SAR Distributions in a Spherical Inhomogeneous Human Head Model Exposed to Electromagnetic Field for 500 MHz – 3 GHz Using FDTD method

Md. Faruk Ali
Department of Instrumentation Technology,
Nazrul Centenary Polytechnic, Rupnarainpur, Burdwan – 713 335, India
faruk_ali@rediffmail.com

Sudhabindu Ray
Department of Electronics and Telecommunication Engineering,
Bengal Engineering and Science University, Shibpur, Howrah – 711 103, India
sudhabin@yahoo.com

Abstract **– Specific absorption rate (SAR) inside spherical human head model for half-wave radiating dipole antenna has been investigated at the frequency range from 500 MHz to 3 GHz using finite difference in time domain (FDTD) method. The effects of variation of reflection coefficient and resonant frequency of the antenna due to presence of head model are also presented in this paper. The human head is modeled as inhomogeneous sphere of 19 cm diameter consists of a uniform core representing human brain, surrounded by two spherical shells representing skull and skin. Distance between the head and antenna is varied from 1 cm to 3 cm to calculate the maximum local SAR induced inside the head. At some frequencies the maximum local SAR becomes more than the FCC and IEEE's upper safety limit for the distance between the head and antenna less than 1 cm and 0.6 Watt radiated power.**

I. Introduction

Radio frequency (RF) hazard due to the interaction between the human head or other body parts and the electromagnetic (EM) wave generated from the wireless communication devices is becoming a burning issue. During the last several years, there have been increasing interests in the application of numerical techniques to calculate the intensity of electric fields in the human head models [1-3]. Different numerical electromagnetic methods played significant roles to calculate SAR because it is not possible to actually measure these values inside a human head. In the present work FDTD [4] method is used to carry out all numerical calculations.

II. Finite Difference In Time Domain

The FDTD method is one of the most successful and versatile techniques in computations involving the electromagnetic waves in three dimensional structures [1,2,5].

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

$$\vec{\nabla} \times \vec{H} = \sigma \vec{E} + \varepsilon \frac{\partial \vec{E}}{\partial t} \tag{2}$$

The parameters σ, μ and ε are conductivity, permeability and permittivity, respectively.

In FDTD method, Maxwell's time dependent curl equations (1) and (2) have been solved by discretizing the space into a number of Yee cells and assigning each cell to the corresponding permittivity and permeability in a time-marching sequence. Following Yee's notation at each grid points all the components of the electric and magnetic fields are calculated. FDTD method requires the use of absorbing boundary conditions (ABC) to accurately terminate the computational domain which allow the propagation of EM waves out of the computational space but at the same time reduce the unwanted reflections from the edges of the region of interest. In this simulation Berenger Perfectly Matched Layer (PML) [6] has been used as the absorbing boundary conditions.

Reflection coefficient (S_{11}) as a function of frequency is determined from the ratio of the Discrete Fourier transform (DFT) of the transient waveforms by:

$$S_{11} = \frac{DFT\left[E_{ref}\right]}{DFT\left[E_{inc}\right]} \tag{3}$$

where, E_{inc} = incident electric field and E_{ref} = reflected electric field. The value of $|S_{11}|$ is computed in dB by:

$$\left|S_{11}\right|_{dB} = 20\log_{10}(\left|S_{11}\right|) \tag{4}$$

From the converged solutions the local SAR in W/Kg at each cell in the head is obtained from the equation [1]:

$$SAR(i,j,k) = \frac{\sigma(i,j,k)\left|E(i,j,k)\right|^2}{2\rho(i,j,k)} \qquad (5)$$

where, E = r.m.s value of the electric field (V/m), σ = conductivity of the head (S/m) and ρ = mass density of the head (Kg/m^3).

III. System Model For FDTD Simulation

To simplify the calculations, other parts of the human body except the head have been excluded in the simulation. The human head along with antenna is modeled as shown in Figure 1, where the Yee cell [δ] length = 0.5 cm. The three layered spherical human head model has a uniform content at its core (representing the human brain) of diameter 17.0 cm which is surrounded by two spherical shells each having width of 0.5 cm representing the skull (bone) and the skin with their respective electromagnetic properties. The outer boundary area as shown in the figure consists of Berenger perfectly matched layers. A metallic material having length 15.5 cm and diameter of 0.5 cm is used as the radiating dipole antenna and 0.6 Watt power is assumed to be radiated from the antenna [5]. In this study, average values of relative dielectric constant (ε_r) and conductivity (σ) of brain, bone and skin of human head at the desired frequency range were interpolated from the Table I and used to calculate both SAR and reflection coefficient (S_{11}). The mass density (Kg/m^3) of the brain (ρ_b) = 1050, bone (ρ_{bn}) = 1180 and skin (ρ_s) = 1080 have been taken during calculation.

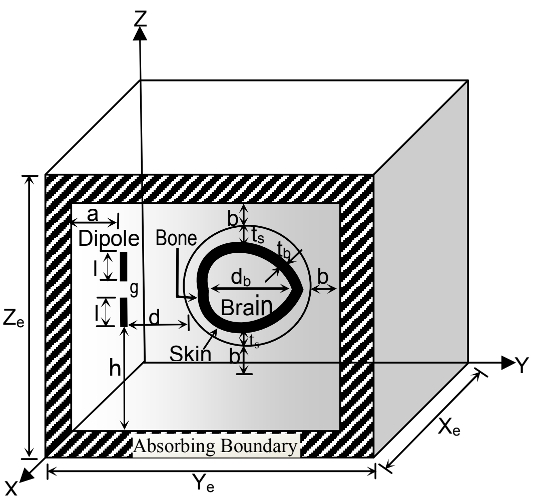


Figure 1. Geometry of the dipole antenna and the human head used for simulation by the FDTD method. [$X_e = 54\delta$, $Y_e = 58\delta$, $Z_e = 62\delta$, $a = b = 2\delta$, $l = 15\delta$, $g = 1\delta$, $d_b = 34\delta$, $t_s = 1\delta$, $t_b = 1\delta$, $d = (4-6)\delta$].

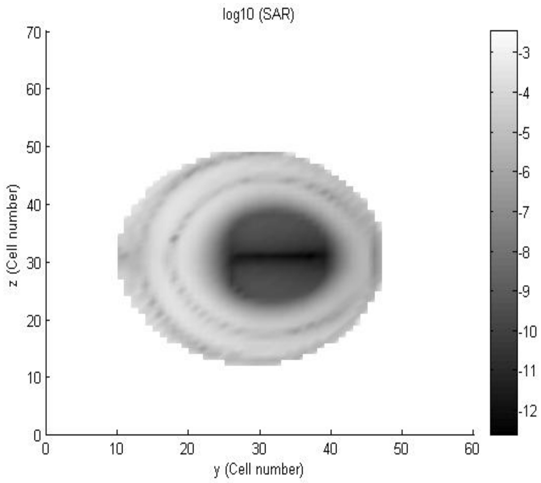
Table I: Relative dielectric constant (ε_r) and conductivity (σ) of the human brain, bone and skin at the different frequencies [2-3].

Frequency (MHz)	Brain		Bone		Skin	
	ε_r	σ (S/m)	ε_r	σ (S/m)	ε_r	σ (S/m)
100	82.0	0.53	7.50	0.067	24.5	0.55
350	60.0	0.65	5.70	0.072	17.6	0.44
900	56.8	1.10	20.90	0.34	41.41	0.87
1800	51.8	1.50	19.34	0.59	38.87	1.88
2450	48.9	1.81	18.55	0.82	38.01	1.46
6000	30.0	5.30	6.00	0.3	23.0	2.6

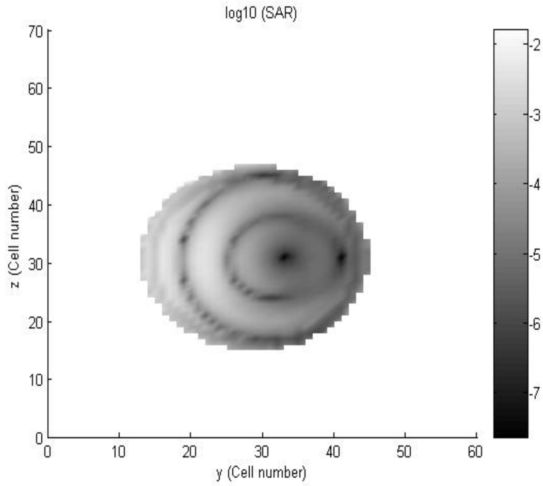
IV. Results

SAR distributions at the middle and the front layers in YZ plane inside the head for 2.0 cm distance between the head and antenna at frequency 835 MHz using a sine wave as the wave source are shown in the Figure 2 (a-b). From Figure 2 (a), it is seen that in the middle layer of head larger value of SAR is induced in the outer section consisting of skin and bone tissues nearer to the antenna side. The value of SAR decreases gradually in the core region of the head consisting of brain due to smaller penetration depth. From Figure 2 (b), it is seen that in the front layer of head, value of SAR uniformly decreases from antenna side to other side since major portion of this layer is consisting of skin and bone tissues. From both the figures it is seen that higher value of SAR is induced in the sectional areas consisting of skin and bone having relatively smaller conductivity than brain [7].

Variation of $|S_{11}|$ with frequency for the half wave dipole antenna placed in free space and at 2.0 cm distance from the head model is shown in Figure 3. When the head model is placed closed to the radiating antenna, it behaves like a parasitic component. As a result, the effective dimension of radiating structure increases and the resonant frequencies for both fundamental and higher order modes move toward lower frequencies during the presence of head. In this study, length of the antenna is 15.5 cm and for the fundamental mode with and with out head it resonates at 835 MHz and 890 MHz respectively. Thus the shifting of resonant frequency towards left is 55 MHz due to presence of the head in front of the antenna at the distance of 2.0 cm. Value of $|S_{11}|$ are -12.18 dB and -11.28 dB at the resonant frequencies 835 MHz and 890 MHz respectively. From the Figure 3, it is also seen that the value of $|S_{11}|$ remains below -10 dB in the GSM band (890MHz – 960MHz) for both with and without head.



(a)



(b)

Figure 2. SAR distribution in the YZ plane of head model (a) middle layer (X = 27 δ) and (b) front layer (X = 17 δ).

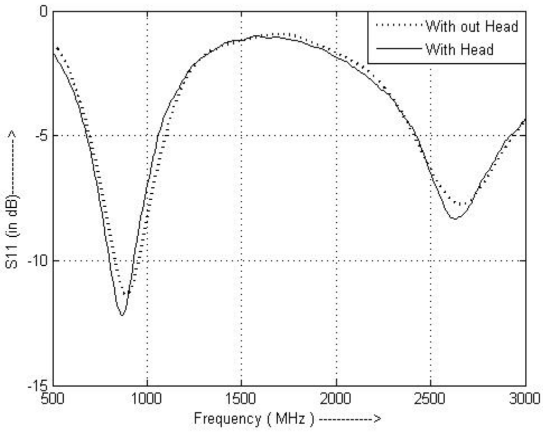


Figure 3. Variation of $|S_{11}|$ vs. frequency of the dipole antenna of length 15.5 cm for with and with out head.

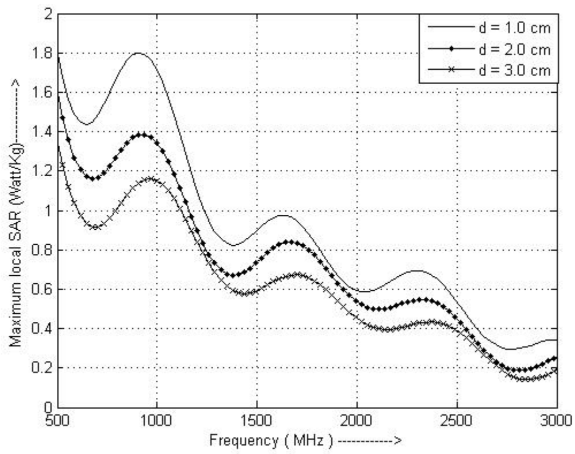


Figure 4. Maximum local SAR distributions in the human head model for different ‘d’.

Figure 4 shows the maximum local SARs induced in the human head are in the range of 1.8 W/Kg to 0.15 W/Kg for the frequency range from 500 MHz to 3 GHz for a set of distance (d) data in the range of 1.0 cm to 3.0 cm. When the distance (d) is less than or equal to 1.0 cm then the maximum local SAR (1.8 W/Kg) is above FCC and IEEE’s upper safety limit (1.6 W/kg) [8,9]. As the distance increases over 1.0 cm then the value of the maximum local SAR goes below the upper safety limit. The curve shows three major peaks near the resonant frequencies. For all ‘d’, the maximum value of maximum local SAR has been found at fundamental resonant frequency near GSM band (890MHz – 960MHz) due to large amount of energy transfer from antenna to head for good impedance matching. But at the other resonant frequencies the value of maximum local SAR doesn’t rise significantly due to higher reflection of electromagnetic wave from the surface of the head which results in smaller absorption. SAR also decreases faster in higher frequency range due to smaller penetration depth.

V. CONCLUSION

In this work both SAR and $|S_{11}|$ have been calculated considering human head as a three layered spherical shaped inhomogeneous dielectric medium consisting of only three different types of tissues for the frequency range from 500 MHz to 3 GHz using FDTD method. Variation of maximum local SAR with frequency has been obtained for a set of distance between the radiating dipole antenna and the head in the range of 1.0 cm to 3.0 cm. Maximum local SAR induced in the head model is found more than the FCC and IEEE’s upper safety limit (1.6 W/Kg) for the distance between head and dipole antenna less than 1.0 cm. With the increase of the distance maximum local SAR decreases. Variation of $|S_{11}|$ with frequency for the half wave dipole antenna of length 15.5 cm placed in free space and at 2.0 cm distance from the head model has been studied. Since the effective dimension of radiating structure increases as a result the resonant frequencies for both fundamental and higher order modes of the dipole antenna move toward lower frequencies during the presence of head. Maximum local SAR is a linear function of conductivities of the head components (brain, skin and bone) but the conductivities are the nonlinear function of frequency and contribute very small change in the resonating frequency of the dipole antenna. As a result the frequency at which peak of maximum local SAR obtained doesn't match with the frequency for minima of $|S_{11}|$.

During the simulation, it is assumed that the dipole antenna is radiating the carrier power continuously but in case of actual handsets discontinuous transmission of power is used to save the power consumption of the handsets. The head model has been assumed to be exposed to the EM field keeping isolated from ground but it is generally in contact with ground through feet and body. Since the human body as well as the head is dispersive, it would be desirable to modify the program so that time domain descriptions of tissue polarization can be incorporated to account for the relaxation mechanisms that are responsible for the frequency-dependent dielectric properties. In future, modification will be made to obtain better realistic analysis.

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