# Analysis of the effects of antenna substrate composite materials on specific absorption rate

M. I. HOSSAIN[a], M. R. I. FARUQUE[a], M. T. ISLAM[b]
[a]*Center of Space Science (ANGKASA), Research Centre Building, Malaysia*
[b]*Dept. of Electrical, Electronic and Systems Engineering, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, 43600 UKM, Bangi, Selangor, Malaysia*

The effects of antenna dielectric substrate materials on the specific absorption rate (SAR) towards the human head are presented in this investigation. The variation of radiation efficiencies of antenna due to different substrate materials are also analyzed and discussed in the close vicinity of head model. An E-shaped planar inverted-F antenna (PIFA) is used as internal handset antenna in this analysis with five different dielectric substrate materials--Bakelite, FR4 glass epoxy, Rogers R04003, Taconic TLC and RT Duroid. Moreover, different thicknesses of each substrate are considered in the experimental setup. The studied cell phone is located beside a specific anthropomorphic (SAM) head phantom in a position of actual handset use. The finite-difference time-domain (FDTD) method with the lossy-Drude model is utilized in this study by using CST Microwave Studio. The SAR values and radiation efficiencies are calculated for two global system for mobile (GSM) frequency band at 900 MHz and 1800 MHz. The results show that the SAR values are affected due to the variation of substrate materials and its thickness. PIFA with RT Duroid substrate is found to be better over all other substrates, which results lower SAR values to the human head in both GSM frequency bands. In addition, the substrate materials affect the SAR values much more at 900 MHz than that of at 1800 MHz. On the other hand, the antenna radiation efficiencies are not affected significantly, but they show small variation at lower and upper frequency bands due to different substrate materials.

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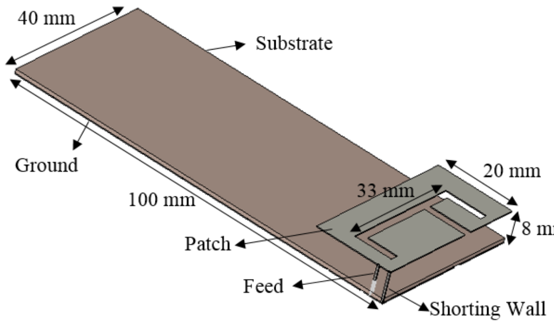
## 1. Introduction

The EM radiation from mobile terminal antenna may disturb human biological system and harm human health. The World Health Organization (WHO) have declared that the use of cell phone potentially cause brain cancer [1, 2]. It is also found that the cell phone radiation doubles the risk of brain tumor at side of head which is closed to the cell phone for more than 10 years use [3]. Besides, thermal effect can occurred when human tissues exposed to infinite EM energy [4]. Due to the enormous uses of portable handset, a lot of concerns regarding cell phone safety have been discussed. The interaction between RF radiation and human tissues are expressed in terms of SAR which denotes absorbed power by human body over certain volume of biological tissues [5]. Several standard organization are responsible for imposing SAR limit for safety of human body, including ICNIRP in Europe [6], FCC in United State [7, 8].

Several factors may affect SAR values such as EM source geometry and frequency, the user body tissue size and their properties. SAR values also depend on the medium and distance between source and user body. The SAR values may be varied due to variation of antenna geometry. An analysis of SAR values using different types of antenna (i.e. mono-pole, helical, patch and Planar Inverted-F Antenna) showed that the mono-pole antenna generates the utmost SAR levels in all tissues, where the patch antenna produces low level of SAR values [9]. On the other hand, handsets with built-in antennas (internal antenna) show variation in the SAR values than that of handsets with external antennas [10]. It was claim from previous research that PIFA structures produced low SAR in the head tissue [11]. Moreover, antenna substrate material has also some effects on EM absorption. In [2], a helical antenna with three different substrate materials (FR-4, Rogers RO4006, and Rogers RO3006) is analyzed in the vicinity of human head. The numerical results indicate that helical antenna with FR-4 produces comparatively lower SAR. The purpose of this investigation is to analyze the effects of PIFA substrate materials on SAR in the human head.

## 2. Antenna and head model

Fig. 1 demonstrates detailed geometry of E-shaped PIFA which is designed for dual band operation. The length and width of substrate are 100 mm and 40 mm respectively.

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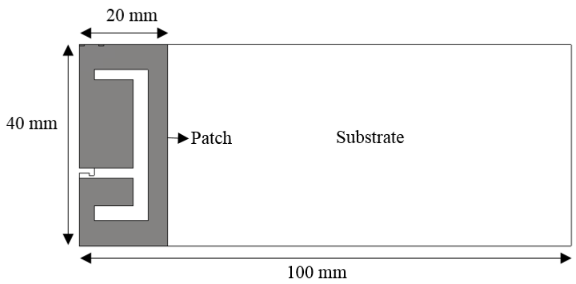



*(b)*

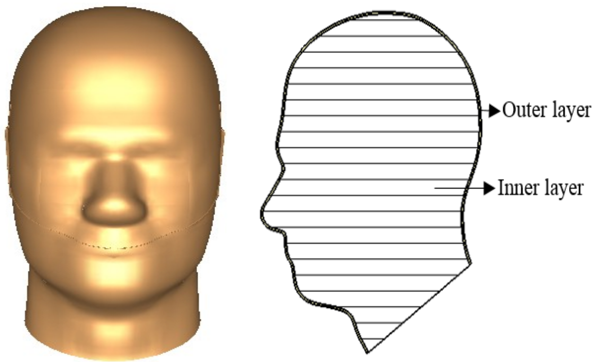
*Fig.1. Geometry of E-shaped PIFA with substrate: (a) 3D view (b) front view.*

The distance between ground plane and patch is 8 mm. The dimension of shorting plane and feed are 8 mm × 1 mm × 0.2 mm and 4 mm × 1 mm × 0.2 mm respectively. The E-shaped patch dimension is 40 mm× 20 mm × 0.2 mm. five different dielectric substrate materials-Bakelite, FR4 glass epoxy, Rogers RO4003, and Taconic TLC are used for antenna substrate to take effects of substrate materials. The properties of substrate materials are included in Table 1. A plastic casing is used to cover PIFA when it is used with head phantom in the cheek position of talk mode.

*Table 1. Electrical properties of substrate materials.*

| Material | Permittivity, $\varepsilon_r$ | Tangent Loss | Surface resistivity (MΩ) | Density (Kg/m$^3$) |
|---|---|---|---|---|
| Bakelite | 4.8 | 0.03 | $5\times 10^{10}$ | 1400 |
| FR-4 | 4.3 | 0.025 | $2\times10^{5}$ | 1850 |
| Rogers RO4003 | 3.55 | 0.0027 | $4.3\times10^{9}$ | 1790 |
| Taconic TLC | 3 | 0.003 | $1.2\times10^{7}$ | 2200 |

The dielectric properties of human tissues, such as permittivity, permeability and conductivity have significant roles in the interaction between EM fields and human body. The dielectric constants are changed due to change in frequency. On the other hand, the permeability of biological tissues, which depends on the water content of tissues, does not vary with frequency. In this paper, a numerical Anthropomorphic Mannequin (SAM) head model, which consists of simulating liquids (for shell and brain), is used. Figure 2(a) and 2(b) represent the 3D view and cross-section view of numerical SAM phantom. Based on dielectric properties, such as permittivity and conductivity of human tissues, the dielectric properties of SAM phantom has been determined by standard organizations. The frequency dependent parameters permittivity and conductivity of human tissues was considered, and the respective values are based on human tissue measurement data as described in [12].




(a) (b)

*Fig. 2. SAM phantom (a) 3D view of SAM phantom, (b) Cross-section view.*

*Table 2. Electrical Properties of head phantom.*

| SAM Material | 900 MHz | | 1800 MHz | |
|---|---|---|---|---|
| | $\varepsilon_r$ | $\sigma$ | $\varepsilon_r$ | $\sigma$ |
| SAM shell | 3.7 | 0 | 3.5 | 0.0016 |
| SAM liquid | 41.5 | 0.97 | 40 | 1.42 |

Moreover, the magnetic permeability of the head tissues was approximated with the vacuum magnetic permeability. Table 2 represents the electrical properties of SAM phantom. Regulation bodies such as IEEE and IEC have established product compliance standards to assess exposure levels due to mobile phone and have specified the use of SAM phantom in such assessments. A 5 mm distance between mobile phone and head model was considered in this study.

### 3. Numerical method

The effects on the SAR are studied through an appraisement of the EM energy in a specified tissues domain with the help of a three dimensional FDTD techniques [13] which is performed by the commercial software from computer simulation technology (CST) microwaves (MWS) studio.

The source and radiation impedance of antenna ($Z_R=R_R+jX_R$) determine the power radiated from antenna which can be evaluated by utilizing the formula (1) [14]:

$$P_R = \frac{1}{2} V_S^2 \frac{R_R}{(Z_R + Z_S)^2} \quad (1)$$

Where, $V_S$ and $Z_S$ represent source voltage and impedance respectively.

The total absorbed power by the user's head can be calculated by formula (2) [14]:

$$P_{abs} = \frac{1}{2} \int_V \sigma \; |E|^2 \; dv \quad (2)$$

SAR can be calculated from induced electric field (E) in the human tissues by using equation (3) [14]:

$$SAR = \frac{\sigma |E|^2}{2\rho} \quad (3)$$

Where, $\sigma$ and $\rho$ express the conductivity and density of human tissue respectively.

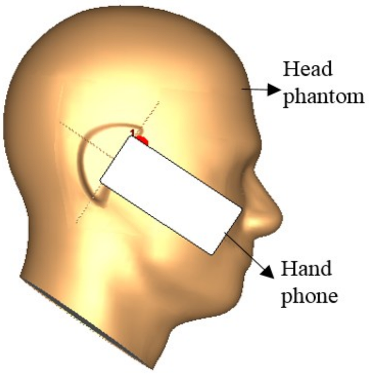


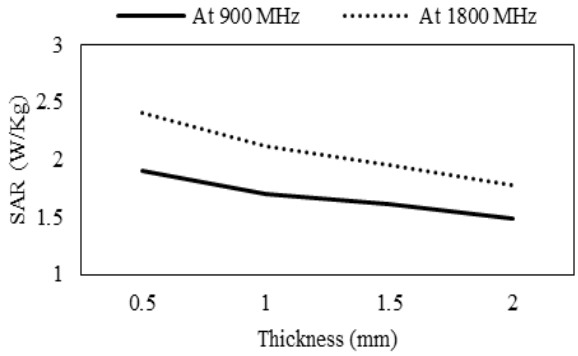

*Fig. 3. Experimental set-up with head phantom and*

Adopting the non-uniform meshing scheme, the majority of the computation was considered to regions along the inhomogeneous boundaries for quick and perfect investigation on finite integral time domain technique (FITD). Figure 3 indicates the simulation set-up with the head and cell phone in talk mode. In Lossy-Drude simulation setup [15], the domain was 128 × 128 × 128 cells in the finite-difference time-domain (FDTD) method. The cell sizes were set as *dx=dy=dz*=0.5 mm. The computation domain was terminated with 12 cells perfect material layer.

## 4. Results and discussion

In this paper, the SAR results have been presented for five different substrate materials. In addition, radiation efficiencies of antenna are observed to clarify the effects of antenna substrate material on antenna performance. For each substrate material, four thicken sheet 0.5 mm, 1 mm, 1.5 mm, and 2 mm are used to take effects of substrate thickness. The SAR values and radiation efficiencies are calculated for two global system for mobile (GSM) frequency band at 900 MHz and 1800 MHz. The SAR values are averaged over 1 g of body tissues using 0.5 W (rms) excitation for antenna.

Fig. 4(a) illustrates the SAR values of PIFA with Bakelite substrate of different thickness. The results show that the thicker substrate produces lower SAR for both lower and upper frequency bands. It is also noted that the SAR values for upper GSM frequency band are always higher than that of lower frequency band. This is due to the fact that the antenna performances for different frequency bands are not identical. Moreover, Figure 4(b) represents the radiation efficiencies of antenna with Bakelite substrate thickness variation. Substrate thickness does not affect the radiation efficiencies significantly for both frequency bands.

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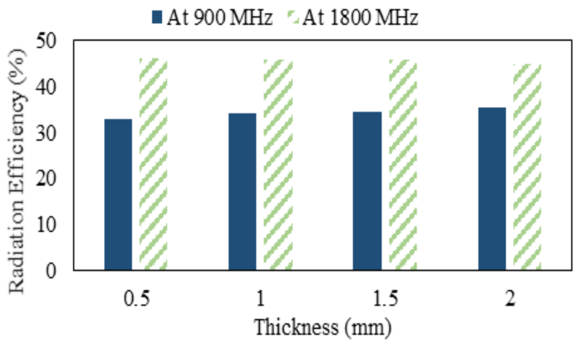
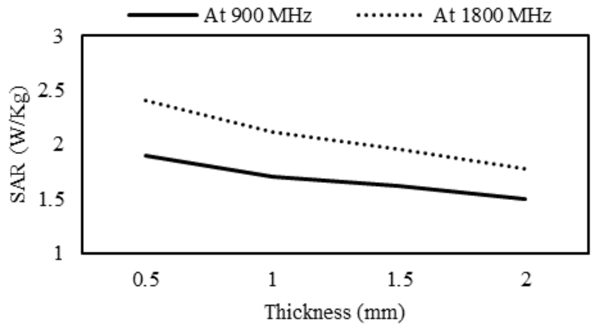



*(b)*

*Fig. 4. PIFA with different thickness of Bakelite substrate (a) SAR values (b) radiation*

The SAR values and radiation efficiencies for PIFA with FR-4 substrate are plotted in Figure 5 varying substrate thickness. For the thickness of 0.5 mm, antenna with Bakelite and FR-4 substrate produce identical SAR values for both frequency bands. But for higher thicknesses of substrate, FR-4 substrate leads to little bit higher SAR values than that of Bakelite. As like as Bakelite substrate effects, the variation of radiation efficiencies are not significant due to the FR-4 substrate thickness. Figure 6(a) and 6(b) illustrate the SAR results and radiation efficiencies in case of PIFA with Rogers RO4003 substrate.

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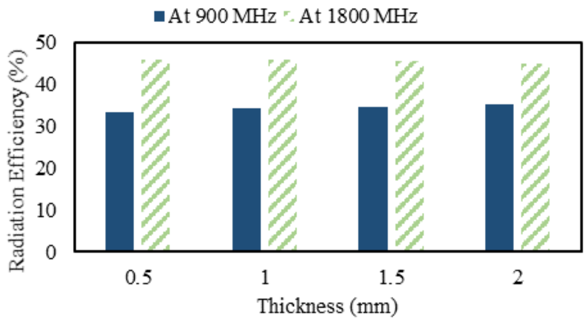


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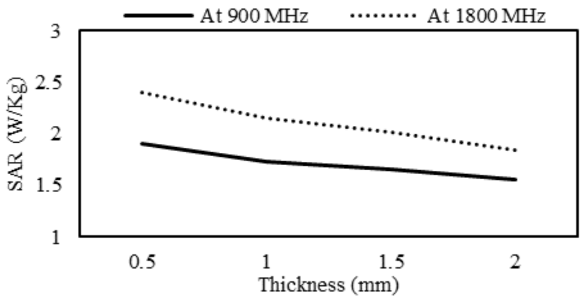
*Fig. 5. PIFA with different thickness of FR-4 substrate (a) SAR values (b) radiation efficiencies.*

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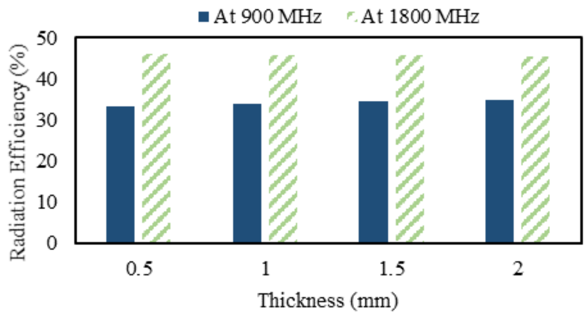


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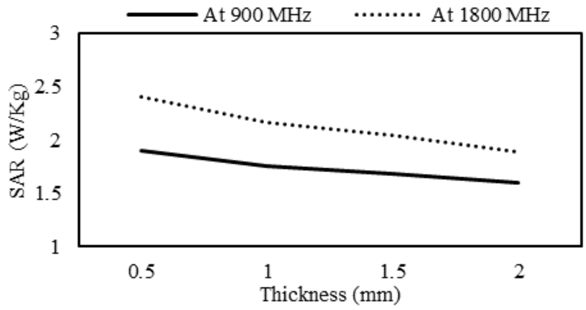
*Fig. 6. PIFA with different thickness of Rogers RO4003 substrate (a) SAR values (b) radiation efficiencies.*

The results indicate that the Rogers substrate leads to little bit higher SAR values than Bakelite and FR-4. For 2 mm substrate thickness, Rogers produces 4.52% higher SAR than that of Bakelite and 3.23% than FR-4 substrate at 900 MHz. At 1800 MHz, Rogers leads to 3.8% and 0.06% higher SAR than that of Bakelite and FR-4 respectively.

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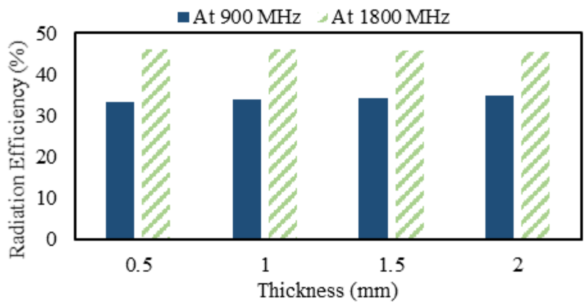


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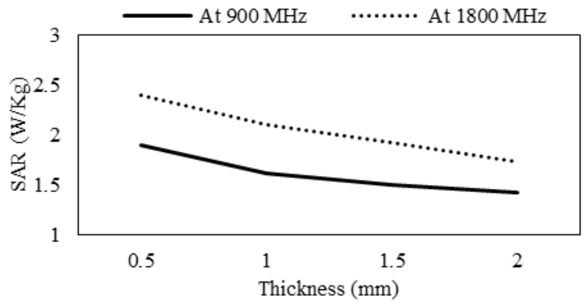
*Fig. 7. PIFA with different thickness of Taconic TLC substrate (a) SAR values (b) radiation efficiencies.*

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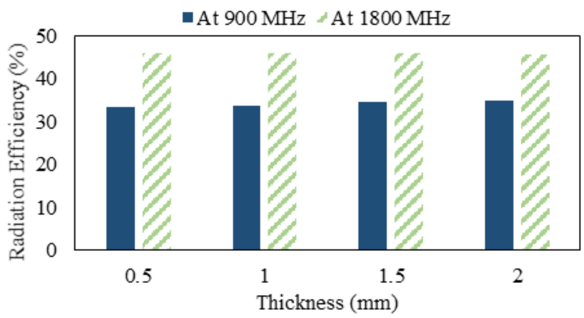


*(b)*

*Fig. 8. PIFA with different thickness of RT Duroid substrate (a) SAR values (b) radiation efficiencies.*

The radiation efficiencies for PIFA with Rogers substrate does not vary significantly for both frequency bands. Fig. 7 represents the SAR and radiation efficiencies for the substrate material Taconic TLC. The results indicate that the Taconic TLC substrate provides identical SAR values for 0.5 mm substrate thickness and further increment in SAR values for higher substrate thickness compared with Bakelite, FR-4 and Rogers RO4003. In case of 2 mm thicken substrate, PIFA with Taconic TLC substrate leads to 7.5% and 6.3% higher SAR for lower and higher GSM frequency bands respectively. Figure 8(a) and 8(b) illustrate the corresponding results of SAR and radiation efficiency of antenna with RT Duroid substrate for both frequency bands. The SAR results of RT Duroid substrate show most promising outcome as it produces lower SAR values for both GSM frequency bands than other four substrate materials. Comparing with antenna with Bakelite substrate, RT Duroid substrate results 3.4% and 2.3% lower SAR for lower and upper frequency bands respectively. In addition, RT Duroid substrate leads to improve little bit radiation efficiency from all other substrates.

## 5. Conclusion

In this investigation, the effects of antenna substrate materials and its thickness on EM absorption have been analyzed with five different substrate materials. An E-shaped PIFA are used to compare the substrate effects at GSM frequencies 900 MHz and 1800 MHz considering SAR in the human head and radiation efficiencies of antenna. The results indicate that the SAR values are affected due to the variation of substrate materials and its thickness. For the substrate thickness 0.5 mm, all substrate material show identical SAR results. But for 2 mm thicken substrate, the SAR from different substrate materials differ from each other. However, PIFA with RT Duroid substrate is found to be better over all other substrates, which produces lower SAR values in the head for both lower and upper frequency bands. The thickness of substrate affects SAR values greatly at the lower frequency band. On the other hand, the antenna radiation efficiencies are not affected significantly due to the substrate materials.

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*Corresponding autor: ipk_eee@yahoo.com