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RESEARCH PAPER

Compact 3D USB dongle monopole antenna for mobile wireless communication bands

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Three-dimensional compact volume internal antenna for universal serial bus (USB) dongle that covers hexa operating bands is proposed in this paper. The volume of the proposed USB dongle is 15×20×4 mm³; it is based on two connected monopoles, one of them is semi-circular monopole ended by three unit cells of meander-line and the other is a bent monopole with four unit cells of high-impedance wire. The proposed antenna is realized on a printed circuit board to reduce the fabrication costs. The coupling between the antenna elements broadens the operating bandwidth, which includes most of the wireless commercial service bands, GSM850/GSM900/UMTS/GSM1800/GSM1900/WCDMA2100/802.11b/g/LTE2600 (824–2690 MHz) as well as 802.11a/n (5150–5825 MHz). The antenna's simulated and experimental results are in good agreement.

Keywords: Compact antenna, High-impedance wire (HIW), Monopole, Universal serial bus (USB), Wireless applications

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I. INTRODUCTION

Today using wireless communication technologies such as WLAN and GSM/UMTS/LTE-WWAN systems in laptops and other digital devices with wireless network access functions are very popular [1]. Universal serial bus (USB) dongle is a small terminal that can be connected to a computer. It has been developed as a wireless adapter designed to compensate for the insufficient bands of laptops and other digital devices. However, there is considerable challenge to realize a small internal multiband antenna design in such an USB dongle with a common volume of $22 \times 55 \times 9\ mm^3$. Extensive research activities have been published toward the development of multiband antennas for wireless USB dongle applications [2–6], monopole antennas [3–4], and planar inverted-F antennas [2]. However, these complicated antennas cannot cover bandwidths broad enough for future communication requirements, especially for GSM 850/900/1800/1900/ UMTS 2100 and LTE700/2300/2500 bands.

In this letter, a hexa-band three-dimensional (3D)-internal monopole antenna for wireless USB dongle application is proposed. It has a simple structure and compact volume. The proposed antenna consists of two arms, a semi-circular monopole ended by three unit cells of meander-line and rectangular monopole with four unit cells of high-impedance wire (HIW) [7], each is responsible for certain bands of operation. The antenna satisfies −6 dB reflection coefficient which is sufficient for wireless broadband GSM (900/1800 MHz), (WiBro, 2.3–2.4 GHz), wireless local area network (WLAN, 2.4–2.485 and 5.15–5.825 GHz), world interoperability for microwave access (WiMAX, 2.5–2.7 GHz), and most of LTE bands and satellite digital multimedia broadcasting (S-DMB, 2.605–2.655 GHz) services. For portable wireless devices, the suitable antenna bandwidth is VSWR 3:1 as in [8–11]. All simulations are carried out using the EM commercial simulator high-frequency structure simulator (HFSS) version 13.0, which is based on the finite-element numerical method.

II. PROPOSED DESIGN OF USB ANTENNA

The evolution of the proposed antenna is shown in Fig. 1. In step 1, shown in Fig. 1(a), the radiating patch is shaped as a semi-circular monopole with radius 10 mm to create a broad band that extends from 1.5 to 2.5 GHz [12–17]. In step 2, shown in Fig. 1(b), a semi-circle slot with 1 mm width is etched in the patch to generate a resonant mode at 1.3 GHz. In step 3, shown in Fig. 1(c), a rectangular monopole is added to generate a resonant frequency at 1.1 GHz. To reduce this frequency and generate another resonant frequency, the monopole is replaced by four cells of HIW [7].

The monopole resonant frequency is now 0.9 GHz and an additional resonant frequency appears at 5.5 GHz. In step 4, shown in Fig. 1(d), three meander unit cells with 1 mm strip width and separation are added to generate two resonant frequencies at 3 and 3.5 GHz. The performance after every the design step is shown in Fig. 2(a). All dimensions are shown in Table 1.

The proposed antenna occupies a volume of about $45 \times 38 \times 0.8\ mm^3$. To fit an USB package, the antenna folded as shown in Fig. 1(e), hence the antenna volume is now $11 \times 15 \times 4\ mm^3$, i.e. the reduction in the antenna volume is

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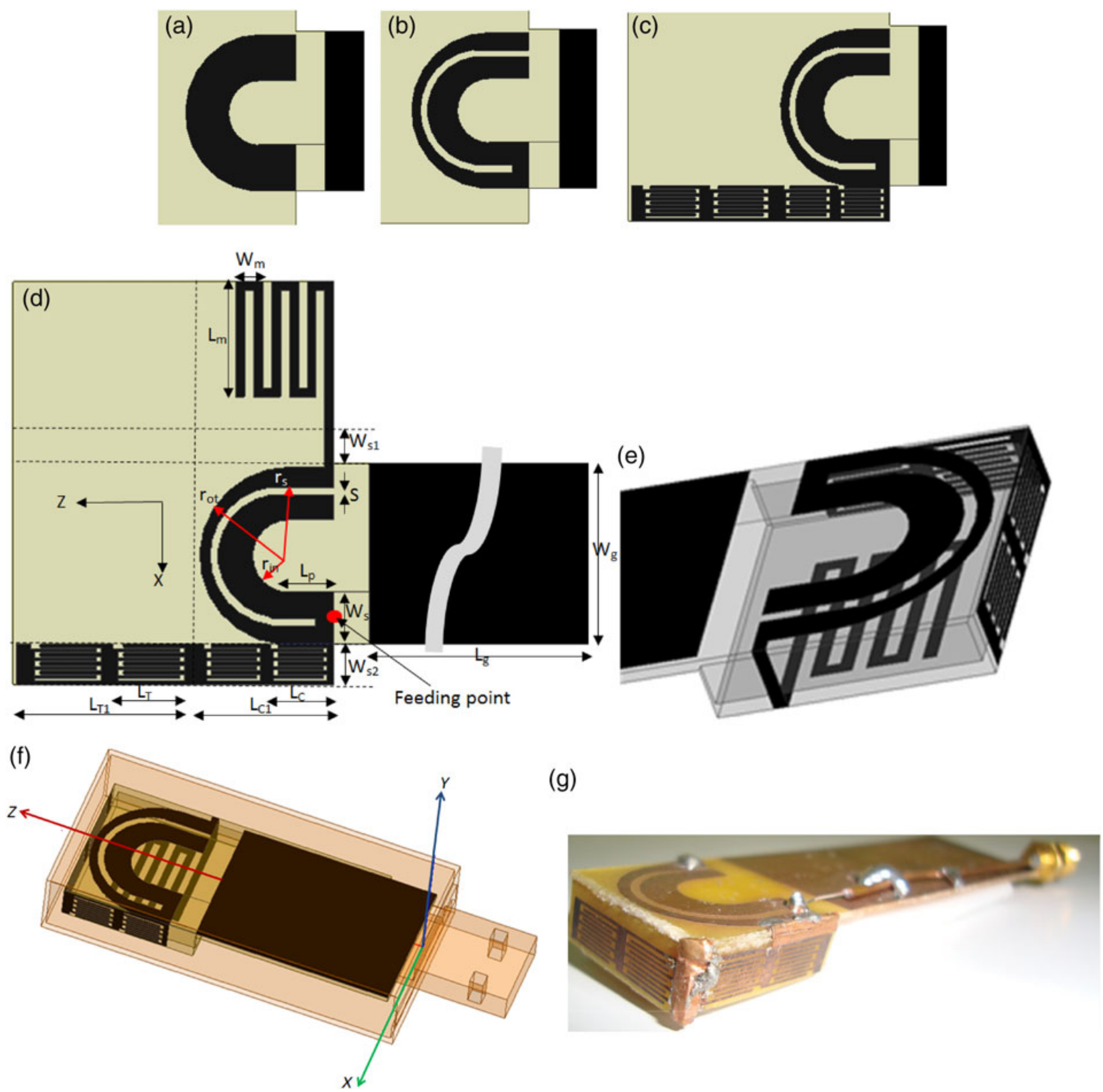

Fig. 1. The design procedure of the proposed antenna (a) step one, (b) step two, (c) step three, (d) step four in 2D layout, dashed lines indicate where the sheet needs to be bent to obtain the 3D version, (e) 3D layout geometry of the internal USB antenna, (f) 3D antenna with package, and (g) photo of the fabricated USB dongle with antenna.

about 14% from the original antenna size. The folded antenna is mounted on a commercial FR4 substrate with thickness of 0.8 mm and relative permittivity (ε_r) of 4.7. The area and size, which serves the USB dongle circuit board as well, is 50×20 mm². The folded antenna has almost the same behavior as the unfolded-one, as shown in Fig. 2(b). Finally, an USB package is added as a polyethylene material with dielectric constant 3.5, loss tangent tan $\delta = 0.02$, area 45×20 mm², thickness 0.5 mm, and different dongle height (4 and 6 mm) as shown in Fig. 1(f). The USB dongle is connected to the laptop ground plane through the USB connector interface that has size 5×8 mm². The package affects the antenna reflection coefficient slightly as shown in Fig. 2(b) and decreases as the USB height is increased from 4 to 6 mm.

The surface current distributions at six operating frequencies, 0.9, 1.4, 1.8, 2.4, 3.5, and 5.2 GHz, are shown in Figs 3(a)–3(f), respectively. Two-dimensional (2D) plots are used to clarify the radiating element at each frequency. The monopole loaded with HIW radiates at 0.9 GHz (Fig. 3(a)) and 5.2 GHz (Fig. 3(f)), the meander line is responsible for radiation at 3.5 GHz (Fig. 3 (e)), and the slotted half-circled monopole is the primary source of radiation at 1.4, 1.8, and 2.4 GHz as shown in Figs 3(b)–3(d), respectively. At these frequencies some of the currents couple to the HIW monopole, which may reduce the radiation efficiency due to current cancellations.

III. RESULTS AND DISCUSSIONS

The prototype of the proposed antenna is fabricated by using photolithographic techniques on commercial FR-4 substrate. The antenna is fed by a 50-Ω coaxial cable as shown

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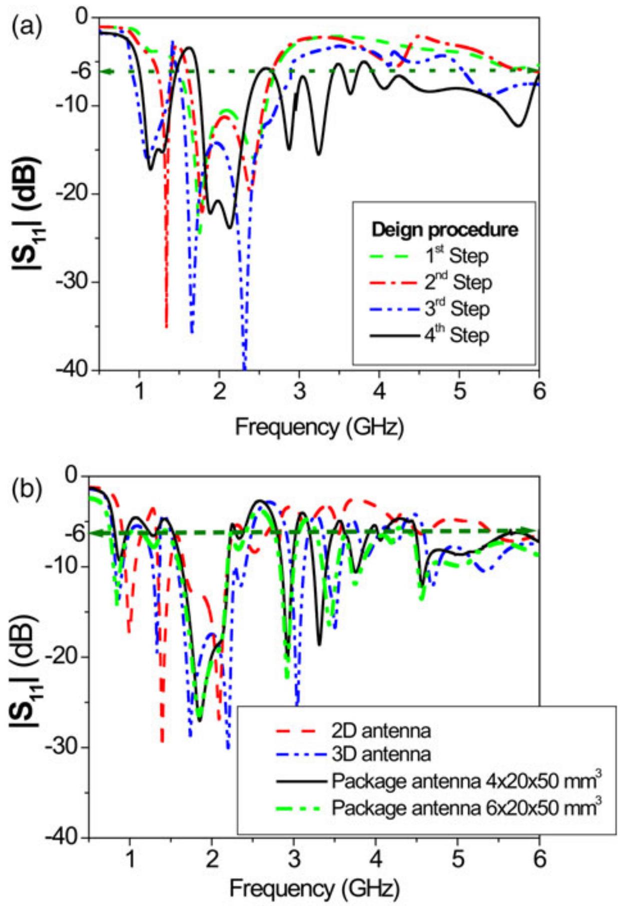

Fig. 2. The simulated $|S_{11}|$ characteristics. (a) At different design steps and (b) effect of package size.

Table 1. The geometric dimensions of the proposed antenna (all dimensions in mm).

L_g	W_g	L_p	W_{s2}	W_{s1}	W_s	L_m	W_m
45	20	4	4	3	4	13	3
r_{in}	r_{ot}	r_s	L_c	L_{c1}	L_T	L_{T1}	S
6	10	8	6.5	14	9.5	20	1

in Fig. 1(e). Measured and simulated $|S_{11}|$ are depicted in Fig. 4 without the package and in Fig. 5 with the package. There is a good agreement between measured and simulated results in both antenna cases. Table 2 shows the simulated antennas parameters, efficiency, gain, and fractional bandwidth. The −6 dB bandwidth covers most of the LTE bands, GSM850/900, DCS1800, PCS1900, UMTS2100, Bluetooth 2400, WiMax (3500–5800), and WLAN 5200.

Figure 5 shows that the reflection coefficient is slightly distorted due to packaging by about 5 dB on average especially at high frequency but still covers the required resonant frequencies. Radiation efficiency is measured over the operating bands using the Wheeler cap method [18–20] and it is shown in Fig. 6, which also shows the simulated one. The average radiation efficiency is around 70% over the operating bands.

Measured radiation patterns in the *XY*- and *YZ*-planes, shown in Fig. 1(d), at six resonant frequencies, 0.9, 1.4, 1.8, 2.4, 3.5, and 5.2 GHz, are shown in Table 3, respectively. For almost all the frequency bands, the normalized co-polarized patterns show near omni-directional radiations and their corresponding cross-polarized patterns exhibit monopole-like. The average difference between the co and cross levels in the main plane is higher than 10 dBi. Some discrepancy appears at certain frequencies that may be attributed

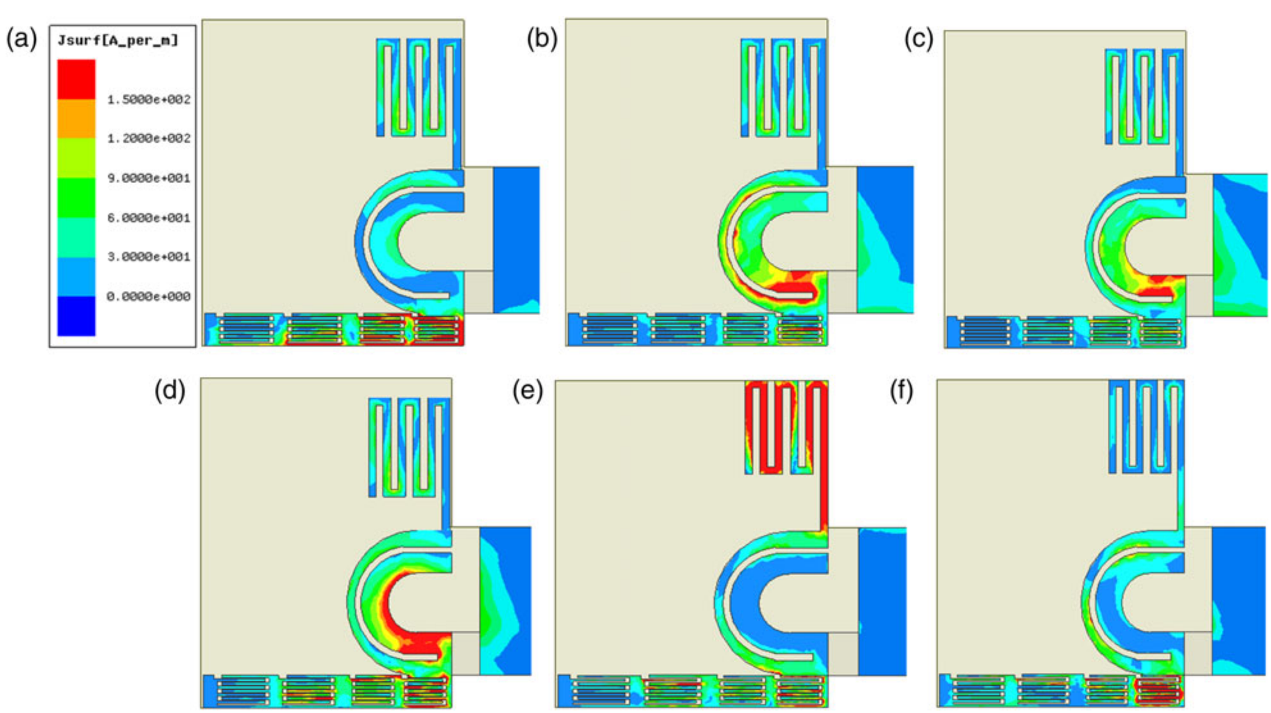

Fig. 3. (a)–(e) The surface current densities for the proposed monopole antenna at 0.9, 1.4, 1.8, 2.4, 3.5, and 5.2 GHz, respectively.

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Table 2. The parameters of the proposed antenna simulated and measured.

Parameters	Simulated results								
Frequency	0.9	1.4	1.8	2.1	2.4	3	3.5	5.2	5.8
Gain (dBi) (S/M)	1.8/1.7	4.1/3.9	4.6/4	2/1.8	3/2.7	4.9/4.5	4.3/4	4.8/4.3	4.5/4
Efficiency % (S/M)	87/75	80/60	85/60	78/80	80/70	85/50	75/60	55/40	55/40
−6 dB BW(%) (S/M)	22/23	11/7	50/45			10/12	5/6	20/24	
Start and end f_r GHz	0.8–0.967	1.21–1.43	1.5–2.49			2.89–3.18	3.35–3.64	4.6–6	

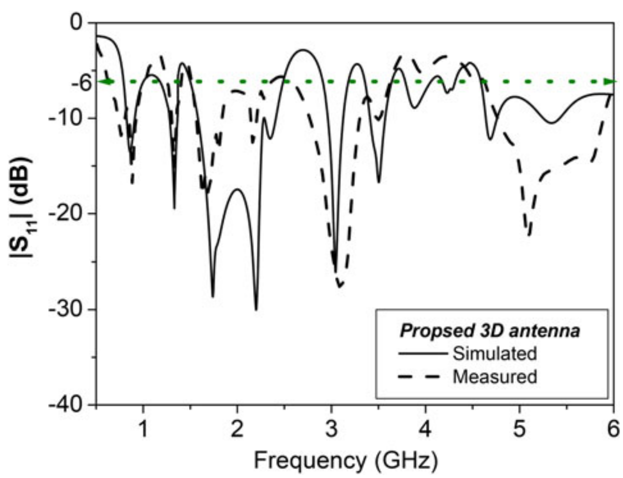

Fig. 4. Measured and simulated reflection coefficients of the proposed antenna.

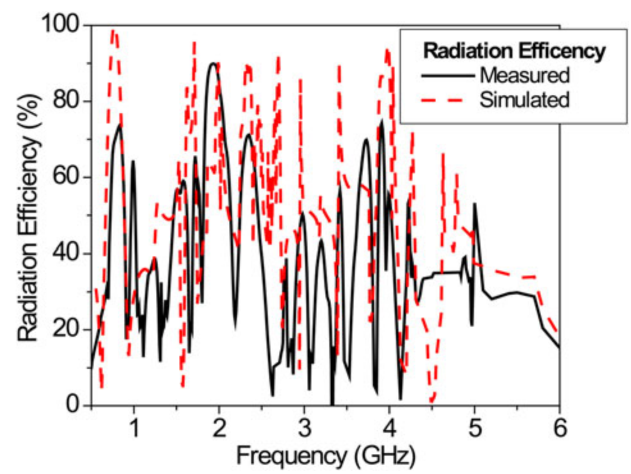

Fig. 6. Measured and simulated radiation efficiency over the operating bands.

to the inadequate size of the absorbers in addition to poor isolation.

The radiation tends to be broadside similar to those obtained for conventional internal patch antennas for mobile phone applications and it follows the current distribution shown in Fig. 3. At 0.9 GHz, the radiation pattern corresponds to a monopole in the *XZ*- and *XY*-planes, from 1.5 to 2.5 GHz which corresponds to a monopole in the *XZ*-plane, while at 3.5 GHz the radiation corresponds to a meander monopole in the *XZ*-plane, and at 5.2 GHz it corresponds to the HIW monopole in the *YZ*-plane. The antenna characteristics such as efficiency, gain and $|S_{11}|<-6$ dB impedance bandwidth are shown in Table 2. The antenna's radiation efficiency is also studied by using the Wheeler cap method [18–20] at the resonant frequencies as shown in Table 2. Results indicate that the size reduction comes at the expense of the radiation efficiency, which reduces by 5–10% at different operating resonant frequencies.

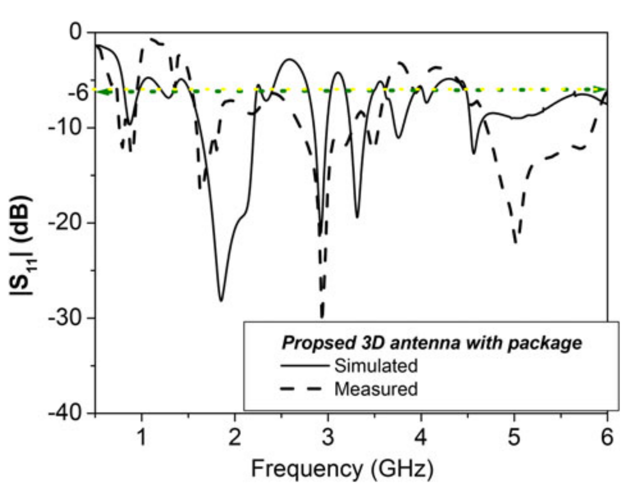

Fig. 5. Measured and simulated reflection coefficients of the proposed antenna with package.

Table 4 shows a brief comparison between our design and the previous published papers. The great advantage of this design is that it is easy to extend the proposed design to cover multi-services and to design 3D monopole antenna with independent tuning, easier fabrication, and reduced design complexity.

IV. CONCLUSION

In this paper, a 3D monopole was designed to operate at many wireless communications bands GSM, UMTS, WCDMA, Bluetooth, ISM, 802.11b/g, LTE, as well as 802.11a/n. The proposed antenna has a simple structure and narrow ground plane, and it is small enough to fit in an USB dongle. It consists of two connected monopoles. One has a slotted semicircular patch terminated by three meander line unit cells, while the other is a bent monopole that has four HIW unit cells. The antenna was successfully designed, implemented, and measured with average radiation efficiency about 70% over the operating bands. The gain varies with frequency with average 3.8 dBi. The antenna's radiation is nearly omnidirectional at the different resonant frequencies. The proposed antenna is a good candidate for USB dongle applications.

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Table 3. Measured radiation pattern E_θ (– –) and E_Φ (—) at 0.9, 1.8, 2.4, 3, 3.5 and 5.2 GHz, respectively.

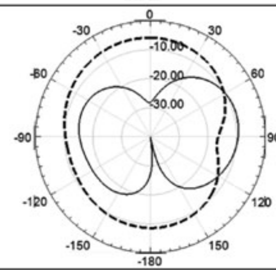
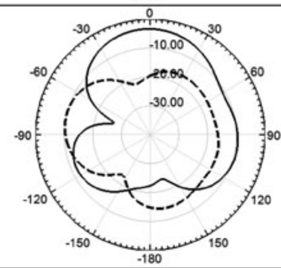
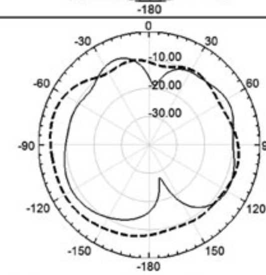
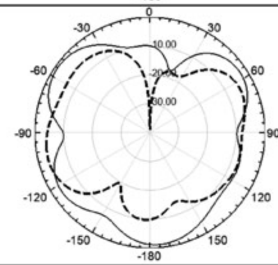
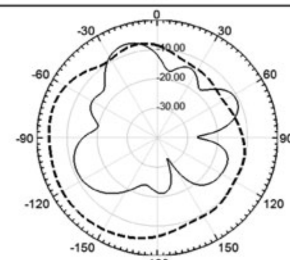
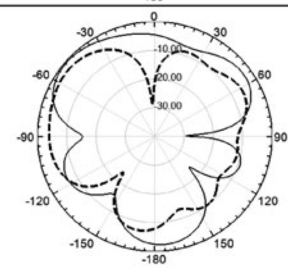
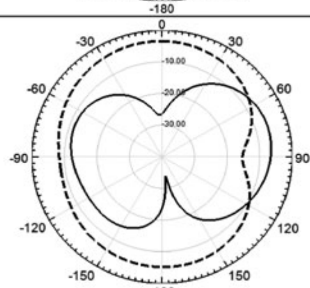
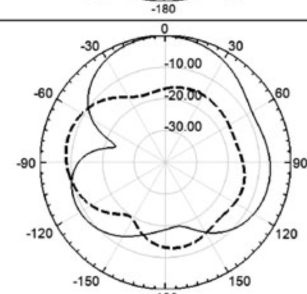
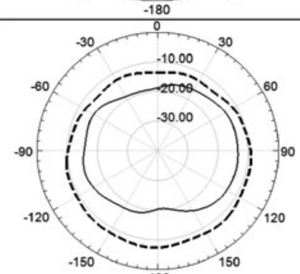
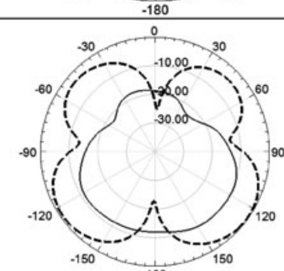
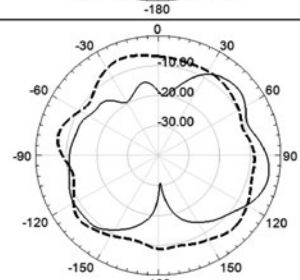
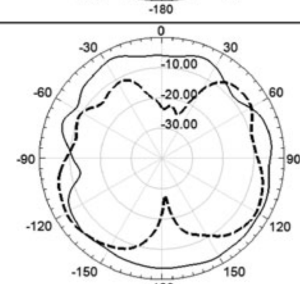
F	XY	YZ
0.9 GHz		
1.5 GHz		
1.8 GHz		
2.4 GHz		
3.5 GHz		
5.2 GHz		

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Table 4. Brief comparison of the proposed antenna with published papers.

	Total volume (mm^3)	Antenna size (mm^3)	Frequency bands (GHz)	Technology based	Bands extension
Ref. [16]	50 × 20 × 0.8	10 × 20 × 0.8	2.4/5.2	Parasitic elements	Complicated
Ref. [17]	50 × 20 × 0.8	10 × 14 × 0.8	2.4/5.2	Fractal shape	Complicated
Ref. [18]	40 × 15 × 0.8	10 × 15 × 0.8	2.4/3.5/5.2	Folded parasitic	Complicated
Our design	45 × 20 × 6	11 × 15 × 4	0.9/1.4/1.8/2.1/2.4/3/3.5/5.2	Folded HIW monopole	Moderate

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