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Calculating the SAR Distribution in Two Human Head Models Exposed to Printed Antenna with Coupling Feed for GSM/UMTS/LTE/WLAN Operation in the Mobile Phone

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***Abstract*- The scope of this paper is to examine the Specific Absorption Rate (SAR) inside the human head model exposed to the radiation of a low-profile printed monopole antenna with coupling feed for GSM/UMTS/LTE/WLAN operation in the slim mobile phone. The presented antenna operates for most of the mobile phone applications such as the GSM850, GSM900, GSM1900, UMTS2100, LTE2300, LTE2500 and WLAN2400 bands. In this study, two different human head models are used: homogenous spherical head and spherical seven layer model. In addition, the effects of operating frequency and the gap distance between the mobile phone antenna and the human head model on distributions of the SAR within the human head are analyzed. All the simulations are done for three different distances between the antenna and the head model (5 mm, 10 mm, 20 mm). Furthermore, the SAR levels for the head tissues are calculated for and with accordance to the two currently accepted standards: Federal Communications Commission (FCC) and International Commission on Non-Ionizing Radiation Protection (ICNIRP). All numerical simulations are performed using the Ansoft HFSS Software and CST Microwave Studio.**

***Index Terms*- Mobile phone, human head model, Specific Absorption Rate (SAR), GSM/UMTS/ LTE/WLAN, FCC, ICNIRP.**

I. INTRODUCTION

With the rapid development of the wireless communication technology and the widely use of mobile phone with billions of subscribers around the world today, more attentions have been drawn to the biological effects of electromagnetic fields. The safety of electromagnetic fields has been the subject of much debate, originally concerned with fields from power lines and more recently with radiated power from handsets, laptops, and base stations [1].

Several internal mobile phone antennas capable of covering eight-band WWAN/LTE operation which includes the LTE700/GSM850/ 900 bands and the GSM1800/ 1900/ UMTS/ LTE2300/2500 bands has been presented in [2,3]. Kin-Lu Wong and Wei-Yu Chen propose a small-size printed loop-type antenna integrated with two stacked coupled-feed shorted strip monopoles for eight-band LTE/GSM/UMTS operation in the mobile phone [2]. In [3] the authors present a planar monopole with a coupling feed and an inductive shorting strip, the antenna's radiating plate occupy a small volume of $3\times6\times40$ mm^3, yet it is capable of generating two wide operating bands to cover the desired frequency ranges of 698–960 and 1710–2690MHz.

For the cellular phone compliance [4], the SAR value must not exceed the exposure guidelines [5, 6]. The SAR limit specified in IEEE C95.1: 1999 is 1.6W/Kg in a SAR 1-g averaging mass while that specified in IEEE C95.1: 2005 has been updated to 2W/Kg in a 10-g averaging mass [5]. This new SAR limit specified in IEEE C95.1:

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2005 is comparable to the limit specified in the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines [6] in Europe, Japan, Brazil and New Zealand. In general, the SAR value is influenced by various parameters such as antenna positions relative to the human body, radiation patterns of the antenna, radiated power and antenna types [7].

The purpose of this study is to investigate the electromagnetic (EM) interaction between a printed monopole antenna with coupling feed for GSM/UMTS/LTE/WLAN operation in the slim mobile phone and a human head. Two human head models are used: a homogeneous spherical head which consists of a glass shell and a sphere as the tissue equivalent materials for the second model is a spherical seven layer model. The seven layers are Skin, Fat, Muscle, Skull, Dura, CSF (Cerebro Spinal Fluid) and Brain. The SAR is calculated at different frequencies and for three different distances (5 mm, 10 mm, 20 mm) between the proposed antenna and the human head models. The whole work of this paper used Ansoft HFSS Software and Computer Simulated Technology (CST) Microwave Studio to run all simulations and to calculate SAR values.

II. ANTENNA DESIGN AND CONFIGURATION

The geometry of the presented planar monopole antenna with a T-shaped coupling feed having a simple structure and comprising a T-shaped driven strip and a coupled radiating structure is shown in Fig.1. A 1.6-mm thick FR4 substrate of length 120 mm and width 40 mm is used as the system circuit board of the mobile phone in the study. The FR4 substrate is of relative permittivity 4.4 and loss tangent 0.02. The antenna occupies a small size of 40×20 mm^2 is printed on the top no-ground portion of the system circuit board with a ground-plane size of 40×100 mm^2 , the antenna is fed by a 50 Ohms coaxial cable. The optimized geometric parameters of the antenna are as follows (units in mm):L1=7,L2=2,L3=2.5,L4=20,L5=3,L6=10, L7=4,W1=1.5,W2=15.25,W3=10.25,W4=3, W5=0.5, W6=40,W7=35,g=0.5, T=13.5.

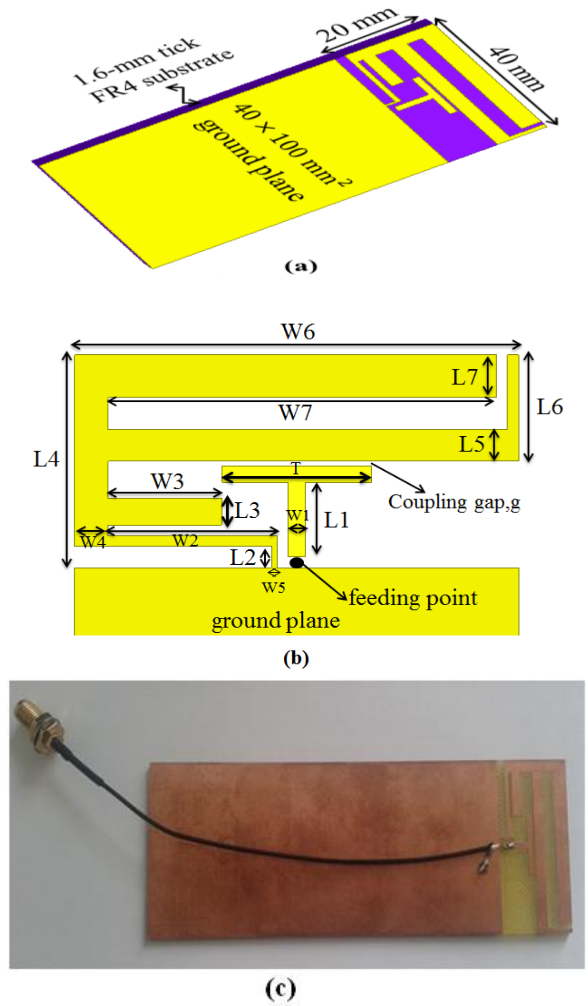

Fig.1. (a) Geometry of the antenna , (b) the metal pattern of the antenna and (c) photograph of the fabricated prototype of the proposed antenna

III. ELECTROMAGNETIC DOSIMETRY, POWER ABSORPTION AND SAR

Electromagnetic dosimetry establishes the relationship between an electromagnetic field distribution in free space and the induced fields inside biological tissues, generally the human body [1].

The Specific Absorption Rate (SAR) is defined as the time derivative of the incremental energy

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(dW) dissipated in an incremental mass (dm) contained in a volume element (dV) of a given density (ρ) [8] [9, 10]:

$$SAR = \frac{d}{dt}\left(\frac{dW}{dm}\right) = \frac{d}{dt}\left(\frac{dW}{\rho dV}\right) \quad (W/kg) \qquad (1)$$

The SAR quantity is related to the internal *E*-field by:

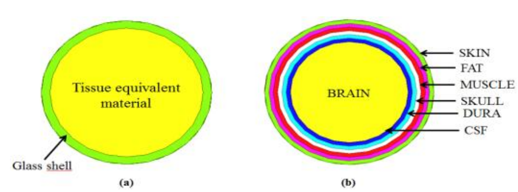
$$SAR = \frac{\sigma E^2}{\rho} \quad (W/kg) \qquad (2)$$

$$E = \left(\frac{\sigma}{\rho} SAR\right)^{1/2} \quad (3) \qquad J = (\sigma \rho SAR)^{1/2} \quad (4)$$

where, ρ is the mass density in kg/m^3, σ is the electrical conductivity of tissue (S /m) , E is the root mean square (rms) of electric field strength in volts per meter and J is the current density (A/m^2) in tissue.

A. Human head model

In this work two spherical human head models have been considered. The first model is a homogeneous spherical head with a diameter of 200 mm consists of a glass shell with 5 mm thickness and dielectric constant εr =4.6 and a sphere with 95 mm radius as the head equivalent materials Fig.2(a). Properties of the head tissue-equivalent dielectric and the glass shell are presented in [11]. The second model is a seven-layered spherical head model (diameter 20 cm).The simulated tissues and thickness are:
Skin (2 mm), Fat (1 mm), Muscle (4 mm), Skull (10 mm), Dura (1mm), CSF (Cerebro Spinal Fluid) (2 mm) and Brain (80 mm), Fig.2(b). The dielectric properties of the seven-layer human head model used in the simulations are given in [12].



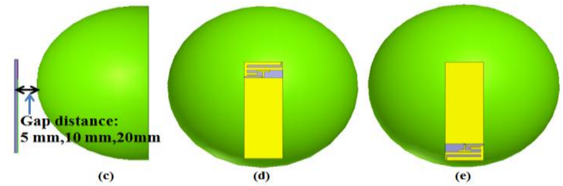


Fig. 2. Human head model. (a) Homogenous head model, (b) head model composed of seven layers , (c) gap distance, (d) antenna at the top position, (e) antenna at the bottom position

IV. SAR ANALYSIS OF THE PROPOSED ANTENNA

The SAR values of the presented low-profile printed monopole antenna with coupling feed for GSM/ UMTS/LTE/WLAN operation in the slim mobile phone are analyzed using Ansoft HFSS and CST MWS. In this study, the input power for the SAR calculation is 24 dBm or 250 mW for the lower band 783-1167 MHz and 21dBm or 125 mW for the upper band 1816-2900MHz.

A. SAR distribution in homogenous head model

The effect of the gap distance between the mobile phone antenna and the homogenous head model has also presented. Fig.3 shows the variation levels of the local SAR and the SAR averaging over a mass of 1 gram, at various gap distances (5 mm, 10 mm and 20mm) between the proposed antenna and the homogenous sphere head model at different frequencies of 900 MHz, 2.1 GHz and 2.3 GHz , the antenna is placed at the bottom of the mobile phone. It can be seen that the levels of the local and average SAR decrease when the gap distance increases, also with penetration into the homogenous head, the SAR levels for all frequencies decrease rapidly.

The corresponding simulated 3D 1-g SAR and 2D 10-g SAR distributions (W/kg) inside the tissue-equivalent material at the frequencies of 900 MHz, 2.1 GHz and 2.3 GHz with the gap distance fixed to 20 mm obtained by Ansoft HFSS and CST MWS are shown in the Fig. 4(a) and Fig.4(b) respectively.

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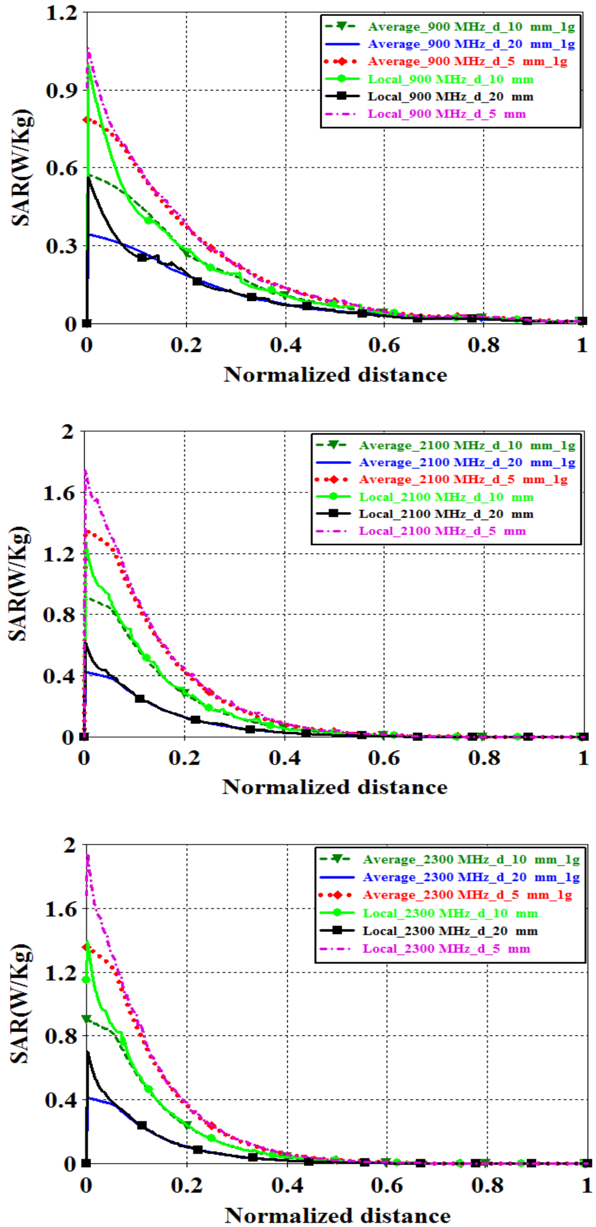
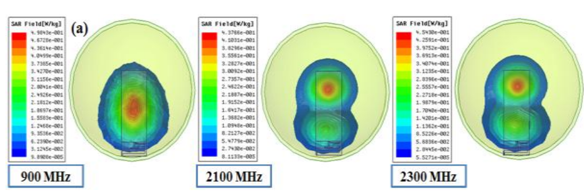


Fig.3. Local SAR and average SAR variation in 1-g head tissues for the homogenous head model, at different frequencies at various gap distances



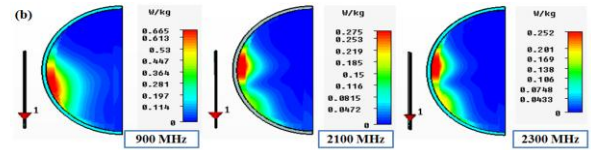


Fig.4. Simulated (a) 3D 1-g SAR and (b) 2D 10-g SAR distributions (W/kg) inside the tissue-equivalent material at the frequencies of 900 MHz, 2100 MHz and 2300 MHz, with 20 mm gap distance using Ansoft HFSS and CST MWS

Table 1: E-Field strength distributions (V/m) , 1-g SAR and 10-g SAR distributions (W/kg) inside the tissue-equivalent material for the antenna placed at the bottom of the mobile phone, with 20 mm gap distance

Software	Ansoft HFSS		CST MWS	
Frequency (MHz)	E-field strength (V/m)	SAR_{1g} (W/kg)	SAR_{1g} (W/kg)	SAR_{10g} (W/kg)
900	2.70×10^1	0.498	0.872	0.665
2100	2.44×10^1	0.437	0.451	0.275
2300	2.26×10^1	0.454	0.432	0.252
2450	2.34×10^1	0.446	0.427	0.242
2600	-	-	0.427	0.234

Table 1 presents a summary of the E-field strength (V/m), the averaged 1-g SAR and 10-g SAR inside the tissue-equivalent material at the aforementioned operating frequencies when the antenna is placed at the bottom of the mobile phone using Ansoft HFSS and CST MWS. The obtained results demonstrated that the presented antenna respects the SAR limits recommended by the FCC, which is 1.6 W/kg averaged over 1-g of tissue and ICNIRP(2 W/kg for the 10-g head tissue).

Table 2 lists the comparison of simulated SAR in 1-g and 10-g head tissues for the proposed antenna placed at the bottom position of the mobile phone with the presence of the phantom head with reference antenna at selective operating frequencies. In this study two gap distances d=5 mm and d=10 mm between the antenna and the phantom head are studied. It is clearly seen that the proposed design shows a lower SAR values in comparison to published work.

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Table 2: Comparison of simulated SAR in 1-g and 10-g head tissues for the proposed antenna placed at the bottom position of the mobile phone with the presence of the phantom head with reference antenna; two gap distances d=5 mm and d=10 mm between the antenna and the phantom head are investigated

	Input power (dBm)	Present work				Published work [13]			
Distance		d=5 mm		d=10 mm		d=5 mm		d=10 mm	
Frequency (MHz)	-	SAR_{1g} (W/kg)	SAR_{10g} (W/kg)	SAR_{1g} (W/kg)	SAR_{10g} (W/kg)	SAR_{1g} (W/kg)	SAR_{10g} (W/kg)	SAR_{1g} (W/kg)	SAR_{10g} (W/kg)
859	24	1.75	1.28	1.37	1.01	2.04	1.43	1.43	1.02
925	24	1.98	1.40	1.51	1.08	2.03	1.32	1.53	1.07
2045	21	1.32	0.782	0.936	0.562	1.37	0.86	0.92	0.57
2300	21	1.26	0.693	0.888	0.495	-	-	-	-
2450	21	1.23	0.65	0.887	0.477	-	-	-	-
2600	21	1.07	0.546	0.819	0.425	-	-	-	-

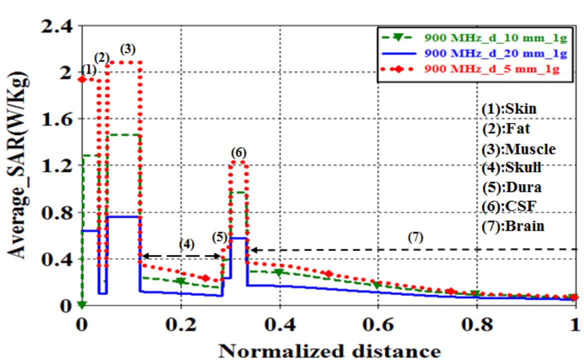
B. SAR distribution in the Seven- layer human head model

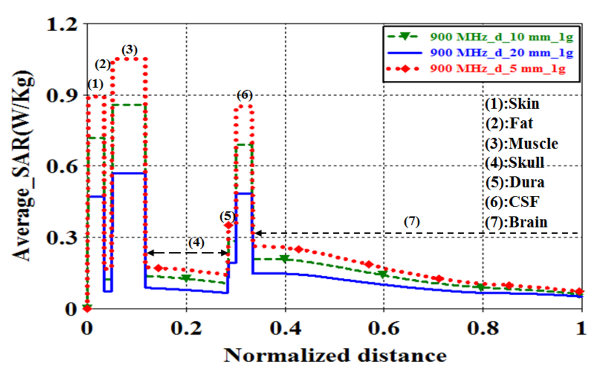
In this research work, the effect of the gap distance between the antenna and the spherical seven layer head model has also studied. The SAR values of the proposed antenna are also investigated by using Ansoft HFSS. Two cases of the antenna placed at the top position and bottom position are illustrated as shown in Fig.2(d) and Fig.2(e) respectively.

The simulated results of the average 1-g SAR distribution within the spherical seven layer human head model at various gap distances (5mm, 10 mm, 20 mm) at selective frequencies of 900 MHz, 2.1 GHz and 2.3 GHz are presented in Fig.5. Notice that the antenna is mounted at the top of the mobile phone of user's head .From Fig.5 ,it can be seen that with a smaller gap distance (5 mm) between the antenna and the human head leads to higher SAR levels inside the human head. As the gap distance increases the levels of the SAR in all tissues are decreased.

The comparison of the average 1-g SAR distribution inside the spherical seven layer human head model at various gap distances at different frequencies of 900 MHz, 2.1 GHz and 2.3 GHz are illustrated in Fig.6. In this case, the antenna is placed at the bottom of the mobile phone as shown in Fig.2(c). Results demonstrate that increasing the gap distance will lead to rapid decrease in the levels of the SAR.

It can be observed that there is a great influence of the gap distance between the antenna and human head on SAR reduction in Fig. 5 and Fig.6. If the distance between the antenna and the spherical seven layer head model is increased from 5 to 20 mm, then the SAR levels also decrease. Furthermore, the SAR levels differ from one tissue to another because different tissues are located differently with respect to the monopole antenna and electric parameters (conductivities, relative permittivity) vary among the tissues. From the simulated results, it can be seen that the SAR values at the bottom position





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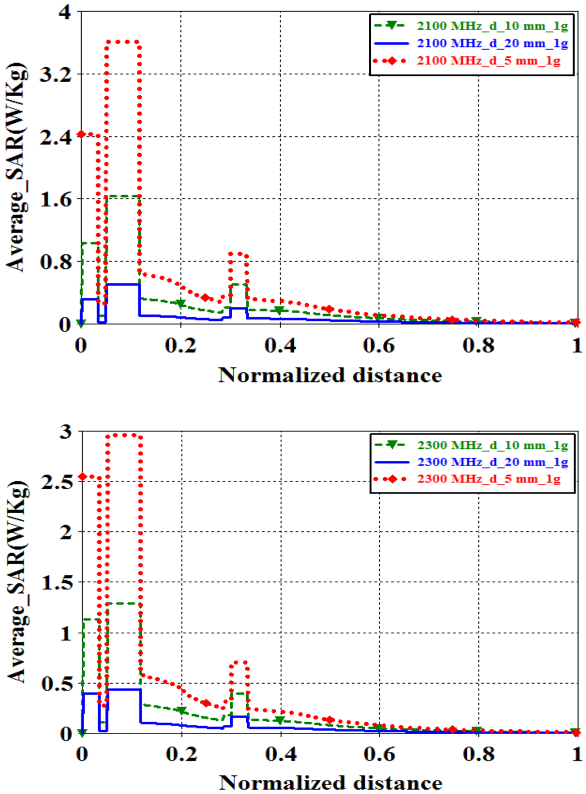

Fig.5. Averaged 1-g SAR distribution within the spherical seven layer head model, at various gap distances at different frequencies, the antenna is placed at the top position of the mobile phone

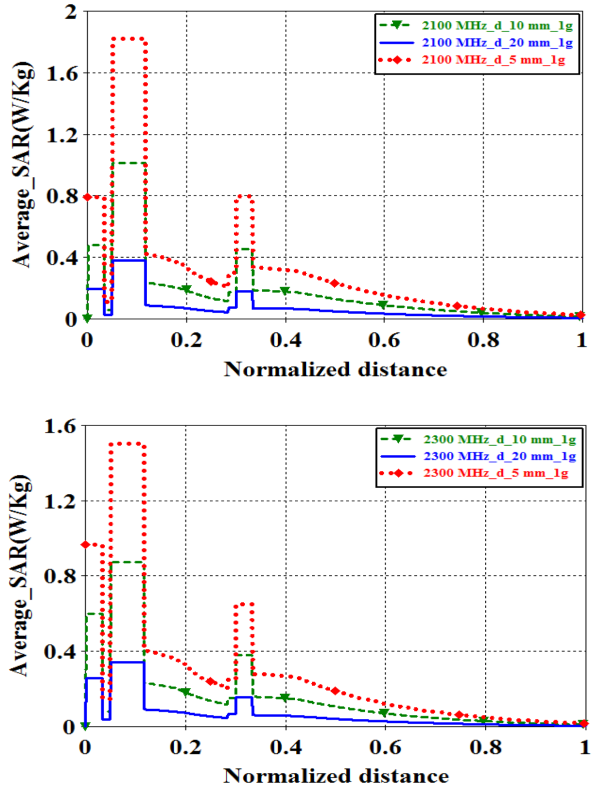

Fig.6. Averaged 1-g SAR distribution within the spherical seven layer head model, at various gap distances at different frequencies, the antenna is placed at the bottom position of the mobile phone

are lower than at the top position. It seems that placing the antenna at the bottom edge is more promising for the practical mobile phone applications.

The simulated SAR values for 1-g and 10-g head tissues obtained by using CST MWS are given in Table 3. From the table, it is observed that the SAR in 1-g head tissue is always higher than SAR in 10-g head tissues. Moreover, the SAR values obtained from this study are all below the SAR limit of 1.6 W/kg for the 1-g head tissue (according to FCC standard) and 2.0 W/kg for the 10-g head tissue (according to ICNIRP standard). The simulation results demonstrated that the proposed antenna is attractive for the practical mobile phone applications.

Table 3: Simulated SAR in 1-g and 10-g head tissues obtained from CST MWS for the antenna placed at the bottom of the mobile phone with the presence of the spherical seven layer head model, with 20 mm gap distance

Frequency (MHz)	Input power (dBm)	SAR_{1g} (W/kg)	SAR_{10g} (W/kg)
900	24	1.04	0.502
2100	21	0.281	0.149
2300	21	0.282	0.147
2450	21	0.334	0.168
2600	21	0.348	0.171

V. THE ANTENNA RESULTS AND DISCUSSION

The low-profile printed monopole antenna with coupling feed for GSM/UMTS / LTE / WLAN operation in the slim mobile phone is fabricated and tested. Fig. 1(c) shows the photo of the fabricated monopole antenna.

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Fig.7 plots the measured and simulated return losses for the constructed prototype. The simulated results are obtained using a full-wave electromagnetic (EM) simulator, CST MWS which is based on Finite Integration Technique (FIT).The simulated results of CST MWS are compared with the Ansoft High Frequency Structure Simulator HFSS which is based on Finite Element Method (FEM), whereas the measured results are tested by using the Anritsu Vector Network Analyzer Master MS2028C. It can be seen from Fig. 7 that the measured and simulated results are in good agreement. From the results it is clearly observed that the antenna is capable of generating two wide operating bands, the lower band has a bandwidth of 384 MHz (783-1167 MHz), while the upper band has 1084 MHz (1816-2900MHz).

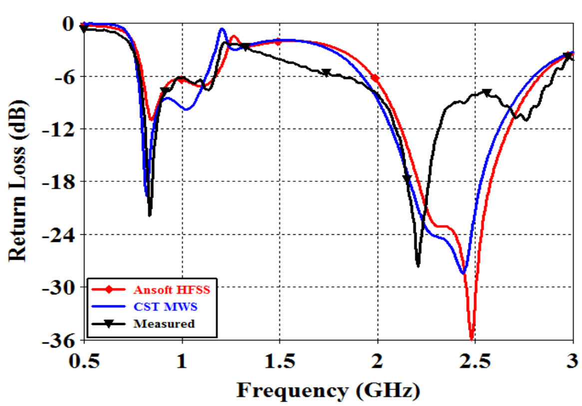

Fig. 7. Measured and simulated return losses by using CST MWS and HFSS for the proposed antenna

The radiation characteristics of the proposed prototype antenna in three principal planes, the φ=0°,φ=90° and θ=90° are also studied. The two-dimensional (2D) radiation patterns at selective frequencies including 900MHz, 2.1GHz and 2.3GHz are shown in Fig. 8.Dipole-like radiation patterns at 900 MHz are presented, and good omnidirectional radiation in the plane (φ=0°) is generally observed. For the radiation patterns in the higher band in the two planes (φ=90° and θ=90°), more variations and nulls in the patterns are seen.

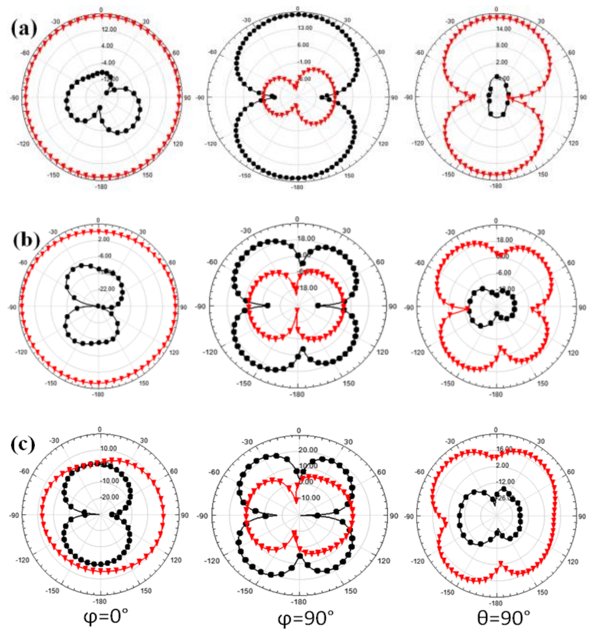

Fig. 8. Radiation patterns in 2D at (a) 900MHz, (b) 2.1GHz and (c) 2.3GHz for the proposed antenna (dB(EPhi) , dB(ETheta))

The comparison of the proposed antenna with the existing antennas [14, 15, 16], in terms of antenna size, area occupied by antenna and bandwidth is shown in Table 4. By comparison, the proposed antenna has a small size and capable of generating two wide operating bands, of 384 MHz (783-1167 MHz) and 1084 MHz (1816-2900MHz).

Table 4: Comparison of proposed antenna performance with reference antennas

Published literature/ proposed	Antenna size mm^2	Area occupied by antenna mm^2	Bandwidth (MHz)
[14]	18×61	1098	868 - 995 / 1550 -2490
[15]	15.5×56.5	875.75	824-960/ 1710-2170
[16]	15×60	900	720–1150 / 1450–2200
Proposed antenna	20×40	800	783-1167 / 1816-2900

VI. CONCLUSION

The objective of the present study was to evaluate the SAR levels within two human head

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models exposed to the radiation of a low-profile printed monopole antenna with coupling feed for GSM/UMTS/LTE/WLAN operation in the slim mobile phone. The effect of the gap distance between the antenna and the human head on distributions of the SAR inside the human head at different frequencies of 900 MHz, 2100MHz, 2300 MHz, 2450 MHz and 2600MHz is studied. The SAR levels for the head tissues are evaluated for and with accordance to the two currently accepted standards: FCC(1.6 W/kg for the 1-g head tissue) and ICNIRP(2 W/kg for the 10-g head tissue). In addition, the SAR values of the presented antenna placed at the top and bottom positions of the mobile phone have also been investigated. Due to different locations with respect to the radiating antenna and different conductivities, not all the tissues experience the same power absorption. Moreover, the SAR values obtained from this research work demonstrate that it is promising for the proposed antenna to be placed at the bottom position of the mobile phone to achieve decreased SAR values for practical applications.

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