Investigating the effects of glasses on electric field distribution from a mobile phone inside the human eye during web surfing

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This paper discusses the effects of the glasses exposed to electromagnetic radiation from mobile phones on the electric field distribution inside the human eye. The numerical analysis has been performed for the case when the mobile phone is used for web surfing at the frequency of 2.6 GHz. Obtained results are presented within different biological tissues from which the human eye model was made. Since the human body consists of various tissues and organs, each needs to be described in terms of its corresponding electromagnetic properties. A realistic 3D model of the human head has been created to obtain the most accurate results. The main aim of this investigation is to determine the electric field distribution in the human eye. For this research, besides the realistic model of a human head, it was necessary to develop a realistic eye model formed of nine different tissues and a model of glasses with a metal frame. A comparative analysis of the model behavior with and without glasses has been carried out to evaluate the effects of the glasses with metal frame. Finally, the paper presents the results of electric field distribution for a horizontal cross-section of the human head model.

Keywords – electric field distribution, electromagnetic radiation, metal frame glasse, mobile phone.

Introduction

During the last few years, the development of mobile devices and communication systems has led to serious concerns about potential health risks. The development of mobile phones, as well as their advantages, has resulted in the popularity of these devices, which are usually used for communication and web surfing in the modern world. As well known, the mobile phone is a source of electromagnet-ic radiation and is located near the human head when used.

During web surfing, the most exposed organ to electro-magnetic radiation is the human eye. In addition, the presence of glasses with metal frames affects the electric field distribution since the metal frame is a very good conductor.

According to previous studies, the safety measures that prescribe the maximum allowable levels for exposure to electromagnetic fields are adopted in safety standards [1], [2], [3], [4]. Also, the electromagnetic field has been characterized as potentially carcinogenic to humans and classified as a group 2B carcinogen [5].

Preliminary studies of the interaction between the hu-man body and the electromagnetic fields of mobile phones are based on very simple models, consisting of only one or more layers, designed to represent the properties of human head tissue. Due to their simplicity, these models cannot consider the boundary conditions at the separate surface between different biological structures [6], [7], [8], [9]. Many studies have mentioned the effect of mobile phone electromagnetic radiation on more complex 3D models of human heads. These realistic models represent the real state of the human head, however, many of these studies do not focus on the effects of glasses on electric field distribution from a mobile phone inside the human eye [10], [11], [13], [14]. Also, some studies on the influence of mobile phone electromagnetic radiation have found that metal objects close to the human head, have a significant impact on the electric field distribution, which can be considered as a potential health hazard to the human body [15], [16]. In these investigations it was found that the SAR values could be many times higher in the presence of metallic objects.

Several studies have involved estimating the impact of wireless eyewear devices on the SAR of a human head during the phone calls. In [17], the authors found that the maximum SAR value of eye tissue was even six times higher when wearing glasses than without them. In [18], the authors pointed out that the simulated SAR values are slightly higher than the allowable value inside the user's eyes.

Another study simulates the impact of mobile phone RF electromagnetic radiation in the presence of metal-frame spectacles. Simulations are done using the basic head model, represented as a three-layer sphere with two small balls representing eyes [19].

People who have visual issues frequently use glasses. Glasses frames can now be manufactured of a variety of materials. However, metal frames are excellent conductors, and they drastically changes the electric field distribution from mobile phone during the web surfing. This study examines the effects of glasses on electric field distribution from a mobile phone inside the human eye during the web surfing. Accordingly, this study is focused on the electric field distribution within the biological tissues of the human eyes that are in the vicinity of glasses frame. The shape of the anatomical human eye model and its features has an important role for the absorption of electromagnetic energy, as well as the operating frequency and the distance between the electro-magnetic source and the exposed object. The numerical calculation of the electric field has been performed at the frequency of 2.6 GHz.

Numerical method and modeling

Model

For the purposes of the current study, it was necessary to create adequate 3D realistic numerical models. It was necessary to create the mobile phone user's head model, model of glasses frame as well as model of actual smart phone. For the quality of the analysis, it is crucial that these models are created so that their characteristics correspond to the morphology, dimensions and biochemical and electromagnetic characteristics of tissues and materials, as much as possible.

Each part of the 3D models was created separately with an adequate software package for 3D modeling, while the CST software package [20], based on the numerical method known as the Finite Integral Technique (FIT), was used to analyze the spatial distribution of the electromagnetic field and SAR from mobile phone within the user's head model. Such approach implies the application of adequate analytical and numerical methods that include appropriate time and spatial discretization of the integral form of Maxwell's equations.

Human head model was developed so that the anatomical and morphological characteristics correspond to an average adult person (Fig. 1) [21], [22], [23]. After designing, the complete model was used for simulation the electromagnetic waves propagation. It is very important that the layers have to be ideally superimposed in order to properly consider the boundary conditions at the separation area between two tissues, during the propagation of EM waves from one tissue into another.

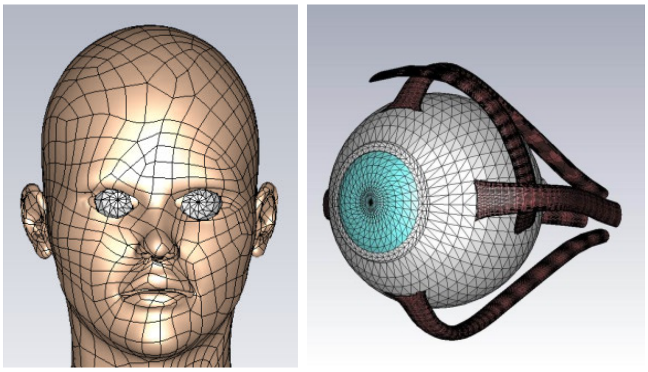


Fig. 1. External appearance of the human head model and human eye model.

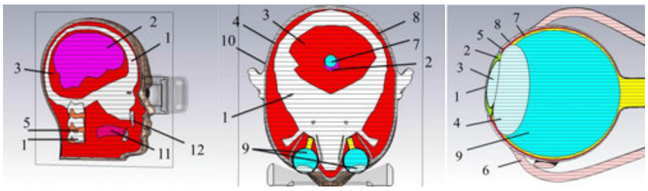


Fig. 2. Construction of the human head and human eye model.

The cross-section of the human head model and model of the human eye with biological tissues and organs (Table 1 and Table 2) is shown in Fig. 2. Numerical designations for tissues and organs from Fig. 2 correspond to numerical designations of tissues and organs given in Table 1 and Table 2.

During the modeling, the electromagnetic parameters of the biological tissues mentioned above are taken into consideration. For each biological organ and tissue contained in the human head model, the appropriate electromagnetic characteristics should be defined. Detailed knowledge of the electromagnetic characteristics of biological tissues and organs (permittivity, conductivity, permeability as well as density) is essential for the understanding of the interaction between electromagnetic radiation and the certain biological organ or tissue. This is due to the effects of propagation, reflection, and attenuation of electromagnetic wave within, in this case human eye, depend on these electromagnetic characteristics. Electromagnetic properties depend on frequencies and their values are shown in Table I and Table II [24].

In order to obtain the most accurate results of electric field inside the human eye, the 3D model of glasses had to be created (Fig. 3b). For the material of glasses frame, the aluminum with the electrical conductivity $\sigma=3.56\text{x}10^7$ S/m has been used. As electromagnetic field source, a mobile phone, which features correspond to an actual smartphone model, has been modeled (Fig. 3a). The mobile phone is designed to contain the following parts: planar inverted F antenna (PIFA), the display, and the mobile housing. The planar inverted F antenna (PIFA), as a source of electromagnetic radiation, was modeled for the frequency of f=2600 MHz, with the output power of P=1 W [25] and impedance of Z=50 Ω.

Table 1

Electromagnetic properties of tissues of the human head model at 2.6 GHz.

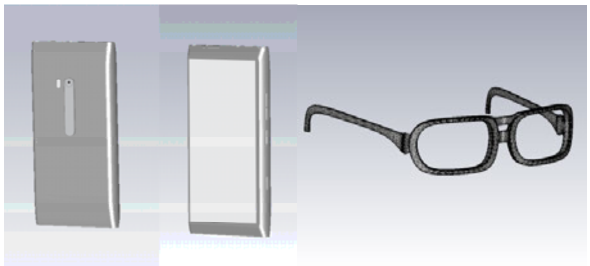
Biological tissue			4G 2.6 GHz	ρ [kgm^{-3}]
1.	Cortical Bones	ε_r	11.3	1908
		σ[Sm^{-1}]	0.424	
2.	Brain	ε_r	44.5	1046
		σ[Sm^{-1}]	2.2	
3.	Cerebrospinal Fluid	ε_r	66	1007
		σ[Sm^{-1}]	3.6	
4.	Fat	ε_r	10.8	911
		σ[Sm^{-1}]	0.288	
5.	Cartilage	ε_r	38.4	1100
		σ[Sm^{-1}]	1.87	
6.	Pituitary Gland	ε_r	57	1053
		σ[Sm^{-1}]	2.09	
7.	Spinal Cord	ε_r	30	1075
		σ[Sm^{-1}]	1.15	
8.	Muscle	ε_r	52.5	1090
		σ[Sm^{-1}]	1.84	
9.	Eyes	ε_r	Table 2	Table 2
		σ[Sm^{-1}]	Table 2	
10.	Skin	ε_r	37.8	1109
		σ[Sm^{-1}]	1.54	
11.	Tongue	ε_r	52.4	1090
		σ[Sm^{-1}]	1.92	
12.	Teeth	ε_r	11.3	2180
		σ[Sm^{-1}]	0.424	

Before any numerical calculation, the key step is to create the mesh of elements. A finer mesh means a greater number of elements, which makes the results more accurate. On the other hand, a finer mesh requires more power-full hardware and computational time (that can last for days for some applications). Therefore, it is essential to find the proper balance between result accuracy and time.

Table 2

Electromagnetic properties of tissues of the human eye model at 2.6 GHz.

Biological tissue			4G 2.6 GHz	ρ [kg m^{-3}]
1.	Cornea	ε_r	51.4	1051
		σ[Sm^{-1}]	2.41	
2.	Iris	ε_r	64.3	1040
		σ[Sm^{-1}]	2.25	
3.	Aqueous Humor	ε_r	69.43	1010
		σ[Sm^{-1}]	2.83	
4.	Lens	ε_r	33.8	1076
		σ[Sm^{-1}]	1.16	
5.	Choroid	ε_r	56.5	1060
		σ[Sm^{-1}]	2.78	
6.	Muscle	ε_r	52.5	1090
		σ[Sm^{-1}]	1.84	
7.	Retina	ε_r	59.25	1039
		σ[Sm^{-1}]	2.17	
8.	Sclera	ε_r	52.4	1032
		σ[Sm^{-1}]	2.15	
9.	Vitreous Humor	ε_r	68.1	1005
		σ[Sm^{-1}]	2.6	



a) *b*)

Fig. 3 - External look of smart phone and glasses.

Results

In this section the electric field distribution will be shown within the tissues of eye model. Fig. 4 shows the position of curves that are used for the calculation values of electric field inside the model of human eye.

Both curves are located in planes normal to the plane of the mobile phone antenna. Curve C1 is located inside the right eye of the human head model, while the curve C2 is positioned inside the left eye.

Comparative analysis of the electric field distribution within the models with and without glasses, at the mentioned frequency, is presented in this section. The electric field strength in the horizontal cross-sections, at the same levels as the curves mentioned above, for the model with (right side) and without glasses (left side), is shown in Fig. 5.

Models with and without glasses are represented at the same figure in order to make results comparable. Further, on the right side of figures, the maximum value of the electric field in the color palette is set to be the same for both models, also to achieve easier comparison of the electric field distribution.

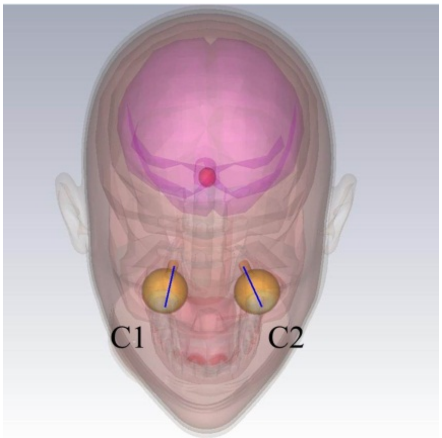


Fig. 4. Human head model with curves for evaluating electric field and SAR.

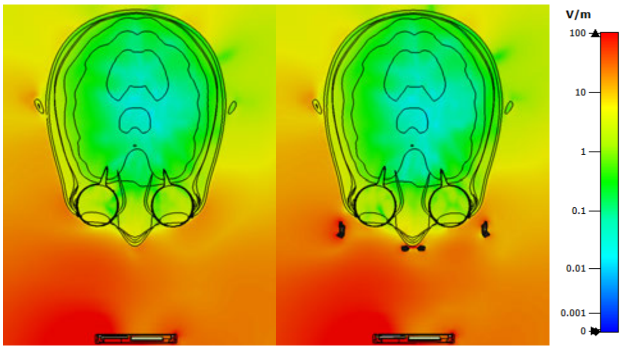
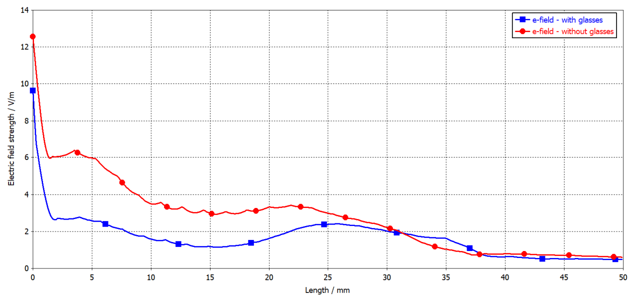
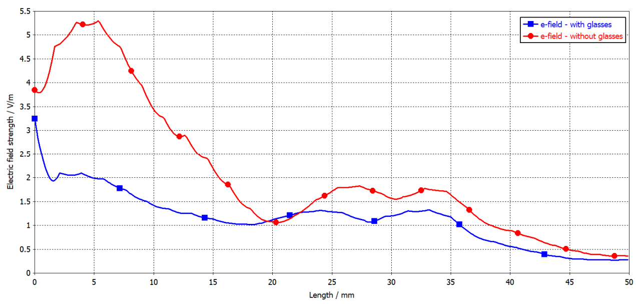


Fig. 5. Electric field distribution within human head model.



a)



b)

Fig. 6. Electric field strength along the curve a) C1 and b) C2.

Fig, 6 and Fig. 7 show the dependence of the electric field along the curve C1 (right eye) and C2 (left eye) as the distance from the radiation source increases, for both models (with and without glasses). It can be noted that the maximum values of electric field strength is not the same inside the left and right eye. This is expected because of the mobile phone antenna pattern**.**

According to previous figures, it is evident that the maximum value of the electric field for both models, occurs in the surface layers of the eye model. While spatial distribution of the electric field shown in Fig, 5, is similar for both cases – with and without glasses, graphs of the electric field strength in Fig, 6 show that the electric field is lower for the model with glasses.

It can be seen from Fig, 6a (curve C1) that the maxi-mum value of the electric field, in the case of model with-out glasses, is 12.56 V/m, while this value for the model with glasses is lower and amounts 9.64 V/m. It is evident that the highest influence of glasses on electric field strength is inside the surface layers of the eye model, since this biological tissue is the nearest to the metal frame.

According to the results represented in the Fig. 6b for the right eye (curve C2), the maximum value of the electric field in the case of model without glasses is 5.29 V/m, while this value for the model with glasses is lower and amounts 3.22 V/m.

The decreasing of values for other tissues of eyes is negligible because they are farther away from the metal frame and their influence is very low.

Conclusion

This study examined the electric field distribution within biological tissues of human eye in the vicinity of metal frame glasses, during the web surfing over mobile phone. The numerical calculation was performed for the frequencies of 4G mobile network and comparative analysis of the models with and without glasses is presented.

According to the obtained results for the electric field strength inside the biological tissues of eye in the vicinity of the metal frame glasses, it can be concluded that the maxi-mum values of the electric field is lower when the glasses is present. The highest influence of glasses on electric field strength can be observed inside the tissues that are nearest to the metal frame.

The maximum value of the electric field in the absence of glasses is almost 1.3 (right eye), that is 1.64 (left eye) times higher than the electric field obtained for the model without glasses. It should be noted that the values of electric field are higher inside the right eye compared to the values obtained for the left eye. As mentioned above, this is expected because of the mobile phone antenna pattern.

Finally, it can be concluded that the presence of glasses with the metal frame decrease the electric field in the biological tissues of the human eye. In generally, based on the results obtained for the electric field strength from mobile phone along the curves, it is evident that the influence of the glasses is the highest for the tissues that are nearest to the frame of glasses. Since aluminum frame is a good conductor, in its presence large amount of electric field is directed away. Therefore, when we wear glasses while surf-ing the Internet on a cell phone, the metal frame of the glasses acts as a kind of shield.

Acknowledgements

The research described in the paper was partially supported by the Ministry of Science, Technological Development and Innovation of Republic of Serbia.

This paper is presented in the 16th International Conference on Applied Electromagnetics – ПЕС 2023, Niš, Serbia.

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Received on: 26.10.2023