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EFFECTS OF USING METAL FRAME GLASSES EXPOSED TO ELECTROMAGNETIC RADIATION FROM MOBILE PHONE

Abstract: *The aim of this study is to estimate the effects of metal frame glasses on the electric field distribution and Specific Absorption Rate (SAR) inside the model of a human head. The numerical solution of the equations of electromagnetic wave propagation has been used to obtain the electric field distribution and values of SAR in the vicinity of the metal frame glasses, exposed to cell phone radiation at the frequency of the 3G mobile network. The assessment of these effects has been performed during the conversation over a mobile phone. In order to obtain the most accurate results, the realistic 3D model of the human head, as well as the model of metal frame glasses have been created. For evaluating the mentioned effects, a comparative analysis of models with and without glasses has been carried out. Therefore, the obtained results are presented within different biological tissues and organs from which the human head model was made.*

Key words: electric field distribution, specific absorption rate, mobile phone, metal frame glasses.

INTRODUCTION

In the last few years, the modern world has significantly increased the use of mobile devices especially due to the development of their advantages. However, since the mobile phone is a source of electromagnetic radiation located near the human head, this development has led to serious concerns about the potential health risks caused by prolonged exposure to electromagnetic radiation. Hence, the major expansion of these devices turned the focus toward the research of the impact of electromagnetic waves on the human body and the estimation of health risks. During the conversation over the mobile phone, the most exposed organ to electromagnetic radiation is the ear, while in the case of texting and surfing the Internet, it is the eye. Besides, the attention should be paid to the presence of metal frame glasses, which affects the electric field distribution and amount of absorbed energy, since the metal frame is a very good conductor.

Based on previous studies, the safety measures that prescribe the maximum allowable levels for exposure to electromagnetic fields are adopted in safety standards [1-4]. Also, the electromagnetic field has been characterized as potentially carcinogenic to humans and classified as a group 2B carcinogen [5]. Initial studies, that refer to the interaction between the human body and EMF from the mobile phone, were based on very simple models that contained only one or several layers that were supposed to represent the human head tissue characteristics. Results obtained using this kind of model are questionable because they do not fully reflect the real state of certain tissues. Because of their simplicity, these models could not consider the boundary conditions at the transitions between different biological tissues and organs [6-9]. Numerous studies refer to the impact of electromagnetic radiation from mobile phones within a more complex, 3D model of a human head. These realistic models represent the actual state of the human head but many of these studies are not focused on the impact of electromagnetic radiation in the presence of metal objects [10-14].

Some studies on the effects of electromagnetic radiation from mobile phones have found that the objects in the vicinity of the human head have caused a significant influence on the electric field distribution and could be considered as a potential health hazard to human body [15, 16]. In these studies, it can be found that the SAR values can be several times larger in the presence of metallic objects.

Some investigations refer to the estimation of the effects of glasses on the SAR inside the human head, resulting from wireless eyewear devices at the phone call state. In [17], the authors have found that the maximal SAR in the ocular tissues with glasses is even six times higher than that without glasses. In [18], the authors found that simulated SAR values are somewhat higher than authorized levels with preoccupant high electromagnetic field distribution close to the eye of the user. Also, one study deals with the simulation of the effects of RF electromagnetic radiation from a mobile phone in the presence of metal frame glasses. Simulations are performed using a very simple model of head, modeled as a three-layer sphere with two little balls representing the eyes [19].

It is common for people who have vision problems to wear glasses. Today, the frames of glasses can be made from different materials but the metal frame, as an excellent conductor, significantly changes the electric field distribution and values of SAR from the mobile phone during the conversation or texting. This study deals with the effects of a mobile phone conversation in the presence of metal frame glasses with the aim to determine the changes in electric field distribution and values of SAR within the human head model. This investigation is focused on the electric field distribution within the biological tissues of the human head that are in the vicinity of the glasses frame. The shape of the anatomical human eye model and its features have an important role for the absorption of electromagnetic energy, as well as the operating frequency and the distance between the electromagnetic source and the exposed object. The numerical calculation of the electric field and the amount of the absorbed electromagnetic energy have been performed at the frequency of 900MHz which is typical for the 3G mobile network.

NUMERICAL METHOD AND MODELING

Model

In order to determine the electric field distribution and values of SAR within the human head with metal frame glasses exposed to the radiation from the mobile phone, the 3D realistic human head model has been developed. It was necessary to create this model with features as close as possible to the real human head. The process of modeling has been performed in few stages. First, the realistic model of a human head was modeled with following tissues and organs: Cortical Bone, Brain, Cerebrospinal Fluid, Fat, Cartilage, Pituitary Gland, Spinal Cord, Muscle, Eyes, Skin, Tongue and Teeth (Figure 1).

The human head model was developed so that the anatomical and morphological characteristics correspond to an average adult person (Figure 2) [20-22]. After designing, the complete model was used for simulation of the propagation of the electromagnetic waves. The layers must 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.

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

Assessment of the effects of exposure to mobile phone radiation is based on the prediction of the induced internal electromagnetic field and the amount of absorbed electromagnetic energy in the human head. The shape of the anatomical human head model and its features have an important role for the absorption of electromagnetic energy, as well as the operating frequency and the presence of other objects. Hence, in order to obtain the most accurate results of the electric field and the SAR inside the human head, in the presence of metal frame glasses, a model of glasses had to be also created (Figure 3b). The material used for the glasses frame is the aluminium with the electrical conductivity σ= 3.56x107S/m.

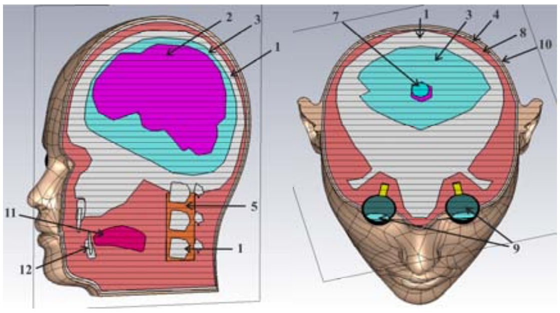


Figure 1. *Cross-section and construction of the human head model*

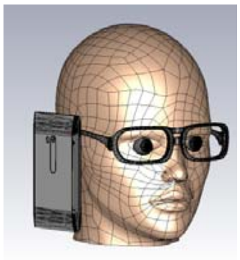


Figure 2. *External appearance of the human head model*

a) *b*)

Figure 3. *External look of smartphone and glasses*

Before any numerical calculation, the electromagnetic characteristics of biological tissues and organs (permittivity, conductivity and permeability) should be defined, in order to understand the interaction between electromagnetic radiation and the body. The effects of propagation, reflection, and attenuation of electromagnetic waves in the body depend on these electromagnetic properties. For each biological tissue used in a model, the appropriate electromagnetic parameters are given in Table 1 [23].

As a source of electromagnetic radiation, the mobile phone which characteristics correspond to an actual smartphone, has been developed (Figure 3a). The mobile phone model contains the following parts: the display, mobile housing and planar inverted F antenna (PIFA). The planar inverted F antenna, as a source of electromagnetic radiation, was modeled for the frequency of 900MHz with the output power P=1W [24] and the impedance Z=50Ω. Generally, the construction of PIFA depends on the producer. One way of PIFA performance, its construction and radiation pattern at certain frequencies can be found in [25].

Table 1. *Electromagnetic properties of tissues of the human head model at 900MHz.*

	Biological tissue		3G 900MHz	ρ [kg m^{-3}]
1.	Cortical Bones	ε_r	12.45	1908
		σ[Sm^{-1}]	0.143	
2.	Brain	ε_r	49.4	1046
		σ[Sm^{-1}]	1.26	
3.	Cerebrospinal Fluid	ε_r	68.60	1007
		σ[Sm^{-1}]	2.410	
4.	Fat	ε_r	11.30	911
		σ[Sm^{-1}]	0.109	
5.	Cartilage	ε_r	42.70	1100
		σ[Sm^{-1}]	0.782	
6.	Pituitary Gland	ε_r	59.70	1053
		σ[Sm^{-1}]	1.040	
7.	Spinal Cord	ε_r	32.50	1075
		σ[Sm^{-1}]	0.574	
8.	Muscle	ε_r	55.00	1090
		σ[Sm^{-1}]	0.943	
9.	Eyes	ε_r	49.60	1052
		σ[Sm^{-1}]	0.994	
10.	Skin	ε_r	41.40	1109
		σ[Sm^{-1}]	0.867	
11.	Tongue	ε_r	55.30	1090
		σ[Sm^{-1}]	0.936	
12.	Teeth	ε_r	12.50	2180
		σ[Sm^{-1}]	0.143	

In order to create the numerical model with the appropriate electromagnetic properties of biological tissues and organs and to determine the spatial distribution of the electromagnetic field within the model, which originates from a mobile phone, we used the CST software package [26]. This software is based on the FIT (Finite Integration Technique) method [27].

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 powerful 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.

SAR calculation

SAR (Specific Absorption Rate) is a measure of the amount of radiofrequency (RF) energy absorbed by the body from the source of electromagnetic radiation. SAR provides a straightforward means for measuring the RF exposure characteristics of the source of electromagnetic radiation, to ensure that they are within the safety guidelines prescribed by adequate safety standards.

When the electromagnetic wave spreads through the human tissue, the energy of electromagnetic waves is absorbed by the tissue. The value of SAR describe the interaction of electromagnetic waves with biological tissues and can be defined as the speed of power dissipation normalized by the density of the material, as in the following equation [28]:

$$\mathrm{SAR} = \frac{\sigma}{\rho}|E|^2 \tag{1}$$

where σ is the electrical conductivity (S m^{-1}) and ρ is the density of the tissue (kg m^{-3}). It should be also noted that the electric field E (V/m) is the r.m.s. value.

In addition, it is very important to define averaged SAR as the ratio of the power absorbed in the tissue and the weight of that biological tissue. This averaged SAR is obtained by integrating the following expression:

$$\mathrm{SAR}_{\mathrm{av}} = \frac{1}{V}\int_V \mathrm{SAR}\,\mathrm{d}V = \frac{1}{V}\int_V \frac{\sigma}{\rho}|E|^2\,\mathrm{d}V\ . \tag{2}$$

Mass averaged SAR is typically calculated for a sample of 1g (SAR_{1g}) and a sample of 10g (SAR_{10g}) but in this study, SAR will be averaged for 1g.

RESULTS

In this section, the electric field distribution and the amount of absorbed energy, during the conversation over the cell phone, are represented within the model of a human head with previously mentioned features. The position of curves (C1, C2 and C3) used for numerical calculation of electric field and SAR are shown in Figure 4. All curves are located in planes normal to the plane of the cell phone. Curve C1 is at the level of the handles, while curve C2 is located below and C3 is located above the level of curve C1. Accordingly, this study is focused on the absorbed energy of the electromagnetic waves in different biological tissues that are located at the level of metal frame glasses. Comparative analysis of the obtained results, for the models with and without glasses, has been carried out.

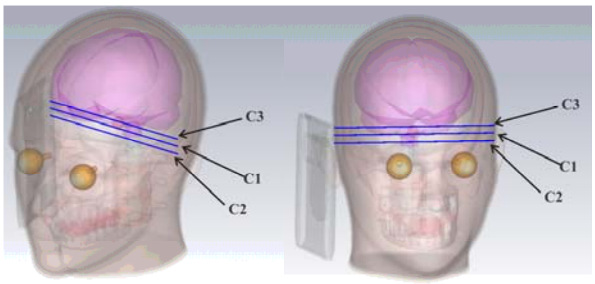
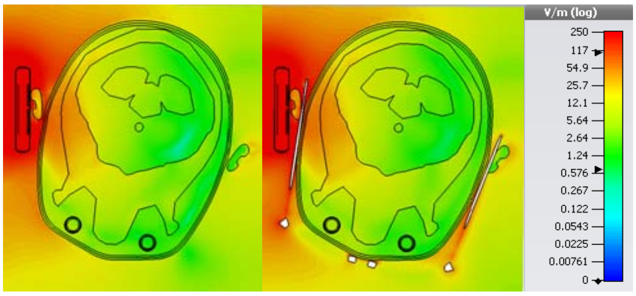


Figure 4. *Human head model with curves for evaluating electric field and SAR.*

Electric field distribution

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 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 Figure 5. Models with and without glasses are represented at the same figure to make results comparable. Further, on the right side of the 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.

It is important to mention that the allowable value of the electric field, prescribed by the standard, is 41V/m at 900 MHz [1-4], for the free space when the human is absent.



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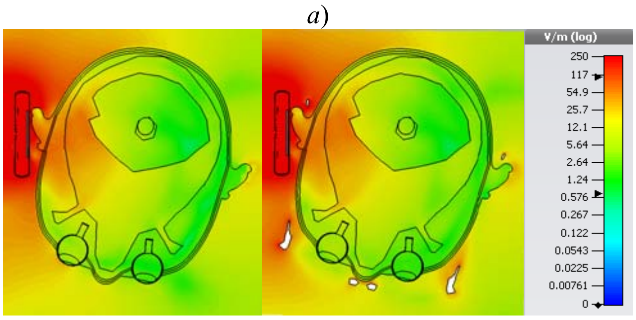

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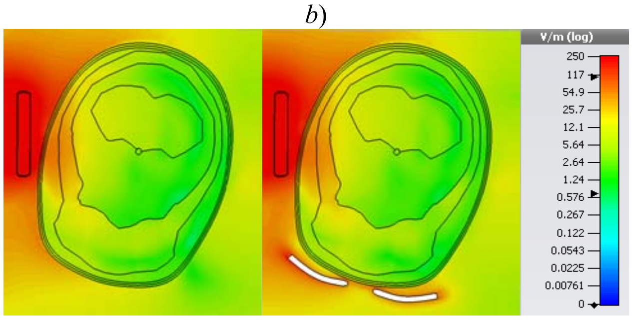

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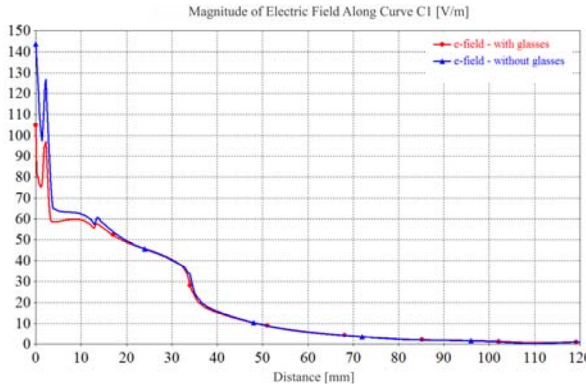
Figure 5. *Spatial distribution of electric field a) C1cross-section, b) C2cross-section and c) C3cross-section*

Figure 6 shows the dependence of the electric field along the curves C1, C2 and C3 as a function of the distance from the radiation source, at the mentioned frequency, for the models with and without glasses. This dependence refers to the plane that passes through the different biological tissues and contains the curves C1, C2 and C3.

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 model. While spatial distribution of the electric field shown in Figure 5 is similar for both cases – with and without glasses, graphs of the electric field strength in Figure 6 show that the electric field is lower for the model with glasses. The maximum values of the electric field inside different biological tissues, for the models with and without glasses, are represented in Table 2. Only the results obtained in biological tissues on which the glasses have an influence are represented in this table. Biological tissues, on which the influence of glasses is negligible, are omitted because the electric field is almost the same for models with and without glasses.

It can be seen from Figure 6a (curve C1) that the maximum value of the electric field is in skin and amounts 104.85 V/m in the presence of glasses, while this value for the model without glasses is higher and amounts 143.69 V/m. It is evident that the highest influence of glasses on electric field strength is inside the skin since this biological tissue is the nearest to the metal frame.



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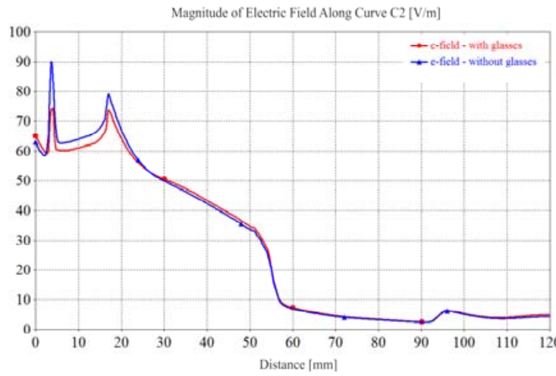

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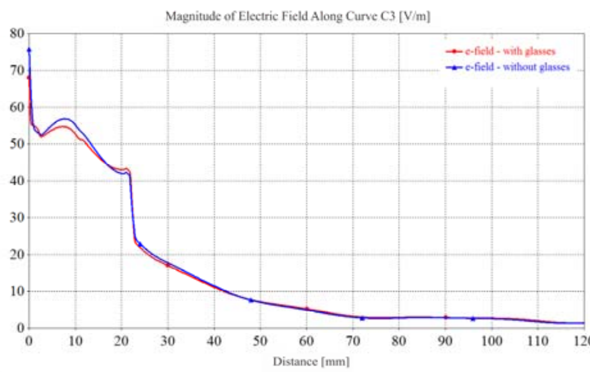

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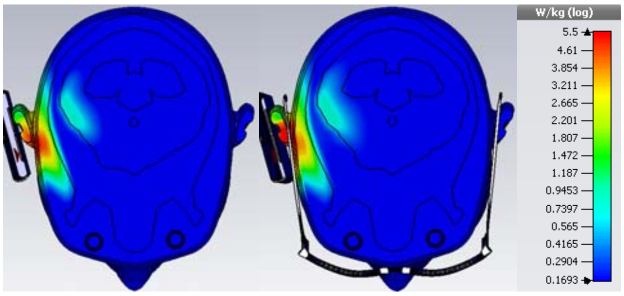
Figure 6. *Electric field strength along the curve a) C1, b) C2 and c) C3*

According to the obtained results, represented in Table 2, the decrease in electric field values in the following tissues is as follows: Fat – 29.86 V/m, Muscle – 23.69

V/m, Skull – 5.653 V/m and Cerebrospinal Fluid – 2.51 V/m. The decrease for the other tissues is negligible because they are farther away from the metal frame and their influence is very low.

Table 2. *Maximum value of the electric field strength inside the certain biological tissue [V/m].*

Biological tissue	Model without glasses	Model with glasses
	E[V/m]	E[V/m]
Skin	143.69	104.85
Fat	126.78	96.92
Muscle	87.31	63.62
Skull	61.083	55.43
Cerebrospinal Fluid	33.96	31.45



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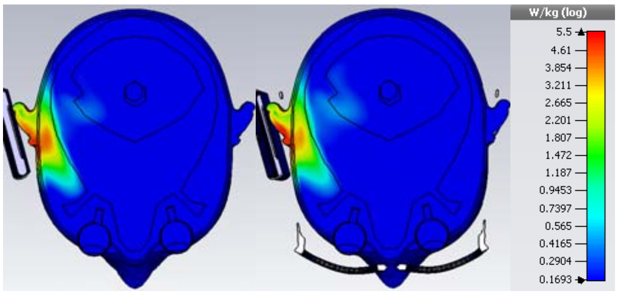

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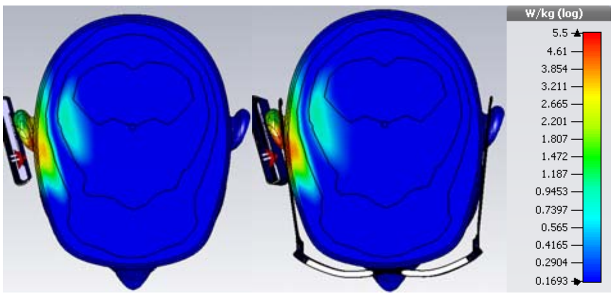

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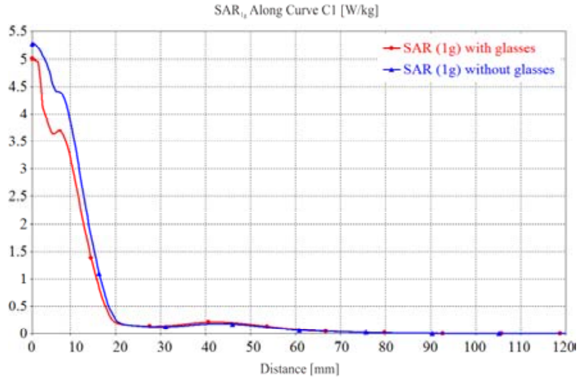
Figure 7. *Specific absorption rate - SAR_{1g} a) C1-cross-section, b) C2-cross-section and c) C3-cross-section*

SAR distribution

This section refers to a comparative analysis of the SAR values averaged for 1g (SAR_{1g}) within the models (with and without glasses) at the mentioned frequency. The amount of absorbed energy from a mobile phone in the horizontal cross-sections, previously presented, located at the level of glasses handles, is shown in Figure 8. These cross-sections contain curves C1, C2 and C3.



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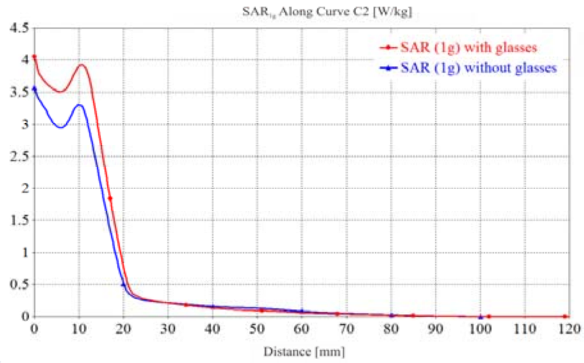

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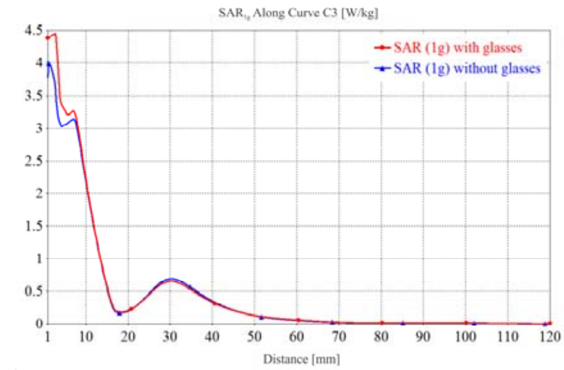

c)

Figure 8. *Specific absorption rate - SAR_{1g} a) C1-cross-section, b) C2-cross section and c) C3-cross section*

The models with glasses (right side) and without glasses (left side) are represented in the same figure to enable comparison. On the right side of the figures, the maximum value of SAR_{1g} in the color palette is set to be the same for both models, also for the easier comparison of SAR_{1g} values within the model.

There is considerable confusion and misunderstanding about the meaning of the maximum reported Specific Absorption Rate (SAR) values for cell phones (and other wireless devices). According to appropriate safety standards, the limit of SAR per 1g tissue should not exceed 1.6W/kg for public exposure from mobile phones [2].

Figures 8a, 8b and 8c show the dependence of the SAR_{1g} values along the curves C1, C2 and C3 on the distance from the radiation source respectively. According to the obtained results represented in previous figures, it is evident that the maximum values of absorbed energy for both models occurs in the surface layers of the model.

Based on Figure 7, the distribution of SAR_{1g} values is similar for both models (with and without glasses). According to the results represented along the curves mentioned above, a significant decrease of the SAR_{1g} value in the presence of glasses with aluminium frame can be noted. The SAR_{1g} peak values inside the different biological tissues for the models with and without glasses are represented in Table 3. The highest influence of glasses on the amount of absorbed energy can be noted in the tissues that are nearest to the metal frame (Figures 7 and 8).

Table 3. *Maximum value of SAR_{1g} [W/kg]*

Biological tissue	Model without glasses	Model with glasses
	SAR_{1g}[W/kg]	SAR_{1g} [W/kg]
Skin	5.299	5.02
Fat	5.18	4.82
Muscle	4.58	3.65
Skull	2.06	1.63
Cerebrospinal Fluid	0.353	0.335

It can be seen from Figure 8 (curve C1) that the maximum value of the SAR_{1g} is inside the skin and it is 5.02 W/kg in the presence of glasses, while this value for the model without glasses is higher and amounts – 5.299 W/kg. According to the obtained results, represented in Table 3, we can observe that the decrease in the amount of absorbed energy in other tissues is as follows: Fat – 0.36 W/kg, Muscle – 0.93 W/kg, Skull – 0.43W/kg and Cerebrospinal Fluid – 0.018 W/kg. The decrease for the other tissues is negligible because they are farther away from the metal frame and their influence is very low. However, the value of the SAR_{1g} within both models inside certain tissues is larger than the maximum allowed values.

CONCLUSION

This study investigated the electric field distribution and the values of the Specific Absorption rate within biological tissues in the vicinity of metal frame glasses, during the conversation over a mobile phone. The numerical calculation was performed for the frequencies of the 3G mobile network. Also, a comparative analysis of the models with and without glasses has been presented.

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

The maximum value of the electric field in the absence of glasses is almost 1.4 times higher than the electric field obtained for the model with glasses. According to values in Table 2, the differences in the electric field strength can be observed. Electric field strength is lower in the presence of glasses, and this decrease for following tissues amounts: Skin – 27%, Fat – 25%, Muscle – 27%, Skull – 9%, and Cerebrospinal Fluid – 7%. The decrease in case of other tissues is negligible since they are farther away from the metal frame.

Therefore, it can be concluded that the presence of glasses with the metal frame decreases the electric field in the biological tissues located near to the frame. However, it should not be forgotten that the value of the electric field inside certain tissues, despite the decrease of almost 30% when the glasses are present, overcomes the allowed values prescribed by safety limits.

Regarding the obtained results that refer to the amount of absorbed energy, a significant decrease in the SAR_{1g} value can be noted in the presence of glasses with aluminium frame. Based on the values shown in Table 3, it is evident that the decrease in the amount of absorbed energy in the presence of glasses inside the following tissues amounts: Skin – 5.2%, Fat – 6.9%, Muscle – 20%, Skull – 25% and Cerebrospinal Fluid – 5%. As for the electric field, the value of the SAR_{1g} within both models inside the certain tissues is larger than the maximum allowed values prescribed by safety limits.

In general, based on the results obtained for the electric field strength and the amount of absorbed energy from the 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 the aluminium frame is a good conductor, in its presence large amount of electric field is directed away. Therefore, every time we wear glasses during the conversation over the cell phone, the metal frame of glasses behaves as a kind of shield.

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EFEKTI UPOTREBE NAOČARA SA METALNIM OKVIROM PRILIKOM IZLOŽENOSTI ELEKTROMAGNETNOM ZRAČENJU

Dejan Jovanović, Vladimir Stanković, Dragana Živaljević, Dragan Vučković, Simona Ilie

Rezime: *Cilj ovog istraživanja je procena uticaja naočara sa metalnim okvirom, na raspodelu električnog polja kao i na specifičnu konstantu apsorpcije (Specific Absorption Rate - SAR), unutar modela ljudske glave. Za dobijanje raspodele električnog polja i vrednosti SAR u okolini naočara sa metalnim okvirom, kada je čovek izložen zračenju mobilnog telefona sa 3G frekvencijom mobilne mreže, primenjeno je numeričko rešavanje jednačina prostiranja elektromagnetnih talasa. Izračunavanje ovih efekata izvršeno je za vreme korišćenja funkcije poziva mobilnim telefonom. Da bi se dobili najtačniji rezultati, kreirani su 3D modeli ljudske glave i metalnog okvira naočara. Za procenu pomenutih efekata izvršena je uporedna analiza modela sa i bez naočara. Takodje, dobijeni rezultati su dati za prostor unutar različitih bioloških tkiva i organa koji čine model ljudske glave.*

Ključne reči: rapodela električnog polja, Specifična konstanta apsorpcije, mobilni telefon, naočare sa metalnim okvirom.