THE THERMAL DISTRIBUTION AND THE SAR CALCULATION OF RF SIGNAL INSIDE THE HUMAN HEAD

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ABSTRACT

This paper presents a numeric finite element (FEM) analysis of the electromagnetic field penetration and a thermal effect of radiofrequency signal in structures, which represent estimates of human biological tissue. An approximate 2D FEM model of human head was created and an irradiation by microwaves of frequency range used in cell phones (0.9 – 1.8 GHz) was simulated. The thermal distribution in the model was calculated and numerical estimates of the Specific Absorption Rate (SAR) inside the anatomical tissue were compared for different frequencies.

1. INRODUCTION

This paper presents a study of electromagnetic field generated by the cell phone and its distribution in the exposed human body, especially in the head. Localized human exposure to electromagnetic field in microwave frequency range is associated to use of cell phone, detection and positioning systems, same medical device etc. There are many transmitters on micro wave (MW) range and persons are exhibited their effects. Some of the energy in the electromagnetic waves emitted by phone is absorbed in the head of the user, mostly in superficial tissue. The direct effect is the heating of the tissue. His thermal effect is usually quantified by the Specific energy Absorption Rate (SAR) [Wkg^{-1}]:

$$SAR = \frac{\sigma \cdot E_{\max}^2}{2 \cdot \rho}, \tag{1}$$

where E_{max} is the maximum value of the electric field [Vm^{-1}], σ is the electric conductivity [Sm^{-1}] and ρ is the mass density [$kg.m^{-3}$].

Indirect effect on exposed head is so-called non-thermal effect. Scientific data indicate that, during exposure to radiation from a mobile phone, variety of biological effects occur at energy levels that do not cause any local increase in temperature. Differences between experimental electroencephalography EEG, with and without the use of the device, have been observed [3].

Our study is focused on the direct effect of the electromagnetic field. We have developed a 2D model from a 3D model of human head to calculate this problem. We have computed thermal distribution inside the head by the help of COMSOL Multiphysic 3.3. We calculated Specific energy Absorption Rate (1) and compared the results with values in Czech code no. 480/2000, the law of the health´s protection from non-ionizing radiation [6].

The objective of our research is to present and evaluate simplified numerical models for dosimetric studies in the MW domain of the EMF (Electro Magnetic Field). This work is focused on the construction of a 2D model that is adequate to the study of EMF penetration, dosimetric estimates, SAR assessment and computation of the thermal effect in the head of cellular phone user.

2. MODEL CONSTRUCTION

Two basic problems occur during the study of non-ionizing electromagnetic field inside the human head:

a) Specification of source.
b) Model of the human head.

An antenna, usually placed near the surface of the head, is the EMF source. Excited with electromagnetic radiation in the MW domain, biological tissues are materials that behave, at a macroscopic scale, as loss dielectrics. The penetration depth in a conductive semi-infinitive space is defined as [*m*]:

$$\delta = \sqrt{\frac{1}{\pi \cdot \mu \cdot f \cdot \sigma}}, \quad (2)$$

where μ is the magnetic permeability [Hm^{-1}], f is the frequency [Hz] and σ is the electric conductivity [Sm^{-1}]. For biological tissue, $\mu = \mu_0 = 4\pi 10^{-7}$ Hm^{-1} and $\sigma \approx 1$ Sm^{-1} and for GSM system frequency (850MHz – 1850MHz) is result δ = (12-17) mm.

2.1. OUTPUT FROM MOBILE PHONE

Electromagnetic field (EMF) produced by the antenna can be described as having several components. Only one of these actually propagates through space. This component is called the radiated field or the far field. The other components of the electromagnetic field remain near the antenna and do no propagate. The strength of the main components of radiofrequency (rf) signal decreases very rapidly with distance. The entire field (all components) near the antenna is called near field. The electric field strength in this region can be relatively high and pose a hazard to the human head [1].

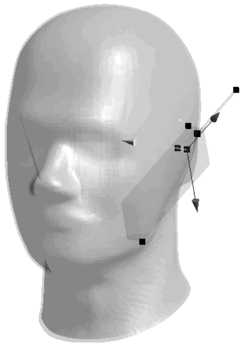
The maximum powers that GSM mobile phones are permitted to transmit are 2W for 900MHz and 1W for 1800MHz. These powers are reduced by the help of adaptive power control and discontinuous transmissions. The adaptive power controls continually adjust the power from phone, so that there is the minimum transmitted power for clear signal. Output power is too dependent on the location of the phone inside the certain cell. The transmitted power usually varies between 0,05W and 1-2W, the maxim levels is maintained very rarely [1].

The antenna is usually constructed of a metal helix or rod, a few centimeters long, and could be considered as a dipole antenna. The dipole configuration is the most common and conventional type for near field of human exposure related to wireless personal communication system in the GSM frequency range (0.5 – 3 GHz). The user is exposed at a distance of 0,5 – 3 cm, in he near field of the antenna. The electric field and magnetic flux density estimated at 2 cm distance of the antenna are about 400 V/m and 1μT for a 2W and 900MHz cell phone, and about 200 V/m and 1μT for a 1W and 1800MHz cell phone. The power density at the same distance is for both phones around the value of 200 W/m^2 [1].

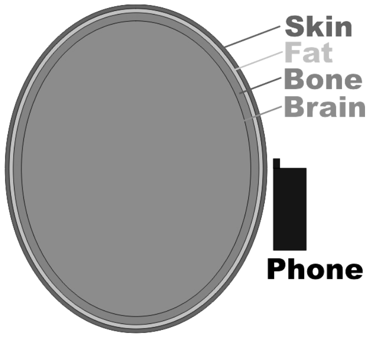
When the exposed head is near the antenna, the electromagnetic field is distributed due to the electric properties of the tissue.

2.2. HUMAN TISSUE MODEL

The need for a reliable computation model in MW dosimetry related to mobile phone technology led us to try several approaches to simulate the human head and the EMF source. It is of common practice to generate simplified 3D models of the human head, in a spherical or elliptical layered structure, as **Fig.1** shows [2].



a) 3D position the mobile phone



b) Simplified a 2D model

Fig. 1 The Model of a human head.

A typical phantom designed for the certification of communication equipment is described in [4]. It consists of a 2mm polyurethane shell ($\sigma_{shell} = 0{,}0012$ Sm^{-1} and $\varepsilon_{shell} = 5$), filled with simulant tissue solution ($\sigma_{simulant} = 0{,}7$ Sm^{-1} and $\varepsilon_{simulant} = 48$ at 835MHz and $\sigma_{simulant} = 1{,}7$ Sm^{-1} and $\varepsilon_{simulant} = 41$ at 1900MHz).

We computed electromagnetic field distribution in a four-layered tissue structure shown in **Fig. 1b** and in a homogenous one. Setting the electrical properties of tissues is quite difficult because of a significant variation of their values among present literature and already presented studies. We used values from the studies of dielectric properties of tissues by Italian National Research Council [5]. There is an on-line database conductivity and relative permittivity of the most of tissue. We used literature **Chyba! Nenalezen zdroj odkazů.** for setting other wanted component.

	Frequency [GHz]	Skin	Fat	Bone	Brain
ε_r [-]	0.9	43.74	5.46	12.45	52.73
	1.8	41.36	5.35	11.78	50.08
σ [Sm^{-1}]	0.9	0.855	0.051	0.143	0.942
	1.8	1.21	0.078	0.275	1.391
k [Wm^{-1}K^{-1}]	0.9	0.528	0.195	0.528	0.5
	1.8	0.528	0.195	0.528	0.5
C_p [JKg^{-1}K^{-1}]	all	3662	2400	1256	3650
μ_r [-]	all	1	1	1	1
ρ [kgm^{-3}]	all	1100	920	1850	1050

Tab. 1 Characteristics of tissue layers

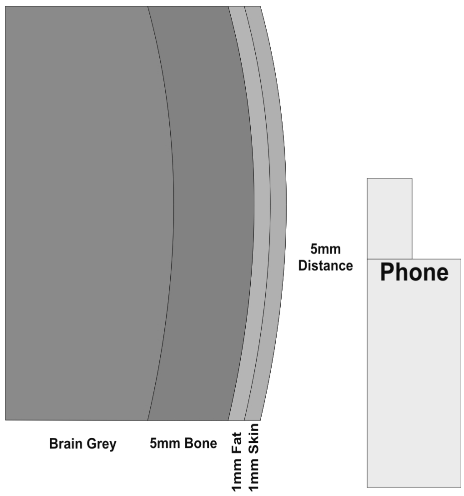


Fig. 2 Simulated model

Where ε_r is the relative permittivity [-]. σ is the electrical conductivity [Sm^{-1}], μ_r is the relative permeability [-], k is the thermal conductivity [Wm^{-1}K^{-1}], ρ is the density [kgm^{-3}] and C_p is the heat capacity [Jkg^{-1}K^{-1}]. The same variables are used in equations (3) and (4).

Our model from **Fig. 2** consists of a 1mm skin shell, a 1mm fat, a 5mm bone and is filled with brain (on average 1489 cm^3, ellipse $a = 0.16m$ and $b = 0.2m$).

2.3. SOFTWARE IMPLEMENTATION

The numerical computation used for the 2D FEM model utilises the RF module of COMSOL Multiphysics 3.3a in the *Electro-Thermal Interaction* application mode and in *Plane Microwave Heating*, *Hybrid-Mode Microwave Heating* and *Transient analysis* submode [8]. The wave equations used for the simulation of wave propagation are:

$$\nabla\times\left(\frac{1}{\mu_r}\nabla\times E_Z\right)-\left(\varepsilon_r-\frac{j\sigma}{\omega\varepsilon_0}\right)k_0^2E_z=0,\qquad \nabla\times\left(\sqrt{\varepsilon_r-\frac{j\sigma}{\omega\varepsilon_0}}\nabla\times H_Z\right)-\mu_r k_0^2 H_z=0 \quad (3)$$

Where μ_r [-] is relative permeability and ε_r [-] is relative permittivity form **Tab.2**.

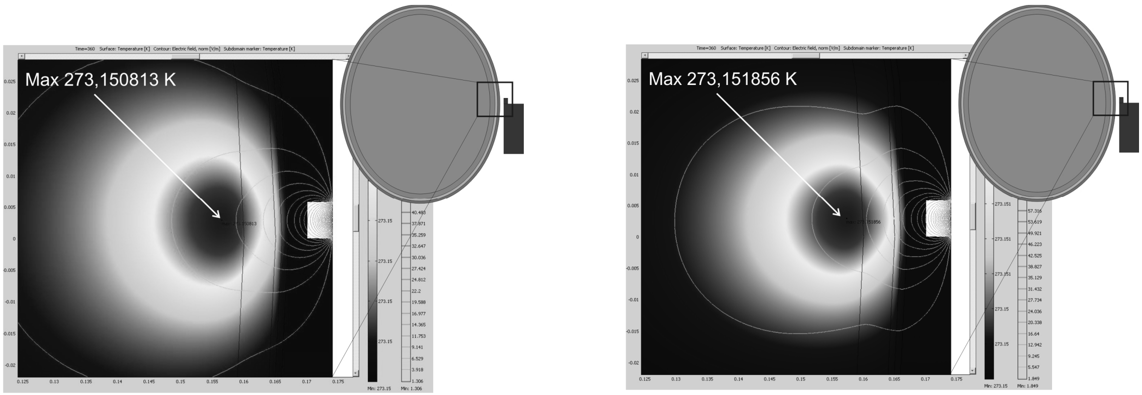
The equation used for calculating the heat distribution is:

$$\delta_{ts}\rho C_p\frac{\partial T}{\partial t}+\nabla(-k\nabla T)=Q \quad (4)$$

Finally energy absorption related to thermal effects in biological tissue is quantified by the Specific Absorption Rate using equation (1).

3. RESULT

We computed thermal distribution caused by rf signal inside the human head model, this is shown in **Fig.3**. On the pictures there are shown only the most interesting area near the phone, where a thermal change can be found. The temperature is constant in other head areas. The maximum temperature is shown in figures, starting temperature was 273,15 K. The pictures show a situation of thermal distribution after 6min. exposition by rf signal.



a) Frequency 900 MHz

b) Frequency 1800 MHz

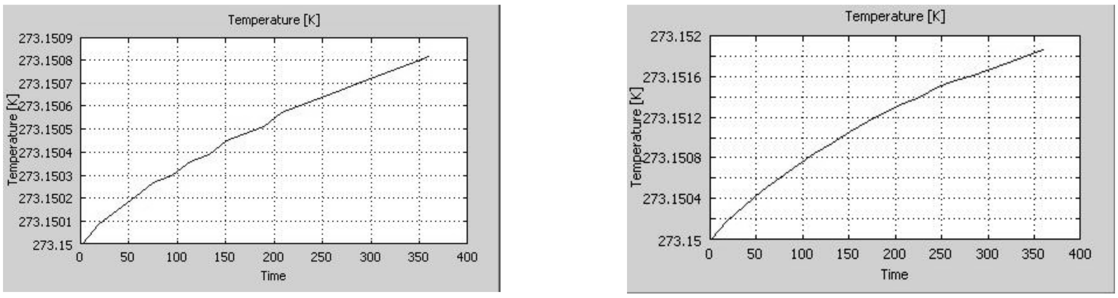
Fig. 3 Thermal distribution inside the head after 6 min exposition.

Because the SAR is defined as exposition on the whole body in the interval of six minutes and the SAR must not be higher than 0.08 Wkg^{-1} for cell phone users [6]. We have to calculate the SAR with the consideration of percentage representation of tissue.

$$SAR_{Head}=0.9527\frac{\sigma_{Brain}\cdot E_{Brain}^2}{2\cdot\rho_{Brain}}+0.0528\frac{\sigma_{Bone}\cdot E_{Bone}^2}{2\cdot\rho_{Bone}}+0.00107\frac{\sigma_{Fat}\cdot E_{Fat}^2}{2\cdot\rho_{Fat}}+0.00108\frac{\sigma_{Skin}\cdot E_{Skin}^2}{2\cdot\rho_{Skin}} \quad (5)$$

At the frequency of 900 MHz, the maximum temperature increase of 0.000813 K was observed and the SAR was calculated as 0.0216 $W.kg^{-1}$. For the frequency of 1800 MHz, the maximum increase in temperature was of 0.001856 K, the SAR was calculated as 0.0516 $W.kg^{-1}$.

The progress of temperature at the point of maximal temperature (as shown in **Fig.3**) during 6 min exposition is shown in **Fig.4**.



a) Frequency 900MHz **b)** Frequency 1800MHz

Fig. 4 The rising of temperature in time, computed in the point of maximum temperature during 6 min exposition.

The direct effect of rf signals was observed, but is very low. In spite of our conditions were extreme, the values of SAR did not exceed a limit defined by Czech law and the rise of temperature is imponderable.

4. CONCLUSION AND DISCUTATION

The model was simplified to four homogenous tissue layers. Thermal losses caused by convection, radiation, perfusion, evaporation and metabolism were not considered. Only the thermal conduction was calculated. Therefore extreme conditions were set up and our results represent the worst case of tissue heating by the phone cell. The direct effect of rf signal is the heating of the exposed tissue, but the temperature rise is negligible in usual conditions. In the future we are going to try to check these results by the help of 3D model of head.

The science researches intimate that the direct effect of rf signal is negligible, next directions of our research are going to be focused on so-called non-thermal effect of rf signal. In our next step we are going to measure and analyse EEG signals during exposition of the head of rf signal.

REFERENCES

[1] Morega M, Machedon A *Specific Conditions for EMF Modeling in Human Exposure from Mobile Phone Technology*, Advanced Topics in Electrical Engineering ATEE 2002, Bucharest, Romania, Nov. 2002, 7 pg., Proc. CD-ROM

[2] Morega M, Machedon A. *EMF Penetration in Biological Tissue when Exposed in the Near Field of a Mobile Phone Antenna*, 4th International Symposium on Advanced Topics in Electrical Engineering, ATEE-2004, Bucharest, Romania, Nov. 2004, Proc. CD-ROM ISBN 973-7728-31-9

[3] Bardasano J.L., Álvarez-ude J., Gutiérrez I., Goya R. *New Device Against Non-Thermal Effects from Mobile Telephones*. The environmentalist, December 2005, Volume 25, pages 257-263, ISSN 0251-1088

[4] CTIA Certification Program, *Test Plan for Mobile Station Over the Air Performance, Cellular Telecommunications & Internet Association Method of Measurement for Radiated RF Power and Receiver Performance*, March 2003 rev. 2.0

[5] IFAC Institute for Applied Physics, *Dielectric Properties of body Tissues in the frequency range 10Hz–100GHz.* [on-line], cite 14. February 2008, URL: <http://niremf.ifac.cnr.it/tissprop/htmlclie/htmlclie.htm>

[6] Czech code no. 480/2000 published on 22.November 2000. Pages 7582-7622.

[7] Stefan Anderson-Engels, *The Bio-Heat Equation* [online] 1999 cite 12. November 2007, URL: <http://kurslab.fysik.lth.se/FED4Medopt/bioheatequation.pdf>.

[8] COMSOL Multiphysics 3.3a - User Manual, Introduction to RF Simulations, 2006.