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ESTIMATION OF THE PENETRATED ELECTRIC FIELD INSIDE A HUMAN HEAD DUE TO EXPOSURE TO ELECTROMAGNETIC RADIATION OF A MOBILE PHONE

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Abstract. *The main aim of this study is the estimation of electric field strength induced inside a human head due to exposure to the electromagnetic radiation of a mobile phone. Numerical calculations are performed using a frequency of 2600 MHz, characteristic of 4G mobile communication networks. Realistic 3D models of the mobile phone, the user's head and an actual smart phone have been created. The head is modeled as a highly non-homogeneous structure containing sixteen homogeneous domains of electromagnetic parameters taken from literature. Our results show that the values of the electric field strength are the highest in the layer nearest to the outer surface of the head.*

Key words: *electric field, electromagnetic radiation, human head, mobile phone.*

1. INTRODUCTION

The number of mobile phones and broadband wireless communication devices has grown rapidly over the past few decades, making them an integral part of modern everyday life. This causes a significant increase in exposure of people to radio frequency (RF) radiation. A human population is directly or indirectly exposed to the RF electromagnetic fields of base stations, mobile phones and other wireless communication devices. Nowadays the total number of mobile phones in use in the world is larger than the total number of its inhabitants. In 2019, the global population was approximately 7.54 billion, while the number of mobile devices exceeded 8.93 billion [1]. Currently, 5.1 billion inhabitants are subscribed to mobile telephone services, which is 67% of the

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world's population. Furthermore, 710 million of new users are expected in the next few years [2].

The previously disclosed data justify the increasing concern of the public that exposure to electromagnetic (EM) waves emitted by the mobile phones can lead to adverse health effects. The impact of electromagnetic fields on living organisms has been the focus of numerous studies conducted over the past several decades. Based on this, standards, recommendations and legal solutions that deal with the permissible levels of exposure to RF radiation have been established. Electromagnetic fields in the frequency range from 30kHz to 300GHz mainly appear in telecommunications technologies, including mobile phones, televisions and radio transmissions.

Analyses and results presented in a large number of publications indicate that exposure to even lower values of the electromagnetic field than permitted can cause various biological and health effects. Thus, in 2011, the World Health Organization's International Agency for Research on Cancer classified electromagnetic radiation from mobile phones as a class 2B carcinogen [3] and recommended the continuation of intensive research.

Many studies aimed to determine the impact of RF radiation from mobile phones on the human body. Corresponding results are published in the form of epidemiological studies based on information from multiple sources, including questionnaires filled out by respondents and data obtained from mobile phone operators. The emphasis was on the following data:

- How regularly the study participants use mobile phones (number of calls per week or month);
- User's age and when they first started using a mobile phone;
- Average number of calls during the day, week or month (frequency);
- Average call duration and
- The total number of hours of mobile phone use, determined by the length of a call, the frequency of use, and the duration of the mobile phone use.

Epidemiological studies [4 - 13] investigate the connection between the frequency of mobile phone use and the increased risk of malignant and benign diseases (glioma, acoustic neuroma-tumors of the nerve cells responsible for hearing, meningioma-tumors in the membranes that protect the brain and spinal cord, salivary gland tumors, etc.). Some of these studies have shown an increased risk of tumor formation due to the excessive use of mobile phones, while the results of another group did not indicate a connection between health problems and exposure to RF radiation.

Recent publications present results of glucose metabolism tests in the brains of users after using mobile phones [14, 15]. Some studies conclude that glucose metabolism is higher in the region of the brain near the mobile phone antenna compared to the opposite side. In contrast, another study suggests that glucose metabolism decreases in the brain area closer to the mobile phone. This experimental research raises new questions regarding possible changes in the organism at the cellular level caused by exposure to electromagnetic radiation. Due to the great diversity of the mentioned studies, in terms of methodology and conditions of exposure to radiation, it is very difficult to make a general conclusion about the potential biological effects of electromagnetic radiation from mobile phones.

Since experimental procedures cannot be carried out on humans due to ethical reasons, numerical calculations offer a convenient way to assess the impact of RF radiation from mobile phones. This assessment is based on the calculation of the penetrating electromagnetic field i.e. the amount of absorbed energy within the user's head. A continuous development of numerical methods and the constant improvement in computer performance allow for consideration of high-resolution models including a lot of compartments of possibly anisotropic electromagnetic parameters. Detailed models and their frequency-dependent characteristics are essential for understanding the interaction of electromagnetic radiation with a specific biological structure. Some studies that use simplified head models [16 - 18] cannot be considered accurate because these models do not take into account boundary conditions on interfaces separating different head tissues. Besides that, the type of antenna, the shape and the model of a device, and also the position of a source related to the observed biological structure enormously influence the amount of electromagnetic energy induced into the human head.

The primary goal of this study is an estimation of the penetrated electromagnetic field, absorbed electromagnetic energy, and potential biological effects due to exposure to electromagnetic radiation of mobile phones. We use the 3D realistic human head model containing several compartments of electromagnetic parameters reported in the literature. A Computer Simulation Technology (CST) [19] software package is used to perform numerical calculations of the electric field at the frequency of 2600 MHz, typical for 4G mobile networks.

2. Models and Method

2.1. Model of a human head

The 3D realistic head model of a mobile phone user is created to contain the following biological tissues and organs: skin, fat, muscle, skull, mandible, tongue, teeth, vertebrae, cartilage, thyroid gland, eyes, cerebrospinal fluid, cerebrum, cerebellum, brain stem and pituitary gland. The head model is presented in Fig. 1, while its sagittal and coronal cross-sections are presented in Fig. 2.

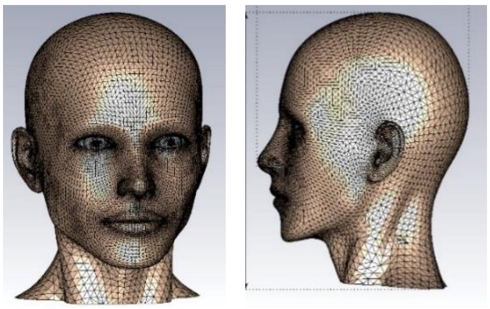


Fig. 1 Front and side view of the head model

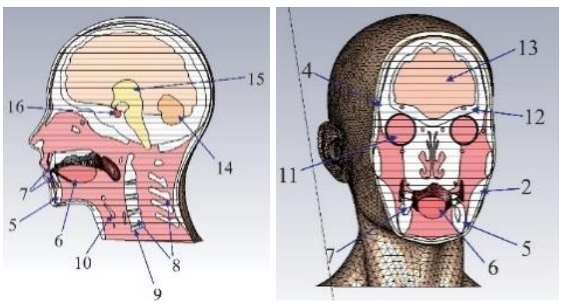


Fig. 2 Sagittal and coronal cross-sections of the head model

Each tissue and biological organ of the head model was created separately using appropriate 3D modeling software. Electromagnetic parameters from the literature were assigned to each organ and tissue inside the model, Fig. 2, and imported into CST. These parameters are: relative dielectric permittivity (ε_r), specific electrical conductivity (σ) and tissue density (ρ). These parameters strongly affect a propagation, reflection and attenuation of electromagnetic waves. For the frequency of 2600 MHz, at which the numerical simulations have been performed, the above mentioned parameters are presented in Table 1 [20]. When connecting the head compartments, it is essential to ensure that the separating surfaces do not overlap. Only in this way, it is possible to satisfy the boundary conditions correctly.

Table 1 Electromagnetic properties of biological tissues and organs at 2600 MHz

	Biological tissue	ε_r	σ[S/m]	ρ[kg/m^3]
1.	Skin	37.8	1.54	1109
2.	Fat	10.8	0.29	911
3.	Muscle	52.5	1.84	1090
4.	Skull	14.8	0.64	1543
5.	Mandible	11.3	0.42	1908
6.	Tongue	52.4	1.92	1090
7.	Teeth	11.3	0.42	2180
8.	Vertebrae	11.3	0.42	1908
9.	Cartilage	38.4	1.87	1100
10.	Thyroid gland	57.0	2.09	1050
11.	Eyes*	47.55	2.08	1060
12.	Cerebrospinal fluid	66.0	3.60	1007
13.	Cerebrum	44.5	2.20	1046
14.	Cerebellum	44.5	2.20	1045
15.	Brain stem	44.5	2.20	1046
16.	Pituitary gland	57.0	2.09	1053

2.2. Model of a mobile phone

An actual smart phone is modeled in CST as a source of EM field (Fig. 3). The model contains the following parts: the planar inverted F antenna (PIFA), a display and mobile housing. The PIFA, as a source of EM radiation, was modeled for the frequency of 2600 MHz, with the output power of P = 1 W [21] and the impedance of Z = 50 Ohm. In general, the construction of the PIFA depends on the producer. One PIFA model considering its performance, construction and radiation pattern at certain frequencies can be found in [22].

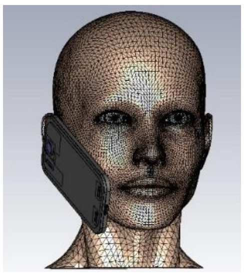


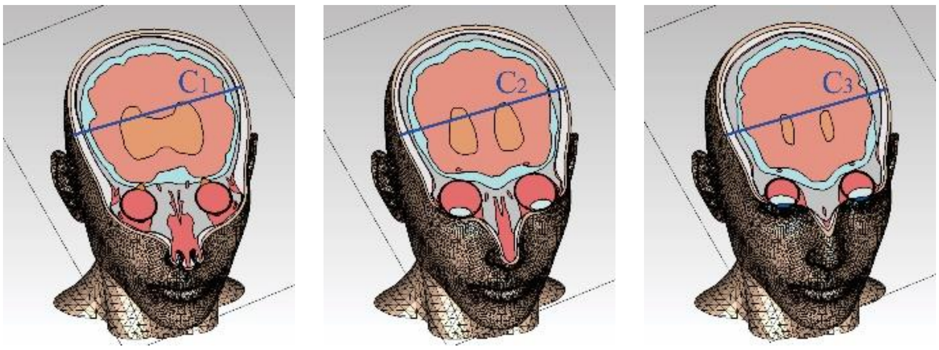
Fig. 3 External view of 3D numerical models of the user's head and a mobile phone in the vicinity of the head

2.3. CST Studio Suite

In order to simulate the propagation of electromagnetic waves of a mobile phone inside biological tissues, the CST Studio Suite software package based on the numerical method known as Finite Integral Technique (FIT) [23] was used. This software for the analysis of 3D electromagnetic problems offers a very good CAD interface for the construction and editing of the models, while the tools for importing and exporting 3D models allow the use of models created with different software for 3D modeling.

2.4. Presentation of results

For a previously described model, electric field distribution inside the human head due to exposure to mobile phone electromagnetic radiation is determined. These values are calculated at different planes (cross-section A, cross-section B and cross-section C) relative to the position of the mobile phone antenna (Fig. 4). Additionally, the values are determined along the lines C1, C2 and C3 perpendicular to the mobile phone and belonging to the cross-sections A, B and C, respectively (Fig. 4).



a) b) c)

Fig. 4 Cross-sections of the user's head model for the presentations of numerical results: a) cross-section A, b) cross-section B and c) cross-section C

3. Results

3.1. Electric field distribution

Distributions of electric field strength inside the human head at the planes A, B and C are presented in Figs. 5-7. Fig. 8 shows electric field strength along the lines C1, C2 and C3 defined in section 2.4.

Figs 5-7 show that the electric field strength is higher in the layers close to the outer boundary of the head (skin, fatty tissue and muscle) at all the observed planes A, B and C.

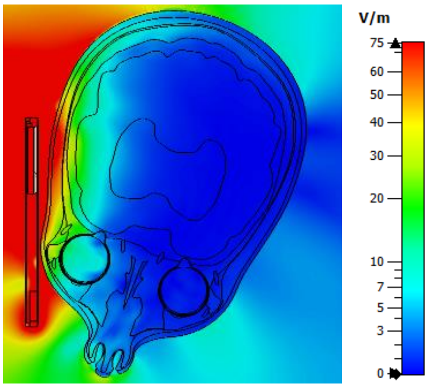


Fig. 5 Electric field distribution within the user's head model – cross-section A

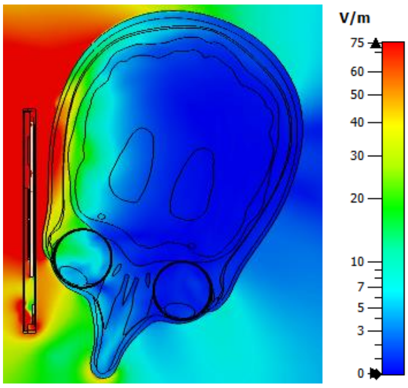


Fig. 6 Electric field distribution within the user's head model – cross-section B

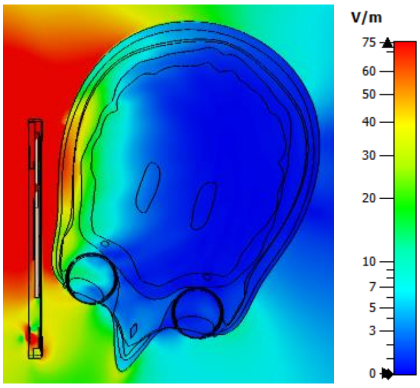


Fig. 7 Electric field distribution within the user's head model – cross-section C

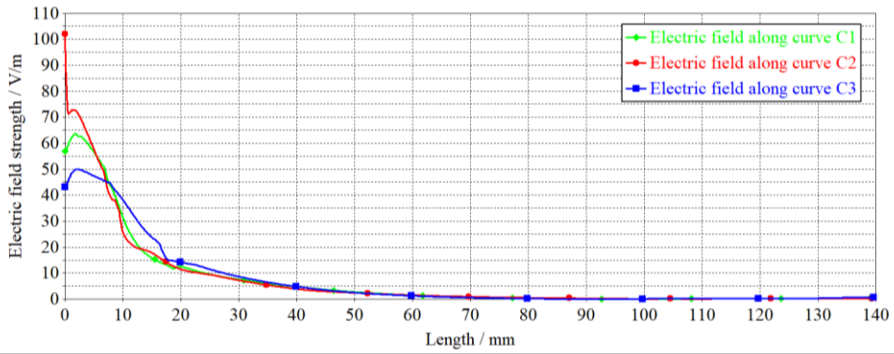


Fig. 8 Electric field strengths along the lines C1, C2 and C3

Maximal induced electric field strengths along line C1 (Fig. 8) in the skin, fat and muscle are 64.93 V/m, 63.40 V/m and 59.30 V/m, respectively. Skull, cerebrospinal fluid and brain experience much lower field strengths equal to 42.20 V/m, 29.15 V/m and 12.32 V/m, respectively. Electric field strengths at line C2 are the largest compared to other lines (and planes) and they are equal to 101.94 V/m, 72.40 V/m and 60.30 V/m in the skin, fat and muscle, respectively. Similar to the line C1, lower electric field are induced inside the inner positioned head compartments, i.e. the strengths of 41.20 V/m inside the skull, 26.15 V/m inside the cerebrospinal fluid and 12.55 V/m inside the brain. The electric field strengths at the line C3 are also much higher in the outer tissues (48.16 V/m in the skin, 48.84 V/m in the fat and 47.23 V/m in the muscle), compared to the more centrally positioned compartments: 43.20 V/m inside the skull, 36.15 V/m inside the cerebrospinal fluid and 14.42 V/m inside the brain tissue.

4. Discussion and Conclusion

This study deals with the electric field distribution within biological tissues inside the human head exposed to the electromagnetic radiation produced by a mobile phone. Numerical calculations are performed for a real head model, consisting of sixteen tissues of electromagnetic parameters taken from the literature. A commercial software package CST Studio Suite is used for numerical calculations at the frequency of 2.6 GHz.

In our simulations, we had three observation planes, one below, one above and one equal to the vertical position of a mobile phone. Additionally, we have observed the induced fields along three lines belonging to the above mentioned planes and perpendicular to the area of a phone. Our results show that the induced electric field strength is higher in the layers close to the outer boundary of the head (skin, fatty tissue and muscle) compared to the inner, more centrally positioned compartments. The largest electric field is within a plane at the same vertical position as the source of radiation, equal to 101.94 V/m, 72.40 V/m and 60.30 V/m in the skin, fat and muscle, respectively. The skin right next to the phone experiences the largest electric field of all calculated values in the model. The observation plane positioned at the highest height experiences the smallest fields in every tissue compared to the other two planes.

Many studies have examined the impact of mobile phone use on human health. In [24], a significant risk of brain cancer has been pointed out in children and adolescents of an average

age of 13 years. Similarly, in [25], Hardell and Carlberg have shown a significant risk of brain cancer in young people due to the use of mobile phones. This leads to the conclusion that excessive exposure to the electromagnetic field of a mobile phone can affect human health. Therefore, our future work will be based on the estimation of the penetrated electric field inside a human head at the frequency of 5G, the newest generation of mobile networks.

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RASPODELA PRODRLOG ELEKTRIČNOG POLJA UNUTAR GLAVE ČOVEKA IZLOŽENOG ELEKTROMAGNETNOM ZRAČENJU MOBILNOG TELEFONA

Glavni cilj ove studije je određivanje jačine električnog polja indukovanog unutar ljudske glave usled izlaganja elektromagnetnom zračenju mobilnog telefona. U numeričkim proračunima se koristi frekvencija 4G mobilne komunikacione mreže, odnosno 2600 MHz. Kreirani su realistični 3D modeli mobilnog telefona, glave korisnika i stvarnog pametnog telefona. Glava je modelovana kao visoko nehomogena struktura koja sadrži šesnaest homogenih domena elektromagnetnih parametara preuzetih iz literature. Naši rezultati pokazuju da su vrednosti jačine električnog polja najveće u sloju najbližem spoljašnjoj površini glave.

Ključne reči: *električno polje, elektromagnetno zračenje, ljudska glava, mobilni telefon.*