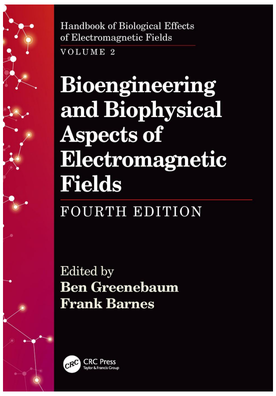

Bioengineering and Biophysical Aspects of Electromagnetic Fields

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Intermediate and Radiofrequency Sources and Exposures in Everyday Environments

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Intermediate and Radiofrequency Sources and Exposures in Everyday Environments

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CONTENTS

2.1 Introduction

Electromagnetic fields (EMFs) in the intermediate frequency (IF) range (3 kHz–10 MHz) share characteristics with extremely low-frequency (ELF) and radiofrequency (RF) EMF (ICNIRP, 1998a, 2009). Up to 10 MHz, the main effect of the interaction between EMF and the body is nerve electrical stimulation. Above this frequency, the main effect is tissue heating.

However, between 100 kHz and 10 MHz both effects occur.[1]* IF EMF have been traditionally considered within the low part of the RF range and very few studies exist until now which focused exclusively on this frequency range (SCENIHR, 2015; Sienkiewicz et al., 2010). IF EMF sources are commonly used for article surveillance (e.g., anti-theft gates) and heating (e.g., induction stoves), although some ELF and RF sources may also emit within this frequency. RF EMF are characterized by their high frequency (10 MHz–300 GHz) and energy which gives them the capacity to heat matter. Sources of RF EMF may also emit in other frequencies, including static, ELF, and/or IF (e.g., mobile phones and other transmitters can emit both RF and ELF EMF), although main emissions are produced within the RF range (Hitchcock, 2015; Hitchcock and Patterson, 1995; Mann, 2011). Microwaves are traditionally considered as the highest extreme of the RF range (300 MHz–300 GHz).

Several physical quantities are used to measure high-frequency EMF, including power density (PD or S, from Specific Power), electric field strength or E-field (in volts per meter, V/m), and magnetic field strength or H-field (in Amperes per meter, A/m). Power density is the power incident on a surface divided by its area. In the International System of units (SI), the unit is Watts per square meter (W/m^2). Although E- and H-fields are vector quantities (i.e., they have magnitude and direction), they are generally treated as just magnitudes, since only these are usually measured and reported in safety evaluations. The relationship between these three quantities can be explained by analogy with Ohm's law. Thus, the PD of an EMF is directly proportional to the product of the electric and the magnetic fields (eq. 2.1) (Hitchcock and Patterson, 1995):

$$\text{PD (W/m}^2) = \text{E (V/m)} \times \text{H (A/m)} \tag{2.1}$$

Other quantities used to characterize RF EMF are specific absorption (SA) and specific absorption rate (SAR). These quantities describe the RF EMF dose and dose rate, respectively, as they refer to the amount of energy absorbed by the body or any other matter. For frequencies up to 10 MHz, dose metrics commonly encountered in the EMF literature are internal electric field and induced current density, which are also related to each other by Ohm's Law (ICNIRP, 1998a). EMF dose metrics are difficult to measure, although measurements performed in phantoms and mathematical models have been developed (Chen et al., 2013; Dimbylow and Mann, 1994; Findlay, 2014) in an effort to estimate internal dose when direct measurements are not feasible.

ELF fields have long wavelengths (~5,000 km at 60 Hz). Thus, exposure to these fields occurs mostly in the near field, where electric and magnetic fields are independent and there is no radiation as such (Hitchcock and Patterson, 1995). However, physical characteristics of high-frequency EMF (i.e., IF and RF fields) differ with distance to the emitting source. In the near field (commonly defined as the space between the source and up to one wavelength), the relationships between electric and magnetic fields are complex and they can be considered independent. In the far field (i.e., the region where the distance from a radiating source exceeds the EMF wavelength), the wave characteristics are more homogeneous (plane-wave model), and the electric and magnetic components of the wave are orthogonal to each other and have a fixed ratio of intensity (Eq. 2.2):

$$\text{E [V/m]} = \text{H [A/m]} \times 377 \text{ ohms,} \tag{2.2}$$

where 377 ohms equals the impedance of free space.

* These are the main significant human health effects which are considered scientifically confirmed under current exposure guidelines (ICNIRP, 1998a; IEEE, 2006).

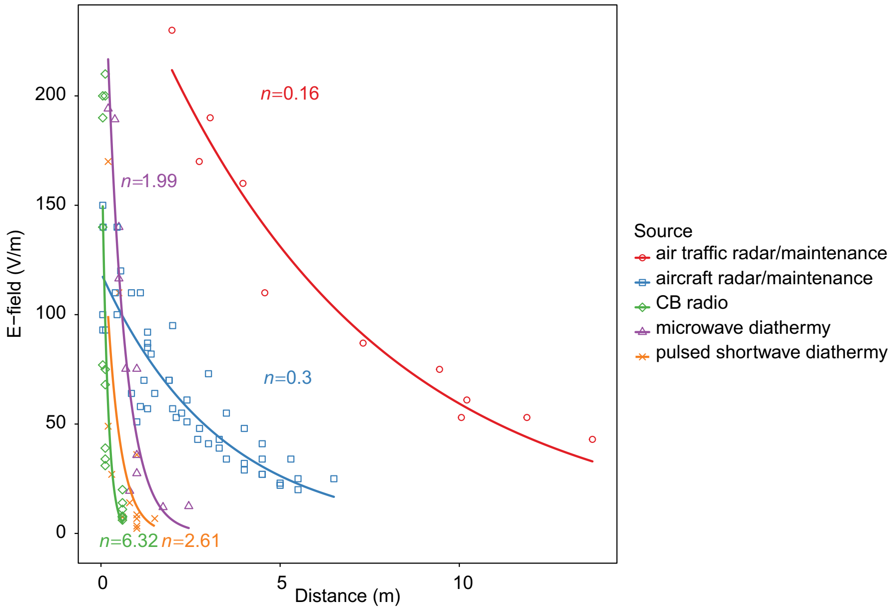

FIGURE 2.1
Electric field strength versus distance for various RF sources. Data collected within the INTEROCC study (Vila et al., 2016). Lines are data fitted by regression to functions of the inverse distance = constant × r^{-n}.

In the far field, the field intensity (e.g., in V/m) decreases inversely with the distance (r) at a rate up to around $1/r^2$, depending on the type of emitting source. Different sources may emit RF EMF with different patterns of propagation. For instance, transmitters, broadcasting, and mobile phone antennas may have a mixture of patterns which vary with distance from the source (Figure 2.1).

The intensity of the electric field may also depend on the frequency of the RF source. Figure 2.2 shows how electric field intensities measured from two RF sources at the same distance may differ depending on their frequency.

In the next section, several RF and IF EMF sources will be described, including information on the levels of exposure to electric and magnetic fields associated with them. These estimates of exposure intensity were obtained by combining information from many literature resources, as part of the INTEROCC project (Vila et al., 2016). The RF and IF EMF sources included here were identified in this study as the most common EMF sources in everyday environments. They have been grouped according to their use/application (e.g., food heating, telecommunication). Thus, both RF and IF EMF sources have been included within each type of application.

2.2 Typical IF and RF EMF Sources and Exposures (3 kHz to 300 GHz)

2.2.1 Food Heating Equipment

Numerous technologies use RF and/or IF EMF to heat, cook, cure, or sterilize foodstuff. Possibly, the most common high-frequency EMF-emitting devices for food heating are microwave ovens and induction cooking stoves.

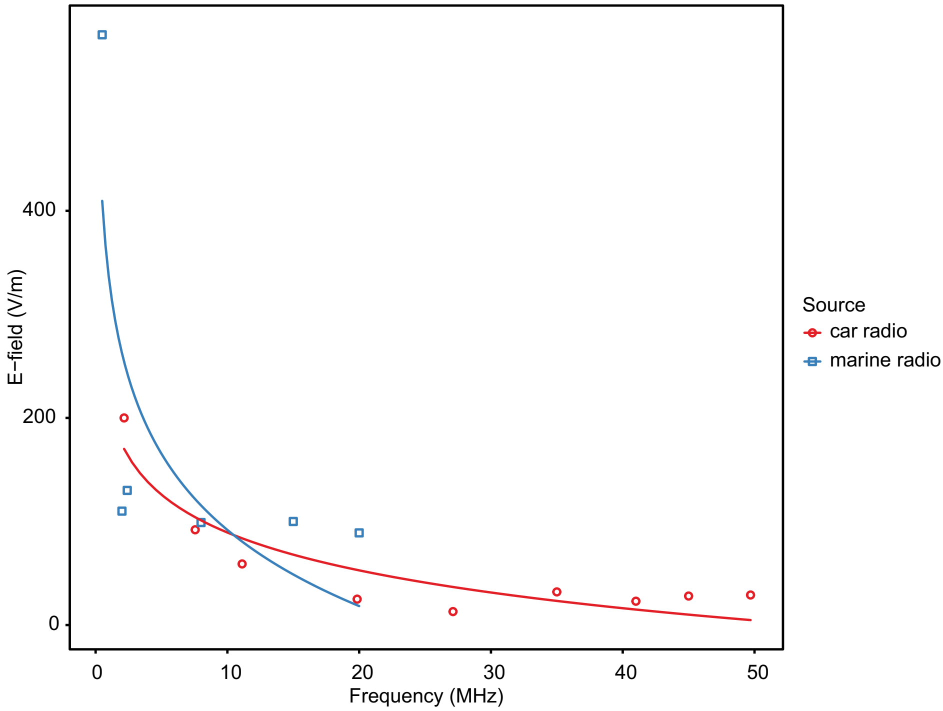

FIGURE 2.2
Electric field strength versus frequency for various RF sources. Data collected within the INTEROCC study (Vila et al., 2016). Curves are modeled regression lines that best fitted the data.

2.2.1.1 Microwave Ovens

Microwave ovens, commonly found in most Western homes nowadays, are one of the most well-known devices for food heating. Domestic ovens use frequencies of 2.45 GHz, while microwave ovens used in industrial and commercial premises often use 915 MHz (21). RF radiation is also used to sterilize food and other materials (e.g., cereals, soils, or waste-water). Average electric fields exposure levels associated with domestic ovens leakage are about 20 V/m (at an average distance of 20 cm) (Mantiply et al., 1997; Plets et al., 2016). Industrial microwave ovens may lead to similar exposures at the operator's eye level (Elder et al., 1974). RF industrial devices are also used for food disinfection. Typical frequencies used are 13.56, 27.12, and 40.68 MHz, in the lower RF range, and 915 or 2,450 MHz, within the MW range (Kim et al., 2012; Lagunas-Solar et al., 2006). To our knowledge, however, information on the operator's exposure to these devices is not available in the literature.

2.2.1.2 Induction Cooking Stoves

In the IF range, induction plates or stoves (22–34 kHz) are commonly found in industrial and commercial premises, as well as in domestic settings. These devices also emit ELF fields and exposure levels depend greatly on the distance to the operator and the number of stoves in use at the time. At distances between 10 and 30 cm from the unit, electric fields mean exposure levels are about 9 V/m, with magnetic fields around 4 A/m (Allen et al., 1994; Stuchly and Lecuyer, 1987).

2.2.2 Industrial Heating

High-frequency EMF are also used in industrial applications to bond, weld, or seal materials such as metals, plastics, wood, or resins, using induction or dielectric heating equipment.

2.2.2.1 Dielectric Heaters

Dielectric heaters, also called RF sealers, heaters or welders, are used to heat dielectric materials, mainly plastics, fabrics, wood, and paper. These devices can weld, mold or seal plastics or cure glues and resins. The most common frequency of operation is 27 MHz, although lower frequencies such as 13.56 MHz are also common. Some devices can reach frequencies up to 70 MHz and some plastic sealers can work with frequency ranges between 6.5 and 65 MHz (Hitchcock, 2015). High exposure levels, especially to E-fields, have been identified in multiple workplace evaluations (Allen et al., 1994; Bini et al., 1986; Conover et al., 1992; Stuchly et al., 1980; Wilén et al., 2004). RF heaters are considered the most common source of excessive emissions of RF fields (ICNIRP, 1998b), with average E-field levels around 400 V/m and maximum values up to 2,000 V/m (Hitchcock and Patterson, 1995). Magnetic fields of approximately 1 A/m are also present around the sealer. Since exposure occurs in the near-field, the coupling between electric and magnetic fields is complex and levels need to be measured separately.

RF heaters can be named depending on the material being heated and their general appearance. Sealing machines, shuttle trays, turntables, and pressure-sealed applicators are the most common subtypes used for heating plastics (Stuchly et al., 1980). Glue heaters/curers are used to heat, cure and/or dry glue, which is then used for joining wood pieces. Typical frequencies used by these devices range from 4 to 50 MHz. Mean exposure levels range from 30 to 300 V/m for electric fields and 0.1 to 0.7 A/m for magnetic fields (Joyner and Bangay, 1986; Stuchly et al., 1980). Microwave heating (2.45 GHz) can be used to cure optical fiber by using UV lamps which incorporate a source of RF radiation. Near the fiber curing units, electric field mean exposure levels are about 30 V/m, with magnetic fields of approximately 0.1 A/m (Cooper, 2002).

2.2.2.2 Induction Heaters and Welders

Industrial heating equipment in the IF range include induction heaters/furnaces, induction welders, and induction soldering devices used to heat/weld metals, and high-frequency arc welding units used in the production of pipes, tubes and beams for spot welding of metal surfaces. Induction heaters use eddy currents to heat metals or semiconductors by generating a strong alternating magnetic field inside a coil. Frequencies in the RF range can reach 27 MHz although lower frequency units (50 Hz) are also commonly used, which produce stronger magnetic fields with deeper penetration. Magnetic field mean exposure levels associated with RF units are about 0.6 A/m at the operator position, where mean electric field levels are about 50 V/m. Lower frequency units can lead to higher exposure levels around the operator, with magnetic field mean exposures about 5 A/m and electric field mean levels about 300 V/m (Allen et al., 1994; Cooper, 2002; Floderus et al., 2002; Mantiply et al., 1997). High-frequency welders usually operate at 400 to 450 kHz, although operational frequencies can reach 3 MHz. Like with other types of welding equipment, operators can get overexposed in the proximity of the cables, and especially when they encircle an arm or the abdomen with the cable because of the requirements of the specific task being performed. Power densities near the worker are around 10 W/m^2 (Hitchcock and Patterson, 1995; Repacholi, 1981).

2.2.3 Semiconductor Manufacturing Equipment

In the chips processing industry, various types of plasma equipment are used with frequencies of 13.56 or 27.12 MHz (e.g., plasma strippers, dry plasma etchers, plasma-enhanced chemical vapor deposition (CVD) and sputtering or metal deposition equipment). Some workplace evaluations have demonstrated that RF leakage can occur even from well-maintained units. Emission levels for E-fields range between 2 and 80 V/m (Cooper, 2002; Ungers et al., 1984).

2.2.4 Medical Applications

Several types of equipment used in the diagnosis and treatment of disease lead to high-frequency EMF exposures. These devices are specifically designed to emit EMF, which are commonly used by physiotherapists to treat specific health problems. Heat is usually applied to patients to achieve muscle relaxation or other purposes. However, unlike patients, therapists and other operators can be exposed to the EMF emitted for longer hours. Therefore, only exposure to operators is considered here.

2.2.4.1 Diathermy Devices

The most common technologies used are continuous or pulsed shortwave (13.56 or 27.12 MHz) and microwave (915 MHz or 2.45 GHz) diathermy. Overexposure of the applicator may occur in the vicinity of the cables, typically unshielded, while the therapist adjusts the equipment during operation. Average electric field levels at about one meter from the source are approximately 60 V/m for pulsed shortwave devices and 300 V/m for continuous shortwave systems. Average magnetic field levels are about 0.20 and 0.70 A/m, respectively. However, maximum exposure levels can reach up to 5,000 V/m for electric fields and 10 A/m for magnetic fields (Allen et al., 1994; Mantiply et al., 1997; Martin et al., 1990; Mild, 1980; Shah and Farrow, 2013; Stuchly et al., 1982).

The antenna design in microwave systems allows directing the beam directly toward the patient, reducing the operator's exposure level. Average exposure levels from microwave devices (2.45 GHz), for distances between 25 and 120 cm from the source, can be approximately 40 V/m for electric fields and 0.3 A/m for magnetic fields (Allen et al., 1994; Martin et al., 1990; Moseley and Davison, 1981). Less common technologies, such as ultrasonic diathermy (0.1–3 MHz), can lead to electric field mean exposure levels of 1 V/m and 0.2 A/m of magnetic fields near the source (Di Nallo et al., 2008).

2.2.4.2 Electrosurgical Applications

Electrosurgical devices are used to cauterize or coagulate tissues. Common frequencies are between 0.5 and 2.4 MHz. Exposure levels may defer depending on the tasks being performed. Surgeons and repairmen typical work distances are between 0.5 and 30 cm from the source. Thus, they can be exposed to mean electric field levels around 740 V/m and mean magnetic fields about 5 A/m. Nurses' mean exposure to electric fields, however, do not commonly exceed 100 V/m in the surroundings of an active equipment (Floderus et al., 2002; Hitchcock, 2015; Liljestrand et al., 2003; Mantiply et al., 1997).

2.2.4.3 Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) and nuclear magnetic resonance (NMR) spectrometers may expose operators and the general public to strong electric and magnetic fields (from static fields to RF fields up to 100 MHz). Average RF electric field levels of repair/maintenance workers can be about 50 V/m, while operators' RF exposure has been typically considered negligible. Static magnetic fields maximum exposure levels of operators near an active device can reach up to 1 T, while mean levels are around 60 mT. Exposure levels of nurses and other technicians are about half the levels associated with operators at distances above one meter from the source. ELF magnetic field mean levels of operators are around 0.6 μT, while nurses and other technicians may be exposed to half this intensity (Bracken, 1994; Smith et al., 1984). Training should be provided to ensure that workers are aware of the tasks associated with the highest levels of exposure (e.g., repair/cleaning or assisting patients near/or inside the magnet's tube, manipulating cables near the magnet) in order to promote exposure reduction.

2.2.4.4 Hyperthermia

Hyperthermia units are used for the treatment of cancer, by applying heat in excess (i.e., above 41°C) to kill cancer cells which tend to be more sensitive to heat than normal cells. Hyperthermia may be used in conjunction with other techniques, such as radio, chemo, and immune therapies, and surgery. Typical frequencies include 13.56, 27.12, 915, and 2450 MHz. Hyperthermia devices are similar to diathermy equipment, although hyperthermia small applicators allow for a more localized treatment. Mean exposure levels to electric fields of operators and other technicians are around 35 V/m between 50 and 200 cm from the source. Mean magnetic fields exposure levels at the same distance range are about 0.2 A/m (Hagmann et al., 1985; Hitchcock and Patterson, 1995; Stuchly et al., 1983).

2.2.5 Radars

Radars are used to detect and monitor moving objects (e.g., aircrafts, ships, or cars). Most radars work in the microwave range of the RF band (300 MHz–15 GHz), using pulse-modulated modes and high transmitting powers (Hitchcock, 2015). Overexposures may occur while performing maintenance tasks in the proximity of commercial radars (e.g., airport traffic control, weather and airport surveillance). Electric field exposure levels associated with these radars differ depending on the activities performed. In the surroundings of the radar, operators can be exposed to an average of 4 V/m at 250–500 m of distance, while repair/maintenance tasks can lead to mean exposure levels around 50 V/m at 1–10 m from the source. Relatively high exposures are also possible inside aircraft cockpits (Tell and Nelson, 1974; Tell et al., 1976), with electric field mean exposures around 80 V/m; near marine/naval radars (Peak, 1975), where mean exposures about 1 V/m are likely to occur at 5–10 m of distance from the source; and police speed devices (Bitran et al., 1992; Bradley, 1991; Fisher, 1993; Lotz et al., 1995). The latter may be hand-held or attached to a vehicle. Exposure of the operator can range from around 6 V/m for fixed radars to 30 V/m for hand-held devices. Security radars are used to detect vehicles and personnel and can lead to mean electric field exposures about 0.5 V/m in the surroundings of the source.

2.2.5.1 Military Radars

Little information exists in the literature about EMF exposure from military radars (mostly pulsed-modulated RF fields at 1–10 GHz with a typical radiated power of 1.5 kW and pulses up to 500 kW). Some available measurements and modeled estimates have shown that exposure levels of most exposed personnel can range from around 30 V/m for acquisition radars to about 300 V/m for illumination radars (Degrave et al., 2009; Szmigielski, 1996). Overall, soldiers in the proximity of directional radars can be exposed to around 10 V/m while the levels associated with non-directional radars can be up to ten times higher. Mean exposure levels inside radar cabins are around 20 V/m (Sobiech et al., 2017).

2.2.6 Telecommunication Transmitters and Antennas

Since the 1930s, the radio section of the International Telecommunications Union (ITU-R), a United Nations specialized agency, has managed the worldwide use of the RF spectrum. Table 2.1 describes the RFs used for telecommunication purposes, as defined by the ITU-R (ITU, 2007).

Telecommunication equipment may be fixed to buildings or built on the ground (e.g., broadcasting antennas). Fixed antennas are typically used for high frequency radio, television, mobile phone, satellite and microwave radio systems, among others. Although, to some extent, we are all exposed to the fields emitted by these antennas, only people living in the proximity of the RF sources or workers involved in repair/maintenance tasks can experiment overexposures.

Transmitters are typically mobile or portable communication devices, either handheld or attached to vehicles. They are frequently used by police, fire, and other emergency services, but also by maintenance staff, security agencies, and other industrial and commercial activities. Portable systems include walkie talkies, cordless telephones, cellular phones, and marine and airplane communication systems. Transmitters commonly attached to vehicles include citizen band (CB) radio and other types of two-way radios. Analogical cordless telephones work with frequencies around 50 MHz, while cellular/mobile phones and modern DECT phones work in the range between 380 up to 3,500 MHz, depending on the technology used. Exposure levels depend on the power of the device and its frequency. Electric field strengths between 20 and 700 V/m have been measured near transmitters attached to vehicles working at 800 MHz. Hand-held transmitters or

TABLE 2.1

ITU Frequency Bands for the Radio Spectrum

ITU Band	Label	Frequency Band	Frequency Range
Extra high frequency	EHF	RF/MW	30–300 GHz
Super high frequency	SHF	RF/MW	3–30 GHz
Ultra high frequency	UHF	RF/MW	300–3,000 MHz
Very high frequency	VHF	RF	30–300 MHz
High frequency	HF	IF-RF	3–30 MHz
Medium frequency	MF	IF	300–3,000 kHz
Low frequency	LF	IF	30–300 kHz
Very low frequency	VLF	IF	3–30 kHz
Ultra low frequency	ULF	IF	300–3,000 Hz
Extremely low frequency	ELF	ELF	30–300 Hz

Note: ELF: Extremely low frequency; IF: Intermediate frequency; MW: Microwave; RF: Radiofrequency.

TABLE 2.2

Characteristics of Telecommunication Antennas/Transmitters

Source	Frequency Band	Frequency Range
DECT (digital)	UHF-MW	900–2,400 MHz
DECT (analogue)	HF-VHF	50 MHz
Mobile communication – GSM	UHF-MW	380–1,900 MHz
Mobile communication – UMTS	UHF-MW	700–3,500 MHz
Mobile communication – LTE	UHF-MW	450–3,700 MHz
Navigational antennas	VLF-LF	10–70 kHz
Radio broadcasting – FM	HF-VHF	87.5–108 MHz
Radio broadcasting – AM	MF-HF	500–1,700 kHz
Roof-top paging antennas	HF-VHF/UHF-MW	152–929 MHz
Shortwave transmission	HF	3–300 MHz
TV broadcasting	UHF	470–854 MHz
TV broadcasting	VHF	54–216 MHz

Note: FM: Frequency modulated; AM: Amplitude modulated; GSM: Global system for mobile communications; UMTS: Universal mobile telecommunications system; LTE: Long-term evolution; DECT: Digital enhanced cordless telecommunications.

transceivers' emissions occur near the head of the users, so recommended exposure limits can sometimes be exceeded (Hitchcock and Patterson, 1995; Lambdin and EPA, 1979; Ruggera, 1979). Table 2.2 summarizes the characteristics of the antennas and transmitters further described in this section.

2.2.6.1 Shortwave Transmission

Shortwave stations use from a few watts to several hundreds of kilowatts to transmit information worldwide, depending on the type of source (e.g., amateur radio operators, commercial broadcasts by governments and private organizations, military communications). Studies looking at the levels of exposure of the general population (Altpeter et al., 2006; Michelozzi et al., 2002) have shown that average magnetic field exposure levels of those living relatively close to the antennas (i.e., ~500 m) are around 10 mA/m (which in far-field conditions corresponds to an electric field strength of around 4 V/m). Workers performing repair/maintenance tasks near energized antennas can be exposed to about 10 V/m, although maximum values up to 100 V/m have also been recorded (Mantiply et al., 1997). The shortwave or high frequency (HF) band is one of the amplitude modulated (AM) radio bands, which also include the low frequency (LF) and the medium frequency (MF) bands, the latter being the most commonly used AM broadcasting band. Measurements for this frequency band have shown mean exposure levels on the ground near the towers between 50 and 200 V/m. Subjects working on the masts can be exposed to similar average levels, with maximum values up to 400 V/m (Allen et al., 1994; Conover, 1999; Mantiply et al., 1997).

2.2.6.2 Navigational Transmitters and Antennas

Similar high-frequency transmitters and antennas are used for navigational purposes by marine boats, such as Fast Patrol Boats (Baste et al., 2010). Frequencies between 2 and 8 MHz and powers between 10 and 250 W are typically used. Mean exposure levels on the boats can be around 10 V/m, although maximum levels over 100 V/m have been measured (Baste et al., 2010; Skotte, 1984; Tynes et al., 1996).

Ground-based communication antennas using the IF range (16–60 kHz) are sometimes used to communicate with boats or submarines at sea. Mean exposure levels near LF antennas can be around 200 V/m while levels around very low frequency (VLF) towers are even higher, with average exposures about 600 V/m (Cooper et al., 2007).

2.2.6.3 FM Radio and TV Transmission

Although broadcast transmitters have much higher radiated power (i.e., several kilowatts against a few hundred watts) compared to mobile telephone base stations, there are fewer masts with TV and/or radio antennas, these are typically located on very tall masts (i.e., over 100 m in height), and beams are directed toward the horizon leading to small exposure levels on the ground (Mann, 2010).

FM radio broadcasting commonly uses a frequency range, differing by country, within the very-high frequency (VHF) band, from 30 to 300 MHz (ITU, 2007). Antenna towers, which are not part of the transmitting system, are usually high and emissions are directed to reach longer distances. Mean exposure levels of the population are around 0.1 V/m although a small proportion of subjects can be exposed to up to 2 V/m. Workers in the surroundings of a tower can be exposed to up to 800 V/m while in the proximity to the emitting antenna, levels can reach 1,000 V/m and about 5 A/m (Allen et al., 1994; Mantiply et al., 1997; Moss and Conover, 1999).

Television transmission may use the VHF or the ultra-high frequency (UHF) bands. Measurements of the general population have shown that most people are exposed to levels around 0.1 V/m while less than 1% of subjects might be exposed to around 2 V/m. Workers at ground level can be exposed to levels around 10 V/m while those climbing the towers can reach up to 900 V/m (Cooper et al., 2007; Mantiply et al., 1997). The TV signal consists of an amplitude-modulated video signal and a frequency-modulated audio signal. The modulation is similar for both VHF and UHF signals. A common input power for the video in Europe is 30 kW while 5 kW is used for the audio, which combined with the antenna gain gives an effective radiated power of 1,000 kW. The number of towers has not increased in the last years due in part to the introduction of new technologies, such as digital radio and TV which use lower power, but larger frequency bandwidth and may lead to higher exposure levels (Mann, 2010).

UHF-TV signals usually work with transmitting powers around 30 kW, which gives an effective radiating power (i.e. input power times antenna gain) up to 5 MW. Measurement campaigns have shown that around 20% of the population is exposed above 0.1 V/m while less than 1% have exposures above 1 V/m. Near the masts on the ground, exposures range between 1 and 20 V/m, while levels over 600 V/m have been measured beside the antenna element (Mantiply et al., 1997; Tell and Mantiply, 1980).

2.2.6.4 Mobile Phone Base Stations and Hand-Held Devices

Current mobile phone telephony operates with frequencies between 800 and 2,100 MHz although specialized systems used by professionals such as police, firemen, or ambulances, use lower frequencies around 400 MHz. Mobile telephony systems involve communication between hand-sets (uplink) with nearby base stations (downlink) which cover specific areas (cells), achieving the desired coverage. In recent years, the number of technologies has increased enormously, and several networks have been put in place, which make use of different frequency bands (Table 2.1). The "Groupe Spécial Mobile" or Global system for mobile communications (GSM) networks cover over 90% of the market. This includes the original 1G analogue network, plus the digital networks 2G and 3G (UMTS). The new 4G network is not part of the GSM standard. An important feature of mobile telecommunication systems is adaptive power control, which allows avoiding unnecessarily high power that would lead to interference and reduced capacity. However, for the purpose of exposure assessment it is assumed that the radiated power equals the maximum possible, although this is seldom used (ICNIRP, 1996). Base station transmitting antennas are formed of vertical arrays of collinear dipoles phased to give a narrow beamwidth (typically between 7 and 10 degrees). The antennas are mounted on buildings or on high towers. They are a source of whole-body exposure of people in their proximity. Exposure of the general public typically occurs in the far field zone, where the electric and magnetic fields vary inversely with distance (radiating far field) and there is commonly compliance with basic limits.

Hand-sets are small portable transceivers that are typically held near the head while calls take place although new technologies have led to new behaviors as mobile phones allow more and more capabilities (e.g., email, Internet, music, games). Modern phones contain internal monopole or dipole antennas mounted on a metal box. Phone calls lead to exposure in the near field of the source since the emitted radiation has a wavelength of a few centimeters, which is the typical call distance. Other configurations may lead to different scenarios of exposure. Methods to estimate the exposure levels associated with some of these scenarios have been proposed (Kelsh et al., 2011; Roser et al., 2015) and modeling approaches using personal use data obtained through questionnaires and mobile apps (e.g., XMobiSense) are under development (Schüz et al., 2011). Exposure in the near field, during calls or other activities, leads to localized energy absorption (ICNIRP, 1996). Demonstration of compliance with basic limits, typically in terms of SAR, is obtained through calculations of absorbed energy and measurements using anatomical tissue-equivalent phantoms. Because of the complex patterns of energy absorption, both calculations and experimental studies have revealed that basic limits might be significantly exceeded when using portable units at lower distances than recommended by manufacturers. For instance, iPhone 4 recommends using and transporting the phone at a minimum distance of 10 mm from the body to comply with European and U.S. basic restrictions. However, this recommendation is frequently breached since phones are commonly held touching the head or transported inside the clothes pockets.

Output power is the main factor determining energy absorption (Hillert et al., 2006; Kelsh et al., 2011). Several exposure limits have been proposed by international organizations to avoid well-established adverse health effects due to significant temperature increase above normal body temperature. Both the International Commission on Non-Ionizing Radiation Protection (ICNIRP, 1998a) and the Institute of Electrical and Electronics Engineers (IEEE, 2006) have proposed basic limits for whole-body and localized (peak spatial) average SAR (Table 2.2). Under normal use and typical peak output powers of 1–2 W, commonly used by most devices, recommended exposure limits are not exceeded (ICNIRP, 1996). However, certain circumstances (e.g., small head-phone separation, higher output power due to low coverage) may lead to violation of these limits.

In occupational settings, dosimetric assessments in the form of SAR values are rarely performed and exposures are typically expressed in units of field strength or power density. Overexposures may occur to maintenance workers while climbing or working on energized antennas mounted on towers or buildings, or on the ground. Exposure levels vary depending on the specific source and exposure configuration. Mean electric fields of an operator can range from around 0.5 V/m, while working on the ground near the mast, to around 13 V/m, while working on the mast (Cleveland et al., 1995; Cooper et al., 2004). There is little information in the literature regarding exposure levels from the use of occupational portable hand-held transmitters/transceivers such as walkie-talkies. Some reviews show that mean electric field strength values are around 500 V/m near the antenna, although maximum levels up to 1,000 V/m are possible (Bernhardt and Matthes, 1992; Mantiply et al., 1997). Mean magnetic field strength levels are around 0.2 A/m, but maximum levels can reach up to 1 A/m (Vermeeren et al., 2015).

Commercial development is under way for the so-called 5G communications system that is intended to serve not only telephones, but a wide variety of "smart" devices (ITU, 2017). Many frequencies are being considered within the range 3–100 GHz, with first priority being given to 3.4-3.8 GHz and 24.25-27.5 GHz. The system will use more numerous base stations that transmit at lower power than current telephone systems. Larger, multiple channel antennas using narrow beam-forming technology are also being considered. Little data are currently available on potential environmental exposures from these devices.

2.2.6.5 Military Telecommunication Transmitters and Antennas

As with military radars, there is also little information in the literature about the levels associated with military telecommunication transmitters and antennas. In a review of military naval equipment (Sylvain et al., 2006), mean electric field levels near (i.e., about 1 m) HF and VLF antennas were found around 70 V/m, while almost 1,000 V/m were measured in some locations. Electric fields emitted by portable radios used by the Polish Armed Forces (Sobiech et al., 2017) showed average levels around 50 V/m near the soldier's head. For manpack radio operators, mean levels might be even higher (around 100 V/m), while mean exposure levels inside vehicles with radio transmitters were found to be around 20 V/m.

2.2.6.6 Miscellaneous Intermediate and RF Antennas

The paging communication system, consisting of fixed transmitters and pagers or beepers (i.e., portable receivers/transceivers), was highly used in the 1980s. However, the widespread use of mobile phones since the 2000s has made this type of system almost a rarity nowadays. However, ground or building-based antennas can still be found in some countries. Mean electric field levels about 50 V/m have been recorded (Cleveland et al., 1995) in the vicinity of paging antennas (around 200 m from the source).

Recent years have seen an increase in the number and types of IF EMF emitting sources. Induction heating equipment for both industrial and domestic purposes, as described above, commonly use frequencies between 400 kHz and 2.4 GHz. Other induction technologies include soldering (10–800 kHz) and welding (208–371 kHz). Mean magnetic field levels around 200 A/m are possible at 30 cm from induction soldering devices; while induction welding equipment can lead to average magnetic field exposure levels around 4 A/m (Jonker and Venhuizen). Some newer technologies include security tags and antennas, such as electronic article surveillance (EAS) and RF identification (RF ID) systems. EAS devices use frequencies between 58 kHz and 9.1 MHz and H-field exposures near them can reach around 25 A/m (Joseph et al., 2012a). RF IDs are similar to EAS systems, except that transponder tags respond with a data signal – not only disturbing the signal between the transmitting and receiving antenna panels – which allows the identification of the detected object due to the transmission of coded information. They usually work with slightly higher frequencies, around 13.56 MHz, and may lead to mean electric fields around 20 V/m and mean magnetic field levels around 2 A/m near the antennas (Senić et al., 2010).

2.3 RF EMF in Everyday Environments

Typical exposure to RF EMF of the general public is difficult to characterize due to the complex nature of RF EMF, the variety of telecommunication technologies and the large spatial and temporal variability associated with these physical agents. RF EMF measurement campaigns and/or long-term monitoring networks have been developed in several countries (Breckenkamp et al., 2012; EPA, 1978; Gotsis et al., 2008; Hankin, 1986; Rufo et al., 2011; Troisi et al., 2008). Available measurements in Europe (Gajsek et al., 2013; Joseph et al., 2010; Sagar et al., 2017) have shown that average levels of RF electric fields tend to be up to ten times below the reference levels for residential exposure recommended by international bodies (ICNIRP, 1998b) or European regulations (EC, 1999). Most measurements tend to be below 1 V/m and only around 0.1% is above 20 V/m. The strictest reference level established by this legislation for environmental (residential) exposure is 28 V/m, which corresponds with the limit set for the 10–400 MHz frequency, typically associated with FM radio and VHF TV broadcasting.

Studies on frequencies associated with mobile telecommunications (Gajsek et al., 2013; Hutter et al., 2006) have shown that mean RF exposure levels tend to be slightly higher in rural areas (0.13 V/m) compared to urban areas (0.08 V/m). This could be due to the need to transmit higher powers to reach longer distances but also to the shielding effect of buildings and other physical obstacles in cities compared to more rural open spaces. RF indoor exposure depends on the number and intensity of sources inside households and those outside. A study in Austria (Tomitsch et al., 2010) found that only 15% of the indoor exposure was due to RF sources inside the house (e.g. DECT phones, WiFi), while 85% was attributed to outside sources. In Germany, mean values around 1 V/m were found near public spaces such as schools or hospitals (Bornkessel et al., 2007). Measurements in Belgium, the Netherlands and Sweden (Joseph et al., 2012b), investigating the impact of new technologies of mobile telecommunications, have shown that the contribution to the total RF electric fields was higher for GSM (>60%), followed by UMTS (>3%) and LTE and WiMAX (<1%). Measurements in the United Kingdom near macro and microcell base stations showed higher levels associated with the latter technology, although all measurements were largely below international exposure limits. The highest intensity measured near a base station was around 9% of the corresponding ICNIRP reference level.

Population exposure to RF fields from TV and radio broadcasting tends to be low, since these transmitters are typically located away from heavily populated areas (Hitchcock, 2015). However, relatively high exposures can happen due to radio AM towers, which need high transmitting powers (up to 70 KW). The mean exposure of the general public in Switzerland due to RF fields from AM radio antennas was established around 0.6 V/m (Altpeter et al., 2006). Comparisons between RF field exposures from analogue and digital TV and radio systems have been carried out in Germany (Schubert et al., 2007). Although overall exposure levels were found to be higher for analogue systems, the planned increase of transmitting power for digital systems will likely reduce these differences in the future.

Exposure levels previously described were mostly obtained through fixed monitoring networks or spot measurements in indoor and outdoor environments, and typically refer to exposures due to specific RF EMF sources. Personal measurements, which potentially reflect exposure levels due to emissions from several sources at once, as well as changes of physical location (e.g., home, work, leisure) are, however, scarce (Sagar et al., 2017). This possibly indicates the difficulty of using personal exposimeters due to technical problems such as body shielding, calibration errors, or measurement artifacts, which tend to lead to under or over estimations of the true exposure levels (Bolte et al., 2011; Knafl et al., 2008).

2.4 Conclusion

Recent years have seen an outstanding increase in the availability and use of high-frequency EMF-emitting sources, with applications in medicine, telecommunication, and manufacturing, but also for cooking/heating of foodstuffs. Without any doubt, these RF and IF EMF sources have meant an enormous technological breakthrough, as they provide new tools that make our lives more comfortable, smarter and more productive, and give access to leisure and updated information in a continuously changing society. However, these advances not only entail benefits but also have the drawback of an important increase in the levels of exposure to high-frequency electric and magnetic fields, compared with the levels due to (unavoidable) exposures from natural sources.

Except for occupational activities, such as maintenance and repair tasks, and the use of mobile telecommunications devices (e.g., mobile phones), exposures to most of these sources occur at distances which can go from a few meters to kilometers and, therefore, are typically below the limits established by national and international regulations. However, exposure limits in place in most Western countries have been established to protect the exposed populations from short-term heating effects due to high exposure levels, since the evidence to date for low-level non-thermal chronic health effects is still considered insufficient to be used in the establishment of environmental and occupational reference levels. Therefore, following the precautionary principle, it would be advisable to reduce, to the degree possible, both the intensity and duration of exposure to these and other EMF sources, to avoid or limit potential not yet clearly identified risks.

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