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MODELING OF PENETRATING ELECTROMAGNETIC FIELDS OF MOBILE PHONES IN EXPERIMENTAL ANIMALS

Abstract: *In order to study biological effects of electromagnetic radiation, it is necessary to know the real values of field components that penetrated the tissue. The study of biological effects is usually performed on experimental animals. The biological effects observed on experimental animals should be linked with penetrating field in the tissue. The penetrating electromagnetic field is almost impossible to measure, and therefore, modeling process must be carried out. The components of the fields in the models of experimental animals are calculated. This paper presents an approach to modeling penetration field and gives contribution to understanding real effects of the fields and the sensitivity of tissues to electromagnetic radiation generated by mobile phones.*

Key words: electromagnetic radiation, mobile phone, experimental rats, electromagnetic modeling.

INTRODUCTION

Application of numerical methods in electromagnetics is becoming necessary and, together with sophisticated software packages, it solves the problems of propagation of electromagnetic (EM) field in much shorter time than traditional methods of electromagnetics. Also, it enables the determination of electromagnetic fields for arbitrary geometries of the source with different material environment, which makes conventional methods less applied.

The numerical calculations in electromagnetics are a combination of mathematical methods and a field theory. Before solving the problem, it is important to establish a correct mathematical model of the problem or its parts. Maxwell's equations and appropriate boundary conditions are necessary practical basis for the modeling of electromagnetic problems. Green's theorem and the method of equivalent sources are essential tools for numerical techniques. Using Stokes' theorem and the theorem of Gauss-Ostrogradskyog Maxwell equations can be transformed from the differential form of the integral form and vice versa.

Methods for numerical modeling of continuous real environment can be divided into: the integral method, differential and variation method.

Differential methods are: Finite Difference Method (FDM), Finite Difference Time Domain Method (FDTD) and Finite Element Method (FEM).

Integral methods are: Charge Simulation Method (CSM), Surface Charge Simulation Method (SCSM), Boundary Integral Equation Method (BIEM), Method of Moments (MoM), Finite Integration Technique (FIT), Multiple Multipole Method (MMP) and Generalized Multiple Technique (GMT).

Other methods can be classified as: Transmission Line Method (TLM), Boundary Elements Method (BEM), Scalar Potential Finite Difference (SPFD), Three-Dimensional Impedance Method (3-D IM), etc.

The methods based on commercial software packages used in the modeling are the following: Finite Difference Time Domain Method (FDTD), Method of Moments (MoM), Finite Elements Method (FEM), Three-dimensional Impedance Method (IM), Scalar-Potential-Finite-Difference (SPFD) method, etc.

There are a number of software packages for simulation based on FDTD of which should be mentioned: XFDTD – Remcom, EMPIRE- IMST, SEMCAD X and FIDELITY. Examples of simulation software packages based on FEM methods are: OPERA 3D-Vector Fields, HFSS and Multiphysics. Software packages for simulation-based on FIT are: CST MICROWAVE SUITE and MAFIA Software packages for simulation-based on other methods can mentioned: MEFiSTo-3D Pro, Micro-Stripes, QuickWave-3D, EMC2000-VF, etc.

In order to determine the biological effects of electromagnetic radiation, it is necessary to study the effects on experimental animals. It is also significant to combine theoretical research on animal models with calculation absorbed electromagnetic energy and experimental studies on test animals under the same exposited condition.

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THE METHOD OF INVESTIGATION OF BIOLOGICAL EFFECTS IN EXPERIMENTAL ANIMALS

However, the analysis of the biological effects requires the knowledge of the field strength, absorbed energy and the SAR in rats' bodies. Therefore, the electromagnetic simulation of field components in the body of test animals has been necessary [1].

To obtain the numerical results of calculation of absorption of EM mobile phone radiation in the experimental animals, it is necessary to define: model of the source (mobile phone) with the antenna pattern characteristic, the experimental animal model with the actual characteristics of tissues and under the conditions of the actual use (Fig. 1),[2,3], the model of wave propagation in half-conductive environment, i.e. the choice of numerical simulation methods (FDM, MoM, FDTD, FIT, etc.).

Figure 1. *Experimental animals with a mobile test phone [3]*

Electromagnetic model of mobile phone

As a source of electromagnetic radiation, a mono-block mobile phone with a dipole antenna has been used (half-wave dipole). It is possible to form another EM model of mobile phone for other type [6]. Some of them are shown in Fig. 2.

a) b) c) d)

Figure 2. *Type of mobile phones*

Three types of mobile phones are usually used (Fig.2): a mono-block phone with a with monopole antenna which is placed on the top of the mobile phone (a), a mono-block phone with a planar inverted-F antennas - PIFA (b and c) and a flip-down phone with a PIFA (d).

Numerical Simulation Method - FDTD Method

FDTD solves Maxwell's equations in the time domain. This means that the calculation of the electromagnetic field values progresses at discrete steps in time. The main reason for using the FDTD approach is the excellent scaling performance of the method as the problem size grows. As the number of unknowns increases, the FDTD approach quickly outpaces other methods in efficiency. FDTD has also been identified as the preferred method for performing electromagnetic simulations for biological effects from wireless devices [3, 4, 7].

In the FDTD approach, both space and time are divided into discrete segments. Space is segmented into box-shaped "cells", which are small in comparison to the wavelength. The electric fields are located on the edges of the box and the magnetic fields are positioned on the faces as shown in Figure 1. This orientation of the fields is known as the Yee cell [7, 8] and is the basis for FDTD. Time is quantized into small steps where each step represents the time required for the field to travel from one cell to the next. Given the offset in space of the magnetic fields from the electric fields, the values of the field with respect to time are also offset. The electric and magnetic fields are updated using a leapfrog scheme where first the electric fields, then the magnetic are computed at each step in time.

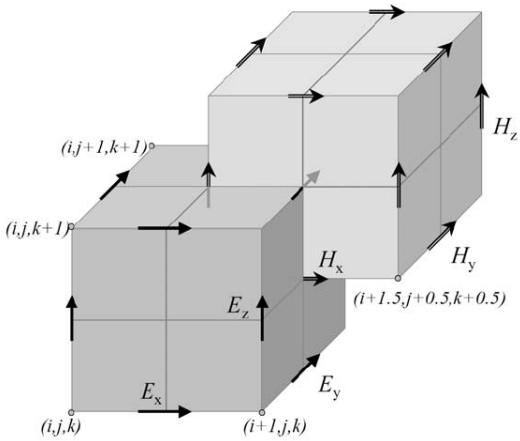


Figure 3. *Electrical and magnetic field components in FDTD grid*

The electric fields at the other nine edges of the FDTD cell will belong to other, adjacent cells. Each cell will also have three magnetic fields originating on the faces of the cell adjacent to the common node of the electric fields as shown in Fig 3.

Within the mesh, materials such as conductors or dielectrics can be added by changing the equations for computing the fields at given locations. Introducing other materials or other configurations is handled in a similar manner and each may be applied to either the electric or magnetic fields depending on the characteristics of the material.

The cell size, the dimensions of the box, is the most important constraint in any FDTD simulation since it determines not only the step size in time, but also the upper frequency limit for the calculation. A general rule of thumb sets the minimum resolution, and thus the upper frequency limit, at ten cells per wavelength. In practice the cell size will often be set by dimensions and features of the structure to be simulated.

An excitation may be applied to an FDTD simulation by applying a sampled waveform to the field update equation at one or several locations. At each step in time, the value of the waveform over that time period is added into the field value. The surrounding fields will propagate the introduced waveform throughout the FDTD grid appropriately, depending on the characteristics of each cell. A calculation must continue until a state of convergence has been reached. This typically means that all field values have decayed to essentially zero (at least 60dB down from the peak) or a steady-state condition has been reached.

Simulation program was carried out REMCOM XFDTD [8].

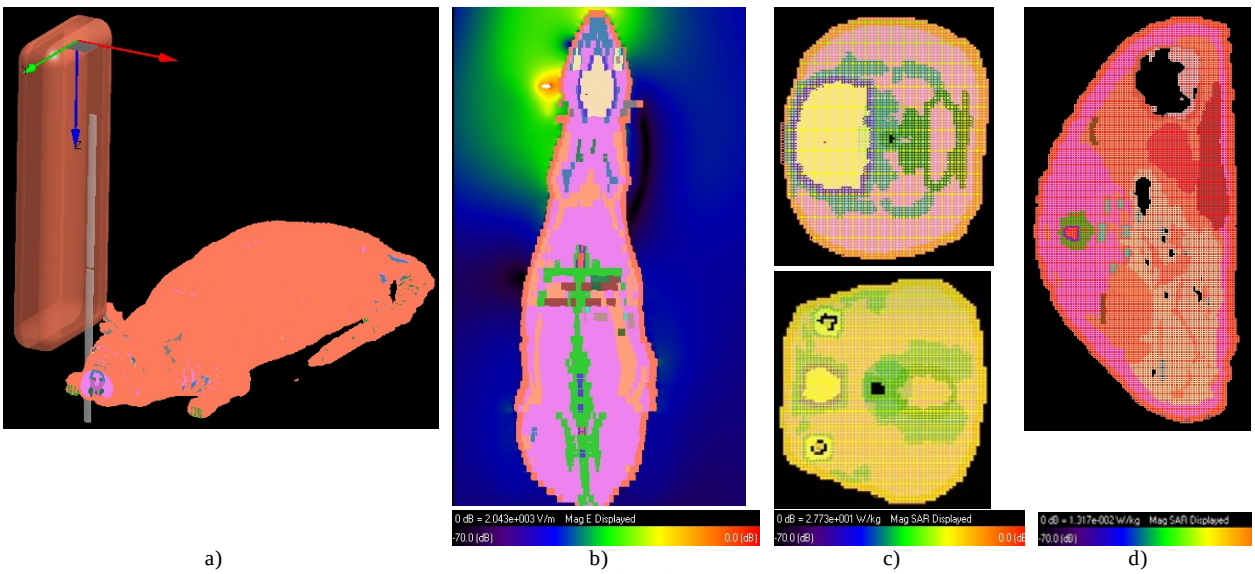
Model of experimental animals

These complimentary animal meshes are provided by The Radio Frequency Branch of the Human Effectiveness Division of the Air Force Research Lab at Brooks Air Force Base [11]. It is significant to know the real position of all tissues in animal body and their electromagnetic characteristics.

Table 1. *EM characteristics for certain biological tissue of experimental animals - rats* [11]

Biol. Material	Conductivity (S/m)	Relative Permittivity	Density (kg/m^3)
Skin	0.693293	39.5868	1125
ligaments	0.951258	46.7184	1220
fat	0.0529249	4.78598	916
blood	1.86817	55.4796	1058
muscle	1.1975	60.7263	1046.9
grey matter	1.0092	51.8029	1038
white matter	2.42613	68.2932	1038
eye sclera	1.68613	67.9	1026
nerve spine	0.606129	33.3591	1038
stomach	1.30105	71.7763	1050
kidneys	1.349	53.898	1150
testicles	1.34108	62.6033	1044
eye lens	0.908172	51.4785	1530
heart	1.722	55.744	1029.8
pancreas	1.66	57.2	1045
body fluid	2.899	67.24	1010
liver	1.33	43.4	1030

RESULTS OF SIMULATION



a) b) c) d)

Figure 4. Calculation of EM field in a rat model:
a) Position of mobile phone and a rat model (Case 1),
b) Electric field in the rat model
c) Distribution of SAR in head of model cross section of brain and eye tissue
d) Distribution of SAR in trunk of model cross section liver

The results for the component fields in free space have been compared with the values measured by Field meter AARONIA HF6080. A source of power used in the simulation programme is 1W. The results matched have been satisfactory.

The results of the calculated field components showed the distribution of components inside the body in two limiting cases when the antenna of the mobile phone is near the rat's head (Case 1) and when it is in the vicinity of the rat's stomach (Case 2). The values of electric and magnetic field and the SAR values for specific organs such as liver, brain and eyes (Tab 2, Tab. 3, Fig. 4 and Fig. 5) have also been calculated. The results thus obtained allow us to obtain the real and adequate data about the biological effects of electromagnetic radiation in experimental animals and their impact on certain organs.

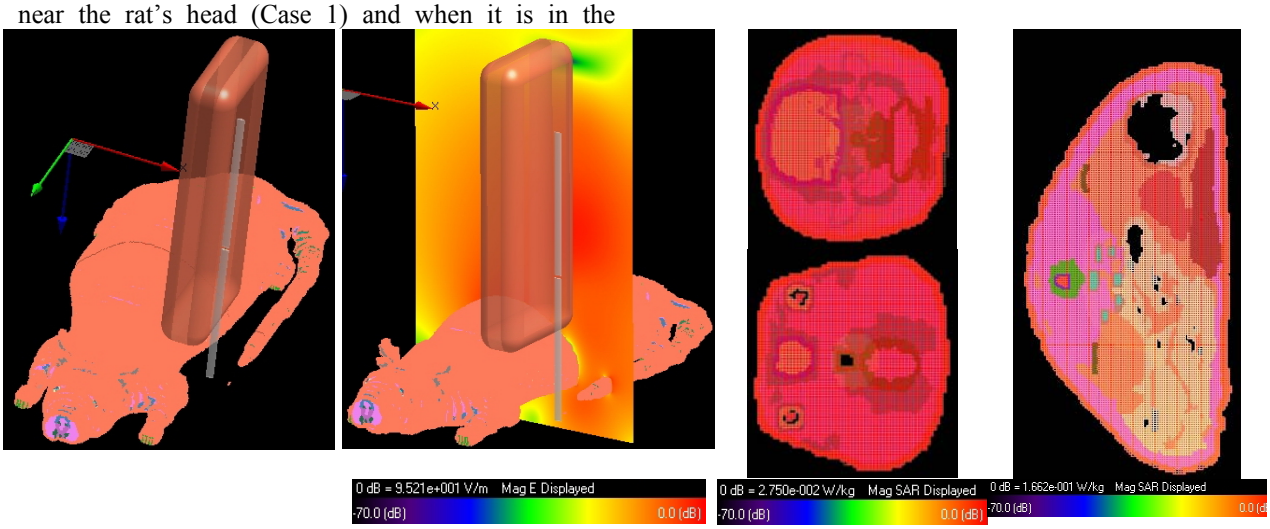


Figure 5. Calculation of EM field in a rat model:
a) Position of a mobile phone and a rat model (Case2),
b) Electric field in the model of a rat
c) Distribution of SAR in head of model cross section of brain and eye tissue,
d) Distribution of SAR in trunk of model cross section liver

Table 2. *Calculation of an electrical field in a certain body part of a rat model*

Organ	Electrical field E(V/m)		
	Position of the antenna		Average
	Next to the head (Case 1)	Next to the trunk of the body (Case 2)	
liver	5.61	10.8	8.205
brain	16.9	7.65	12.275
eye	13.8	4.31	9.05

Table 3. *Calculation SAR in some part of body in model of rat*

Organ	SAR(W/kg)		
	Position of the antenna		Average
	Next to the head (Case 1)	Next to the trunk of the body (Case 2)	
liver	0.0132	0.166	0.089
brain	0.148	0.046	0.097
eye	0.147	0.026	0.0865

CONCLUSION

The results of the field components in a free space show a satisfactory match with the values measured by the meter boxes. The results of electric field distribution in the mice bodies suggest that there is an unequal distribution of the fields, which depends on the position of the sources and characteristics of each tissue. It is important to note that there are tissues which absorb 10 times higher amounts of energy than the tissues adjacent to them. We should try to find the possible biological effects of radiation on these tissues. These effects were presented and discussed in various papers which analyzed biochemical indicators of the effects of electromagnetic fields. Such calculation enables us to develop the biological quantifiers of the effects of electromagnetic fields, which is studied by dosimetry. The quantifiers thus obtained could be applied on the human tissue.

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BIOGRAPHY

Dejan D. Krstić was born in Niš, Serbia, in 1969. He received the degree in Engineering and M.Sc. degrees from the Faculty of Electronic Engineering, University of Niš in 1994 and 1999 respectively. He obtained the Ph.D. degree from the Faculty of Occupational Safety, University of Niš in 2010. He has been engaged as a lecturer at the Faculty of Occupational Safety from 1995. He is the founder of the Laboratory of Electromagnetic Radiation and Center for Technical Systems Safety. Dr Krstić research interests are biological effects of electromagnetic radiation, numerical methods for electromagnetic field calculation and safety technical systems. He published 74 papers in international journals or conference proceedings as author and co-author, and seven textbooks.

MODELOVANJE PRODRLIH ELEKTROMAGNETNIH POLJA MOBILNIH TELEFONA U EKSPERIMENTALNIM ŽIVOTINJAMA

Dejan Krstić, Darko Zigar, Dejan Petković, Nenad Cvetković, Vera Marković, Nataša Đinđić, Boris Đinđić

Rezime: *Da bi se proučavali biološki efekti elektromagnetnih polja neophodno je poznavati vrednosti komponenata elektromagnetnog polja prodrlog u tkiva. Proučavanje biološki efekata se obično vrši na eksperimentalnim životinjama. Neophodno je izvršiti povezivanje uočenih bioloških efekata na eksperimentalnim životinjama sa prodrlim poljima u tkivo. Prodrlo elektromagnetno polje je skoro nemoguće meriti i zbog toga je kroz proces modelovanja potrebno izračunati komponente elektromagnetnog polja u modelu eksperimentalnih životinja. U radu je prikazan postupak modelovanja prodrlih poja i dat je doprinos razumevanju realnih efekata polja i senzitivnosti tkiva na dejstvo elektromagnetnih zračenja generisanog mobilnim telefonom.*

Ključne reči: electromagnetno zračenje, mobilni teelfoni, eksperimentalne životinje - pacovi, elektromagnetno modelovanje.