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HUMAN EM EXPOSURE MODELING USING FDTD AND METHOD OF AUXILIARY SOURCES

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Abstract. The motivation of this paper is to conduct a comparative analysis of the temperature and temperature rise during EM exposure, obtained using conventional Pennes bio-heat equation and a modified model considering blood perfusion. This article deals with a mobile communication system base station's radiation interaction with a human model inside the room and inner field and its amplification by the walls, that in some cases act like a resonator. The calculations were conducted for frequencies used in the standard mobile frequency range.

Keywords and phrases: EM exposure, FDTD method, SAR, temperature rise.

AMS subject classification (2010): 65Z99.

1 Introduction. Due to a tremendous increase of Mobile phones and other wireless communication devices' number and their use in everyday life, it is very important to study their EM influence on humans, since the excitation source is located very close to the user. In the Laboratory of Applied Electrodynamics and Radio-engineering (LAE) the researches are conducted in two directions: 1) The EM exposure study for the small-scale scenarios is conducted on non-homogenous discrete human models with FDTD method. The purpose of research is to estimate the absorbed EM field energy in the tissue (SAR) and temperature rise caused by it. 2) In case of large-scale scenarios the aim of the research is to investigate EM exposure influence on a human homogenous model located in a room and to study possible resonant fields created by multiple reflections inside the room. The consideration of other surrounding objects (like room walls, cars, etc.) is realized with the Method of Auxiliary sources (MAS).

2 Models, methods and results of calculations. The bio-heat equation [1] has been used for many years to simulate heat exchange in human tissues.

$$c_p \rho \frac{\partial T}{\partial t} = \nabla \cdot \left(k \nabla T \right) + \rho \, SAR + A - B(T - T_b) \quad (1)$$

This equation does not take into account heat transfer effects by the blood. The modified bio-heat equation presented in [2] has been used to calculate temperature and temperature rise. For the numerical simulations were used a child ("Thelonius") and

$$c_p\rho\frac{\partial T}{\partial t}=\nabla\cdot\left(k\nabla T\right)+\rho\, SAR+A(\vec{r},t)-\alpha\left(T(\vec{r},t)-T_b(\vec{r},t)\right)$$

$$\begin{cases} T_b(\vec{r},t)=T_{b_0}+\dfrac{\Delta t}{V_0}\sum v_i S_i (T_i-T_{b_0}), r\notin Sources, \\ \qquad \Delta t<\dfrac{V_{\min}}{v_{\max} S_i} \\ T_b(\vec{r},t)=const, \vec{r}\in Sources \end{cases} \tag{2}$$

a woman ("Ella") voxel models from virtual family [3]. The frequency dependent tissue parameters for the EM simulation and the thermal tissue parameters have been used from [3].

To solve EM and thermal problems FDTD Lab program package was used. In order to use the modified bio-heat equation, described in [2], we have to prepare the human models for simulations. It involves building the arterial and venous vascular networks and calculating the capillary flow blood field. The peaks of temperature rise values in a child and woman heads for the modified bio-heat equation in most cases are lower (fig.1.a), (fig.1. c). But these values for the inner tissues (brain) are higher (Fig.1. b), (Fig. 1. d). The 1g and 10g SAR values are also close for the altered and original models.

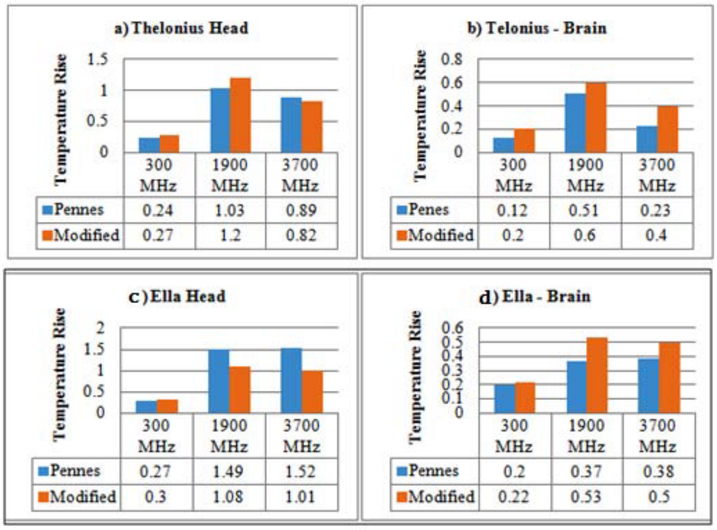

Figure 1: Temperature rise for the Ella and Telonius head (a, c) models and temperature rise for the Ella and Telonius brain (b, d) at 300MHz, 1900MHz and 3700MHz.

For both models the peak values of SAR and temperature rise are lower for low frequencies and higher for higher frequencies. This is explained by the penetration depth, which is higher at lower frequencies and the energy is distributed in a larger volume, while at high frequencies it's mostly absorbed in the thin boundary layer.

3 MAS methodology for large-scale scenarios and some numerical results. In the article [4] a detailed investigation is presented with a justification of a possibility to use a homogenous dielectric human shaped body "Mummy" with averaged permittivity and losses values (according to muscle, bone and blood). The use of such model is needed to implement the Method of Auxiliary Sources for calculations diffraction problems on human model for the big scenarios, when it is located inside the room with a window. Application of the MAS is deduced to the construction of two couples of closed auxiliary surfaces inside and outside the "Mummy" and also inside and outside the surrounded semi open surface like the room [4]. Along the surfaces of the "Mummy" and so called the room, as it is possible homogeneously, we distribute the N and M numbers of points, correspondingly. The combined dipole (Huygens source) was used as auxiliary source for the calculations:

$$\vec{E}_{comb} = \vec{E}_{el} + \sqrt{\mu / \varepsilon}\,\vec{E}_{mag},\ \vec{H}_{comb} = \vec{H}_{el} + \sqrt{\mu / \varepsilon}\,\vec{H}_{mag}$$

Where $\vec{E}_{el}$, $\vec{H}_{el}$ and $\vec{E}_{mag}$, $\vec{H}_{mag}$ - rather field of the electric and magnetic dipoles

On these auxiliary surfaces from both sides the same numbers combined auxiliary sources are distributed with unknown complex amplitudes.

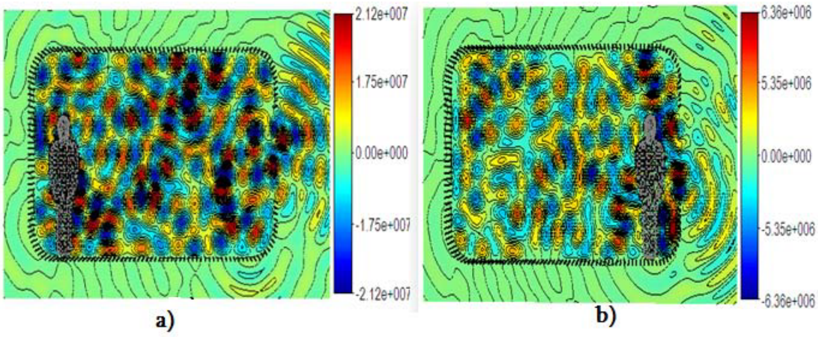

Figure 2: Near field distribution in the room at the 899.19 MHz resonant frequency when human is located far a) and near b) from the window.

Boundary conditions:

$$\left.\begin{array}{l} \vec{E}^{out}|_{\tau_1}=0 \\ \vec{E}^{out}|_{\tau_2}=0 \\ \vec{H}^{out}|_{\tau_1}=0 \\ \vec{H}^{out}|_{\tau_2}=0 \end{array}\right\},i=1,M \qquad \left.\begin{array}{l} \vec{E}^{out}_{body}|_{\tau_1}=\vec{E}^{out}|_{\tau_1} \\ \vec{E}^{out}_{body}|_{\tau_2}=\vec{E}^{out}|_{\tau_2} \\ \vec{H}^{out}_{body}|_{\tau_1}=\vec{H}^{out}|_{\tau_1} \\ \vec{H}^{out}_{body}|_{\tau_2}=\vec{H}^{out}|_{\tau_2} \end{array}\right\},i=1,Mw \qquad \left.\begin{array}{l} \vec{E}^{out}_{body}|_{\tau_1}=0 \\ \vec{E}^{out}_{body}|_{\tau_2}=0 \\ \vec{H}^{out}_{body}|_{\tau_1}=0 \\ \vec{H}^{out}_{body}|_{\tau_2}=0 \end{array}\right\},i=1,M \qquad \left.\begin{array}{l} \vec{E}^{out}_{body}|_{\tau_1}=\vec{E}^{in}_{body}|_{\tau_1} \\ \vec{E}^{out}_{body}|_{\tau_2}=\vec{E}^{in}_{body}|_{\tau_2} \\ \vec{H}^{out}_{body}|_{\tau_1}=\vec{H}^{in}_{body}|_{\tau_1} \\ \vec{H}^{out}_{body}|_{\tau_2}=\vec{H}^{in}_{body}|_{\tau_2} \end{array}\right\},i=1,N$$

These unknown complex amplitudes of the auxiliary sources could be found by the boundary conditions satisfying using the collocation method for the scattered field on the human body model - as on the dielectric.

In order to compute the wall transparency coefficient the effect of averaged boundary conditions is first used [4]. According to our idea the wall transparency can be regulated by changing the collocation point number on the wall surface. Reducing this number implies an increase in the total error in the implementation of the relevant boundary conditions.

The results of numerical calculations show that in case of a small number of collocation points inside the field can seep between, creating the effect of a wall transparency.

Several scenarios have been studied for two different human model positions (when human is located near the window and far from the window) for the different walls transparency. Some of results are presented in Fig.2.

4 Conclusions. Several exposure scenarios for the modified bio-heat equation have been studied. It has been shown that the temperature rise values for the modified model are very close to the convention Pennes equation. In order to study the large-scale exposure scenarios the MAS methodology was used. The new, MAS based, program package has been created for simulations. The MAS methodology was used to simulate surface with different transparency. The calculations, conducted with the created program package, showed the presence of resonance and reactive fields in several big scenarios which could be dangerous for a human.

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