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SAR Analysis Using a Dipole Antenna in a Non-layered and Multi-layered Human Head Model

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Abstract— The public complaints about health are on the rise as a result of mobile phone usage. Limits on the radiation strength emitted by these devices have already been recommended by standard bodies such as The Federal Communication Commission (FCC) of the United States and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) to safeguard public from excessive exposure to electromagnetic fields. Some recent research have found that long-duration use of calls on mobile phones increases the incidence of health hazards and has negative consequences. After survey the research on investigation of specific absorption rate (SAR) in the human head is becoming increasingly essential. In proposed work, Investigations were done on how human head model and electromagnetic source interacted. The goal of this work is to demonstrate that the one layer head model is not a good model rather appear to be unreliable to evaluate SAR since genuine human skull tissue is not modelled in the same way. But investigation of SAR in six layers (Brain, CSF, Dura, Bone, Fat and Skin) human head appears better and reliable. Affection to the six layered human head may be dominant when exposed to electromagnetic (EM) fields.

Keywords- Human head model, Specific Absorption Rate, Half wave dipole antenna, Mobile Phone.

I. INTRODUCTION

We all know that the human head is made up of multiple layers of tissue, and modelling it is a difficult task. Furthermore, Because of the genuine properties of tissues differ greatly from those of phantoms, phantoms are not good models for human tissue. As a result, the multilayer phantom model is an excellent option for human head simulation. There are several techniques for assessing SAR at the moment, including two well-known ones that assess conformity with certain SAR requirements. One approach measures the electric field strength; the other examines the pace at which the temperature of a liquid analogous to tissue is changing. The human head or another bodily component might be the object. [1]

- Electric field strength measurement: The researchers are developing a method for measuring within the human body using a small electric field at radio frequency (RF). Small antennas receive weak RF signals, but a comparable antenna placed 15–50 cm distant can measure the strength of the electric field.
- Using an electric field probe or a temperature sensor, one can simply measure point SAR. SAR = c $\Delta T/\Delta t$ [w/kg], Where c represents specific heat, ΔT represents temperature elevation, and Δt represents heating time. [2]

In order to accurately assess electromagnetic field exposure in the human head, the head models must be taken into account. The suggested model is based on age-dependent dielectric tissue characteristics as well as age-specific anatomical structure. Variations in cell number and size, as well as the amount of bodily water content, may occur after the development of human tissues. These kinds of changes can be seen in the dielectric characteristics of tissues in the human head.

This paper endeavors to access specifically power absorbed by each layer of tissue due to EM exposure from mobile cell to evaluate SAR in human adult head. The use of HFSS software to simulate design of one layer and six layer adult head model as well as a dipole antenna to measure SAR in both head model. The section antenna model design includes design of HW dipole with a center frequency of 1800 MHz is meant to operate as a mobile phone. For satisfactory results, we also tested performance metrics such radiation pattern, gain, VSWR, and return loss. The section head model design includes modelling of the adult heads that are one layer and six layers head models.

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The six layer head includes Brain, CSF, Dura, Bone, Fat and Skin layers. Under the next section, E-field measurement and absorbed power measurement gives description with the degree of EM absorption penetrated in each layer being examined for SAR assessment. SAR has been estimated in both scenarios i.e. for one layer and six layer head models and it reveals that SAR increases in a six-layer human skull versus a one-layer human head due to layer-by-layer differences in conductivity, permittivity, and permeability.

II. MODEL DEVELOPEMENT

A. Antenna Model Design

The simulation of half wave dipole antenna been done with HFSS by following the procedures in the flowchart shown in Fig.1, which displays the general stages for getting a simulation of the proposed antenna with 1800 MHz center frequency.

A dipole antenna (shown in Fig. 2) with a single excitation port is positioned in free space in this experiment. For a certer frequency of 1.8 GHz, dipole is 79.44 mm long. Because the feed gap is 0.3972 mm, the length of each dipole arm is 39.72 mm and the radius is 0.167 mm. Copper was chosen as the material for the dipole arms because it is a great electric conductor. In the feed gap is a lumped port excitation with a 50 Ω internal resistance. Summary of antenna design parameters shown in Table 1.

Simulation was used to examine performance characteristics such as return loss, voltage standing wave ratio, radiation pattern, and gain in order to improve findings. The suggested HW dipole antenna has a return loss of -20.7710 dB and a bandwidth of 424.3 MHz, as shown in fig.3. The VSWR was 1.5901 dB, as shown in fig.4, with a greater gain indicated by the 3D Radiation Pattern in fig.5.

TABLE I. ANTENNA DESIGN PARAMETERS SUMMERY

Sr. No	*Parameters*	*Values*
1	Frequency (fr)	1800 Mhz
2	Radius (R)	0.167 mm
3	Wavelength (λ)	167 mm
4	Dipole Arm (L/2)	39.72 mm
5	Length (L)	79.44 mm
6	Gap (g)	0.3972 mm
7	Maching Impedance (Z0)	50 mm

B. Design of Human Head Model

The human head model, which is spherical and multilayered, has been taken into account in this study [3]. In Fig. 6, a stratified general structure of Six-layer tissue model is seen. The skin is 1.0 mm thick, the fat, bone, dura, cerebrospinal fluid (CSF) and the brain are 1.4, 4.1, 0.5, 2.0, 81 mm thick respectively [9]. Normally, the thickness of constituent layers in multilayer head model varies by age, gender and individual. These components make up the layered media. Figures 7 and 8 depict single-layer and six-layer head models that have been simulated using the suggested simulation software in accordance with the specifications mentioned in Table III.

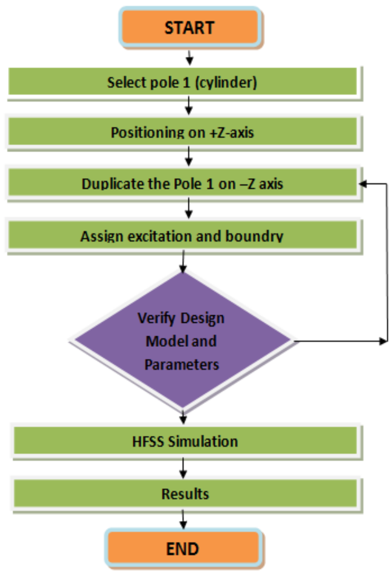

Figure 1. Flow Chart for Design Simulation of Half Wave Dipole Antenna

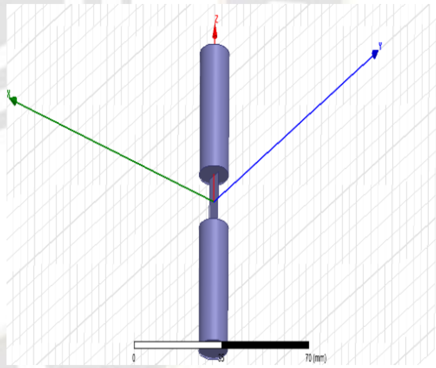

Figure 2. An 1800 MHz Half Wave Dipole Antenna

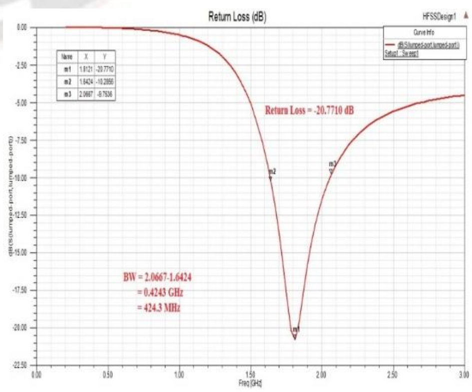

Figure 3. Bandwidth and Return Loss curve for a HW dipole antenna

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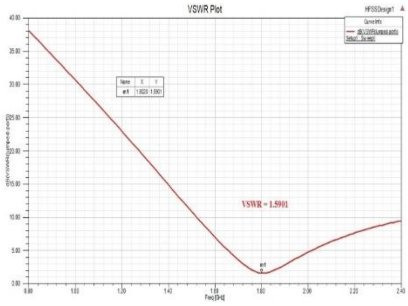

Figure 4. HW dipole antenna VSWR Plot

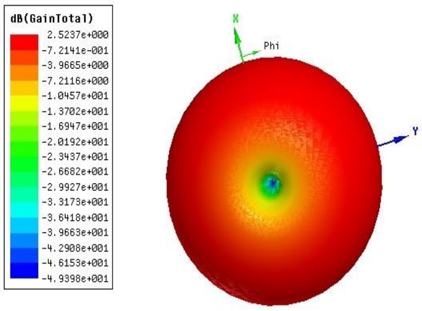

Figure 5. HW dipole antenna with greater Gain and a 3D Radiation Pattern

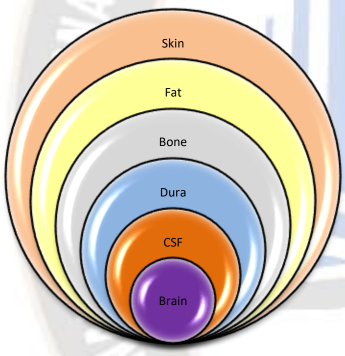

Figure 6. Six-layered model of a human head

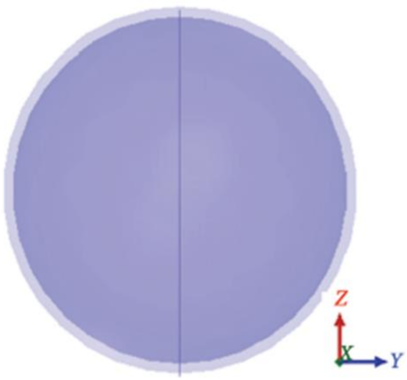

Figure 7. Single layered design model of Human Head

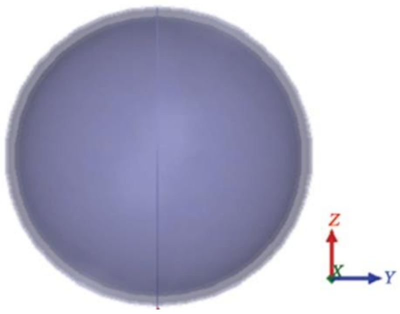

Figure 8. Six layered design model of Human Head

III. E- FIELD MEASUREMENT

A. *SAR (Specific Absorption Rate)*

It describes how quickly the body absorbs RF energy when exposed to an electromagnetic field. It measures the energy that tissue absorbs per unit mass of tissue. The watt per kilogram (W/kg) is the unit of measurement.

$$SAR = \sigma|E|^2/2\rho \quad (1)$$

In equation 1, sigma (σ) stands for electrical conductivity in S/m, where rho (ρ) stands for mass density in kilogrammes per cubic metre and E stands for electric field intensity in volts per metre. Some studies [7] used the ICNIRP [4], IEEE [5], and FCC [6] standards to provide some baseline SAR limit values. As shown in Table 2, these values are taken for the exposure of regular people in an uncontrolled environment in the extremities (which are not a part of the head). Peak SAR values, averaged across any 10 gramme of tissue, must be up to or below the limit of 2 W/kg, as per the ICNIRP recommendations and the IEEE standard.

To begin, one-layer head model will be used for measurement, followed by a six-layer head model with standard head equivalent material parameters. Permittivity 39, Conductivity 0.9 S/m, and Thickness 90 mm are the dielectric characteristics. The field radiated by a mobile phone (dipole antenna) with the frequency band of interest is exposed to the one layer and six layer models. The dipole, which was detailed in depth in the antenna model section, was placed 5 mm away from both the one and six layer head models. The required dielectric parameters and geometrical specifications for HFSS simulation are listed in Table III.

TABLE II. COMMON LIMITS FOR SAR [6]

	ICNIRP 1998	*FCC OET B-65/2001*	*IEEE 2005*
Extremities	4 W/kg over 10 g	4 W/kg over 10 g	4 W/kg over 10 g
Other tissues	2 W/kg over 10 g	1.6 W/kg over 1 g	2 W/kg over 10 g

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TABLE III. LAYER-WISE DIELECTRIC TISSUE PROPERTIES FOR HUMAN HEAD [9]

Tissue	*Permittivity*	*Conductivity (S/m)*	*Thickness (mm)*
Skin	37.21	1.25	1.0
Fat	9.38	0.26	1.4
Bone	16.4	0.45	4.1
Dura	37.21	1.25	0.5
CSF	77.3	2.55	2
Brain	43.22	1.29	81

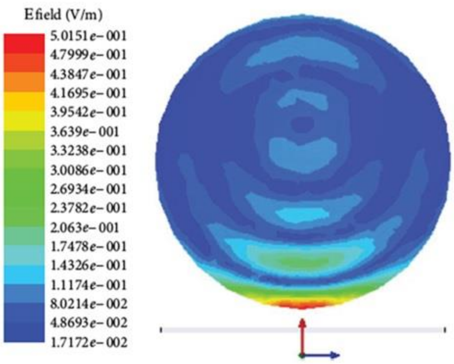

Figure 9. E-field measurement in a 1-layer HFSS-designed head model

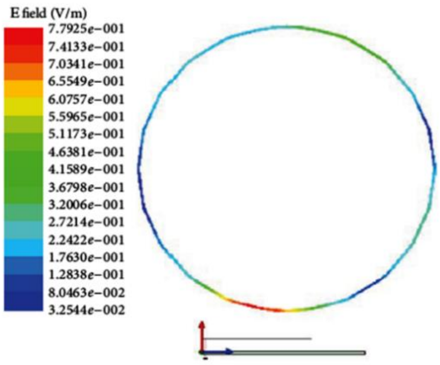

Figure 10. Measurement of the E- field in the SKIN-layer of 6-layer HFSS-designed head model

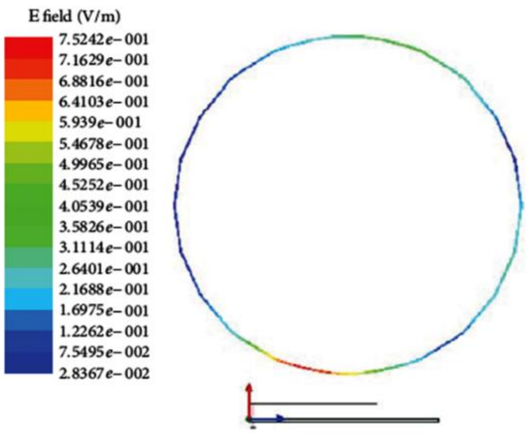

Figure 11. E-field measurement in the FAT layer of a 6-layer HFSS-designed head model

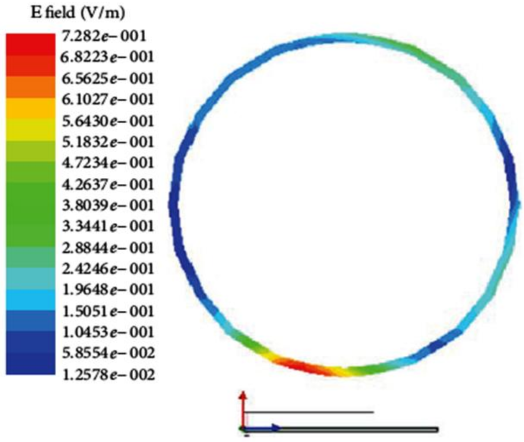

Figure 12. E-field measurement in the BONE layer of a 6-layer HFSS-designed head model

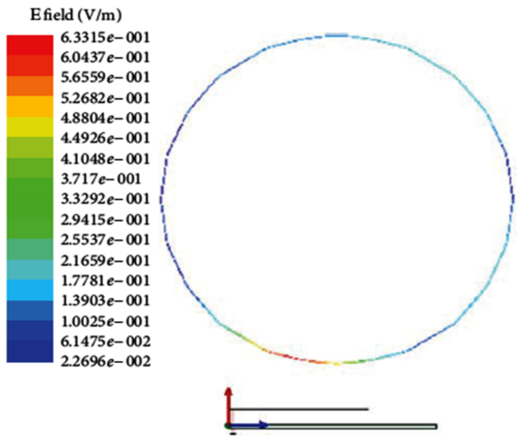

Figure 13. E-field measurement in the DURA-layer of 6-layer HFSS-designed head model

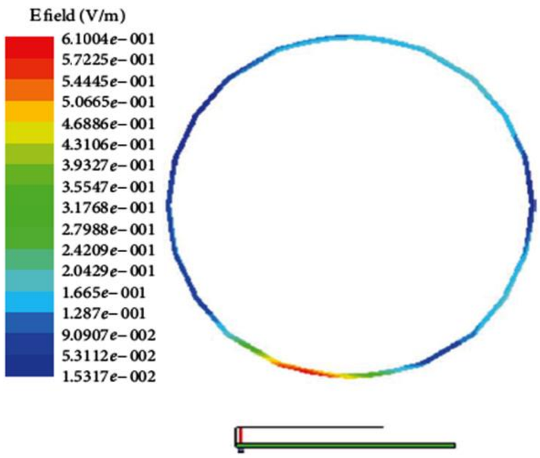

Figure 14. E-field measurement in the CSF layer of a 6-layer HFSS-designed head model

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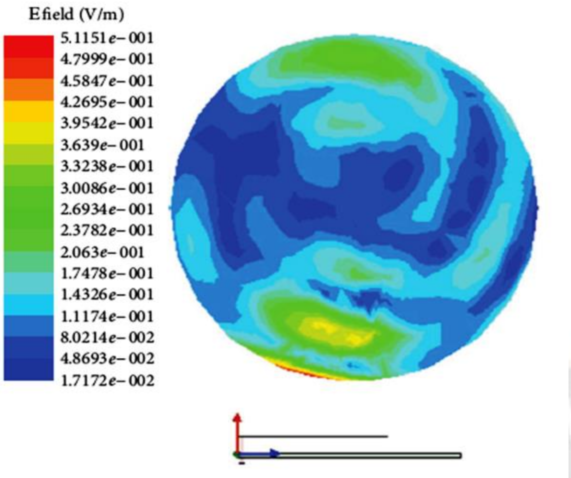

Figure 15. E-field measurement in the BRAIN-layer of a 6-layer HFSS-designed head model

IV. Results and Discussuion

When exposed to electromagnetic radiation, biological tissue exhibits a dispersive tendency and absorbs power. Power levels also typically tend to increase the severity of tissue injury [10]. When the EM wave reaches the tissue layer, at higher frequencies, the EM absorption increases which is due to the high tissue permittivity, the wavelength is reduced [11] causing tissue warmth. In fact, distinct biological tissues have a frequency-dependent dielectric constant and behave like a lossy dielectric substance. Tissue heating near the skin's surface can be considerable under adiabatic circumstances, while the temperature increase in the interior body tissues is less pronounced. [12]

This section presents the results of E-field measurements made using a dipole on a 1-layer and 6-layer simulated head model. The E-field measurement in a one-layer model of the human skull is shown in Figure 7. The single-layer head is made up of material that is equivalent to head tissue. For an adult person, the dielectric properties of the material and geometrical parameters for the head model are examined. The EM generated with a mobile phone (dipole antenna) with the frequency band of 1800 Mhz indicated in antenna model design was exposed to a one-layer Model of a human skull with a 5 mm gap between it and the electromagnetic source. The maximum value of E-field after evaluation in a one-layer human head model is 5.0151 x 10-1 volts per metre as shown.

In addition, a six-layer model of a human skull was used to investigate the e-field. The six-layer human head model's dielectric parameters and geometrical requirements, which were applied in earlier investigations, are listed in Table 3 [8]. [9] [13] With a 5 mm gap between the head and the antenna model, this six-layer human head model was exposed to an electromagnetic field source (dipole antenna) in the 1800 MHz frequency band. The skin layer was the first to experience the e-field, followed one by one by the fat, bone, dura, CSF, and brain layers. Figure 8 depicts the E-field measurements in the Brain, CSF, Dura, Bone, Fat and Skin of a 6-layered head model.

TABLE IV. Layer-wise dielectric tissue properties for human head [9]

Model	*Layer*	*Conductivity*	*Maximum E-field strength V/m*	*Maximum SAR W/kg*
1 layer head model + dipole antenna	Head Equivalent Material	0.9	5.0151×10^{-1}	3.2147×10^{-5}
6 layer head model + dipole antenna	Brain	1.29	5.1151×10^{-1}	3.5392×10^{-4}
	CSF	2.55	6.1004×10^{-1}	8.0788×10^{-5}
	Dura	1.25	6.3315×10^{-1}	6.2532×10^{-5}
	Bone	0.45	7.2820×10^{-1}	2.1344×10^{-4}
	Fat	0.26	7.5242×10^{-1}	4.7128×10^{-4}
	Skin	1.25	7.7925×10^{-1}	1.4738×10^{-4}

Table 4 displays specifics on the SAR value for one layer and six layer head models. A one-layer head model has a lower SAR when compared to a six-layered head model. EM absorption also increases with distance from the skin layer to the brain layer. The SAR in the skin layer observed increased significantly. Very little water is present in fat tissue, which results in drastically reduced permittivity and conductivity. We found the highest SAR value in the Fat layer and the lowest SAR in the Dura layer. Despite being the innermost layer, the brain layer appears to have the second highest SAR value. The varying dielectric characteristics of human tissue have just been discovered. [14] [15]. S. L. Bangare et al. [18-19] worked in the disciplines of ML and IoT. The LRA-DNN approaches have been proposed by N. Shelke et al. [20]. S. Gupta et al. [21] demonstrated effective extraction techniques. CNN approaches were used by G. Awate et al. [22]. The network security work was proposed by Xu Wu et al. [23]. Deep neural networks were employed well for brain tumor research by A. S. Ladkat et al. [24]. Modernized techniques for feature extraction and leaf categorization called Bezier control points-based features and Capsule Network have been used by S. D. Pande et al. [25–27].

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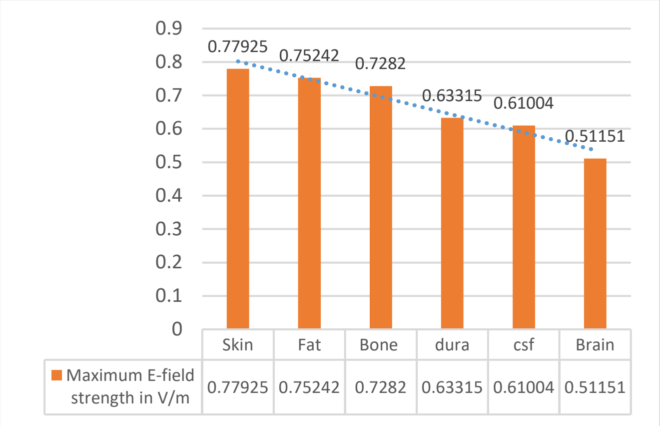

Figure 16. E-field variation in tissue layer with change in distance from source

SAR changes in a 6-layer head compared to a one-layer head due to changes in conductivity, permeability and permittivity layer by layer.

V. Conclusion

This investigation examined how human head models interacted with an electromagnetic source. According to the findings, layered head tissue may absorb electromagnetic fields more completely than homogenous tissue or a single layer head model. This is a result of impacts whose magnitude had not been anticipated or was not yet apparent. The results reveal that in a 6- layer head model, the e-field exposure is more dominant than in a one layer head model. To protect against the biological effects of cell phones, it is vital to limit their use. Furthermore, from fig. 9, it has been shown that when the separation between the source and the head of a person increases, the human head's e-field strength weakens. So keeping a safe distance from a mobile phone may spare one from harm.

The wireless gadgets that may be carried in the hand or installed on the body must be cautiously assessed for compliance includes a safety limits on SAR for RF-exposure. It is necessary to modify the applicable standards to take into consideration the effects of electromagnetic field coupling with layered brain tissue. The SAR evaluation results in both head models may indicate that standard SAR values may needs to be sought again. The work given in this paper isn't finished; many other relevant issues, such as RF absorption by a child's head, will be investigated further.

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