

A NOVEL TRIPLE-BAND RECTANGULAR RING ANTENNA WITH TWO L-SHAPED STRIPS FOR WIMAX AND WLAN APPLICATIONS

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Abstract—A low-profile microstrip planar monopole antenna with triple-band operation for WiMAX and WLAN applications is proposed in this paper. The antenna has a simple structure which consists of a rectangular ring patch, two inverted L-shaped strips extending from the rectangular ring patch, and a microstrip feed line. By adding two L-shaped strips on the rectangular ring patch, three resonant modes can be excited independently. The antenna has a simple structure and a compact size of $21 \times 33 \times 1.6 \text{ mm}^3$. The measured -10 dB impedance bandwidth of the proposed antenna covers 2.39–2.51 GHz, 3.26–4.15 GHz, and 5.0–6.43 GHz, which can fully cover the 2.4/5.2/5.8 GHz WLAN bands and 3.5/5.5 GHz WiMAX bands. A prototype is fabricated, and then measured. The experimental and simulation results show good impedance bandwidth, radiation pattern and stable gain across the operating bands.

1. INTRODUCTION

In recent years, with the rapid development of wireless local area network (WLAN) and worldwide interoperability for microwave access (WiMAX), much attention have been paid to multi-band antennas. Antennas for WLAN or WiMAX applications have been presented and reported [1–5]. However, various types of antenna [6–13] which can both cover WLAN and WiMAX bands have attracted more and more

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attention in recent years, such as a circular ring and a Y-shaped strip antenna [6], double coupled C-shaped strips antenna [7], a rectangular patch with two slots CPW-fed antenna [8]. What a pity, these antennas have disadvantages to some extent, such as incapable well match for the whole WLAN/WiMAX bands, complex structure, and high overall size. In [9], the antenna can cover the whole 2.4/5.2/5.8 GHz WLAN and 3.5/5.5 GHz WiMAX bands but with a relative large size of $20 \times 42.5 \text{ mm}^2$ and a complex structure. In [10–12], the antennas proposed can only cover 2.4/5.8 GHz WLAN and 3.5 GHz WiMAX bands, 2.4/5.2 GHz WLAN and 3.5 GHz WiMAX bands, 5.2/5.8 GHz WLAN and 3.5/5.5 GHz WiMAX bands, respectively. In [13], the antenna can not cover the WLAN/WiMAX bands simultaneity, though it can meet the requirement of the WLAN or WiMAX standard by tuning the width of the inverted-L shaped stripes.

In this paper, a novel compact microstrip-fed planar monopole antenna designed with triple-band operation is proposed for WLAN and WiMAX applications. This antenna has a very simple structure, it is convenient to tune the resonant frequencies by adjusting the length of the resonant L-shaped strips. The proposed antenna consists of a rectangular ring patch, two inverted L-shaped strips extending from the rectangular radiation patch, and a microstrip feed line. By properly selecting the dimensions of the proposed antenna, good triple-band impedance bandwidth and radiation characteristics suitable for the WLAN/WiMAX communication systems can be obtained. Measured results show that the antenna has the impedance bandwidth of 120 MHz (2.39–2.51 GHz), 890 MHz (3.26–4.15 GHz), and 1430 MHz (5.0–6.43 GHz), which can both well cover the 2.4/5.2/5.8 GHz WLAN bands and 3.5/5.5 GHz WiMAX bands. Details of the antenna design, simulated results, and measured results are presented and discussed.

2. ANTENNA DESIGN

As shown in Figure 1, the configuration of the proposed antenna is designed, optimized, and fabricated on a 1.6 mm thick FR4 substrate with permittivity of 4.4 and a loss tangent of 0.02. The overall size of the antenna is $21 \times 33 \times 1.6 \text{ mm}^3$. The rectangular ring patch is fed by a 50Ω microstrip line. Two inverted L-shaped strips are employed to produce two resonant modes. The width of the upper L-shaped strip is fixed at $w_d = 2 \text{ mm}$, which is the same as the rectangular ring. The width of the lower L-shaped strip is fixed at $u = 0.4 \text{ mm}$. The dimensions of the proposed antenna are optimized and shown in Table 1.

As depicted in Figure 2(a), the evolution process of the proposed

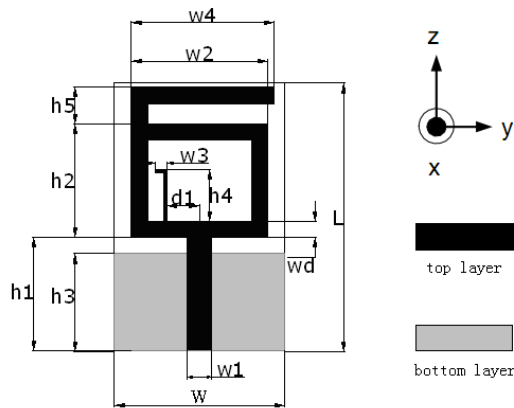


Figure 1. Geometry of the proposed triple-band antenna.

Table 1. Optimal parameters of the proposed antenna (see Figure 1).

Parameter	W	H	w_1	w_2	w_3	w_4	w_d	h_1	h_2	h_3	h_4	h_5	d_1	u
Value (mm)	21	33	3	16.8	1.5	17.5	2	14	14	12	6	4.5	4	0.4

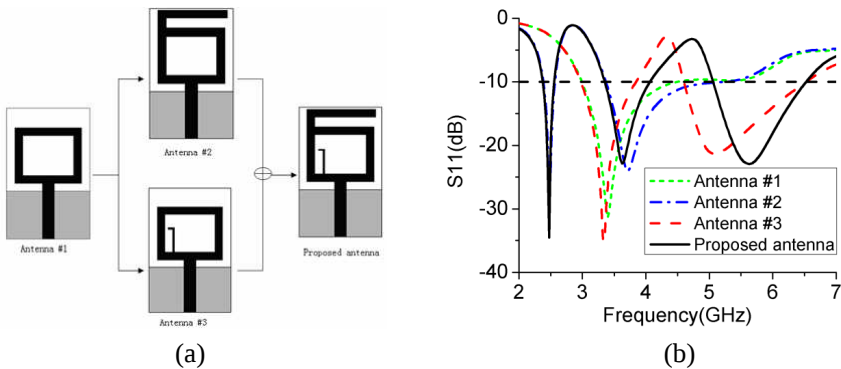


Figure 2. (a) The design process of the proposed antenna. (b) Simulated S_{11} for prototypes Antenna #1, Antenna #2, Antenna #3 and proposed antenna.

antenna and corresponding simulated S_{11} is shown. It begins with the design of Antenna #1, which consists of a rectangular ring patch and a microstrip feed line. From its corresponding S_{11} results presented in Figure 2(b), the first resonant mode is initially observed at around

3.4 GHz and Antenna #1 covers the operating band from 3.0–4.49 GHz. Then, an inverted L-shaped strip is added on the top of the rectangular ring on Antenna #1 (Antenna #2) to excite another resonant mode at around 2.48 GHz. From its corresponding S_{11} results presented in Figure 2(b), Antenna #2 has impedance bandwidths of 2.39–2.56 GHz and 3.37–5.19 GHz resonated at 2.48 GHz and 3.72 GHz, respectively. At the same time, another L-shaped strip is added into the rectangular ring on Antenna #1 (Antenna #3) to excite the highest resonant mode at around 5.09 GHz. From its corresponding S_{11} results presented in Figure 2(b), Antenna #3 has impedance bandwidths of 2.98–3.84 GHz and 4.61–6.52 GHz resonated at 3.33 GHz and 5.09 GHz, respectively. Finally, the proposed antenna is obtained by making a synthesis on the basis of Antenna #2 and Antenna #3. From its corresponding S_{11} results presented in Figure 2(b), the proposed antenna has impedance bandwidth for $S_{11} \leq -10$ dB of 170 MHz (2.38–2.55 GHz) resonated at 2.48 GHz, 720 MHz (3.34–4.06 GHz) resonated at 3.66 GHz, and 1460 MHz (5.07–6.53 GHz) resonated at 5.64 GHz, which can both well cover the 2.4/5.2/5.8 GHz WLAN bands and 3.5/5.5 GHz WiMAX bands.

For better understanding the excitation behavior of the proposed antenna, surface current distributions at 2.45, 3.5, and 5.5 GHz are studied and displayed in Figure 3. It can be clearly seen from the figure that the current distribution at three resonant frequencies is different. For the first resonant mode, a large surface current density is observed along the upper inverted L-shaped strip, whereas for the second resonant mode, the current distribution becomes more concentrated along the whole rectangular ring and the upper invert

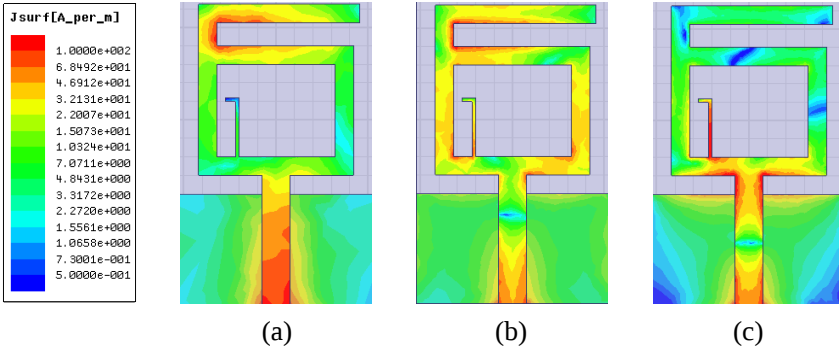


Figure 3. Simulated surface current distribution of the proposed antenna at (a) 2.45 GHz, (b) 3.5 GHz, (c) 5.5 GHz.

L-shaped strip. For the third resonant mode, the current distribution becomes more concentrated along the lower inverted L-shaped strip and the bottom of the rectangular ring. However, they have a common feature that a large surface current density is concentrated along the microstrip feed line.

Thus, both from the S_{11} characteristic curves and surface current distributions, we can clearly comprehend the function of each part of the proposed antenna. Apparently, the upper L-shaped strip and the lower L-shaped strip generate the lowest resonant mode at 2.45 GHz and the highest resonant mode at 5.64 GHz, while the rectangular ring generate the medial resonant mode at 3.66 GHz.

Each length of the resonant strip L ($L_1 = w_4 + h_5$, $L_2 = w_3 + h_4$) should be $\lambda_g/4$, where λ_g is the guided wavelength. So the length of each L-shaped strip can be obtained approximately from the following

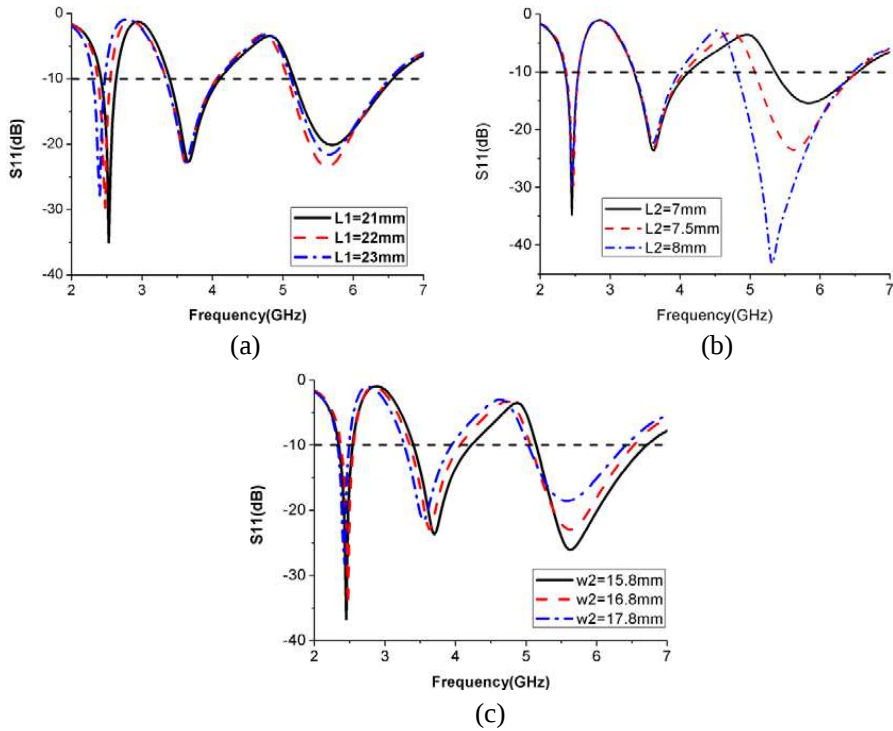


Figure 4. Simulated S_{11} for (a) various L_1 , (b) various L_2 , (c) various w_2 .

formula:

$$L \approx \lambda_g/4 = \frac{c}{4f\sqrt{\frac{\epsilon_r+1}{2}}} \quad (1)$$

where ϵ_r is the dielectric constant, c is the velocity of light in free space, f is the centric frequency of the adding resonant band, respectively. The optimal lengths of L_1 and L_2 are 22 mm and 7.5 mm, which is about $\lambda_g/4$ at 2.45 GHz and 5.64 GHz, respectively.

Figure 4 depicts the simulated S_{11} curves for different values of L_1 , L_2 and w_2 . From the Figure 4(a), it is observed that the lowest resonant mode is shifted to lower frequency when L_1 increased from 21 mm to 23 mm. From the Figure 4(b), as L_2 increased from 7 mm to 8 mm, the highest resonant mode is shifted to lower frequency while the other two resonant modes are barely affected. Besides, the performance of the highest resonant mode is obviously improved when L_2 increase. From the Figure 4(c), it can be concluded that the medial resonant mode and the highest resonant mode are shifted to lower frequency when w_2 increased from 15.8 mm to 17.8 mm. Therefore, from the Figure 4, we conclude that the three resonant modes can be obtained and tuned independently by adjusting the length and position of the three branches.

3. RESULTS AND DISCUSSION

Based on the optimal dimensions listed in Table 1, a prototype of the triple-band antenna is fabricated and experimental investigated. Figure 5(a) shows the photograph of the fabricated antenna. The

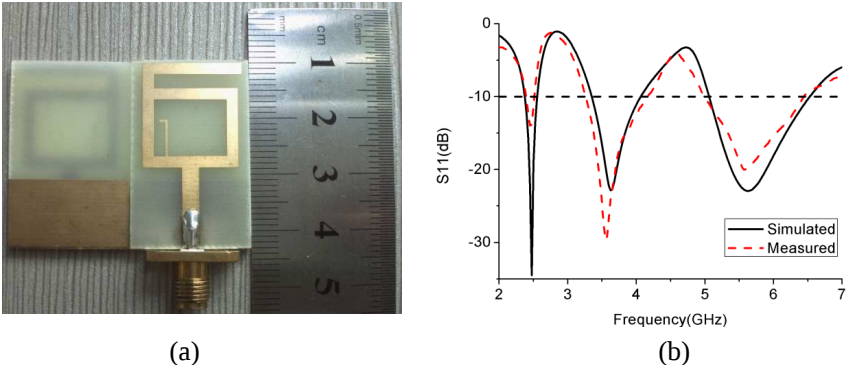


Figure 5. (a) Photograph of the proposed antenna. (b) Measured and simulated S_{11} of the proposed antenna.

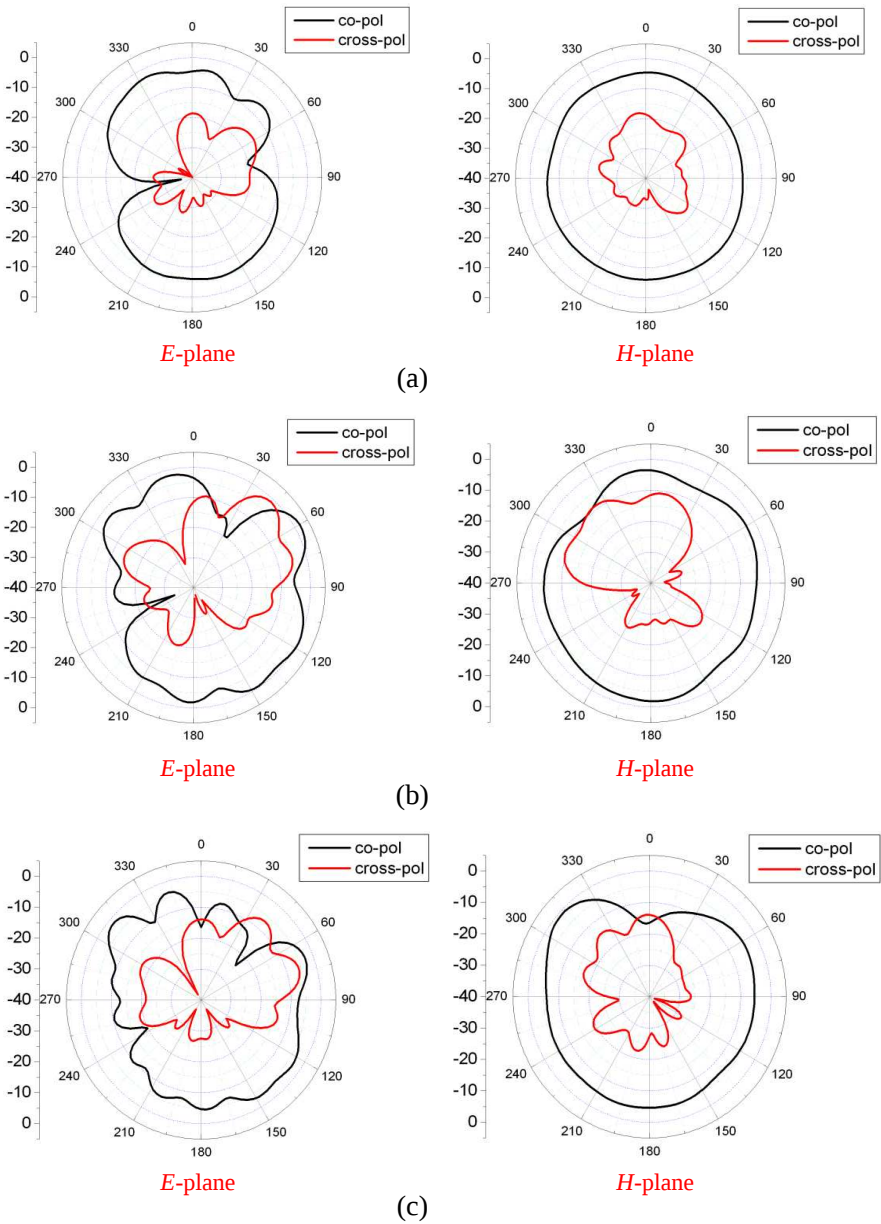


Figure 6. Measured radiation patterns for the proposed antenna at (a) 2.45 GHz, (b) 3.5 GHz, and (c) 5.5 GHz.

measured results are performed by using a vector network analyzer (Agilent PNA E8363B). Figure 5(b) describes the simulated and experimental S_{11} against the frequency for the antenna, where fairly good agreements between them have been achieved. For better comparison, the measured and simulated results of the proposed antenna are plotted in Figure 5(b) and listed in Table 2. The measured impedance bandwidths for $S_{11} \leq -10$ dB are about 130 MHz (2.39–2.51 GHz) resonated at 2.47 GHz, 890 MHz (3.26–4.15 GHz) resonated at 3.63 GHz, and 1430 MHz (5.0–6.43 GHz) resonated at 5.58 GHz, which can be used for the 2.4/5.2/5.8 GHz WLAN and 3.5/5.5 GHz WiMAX bands.

Table 2. Measured and simulated impedance bandwidths of the proposed antenna.

	First resonant mode		Second resonant mode		Third resonant mode	
	f_1 (GHz)	BW (GHz)	f_2 (GHz)	BW (GHz)	f_3 (GHz)	BW (GHz)
Measured	2.47	2.39–2.51	3.63	3.26–4.15	5.58	5.0–6.43
Simulated	2.48	2.38–2.55	3.66	3.34–4.06	5.64	5.07–6.53

The far-field radiation patterns in XOZ plane (H -plane) and YOZ plane (E -plane) for the frequencies at 2.45, 3.5, and 5.5 GHz are depicted in Figure 6. These results present that fairly good omnidirectional patterns are achieved in the XOZ plane over the operating bands, and the patterns in the YOZ plane are close to bidirectional. Figure 6 shows that the measured radiation patterns of the antenna are almost stable in both planes.

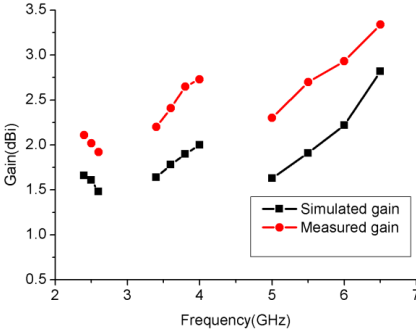


Figure 7. Peak gains of the proposed antenna.

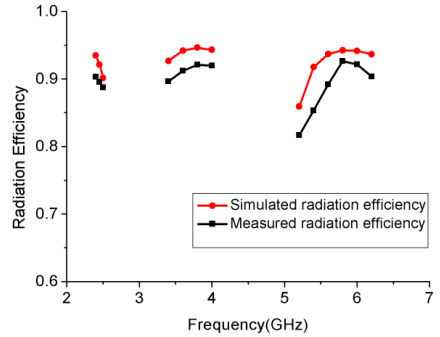


Figure 8. Measured and simulated radiation efficiency of the proposed antenna.

The peak gain of the proposed antenna across the triple operating bands is illustrated in Figure 7. As can be seen, stable gain variations across the three desired bands have been achieved. Figure 8 shows the measured and simulated radiation efficiencies of the proposed antenna. Obviously, in the 2.45, 3.5, and 5.5 GHz bands, the measured radiation efficiencies are better than 85% in average.

4. CONCLUSION

A low-profile microstrip planar monopole antenna with triple-band operation for WiMAX and WLAN applications is proposed in this paper. The antenna has a simple structure and a compact size of $21 \times 33 \times 1.6 \text{ mm}^3$. By adding two L-shaped strips on the rectangular ring patch, the antenna can excite three resonant modes. The measured -10 dB impedance bandwidth of the proposed antenna covers 2.39–2.51 GHz, 3.26–4.15 GHz, and 5.0–6.43 GHz, which meets the specifications of WLAN 2.4/5.2/5.8 GHz and WiMAX 3.5/5.5 GHz.

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