Increase in Specific Absorption Rate (SAR) Of Mobile Phone - A Threat to Human

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Abstract – **Drastic increase of mobile phone usage increases the concern about the effect of electromagnetic radiation on human brain. During the last decade, several researches were conducted in this area and reported the effect of radiation on brain. Unfortunately most of these findings cannot be reproduced. Findings of a number of studies ascertain that, there is no clear evidence to link the relationship between the adverse effects and mobile phone usage. The reason of the changes observed in human body due to radiation and the causes that leads to non reproducibility of these results has to be investigated. In [1] it is reported that, adverse effect of radiation occurs in cellular level if SAR is much higher. So we tried to study the change in SAR using FDTD simulation by increasing the power of excitation. Frequency range is selected as the specified range of frequency permissible for mobile phone communication. The value of SAR obtained for the above specified range of frequency is found within the permissible limit insisted by ICNIRP/IEEE. But on increasing the magnitude of power of excitation, the magnitude of SAR also increased. It can be concluded that, if the transmitting power is not within the permissible limit, there is a possibility to increase the values of SAR, which may cause health hazards.**

Keywords: **Mobile phone radiation, SAR, FDTD.**

I. INTRODUCTION

Some of the studies [2-12] conducted to study the effects of mobile phone exposure on brain shows that long-term usage of mobile phones can damage health. Electromagnetic fields are divided as ionizing and non ionizing (manmade). Frequency of non ionizing radiation does not exceed frequency of visible light.($< 8x10^{14}$ Hz). Mobile phones generate a modulated radio frequency electromagnetic field (RF-EMF), in the range of 900MHz to 2200MHz ($9x10^8$ Hz - $22x10^8$ Hz). This comes under the frequency zone of ultra high frequency having frequency range of 0.3-3 GHz ($3x10^8$Hz – $30x10^8$ Hz) and wavelength of 1 - 0.1 m. very much below the wavelength of visible light. The spectrum above 300THz ($3x10^{14}$ Hz)[13] like ultraviolet rays, x-rays and gamma rays are able to ionize the tissues.

The Interphone study had conducted research across 13 countries from 2000-2010 to find the relationship between mobile phone usage and increase in brain tumor. This couldn't establish any link between mobile phone usage and cancer. But they had published its result in 2010 that the increased risk of brain cancer is not established from the data of Interphone study and further investigations are needed to investigate the impact of radiations since the duration of call time and the pattern of usage of mobile phone had changed. In 2011, International Agency for Research on Cancer (IARC) had classified mobile phone radiation on the IARC scale into Group 2B - Possibly carcinogenic [IARC, 2011] based on a study report published during the early stage of interphone study. After that, WHO précised that even though adverse health effects have not been established by mobile phone use, measures has to be taken to reduce the effect of radiation on the human body. Then controlling agencies of every country reduced the permissible SAR limit. This leads to the reduction of SAR from 2W/Kg to 1.6W/Kg in India. All these increased the anxiety and concern of human beings about health hazards due to mobile phone usage.

Two types of effects are produced in human tissues due to radiation thermal and non thermal. Non thermal effects includes changes in molecular and cellular level. This can be valued by genotoxicity and non genotoxicity studies. The genotoxic effects include micronucleus (MN) formation, chromosomal aberration, primary DNA damage, sister chromatid exchange, and mutation. Nongenotoxic studies includes cell proliferation and cell cycle distribution, gene expression (mRNA and protein), Transcriptomics (Microarray analysis) to find the changes in the immune system, apoptosis, and reactive oxygen species (ROS) production. The result of study [1] shows that RF energy does not slice intracellular DNA directly. Most genotoxicity studies have shown negative effects except for exposure to RF (Radio frequency) fields with an extremely high value of SAR. Microarray analysis has not provided definite evidence of an effect of RF exposure on cellular functions like apoptosis, the immune system, and ROS production.

Thermal effects are based on energy absorption of the tissue, which causes the oscillations and vibrations of molecules. The rate at which radiation is absorbed by the human body is measured by the Specific Absorption Rate (SAR). The maximum power output from a mobile phone is regulated by the mobile phone standard and by the regulatory agencies in each country. The SAR limit permitted over a volume of 1 gram of tissue is fixed as 1.6 W/kg, in India. As per specification by the manufacturer the peak power of GSM mobile is 2 watts , CDMA is less than 1 Watt. The mobile phone standard and by the regulatory agencies in each country give guidelines about maximum power allowable for mobile phone and base station. But practically according to the reception quality and signal strength, the power level is increased or decreased automatically in cell phone and the base station, within a certain span, to accommodate different

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situations like nearer or farther to the station . So there is a possibility to increase the power level beyond the specified limit, can lead to the production of high SAR, which is harmful to human beings.

In this paper we tried to determine the Specific Absorption Rate (SAR) on human head tissues exposed to radiation between the frequency of 900MHz and 2200MHz, since those are the typical frequencies for mobile communications systems. In order to determine the SAR, we used simulation of EMR using FDTD (Finite Difference Time Domain)[13-20], which is a numeric method in time domain, obtained from the Maxwell equations in differential mode. The value of SAR at various excitation levels are calculated and analyzed.

The paper is outlined as follows: The basic theory of the method of FDTD included in section 2. Results obtained and the discussions of the result are detailed in section 3. And section 4 includes conclusion and scope of further work.

II. METHODS

A. Electromagnetic Waves

According to quantum theory, electromagnetic radiations are transmitted as photons and energy of photon is $E = h\upsilon$ where h is the Plank's constant ($6.625x10^{-34}$J s) and υ is the photon's frequency. To ionize a matter, an electron is to be freed from an atom; the radiation has to break the chemical bond between two electrons. The energy of atomic electron (energy of chemical bond) is 1 eV ($1.6x10^{-19}$J). A single photon is able to ionize the matter when it is absorbed by atomic electron. From the above relationship, we can derive the magnitude of frequency of radiations to get it absorbed is greater than maximum frequency of visible light. So the electromagnetic spectrum having frequency less than visible light cannot produce ionization of the matter.

Coupled Electric and magnetic field obeys wave equation, electromagnetic radiation are transmitted in air/vaccum with a velocity c (velocity of light)[13]

$$c = \frac{1}{\sqrt{\varepsilon_0 \mu_0}} \tag{1}$$

The electromagnetic radiation is a form of energy made of electric and magnetic field varying in both time and space. The total energy of EMR is $\varepsilon_0 E^2$.

B. Specific Absorption Rate(SAR)

SAR is used as a measure of absorption of non ionizing electromagnetic radiation which is defined as ratio of absorbed power P per unit mass or ratio of energy absorbed per unit time

$$SAR = \frac{P}{m} \text{ W/Kg} \tag{2}$$

in terms of electric field,

$$SAR = \frac{\sigma E^2}{\rho} \tag{3}$$

The SAR can be estimated by using the magnitude of Electrical field obtained from the numerical modeling using FDTD which simulate the spatial distribution of radiation within the body.

C. Maxwell Equations

As per Maxwell's equation all electromagnetic phenomena can be expressed in terms of a coupled system of partial differential equations . Maxwell's equations as given below

$$\nabla \times \bar{E} = -\frac{\partial \bar{B}}{\partial t} \tag{4a}$$

$$\nabla \times \bar{H} = \frac{\partial \bar{D}}{\partial t} + \bar{J}_c \tag{4b}$$

$$\nabla . \bar{D} = 0 \tag{4c}$$

$$\nabla . \bar{B} = 0 \tag{4d}$$

(4a) and (4b) can be rewritten as:

$$\frac{\partial \bar{H}}{\partial t} = -\frac{1}{\mu} \nabla \times \bar{E} \tag{5a}$$

$$\frac{\partial \bar{E}}{\partial t} = \frac{1}{\varepsilon} \nabla \times \bar{H} - \frac{\sigma}{\varepsilon} \bar{E} \tag{5b}$$

It is seen that the time derivative of the E field is related to the curl of the H field while examining the Maxwell's curl equation. Thus the temporal rate of change in the E field is related to the spatial rate of change of the H field. Eqn (5a) can be written as

$$\frac{\partial}{\partial t}\left(H_x \hat{a}_x + H_y \hat{a}_y + H_z \hat{a}_z\right) = -\frac{1}{\mu} \begin{vmatrix} \hat{a}_x & \hat{a}_y & \hat{a}_z \\ \frac{\partial}{\partial x} & \frac{\partial}{\partial y} & \frac{\partial}{\partial z} \\ E_x & E_y & E_z \end{vmatrix} \tag{6}$$

A similar equation can be defined for (5b) as well, and after equating x, y and z components on both sides of (5a) and (5b), the following scalar equation set is obtained

$$\begin{aligned}
\frac{\partial H_x}{\partial t} &= \frac{1}{\mu}\left(\frac{\partial E_y}{\partial z} - \frac{\partial E_z}{\partial y}\right) \\
\frac{\partial H_y}{\partial t} &= \frac{1}{\mu}\left(\frac{\partial E_z}{\partial x} - \frac{\partial E_x}{\partial z}\right) \\
\frac{\partial H_z}{\partial t} &= \frac{1}{\mu}\left(\frac{\partial E_x}{\partial y} - \frac{\partial E_y}{\partial x}\right) \\
\frac{\partial E_x}{\partial t} &= \frac{1}{\varepsilon}\left(\frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z} - \sigma E_x\right) \\
\frac{\partial E_y}{\partial t} &= \frac{1}{\varepsilon}\left(\frac{\partial H_x}{\partial z} - \frac{\partial H_z}{\partial x} - \sigma E_y\right) \\
\frac{\partial E_z}{\partial t} &= \frac{1}{\varepsilon}\left(\frac{\partial H_y}{\partial x} - \frac{\partial H_x}{\partial y} - \sigma E_z\right)
\end{aligned} \tag{7}$$

D. Finite Difference Time Domain (FDTD) Method

The magnitude of the fields in EMR can be calculated by discretizing the Maxwell's equation with central

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difference approximation [13-20]. K Yee proposed this method. By the finite difference approximation, A new value of the E field is expressed in terms of the old value of the E field and the spatial partial derivatives of the old value of the H field. Thus the field components are calculated iteratively by marching-on in time. Similarly magnitude of H field also can be calculated iteratively by finite difference method. This forms coupled system of difference equations which can be solved in a leap-frog manner.

The expression to calculate derivative $\frac{\partial E_x}{\partial t}$ of field E by using finite difference expression using central difference can be written as

$$\frac{E_x^{n+\frac{1}{2}}(i)-E_x^{n-\frac{1}{2}}(i)}{\Delta t} \quad (8)$$

The increment in time domain is fixed as Δt and assumed that the magnitude E_x^n is located at the center of the cell. Similarly $\frac{\partial E_x}{\partial t}$ can be written in 3D as

$$\frac{E_x|^{n+\frac{1}{2}}_{i+\frac{1}{2},j,k} - E_x|^{n-\frac{1}{2}}_{i+\frac{1}{2},j,k}}{\Delta t} \quad (9)$$

Yee algorithm explained in next section is used for the calculation of electric and magnetic fields.

E. The Yee Algorithm

The Maxwell's equations is discretized both in time and space with central difference approximations. A special notation introduced by Yee (involving superscripts and subscripts) is used, as explained below. The notation (i, j, k) is used for integers, $(\Delta x, \Delta y, \Delta z)$ for space increments in the $x, y,$ and z directions and any field component A is represented as $A^n{}_{i,j,k} = A(i\Delta x, j\Delta y, k\Delta z, n\Delta t)$. Consider the first expression in Eqn (7)

$\frac{\partial H_x}{\partial t} = \frac{1}{\mu}\left(\frac{\partial E_y}{\partial z} - \frac{\partial E_z}{\partial y}\right)$ can be expanded in time derivative form as

$$\frac{H_x|^{n+1}_{i,\ j+\frac{1}{2},\ k+\frac{1}{2}} - H_x|^{n}_{i,j+\frac{1}{2},k+\frac{1}{2}}}{\Delta t} = \frac{1}{\mu_{i,j+\frac{1}{2},k+\frac{1}{2}}} \left[\frac{E_y|^{n+\frac{1}{2}}_{i,j+\frac{1}{2},k+1} - E_y|^{n+\frac{1}{2}}_{i,j+\frac{1}{2},\ k}}{\Delta z} - \frac{E_z|^{n+\frac{1}{2}}_{i,j+1,k+\frac{1}{2}} - E_z|^{n+\frac{1}{2}}_{i,j,k+\frac{1}{2}}}{\Delta y}\right] \quad (10)$$

In similar manner we can derive expressions for $H_y|^{n+1}_{i+\frac{1}{2},j,k+\frac{1}{2}}$ and $H_z|^{n+1}_{i+\frac{1}{2},j+\frac{1}{2},k}$

Similarly the time derivative of the fourth expression from Eqn (7)

$$\frac{\partial E_x}{\partial t} = \frac{1}{\varepsilon}\left(\frac{\partial H_z}{\partial y} - \frac{\partial H_y}{\partial z} - \sigma E_x\right)$$

can be written as

$$\frac{E_x|^{n+\frac{1}{2}}_{i+\frac{1}{2},j,k} - E_x|^{n-\frac{1}{2}}_{i+\frac{1}{2},j,k}}{\Delta t} = \frac{1}{\varepsilon_{i+\frac{1}{2},j,k}}\left[\frac{H_z|^{n}_{i+\frac{1}{2},j+\frac{1}{2},k} - H_z|^{n}_{i+\frac{1}{2},j-\frac{1}{2},k}}{\Delta y} - \frac{H_y|^{n}_{i+\frac{1}{2},j,k+\frac{1}{2}} - H_y|^{n}_{i+\frac{1}{2},j,k-\frac{1}{2}}}{\Delta z}\right] - \sigma|_{i+\frac{1}{2},j,k} E_x|^{n}_{i+\frac{1}{2},j,k} \quad (11)$$

Similarly $E_y|^{n+\frac{1}{2}}_{i,j+\frac{1}{2},k}$ and $E_z|^{n+\frac{1}{2}}_{i,j,k+\frac{1}{2}}$ can be derived.

As per these expressions, the field components are staggered in space and time. That is, the electric and magnetic field components are defined at different space points and different time instants. This can be graphically represente as edges of a cube called Yee Cell (Fig-1).

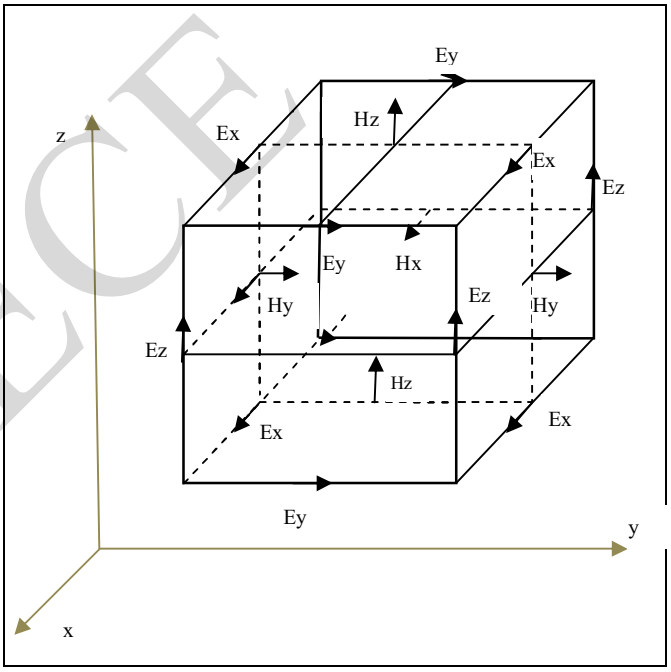


Fig.1: Yee Cell

Yee cell is the building block of the FDTD grid. As shown in Fig .1, every E component is surrounded by four circulating H components, and every H component is surrounded by four circulating E components. If the front face is considered in particular, H_x is expressed in terms of the E_z values at the left and right and E_y values at above and below.

The cell-size Δz is chosen with respect to the minimum wavelength in the simulation, otherwise all other frequencies will be filtered by mesh. The material bodies inside the area can be specified by constitutive relations at each point. The material may be air (vaccum), conducting metal (PEC), insulators and any anisotropic or bianisotropic

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materials. Then six spatio-temporal difference equations relating the field components

$H_x|^{n+1}_{i,j+\frac{1}{2},\ k+\frac{1}{2}}$, $H_y|^{n+1}_{i+\frac{1}{2},j,k+\frac{1}{2}}$, $H_z|^{n+1}_{i+\frac{1}{2},j+\frac{1}{2},k}$, $E_x|^{n+\frac{1}{2}}_{i+\frac{1}{2},j,k}$, $E_y|^{n+\frac{1}{2}}_{i,j+\frac{1}{2},k}$, $E_z|^{n+\frac{1}{2}}_{i,j,k+\frac{1}{2}}$ can be derived from the above equations.

Once the computational domain is established, sources must be specified according to the type of excitation to be modeled. The source can be plane wave, a current on a wire, or an electric field between metal bodies.

F. Source Signals

The selection of source signal is also important since it represents the antenna used in mobile phone. Commonly used source signals are the sinusoidal signal or the Gaussian pulse. A modulated signal has to be used in order to avoid occurrence of high frequency at the beginning of the simulation.

G. Boundary Conditions

We cannot simulate the propagation of the signal indefinitely, and we need to terminate the simulation in the FDTD grid. This is done by defining Absorbing Boundary Conditions (ABCs) over the outer boundary as desired. The Perfectly Matched Layer (PML) approach, which is a material layer absorbs electromagnetic waves without any reflection is used for simulation.

H. Stability Condition for the FDTD Equations

The spatio-temporal discretization of Maxwell's curl equations leads to a coupled system of difference equations. The solution of these equations is obtained iteratively starting from the initial condition. The system with difference equation is said to be stable if the solution stays bounded for all time instants. The stability condition, the relationship between space and time increments, is given by Courant stability Criteria. To ensure the stability of FDTD analysis, time step must be limited by the equation given below (as per Courant stability Criteria)

$$\Delta t \leq \frac{1}{c\sqrt{\frac{1}{(\Delta x)^2}+\frac{1}{(\Delta y)^2}+\frac{1}{(\Delta z)^2}}} \qquad (11)$$

Let $\Delta x = \Delta y = \Delta z = \Delta$ then $\Delta t \leq \frac{\Delta}{c\sqrt{3}}$

From the converged solutions of FDTD expressions, the local SAR at $(i,j,k)^{th}$ cell inside the head is obtained using the following equation

$$SAR(i,j,k) = \frac{\sigma(i,j,k)|E(i,j,k)|^2}{2\rho(i,j,k)} W/Kg \qquad (12)$$

where, E is the r.m.s value of the electric field in V/m , σ is the conductivity of the head in S/m and ρ is the mass density of the head in Kg/m³. Maximum local SAR is obtained by finding the maximum value of SAR(i,j,k) for the whole head model at each frequency and the location of maximum local SAR may or may not be same for different frequencies.

III. RESULTS

A. Simulation using FDTD

Here the simulation of FDTD method is done in 3D which is more complex due to the fact that all vector field components ($E_x, E_y, E_z, H_x, H_y, H_z$) are non-zero in general and each component is a function of three coordinate variables. The computational domain is a cube with side length 3cm and size of cell is $\frac{\lambda}{10}$. Computation domain is fixed as cube of 3X3X3 cm with cell size as 0.033cm ($\Delta x = \Delta y = \Delta z = 0.033$ cm), which means that there are 91x91x91 = 753571 Yee cells in the grid. The time increment satisfies $\Delta t = \frac{\Delta x}{2c_0}$. The source of excitation is selected as sinusoidal pulse and kept at 0.375 cm away from the corner. This is to generate a electro magnetic radiation similar to that generated by keeping a mobile phone near the ear. The PML approach is used as boundary condition. The figure 2 shows the radiation pattern obtained for 900MHz during an instant of time (at time step 170).

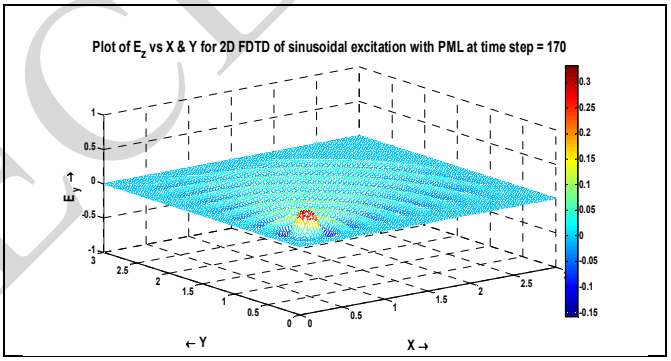


Fig 2: Snap shot of E_z over x-y plane at time =170

B. Calculation of SAR

To obtain electric field E, a sinusoidal pulse of unit amplitude is used as source of excitation. The equivalent antenna input impedance is 50 Ω. And input power of mobile phone is 0.6 watts. The value of SAR is calculated using the formula (12) given can rewrite as below

$$SAR(i,j,k) = \frac{\sigma(i,j,k)\left\{|E_x(i,j,k)|^2+|E_y(i,j,k)|^2+|E_z(i,j,k)|^2\right\}}{2\rho(i,j,k)} W/Kg \qquad (13)$$

The simulation is performed for the frequencies from 900 MHz to 1800 MHz, since those are the typical maximum and minimum value of frequencies for mobile phone communications. The values for the different parameters needed to calculate SAR are presented in Table- 1 and Table-2.

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Table 1: Electromagnetic Properties for Humn Head Tissues at 900 MHz

Tissue	ε_r	σ (S/m)	ρ (Kg/m3)
Skin/Fat	23.000	0.630	1.000
Muscle	59.000	1.260	1.000
Bone	5.4000	0.045	1.200
Brain	51.000	1.460	1.050

Table 2: Electromagnetic Properties for Humn Head Tissues at 1800 MHz

Tissue	ε_r	σ (S/m)	ρ (Kg/m3)
Skin/Fat	38.870	1.190	1.000
Muscle	59.370	2.040	1.000
Bone	11.500	0.230	1.200
Brain	43.540	1.150	1.050

Value of SAR is calculated using the simulated value of electric field at 900MHz and 1800MHz using three powers of excitation of 0.6watts, 1.2 watts and 1.8watts (Fig -3).

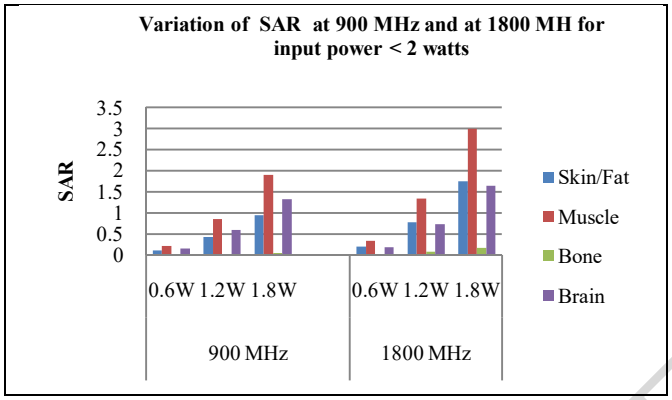


Fig .3: Values Of SAR Obtained At 900 MHz And 1800 MHz On Using An Input Power Of 0.6watts And 1.2 Watts.

Maximum value of electric field is used for the calculation of SAR. The SAR values of muscle/fat is large and is 0.2, 0.8 and 1.9 W/Kg at 900MHz for the input powers of 0.6watts, 1.2 watts and 1.8watts respectively. For 1800MHz, the SAR values obtained for muscles are 0.33, 1.33 and 3 W/Kg. All the values of SAR at 900MHz are within the prescribed limit by the regulating authority. As per regulations, the value allowed for head is 2 W/Kg by ICNIRP and 1.6 W/Kg by IEEE. But the value of SAR obtained for 800MHz) at 1.8 watts is 3 W/Kg , greater than the prescribed limit.

But on increasing the amplitude of the pulse used for excitation, the value of SAR increased and reached beyond the prescribed limit. The values obtained are plotted in Fig -4 for 900MHz and in Fig 5 for 1800Mhz. . The amplitude of exciting pulse is related to power as 1: 0.6.

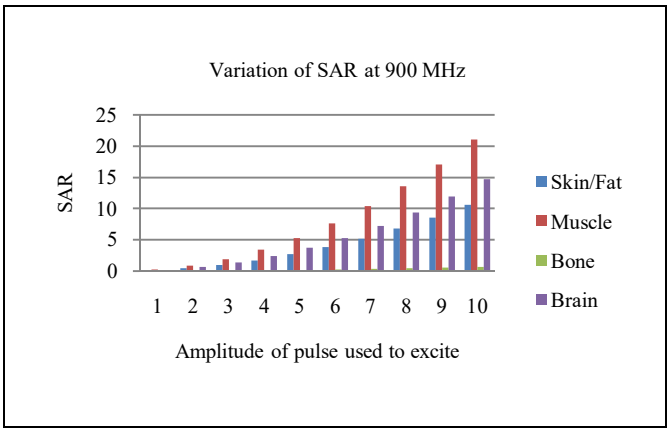


Fig -4 Values of SAR obtained at 900MHz and 1800MHz on using an input power of 0.6watts and 1.2 watts.

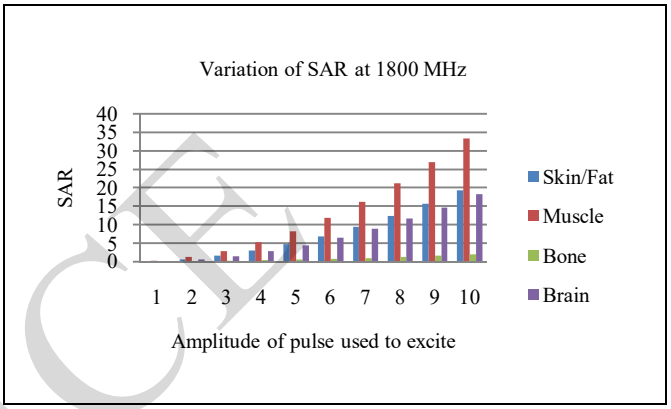


Fig .5: Values Of SAR Obtained At 900 MHz And 1800 MHz On Using An Input Power Of 0.6watts And 1.2 Watts.

The maximum value of SAR is obtained for muscles/fat and this increases very rapidly (Fig 2 and Fig 3) with the increase in the amplitude of excitation. For amplitude of excitation of 2 units, the values of SAR at both frequencies are within the safe limit. But for a amplitude of 3 units, SAR at 900MHz is 1.9W/Kg for muscle and SAR at 1800MHz is 3W/Kg which is above the specified limit. Maximum power allowed for CDMA is phone is 2watts. For greater values of amplitude of excitation (>3 units), SAR at both frequencies are above the prescribed safe limit.

IV. CONCLUSION

Muscle is more affected while increasing the power of excitation, The increase in SAR shows more radiation is absorbed this may cause temperature increase. This can increase or decrease the stress in muscles.

At the time most mobile phones were used for voice communication only, but since the arrival of the videophone, in spite of technological refinements SAR levels are on increase. The earth's natural electric and magnetic fields are static and seems as bio inactive. Week fields also have same behaviour. For frequencies below 10^6Hz, two fields (electric and magnetic) are not connected and the intensities are

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measured separately. This is the reason for living organism are able to get adapted to week external stressors.

The mobile phone standard and the regulatory agencies in each country give guidelines about maximum power allowable for mobile phone and base station. But practically according to the reception quality and signal strength, the power level is increased or decreased automatically in cellphone and the base station, within a certain span, to accommodate different situations like nearer or farther to the station . So there is a possibility to increase the power level beyond the specified limit, can produce high SAR, which is harmful to human beings.

SAR for the specified range of frequency for mobile phone communication is found within the specified limit insisted by ICNIRP/IEEE. But on increasing the magnitude of power of excitation, the SAR is increased. It can be concluded that if the transmitting power is not within the limit, there is a possibility to increase the values of SAR and causes health hazards. So instead of specifying only the value of SAR, magnitude of power dissipated has to be specified and there will be provision to check and control those values within the range.

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