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Compact Tri-Band Trapezoid CPW-Fed Antenna with SRR Structure for WLAN/WiMAX Applications

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Abstract—A compact triple-band monopole antenna covering WLAN/WiMAX bands is investigated in this paper. The proposed antenna has a compact size of $36 \times 25\,\text{mm}^2$ and consists of a circular ring, a split ring radiator and a trapezoid coplanar waveguide-fed structure. The antenna covers three distinct bands of 2.27–2.55 GHz, 3.23–4.14 GHz, and 5.08–6.03 GHz for WLAN and WiMAX applications. To validate the proposed design, prototype is fabricated, and measurement is carried out. Good performances of gain, radiation pattern and efficiency have also been obtained.

1. INTRODUCTION

In recent years, the prodigious development rate of wireless communication technology has far exceeded imagination. Portable devices, such as mobile phones and laptops, widely use wireless local area network (WLAN) and Worldwide Interoperability for Microwave Access (WiMAX) for Internet access [1]. Therefore, in order to satisfy the WLAN standards of 2.4–2.484 GHz (IEEE 802.11b/g)/5.15–5.825 GHz (IEEE 802.11a) and WiMAX standards of 2.5–2.69 GHz/3.4–3.69 GHz/5.25–5.85 GHz, there is a great demand for designing compact, low profile and multiband antennas for mobile terminals [2]. Planar monopole antenna could be a good candidate for its important features of wide impedance bandwidth, simple configuration, omnidirectional radiation pattern and low cost.

In view of practical needs, various methods were proposed to realize dual-band, triple-band and multi-band antennas to cover the whole WLAN/WiMAX bands. The design of the antennas proposed in the previous studies can be mainly summarized to three methods. The first method can be realized by introducing multiple branch strips or slots, as well as parasitic elements to a monopole antenna, and then multiple resonance modes can be excited [3–8]. The second one can be carried out by producing two band-notches into an ultra-wideband antenna, so that triple operating bands can be yielded [9, 10]. Others can be classified as combination of the two methods [1, 2, 11, 12].

In this investigation, a compact triple-band monopole antenna for WLAN/WiMAX bands is proposed. The antenna comprises a circular ring around and a goblet-shape-like strip inside. The trapezoid CPW-fed structure works as a balun, which converts between the unbalanced coaxial cable and the balanced symmetrical loop antenna. Thus, the efficiency and gain of the antenna are enhanced. By etching an extra rectangular split ring resonator (SRR) onto the original monopole antenna, better impedance matching is achieved, broadening the bandwidth especially the middle band covering from 3.23 GHz to 4.14 GHz. The small gap within the SRR structure produces large capacitance values which lower the resonance frequency and reduce the area of the antenna. By utilizing a modified trapezoid coplanar waveguide (CPW) feed structure and optimizing the dimension of the strip, the upper band is broadened and covers from 5.08 GHz to 6.03 GHz. Compared with a conventional UWB planar monopole antenna, the proposed antenna tunes the bandwidth of middle band more easily, by optimizing the lengths of $d1$ and $d2$, and obvious change can be found from 3.2–4.1 GHz. In addition,

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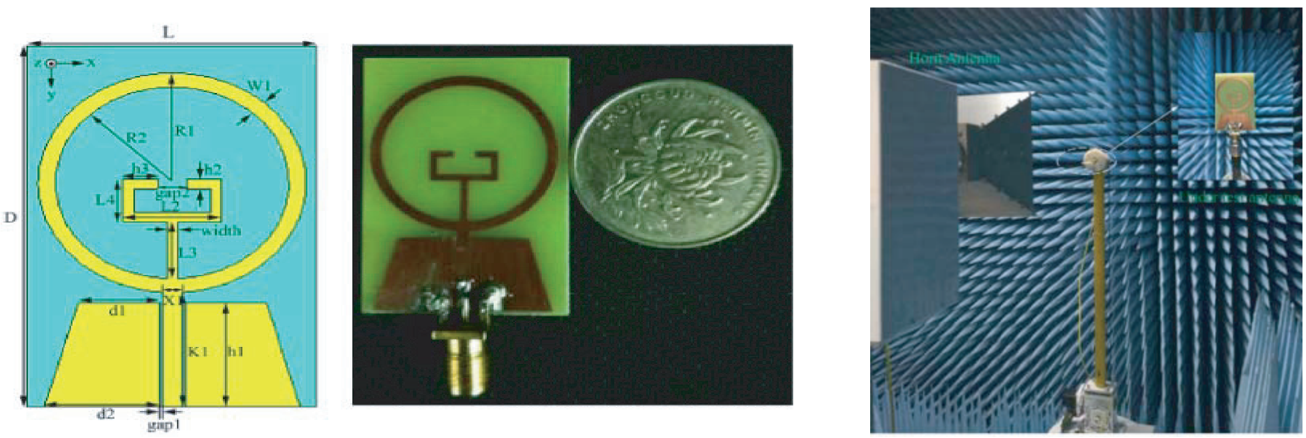
the CPW structure also improves the impedance matching at high frequency. To validate the proposed design, prototype has been fabricated, and experimental measurements are also carried out.

2. ANTENNA DESIGN AND CONFIGURATIONS

The geometry and dimensions of the proposed triple-band antenna are depicted in Fig. 1 and Tab. 1. The proposed antenna is fabricated on a cheap FR4 dielectric substrate with thickness of 1.0 mm, relative permittivity of 4.4 and dielectric loss tangent of 0.02. The overall size of the antenna is only $36 \times 25\,\text{mm}^2$.



(a) (b) (c)

Figure 1. (a) Geometry of the proposed antenna. (b) Prototype of fabricated antenna. (c) Measurement of the proposed antenna in microwave anechoic chamber.

Table 1. Parameters of the proposed antenna.

Parameter	Size (mm)	Parameter	Size (mm)	Parameter	Size (mm)
$R1$	11.6	$h2$	1	$gap1$	0.28
$R2$	10.1	$h3$	3	$gap2$	2.5
$L2$	8.5	D	36	$d1$	7
$L3$	6	L	25	$d2$	10
$L4$	4.5	$K1$	12	$X1$	1.6
$W1$	1.5	width	1	$h1$	11

The main radiating elements of the antenna are composed of a circular ring and a goblet-shape radiator etched on upper surface with nothing at the bottom. Within the design, two equal trapezoid ground planes of size $8.5 \times 11\,\text{mm}^2$ are placed symmetrically on each side of the feeding line. Better impedance matching can be obtained by employing the tapered ground planes. The feed line is connected to a coaxial cable through a $50\,\Omega$ SMA connector. Commercial software of computer simulation technology (CST) is used to optimize parameters for triple-band operation of the proposed compact antenna, and the optimized parameters are listed in Tab. 1.

The design evolutions of the proposed monopole antenna are illustrated in Fig. 2, and its corresponding simulated return losses under -10 dB levels are illustrated in Fig. 3. The design starts with the first antenna (Ant. a), which consists of a circular ring and a $50\,\Omega$ CPW-fed structure. It can be seen from Fig. 3 (black line) that only two operating bands under -10 dB level from 2.507 to 3.299 GHz and from 5.466 to 5.873 GHz are achieved. Then, by adding an SRR structure inside the circular ring, the antenna (Ant. b) can excite another resonant mode without increasing the overall size.

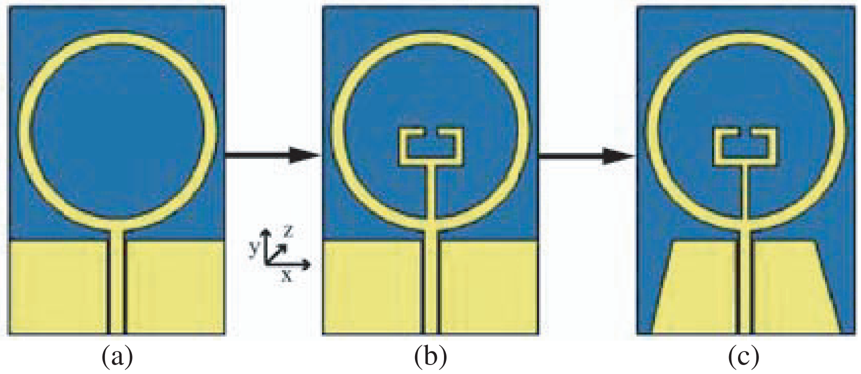


Figure 2. Design evolution of the proposed antenna, (a) Ant. a, (b) Ant. b, (c) proposed antenna.

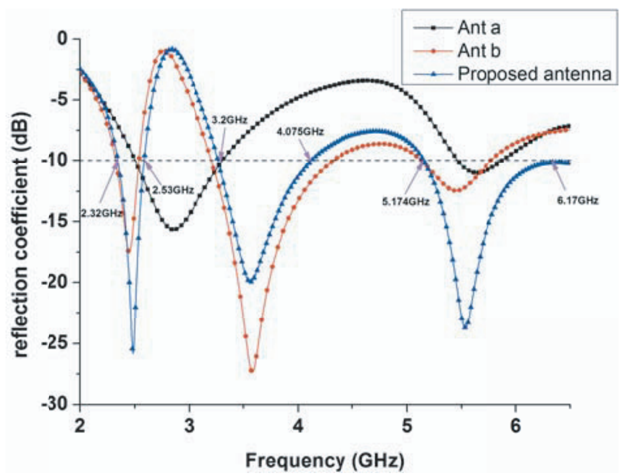


Figure 3. Simulated reflection coefficient graphs of the antennas mentioned in the design evolution process.

The impedance bandwidths of Ant. B (red line in Fig. 3) can cover the bands of 2.37 GHz–2.62 GHz, 3.35 GHz–4.50 GHz and 5.15 GHz–5.89 GHz; however, the impedance matching of the higher operating band is limited. It is worth to mention that the configuration of the CPW-fed structure also affects the bandwidth of the antenna. In order to achieve good impedance matching in upper operation band, the trapezoid ground planes are adopted in the proposed antenna (Fig. 3(c)). The simulated S_{11} graph of the proposed antenna is depicted in Fig. 3 (blue line), with three bands of 2.32–2.53, 3.2–4.075 and 5.174–6.17 GHz, respectively, which cover all the WLAN/WIMAX bands.

3. RESULTS AND DISCUSSION

To validate the simulation results, S-parameter of the proposed antenna is measured by using Agilent HP8719ES. Fig. 4 shows the simulated and measured return losses of the proposed antenna. As indicated in Fig. 4, good agreement between the measured and simulated results is achieved. Three fractional impedance bandwidths under -10 dB level are 12% (2.27–2.55 GHz), 25% (3.23–4.14 GHz), and 17% (5.08–6.03 GHz), respectively, which completely satisfy the bandwidths requirements for WLAN/WIMAX applications.

Parameter study of the length of $d1$ with respect to frequency bandwidth is shown in Fig. 5. As the length of $d1$ increases, the middle and higher bands shift to higher frequency, and wider bandwidth can be achieved. Moreover, the impedance matching has obviously been improved at higher band, whereas its impact on lower frequency band can be ignored. However, in order to cover the whole

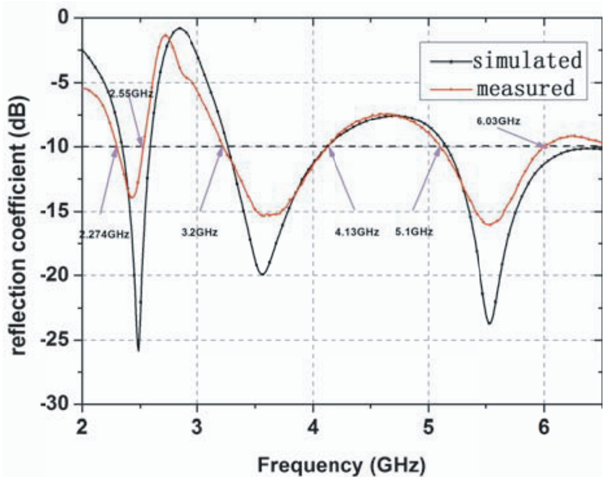


Figure 4. Simulated and measured reflection coefficient of proposed antenna.

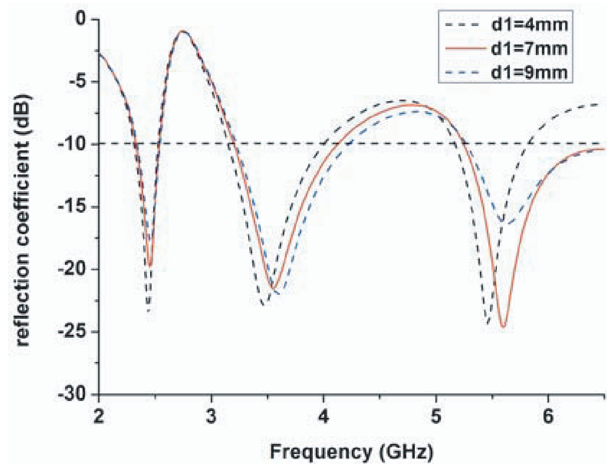


Figure 5. Simulated reflection coefficient of the proposed antenna by tuning parameter $d1$.

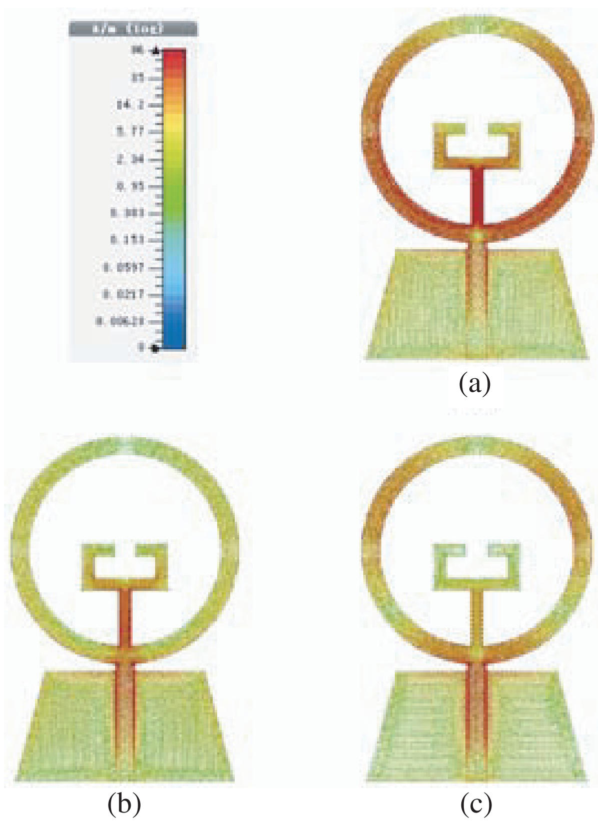


Figure 6. Simulated surface current distribution of the proposed antenna at (a) 2.5 GHz, (b) 3.5 GHz, (c) 5.5 GHz.

WLAN/WiMAX frequency bands, $d1$ is optimized to 7 mm, and the bandwidth for higher band is enlarged to cover 5.249–8 GHz. In conclusion, $d1$ can be regarded as an important parameter for tuning upper frequency bandwidth of this antenna. Other parameters such as $R1$, $L2$, and $L3$ have also been studied; however, their impacts on each frequency band are not independent.

To better understand the working principle of the antenna, simulated surface current distributions at 2.5, 3.5 and 5.5 GHz are illustrated in Fig. 6. At the resonance frequency, the length of current path is half of the wavelength, and the 50 Ω microstrip line also works as part of the radiator while surface current flows on it. For the circular ring structure, the effective length can be the diameter of the ring. Therefore, the current path length for the first resonance frequency an be given as: $L1 = 2*R1+L3+h2$. The effective relative dielectric constant of the substrate can be calculated as $\varepsilon r = 3.86$. Then

$$f1 = \frac{c}{2L1\sqrt{\varepsilon_r}} = 2.528\,\text{GHz}.$$

For the middle frequency band, from Fig. 6, it can be seen that the effective length for the resonance mode is the sum of the length of 50 Ω microstrip line and length of the strip $L3$; therefore, the effective length can be concluded as: $L2 = K1 + L3 + h2 + W1$. Then

$$f2 = \frac{c}{2L2\sqrt{\varepsilon_r}} = 3.72\,\text{GHz}.$$

And for 5.5 GHz band. $L3 = K1 + W1$. Then

$$f3 = \frac{c}{2L3\sqrt{\varepsilon_r}} = 5.65\,\text{GHz}.$$

From Fig. 6(a), one can conclude that surface current mainly focuses on the circular ring radiator and goblet-shape-like strip, which clearly indicates that the goblet-shape-like strip and circular ring generate the first resonant frequency at 2.5 GHz together. Concerning the second resonant mode at 3.5 GHz (Fig. 6(b)), surface current accumulates mainly on the goblet-shape-like strip structure. Hence, the 3.4–3.69 GHz WIMAX resonant frequency band is generated mainly due to the goblet-shape strip. In addition, as shown in Fig. 6(c), surface current distributed at 5.5 GHz distributes on the circular

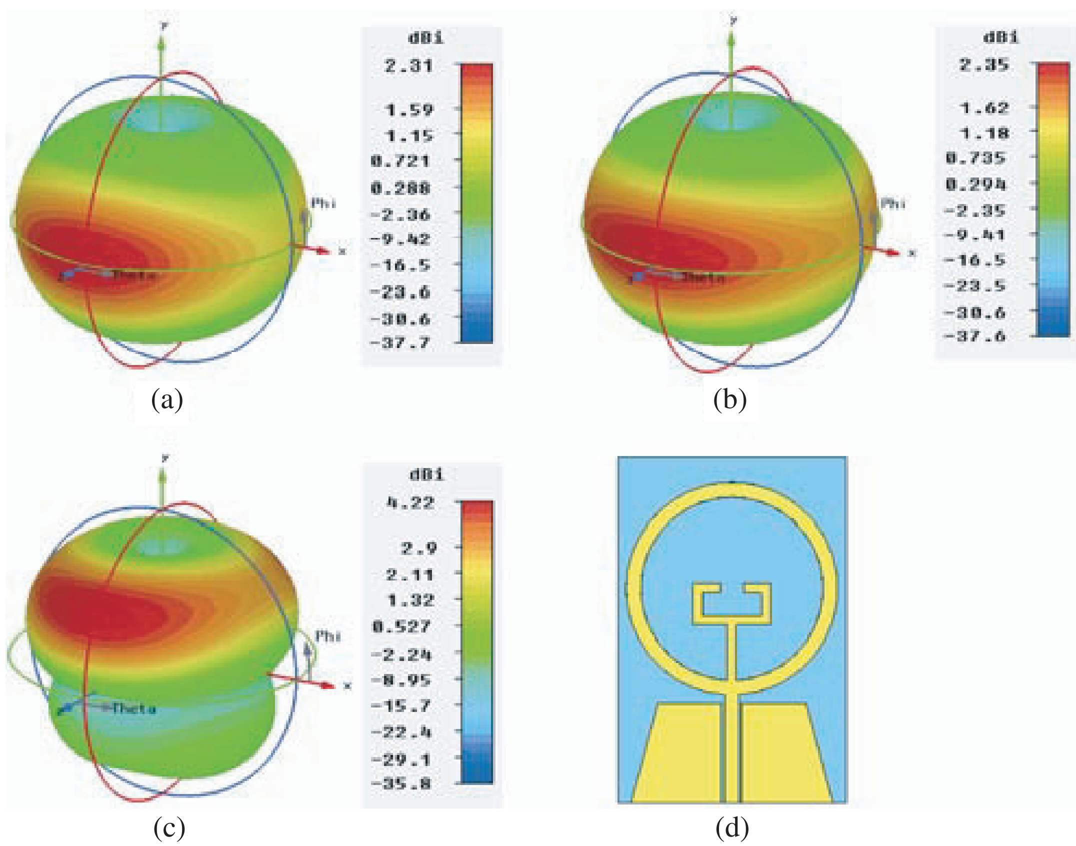


Figure 7. Simulated 3-D radiation patterns of the proposed antenna at different frequencies, (a) 2.5 GHz, (b) 3.5 GHz, (c) 5.5 GHz, (d) the orientation of the antenna referenced to the 3-D radiation patterns.

ring periodically. This is mainly caused by the higher order mode generated by monopole antenna. Moreover, the current density on the microstrip line also changes, which signifies that the microstrip feed line is responsible for the generation of the resonance at 5.5 GHz and also promotes the radiation characteristics at this frequency band.

The simulated 3-D radiation patterns at different frequencies of 2.5, 3.5, and 5.5 GHz are shown in Fig. 7. From the perspective view, one can conclude that at 2.5 and 3.5 GHz, the antenna exhibits a symmetric omnidirectional radiation pattern in *xoz* plane (*H* plane) and dipole-like pattern in *yoz* plane (*E* plane), but the shape of the co-pol *E*-plane radiation pattern at 5.5 GHz is slightly distorted.

The fabricated prototype of the proposed antenna is measured in a microwave anechoic chamber. Fig. 8 shows the radiation pattern of co-pol (black and red dotted line) and cross-pol (blue and purple dotted line) normalized radiation patterns in the *E* plane (*yoz* plane) and *H*-plane (*xoz* plane) at the central operating frequencies of 2.5, 3.5, and 5.5 GHz, respectively. Based on these radiation patterns,

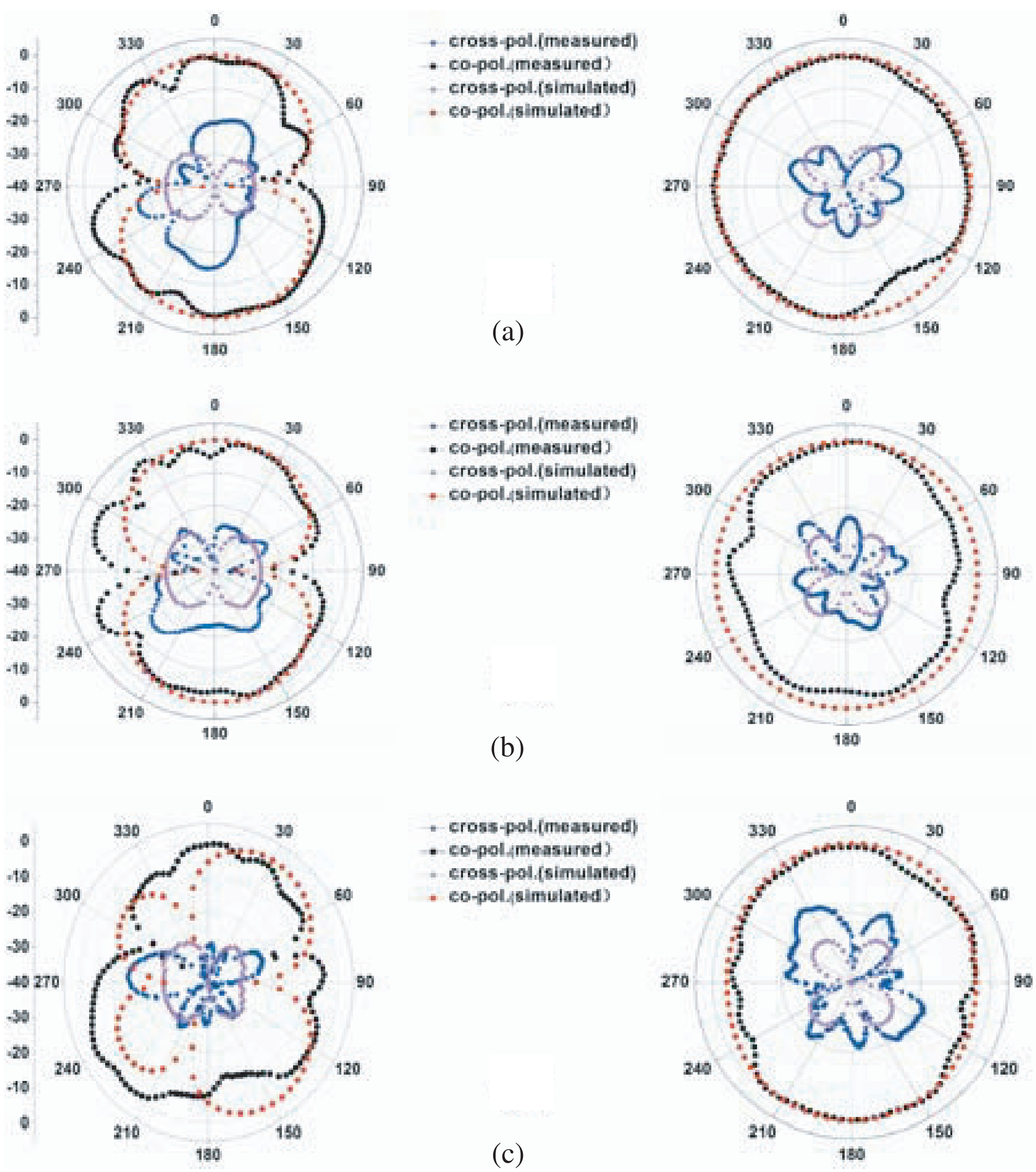


Figure 8. Simulated and measured radiation patterns: (a) *yoz* (*E* plane) and *xoz* plane (*H* plane) patterns at 2.5 GHz, (b) *yoz* and *xoz* plane patterns at 3.5 GHz, (c) *yoz* and *xoz* plane patterns at 5.5 GHz.

the proposed antenna presents an omnidirectional radiation in H-plane (xoz plane) and keeps eight-shaped radiation patterns similar to monopole antenna in E plane (yoz plane).

The simulated and measured peak gains of the antenna at 2.5, 3.5, and 5.5 GHz are shown in Fig. 9. The measuring process is mainly as follows. Firstly, two standard horn antennas working at 2–18 GHz are brought to test as the reference standard antenna. Then, replace the receiving horn antenna by the proposed antenna and obtain another set of data. Through subtracting the first set of data from

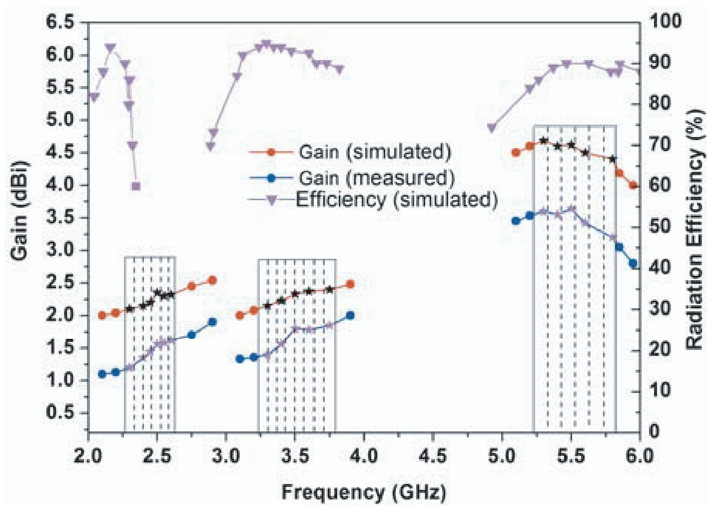


Figure 9. Simulated and measured gain as well as simulated efficiency of the proposed antenna.

Table 2. Comparison of dimension, bandwidth, gain, efficiency between similar antennas.

Reference Antenna	Dimension (mm × mm)	Desired bands: WLAN: 2.4–2.484 GHz, 5.15–5.35 GHz, 5.725–5.825 GHz WIMAX: 2.5–2.69 GHz, 3.4–3.69 GHz, 5.25–5.85 GHz	Peak Gain (dBi)	Efficiency (%)
[2]	23 × 30	2.4–2.63 GHz, 3.23–3.8 GHz, 5.15–5.98 GHz	1.2–2.29, 0.38–0.9, 1.25–3.45	/
[5]	34 × 18	2.41–2.63 GHz, 3.39–3.70 GHz, 4.96–6.32 GHz	−0.1–0.28, 0.24–1.42, 2.67–4.76	86.3%, 87.6%, 85.9%
[6]	30 × 27	2.39–2.54 GHz, 3.37–3.73 GHz, 5.02–6.19 GHz	1.35, 1.98, 2.6	/
[7]	35 × 25	2.34–2.50 GHz, 3.07–3.82 GHz, 5.13–5.89 GHz	2.05, 2.6, 3.55	/
[12]	38 × 25	2.4–2.7 GHz, 3.1–4.15 GHz, 4.93–5.89 GHz	1.85, 2.19, 2.57	/
Proposed	36 × 25	2.27–2.55 GHz, 3.23–4.14 GHz, 5.08–6.03 GHz	1.2–1.6, 1.4–1.8, 3.05–3.65	80%–94%, 85%–95%, 94%

the second set of data, the peak gain about the proposed antenna can be achieved. At lower band, the measured peak gain of the antenna varies from 1.2 to 1.6 dBi, while the radiation efficiency ranges from 80% to 94%. Among the middle band, the measured peak gain of the antenna varies from 1.4 to 1.8 dBi accompanied by the radiation efficiency varying from 85% to 95%. Within the higher operating band, the gain of the antenna varies from 3.05 to 3.65 dBi, whereas the radiation efficiency is about 90%. When this antenna is applied to WLAN and WiMAX applications, the communication efficiency and gain will be decreased other than the resonant bands. Due to the machining tolerance, measurement environment and welding roughness, for example, the antenna is incapable of keeping parallel and vertical relative to transmitting antenna, and cable losses cannot be ignored. The measured gain is about 1 dBi lower than the simulated one.

Taking into account the topic, comparisons between other similar antennas in aspects of bandwidth, gain, efficiency are listed in Tab. 2.

4. CONCLUSION

A compact triple-band monopole antenna for WLAN/WiMAX bands is presented. By utilizing rectangular SRR and trapezoid CPW-fed structures onto the original monopole antenna, three operating bands (2.27–2.55 GHz, 3.23–4.14 GHz, and 5.08–6.03 GHz) have been generated. According to the simulated and measured results, good performance of frequency bands, gain, and radiation pattern are obtained. The results indicate that the proposed antenna could be a promising candidate for WLAN/WIMAX applications.

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