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Modeling the Effect of Electromagnetic Waves Produced by Mobile Phone Base Station on human body Tissue

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Abstract: In this work, we studied the effect of electromagnetic radiation produced from mobile phone at 900 MHz frequency on the human body tissues. We modeled human body tissue by four layered system to represent skin-fat-muscles-organs respectively. We used Finite-Difference Time-Domain (FDTD) method to calculate the distribution of the electromagnetic fields inside the human body tissues, the absorbent power and the Specific Absorption Rate (SAR). A one dimensional FDTD algorithm has been built, some simulations for electromagnetic wave through the human body tissues is made. Results show that electromagmatic fields penetrate the body tissues and attenuate fast to reach zero at the organs layer. The absorbent power and SAR show maximum at the skin and the fat layers.

Keywords: *electromagnetic waves, life tissues, specific absorption rate, finite difference time domain method (FDTD).*

Introduction

The rapid growth of wireless communication technology and the widespread use of mobile phone followed with great concern on their safety on the biological tissues. It has been numerous reports on the effect of the electromagnetic (EM) radiation on the human tissues [1-2].

In the past few years, very rapid development in mobile cellular communication has drawn attention to possible health risks of the electromagnetic energy (EM) emitted from the transmitters of hand-held phones. The interaction between a human head and a hand-held phone under various conditions should be quantitatively evaluated in order to establish the safety in cellular mobile communication systems [3-5].

The EM interaction between the mobile and the user can be treated by two different points of view : First view focused on the impact of the user on the mobile. In this case, the tissue of the user represents a large dielectric and lossy material distribution in the near field of a radiator. It is obvious that therefore all antenna parameters such as impedance, radiation characteristic and radiation efficiency will be affected by the properties of the tissue. Moreover, the effect can differ with respect to the individual habits

The second view focused on the exposure of the user to the EM field of the radiating device. The absorption of electromagnetic energy in the human tissue (SAR – Specific Absorption Rate) generated by mobile phones has become a point of critical public discussions due to possible health risks [6,7]. The SAR distributions in a human head exposed to EM fields from hand-held mobile phones have been estimated through experimental [8], and numerical calculations [9-10].

Recent progress in computer technology enables us to use FDTD method to numerically calculate the EM interactions of inhomogeneous, realistic human head and mobile phone models. In FDTD, spatial and time derivatives in Maxwell's equations are replaced with their central difference approximations in specially organized unit cells [11]. 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 [12-13].

The theoretical analysis of the biological thermal effect of millimeter waves in layered dielectric slabs in human body has been studied [14-17]. The model is a plane homogeneous slab of tissue under the irradiance of normal incidence plane wave. The effect of the incident wave has been studied by calculating absorbent power, specific absorption rate, temperature, the electromagnetic field and their distributions in the human tissue.

A Multi-layered structure representing simplified model of the human head irradiated by plane wave in the frequency range of 100MHz-300Ghz is investigated [18]. General electromagnetic formulation on the absorption properties of the layered head model is given. Exact analytical expressions are given for the plane wave complex reflection coefficient as a function of frequency at the interference of the stratified structure. Results highlight the position of maximum power absorption values and their dependence on frequency and dielectric parameter.

In this study, EM interaction of a human body skin and a mobile phone base station (GSM with frequency 900MHz) is investigated by using an FDTD algorithm. Next section will describe the body model introduce in our work. Fields and fields equations are explicitly given in section 3. Section 4 presents the calculations of Power Density and SAR flow of EM waves. The finite difference time domain (FDTD) method is introduced in section 5. Results and discussions are given in section 6. Final conclusion is given in section 7.

1. Generic body model

In order to characterize the absorption in the body tissue, a generic body model was defined as four planar layers of tissues with different dielectric properties skin, fat, muscles, and organs (Figure 1). It is assumed that a plane wave with frequency equals 900MHz is normally incident upon the interface between the air and the body tissue. The electric field is assumed to propagate in the z direction with polarization at the x direction.

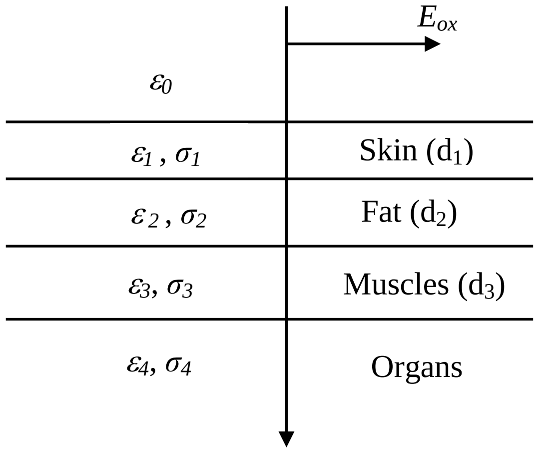


Figure (1): A plane electromagnetic wave is incident vertically upon the plane-layered slabs of medium in Z direction

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

$$\varepsilon_{ri}^* = \varepsilon_{ri} - j\frac{\sigma_i}{\omega\varepsilon_0}, \qquad (1)$$

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, which 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 free space is assumed for the exterior of the model with wave number $k_0 = \omega\sqrt{\varepsilon_0\mu_0}$.

Skin tissue has a real relative permittivity of ε_{r1} =41.4 and conductivity of σ_1 =0.866 S/m [19]. Fat tissue has very low water content and therefore significantly low relative permittivity and conductivity (ε_{r2} =5.5, σ_2 =0.05 S/m at 900 MHz) [19], whereas muscle tissue has a relative permittivity of ε_{r3} =55 and conductivity of σ_3 =0.94 S/m at the same frequency. Most other body tissues with higher water content have similar dielectric properties (Table 1).

Table (1) dielectric properties for human body at frequency 900MHz

Tissue name	**Conductivity σ [S/m]**	**Relative permittivity**	**Density ρ [kg/m^3]**
Air	0	1	1.229
Skin	0.86674	41.405	1100
Fat	0.051043	5.462	1100
Muscle	0.94294	55.032	1040
Organs	1.3921	58.675	1030

The structure has layered media consists of the skin of thickness d_1=0.00073164 m, the fat of thickness d_2=0.02441, the Muscle of thickness d_3=0.04236, and the organs layer of infinite thickness tissue [20].

2. Fields and fields equations

The field equations in the conductive media where $\sigma \neq 0$ are

$$(\nabla^2 - \gamma_i^2)\boldsymbol{E}_i = 0, \quad i = 1,2,3,4, \qquad (2)$$

$$(\nabla^2 - \gamma_i^2)\boldsymbol{H}_i = 0, \quad i = 1,2,3,4, \qquad (3)$$

where γ_i is the complex propagation constant and equals to

$$\gamma = j\mu_0\varepsilon_0\varepsilon_r^* \qquad (4)$$

where ε_r^* is the complex relative permittivity of the medium as defined in equation (1).

In the free space the equations are simply reduce to

$$(\nabla^2 - \gamma_0^2)\boldsymbol{E}_0 = 0, \qquad (5)$$

$$(\nabla^2 - \gamma_0^2)\boldsymbol{H}_0 = 0, \qquad (6)$$

where $\gamma_0 = j\omega\sqrt{\varepsilon_0\mu_0}$ is the propagation constant in free space. In the case of the wave traveling in the *z*-direction the solutions of equation (5) and equation (6) are,

$$E_{0x} = A_0 e^{-\gamma_0 z} + B_0 e^{\gamma_0 z} \qquad (7)$$

$$H_{0y} = \frac{1}{\eta_0}\left(A_0 e^{-\gamma_0 z} - B_0 e^{\gamma_0 z}\right) \qquad (8)$$

where $\eta_0 = \sqrt{\frac{\mu_0}{\varepsilon_0}}$ is the characteristic impedance in free space. The amplitude of incident wave is A_0. In the other four layer of the model, the solution of equation (2) and equation (3) are

$$E_{ix} = A_i e^{-\gamma_i z} + B_i e^{\gamma_i z} \qquad (9)$$

$$H_{iy} = \frac{A_i}{\eta_i} e^{-\gamma_i z} - \frac{B_i}{\eta_i} e^{\gamma_i z} \qquad (10)$$

where $\gamma_i = j\sqrt{\omega\mu_0\varepsilon_i - j\omega\mu_0\sigma_i}$ and $\eta_i = \sqrt{\frac{\mu_i}{\varepsilon_i - j\frac{\sigma_i}{\omega}}}$. The reflected amplitude is not exist at the last slab, that is B_4 =0. Taking into account the boundary conditions $E_{i-1,x} = E_{i,x}$, $H_{i-1,y} = H_{i,y}$, we get the values of *A*'s and *B*'s. The distribution of the field can be then determined in the human body.

3. Power Density and SAR flow of EM waves

Once the induced electric field inside the stratified structure is known, the power density (W/m^3) absorbed in the conductivity σ_i along the i^{th} layer from the sinusoidal field of the amplitude E_i is given

$$P_i = \frac{|E_i|^2 \sigma_i}{2} \qquad (11)$$

Specific absorption rate (SAR) in units of (W/kg) is the most important dosimetric parameter for the evaluation of the exposure hazard at radio and microwaves frequencies [21, 22]. It is the biological electromagnetic estimation that defined as the power dissipation rate normalized by material density [23]. It can be shown that:

$$SAR_i = \frac{P_i}{\rho_i} \qquad (12)$$

where ρ_i (Kg/m^3) is the density of the tissue.

4. The finite difference time domain (FDTD) solution to Maxwell's 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 [24]. 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

$$\varepsilon\frac{\partial \boldsymbol{E}}{\partial t} = \nabla \times \boldsymbol{H} - \boldsymbol{J}, \qquad (13)$$

$$\frac{\partial \boldsymbol{H}}{\partial t} = -\frac{1}{\mu_0}\nabla \times \boldsymbol{E}, \qquad (14)$$

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

In 1-D, we consider only E_x and H_y 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. $\frac{\partial}{\partial x} = 0$ and $\frac{\partial}{\partial y} = 0$. Then Equations (13,14) can be reduced to

$$\frac{\partial E_x(t)}{\partial t} = -\frac{1}{\varepsilon_0\varepsilon_r}\frac{\partial H_y(t)}{\partial z} - \frac{\sigma}{\varepsilon_0\varepsilon_r}E_x(t) \qquad (15)$$

$$\frac{\partial H_y(t)}{\partial t} = -\frac{1}{\mu_0}\frac{\partial E_x(t)}{\partial z} \qquad (16)$$

In the FDTD formulation, the central difference approximations for both the temporal and spatial derivatives are obtained at $z = k\Delta z$ and $t = n\Delta t$ for the first equation:

$$\frac{E_x^{n+1/2}(k)-E_x^{n-1/2}(k)}{\Delta t} = -\frac{1}{\varepsilon_0\varepsilon_r}\frac{H_y^n(k+1/2)-H_y^n(k-1/2)}{\Delta z} - \frac{\sigma}{\varepsilon_0\varepsilon_r}\frac{E_x^{n+1/2}(k)+E_x^{n-1/2}(k)}{2} \qquad (17)$$

and for the second equation:

$$\frac{H_y^{n+1}(k+1/2)-H_y^n(k+1/2)}{\Delta t} = -\frac{1}{\mu_0}\frac{E_x^{n+1/2}(k+1)-E_x^{n+1/2}(k)}{\Delta z} \qquad (18)$$

In the equations (17 and 18), n is the time index and k is the spatial index, which indexes times $t = n\Delta t$ and positions $z = k\Delta z$, or times $t = (n \pm \frac{1}{2})\Delta t$ and positions $z = (k \pm \frac{1}{2})\Delta z$. The time index is written as a superscript, and the spatial index is within brackets. Equations (17 and 18) can be rearranged as a pair of 'computer update equations', which can be repeatedly updated in loop, to obtain the next time values of $E_x^{n+1/2}(k)$ and $H_x^{n+1/2}(k+1/2)$, corresponding the $E_x(t+\Delta t/2, z)$ and $H_y(t+\Delta t/2, z+\Delta z/2)$. In equations (15 and 16), ε_0 and μ_0 differ by several orders of magnitude. As a result, E_x and H_y will differ by several orders of magnitude. Numerical error is minimized by making the following change of variables as

$$\tilde{E}_x = \sqrt{\frac{\varepsilon_0}{\mu_0}} E_x \qquad (19)$$

which bring the field quantities to similar levels. Implementing the changing of variables, equations (17 and 18) become

$$\tilde{E}_x^{n+1/2}(k) = \frac{1-\frac{\Delta t.\sigma}{2\varepsilon_0\varepsilon_r}}{1+\frac{\Delta t.\sigma}{2\varepsilon_0\varepsilon_r}}\tilde{E}_x^{n-1/2}(k) - \frac{1/2}{\varepsilon_r\left(1+\frac{\Delta t.\sigma}{2\varepsilon_0\varepsilon_r}\right)}[H_y^n(k+1/2)-H_y^n(k-1/2)] \qquad (20)$$

$$H_y^{n+1}(k+1/2) = H_y^n(k+1/2) - \frac{1}{\sqrt{\varepsilon_0\mu}}\frac{\Delta t}{\Delta z}[\tilde{E}_x^{n+1/2}(k+1)-\tilde{E}_x^{n+1/2}(k)] \qquad (21)$$

The most important points in FDTD calculations are the stability and numerical dispersion [25]. Choosing the cell size to be used in an FDTD formulation is similar to any approximation procedure: enough sampling points must be taken to ensure that an adequate representation is made. For stability purposes, a good rule of thumb, we need to choose the cell size Δz to allow 10 to 15 points per wave [26]. We used in all our simulations a time step $\Delta t = \frac{\Delta z}{2c_0}$ where c_0 is the speed of light in free space.

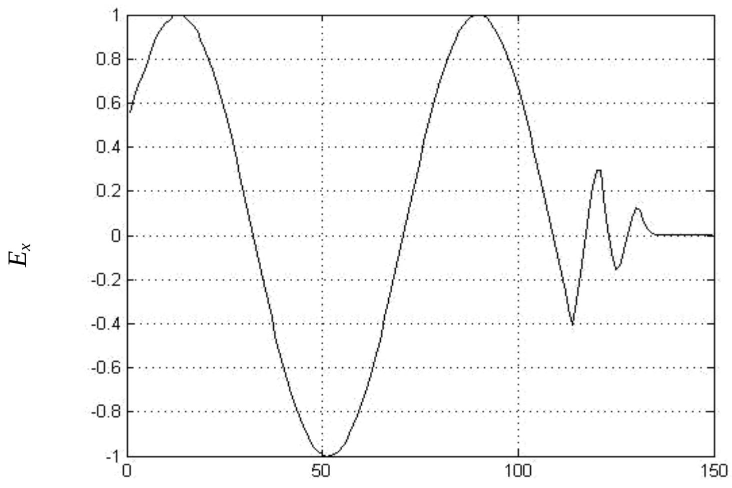
5. Results and discussion

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 human body tissue.

FDTD Methods have become almost the most important time domain simulation techniques used in broad range of electromagnetic problem. FDTD method implemented 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 900MHz. We chose the cell size to be 10th the wavelength, as explained earlier, at this layer as follows,

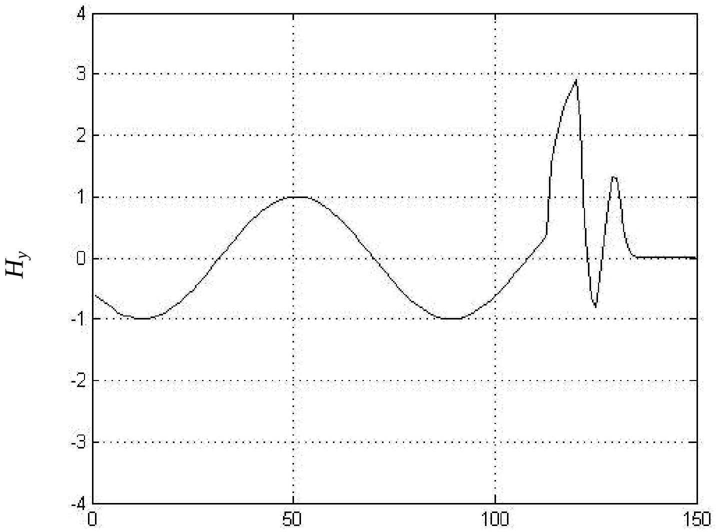
$$\text{cell size} = \frac{1}{10}\lambda_m = \frac{1}{10}\frac{c_o/\sqrt{58.675}}{900\text{MHz}} = 0.0043 \qquad (21)$$

Figure (2) illustrates the electric field distributions in the human body tissue. It can be seen that the incident wave which assumed a sinusoidal electric field penetrates the first skin layer at cell 114. The field propagates inside the human tissues. It is evident that the field attenuate very fast in human tissue. In last layer the electric field is zero at cell 135 steps which is deep in layer four.



FDTD cells

Figure (2): simulation of the propagation of the electric field of 900MHz into human body tissue



FDTD cells

Figure (3): simulation of the propagation of the Magnetic field of 900MHz into human body tissue.

The distribution of the magnetic field in the human body tissue is illustrated in Figure (3). The magnetic field attenuates as it gets inside the human tissues and fads away inside the 4th layer. Figure (2) and (3) indicates that the fields absorbed by the human body and it deeply penetrates the tissues reaching the organs layer where is finally vanishes. Power density and Specific absorption rate (SAR) distribution is shown in figure (4). The maximum absorption is found to be inside the skin and the fat tissues. The skin and the fat tissue correspond to the FDTD cells (114-115).

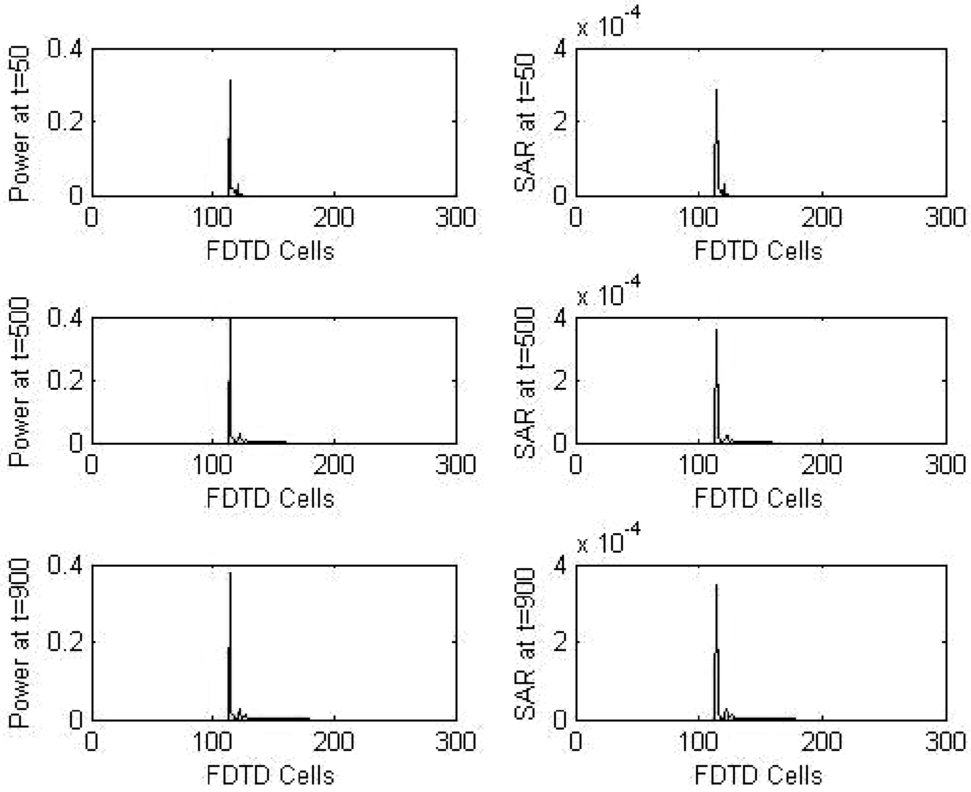


Figure (4): Simulation of power density and SAR inside the human body tissues at different time steps.

6. Conclusion

Four-layered structure representing simplified model of human body tissue irradiated by plane waves produced by mobile phone base station, is investigated. The four layers represent the skin-fat-muscles-and organs 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, attenuates rapidly and finally reaches zero at the organs layer. Absorbent power and SAR have maximum values at the skin and fat layers. According to our study, the human orangs are protected by the skin and the fat tissues. However, the skin and the fat layers are in risk because they strongly absorbed the propagated field.

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