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Prediction of SAR of Electromagnetic Radiation due to Virtual Reality Headsets in the Human Head

***Abstract**. Virtual reality (VR) headsets, 5G device, expose electromagnetic radiation to the human head led to concerns about the health effects. The purpose of this study is to predict the specific absorption rate (SAR) due to VR headsets in the human head. The study involves two biological models. Model A is a flat specific anthropomorphic mannequin (SAM). Model B is Model A inserted with a designed brain. The results are found that the SAR of model B is higher than that of model A, under the standard limits and not affected by temperature, short term memory, or memory load.*

Streszczenie.** Urządzenia wirtualnej rzeczywistości generują pola elektromagnetyczne. W artykule analizowano współczynnik SAR takich urządzeń dla dwóch modeli. **Analiza współczynnika SAR dla urządzęń. Wirtualnej rzeczywistości

Keywords: SAR, Virtual Reality Headsets, Human Head
Słowa kluczowe: wirtualna rzeczywistość, współczynnik SAR.

Introduction

There is much concerns about the effect from electromagnetic energy absorption in human head. In particular, 5G wireless technology will provide a higher speed compared to the previous generation and support connections for a number of devices. Many studies have mentioned that researchers have attempted to prove this electromagnetic absorption. The World Health Organization (WHO) cooperated with the International Radiation Protection Association (IRPA) to develop the International Commission on Non-Ionizing Radiation Protection (ICNIRP). The ICNIRP establishes the safety parameters for investigations and has developed international guidelines to limit exposure to electromagnetic fields (EMF) to provide protection against all established adverse health effects [1-5]. Tissue heating is the established biological effect of high frequency (HF) EMF. The evaluation of this HF exposure is based on the determination of the SAR related to the electric field induced in the tissue [6]. The issued studies on SAR evaluation in biological tissues can be divided into four types.

The first type focuses on varying head size and including other organs such as a hand paticularly the Asian-sized hand. This group of studies measures the peak and total SAR in a 1 g and 10 g tissue mass at 835 MHz to 2100 MHz. Results show that the SAR of a bigger head is more than for a smaller head. Additionally, the existence of a hand included to the head affects the SAR, which is in the range of 0.016–3.11 W/kg for the total SAR [7-10]. The second type of study has concentrated on the head, including metallic components such as a helmet, hand ring jewellery, ring metallic objects and perfectly conducting spectacles. The study revealed that the maximum SAR can be increased up to six times as compared with no object via metallic components. The maximum SAR was found to be between 0.059 and 3.12 W/kg [11-14].

The third type of study focused on the effects on the brain. Problems in dosimetry of SAR variation in a brain phantom due to exposure by a 3G mobile phone are located. An age of the brain phantom are also proved. The results showed that the SAR of the brain was lower than a SAM head whose maximum SAR is 0.199–9.95 W/kg. The SAR results obtained for a 10-g average mass are considered to be lower than the safety exposure limit according to ANSI/IEEE standards [15-19]. The last type of study has focused on the temperature increase that can result from a thermographic camera. Cellular phone at different frequencies and obliquely incident plane wave are applied to expose to the human head. They showed that the average SAR for the 10-g mass had a larger global correlation with the corresponding RF-induced temperature rise distribution. Their total SAR values were approximately 0.147–5.66 W/kg [20-22].

However, the mentioned studies about electromagnetic radiation due to mobile phones have been analyzed into details in the last one or two decades which have not informed the medical effects, especially regarding the temperature in the human brain or cognitive function. Moreover, studies have not been previously reported on the SAR from 5G devices, such as VR headsets. This study aimed to analyze the SAR from two head models that involved a mobile phone that had a working frequency in the range of 850 MHz to 1900 MHz for an average tissue mass of 1 g and 10 g. We focused on the change in SAR value and the interactions that had a medical effect. Furthermore, a VR headset with a frequency of 60 GHz include of the human head model to comparing with the mobile phone case. As is known, the working frequency of the antenna of mobile phones is either 900 MHz or 1800 MHz in the 2G band and up to 850 MHz or 1900 MHz in the 3G band of the global system of mobile communications in Thailand [23]. However, the working frequency of antennas of VR headsets is 60 GHz in the 5G band.

Specific Absorption Rate (SAR)

The SAR is a dosimetry measurement that indicates the amount of electromagnetic energy that biological tissue absorbs, presented in Watt per kilogram (W/kg). The measurement of the SAR is based on the E-field probe method and the thermographic method. The SAR is calculated from the time derivative of the incremental energy dissipated in an incremental mass contained in a volume element of a given density. The formula for SAR is [24-25]:

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

where: E – internal peak electric field, σ – conductivity, ρ – mass density. The conductivity and mass density are of the biological tissue. The electric field is obtained from the inhomogeneous Helmholtz equation. In thermographic experiments, the peak SAR can also be computed by [26]:

$$SAR = \frac{C \bullet \Delta T}{\Delta t} \tag{2}$$

where: C – specific heat of the biological tissue, ΔT – temperature rise at the point, Δt – exposure duration.

Tissue volumes that are commonly used to measure SAR are 10 g according to the ICNIRP Guidelines 1998 and the Radiation Protection Standard (Australia) and 1 g according to the American National Standard Institute (ANSI). In the cubic model, the total 10 g average SAR has been calculated from the SAR in the cube with a volume of 21.56*21.56*21.56 mm^3 (10.02 g). Likewise, the total 1 g average SAR has been calculated with a volume of 10*10*10 mm^3 (1 g) [27].

The ICNIRP and Australian standard limit the SAR value to 2 W/kg per 10 g of average mass. The American National Standards Institute (ANSI) set the limit for the SAR value at 1.6 W/kg per 1 g of average mass. Moreover, in 1991, the Institute of Electrical and Electronics Engineers (IEEE) recommended a method to protect against the negative effects on the human body, which can absorb energy from electromagnetic fields in frequencies ranging from 3 kHz to 300 GHz. Subsequently, the IEEE implemented the IEEE Std. 1528TM-2013 to provide a calculation of the peak spatial–average SAR for practical situations [28-30].

Medical Effect

Electromagnetic energy can overcome the temperature regulation of the body when the total SAR value exceeds 4 W/kg. At that point, tissues will overheat [31-32]. A 1-W/kg total SAR causes an increase of 1°C in the human body, taking thermal regulation into account. It is particularly important to avoid electromagnetic exposure of the head. Furthermore, the effects of electromagnetic energy on human cognition are listed in Table 1.

Table 1. Effects of electromagnetic energy on human cognition

Type of SAR	Amount (W/kg)	Frequency (MHz)	Effect
Avg.	0.683	900	Memory load was varied from 0 to 3 items in an n-back test.
Avg.	0.79	1800	Mobile phone use facilitates word recall memory in male but not female subjects only in the short term.
Peak	0.5	900	Exposure affects repeated simple and choice reaction times and causes an increase in local tympanic temperature with no effect on speed or accuracy measures, visual search task, or descending subtraction tasks.

Simulation Method

Model A (i.e., flat SAM) is an improved version of the head model named the SAM phantom, which is proved and referred to in the IEEE Std. 1528™-2013 and IEC 62209-1, as shown in Figure 1 (a) [33].

Model B, which is a combination of the flat SAM that surrounds the designed brain, has two layers, as shown in Figure 1 (b). The brain is an 85-mm radius equivalent sphere that imitates a realistic brain. The realistic brain has two main components: the outer part (i.e., grey matter) and the inner part (i.e., white matter). White matter affects thermal considerations and nervous system and is comprised of axons and myelin. However, gray matter only affects nervous system and consists of neurons and dendrites [35-36].

The thickness of skull of both models is approximately 5 mm [36]. The relative permittivity of the brain depends on frequencies, as shown in Table 2. The material of Model A is defined as a simple average liquid, and the material of Model B is defined as a composition; both models consist of the properties listed in Table 3.

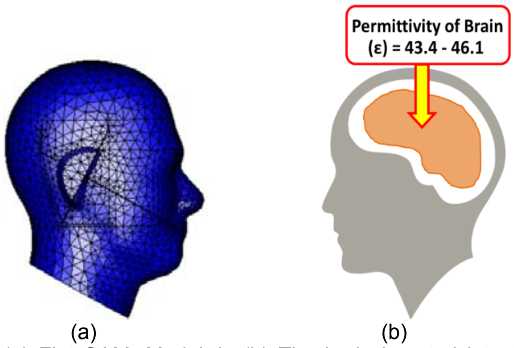

Fig.1. (a) Flat SAM; Model A. (b) The brain inserted into the flat SAM; Model B

Table 2. Relative permittivity of the brain

Frequency (MHz)	850	900	1800	1900
Relative Permittivity (ε_r)	46.1	45.8	43.6	43.4

Table 3. Electrical properties of both models

	Relative Permittivity (εr)	Permeability (μ)	Density (ρ)	Conductivity (σ)
Model A	42	1	1,000 kg/m^3	1 S/m
Model B	43.4–46.1	1	1,030 kg/m^3	0.77–1.15 S/m

The mobile phone model used for SAR simulation is a general monopole cell phone named “IEEE Mobile Phone” that meets the IEEE standard. The 1-W input power mobile phone consists of two components: a chassis and a monopole helical antenna, as shown in Figure 2. The chassis is made of a perfect electric conductor (PEC) ground plane. The distance between the head and the phone is 5 mm. The effective frequency of the mobile phone antenna is approximately 900 MHz, which is interpreted either through the magnitude of the S-parameter (S_{11}) or the return loss. The antenna design is confirmed by the simulation of S_{11}, as shown in Figure 3.

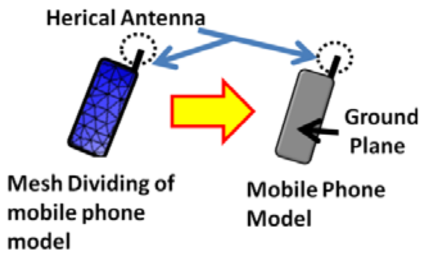

Fig.2. Mobile Phone model with the helical antenna and ground plane.

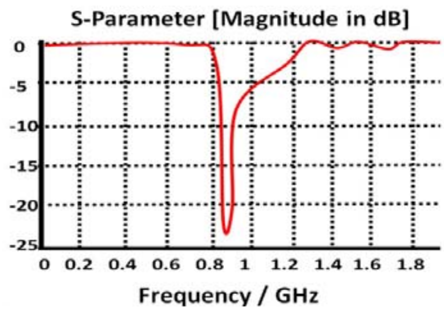

Fig.3. Simulation of the S-Parameter of the IEEE Mobile Phone 900 MHz (effective frequency of the monopole helical antenna).

The virtual reality headset model consists of two parts. The first part is a single band microstrip patch antenna that operates at 60-GHz millimeter wave [37], as shown in Figure 4. The other part is a case that is made from two types of material (i.e., polycarbonate and polyimide), as shown in Figure 5.

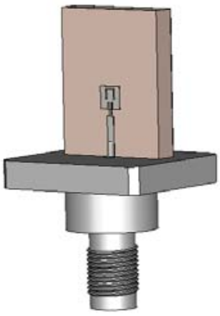

Fig.4. 5G 60-GHz antenna for the VR headset.

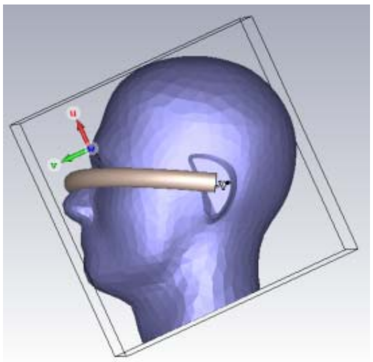

Fig.5. Model A with the VR headset.

The method used for mesh division is perfect boundary approximation (PBA), which uses sub-cellular data with a second-order algorithm for arbitrary shaped boundaries [38]. The numerical electromagnetic problem is analyzed by the transient or finite element method (FEM). The simulations are performed using the commercial application software CST, which uses these following processes. First, a surface on the anatomical model is selected for the average SAR calculation. Then, the search for 1-g or 10-g cube is iteratively accomplished, and integrated losses in the cube are obtained. These numerical schemes are utilized in case of boundary treatment according to the averaging standard in IEEE C95.3.

Results and Discussion

To begin with mobile phones, the peak and total SARs are simulated at four working frequencies and two averaging mass tissues with approximately 205,000 mesh cells. The four working frequencies include 850, 900, 1800, and 1900 MHz. The 900-MHz frequency is the effective frequency of the IEEE mobile phone antenna. The results of other frequencies in GSM, as mentioned above in the Introduction part, are compared with the result for 900 MHz. Depending on the standards, the two averaging mass tissues are 1 g and 10 g.

Table 4 shows that the peak SAR values increase with an increase in the frequencies for the 10-g averaging mass tissue. The peak SAR values of Model B are higher than those of Model A. Because Model B has two layers of biological tissues, the model exhibits the reflection and refraction of the wave. The peak SAR value of Model A is compared with that obtained by Eduard [39] for the 10-g averaging mass and 900 MHz; a difference of 0.15 W/kg was obtained. Besides, in Joo [40] for the 1-g averaging mass and 1800 MHz; a difference of 0.12 W/kg was gained.

Table 4. Peak SAR value for all simulation conditions

Frequency (MHz)	Mass Tissue (g)	Peak SAR (W/kg)	
		Model A	Model B
850	1	5.21	8.914
	10	6.33	6.6
900	1	5.49	9.136
	10	6.48	6.774
1800	1	0.21	22.63
	10	8.41	13.08
1900	1	0.284	23.41
	10	9.46	11.72

The peak SAR values of model B are considerably higher than those of the four types from the literature review. The peak SAR values are higher than the total SAR values, as shown in Table 5. The total SARs of model B are equivalent at the same frequency. This result may be fundamentally attributed to the impact of different relative permittivity.

Table 5. Total SAR value for all simulation conditions

Frequency (MHz)	Mass Tissue (g)	Total SAR (W/kg)	
		Model A	Model B
850	1	0.078	0.18
	10	0.158	0.18
900	1	0.082	0.21
	10	0.17	0.21
1800	1	0.03	0.27
	10	0.195	0.27
1900	1	0.08	0.316
	10	0.22	0.316

Furthermore, according to the tendency of the relative permittivity in the frequency term in Table 2, it is determined that the SAR values are the reverse variation of the relative permittivity. The results showed that the total SAR values were less than the limitation of the standards. In addition, higher computing performance is needed to increase the accuracy of the result due to many mesh cells and harmonic problems.

The SAR results in Table 4 (i.e., peak SAR) and Table 5 (i.e., total SAR) for mobile phones are compared with the medical aspects in Table 1, and the following conclusions can be made. First, all results do not exceed 0.79 W/kg except for model A 1-g average mass at 1900 MHz. Consequently, total SAR values do not cause temperature increase. Nevertheless, peak SAR produces an increase in temperature. Finally, memory load, short term memory, and local tympanic temperature are implemented as usual due to all SAR.

Table 6 shows the SAR results for the VR headset with a 60-GHz antenna. In the beginning, the SAR of the VR case made from polycarbonate is the highest among the three materials. On the other hand, the SAR of the VR case made from polyimide is the lowest. In addition, the total SAR does not depend on the material of the VR case. Next, total SAR of the lossy material is lower than that of the loss-free material since lossy material causes lost electromagnetic energy radiation. Furthermore, the total SARs of each material are the same. Moreover, the peak SAR of 1 g is higher than that of 10 g because of the smaller of cube 1 g average SAR. Furthermore, the peak SAR 1-g is approximately 5 times that of the peak SAR 10 g. Eventually, the SAR based on VR is much higher than that for mobile phone at 850-900 MHz but lower than that at 1800-1900 MHz.

Table 6. SAR values affected by the VR headset with different materials

Model	peak SAR	total SAR
Model A + VR (vacuum case) 10 g	9.3060	0.2457
Model A + VR (vacuum case) 1 g	55.0023	0.2457
Model A +VR (polyicarbonate (loss free) case) 10 g	9.3710	0.2470
Model A + VR (polyicarbonate (loss free) case) 1 g	55.8151	0.2470
Model A + VR (polyicarbonate (lossy) case) 10 g	9.1600	0.2576
Model A + VR (polyicarbonate (lossy) case) 1 g	49.1544	0.2576
Model A + VR (polyimide (loss free) case) 10 g	8.9210	0.2363
Model A + VR (polyimide (loss free) case) 1 g	52.9281	0.2363
Model A + VR (polyimide (lossy) case) 10 g	9.3714	0.2452
Model A + VR (polyimide (lossy) case) 1 g	50.1824	0.2452

The distribution of SAR values for all conditions is compared with those previously published in literature reviews, as shown in Table 7. Table 7, which consists of peak and total SAR, shows that the interval of each work exhibits the same trend. The lower SAR and total SAR of each groups are significantly different. However, the upper and peak SARs of this study predicting the VR headset with a high frequency band antenna at 60 GHz are approximately ten times over the others affected by mobile phones. Nonetheless, according to the health standards, all groups showed that SAR was within the limit.

Table 7. SAR distribution compared with those in literature reviews

Research	SAR (W/kg)
Group 1	0.016-3.11
Group 2	0.059-3.12
Group 3	0.199-9.95
Group 4	0.147-5.66
This work	0.03-55.82

Conclusions

According to the WHO and IEEE, it is essential to predict electromagnetic absorption by biological tissues for modern electronic devices as wireless virtual reality headset at a 60-GHz frequency compared with mobile phones at 850, 900, 1800 and 1900 MHz frequencies. The proposed variable is SAR, which is calculated using the perfect boundary approximation via the transient or finite element method and also interpreted by medical effects. The results show that the SAR values of flat SAM for the VR headset are higher than the flat SAM values for the IEEE mobile phone. For the mobile phone, the peak SAR values of flat SAM (model A) for the 10 g mass average and for the more realistic model (model B) for the 1-g mass average increased with an increase in the frequencies. The more realistic model (model B) generates higher SAR. For the VR headset, the peak SAR of each material is approximately 9 W/kg and 50 W/kg for 10 g and 1 g average masses, respectively. Regarding the material of case, the VR headset should be made from polyimide. In addition, the total SAR values did not surpass the restrictions indicated by worldwide benchmarks. Hence, VR headsets and mobile phones are safe. However, the 900-MHz antenna resulted in the SAR values with high precision in the 850-900 MHz range. New antennas in the 1800-1900 MHz range should be constructed to obtain SAR values with high precision. After comparing the SAR values in Tables 4-6 and the effects of electromagnetic energy on human cognition in Table 1, it was determined that the electromagnetic energy in all simulated conditions did not cause any harm. The more realistic model and CST can be used to predict SAR from other electronic devices. Nevertheless, further studies on the heat transfer and continuation of electromagnetic energy will provide more data to confirm that mobile phones, VR headsets and other electronic devices do not produce any harmful effects on human heads.

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