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Analysis of Specific Absorption Rate at 900MHz

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Abstract: This paper presents a critical analysis of specific absorption rate (SAR) at 900 MHz in different scenarios with the various factors which play an important role in the analysis of SAR. The effects of frequency, dielectric properties of biological tissues, type of antenna and its distance from measuring biological tissue are studied by making the reference of available literatures. A human head model is constructed through simulations to analyze the specific absorption rate and heat distribution in brain tissue.

Keywords: SAR, dielectric properties, blood perfusion rate, finite element method.

I. INTRODUCTION

Evolution of wireless technology has made the life of human beings much easier than before. In the past fifteen years, due to rapid growth in the mobile communication technology, the effect of electromagnetic radiations on human health which is received from mobile phones has become an important topic to study and research.

A mobile phone consists of an omni-directional antenna which ideally radiates in all directions. These radiations are absorbed by lossy materials such as biological tissues, which results in temperature increase in the material. Absorption of radiations beyond a certain limit may also lead to adverse health effects. In [1] authors have reported that a very small temperature rise in hypothalamus of 0.2–0.3^{o}C leads to altered thermoregulatory behaviour. The amount of this absorbed radiation is provided by Specific Absorption Rate (SAR) which is defined as the power absorbed per mass of the tissue in watts/kg. Human head is considered as the most sensitive part of the entire human body. Therefore most of the research has been carried out only on human head. The temperature increase inside the human head, however, cannot be measured directly. In order to overcome this difficulty, a well-known bioheat equation was proposed by Pennes [2] for following the time variation of temperatures in different biological tissues. Pennes suggested that the dissipation of the temperature is due to conduction with other tissue types, convection through blood perfusion rate and radiation to the surroundings. Different countries follow different standards for specific absorption rate (SAR) analysis. In United State, for exposure to RF energy from wireless devices, the allowable Federal Communications Commission (FCC) SAR limit is 1.6 W/kg, averaged over 1gram of tissue for duration of 30 minutes [3]. While in Europe, according to International Commission of Non-ionizing Radiation Protection (ICNIRP) the allowable SAR limit is 2W/kg, averaged over 10 gram of tissue for duration of 6 minutes [4]. Additionally IEEE C95.1 gives recommendation to prevent harmful effects in human beings exposed to electromagnetic fields in the frequency range from 3 kHz to 300 GHz [5]. Experimental methods to evaluate SAR are quite costly and also time consuming. It is against the law and moral to expose a human being to electromagnetic radiations for experimental purpose. Moreover, numerical analysis through simulations provides more flexibility to analyse the same. Therefore several different kinds of models can be used to investigate SAR and heating effects. These include Finite Element Method (FEM), Finite Difference Time Domain Technique (FDTD), Finite Difference Method (FDM), Charge Simulation Method (CSM), Boundary Integral Equation Method, Method of Moments (MoM), Finite Integration Technique (FIT) etc. to make predictions without needing laboratory tests. Among these methods FDTD [6] and FEM [7] are popular choice for performing the numerical analysis of SAR, as these models have shown very accurate results. Between the two, FEM is found to be a more powerful technique for handling problems involving complex geometries due to its flexible tetrahedral meshing scheme when compared with cubic Yee-type grids of FDTD method [8].

The most important aspect for performing the analysis of SAR is the selection of the method to carry out the required measurements. Variations in parameters i.e. difference in frequencies, type of biological tissues, density of the tissue, type of antenna, distance of antenna from the measuring tissue, duration and the amount of exposed radiation lead to different amount of absorption and SAR values. This paper presents a technique to calculate the specific absorption rate (SAR) using finite element method in a human head model exposed to frequency range used in GSM-900 mobile phones.

II. METHOD AND MODEL

In this study a realistic adult head model is developed from MRI scans of a human head. This model is comprised of skin and brain tissue. Finite element method (FEM) is adopted to carry out this study. FEM is a numerical method for finding approximate solutions of irregular, continuous physical systems. It involves dividing the domain of the problem into simple geometric shapes or subdomain called finite element. Each subdomain is represented by a set of element equations to the original problem. Finally it recombines all sets of element equation for providing the end solution of the problem.

In this study, a square patch antenna is considered as a source of electromagnetic radiations and is placed at the left side of the head model at a distance of 1cm. Figure 1 is illustrating the human head model exposed to radiations from a mobile phone which consists of square patch antenna.

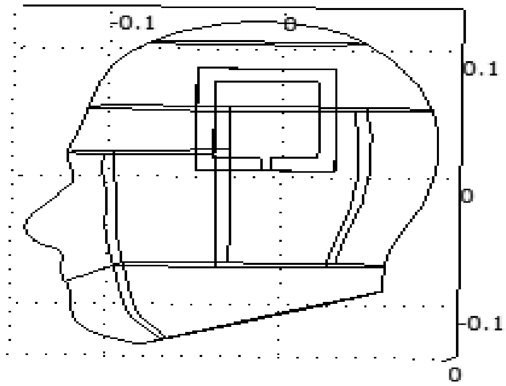

Fig.1 Head model with square patch antenna.

900 and 1800 MHz spectrum are widely used in the field of GSM mobile communication. The maximum power that GSM phones are permitted to transmit are 2W (900 MHz) and 1W (1800 MHz). However, the average power transmitted by a phone is never more than one-eighth of these maximum values (0.25 W and 0.125W respectively). Radio waves become less penetrating into the body tissues as the frequency increases. It is observed that due to short wavelength at higher frequencies radio power penetrates to small distances. Higher the frequency lesser will be the depth of penetration. When tissues are exposed to radiation depth of penetration depends on frequency and electrical properties of tissue. Depth of penetration is provided according to equation (1) as follows:

$$\delta = \sqrt{\frac{1}{\pi \mu \sigma f}} \qquad (1)$$

Where, δ is the penetration depth (m), μ is the tissue magnetic permeability (H/m), σ is the tissue electric conductivity (S/m), and f is the RF source frequency (Hz).

A. *Effect of type of tissue*

The Two important properties of a tissue that play a significant role to determine how electromagnetic radiations are absorbed by biological tissue are permittivity and conductivity. Different tissues have different value of dielectric properties, which are functions of several variables, such as frequency, geometry and size of tissue, and water contents. The magnitude of these dielectric properties in each tissue will directly affect the amount of SAR within the particular biological tissue. Figure 2 is describing the dependence of conductivity and permittivity on frequency [9]. On exposure to radio waves, electromagnetic radiations are not absorbed uniformly throughout the body, even if the incident radiation has uniform power density. In general, a wetter material corresponds to more loss while the drier a material is, the lesser lossy it becomes. High-water content tissues like muscles will absorb more radiations than drier tissues such as fat and bone.

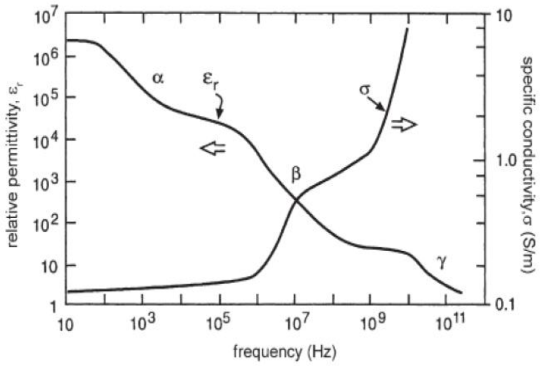

Fig.2 Frequency dependence of the dielectric properties of biological

Akimasa Hirata et al. [10] suggested that one of the most dominant factors which affect the correlation between peak SAR and maximum temperature increase is blood flow in tissues. Dielectric and thermal properties of brain tissue are tabulated in Table 1

TABLE 1. Dielectric and thermal properties [11]

Tissue type	**900 MHz**				
	$\boldsymbol{\varepsilon_r}$	**σ (S/m)**	**ρ (kg/m^3)**	**C_p (J/kg.K)**	**ω_b (1/s)**
Brain	56.8	1.1	1050	3650	0.00883

B. *Effect of type of antenna and its distance from measuring tissue*

Another very important parameter that affects the energy absorbed in the biological tissue when exposed to radiation from mobile phone is the distance between the antenna and tissue. The rate at which radiations emitted from a fixed, constant source of electromagnetic radiation passes through a surface at a distance d from the source is proportional to $1/d^2$. This is known as the Inverse Square Law. According to this law the radiation flow falls off rapidly as the distance between the radiating source and receiving tissue increases. For example, by doubling the distance, radiations will be decreased by a factor of four. According to [12], [13] if the distance between the antenna and human head increases then the value of SAR decreases. Not only the distance but also the size and type of antenna and its efficiency affect the SAR values [14]. In [15] a comparative study has been performed among patch, monopole, dipole and PIFA antenna. PIFA antenna yields the highest SAR levels in head tissue, while the patch is most likely to meet the safety standard. This conclusion is of great importance during the manufacturing of mobile phones, as it can provide useful information about the selection of transceiver’s antenna considering the stimulated health hazards.

III. MATHEMATICAL MODELLING

Mathematical models are developed to measure the electromagnetic field distribution and SAR with relation to temperature gradient within the brain tissue of human head model. The specific absorption rate provides the amount of absorbed radiation inside the tissue per unit of mass when a radiating antenna is placed near to that tissue. SAR can be calculated by equation (2) as follows:

$$\text{SAR} = \frac{\sigma E^2}{\rho} \qquad (2)$$

Where, σ is electrical conductivity (S/m), E is electric field intensity (V/m), and ρ is the density of the tissue (Kg/m^3).

When exposed to radiations, the distribution of electromagnetic field is calculated using Maxwell's equation (3) as follows:

$$\nabla \times \frac{1}{\mu_r} \nabla \times E - {k_0}^2 \varepsilon_r E = 0 \qquad (3)$$

Where, E is the electric field intensity (V/m), μ_r is the relative magnetic permeability, ε_r is the relative permittivity and k_0 is free space wave number.

The absorbed energy by the biological tissues is converted to thermal energy and causes a temperature increase. For the purpose of heat transfer analysis the temperature of biological tissues is modelled using the following Pennes' bio-heat equation (4) as follows [2]:

$$\rho C \frac{\partial T}{\partial t} = \nabla \cdot (k \nabla T) + \rho_b C_b \omega_b (T_b - T) + Q_{met} + Q_{ext} \qquad (4)$$

Where, ρ is the tissue density (kg/m^3), k is thermal conductivity (W/m.K), C_b is specific heat capacity (J/kg.K), Q_{met} is metabolism heat source (W/m^3), Q_{ext} is external heat source (W/m^3) and ω_b is the blood perfusion rate (1/s). The external heat source term is equal to the electromagnetic power absorbed.

IV. RESULTS AND DISCUSSION

After validating the mathematical model, simulation is performed for a mobile phone consisting a patch antenna radiating maximum 1W power at 900 MHz. When exposed to the radiations some part of it is reflected and relative portion is absorbed and transmission depends on the thickness of the tissue. Fig. 3 and Fig. 4 are showing the obtained values of SAR and corresponding rise in brain temperature at 900 MHz respectively. The simulation results are specified in Table 2. In Fig. 3 different colours are showing the variation in SAR values. Maximum obtained value of SAR is 0.198 W/kg in brain tissue of the human head model. The human body tries to regulate its core temperature through some effective means. The initial body temperature is considered as 37℃. It is found that SAR values falls off rapidly from skin to brain region. The SAR percentage for the skin tissue is relatively high than the brain tissue due to its closeness from the radiating antenna and the presence of high water contents. It is not possible to obtain the exact amount of rise in temperature in biological tissues. Fig. 4 depicts the variation in temperature. Maximum value of SAR is very less than the FCC safety standard.

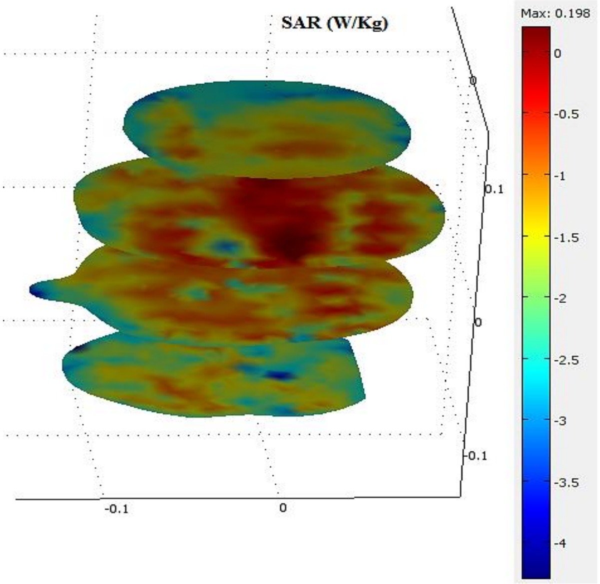

Fig. 3 SAR distribution in brain region of human head model at 900 MHz.

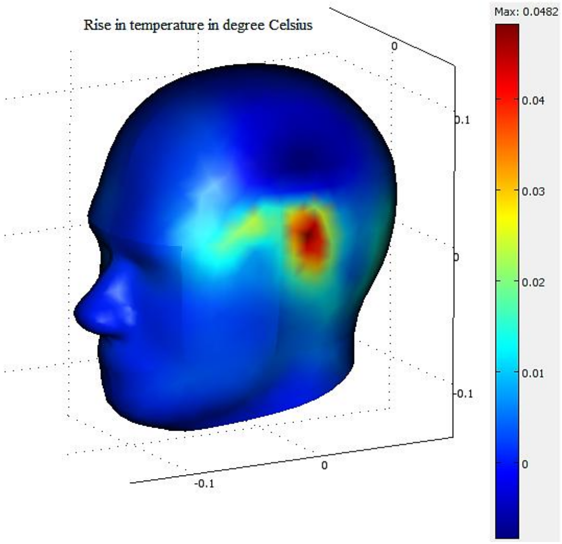

Fig. 4 Temperature distribution in human head model at 900 MHz.

TABLE 2. Simulation results at 900 MHz

Tissue type	Frequency (MHz)	Power radiated (W)	SAR_{max} (W/kg)	Rise in temperature (℃)
Brain	900	1	0.198	0.048

V. CONCLUSION

This study presents the numerical simulation of SAR and distribution of temperature in a human head model at 900 MHz frequency. In this paper, different parameters are considered that have considerable impact to evaluate the SAR values. The effect of these parameters on SAR calculations and heat distribution analysis in biological tissues is discussed by considering the research work done by different researchers in the corresponding field. It is found that antenna distance from measuring tissue and dielectric properties of biological tissues have a significant impact in the analysis of SAR. Finite element method is found to be an effective technique to perform the numerical analysis in complex geometries like biological tissues in the evaluation of SAR.

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