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SAR in Life Tissue at GSM Frequencies

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Abstract-In this paper, the power density and specific absorption rate (SAR) distribution in multi-layered life tissues and exposed to electromagnetic field emitted from hand-held cellular phone operating in the 900 MHz is studied. We modeled a life tissue by four layered system to represent skin-fat-muscles-organs respectively. Matlab program and finite difference time domain (FDTD) computations were used to evaluator the electric, magnetic field, power density and specific absorption rate. A one dimensional FDTD algorithm has been built, some simulations for electromagnetic wave through the life tissue is made. Results show that electromagnetic fields penetrate the life tissues and attenuate fast to reach zero at the organs layer. The absorbent power and SAR show maximum at the skin and fat layers.

Keywords- Life Tissue ,Specific Absorption Rate, Finite Difference Time domain Method(FDTD), Power Density, Electromagnetic Waves

1. Introduction

The use of mobile phone by people has grown substantially in the last years. In parallel with this, an increased concern by the scientific community, the authorities and the population regarding the safety of these phones has raised.

The Finite-Difference Time-Domain (FDTD) is the most often used method for evaluating of electromagnetic fields in human tissue. The heating effects resulted from using a mobile phone operating near a metal wall has been studied [2]. The finite-difference time-domain (FDTD) simulation scheme was used in the simulation. The simulated physical domain consists of a dipole antenna, a high-resolution human head model. The temperature rise in a human head caused by absorbed power in the form of SAR from a cellular telephone has been computed using a bio-heat equation approach. The SAR is computed using an FDTD solver for a reasonable cellular telephone model that radiates at 900 MHz. The issue of temperature rise in the eye caused by electromagnetic fields has generated some interest due to the low blood flow through the eye tissue has been evaluated [4].Computation of electromagnetic field inside a tissue at mobile communication has been studied, which presents a new approach to calculate the electromagnetic field inside a tissue, composed of electrically excitable cell by means of the FDTD (finite difference time domain method) [5,6]. A simple planar multi-layered head model irradiated by plane wave in the frequency range of 100 MHz - 300 Ghz is investigated by Akram and Andrew in [7], and it consists of skin, fat, bone, Dura, CSF and brain. The electromagnetic waves of different power levels and different frequencies penetrate into the human body causing health risks; this is of great public concern.

In this paper, a simple planar multi-layered life tissue model will be used to calculate the electric field, magnetic field, power density and Specific Absorption Rate (SAR) distributions inside the model when exposed to electromagnetic waves produced from mobile phone using the Finite Difference Time Domain (FDTD) Method.

2. Numerical Method and Modelling

The diagram of multi-layered life tissue was consisting of four planar layers of tissues with different dielectric properties, skin, fat, muscles, and kidney (**Figure 1**). It is assumed that a plane wave with frequency 900 MHz is vertically incident from mobile phone upon the interface distance between the air and the life tissue is 5 cm, 10 cm,15 cm,20 cm, 25 cm, 30 cm. The electric field is assumed to propagate in the *z* direction with polarization at the *x* direction.

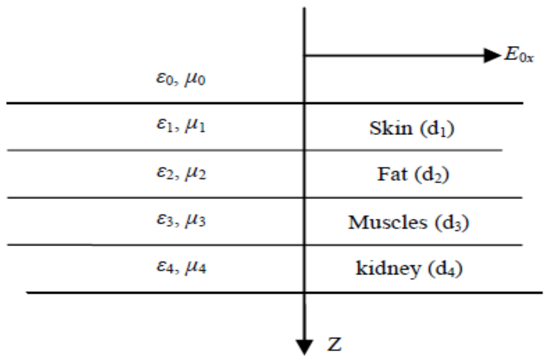

Fig 1: A plane wave is vertically incident upon the inter-face between the air and the life tissue

The structure has layered media consists of the skin of thickness $d1$ = 0.00073164 m, the fat of thickness $d2$ = 0.02441, the Muscle of thickness $d3$ = 0.04236, and the organs (kidney) layer of infinite thickness tissue [8].

The dielectric properties of the layers are donated with the complex permittivity ε_r^*

$$\varepsilon_r^* = \varepsilon_r - j\frac{\sigma}{\omega\varepsilon_0} \quad \text{…………..(1)}$$

Where ε_r is the real relative part of the permittivity, σ is the conductivity and ω is the radial frequency of the signal. The quantity $\sigma/\omega\varepsilon_0$ is called the loss tangent. It describes the looseness of the medium. Since the human tissues are nonmagnetic, it has been assumed that $\mu i = \mu 0$, where *i* stands for 1, 2, 3, and 4 which represents the four layers.The dielectric properties for each two frequencies are illustrated in **Table 1**.

Tissue Name	Conductivity σ [S/m] by 900 MHz	Relative Permitivity by 900 MHz	Density ρ [kg/m3]
Air	0	1	1.229
Skin	0.86674	41.405	1100
Fat	0.051043	5.462	1100
Muscle	0.94294	55.032	1040
Kidney	1.3921	58.675	1030

Table 1. Dielectric properties for human body at frequency 900 MHz

3. The Finite Difference Time Domain (FTD) Method Solution to Maxwells Equations.

The finite difference time domain (FDTD) method is a full-wave, dynamic, and powerful solution tool for solving Maxwell's equations, introduced by K. S. Yee [9]. The algorithm involves direct discriminations of Maxwell's equations by writing the spatial and time derivatives in a central finite difference form. The time-dependent Maxwell's curl equations in general form, which will allow us to simulate propagation in media that have conductivity are

$$\varepsilon\frac{\partial E}{\partial t} = \nabla \times H - J$$

$$\frac{\partial H}{\partial t} = -\frac{1}{\mu_0}\nabla \times E \quad \text{…..2\&3}$$

where $\overline{J} = \sigma\overline{E}$ is the current density

In 1-D, we consider only *Ex* and *Hy* are not equal to zero and traveling in the *z*-direction. In addition, we assume that the fields do not vary in the *x-y* plane, *i.e.*

$$\frac{\partial}{\partial x} = 0$$

$$\frac{\partial}{\partial y} = 0$$

Then Equations (2) and (3) can be reduced to

$$\frac{\partial E_x(t)}{\partial t} = -\frac{1}{\varepsilon_0\varepsilon_r}\frac{\partial H_y(t)}{\partial z} - \frac{\sigma}{\varepsilon_0\varepsilon_r}E_x(t)$$

$$\frac{\partial H_y(t)}{\partial t} = -\frac{1}{\mu_0}\frac{\partial E_x(t)}{\partial z} \quad \text{..4\&5}$$

In the FDTD formulation, the central difference approximations for both the temporal and spatial derivatives are obtained at

$$t = n\Delta t$$

$$z = k\Delta z$$

for the first equation:

$$\frac{E_x^{n+1/2}(k) - E_x^{n-1/2}(k)}{\Delta t} = -\frac{1}{\varepsilon_0\varepsilon_r}\frac{H_y^n(k+1/2) - H_y^n(k-1/2)}{\Delta z} - \frac{\sigma}{\varepsilon_0\varepsilon_r}\frac{E_x^{n+1/2}(k) + E_x^{n-1/2}(k)}{2} \quad \text{…..6}$$

And for the second equation

$$\frac{H_y^{n+1}(k+1/2) - H_y^n(k+1/2)}{\Delta t} = -\frac{1}{\mu_0}\frac{E_x^{n+1/2}(k+1) - E_x^{n+1/2}(k)}{\Delta z} \quad \text{…….7}$$

Ex and *Hy* will differ by several orders of magnitude. Numerical error is minimized by making the following change of variables as

$$\tilde{E}_x = \sqrt{\frac{\varepsilon_o}{\mu_o}}E_x$$

Equation changes to

$$\tilde{E}_x^{n+1/2}(k) = \frac{1 - \frac{\Delta t\cdot\sigma}{2\varepsilon_0\varepsilon_r}}{1 + \frac{\Delta t\cdot\sigma}{2\varepsilon_0\varepsilon_r}}\tilde{E}_x^{n-1/2}(k) - \frac{1/2}{\varepsilon_0\left(1 + \frac{\Delta t\cdot\sigma}{2\varepsilon_0\varepsilon_r}\right)}\left[H_y^n(k+1/2) - H_y^n(k-1/2)\right] \quad \text{…..8}$$

$$H_y^{n+1}(k+1/2) = H_y^n(k+1/2) - \frac{1}{\sqrt{\varepsilon_0\mu}}\frac{\Delta t}{\Delta z}\left[\tilde{E}_x^{n+1/2}(k+1) - E_x^{n+1/2}(k)\right] \quad \text{…9}$$

In FDTD method, for stability purpose, we use in all our simulation a time step

$$\Delta t = \frac{\Delta z}{2c_0}$$

where c_0 is the speed of light in free space

4. Results and Discussion

Numerical simulation is used to calculate the field equations of plane layer medium with boundary conditions. The distributions of electric field, power of absorption and specific absorption rate have been evaluated in life tissue where the power density (W/m3) absorbed in the conductivity σi along the *ith* layer from the sinusoidal field of the amplitude *Ei* is given

$$P_i = \frac{\{|E_i|^2\sigma_i\}}{2}$$

And specific absorption rate (SAR) in units of (W/kg) is the most important parameter for the evaluation of the exposure hazard at radio and microwaves frequencies. It is the biological electromagnetic estimation. It is defined

as the power dissipation rate normalized by material density .
It can be shown that:

$$SAR = \frac{P_i}{\rho_i}$$

where ρi (Kg/m3) is the density of the tissue

FDTD Methods have become almost the most important time domain simulation techniques used in broad range of electromagnetic problem. FDTD method im-plemented in MATLAB program was used to compute the distribution of electric and magnetic fields in the four layer life tissue. The cell size has been calculated by taking into consideration the wavelength in the tissue with the highest relative dielectric constant, because this has the corresponding shortest wavelength. In our model, the highest relative dielectric constant is for the organs which is 58.675 at 900 MHz. Thus the cell size is calculated to be 10th the wavelength at this layer as follows

$$\text{Cell size} = \lambda/10$$

$$= \frac{c/\sqrt{\varepsilon_r}}{f*10}$$

$$=0.0043$$

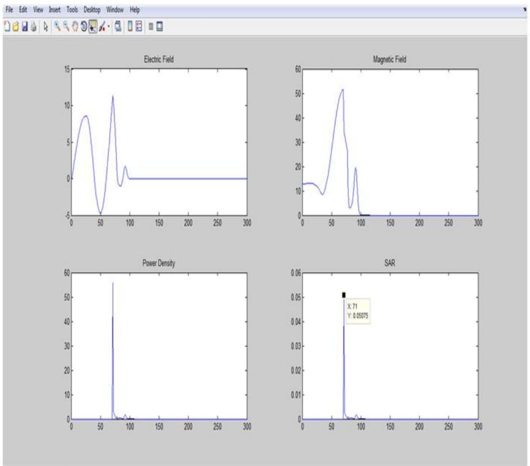

Fig2:Electric field, magnetic field, power density and SAR for distance of 30cm

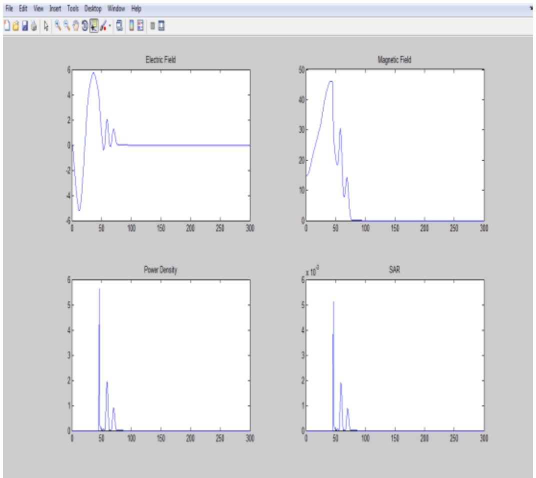

Fig 3: Electric field, magnetic field, power density and SAR for distance of 20cm

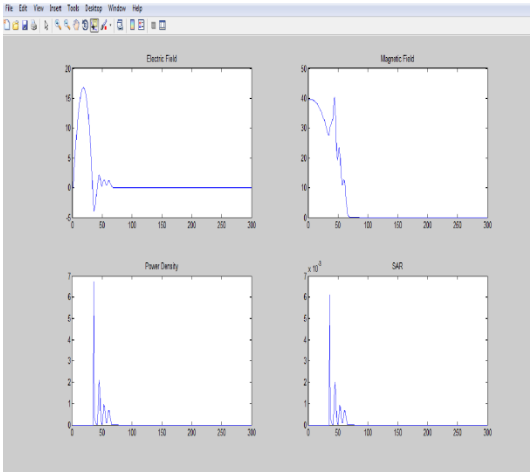

Fig 4: Electric field, magnetic field, power density and SAR for distance of 15cm

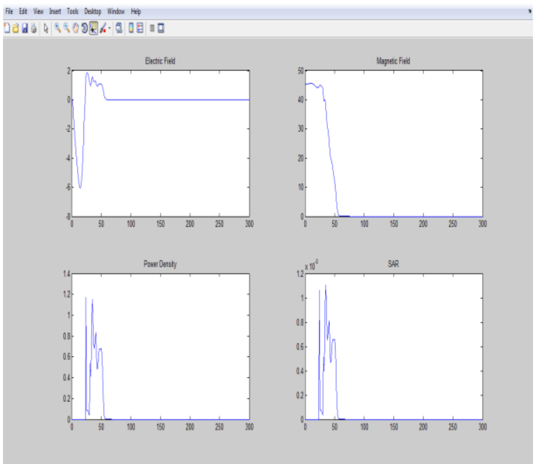

Fig 5: Electric field, magnetic field, power density and SAR for distance of 10cm

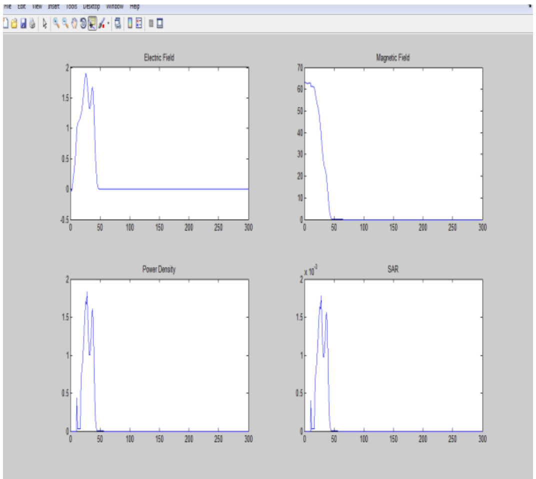

Fig 6: Electric field, magnetic field, power density and SAR for distance of 5cm

5. Conclusion:

Four-layered structure representing simplified model of life tissue irradiated by plane waves produced by mobile phone is investigated. The four layers represent the skin-fat-muscles-and kidney respectively. FDTD is used to study the distribution of the electromagnetic fields in the body tissues, the absorbent power, and SAR distribution. It is found that the fields penetrates the skin and attenuates rapidly till they reach zero at the organs layer. Absorbent power and SAR have maximum values at the skin and fat layers. According to our study, the human organs are protected by the skin and fat layers. However, the skin and fat layers are in risk because they are strongly absorbed the propagated field.

As the distance of mobile phone radiations from the tissue layer decreases, the EM wave radiations penetrates more deeply up to the organ layer.

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