VOL. 22, NO. 1, 2023, 63-69
www.elektrika.utm.my
ISSN 0128-4428

ELEKTRIKA
Journal of Electrical Engineering

SAR Measurement from Mobile Phone and Its Effect to Human Body

Noor Azlinda Ahmad* and **Putri Fhazleen Shaharun**

Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Skudai, Johor, Malaysia

*Corresponding author: noorazlinda@utm.my

Abstract: Electromagnetic fields are created by radiofrequency waves. However, the RF emitted by a mobile phone's antenna is insufficient to cause significant heating of tissues in the ear or head. The focus of this research is to look further into SAR measurement of how much RF radiation is absorbed by tissues in the human body. A CST Microwave studio, a high-performance 3D EM analysis software, is used for this project to design, analyse, and measure electromagnetic (EM) components and systems, and perform SAR calculation as a post-processing step after the simulation. It is shown in the result that the human body does absorb energy from radiofrequency radiation emitting devices. Heating to the area of the body where a cell phone is held is the only consistently recognized biological effect of radiofrequency radiation absorption in humans, but heating is insufficient to measurably increase the body temperature.

Keywords: Electromagnetic field, radiofrequency. SAR measurement, biological effect.

Article History: received 21 August 2022; accepted 1 February 2023; published 28 April 2023.

1. INTRODUCTION

In the last few years, the number of individuals that own or use a smartphone has increased drastically according to Statista, 6.6 billion people use smartphones, and that is 83.72 % of the world's population. In comparison, there were only 3.7 billion users in 2016 or 49.40 % of the worldwide population [1]. The development of low-cost mobile phones and lower-cost service plans have contributed in promoting smartphone usage all across the Asia-Pacific region. In 2019, the Asia-Pacific region's smartphone usage rate was 64 %, with the figure estimated to surge to 81 % by 2025 [2]. Considering the rising number of the Asia-Pacific smartphone industry, Malaysia's mobile market is likely to increase rapidly to approximately 5 % per year in the coming years.

Mobile phones communicate by sending radio waves over a network of permanent antennas known as base stations. A mobile phone is a low-power, single channel two-way radio. It has a transmitter as well as a receiver. It emits RF radiation in order to communicate with the base station. Radio waves, also known as electromagnetic fields, transmit digitized sound or data in the form of oscillating electric and magnetic forces (EMF). Radio frequency waves are electromagnetic fields, and unlike ionizing radiation such as X-rays or gamma rays, they are thought to be incapable of breaking chemical bonds or causing ionization in the human body. Throughout the last two decades, a massive number of researches were conducted to determine whether mobile phones offer a possible health danger [3].

According to [4], the radiation released by the antenna of mobile phone is inadequate to cause considerable heating of tissues in the ear or head, however an increase in skin temperature potentially arise if the mobile phone is placed too near to the ear or head, blocking airways and circulation. In response to public and governmental concern, World Health Organisation (WHO) [5] through the International Electromagnetic Fields (EMF) Project has investigated scientific evidence of potential detrimental health implications from electromagnetic fields. Further, the International Body for Research on Cancer (IARC), a WHO specialized agency, assessed the genotoxic potential of radiofrequency fields, such as those emitted by mobile phones, in May 2011. The Malaysian Communications and Multimedia Commission (MCMC) also, is presently following recommendations on permitted exposure levels issued by Jabatan Telekom Malaysia in August 1998. These rules are based on worldwide standards intended to reduce the potential impact of radiation on health [6].

The amount of RF radiation can be absorbed by tissues in human body is determined based on SAR reading. It represents the average rate of energy absorption per kilogramme of tissue (watts per kg). This statistic is used to verify whether mobile phone meets the safety standards. The exposure limit is defined substantially below ranges believed to trigger biological damage, taking into account the body's ability to eliminate heat from tissues that receive energy from the mobile phone. The Federal Communications Commission (FCC) of the United States has set a SAR limit of 1.6 watts per kilogramme (1.6 W/kg) for RF exposure to radiation from mobile phones. According to ICNIRP (International Commission on Non-Ionizing Radiation Protection) [7], the localised SAR in the skull should be limited to 2 W/kg averaged across any 10 g mass of tissues in the head (0.02 W absorbed in each 10g mass of tissues in the head). This is because a SAR of 4W/kg is connected with a slight amount Celsius spike in normal body temperature.

2. METHODOLOGY

2.1 Simulation work

The accessible structured model from the component library and generated CAD 3D files were used to model the human biological model and the mobile phone models for this project. The Specific Anthropomorphic Mannequin (SAM) is a human head and handgrip model that comprises of a plastic shell filled with a tissue imitating liquid that is classified as broadband frequency-dependent materials. The 90th percentile of male population head size was used to define it for standardized certification reasons. For a comprehensive mobile phone system simulation, the mobile phone was also employed as part of the setup from SAM Head, hand and mobile phone given by CST Studio. Other mobile phone models were selected from the 3D CAD database that is exact replicas of the real phones. The materials as well as its components are appropriately specified, including their dielectric properties.

Microwave and radiofrequency waves template are used as the project template to simulate and measure the exposure. The template can also be used for any field exposure, be it radiation, or SAR analysis measurement. The next step is to specify all of the exposure field specifications, such as the maximum and minimum frequency, as well as the types of field monitors utilized. After initializing all of the relevant field exposure details, the human head and mobile phone hand held models were imported as a sub-project file from the project library. The model must then follow the dielectric characteristics of human body tissue by specifying the human body structures' mass-energy absorption coefficients, such as rho, ρ (permittivity) and mu, μ (permeability).

2.2 Simulation Model

2.2.1 Human head and body model

The SAM head (Standard Anthropomorphic Model) is a homogenous model of the human head consisting of two parts, fluid and shell. There are three elements to this SAM model: a head, a hand, and a cell phone, as represented in Figure 1. This model can be obtained from CST component library. It shows how to construct up a systematic mobile phone system simulation, complete with a SAR evaluation. The head liquid and hand material are specified as broadband frequency-dependent materials that meet the requisite qualities at all frequencies of interest.

Figure 1. SAM Head, Hand and Mobile Phone model

Meanwhile, A comprehensive model of both complicated anatomical structure and the tissue characteristics, which often vary with age, frequency, and temperature, are required for realistic modelling of EM propagation throughout the body. CST provides voxel based and CAD-based body models as presented in Figure 2. Variety of ages, sizes, and sex of the model are tabulated in Table 1.

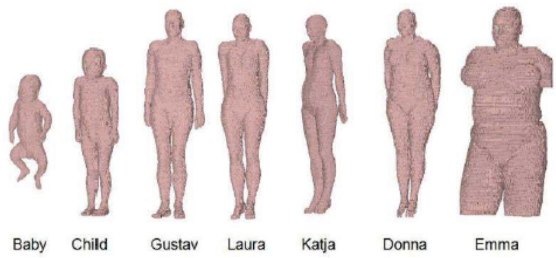


Figure 2. CST Voxel Family Model

Table 1. CST Voxel Data

Model	Age	Sex	Height (cm)	Weight (kg)
Baby	8 month	F	57	4.2
Child	7 yrs.	F	115	21.7
Gustav	40 yrs.	F	176	79
Laura	26 yrs.	F	170	81
Katja	38 yrs.	M	176	69
Donna	43 yrs.	F	163	51
Emma	43 yrs.	F	163	62

2.2.2 Mobile Phone Model

To accomplish DCS band (3G, at point 2 and 3), the mobile phone model system uses two patch antennas placed on the phone's back cover. An extra patch antenna and two conformal PIFA antenna on the both side of the model are also installed to cover specific bands for 4G IMT-E (E-UTRA band 7, at point 6) and Wi-Fi or Bluetooth bands (at point 4 and 5), as shown in Figure 3.

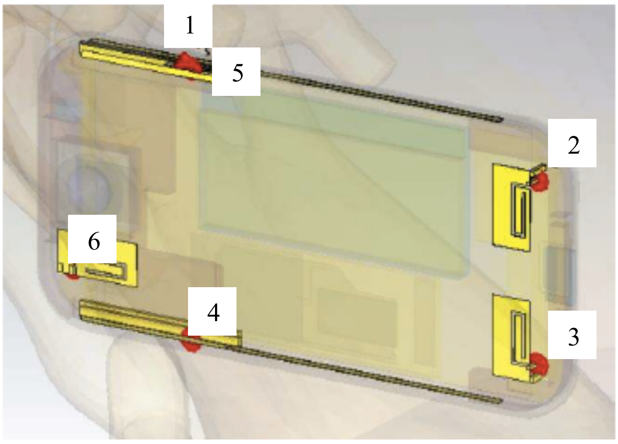


Figure 3. Mobile phone model

In addition, two imitation models of commercially available phones were utilized for the purpose of conducting research on the SAR value employing a variety of mobile phone models. It is to imitate a 3G model by using a Nokia 5800 design that follows the real device's respective material and components, and it is to imitate a 2G model by using a Siemens M65 that also follows the real device's respective component and material.

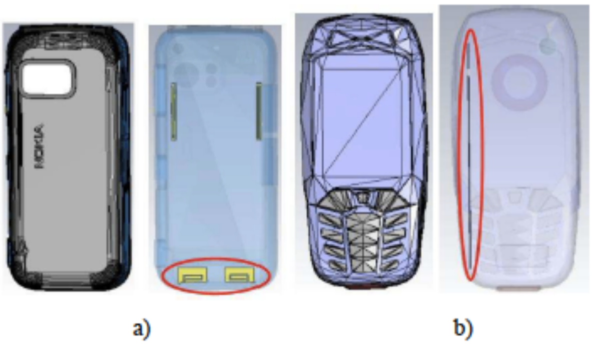


Figure 4. Imitated phone model of (a) Nokia 5800 and (b) Siemens M65.

In order to investigate the effects of EM field exposure from mobile phone to human body, two factors that will be influencing public safety and health hazards in term of the RF exposure was analyzed and presented un this paper. The factors are effect of distances between mobile phone and human body, the frequency variations of field monitor used such as far field type and types of mobile phone used. The results are presented and discussed in the following section.

3. RESULTS AND DISCUSSION

3.1 Effect of distance

The distances between the human head and mobile phone are simulated at 900 MHz, with the initial distances set to 0 mm. As can be seen in Figure 5 the EM field radiation strength are visualized as a reddish-orange colored contour producing a -12.25 dB radiation efficiency and its total efficiency is -17.72 dB. Meanwhile the SAR produced by the EM radiation is 1.49 W/Kg at 10 g body averaged presented in Figure 6 and 3.09 W/Kg at 1 g body tissue averaged as shown in Figure 7.

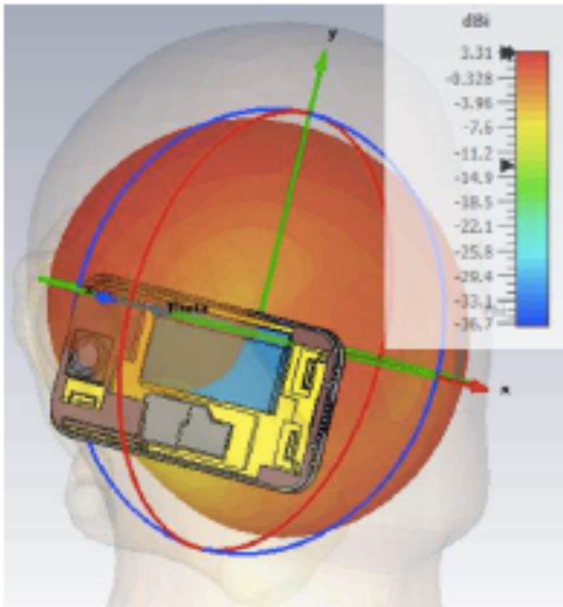


Figure 5. Far field radiation pattern at distance, d = 0 mm

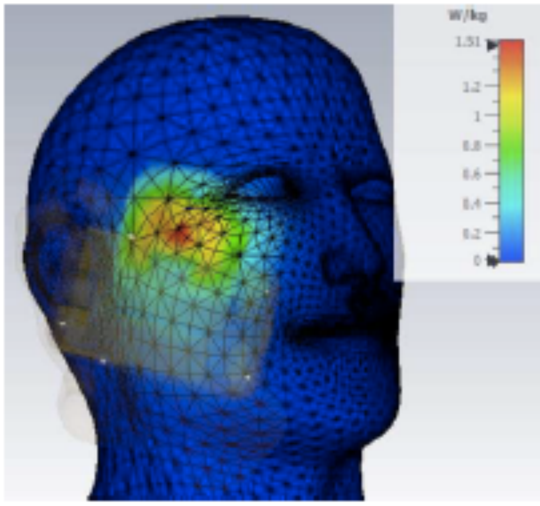


Figure 6. SAR Distribution at 10g body tissue averaged

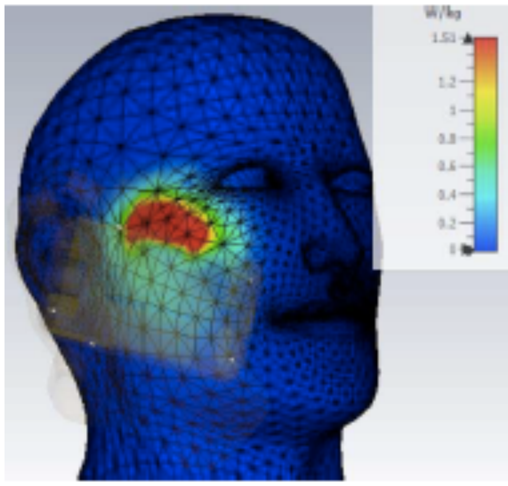
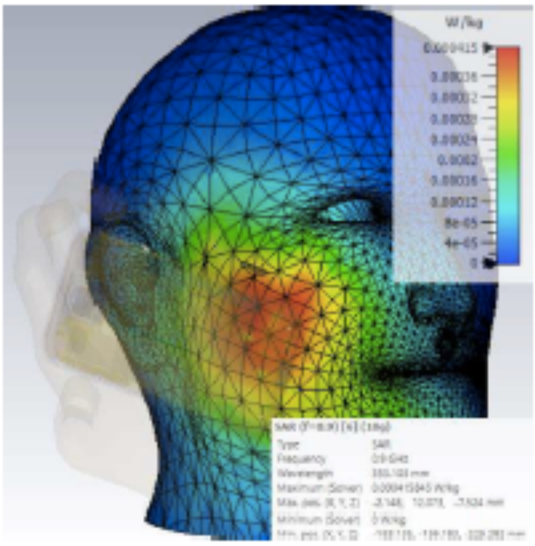
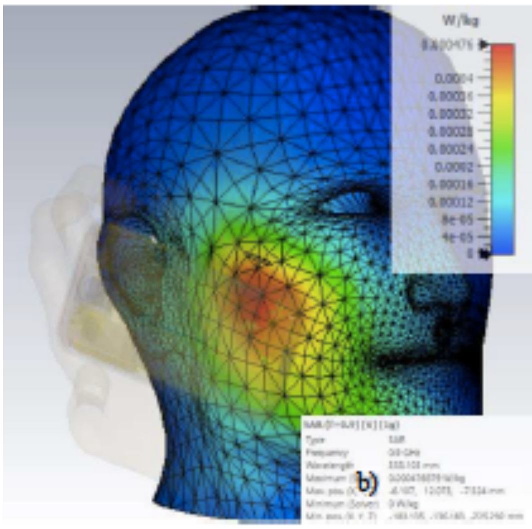


Figure 7. SAR Distribution at 1 g body tissue averaged.

The distance between the human head and the mobile phone is then changed to 50 mm, and the simulation is still running at 900 MHz. The EM field radiation colored contour of yellowish-orange produces -5.38 dB radiation efficiency and a total efficiency of -12.06 dB. The SAR generated by EM radiation is 0.00041 W/Kg at 10 g body averaged and 0.00047 W/Kg at 1 g body tissue averaged (Figure 8), indicates that about 0 W/kg SAR values measured on the human head. Table 3 tabulates the calculated results of the remaining SAR measurements taken at a variety of distances.



(a)



(b)

Figure 8. Far field radiation pattern at distance, d = 0 mm SAR Distribution shown at (a) 10 g body tissue averaged and (b) 1 g body tissue averaged.

As the distance between the human head and the mobile phone increases, the EM field radiation of the farfield reading shows that greater reflection occurs during antenna signal transmission. The correlation between the SAR reading and the distances increase, the SAR reading decreases. According to [8], shorter gap distances result in higher field intensities, as measured by SAR. The allowable limit at 1.6 W/kg also indicates that at 0 mm apart, during operating frequency of 900 MHz, 2.1 GHz and 3.5 GHz, the SAR reading are above threshold. International authorities considered the SAR values at 10 g body tissue averaged to be acceptable since it is below their limit of 2.0 W/kg, however at 1 g body tissue averaged, the SAR values is found to be above the acceptable limits. When the SAR limits are anticipated of being exceeded, it is not safe for public health and can cause heating to the body tissue.

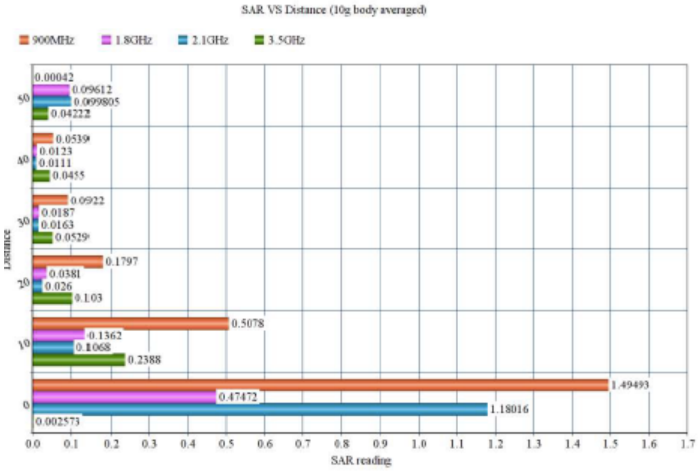


Figure 9. Correlation of SAR values (W/kg) and Distance (mm) at 10 g body averaged.

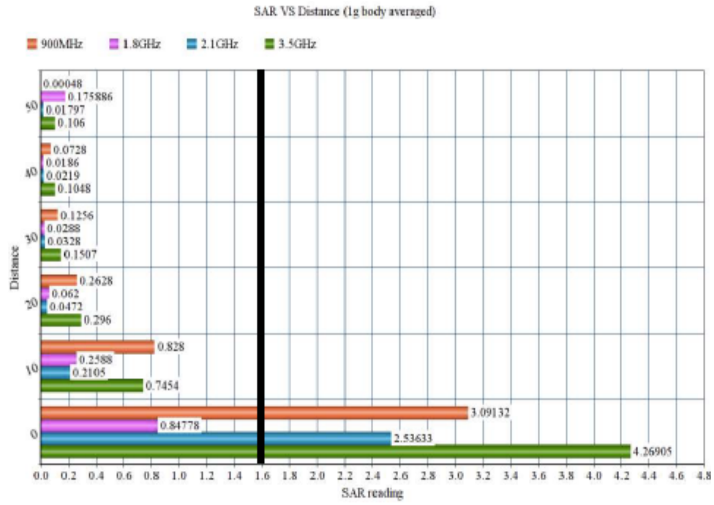


Figure 10. Correlation of SAR values (W/kg) and Distance (mm) at 10 g body averaged.

3.2 Effect of frequency

The variations in frequency ranges were assessed as another variable in this study. The primary communications bands examined are 900 MHZ and 1.8 GHz, which correspond to the 3G and 4G bands, respectively. At frequency 900 MHZ, EM field radiation and SAR values obtained is shown in Figure 8 previously. Meanwhile, at frequency 1.8 GHz, the EM field radiation pattern, presented in yellowish orange in Figure 11 has a radiation efficiency of -9.37 dB and a total efficiency of -17.78 dB, which describes their efficiency in transmitting the signals when, the efficiency in range from -15 dB to -20 dB. This indicates that the signal shows less reflection.

Table 3. SAR Values at varieties of distances for (a) 1g body averaged and (b) 10 g body averaged

Head and Hand		Frequency (GHz)				
Distance (mm)		0.9±0.5 (2G)	1.8±0.5 (3G)	2.1±0.5 (4G)	3.5±0.5 (5G)	Standard Limits
10mm	1g-SAR (W/Kg)	0.8280	0.2588	0.2105	0.7454	1.6W/kg
20mm	1g-SAR (W/Kg)	0.2628	0.0620	0.0472	0.2960	
30mm	1g-SAR (W/Kg)	0.1256	0.0288	0.0328	0.1507	
40mm	1g-SAR (W/Kg)	0.0728	0.0186	0.0219	0.1048	

(a)

Head and Hand		Frequency (GHz)				
Distance (mm)		0.9±0.5 (2G)	1.8±0.5 (3G)	2.1±0.5 (4G)	3.5±0.5 (5G)	Standard Limits
10mm	10g-SAR (W/Kg)	0.5078	0.1362	0.1068	0.2388	2.0W/kg
20mm	10g-SAR (W/Kg)	0.1797	0.0381	0.0260	0.1030	
30mm	10g-SAR (W/Kg)	0.0922	0.0187	0.0163	0.0529	
40mm	10g-SAR (W/Kg)	0.0539	0.0123	0.0111	0.0455	

(b)

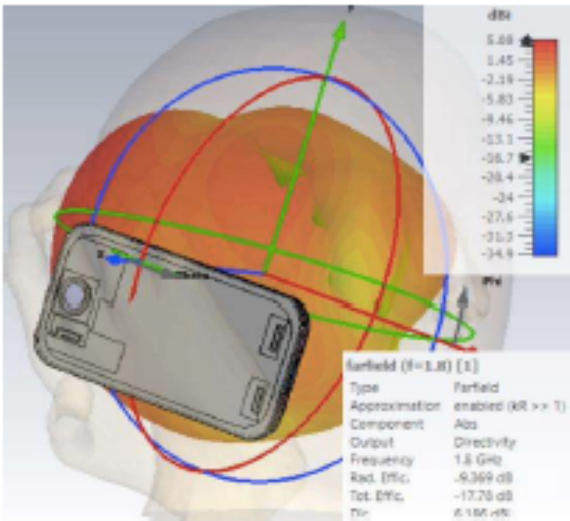
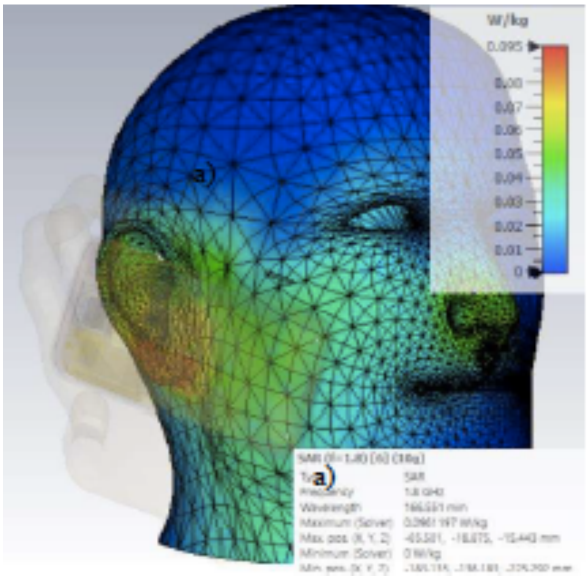


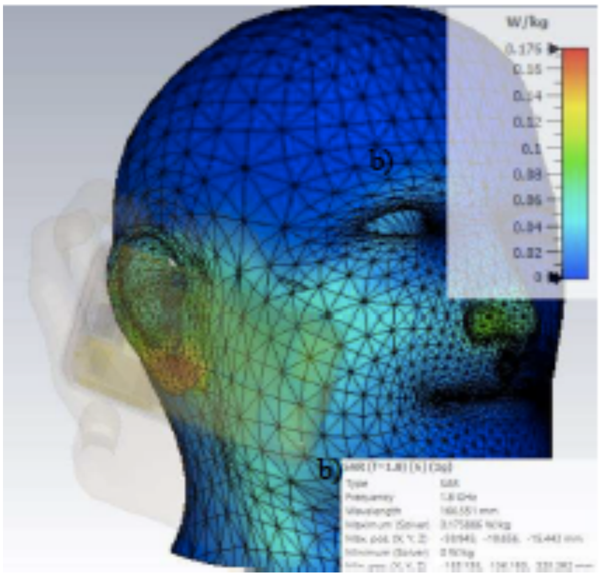
Figure 11. Far field radiation pattern at 1 GHz frequency

Further, Figure 12 shows the SAR distribution, which was 0.096 W/kg for 10 g body tissue averaged and 0.18 W/kg for 1 g body tissue averaged.

Based on the simulation results presented, the relationship between SAR and frequency are measured at 0 mm apart using 4G phone mobile at 900 MHz, 1.8 GHz, 2.1 GHz, 2.3 GHz and 3.5 GHz (Figure 13). At 10 g body averaged, all of the results are acceptable, but, when compared to 1 g, several results are greater than the standard limit that have been established by the authorities, which is 1.6 W/kg. Based on the simulation results, the real operating frequencies for 4G are at 1.8 GHz and 2.1 GHz. Consequently, it is possible that this could be the reason why only these two values are acceptable and fall within the restrictions for both averaged masses.



(a)



(b)

Figure 12. SAR distribution at 1 GHz frequency for (a) 10 g body tissue averaged and (b) 1 g body tissue averaged.

3.3 Types of mobile phone model

The Specific Absorption Rate (SAR) of various different mobile phone models was analyzed in order to explore their absorption, regardless of the materials and dielectric factors that may affect SAR of each model. SAM, the current biological head model in use from previous simulation, was also used in this investigation to test the 2G, 3G, and 5G phone models, which were all held between the human head's cheek and the hand model. Each model's operating frequency corresponds to a certain frequency band, 850 MHz and 1900 MHz for the 2G model, 1900 MHz and 2.1 GHz for the 3G model, and 6.0 GHz and 10 GHz for the 5G model. Figure 14 shows the color-contoured radiation pattern of their electromagnetic field. The SAR values obtained for different types of phone model are summarized in Table 4.

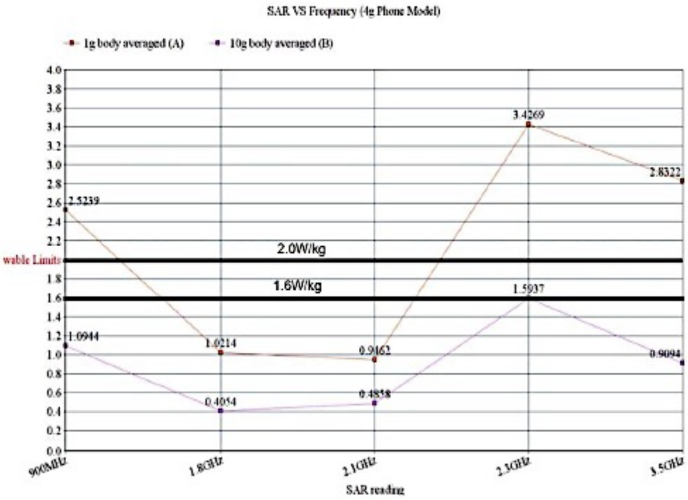
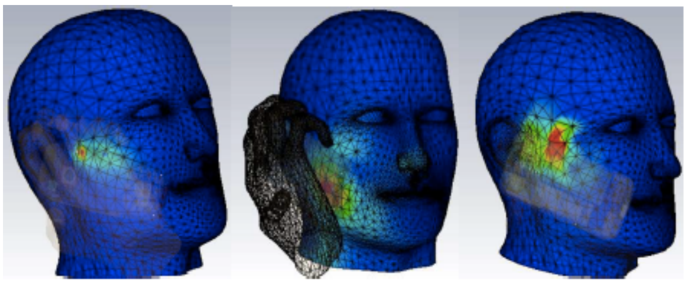


Figure 13. Correlation of SAR (W/kg) values and Frequency (Hz) at 1 g and 10 g body averaged



(a) (b) (c)

Figure 14. SAR Distribution for (a) 2G model (b) 3G model and (c) 5G model.

The operating frequencies that are utilized for each model follow the frequency bands that are used for that model. For example, the 5G model operates at frequencies 4.8 GHz and 6.0 GHz, the 3G model operates at frequencies 1.9 GHz and 2.1 GHz, and the 2G model operates at frequencies 850 MHz and 1.9 GHz. Therefore, the correlation between SAR and different models of mobile phones does not significantly differ from one another. However, the SAR reading for the 4G model at 1 g body tissues average that works at 2.3 GHz exceeds the permissible level of 1.6W/kg as illustrated in Figure 15.

Table 4. SAR Values for different types of mobile phone model

Phone Model	Frequency	1g-SAR (W/Kg)	10g-SAR (W/Kg)
2G	850MHz	0.00749	0.00203
	1.9GHz	0.01629	0.00824
3G	1.9GHz	0.000294	0.000179
	2.1GHz	0.000875	0.000475
4G	2.1GHz	0.9462	0.4858
	2.3GHz	3.4269	1.5938
5G	4.8GHz	0.0562	0.0146
	6.0GHz	0.0079	0.0018

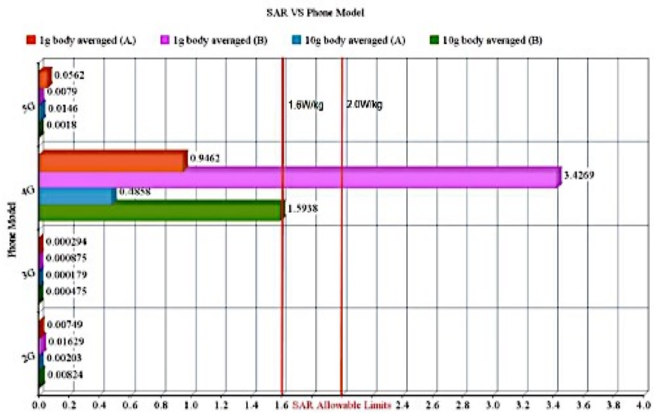


Figure 15. Correlation of SAR (W/kg) values and Different Phone Models at 1 g and 10 g body averaged.

From the simulations that have been conducted, it can be seen that factors such as the distance between the telephone and the human head used, as well as the frequency variation of our communication band and their phone models structured and materials also will give various SAR readings. SAR readings should be within the limitations that have been introduced by the authoritative body or agency entrusted with regulating the value of SAR on the human body before it could be commercialized as to ensure public health and safety. There is no substantial evidence that those exposed to levels at or below the ICNIRP limits [7] for localized SAR are at risk for serious health effects, including cancer.

4.0 CONCLUSION

In conclusion, the result of EMF exposure between mobile phone and human can be analyzed through its specific absorption rate (SAR) of the body tissue and the impact of the distances, frequency and bands, and different phone models between the human model and the mobile phone model. Where it is aimed to compare the results with the limits, 1.6 W/kg for averaged of 1g body tissue and 2.0 W/kg for 10g, set by the authorities, International Committee of Non-Ionizing Radiation Protection (ICNIRP), World Health Organization (WHO) and IEEE [9].

ACKNOWLEDGEMENT

This research is fully supported by TDR grant, 06G50 and CRG grant 4B486. The authors fully acknowledged Ministry of Higher Education (MOHE) and Universiti Teknologi Malaysia for the approved fund which makes this important research viable and effective

REFERENCES

[1] Turner, A. (2022, June 30). How many people have smartphones worldwide (July 2022). BankMyCell. Retrieved July 13, 2022, from https://www.bankmycell.com/blog/how-many-phones-are-in-the-world

[2] Müller, J. "Malaysia: 4G LTE population coverage 2020". Statista. Retrieved January 4, 2022, from https://www.statista.com/statistics/1051191/malaysia-4g-lte-populationcoverage/

[3] Kunter, F. Ç., Gunduz, C., & Seker, S. S. "Computation of SAR and temperature values in the human head due to 2G, 3G, 4G mobile wireless systems". Journal of Aerospace Technologies, vol. 11, issue 1, pp. 1-6, 2018.

[4] S. Kumari and S. Raghavan, "Biological effects of microwave," International Conference on Information Communication and Embedded Systems (ICICES2014), 2014, pp. 1-6, doi: 10.1109/ICICES.2014.7034127.

[5] World Health Organization. (2018). Electromagnetic fields and public health: mobile phones. 2014.

[6] Kwan-Hoong, N., "Radiation, mobile phones, base stations and your health." Malaysian Communications and Multimedia Commission, 2003.

[7] International Commission on Non-Ionizing Radiation Protection. *Guidelines for limiting exposure to electromagnetic fields (100 kHz to 300 GHz)*. Health physics, 118(5), 483-524, 2020.

[8] Wessapan, T., Srisawatdhisukul, S., & Rattanadecho, P. "Specific absorption rate and temperature distributions in human head subjected to mobile phone radiation at different frequencies". International Journal of Heat and Mass Transfer, 55(1-3), 347-359, 2012.

[9] IEC/IEEE International Standard. Determining the peak spatial-average specific absorption rate (SAR) in the human body from wireless communications devices, 30 MHz to 6 GHz-Part 1: General requirements for using the finite-difference time-domain (FDTD) method for SAR calculations. IEC/IEEE 62704-1: 2017.