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EFFECTS OF ELECTROMAGNETIC ABSORPTION TOWARDS HUMAN HEAD DUE TO VARIATION OF ITS DIELECTRIC PROPERTIES AT 900, 1800 AND 1900 MHz WITH DIFFERENT ANTENNA SUBSTRATES

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Abstract—This paper analyzes and discusses the effect of the electromagnetic absorption by human head against variation of head dielectric properties at 900, 1800 and 1900 MHz. The characteristics of helical antenna and its substrates with variation in human head dielectric properties are simulated by implementing finite-difference time-domain (FDTD) method using CST Microwave studio. The variations in human head dielectric properties were manipulated by increasing and decreasing 10% and 20% of each of the human head dielectric properties. In this paper, SAR values increase with increment of head conductivity, and increment of head permittivity and head density lead to decrement of SAR values. Helical antenna with substrate of FR4 results in higher SAR values in all frequency exposures. The head SAR values are higher with higher frequency exposures. The helical antenna with substrate of Rogers RO3006 (loss free) is found to be better over FR4 and Rogers RO4003 (loss free), which contributes towards much lower SAR values in all GSM frequency bands exposure.

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1. INTRODUCTION

Mobile phone technology was introduced in the early twentieth century. Now the technology has rapidly evolved and been utilized across the globe. Though this technological front is important, we need to be aware of some inherent dangers that it presents. Microwave radiation have been discussed and debated among researchers in this field. This radiation affects human health which disrupts the biological system of human body by electromagnetic waves emitted from the mobile phone towards its user [1–9]. There was also a claim from previous research that with over 10 years of using this technology, radiation from mobile phone potentially doubles the risk of brain tumor at the side of the head where the mobile phone has been used over a period of time [10]. Research found that the risk of brain cancer doubled in adults with overuse of mobile phone and five times among youngsters [11]. Recently, the World Health Organization (WHO) have stated that the mobile phone potentially leads to brain cancer [12–17]. The International Agency of Research Cancer (IARC) has grouped electromagnetic fields into Group 2B which is carcinogenic towards human. A lot of concerns regarding wireless devices safety have been discussed due to abundance application of wireless communication in these days. Microwaves radiated from mobile phone interacted with body tissues which produce internal electric and magnetic fields and cause thermal effect with close proximity of handset towards the body in particular time duration [18, 19]. Investigations have been done pertaining the effects of radio frequency (RF) radiation upon human body using various models and scenarios [20].

Several international authoritative bodies are responsible for regulating safe SAR limit in exposed onto human tissues [21], including International Commission on Non-Ionizing Radiation Protection (ICNIRP) in Europe. The ICNIRP regulates safe limit of SAR of 2 W/kg over 10 g sample of body tissue. Japan, Brazil and New Zealand are the other countries following this regulation. In the United States, Federal Communications Commission (FCC) set SAR limit of 1.6 W/kg over 1 g of body tissues [21–23]. Other countries abiding to this standard are Canada, Australia and Taiwan. In Malaysia, the authoritative body of Malaysian Communication & Multimedia Commission (MCMC) regulates safe SAR limit of a mobile phone that follows the standard of ICNIRP.

RF radiations that penetrate through human body from mobile phone are measured in terms of SAR. SAR denotes power absorbed by human from handset over certain volume of body tissue [24–27]. SAR is directly proportional to body conductivity and inversely proportional to body permittivity [28]. SAR is influenced by dielectric values of human body, and these values are very much dependent on the orientation, human-body and frequency exposure. The conductivity, σ, and relative permittivity, ε, of human tissues are the determining factors for both optimal RF communication and dosimetry [29–32]. Human body tissue with higher water content is more susceptible to absorbing radiation or so called power radiated from handset. Higher water content shows that the particular body tissue is greater in conductivity which increases SAR values. The permittivity and conductivity are frequency dependent [2, 33]. The peak of spatial SAR in a child and adult head models is exposed to 900 MHz mobile telephone using the finite-difference time-domain (FDTD) method, and it is found that variation of the 1 g or 10 g average spatial SAR peak with different dielectric properties is within 10% [33, 34]. The average SAR values are always inversely proportional with variations of body permittivity. There is also some estimation of the dependence of SAR values on the variability in dielectric values which should be determined.

The specific absorption rate has been adopted as the reliable parameter for RF power safety for performing magnetic resonance imaging experiments proposed by Rojas et al. [35]. They have calculated SAR using numerical method based on finite element method and 3D model of a rat's brain modeled using the software AUTODESK 3DS MAX. This brain model has adopted the tissue properties including the tissue's conductivity and permittivity from a database of Gabriel et al. 1996 [36]. The authors have developed a parametric model to describe the variation of dielectric properties including the permittivity and conductivity of body tissues as a function of frequency. The body tissues' conductivity and permittivity are frequency dependent. Therefore, at each frequency exposure, the body tissues have specific dielectric properties. In Gabriel et al.'s experiment the frequency spectrum was from 10 Hz to 100 GHz. Since Rojas et al. calculated SAR at frequencies of 10, 50, 100, and 300 MHz, the tissues' conductivity and permittivity are included in the mentioned database prepared by Gabriel et al.

This paper focuses on analysis of the effect of electromagnetic absorption towards human head with variations of dielectric properties with frequency exposure of 900, 1800 and 1900 MHz together with different antenna substrates.

2. MODELS AND METHOD

2.1. Models

The model used for the head was the Specific Anthropomorphic Mannequin (SAM) Phantom with mobile phone model attached together with helical antenna. The head model consists of inner and outer layers having specific dielectric properties similar to an actual human head. The dielectric properties were constant at all times at a particular frequency exposure, and its properties were changed due to particular changes towards the head. The helical antenna attached onto the handset was the radiation source, and electromagnetic absorption upon the head was measured. Operational frequencies used in this work were 900, 1800 and 1900 MHz. The effects of SAR values were also analyzed using three different substrates of the antenna which were FR4, Rogers RO3006 (loss free) and Rogers RO4003 (loss free). Variations of 10% and 20% of each of the head's dielectric properties were made, and SAR values were evaluated.

Dielectric properties of substrates for helical antenna are shown in Table 1.

Table 1. Dielectric properties of substrates for helical antenna.

Type of Substrate	Permittivity, ε_r	Conductivity, σ [S/m]
Rogers RO3006 (loss free)	6.15	0.61
Rogers RO4003 (loss free)	3.38	0.71
FR4	4.30	0.27

Homogeneous human head dielectric properties at 900, 1800 and 1900 MHz are listed in Table 2.

Table 2. Homogeneous human head dielectric properties.

Frequency [MHz]	Permittivity, ε_r	Conductivity, σ [S/m]	Density, ρ [kg/m^3]
900	41.5	0.97	1030
1800	40.0	1.40	1030
1900	40.0	1.40	1030

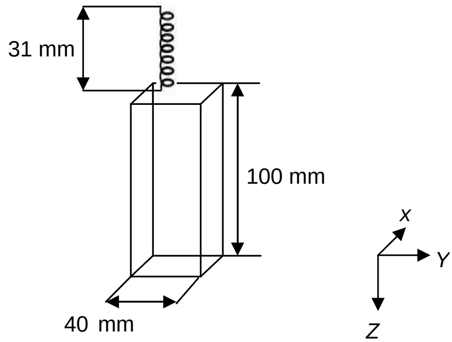


Figure 1. Helical antenna with mobile phone model.

The homogeneous head model used was SAM Phantom with Helix Antenna. A simple Perfect Electric Conductor (PEC) conducting box was modeled as a mobile phone with dimensions of $18 \times 40 \times 100$ mm ($X \times Y \times Z$). The length and radius for helical antenna are 31 mm and 5 mm, respectively. The dimensions of the helical antenna with mobile phone model are shown in Figure 1.

2.2. Method

The whole work of this paper used Computer Simulated Technology (CST) Microwave Studio 2011 for all simulations. The technique of finite integration time-domain (FITD) of finite-difference time-domain (FDTD) method was applied to run all simulations and to calculate SAR values. Dielectric properties for the homogeneous human head and antenna substrate were set accordingly. This FDTD [37, 38] method calculates SAR values by dividing the head cells into smaller cells with proper meshing properties.

Thereby approximately 5 mm of separation distance between human head and the handset was set. Mesh properties had been set from mesh density control by selecting lines per wavelength of 8, lower mesh limit of 10, mesh line ratio limit of 200, hexahedral mesh type and having total mesh cells of 1,835,460. There are two general holding positions of the mobile phone used by the users which are on cheek and tilt positions. The orientations of the mobile phone are shown in Figure 2.

SAR is a measure of power radiated absorbed by human body over specific volume of the head tissue and calculated in terms of Watts/kilogram (W/kg). The following is the equation to calculate

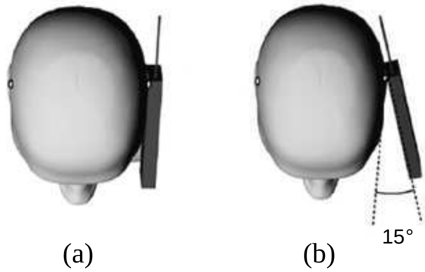


Figure 2. (a) Cheek position. (b) Tilt position.

SAR values.

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

where σ is the tissue conductivity (S/m), E the root mean square (rms) electric field (V/m), and ρ the tissue density (kg/m^3). The output power used for this simulation was 0.25 W. This output power of mobile phone or the radiated power could go as high as 1 W or 2 W depending on the location between the base station and mobile station. Further away from those two stations there is higher radiated power from mobile phone. The method used to calculate SAR in this simulation is the IEEE C95.3 standard.

3. EFFECT OF HUMAN HEAD TISSUE PROPERTIES ON SAR DISTRIBUTION

3.1. Variations of Dielectric Properties on SAR Values

Each part of the human body had different dielectric properties dependent on the frequency exposure. The work in this paper focused on the effect of electromagnetic absorption onto the human head. The dielectric properties in the head remained the same at all times unless the head underwent such changes, then only the properties also changed accordingly. The properties consist of head conductivity, σ, and head permittivity, ε. Once the head conductivity increases, SAR values also increases. SAR value contradicts with head's permittivity where increases in permittivity result in drop of SAR values. The conductivities of human give more significant effect on SAR values in most frequency exposure. This can be analyzed from the RF energy absorbed towards human and presented in terms of SAR values [10]. This electromagnetic (EM) radiation is absorbed more from handset by human tissues with higher conductivity than human tissues with lower conductivities. However, the areas of human body with lower conductivity and SAR values had a potential of absorbing the energy of adjacent area of higher conductivity and higher SAR values.

3.2. Different Frequency Exposure

At different frequency exposures, SAR values varied. Generally, total radiated power are lower in higher frequency, and the maximum SAR values are lower in lower frequency [15], which shows higher penetration of EM towards the head, thus, more radiation is deposited on human head, and the SAR values increase.

3.3. Different Antenna Substrate

Each substrate used to build an antenna had its own dielectric properties and thus had specific potential of absorbing and depositing the radiation from the mobile phone onto human head. Particular substrate with higher conductivity generally deposits higher radiation towards the head rather than substrate of lower conductivity. For instance, antenna substrate with higher conductivity deposits radiation onto human with lower conductivity. This may not hold true for SAR values as compared to antenna substrate of higher conductivity onto human with higher conductivity.

4. RESULTS AND DISCUSSION

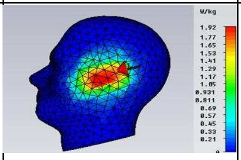
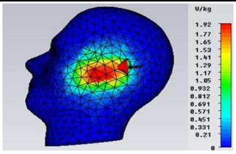
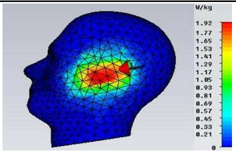
In this section, results will be discussed based on the SAR values at each operational frequency with variations of 10% and 20% of human head dielectric properties and with different types of helical antenna substrate used. Also, SARs of 1 g and 10 g of head tissue and radiation pattern from the simulations will be further discussed.

4.1. SAR at 900 MHz

Each of the SAR values presented in the following tables (3–6), consists of three different antenna substrates, namely FR4, Rogers RO3006 (loss free), and Rogers RO4003 (loss free) with variations of dielectric properties of head.

The SAR values with variations of dielectric properties of human head for all three substrates have the same trends. The red color denotes the highest radiation deposited in the head area while the blue color area denotes the head area with lower radiation from handset.

Table 3. SAR values of head without dielectric variations.

Antenna's substrate	FR4		Rogers RO3006 (loss free)		Rogers RO4003 (loss free)	
						
Values of SAR (W/kg)	1 g: 1.921	10 g: 1.403	1 g: 1.924	10 g: 1.405	1 g: 1.921	10 g: 1.402

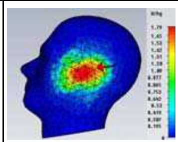
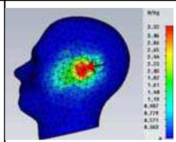
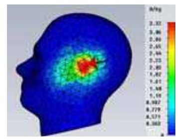
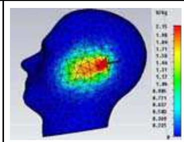
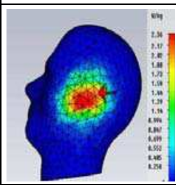
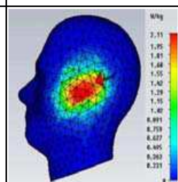
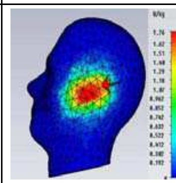
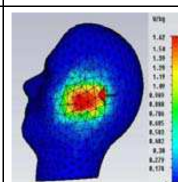
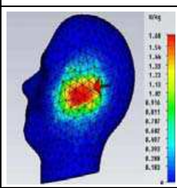
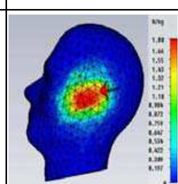
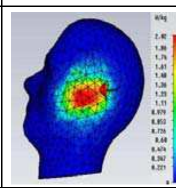
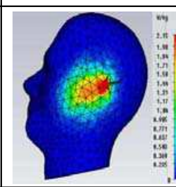
The highest human head SAR values resulted from using antenna substrate of FR4 over the rest substrates. Specific dielectric properties of each substrate influenced SAR values. Substrate with higher conductivity was able to conduct more electricity and more power deposited onto the head and increased SAR values. Table 4 shows SAR values of head with antenna substrate of FR4. Table 3 shows the normal SAR values without variations of dielectric properties for 1 g and 10 g of head tissue samples with antenna substrate of FR4 are 1.9214 W/kg and 1.40236 W/kg, respectively. SAR values increased with increased human head conductivity. Head with higher conductivity absorbed more radiation from handset and thus, resulted in higher SAR values. The conductivity is directly proportional to SAR values whereas in density it is inversely proportional. Human head with higher density had lower resolution in calculating SAR values and resulted in lower SAR values. Overall, SAR values are higher in lower volume of head tissue than higher volume of head tissue. It was found that head tissue of 1 g resulted in higher SAR values over 10 g of head tissues. It is shown that 1 g head tissue tends to absorb more power radiated from handset, because the power emitted from the antenna of a handset was well distribution over 1 g of head tissue.

4.2. SAR at 1800 MHz

Each of the SAR values presented in the following tables (7–10), which consist of three different antenna substrates, including FR4, Rogers RO3006 (loss free), and Rogers RO4003 (loss free) with increased and decreased head dielectric properties.

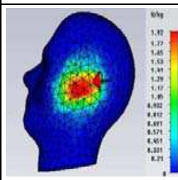
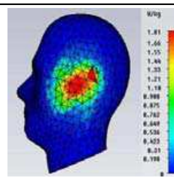
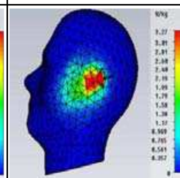
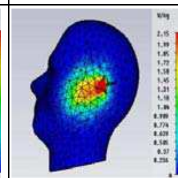
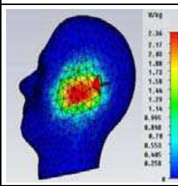
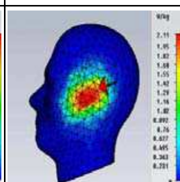
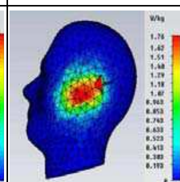
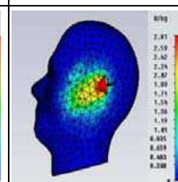
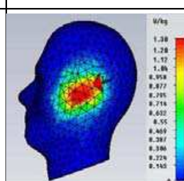
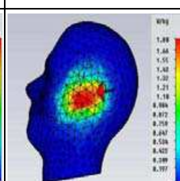
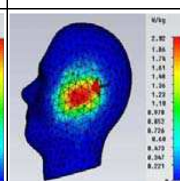
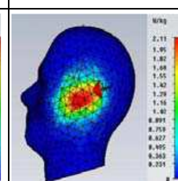
The effects of radiation onto human head are presented in all tables. The head area receives the highest radiation indicated with the red color area whereas the blue area denotes the head area absorbing lowest radiation from handset.

Table 4. SAR values with antenna substrate of FR4.

Changes of Permittivity	ε − 20%		ε − 10%		ε + 10%		ε + 20%	
								
Values of SAR (W/kg)	1 g: 1.786	10 g: 1.252	1 g: 3.323	10 g: 2.064	1 g: 3.263	10 g: 2.037	1 g: 2.145	10 g: 1.413
Changes of Density	ρ − 20%		ρ − 10%		ρ + 10%		ρ + 20%	
								
Values of SAR (W/kg)	1 g: 2.356	10 g: 1.704	1 g: 2.111	10 g: 1.538	1 g: 1.759	10 g: 1.292	1 g: 1.623	10 g: 1.199
Changes of Conductivity	σ − 20%		σ − 10%		σ + 10%		σ + 20%	
								
Values of SAR (W/kg)	1 g: 1.675	10 g: 1.282	1 g: 1.799	10 g: 1.344	1 g: 2.021	10 g: 1.444	1 g: 2.145	10 g: 1.415

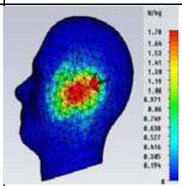
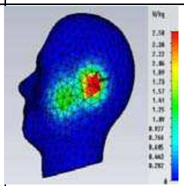
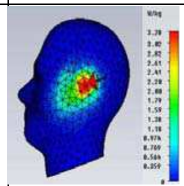
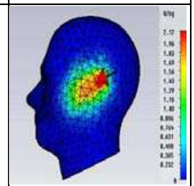
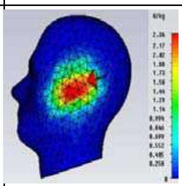
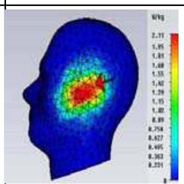
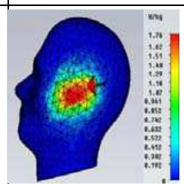
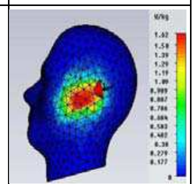
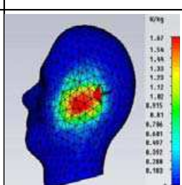
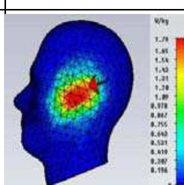
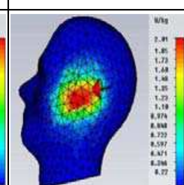
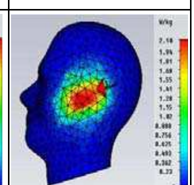
In this operational frequency, the antenna with substrate of Rogers RO4003 (loss free) results in the highest human head SAR values over antennas with substrate of FR4 and Rogers RO3006 (loss free). Table 10 shows the results of SAR values. It is shown that SAR values are higher with the decrement of permittivity of head tissue than the increment of head tissue permittivity. Permittivity of head tissue is frequency dependent. As frequency goes higher, the permittivity goes lower. The SAR 1 g values with variation of head permittivity vary from 0.51% to 14.63% from the original of SAR value of human head. This is considerably low and has not much difference from the SAR values without the variation of head permittivity. As the density

Table 5. SAR values with antenna substrate of Rogers RO3006 (loss free).

Changes of Permittivity	ε − 20%		ε − 10%		ε + 10%		ε + 20%	
								
Values of SAR (W/kg)	1 g: 1.806	10 g: 1.266	1 g: 3.359	10 g: 2.086	1 g: 3.265	10 g: 2.038	1 g: 2.154	10 g: 1.419
Changes of Density	ρ − 20%		ρ − 10%		ρ + 10%		ρ + 20%	
								
Values of SAR (W/kg)	1 g: 2.359	10 g: 1.706	1 g: 2.114	10 g: 1.539	1 g: 1.761	10 g: 1.294	1 g: 2.812	10 g: 1.666
Changes of Conductivity	σ − 20%		σ − 10%		σ + 10%		σ + 20%	
								
Values of SAR (W/kg)	1 g: 1.305	10 g: 0.998	1 g: 1.799	10 g: 1.344	1 g: 2.019	10 g: 1.444	1 g: 2.113	10 g: 1.479

of the human head decreased, there was a significant rise of SAR values for both decrements of 10% and 20%. Apparently, SAR values drop with the increment of head density. This can also be approved from Equation (1), where the density is inversely proportional to SAR values. Here it is also indicated that the difference between SAR 1 g values with variation of head density is from 7.24% to 22%. Lower density of head tissue gives higher SAR values due to better resolution of calculating SAR values. Higher density of head tissue tends to hinder the effect of radiation absorption towards the head. The other

Table 6. SAR values with antenna substrate of Rogers RO4003 (loss free).

Changes of Permittivity	ε – 20%		ε – 10%		ε + 10%		ε + 20%	
								
Values of SAR (W/kg)	1 g: 1.775	10 g: 1.242	1 g: 2.579	10 g: 1.698	1 g: 3.280	10 g: 2.048	1 g: 2.125	10 g: 1.403
Changes of Density	ρ – 20%		ρ – 10%		ρ + 10%		ρ + 20%	
								
Values of SAR (W/kg)	1 g: 2.355	10 g: 1.703	1 g: 2.110	10 g: 1.537	1 g: 1.758	10 g: 1.292	1 g: 1.622	10 g: 1.199
Changes of Conductivity	σ – 20%		σ – 10%		σ + 10%		σ + 20%	
								
Values of SAR (W/kg)	1 g: 1.673	10 g: 1.279	1 g: 1.789	10 g: 1.336	1 g: 2.010	10 g: 1.437	1 g: 2.104	10 g: 1.473

component of dielectric properties is conductivity of the head. As the conductivity of head was increased to 10% and 20%, SAR values also increased and vice versa. Higher conductivity of the head indicates that the head more readily absorbers radiation from the mobile phone. Thus, higher radiation causes SAR values to increase. In all results, SAR values in 1 g of head tissue show higher values than in 10 g of head tissue. More power absorbed from the mobile phone onto the head indicates higher radiation deposited towards the head, due to at lower mass of head tissue. Radiation is well distributed and effectively absorbs by the head.

Table 7. SAR values of head without dielectric variations.

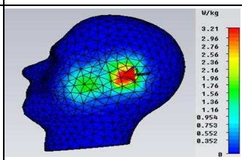
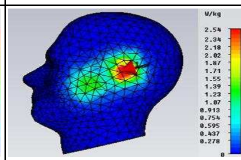
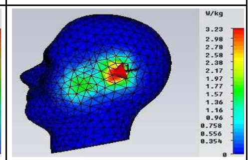
Antenna's substrate	FR4		Rogers RO3006 (loss free)		Rogers RO4003 (loss free)	
						
Values of SAR (W/kg)	1 g: 3.214	10 g: 1.901	1 g: 2.540	10 g: 1.629	1 g: 3.235	10 g: 1.913

Table 8. SAR values with antenna substrate of FR4.

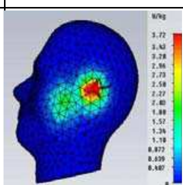
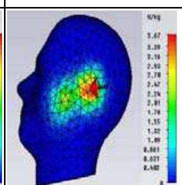
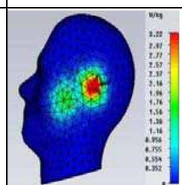
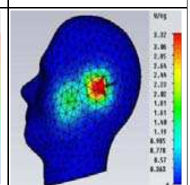
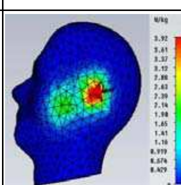
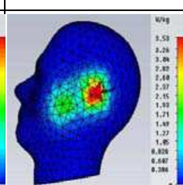
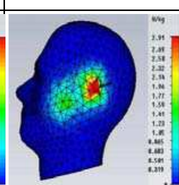
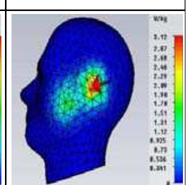
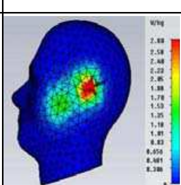
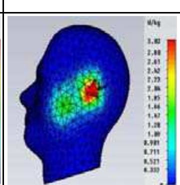
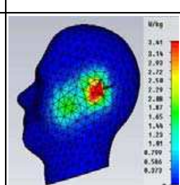
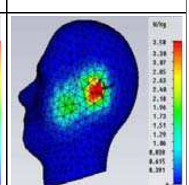
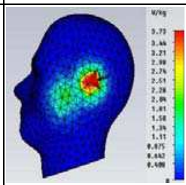
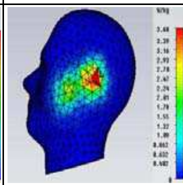
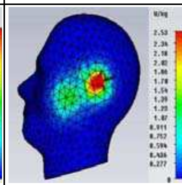
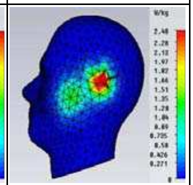
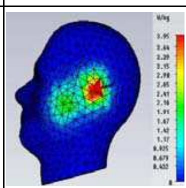
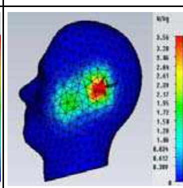
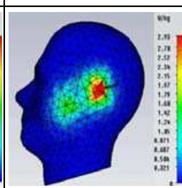
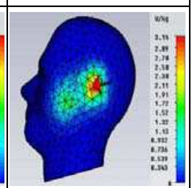
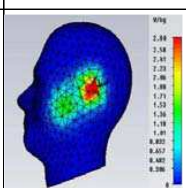
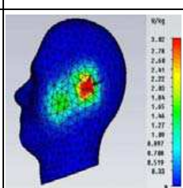
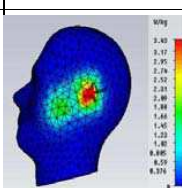
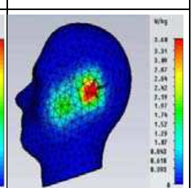
Changes of Permittivity	ε – 20%		ε – 10%		ε + 10%		ε + 20%	
								
Values of SAR (W/kg)	1 g: 3.719	10 g: 1.922	1 g: 3.673	10 g: 2.059	1 g: 3.221	10 g: 1.759	1 g: 3.319	10 g: 1.784
Changes of Density	ρ – 20%		ρ – 10%		ρ + 10%		ρ + 20%	
								
Values of SAR (W/kg)	1 g: 3.921	10 g: 2.252	1 g: 3.534	10 g: 2.086	1 g: 2.979	10 g: 1.761	1 g: 3.117	10 g: 1.643
Changes of Conductivity	σ – 20%		σ – 10%		σ + 10%		σ + 20%	
								
Values of SAR (W/kg)	1 g: 2.797	10 g: 1.741	1 g: 3.033	10 g: 1.839	1 g: 3.411	10 g: 1.969	1 g: 3.578	10 g: 2.022

Table 9. SAR values with antenna substrate of Rogers RO3006 (loss free).

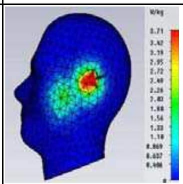
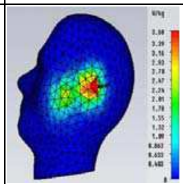
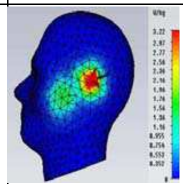
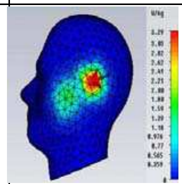
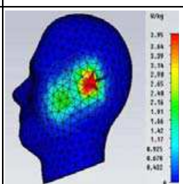
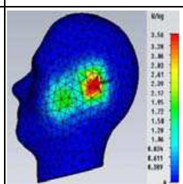
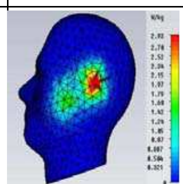
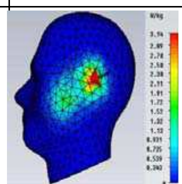
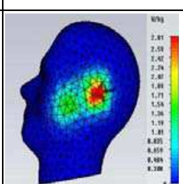
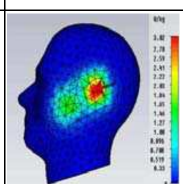
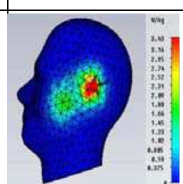
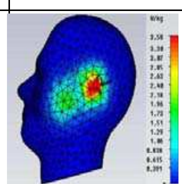
Changes of Permittivity	ε − 20%		ε − 10%		ε + 10%		ε + 20%	
								
Values of SAR (W/kg)	1 g: 3.733	10 g: 1.928	1 g: 3.677	10 g: 2.060	1 g: 2.534	10 g: 1.601	1 g: 2.476	10 g: 1.486
Changes of Density	ρ − 20%		ρ − 10%		ρ + 10%		ρ + 20%	
								
Values of SAR (W/kg)	1 g: 3.949	10 g: 2.267	1 g: 3.559	10 g: 2.099	1 g: 2.999	10 g: 1.773	1 g: 3.139	10 g: 1.655
Changes of Conductivity	σ − 20%		σ − 10%		σ + 10%		σ + 20%	
								
Values of SAR (W/kg)	1 g: 2.802	10 g: 1.744	1 g: 3.021	10 g: 1.831	1 g: 3.435	10 g: 1.981	1 g: 3.595	10 g: 2.032

4.3. SAR at 1900 MHz

Each of the SAR values presented in the following tables (11–14), consists of three different antenna substrates which include FR4, Rogers RO3006 (loss free), and Rogers RO4003 (loss free) with variations of head dielectric properties.

The highest radiation deposited onto human head is shown with the red area in all tables listed above. Generally, higher radiation absorbed by the head shows higher SAR values. The blue area shows the head area which receives the lowest radiation from handset.

Table 10. SAR values with antenna substrate of Rogers RO4003 (loss free).

Changes of Permittivity	ε – 20%		ε – 10%		ε + 10%		ε + 20%	
								
Values of SAR (W/kg)	1 g: 3.708	10 g: 1.915	1 g: 3.680	10 g: 2.064	1 g: 3.218	10 g: 1.757	1 g: 3.286	10 g: 1.766
Changes of Density	ρ – 20%		ρ – 10%		ρ + 10%		ρ + 20%	
								
Values of SAR (W/kg)	1 g: 3.946	10 g: 2.268	1 g: 3.557	10 g: 2.100	1 g: 3.001	10 g: 1.772	1 g: 3.137	10 g: 1.654
Changes of Conductivity	σ – 20%		σ – 10%		σ + 10%		σ + 20%	
								
Values of SAR (W/kg)	1 g: 3.814	10 g: 2.162	1 g: 3.019	10 g: 1.830	1 g: 3.433	10 g: 1.983	1 g: 3.577	10 g: 2.022

Using antenna with substrate of FR4 results in the highest SAR values. Different SAR values are obtained due to different dielectric properties of the antenna substrate and human head. The human head dielectric properties were constant at all times at a particular frequency exposure unless the head was put into another frequency exposure, which caused the head dielectric properties to change accordingly. Table 12 shows SAR values in human head at 1900 MHz with antenna substrate of FR4. SAR values show a sudden increase with increment of 10% of head permittivity. Variations of head's conductivity and density result in SAR values which fluctuate averagely. SAR values

Table 11. SAR values of head without dielectric variations.

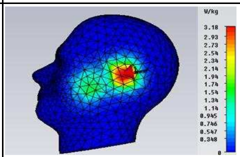
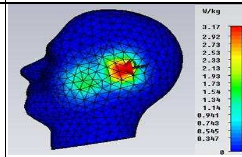
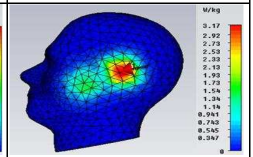
Antenna's substrate	FR4		Rogers RO3006 (loss free)		Rogers RO4003 (loss free)	
						
Values of SAR (W/kg)	1 g: 3.182	10 g: 1.769	1 g: 3.171	10 g: 1.762	1 g: 3.171	10 g: 1.762

Table 12. SAR values with antenna substrate of FR4.

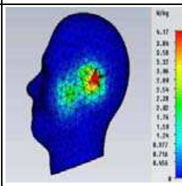
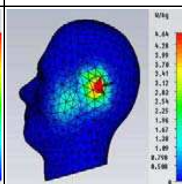
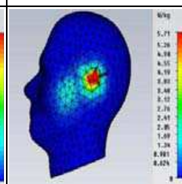
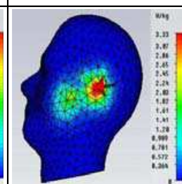
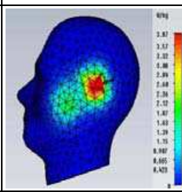
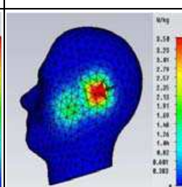
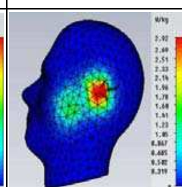
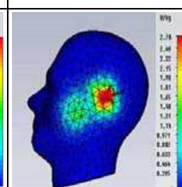
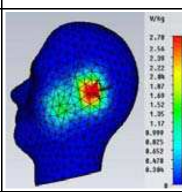
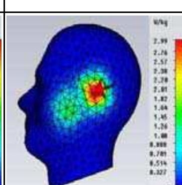
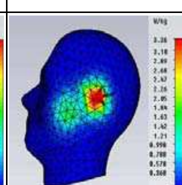
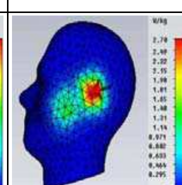
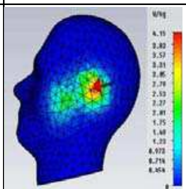
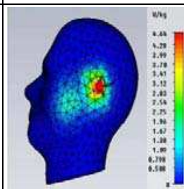
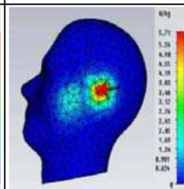
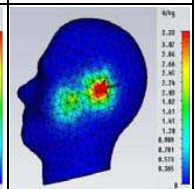
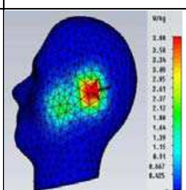
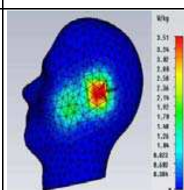
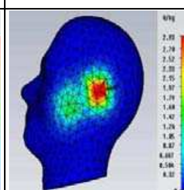
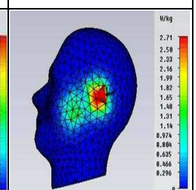
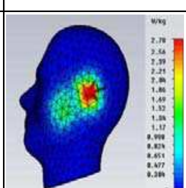
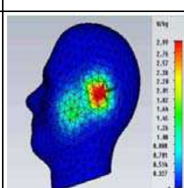
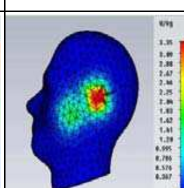
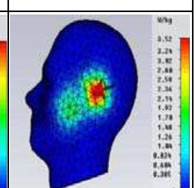
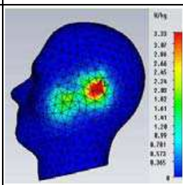
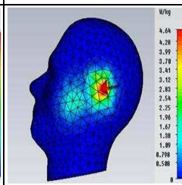
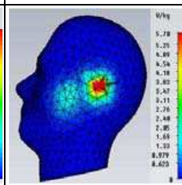
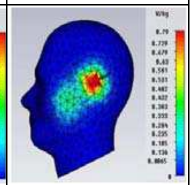
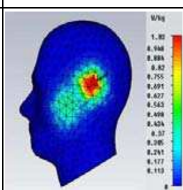
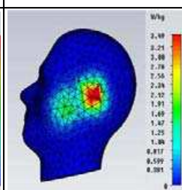
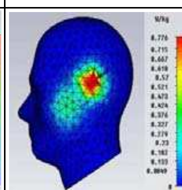
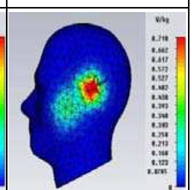
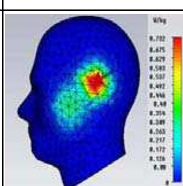
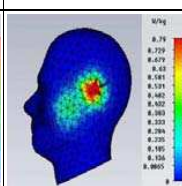
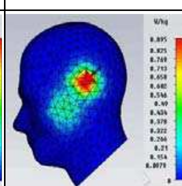
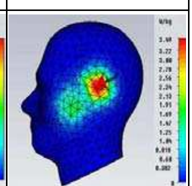
Changes of Permittivity	ε – 20%		ε – 10%		ε + 10%		ε + 20%	
								
Values of SAR (W/kg)	1 g: 4.168	10 g: 2.154	1 g: 4.641	10 g: 2.426	1 g: 5.707	10 g: 2.535	1 g: 3.305	10 g: 1.859
Changes of Density	ρ – 20%		ρ – 10%		ρ + 10%		ρ + 20%	
								
Values of SAR (W/kg)	1 g: 3.869	10 g: 2.103	1 g: 3.499	10 g: 1.922	1 g: 2.921	10 g: 1.817	1 g: 2.701	10 g: 1.705
Changes of Conductivity	σ – 20%		σ – 10%		σ + 10%		σ + 20%	
								
Values of SAR (W/kg)	1 g: 2.780	10 g: 1.647	1 g: 2.992	10 g: 1.715	1 g: 3.362	10 g: 1.816	1 g: 2.701	10 g: 1.705

Table 13. SAR values with antenna substrate of Rogers RO3006 (loss free).

Changes of Permittivity	ε – 20%		ε – 10%		ε + 10%		ε + 20%	
								
Values of SAR (W/kg)	1 g: 4.153	10 g: 2.145	1 g: 4.641	10 g: 2.427	1 g: 5.705	10 g: 2.536	1 g: 3.333	10 g: 1.859
Changes of Density	ρ – 20%		ρ – 10%		ρ + 10%		ρ + 20%	
								
Values of SAR (W/kg)	1 g: 3.881	10 g: 2.109	1 g: 3.510	10 g: 1.928	1 g: 2.929	10 g: 1.828	1 g: 2.709	10 g: 1.710
Changes of Conductivity	σ – 20%		σ – 10%		σ + 10%		σ + 20%	
								
Values of SAR (W/kg)	1 g: 2.776	10 g: 1.644	1 g: 2.991	10 g: 1.715	1 g: 3.353	10 g: 1.811	1 g: 3.517	10 g: 1.849

show a similar changing pattern to the former frequency exposure due to increment and decrement of 10% and 20% of head's conductivity and density. By increment and decrement of 10% and 20% of head permittivity, SAR values vary from 3.85% to 79.33% for 1 g of head tissue, which indicates that the head's permittivity has a significant impact on SAR values. The variation of SAR is between 5.05% and 43.13% with variations of head permittivity for SAR 10 g. Head density is inversely proportional to SAR values. Table 12 shows SAR values

Table 14. SAR values with antenna substrate of Rogers RO4003 (loss free).

Changes of Permittivity	ε − 20%		ε − 10%		ε + 10%		ε + 20%	
								
Values of SAR (W/kg)	1 g: 3.334	10 g: 1.861	1 g: 4.641	10 g: 2.427	1 g: 5.696	10 g: 2.528	1 g: 0.790	10 g: 0.446
Changes of Density	ρ − 20%		ρ − 10%		ρ + 10%		ρ + 20%	
								
Values of SAR (W/kg)	1 g: 1.029	10 g: 0.544	1 g: 3.487	10 g: 1.915	1 g: 0.776	10 g: 0.422	1 g: 0.718	10 g: 0.435
Changes of Conductivity	σ − 20%		σ − 10%		σ + 10%		σ + 20%	
								
Values of SAR (W/kg)	1 g: 0.732	10 g: 0.427	1 g: 0.790	10 g: 0.446	1 g: 0.895	10 g: 0.472	1 g: 3.489	10 g: 1.835

accordingly. For head density variation, SAR 1 g varies between 15.13% and 21.5%. SAR 10 g, however, varies from 3.64% to 18.86%. SAR values with variations of head's permittivity and conductivity show no significant change in SAR values. Lower SAR values are due to higher density of human head, which indicates that higher density reduces the resolution in calculating SAR values. Besides, it is shown that the power radiated from the handset is non-uniformly distributed towards the head tissue. Thus, lower radiation is absorbed onto human head with less SAR values. In every increment of head conductivity, SAR values also increase. With increased head conductivity, the head is prone to absorb more radiation from the handsets.

The substrate of antenna does give impact on SAR values by varying different substrates (Rogers RO3006, Rogers RO4003 and FR4). Comparison has been made between this research and previous research of Keshvari et al [2] for $\sigma + 10\%$ at frequency of 900 MHz. For the case of $\sigma + 10\%$ at frequency of 900 MHz, the previous research [2] achieved 2.551 W/kg (SAR 1 g), which is higher than the value achieved in this study by 0.536 W/kg. At the same frequency for $\sigma + 20\%$, the achieved SAR 1 g value in this work is 2.145 W/kg which is also lower than the value found in [2], which was 2.762 W/kg. From this analysis, it can also be observed that the SAR value is decreased as the frequency increases as it does in UMTS (1885 MHz–2200 MHz), WLAN (5.15 GHz–5.835 GHz).

In overall results, SAR in 1 g head tissue was always higher than SAR in 10 g head tissues, due to head tissue with lower volume and better resolution in calculating SAR values. In higher mass of tissue, SAR values were hindered and resulted in lower SAR values. The head had constant dielectric properties at a particular frequency exposure at all time. However, these dielectric properties have the potential to deviate from its normal properties if the body undergos particular pressure. Body temperature rise also causes the dielectric properties to shift from normal baseline. These are the possible factors that affect the dielectric properties of head other than the head exposed to different frequency exposures.

5. CONCLUSION

From the research, SAR values were dependent on head dielectric properties. The changes of head dielectric properties influenced head SAR values. Higher volume of 10 g head tissues resulted in lower SAR values as compared to 1 g of tissue. Smaller volumes of tissue samples (i.e., SAR 1g) show higher resolution of SAR values. A helical antenna with substrate of FR4 resulted in the highest SAR both in 900 MHz and 1900 MHz, whereas in 1800 MHz, a helical antenna with substrate of Rogers RO4003 (loss free) showed the highest SAR values. Conductivity of the head majorally influenced SAR over the rest of head dielectric properties. SAR of head with antenna substrate of Rogers RO3006 (loss free) was found to result in lower SAR values at all frequency exposures.

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