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Radiation analysis in human brain and skull exposed at 915 MHz, 1900 MHz and 2450 MHz frequencies and radiation minimization methods

Pragati Sharma
sharmaprag79@gmail.com
Mewar University, Chittorgarh, Rajasthan

Dr. Gulzar Ahmed
gulzarahmed@gmail.com
Mewar University, Chittorgarh, Rajasthan

Dr. A. K. Gautam
drakgautamsd@gmail.com
S. D. College of Engineering and Technology, Muzaffarnagar, Uttar Pradesh

ABSTRACT

In India, cell phone use is increasing day by day with a very high growth of 50 million in 2005 to approximately 530 million now and the number is increasing more. When the mobile phone comes in close proximity to the human body then it is quite harmful due to the fact that it emits electromagnetic radiation. Now, 4G is in existence and it offers a huge variety of features. The dependence on mobile phones increases with 4G which is an alarming factor because continuous slow radiation is affecting the health. When RF products came into public use, there was a requirement for fixing emission standards. These standards were set by ICNIRP, FCC, IEEE, etc. regulating committees. The harmful radiation is described in terms of the Successive Approximation Rate (SAR). The SAR limit is specified as 1.6 Watts/kilogram for part of the body (head exposure) and 0.08 Watts/kilogram for the whole body. In this paper, the SAR measurement is observed up to 5 mm inside the brain and skull at different distances between the human brain/skull vs mobile phone through a wide variety of radiation prone devices. The objective of the paper is to investigate the thermal radiation of the electromagnetic waves inside the human head through statistical calculations. The close distance up to which SAR may be harmful to the human brain has been tried to found out so that a safe distance could be predicted. Paper also investigates possible methods to minimize mobile phone radiation on exposed tissues.

Keywords*— Specific Absorption Rate (SAR), Global System for mobile communication (GSM), Mobile phone, Code Division Multiple Access (CDMA), Universal Mobile Telecommunication Standard (UMTS),4G, Radio Frequency Electromagnetic Field (RF-EMF), Mobile Station (MS), Human body*

1. INTRODUCTION

In general, the radio frequency covers the range from 30 kHz to around 300 GHz. This high range of the spectrum is used for wireless communication, satellite communication, radar, etc. The mobile communication lies in wireless communication. It is noticed that when a device working in MHz range having some radiated power comes in direct contact with human body then the body gets exposed and the radiation absorbed by the body may create some harmful effect inside it if the exposure is getting beyond the safe limits described by many national and international agencies working in this regard as National Council on Radiation Protection and Measurement (NCRP) ' World Health Organization(WHO), Federal Communications Commission (FCC), International Commission on Non Ionizing Radiation Protection (ICNIRP), The Institute of Electrical and Electronics Engineers(IEEE) etc. Moreover there is evidence in WHO reports that 'The radiofrequency electromagnetic field as possibly carcinogenic to humans, based on an increased risk for glioma-a malignant type of brain cancer- associated with wireless phone use'[1]. Mobile phone radiation comes in the category of 'Near field exposure' while Base Station (BTS) radiation comes in the category of 'Far-field exposure' as shown in Figure-1. In mobile phones, the user's exposure is localized to that part of the body closest to the phone antenna while whole body is exposed to RF emissions from base station. Mobile phone radiation is measured in form of Successive Approximation Rate (SAR).

SAR is expressed as the energy absorbed per mass of tissue and has a unit of watt/kilogram. Its maximum level for modern handsets has been set by regulating agencies as 1.6 watts/ Kg for partial body. The value of SAR (i.e. radio wave penetration inside the body) is maximum at close distances with the mobile phone. The increased value of SAR may be dangerous for tissues and they may suffer serious heat damage. In extreme cases, RF-induced heating can cause blindness, memory loss and other health problems. The dielectric properties of a biological tissue result from the interaction of electromagnetic radiation with its constituents at the cellular and molecular level. The relative permittivity is quite higher at very low frequencies range which decreases with increase in frequency. The dispersion, in the gigahertz range is due to the polarization of water molecules while the dispersion in the hundreds of kilohertz range is due to the polarization of cellular membranes. [2, 3]

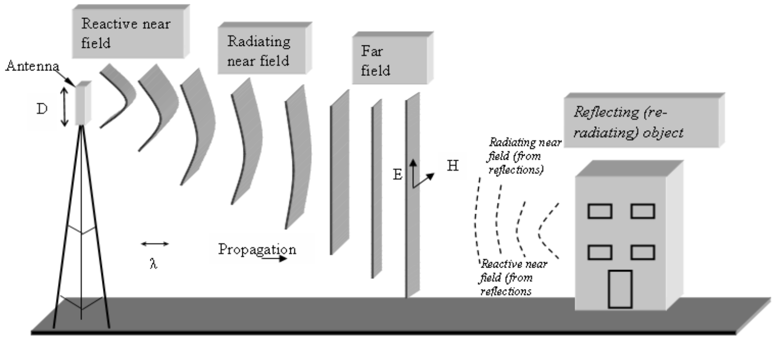

Fig. 1: Near field and Far-field concept

Electromagnetic radiation is calculated in this paper for the human brain and skull from 900 MHz, 1900 MHz and 2450 MHz frequencies up to a depth of 5 mm inside and then possible SAR is predicted. Dielectric parameters of human brain and skull are shown in Table-1. Frequencies are chosen to work in 2G, 3G and Wi-Fi range of cellular communication.

Table 1: Dielectric properties of human brain and skull

Frequency (MHz)	Brain		Skull	
	ε_r (F/m)	σ (S/m)	ε_r (F/m)	σ (S/m)
915	45.7	0.77	16.6	0.24
1900	43.4	1.20	15.5	0.46
2450	42.5	1.51	15.0	0.60

2. MATERIALS AND METHODS

2.1 Induced and Incident electric field for near field communication

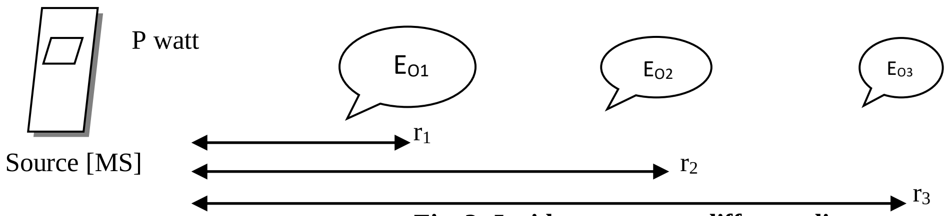

Fig. 2: Incident power at different distances

Let, the mobile is radiating power 'P' watt. This power gradually decreases with an increase in distance. Thus

$$P \alpha 1/r \quad (1)$$

The electric field at a distance 'r' is given by

$$P/4\pi r^2 = E_o^2 \varepsilon_o c/2$$

$$E_o = 7.746\sqrt{P}/r \quad \text{V/m} \quad (2)$$

Here, P is the total effective radiated power in a given direction.

The maximum power radiated by a mobile phone is 2Watt for GSM operated a phone while it reduced to 1Watt for CDMA phones. LTE operated phones emit very low power i.e. approximately 200 milli Watt. Incident electric field is calculated for various frequencies and emitted power level:

2 Watt for 915 MHz

$$E_o = .746 \times (\sqrt{2})/r$$

$$= 10.95\ /r\ V/m \quad (3)$$

1 Watt for 1900 MHz

$$E_o = 7.746 \times (\sqrt{1})/r$$

$$= 7.746/r\ V/m \quad (4)$$

0.2 Watt for 2450 MHz

$$E_o = 7.746 \times (\sqrt{0.2})/r$$

$$= 5.48\ /r\ V/m \quad (5)$$

2.2 Charge induced in human tissue

The charge induced in human tissue can be represented by [4]

$$E_i = E_{0n}\exp^{(-z/\delta)} \quad (6)$$

Where, E_{0n} is the electric field at which human head is exposed, z is the thickness of tissue and δ is the skin depth [equals to 1/qw]. Basic structure of human head is shown in figure 3.

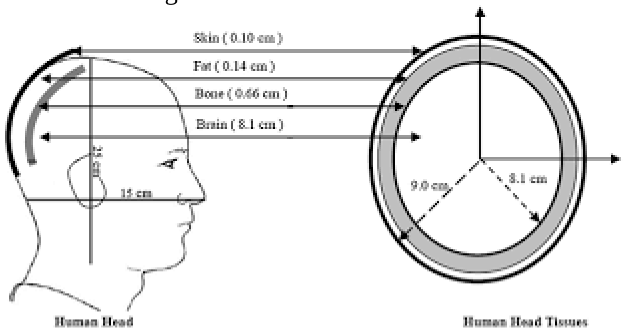

Fig. 3: Human head structure

2.3 Specific Absorption Rate (SAR)

SAR is the unit of measurement of RF energy absorbed by the body during exposure to EM radiation [5]. The basic radiation pattern of antenna is given in figure 4. SAR is being evaluated here for three different frequencies band i.e. 915MHz, 1900 MHz and 2450MHz. The SAR values were evaluated for different distances from MS to user (5 cm to 25 cm) and for different depths (1mm to 5 mm) inside the body. The amount of "absorbed" vs. "exposed" radiation depends on many parameters like nature, amount and duration of radiation. It also depends on individual body conditions like permittivity, permeability, and conductivity. Radiation from cell phone antenna is quite high towards main lobe direction and gets minimized for secondary lobes.

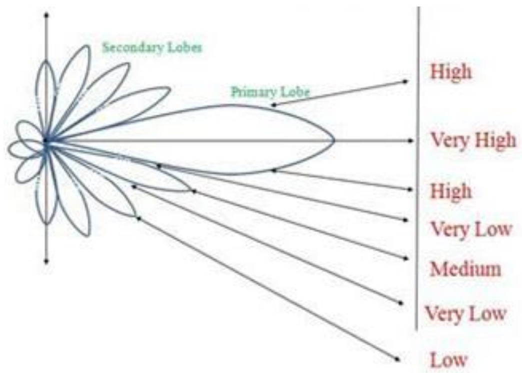

Fig. 4: Radiation pattern from antenna

It can be described as the mass averaged rate of energy absorption in body tissue. In terms of the energy absorbed *dW* in the mass element *dm* in time *dt*, SAR is given by Adair and Peterson [6]:

$$\mathrm{SAR} = d/dt\,(dW/dm)\ \mathrm{W/kg} \quad (7)$$

If the volume of the element is dV and ρ is the density of element, $dm = \rho dV$, hence

$$\mathrm{SAR} = d/dt\,(dW/\rho dV) \quad (8)$$

By using Poyinting vector theorem for sinusoidal electromagnetic field, we get:

$$\mathrm{SAR} = \sigma E_i 2/\rho \quad (9)$$

Where
σ is conductivity
ρ the tissue density and
E_i is the electric field inside that tissue.
SAR is being calculated here at 915MHz for GSM, 1900 MHz for CDMA and 2450 MHz for Wi-Fi.
SAR values for some mobile phones are given which is find out by *#07# code-

Table 2: High Value SAR Mobile Phones (In decreasing order)

Mobile Phone	SAR (Watt/Kg)
Lenovo K3 Note	1.59
iPhone	1.58
Black Berry curve 9320	1.56

Nokia 105	1.48
Nokia Asha 503	1.43
Black Berry Z30	1.41
Nokia Lumia925	1.40
Motorola Moto X11	1.40
Samsung S 300	1.14
iPhone 6S	1.14

Table 3: Low Value SAR Mobile Phones (In increasing order)

Mobile Phone	SAR (Watt/Kg)
Micromax unite	0.20
Micromax A 310	0.29
LG 450	0.36
Samsung Galaxy Grand	0.374
Microsoft Lumia 535	0.46
Redmi Note 4G	0.464
Samsung Galaxy A5	0.65
iPhone 3GS	0.67
Lenovo K4 Note	0.844

3. FACTS ABOUT MOBILE PHONE GENERATIONS

All the mobile generations have some prominent features for which they are developed or designed. Along with the pros of technology, it has some drawbacks too. In brief the generations are described as that 1G was the generation of analog phones with very low speed and unreliable connection which was very soon overshadowed by 2G that was GSM. GSM was using FDMA and TDMA technologies. The supporting phones were designed so that once a call is made from host to end user then the mobile phones reduce their radio frequency output power as minimum as it could be required to maintain the connection. It is reduced up to 20 mW. But the case becomes critical if the mobile phone is at boundary level of the Base Station. At this time, Mobile phone increases its power radiating to maintain the link without getting the call drop. This is the case when the chances to get expose in radiation are maximum for the mobile user. The channel data rate in GSM is as maximum as 270 Kbps.

3G technology was designed to operate the mobile phone at low power than previous generations. This is beneficial to keep the radiation low. The CDMA handsets having 3G technology radiate a maximum power of 1Watt but with the use of adaptive power control techniques, mobile phones become smart and can control their power to operate at lower levels maintaining good communication. 3G has 1Mbps upload speed and a maximum of 6 Mbps download speed while 4G can be expressed as the generation of higher data rates with low battery power consumption. It can provide the data rate of 1GBPS for downlink and 500MBPS for uplink. 4G latency period is designed as lower than 100 ms for fast speed of operation.

4. RESULTS AND DISCUSSIONS

The GSM is a fully digital system utilizing the 900 MHz and 1800 MHz band and based on TDMA technology while the 3G system uses common frequency spectrum worldwide (1800–2200 MHz) and have wide range of telecommunication services (Voice, data, multimedia, internet). 4G works around 2400 MHz band. The condition of exposure getting worse for those people who lie in general population/ uncontrolled exposure. The situation occurs to those who live in vicinity of wireless transmitters and are potential for exposure. ICNIRP limits for SAR are mentioned here:

Table 4: ICNIRP Limits for Occupational/Controlled exposure (W/Kg)

Whole Body [Average over entire body]	Partial Body [Average over 1 Gram of tissue]	Hands, Wrists, Feets, Ankles [Average over 10 Gram of tissue]
0.4	8.0	20.0

Table 5: ICNIRP Limits for General Population/Uncontrolled exposure (W/Kg)

Whole Body [Average over entire body]	Partial Body [Average over 1 Gram of tissue]	Hands, Wrists, Feets, Ankles [Average over 10 Gram of tissue]
0.08	1.6	4.0

Many International and National agencies agree that the exposure of the general public should be kept below the whole body SAR of 1.6 W/kg and partial body SAR of 0.08 W/Kg for safe exposure of cellular devices. The agencies working in this regard are International Commission on Non Ionizing Radiation Protection (ICNIRP) [7], The Institute of Electrical and Electronic Engineers (IEEE) [8], Federal Communications Commission (FCC) [9], National Council on Radiation Protection and Measurement (NCRP) [10].

As we know that the radiated electric field varies inversely with distance from the transmitter ($P= 1/4\pi R^2$).This electric field propagates around the antenna and the strength of it varies with the distance as shown in Table-6. Mobile phone transmission power is assumed as 2 Watt for 915 MHz, 1 Watt for 1900 MHz and 0.2 Watt for 2450 MHz frequencies respectively [10]. Table 7-9 shows variation of SAR in brain at 915 MHz, 1900 MHz, and 2450 MHz. Table-10-12 shows variation of SAR in skull at 915 MHz, 1900 MHz and 2450 MHz.

Table 6: Incident electric field at different distances from MS

MS POWER $_{max}$ @ FREQUENCY	Incident electric field E_O V/m at distance (MS vs. tissue)				
	5cm	10cm	15cm	20cm	25cm
GSM Phone with 2W power @ 915 MHz	219.90	109.54	73.02	54.77	43.82
CDMA Phone with 1W power @ 1900 MHz	154.92	77.46	51.64	38.73	30.98
4G phone with 0.2W power @ 2450 MHz	69.28	34.64	23.09	17.32	13.86

Table 7: The variation of SAR in the brain at different distances (in cm) from MS operating at 915 MHz

Power of MS	distance (MS vs. brain)	Incident Electric Field (E_o) V/m	SAR(W/kg) inside the brain at the depth- [All calculations are based on induced electric field inside tissue]				
			1.0 mm	2.0 mm	3.0 mm	4.0 mm	5.0 mm
2W	5 cm	219.90	**34.65**	**33.21**	**31.83**	**30.51**	**29.24**
	10 cm	109.54	**8.60**	**8.24**	**7.90**	**7.57**	**7.26**
	15 cm	73.02	**3.82**	**3.66**	**3.51**	**3.36**	**3.22**
	20 cm	54.77	**2.15**	**2.06**	**1.98**	**1.89**	**1.81**
	25 cm	43.82	1.38	1.32	1.26	1.21	1.76

Table 8: The variation of SAR in the brain at different distances (in cm) from MS operating at 1900 MHz

Power of MS	distance (MS vs. brain)	Incident Electric Field (E_o) V/m	SAR(W/kg) inside the brain at the depth- [All calculations are based on induced electric field inside tissue]				
			1.0 mm	2.0 mm	3.0 mm	4.0 mm	5.0 mm
2W	5 cm	154.92	**26.13**	**24.40**	**22.80**	**21.30**	**19.90**
	10 cm	77.46	**6.53**	**6.10**	**5.70**	**5.33**	**4.98**
	15 cm	51.64	**2.90**	**2.71**	**2.53**	**2.37**	**2.21**
	20 cm	38.73	**1.63**	1.52	1.42	1.33	1.24
	25 cm	30.98	1.02	0.96	0.89	0.84	0.78

Table 9: The variation of SAR in the brain at different distances (in cm) from MS operating at 2450 MHz

Power of MS	distance (MS vs. brain)	Incident Electric Field (E_o) V/m	SAR(W/kg) inside the brain at the depth- [All calculations are based on induced electric field inside tissue]				
			1.0 mm	2.0 mm	3.0 mm	4.0 mm	5.0 mm
0.2W	5 cm	69.28	**6.46**	**5.92**	**5.43**	**4.98**	**4.57**
	10 cm	34.64	**1.61**	1.48	1.36	1.25	1.14
	15 cm	23.09	0.72	0.66	0.60	0.55	0.51
	20 cm	17.32	0.40	0.37	0.34	0.31	0.29
	25 cm	13.86	0.26	0.24	0.22	0.20	0.18

Table 10: The variation of SAR in the skull at different distances (in cm) from MS operating at 915 MHz

Power of MS	distance (MS vs. brain)	Incident Electric Field (E_o) V/m	SAR(W/kg) inside the brain at the depth- [All calculations are based on induced electric field inside tissue]				
			1.0 mm	2.0 mm	3.0 mm	4.0 mm	5.0 mm
2W	5 cm	219.90	**6.14**	**6.00**	**5.87**	**5.74**	**5.62**
	10 cm	109.54	1.52	1.49	1.46	1.43	1.39
	15 cm	73.02	0.68	0.66	0.65	0.63	0.62
	20 cm	54.77	0.38	0.37	0.36	0.35	0.34
	25 cm	43.82	0.24	0.23	0.23	0.22	0.22

Table 11: The variation of SAR in the skull at different distances (in cm) from MS operating at 1900 MHz

Power of MS	distance (MS vs. brain)	Incident Electric Field (E_o) V/m	SAR(W/kg) inside the brain at the depth- [All calculations are based on induced electric field inside tissue]				
			1.0 mm	2.0 mm	3.0 mm	4.0 mm	5.0 mm
1W	5 cm	154.92	**5.71**	**5.47**	**5.23**	**5.01**	**4.79**
	10 cm	77.46	1.43	1.37	1.31	1.25	1.20
	15 cm	51.64	0.63	0.61	0.58	0.56	0.53
	20 cm	38.73	0.36	0.34	0.33	0.31	0.30
	25 cm	30.98	0.24	0.22	0.21	0.20	0.19

Table 12: The variation of SAR in the skull at different distances (in cm) from MS operating at 2450 MHz

Power of MS	distance (MS vs. brain)	Incident Electric Field (E_o) V/m	SAR(W/kg) inside the brain at the depth- [All calculations are based on induced electric field inside tissue]				
			1.0 mm	2.0 mm	3.0 mm	4.0 mm	5.0 mm
0.2W	5 cm	69.28	1.47	1.39	1.31	1.24	1.17
	10 cm	34.64	0.37	0.35	0.33	0.31	0.29

	15 cm	23.09	0.16	0.15	0.15	0.14	0.13
	20 cm	17.32	0.09	0.09	0.08	0.08	0.07
	25 cm	13.86	0.06	0.05	0.05	0.04	0.04

Graphical presentation of table 7 to 12 is shown in figures 5 to10.

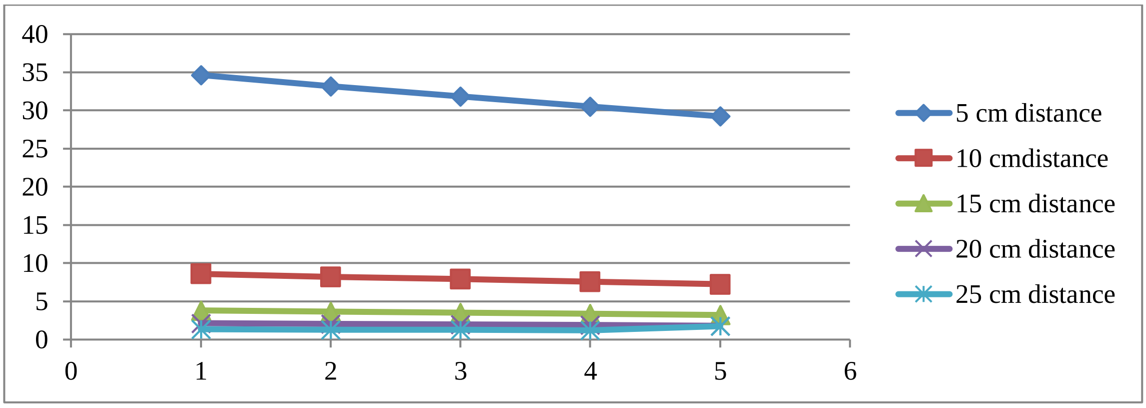

Fig. 5: SAR impact inside brain at 915 MHz [Depth of tissue is 1-5 mm]

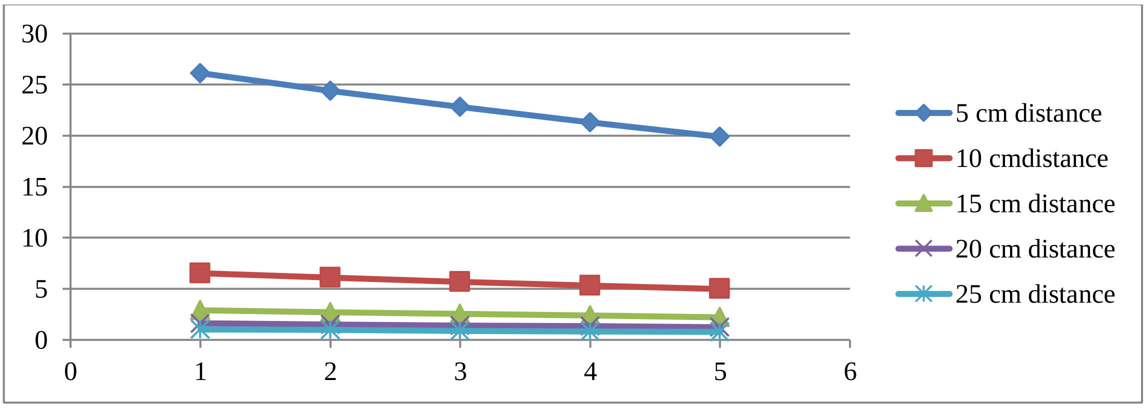

Fig. 6: SAR impact inside brain at 1900 MHz [Depth of tissue is 1-5 mm]

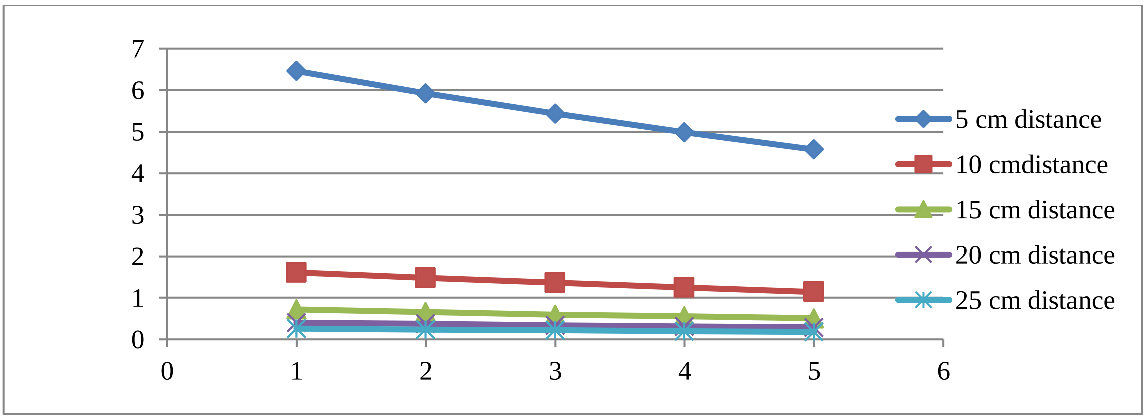

Fig. 7: SAR impact inside brain at 2450 MHz [Depth of tissue is 1-5 mm]

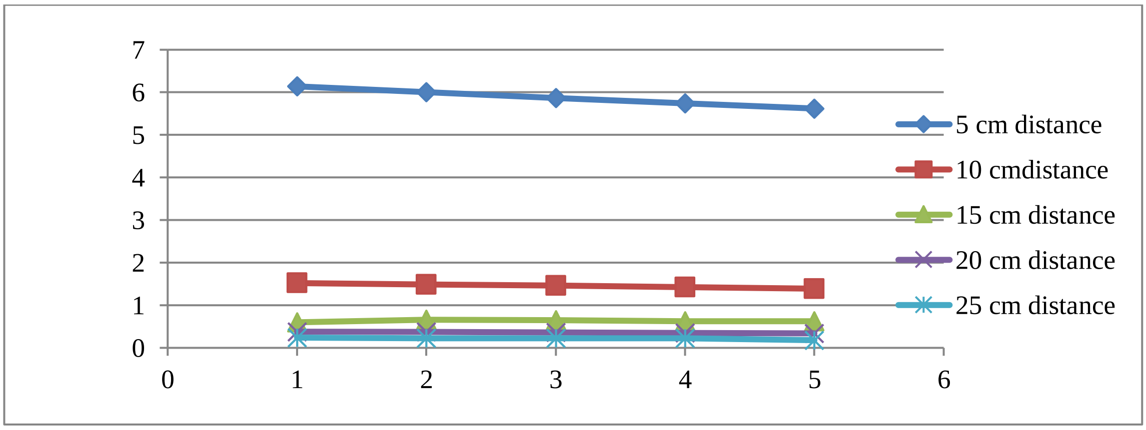

Fig. 8: SAR impact inside skull at 915 MHz [Depth of tissue is 1-5 mm]

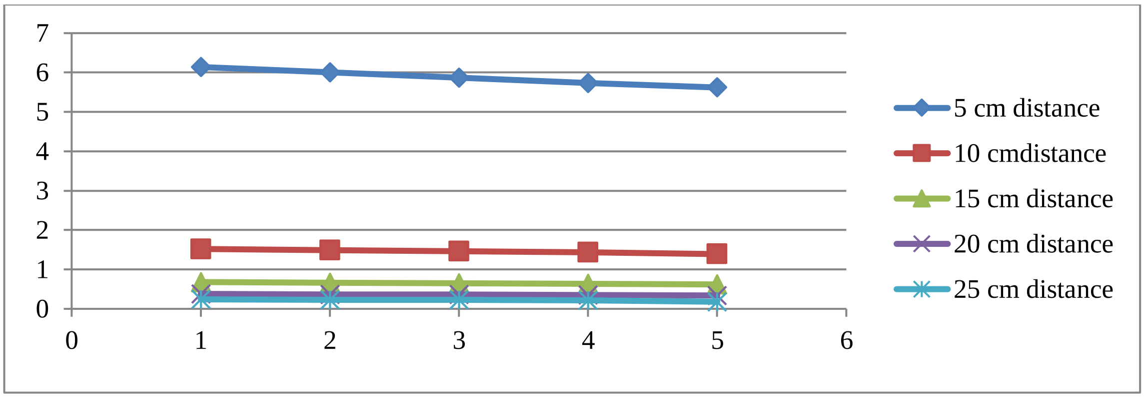

Fig. 9: SAR impact inside Skull at 1900 MHz [Depth of tissue is 1-5 mm]

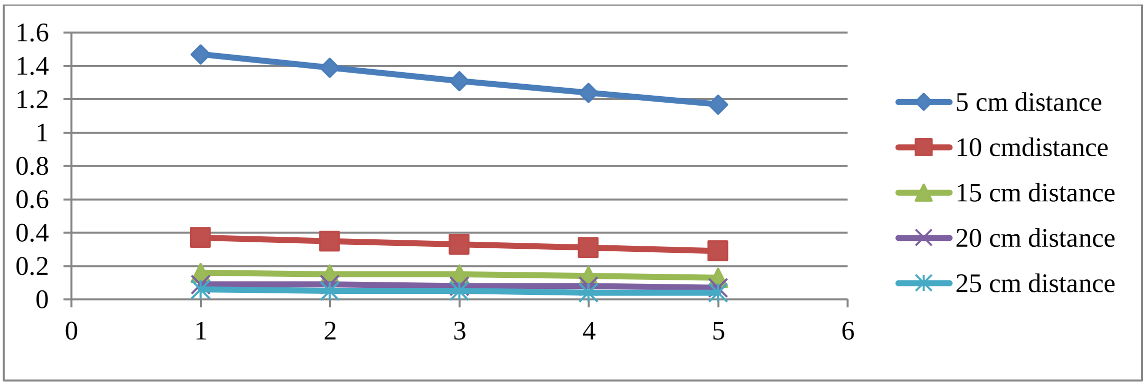

Fig. 10: SAR impact inside Skull at 2450 MHz [Depth of tissue is 1-5 mm]

5. RADIATION MINIMIZATION METHODS

The amount of radiation depends on many parameters like frequency of transmission/reception, size of antenna used, permittivity, permeability, etc. If any parameter gets change, the radiation changes in result. Some methods are suggested to reduce this radiation for the welfare of mankind and society. Radiation can be minimised by attaching an RF shield to mobile phones, using microwave absorbers, using highly directive antennas, using metamaterials, using split ring resonators and RF safe accessories. The idea behind the concept is to use low conductivity materials which results in very small induced current in material during EM wave exposure. Any shield which is made up of ferrimagnetic material can be used to manufacture RF shield. The property of ferrite material is that it shows very small conductivity at RF exposure. The application of the RF shield is beneficial because it does not degrade antenna performance. Microwave absorbers may be another option to minimize SAR. These are designed to have high permeability which defines magnetic loss properties and high permittivity which is a measure of dielectric loss properties. This combination of high permeability and permittivity makes microwave absorber very effective in eliminating high frequency electromagnetic interference and in this way, it contributes to minimising the radiation. An antenna giving transmission in a particular direction is more powerful than the omni-directional antenna. This is also a good option to provide better coverage in rural areas without an increase in tower power. Directives antennas actually concentrating their main lobe in one direction rather than 360^o coverage. The use of directive antennas reduces radiation in human head. The only drawback is that signal degradation occurs in case of multipath reception or fading conditions. The planer monopole antenna with a T shape coupling feed design is also effective for SAR reduction [10]

Another alternative to reduce radiation is metamaterials. These are artificial materials having an array of structures smaller than a wavelength of interest and can interact with electromagnetic radiation in the desired fashion. These materials are designed that it can have the property of “Negative index of refraction”. The metamaterials are designed through nano-scale objects combining together to achieve the variation in permittivity and permeability on a very small scale. Head SAR can be reduced by placing the Square Metamaterials (SMMs) in between head and antenna. The advantage of metamaterial is that it shows very fine electromagnetic properties against radiation. Split ring resonators are also a good option for radiation minimization. These are placed in between the human head and antenna. These resonators possess a negative refraction index and can exhibit negative permeability when grouped in an array. The split is designed in opposite side to achieve the resonance at wavelength much larger than diameter of ring. In this way, the resonant frequency can be controlled to minimise radiation effects.The split ring resonators are grouped together for strong magnetic coupling and low radiative losses.It is also suggested that by adding a small metal strip towards the backside of the antenna of mobile phones, the overall size of the antenna can be reduced. The metal strip is able to reduce the antenna size by varying the resonant frequency, Therefore SAR can be minimized. Some devices like radio safe headphones, protection cases of mobile and mobile screens are designed as radio safe accessories. These accessories can be used to minimize radiation effects on human body.

6. CONCLUSION

Calculations are done for human brain and skull parameters and concluded that the skull is less prone to radiation in comparison to brain. It is fact that the SAR value is a function of conductivity, permeability, and square of induced electric field (E_i). It can be concluded from table7 to12 that SAR is getting decrease with the decreasing incident and induced power in the tissue. The induced electric field depends on frequency as well as transmitter power level. It can be made safer by decreasing the transmitter radiation by operating transmitter at low power level but the drawback is that we need a number of repeaters to send signal at a long distance. It is also investigated that higher frequencies used in 2G, 3G and Wi-Fi wireless communication are radiation prone and harmful for human health. The radiation becomes more harmful and beyond the tolerable limits as the distance from transmitter becomes less because the penetrating power is very high near transmitter and gets decreases as the distance is increased. One better step to minimize the radiation is to avoid the call in fringe areas where the phone is searching for the network and the signal is poor. In this condition, mobile phone antenna produces maximum radiation and uses its maximum power to search the network to maintain the services. Various methods like split ring resonator, use of metamaterials, RF safe devices, RF shield from ferromagnetic material, microwave absorbers and highly directive antennas are some examples to minimize the radiation upto some extent.

7. ACKNOWLEDGEMENT

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