INTERNATIONAL COMMISSION ON NON-IONIZING RADIATION PROTECTION

ICNIRP STATEMENT

ON EMF-EMITTING NEW TECHNOLOGIES

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The International Commission on Non-Ionizing Radiation Protection*

INTRODUCTION

RECENT DEVELOPMENTS in telecommunication and wireless technology have led to increasing numbers of new devices and systems that emit radio frequency (RF) electromagnetic (EM) energy. Implementing these developments has resulted in large numbers of individuals at the workplace or in the general public being exposed to RF-EMFs.

The guidelines of the International Commission on Non-Ionizing Radiation Protection (ICNIRP 1998) provide advice for permissible exposure levels that cover the entire spectrum of non ionizing radiation (NIR), including the RFs used in new technologies. However, there are questions being posed about health effects associated with exposure to these new systems and devices, which have not been tested per se in terms of health risks. They may have signal characteristics that are unique and different from the currently used technologies, and they may also cause the total level of exposure to rise because of the superposition of electromagnetic fields (EMFs) emitted by new and existing sources.

The aim of this Statement is to compile a list of the new technologies under development, soon-to-be or recently deployed, which could lead to increased levels of exposure to NIR at the workplace or in daily life, and to assess the need for further research to evaluate their NIR safety and health implications. However, the technologies that are included in this Statement are not limited to mobile or wireless communications; they encompass all EMF-emitting devices. Given the technological, regulatory and marketing challenges, the timing of the introduction or deployment of any of the products is somewhat uncertain. It should be noted that experience of the cellular mobile telephone industry indicates that once the new technology is deployed, the adoption rate could easily explode. While it takes advanced technology to develop a product, the availability of low-price, high-quality, and high-performance components from around the world would push the price of the new product down through large-scale production. See the Appendix for lists of technical and organizational acronyms.

MOBILE COMMUNICATION AND WIRELESS TECHNOLOGIES

While the present document focuses on new mobile communication and wireless technologies, the motivation comes from the rapid growth of the cellular mobile telephone industry and the pervasive use of wireless devices in all walks of life. We will therefore begin with a brief discussion on the evolution of cellular mobile communication technologies, although the distinction among various generations of mobile communications is blurring. Note that a description of the earlier generations is useful, especially for epidemiological studies of cell phone exposures.

Generations of Mobile Communications

1G systems

The first generation (1G) mobile telephones were analog systems—typically operating at 450 MHz using frequency modulation. The analog systems deployed in various parts of the world were slightly different: namely, Nordic Mobile Telephony (NMT) mainly in the North European countries, American Mobile Phone Service (AMPS) in the U.S., and the Nippon Telegraph and Telephone (NTT) system in Japan. The radiated powers of the 1G systems are typically 600 mW. At present, these services have either stopped or are running at a low level of traffic in most parts of the world. Apart from mobile handsets and base stations, analog systems are also used for cordless telephones. These 1G devices are important for the epidemiological studies of long-term exposures or any effect associated with long latency.

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2G systems

The major breakthrough in mobile communications began with the second generation (2G) digital systems. These have become the dominant service with more than one billion users worldwide. However, the 2G systems differ around the world. In Europe and parts of Asia and the Americas the Global System for Mobile Communications (GSM) system is dominating. It features carrier frequencies at 900 and 1,800 MHz (1,900 MHz in U.S.). The bandwidth is around 250 kHz with a 9.6 kbit/s data rate. It uses a Time Division Multiple Access (TDMA) technique—each user is "on" for 4.615/8 = 0.58 ms, then comes back periodically at a frequency of 217 Hz. The remaining 7/8 of the time is used for other users. Thus, from the RF power point of view it uses bursts for transmission. Apart from the access frequency of 217 Hz and its harmonics, there are various control and system signals giving rise to power variations at the frequencies of 2 and 8 Hz.

The information (voice or data) is carried by the RF signal in a continuous phase-only manner, so as long as the user is "on," the power is constant. This is also called constant-envelope modulation. As will be seen later, most other evolving systems do not have this property of constant envelope.

IS-95. The IS-95 is the North American version of the Code Division Multiple Access (CDMA) standard known as cdmaOne. The CDMA standard is significantly different from the GSM standard. The IS-95 is a so-called direct-sequence spread spectrum system where the users are "on" simultaneously, but separated by different codes, which are "spread" on the carrier to a wider bandwidth than dictated by the un-spread scheme. The speed of the spreading is known as the chiprate, which for IS-95 is 1.2288 Mchip/s in a bandwidth of 1.25 MHz. One immediate consequence is the lack of the pulsing characteristic common in TDMA systems. Further discussion of the CDMA technique is deferred to the 3G systems.

PDC. The Personal Digital Cellular (PDC) system is a TDMA system operating in the 800 MHz and 1.5 GHz bands and is used primarily in Japan. The system also has packet transmission capability, named the Personal Digital Cellular-Packet (PDC-P) system, which was introduced in 1997. As the PDC-P is based on the PDC system, the radio characteristics are very similar, i.e., using 3-channel TDMA. With a single TDMA time slot, PDC-P can provide 9.6 kbit/s packet access and 28.8 kbit/s with three time slots. Moreover, i-mode service is available on PDC-P channels.

2.5G systems

The popularity of the Internet and personal computers created a need for higher data rates on wireless networks than available with 2G systems, which were designed mainly for voice applications. The term "2.5G" is used to denote an enhanced GSM system with high speed data services.

GPRS. In an effort to increase the data rate within existing systems while waiting for the 3G systems to deploy, a General Packet Radio Service (GPRS) evolved. GPRS supports a much better data rate (up to a maximum of 140.8 kbit/s) and is packet-based rather than connection-oriented. It is deployed in many places where GSM is used. GPRS achieves the higher data rates by combining several timeslots, in practice 2–3. There is also a circuit-switched version of combining time slots—High-Speed Circuit Switched Data (HSCSD)—as a GSM-enhancement technology. HSCSD bumps up the bit rate and allows the system to combine TDMA "timeslots," delivering data speeds up to six times faster than standard GSM systems.

It is generally assumed that there is a greater need for downloading than transmitting, so the capabilities are asymmetric; for example, 14 kbit/s in the uplink (one timeslot) and 28–64 kbit/s in the downlink. Since the system is packet-based with the user always on, it is more the amount of data transmitted and received than the time elapsed that counts. It should be stressed that the exposure may be quite different for the data transmission applications, since the mobile phone may no longer be held near the ear. Because the specific absorption rate (SAR) falls off with distance, this reduces considerably the actual exposure to the head.

EDGE. There is also another evolution path from 2G—known as Enhanced Data rate for GSM Evolution (EDGE)—which uses higher order modulations. However, the signal power in EDGE may vary from symbol to symbol, i.e., it is not constant-envelope modulation. It requires a good radio connection, so adaptive techniques are used to control power variations when possible. The information-bearing high data rate-related power is not constant, and is from a biological point of view a truly amplitude-modulated signal. It could offer wireless multimedia internet protocol (IP)-based services and applications at theoretical maximum speeds of 384 kbit/s with a bit rate of 48 kbit/s per timeslot and up to 69.2 kbit/s per timeslot, under good radio conditions. Power control schemes also introduce power variations.

It should be noted that i-mode was the first service that enabled cellular telephones to access and navigate the Web. It was an overlay on the Japanese PDC system with packet transmission. Thus, unlike voice calls which are circuit-switched and only function after dial-up, i-mode communications are "always-on" provided you are in an area where i-mode signals are present. It gives the user instant access to text messaging, email, and other Internet-based information, entertainment and multimedia content via high-speed GPRS technology.

3G systems

While the intention of the International Telecommunications Union (ITU) was to establish a truly global system, commercial factors prevented this from happening. There are common features though, in the sense that spread spectrum (like in IS-95) is a dominant access scheme for multiple users. It was again the drive to higher data rates, in general 384 kbit/s and up to 2 Mbit/s in indoor environments, that was the main goal (Etoh 2005). At the same time, new frequency bands around 2 GHz were released for the new service.

CDMA2000. CDMA2000 is the North American version of the 3G CDMA network. It differs from W-CDMA mainly in the network architecture. There are some differences in the frequency allocations and the chiprate (Vanghi et al. 2004).

W-CDMA (Universal Mobile Telecommunications System, UMTS). The global standard for third generation (3G) wireless communications, IMT-2000, is a family of 3G standards, which includes W-CDMA and UMTS. When combined, W-CDMA and UMTS are referred to as UTRA. W-CDMA is the underlying standard and W-CDMA functions as the air interface for UMTS. The specific frequency bands originally defined are 1,885–2,025 MHz and 2,110–2,200 MHz for uplink (from user to base station) and downlink, respectively. W-CDMA uses a pair of 5-MHz channels, one in the 1,900 MHz range for uplink and one in the 2,100 MHz range for downlink. In contrast, CDMA-2000 uses one or more arbitrary 1.25 MHz channels for each direction of transmission. Thus, W-CDMA has a wider bandwidth requirement. W-CDMA supports up to 2 Mbit/s data transfer rates, although typical users can expect performance of around 64 kbit/s in a heavily-loaded real-world system. However, this is still much greater than the 14.4 kbit/s of a single GSM error-corrected data channel or multiple 14.4 kbit/s channels in HSCSD, and offers the prospect of practical inexpensive access to the World Wide Web on a mobile device and general use of a Multimedia Messaging Service (MMS).

Two different modes are in use: frequency division duplex (FDD), where the uplink and downlink communications are separated in different frequency bands, and time division duplex (TDD), where the same frequencies are used both ways, but separated in different time slots. This allows for the further advantage of having asymmetric transmission, such as using relatively more timeslots for downlink than uplink. The following frequencies have been allocated to W-CDMA:

- FDD Mode: Uplink 1,920–1,980 MHz and 1,850–1,910 MHz; Downlink 2,110–2,170 MHz and 1,930–1,990 MHz;
- TDD Mode: Downlink and Uplink 1,900–1,920 and 2,010–2,025 MHz; and Downlink and Uplink 1,850–1,910 and 1,930–1,990 MHz.

The most commonly applied access mode is FDD. Users are separated by different codes, a high data rate modulation on top of the information. This means that the actual bandwidth is much higher than needed for the basic information rates; in the present system around 5 MHz. The basic rate for the codes is called the chiprate, and for W-CDMA the chiprate is 3.84 Mbit/s. The 60 MHz FDD frequency bands are divided into 5 MHz bands, which may be used by one operator or by different operators, depending on the regulations in the specific region or country. This fact should be considered when evaluating the total radiation from base station antennas.

A requirement for the correct use of a CDMA system is that signals from all users arrive at the base station with the same power level, otherwise interference between the users will render it useless. Thus, strict and fast power control is enforced at a rate of 1,500 Hz with steps as small as 1 dB. This means that the power radiated from a handset (and thus the SAR) will have a 1,500 Hz component. An additional factor contributing to power fluctuations (or discrete frequencies) is the non-constant-envelope feature. In contrast to GSM, the high data rates are seen in the spectrum of the power with a spectral peak at 3.84 MHz and a continuous spectrum below that. An example is shown in Fig. 1.

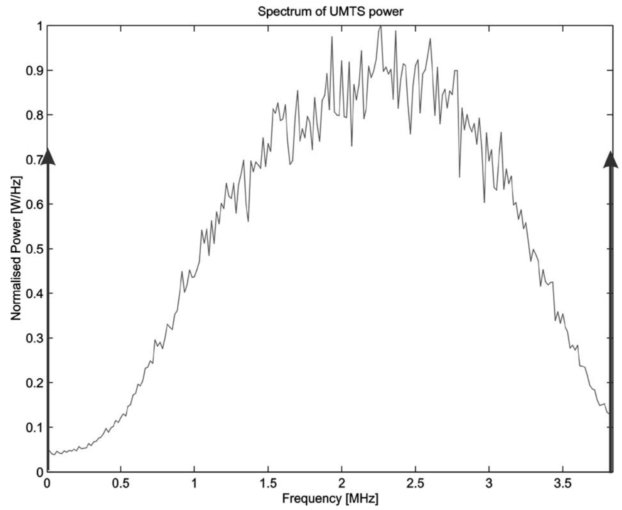

Fig. 1. A typical spectrum of the power variations in a W-CDMA handset signal (Bach Andersen et al. 2001).

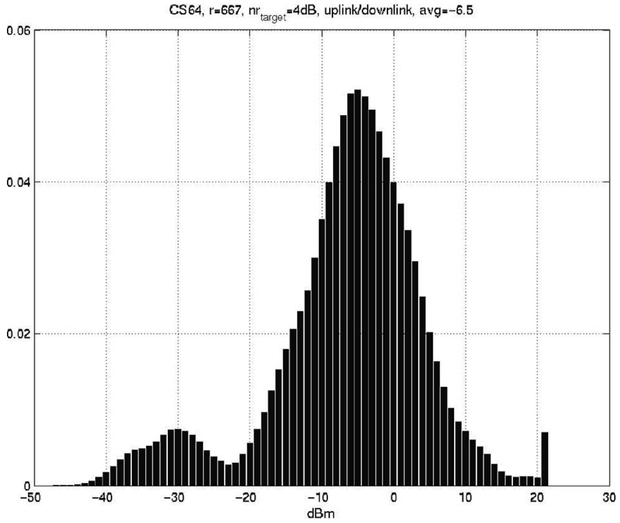

Fig. 2. Distribution of handset power in a small urban cell for a W-CDMA system (Bach Andersen et al. 2001).

The maximum power radiated from a handset is governed by different classes. The most common is class 4 with a maximum radiated mean power of 125 mW: note that this is a factor of 2 less than the maximum mean power for GSM. In practice the power radiated may be much less if the distance to the base station is small, as in GSM. Fig. 2 shows a distribution of handset powers for a small urban cell, with a mean value of −6 dBm (6 dB below 1 mW, i.e., 0.25 mW). For a larger rural cell a much higher fraction of the powers would be near the maximum value. Nevertheless, the SARs are expected to fall within the ICNIRP basic restrictions. However, more information may be needed for the different chiprates and the higher rates of power fluctuations associated with the automatic power level control feature (APC).

Another reason for the small powers is the so-called processing gain, which is equal to the ratio between the system bandwidth and the information bandwidth. For speech this ratio is large, for heavy data transmission it may be close to one, and the benefit disappears.

HSDPA. Compared to fixed networks the data rate of 384 kbit/s is rather small, so efforts have been made to increase the maximum data rates of W-CDMA by using adaptive modulation and coding under favorable conditions. Also, the burst natures of packet transmissions are utilized so other users can utilize the channel when one user has a pause. The system is called High Speed Downlink Packet Access (HSDPA) and allows transmission of up to 14 Mbit/s over a 5 MHz channel bandwidth. Naturally, this gives even higher rate power fluctuations than basic W-CDMA.

Beyond 3G

The quest for higher data rates is continuing, and the International Telecommunications Union (ITU) has set as goals 100 Mbit/s for general environments and 1 Gbit/s (1,000 Mbit/s) for indoors. This would require higher bandwidths and higher carrier frequencies, as well as advanced antenna technologies and adaptive modulations, as for 3G. It is difficult to predict exactly which technologies and access schemes will be applied, but one likely candidate is the Orthogonal Frequency Division Multiplexing (OFDM) system. OFDM is essentially a multi-carrier system where the wide bandwidth is divided into a large number of narrowband carriers, and thus avoids the inter-symbol-interference characteristic of wide bandwidth systems. Like the other systems mentioned, this suffers from power fluctuations, often stated as a peak-to-mean ratio. The carrier frequencies will typically be below 6 GHz, since it is difficult to accept the Doppler frequencies for higher carrier frequencies (Etoh 2005).

In mobile telephony the development is moving from transmitting voice mostly to transmitting voice and data services built in, whereas in computing the developmental trend is from transmitting data to transmitting data and voice services built in. Both developments would likely converge to bring about new applications and technological challenges. It is becoming increasingly apparent that the major cellular mobile systems will evolve into a 4G environment with higher bandwidth, shorter latency, and all-IP networks. In all cases, existing air interfaces will be replaced using Orthogonal Frequency Division Multiple Access (OFDMA) for the downlink and OFDM for the uplink, similar to WiMAX (see later text). A combination of smart antenna technologies and Scalable OFDM (SOFDMA) will enhance the effective spectral efficiency through spectrum reuse and smart networking schemes. The use of frequency domain techniques will enable designs using Multiple-Input Multiple-Output (MIMO) algorithms for more effective systems.

There are millimeter frequencies under consideration for various specific applications, but no mobile systems at the present time.

Non-Mobile Wireless Communications

Wireless LANs

Simultaneous with cellular mobile communication, significant developments have taken place in the area of Wireless Local Area Networks (WLAN), with rather short-range communication between an access point (a base station) and one or several users. The difference from the various generations of cellular mobile systems discussed above is the lack of overall network infrastructure, mobility, and handover between access points. WLANs are ad-hoc systems set up in homes, hotels, cafes, office buildings, airports, city parks, and corporate and university campuses as hotspots, and usually are

Table 1. The main features of the different extensions of the IEEE 802.11 Standard.

Standard	Description	Frequency (GHz)	Data rate (Mbit/s)	Year
IEEE 802.11	Original standard, exploiting the ISM band	2.4	2	1997
IEEE 802.11b	Enhanced data rate in the ISM band	2.4	11	1999
IEEE 802.11a	Fastest version of the standard, exploiting the UNII band	5.7	54	1999
IEEE 802.11g	Same 802.11a speed, but in the ISM band	2.4	54	2003
IEEE 802.11h	Modification of 802.11a to ensure usability in Europe	5.7	54	2003

Table 2. Assigned frequency bands and allowed maximum radiated powers.

Frequency band (MHz)	USA (FCC)		Europe (CEPT)	
	Radiated power (dBm)	EIRP (dBm)	Radiated power	EIRP (dBm)
2,400–2,483.5	30	36	—	20
5,150–5,250	17	23	—	23
5,250–5,350	24	30	—	23
5,470–5,725	24	30	—	30
5,725–5,850	30	36	Unavailable frequency band	

connected to the Internet through the backbone connection of the access point, as an extension to wired LANs. It allows mobility of terminals in a well-defined area. As the popularity of portable devices such as laptop computers and personal digital assistants (PDAs) grows, WLAN has become the communication infrastructure of choice.

WLANs have been standardized through the Institute of Electrical and Electronic Engineers (IEEE) Standard Organization (IEEE 802.11 Standard, IEEE 1999). The IEEE C standard is a complex family of standards, allowing operation at higher speeds and in additional frequency bands (Riezenman 2002). The main features of the different extensions of the IEEE 802.11 Standard, commonly identified by letters of the alphabet, are summarized in Table 1.

The trademark Wi-Fi (acronym stands for Wireless Fidelity) was originally used to certify IEEE 802.11b compliant devices to ensure their interoperability. However, it is now used by the Wi-Fi Alliance to certify all IEEE 802.11 compliant devices, independent of the particular standard extension used (a, b, g, or h) (Ferro and Potortì 2005). Note that the ISM (Industrial, Scientific, and Medical) bands are used for license free communications, in contrast to the prices paid for the use of the 3G spectrum in most countries. This is also the case for the popular Bluetooth (http://www.bluetooth.com/) short-range cable replacement system, operating in the 2.4 GHz band.

The IEEE 802.11 standard does not impose any limit on the maximum radiated power, because such limits, together with the available frequency bands, are decided by different regulatory bodies, such as the FCC (Federal Communications Commission 2005) in the U.S. and CEPT (European Conference of Postal and Telecommunications Administrations 2002, 2004) in Europe. The assigned frequency bands and allowed maximum radiated powers [also expressed in terms of Effective Isotropically Radiated Power (EIRP) for USA and Europe] are summarized in Table 2. The majority of Wi-Fi systems available on the market are IEEE 802.11b devices operating with a maximum EIRP of 100 mW (20 dBm). The modulation schemes employed by WLANs include frequency hopping and direct sequence spread spectrum in the 2.4 GHz band and OFDM in the 5 GHz band. WLAN transmissions are intermittent, which leads to power fluctuations at the data rates or higher. Therefore, time-averaged powers are lower and depend on the quantity of data being transmitted.

WiMAX

The name WiMAX was introduced in 2001 as the air interface technology for wireless data transmission over long distances. It is the acronym for Worldwide Interoperability for Microwave Access and is based on the IEEE 802.16 standard. It provides connectivity from point-to-point links to full cellular mobile type access. It enables, for example, wireless browsing of the Internet on a laptop computer. WiMAX provides the technology for delivery of last mile broadband wireless access as an alternative to cable. In many ways, it is closer to Wi-Fi than 3G cellular mobile technologies.

The 802.16d and 16e standards are the most widely employed WiMAX standards, covering the 2 to 11 GHz frequency range (IEEE 2005). IEEE 802.16e uses the SOFDMA instead of the OFDM version with 256 subchannels in 802.16d. The updated version 802.16e also makes use of multiple antenna support through MIMO

Table 3. Representative products.

Product category	Product category
Access point	Keyboard and mouse
Audio and visual	Medical
Automotive	Mobile phone
Component	Music
Gaming	Office equipment
GPS	Personal computer
Handheld	Printer
Headset	Services and tools
Home environment	Unique products

communication and signal processing technology. There is no globally agreed spectrum for WiMAX although economy of scale is driving it toward 2.3 GHz, 2.5 GHz and 3.5 GHz, for mobile phones and laptop computers. The typical channel width is between 3.5 MHz and 10 MHz. Under ideal operating conditions, symmetrical uplink and downlink speeds of 70 Mbit/s could be achieved. However, the speeds deliverable in practice are about 10 Mbit/s at 10 km. One of the significant advantages of WiMAX is spectral efficiency. Thus, exposure to RF fields is expected to be at or below exposure limits in 3G applications.

Bluetooth

Short-range wireless connectivity is achieved using the Bluetooth cable replacement system, which operates around 2.45 GHz. Devices incorporating Bluetooth wireless technology include mobile phone headsets and computer accessories such as printers, keyboards, mice and PDAs. This technology is being increasingly used in business and in the home. The Bluetooth Specialist Interest Group (Bluetooth SIG), which is a trade association, lists over 500 products using Bluetooth technology; some representative products are given in Table 3.

The technology can support small networks, known as piconets, with a point-to-multipoint configuration. The communication is normally over very short ranges, from a few meters to tens of meters. Devices for these applications have very low output powers of only a few mW, about one hundred times lower than mobile phones. Power requirements are given as power levels at the antenna connector and three power classes are defined (see Table 4). The nominal output power of devices in Class 2 or 3 is about 1 mW, although reduction of power is possible through optional power control. Power control down to −4 dBm is mandatory for Class 1 devices and the step size is in the range 2–8 dB. Control to lower powers for optimizing power consumption and minimizing overall interference is optional for Class 1 devices. Power control is also an option for Class 2 and 3 devices. A lower power limit of less than −30 dBm is suggested for all power classes but is not mandatory. Bluetooth devices in these classes are intended to communicate over short ranges. The low power outputs will give rise to correspondingly low exposures, well below guideline levels.

Table 5. The DECT standard.

DECT parameters	Range
Frequency band	1,880–1,900 MHz
Carrier spacing	1.728 MHz
Modulation	GFSK
Radio access	FDMA TDMA TDD
Number of time slots	12
Number of carriers	10
Total duplex channels	120
Bit rate	1.15 Mbit/s
Maximum data rate	552 kbit/s
Frame duration	10 ms
Error detection	CRC
Speech coding	32 kbit/s ADPCM
Channel assignment	Dynamic channel selection
Mobility speed	20 km/h
Peak power (average)	250 mW
Average power	10 mW
DECT range	300 m

DECT

Digital Enhanced Cordless Telecommunication (DECT) is a digital technology which originated in Europe, and is now being adopted worldwide. DECT technology is a flexible digital cordless access system for communications in home, office and public environments. DECT is mainly known for high quality voice communications, but it has widespread applications like Internet access and internetworking with other fixed or wireless services. Indeed, devices with DECT-based transmission have been introduced for on-demand services. The DECT standard uses a radio spectrum for wireless communication in the 1,880 to 1,900 MHz band

Table 4. Power requirements.

Item	Power Class 1	Power Class 2	Power Class 3
Maximum output power (P_{max})	100 mW (20 dBm)	2.5 mW (4 dBm)	1 mW (0 dBm)
Nominal output power	n/a	1 mW (0 dBm)	n/a
Minimum output power at maximum power setting	1 mW (0 dBm)	0.25 mW (−6 dBm)	n/a
Range of mandatory power control	−4 dBm to P_{max}	n/a	n/a

using Gaussian Frequency Shift Keying (GFSK) modulation (Table 5). DECT is designed to be compatible with any type of telecommunication network. DECT applications include residential, Public Switched Telephone Network (PSTN), Integrated Services Digital Network (ISDN), GSM, voice, fax, modem, e-mail, Internet, and others.

A simple DECT system consists of a fixed part commonly known as a base set and a portable part known as a cordless handset, which is common in a household system capable of making a voice communication. The DECT base set is continuously transmitting on at least one channel to provide a beacon for DECT phones. The handsets in the coverage area of the base set will verify their identity and lock on to the base set. This transmission can be part of the active transmission or a dummy bearer transmission. The base set's beacon transmission carries broadcast information in multi-frame, multiplexed structure on base set identity, system capabilities, Radio Fixed Parts (RFP) status and paging information for incoming call set-up. The DECT band is divided into 10 equal sub-bands. Within a frequency channel, transmit and receive channels are separated by time slots through a TDMA scheme.

RFID technologies

Radio Frequency Identification (RFID) technology is being applied to a variety of applications such as logistics and inventory management in many industries including retail, manufacturing, aerospace, automotive, pharmaceutical, transportation, medical/healthcare, and information technology. A major incentive is to use the wireless automatic identification technology to streamline enterprise operations.

Advantages of RFID compared to other automatic identification systems are that they are stable, mobile, non-contact, rewritable, in small and thin shapes, ambient temperature resistant, and capable of coating, multiple-reading, and individual identification.

RFID systems consist of RF tags and RF readers or interrogators (Finkenzeller 1999). RF tags are attached or implanted in the objects to be detected or tracked by RF readers. Active RF tags with batteries radiate higher-strength RF signals, which are mainly used in large spaces, e.g., factories or container parks. Passive RF tags are transponders which have no battery but operate with RF power transmitted from an RF reader without any contact. The convenience of passive RF tag systems has rendered it the technology of choice for applications that require large numbers of IDs or lower cost compared to active RF tag systems. Therefore, the description is focused on the passive RF tag systems.

Many types of passive RF tags have been developed. The card type RF tags are very popular in automatic ticket gates, in railway stations for example. Other types include the heat-resistant type for dry cleaning facilities, the glass-case implantable type for animals, outdoor types for transportation containers, and the adhesion-sheet type for apparels and for books in libraries.

Tunnel or gate type RF readers have been developed for use in manufacturing facilities. Gate types are also used for Electronic Article Surveillance (EAS) in retail stores and libraries. Hand-held type RF readers are used in cases where long-distance communication is not required, e.g., logistic, inventory, and customer management. The panel type RF readers are installed in counters in libraries or checkouts in cafeterias for objects embedded with an RF tag.

Most RFID systems operate at frequencies from 100 kHz to 2.45 GHz or higher (e.g., 5.8 GHz). Different wireless communication methods are used for the lower and higher frequencies:

1. Inductive coupling is used at 13.56 MHz or lower frequencies. The EMF from a coil or coils in an RF reader couples with a loop or coil antenna in the RF tag. The received RF energy changes the load of the antenna in the RF tag and the RF reader senses this change. This method is most suited for relatively short communication ranges (up to 1 m) and it is capable of fast processing with multi-reading and anti-collision functions. The capacity of this method would deteriorate if an RF tag is attached to a metal object;
2. Propagation coupling is used at higher frequencies, especially around 1 GHz (referred to as UHF) and 2.45 GHz. In operation, the RF reader transmits an EM wave. The RF tag captures the RF energy of the EM wave from the RF reader. The RF tag generates and emits an EM wave, using the absorbed energy, which is received by the RF reader. This method affords a longer communication range (1–5 m). However, the communication range can deteriorate due to water/vapor absorption and electromagnetic interference (EMI) from other equipment.

The specifications of RFID have been standardized internationally in several International Organization for Standardization (ISO) and ISO/International Electrotechnical Commission (IEC) documents (ISO 11785, ISO 14223-1, ISO/IEC 10536-2, ISO/IEC 1443-2, -3, -4, ISO/IEC 15693-2, -3, ISO 10374, ISO/IEC 18000) (ISO 2007). Electromagnetic fields from RFID devices used in the public environment are generally lower than the ICNIRP guidelines. Electromagnetic fields in the proximity of RF reader antennas can however be locally higher than the ICNIRP reference level. For example, the operation level of the magnetic field for the card type RF tag is specified from 0.15–5 A m^{-1} at 13.56 MHz in ISO/IEC 15693-2, while the corresponding ICNIRP reference level at 13.56 MHz is 0.073 A m^{-1} for the general public. Because EMFs from RFID rapidly decrease with distance and are emitted intermittently, spatial and temporal averaging should be applied when evaluating the EM exposure. Note that a detailed numerical simulation has shown that the induced current density in a human body in a gate type RF reader (EAS) is lower than the ICNIRP basic restriction (Gandhi and Kang 2001). The impact of the inductive coupling type RFID system as well as EAS and security systems have been described in another statement (ICNIRP 2004a).

The output power of RF readers ranges from several 100 mW to several watts, which is significantly lower than that of a typical base station antenna but higher than that of a cellular phone. Local SAR evaluation may be required for comparison with the ICNIRP basic restriction if an RF reader is located in proximity to a human body.

As more RFID systems are implemented in various business processes, human exposure to EMFs due to RFID will increase significantly. Exposure levels from each device are very small while the number of simultaneous exposures can be very large and the locations of the sources are unknown. This exposure scenario is very different from many other RF equipment. Practical methods for evaluation of human-body exposure to EMFs from RFID devices may therefore be necessary.

UWB technology

Ultra-wide-band (UWB) technology is mainly used in imaging, sensing, and communication systems (Kaiser et al. 2007). Examples of imaging and sensing systems include vehicular radar, ground penetrating radars (GPRs), through-wall sensing, and medical imaging, while communications systems include hand-held transceivers, sensor networks, Wireless Personal Area Networks (WPAN), etc.

The FCC defines a UWB device as any device where the fractional bandwidth is greater than 0.20 or occupies 0.5 GHz of spectrum (FCC 2002). The effect of this definition is that UWB systems with a center frequency greater than 2.5 GHz need to have a −10 dB bandwidth of at least 500 MHz, while UWB systems operating with a center frequency below 2.5 GHz need to have a fractional bandwidth of at least 0.20. FCC based its definition of an UWB device on the −10 dB bandwidth, rather than the −20 dB bandwidth used earlier, because UWB devices operate so close to the noise floor that in many cases it may not be possible to measure the −20 dB bandwidth. FCC also proposed that the bandwidth be determined using the antenna that is designed to be used with the UWB device.

Specifically, for UWB applications, FCC allows the use of the frequency range below 0.96 GHz, between 1.99 and 10.6 GHz, and between 22 and 29 GHz in the U.S. In particular, FCC has stipulated the following definitions: low frequency imaging systems are those whose −10 dB bandwidth is contained below 960 MHz; mid-frequency imaging, consisting of through-wall imaging systems and surveillance systems, that operate with the −10 dB bandwidth within the frequency band 1,990–10,600 MHz; and high frequency imaging systems, equipment that operates exclusively indoors, and hand-held UWB devices that may operate anywhere, including outdoors and for peer-to-peer applications, that operate with a −10 dB bandwidth within the frequency band of 3,100–10,600 MHz. Vehicular radar systems operate with the −10 dB bandwidth within the frequency band of 22–29 GHz and with a carrier frequency greater than 24.075 GHz.

The average emission limits for UWB systems, in terms of EIRP measured in dBm with 1 MHz resolution bandwidth, are given in Table 6. It must be noted that the highest value in the table is −41.3 dBm/MHz, which corresponds to 75 nW/MHz.

Like most UWB systems, the average emissions from vehicular radar systems in driver assistance systems

Table 6. The average emission limits for UWB systems.

Frequency band (MHz)	Imaging below 960 MHz	Imaging mid frequency	Imaging high frequency	Indoor applications	Hand held including outdoor	Vehicular radar
0.009–960	−41.3	−41.3	−41.3	−41.3	−41.3	−41.3
960–1,610	−65.3	−53.3	−65.3	−75.3	−75.3	−75.3
1,610–1,990	−53.3	−51.3	−53.3	−53.3	−63.3	−61.3
1,990–3,100	−51.3	−41.3	−51.3	−51.3	−61.3	−61.3
3,100–10,600	−51.3	−41.3	−41.3	−41.3	−41.3	−61.3
10,600–22,000	−51.3	−51.3	−51.3	−51.3	−61.3	−61.3
22,000–29,000	−51.3	−51.3	−51.3	−51.3	−61.3	−41.3
Above 29,000	−51.3	−51.3	−51.3	−51.3	−61.3	−51.3

are low, but widespread adoption and associated high traffic density in many urban environments could potentially lead to an increased ambient RF power level.

With regard to imaging systems, UWB signals are appealing due to their low probability of interception, non-interfering signal waveform, precision ranging, and localization (Taylor 1995). In this application, UWB radar has the possibility to probe the motion of the internal organs of the human body with a remote non-contact approach (McEwan 1994). For example, an UWB radar was able to detect, non-invasively, the movements of the heart wall. In practice, vocal cords, vessels, bowels, heart, lung, chest, bladder, and fetus, and any body part of adequate size can be monitored by an UWB radar. Recently, UWB systems have also been used for breast tumor detection (Fear et al. 2002).

As for communication systems, UWB communication is a transmission technology promising less complex hardware. Transmission takes place in baseband, i.e., no hardware is required for mixers and RF oscillators, as would be necessary in narrowband systems. In this area UWB signals are used for applications requiring either high bit rates over short ranges or low bit rates over medium-to-long ranges (Di Benedetto and Giancola 2004). The high bit rate/short range case includes WPAN for multimedia traffic, cable replacement such as wireless USB, and wearable devices, e.g., wireless headphones. The low bit rate/medium-to-long range case applies to long-range sensor networks such as indoor/outdoor distributed surveillance systems, non-real-time data applications, e.g., e-mail and instant messaging, and in general all data transfers compatible with a transmission rate in the order of 1 Mbit/s over several tens of meters.

In UWB systems, a radiating antenna could be placed very close to the human body (hand-held radio, wireless headphones, etc.) at the same time another radiating antenna could be broadcasting. Thus, in principle, both near-field and far-field human exposure can take place. Since the fields radiated by UWB systems are broadband or multiple frequency, according to ICNIRP guidelines, the exposure assessment is based on the summation formula in the frequency range of UWB systems, where the relevant dosimetric parameter is the SAR.

Finally, an aspect of UWB to be taken into account is that it is a form of broadband EM radiation, which can increase the level of noise floor for radiocommunication services or block receiver front ends. Communication systems such as cellular phones, WLANs, etc., often employ adaptive power control. When such systems find the quality of service is degrading, they ramp up their transmitter power to compensate. Thus, it is conceivable that an indirect consequence of UWB systems could be a rise in average SAR as cellular phones, etc., are caused to use increased powers.

Digital video broadcasting

Digital video broadcasting (DVB) systems transmit programs through different techniques, such as satellite (DVB-S), terrestrial antennas (DVB-T), and terrestrial television for hand-helds (DVB-H). It replaces analog broadcasting with digital systems. In the case of DVB-T, the conventional analog signals characterized by amplitude modulation are replaced with integrated digital pulses and repetitive transients modulations similar to WLAN spread over many individual frequencies.

The modulation schemes used vary with different services; for example, DVB-S uses Quadrature Phase Shift Keying (QPSK), and DVB-T uses QPSK in combination with OFDM and hierarchical modulation to allow more efficient use of available frequencies. Therefore, frequencies for conventional analog broadcasting are made available for additional broadcasting and other services. Indeed, DVB-H mobile TV has become a reality in some locations along with the availability of hand-held receivers.

Telemedicine

Telemedicine involves the use of wireless communication technologies for medical diagnosis, treatment, and patient care. Current aims of telemedicine are to provide remote access to medically relevant data and expert-based health care to remote sites through modem telecommunication and information technologies. At present, the number of telemedicine sites and variety of clinical applications are increasing. Potentially, telemedicine could involve large numbers of people with body-worn sensors and transmitters. Present development involves a combination of some of the wireless communication technologies (e.g., GSM, WLAN, WPAN, and Bluetooth) to acquire physiological data, monitor patients and manage diseases in a cost-effective manner. This may be done by applying sensors to the patient and sampling them on demand or on a regular basis within hospitals using WLAN or after discharge via mobile telecommunication in their homes. Thus, it could take place either in real time or the data could be stored and then forwarded for subsequent examination. In contrast to the conventional use of medical devices, the wireless sensors are body-worn and can be used intermittently over a long period of time for large numbers of people (e.g., patients).

Other Non-Communication Uses

Ground penetrating radar

Ground penetrating radar (GPR), surface penetrating radar, or subsurface radar are all names that refer to the same technique used to locate objects and (or) interfaces situated in a region not penetrable by the eyes. GPR is similar to the conventional free-space radar used to detect backscattered radiation from a target to evaluate its position and velocity. GPR systems are made of a transmitting part (source and antenna) which transmits EM power to the region under investigation, and a receiving part which collects the reflected power and, through signal processing techniques, elaborates it to extract the requested information. The presence of the interface between the air where the antenna is located and the region under investigation, and its influence on the reflected signal, are the fundamental differences between GPR and conventional radar.

GPR is used as an alternative technique to seismic methods, sonar, or other specific techniques, its main advantage over those techniques being the general purpose principles of operation and the use of remote, non-contacting transducers to radiate and receive the EM energy. Moreover, it has the highest resolution in subsurface imaging of any geophysical method, approaching centimeters under the right conditions (Leon et al. 1994).

The design of GPR systems is largely applications-oriented and the overall design philosophy, as well as the details, depends on the target type and the background medium. The bandwidth of the received signal is directly linked to the number of features (geological strata or buried objects) that will be resolved. Since penetration depth decreases with frequency, usually GPR systems work with frequencies less than 1 GHz. In long-range investigations, frequencies as low as a few tens of MHz have also been used. On the other hand, resolution is higher for higher frequencies. Consequently, low frequency antennas (10–120 MHz) radiate long wavelength EMFs that can penetrate up to 50 m or more in certain conditions, but are capable of resolving only very large subsurface features. In contrast, the penetration depth of a 900 MHz EMF is about 1 m, and often less in typical ground conditions, but the generated reflections can resolve features down to a few centimeters in diameter (Carin 2001; Daniels 1996).

Usually, GPR systems use very narrow pulses (e.g., pulse duration 1 ns) with low mean power (e.g., peak pulse power 50 W, mean pulse power 50 mW) and the received power is at least one order of magnitude below the transmitted one. It should be noted that GPR systems, on the basis of the FCC classification reported in FCC (2002), belong to the imaging system class; as a consequence, their transmitted power should conform to Table 6, at least in the U.S.

Since antenna frequency, radiation pattern and radiated power strongly depend on the application, it is very difficult to define general exposure conditions with reference to GPR systems as a whole. In particular, to evaluate the operator exposure to the GPR EMF, it must be considered that the operator will be in the near-field of the transmitting antenna, so that the exposure evaluation should be conducted considering the SAR according to the formula for multiple-frequency exposure (ICNIRP 1998).

Induction heating (IH) cooking hobs

Recently, domestic induction heating (IH) hobs (stoves or cook tops) have gained popularity in Japan and European countries, even though they were introduced into the market some time ago.

When electrically-conducting materials are immersed in an alternating magnetic field, they can be heated as a result of eddy current losses (Joule effect). This heating technique has been applied mainly for industrial purposes, such as in metal furnaces. Induction heating is also used as a cooking tool. Aside from high-power (5–10 kW) equipment for commercial catering use, low-power (1–3 kW) IH hobs are produced as domestic kitchen appliances. The advantages of IH hobs include cleaner operation and the possibility of reduced fire hazards. As many as 300,000 units per year are projected for sales in Europe alone (Gaspard 1998).

IH hobs operate at the intermediate frequencies of 20 to 50 kHz to take advantage of efficient energy usage and to avoid the audible noise created by cooking utensils (pots, pans, and other containers) made of cast iron and stainless steel having high magnetic permeability (ICNIRP 2003; Litvak et al. 2002; Wennberg 2001). More recent developments in IH hobs have enabled the use of aluminum cookware at higher frequencies (over 60 kHz) (Suzuki and Taki 2005).

The strength of the electric field in the vicinity of IH hobs is much lower (a few tens of volts per meter at a distance of 10 cm from the stove edge) than the strength of the magnetic field (Stuchly and Lecuyer 1987). A typical waveform of the magnetic field is shown in Fig. 3. It consists of a carrier wave (26.1 kHz in the example), amplitude-modulated at a frequency of 100 Hz (for 50 Hz power) or 120 Hz (for 60 Hz power). In general, the harmonic content is significantly higher, and the operating frequency depends on the output power setting. For a given power setting, the magnetic field strengths around the hob depend on the material and size of the utensils. The magnetic fields decrease rapidly with distance, and are characterized by the magnetic field distributions of a magnetic dipole or a current loop (Yamazaki et al. 2004).

In practice, the magnetic field strength experienced by the user depends on the user's position, i.e., where the operator is likely to stand (IEC 2005), or whether a person is leaning over the top of the hob or not (Stuchly

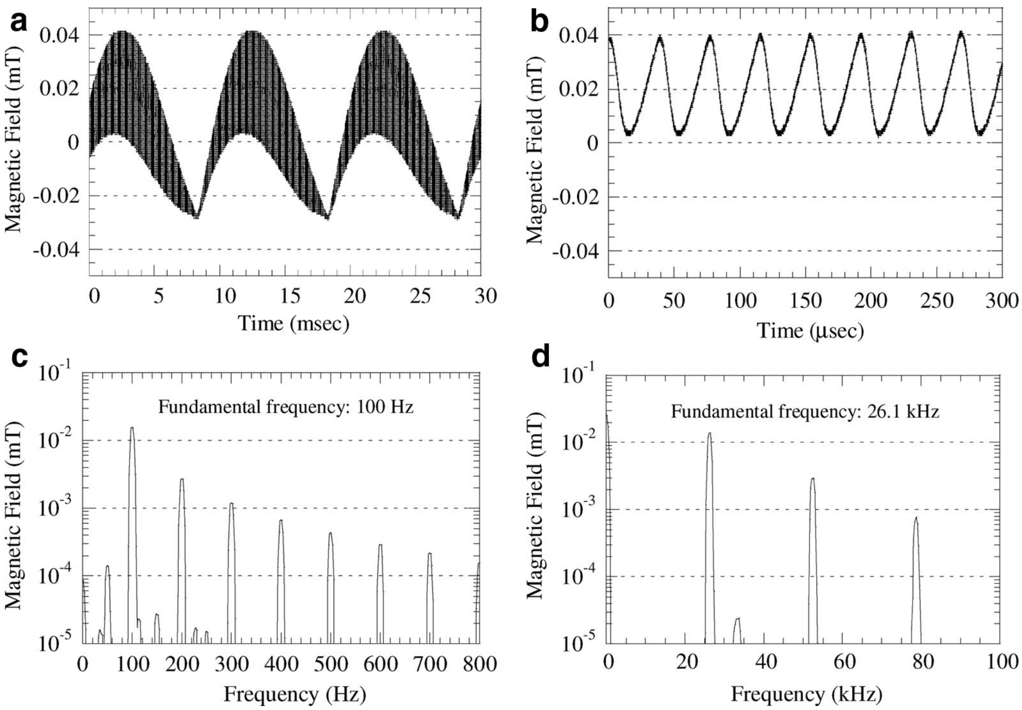

Fig. 3. Example of measured magnetic field generated by IH hob: (a) and (b) waveforms of magnetic field; (c) and (d) frequency characteristics.

and Lecuyer 1987). Numerical calculations of induced current showed that only parts of the body of the operator (in particular, the hands) are exposed to magnetic fields above the reference level (Burais 1998). Other reports indicate that the maximum induced currents averaged over 1 cm^2 perpendicular to the current direction are lower than the ICNIRP's basic restrictions, while the maximum magnetic field may exceed the reference levels (Suzuki and Taki 2005).

Note that for complex multiple-frequency fields, with complex non-sinusoidal waveforms such as those generated by the IH hob, ICNIRP guidelines provide a summation procedure for the various frequency components. In addition, the guidelines provide an alternative method of assessment based on a weighting function (ICNIRP 2002).

Medical MRI equipment

Magnetic resonance imaging (MRI) is an imaging technique that employs strong DC magnetic fields, rapidly switched gradient magnetic fields, and RF EMFs. It can image soft tissues—unobstructed by bone—with enhanced contrast, compared to x-ray computed tomography. Moreover, the ability to provide images in numerous freely selectable planes in terms of number and orientation without requiring the repositioning of the patient, has rendered MRI a very effective and important tool for soft tissue medical imaging. Indeed, it has become the radiological modality of choice for a great number of diagnostic procedures.

Because of its design, a conventional MRI system operating at 1.0 T is unlikely to expose radiological staff to field levels in excess of basic restrictions. Some newer open 0.7 T MRI systems allow medical personnel to perform interventional procedures on patients under MRI guidance. Despite this success the diagnostic possibilities are far from being exhausted. Higher static fields and consequently higher RF fields offer new possibilities of imaging target molecules. Therefore, the devices need to be classified in conventional devices up to 2 T, in devices which may need patient monitoring (>2 T up to 4 T) and devices where applications need to be governed by ethical risk/benefit estimations (>4 T). Depending on the class, it is no longer assured that basic requirements are met during occupational exposure, in particular concerning partial-body exposure of hands, heads or torsos. It is possible that hands, heads or torsos exposed under such conditions may exceed current safety guidelines, especially for gradient fields (ICNIRP 2004b). The gradient field is lower than the static magnetic field but it is pulsed rapidly in time and is a function of the imaging technique and design of the MRI system. It is important to note that the time rate of change of the gradient magnetic field is closely related to the strength of the electric field induced inside the body.

Recently, the demand for increased spatial resolution and high signal-to-noise ratio (SNR) from MRI instruments and imaging target molecules has prompted the use of higher and higher magnetic fields (as high as 11 T). This development intrinsically requires higher RFs for MRI, which, in principle, can not only augment the amount of RF power deposition inside the patient's body, but also increase the EMF exposure for workers using MRI equipment in the hospital environment and workers employed in supporting, servicing, developing and manufacturing this equipment. There has been particular interest in the exposure of the head, torso, and limbs to the gradient fields, which may be substantial under certain operational environments. Some recent investigations have shown that exposure to the stray magnetic field of whole-body 7 T MRI may affect neurobehavioral performance such as visual perception and hand-eye coordination, but there was no effect on working memory (Glover et al. 2007). The effect appears to depend on the dynamic field component generated by head movements (~150–300 mT/s) and not on the static magnetic field.

In the near future it may be necessary to classify MRI systems, such as classifying conventional systems as scanners with magnetic fields up to 2 T, scanners which need patient monitoring (>2 T up to 4 T), and scanners where their application needs to be governed by ethical risk/benefit estimations (>4 T). Depending on the class and use, the basic restrictions may not be met during occupational exposures, especially with regard to partial-body exposure of hands, heads, or torsos.

Electrified trains and magnetically levitated vehicles (MAGLEVs)

High-speed ground transport systems for intercity passenger and long distance travel have been in active development ever since limitations of existing transport modes became apparent. At present, several of the high-speed electric transportation systems (including the electrified train and the magnetically levitated vehicle) have been put into commercial operation in various parts of the world. These high-speed electric transportation systems generate complex electric and magnetic fields (EMFs) with various frequency components and have a complex spatial distribution. Because of their unique character, it is difficult to describe the entire environmental electric and magnetic fields from these systems. Therefore, in this section, examples from commercial systems are shown together with a description of the MAGLEV systems as advanced guided ground transportation systems.

Electrified trains (commuter in Japan and TGV in France). In electrified train systems, motors, variable voltage and variable frequency (VVVF) inverters, inductors and other electric devices are the major sources of EMFs. The EMF sources are located under the floor of the train car and generate complex magnetic fields in frequency and in distribution. Moreover, the frequency and distribution of the magnetic field change depending on the vehicle condition such as mode of run (acceleration, constant speed, deceleration, or free running). There are only a few papers describing the distribution of EMFs in electric transportation systems. For example, maximum static magnetic fields in DC electrified trains up to 1.5 mT were shown on the floor above the inductor, but the magnetic field decreased to below 1 mT 20 cm above the floor level (Mizuma and Kato 1999). For the time-varying magnetic field, the maximum density is 50 μT on the floor above a VVVF inverter.

EMFs measured from a commercial TGV vehicle showed that the spatially averaged static magnetic field density inside the car was 54.5 μT and the maximum was 96.2 μT. At 50 to 60 Hz, the average magnetic field was 3.05 μT and the maximum was 16.5 μT (U.S. DOT 1993).

Advanced Guided Ground Transportation Systems

Transrapid—Transrapid is a German MAGLEV system that has been operating in Shanghai, China, since 2003. EMFs measured in prototype vehicles of Transrapid (TR-07) were reported by the U.S. Department of Transportation (U.S. DOT 1993). In TR-07 cars, the average static magnetic field density was 49.8 μT and the maximum was 98.1 μT at a point 175 cm above the floor. Below this height, the static magnetic field exceeded 500 μT and no reliable measurement has been reported at this point. At 50 to 60 Hz, the average magnetic field was 1.6 μT and the maximum was 4.3 μT at a point 12 cm above the floor.

Superconducting MAGLEV—Superconducting MAGLEV systems are currently under development in Japan. While they have been technically approved, these systems have not been put into commercial use. They use superconducting magnets (SCM) for levitation, guidance and propulsion of the vehicle. Therefore, a unique alternating magnetic field in the form of an extremely-low-frequency, intermittent pulsed magnetic field is generated near the tracks by the moving SCMs on the vehicle. A few measurements of MAGLEV have been conducted so far. One report showed that the magnetic fields were between 45 μT (19.3 m from the SCM) and 268 μT (7.5 m from the SCM), outside the vehicle. The frequency of the magnetic field can be up to 6.4 Hz at 500 km h^{-1} (Sasakawa et al. 1998).

HSST Trains—HSST uses resistive magnets for levitation and propulsion. The first commercial line, named "Linimo," has been in operation since March 2005 in Aichi, Japan. There is no report of magnetic field measurement inside a Linimo vehicle. In a predecessor vehicle (H-200 type), the levels of stray magnetic fields were up to 1 μT for the static magnetic field at 10 cm above floor and 100 μT for 10–20 Hz above its VVVF inverter (Mizuma and Kato 1999).

Note that magnetic field levels across the high-speed ground transport systems range over many orders of magnitude (from a few μT to several mT). Specifically for the system mentioned above, the static magnetic fields vary from 1 μT to 1.5 mT, while the AC magnetic fields vary from 1 to 100 μT. A comparable observation was made across the whole range of transportation systems (Muc 2001). It is important to recognize that the extent and distribution of magnetic fields associated with transportation systems vary considerably with location inside or outside the vehicle. Even more important is that the extent and distribution of exposure within the body of the person receiving the exposure varies considerably. Nevertheless, for members of the general public, the range of EMF exposures in existing and developing high speed transportation systems is comparable. However, the exposures may be very different with regard to the frequency contents.

Wireless transport of electrical energy

The concept of wireless-power transmission (WPT) from solar-power satellites (SPS) envisions the generation of electric power by solar energy in space for use on Earth [NRC 2001; Lin 2002; International Scientific Radio Union (URSI) 2007]. The system would involve placing a constellation of solar power satellites in geostationary Earth orbits. Each satellite would provide between 1 and 6 GW of power to the ground, using a 2.45 or 5.8 GHz microwave beam (see Table 7). The power-receiving rectenna on the ground would be a structure measuring 1.0 to 3.4 km in diameter. The higher (5.8 GHz) frequency has been proposed since it has a similar atmospheric transparency. Although, in principle, the higher frequency could involve a reduced size for the transmitting and receiving antennas, as can be seen from Table 7 current designs have opted for larger transmitting antennas and smaller rectenna sites, but a larger power density on the ground to conserve land use, especially in Japan.

A joint effort between the Department of Energy (DOE) and the National Aerospace Administration (NASA) in the U.S. extensively investigated the feasibility of SPS-WPT during 1976–1980. The effort generated a Reference System Concept for Solar Power Satellites. The DOE–NASA Reference System involved placing a constellation of solar power satellites (5 × 10 × 0.5 km deep) in geostationary Earth orbits, each of which would provide 5 GW of power to major cities on the ground, using a 2.45 GHz microwave beam. The Reference System's 60 such satellites were contemplated to deliver a total of 300 GW of generating capacity. The transmitting antenna was about 1 km in diameter. The power-receiving rectenna on the ground was a 10 × 13 km structure.

Japan's Ministry of Economy, Trade and Industry (METI) announced plans to launch research for a solar-power-generation satellite and to begin operating a giant solar power station by 2040. This program is expected to design and operate an SPS-WPT system that would ensure the microwaves would not interrupt cellular mobile telephone and other wireless telecommunications services. The Japan Aerospace Exploration Agency (JAXA) has proposed and evaluated various system configurations for operation at 5.8 GHz (see Table 7). For example, the JAXA-2 model would have a maximum power density of 1,000 W m^{-2} on the ground. A smaller transmitting system would have 260 W m^{-2} at the rectenna site on the ground.

The ICNIRP guidelines are 50 or 10 W m^{-2} for occupationally exposed persons vs. the general public, at either 2.45 or 5.8 GHz (ICNIRP 1998). Note that the average absorption remains fairly stable for frequencies above 2 GHz (Lin and Gandhi 1996; Lin and Bernardi

Table 7. System configurations.

System parameters	NASA	JAXA	JAXA-2
Frequency	2.45 GHz	5.8 GHz	5.8 GHz
Total transmitted power	6.72 GW	1.3 GW	1.3 GW
Maximum power density in beam	22,000 W m^{-2}	630 W m^{-2}	1,140 W m^{-2}
Minimum power density	2,200 W m^{-2}	63 W m^{-2}	114 W m^{-2}
Maximum power/element	185 W	0.95 W	1.7 W
Number of antenna elements	97 million	3,450 million	1,950 million
Element spacing	0.75 λ	0.75 λ	0.75 λ
Transmit antenna size	1.0 km dia	2.6 km dia	1.93 km dia
Amplitude taper	10 dB Gaussian	10 dB Gaussian	10 dB Gaussian
Rectenna size	1.0 km dia	2.0 km dia	2.45 km dia
Max power density above rectenna	230 W m^{-2}	1,800 W m^{-2}	1,000 W m^{-2}

2007), except when the frequency becomes much higher, i.e., at 10 GHz, where the skin effect takes over, the maximum tolerable exposure at 5.8 GHz would be essentially the same as for 2.45 GHz.

As can be seen from Table 7 at the center of the microwave beam, where power densities would be maximum, the proposed power densities range from 23 to 180 mW cm^{-2} (230 to 1,800 W m^{-2}) above the rectenna. At 2.45 GHz, the power density is projected to be 1.0 W m^{-2} at the perimeter of the rectenna. Beyond the perimeter of the rectenna site or 15 km, the side lobe peaks would be less than 0.1 W m^{-2}. Clearly, beyond the perimeter of the rectenna, the potential exposure would be well below that currently permissible to the general public.

The danger of loss of control of highly focused beams may be minimized by tightly tuned phased array techniques and by automatic beam defocusing to disperse the power in the event it occurs. Defocusing would degrade the beam toward a more isotropic radiation pattern, which would give rise to even lower power density on the ground (Osepchuk 1996).

Near the center of the microwave beam, power densities would be greater than the ICNIRP occupational reference levels. Except for maintenance personnel, human exposure would normally not be allowed at this location. In the case of occupationally required presence, protective measures such as glasses, gloves and garments could be used to reduce the exposure to within guideline levels.

CONCLUSION

The cellular mobile communication systems of the future will likely continue to have speech as an important usage as in present systems. However, their functions will be significantly enlarged by additional services such as interactive games, new information, and entertainment services such as mobile video and television. The exposure from future handsets would be lower due to less power output than in present systems but would probably last longer per use.

For non-speech use, the exposure will be even lower due to greater distances of separation from the body, but will probably last longer per use. However, the bandwidth will increase and with it power fluctuations at higher and higher frequencies. It remains an open question whether non-constant power variation with time has any significant biological effect.

The popularity of cellular mobile telephones and the Internet is having a tremendous impact on future wireless communication systems. In addition to voice, Internet-based devices will use the IP and Internet addresses to establish communications between almost anything of interest. This could be communication between machines for control purposes, or communication between sensors in the environment in huge sensor networks for life, safety and environmental monitoring. Since these sensors are of low power and low energy for a battery-driven sensor to work for years at a time, exposure would be very low.

In the case of RFID, wireless communications take place between an active and a passive device. The trend in wireless communication is toward increased use of the electromagnetic spectrum, but in general at lower power levels and shorter ranges. From a health point of view, the exposures will be of lower level compared with those from the long-range systems discussed under the 2G mobile systems.

A number of significant other or non-communication uses of nonionizing EM energy are emerging in the domains of transportation, energy, household appliances, and health care establishments. In contrast to communications, these applications tend to rely on higher powers and thus generate higher field strengths. However, in most situations, exposure of humans is generally restricted to lower levels. In general, the RF spectrum will be used and reused more intensively in all frequency bands; previous gaps such as intermediate frequencies will likely be filled with new applications, and the use is extended upward to even higher RFs.

The experience of the cellular mobile telephone industry has demonstrated that once new technology is deployed, the adoption rate could easily explode through large-scale production and distribution. It is therefore important to be aware of the rapid development of new sources of NIR and to continue the scientific assessment on the various health aspects related to these innovations. This would include different exposure scenarios with regard to body site, duration of use, target population, and also to simultaneous exposure to complex multiple frequencies spread over a potentially large frequency range.

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LIST OF TECHNICAL ACRONYMS

AC, Alternating Current
ADPCM, Adaptive Differential Pulse Code Modulation
AMPS, American Mobile Phone Service in the U.S.
APC, Automatic Power Control
CDMA, Code Division Multiple Access scheme
CRC, Cyclic Redundancy Codes
DVB, Digital Video Broadcasting systems
DVB-H, DVB terrestrial television for hand-helds
DVB-S, DVB by satellite
DVB-T, DVB by terrestrial antennas
EAS, Electronic Article Surveillance
EDGE, Enhanced Data rate for GSM Evolution
EIRP, Effective Isotropic Radiated Power
EM, Electromagnetic
EMF, Electromagnetic Field
FDD, Frequency Division Duplex
GFSK, Gaussian Frequency Shift Keying
GPR, Ground Penetrating Radars
GPRS, General Packet Radio Service
GSM, Global System for Mobile Communications
HSCSD, High-Speed Circuit Switched Data
HSDPA, High Speed Downlink Packet Access
HSST, Trains using resistive magnets for levitation and propulsion in Japan
IH, Induction Heating, i-mode, overlay on Japanese PDC system to access and navigate the Web
IMT-2000, International Mobile Telecommunications-2000
IP, Internet Protocol
IS-95, North American version of the Code Division Multiple Access
ISDN, Integrated Services Digital Network
ISM, Industrial, Scientific, and Medical bands
MAGLEV, Magnetically Levitated Vehicle
MIMO, Multiple-Input Multiple-Output
MMS, Multimedia Messaging Service
MRI, Magnetic Resonance Imaging
NIR, Non Ionizing Radiation
OFDM, Orthogonal Frequency Division Multiplexing
OFDMA, Orthogonal Frequency Division Multiple Access

PDA, Personal Digital Assistant
PDC, Personal Digital Cellular system
PSTN, Public Switched Telephone Network
QPSK, Quadrature Phase Shift Keying
RF, Radio Frequency
RFID, Radio Frequency Identification Technology
SAR, Specific Absorption Rate
SCM, Superconducting Magnets
SOFDMA, Scalable OFDMA
SNR, Signal-to-Noise Ratio
SPS, Solar Power Satellites
TDD, Time Division Duplex
TDMA, Time Division Multiple Access Technique
TGV, Electrified trains (in France)
UHF, Ultra High Frequency band
UMTS, Universal Mobile Telecommunications System
UTRA, combined, W-CDMA and UMTS
UWB, Ultra-Wide-Band signals
VVVF, Variable Voltage and Variable Frequency
W-CDMA, Wideband Coded Division Multiple Access
Wi-Fi, Wireless Fidelity, also a trademark of Wi-Fi Alliance
WiMAX, Worldwide Interoperability for Microwave Access
WLAN, Wireless Local Area Networks
WPAN, Wireless Personal Area Networks
WPT, Wireless-Power Transmission

LIST OF ORGANIZATIONAL ACRONYMS

CEPT, European Conference of Postal and Telecommunications Administrations
DECT, Digital Enhanced Cordless Telecommunication
DOE, Department of Energy in the U.S.
DOT, Department of Transportation in the U.S.
FCC, Federal Communications Commission in the U.S.
ICNIRP, International Commission on Non-Ionizing Radiation Protection
IEC, International Electrotechnical Commission
IEEE, Institute of Electrical and Electronic Engineers
ISO, International Organization for Standardization
ITU, International Telecommunications Union
JAXA, Japan Aerospace Exploration Agency
METI, Japan's Ministry of Economy, Trade and Industry
NASA, National Aerospace Administration in the U.S.
NMT, Nordic Mobile Telephony
NTT, Nippon Telegraph and Telephone Corporation
URSI, International Scientific Radio Union

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