CHAPTER – 2

UNDERSTANDING EMR, ITS SOURCES AND EFFECTS

2.1 History

Most commonly used term in Electromagnetic Radiations (EMRs) i.e. Radio wave, is a type of electro-magnetic field. EMR existed in nature before man came into existence. There are electro-magnetic fields of various frequencies from outer space reaching earth in addition to ultraviolet rays or visible light.

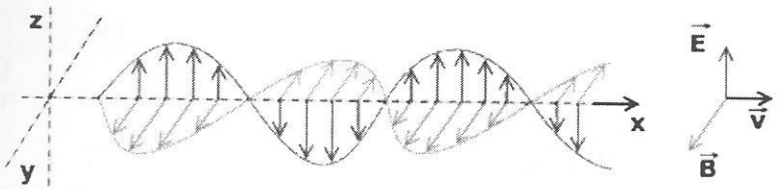
Mankind began using radio waves more than 100 years ago with the invention of wireless communication by Marconi and Tesla. In India the first wireless use was in 1902, commercial radio broadcast started in 1927 and the first Television broadcast in 1959 and since then the radio waves have been contributing towards advancement of culture, security and innumerable day to day services. It has now become part of our way of life, being used for TV, radio, mobile phone, weather satellite, Global Positioning System (GPS), disaster management, remote sensing, etc. As we cannot see it or feel it directly, it is quite obvious to have some anxieties against radio waves and it becomes important to understand the safety aspects of the use of Electromagnetic Radiations. With the new wireless technologies being introduced at a rapid pace our use of radio wave is poised to continue to increase.

2.2 Understanding Electromagnetic Radiation

Electromagnetic Radiation (EMR) is a form of radiant energy released by certain electromagnetic processes. Visible light is one type of EMR. Other

familiar forms are invisible EMRs such as X-rays, infrared light and radio waves. Classically, Electromagnetic Radiations consist of Electromagnetic waves which are synchronized self-propagating oscillations of electric and magnetic fields, which propagate at the speed of light. The oscillations of the two fields are perpendicular to each other and perpendicular to the direction of wave propagation and energy, forming a transverse wave as shown in Fig. 2.1 below.

Fig. 2.1: Electromagnetic Radiations



Electric and magnetic fields are fundamental forces in nature. Together they create invisible electromagnetic waves which pass through the environment - like waves or ripples on the surface of water. Electromagnetic waves have different properties and uses, depending on their wavelength. Radio waves occur within a specific range of wavelengths and are useful for transmitting sound and digital signals.

Electromagnetic waves travel with the speed of light. They can be characterized by either the frequency or wavelength of their oscillations. The range of all possible frequencies of EMRs is called as the electromagnetic spectrum. The Electromagnetic spectrum includes: gamma rays, X-rays, ultraviolet radiation, visible light, infrared radiation, microwaves and radio waves, in order of decreasing frequency and increasing wavelength. Thus the electromagnetic spectrum extends from below low frequencies used for

communication to gamma radiations at the short wavelength (high frequency) end, thereby covering wavelengths from thousands of kilometers down to the size of an atom. Table 2.1 below, depicts the electromagnetic spectrum,

Table 2.1: Electromagnetic spectrum

Class			Frequency	Wavelength
Ionizing radiation	Γ	Gamma rays	300 EHz	1 pm
			30 EHz	10 pm
	HX	Hard X-rays		
			3 EHz	100 pm
	SX	Soft X-rays	300 PHz	1 nm
			30 PHz	10 nm
	EUV	Extreme ultraviolet		
			3 PHz	100 nm
Visible	NUV	Near ultraviolet	300 THz	1 μm
	NIR	Near infrared		
			30 THz	10 μm
	MIR	Mid infrared		
			3 THz	100 μm
	FIR	Far infrared		
Micro-waves and radio waves	EHF	Extremely high frequency	300 GHz	1 mm
			30 GHz	1 cm
	SHF	Super high frequency		
			3 GHz	1 dm
	UHF	Ultra high frequency		
			300 MHz	1 m
	VHF	Very high frequency		
			30 MHz	10 m

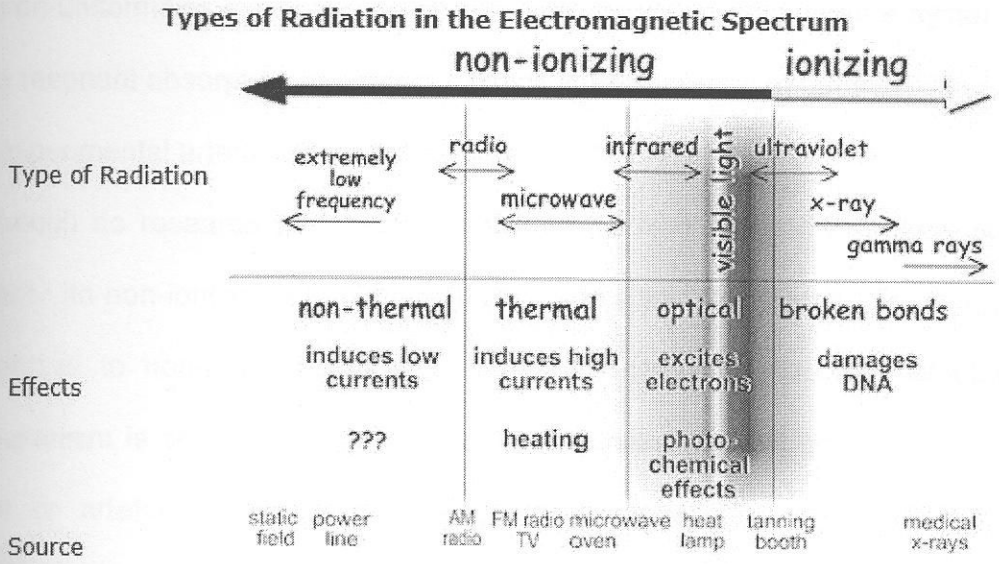
	HF	High frequency	3 MHz	100 m
	MF	Medium frequency	300 kHz	1 km
	LF	Low frequency	30 kHz	10 km
	VLF	Very low frequency	3 kHz	100 km
	ULF	Ultra low frequency	300 Hz	1 Mm
	SLF	Super low frequency	30 Hz	10 Mm
	ELF	Extremely low frequency	3 Hz	100 Mm

2.3 Effects of Electromagnetic Radiations

EMRs carry energy and can impart the same to the matter with which they interact. When EMRs are absorbed by an object, energy of the waves is converted into heat. The effects of EMRs upon biological systems depend both upon the radiation's power and its frequency. For EMR of visible or lower frequencies (i.e. radio, microwave, infrared), the effect on cells and other materials is determined mainly by the power of EMR and caused primarily by heating effects from the combined energy transfer of many photons, called as non-ionizing radiation (NIR). By contrast, for ultraviolet and higher frequencies (i.e. X-rays and gamma rays), chemical materials and living cells can be further damaged beyond that done by simple heating, since individual photons of such high frequency have enough energy to cause direct molecular damage. This is

called as ionizing radiation. Figure 2.2 below, taken from North Carolina Radiation Protection Section, Non-Ionizing Radiation website, shows non-ionizing and ionizing radiations in the Electromagnetic spectrum.

Figure 2.2: Non-ionizing and Ionizing radiations in the Electromagnetic spectrum



(Source: North Carolina Radiation Protection Section, Non-Ionizing Radiation website http://ncradiation.net/NonIonizing/NonIonizing.htm)

Radio devices emit non-ionising radiation. EMR of the ionizing radiation type is considered to be bad, as it can rip the molecules apart and cause DNA (Deoxyribonucleic Acid) damage. But, what about EMR that is non-ionizing? If it doesn't break the chemical bonds, does that mean it is safe? Thus a further and more vexing question is, whether there may exist a form of RF energy absorption that may not manifest itself in a measurable increase in tissue temperature, but could nevertheless be linked to bio-effects. These have been termed athermal or

non-thermal effects, but since there is still the possibility of these being due to a local thermal mechanism, the term 'low-level effects' is preferred.

As per the Australian[5] Protection Series No. 3, these effects could be due to,

a) a differential uptake of RF energy by specific cell types or cellular components;

b) non-uniformities in energy absorption patterns within an exposure system;

c) a resonant absorption mechanism which is non-thermal in nature;

d) experimental artefact or statistical anomaly.

Although no research to-date has definitively linked specific diseases, such as cancer, to non-ionizing EMR, there have been a lot of recent studies suggesting exposure to non-ionizing radiation can have some effects, too. Whether the mechanism is actually thermal or not, or whether these reported bio-effects are real or artefactual, the effects suggesting statistically significant biological interactions need to be replicated satisfactorily.

2.4 All objects emit Electromagnetic Radiations continuously

All objects, including sun, earth, human beings, etc., with temperature greater than absolute zero (i.e. -273.15°C) emit EMRs continuously. They emit radiation over a wide range of wavelengths however the amount of energy emitted at each wavelength is not the same. A hotter object will radiate more energy at higher frequencies/ shorter wavelengths and a cooler object radiates most of its energy at lower frequencies/ longer wavelengths. Sun has an average temperature of

[5] Australian Radiation Protection and Nuclear Safety Agency, Radiation Protection Standard (2002), *Maximum Exposure Levels to Radiofrequency Fields — 3 kHz to 300 GHz*, Radiation Protection Series Publication No. 3

about 5800K and the wavelength where most of the sun's energy comes from (or wavelength of peak emission) is in the visible portion of the spectrum (it comes exactly at 0.5 micrometers, which is the wavelength of green light). Similarly earth has an average temperature of about 288K and it emits most of its energy at about 10 micrometer wavelength. Also the total amount of energy an object emits is related to its temperature. Objects with a higher temperature will emit more energy than cooler objects.

Additionally, there are electronic devices, emitting EMRs. Even an electric wire carrying current through it, emits EMRs. Radiation emitting devices include electronic products, such as medical and non-medical equipments, lasers, x-ray systems, ultrasound equipments, microwave ovens, mobiles, cordless phones, wireless door bells, wireless routers/ modems, wireless gaming equipments, blue tooth enabled equipments, etc. According to the Food and Drug Administration (FDA is a federal agency of the U.S. Government), a radiation-emitting device is any product that uses electricity to power an electronic circuit. Most home appliances like TVs, laptops, tablets, electric heaters, voltage transformers, electric motors in various appliances viz. refrigerator, air-conditioning systems, fans, washing machines, sewing machines, analog clocks, hair dryers, electric shavers, aquarium & ponds filters, etc. emit EMRs in the range of Low Frequencies (LF) to Extremely Low Frequencies (ELF).

2.4.1 Electromagnetic Radiations from microwave ovens

The microwave oven can be found in almost every kitchen in the modern world. Microwave ovens use the heating effect of EMRs (in the frequency of

water molecules) to heat the fluid in the food and by that, to heat the food itself. The frequency used in microwave is around 2.4 GHz and it is similar to the frequencies used for communication i.e. mobile phones. When a microwave oven is on, part of the radiation goes through the protection shield-filter, which is part of the microwave oven door and spreads into the room. The part of the radiation that escapes from the oven is relatively small and can't cook our body during the short time it is on, but it is definitely not recommended to look into the oven for those several seconds (possible damage to the eye protein).

2.4.2 Electromagnetic Radiations from wireless routers/ modems

Wireless Internet routers or Wi-Fi modems use EMRs to send the signals to the computer through walls. The Wi-Fi routers/ modems that make it so convenient to get online, emit EMRs in the low gigahertz frequency level. In fact, the typical home or office wireless modems transmit radio signals in the same general frequency range as the frequency that microwave ovens use to cook food. Wi-Fi routers not getting turned off at night worsens the situation. They stay on, connecting the machines to the internet whether we are surfing or not and flooding the space with EMRs 24/7.

2.4.3 Electromagnetic Radiations from cordless phones

All cordless phones emit EMRs. The frequency of the signal is different from one type of phone to the other. Some old cordless phones work on ~50Mhz or ~90Mhz frequency, while others use ~900Mhz, ~1.7GHz, 1.9GHz, 2.4GHz and also 5.8GHz. EMR is emitted both from the base station and from the handset. The levels of the radiation are constant in most of the cordless phones and

depend on the maximum distance (between the base station and the handset) that the phone can support. There are digital (new) and analog (old) cordless phones. In most digital cordless phones the base station transmits and therefore emits radiations, all the time, even when not making a call. Sitting next to phone's base station will expose to high to mid-levels of EMRs. If the phone's base station is placed next to a wall, high to mid-levels of EMRs pass through on the other side of that wall. The handset usually emits EMRs only when making a call.

2.4.4 Electromagnetic Radiations from mobile phones

A mobile handset or a cellular phone is a low-power, two way radio. It contains a transmitter and a receiver. It emits EMR to transmit information to the base station and it also acts like a receiver of information. Radio signals in a mobile phone are generated in the transmitter and emitted through its antenna. Mobile phones operate at frequencies between 450 and 2700 MHz with peak powers in the range of 0.1 to 2 watts. In India mobile phones operate in the frequency range[6] of:

- 869 - 890 MHz (CDMA)
- 935 - 960 MHz (GSM900)
- 1805 – 1880 MHz (GSM1800)
- 2110 – 2170 MHz (3G)

Analog mobile phones which are being phased out, use up to 2 watt, while a digital mobile phone has an average power level of 0.25 watt. Phones typically operate at much lower levels during normal use as the phone power is

[6] Government of India, Ministry of Communications & IT, Department of Telecommunications, *Mobile Communication – Radio Waves & Safety*

automatically adjusted to the minimum radio signal level needed for call quality. This extends battery life. The handset only transmits power when it is turned on.

Different mobile handsets create varying electromagnetic fields owing to differences in their design and construction, as well as their electronics and antenna. It is indicated by the SAR (Specific Absorption Rate) value or limit. SAR is the rate at which Radio Frequency (RF) energy is absorbed in the human body over a given time and expressed as the power absorbed per unit mass. SAR values are usually expressed in the units of watts per kilo gram (W/kg) of tissue. This measurement is used to determine whether a mobile phone complies with safety norms/ guidelines.

Every model of mobile handset has specific SAR value. The SAR rating of mobile handset is a specified value which indicates that the device will never exceed the maximum level of consumer RF exposure as indicated in the rating. It does not indicate the amount of RF exposure the consumers experience during the normal use of the device. The actual SAR level of an operating device can be below the maximum value and variable, depending on a number of factors. A mobile phone which operates at lower power is considered more efficient. In India, the SAR limit for cell phones prescribed is 1.6 W/Kg averaged over one gram of human tissue.

2.4.5 Electromagnetic Radiations from various towers

The most common types of towers, include those for FM/AM radio, TV transmission and Communication networks using GSM (Global System for Mobile communication), CDMA (Code Division Multiple Access) & WLAN/ Wi-Fi/

Wi-Max technologies. Various towers contain radio transmitter and receivers with antennas mounted on them at the heights, varying from 50 to 200 feet. The antennas transmit and receive EMRs in the form of radio waves, which occupy the VHF and UHF frequencies. Details of various towers and mobile as sources of EMRs taken from TRAI Information paper No. 01/2014-QoS published on 30th July, 2014, are shown below in Table 2.2.

Table 2.2: Towers and mobiles as sources of Electromagnetic Radiations

Sl. No.	EMF Source	Operating Frequency	Transmission Power	Number
1.	AM/FM Tower	540 KHz – 108 MHz	1 KW – 30 KW	380
2.	TV Tower	48 MHz – 814 MHz	10 – 500 Watt	1201
3.	Wi-Fi	2.4 – 2.5 GHz	10 – 100 mW	
4.	Cell Towers	800, 900, 1800, 2100, 2300 MHz	10 – 20 W	~ 5 lakh
5.	Mobile Phones	GSM-1800/CDMA GSM-900	1 W 2 W	900+ Million

(Source: TRAI Information paper No. 01/2014-QoS published 30th July, 2014)

What we have to be cautious of, is extensive exposure to high level of radiation, whether it's natural or artificial.

2.5 Electromagnetic Radiation from mobile towers[7]

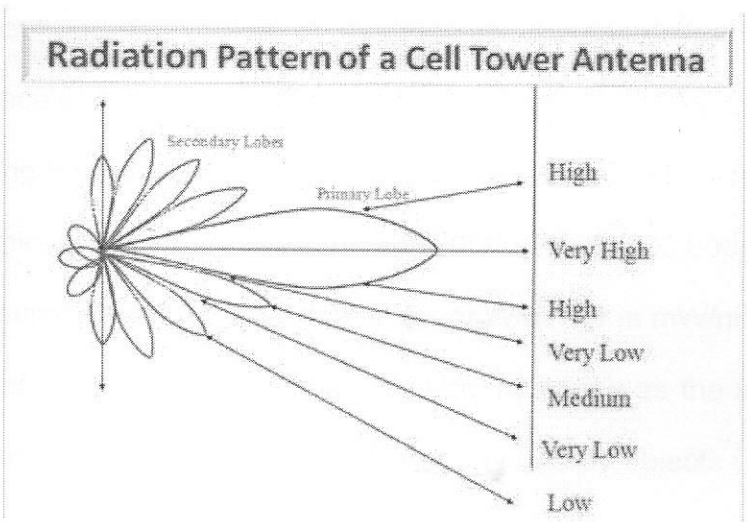
For providing mobile services, telecom service providers establish base transceiver stations (BTSs), at suitable locations, as per their RF Network Planning, for proper coverage of the area and for meeting capacity requirements. A typical BTS is an equipment that facilitates wireless communication between

[7] Telecom Regulatory Authority of India (30th July, 2014) *Information paper No. 01/2014-QoS on Effects of Electromagnetic Field Radiation from Mobile Towers and Handsets*

user equipment e.g. a mobile phone and a network of the telecom service provider.

BTS contains a number of radio transmitters and each of these has the same maximum output power. The outputs from the individual transmitters are then combined and fed via cables to the base station antenna, which is mounted at the top of a tower/ mast (or other suitable structure). Thus the radiated power would ideally be equal to the sum of the output power from the transmitters except for a small loss that occurs in the combiner and connecting cables. It should be noted that all the transmitters are not operational continuously; this depends on the call traffic in each of the sectors. However the level of exposure is maximum at the time of peak traffic when all the channels are utilized and hence sectors with higher call traffic carry the risk of having maximum EM exposure.

Figure 2.4: Radiation from mobile BTS



(Source: TRAI, Information paper No. 01/2014-QoS published 30th July, 2014)

The real source of EM 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. Rectangular shaped "Panel" antennas[8] are the most commonly used, which direct the radio signal power outward, in a beam that is typically very narrow in the vertical direction but quite broad in the horizontal direction. Radiation will be highest from the primary lobe in the horizontal direction. There is also radiation from secondary lobes which ranges from medium to very low when transmitting horizontally as seen in the figure 2.4 above. Hence, the direct exposure to the primary lobes along the line of antenna is the most severe of the exposed radiation. The radiation levels relatively taper as one moves away from the line of the antenna to its side lobes. The transmission power levels and the gain of the antennas used for transmission are the major factors to be considered when dealing with exposure levels.

The distance from the source of radiation is another critical factor. The radiation level received from an antenna, usually measured as power density is the power passing through $1m^2$. The power is usually measured in watts (W), mill watts (mW) or microwatts (μW), where 1W = 1,000mW = 1,000,000μW, and the intensity is measured in watts per square meter or W/m^2 (or in mW/m^2 or $\mu W/m^2$). Since the area of a sphere surrounding a source increases as the square of its radius, then in an ideal case (in the absence of any nearby objects including the ground) the power falls off by $1/R^2$, where R is the distance. As one moves away

[8] http://www.mcf.amta.org.au/pages/Fact.Sheets (accessed 5 March 2016)

from antenna the power received weakens very quickly and is reduced to $1/4^{th}$ when distance from the source doubles and $1/9^{th}$ when distance is tripled and so on.

The power of a base station varies depending on the area that needs to be covered and the number of calls processed. This is low compared to other transmitters such as radio and television, which usually work at power levels ranging from several kilowatts to several megawatts. Assessments of personal exposure levels are most accurately achieved through onsite field measurements. Theoretical calculations are also common but are complicated by the many factors that influence the actual exposure such as the height, tilt and direction of antenna, absorption from trees and plants or reflections from buildings, as well as distance.