East African Scholars Journal of Engineering and Computer Sciences
Abbreviated Key Title: East African Scholars J Eng Comput Sci
ISSN: 2617-4480 (Print) & ISSN: 2663-0346 (Online)
Published By East African Scholars Publisher, Kenya

OPEN ACCESS

Volume-3 | Issue-2 | Feb-2020 | DOI: 10.36349/easjecs.2020.v03i02.04

Review Article

A Low-SAR Planar Monopole Antenna for Mobile Communications

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Article History
Received: 08.01.2020
Accepted: 18.01.2020
Published: 28.02.2020

Journal homepage:
https://www.easpublisher.com/easjecs

Quick Response Code

Abstract: This paper implies a new mobile antenna architecture to reduce the value of the SAR and to cover many mobile operating bands and other wireless applications. The frequencies covered are GSM 900, DCS 1800 and most of the LTE bands. It also covers the AWS, WiMAX and WLAN bands. The antenna is constructed from a meander line which connected with ground plane via a shorting strip. The operating bands range from 0.893 GHz – 0.967 GHz, 1.59 GHz -1.858 GHz, 3.22 GHz - 3.464 GHz and 5.28 GHz -5.67 GHz. In addition, the first and second band of the antenna can be adjusted by using different meander line lengths with changing the position of shorting strip, while the other bands can be tuned by adjusting the monopole length. The antenna occupies ($40\times110\times1.6$ mm^3), so the proposed antenna is therefore ideal for many wireless handheld devices.
Keywords: Antenna, Mobile communications, Radiation pattern SAR, and SAM phantom.

1. INTRODUCTION

Communication technologies have recently grown rapidly in such a way that it enables mobile phones to function in a range of communication services. This has led to a great competition in the design of antennas with some desirable features such as multiband service, light weight, low SAR and low profile. The primary cause of electromagnetic (EM) radiation is mobile phones, which constitute a severe health hazard owing to their ability to enter human body tissues (Hossain, M. I. *et al.*, 2015). According to the World Health Organization (WHO), important pollution is caused by radio frequency (RF) which may pose a threat to human health. If the human body is exposed to elevated levels of EM wave radiation for a lengthy span of moment, this can contribute to sister chromatide exchange (SCE), brain cancer, and several illnesses. Specific absorption rate (SAR) is the power absorbed by body tissues, typically averaged either over the whole body or over a small part volume (typically $1g$ or $10g$ of tissue). The limit was set as 2 W/kg regarding any 10 gm of human tissues according to IEEE C95.1:2005 by both mentioned organizations. On the other hand, SAR limit has been specified to 1.6 W/kg regarding 1 gm human tissues by the Federal Communication Commission (FCC) of United States (Hossain, M. I. *et al.*, 2015; & Zhang, M., & Alden, A. 2011). SAR is a basic parameter in the health risk analysis of electromagnetic energy absorption in the human body. It assesses the quantity of energy consumed per unit mass of tissue during mobile phone use. This parameter can be calculated using equation (1):

$$SAR=\int \frac{\sigma\,(r)\,|E\,(r)|^2}{\rho\,(r)}\,d(r) \qquad (1)$$

Where σ is the electrical conductivity of the sample (S/m), ρ is the density of the sample (kg/m³), and E is the RMS electric field (V/m). In (Lin, S. Y., & Huang, K. C. 2005), a compact microstrip-patch antenna has been intended for Global Positioning System and digital communication system (DCS) apps. In addition, a multi-band microstrip-patch antenna for the global mobile system (GSM), wireless local area network (WLAN) and the worldwide microwave access interoperability (WiMAX) apps has been provided in (Costantine, J. *et al.*, 2007). It should be assured that, the devices must function well under the actual condition of the person holding the device against his or her head, as the human body can interfere in the function of the nearby antennas. User closeness to the cell phone contributes to adverse impacts on the performance of the antenna, including impedance detuning, resonance frequency changing, and radiation efficiency degradation (Pelosi, M. *et al.*, 2010). Many studies have been performed in latest years to reduce the SAR. In (Faruque, M. R. I. *et al.*, 2015), M. R. I. Faruque proposed a new design of a dual band PIFA

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antenna with an E-shaped patch to be operated at 0.9 GHz and 1.8 GHz to reduce the specific absorption rate in the human head. The proposed antenna was performed by modifying the conventional ground plane of the PIFA antenna using a flat one-dimensional metamaterial array (DNG metamaterial) to create a new metamaterial embedded in the PIFA antenna. In (Nasser, N. *et al.*, 2018), the reduction of SAR is done by leading a U-edge wall made of an engrossing water material at each corner of the ground plane.

In this paper, a planar monopole antenna consists of a meander line which connected with ground plane via a shorting strip that can be operated in GSM, DCS and other high band (AWS, WIFI and WIMAX). The design of the antenna also focuses on the impact of the user phantoms and other components on the performance of the antenna. In addition, the SAR values in the user's head are evaluated.

2. ANTENNA CONFIGURATION

Fig .1 shows the configuration of the proposed antenna for the mobile handset applications. This antenna consists of resonating branches, 50 Ω microstrip line, shorting strip with dimension ($1\times0.1 mm^2$), and a mobile circuit board. The mobile circuit board is made of a FR4 substrate with dielectric constant of 4.4 and loss tangent of 0.025. The dimension of the circuit board is chosen as 40×110 mm^2 with height (*h*) of the substrate 1.6 mm. Fig. 1 shows the details of the proposed antenna which is printed on the non-ground portion of size 22×40 mm^2 on one side of the circuit board which is fed by 50 Ω microstrip line, printed on the same side of the antenna whereas the ground plane of size 40×88 mm^2 is printed on the opposite side of the antenna.

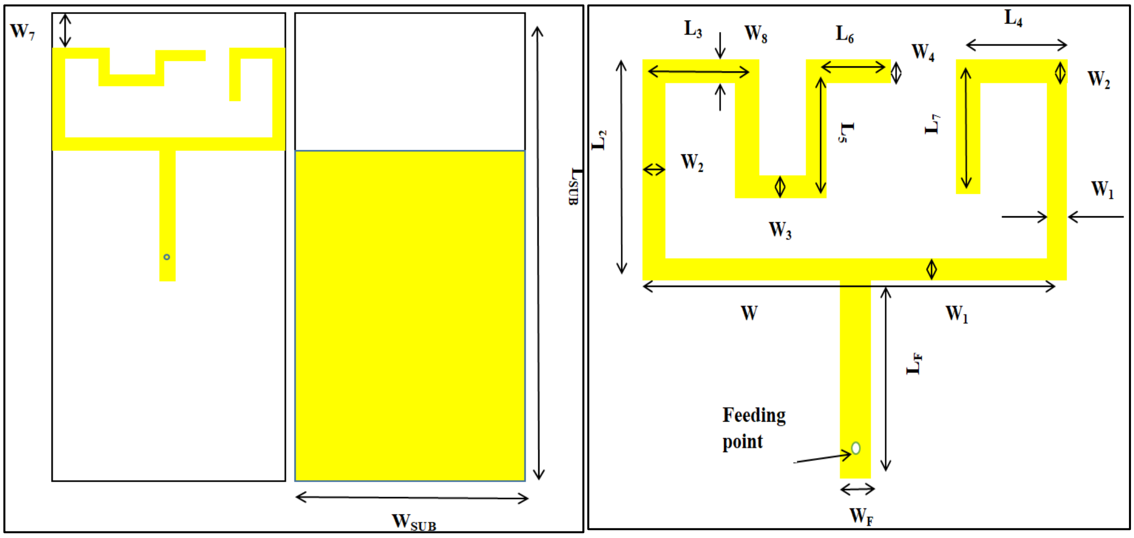


Fig. 1: (a) The configuration of the proposed antenna and (b) The detail dimensions of the proposed antenna.

The shape parameters of the antenna are optimized using finite different time domain method (FDTD) based CST to achieve the GSM900 (0.894 GHz – 0.967 GHz) and higher LTE bands along with GSM, AWS, WLAN, and WiMAX bands (1.69 GHz – 3.8 GHz), 1.59 GHz – 1.858 GHz, 3.22 GHz - 3.464 GHz and 5.28 GHz - 5.67 GHz. GSM900 are referred as lower and higher frequency bands.

The Optimized Shape Parameters Of Proposed Antenna Are Shown In Table 1.

Table 1: Optimized shape parameters of the proposed antenna in mm.

Parameter	Value	Parameter	Value	parameter	Value	parameter	Value
L_{SUB}	110	L_3	7	L_2	18	W_7	1
W_{SUB}	40	W_3	1	W_1	1	L_5	6
L_g	88	L_4	10	W_2	1	L_6	7
L_1	18	W_4	1	L_F	10	W_8	1
L_7	10	W_F	1				

3. SIMULATION RESULTS AND DISCUSSION

Antenna performance has been stated to rely on a wide range of parameters including return loss, radiation efficiency . These parameters are particularly important for the design of the handheld antenna. Antenna is modeled on the CST microwave studio simulation software.

A. Return Loss

As shown in Fig. 2, for the suggested antenna, the -10 dB BW are attained 73 MHz (894-967) at 929

MHz, 262.7 MHz (1595.4-1858.1) at 1.7 GHz, 243.3 MHz (3221.2-3464.5) at 3.4 GHz and 383 MHz (5.287-5.67) at 5.4GHz. The reflection coefficients obtained from simulation are -14.38 dB at 0.92 GHz, -18.211 dB at 1.7 GHz, -12.14 dB at 1.8 GHz, -17.74 at 3.4 GHz and -31.275 dB at 5.4 GHz.

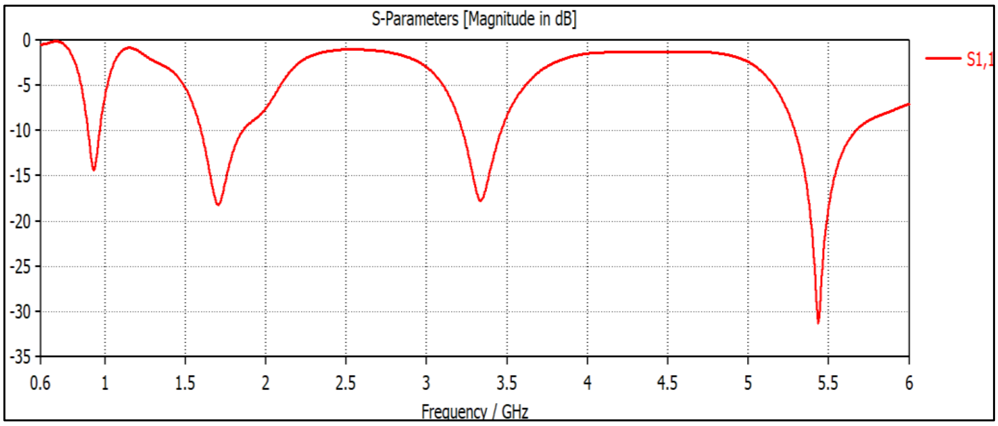


Fig. 2: Return loss of proposed antenna

B. Surface Current Distribution

In order to have a clearer view of the behavior of the implemented antenna, surface current distributions are investigated at 0.92 GHz, 1.7 GHz, 1.8 GHz, 3.4 GHz and 5.4 GHz frequencies using CST software as published in Fig. 3.

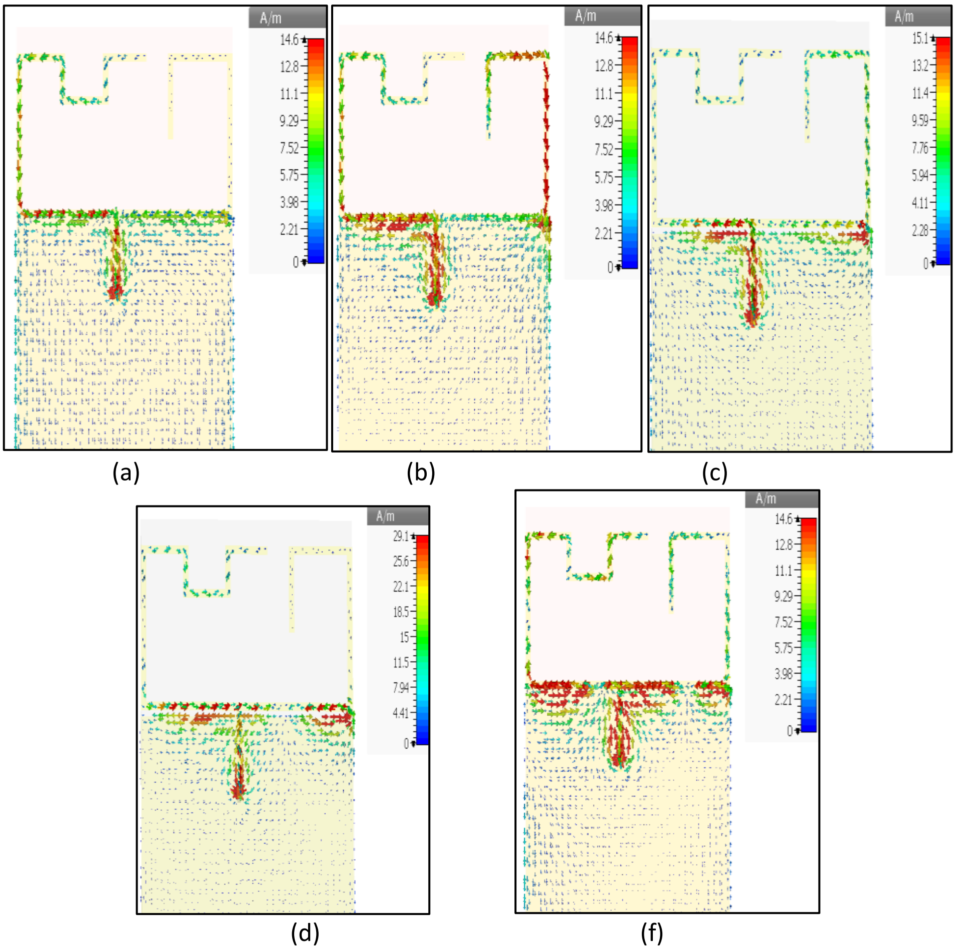
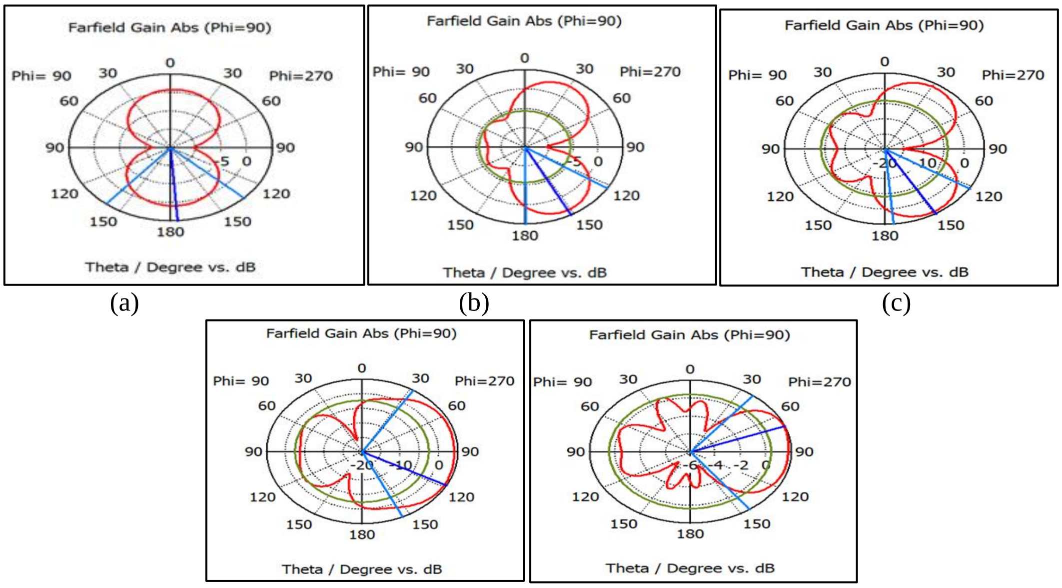


Fig. 3: Current distribution (a) 0.92 GHz, (b) 1.7 GHz, (c)1.8 GHz, (d)3.4 GHz and (e) 5.4 GHz

C. Far-Field Radiation Patterns

The gain acquired in this research is the desirable gain from intended antenna. Simulated polar pattern at 0.92 GHz, 1.7 GHz ,1.8 GHz, 3.4 GHz and 5.4 GHz of the intended antenna at ϕ =90 ° reductions for reflection are registered in Fig. 4. The simulated directivity, gain and efficiency of the intended antenna reached 2.245 dBi , 1.223 dBi and 79% for 0.92 GHz

,4.48 dBi ,4 dBi and 89% for 1.7 GHz, 4.715 dBi ,4.255 dBi , 89.87% for 1.8 GHz, 5.5 dBi , 4.371 dBi , and 77% for3.4 GHz and 4.090 dBi , 2.27 dBi , and 65.7% for 5.4 GHz.



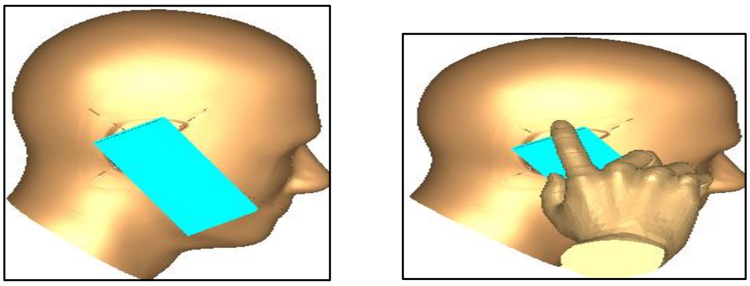
(a) (b) (c)

(d) (e)

Fig. 4: Radiation pattern for proposed antenna (a) 0.92 GHz, (b) 1.7 GHz, (C) 1.8 GHz, (d) 3.4 GHz and (f) 5.4 GHz

D. SAR Calculations

The proposed antenna is also investigated in vicinity of the mobile environment. Mobile environment is made of the plastic housing (50×120×13 mm^3). In this section, the SAR is calculated for proposed antenna once by placing antenna with near human head phantom (SAM), and another time by placing antenna with near human head and hand phantom in talking mode as shown in Fig. 5. The simulation is carried out using CST simulation tools. This simulation based on FDTD. The head model consists of shell and liquid with dielectric properties liquid is confined in the shell which is the outer layer, as well as hand dielectric properties (Certification, C. T. I. A. 2005).



(a) (b)

Fig.5: The intended antenna (a) with head model and (b) with human head hand model

The effect of human head model and human head with hand model on the return loss of the intended antenna is shown in Fig. 6. It shifted all resonance frequencies with changing in impedance matching.

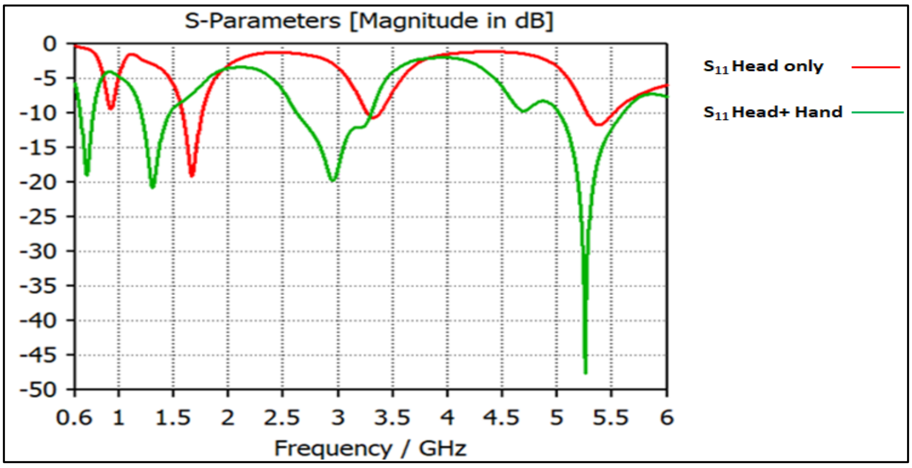


Fig. 6: The effect of head and head–hand models on S_{11}

The SAR calculated for proposed antenna at 0.92 GHz, 1.7 GHz, 1.8 GHz, 3.4 GHz and 5.4 GHz (1g & 10g) in the vicinity of human head only illustrated in Fig. 7.

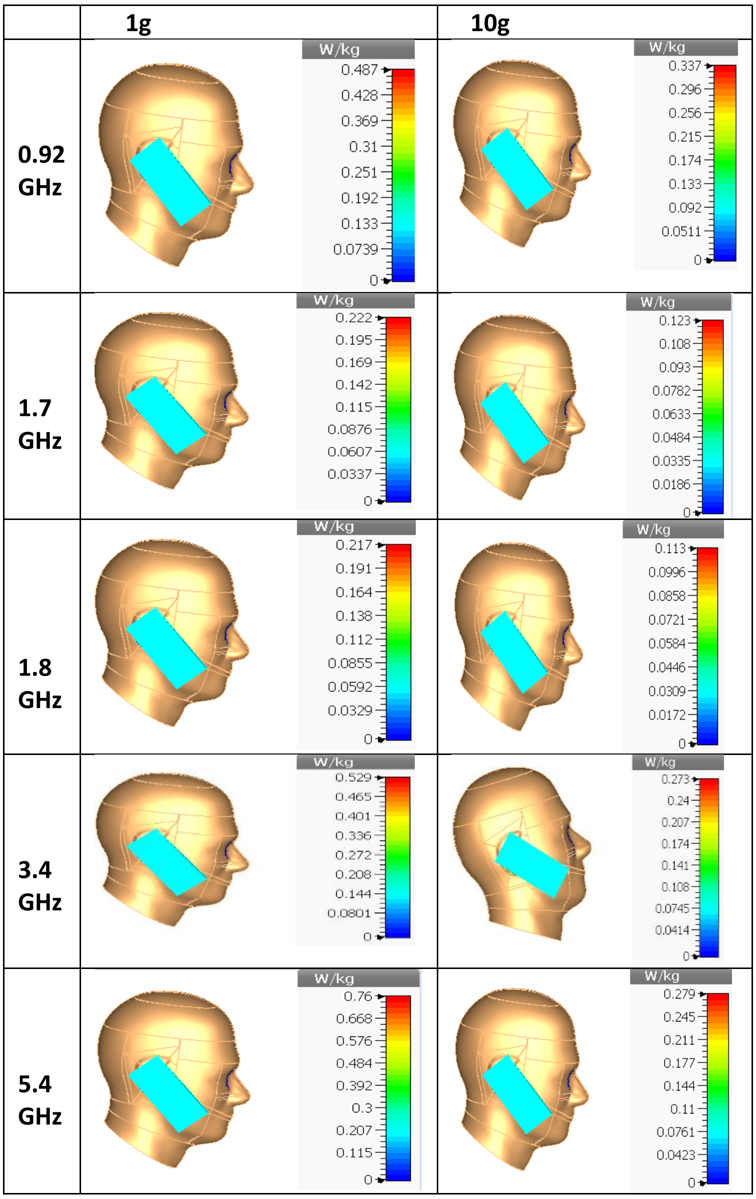


Fig. 7: SAR distribution of proposed antenna on SAM head

The SAR calculated for proposed antenna at 0.92 GHz, 1.7 GHz, 1.8 GHz, 3.4 GHz and 5.4 GHz (1g & 10g) in the vicinity of human head and hand illustrated in Fig. 8.

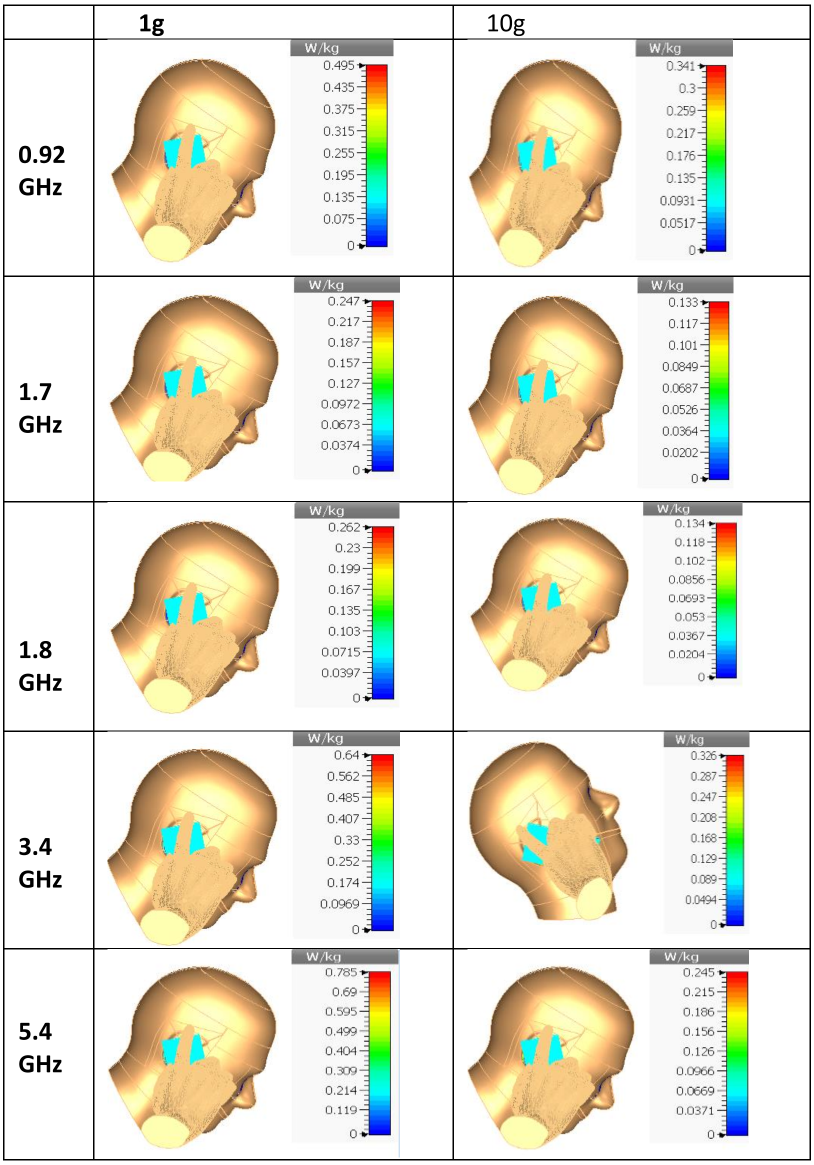


Fig. 8: SAR distribution of proposed antenna on SAM head and hand

The calculated values of SAR over 1g and 10g head tissues are given in Table 2, and the calculated values of SAR over 1g and 10g head tissues with hand are given in Table 3.

Table 2: SAR values of antenna on SAM head.

Frequency (GHz)	**0.92**	**1.7**	**1.8**	**3.4**	**5.4**
Input power(mw)	250	125	125	125	125
SAR(1g) w/kg	0.487	0.222	0.217	0.529	0.76
SAR(10g) w/kg	0.337	0.123	0.113	0.2733	0.279

Table 3: SAR values of antenna on SAM head and hand

Frequency (GHz)	**0.92**	**1.7**	**1.8**	**3.4**	**5.4**
Input power(mw)	250	125	125	125	125
SAR (1g) w/kg	0.495	0.247	0.262	0.64	0.785
SAR (10g) w/kg	0.341	0.133	0.134	0.326	0.245

Table 4 illustrates the performance of the suggested antenna without any models, with human head tissues and with human head and hand.

Table 4: The performance of suggested antenna

Frequency/GHz		0.92	1.7	1.8	3.4	5.4
Gain /dB	Without	1.223	4	4.255	4.371	2.27
Efficiency / %	models	79	89	89.87	77	65.7
Gain /dB	With head	-7.739	-3.962	-3.613	1.896	3.538
Efficiency / %	model	5.04	9.67	10.28	25.83	41.72
Gain /dB	With head	-11.27	-4.768	-4.445	1.6	3.186
Efficiency / %	+hand model	2.4	7.2	7.4	17.54	31.04

4. CONCLUSION

A planar multi-band monopole antenna is presented for mobile handset applications. The proposed antenna has been designed to operate in the GSM (0.9 GHz), DCS (1.8 GHz), AWS (1.7 GHz), WLAN (3.4 GHz) and WiMAX (5.4 GHz) bands. Good radiation characteristics are at all resonant frequencies with directivity, gain and efficiency of the intended antenna reached 2.245 dBi, 1.223 dBi and 79% for 0.92 GHz ,4.48 dBi, 4 dBi and 89% for 1.7 GHz, 4.715 dBi ,4.255 dBi , 89.87% for 1.8 GHZ, 5.5 dBi, 4.371 dBi, and 77% for 3.4 GHZ and 4.090 dBi, 2.27 dBi, and 65.7% for 5.4 GHz. Firstly, SAR calculation is performed on the human head phantom. Then, SAR is calculated on human head with hand to simulate the calling mode using CST simulator. In both cases, the simulation is performed with input power of 250 mw for 0.92 GHz and input power of 125 mw for higher frequencies. The calculated SAR values are observed to be below the limits of the standards of IEEE and FCC for 1g and 10g of tissues.

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