HUMAN HEAD

AND SAFETY CONDITIONS

IN ELECTROMAGNETIC ENVIRON

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ABSTRACT

The electromagnetic equivalent of a biological head is postulated. The ideal conditions for working of the human brain in a safe condition are derived. The field equations are written in spherical coordinates with $(FD)^2TD$ method for the scattering of the circular current loops around the head. Then the equations are solved under the boundary conditions coming from the equivalence principle. The currents induced and the SAR in an equivalent human head model are calculated. The electromagnetic equivalent for the dynamics of a neuron in the brain is given. Safety conditions are derived for mental activity in an electromagnetic environment.

INTRODUCTION

The human body is always in the exposure of various external electromagnetic sources. Some recent studies concern with the influences of outer radiation related to electromagnetic waves to the human body. The interaction mechanism is very complicated to understand and explain the phenomena since the human body contains extremely complex mediums. The muscles, bones, bloods, skins, cells, and *etc.* have been distributed irregularly in the body; therefore, if one focuses to construct the mediums, discontinuities, boundaries, and the geometrical and physical properties of a human body as an electromagnetic environ then it exhibits unusable trajectories for the computational purposes.

Some papers put various partitions with special electromagnetic parameters instead of some kinds of organ [1]-[3]. However, such partitions are trial and cannot give compact model that will be suitable for every human body. This brings an idea that a compact model must be defined and the basis of the model must remain same from human to human but some characteristic parameters may differ from human to human. Such a model will be equivalent to human for bio-electromagnetic purposes. The idea of electromagnetic equivalent structures for human body may solve the difficulties in the analysis problem [4].

Why we need a bio-electromagnetic equivalent for the human? The neural structure in human body plays a role on the electromagnetic interaction and we cannot calculate the interactions by using merely the electromagnetic parameters such as permittivity, permeability, and conductivity, effectively. Similar problem comes with the blood movements. This report is focused to modeling the human head as a bio-electromagnetic equivalent object. It is not suitable to give the influence of electromagnetic radiation on neurons with a priori prepositions.

The neural structure and the flow of the blood are modeled with the equivalent surfaces. The neural stimulation is modeled with dipoles or dipole layers. The electromagnetic effect may be considered as the scattering of an external electromagnetic radiation from the model body. When we think off interaction mechanism to put equivalent volumes for skin, bone, muscle, and brain will be acceptable easily. We may calculate the equivalent parameters of specific persons by external field measurements around a human head. If those equivalent parameters are obtained first, then they may be used always for that person after that measurement for various sources of the electromagnetic radiation. However, to put some volumes for the neurons and blood flow will not be acceptable since both have net structures.

THE METHOD

The effects of equivalent surfaces, loops and dipoles play a role on boundary conditions. We will construct an inverse problem if we measure the external field around the head due to external sources located near or far from human. This inverse problem is solvable by FDTD method. The solution gives various electromagnetic parameters, geometrical parameters, and surface currents. What can we do by those parameters? Let us determine these parameters in the normal outer conditions, first. They will give the normal stimulant currents in the human head. Second, let us determine these parameters in a specific outer condition: for example, by putting a field source near the human head. These parameters will define the conditional stimulant currents in the human head. The comparison of normal and conditional stimulant currents classifies the interactions between the human head and the external electromagnetic radiation and defines the safety margins for a healthy head during mental activities.

The Field Calculation by $(FD)^2TD$

The components of the electric field are derived as following equations in (I,J,K) cell where $J^{n+1}(I,J,K)$ defines the components of the total current densities of the equivalent neural dipoles:

$$E_r^{s,n+5/2}(I,J,K) = -S_0 J_r^{n+1}(I,J,K) - E_r^{i,n+5/2}(I,J,K) + S_1 E_r^{i,n+3/2}(I,J,K) + S_2 E_r^{i,n+1/2}(I,J,K) + \\ + S_3 E_r^{i,n-1/2}(I,J,K) + S_1 E_r^{s,n+3/2}(I,J,K) + S_4 E_r^{s,n+1/2}(I,J,K) + S_5 E_r^{s,n-1/2}(I,J,K) + \\ + \frac{S_0 \cos(J\Delta\theta)}{R(I)\sin(J\Delta\theta)} H_\phi^{s,n+1}(I,J,K) - \frac{S_0}{R(I)}\left[\frac{H_\phi^{s,n}(I,J,K) - H_\phi^{s,n}(I,J-1,K)}{\Delta\theta(J-1)}\right] + \\ + \frac{-S_0}{R(I)}\left[\frac{H_\theta^{s,n}(I,J,K) - H_\theta^{s,n}(I,J,K-1)}{\sin(J\Delta\theta)\Delta\phi(K-1)}\right] \tag{1a}$$

$$E_\theta^{s,n+5/2}(I,J,K) = -S_0 J_\theta^{n+1}(I,J,K) - E_\theta^{i,n+5/2}(I,J,K) + S_1 E_\theta^{i,n+3/2}(I,J,K) + S_2 E_\theta^{i,n+1/2}(I,J,K) + \\ + S_3 E_\theta^{i,n-1/2}(I,J,K) + S_1 E_\theta^{s,n+3/2}(I,J,K) + S_4 E_\theta^{s,n+1/2}(I,J,K) + S_5 E_\theta^{s,n-1/2}(I,J,K) + \\ + \frac{-S_0}{R(I)} H_\theta^{s,n+1}(I,J,K) - S_0\left[\frac{H_\phi^{s,n}(I,J,K) - H_\phi^{s,n}(I-1,J,K)}{\Delta R(I-1)}\right] + \\ + \frac{-S_0}{R(I)}\left[\frac{H_r^{s,n}(I,J,K) - H_r^{s,n}(I,J,K-1)}{\sin(J\Delta\theta)\Delta\phi(K-1)}\right] \tag{1b}$$

$$E_\phi^{s,n+5/2}(I,J,K) = -S_0 J_\phi^{n+1}(I,J,K) - E_\phi^{i,n+5/2}(I,J,K) + S_1 E_\phi^{i,n+3/2}(I,J,K) + S_2 E_\phi^{i,n+1/2}(I,J,K) + \\ + S_3 E_\phi^{i,n-1/2}(I,J,K) + S_1 E_\phi^{s,n+3/2}(I,J,K) + S_4 E_\phi^{s,n+1/2}(I,J,K) + S_5 E_\phi^{s,n-1/2}(I,J,K) + \\ + \frac{S_0}{R(I)} H_\phi^{s,n+1}(I,J,K) + S_0\left[\frac{H_\theta^{s,n}(I,J,K) - H_\theta^{s,n}(I-1,J,K)}{\Delta R(I-1)}\right] + \\ + \frac{S_0}{R(I)}\left[\frac{H_r^{s,n}(I,J,K) - H_r^{s,n}(I,J-1,K)}{\Delta\theta(J-1)}\right] \tag{1c}$$

Here n, s, and i illustrate the time step, scattered field, and incident field, respectively and we put the following definitions where the σ, σ_1, σ_2, and σ_3 are the conductivities obtained by Debye's dispersion characteristic:

$$S_0 = \frac{\Delta t}{\varepsilon_2 + \sigma_3} \; , \qquad S_2 = \frac{-\sigma(\Delta t)^3 - (\varepsilon - \varepsilon_0 - \sigma_1)(\Delta t)^2 + 2(\varepsilon_1 + \sigma_2)\Delta t}{(\varepsilon_2 + \sigma_3)} - 3 \quad (2a)$$

$$S_1 = \frac{-(\varepsilon_1 + \sigma_2)\Delta t}{(\varepsilon_2 + \sigma_3)} + 3 \, , \qquad S_3 = \frac{-(\varepsilon - \varepsilon_0 - \sigma_1)(\Delta t)^2 - 2(\varepsilon_1 + \sigma_2)\Delta t}{(\varepsilon_2 + \sigma_3)} + 1 \quad (2b)$$

$$S_4 = \frac{-\sigma(\Delta t)^3 - (\varepsilon + \sigma_1)(\Delta t)^2 + 2(\varepsilon_1 + \sigma_2)\Delta t}{(\varepsilon_2 + \sigma_3)} - 3 \, , \qquad S_5 = \frac{(\varepsilon + \sigma_1)(\Delta t)^2 - (\varepsilon_1 + \sigma_2)\Delta t}{(\varepsilon_2 + \sigma_3)} + 1 \quad (2c)$$

Safety Conditions

If the incident field absent then we say the environment is in an ideal condition for the safety of human head. The ideal condition defines the case that the brain in the human head works regularly. The human brain is identical to the equivalent neural dipoles with the initial current densities in the case of ideal condition. These ideal conditions are derived. The equivalent neural magnetic dipole and the equivalent radius of the initial layer surface are given. The current densities of these magnetic dipoles induce the vertical current stimuli and the horizontal current stimuli to the neuron. Let us consider E field polarized in radial direction and H field polarized in θ direction. The equivalent neural dipoles induce the following vertical current stimuli I_i^v and the horizontal current stimuli I_i^h to the neuron i in the case of ideal condition, respectively:

$$I_i^{v,1}(1,1,1) = -\frac{2\pi R(0)}{R(1)} H_\theta^{s,1}(1,1,1) \, , \qquad I_i^{h,1}(1,1,1) = \pi R(0) \frac{H_\theta^{s,0}(1,1,1) - H_\theta^{s,0}(0,1,1)}{R(1) - R(0)} \quad (3)$$

Here, the R(0) and R(1) are the radius of the equivalent neural magnetic dipole and the equivalent radius of the initial layer surface, respectively.

The limits of the US-EPA options produce the current stimuli to the neuron for magnetic polarization. The reached results show that the limit of EPA is too high and it has to be decreased [4]. The SAR at the limits of the US-APE options for the H_θ-polarization between 10 and 300 kHz is given in Fig. 1. If the average radius of the brain is relatively small to the radius of equivalent neural dipole then SAR increases. This condition coincides with the “*fētūs*” case.

The dynamics of a neuron in the brain are obtained as simultaneous system of equations with the vertical (horizontal) membrane capacitance, input, and output and the weights and the transmembrane resistance. We call these equations the electromagnetic equivalent for the dynamics of a neuron in the human brain. Equation (4) describes the dynamics of a neuron in the brain by the following equations where C_i^v (C_i^h), x_i^v (x_i^h), and y_i^v (y_i^h) are the vertical (horizontal) membrane capacitance, input, and output and the w_{ij} and R_i are the weights and the transmembrane resistance, respectively:

$$C_i^v \frac{x_i^{v,n+1/2} - x_i^{v,n-1/2}}{\Delta t} = \sum_j w_{ij} y_j^{v,n} - \frac{x_i^{v,n}}{R_i} + I_i^{v,n} \, , \qquad C_i^h \frac{x_i^{h,n+1/2} - x_i^{h,n-1/2}}{\Delta t} = \sum_j w_{ij} y_j^{h,n} - \frac{x_i^{h,n}}{R_i} + I_i^{h,n} \quad (4)$$

The presence of an external field generates variations on vertical current stimuli I_i^v and the horizontal current stimuli I_i^h. These variations produce variations on inputs x_i^v (x_i^h) and outputs y_i^v (y_i^h) according to following variations:

$$\delta\left(C_i \frac{dx_i^{v(h)}(t)}{dt} \right) + \delta\left(\frac{x_i^{v(h)}(t)}{R_i} \right) - \delta I_i^{v(h)}(t) = \delta\left(\sum_j w_{ij} y_i^{v(h)}(t) \right) \quad (5)$$

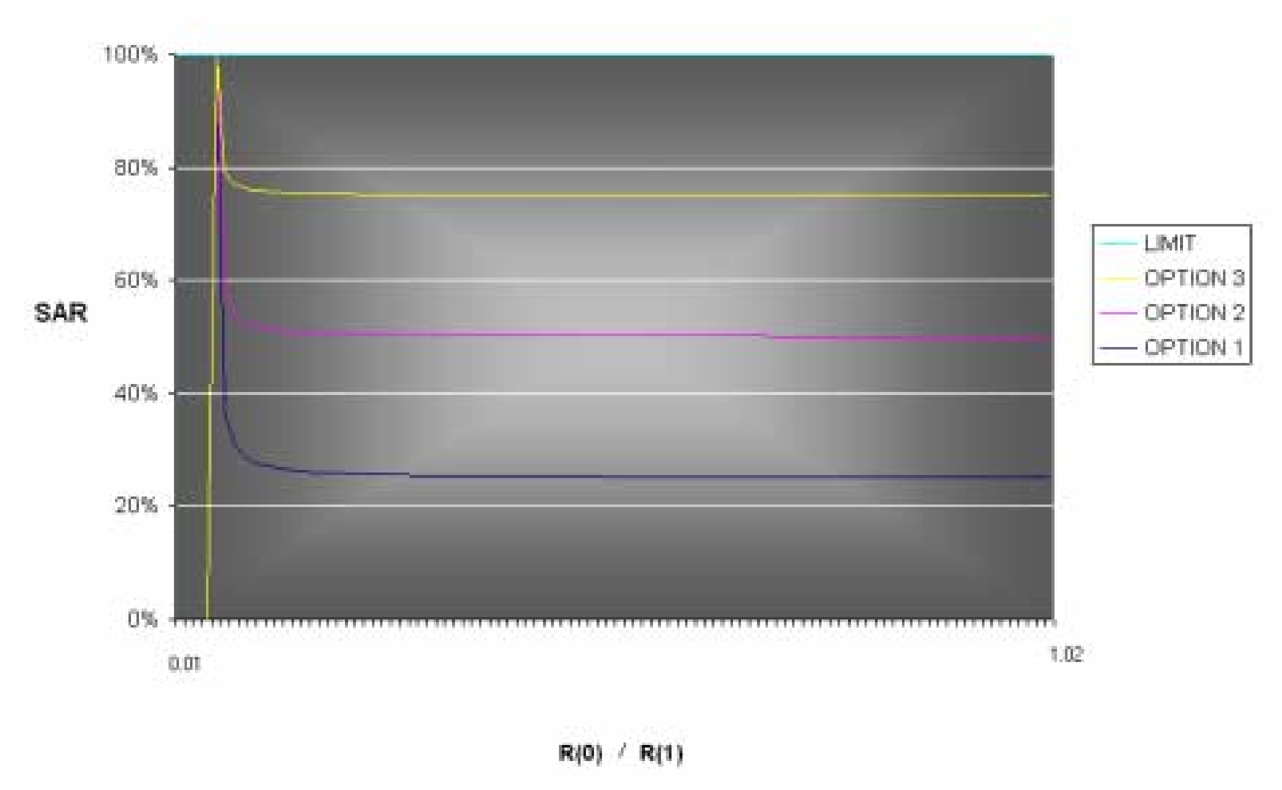

Fig. 1. The SAR at the limits of the US-APE for the H_θ-polarization between 0.01 and 0.3 MHz.

If the current stimuli variations do not affect the inputs then the neurons are not affected mentally. We call the neuron is self-stable in this case. The variations of current stimuli generate following variations on the output of self-stable neurons:

$$\delta\left(\sum_j w_{ij}\, y_i^{v(h)}(t)\right) = -\delta I_i^{v(h)}(t) \tag{6}$$

CONCLUSIONS

The electromagnetic equivalent of a biological head is postulated. The ideal conditions for working of the human brain in a safe condition are derived. The field equations are written in spherical coordinates with $(FD)^2TD$ method for the scattering of the circular current loops around the head. Then the equations are solved under the boundary conditions coming from the equivalence principle. The currents induced and the SAR in an equivalent human head model are calculated. The electromagnetic equivalent for the dynamics of a neuron in the brain is given. Ideal and safety conditions are derived for mental activity in an electromagnetic environment.

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