EVALUATION OF THE ELECTROMAGNETIC FIELD INFLUENCE TO HUMAN TISSUES

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ABSTRACT

The presented paper tries to evaluate the complete influence of non-ionizing electromagnetic field with the frequency used in cell phone to human tissue.

Firstly, the project is focused on the direct effect of electromagnetic field – thermal effect. Finite Element Method (FEM) was programmed in MATLAB and used for calculating Specific Absorption Rate (SAR) and thermal distribution. Thermal distribution on head surface was measured with the cell phone which is able to guarantee the maximum power.

Next part of this project is focused on indirect effect of electromagnetic field – so called "non-thermal effect". EEG signal has been sensed during using the cell phone. Changes or abnormalities in the spectrum of each wave in comparison with EEG signal measured without cell phone have been looked for.

1. INTRODUCTION

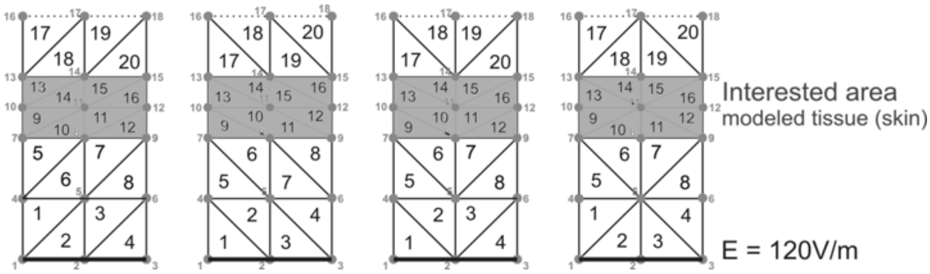
The maximum power of the cell phone at *900 MHz* frequency is *2 W* [1] and the antenna is very near to the human head in several cases. It is true that the power is reduced by the help of adaptive power control and discontinuous transmissions. Real power usually varies between *0,05 W* and *1-2 W*, the maximum levels are maintained very rarely [2], in [7] is used power *250mW*. But if anywhere is very low signal, there is possible to communicate at maximum power level. Therefore this project presents the worst possible case.

2. THERMAL EFFECT OF ELECTROMAGNETIC FIELD

This section is focused on the numeric model of the human head and modelling the thermal effect by finite element method (FEM). The electromagnetic field propagation, attenuation and energy conversation on temperature have been studied. As the next step, thermal distribution on the human head surface around the irradiation ear has been measured and evaluated.

2.1. MODEL PREPARATION

The discretization of the domain is the first and the most important step in any finite element analysis because the manner in which the domain is discretized will affect the computer storage requirements, the computation time, and the accuracy of the numerical result [3]. Only triangular elements have been used in this project.



a) b) c) d)

Figure 1: Used non-uniform two-dimensional finite element mesh.. (a,b) One-directional mesh, (c) Arrow mesh and (d) Diamond mesh

The next step is selection of an interpolation function that provides an approximation of the unknown solution within the element. The linear triangular elements have been used. The unknown function Φ within each element is approximated as:

$$\Phi^e(x,y) = a^e + b^e x + c^e y \tag{1}$$

The Ritz method [3] for formulation equations system has been used. Matrix ***K*** and ***b*** by equation 2 for each element had to be organized.

$$K_{ij}^e = \sum_{e=1}^{e(\max)} \left(\frac{1}{4\Delta^e} \left(\alpha_x^e b_i^e b_j^e + \alpha_y^e c_i^e c_j^e \right) + \frac{\Delta^e}{12} \beta^e \left(1 + \delta_{ij} \right) \right), \quad b_i^e = \sum_{e=1}^{e(\max} \frac{\Delta^e}{3} f^e \tag{2}$$

Where index *e* denotes individual element, constants *a*, *b* and *c* are coupled with size and type of the elements. Parameters α, β and *f* are not constants within each element, but these are known parameters associated with the physical properties of the domain. They are given from the main equation for computing second-order differential equation [3] (3)

$$-\frac{\partial}{\partial x}\left(\alpha_x \frac{\partial \Phi}{\partial x} \right) - \frac{\partial}{\partial y}\left(\alpha_y \frac{\partial \Phi}{\partial y} \right) + \beta \Phi = f \tag{3}$$

The field in lose in-homogeneity space [4] has been considered and parameters have been set as:

$$\alpha_x = \alpha_y = \frac{1}{\mu_r}, \; k^2 = -j\omega\mu(\sigma + j\omega\varepsilon), \; \beta = -k^2\left(\varepsilon_r - \frac{j\sigma}{\omega\varepsilon} \right), \; f = 0, \; \Phi = E_z \tag{4}$$

Setting boundary condition is very important next step. Only the Dirichlet boundary condition has been considered, where the unknown function Φ is known on boundary nodes. This simplest boundary condition has been applied into computing by re-arranging and erasing certain row and column in ***K*** and ***b*** matrix. [3]. Electric field has been set on *120Vm*$^{-1}$, because it is the largest value on the surface of the head for *900MHz* and power *2W* [9]. The result solution can be obtained by solving equation (5).

$$K\Phi = b \tag{5}$$

2.2. TEMPERATURE PROFILE AND SAR CALCULATION

The equation used for calculation the heat distribution [5] is:

$$\rho C_p \frac{\partial T}{\partial t} = \frac{1}{2} \mathrm{Re}\left[(\sigma - j\omega\varepsilon) E \cdot E^* \right] \tag{6}$$

Final energy absorption is related to thermal effects in biological tissue and is quantified by the Specific Absorption Rate (SAR) [Wkg^{-1}] [7] by using equation (7).

$$SAR = \frac{\sigma \cdot E_i^2}{2\rho} = \frac{c \cdot \Delta T}{\Delta t} \qquad (7)$$

Where E_i is calculated the electric field [Vm^{-1}]. Other constants have been set as skin-model [7]: $\sigma = 0{,}85\ Sm^{-1}$ (electric conductivity), $\rho = 1100\ kgm^{-3}$ (mass density), ε_r=43 (permittivity) and $c = 3662\ Jkg^{-1}K^{-1}$(specific heat capacity).

The maximum safety limit for SAR value is defined by Czech code no. 480/2000, the law of the health's protection from non-ionizing radiation. The maximum values are: $0{,}4\ Wkg^{-1}$ for staff and $0{,}08\ Wkg^{-1}$ for other people.

2.3. Results for thermal effect

Two dimensional FEM has been programmed in MATLAB. Four kinds of mesh from figure 1 have been tested. The result distribution of electric field can be seen in figure 2. Consequently the thermal effect and SAR value have been calculated. SAR profile with maximum temperature only inside the skin tissue is shown on figure 3

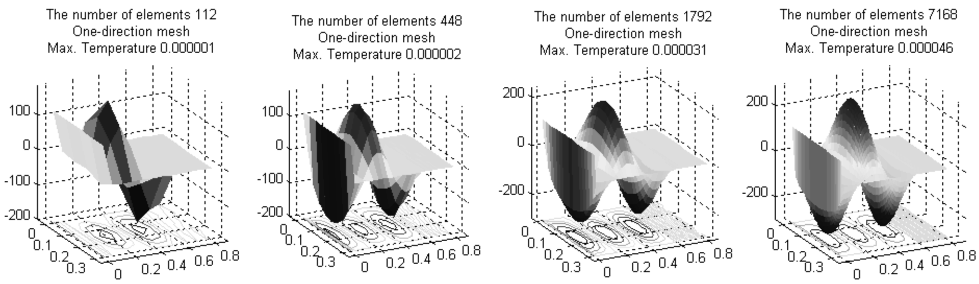


Figure 2: Resulting field distribution for various number of elements.

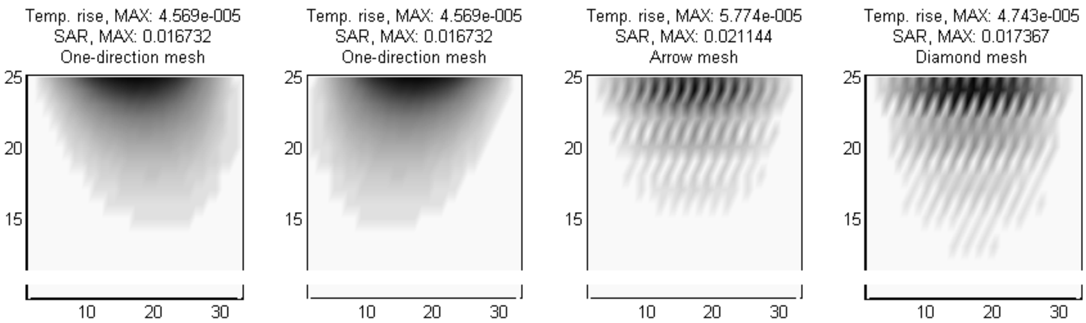


Figure 3: Resulting SAR profile only in interested area for 4 mesh types from figure 1.

From figures is evident, that the best mesh is one-direction mesh. Above each picture from figure 3 has been calculated the maximum grown of temperature and the maximum Specific Absorption Rate inside the interested area. This shows that the limits ($0{,}08\ Wkg^{-1}$ for everyone) have not been exceeded although the worst cases have been studied.

2.4. Practical result of termal change

To ensure the worst case, we had to be sure that used cell phone was transmitting with maximum power level which is *2 W*. Power level is determined by quality of received signal from Base Transceiver Station (BTS). During the call realization, cell phone is sending messages with received signal quality. According this messages BTS sets the power control level for cell phone. The invariant power level in this measurement was reached by editing the Layer 3 messages. The BTS sets the best power control level for cell phone (*2 W*) because it was reporting it had very poor signal [1].

Eight thermal sensors were placed around the right ear as it is shown on figure 4. Data from sensors were sampled every *0.5 s* and stored in PC. Firstly the temperature was sensed for a *40 min* period without using the cell phone and than for a *30 min* period with cell phone near to the right ear. Obtained data are shown in figure 4.

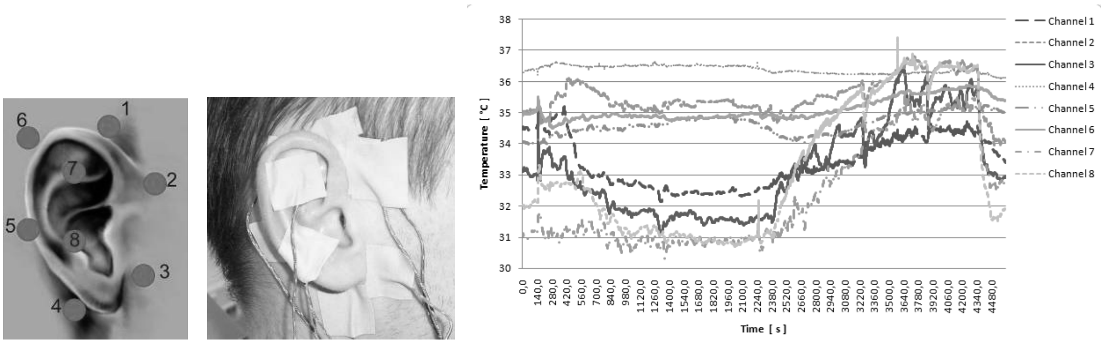


Figure 4: Disposition of thermal electrodes around the right ear and temperature progress during whole measuring period

There is obviously seen the temperature rising during phoning time. The temperature fell back down rapidly after ending call. Significant thermal change is in channels 3, 7 and 8. The thermal increase was obviously caused by heating from the case of mobile device rather than heating from RF signal absorption.

3. NON-THERMAL EFFECT OF ELECTROMAGNETIC FIELD

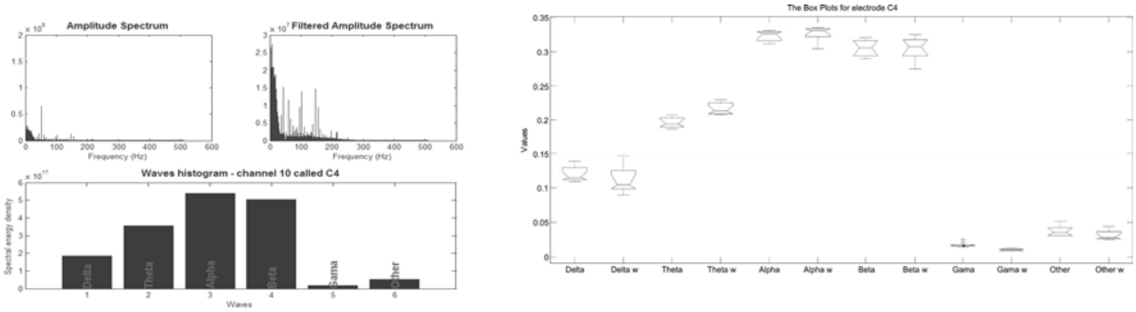
ALIEN measuring system and conventional electrode position system 10-20 [8] have been used for sensing EEG signal during exposing time. Sampling frequency has been chosen on *1024 Hz*. EEG signal has been sensed for *30 min* and always firstly without using cell phone, then with using cell phone and again without cell phone. This procedure ensures more accuracy statistic. Measuring time sufficiently restricts random fluctuations in EEG signal as well.

All measured data have been processed in MATLAB. Firstly the data have been filtered by FIR filters – line frequency has been vanished by *50 Hz* filter, low-pass filter *1 Hz* has removed DC component and high-pass filter *400 Hz* has removed unnecessary high frequencies. Then EEG signal has been dissociated to separate waves. Frequency range of individual wave has been set: *Delta 1-4Hz, Theta 4-7.5 Hz, Alpha 8-13 Hz, Beta 14-26 Hz, Gama 30-45 Hz*. [8]. Other higher frequencies with range from *53 Hz* to *400 Hz* have been analyzed together.

The power spectral density (PSD) (8) has been calculated for every wave.

$$C(w) = \frac{1}{N}\left|S(w)\right|^2 \tag{8}$$

Developed program is able to show histograms with the percentage representation of the power spectral density of separate waves for further analysis (figure 5a). Program flicks through all electrodes and evaluates significant statistical changes in PSD in every wave. The Krukall-Wallis test has been applied for decision whether changes from figure 5b are statistical significant on significant level 5%. Most of the *p-values* obtained from Kruskal-Wallis test indicate to refusal the null hypothesis that all samples are drawn from the same population. It means that changes in PSD in individual EEG waves are statistical significant on significant level 5%.



a) b)

Figure 5: a) EEG signal processing from electrode C4 b) Statistical plot for electrode C4. Index "w" means data measured with using the cell phone.

4. CONCLUSION

The direct effect of radio-frequency signal is the heating of the exposed tissue, but as the model shows, the temperature rise is very low in the worst conditions. Presented simplified model and measured results are in consensus with other scientific research [7][2]. From practical temperature measurement is evident, that the temperature rise is only on the ear. It means on the place, where the phone has been pushed and the local increase has been caused by heating from the case of mobile device.

From the EEG signal processing appears that the electromagnetic field causes significant changes in brain electrical activity (EEG signal). Or more precisely the EEG signal sensed with and without using the cell phone came largely from different population.

Future work will put more emphasis on EEG signal processing. Better and more powerful time-frequency algorithms will be applied to EEG signal processing. More people will be measured for better statistical tests. Other tests will be applied for confirmation or rejection statement presented in this paper.

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