COMPUTATION OF SAR AND TEMPERATURE VALUES IN THE HUMAN HEAD DUE TO 2G, 3G, 4G MOBILE WIRELESS SYSTEMS

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ABSTRACT

In this study, to examine the impact of distance, angle and frequency on the human head during the regular functioning of a mobile phone, a head model is constructed via COMSOL software dataset. The handset antenna has been configured with a patch antenna being a radiation source at 900 MHz, 1800 MHz and 2100MHz, respectively. Temperature increase and specific absorption rate distribution on the user's head with various angles and distances are simulated by using finite element method. Moreover, the simulations are also repeated during the voice and video calls with varying distances. It is observed that the values that are obtained in the simulations are in good agreement with the basic limitations set up by IEEE and ICNIRP, designating that the safety restrictions will not be dared by the usage of user.

Keywords: *Human Head Model, Specific Absorption Rate, Temperature Increase, Finite Element Method*.

İNSAN KAFASINDAKİ 2G, 3G, 4G MOBİL TELSİZ SİSTEMLERİNİN SEBEP OLDUĞU SAR VE SICAKLIK DEĞERLERİNİN HESAPLANMASI

ÖZET

Bu çalışmada, günlük cep telefonu kullanımı sırasında, uzaklığın, açının ve frekansın etkisini incelemek için, COMSOL yazılım veriseti tabanlı kafa modeli kullanılmıştır. Cep telefonu, sırasıyla, 900 Mz, 1800 MHz ve 2100 MHz'de yayınım kaynağı olan patch anten ile birlikte modellenmiştir. Insan kafasındaki sıcaklık artışı ve özgül soğurma oranı dağılımı, çeşitli açı ve uzaklıklarla birlikte sonlu elemanlar yöntemi kullanılarak benzetimleri yapılmıştır. Ayrıca, sesli ve görüntülü aramalar sırasında değişen uzaklıklarla birlikte benzetimler tekrarlanmıştır. Benzetimlerde elde edilen değerlerin IEEE ve ICNIRP'nin kabul ettiği temel sınırlandırmalarla uyum içinde olduğu gözlenmiştirki bu da güvenlik sınır değerlerinin kullanıcının kullanımı ile sorgulanamayacağını göstermektedir.

Anahtar Kelimeler: *İnsan Kafası Modeli, Özgül Soğurma Oranı, Sıcaklık Artışı, Sonlu Elemanlar Yöntemi.*

1. INTRODUCTION

Up to date, due to the health implications, there is a rising public anxiety about the electromagnetic (EM) waves radiated from wireless devices. Radio frequency (RF) exposure causes temperature rise in the human body which leads to physiological damage. During the exposure, it is important to analyse the temperature distribution and specific absorption rate (SAR) levels of the body tissue, so that they can be compared with the limits determined by authorities such as International Committee on Non-Ionising Radiation Protection (ICNIRP), World Health Organization (WHO), and IEEE [1-3].

Guyton et. al [4] has investigated that for 30 min longer EM wave exposure durations, the allowable temperature elevation in the human brain is 4.5 ^{0}C, and 10 ^{0}C – 15 ^{0}C in the skin. Thus, human brain is vulnerable organs to EM waves. Therefore, several researches have been calculated the temperature rise in the user's head for exposure to EM waves from mobile phones [4-18]. Guy et. al [8] has quantified SAR distributions in man, woman, and child models exposed to UHF mobile-antenna fields. Yioultsis et. al [9] has examined the effect of the exposure due to a variety of ordinarily used mobile phones and communication antennas on human beings. In the following years, Hirata et. al. [10] examined the

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correlation of the temperature escalation in the brain and head with the maximum SAR value due to mobile antennas. In the same year authors have published paper regarding the rise on the temperature due to exposure in between 900 MHz and 2.45 GHz frequency range [11] and furthermore in 2013, for whole body from 30 MHz to 6 GHz, they have figured out the temperature increase and the SAR for a plane wave exposure [12]. Under continuous RF exposure, the time to achieve the thermal steady-state has also been studied with an antenna at 835 MHz which has the varieties of power values [13]. In addition, it is investigated in [14] that various phone brands operating at 900 MHz have various temperature elevation values in the human head. SAM phantom model has been constructed to examine the EM energy assimilation in the human head due to the RF exposure at 900 MHz using planar inverted F antenna (PIFA), and the microstrip patch antenna as a handset antenna model, respectively [15,16].

Until 2015, adequate concentration has not been shown to the angle and the distance variations between the antenna and the human head [17]. It is aimed in this study to analyse the consequences of the distances between the human head and the handset antenna on the SAR and the temperature. Furthermore, this study examines the influences of angles between the antenna and the human head on temperature and SAR values at frequencies used in GSM-900, GSM-1800 and GSM-2100 mobile phones. Moreover, the exposure effects during the voice and the video calls are presented as well.

2. THEORETICAL BACKGROUND

In this study, in order to make a comparison with the previous researches in the literature [9], antenna power is set the same at 600 mW. After preparing lab environment, simulations are performed to obtain SAR values on human head surface. SAR is the power absorption by the unit mass of a tissue (W/kg), and it is given with the Equation (1) which presents the rate of deposition into tissue.

$$SAR = \sigma E^2/\rho \qquad (1)$$

where E is electric field inside the human body, ρ is the mass density of the tissue (kg/m^3) and σ is the conductivity.

When the human head is exposed to EMFs, blood flow and metabolic range parameters should be taken into consideration. The relation between EMFs and heat transfer can be calculated by Pennes' bioheat equation introduced in 1948 [19]:

$$\rho c \frac{\partial T}{\partial t} = \nabla.(k\nabla T) + \rho Q_{met} + \rho(SAR) - B(T - T_{blood}) \qquad (2)$$

where the ρ[kg/m^3] is the material density, c[J/(kg°C)] is the specific heat capacity, k[W/(m°C)] is the thermal conductivity, Q_{met}[W/kg] is the metabolic heat generation rate, B[W/m^3°C] is the blood perfusion coefficient, ω[L/(s*kg)] is the blood perfusion rate, and T_{blood} is blood temperature [19].

3. SIMULATIONS

Since different tissue parameters and head models are used in each study in the literature, it is very difficult to make meaningful contributions. In this study, the effects of distance, the angle and the frequency on temperature distribution and SAR values in the human head are investigated, thus these variations are so important in terms of safety and health hazards due to RF exposures.

In order to analyse the effect of radiation on human brain, SAR values are shown on logarithmic scale. Moreover, the brain structure is sliced to show clearly the penetration of the radiation.

3.1. Influences of Distance Between Human Head and Handset Antenna

In this part, it is aimed to analyse the impacts of the distances between the user's head and the mobile phone model on SAR and temperature rise at 900 MHz. The distance is changed from 0 mm to 6 mm in 2 mm intervals. Maximum SAR and temperature rise results summarized in Figure 1. It can be clearly inferred from the results that as the remoteness between the mobile phone and user's head elevates, SAR and temperature values decline.

3.2. Effects of Frequency Variation

This part of the study highlights the influences of frequency on the temperature and SAR distribution in the head during EM field exposures. The main frequency bands which are used for GSM communication, 900 MHz, 1800 MHz and 2100 MHZ are chosen. The simulation results are given in Figure 2 and Figure 3 for SAR and temperature, respectively.

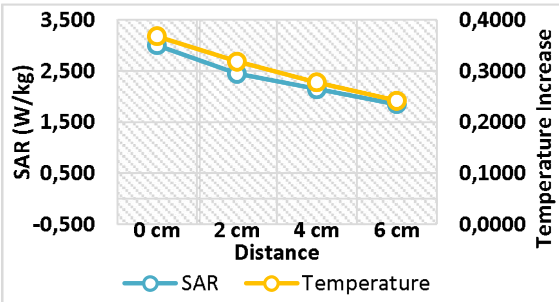

Figure 1. Effects of distance variation of SAR [W/kg] and temperature [^{0}C] at 900 MHz.

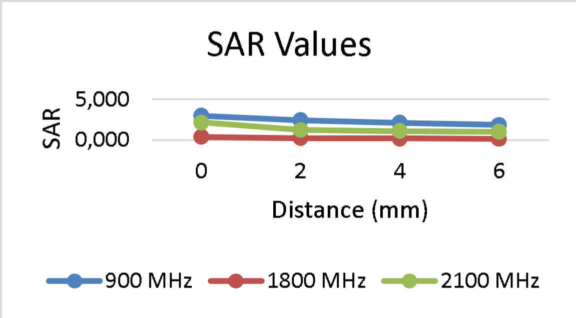

Figure 2. Variation of SAR [W/kg] values versus varying frequency.

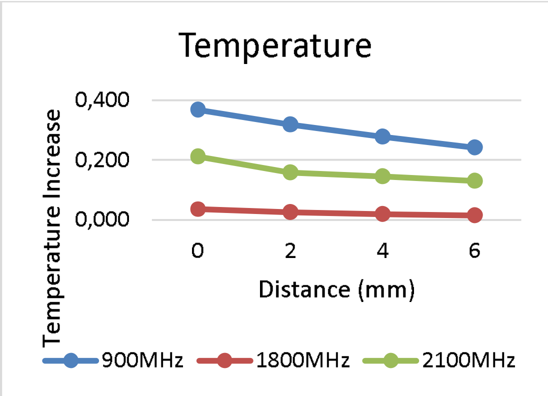

Figure 3. Variation of temperature increase [^{0}C] versus varying frequency.

Many countries have started to use 4G technology. In Turkey, citizens can currently make a 4G call since 2016. Due to the increase of the bandwidth, people can also make video conference calls with high quality. However, these developments suffer from health issue trade-off. In order to evaluate health hazards of 4G, voice call at 2.1 GHz and the video call at 900 MHz are simulated. SAR and temperature values during the voice call are listed in Table 1 with varying distances from the head and the handset antenna. Temperature and SAR values during the voice call versus distances are depicted in Figure 4.

Table 1. The effect of voice call at 2.1 GHz.

Distance (mm)	SAR (W/kg)	Temperature (^{0}C)
0	0.3336	0.211
2	0.0943	0.158
4	0.0425	0.144
6	0.0070	0.129

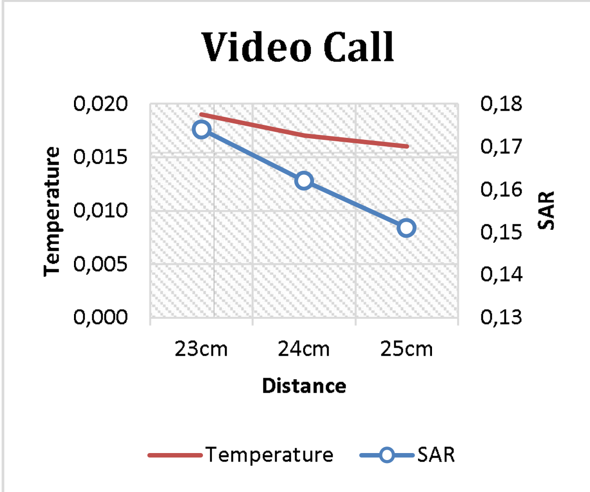

Figure 4. SAR [W/kg] and temperature [^{0}C] values for video call at 900 MHz.

3.3. Influences of Angle Between Head and Antenna

While people talking on cell phones, human head can be exposed to radiation at various angles. Therefore, it is crucial to analyse the effect of various angles between the antenna and the human head on the SAR and temperature values. The simulations are repeated starting from 0 degree to 25 degrees in 5 degree intervals. Figure 5, Figure 6 and Figure 7 depict the results for varying angle values at 900 MHz, 1800 MHz and 2100 MHz, respectively. For each frequency, SAR and temperature distributions on the head are shown in Figure 8, Figure 9 and Figure 10 when the angle between user head and the antenna is fixed to 25 degrees.

According to the simulations, it can be stated that when the angle increases, both SAR and temperature values have a tendency to decrease. Summary of 900 MHz angle variation studies can be seen on Fig. 5.

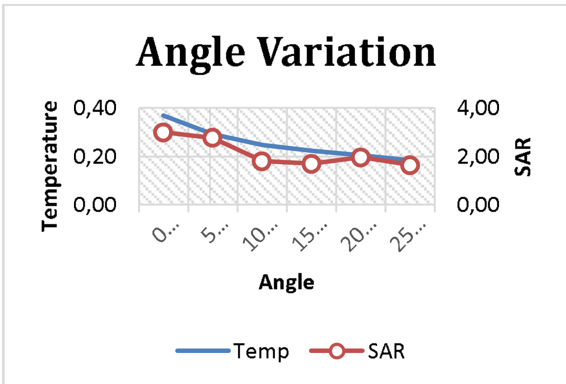

Figure 5. SAR [W/kg] and temperature [^{0}C] increase values at 900 MHz with different angles.

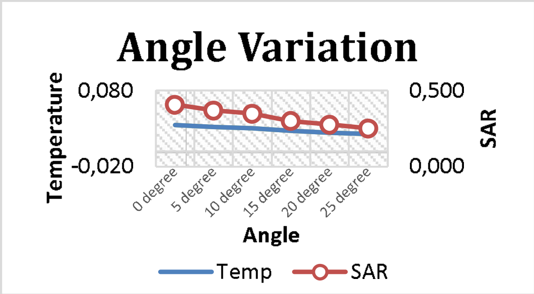

Figure 6. SAR [W/kg] and temperature [^{0}C] increase values at 1800 MHz with different angles.

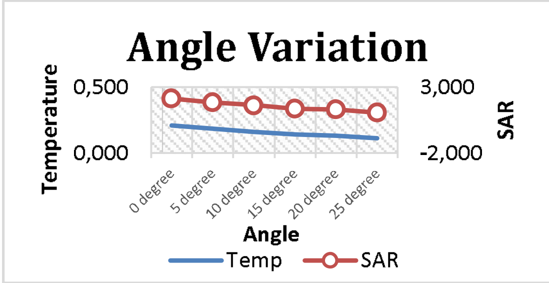

Figure 7. SAR [W/kg] and temperature [^{0}C] increase values at 2100 MHz with different angles.

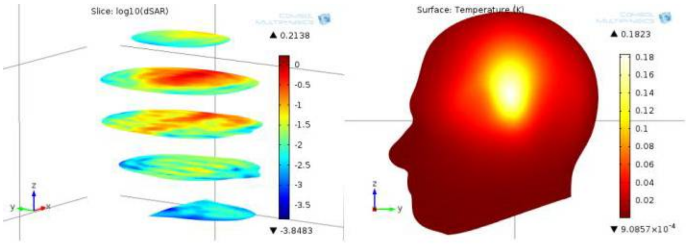

Figure 8. SAR [W/kg] and temperature [^{0}C] increase for 900 MHz at 25 degree angle.

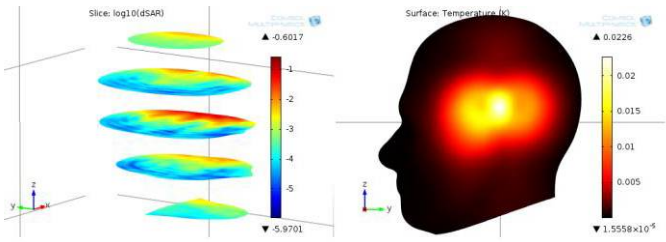

Figure 9. SAR [W/kg] and temperature [^{0}C] increase for 1800 MHz at 25 degree angle.

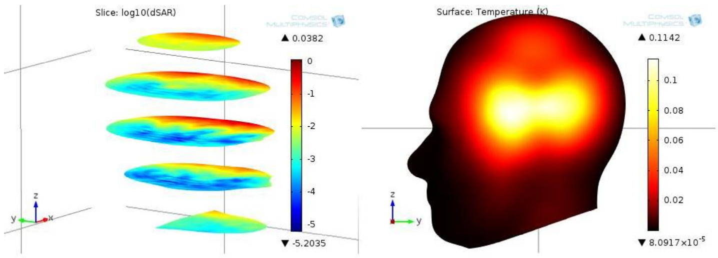

Figure 10. SAR [W/kg] and temperature [^{0}C] increase for 2100 MHz at 25 degree angle.

The degree is inversely proportional with SAR and temperature values. On the other hand, it is important to imply that shifts on the angle are not effective on SAR and temperature increase as much as distance variation.

4. CONCLUSIONS

Temperature increases and SAR distributions in terms of varying angles and distances between the antenna and the user's head have been investigated due to EM waves exposure from a patch antenna for 2G, 3G, and 4G mobile wireless systems. As the distance between the antenna and the user's head increases from 0 mm to 6 mm, SAR distribution in the human head declines from 3.0 W/kg to 1.82 W/kg. The maximum temperature increase in the head is declined from 0.36 ^{0}C to 0.25 ^{0}C. The simulated SAR and temperature distributions are generally in compliance with the literature such that the values are decreasing with the increasing distances.

In the simulations of finding the relation between the SAR and temperature values with the angle of antenna, it is detected the angle and SAR - temperature values are inversely proportional to each other. It is found in the simulations of the voice and the video calls that temperature increase and SAR distribution values are declining as the distance is rising. The obtained results confirm the importance of the position of the mobile phones while having voice and video calls.

Comparing and evaluating study results should be handled with extreme care. Because, different tissue parameters, varying human head models and antenna types, undefined distance values between the antenna and the human head may result in uncertainties and mismatches in between the simulations.

All in all, different methods produce different results. For instance, on highly-curved surfaces FDTD has poor performance. Additionally, mesh sizes also affect the results. Although coarser meshes have less accurate results compared to finer meshes, in order to decrease the simulation complexity and time, finer mesh rate should be reduced.

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5. REFERENCES

[1] ICNIRP "Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to300 GHz)," Health Physics, Vol. 74, 494-522, 1998.

[2] WHO, World Health Organizations Fact Sheet No.193, "Electromagnetic fields and public health, mobile telephones and their base stations," July 2000.

[3] IEEE, "IEEE standard for safety levels with respect to human exposure to radio frequency electromagnetic fields, 3 khz to 300 GHz," IEEE Standard C95.1, 2005.

[4] C. Guyton, J. E. Hall, "Textbook of Medical Physiology," Philadelphia, PA: Saunders, 1996.

[5] Kang, X. K., Li, L. W., Leong, M.S., Kooi, P.S., "A spheroidal vector wave function analysis of field and SAR distributions in a dielectric prolate spheroidal human head model," *Progress In Electromagnetics Research,* Vol. 22, 149-179, 1999.

[6] Li, L. W., Leong, M.S., Kooi, P.S., Yeo, T.S., "Specific absorption rates in human head due to handset antennas: A comparative study using FDTD method," *Journal of Electromagnetic Waves and Applications,* Vol. 14, 987-1000, 2000.

[7] Gandhi, O. P., Li, Q. X., Kang, G., "Temperature rise for the human head for cellular telephones and for peak SARs prescribed in safety guidelines," *IEEE Transactions on Microwave Theory and Technology,* Vol. 49, 1607-1613, 2001.

[8] Guy, W., Chou, C.K., "Specific absorption rates of energy in man models exposed to cellular UHF mobile-antenna fields," *IEEE Transactions on Microwave Theory and Technology,* Vol. 34, Issue:6, 671-680, 1986.

[9] Yioultsis, T.V., Kosmanis, T.I., Kosmidou, E.P., Zygiridis, T.T., Kantartzis, N.V., Xenos, T.D., Tsiboukis, T.D.,"A comparative study of the biological effects of various mobile phone and wireless LAN Antennas," *IEEE Transactions on Magnetics,* Vol. 38, No. 2, 777-780, 2002.

[10] Hirata A., Shiozawa, T. "Correlation of maximum temperature increase and peak SAR in the human head due to handset antennas," *IEEE Transactions on Microwave Theory and Technology,* Vol. 51, No. 7, 1834-1841, 2003.

[11] Hirata A., Morita, M., Shiozawa, "Temperature increase in the human head due to a dipole antenna at Microwave frequencies," *IEEE Transaction on Electromagnetic Compatibility,* Vol. 45, No.1, 109-116, 2003.

[12] Hirata A., Laakso, I., Oizumi, T., Hanatani, R., Chan, K.H., Wiart, J., "The relationship between specific absorption rate and temperature elevation in anatomically based human body models for plane wave exposure from 30 MHz to 6 GHz," *Physics in Medicine,* Vol. 58, No.4, 903-908, 2013.

[13] Kim W., Yook, J., "Thermal steady state in human head under continuous EM exposure," *2005 IEEE MTT-S International Microwave Symposium Digest*, 1805-1808, 2005.

[14] S. I. Al-Mously, "Computation of the temperature-rise in the human head due to different mobile phone models," *IEEE Microwave Symposium (MMS), 2010 Mediterranean*, pp. 370-373, 2010.

[15] Mat, M.H., Malek, M. F., Zulkefli, M.S., Suzanna, H.R., "Preliminary study of electromagnetic energy absorption in the head due to the exposure of radio frequency at 900MHz," *IEEE Symposium on Computers and Informatics,* pp. 228-231, 2012.

[16] Citkaya, A.Y., Seker S. S., "FEM modeling of SAR distribution and temperature increase in human brain from RF exposure," *International Journal of Communication Systems,* 2012.

[17] Stankovic, V., Jovanovic, D., Krstic, D., Cvetkovic, N.,"Electric field distribution and SAR in human head from mobile phones," *9th International Symposium in Advanced Topics in Electrical Engineering, ATEE, Bucharest, Romania, 7-9 May,* 2015.

[18] Hossain, M.I, Faruque, M.R.I., Islam, M.T. "Analysis on the effect of the distances and inclination angles between human head and mobile phone on

SAR," *Progress in Biophysics on Molecular Biology*, Vol. 119, Issue 2, 103-110, 2015.

[19] H. H. Pennes, "Analysis of tissue and arterial blood temperatures in the resting human forearm," *Journal of Applied Physiology,* Vol. 85, No.1, 5-34, 1998.

VITAE

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