SAR Analysis in a Realistic Grounded Human Head for Radiating Dipole Antenna

Md.Faruk Ali
Dept. of Electronics and Instrumentation Engg.
Nazrul Centenary Polytechnic
Rupnarayanpur, Burdwan-713 335, India
faruk_ali@rediffmail.com

Sudhabindu Ray
Dept. of Electronics and Telecommunication Engg.
Jadavpur University
Jadavpur, Kolkata-700 032, India
sudhabin@etce.jdvu.ac.in

***Abstract*—Specific Absorption Rate (SAR) averaged over 10 g, 1 g and 0.1 g mass of head tissue induced inside a realistic grounded human head in the near-field of a half-wave radiating dipole antenna has been computed using Finite Difference in Time Domain (FDTD) method. The head is modeled using voxel based anthropomorphic phantom data considering the electrical parameters of different anatomical internal structures of the human body. Results obtained from the simulation show that maximum local SAR increases significantly for smaller mass average. Maximum 0.1-g SAR of 3.75 W/kg is obtained for 4 mm distance between head and antenna with 0.6 W radiated power.**

Keywords- FDTD; near-field; SAR; Zubal phantom; CT scan; human head model.

I. INTRODUCTION

In the recent years, cellular telephones and mobile wireless communication systems are being introduced into society at a very rapid rate. Electromagnetic (EM) waves radiated from these devices interact with human head and other body parts and may cause radiofrequency (RF) hazards. Safety guidelines for RF health hazards are set in terms of SAR which is defined as the rate at which a person absorbs EM energy per unit mass [1] and SAR averaged over *X* gram of tissue can be denoted by *X*-g SAR. Localized SAR averaged over 10-g and 1-g of tissue i.e. peak 10-g SAR and peak 1-g SAR not exceeding 2.0 W/kg and 1.6 W/kg are recommended by IEEE/ANSI/FCC as the upper safety limit [2-3].

It is difficult to experimentally measure SAR or EM field distributions inside human body. Therefore, various numerical techniques play significant roles to calculate EM field components and SAR inside human body. FDTD method [4] is one of the widely used techniques to simulate the EM field distributions in three dimensional structures [5-11]. Calculation of SAR and maximum local SAR (MLSAR) in human head is reported in several research papers and articles.

In this work, peak 10-g and 1-g SAR have been studied using FDTD method for a realistic grounded human head model consisting of twenty two types of tissues exposed to EM waves radiated from a half-wave dipole antenna designed for GSM900 band (890-960 MHZ). Simulated SAR values are compared with the available safety limits. The study is farther extended to higher resolution of 0.1-g SAR where safety standards are not available. For all simulations in-house FDTD code is developed using commercially available MATLAB [12] software. Commercially available FDTD based EM simulation software FIDELITY [13] is used to validate the performance of in-house FDTD code.

II. MODEL AND METHOD FOR ANALYSIS

A. Human Head Model

The human head model has been constructed from Zubal phantom which is based on CT scan data of a 35 year old male weighing 155 lbs and measuring 5′10″ in height [14]. The man has been considered to be clinically normal and had no head abnormalities. MATLAB program is used to read, resample and reshape the phantom volume data consists of 128×128×243 cubic cells. To simplify the numerical calculations, the resolution of volume is reduced by 50% and other parts of the human body except the head are excluded in the simulation. Midsaggital, midcoronal and 3-dimensional geometry of the human head model along with the dipole antenna used in the simulation are shown in Figure 1 (a-c). The head is comprised of twenty two types of tissues; i.e., grey matter, white matter, cerebellum, skin, bone, muscle, fat, lense, eyeball, tongue, blood, cartilage, CSF, parotid gland, retina, teeth, trachea, spinal chord, nerve, eye sclera, bone marrow, pituitary gland and mouth cavity/sinuses. Mass density (ρ), mass of one cell, relative dielectric constant (ε_r) and conductivity (σ) of different tissues are obtained from the literature [15]. Relative dielectric constant, conductivity, mass density and mass of one 4 mm × 4 mm × 5 mm volume cell for different tissues are shown in TABLE I. Frequency dependent ε_r and σ are determined by interpolating the available data.

B. Ground Plane

Human head floating in free space is not a realistic situation. In reality, head is connected to dielectric body mass and ground plane is beneath the body mass. But in this work, as to simplify the numerical calculations other parts of the human body except the head are excluded so in order to approach towards a more practical condition a conductive ground plane is added under the human head model.

C. FDTD Method

The FDTD method has been used to investigate the interactions between the human head model and EM waves radiated from a half-wave dipole antenna. The simulation domain enclosing head model and dipole antenna consists of 65×74×70 Yee cells with cell dimension of 4 mm × 4 mm × 5 mm. The time step (δt) used in this simulation is limited by Courant stability criterion:

$$\delta t \le \frac{\sqrt{\left(\frac{1}{\delta_x^2}+\frac{1}{\delta_y^2}+\frac{1}{\delta_z^2}\right)}}{c} \qquad (1)$$

where, c is the speed of light in free space and $\delta_x = \delta_y = 4$ mm and $\delta_z = 5$ mm.

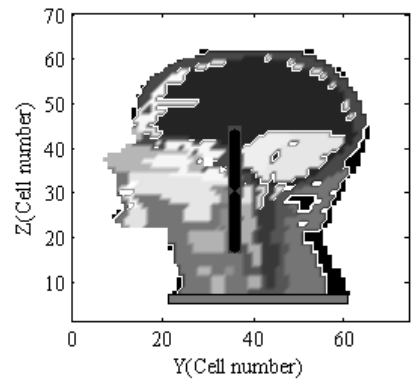
D. Perfectly Matched Layer (PML)

Perfectly Matched Layer (PML) is used to remove unwanted reflection from the boundary. When electromagnetic wave enters into the PML, it decays successively with space and its effects get nullified at the boundary layer. In this simulation 5-point Unsplit Step 3D-PML has been used [16].

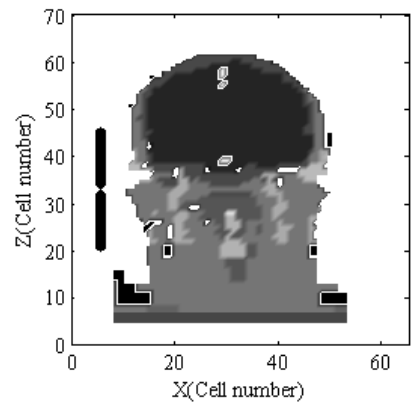
E. Antenna Model

A dipole antenna made with aluminum having length (L) of 14.5 cm and 4 mm × 4 mm cross sectional area is chosen as the radiating element. In this study, FDTD model for a one-cell feeding gap of thin-wire antenna has been used for simulation [17]. In real case, for normal use value of radiated power from cellular phone is 250 mW but it can reach to 1 W or 2 W when the phone is far away from the mobile base station [18]. In this simulation as the cellular phone is modeled as an equivalent dipole antenna and placed close to human head so during calculation of SAR, 0.6 W power is used to feed the dipole antenna at the GSM900 band. Frequency dependent reflection coefficient $S_{11}(f)$ of the dipole antenna is determined from the ratio of the Discrete Fourier Transform (DFT) of incident and reflected waveforms [6]:

$$S_{11}(f) = \frac{DFT\left[E_{ref}\right]}{DFT\left[E_{inc}\right]} \qquad (2)$$



(a)



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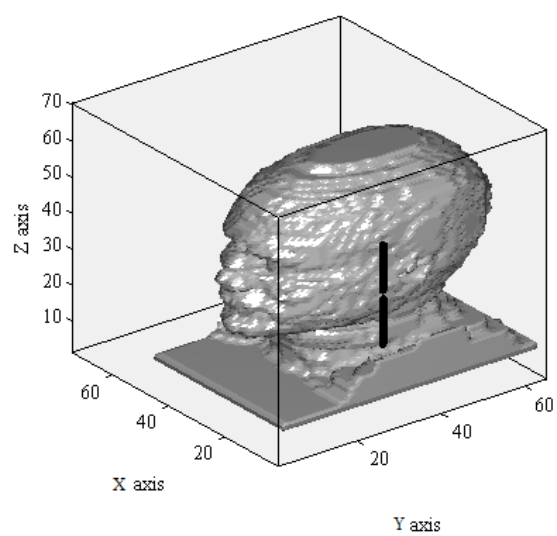


(c)

Figure 1. (a) Midsaggital (b) midcoronal and (c) 3-dimensional geometry view of human head model along with dipole antenna.

where, E_{inc} = incident electric field and E_{ref} = reflected electric field.

S_{11} is computed in dB by:

$$S_{11} = 20\log_{10}\left(\left|S_{11}\right|\right) \quad (3)$$

F. SAR Calculation

From the converged solutions the local SAR at $(i,j,k)^{th}$ cell inside the head is obtained from the following relation [10]:

$$SAR(i,j,k) = \frac{\sigma(i,j,k)\left|\hat{E}(i,j,k)\right|^2}{2\rho(i,j,k)} = \frac{\sigma(i,j,k)\left\{\left|\hat{E}_x(i,j,k)\right|^2 + \left|\hat{E}_y(i,j,k)\right|^2 + \left|\hat{E}_z(i,j,k)\right|^2\right\}}{2\rho(i,j,k)} \quad \text{(W/kg)} \quad (4)$$

where, $\hat{E}_x$, $\hat{E}_y$ and $\hat{E}_z$ are the peak values of the electric-field components (V/m), σ = conductivity (S/m) and ρ = mass density of the head tissues (Kg/m³). Peak 10-g SAR is obtained by finding the value of maximum local SAR with the corresponding FDTD cell and is repeated until the required mass of 10 g is obtained similarly peak 1-g and 0.1-g SAR are calculated [19].

III. RESULTS

Return loss of the 14.5 cm half wave dipole antenna is computed using the MATLAB program based on the FDTD and compared with FIDELITY results. Variations of S_{11} with frequency for the half wave dipole antenna computed using FDTD code and FIDELITY are shown in Figure 2. The result obtained using the MATLAB program shows close agreement with that obtained from FIDELITY. At the fundamental mode, the antenna resonates at 930 MHz and the value of S_{11} remains below –10 dB within GSM 900 band. Values of S_{11} at the fundamental resonance frequency obtained from MATLAB program and Fidelity are –14.14 dB and –15.17 dB, respectively.

After return loss calculation is over, head model along with the antenna is simulated for 0.7 to 1.3 GHz. SAR distributions at the midsagittal YZ and midcoronal XZ planes at 930 MHz for d = 0.4 cm are shown in the Figure 3 (a-b). The distribution of SAR inside the head for all sectional planes shows similarity with propagating wave field pattern. In midsagittal plane SAR is found maximum near the outer region of head close to antenna and then decreases and increases periodically with continuous decrease in the average level with the increases of distance from antenna. In midcoronal plane, SAR holds higher value in the central parts and the average level decays gradually towards outer region.

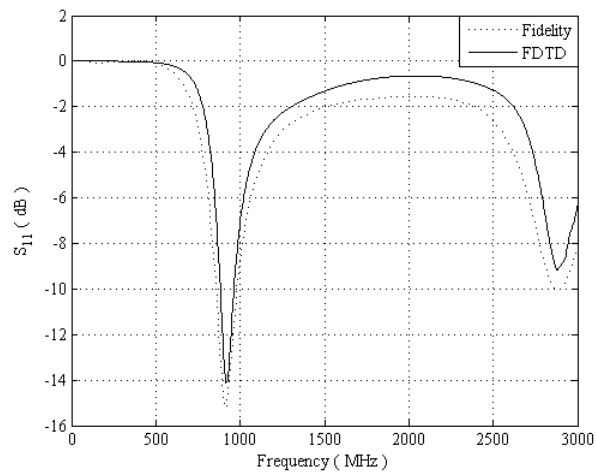
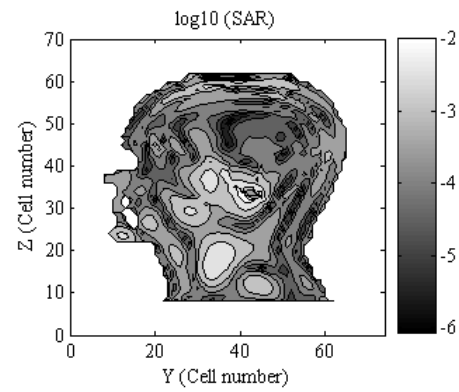
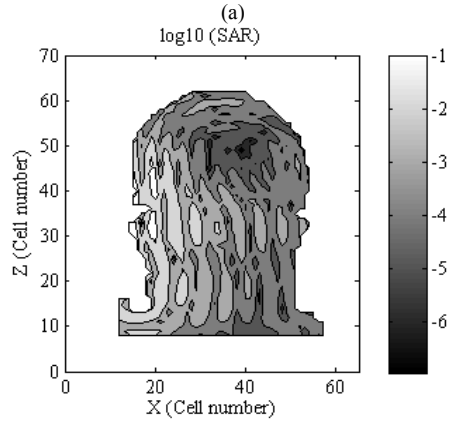


Figure 2. Variation of S_{11} vs. frequency of the dipole antenna of length 14.5 cm placed in free space.



(a)



(b)

Figure 3. SAR distribution in the (a) midsagittal YZ plane (X=34 Yee cell) and (b) midcoronal XZ plane of the human head model (Y=37 Yee cell).

Variation of peak SAR with frequency for 10-g, 1-g and 0.1-g mass is shown in Figure 4. For all resolutions, peak SAR values attain to maximum near the antenna resonance frequency. The maximum value of peak 10-g, 1-g and 0.1-g SARs induced in the head are 1.07 W/kg, 2.45 W/kg and 3.75 W/kg, respectively. Value of peak 10-g SAR is below the recommended safety limit of 2.0 W/kg whereas the value of peak 1-g SAR is more than the recommended safety limit of

1.6 W/kg. For peak 0.1-g SAR, the value becomes more than twice of recommended safety limit set for 1-g SAR. This result shows that the absorbed power at the frequency band of study is not uniform throughout the 10 gm or 1 gm mass and it is concentrated to smaller mass in the form of node.

TABLE I. DIELECTRIC CONSTANT (ε_r), CONDUCTIVITY (σ) AND MASS DENSITY (ρ) OF THE HUMAN HEAD TISSUES

Tissue Type	Dielectric Constant (ε_r) [930 MHz]	Conductivity σ (S/m) [930 MHz]	Mass density ρ (kg/m^3)	Mass of one cell (g)
Brain	50.6800	0.9295	1030	0.0824
Cerebellum	57.5980	1.0020	1030	0.0824
Skin	48.0980	0.6657	1010	0.0808
Bone	13.2700	0.0869	1850	0.1480
Muscle	57.5960	0.7834	1040	0.0832
Fat	5.6000	0.0403	920	0.0736
Lense	48.4900	0.6580	1100	0.0880
Eyeball	74.1000	1.9700	1010	0.0808
Tongue	58.2090	0.7590	1040	0.0832
Blood	64.8200	1.3320	1000	0.0800
Cartilage	46.0430	0.5690	1100	0.0880
CSF	71.7090	2.2380	1010	0.0808
Parotid Gland	49.6000	1.0300	1050	0.0840
Retina	58.2090	0.9899	1020	0.0816
Teeth	13.2770	0.0869	1850	0.1480
Trachea	44.6850	0.6237	1040	0.0832
Spinal Chord	36.0650	0.4329	1040	0.0832
Nerve	36.0650	0.4329	1040	0.0832
Eye Sclera	58.2090	0.9899	1030	0.0824
Bone Marrow	5.7099	0.0283	1000	0.0800
Pituitary Gland	55.2200	1.0000	1040	0.0832
Mouth cavity or sinus	1.0000	0.0000	1.200	0.0001

IV. CONCLUSIONS

In this work SAR distributions and peak SAR averaged over 10-g, 1-g and 0.1-g mass of head tissue induced inside a CT scan data based human head model consisting of twenty two types of tissues have been studied using FDTD method considering variation of electrical properties of tissue with the variation of frequency. Variation of peak 10-g, 1-g and 0.1-g SAR with frequency in the range of 700 MHZ to 1.3 GHz have been obtained without considering duty cycle of mobile communication systems for a distance of 0.4 cm between the radiating dipole antenna and the head with input power of 0.6 W. The study shows that for smaller mass average the peak SAR value increases significantly and the value of peak 0.1-g SAR has been found more than thrice than that of peak 10-g SAR.

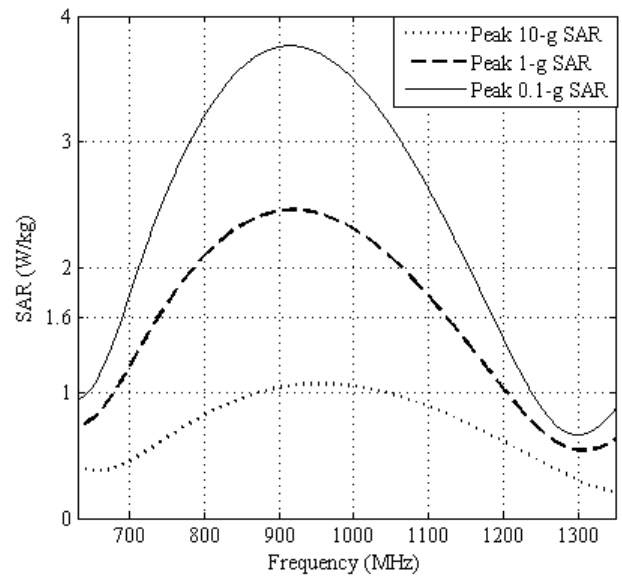


Figure 4. Peak 10-g, 1-g and 0.1-g SAR vs. Frequency induced in the realistic grounded human head model for d = 4 mm.

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