IEEE Committee on Man and Radiation

COMAR Technical Information Statement

Safety Issues Associated With Base Stations Used for Personal Wireless Communications

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Abstract

The Institute of Electrical and Electronics Engineers (IEEE) Committee on Man and Radiation (COMAR) acknowledges public concerns about the safety of exposure to radio frequency (RF) fields from base station antennas used for cellular telephone and other wireless communications services.

Guidelines for limiting such exposure have been developed by several voluntary organizations and government agencies in the United States and elsewhere [1-4]. Within the USA, the Federal Communications Commission (FCC) requires that all licensed telecommunications facilities comply with its exposure guidelines [5]. These guidelines were developed to protect workers and the general population from harmful exposure to RF radiation and have been promulgated because of FCC legal responsibilities under the National Environmental Policy Act of 1969 (NEPA). The consensus of the scientific community, as reflected in these exposure guidelines, is that exposure to RF radiation below recommended limits in these guidelines is safe.

In nearly all circumstances, public exposure to RF fields near wireless base stations is far below recommended safety limits. In unusual cases, typically with base station antennas located on rooftops, personnel might be exposed to RF fields above recommended limits depending on operating power levels and accessibility to antennas. In such cases, access to areas where exposures might be above safety guidelines should be restricted. In addition, RF fields in the main beam and within a meter or so of some base station antennas may present the potential for RF interference with susceptible electronic devices such as pacemakers, implanted defibrillators, body-mounted devices, and other medical equipment. Personnel using such electronic devices should consult with their physicians about any susceptibility of these devices to radio frequency interference prior to working immediately next to these antennas. Personnel should follow appropriate work procedures, possibly including the use of survey meters or personal monitors, while working close to active transmitting antennas.

BACKGROUND

The use of cellular telephones has increased steadily since their introduction in 1978. Worldwide, 500 million users of cell phones are expected by the year 2001, and 700 million users are expected by the year 2003. Similar technologies, including specialized mobile radio (SMR) and personal communications services (PCS) are also being introduced in many areas.

Cell phones operate by communicating with a nearby base station, which contains a low-powered radio transceiver and antenna. The antenna is usually mounted on a tower, the roof of a building, or on another structure that provides the required height for proper coverage. The base station relays calls between the user and the telephone system. In the year 2000, industry sources report that about 100,000 base stations will be in use in the United States.

Apart from concerns about aesthetic/visual impacts of antenna towers, many individuals have expressed concern about possible health risks of RF radiation from these installations, particularly for people residing close to the antennas.

This technical information statement (TIS) explains the basic operating characteristics of the various cellular and related personal wireless communication services, and resulting exposure levels to workers and the general public. These exposure levels are compared to the FCC and other safety guidelines. An Appendix describes wireless cellular systems in more detail, and includes a glossary of terms.

BASE STATIONS

Cellular communication systems require the use of many base stations located throughout a service area. When a user places a call, his or her handset communicates with a nearby base station, which then relays the call to a central switching office and then to the conventional land line telephone network. As the user moves about, he or she is "handed off" to other base stations.

Thus, each base station is a low power radio station that serves users in a small geographic region called a cell. The location of each base station is determined by two different needs on the part of the system. One is to provide adequate coverage (i.e. provide adequate signal strength throughout the entire service area). The second is to provide adequate capacity (i.e. provide enough free channels to accommodate any user who might wish to use the system). As a system grows, base stations are installed closer together (to increase capacity) but operated at lower power levels (to prevent interference among base stations). Thus, in urban areas base stations are closer together, but are operated at lower power levels, than in rural areas where the cells tend to be larger.

The antenna height is critical: it must be high enough to provide coverage throughout the cell, but low enough to preclude interference with remote cells that re-use the same frequencies. Depending on the needs of the system, the antennas may be from 10 to 100 meters above ground. Base station antennas are frequently located on tall tapered poles (called monopoles), much like lamp standards, or on towers of a metal strut lattice construction. Base station antennas may also be located on existing structures, such as water tanks, high-voltage transmission-line towers, or

buildings. To reduce the aesthetic impact of their systems on communities, companies generally prefer to install their antennas on existing structures, and to co-locate where possible (i.e. locate base stations from different companies on the same structure.)

RADIATED POWER AND LEVELS OF PUBLIC EXPOSURE FROM BASE STATIONS

Base stations transmit at levels that are determined by FCC limits and the operational needs of the carrier. For cellular carriers, the FCC permits an effective radiated power (ERP) up to 500 watts per channel (depending on the geographical area and tower height). A cellular base station may transmit using 21 channels, or more, per sector. The maximum ERP for other wireless services varies, but is generally 1000 watts or less.

The ERP of most base stations, however, is determined by system requirements and is generally far below the FCC limits. In urban areas, with small cells, many base stations commonly operate at ERPs below 16 watts per channel. In areas of very high demand, providers install "microcells" in buildings, which usually operate at ERPs below 1 watt per channel. Although the levels of public exposure to RF energy from any base station would vary depending on location and ERP, because the ERP used for smaller cells is lower than for larger cells, the overall exposure to RF energy from any system will not increase in proportion to the number of its base stations in an area.

Another factor that determines the level of exposure from a base station is the nature of the antennas that it employs. Base station antennas are usually either omnidirectional antennas, which radiate uniformly in all directions in the horizontal plane, or directional antennas, which radiate energy almost exclusively from their front surfaces.

Cellular systems most commonly employ a sectorized arrangement, with three sets of directional transmitting and receiving antennas oriented 120 degrees apart, aimed at the horizon. The antennas produce a beam that is narrow in the vertical direction but quite wide in the horizontal direction. While most of the energy is contained in the narrow beam, as the beam progresses, a small amount of energy is directed towards the ground (to provide coverage). As one moves away from the antenna, the signal in this narrow beam decreases in strength as the inverse square of the distance from the antenna.

Because of the narrow beam pattern, RF fields are much weaker outside of the main beam than within it. The RF exposure a person receives from a base station thus depends on both the distance from the antenna, and on the angle below the direction of the main beam. At ground level, the signal is relatively weak near the base of an antenna tower (since the main beam is passing directly overhead). For most base stations, the signal strength at ground level increases gradually with distance from the tower, reaches a maximum between 50 - 200 meters from the base of the tower, and then decreases at still greater distances. At all places on the ground, however, these signal levels are very low compared with regulatory guidelines.

Exposure Limits

The Table below summarizes FCC and other major exposure guidelines [1-4] at frequencies used by cellular and PCS communications systems.

COMPARISON OF SAFETY GUIDELINES AT FREQUENCIES USED FOR CELLULAR AND PCS

Service		**Exposure Limit, watts per square meter (W/m-sq)**				
		FCC (1997) [1]	IEEE (1991) [2]	ICNIRP (1998) [3]	NRPB (1993) [4]	NCRP (1986) [5]
Cellular (824 - 894 MHz)	General Public	5.5 - 6.0	5.5 - 6.0	4.4 - 4.5	31 - 33	5.5 - 6.0
	Occupational	28 - 30	28 - 30	21.8 - 22.4	31 - 33	28 - 30
PCS (1850 - 1990 MHz)	General Public	10	10 - 15	7.5 - 10	92 - 100	10
	Occupational	50	50 - 73	37.5 - 50	92 - 100	50

Notes
[1] U.S. Federal Communications Commission, Washington DC
[2] Institute of Electrical and Electronics Engineers The 1991 IEEE C95.1 standards was approved by the American National Standards Institute (ANSI) in 1992 for use as a US National Standard.
[3] International Commission on Non-Ionizing Radiation Protection
[4] National Radiological Protection Board (United Kingdom). Note that this standard has the same limits for occupational and general public exposure (except for a narrow portion of the spectrum).
[5] National Council on Radiation Protection and Measurements.

Typical exposure levels from tower-mounted cellular base stations are 100 times or more below these limits. Because of the higher gain antennas used for PCS, the corresponding levels are even lower than those associated with antennas used for older style cellular service. This has been confirmed by calculations (based on the characteristics of the antennas) as well as by direct measurements [6]. For example, at the base of a 45 meter tower with a cellular base station operating on 96 channels, 100 watts ERP per channel, the maximum measured RF field intensity was 0.02 W/m-sq. Lower values were measured for base station antennas located on taller towers.

Inside buildings the RF field intensity will be lower than outside, since a substantial fraction of the signal is absorbed when it passes through most building materials. One study reported that RF exposure levels on the top floors of buildings with roof-mounted cellular base station

antennas were less than 0.004 W/m-sq per 100 W ERP per channel [7]. This would correspond to levels below 0.084 W/m-sq for a base station employing 21 channels per sector. Exposures in nearby buildings would be similarly low since roof-mounted antennas are generally mounted on the highest roof available and nearby buildings will not be close enough for safety guidelines to be exceeded.

To summarize, RF exposure levels in areas of public access from cellular and PCS base stations aregenerally far below FCC and other safety guidelines. The FCC does not require routine assessment of RF fields from base stations, except for certain roof mounted antenna installations or for certain other installations where the antennas are mounted lower than 10 m above grade. P> Wireless communication is a rapidly expanding industry, and more wireless systems are coming on line, each with its own system of base stations. This may tend to increase levels of public exposure to RF energy over time. These systems are generally based on cellular designs with many low-power transmitters located through the service area. Increased service is provided in populated areas with a larger number of base stations, each with reduced power. This should ensure that levels of public exposure to RF energy from these systems will remain far below regulatory limits.

Rooftop - Mounted Base Stations

Close to some base station antennas, RF field levels in the beam can exceed safety guidelines. The distance from the antenna at which the guidelines for general population exposure are exceeded depends on the radiated power, the antenna type, and other factors, but typically is in the range of 3-10 meters from the radiating surface of a fully loaded cellular antenna and considerably less for most PCS antennas. (Directional or "panel" antennas do not radiate significant amounts of energy from their back surfaces, tops, bottoms, or sides.)

Consequently, base station antennas mounted on rooftops or other structures require special attention if personnel might intercept the beams of the antennas. Moreover, several different antennas, whose operating characteristics might be unknown, could be located on a given rooftop. Such areas are generally not accessible to the general public, but may be entered by service personnel. A particular concern arises when antennas are mounted on elevator penthouses at head height or below, or on "sleds" some distance in from the building parapet, in such a way that personnel can walk in front of the antennas.

In such cases areas where exposure might exceed FCC guidelines should be identified by direct measurements or calculations. Access to such areas should be restricted and/or appropriate signs provided. Individuals working in the vicinity of transmitting antennas should follow appropriate work procedures. Workers can be equipped with survey meters or personal monitors, and should be trained to recognize and avoid areas with excessive exposure levels. In some special circumstances, for example when it is not practical to turn off transmitters during maintenance operations, trained personnel can wear protective suits to reduce exposure when working close to an antenna and in its main beam.

Roof-mounted base station antennas are normally designed to radiate energy in the horizontal direction away from the building, and they radiate very little energy into the building itself. Therefore, exposure to residents inside a building with roof-mounted base station antennas is invariably very low.

Co-Location of Base Stations

For economic reasons, as well as to reduce the aesthetic impact of wireless communications on local communities, it is becoming common practice (and is often required by local ordinances) for multiple wireless companies to locate their antennas on a single tower or rooftop (co-location). Contemporary exposure guidelines and standards (e.g. IEEE C95-1 - 1991) and government agencies (in the USA, the FCC) require that the exposure from each antenna be added together as a fraction of the maximum permissible exposure (MPE) limit at each particular frequency. The sum of these fractions must be less than 1 in order for the site to be in compliance.

While it is unlikely that RF fields associated with conventional wireless base station transmitters in areas of uncontrolled public access will exceed recommended exposure guidelines, in some cases, e.g., where there may be a variety of antennas for different services, a detailed safety analysis may be requiredto evaluate compliance. Typically, paging antennas present the greatest potential for higher exposure.

Scientific Basis of Standards

The purpose of the RF exposure standards is to prevent exposures that are potentially hazardous, based on present knowledge.

The IEEE and other exposure guidelines have been developed by expert groups that critically evaluate the scientific literature on biological effects of electromagnetic fields, to identify the lowest exposure level for which credible evidence exists for any reproducible adverse effect that can be related to human health. Most of these studies have involved short-term exposures to animals, sometimes at high power levels, although a limited number of long-term animal and human (epidemiological) studies have been examined as well. A variety of RF-induced biological effects have been reported, most of which are associated with excessive heating. The various exposure guidelines incorporate safety factors to keep exposures below levels that are considered to be potentially hazardous, even under worse-case exposure conditions: a safety factor of 10 for occupational exposure and 50 for the general public.

Most major exposure guidelines are developed in a careful, open consensus process that involves extensive review at several levels, and opportunity for comment by a broad spectrum of potentially interested parties. Moreover, major standards setting organizations require periodic revision of the standards, in response to new scientific information as it becomes available.

CONCLUSIONS

This technical information statement describes the levels of public exposure to RF energy from cellular base station antennas, with respect to appropriate exposure guidelines. Levels of public exposure are normally far below the recommended guidelines. Consequently, wireless base stations are not considered to present a risk to the general population including aged people, pregnant women, and children.

In special circumstances workers, and possibly members of the public, could be exposed to fields greater than the exposure guidelines. In these cases, generally on rooftops, access should be restricted. Appropriate signs and procedures should be implemented. In addition, there may be some risk to personnel with heart pacemakers, implanted defibrillators, or other body-mounted medical electronic devices when they are close (within a meter or so) and in the main beam of an operating base station antenna [8]. Personnel working close to such antennas should follow appropriate work procedures, including the use of survey meters or personal monitors, protective suits, or turning the transmitters off during maintenance procedures.

APPENDICES

FREQUENCIES AND OPERATING PROTOCOLS OF CELLULAR WIRELESS COMMUNICATION SYSTEMS

The early cellular networks used an analog transmission protocol (called frequency-division multiple access - FDMA), in which speech frequency modulates a continuous wave carrier. In the USA, these systems operate in the 824-894 MHz frequency range (824-849 MHz for mobile/hand-held units and 869-894 MHz for the base stations), which was formerly allocated to UHF television channels 69-84.

At the beginning of the 1990s these systems were reaching the limits of their capacity in many service areas. This led to the introduction of new classes of cellular service using digital techniques, such as time-division multiple-access (TDMA), hybrid TDMA/FDMA, and more recently code-division multiple-access (CDMA). These digital systems operate in the same frequency band as the analog systems, but provide more voice channels per radio channel. In Europe, the most commonly used cellular system is called GSM (Global System for Mobile Communication), which is a hybrid TDMA/FDMA system, and operates in the 935-960 frequency band.

Personal Communication Services (PCS) is a newer wireless technology that operates in the 1850-1990 MHz band, using both TDMA and CDMA technologies. Compared with analog cellular systems, PCS systems operate at lower power levels, with more closely spaced cells and lower power handsets.

In the USA, the Federal Communications Commission originally authorized up to two cellular service providers per service area. However, to promote competition, new frequency bands have been created, and new services are being introduced. These include specialized mobile radio (SMR) and enhanced specialized radio (ESMR), which operate at frequencies close to those used for cellular service. In addition, two PCS carriers are also licensed to operate in many regions of the United States.

Offsetting the increased number of wireless carriers, the progression of cellular technology from analog to digital systems with improved performance, has led to a steady reduction of base station and phone transmitter powers. Additionally, modern systems are designed to reduce the power of both the base station and handset when the user is close to a base station, which further reduces average power levels.

For additional information about wireless telephone systems, readers are referred to discussions by Millington [9] and Rappaport [10].

GLOSSARY AND ACRONYMS

ANSI - American National Standards Institute

EPA - (USA) Environmental Protection Agency

FDA - (USA) Food and Drug Administration

ICNIRP - International Commission on Non-Ionizing Radiation Protection

IEEE - The Institute for Electrical and Electronics Engineers

NCRP - National Council on Radiation Protection and Measurements

NIOSH - (USA) National Institute for Occupational Safety and Health

NRPB - National Radiation Protection Board (United Kingdom)

OSHA - (USA) Occupational Safety and Health Administration

Analog Communications Channel — A communication channel in which the message being transmitted, for example voice, directly modulates the amplitude or frequency of a higher frequency RF or microwave (MW) signal.

CDMA (Code Division Multiple Access) - A method of coding the digitized messages of several users and transmitting them at the same time using a single communication channel. Each user's message is decoded independently of the others.

Cellular Phone System - A system for mobile wireless communication where blocks of frequencies (channels) can be reused by dividing a geographical area into hexagonal "cells" each of which contains a transmit/receive base station antenna. A mobile user within a cell communicates with the base station in that cell or an adjacent cell depending on the strength of the received signals. As the user moves from cell to cell, the connection between the user and network is maintained by "handing-off" the user from one base station to another, i.e., switching to a channel assigned to that base station.

Digital Communication Channel - A communication channel in which the message is encoded as a series of "ones" and "zeros" (binary code). This can be done in several ways, but a common scheme has the phase of a component of the transmitted signal switched in discrete steps to represent the "zeros" and "ones," respectively.

Directional Antenna - An antenna that radiates energy efficiently in a specific direction. For example, the energy from directional antennas used for personal wireless service, often called "high-gain," "panel," or "sector" antennas, is usually propagated in a relatively narrow beam in the vertical plane (of the order of 10 degrees) and typically 120 degrees in the horizontal plane.

Downlink - The communication connection (transmitted signal) from a base station to a mobile station.

ERP (Effective Radiated Power) - A measure of how well an antenna concentrates the radiated energy in a specific direction. An analogy can be drawn in a comparison between an ordinary light bulb and a spotlight. At a given distance, the light that falls on a surface in the beam of a 100 W spotlight is much brighter than that from an ordinary 100 W bulb at the same distance, because the spotlight concentrates the light into a beam. Correspondingly, the light that falls on a surface that is not in the beam of the spotlight is much less than that from the ordinary light bulb at the same distance.

FDMA (Frequency Division Multiple Access) - A method for carrying multiple messages during a RF or MW transmission by encoding the messages of different users as modulations of different carrier frequencies.

GSM (Global System for Mobile Communications) - A hybrid TDMA/CDMA scheme widely used throughout Europe, and also becoming available in the USA.

High-Gain Antenna - an antenna whose radiation pattern is concentrated in a more or less narrow beam, i.e. a "directional antenna".

Microwatt (μW) - a power of one millionth of a watt.

Microwave (MW) - An electromagnetic wave with a wavelength between about one millimeter and 30 centimeters corresponding to a frequency between 300 GHz and 1 GHz.

Milliwatt (mW) - a power of one thousandth of a watt.

Omni-Directional Antenna - An antenna that radiates energy more or less uniformly over an angle of 360 degrees in the horizontal plane around the antenna. Sometimes called a "low-gain" antenna. The familiar "whip" antennas are omnidirectional in their radiation patterns.

PCS (Personal Communication Service) - A term used by cellular service providers for digital service primarily in the 1800 - 2000 MHz frequency band. The term distinguishes this newer wireless protocol from cellular service at lower frequencies.

Power Flux - sometimes called "power density," is a measure of the radiated power reaching unit area of a surface. The accepted unit for this parameter is watts per square meter (W/m-sq). However, the older measure milliwatts per square centimeter (mW/cm-sq) is still encountered. 1 mW/cm-sq is equivalent to 10 W/m-sq.

Radio Frequency (RF) - frequencies of electromagnetic waves between approximately 3 kHz (3,000 Hz) and 300 GHz (3 x 10^11 Hz). Sometimes, a distinction is drawn between radio waves, which have frequencies between 3 kHz and 1 GHz, and microwaves, which have a frequency between 1 GHz and 300 GHz.

SAR (Specific Absorption Rate) - A measure of the rate at which electromagnetic energy is absorbed by an exposed object. SAR, measured in watts per kilogram (W/kg), is the basic quantity from which modern RF and MW safety criteria (exposure limits) are derived.

TDMA (Time Division Multiple Access) - A method for combining the messages of several users on a single radio channel by assigning each user a different time segment of each transmit interval.

Transceiver - A term used to describe a communication device that can both receive (detect) signals, and transmit signals.

Uplink - The communication connection (transmitted signal) from a mobile station to a base station.

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