# Biological Implications of Microwave Electromagnetic Field

[Sovan Mohanty & Hardesh kumar singh]

***Abstract*: The bodies of human beings and all animals are actuated by a complex network of noiseless, lossless transmission lines or axons controlled by a parallel processing computer or brain. So the body of human being is very much equivalent to a complex electronic and electrical circuit and this circuit can be controlled internally as well as externally effectively provided radio frequency power applied to it in a controlled and delicate manner. The question of hazard also arises from the unintentional exposure to radiation from high power radio, TV, radar and wireless transmitter. It is of concern to human that radio frequency heating can occur internally without much awareness because our heat sensors are on the skin. The effect becomes apparent at higher frequencies. Often question arises why transmission line effect usually noticeable at high frequency? What happens at low frequency? What are the definitions of high and low? What is near field and far field? How this effect creates nonlinearity in the atmosphere which has adverse impact on the life of animals and plants? Thus safe power spectral density and spectrum guidelines are mandatory to avoid being cooked internally without even realizing it.**

***Keywords*: Electromagnetic radiation, SAR, Resonant frequency, Radiation doses, Power spectral density.**

## I. Introduction

The study of human exposure to radio frequency (RF)/ microwave radiation (MW) has been subject of widespread analysis and discussion. It is well known fact that with any exposure to radiation involve some health risk. Therefore it is required to quantify the radiation exposure on the human body in order to optimize the safety guideline for safe exposure level. The absorption of RF/MW radiated energy causes biological reactions to occur in the tissue of the human body. In order to determine safe exposure levels and to understand the effect of RF/MW radiation it is necessary to know the absorption characteristics of the human tissues. Factors which govern energy absorption include: 1) strength of the external electromagnetic (EM) field 2) resonant frequency of the human body with respect to space and time 3) frequency of the RF/MW source 4) the degree of hydration of die tissue and 5) the physical dimensions, geometry, and orientation of the absorbing body with respect to the radiation EM field. The most commonly accepted measure is the Specific Absorption Rate (SAR). Based on the known absorption rates and the inherent biological effects of RF/MW radiated energy it is feasible to set certain standards regarding the safe exposure levels.

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## II. Theoretical Analysis:

### A. *Electromagnetic Radiations (technical analysis):*

Electromagnetic radiation has both electric and magnetic field components, which are phase orthogonal to each other and orthogonal to the direction of propagation of energy. Radiation from charges can also be analyzed from kinetic energy perspective. Newton's second law of motion states that a force is needed to accelerate a particle. The force transfer energy to the particle thus increasing its kinetic energy. Electromagnetic radiation, be it RF, thermal or optical or optical radiation is created by changing the energy of electrons or other charged particles. This expression includes not only changes in energy of free electrons due to acceleration and deceleration but also the change in energy of electrons bound in atoms due to change in orbital quantum state changes[1]. The radiated power for the field created by an alternating current is

$$\sqrt{(Radiated\ field)} = I \times L \times f \ldots (1)$$

Where, I=current, L=length and f= frequency

The power density of an electromagnetic field at a distance 'r' from the source can be represented by a series in 1/r. Thus

$$Field\ power\ density = \frac{C_1}{r^2} + \frac{C_2}{r^2} \ldots(2)$$

Thus a given circuit will radiate more at higher frequencies [1]. Where exactly does this far field start from? The receiver should be located at least at a distance 'r' [5] where

$$r > 2\frac{D^2}{\lambda}$$

Electromagnetic radiation can be classified into two categories that are ionizing radiation and non-ionizing radiation. If it is capable of ionizing atoms and breaking chemical bonds then it is called ionizing radiation otherwise it is called non-ionizing radiation. Ionizing radiation is associated with two major potential hazards: electrical and biological. High power electromagnetic radiation can cause electric currents strong enough to create sparks when an induced voltage exceeds the breakdown voltage of the surrounding medium. These sparks can then ignite flammable materials or gases, possibly leading to an explosion. The biological effect of electromagnetic fields is to cause dielectric heating. Complex biological effects of weaker non-thermal electromagnetic fields also exists, including weak Extremely Low Frequency magnetic fields and modulated Radio Frequency and microwave fields. Magnetic fields induce circulating currents within the human body and strength of these magnetic fields depends directly on the intensity of the impinging magnetic field. These currents cause nerves and muscles to stimulate which in turn affects biological processes. The influence of the weak EM radiations on human can be realized as sequence of events which includes exposure to EM radiations which when absorbed modulates the biological field patterns, accumulation of energy and information into the body fluid, change in the functional activities of cell which finally results into some disease. Whether the source of radiation is natural or man-made, whether it is a small dose of radiation or a large dose, there will be some biological effects.

### B. *The lossless, noiseless active transmission line (Axon):*

The nervous systems of animal consist of many nerve cells called neurons and each having an active transmission line. The axon is an active transmission line with EMF inputs all along it so that distortion of the signal in terms of attenuation and phase altercation is absolutely zero. At the input end a structure called dendrites interface with active transducer is highly sensitive to heat, pressure or other stimuli. When excitations voltage it receives from the dendrite exceeds threshold limit, it generates a signal on the axon to the end region, actuating a motor unit or another axon. Many neurons may be connected in series by structures called synapses in which output dendrites of one neuron connect with the input dendrites of the next neurons. The velocity of propagation of signal along a particular axon is proportional to its shape but approximately it is about 100 m/s. The axon is enclosed in a myelin sheath which basically acts as a passive insulator. By diffusion of ions from the surrounding medium emf is induced within the system. The induced voltage produces a current via the axon which triggers the next node. The diffusion of Potassium ions and miscellaneous leakage ions keeps the inner axon negative by about 100mV [2]. But on excitation the diffusion of sodium ions swing the potential positive for the period of impulse which is typically a few tenths of millisecond. The recovery of the axon to its normal negative potential after the passage of the impulse is accomplished in less than 1ms.As the full impulse voltage is received at the terminals, the axon transmission line has zero attenuation and it implies noiseless nature of the transmission line.

### C .*The circuit analysis of transmission line:*

We can model the transmission line using a basic circuit that consists of an infinite series of R, L and C elements and a small conductance G because all dielectric exhibits some leakage. Because the elements are infinitesimal, the model parameters (L, C, R, and G) are usually specified in units per meter. How does this circuit react at different frequencies? Inductive and capacitive reactance depends on frequency. At low frequencies, the LC pairs introduce negligible delay and impedance, reducing the model to a simple pair of ideal wires. At higher frequencies, the LC effects dominate the behavior and it cannot be ignored. We can calculate the speed of light in a transmission line from the permittivity (ε) and permeability (μ) of the dielectric between the conductors i.e

$$\nu = \frac{1}{\sqrt{\mu\varepsilon}}$$

As the signal travels along the transmission line, the voltage wave defines the voltage at each point and the current wave defines the current at each point. Along the entire length of the line, the ratio of the voltage to the current is constant. The ratio is the “characteristic impedance,” Zo and is defined by the geometry of the line and the permittivity and permeability of the dielectric. Whenever an electromagnetic wave encounters a change in impedance, some of the signal is transmitted and some of the signal is reflected. The difference between the impedances determines the amplitude of the reflected and transmitted waves [3]. The reflection coefficient ρ, for the voltage wave is

$$\rho = \frac{V_{ref}}{V_{inc}} = \frac{(Z_2 - Z_1)}{(Z_2 + Z_1)} \ldots (3)$$

Whereas the transmission coefficient is

$$\Gamma = \frac{V_{txd}}{V_{inc}} = 1 + \rho \ldots (4)$$

An interesting and often under emphasized fact is that the amount of reflection is independent of frequency and occurs at all frequencies [4]. This fact seems contrary to the common belief that reflections are high-frequency phenomena. The transmission-line effects (overshoot and oscillation) become apparent when the rise time is short compared with the transmission-line delay, t. Such signals are therefore in the domain of high-frequency design. There are two ways in which a transmission line can be modeled (i) wave guide model (ii) circuit model. So both form of ideal model of the transmission line are almost equivalent to the active transmission line i.e. axon, where losses is negligibly small and data carrying speed of the circuit is significantly high. But when transmission line is being exposed to the high frequency and high power signaling environment then reactive part of the circuit will dominate. Because of sustained and continuous exposure to the adverse atmosphere the sensitivity of the input transducer will decay at a rate which is directly proportional duration and magnitude of the power density exposure. As a result transmission line will become noisy and it’s propagation coefficient alters [15]. Thus there’ll be change in magnitude and phase of the signal and body as a system become unsynchronized and incoherent. There will be phenomenal change in computational capability where probability of error is maximum. It leads to generation of numerous diseases.

## III. *RF/MW Energy Deposition*

The absorption of RF/MW radiated energy causes biological reactions to occur in living organisms. In order to understand the potential effects of RF/MW radiation, it is important to quantify the absorption characteristics of biological materials. Researchers have identified several principal factors that govern the absorption of RF/MW energy by the human body. Experimental results have indicated that clothing thickness, physical dimensions, degree of hydration, and the resonance frequency of the human body are important parameters that determine the amount of energy absorbed by the body.

## A. *Specific Absorption Ratio (SAR)*

SAR is a measure of the amount of radio frequency (RF) energy that is absorbed by the tissue in the human body that is measured in watts per kilogram. The exposure limit takes in consideration with the body's ability to remove heat from the tissues that absorb energy from the cell phone & is set well below levels known to show biological effects. The U. S. Federal Communications Commission (FCC) & International Commission on Non-Ionizing Radiation Protection (ICNIRP) recommend the localized SAR in the head is to be limited to 1.6 to 2 Watts per kilogram averages over any 10g mass of tissues in the head [13].

## B. *Depth of Penetration of Energy*

It is known that RF/MW radiated energy will be absorbed by the tissue of the human body. The depth of energy penetration into the tissue depends primarily on the wavelength of the incident radiation and the water content of the tissue. Energy emitted in the millimeter-wave band is not likely to penetrate to more than about 1or 2 mm into the tissue. Essentially, RF/MW energy radiated at wavelengths less than 3 centimeters will be captured in the outer skin surface. RF/MW wavelengths from 3 to 10centimeters will penetrate to a depth of about 1to 10 mm. The greatest depth of penetration into the body will occur at wavelengths between 25 to 200 centimeters. At these wavelengths RF/MW radiated energy can directly affect internal body organs and cause serious injury. The human body is reported to be transparent to RF/MW radiated energy emitted at wavelengths greater than 200 centimeters. Also, at frequencies above 300 MHz it has been observed that the depth of energy penetration fluctuates rapidly with changes in frequency [13]. In general, the depth of energy penetration into the body will decline as the frequency of the incident radiation increases. At 10GHz, the absorption of RF/MW energy will be similar to IR radiation. The water content of the human tissue will also influence the depth of energy penetration into the body. Millimeter-wave radiation is reported by Gandhi and Riazi to penetrate less than 2 mm into the body because of the "Debye relaxation of the water molecules" in the tissue [6]. He discovered that EM waves are absorbed by a dielectric because of molecular dipoles present in the dielectric material. Water molecules are essentially dipoles constructed from atoms of hydrogen and oxygen. Biological materials such as skin are dielectrics that consist mostly of water. Hence, these dielectrics are rich in molecular dipoles and are able to quickly absorb millimeter-wave radiation. High frequency radiation emissions are not expected to penetrate deeply into the human body.

## C. *Effect of Geometry*

The orientation of the human body with respect to the incident EM field will determine the amount of RF/MW energy that is absorbed by the tissue. The condition for maximum absorption occurs when the electric field is parallel to the major axis of the body and the direction of the field propagation is from arm to arm.

## D. *Effect of Resonance Frequency*

Researchers have reported that the human body will absorb the greatest amount of RF/MW energy from sources radiating at the whole-body resonance frequency. The ANSI Standard reports that the human body will absorb 7 times more energy from radiation emitted at the resonance frequency than at a frequency of 2450 MHz. Experiments conducted on fabricated human models have been used to determine the resonance frequency of the human body. The free space whole-body resonance frequency is reported to be between 61.8-77 MHz for a Standard Model of Man. The standard model depicts an average man of height 175 cm. The ANSI Standard reports the whole body resonance frequency to be 70 MHz. It has been reported that the maximum absorption of energy will occur at frequencies where the free space wavelength **(λ)** of the incident radiation is about 2.50-2.77 times greater than the major length (L) of the body (i.e. 9>23.50L-2.77L) [6]. This formula puts the value of the resonant frequency between 61.8-68.5 MHz for a standard model of man. When the human body is in contact with the electrical ground, the whole body resonance frequency is reduced to about 47 MHz. The free space resonance frequency of the human head is about 375 MHz [13]. The head resonance will occur when the free space wavelength of the incident radiation is about 4 times the diameter of the head. The condition for maximum energy absorption occurs when the direction of the EM field propagation is parallel to the long axis of the body. This orientation differs from the condition determined for RF/MW energy absorption by the whole-body.

## E. *Effect of Clothing:*

Clothing can act as an impedance matching transformer for RF/MW radiation. It is reported that the coupling efficiency of clothing may be as high as 90-95 percent for incident radiation in the millimeter-wave band [6]. They determined that the thickness of the clothing and frequency of the incident radiation are important factors in the coupling condition. It has been observed that wet or damp clothing may actually reduce the amount of energy absorbed by the body because of the Debye relaxation of the water molecules.

# IV. Electromagnetic Hazards

***(Biological Point of View)***

The response of biological materials to the absorption of thermal energy is the most perceptible effect of exposure to RF/MW radiation. Pulsed radiation appears to have the greatest impact on biological materials. The energy emitted from an RF/MW source is absorbed by the- human tissue primarily as heat. In this case, the radiated energy is disposed in the molecules of the tissue. Dipole molecules of water and protein are stimulated and will vibrate as energy is absorbed throughout the irradiated tissue area. Ionic conduction will also occur in the same area where the radiation is incident. It is from these two natural processes that radiant energy is converted into heat. Non-thermal responses can be less noticeable and are often more difficult to explain than thermal effects. These responses are related to the disturbances in the tissue not caused by heating. Electromagnetic fields can interact with the bioelectrical functions of their radiated human tissue**.** Some research suggests that the human body may be more sensitive to the non thermal effects of RF/MW radiation. These two mechanisms are commonly called direct and indirect effects.

## A. *Direct Effect:*

If radiation interacts with the atoms of the DNA molecule, or some other cellular component critical to the survival of the cell, it is referred to as a direct effect. Such an interaction may affect the ability of the cell to reproduce and, thus, survive. If enough atoms are affected such that the chromosomes do not replicate properly, or if there is significant alteration in the information carried by the DNA molecule, then the cell may be destroyed by “direct” interference with its life-sustaining system.

## B. *Indirect Effect:*

If a cell is exposed to radiation, the probability of the radiation interacting with the DNA molecule is very small since these critical components make up such a small part of the cell. However, each cell,just as is the case for the human body, is mostly water. Therefore, there is a much higher probability of radiation interacting with the water that makes up most of the cell’s volume.When radiation interacts with water, it may break the bonds that hold the water molecule together, producing fragments such as hydrogen (H) and hydroxyls (OH). These fragments may recombine or may interact with other fragments or ions to form compounds, such as water, which would not harm the cell.However, they could combine to form toxic substances, such as hydrogen peroxide ($H_2O_2$), which can contribute to the destruction of the cell. Cellular Sensitivity to radiation (from most sensitive to least sensitive) Lymphocytes and Blood Forming Cells, Reproductive and Gastrointestinal (GI) Cells, Nerve and Muscle Cells. Not all living cells are equally sensitive to radiation. Those cells which are actively reproducing are more sensitive than those which are not. This is because dividing cells require correct DNA information in order for the cell’s offspring to survive. A direct interaction of radiation with an active cell could result in the death or mutation of the cell, whereas a direct interaction with the DNA of a dormant cell would have less of an effect. [11] As a result, living cells can be classified according to their rate of reproduction, which also indicates their relative sensitivity to radiation. This means that different cell systems have different sensitivities. Lymphocytes (white blood cells) and cells which produce blood are constantly regenerating, and are, therefore, the most sensitive. Reproductive and gastrointestinal cells are not regenerating as quickly and are less sensitive. The nerve and muscle cells are the slowest to regenerate and are the least sensitive cells [13]. Cells, like the human body, have a tremendous ability to repair damage. As a result, not all radiation effects are irreversible. In many instances, the cells are able to completely repair any damage and function normally. If the damage is severe enough, the affected cell dies. In some instances, the cell is damaged but is still able to reproduce. The daughter cells, however, may be lacking in some critical life-sustaining component, and they die. The other possible result of radiation exposure is that the cell is affected in such a way that it does not die but is simply mutated. The mutated cell reproduces and thus perpetuates the mutation. This could be the *beginning of a malignant tumor* [14]. Cells are most sensitive when they are reproducing, and the presence of oxygen increases sensitivity to radiation. Anoxic cells (cells with insufficient oxygen) tend to be inactive, such as the cells located in the interior of a tumor. As the tumor is exposed to radiation, the outer layer of rapidly dividing cells is destroyed, causing it to “shrink” in size. If the tumor is given a massive dose to destroy it completely, the patient might die as well. Instead, the tumor is given a small dose each day, which gives the healthy tissue a chance to recover from any damage while gradually shrinking the highly sensitive tumor.

# V. RF/MW Radiation Exposure Standards

The transmission power in the handset is limited to a maximum of 2 watts in GSM850/900 and 1 watt in GSM1800/1900. The transmission power in the handset is limited to a maximum of 6 to 7mW

TABLE-2

| Mobile Technology | Power Level | Mode of transmission |
|---|---|---|
| GSM | 1-2 W | Burst |
| CDMA | 6-7 mW | Continuous |

In addition to the safe level guideline for radio frequency waves, there are even more stringent requirements for controlling unintentional radiation from electronic equipment which could interfere with other systems. A requirement of the U.S Federal Communication Commission (FCC) is that unintentional radiation from electronic equipment be less than 100 μV/m at a distance of 3m. Table-3 of power density, field strength and time to heat 10 liters of water at 1º C [1].

TABLE-3

| Category | Power Density | dB | Electric Field | Time to heat 10 liter 1º C |
|---|---|---|---|---|
| MegawattTX | 2.4 MW/m² | 61 | 30 kV/m | 18 ms |
| IEEE safe level for humans | 2W/m² | 0 | 27.5V/m | 5.8 hrs |
| FCC level for equipments | 27 pW/m² | -109 | 100µV/m | 53 million years |

## VI. Conclusion

International Agency for Research on Cancer (IARC), a part of the World Health Organization, announced that after a concentrated week of combing the scientific literature on cell phone use and brain cancer, it decided to classify radio-frequency electromagnetic fields from cell phone use as “Possibly carcinogenic." [12]Experimental evidence has shown that exposure to low intensity radiation can have a profound effect on biological processes. Adherence to standard should provide protection against harmful thermal effects and help to minimize the interaction of EM fields with the biological processes of the human body. It is essentially the absorption of RF/MW energy that causes stress and trauma to biological systems. The greatest amount of energy will be absorbed when the incident radiation is emitted at the resonance frequency of biological material. The generation of such signal creates transient responses that will match the resonant frequencies of biological materials. Recent event in the world like Fukushima meltdowns, and the introduction of radioactivity across the globe, indicate that accurate measurements are needed on subsequent changes in environmental radioactivity and in health status. So we need to monitor our surrounding actively to prevent it from disaster.

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