INVESTIGATION OF HIGH – FREQUENCY ELECTROMAGNETIC FIELDS RADIATED BY MOBILE PHONE

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Abstrakt Mobilné telefóny sa stali v priebehu niekoľkých rokov bežnou súčasťou nášho každodenného života a počet ich užívateľov každoročne rastie. Otázka ich bezpečnosti pre ľudské zdravie sa dostala do popredia záujmu laickej a odbornej verejnosti. Príspevok sa zaoberá mobilnými telefónmi ako zdrojmi vysokofrekvenčných elektromagnetických polí. Sú tiež uvedené niektoré metódy vyšetrovania týchto polí.

Summary In the last few years mobile phones have become an usual part of our daily life. The number of their users increases rapidly every year. Frequently asked question among general public and among specialists is safety of mobile phones for human health. Paper deals with mobile phones as sources of high - frequency electromagnetic fields. Some investigation methods of these fields are presented.

1. INTRODUCTION

Electromagnetic fields are all around us. There are two main kinds of electromagnetic fields according to their sources. The first are natural low – frequency electromagnetic fields that come from two main sources i.e. from the sun and from thunderstorm activity. The second are man – made fields at much higher intensities (frequencies, respectively). Nor interaction of these two kinds of fields and their impact on biological objects are fully understood yet. Mobile phones belong to the common sources of high – frequency electromagnetic fields that became in a short time part of our everyday life. That is the reason for what the question of their safety is very frequent and important. In the paper some of investigation methods of EM fields radiated by mobile phones are presented.

2. METHODS OF INVESTIGATION OF EM FIELD

The methods of investigation of electromagnetic field can be divided to experimental and theoretical.
Experimental methods can give us quite good and exact results provided that the measuring equipments are of good quality and accuracy. The accuracy of measurement of EM field quantities of certain source depends apart from other things on eliminating of influence of other sources or eliminating their mutual interference. The measurements can be taken on real objects or on models. Since attention in the paper is focused on problems of EM field radiated by mobile phones, the experimental measurements may be taken directly on human bodies or on models of parts of human body under investigation (i.e. of head, limbs, trunk, etc.). There are various models worked out at universities or research centers. Their development has been initiated by World Health Organization and by government of individual countries. Leading producers of mobile phones continuously pay for their own research, and WHO pays teams of independent experts in the field of medicine, psychology and also physicists and experts in electrical engineering. There has been used various methods. From the testing of hundreds of volunteers, where EM field absorbed by human head during phone call and during sleep was measured as far as the detecting of EEG changes. Also testing of human cells "in vitro" exposed to high – frequency EM fields, is one of methods used very frequently. Direct measurement on human beings has some disadvantages. One of these is problem with placing of testing electrodes on individual parts of human body other is mental or physical discomfort of measured person which can affect the results.
For these reasons, more and more scientists use measurements on models of human body parts. One of most frequently used models of human head is model with simple geometry, i.e. spherical model. The more precise model is based on the fact, that the head is flattened in its temporal part. The sphere or flattened sphere used to be filled with a homogeneous liquid dielectric constant (permittivity) of which equals to the mean value of the human brain tissue. The model of a human head where the change of permittivity in individual tissues (skin, fat, bone, bone marrow, brain) would be included into design is difficult to develop and it would be quite expensive. To obtain correct results it is necessary to compare measured values of EM field quantities to those obtained with the use of simulation. At the present time the simulation of EM field radiation is one of methods used in many cases. The simulation model can be designed both for mobile- phone (as a source of high – frequency electromagnetic field) and human head.
Problems of electromagnetic field radiation can be expressed by generally known Maxwell's curl equations. These equations in linear, isotropic,

nondispersive region of space take the following symetric form:

$$\frac{\partial \bar{H}}{\partial t} = -\frac{1}{\mu}\nabla\times\bar{E} - \frac{\rho}{\mu}\bar{H} \quad , \tag{1}$$

$$\frac{\partial \bar{E}}{\partial t} = \frac{1}{\varepsilon}\nabla\times\bar{H} - \frac{\sigma}{\varepsilon}\bar{E} \quad . \tag{2}$$

Here μ is permeability, ρ is magnetic resistivity, which is generally taken to be zero, σ is conductivity, ε is permittivity. (All of these in general can vary throughout the medium.) Magnetic field intensity $\bar{H}$ and electric field intensity $\bar{E}$ are given in Cartesian coordinate system by their components, that is. $\bar{H} = \bar{H}_x + \bar{H}_y + \bar{H}_z$ and $\bar{E} = \bar{E}_x + \bar{E}_y + \bar{E}_z$. Problem, however is, that these equation can be exactly solved only in cases of shapes with simple geometry. All the others have to be solved only by approximate methods. There are many of them. Numerical methods belong to the most frequently used. One of these methods is the FDTD (the Finite Difference Time Domain method).

3. THE FDTD METHOD

The method has been introduced in sixties of 20-th century. Its author is Kane S. Yee [1], but it has not been widely used up till nineties because lack of powerful computers. At the present time it is one of preferred method for investigation of electromagnetic field. It can be used for to solve numerous scattering problems on microwave circuits, dielectrics and electromagnetic absorption in biological tissue at microwave frequencies. With this method it is also possible to determine the space distribution of EM field nearby mobile phone or to study mutual influence of human head and handset antenna and other parameters of interest. The Maxwell's equations (1), (2) can be written as six scalar equations in Cartesian coordinates [1], where each magnetic field component depends on two electric field components orthogonal to its direction and each electric field component is dependent on two magnetic components orthogonal to its direction. Region of interest, which is three-dimensional, is divided into a grid consisting of elementary cubic cells. The space grid has to be such size, that over one time and size increment, the electromagnetic field does not change significantly. The more cells, that is region under investigation divided to, the more precise are the results. The dimension of cell depends on frequency of incident wave. To have meaningful results, the recommended size of a cell $\delta = \Delta x + \Delta y + \Delta z$ has to be less or equal to 1/10 wavelength. It is generally known, that at the boundary of two media, the equations must satisfy boundary condition for electric field tangential components and for electric induction normal components. In this case it deals with boundary of the air and skin of human head. The incident wave changes its velocity due to changed permittivity of the skin. The change of the velocity v can be calculated from the following expression

$$v = \frac{c}{\sqrt{\mu_r \varepsilon_r}} \quad . \tag{3}$$

Here μ_r is relative permeability of skin, which is usually taken to be zero and ε_r is relative permittivity of skin and its value is equal to 40. By discretisation of the abovementioned six scalar equations we get system of six coupled explicit equations, where Δt is time increment and n is time index [1]. Equations take the form

$$H_x^{n+1/2}(i, j+1/2, k+1/2) = H_x^{n-1/2}(i, j+1/2, k+1/2) + \frac{\Delta t}{\mu\delta}\begin{bmatrix} E_y^n(i, j+1/2, k+1) - E_y^n(i, j+1/2, k) + \\ E_z^n(i, j, k+1/2) - E_z^n(i, j+1, k+1/2) \end{bmatrix} \tag{4}$$

$$H_y^{n+1/2}(i+1/2, j, k+1/2) = H_y^{n-1/2}(i+1/2, j, k+1/2) + \frac{\Delta t}{\mu\delta}\begin{bmatrix} E_z^n(i+1, j, k+1/2) - E_z^n(i, j, k+1/2) + \\ E_x^n(i+1/2, j, k) - E_x^n(i+1/2, j, k+1) \end{bmatrix} \tag{5}$$

$$H_z^{n+1/2}(i+1/2, j+1/2, k) = H_z^{n-1/2}(i+1/2, j+1/2, k) + \frac{\Delta t}{\mu\delta}\begin{bmatrix} E_x^n(i+1/2, j+1, k) - E_x^n(i+1/2, j, k) + \\ E_y^n(i, j+1/2, k) - E_y^n(i+1, j+1/2, k) \end{bmatrix} \tag{6}$$

$$E_x^{n+1}(i+1/2, j, k) = A_{i+1/2,j,k}E_x^n(i+1/2, j, k) + B_{i+1/2,j,k}\begin{bmatrix} H_z^{n+1/2}(i+1/2, j+1/2, k) - \\ H_z^{n+1/2}(i+1/2, j-1/2, k) + \\ +H_y^{n+1/2}(i+1/2, j, k-1/2) - \\ H_y^{n+1/2}(i+1/2, j, k+1/2) \end{bmatrix} \tag{7}$$

$$E_y^{n+1}(i, j+1/2, k) = A_{i,j+1/2,k}E_y^n(i, j+1/2, k) + B_{i,j+1/2,k}\begin{bmatrix} H_x^{n+1/2}(i, j+1/2, k+1/2) - \\ H_x^{n+1/2}(i, j+1/2, k-1/2) + \\ +H_z^{n+1/2}(i-1/2, j+1/2, k) - \\ H_z^{n+1/2}(i+1/2, j+1/2, k) \end{bmatrix} \tag{8}$$

$$E_z^{n+1}(i,j,k+1/2) = A_{i,j,k+1/2} E_z^n(i,j,k+1/2) + B_{i,j,k+1/2} \begin{bmatrix} H_y^{n+1/2}(i+1/2,j,k+1/2) - \\ H_y^{n+1/2}(i-1/2,j,k+1/2) + \\ + H_x^{n+1/2}(i,j-1/2,k+1/2) - \\ H_x^{n+1/2}(i,j+1/2,k+1/2) \end{bmatrix} \qquad (9)$$

Here terms A and B are given by

$$A_{i,j,k} = 1 - \frac{\sigma(i,j,k)}{\varepsilon(i,j,k)} , \qquad (10)$$

$$B_{i,j,k} = \frac{\Delta t}{\varepsilon(i,j,k)} . \qquad (11)$$

Then all components of electric and magnetic field intensity are calculated in each time step. The cell size corresponds with material in which the field is calculated. The greater is the permittivity of material the shorter is the wavelength for a given frequency and the smaller is the cell size. Number of cells is usually up to 1,5 million, otherwise the simulation is demanding relate to computational time and memory of the computer. The graphical representation of elementary Yee's cell is in the Fig.1, where electric field components are on the edges and magnetic field components are in the centres of cell sides.

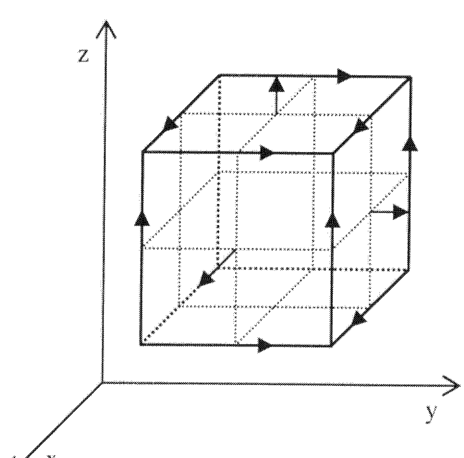

Fig.1.Elementary Yee's cell.

When testing electromagnetic field radiated by mobile phone into human head, to have valid and accurate results, it is necessary to take into account single tissue types, that are skin, bone, fat, muscle, blood, nerve and brain, each with different frequency dependent electrical parameters. It is also useful to compare the values of EM field obtained by computational simulation to those obtained bz measurement on real human head or better on appropriate model of human head. Then to achieve better agreement of single methods it is possible for example to refine the space grid or certain parts in the region under investigation.

4. CONCLUSION

Some methods of investigation of electromagnetic field radiated by mobile phone into a human head are presented in the paper. The FDTD method, as a variant of the Finite Element Method is one of most popular and convenient method of EM field problems solving, because is based on direct solving of Maxwell's equations in the region of interest. Certain disadvantage of this method is that it makes strong demands on computer resources. Some reports state the need of 32 MB memory at least, or 128 MB or more is preferred. When the cells number is 1,5 million, the computational time is about 30 min. The development of an appropriate model still continues and requires much work.

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