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EVALUATION OF INTERACTION OF THE MOBILE TERMINAL ANTENNA ELECTROMAGNETIC FIELD WITH THE USER'S HEAD

The paper evaluates interaction of the electromagnetic field (EMF) of the mobile terminal (MT) antenna with the biological model of human head during telephone conversation by modelling this process in FECO software complex. This has made it possible to determine the value of specific absorption rate (SAR), which is one of the mobile terminal characteristics, in biological tissues of MT user head at various distances between them. This enables verification of SAR value compliance with the requirements of international standards as to the permissible electromagnetic impact of mobile terminals, as well as determining actual radiation power of the antenna of mobile communication means (MCM) at the design stage.

Key words: *electromagnetic field, mobile terminal antenna, radiation power of the antenna, absorption rate in the human body, electric field intensity.*

Introduction

Nowadays, modern mobile terminals belong to the most complex microwave devices, because their small volume resides a large number of chips, which perform a variety of functions under limited power supply conditions. As it is known, the mobile terminal has a certain amount of power, radiated by its antenna, in order to provide the required quality and mobile range. However, in the conditions of widespread use of mobile terminals, one of the important challenges of MCM design and of electromagnetic ecology is evaluation of the antenna EMF impact on the head of MT user during a phone conversation in order to verify the compliance of electromagnetic radiation value with international standards as well as to determine actual radiation power of the antenna.

Problem statement

Transition to the third- and fourth-generation networks significantly complicates MT design process. Experimental studies are becoming more labor-consuming and expensive. Strict requirements to the level of radiation power, absorbed in MT user body (i.e. SAR – specific absorption rate) [1], which characterizes the degree of the "phone – man" influence, require complex and expensive measurements. Such control means should be non-invasive (it is impossible to directly measure the field inside the human body or individual organs) and should not cause distortions (introduction of measuring probes into the near field of mobile phones changes their parameters). Under such conditions the role of mathematical modeling (simulation) of high-frequency electromagnetic fields, created by mobile terminals, and primarily, calculation of the level of radiation power, absorbed by the human body, increases significantly.

There are a number of works, for example, [2, 3, 4], which describe the sequence of steps of a mobile terminal antenna development, calculation of SAR values depending on the antenna position inside the mobile terminal as well as calculation and evaluation of the degree of electromagnetic radiation influence on the user in terms of the biological effect, that is, the organism reaction to the level of electromagnetic radiation (for example, the head heating temperature value), and to the time of its action. The analysis of these works has shown that the problems of determining the values of SAR and power losses of MT antenna EMF depending on the distance between the mobile terminal and the user's head during a phone conversation as well as taking into account changes of MT characteristics in close vicinity to the user's head remained outside their attention. Therefore, the aim of this work is simulation of the process of MT antenna EMF interaction with the human head during a phone conversation in order to determine the values of SAR and power losses of MT antenna EMF at different distances between MT and the user's head.

Energy relations of electromagnetic field near the antenna of mobile terminal

According to the normative document [5], the concept of specific absorption rate (SAR) is defined as a time derivative of EMF energy increment, which is absorbed (scattered) by the mass increment, contained in an infinitely small volume element of a given density, and is described by the expression:

$$SAR = \frac{d}{dt}\left(\frac{dW}{dm}\right), \tag{1}$$

where SAR – specific absorption rate of radiation, W/k; dW – energy increment; $dm = \rho dV$ – mass increment in volume V; dV – infinitely small volume element; ρ – density of human biological tissue.

In other words, SAR is EMF energy conversion into another form of matter (heat), when a body of a given mass approaches the radiation source. As a result, power losses of MT-radiated EMF occur. So, we propose to determine actual power of MT antenna radiation by the expression:

$$P_{\Sigma actual} = P_{\Sigma} - P_{\text{user loss}} , \tag{2}$$

где $P_{\Sigma actual}$ – actual radiation power of MT antenna; P_{Σ} – radiation power of MT antenna; $P_{\Sigma} = \oint\limits_{S} \Pi \cdot dS$; $\vec{\Pi}$ – Poynting's vector, which indicates energy motion direction and the value of which is equal to the density of its flow; S – unit space area, perpendicular to the direction of Poynting's vector propagation; $Pus_{\text{user loss}}$ – power losses in MT user body.

Thus, for finding actual radiation power of MT antenna at MT design stage it is necessary to take into account the absorption rate in the human head during phone conversation.

Modelling of the interaction of MT antenna EMF with the user's head

In this work interaction of the phone electromagnetic radiation with the user's head was investigated using FEKO v 5.5 software [6]. This software is based on the FDTD method (the method of finite difference time domain), which is one of the most popular methods of computational electrodynamics, based on sampling of Maxwell equations written in differential form, and makes it possible to find all the necessary characteristics of the field in near and far zones.

First, MT antenna was simulated and some of its characteristics were calculated, primarily, complex reflection coefficient modulus of MT, directivity diagram (DD) in the absence of the user's head near MT and then at several distances between the head and MT.

Evidently, a large dielectric body, namely, the human head model, which is located in the near field of MT antenna, should effect the antenna characteristics – reflection coefficient modulus (Fig. 1) as well as its directivity diagram (Fig. 2). This is confirmed by numerical computation of MT characteristics in the presence of human head, performed using FECO.

Fig. 1 shows frequency dependencies of the complex reflection coefficient modulus S_{11} (dependence of its antenna matching in free space) at the distances of 0 mm and 5 mm between the MT antenna and the user's head as well as in its absence. This characteristic indicates that at different distances between MT and the user's head working (resonance) frequency is changed.

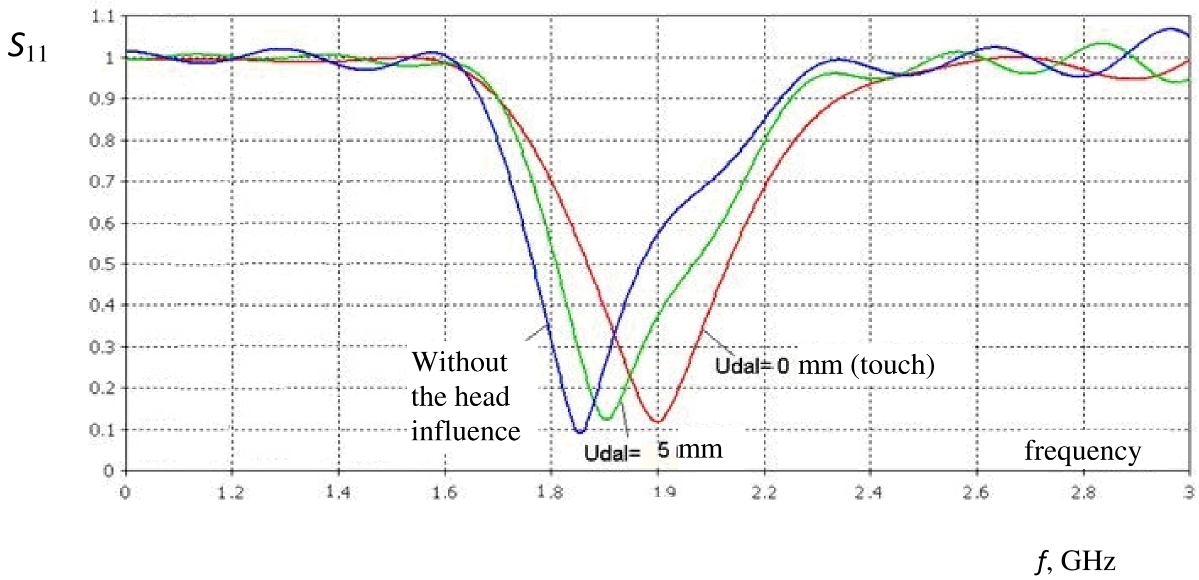

Fig. 1. Calculated antenna frequency characteristics in the absence and in the presence of the user's head phantom

If S_{11} = 1, the entire power is reflected from the antenna and no power is radiated. If S_{11} = 0, it means that power supplied to the antenna is fully radiated without any losses. Permissible limits of this value vary, as a rule, from 0 to 0.3. It is evident from the graph, that in the absence of the head influence, working frequency is at the level of 1.82 GHz and S_{11} = 0.1, while in the presence of the user's head at a distance of 5mm frequency response shifts to the right. The most important thing, however, is that at working frequency of 1.82 GHz the modulus of complex reflection coefficient increased to 0.3, i.e. it increased three times. Therefore, now reflection intensity increased, or the head absorbed larger amount of radiated power.

Fig. 2 shows MT antenna directivity diagrams for the distances from 0 to 10 mm between the antenna and the user's head.

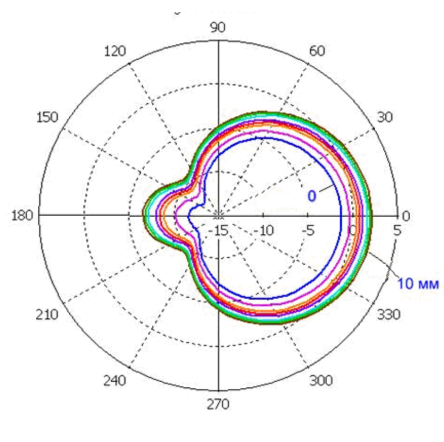

Fig. 2. MT antenna directivity diagram for the distances from 0 to 10 mm from antenna to the human head

In Fig. 2 the human head escapes the antenna field in the direction φ = 180 °. So, radiation field is much smaller in this direction.

Thus, the above data indicate the fact of influence of the human head presence near MT during a phone conversation on the mobile terminal characteristics, which requires taking into account these phenomena at MCM design stage.

During the research SAR calculations were performed for different distances between MT antenna and the human head. Calculation of the field, created by the antenna, was conducted at frequency of 1.8 GHz for PIFA antenna power of 2W, depending on the distance between the head and the antenna (from 0 to 10 mm). The human head model was in the form of a three-sphere ball with a single center. Each sphere had biological parameters of the user's head tissues – namely, the brain, bone, skin.

Under the influence of the mobile terminal user, the efficiency of antenna, determined by FECO software, decreased (within 10 %), there appeared power losses (within 20 % of the entire radiation power), which resulted in the radiation intensity reduction (e. g., directivity diagram), explained by the antenna mismatch with the excitation device. Fig. 3 presents a calculated energy characteristic of the antenna (specifically for SAR) for the distance of 0 mm between the head and the antenna.

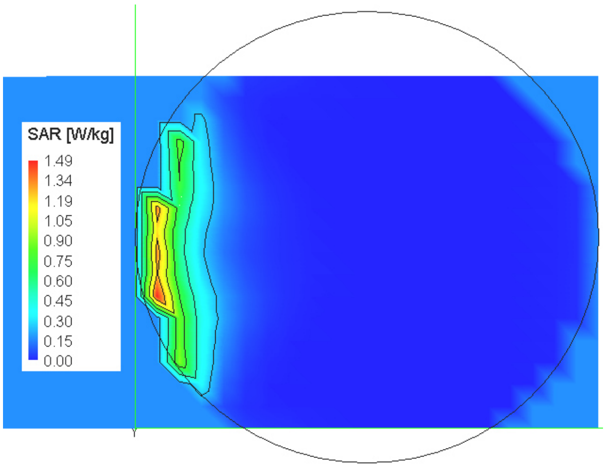

Fig. 3. Visualization of SAR levels in the human head model at a distance of 0 mm from the mobile terminal antenna

In order to determine relationship between the value of SAR and the distance between MT and the user's head we propose to represent the known expression [1] for finding SAR in the following form:

$$SAR(r) = \frac{\sigma \cdot E(r)^2}{\rho}, \quad (3)$$

where σ – specific electric conductivity of human body tissue, Sm/m; $E(r)$ – mean square value of the electric field strength in the tissue, V/m; r – distance between MT and user's head; ρ – density of the body tissue, kg /m^3.

Using expression (3) and the values of E-field vector, obtained with FECO software, we calculated the values of SAR for the distances from 0 to 5 mm between MT the user head during phone conversation. The results of calculation of maximal specific absorption rate in the human head and corresponding values of the power losses of MT antenna EMF are presented in Table 1.

From Table 1 it is evident that the highest SAR value at the frequency of 1.8 GHz, observed at the distance of 0 mm between MT and user's head, is 1.49 W/kg, which corresponds to the established norm [5] of 2 W/kg according to European standards.

Dependence of SAR on the distance between the antenna and the human head has quite predictable character, namely, the SAR value decreases with the reduction of the distance between the antenna and the head.

It should be noted that absorption and distribution of electromagnetic energy in the human organism is an extremely complex phenomenon that depends on the mass, shape and size of the body, the body orientation relative to the field vectors as well as on the electrical properties of the body and the environment. Other variables that may play a significant role in possible biological effects are those, which characterize the environment (the ambient air temperature, air velocity, relative humidity and isolation of the body), as well as those that characterize the individual (e. g., age, gender, activity level, exhaustion or diseases). As numerous factors may interact, in order to determine definite biological results of the influence of electromagnetic fields, any documentation on the organization of protection measures should consider maximal strengthening of biological effects resulting from the interaction of the body field, environmental conditions and physiological parameters.

Table 1

Dependence of the maximal values of SAR and lost power $P_{user\ loss}$ on the distance between the antenna and the human head at frequency close to 1.8 GHz

Distance from the MT antenna and the user's head, *r*, mm	SAR_{max}, W/kg	$P_{user\ loss}$, W
0	1.49	0.399
1	1.45	0.397
2	1.33	0.391
3	1.30	0.384
4	1.29	0.377
5	1.28	0.369

The obtained model of MT antenna interaction with the user's head has the following advantages as compared to real mock-ups and the use of physiological solutions.

Computational model parameters could be almost freely selected from the wide range, e.g. location of electrodes, body location in the reflection system, modifications in designing the devices, etc.

Exposure parameters could vary over wide-range, including radiofrequencies, which is difficult to achieve using a commercial magnetic resonance tomograph.

Geometric and physiological parameters of the computational model are often more accurate as compared to those of a phantom.

The necessary amounts of computations could be rather large, but this is not an obstacle for modern computers.

During the research it was determined that in the general case SAR value depends on the following factors:

– incident field parameters, e.g. frequency, intensity, polarization, "source – object" geometrical configuration (near or far zones);

– characteristics of the body, exposed to radiation, e. g. its size, internal and external geometry, dielectric properties of different tissue components;

- the effects of shielding or reflection from other objects in the field near the exposed body.

Theoretically obtained results of this work were compared with the data of experimental research conducted by RF Exposure Lab, LLC (the USA) [7]. In the framework of this research measurements of SAR value were performed for various MT models: Motorola Droid, iPhone, Blackberry Curve, Samsung SGH-T255G in the frequency range of 18800 MHz of GSM standard for the distance of 4mm from MT to the human head phantom at maximal power. In the investigation of MT of iPhone model the obtained value of SAR was 1.163 W/kg.Comparison of the experimental results with the theoretically obtained SAR value, which is 1.229 W/kg for the same distance, has made it possible to determine the difference of 9 %. This means that the obtained values of power loss for electromagnetic field energy absorption in the user's head can be considered adequate and may be taken into account at the stage of MT antenna design in order to refine transmission power value of the mobile terminal and to provide permissible degree of influence on biological objects.

Conclusions

Taking the above-mentioned into account, the following conclusions can be made:

1. In the work interaction of the electromagnetic field of the mobile terminal antenna and the human head during phone conversation is estimated through determination of SAR, characterizing the degree of such interaction, power loss of MT antenna EMF depending on the distance between the phone and the user's head in the range from 0 to 5 mm.

2. On the results of simulation in FECO software complex and investigation of the MT antenna EMF characteristics it was found that in the presence of the user's head near the mobile terminal during phone conversation EMF power losses occur due to the absorption power that appears in biological tissues of the phone user head, which results in the decreased radiation intensity and the directivity diagram size. This leads to the antenna efficiency reduction within 10 %. Therefore, the author first proposed an expression for calculating the actual radiation power of MT antenna, which took into account power losses of the antenna EMF due to the specific absorption power, which appears in the biological tissues of the phone user head. Comparison of the calculated MT SAR values, obtained during simulation, with experimental data of RF Exposure Lab, indicated a 9 % difference.

3. The obtained results and the developed simulation model of the influence of MT antenna EMF on the user's head may be recommended for use at the stage of designing mobile terminal antennas with pre-defined frequency characteristics. This will provide more accurate calculation of the actual power of MT antenna and at the same time will make it possible to determine whether the degree of electromagnetic radiation influence on the biological objects complies with the established norms.

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