column 3 of:

(i) Table 2 for Controlled Environments.

(ii) Table 3 for Uncontrolled Environments.

Note 1: For any conducting metallic object that a person may come into contact with, that is located near a high-intensity RF field, contact currents shall be measured using an instrument consisting of an electrical circuit having the impedance of the human body.

Note 2: In controlled environments, the maximum permitted currents may be perceptible (such as a tingling or warming sensation), but are not sufficient to cause any pain or damage such as burns.

(c) Where the electromagnetic energy consists of a number of frequencies in the same or different frequency bands shown in Column 1 of Tables 2 and 3, the ratio of the square of the measured current in each frequency to the square of the limit at that given frequency shown in Column 2 or 3 (depending on whether it is induced or contact current) shall be determined and the sum of all ratios thus obtained for all frequencies shall not exceed unity, when time averaged. The limit, as applied to multiple frequencies, can be expressed as:

$$\sum_{f = 3\text{ kHz}}^{110\text{ MHz}} r_f \leq 1 \qquad (2.1)$$

where f is the frequency for which measurements were taken and r_f is the ratio of the square of the measured current in each frequency to the square of the limit at that given frequency, expressed as:

$$r_f = \left[\frac{\textit{Measured Time-Averaged Value of Current at } f}{\textit{Current Limit at } f}\right]^2 \qquad (2.2)$$

Table 2. Induced and Contact Current Limits for Controlled Environments.

1 **Frequency (MHz)**	**2** **Rms Induced Current (mA) Through**		**3** **Rms Contact Current (mA) Hand Grip and Through Each Foot**	**4** **Averaging Time**
	Both Feet	**Each Foot**		
0.003 - 0.1	2000 f	1000 f	1000 f	1 s
0.1 - 110	200	100	100	6 min

Notes: 1. Frequency, f, is in MHz.
2. The above limits may not adequately protect against startle reactions and burns caused by transient spark discharges for intermittent contact with energized objects.

Table 3. Induced and Contact Current Limits for Uncontrolled Environments.

1 Frequency (MHz)	2 Rms Induced Current (mA) Through		3 Rms Contact Current (mA) Hand Grip and Through Each Foot	4 Averaging Time
	Both Feet	Each Foot		
0.003 - 0.1	900 f	450 f	450 f	1 s
0.1 - 110	90	45	45	6 min

Notes: 1. Frequency, f, is in MHz.

2. The above limits may not adequately protect against startle reactions and burns caused by transient spark discharges for intermittent contact with energized objects.

(d) For frequencies between 3 kHz and 100 kHz, the averaging time to be applied to the induced and contact current measurements shall be 1 second. For frequencies between 100 kHz and 110 MHz, time averaging shall be applied to the square of the induced and contact currents and shall be consistent with the averaging time in Tables 5 and 6, provided that the time-averaged square of the current in any 6 min (or 0.1 h) period does not exceed the limit given in the following relation:

$$I_{av}^2 = I_{lm}^2 \frac{6}{T_{exp}} \tag{2.3}$$

where I_{av} is the maximum allowable time-averaged current for exposure times less than 6 min, I_{lm} is the current limit through each foot (100 mA for controlled environment and 45 mA for uncontrolled environment) as specified in Tables 2 and 3, and T_{exp} is the exposure time in minutes during any 6 min period. Shown in Table 4 are the higher values of I_{av} that may be allowed for exposure times less than 6 min.

Table 4. Time-Averaged Induced and Contact Current Limits for Different Exposure Times for the Frequency Band 0.1-110 MHz, Applicable to Controlled and Uncontrolled Environments.

Exposure Time (min)	Time-Averaged Induced/Contact Current (rms) through Each Foot (mA)	
	Controlled Environment	Uncontrolled Environment
≥ 6	100	45
5	110	49
4	123	55
3	141	64
2	173	78
1	245	110
0.5	346	155
< 0.5	350	155

Note: The above limits may not adequately protect against startle reactions and burns caused by transient spark discharges for intermittent contact with energized objects.

2.2 Electric and Magnetic Field Strength Limits

In the far-field zone, electric field strength, magnetic field strength and power density are interrelated by simple mathematical expressions, where any one of these parameters defines the remaining two. In the near-field zone, both the unperturbed electric and magnetic field strengths shall be measured, since there is no simple relationship between these two quantities. Instrumentation for the measurement of magnetic fields at certain frequencies may not be commercially available. In this case, the electric field strength shall be measured and used for assessing compliance with the basic restrictions in this code.

Individuals should not be exposed to electromagnetic energy in a frequency band listed in Column 1 of Tables 5 and 6, if:

(a) the electric or magnetic field strengths exceed the values, when averaged spatially and over time, specified in Column 2 or 3 of:

(i) Table 5 for Controlled Environment.

(ii) Table 6 for Uncontrolled Environment.

(b) the power density exceeds the values, when averaged spatially and over time, specified in Column 4 of:

(i) Table 5 for Controlled Environment.

(ii) Table 6 for Uncontrolled Environment.

Spatial averaging is to be carried out over an area equivalent to the vertical cross-section of the human body (Section 2.4). A time-averaging period of 6 min should be employed for frequencies up to 15 000 MHz. For frequencies above 15 000 MHz, the averaging time to be used, in minutes, shall be:

$$\text{Averaging Time} = 616\,000/\, f^{1.2}$$

where f is the frequency in MHz.

Where the electromagnetic energy consists of a number of frequencies in the same or different frequency bands shown in Column 1 of Tables 5 and 6, then the ratio of the measured value at each frequency to the limit at that given frequency shown in Column 2, 3, or 4 shall be determined and the sum of all ratios thus obtained for all frequencies shall not exceed unity, when averaged spatially and over time. For field strength measurements, the measured values and the limits shall be squared before determining the ratios. The limit, as applied to multiple frequencies, can be expressed as:

$$\sum_{f\,=\,3\text{ kHz}}^{300\text{ GHz}} R_f \leq 1 \qquad (2.4)$$

where f is the frequency for which measurements were taken and R_f is the ratio of the measured value at each frequency to the exposure limit at that given frequency, and where the electric or magnetic field strength is measured,

$$R_f = \left[\frac{\textit{Measured Value of Field Strength at } f}{\textit{Exposure Limit of Field Strength at } f}\right]^2 \qquad (2.5)$$

or where the power density is measured,

$$R_f = \frac{\textit{Measured Value of Power Density at } f}{\textit{Exposure Limit of Power Density at } f} \quad (2.6)$$

Table 5. Exposure Limits for Controlled Environments.

1 Frequency (MHz)	2 Electric Field Strength; rms (V/m)	3 Magnetic Field Strength; rms (A/m)	4 Power Density (W/m²)	5 Averaging Time (min)
0.003 - 1	600	4.9		6
1 - 10	$600/f$	$4.9/f$		6
10 - 30	60	$4.9/f$		6
30 - 300	60	0.163	10*	6
300 - 1 500	$3.54f^{0.5}$	$0.0094f^{0.5}$	$f/30$	6
1 500 - 15 000	137	0.364	50	6
15 000 - 150 000	137	0.364	50	$616\,000/f^{1.2}$
150 000 - 300 000	$0.354f^{0.5}$	$9.4 \times 10^{-4} f^{0.5}$	$3.33 \times 10^{-4} f$	$616\,000/f^{1.2}$

* Power density limit is applicable at frequencies greater than 100 MHz.

Notes: 1. Frequency, f, is in MHz.
2. A power density of 10 W/m^2 is equivalent to 1 mW/cm^2.
3. A magnetic field strength of 1 A/m corresponds to 1.257 microtesla (μT) or 12.57 milligauss (mG).

Table 6. Exposure Limits for Uncontrolled Environments.

1 Frequency (MHz)	2 Electric Field Strength; rms (V/m)	3 Magnetic Field Strength; rms (A/m)	4 Power Density (W/m²)	5 Averaging Time (min)
0.003 - 1	280	2.19		6
1 - 10	$280/f$	$2.19/f$		6
10 - 30	28	$2.19/f$		6
30 - 300	28	0.073	2*	6
300 - 1 500	$1.585f^{0.5}$	$0.0042f^{0.5}$	$f/150$	6
1 500 - 15 000	61.4	0.163	10	6
15 000 - 150 000	61.4	0.163	10	$616\,000/f^{1.2}$
150 000 - 300 000	$0.158f^{0.5}$	$4.21 \times 10^{-4} f^{0.5}$	$6.67 \times 10^{-5} f$	$616\,000/f^{1.2}$

* Power density limit is applicable at frequencies greater than 100 MHz.

Notes: 1. Frequency, f, is in MHz.
2. A power density of 10 W/m^2 is equivalent to 1 mW/cm^2.
3. A magnetic field strength of 1 A/m corresponds to 1.257 microtesla (µT) or 12.57 milligauss (mG).

2.2.1 Peak Field Strength Limit for Pulsed Fields

While the average power density of pulsed waves shall be within the limits specified in Tables 5 and 6, the peak value of the instantaneous electric field strength (temporal peak) in the frequency range of 0.1 to 300 000 MHz shall not exceed 100 kV/m.

For exposures to pulsed RF fields in the range of 0.1 to 300 000 MHz, peak pulse power densities are limited by the use of time averaging and the limit on peak electric field, with one exception: the total incident energy density during any one-tenth second 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(9).

This can be expressed as:

$$\sum^{0.1s} W_p \, T \leq \frac{W_a \; T_a}{5} \qquad (2.7)$$

where,

W_p = peak RF power density, in W/m^2

W_a = power density limit as specified in column 4 of Table 5 or 6, in W/m^2

T = pulse duration, in seconds

T_a = averaging time as specified in column 5 of Table 5 or 6, in seconds.

A maximum of five pulses with pulse durations less than 100 ms is permitted during any period equal to the averaging time. If there are more than five pulses during the averaging time, or if the pulse duration is greater than 100 ms, normal time averaging calculations apply.

2.3 Time Averaging

For frequencies between 3 kHz and 100 kHz, the averaging time for induced and contact currents shall be 1 second (Section 2.1.2). For frequencies greater than 100 kHz and up to 15 000 MHz, time averaging provisions in this code take into account that the basic restrictions are designed to limit temperature increases in tissues. Temperature increases in living tissue due to RF energy absorption follow a well-defined pattern with a time constant of approximately 6 minutes (thermal time constant), where **63%** of the steady state temperature increase occurs within 6 min. Time averaging permits exposures to be greater than the limits outlined in Sections 2.1 and 2.2 over short periods of time, provided that the total absorbed energy in any 6 min period does not exceed the energy absorbed from a constant (time invariant) exposure at the limits outlined in Sections 2.1 and 2.2. Since time averaging is based on absorbed energy considerations, the electric and magnetic field intensities shall be squared before time averaging is applied, while the power density and SAR are applied directly.

In situations where the exposure intensity varies significantly with time within a period of 6 min, time-averaged values must be calculated from multiple measurements, otherwise a single measurement is sufficient. Some instruments have time averaging capabilities; however, if this feature is not available, time averaged values over 6 min can be obtained by using the following formulae:

(a) To obtain the time-averaged rms electric (E) or magnetic (H) field strength, use the applicable formula:

$$E = \left[\frac{1}{6} \sum_{i=1}^{n} E_i^2 \Delta t_i \right]^{0.5} \quad (2.8)$$

or

$$H = \left[\frac{1}{6} \sum_{i=1}^{n} H_i^2 \Delta t_i \right]^{0.5} \quad (2.9)$$

where E_i and H_i are the sampled rms electric and magnetic field strengths, respectively, which are considered to be constant in the ith time period, Δt_i is the time duration, in minutes, of the ith time period and n is the number of time periods within 6 min.

(b) To obtain the time-averaged power density W, use the formula:

$$W = \frac{1}{6} \sum_{i=1}^{n} W_i \, \Delta t_i \quad (2.10)$$

where W_i is the sampled power density in the ith time period.

(c) To obtain the time averaged SAR, use the formula:

$$SAR = \frac{1}{6} \sum_{i=1}^{n} (SAR)_i \, \Delta t_i \quad (2.11)$$

where $(SAR)_i$ is the sampled SAR in the ith time period.

Note 1: In all of the previous formulae, the following relationship shall be satisfied:

$$\sum_{i=1}^{n} \Delta t_i = 6 \text{ min} \quad (2.12)$$

Note 2: For pulsed fields, E_i and H_i are rms values, and W_i is the value averaged over the time interval Δt_i. If peak values are measured, the rms or average values shall be calculated.

2.4 Spatial Averaging

Spatial averaging takes into account that the maximum exposure limits for electric and magnetic field strengths and power density are derived from the basic restrictions for whole body averaged SAR (Section 2.1). The whole body averaged SAR will be equal to or less than the value in Table 1 for exposure to a uniform plane wave of intensity given in Table 5 or 6, respectively, for polarization along the body axis and for all human body sizes. It is important to note that the limits in Tables 5 and 6 represent the worst case coupling of absorbed power for all human body sizes at all frequencies. In most realistic situations, the exposure field is not uniform and therefore the field strength or power density should be spatially averaged before being compared to the maximum exposure limit.

Measurements to determine conformity with the limits specified in Section 2.2 shall be performed with field sensors (probes) placed at least 0.2 m away from any object or person. To determine the spatially averaged value, local values (including the maximum value) shall be measured over the projected surface area (flat plane), equivalent to the head and trunk region of persons (adults or children) who would occupy the area of the incident fields. It is advisable that the measurement points are uniformly spaced within the sampling area. Local values should be measured in nine or more points. Where the field is reasonably uniform (within 20%), a measurement in one location representative of the space that is occupied by a person is sufficient. Otherwise, the spatially averaged values shall be calculated from the following formulae:

$$E = \left[\frac{1}{n}\sum_{i=1}^{n} E_i^2\right]^{0.5} \tag{2.13}$$

$$H = \left[\frac{1}{n}\sum_{i=1}^{n} H_i^2\right]^{0.5} \tag{2.14}$$

$$W = \frac{1}{n}\sum_{i=1}^{n} W_i \tag{2.15}$$

where n is the number of locations, E_i, H_i and W_i are the electric field strength, the magnetic field strength and the power density, respectively, measured in the i^{th} location.

Definitions

antenna – A device for radiating or receiving radiofrequency (RF) energy.

basic restriction – Dosimetric limit directly related to established health effects that incorporate safety factors and are expressed in terms of internal body currents or specific absorption rate (100 kHz to 6 GHz).

contact current – Current flowing between an energized, isolated, conductive (metal) object and ground, through the human body.

continuous wave (CW) – Successive oscillations which are identical under steady-state conditions (an unmodulated electromagnetic wave).

controlled environment – A condition or area where exposure is incurred by persons who are aware of the potential for RF exposure and are cognizant of the intensity of the RF fields in their environment, where exposures are incurred by persons who are aware of the potential health risks associated with RF exposure and whom can control their risk using mitigation strategies.

electric field – The region surrounding an electric charge, in which the magnitude and direction of the force on a hypothetical test charge is defined at any point.

electromagnetic radiation – The propagation of time-varying electric and magnetic fields through space at the velocity of light.

extremities – Limbs of the body, including upper arms and thighs.

far-field zone – The space beyond an imaginary boundary around an antenna. The boundary marks the beginning where the angular field distribution is essentially independent of the distance from the antenna. In this zone, the field has a predominantly plane-wave character.

field strength – The magnitude of the electric or magnetic field, normally a root-mean-square (rms) value.

frequency – The number of sinusoidal cycles made by electromagnetic waves in one second; usually expressed in units of hertz (Hz).

general public – Individuals of all ages, body sizes and varying health status, some of whom may qualify for the conditions defined for the controlled environment in certain situations.

induced current – Current induced in a human body exposed to RF fields.

magnetic field – A region of space surrounding a moving charge (e.g. in a conductor) being defined at any point by the force that would be experienced by another hypothetical moving charge. A magnetic field exerts a force on charged particles only if they are in motion, and charged particles produce magnetic fields only when they are in motion.

near-field zone – A volume of space generally close to an antenna or other radiating structure, in which the electric and magnetic fields do not have a substantially plane-wave character, but vary considerably from point to point.

non-thermal effects – Biological effects ascribed to exposure to low-level electromagnetic fields, at levels below the threshold to induce thermally-related biological effects.

power density – The rate of flow of electromagnetic energy per unit surface area usually expressed in W/m^2 or mW/cm^2 or $\mu W/cm^2$.

radiofrequency (RF) – A frequency or rate of oscillation within the range of about 3 kHz to 300 GHz.

radiation (electromagnetic) – The emission or transfer of energy through space in the form of electromagnetic waves.

RF device – A device which generates and/or utilizes RF energy.

rms – root mean square. Mathematically, it is the square root of the average of the square of the instantaneous field or current taken throughout one period.

safety – The absence of detrimental health effects from RF exposures.

SI – An acronym of Système international d'unités (International System of Units).

specific absorption rate (SAR) – The rate of RF energy absorbed in tissue per unit mass. Quantitatively, it is the time derivative (rate) of the incremental energy (dW) absorbed by an incremental mass (dm) contained in a volume element (dV) of given mass density (ρ).

$$SAR = \frac{d}{dt}\left[\frac{dW}{dm}\right] = \frac{d}{dt}\left[\frac{dW}{\rho dV}\right]$$

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

$$SAR = \frac{\sigma E^2}{\rho}$$

where σ is the tissue conductivity (S/m), E is the rms electric field strength induced in the tissue (V/m) and ρ is the mass density (kg/m^3).

thermal effects – Biological effects resulting from heating of the whole body or a localized region, where a sufficient temperature increase has occurred that results in a physiologically significant effect.

uncontrolled environment – A condition or area where exposures are incurred by persons that do not meet the criteria defined for the controlled environment.

wavelength – The distance travelled by a propagating wave in one cycle of oscillation.

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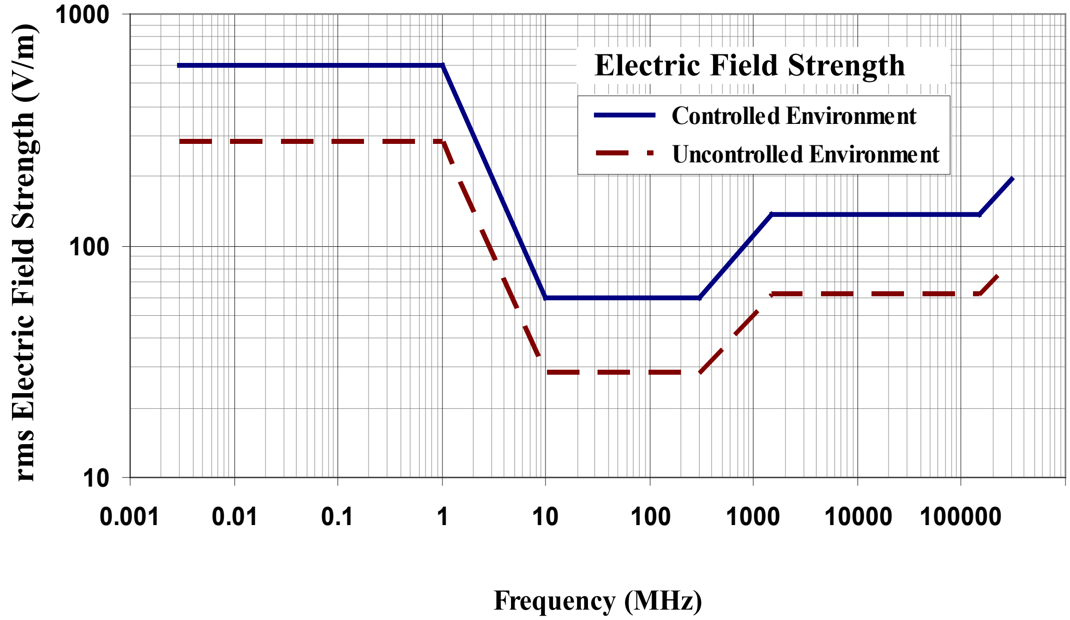
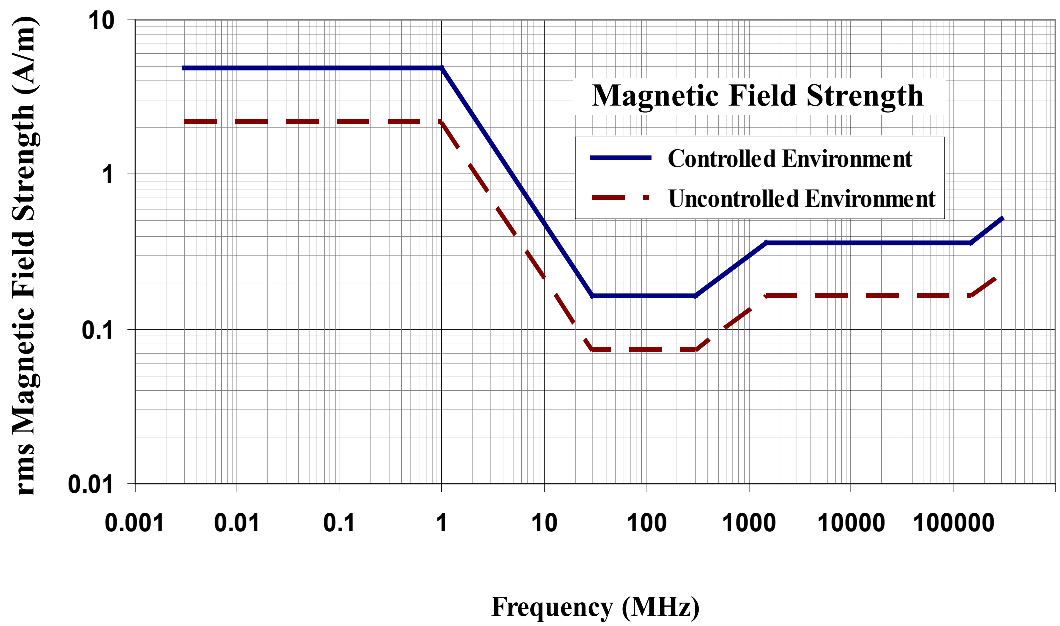
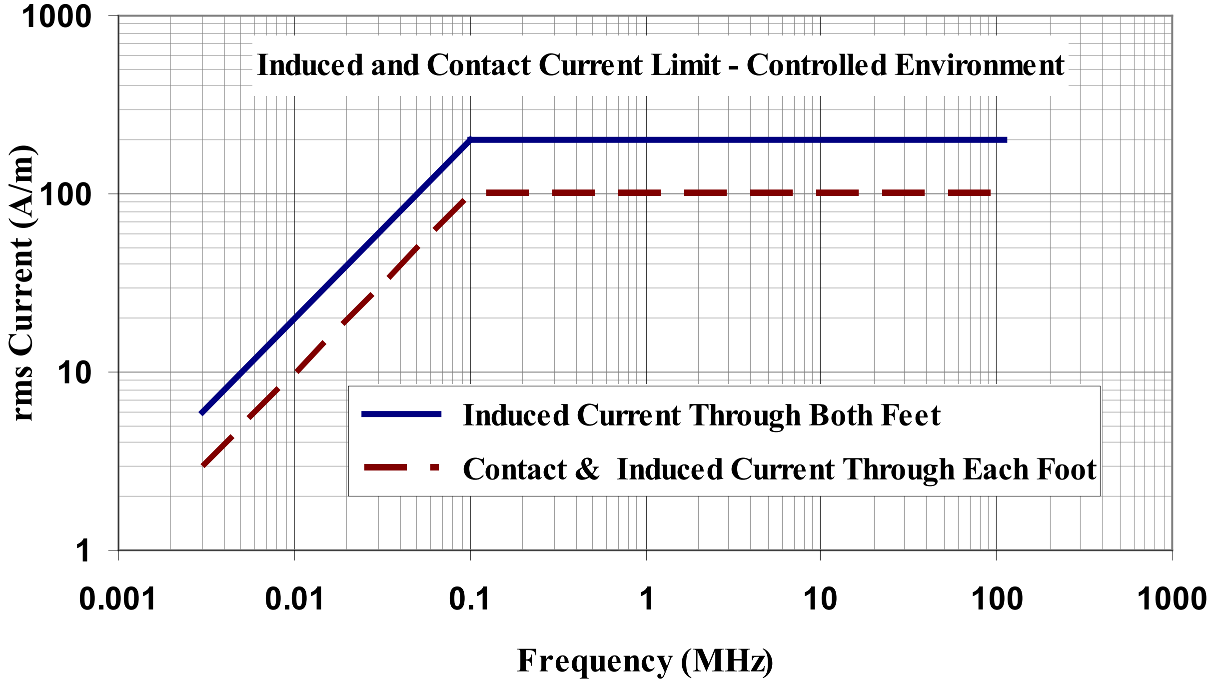
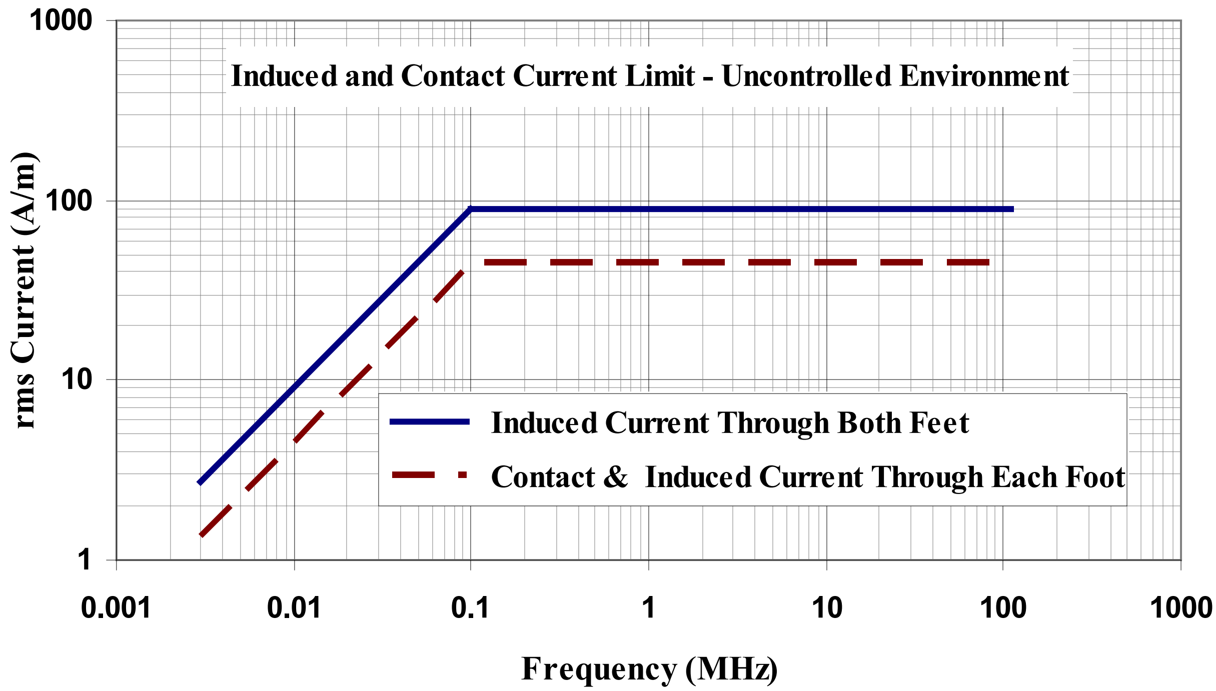
Appendix I – Maximum Exposure Limits for RF energy






Induced and Contact Current Limit - Controlled Environment
Induced Current Through Both Feet
Contact & Induced Current Through Each Foot
rms Current (A/m)
1000
100
10
1
0.001
0.01
0.1
1
10
100
1000
Frequency (MHz)


Induced and Contact Current Limit - Uncontrolled Environment
Induced Current Through Both Feet
Contact & Induced Current Through Each Foot
rms Current (A/m)
1000
100
10
1
0.001
0.01
0.1
1
10
100
1000
Frequency (MHz)