NUMERICAL MODELING OF ELECTROMAGNETIC FIELD EFFECTS ON THE HUMAN BODY

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Summary Interactions of electromagnetic field (EMF) with environment and with tissue of human beings are still under discussion and many research teams are investigating it. The human simulation models are used for biomedical research in a lot of areas, where it is advantage to replace real human body (tissue) by the numerical model. Biological effects of EMF are one of the areas, where numerical models are used with many advantages. On the other side, this research is very specific and it is always quite hard to simulate realistic human tissue. This paper deals with different possibilities of numerical modelling of electromagnetic field effects on the human body (especially calculation of the specific absorption rate (SAR) distribution in human body and thermal effect).

1. INTRODUCTION

The scientists want to minimize a human body exposure by research biological effects of RF electromagnetic field in this time. With the availability of improved computer technology, various numerical techniques have been developed for solution of EMF interactions with heterogeneous objects in electrical composition. There are many applications for simulations and modeling EMF effects on human body. By radiofrequency (RF) fields, there are made mostly SAR simulations with numerical models of human body (SAR is the rate at which energy is absorbed in body tissues, in watts per kilogram [W/kg]; it's the dosimetric measure that has been widely adopted at frequencies above about 100 kHz) and thermal effects.

2. NUMERICAL METHODS

The analysis of a realistically heterogeneous model for humans is a difficult theoretical task. The bases of this analysis are Maxwell's equations. There have been used special models and techniques, each valid only in a limited range of frequencies or other parameters. A combination of techniques has been used to obtain SAR for various models as a function of frequency and time. Each of these techniques provides information over a limited range of parameters with certain level of accuracy. To the wide array of methods belong:

- *Extended- boundary condition method (EBCM)*
- *Iterative extended- boundary condition method (IEBCM)*
- *Method of moments (MOM)*
- *Finite element method (FEM)*
- *Finite –element time –domain method (FETD)*
- *Generalized multipole technique (GMT)*
- *Conjugate gradient-fast Fourier transform (CG-FFT)*
- *Volume surface integral equation method (VSIE)*
- *Quasi-static admittance and impedance methods*
- *Finite-difference time-domain method (FDTD)*

FDTD is the most widely used method for bioelectromagnetic applications in the range of a few MHz to several GHz [1]. An extension of the FDTD method is the *Frequency-depended finite – difference time-domain method* ($(FD)^2$ *TD*). It enables broad-band bioelectromagnetic simulations by including the effect of frequency dispersion in tissues. This method has been used to calculate SAR and current distributions in the human body.

FDTD method is one of the best methods for computation EMF and it becomes quickly more efficient in terms of computer time and memory than other methods since there is no matrix to fill and solve. FDTD can provide results for a wide spectrum of frequencies from just one calculation using transient pulse excitation and FFT (Fast Fourier Transformation). This method is based on a solution grid. The grid is fundamentally different than those used by other methods. The FDTD grid is composed of rectangular boxes. Each box edge is an electric field location, and the material for each mesh edge can be specified independently of other edges. Geometry is formed by assigning different materials to different mesh edges. The regular grid is chosen by means of calculations for each grid element and it is extremely fast. This allows very precise approximations to the actual physical geometry. The FDTD strategy is to use many very small mesh elements that can be computed quickly and with very little computer memory. This means that it is a routine to make FDTD calculations with millions of cells in a few minutes. It is impossible to solve the problem by methods based on matrix calculating [2].

Another advantage is a fact, that thermal solver is completely compatible with the electromagnetic solver. On the figure 1 principle of thermal solving by using FDTD grid is shown. Indices i ,j, k refer to the temperature node $T_{i,j,k}$ position in a rectilinear grid. The heat generation term is represented by its spatial average value $Q_{i,j,k}$ inside the control-volume given by the product $\delta x_i\ \delta y_j\ \delta z_k$ of the cell dimensions. The distance between the temperature nodes $T_{i,j,k}$ and $T_{i+1,j,k}$ is δSX_{i+1}. The $k'^{x+}_{i,j,k}$ is weighted thermal conductivity, which replaced thermal conductivity $k_{i,j,k}$ for reason of physical consistency.[3]

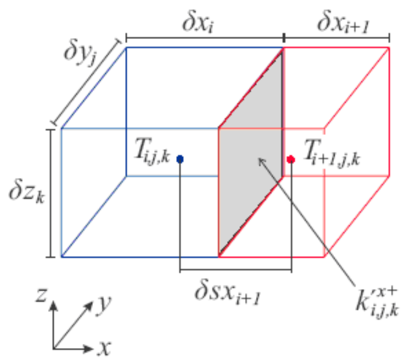

Figure 1: Grid geometry of thermal solves

Table 1: Electrical properties of various human tissues [5]

Tissue type	**Conductivity σ [S/m]**	**Relative ermittivity ε_r [-]**	**Density ρ [kg/m^3]**	**Specific heat c_s [J/kg.K]**	**Thermal conductivity *k* [W/m.K]**
Bone	0.3406	20.7823	1810	1256	0.528
Brain	0.9434	52.7133	1030	3710	0.528
Skin	0.8674	41.3923	1010	3662	0.528
Muscle	0.9438	55.0261	1040	3639	0.528
Blood	1.5390	61.3524	1060	3894	0.528

3. SAR NUMERICAL MODELING

The FDTD method has been used for many applications including calculating SARs and induced currents in the human body and etc.

The electrical properties of various biological tissues, permittivity and conductivity are very important by SAR calculating. Permittivity and conductivity depend on frequency. Various parameters by SAR calculating with EMF from mobile phone are:

- operational frequency and antenna power
- mutual positions of the device and head
- design of the device
- size and the shape of human head
- distribution of tissues within the head
- electrical properties of the tissues [4]

Examples of electrical properties of various human tissues are in table the 1. Electrical properties are functions of frequency and due to this reason, the frequency of EMF has to be known before the simulations begin. Values in the table 1 are valid at frequency 902.5 MHz, which is one of the used frequencies in GSM.

In RF fields the temperature rises in the brain per unit SAR. The parameter SAR has been calculated for exposures at mobile phone frequencies and it is defined by mobile phone as [3]:

$$SAR = \frac{\sigma_E}{2\rho}\left|\vec{E}\right|^2 = c\frac{dT}{dt} \qquad (1)$$

where: c is the specific heat capacity,
σ_E is the electric conductivity,
ρ is the mass density of the tissue,
E is the induced electric field vector;
dT/dt is the temperature increase in the tissue.

For the importance of mobile telephony as a source of exposure, the studies carried out at 800–1900 MHz to provide the most important data for recommending restrictions on SAR to avoid thermal effects in the brain [6].

In the uncontrolled environments, a peak SAR of 1.6W/kg, as averaged over any 1 g of tissue must not be exceeded. The limit on the peak SAR is fixed at 1W/kg, as averaged over any 100g of tissue. The hand-held cellular mobile phone is stated to be safe when a cellular mobile phone's radiated power is less than 0.7 W (at 900MHz) and when the distance to human head is bigger than 2.5 cm [4][7].

The principle of calculation of average absorption or whole–body SAR for the model of the human body shows the figure 2.

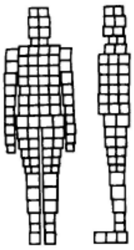

Figure 2: Cubic-cell representation of human body [8]

The more exact representation of human body are complicated models doing and testing in applications for numerical modelling of EMF.

4. APPLICATIONS FOR NUMERICAL MODELS

The experimental phantoms have been developed to understand coupling of EM fields to models of the biological systems. Early analyses were based on spheres, cylinders, spheroids, ellipsoids and large-block models (cubical mathematical cells arranged in the shape of a human body).

Detailed modeling of the internal heterogeneities of the body is very difficult and it has been made only on a very limited scale. More often there have been used simple homogenous models but they are incapable of giving accurate SAR distributions. By near-field sources such as wireless telephones there have been shown peak 1-g SARs for SAR compliance testing with an uncertainty of ±20 percent. In the development of homogenous models there have been increased heterogeneous anatomically based models of human body. They have been based on anatomical sectional diagrams. More resent versions are based on Magnetic Resonance Imaging (MRI) scans of living humans or cadavers such as "visible man" and "visible woman" developed by National Library of Medicine. Development of models suitable for FDTD calculations is not trivial. MRI and Computed Tomography (CT) scans provide voxel maps of density, but many of the tissues have the same similar densities. Many of the regions outside of the major organs require a detailed understanding of anatomy to determine what tissues are present, for example fat, fluid, air. FDTD calculations use the tissue electrical properties and mass density at each voxel location. With memory of PCs, computer workstations and parallel processors it is possible to run anatomically based whole-body models with high resolution by the help of modern software applications [1].

The well-known applications for modeling and simulation of SAR distribution in human tissue are FEMLAB and SEMCAD:

The software FEMLAB has an electromagnetic module for these EMF numerical applications. It is possible to solve the SAR value for a 3D human head (figure 3), using MRI data for both geometry and material properties. Absorbed radiation (the SAR value) is a common measure of the danger for certain devices such as mobile phones [9].

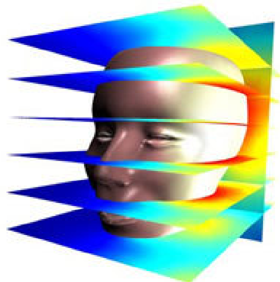

Figure 3: SAR distribution by 3D human head in FEMLAB. [10]

SEMCAD is an all purpose electromagnetic FDTD solver which offers extended capabilities for numerical dosimetry and the simulation of antennas. Its ACIS-based three dimensional solid modeling interface combined with a flexible automatic mesh generator enables the fast and easy design of complex shaped geometrical structures. The FDTD method has been successfully applied on many different electromagnetics problems such as for example scattering, radiation of antennas and SAR distribution in biological objects. SEMCAD can work with homogenous and heterogeneous models of human body. In the figure 4 and 5 there are models of human head with mobile phone used in software SEMCAD. [3]

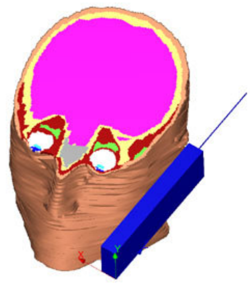

Figure 4: Example of heterogeneous head model with mobile phone in SEMCAD [3]

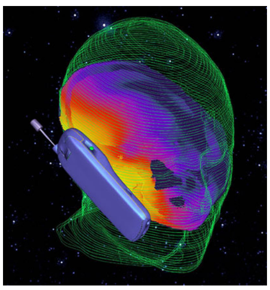

Figure 5: Presentation of SAR value levels in 3D human head in SEMCAD. [3]

It is possible to do two kinds of simulations, electromagnetic and thermal simulations.

Results of simulations in SEMCAD are SAR distribution, electric and magnetic intensity inside of tissues and other electromagnetic values. These values are used in simulation of electromagnetic heating of the model (thermal simulation). The application is fast and good for the interpretation of results.

5. CONCLUSION

Numerical modeling is very popular in this time, also in bioelectromagnetic applications. Computers computation power is still raising and very complicated simulations, which took a lot of time in the past, can be solved within a few minutes nowadays. The biggest advantages of computer numerical human models are the price and the safety. Realistic experiment causes a relatively high exposure of EMF to object, what is eliminated by using numerical modeling. Accuracy of numerical methods depends on the amount and accuracy of inputs and for example on the size of voxels in the case of FDTD.

Very interesting work can consist in comparison accuracy of numerical methods and measurement by using phantoms (3D models of human's tissues or parts of body, electrical parameters of which are similar or identical to the represented tissues). I would like to make similar comparison in my future work.

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