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DESIGN OF LOW SAR PLANAR MONOPOLE ANTENNA FOR MOBILE WIRELESS COMMUNICATION APPLICATIONS

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Abstract—Simple internal multiband monopole antenna with low SAR for most of wireless mobile communication applications is presented in this paper. The proposed antenna is an unequal arms monopole antenna with a meander strip in the other substrate side. The antenna has a simple structure and is sufficiently small in size to be easily fit on the housing of mobile or USB dongle with size $18 \times 15 \times 0.8\,\text{mm}^3$. The antenna is designed to operate at multi-bands to occupy most of allocated wireless communication devices by using high frequency structure simulator ver. 13 (HFSS). The proposed antenna has acceptable gain and efficiency while providing broadside radiation pattern that covers the horizontal plane. The antenna design and experimental results are in agreement. Moreover, the specific absorption rate (SAR) in the human head is investigated by CST 2012 Microwave Studio Hugo Voxel Model.

1. INTRODUCTION

Due to the rapidly growing demand for multiple services in a mobile terminal and high-speed interconnection among consumer electronic devices, various antennas for USB dongle application have been introduced [1]. To provide multi-band internal antennas for mobile wireless communication systems such as the global system for mobile communication (GSM) and digital communication system (DCS) as the second generation cellular system, a variety of antenna designs based on the monopole antenna have been reported [2–4]. Also, the third and fourth generation Wi-Fi/Wi-MAX, LTE operations are

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needed for designing antenna for modern applications. To provide additional functions such as plug-and-play, the conventional USB (universal serial bus) dongle is used in laptop, portable multimedia players (PMP) and personal digital assistants (PDA) [4]. Due to the rapidly growing demand for multiple services on a mobile terminal as shown in Table 1, various multiband antennas for USB dongle applications have been introduced [5].

Most of these designs generally require complicated two- or three-dimensional antenna configurations. As a result, it provides not only a large size in the radiator in wireless USB dongle devices but also some of these complicated antennas cannot cover some of these wireless bands [6, 7]. Recently, USB dongle antennas, which provide various mobile services such as mobile and ultra-wideband (UWB) communications [8–10], have been reported. However, these antennas are not suitable for USB dongle applications because of their large antenna volume, not easy for fabricated and ground size, which cannot be incorporated within the limited space that is available for USB dongle applications.

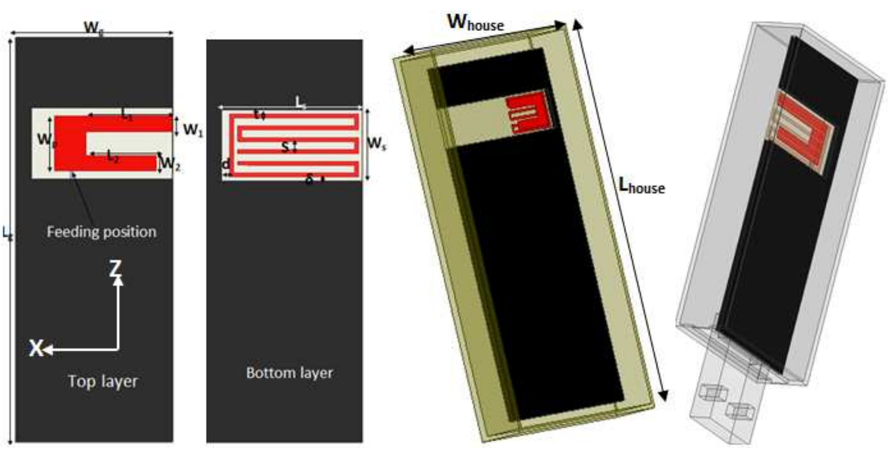
Recent papers based on a great amount of scientific work, challenge the traditional scientific point of view which establishes the thermal effects of electromagnetic radiations as the only ones of concern for the human health. With more than two billion portable handsets worldwide, this equipment is of great concern because it is used very near of the head or another part of the body. Key on the potential risk of using a mobile phone terminal is the specific absorption rate (SAR) of electromagnetic energy that it generates on the head. In order to limit the biological effects resulting from exposure to RF radiation, safety limits are usually defined in terms of the specific absorption rate (SAR). The IEEE C95.1:2005 standard defines the SAR limit to be 2 W/kg in a 10 g averaging mass [11].

In this paper, a low SAR simple monopole antenna with a meander-strip on the other side of the substrate is proposed for wireless mobile applications. The proposed antenna has a simple structure, enough bandwidth to cover most of future wireless communication services and compact volume which is suitable for fitting in either USB dongle applications or mobile handset. The antenna satisfies voltage standing wave ration VSWR 1 : 3 requirements [14, 15] for wireless broadband GSM, most of LTE bands, WiBro, wireless local area network WLAN, world interoperability for microwave access Wi-MAX as shown in Table 1. All antenna simulations in free space were carried out using the EM commercial simulator, HFSS ver. 13.0 while, the proposed antenna testing near from human head were completed by using CST 2012 hugo voxel dispersive model.

2. DESIGN PROCEDURE OF PROPOSED ANTENNA

The configuration of the proposed internal monopole antenna is shown in Figures 1(a) and (b). The geometry of printed monopole antenna with polyethylene mobile housing case is shown in Figure 1(c) while USB housing dongle is shown in Figure 1(d). The antenna dimensions are $L_1 = 15\,\text{mm}$, $L_2 = 13\,\text{mm}$, $W_1 = W_2 = 2\,\text{mm}$, $W_p = 7\,\text{mm}$, $L_g = 45\,\text{mm}$, $W_g = 20\,\text{mm}$, $L_s = 18\,\text{mm}$, $W_s = 9\,\text{mm}$, $d = 1\,\text{mm}$, $S = 1.5\,\text{mm}$, $t = 0.5\,\text{mm}$ and $\delta = 0.5\,\text{mm}$. The mobile substrate has an area of $50 \times 80\,\text{mm}^2$, on which the antenna dimensions are $18 \times 15\,\text{mm}^2$ and $L_{housing}$ and $W_{housing}$ are $55 \times 85\,\text{mm}^2$ however, the USB dongle has an area of $50 \times 20\,\text{mm}^2$, with same antenna dimensions.

The design starts by the conventional printed rectangular monopole that operates at 2.2 GHz as shown in Figure 2. Then, etching a rectangular strip to create U shaped monopole antenna with equal arms to improve the bandwidth, the response of this design is also shown in Figure 2. Two unequal arms of monopole are proposed to provide more bands to the antenna as shown in the same figure. Finally, the design ended by adding bending meander strip in the other side with width 0.5 mm to design a lower resonant frequency as shown in Figure 2. The proposed antenna can be capsulated inside the housing whatever mobile or USB dongle to operate as an internal antenna. It achieves wide bandwidths at about 0.9 GHz



(a) (b) (c) (d)

Figure 1. Geometry of the proposed monopole. (a) Upper, (b) bottom layer, (c) in mobile housing and (d) USB housing.

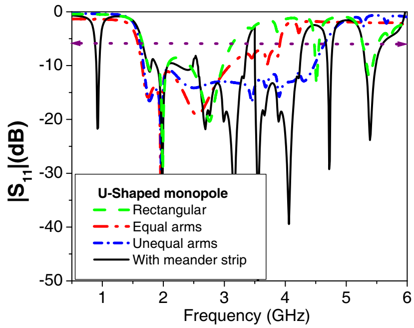


Figure 2. Simulated reflection coefficient of the design procedure.

Table 1. Operating bands and corresponding frequency range for wireless communications.

System	Operating band GHz		Frequency range GHz
GSM	0.824		0.824/0.915
	1.71		1.710/1.910
DCS/PCS	1.75		1.710–1.880
WCDMA2100 UMTS2100	0.9		0.925/0.960
	1.8		1.805–1.880
	2.1/2.62		2.110–2.170/2.620–2.690
LTE	40 band channel		0.7/2.300/2.500/2.690
Wi-Fi IEEE 802.11	2.4		2.4–2.5
	5	5.2	5.15–5.35
		5.5	5.47–5.725
		5.8	5.725–5.875
Mobile WiMax IEEE 802.16e 2005	2.3/2.6		2.3–2.4/2.5–2.69
	3.4/3.5/3.8		3.3–3.4/3.4–3.6/3.4–3.6
Fixed Wi-Max, IEEE 802.16-	3.7		3.4–3.8

and 1.5 GHz to 3.8 GHz and from 5.2 GHz to 5.5 GHz to cover the operation bands as shown in Table 1 [10]. The simulated results for both USB substrate and mobile substrate are very similarly the same. The current distributions at different resonant frequencies at 0.9 GHz, 1.5 GHz, 1.8 GHz, 2.4 GHz, 3.5 GHz and 5.2 GHz, respectively are shown in Figure 3. It shows that each resonant frequency could be

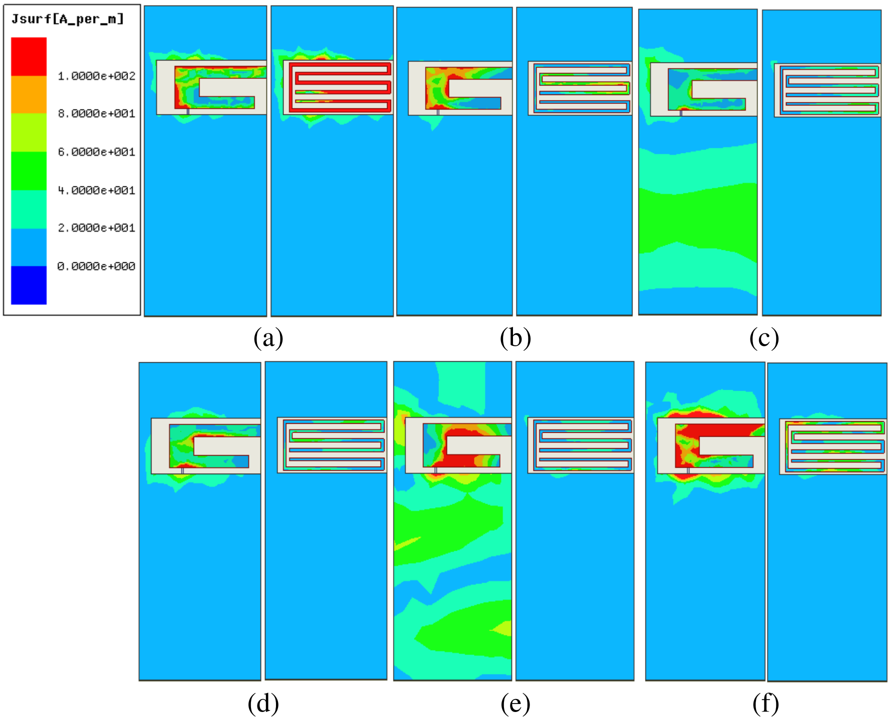


Figure 3. The current distribution for the proposed antenna at (a) 0.9 GHz, (b) 1.5 GHz, (c) 1.85 GHz, (d) 2.4 GHz, (e) 3.5 GHz and (f) 5.2 GHz, respectively.

controlled through each corresponding there's dimension. The surface current magnitude is high (red colours) around the element with the corresponding resonant frequency that works for. The surface current magnitude is distributed around the meander strip at 0.9 GHz. The surface current distributions corresponding to resonant frequencies extended from 1.5 GHz to 3.8 GHz are more affected by the unequal arms of the U shaped monopole antenna with slight effect of meander strip.

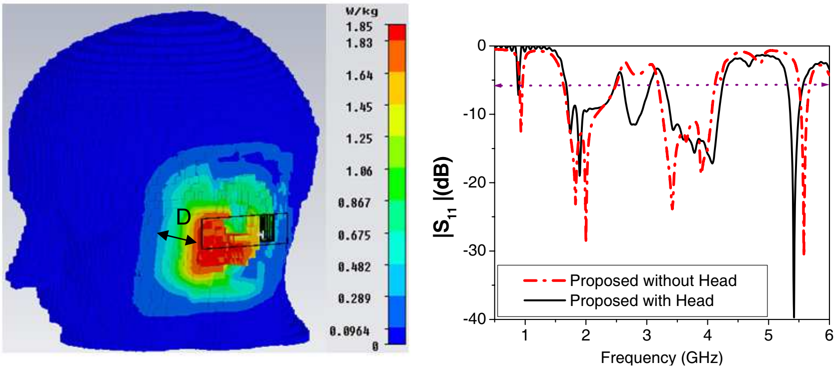
3. EFFECT OF HEAD MODEL AND SAR CALCULATION

The Specific Absorption Rate (SAR) is the basic restriction for electromagnetic exposure of a user of a mobile phone and is a fundamental parameter when discussing the health risks of electromagnetic power absorption in the body [12]. This quantity is defined as

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

where ρ (kg/m^3) and σ (S/m) are the body tissue density and conductivity, respectively. E (V/m) is the r.m.s value of the electric field strength in the tissue.

The proposed antenna in the presence of the head model using the CST microwave studio 2012 Hugo Voxel model at 2.4 GHz is shown in Figure 4(a). The r.m.s. reference antenna power is 0.5 W and the distance between the head and the antenna is 0 mm. The reflection coefficient of the proposed antenna for mobile handset with/without the presence of the head model is shown in Figure 4(b). It is clearly seen that there is a good agreement between the proposed antennas with/without head model and there is a small shift in resonant frequencies 0.9 GHz and 5.2 GHz and decreasing the amount of power radiated due to the power absorbed by the human head tissues. The 10-g SAR results are illustrated in Table 2, it is clearly seen the 10-g SAR results at all frequencies meet the SAR limits of 2.0 W/kg standards. The SAR in the head has a peak of 1.97 W/Kg at 5.2 GHz. Moreover, mounting this antenna in the backside of handheld devices or profiling these devices might be the simplest way to reduce SAR to lower levels [15, 16]. The easiest way to reduce the effect of the RF on the human tissues is to place the antenna away from the user or in



(a) (b)

Figure 4. (a) The proposed antenna with head model at GSM 1.85 GHz. (b) The $|S_{11}|$ of the proposed antenna with/without head model.

Table 2. The simulated SAR values of the proposed antenna with 0 mm distance from the head.

Frequency (GHz)	0.9	1.85	2.1	2.4	3.8	5.2
SAR Value (W/kg)	1.55	1.89	1.94	1.95	1.65	1.97

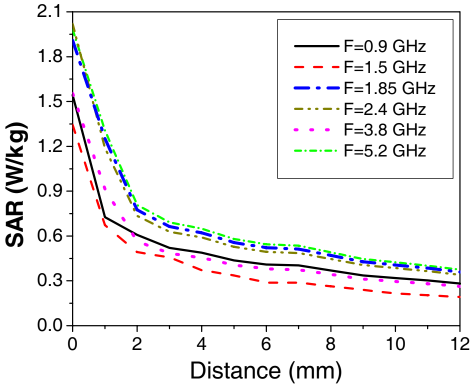


Figure 5. Variation of SAR with the distance from the head at different frequencies.

the back of the handset; and then, the average SAR may be reduced. Hence, the minimum SAR value obtains at lowest resonant frequency 0.9 GHz and this could be attributed due to the largest wavelength having minimum ability of penetration in the human head.

The effect of distance at the different resonant frequency on the SAR values is shown in Figure 5. For example at 1.85 GHz, the SAR values reduced from 1.85 to 0.21 w/kg when increasing the distance between the proposed antenna and the head model from 0 mm to 12 mm, as shown in Figure 5.

The effect of distance between human head model and antenna D on the antenna radiation efficiency is also studied as shown in Table 3. Table 3 shows that the radiation efficiency decreased in the presence of human head and at distance $D = 0$ mm the lowest frequency 0.9 GHz the antenna radiation efficiency has the largest effect than the highest frequency 5.2 GHz. At the distance increased the radiation efficiency increase until $D > 12$ mm the radiation efficiency near from free space efficiency.

Table 3. Effect of head model on the radiation efficiency.

Freq. (GHz)	0.9	1.5	1.8	2.1	2.4	3	3.8	5.2
Radiation Efficiency (%)								
Free space	70	80	90	92	86	85	86	95
$D = 0\,\text{mm}$	30	40	50	60	55	50	55	70
$D = 3\,\text{mm}$	33	45	55	70	65	60	57	80
$D = 6\,\text{mm}$	37	45	60	75	70	65	60	85
$D = 9\,\text{mm}$	50	60	75	80	77	73	72	80
$D = 12\,\text{mm}$	55	70	85	85	82	80	82	90

(a) (b) (c)

Figure 6. The fabricated antenna. (a) Monopole antenna without lower strip, (b) monopole antenna with lower strip and (c) bottom layer to show the meander strip.

4. RESULTS AND DISCUSSION

The proposed antenna is fabricated on a 0.8 mm thick FR4 substrate with a relative dielectric constant of 4.7 and $\tan\delta = 0.02$. The proposed antenna uses two separate resonant strips, the main strips is U-shaped monopole antenna with different arm lengths. The second strip is bending meander strip on the other substrate side; the second strip slightly effects on the antenna's higher resonant mode especially at 3.5 GHz, and vice versa. The steps of the reflection coefficient design procedure are shown in Figure 2. This characteristic makes

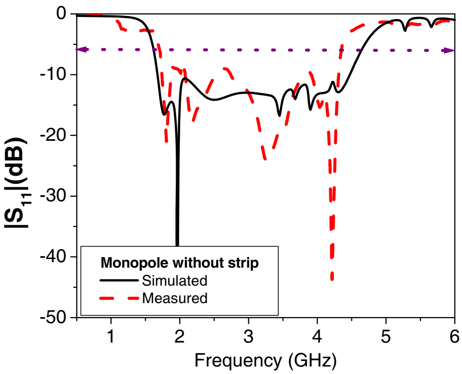


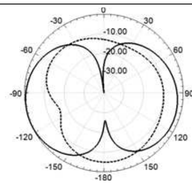
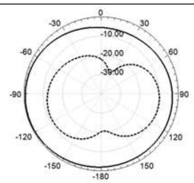
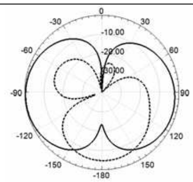
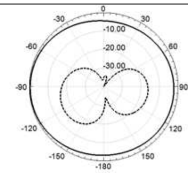
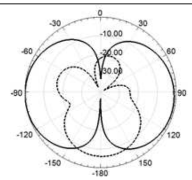
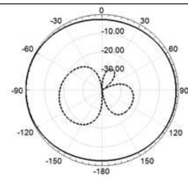
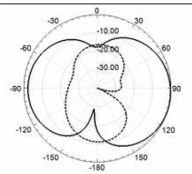
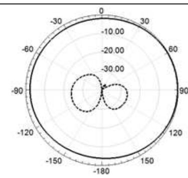
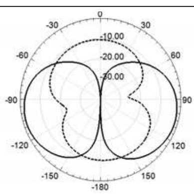
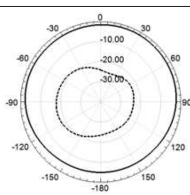
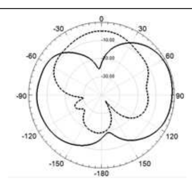
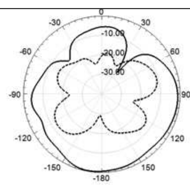
Figure 7. Comparison of simulated and measured reflection coefficient of proposed antenna without lower strip.

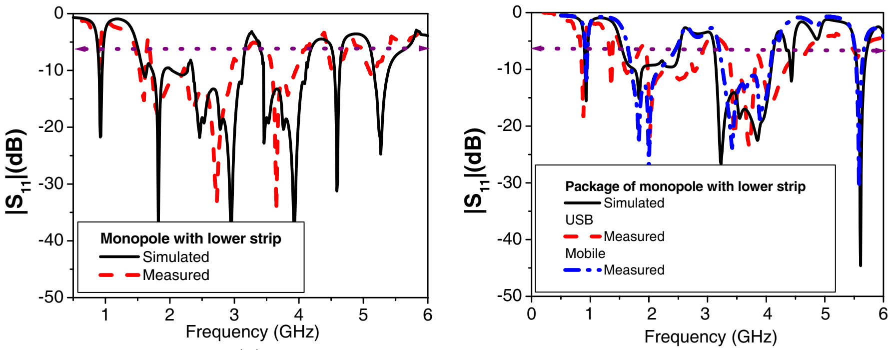
Table 4. Proposed USB antenna parameters.

	Antenna Parameter							
Freq.	0.9	1.5	1.85	2.1	2.4	3	3.8	5.2
Gain (dBi) (Sim.)	1.6	3.6	2.75	2.2	2.1	2.8	3.2	3.8
Efficiency % (Sim.)	60	80	90	92	86	85	86	95
−6 dB Fractional BW (MHz)	90	2300						300

the proposed antenna easy to implement for wireless communication operation. The antenna's excited higher resonant mode can be controlled solely by strip 1, while the lower resonant mode is controlled by strip 2. The two antennas configurations, without lower strip and with lower strip were fabricated by using photolithographic techniques as shown in Figure 6. The comparison between simulated and measured reflection coefficient of just U shaped monopole antenna with unequal arms is shown in Figure 7 and the antenna with USB housing is shown in Figure 6(a). The impedance bandwidth is extended from 1.6 GHz up to 4.6 GHz. The comparison between simulated and measured reflection coefficient of the monopole antenna with lower meander strip is shown in Figure 8(a) and the fabricated photo for both substrate sides is shown in Figures 6(b) and (c). The lower meander strip is used to create the lower resonant frequency and can be controlled by the variations of the length of strip. The effect of USB housing as shown in Figure 1(d) is obtained in Figure 8(b). The

Table 5. The measured radiation pattern in YZ and XY planes at the resonant frequency of the three turns meander-shaped strip, E_Φ: Black solid lines, E_θ: Black dotted lines.

GHz	YZ (Φ =90°)	XY (θ =90°)
0.9		
1.5		
1.8		
2.5		
3.5		
5.2		



(a) (b)

Figure 8. Comparison of simulated and measured reflection coefficient. (a) Proposed antenna and (b) proposed antenna with USB dongle housing.

effect of the USB dongle housing on the antenna performance was also studied experimentally. As is shown in Figure 8(b), the effects of the USB dongle on the impedance bandwidth is moderate but still cover the proposed bands. The measured and simulated results are in good agreement.

The measured results show that the −6 dB reflection coefficient bandwidth of the proposed antenna (the impedance bandwidth definition of 3 : 1 VSWR), has a lower resonant mode that reaches 90 MHz (860–950) MHz, while that of the other resonant modes are almost 2.3 GHz (1.5–3.8) GHz.

Table 4 shows the simulated antennas parameters, efficiency, gain and fractional bandwidth. The radiation characteristics of the designed prototype were also studied.

Table 5 plots the measured radiation patterns at 900 MHz, 1.5 GHz, 1.8 GHz, 2.4 GHz, 3.5 GHz and 5.2 GHz, respectively. Monopole-like radiation patterns are observed, which are broadside radiation pattern similar to those obtained for conventional internal patch antennas for mobile phone applications.

5. CONCLUSION

This paper described the design and characteristics of a low SAR internal monopole antenna with simple compact configuration for mobile wireless communication applications. The proposed antenna can be fabricated easily by etching a rectangular monopole antenna with unequal arms U shaped slot and a meandering strip on the other side on the same board. The antenna has very wide −6 dB reflection coefficient with bandwidth of 2.3 GHz (1.5–3.8) GHz, and bandwidth of 0.3 GHz (5.2–5.5) GHz, in addition to a bandwidth of 90 MHz (860–950) MHz which easily covers most of the traditional and future services in the laptop computers. Finally the radiation efficiency, SAR, antenna gain, and radiation pattern are acceptable. The proposed antenna is very promising for mobile applications, because it is easily fabricated. Both simulator CST and HFSS were used to modelling the antenna with and without human head, respectively.

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