Indian Journal of Radio & Space Physics
Vol 41, October 2012, pp 557-565

Assessment of electromagnetic radiation from base station antennas

R K Singh

Bharat Sanchar Nigam Limited, BRS Nagar, Ludhiana 141 001, India
E-mail: rajivinbhu@gmail.com

Received 8 November 2011; revised 12 August 2012; accepted 21 August 2012

There is a strong perception relating to existence of a high level of non-ionizing electromagnetic radiation in the vicinity of base station antennas. In the present paper, electromagnetic radiation from base station antennas installed for various wireless communication purposes has been investigated based on equivalent isotropically radiated power calculations. For this purpose, a typical wireless communication site has been selected where GSM, CDMA, 3G/UMTS, and WiMAX antennas are installed. The overall ratio of equivalent isotropically radiated power (EIRP) and threshold EIRP combining all services at this particular site has been calculated at ground level and nearby buildings. It has been found that the ratio of EIRP and threshold EIRP is less than unity and thus, the particular site is normally compliant and does not impose any adverse health effects. For general public, the exclusion zone (compliance distance) from GSM, CDMA, 3G/UMTS, and WiMAX antennas have been found at 7.30, 6.076, 7.436, and 6.861 m, respectively.

Keywords: Electromagnetic radiation, Non-ionizing radiation, Equivalent isotropically radiated power, Base station antennas

PACS Nos: 84.40.Ba; 92.60.Ta; 87.50.-a

1 Introduction

The effect of electromagnetic radiation on human health is the subject of recent interest and study as a result of the enormous installation of cellphone towers in thickly populated areas of cities throughout the world. There is a perception relating to existence of a high level of electromagnetic radiation in the vicinity of these towers, which may cause adverse biological effects[1-17]. In the absence of suitable policy directives for cell tower installations, monitoring, effective control and execution at all levels by governmental bodies, such mushrooming of cellphone transmitting towers could create a sense of panic amongst general public.

As the cellphone base and various wireless technologies such as Worldwide Interoperability for Microwave Access (WiMAX), Wireless Broadband (WiBro), Advanced Evolution Data Optimized (EV-DO), Long Term Evolution (LTE)-Advanced, etc. are rapidly expanding and evolving. The requirement for cell towers will also grow proportionately. It is, therefore, high time that a strict regulatory regime is established as early as possible to avoid possible fallout.

According to World Health Organization (WHO), INTERPHONE (an 13-country coordinated case-control study), Independent Expert Group on Mobile Phones (IEGMP), and Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR) study researches, it has been found that electromagnetic radiation can contribute to health deficiency including the increased risk of brain tumours, eye cancer, salivary glands tumours, testicular cancer, and leukaemia[1-3]. Several surveys have found a variety of self-reported symptoms for people who live close to base stations[4-6]. Collectively, they have not provided evidence of a relationship, but they have had sufficient limitations to leave the question unresolved[7-8]. International Commission on Non-Ionizing Radiation Protection (ICNIRP) study has concluded that the exposure levels due to cell phone base stations are generally around one-ten-thousandth of the guideline levels[9]. Moreover, the WHO has classified mobile phone radiation on the International Agency for Research on Cancer (IARC) scale into Group 2B-possibly carcinogenic to humans[10]. That means that there ‘could be some risk’ of carcinogenicity, so additional research into the long-term, heavy use of mobile phones/wireless technologies needs to be conducted. Hence, there is a need for not only controlling the haphazard installation of the towers but also undertaking systematic study for measurements of the radiation levels in some selected high population density urban areas to ensure that the power density levels are well below the prescribed threshold limits. The results need to be made available for public education and scrutiny. Further, it is better to take preventive measures and even try to mitigate the radiation levels to provide greater protection to general public and workers. The present paper focuses on the different types of electromagnetic radiation and their possible effects on human health. The exposure limits for the frequency range of interest, assessment of exposure level based on numerical calculations, the results obtained at the selected site for the study have been presented.

2 EM radiation and standards

Electromagnetic (EM) radiation is a form of energy exhibiting wave-like behaviour as it travels through space. It has both electric and magnetic field components, which oscillate in phase perpendicular to each other and perpendicular to the direction of energy propagation. Figure 1 shows different forms of electromagnetic energy in the entire spectrum of EM radiation with the range of frequencies, sources, their energies, and effects.

When referring to biological radiation exposures, EM radiation is divided into two types: ionising and non-ionising. Because the human body is composed of about 60 percent water, ionising and non-ionising radiations refer to whether the RF energy is high enough to break chemical bonds of water (ionising) or not (non-ionising). Technically, all radiation and fields of the electromagnetic spectrum that do not normally have sufficient energy to produce ionization in matter; characterized by energy per photon less than about 12 electron volts (eV), wavelengths greater than 100 nanometers (nm), and frequencies lower than 3×10^{15} Hz is termed as non-ionizing radiation[11]. Clearly, radiation that has enough energy to move atoms in a molecule around or cause them to vibrate or pump an electron to a higher energy state but not enough to remove electrons is termed as non-ionizing radiation. Extremely low frequency (ELF), radio waves, microwaves, infrared, visible light, and near ultraviolet are all examples of non-ionizing radiation. Here, it is noteworthy that static fields do not radiate and the light from the Sun is also largely composed of non-ionizing radiation, with notable exception of some ultraviolet rays.

On the other hand, ionizing radiation has enough energy to remove tightly bound electrons from atoms and thus, creating ions. High frequency ultraviolet rays, X-rays, gamma rays, and cosmic rays are examples of ionizing radiation and have enough high energy to strip off electrons or even break up the nucleus of atoms and thereby releasing huge amount of energy which may disrupt the chemical bond and ultimately results in ionization in the human body[11].

Exposure to very high levels of RF radiation can be harmful due to the ability of RF energy to rapidly heat biological tissues. Adverse effects (tissue damage) in humans could occur during exposure to high RF levels because of the body's inability to cope up with or dissipate the excessive heat that could be generated. The eyes, knee caps and the testes are particularly vulnerable to RF heating because of the relative lack of blood flow in these organs to dissipate the excessive heat[11].

After examining the problems arising from non-ionizing radiations, the ICNIRP has developed international guidelines on exposure limits. These

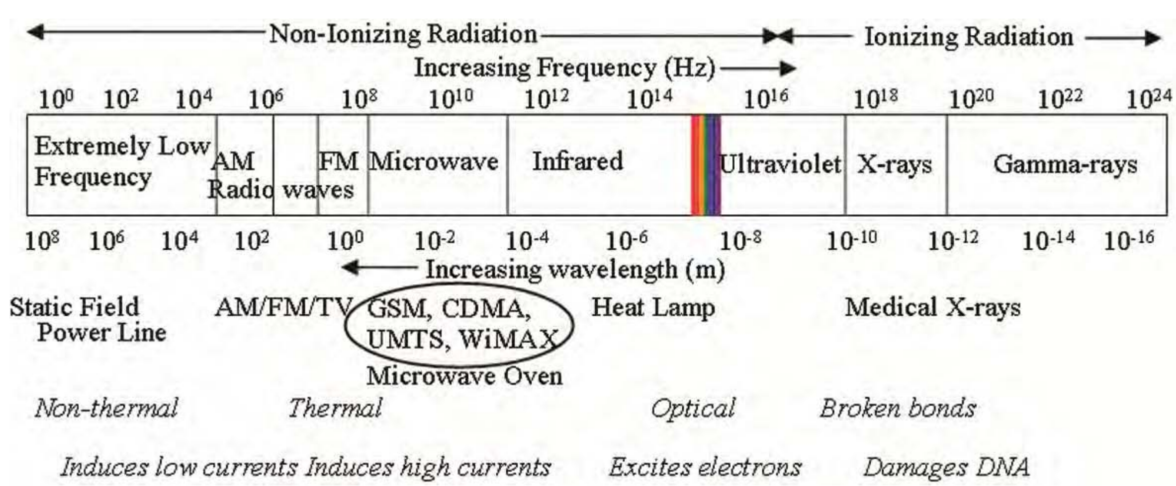

Fig. 1 — EM spectrum indicating radiation zones

reference limits are tabulated in Table 1 for the frequencies of interest[9]. Here, 'occupational' refers to operational and maintenance staff. Thus, the reference levels for general public and occupational exposure to time varying electric, magnetic, and electromagnetic fields can be easily found for Global System for Mobile communication (GSM), Universal Mobile Telecommunication System (UMTS), Code Division Multiple Access (CDMA), Worldwide Interoperability for Microwave Access (WiMAX), etc. from Table 1. It is noteworthy that these communication systems are strongly time dependent, so, it is required to take average of the measured quantity over a defined period and measurements should be made during time of peak usage. For example, ICNIRP reference (i.e. field) limits are to be averaged over any 6-minute period below 10 GHz and over a $68/(1000f)^{1.05}$-minute period for frequencies exceeding 10 GHz (where, *f,* is the frequency in MHz)[9].

In any particular exposure situation, measured or calculated values of any of these quantities can be compared with the appropriate reference level. Compliance with the reference level will ensure compliance with the relevant quantities like current density (electric/magnetic field intensity), specific absorption rate (SAR), and power density. If the measured or calculated value exceeds the reference level, it is necessary to test compliance with the relevant field quantity and to determine whether additional protective measures are necessary.

Based on the reference levels set by ICNIRP, the compliance distances from base station antenna have been calculated with the help of equivalent isotropically radiated power in the direction of maximum antenna gain *(eirp*, in watts) (Table 2)[9]. The *eirp* is the product of the power supplied to the antenna and the maximum antenna gain relative to an isotropic antenna. Thus, three types of exposure zones have been identified (Fig. 2):

i) *compliance zone* (potential exposure to EMF is below the applicable limits),

ii) *occupational zone* (potential exposure to EMF is below the limits for occupational exposure but exceeds the limits for general public exposure), and

iii) *exceedance* zone (potential exposure to EMF exceeds the limits for both, occupational and general public exposure).

It should be always assured that for distances greater than the compliance distance, the radiation level is under the limit. It means that if a lower amount of data concerning a radiating source is available, then the higher overestimation of the compliance distances is required.

Table 1 — Reference level set by ICNIRP

Type of exposure	Frequency range (*f*), MHz	E-field strength, V m^{-1}	H-field strength, A m^{-1}	Power density, W m^{-2}
General public	400-2000	$1.375f^{½}$	$0.0037f^{½}$	*f*/200
	2000-300000	61	0.16	10
Occupational	400-2000	$3f^{½}$	$0.008f^{½}$	*f*/40
	2000-300000	137	0.36	50

3 Assessment of exposure level

The real source of electromagnetic radiation is the transmitting antenna – not the transmitter itself, because the transmitting antenna is the main source that determines electromagnetic field distribution in the vicinity of a transmitting station. So, it is required to consider the appropriate region of the field of an antenna. The space surrounding an antenna is generally subdivided into four regions: reactive near-field, reactive-radiating near-field, radiating (Fresnel) near-field, and radiating far-field[14]. Radial distance of reactive near-field is $0.62(D^3/\lambda)^{1/2}$; where, D, is the largest dimension of the antenna; and λ, the wavelength (to be valid, D must be large compared to the wavelength). Radial limit of the radiating near-field is $2D^2/\lambda$. The field region beyond radiating near-field (distance $\geq 2D^2/\lambda$) is radiating far-field where the field pattern is essentially independent of the

Table 2 — Compliance distances from base station antenna

Type of exposure	Frequency range (*f*), MHz	Compliance distance, m
General public	400-2000	$6.38(eirp/f)^{1/2} \approx 8.16(erp/f)^{1/2}$
	2000-300000	$0.143(eirp)^{1/2} \approx 0.184(erp)^{1/2}$
Occupational	400-2000	$2.92(eirp/f)^{1/2} \approx 3.74(erp/f)^{1/2}$
	2000-300000	$0.0638(eirp)^{1/2} \approx 0.0184(erp)^{1/2}$

Fig. 2 — Marking of different zones around a base station antenna

distance from the antenna[14]. Thus, assessment of exposure level in any field region for cellphone frequency bands of interest can be easily done.

For the assessment of the exposure level, it is required to measure the field quantities like electric field intensity (E) or magnetic field intensity (H) or SAR[15-17]. The selection of the field quantity to be measured depends on where (near or far field region) the observer is, and on the field impedance (E/H) (Table 3).

Assessment of exposure levels can be done either by measurement or by numerical calculations or by electromagnetic software simulations. All these methods have almost similar level of uncertainty and accuracy depending on the method and equipment or software used[18]. Since assessment of exposure level by measurement is not always possible due to one or more reasons. So, several other methods are used for the assessment, for example, by numerical calculations or by software simulations. Lots of electromagnetic simulation softwares, like CST Microwave Studio, HFSS, MAGIC, Orthoslice, IE3D, WASP-NET, MicroWave Wizard, FEKO, EM Simulator, etc. are commercially available and are being used for microwave analysis, design, and optimization. Such simulation software make use of different numerical methods like finite-difference time-domain (FDTD), method of moments (MOM), multiple-region finite-difference time-domain (MR-FDTD), numeric electromagnetic code (NEC), ray tracing model, etc. There is no single EM software application or approach that solves all problems equally well since each one has some strength and weakness. The selection of the appropriate numerical method depends on structure to be simulated (antenna, microstrip lines, transmission lines, waveguide structures), availability of computer resources (memory), simulation time constraints, quantity to be observed (SAR/E-field/H-field/power density), field zone (near/far-field) where the exposure assessment is required, topology (open/closed) of the surrounding, accuracy of measurements, etc. (Table 4).

Another approach for exposure assessment is to go for synthetic modelling of any antenna system. In such modelling, each antenna is considered to be made of several elementry sources (say, dipole antenna) and each of them considered as a separate radiating source[14]. But the accuracy is somewhat lower due to neglegence of coupling between elementary radiating sources.

For the calculations of field quantities, the point source model of the antenna system can also be used but with some limitations[14]. In this modelling, the radiating source is represented by one point source situated in the antenna electric centre and having a radiation pattern of the considered radiating source. The boundaries of the field regions has to be calculated by taking the actual size of the raditing source because this model does not take into account the antenna size. So, the applicability of this model, specially in near field calculations, is limited. If the results of calculations are to be accurate, the minimum distance between the point of investigation and the transmitting antenna has to fulfill requirements for the far-field region [distance = max $(3\lambda, 2D^2/\lambda)$].

3.1 Assessment of exposure by EIRP calculations

Calculation of equivalent isotropically radiated power (EIRP) is an efficient method for the assessment of exposure level of a base station antenna. In this method, site survey is done and several parameters like location parameters, operating parameters, and environment parameters are recorded. Now, assessment of EIRP and threshold of *eirp* ($EIRP_{th}$) are done at various publicly accessible points (on ground, on rooftop, at adjacent buildings, etc.) in the environment surrounding the base station antenna.

Table 3 — Selection of field quantity to be measured for assessment of exposure level in different regions

Field zone	Field impedance	Measured quantity
Reactive near-field	$\neq Z_0$ (free space impedance)	E/H/SAR, Preferably SAR
Reactive radiating near-field	Not known	Both E and H
	$E/H > 120\pi$	E
	$E/H < 120\pi$	H
Radiating near-field	$E/H \approx Z_0$	E
Radiating far-field	$E/H = Z_0$	E or H

Table 4 — Selection of appropriate numerical method for assessment of exposure level

Field zone	Topology of surrounding	Measured quantity	Suitable numerical method
Near-field	Open/Closed/ Multiple scatters	E or H	FDTD, MOM
	Open	SAR	FDTD
	Closed/Multiple scatters	SAR	FDTD, MR-FDTD
Far-field	Open	E or H	Ray Tracing, MOM
	Multiple scatters	E or H	Ray Tracing

Base stations often contain more than one transmitter and the output of each transmitter is combined before being fed via cables to radiating antennas, which is mounted at the top of the tower. When the signals are combined, the radiated power would ideally be equal to the sum of the output powers from the individual transmitters, but some loss occurs in the combiner and connecting cables. These losses greatly reduce the power radiated by antennas. The power that is fed into the base station antenna is launched into an electromagnetic wave at allocated frequency of the particular service, e.g. 900 MHz / 1800 MHz / 2100 MHz / 2.63 GHz, travelling away from the tower. Base station antennas transmit at least one radio signal continuously to carry signaling information known as control channel that is used to set up calls. In addition to carry signaling information, these control channels also handle few numbers of calls. Some extra non-signaling carriers are often used to handle transmission and reception of several calls simultaneously. The control channel is transmitted at full power in all timeslots, even when no calls are being handled, whereas non-signaling channels are only transmitted when several simultaneous calls are to be handled. Taking all these consideration, the *EIRP* for an operator service is given by *EIRP* of control channel [e.g. Broadcast Control Channel (BCCH) for GSM and common-pilot channel for CDMA/UMTS] as[13]:

$$EIRP_{BCCH} = P_t - P_l - (L \times C_L) + G \qquad \text{... (1)}$$

where, P_t, P_l, L, C_L, and G, are transmitter output power, combiner loss, RF cable length, RF cable loss per 100 m length, and antenna gain, respectively.

Now, total *EIRP* of the particular service (e.g. GSM/CDMA) of an operator is given by:

$$EIRP_{Total} = EIRP_{BCCH}\{1 + m \times n \times (N-1)\} \qquad \text{… (2)}$$

where, *m, n,* and *N,* are diversity factor, ATPC factor (Automatic Transmit Power Control – a feature of transmitter that adjusts the transmitter output power based on the varying signal level at receiver), and number of carriers per sector in worst case, e.g. if two sectors are having three carriers while the third one has four carriers, the value of N would be four.

The threshold value of *EIRP* should be calculated at the position where the power density is maximum within the exposure assessment area. The most important parameter for determining the exposure due to elevated antennas (broad coverage antenna–omnidirectional or sectional) used for wireless communication is the vertical (elevation) antenna pattern. The horizontal (azimuth) pattern is not relevant because the exposure assessment assumes exposure along the direction of maximum radiation in the horizontal plane. The area accessed by public can be different for different installation circumstances. The various accessibility categories are shown in Figs. 3-6 (Ref. 13).

Estimation of $EIRP_{th}$ in the frequency range 400-2000 MHz for general public at ground points (Fig. 3) is given by:

$$EIRP_{th} = Lesser\ of \left\{ \frac{\pi f (h-2)^2}{200 A_{sl}};\ \ \frac{\pi f}{200}\left[\frac{h-2}{\sin(\alpha + 1.129\,\theta_{BW})}\right]^2 \right\} \qquad \text{… (3)}$$

and $EIRP_{th}$ in the frequency range 2-300 GHz for general public at ground points (Fig. 3) is given by:

$$EIRP_{th} = Lesser\ of \left\{ \frac{10\pi (h-2)^2}{A_{sl}};\ \ 10\pi\left[\frac{h-2}{\sin(\alpha + 1.129\,\theta_{BW})}\right]^2 \right\} \qquad \text{… (4)}$$

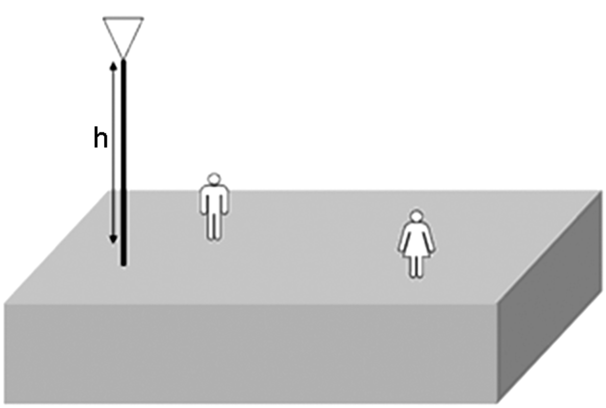

Fig. 3 — Accessibility category 1

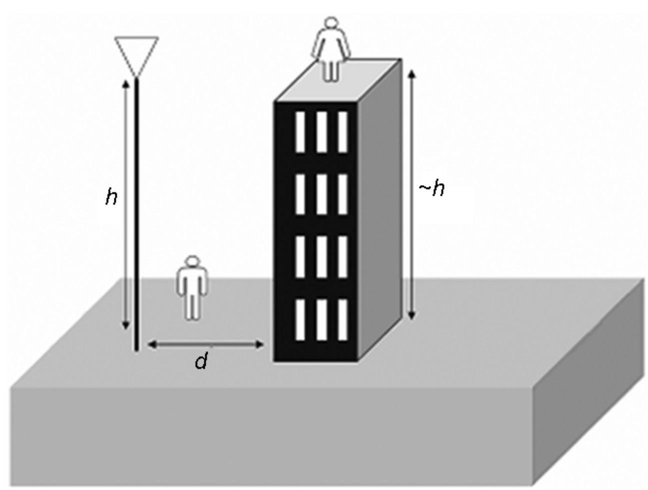

Fig. 4 — Accessibility category 2

where, A_{sl}, is the attenuation of the largest side lobe of the antenna in vertical pattern w.r.t. main lobe; α, total tilt (electrical tilt + mechanical tilt); θ_{BW}, antenna vertical 3-dB beam-width; h, height of the antenna above ground level (AGL); and f, operating frequency.

For accessibility category 2, $EIRP_{th}$ in the frequency range 400-2000 MHz for general public (Fig. 4) is given by:

$$EIRP_{th} = Lesser\ of \left\{ \frac{\pi f (h-2)^2}{200 A_{sl}};\quad \frac{\pi f d^2}{200} \right\} \quad \dots (5)$$

and $EIRP_{th}$ in the frequency range 2-300 GHz for general public (Fig. 4) is given by:

$$EIRP_{th} = Lesser\ of \left\{ \frac{10\pi (h-2)^2}{A_{sl}};\quad 10\pi d^2 \right\} \quad \dots (6)$$

For accessibility category 3, $EIRP_{th}$ in the frequency range 400-2000 MHz for general public (Fig 5) is given by:

$$EIRP_{th} = Lesser\ of \left\{ \frac{\pi f (h-2)^2}{200 A_{sl}};\quad \frac{\pi f}{200 A_{sl}} \left[\frac{d^2 + (h-h')^2}{d} \right]^2 \right\} \quad \dots (7)$$

and $EIRP_{th}$ in the frequency range 2-300 GHz for general public (Fig. 5) is given by:

$$EIRP_{th} = Lesser\ of \left\{ \frac{10\pi (h-2)^2}{A_{sl}};\quad \frac{10\pi}{A_{sl}} \left[\frac{d^2 + (h-h')^2}{d} \right]^2 \right\} \quad \dots (8)$$

For accessibility category 4, $EIRP_{th}$ in the frequency range 400-2000 MHz for general public (Fig. 6) is given by:

$$EIRP_{th} = Lesser\ of \left\{ \frac{\pi f}{200 A_{sl}} \left[\frac{a^2 + (h-2)^2}{a} \right]^2;\quad \frac{\pi f}{200} \left[\frac{h-2}{\sin(\alpha + 1.129\theta_{BW})} \right]^2 \right\} \quad \dots (9)$$

and $EIRP_{th}$ in the frequency range 2-300 GHz for general public (Fig. 6) is given by:

$$EIRP_{th} = Lesser\ of \left\{ \frac{10\pi}{A_{sl}} \left[\frac{a^2 + (h-2)^2}{a} \right]^2;\quad 10\pi \left[\frac{h-2}{\sin(\alpha + 1.129\theta_{BW})} \right]^2 \right\} \quad \dots (10)$$

Here, it is important to mention that the $EIRP_{th}$ for occupational category is five times of the value of $EIRP_{th}$ for general public.

For a shared site, the $EIRP$ and $EIRP_{th}$ has be to calculated as above and the cumulative ratio should be less than unity at all points outside the exceedance zone for normally compliant site, i.e.:

$$\sum (EIRP / EIRP_{th}) = \left\{ (EIRP_{Total} / EIRP_{th})_{Op1} + (EIRP_{Total} / EIRP_{th})_{Op2} + \dots\dots \right\} < 1 \quad \dots (11)$$

4 Results and Discussion

For the study, a typical site installed for wireless communication purpose at Bharat Nagar, Ludhiana, India has been selected. This site provides four different services (GSM, 3G/UMTS, CDMA, and WiMAX). The assessment of exposure level has been done for this site using the calculation of equivalent isotropically radiated power from all the antennas. For this purpose, site data and relevant technical data for each service have been collected and tabulated in Table 5. The $EIRP$

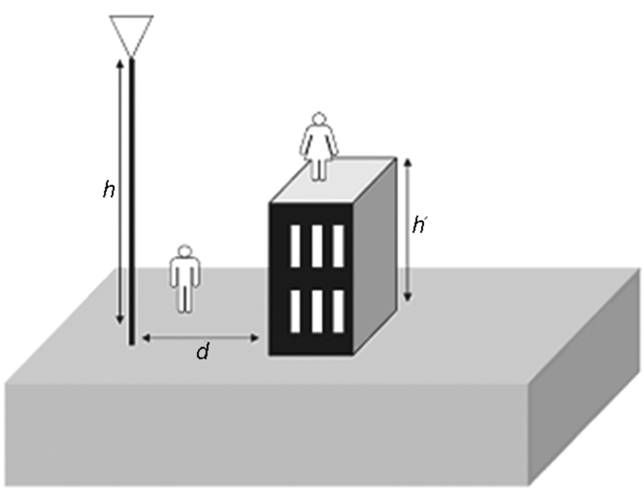

Fig. 5 — Accessibility category 3

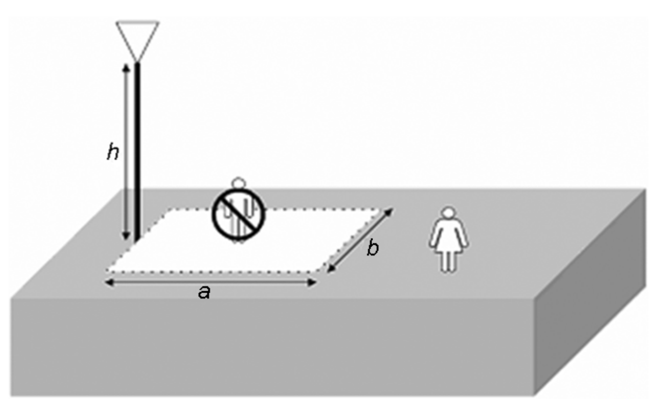

Fig. 6 — Accessibility category 4

Table 5 — EIRP calculation data for a typical wireless communication site

	Item	Units	GSM	3G/UMTS	CDMA	WiMAX
Site data	Site name		Bharat Nagar, LDH	Bharat Nagar, LDH	Bharat Nagar, LDH	Bharat Nagar, LDH
	Lat / Long		30°54'15"N, 75°50'24"E	30°54'15"N, 75°50'24"E	30°54'15"N, 75°50'24"E	30°54'15"N, 75°50'24"E
	Building height (agl)	m	15	15	15	15
	Antenna height (agl)	m	26	28	30	32
Technical data	Base channel frequency	MHz	949.8	2127.6	830.66	2645.5
	Carriers / sector (worst)		4	3	3	3
	Antenna gain	dBi	18	17.6	15.8	17.5
	Total tilt	deg	3	3	3	1
	Total tilt	rad	0.052359878	0.052359878	0.052359878	0.017453293
	Vertical beamwidth	deg	8	7.9	9.6	7.4
	Vertical beamwidth	rad	0.13962634	0.137881011	0.167551608	0.129154365
	Side lobe attenuation (asl)	dBm	13.2	13.1	11.4	11.6
	Side lobe attenuation (asl)	W	0.02089296	0.020417379	0.013803843	0.014454398
	Tx power	dBm	43	43	43	43
	Combiner loss	dBm	3	0	3	1.2
	RF cable length	m	40	40	45	45
	Unit loss in cable	dB/100m	6	5.75	4	1
	EIRP (Base channel)	W	363.0780548	676.0829754	251.1886432	767.3614894
	EIRP (Base channel)	dBm	55.6	58.3	54	58.85
	DTX factor		0.9	1	1	1
	ATPC factor		0.9	1	1	1
	EIRP (TCH) incl DTX, ATPC	W	882.27967	2028.248926	502.3772863	1534.722979
	EIRP (Total)	W	1245.3577	2704.331902	753.5659295	2302.084468
	EIRP threshold 1 (ETH1)	W	197659.3388	497632.2385	178720.2666	1069619.606
	EIRP threshold 2 (ETH2)	W	154164.922	1039624.113	740694.3175	1955114.324
Result	EIRP threshold (Min of ETH1 AND ETH2)	W	154164.922	497632.2385	178720.2666	1069619.606
	EIRP/EIRP threshold	<1	0.00807809	0.00543440	0.00421645	0.00215225
	Individual compliance		Yes	Yes	Yes	Yes
	Total EIRP/EIRP $_{TH}$	<1	0.01988119			
	Normally complied	Yes				

calculations for all the four services have been done using Eqs (1) and (2). The threshold value of *EIRP* ($EIRP_{th}$) calculations have been done at ground level (accessibility category 1) as per Eqs (3) and (4) depending on the frequency of operation. Individual ratio of *EIRP* and $EIRP_{th}$ for each service has been found to be less than unity. The total $EIRP/EIRP_{th}$ ratio at ground level is also less than unity which shows that there is negligible or no adverse health implications due to EM radiation from this particular site.

Based on the exposure limits prescribed by ICNIRP (Table 2), calculations have been done for the compliance distance to the transmitting antenna at which exposure limits are achieved. Such distances (exclusion zone) are different for different types of transmitting antennas and different type of exposure (Table 6). It is evident from Table 6 that the compliance distance for various services is smaller than the near-field/far-field spherical boundary ($2D^2/\lambda$). Since the compliance distance is calculated by assuming far-field conditions, as the point of investigation move outwards towards the far-field spherical boundary, the far-field conditions will be satisfied, and the point of investigation is now much further away from the antenna. Therefore, in this scenario, if the public has no access to the near-field

Table 6 — Compliance distances from Bharat Nagar site

Name of the service	Compliance distance, m	
	General public	Occupational
GSM	7.3055288	3.3435962
CDMA	6.076726	2.7811975
3G/UMTS	7.4364564	3.3178036
WiMAX	6.8611461	3.0611267

region, then the installation is in compliance and the overall exclusion zone is assumed to be the near-field/far-field spherical boundary. In such conditions, where compliance distance falls in the near-field region, accurate evaluation of the field near the antenna is required and overall larger dimension of both the near-field/far-field boundary and compliance distance is used to determine the new limit of the compliance zone. In addition to method of moments, there exist several other numerical methods like FDTD, MR-FDTD depending on the particular topology, e.g. open/closed/multiple scatters, to evaluate the field if the details of the antenna construction and geometry are known. Such methods can also take into account scattering from objects near the antenna and are able to evaluate the precise variation of quantity to be measured at all distances and in all directions from antenna.

Table 7 — EIRP/EIRPth calculation summary

	Item		Units	GSM	3G/UMTS	CDMA	WiMAX
Site data	Site Name			Bharat Nagar, LDH	Bharat Nagar, LDH	Bharat Nagar, LDH	Bharat Nagar, LDH
	Lat./Long.			30°54'15"N, 75°50'24"E	30°54'15"N, 75°50'24"E	30°54'15"N, 75°50'24"E	30°54'15"N, 75°50'24"E
	Building height (agl)		m	15	15	15	15
	Antenna height (agl)		m	26	28	30	32
Adjacent building data (within 100 m radius)	Units			Distance	Azimuth	Height	
				m	deg	m	
	Building 1 (B1)			35	70	10	
	Building 2 (B2)			25	338	15	
	Building 3 (B3)			42	242	12	
	Building 4 (B4)			65	136	20	
Calculation data for adjacent building & ground	EIRP/EIRP$_{th}$ Calculation for general public						
	Operator/Service		Ground	B1	B2	B3	B4
	GSM	EIRPTh1	197659.339	411106.46	411106.46	411106.46	411106.46
		EIRP Th2	154164.922	1277926.41	635520.341	1554337.7	3067101.67
		EIRP Th(Min of ETH1 & ETH2)	154164.922	411106.46	411106.46	411106.46	411106.46
		EIRP/EIRPth	0.00807809	0.00302928	0.00302928	0.00302928	0.00302928
	3G /UMTS	EIRPTh1	497632.2385	1039624.113	1039624.113	1039624.113	1039624.113
		EIRP Th2	1039624.113	3012287.328	1551281.58	3557409.055	6695993.56
		EIRP Th(Min of ETH1 & ETH2)	497632.2385	1039624.113	1039624.113	1039624.113	1039624.113
		EIRP/EIRPth	0.00543440	0.002601259	0.002601259	0.002601259	0.002601259
	CDMA	EIRPTh1	178720.2666	740694.3175	740694.3175	740694.3175	740694.3175
		EIRP Th2	740694.3175	2036543.036	1092146.213	2334991.791	4182813.109
		EIRP Th(Min of ETH1 & ETH2)	178720.2666	740694.3175	740694.3175	740694.3175	740694.3175
		EIRP/EIRPth	0.00421645	0.001017378	0.001017378	0.001017378	0.001017378
	WiMAX	EIRPTh1	1069619.606	1955114.324	1955114.324	1955114.324	1955114.324
		EIRP Th2	1955114.324	5179378.919	2903634.997	5766941.954	9814473.895
		EIRP Th(Min of ETH1 & ETH2)	1069619.606	1955114.324	1955114.324	1955114.324	1955114.324
		EIRP/EIRPth	0.00215225	0.001177468	0.001177468	0.001177468	0.001177468
	Overall EIRP/EIRPth		0.0198812	0.0078254	0.0078254	0.0078254	0.0078254
Result	Normally compliant (<1)		Yes	Yes	Yes	Yes	Yes

It is the responsibility of the wireless service provider to ensure provision of proper signage warning entry of general public of the exclusion zones. The 'danger signboard' should be placed on the tower structure; 'warning signboard' should be placed at the entry point of the exclusion zone and the 'caution signboard' should be placed at the entrance of the base station compound in case of ground base tower (GBT) or at the entry point of the roof of the building in case of roof top tower (RTT).

Further, the assessment of $EIRP_{th}$ at four nearby buildings (accessibility category 3) has been done using Eqs (7) and (8). It has been found that the overall EIRP/$EIRP_{th}$ ratio at all the four buildings are less than unity (Table 7). Thus, it can be concluded that this particular site is normally compliant and does not cause adverse health effects. But, it is important to note that the present threshold limits prescribed by the ICNIRP are considered to be rather too generous and hence, there is a need to review and remedy the situation and not wait until it becomes the subject matter of a public interest petition in the light of possible environmental adverse effects.

5 Conclusions

The operators providing wireless communication should consider seriously this study and ITU-T recommendations, especially K.52, K.61 and K.70 (Refs 12-14), in order to keep the operation of base station transceivers in compliance with regulations concerning environmental protection against non-ionizing radiation. Further, it is important to note that the present threshold limits prescribed by the ICNIRP are considered to be rather too generous and hence, there is a need to review and remedy the situation and not wait until it becomes the subject matter of a public-interest petition in the light of possible environmental adverse effects.

Acknowledgements

The author would like to express gratitude to all those who made it possible to complete this work. The author would like to thank Bharat Sanchar Nigam Ltd for giving permission to commence this work, to do the necessary research work and to use departmental facilities and resources.

References

1 Interphone Study Group, Brain tumour risk in relation to mobile telephone use: Results of the Interphone international case-control study, *Int J Epidemiol (UK)*, 39 (2010) pp 675-694.

2 Independent Expert Group on Mobile Phones (IEGMP), *Mobile phones and health* (IEGMP, Chilton), 2000.

3 Scientific Committee on Emerging and Newly Identified Health Risks (SCENIHR), *Health effects of EMF*, (SCENIHR, EC, Brussels), 2009.

4 Santini R, Santini P, Danze J M, LeRuz P & Seigne M, Survey study of people living in the vicinity of cellular phone base stations, *Electromagn Biol Med (UK)*, 22 (1) (2003) pp 41–49.

5 Navarro Enrique A, Segura J, Portolés M & de Mateo Claudio Gómez-Perretta, The microwave syndrome: A preliminary study in Spain, *Electromagn Biol Med (UK),* 22 (2) (2003) pp 161–169.

6 Abdel-Rassoul G, El-Fateh O Abou, Salem M Abou, Michael A, Farahat F, El-Batanouny M & Salem E, Neurobehavioral effects among inhabitants around mobile phone base stations, *Neuro Toxicol (USA)*, 28 (2) (2007) pp 434–440.

7 Swerdlow Anthony J, Feychting Maria, Green Adele C, Kheifets Leeka & Savitz David A, Mobile phones, brain tumours and the Interphone study: Where are we now?, *Environmental health perspectives*, (US Federal Govt, New York), 2011, pp 1-22.

8 Ahlbom A, Feychting M, Green A, Kheifets L, Savitz D A & Swerdlow A J, Epidemiologic evidence on mobile phones and tumour risk: a review, *Epidemiol (USA)*, 20 (2009) pp 639-652.

9 ICNIRP, ICNIRP statement on the Guidelines for limiting exposure to time-varying electric, magnetic, and electromagnetic fields (up to 300 GHz), *Health Phys (Germany)*, 97 (3) (2009) pp 257-258.

10 *IARC classifies radiofrequency electromagnetic fields as possibly carcinogenic to humans*, http://www.iarc.fr/en/media-centre/pr/2011/pdfs/pr208_E.pdf.

11 Ekta Singh, Cell phone hazards and recommendations, *J Telecommun (India)*, 59 (6) (2011) pp 44-50.

12 ITU-T Recommendation K.52, *Guidance on complying with limits for human exposure to electromagnetic fields*, (ITU, Geneva, Switzerland), 2004.

13 Recommendation ITU-T K.61, *Guidance on measurement and numerical prediction of electromagnetic fields for compliance with human exposure limits for telecommunication installations* (ITU, Geneva, Switzerland), 2008.

14 ITU-T Recommendation K.70, *Mitigation techniques to limit human exposure to EMFs in the vicinity of radio communication stations* (ITU, Geneva, Switzerland), 2007.

15 CENELEC EN 50383:2002, *Basic standard for the calculation and measurement of electromagnetic field strength and SAR related to human exposure from radio base stations and fixed terminal stations for wireless telecommunication systems (110 MHz–40 GHz)* (European Committee for Electrotechnical Standardization, Brussels), 2002.

16 CENELEC 50413:2007, *Basic standard on measurement and calculation procedures for human exposure to electric, magnetic and electromagnetic fields (0 Hz–300 GHz)* (European Committee for Electrotechnical Standardization, Brussels), 2007.

17 IEC/CENELEC 62311:2007, *Assessment of electronic and electrical equipment related to human exposure restrictions for electromagnetic fields (0 Hz – 300 Hz)* (European Committee for Electrotechnical Standardization, Brussels), 2007.

18 ISO/IEC MISC UNCERT, *Guide to the expression of uncertainty in measurement* (International Organization for Standardization, Geneva), 1995.