Effects of Substrate Material and Dielectric Properties on Electromagnetic Energy Absorption Over GSM Bands

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Abstract— **This paper analyzes the effects of electromagnetic (EM) absorption towards human head with variations of human head dielectric properties. The human head exposed to 900, 1800 and 1900 MHz operational frequencies. Specific absorption rate (SAR) was the parameter used to measure the interactions of EM waves towards human head. The mobile phone attached with helical antenna together with human head simulated through finite-difference time-domain (FDTD) method using Computer Simulated Technology (CST) Microwave Studio. The human head dielectric properties were varied with increment and decrement of 10 % and 20 % of each of the properties. Through this study, it was found out that conductivity was directly proportional to SAR values while permittivity was inversely proportional with SAR values. In all frequency exposures, helical antenna with substrate of FR4 resulted in the highest SAR values. It was found that, helical antenna with substrate of Rogers RO3006 (loss free) had contributed the lowest SAR values in all operational frequencies exposed.**

Keywords-Different Substrate Material, Finite-Difference Time-Domain (FDTD) method, Ingestible Wireless Device (IWD), Specific Absorption Rate (SAR)

I. INTRODUCTION

The technology of mobile communications had been spread across the globe. It was introduced decades ago and now the number of users kept increasing each day. Over the years ago, researches started to investigate its effect toward human health. The electromagnetic (EM) waves emitted from mobile phone influenced the human biological system. Specific absorption rate (SAR) is the parameter which measured the EM wave interactions with human body [1-4]. There had been many concerns of SAR values induced from commercial mobile phone antennas which EM waves emitted onto human [5]. EM waves disrupted human biological system as it penetrated through human [6-9]. Previous research found out that mobile phone used over ten years had the potential to twice the risk of brain tumor on the side of the head where the mobile phone used [10]. EM waves were the radiation emitted from the mobile phone that contributed to human health hazards. Once the EM waves penetrated through human and became dense over a period of time, it caused thermal effect [11].

There are specific international authoritative bodies which controlled and regulated safe limit of SAR which exposed toward human [2], [12-13]. In Europe, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) set the limit of 2 W/kg over 10 g tissues [14]. In the United States, Federal Communications Commission (FCC) set the limit of 1.6 W/kg over 1 g of body tissue [15].

The dielectric properties of human were one of the factors which determine the intensity of EM wave absorption towards human. The waves were known as the radiation which radiated from the in-used mobile phone. Once a mobile phone engaged in communications, the signals from the phone were radiated in terms of EM waves. Over-excess waves radiated over long conversation over the phone caused higher absorption of waves penetrated through the body. This radiation absorbed measured in terms of specific absorption rate (SAR) values. This SAR values were directly proportional to body's conductivity and inversely proportional to body's permittivity [16]. Human body tissues with higher water content produced higher SAR values than human body with lower water content tissues. Conductivity and permittivity of human dielectric properties were frequency dependent [17-23].

The purpose of this paper is to analyze the effect of EM absorption toward human head with variations of human head dielectric properties which exposed to 900, 1800 and 1900 MHz also with different types of mobile phone antenna substrates.

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II. MODELS AND METHOD

A. Models

Specific Anthropomorphic Mannequin (SAM) phantom utilized as the head model which attached with a helical antenna. This head model consists of the inner and outer layers. It had similar dielectric properties with the actual human head at specific frequency exposures. The dielectric properties of the head were constant at all times within a single frequency exposure. This helical antenna attached onto the mobile phone which was the radiation source and EM absorption toward the head measured. In this work, operational frequencies used were 900, 1800 and 1900 MHz. Rogers 3006 (loss free), Rogers RO4003 (loss free) and FR4 were the substrates used for the helical antenna and variations of 10 % and 20 % of the head dielectric properties evaluated its SAR values. Dielectric properties of substrates for the helical antenna are as shown in Table I.

TABLE I. DIELECTRIC PROPERTIES OF SUBSTRTATES FOR HELICAL ANTENNA

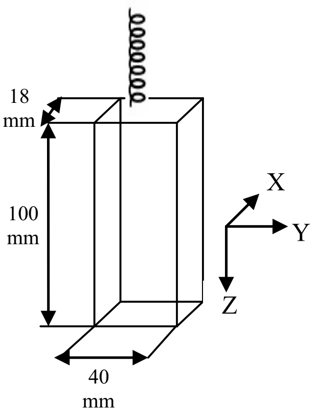
Dielectric Properties of Substrates		
Types of Substrate	***Permittivity, ε_r***	***Conductivity, σ (S/m)***
Rogers 3006 (loss free)	6.15	0.61
Rogers 4003 (loss free)	3.38	0.71
FR4	4.30	0.27

Human head dielectric properties at 900, 1800 and 1900 MHz are as in Table II.

TABLE II. DIELECTRIC PROPERTIES OF HUMAN HEAD

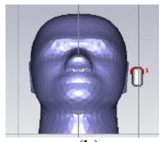
Dielectric Properties of Human Head			
Frequency (MHz)	***Permittivity, ε_r***	***Conductivity, σ (S/m)***	***Density, ρ (kg/m^3)***
900	41.5	0.97	1030
1800	40.0	1.40	1030
1900	40.0	1.40	1030

A simple Perfect Electric Conductor (PEC) box modeled for the mobile phone with helical antenna attached on top. The dimensions of the mobile phone was 18 x 40 x 100 mm (*X* x *Y* x *Z*).



(a)

The length and radius of the helical antenna were 31 mm and 5 mm respectively. Figure 1 shows the dimensions of the mobile phone model.



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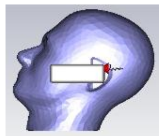

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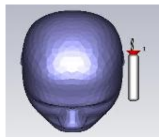

(d)

Figure 1. (a) Mobile Phone Dimensions (b) Front View (c) Side View (d) Top View

B. Method

The SAR calculations were done by using CST Microwave Studio 2011. Finite Integration Time Domain (FITD) technique of Finite-Difference Time-Domain (FDTD) method applied for these works. Appropriate mesh properties were set for all simulations. The separation between the mobile phone and the head was approximately 5 mm. The orientation of the mobile phone was placed in cheek position toward the head in parallel without separation angle. SAR calculated by applying the following equation.

$$\mathrm{SAR} = \frac{\sigma\,|E|^2}{2\,\rho} \quad (1)$$

Where the σ is the tissue conductivity (S/m), E is the root mean square (rms) electric field (V/m) and ρ is the tissue density (kg/m^3). The radiated power used for all simulations was 0.25 W and the IEEE C95.3 standard used as the averaging method to calculate SAR values.

III. RESULTS AND DISCUSSION

A. SAR at 900 MHz of Helical Antenna with Substrate of FR4

Helical antenna with substrate of FR4 showed the highest SAR values over the rest substrates used. Different SAR values resulted due to different substrates with different dielectric properties. Frequency exposure and placement of the antenna onto the mobile phone also influenced SAR values. Figure 2 showed the SAR values of without variations of head dielectric properties were 1.9214 W/kg and 1.40236 W/kg for

SAR 1g and SAR 10 g respectively. As the conductivity of head was directly proportional to SAR values, SAR increased as the conductivity increased. Head tissue with higher conductivity was more readily to absorb EM waves emitted from mobile phone. By this, more radiation penetrated through human head.

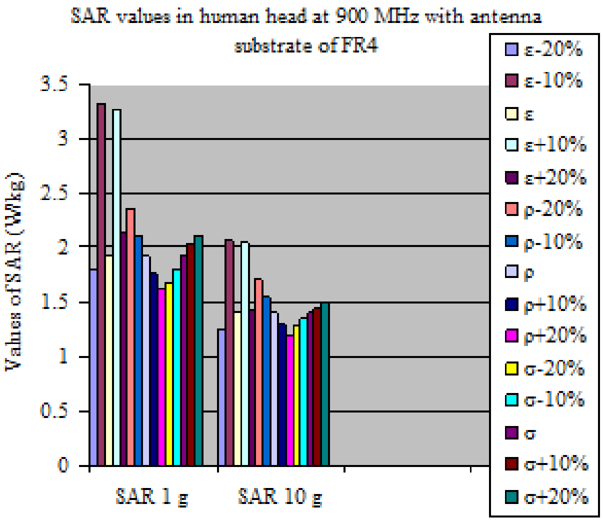

Figure 2. SAR values of head at 900 MHz with antenna substrate of FR4

The density of the human head was inversely proportional to SAR values. Thus, with each increment of head density, SAR values dropped compared to SAR values of without variations of head dielectric properties. Higher density of human head reduced the resolution of calculating SAR values. Thus, SAR of the human head resulted in much lower values.

B. SAR at 1900 MHz of Helical Antenna with Substrate of FR4

SAR values fluctuated as the head dielectric properties varied. These variations of head dielectric properties varied with increment and decrement of 10 % and 20 % with each of the properties. At this frequency exposure, helical antenna with substrate of FR4 resulted in the highest SAR values above all substrates. SAR values increased sharply with increment of 10 % of head permittivity.SAR values varied among 3.85 % to 79.33 % for 1 g head tissue with variations of head permittivity. This showed that the head's permittivity significantly affect SAR values. By means that, it allows more EM waves penetrated through human head. Thus, higher radiation absorbed. On the other hand, as the head density increased, SAR values decreased. This happened due to the power radiated from mobile phone was nonuniformly distributed over the head tissue with higher density. The other parameter which affects SAR values was conductivity. SAR values increased with the increased of head conductivity. This increased the EM waves absorption or radiation from mobile phone onto the human head. Fig.3 showed the SAR values in human head at 1900 MHz with antenna substrate of FR4.

From overall results obtained, all SAR 1 g values were higher than SAR 10 g values. Higher resolution in calculating SAR values in smaller volume of tissue compared to higher volume of tissue. Higher volume of head tissue potentially hindering the SAR values which present in the head tissue [18-20]. Human head dielectric properties were constant at all times upon a specific frequency exposure. The head dielectric properties tend to vary once the head is under pressure or exposed to a higher temperature condition compare to ambient temperature.

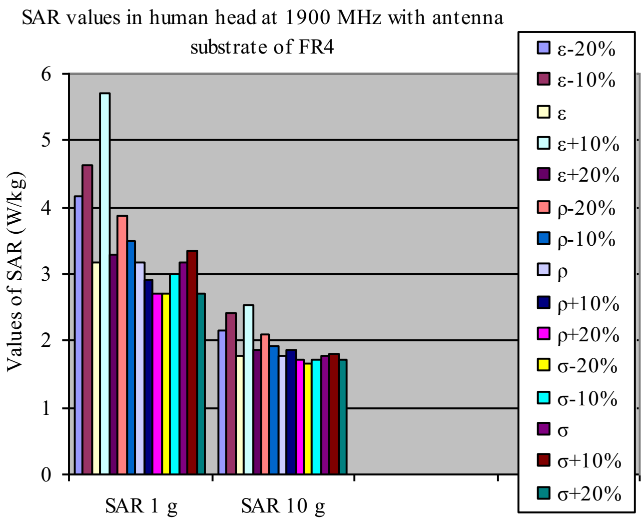

Figure 3. SAR values in human head at 1900 MHz with antenna substrate of FR4

Overall SAR values of the human head using helical antenna at 900 and 1900 MHz showed significant changes in SAR values due to variations of head dielectric properties. These properties relatively changed with the variations of head dielectric properties. It also showed that SAR at higher frequency exhibited higher values. Frequency was also one of the factors which influenced SAR in human head. The human head dielectric properties depend on the exposure of the frequency. As long as the head was being exposed towards a particular frequency, constant dielectric properties of head exhibited and different dielectric properties of human head portrayed on a human if the human exposed to another frequency exposure.

C. SAR at 900 MHz of Helical Antenna with Substrate of Rogers RO4003 (loss free)

There were increment and decrement of SAR values using the helical antenna with substrate of Rogers RO4003 (loss free) and exposed towards this operational frequency. Overall SARs resulted in almost low values compared to all substrates used and at different frequency exposures. From the results showed that there were bold fluctuations of SAR with variation of human head permittivity. SAR values without increment and decrement of 10 % and 20 % of head dielectric for 1g and 10 g were 1.92057 W/kg and 1.40241 W/kg respectively. The highest SAR ruled out with value of 2.5795 W/kg for SAR 10 g. This SAR 10 g had deviated in increment from the original SAR 10 g values without any head dielectric properties by 41.31 %. There were more subtle changes in SAR with regards of variations of head density and conductivity. Fig. 4 showed the SAR values in human head at 900 MHz with antenna substrate of Rogers RO4003 (loss free).

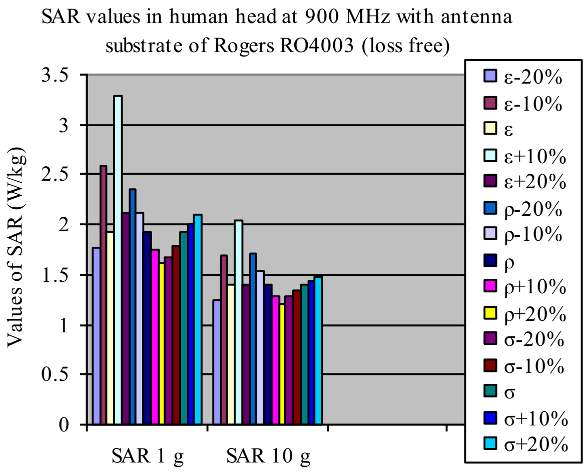

Figure 4. SAR values in human head at 1900 MHz with antenna substrate of Rogers RO4003 (loss free)

D. *SAR at 1800 MHz of Helical Antenna with Substrate of Rogers RO4003 (loss free)*

At this frequency exposure, helical antenna with substrate of Rogers RO4003 (loss free) produced quite significant SAR values compared to SAR values at 900 and 1900 MHz. SAR values increased and decreased with variations of human head dielectric properties. One of the dielectric properties which influenced SAR values significantly was the head density. SAR 1 g values with variation of head density varied from 7.24 % to 22.0%. Higher density of head tissue tends to obscure the resolution in calculating SAR values. Thus, SAR values dropped. This could be approved from (1). Head density is inversely proportional to SAR values. Head permittivity was the other component which influenced the EM waves absorbed through human head which contributed to SAR values. The head permittivity varied from 0.51 % to 14.63 %. This showed that the permittivity of head caused insignificant changes on SAR values. The SAR values of this result as shown in Fig. 5.

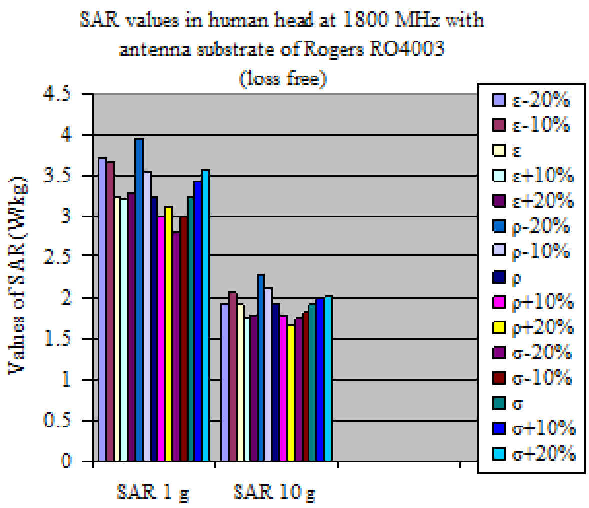

Figure 5. SAR values of head at 1800 MHz with antenna substrate of Rogers RO4003 (loss free)

Based on absorption of EM waves at all operational frequency exposures; 900, 1800 and 1900 MHz onto human head, SAR values changes with the changes of the human head dielectric properties. There were three parameters which influenced SAR calculation of human head, namely the head permittivity, head conductivity and head density. Fig. 4 and Fig. 5 showed a strong correlation between head conductivity and resulted SAR values. As the conductivity of the head increased, SAR values also increased. The head conductivity is linearly proportional to SAR values. On the other hand, the density of the head is inversely proportional to SAR values. It showed that, as the head density increased, SAR values dropped to a certain value. Also, it could be observed that this head density significantly affecting the SAR of the head. SARs recorded upon variations of head density had dramatically changed the SARs of human head.

IV. CONCLUSION

From the work done, SAR values very much dependent with the head dielectric properties. It determined how much EM waves to penetrate through human head. Frequency exposure also affects SAR values and changes SAR values of the head at different frequency that the head exposed to. At higher volume of tissue, SAR values usually decreased due to high volume of tissue and tend to obscure the presence of SAR. Conductivity of the head found to be the parameter which influenced the most towards SAR values. As the head conductivity increased, SAR values also increased and vice versa. All in all, helical antenna with substrate of Rogers RO3006 (loss free) found to be the best substrate which resulted in lower SAR values upon all different frequency exposures and variations of head dielectric properties.

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