Cell Phone and RF Safety Awareness

by

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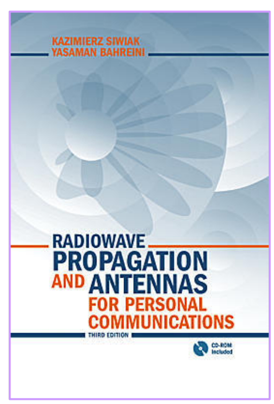
Material to support this course appear in Chapters 9 and 10 of the text book *Radiowave Propagation and Antennas for Personal Communications – Third Edition*, by K. Siwiak and Y. Bahreini, Artech House: MA, 2007.



Introduction

This course explains radio frequency (RF) exposure and presents an awareness of exposure safety with respect to transmitters and antennas, such as cell phones, and other transmitting devices regulated by the FCC. Technical terms will be explained and concepts will be clarified with analogies to familiar experiences. The electromagnetic spectrum is shown with special attention to the delineation between non-ionizing radiation (which is the focus of this course), and ionizing radiation. The mechanism of RF absorption by the body is shown and the concept of specific absorption rate (SAR) is identified as basis of FCC compliance limits for RF exposure. Several natural radiation sources are identified in contrast to the levels in the compliance standard. We see that limits for hand-held devices are governed by localized SAR, but whole body exposure to more distant antennas are governed by field strength values. Details of the FCC compliance limits are shown. Finally, the complexity of the field of even a simple dipole above an earth ground reveals some of the difficulties in evaluating compliance with exposure limits.

What is RF Exposure?

Exposure occurs whenever and wherever a person is subjected to electric, magnetic or electromagnetic fields other than those originating from physiological processes in the body and other natural phenomena. All transmitters regulated by the Federal Communications Commission (FCC), including cell phones, customer-end fixed wireless antennas (either satellite or terrestrial) are <u>required</u> to meet the applicable Commission regulations regarding RF exposure limits. The limits established in the guidelines are designed to protect the public health with a *large margin of safety*. These limits have been endorsed by federal health and safety agencies, such as the Environmental Protection Agency and the Food and Drug Administration. The Commission requires that providers of fixed wireless service exercise reasonable care to protect users and the public from RF exposure in excess of the Commission's limits. In addition, as a condition of invoking protection under the rule from government, landlord, and association restrictions, a provider of fixed wireless service must ensure that customer-end antennas are labeled to give notice of potential RF safety hazards posed by these antennas[1].

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[1] Over-the-Air Reception Devices Rule, Preemption of Restrictions on Placement of Direct Broadcast Satellite, Broadband

Terminology

Terms and units specific to understanding RF exposure and RF safety for FCC purposes are given below.

Electric field strength (*E*). A field vector quantity that represents the force (***F***) on an infinitesimal unit positive test charge (***q***) at a point, divided by that charge. Electric field strength is expressed in units of rms volts per meter (V/m).

Magnetic field strength (*H*). A field vector that is equal to the magnetic flux density divided by the permeability of the medium. Magnetic field strength is expressed in units of rms amperes per meter (A/m).

General population/uncontrolled exposure. Applies to human exposure to RF fields when the general public is exposed, or in which persons who are exposed as a consequence of their employment may not be made fully aware of the potential for exposure, or cannot exercise control over their exposure. Members of the general public always fall under this category when exposure is not employment-related.

Occupational/controlled exposure. Applies to human exposure to RF fields when persons are exposed as a consequence of their employment and in which those persons who are exposed have been made fully aware of the potential for exposure and can exercise control over their exposure. Occupational/controlled exposure limits also apply where exposure is of a transient nature as a result of incidental passage through a location where exposure levels may be above general population/uncontrolled limits (see definition above), as long as the exposed person has been made fully aware of the potential for exposure and can exercise control over his or her exposure by leaving the area, or by some other appropriate means.

Maximum permissible exposure (MPE). The root means square (rms) and peak electric and magnetic field strength, their squares, or the plane-wave equivalent power densities associated with these fields to which a person may be exposed without harmful effect and with an acceptable safety factor.

Power density (S). Power per unit area normal to the direction of propagation, usually expressed in units of watts per square meter (W/m^2) or, for convenience, milliwatts per square centimeter (mW/cm^2) or microwatts per square centimeter ($\mu W/cm^2$). For plane waves, power density, electric field strength (*E*) and magnetic field strength (*H*) are related by the intrinsic impedance of free space (377 ohms). Although many survey instruments indicate power density units ("far-field equivalent" power density), the actual quantities measured are E or E^2 or H or H^2.

Power density, plane-wave equivalent or far-field equivalent. Commonly-used terms associated with any electromagnetic wave, equal in magnitude to the power density of a plane wave having the same electric (*E*) or magnetic (*H*) field strength.

Radiofrequency (RF) spectrum. Although the RF spectrum is formally defined in terms of frequency as extending from 0 to 3,000 GHz, for purposes of the FCC's exposure regulations, the frequency range of interest is 300 kHz to 100 GHz.

Specific absorption rate (SAR). A measure of the rate of energy absorbed by (dissipated in) an incremental mass contained in a volume element of dielectric materials such as biological tissues. SAR is usually expressed in terms of watts per kilogram (W/kg) or milliwatts per gram (mW/g). Guidelines for human exposure to RF fields are based on SAR thresholds where adverse biological effects may occur. When the human body is exposed to an RF field, the SAR experienced is proportional to the squared value of the electric field strength induced in the body.

The Electromagnetic Spectrum

The electromagnetic spectrum, see Figure 1, extends from the "zero frequency, 0 Hz" static fields due to charges and direct currents, up to radiation associated with atomic particles. It spans the frequencies that deliver AC power (tens of Hz), through the radio frequencies (tens of kHz to hundreds of GHz) that enable our wireless devices, AM, FM and digital radio and television, and our cell phones. It extend upward through microwaves, millimeter waves, infrared, visible light, then ultraviolet, X-rays and gamma rays.

In Figure 1 we can identify electromagnetic emissions at frequencies from just a few Hertz (25 to 60 Hz power lines) up through the *radio frequencies*, then light, X-rays and Gamma Rays. The realm of radio waves is generally accepted to span the spectrum from 9 kHz to 275 GHz, which is the range of frequencies that includes cell phones (700 – 6,000 MHz) and transmitters of interest in RF exposure. Even though the FCC does not concern itself with physiological processes, it is interesting to note that the human body radiates an average of 120 W, equivalent to about 2,500K calories per day, (dashed green trace) peaking at a frequency near 24 THz. The spectral shape of human body radiation follows the black body[2] emissions curve even at radio frequencies. The RF emission for a single human body exceeds FCC limits for UWB transmitter emissions at frequencies above about 190 GHz[3].

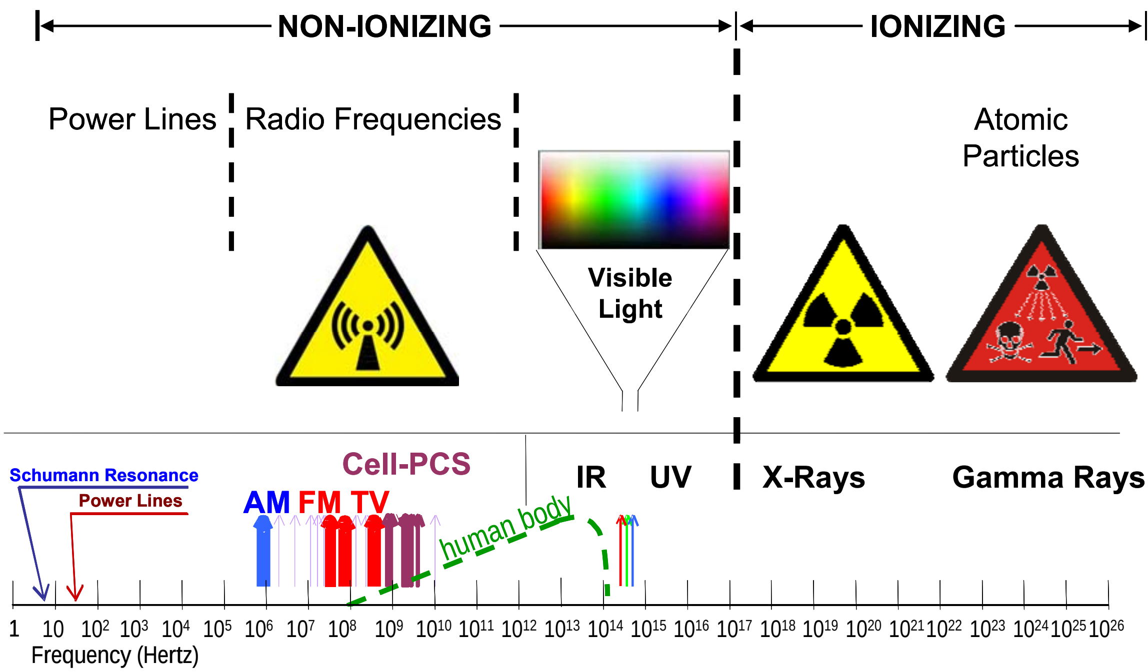

Figure 1 – We encounter emissions from all parts of the electromagnetic spectrum.

The portrayal of the electromagnetic spectrum in Figure 1 helps to put into perspective terms like "ionizing", "non-ionizing", and the relative position of the "radio frequencies", which contain, among other services, the cell phone frequencies.

There is a major division in the electromagnetic spectrum which occurs somewhat above the frequencies of violet light, and extends upward in frequency into ultra-violet light and then X-rays and gamma rays. To enable further discussion, we introduce the *photon*, which at any

[2] Obukhova A. A., Baturina T. D., "Measurement of thermal radiation of the human body in the radiofrequency band," Fiziologia Cheloveka [Human Physiology], 1992 Mar-Apr;18(2):93-9, (in Russian).

[3] http://www.timederivative.com/2005-04-032rX-UWB&black-body-radiation.pdf, UWB Radiation Compared with Human "Black Body" Radiation.

frequency is the smallest quantum of energy that can radiate. The energy W of a photon at any frequency, f Hz, is

$$W = hf \tag{1}$$

where h=6.626×10^{-34} J-s is Plank's constant. When the single photon energy exceeds about 10 electron volts (about 1.6×10^{-18} J), individual photons can knock electrons out of atoms and molecules no matter what is the intensity of the radiation. The required photon energy occurs at frequencies greater than about 10^{17} Hz, or frequencies at ultra-violet light and higher. From Equation (1) it is clear that the ionization potential increases with frequency. Figure 2 depicts the mechanism by which ionizing radiation can cause cell mutation, giving rise to cancer and to the growth of tumors. Radiation including the UV spectral component, is a known carcinogen, and a suntan is the onset of a nuclear radiation burn.

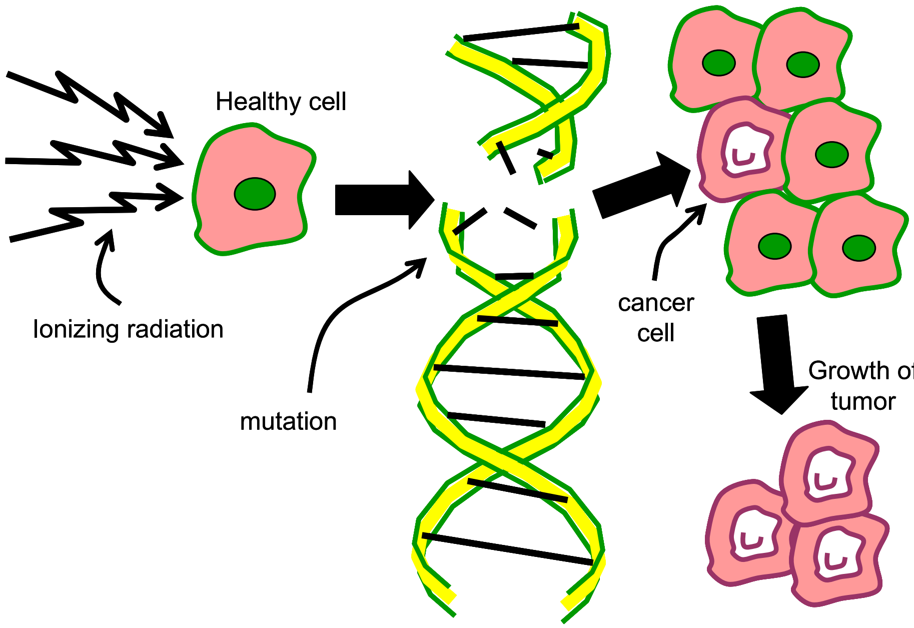

Figure 2 – Ionizing radiation can cause the development of cancer.

Ionizing radiation is radiation at a high enough frequency so that a photon at that frequency has enough energy to remove tightly bound electrons from the orbit of an atom, causing the atom to become charged or ionized.

The above discussion puts into perspective ionizing and non-ionizing electromagnetic radiation. Only the highest frequency portion of the electromagnetic spectrum, that portion above violet light, which includes X-rays and gamma rays is ionizing. The electromagnetic spectrum relevant to the FCC RF exposure compliance requirements is far into the non-ionizing range, and extends from 300 kHz to 100 GHz, and that will be our focus. Our highest frequency of interest, 100 GHz = 10^{11} Hz is six orders of magnitude smaller (a factor of a million smaller), and with photon energies 1/1,000,000 of the energy threshold of dangerous ionizing radiation. Cell phone frequencies are more than 10 million times lower than the ionizing frequencies. Photons in the RF spectrum do not carry enough energy to ionize atoms or molecules no matter what is the radiation intensity. A known and documented effect on humans of non-ionizing radiation is the heating of tissue caused by absorption of RF energy.

The Mechanism of RF Energy Absorption

The rate at which energy is absorbed by the human body is called the specific absorption rate (SAR), and is defined as the time (t) derivative (d/dt) of incremental energy (dW) absorbed by an incremental mass (dm) contained in a volume element (dV) of a given density (ρ)

$$\mathrm{SAR} = \frac{d}{dt}\frac{dW}{dm} = \frac{d}{dt}\frac{dW}{\rho dV} \tag{2}$$

Electromagnetic energy incident on the human body can be written in terms of an rms electric field E (in V/m), and the body tissue can be characterized by its electrical conductivity σ (in S/m) and by ρ, its mass per volume (in kg/m^3). The SAR is

$$\mathrm{SAR} = \frac{\sigma E^2}{\rho} \quad \text{W/kg.} \tag{3}$$

The basic premise of RF exposure standards is that the severity of an effect is directly related to the rate of RF energy absorbed, hence the introduction of the concept of SAR. Electromagnetic fields external to the human body are not easily related to fields in the human body, so the determination of SAR is complex and often relies on precise measurements and/or computer simulations, the details of which are beyond the scope of this course.

Determination of SAR is prescribed for localized sources, such as transmitters that are hand-held or body mounted, that is, transmitters that are in very close proximity to the body. When the transmitting antenna is far from the human body, a whole body exposure occurs and the exposure is measured in terms of "far-field equivalent" rms electric (*E*) and rms magnetic (*H*) fields.

Guidelines and Regulations for human exposure to RF fields are based on SAR thresholds where adverse biological effects may occur. A *large margin of safety* is built into the standards. We can illustrate threshold behavior with an example. Consider heating from a surface-type kitchen oven-range. In particular, let's use as our example an electric oven having a glass/ceramic surface which is heated from below by an electric element. We seek a "safe" heating level threshold whereby you can keep your hand on the oven surface near the "burner" without damage to human tissue, see Figure 3.

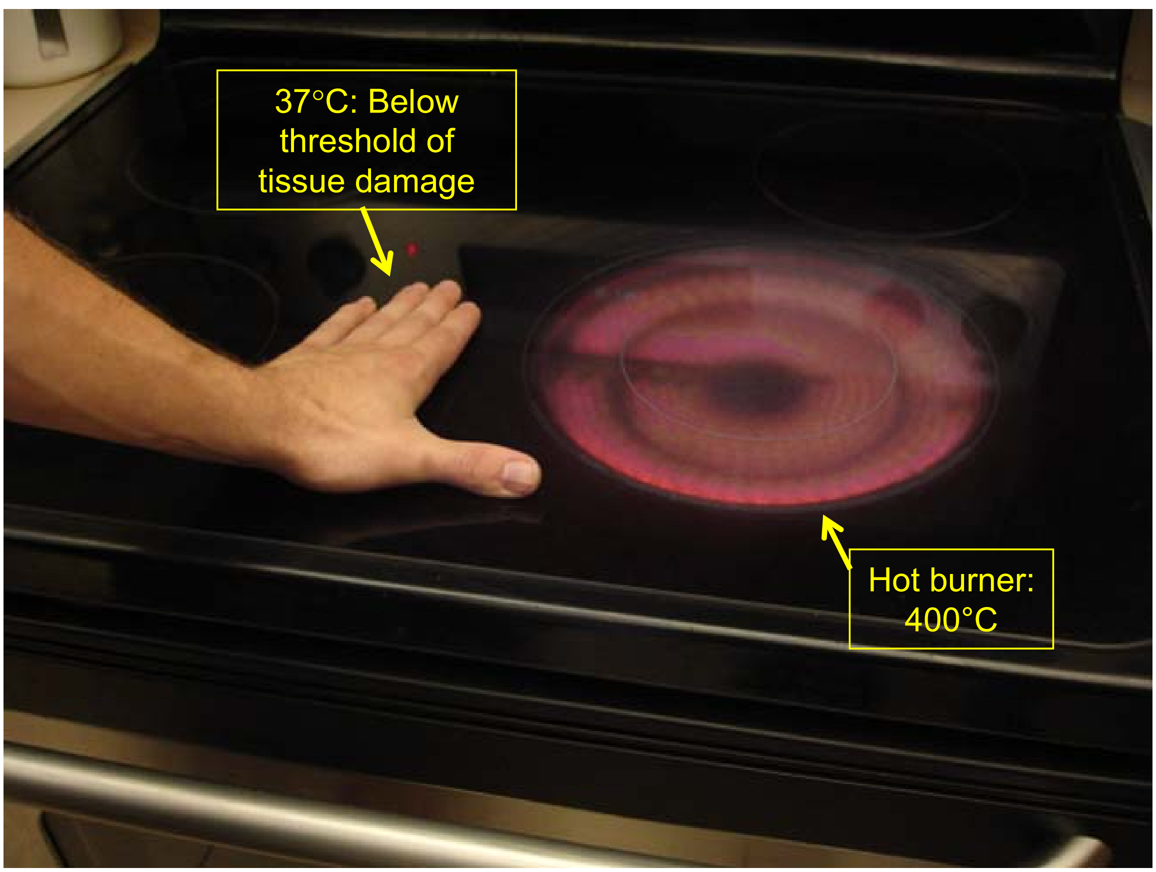

Figure 3 – Illustrative example: determining a safe heating level.

That safe threshold be can be anywhere from "zero exposure" – burner is OFF, up to some level, that heats the surface to some 10's of degrees above the ambient temperature level. We can determine a heating level that is clearly dangerous – it will burn flesh. But lets instead base a safety threshold temperature for the oven burner surface at 37.0°C, which is the same as the core human body temperature.

So now we have a way to set our "SAR" standard for a hand on the surface of an electric oven. Clearly the level is safe, and clearly, heating levels below that level are no safer than "safe". There is no other known hazard to the hand from the electric oven heater element. We note that the heating occurs with waves that are at very very high frequencies, in the infrared region, but below the glowing temperature of the full-ON burner element, which is observed to glow red. These are dramatically higher frequencies than those used by cell phones, but still much lower, by several orders of magnitude lower, than the ultra-violet (UV) frequencies, which are known to be carcinogenic. The cell phone standard was set in exactly the same way, and for the same reason. Levels at the limit of the standard are just as safe as levels below that standard because the standard was set so far below the threshold of any known effect in the first place. The SAR limit has a *large margin of safety*.

Working closely with federal health and safety agencies, such as the Food and Drug Administration (FDA), the FCC has adopted limits for safe exposure to radiofrequency (RF) energy. These limits are given in terms of a unit referred to as the Specific Absorption Rate (SAR), which is a measure of the amount of radio frequency energy absorbed by the body when using a mobile phone. The FCC requires cell phone manufacturers to ensure that their phones comply with these objective limits for safe exposure. Any cell phone at or below these SAR levels (that is, any phone legally sold in the U.S.) is a "safe" phone, as measured by these standards. The FCC limit for public exposure from cellular telephones is an SAR level of 1.6 watts per kilogram (1.6 W/kg). That limit is a peak value measured over a volume of any one gram of body tissue. By comparison, the human head has a mass of about 5 kg and radiates about 25 W of heat, or 5 W/kg. Testing procedures for determination of SAR are beyond the scope of this course and are available elsewhere[4].

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[4] IEEE Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR) in the Human Head from Wireless Communications Devices: Measurement Technique, IEEE Std 1528-2003, IEEE, Inc., June 12, 2003.

RF Standards for Whole Body Exposure

Transmitting devices, including cell phones, WiFi access points and clients, etc., expose people to radio frequency energy. In 1996 the U.S. Congress directed[5] the Federal Communications Commission (FCC) to define compliance requirements regarding transmitting radio equipment. The FCC compliance requirements, as contrasted with compliance *guidelines* elsewhere, carry the force of regulation.

Natural EM (electromagnetic) fields come from three main sources: the Sun, at levels up to 1,300 W/m^2 (or 130 mW/cm^3) at all frequencies, far less at RF, and thunderstorm activity (quasi-static electric fields in the several V/m range), and the Earth magnetic field (of order 40 A/m). Even the human body radiates at an average rate of about 120 W, including about 25 W from the human head and neck.

In the last 100 years, man-made RF fields at much higher intensities and with a very different spectral distribution have altered this natural EM background in ways that are still under study. RF fields are classified as *non-ionizing radiation* because the frequencies are much too low for photon energy to ionize atoms. Still, at sufficiently high power densities, they pose the possibility of heating body tissue. Various standards organizations and government entities, including ANSI/IEEE[6] (American National Standards Institute/Institute of Electrical and Electronics Engineers), EPA (US Environmental Protection Agency), FCC (US Federal Communications Commission), NCRP[7] (National Council on Radiation Protection and Measurements) have issued documents on RF exposure, protection guidelines and/or compliance regulations. Details of studies and of the biological aspects have been collected by Gandhi[8], Lin[9] and more recently by the ICNIRP[10] (International Commission on Non-Ionizing Radiation

[5] 47 CFR Part 1.1310.
[6] *IEEE Recommended Practice for the Measurement of Potentially Hazardous Electromagnetic Fields - RF and Microwave*, IEEE C95.3-1991 (Revision of ANSI C95.3-1973 and ANSI C95.3-1981), Institute of Electrical and Electronics Engineers, New York, 27 April 1992.
[7] "Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields," *NCRP Report No. 86*, 1986.
[8] Gandhi O. P., editor, *Biological effects and medical applications of electromagnetic energy*, Prentice-Hall, Inc., Englewood Cliffs, NJ, 1990.
[9] Lin, J. C., Editor, *Electromagnetic Interaction with Biological Systems*, Plenum Publishing, New York, 1989.
[10] ICNIRP (2009): "Exposure to high frequency electromagnetic fields, biological effects and health consequences (100 kHz-300 GHz)", online: http://www.icnirp.de/documents/RFReview.pdf

Protection). Radio frequency exposure and compliance for mobile communication devices are explained by Chou and Petersen[11].

Biological tissues exposed to RF energy will absorb the energy and convert it to heat as governed by Equation (3). External fields couple most efficiently to the body when the electric field is aligned with the body axis in the whole-body half-wave resonance range. For adult humans the resonance is between 30 MHz and 100 MHz[12]. The whole-body resonance is the same phenomenon that makes possible a dramatic antenna performance enhancement for body-worn receivers operating in the 30 – 100 MHz range as seen in Figure 4.

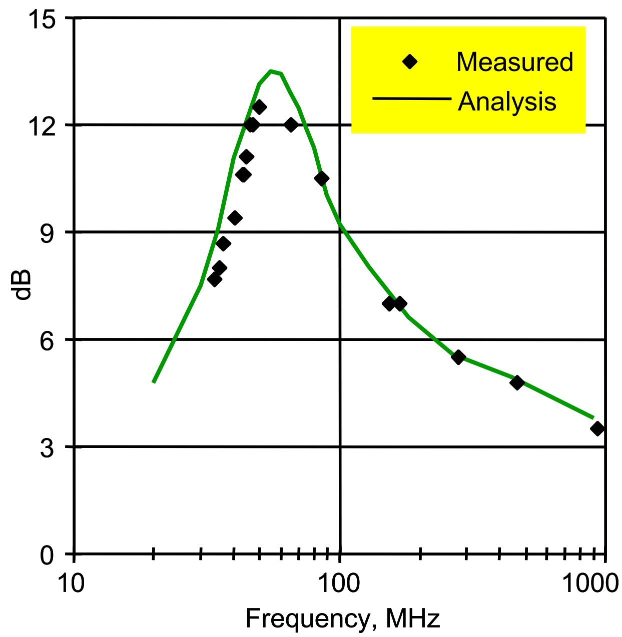

Figure 4 – Enhancement of body-worn radio receivers.

For small infants the resonant range extends upwards, so special attention is paid to RF exposure in the resonant frequency region of 30 to 300 MHz. Additionally, body parts may exhibit resonant behavior. The adult head, for example is resonant around 400 MHz, while a baby's

[11] C-K Chou and Ron Petersen, Chapter 6 in: Kyohei Fujimoto, "Mobile Antenna Systems Handbook", Artech House: MA, 2008.

[12] Chapter 10 in *Radiowave Propagation and Antennas for Personal Communications – Third Edition*, by K. Siwiak and Y. Bahreini, Artech House: MA, 2007.

smaller head resonates near 700 MHz. Body size thus determines the frequency at which RF energy is absorbed most efficiently[13]. As the frequency is increased above resonance, less RF heating generally occurs, and because the RF skin depth decreases with increasing frequency, the heating is increasingly confined to surface tissue. All these factors have led to RF exposure guidelines and regulations that have varying limiting levels of power density exposure with frequency, and in some cases, separate exposure limits for electric and magnetic fields. Note that SAR as defined in Equation (2) and SAR *limits* are frequency independent. The coupling mechanism that results in the internal body fields, as E in Equation (3), however, involves resonances hence is frequency dependent. Tissue heating is the primary effect of concern in the RF electromagnetic fields standards, SAR is the relevant mechanism, and the fields external to the tissue which give rise to the SAR are what we attempt to control per the relevant exposure standards.

Radiated RF Exposure Guidelines and Regulations

Hundred of documents world-wide relate to standards and regulations concerned with RF electromagnetic fields. Although good agreement was found among many of those documents in the basic limits for the whole-body SAR, specifications for local peak SARs varied an order of magnitude. In the specification of field strength and power density, limits ranged over two orders of magnitude in some cases. Furthermore, many documents were not self-consistent in derived field strength limits as compared with specified basic restrictions.

ANSI issued RF protection guidelines in 1982 and these were adopted in part by the NCRP (National Council on Radiation Protection and Measurements) in the U.S. in 1986[14]. The ANSI guidelines were later replaced by the ANSI/IEEE C95.1-1992 guidelines, now C95.1 2005[15]. The protection guidelines distinguish between the *controlled environment* and the *uncontrolled environment*. They further distinguishes between the effects of electric and magnetic fields at frequencies below 100 MHz. Additionally the duration of exposure to electric and magnetic fields is considered. In 1996 the U.S. FCC, by a mandate from Congress, issued regulatory limits for the MPE (maximum permissible exposure) for the *Occupational/Controlled* and *General*

[13] Durney C. H., H. Massoudi, M. F. Iskander, *Radiofrequency Radiation Dosimetry Handbook*, Fourth Edition, USAFSAM-TR-85-73, USAF School of Aerospace, Brooks AFB, TX 78235, October 1986.
[14] "Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields," *NCRP Report No. 86*, 1986.
[15] *IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electromagnetic Fields 3 kHz to 300 GHz*, IEEE C95.1-2005, IEEE, New York, 19 April 2006.

Population/Uncontrolled environments. The FCC adopted a combination of the IEEE/ANSI 1991 standard and the work of the ICNIRP. The substance of the FCC standard is contained in *OET Bulletin 65, Edition 97-01*[16]. The FCC whole body exposure field strength limits are based on a whole body SAR of 0.4 W/kg for the *Occupational/Controlled* and 0.08 W/kg for the *General Population/Uncontrolled* environments. By comparison, an adult body with a mass of 77 kg emits about 120 W, or close to 1.6 W/kg.

We will investigate these Federally mandated FCC limits in more detail. Table 1 summarizes the FCC limits for *Occupational/Controlled* environments, and Table 2 summarizes the limits for *General Population/Uncontrolled* environments. Both Tables are current as of 25 August 2010. The FCC defines *Occupational/Controlled* to apply in situations in which persons are exposed as a consequence of their employment provided those persons are fully aware of the potential for exposure and can exercise control over their exposure. Radio amateurs and their immediate households fall into this category.

General Population/Uncontrolled exposures apply in situations in which the general public may be exposed, or in which persons that are exposed as a consequence of their employment may not be fully aware of the potential for exposure or can not exercise control over their exposure. The neighbors of radio amateurs also fall into this category.

Table 1 FCC limits for *Occupational/Controlled* environments.

Frequency range, f (MHz)	*rms electric field strength,* E (V/m)	*rms magnetic field strength,* H (A/m)	*Power density* S (mW/cm^2)	*Averaging time* (minutes)
0.3-3.0	614	1.63/f	(100)*	6
3.0-30	1842/f	4.89/f	(900/f^2)*	6
30-300	61.4	0.163	1.0	6
300-1,500	--	--	f/300	6
1,500-100,000	--	--	5	6
*Plane-wave equivalent power density.				

[16] *OET Bulletin 65, Edition 97-01*, "Evaluating Compliance with FCC Guidelines for Human Exposure to RadioFrequency Electromagnetic Fields," Federal Communications Commission, Office of Engineering and Technology, Washington, D. C., August 1997.

Table 2 FCC limits for *General Population/Uncontrolled* environments.

Frequency range, *f* (MHz)	*rms electric field strength,* *E* (V/m)	*rms hagnetic field strength,* *H* (A/m)	*Power density* *S* (mW/cm²)	*Averaging time* (minutes)
0.3-1.34	614	1.63/*f*	(100)*	30
1.34-30	824/*f*	2.19/*f*	(180/f^2)*	30
30-300	27.5	0.073	0.2	30
300-1,500	--	--	*f*/1500	30
1,500-100,000	--	--	1.0	30
*Plane-wave equivalent power density.				

Both of the Tables 1 and 2 recognize the whole-body resonant region and apply stricter limits in the 30 to 300 MHz range. They also deal differently with individuals that are aware of and in control of their circumstances, and those that may not be aware of and have no control over their exposure.

Compliance with RF Exposure Standards

Once MPE regulations are set, the remaining task is one of compliance. We present the 1996 FCC limits as an example. Both the electric and magnetic field quantities in Tables 1 and 2 are *total magnitude* rms (root mean square) values. That is, electric field E and the magnetic field H in the tables are

$$E = \sqrt{\left|E_X^2\right| + \left|E_Y^2\right| + \left|E_Z^2\right|} \tag{4}$$

and

$$H = \sqrt{\left|H_X^2\right| + \left|H_Y^2\right| + \left|H_Z^2\right|} \tag{5}$$

as can be measured by "isotropic probes" such as described by US patent 4,588,933[17] or by equivalent probes described in the IEEE recommended practices[18]. Figure 5 shows graphs of

[17] Babij, T. M. and H. Bassen, "Broadband isotropic probe system for simultaneous measurement of complex E- and H-fields," *US Patent 4,588,993*, issued May 13, 1986.

essentially all of the limits defined in Tables 1 and 2 with the added provision that the quantity *S* mW/cm^2 is *defined* and evaluated in both the near and far fields in terms of the electric fields by

$$S_E = 0.1 \cdot \left\{ \left| E_X^2 \right| + \left| E_Y^2 \right| + \left| E_Z^2 \right| \right\} / 377 \quad (6)$$

and the magnetic fields by

$$S_H = 0.1 \cdot \left\{ \left| H_X^2 \right| + \left| H_Y^2 \right| + \left| H_Z^2 \right| \right\} \cdot 377 \quad (7)$$

with *E* V/m and *H* A/m. Finally,

$$S = greater\ of \begin{cases} S_E \\ S_H \end{cases} \quad (8)$$

In the free space far field $S_E = S_H$ and the quantity *S* is the power density. The 1996 FCC limits show a single trace for *S* only because those limits do not make a distinction in "far-field equivalent" power density between electric and magnetic fields at the lower frequencies.

The MPE limits are applied to mixed frequency fields by weighting their individual far-field equivalent power densities, as found by Equation (8), in accordance with exposure limit at each frequency. That is, the combined power densities are conditioned on

$$\sum_{i=1}^{N} \frac{S_i}{L_i} = \frac{S_1}{L_1} + \frac{S_2}{L_2} + \frac{S_3}{L_3} + \cdots \frac{S_N}{L_N} \leq 1 \quad (9)$$

where L_i are the exposure limits at the respective frequencies.

The frequency dependence of the standard is evident in the reduced permissible exposure over the whole body resonant range from 30 to 300 MHz.

[18] *IEEE Recommended Practice for the Measurement of Potentially Hazardous Electromagnetic Fields - RF and Microwave*, IEEE C95.3-1991 (Revision of ANSI C95.3-1973 and ANSI C95.3-1981), Institute of Electrical and Electronics Engineers, New York, 27 April 1992.

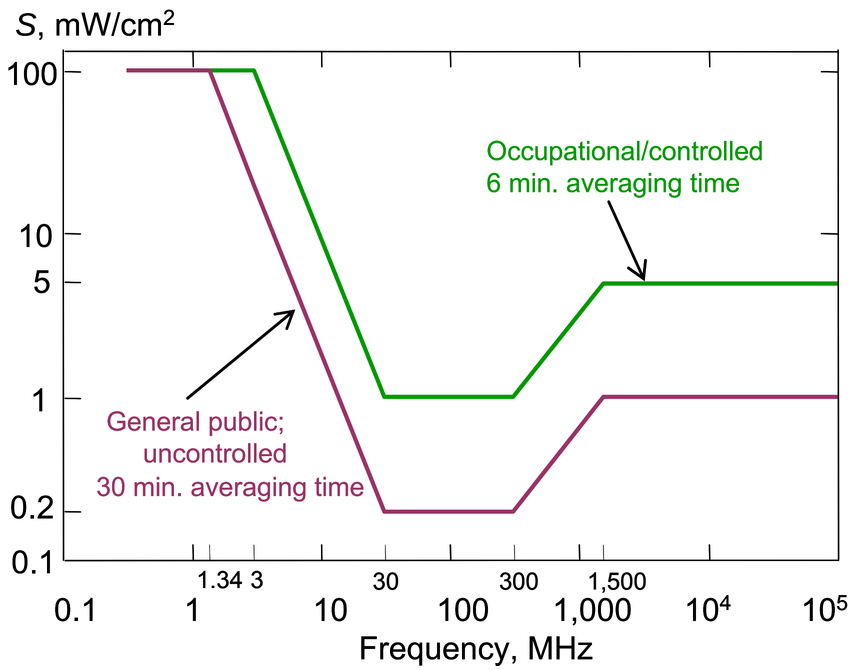

Figure 5 – A representation of FCC RF maximum permissible exposure limits.

Boundaries such as earth ground alter the wave impedance so that electric and magnetic fields must be considered separately, even in the far field of the source. This is illustrated by considering an example of a horizontal dipole 15 m above the earth operating at 30 MHz with 1,500 W supplied power. The parameters chosen here are for illustrative convenience[19]. The electric and magnetic fields each obey the boundary conditions at the air-earth interface. The magnetic field is enhanced, while the electric field is diminished at ground level. When normalized to the MPE of the 1996 FCC standard, the total magnetic field in decibels relative to the standard is shown in Figure 6, while the total electric field contours similarly normalized are picture in Figure 7. Ignoring the exposure averaging time in the standards, permissible *general population* exposure levels are the regions outside the "0 dB" contours. Significantly, the magnetic field contours of Figure 6 are substantially different from the electric field contours shown in Figure 7. Magnetic fields peak at ground level while electric fields peak a quarter wavelength above ground. This is a consequence the ground reflection and has nothing to do with whether the fields are near or far with respect to the dipole antenna. The *wave impedance*

[19] Hare E., *RF Exposure and You*, The American Radio Relay League, Newington CT, 1998.

evaluated on the total fields is simply not equal to the *intrinsic impedance* associated with the medium.

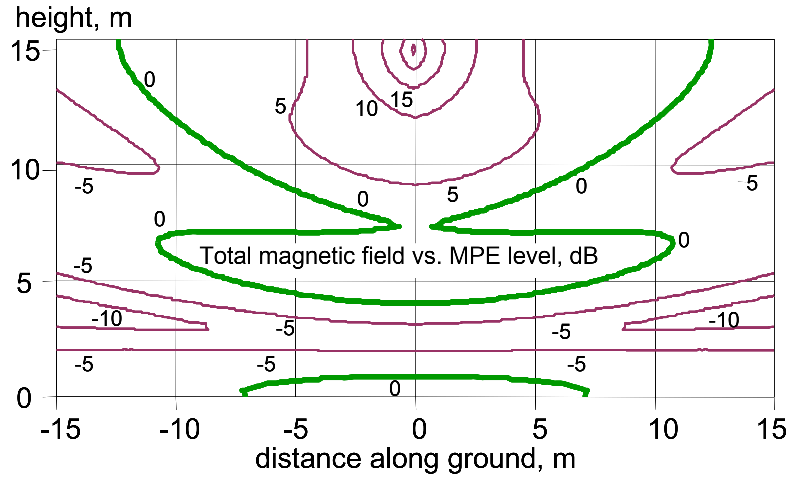

Figure 6 – Magnetic fields relative to MPE limits.

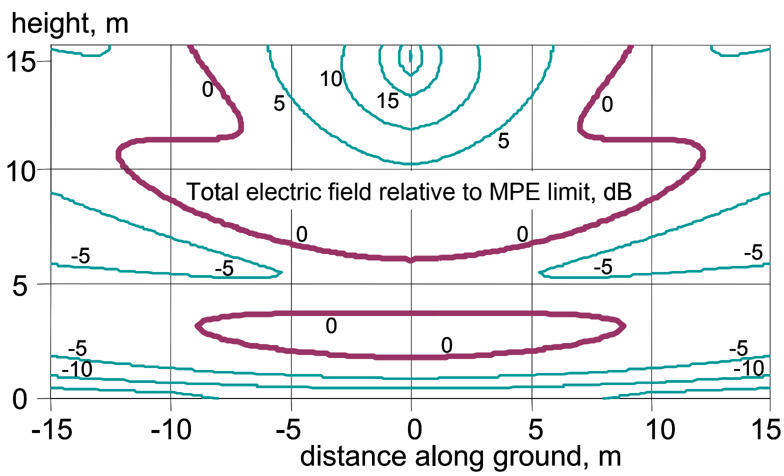

Figure 7 – Electric fields relative to MPE limits.

The compliance standard is written around the maximum of the either the electric or magnetic field limit, as calculated by Equation (8). That quantity is pictured in Figure 8. The "0 dB" contours represent the limits within which either the electric or magnetic fields exceed the MPE level of the standard. If the power transmitted by the dipole were reduced by 5 dB, then the MPE limit contour would be represented by the "5 dB" contour in Figure 8. The figures illustrates that the determination field levels relative to MPE levels leads to complex results even for the very simple case of a simple dipole antenna in the presence of a single boundary.

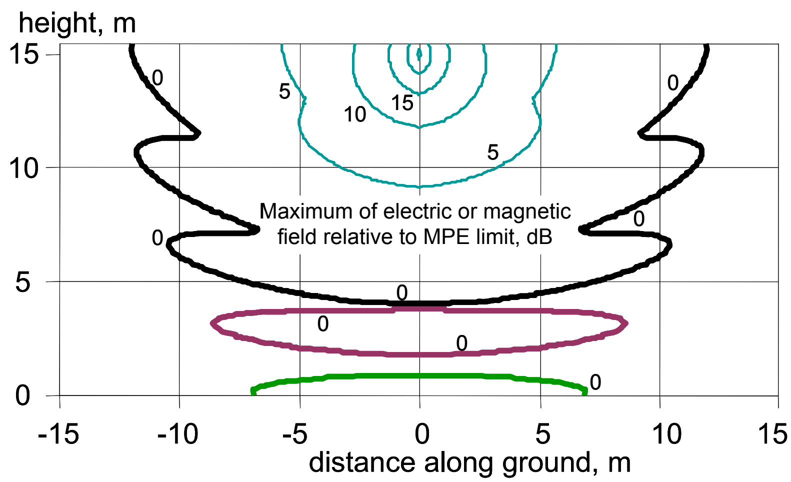

Figure 8 – Greater of magnetic or electric field relative to MPE limits.

One way of conservatively accounting for the ground reflection for RF MPE , and to avoid the complexity of determining the actual fields, is to increase "free space" field by 6 dB to account for a maximum possible reflection contribution from the ground, then evaluate the result against an MPE limit.

47 CFR specifies the criteria to be used to evaluate the environmental impact of human exposure to radiofrequency (RF) radiation in Sec. 1.1307(b). Portable devices are to be evaluated according to the provisions of Sec. 2.1093. Further detailed information on evaluating compliance with the limits can be found in the FCC's OST/OET Bulletin Number 65, "Evaluating Compliance with FCC-Specified Guidelines for Human Exposure to Radiofrequency Radiation".

Summary

The FCC compliance standards are based around different limits for the General population/uncontrolled environment and Occupational/controlled environment depending on whether the exposure applies to persons who are, or are not made fully aware of the exposure. The frequency range of interest for FCC exposure regulations is the RF range between 300 kHz and 100 GHz . The exposure limits are based on a large margin of safety to the specific absorption rate (SAR) thresholds where adverse biological effects may occur.

