Progress In Electromagnetics Research Letters, Vol. 32, 49–57, 2012

A NOVEL CIRCULAR SLOT ANTENNA WITH TWO PAIRS OF T-SHAPED SLOTS FOR WLAN/WIMAX APPLICATIONS

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Abstract—A novel circular slot antenna with two pairs of T-shaped slots is proposed for satisfying WLAN and WiMAX applications simultaneously. The proposed antenna consists of a $50\,\Omega$ microstrip feed line with a tuning stub on the top and a circular slot ground plane with an embedded straight strip and two pairs of etched T-shaped slots on the bottom side. By carefully adjusting the length of the straight strip, the proposed antenna can operate in two separate bands. With the use of two pairs of T-shaped slots, a new resonant frequency has been excited, and the impedance bandwidth can be widened. The measured results show that the 10 dB return loss bandwidths of the proposed antenna are 760 MHz (3.18–3.94 GHz) and 1002 MHz (5.05–6.07 GHz), which can cover both 5.2/5.8 GHz WLAN bands and 3.5/5.5 GHz WiMAX bands. The design evolution and parametric study of the proposed antenna are presented to provide information for designing and optimizing such an antenna. Furthermore, good omnidirectional radiation patterns with appreciable antenna gain are obtained over the operating bands.

1. INTRODUCTION

Due to the rapid development of modern portable wireless communication devices, it is necessary to integrate multiple communication systems into a broadband or multiband antenna. In order to satisfy the IEEE 802.11 WLAN standards and the WiMAX standards simultaneously, multiband antennas with large impedance bandwidth and planar structure are required. For this, several types of antennas have been

Received 6 April 2012, Accepted 24 May 2012, Scheduled 1 June 2012

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proposed for WLAN/WiMAX applications, such as planar inverted-F antennas (PIFAs) [1–3], monopole antennas [4–7], and slot antennas [8–12]. The PIFA antenna provides many desirable characteristics such as multiband operation and compact size while it has a complex structure and its 3D structure may be challenging in fabrication. The monopole antenna has been well-known in the past decades for its attractive properties such as light weight, compact size and easy to fabricate. However, one of the main issues of the monopole antenna is the narrow bandwidth. The slot antenna has been extensively investigated by many researchers owing to its attractive characteristics such as low cost, low profile, wide bandwidth, and easy to integrate with other planar circuits. However, the slot antenna proposed in [10] can only satisfy the WiMAX standards. Though the oval-ring slot antenna reported in [11] can meet the requirement for WLAN and WiMAX simultaneously, it has a large size. The circular slot antenna studied in [12] has a much more complex structure for practical engineering applications.

In this paper, a compact circular slot antenna with two pairs of T-shaped slots for WLAN/WiMAX applications is presented. A straight strip embedded in the circular slot is used for dual bands operation. Besides, with the use of two pairs of T-shaped slots etched on the ground plane, a new resonant frequency close to the higher resonant frequency is excited and the impedance bandwidth of the higher band can be widened. Suitable radiation characteristics and appreciable antenna gain for use in 5.2 (5.15–5.35)/5.8 (5.725–5.825) GHz WLAN and 3.5 (3.4–3.6)/5.5 (5.25–5.85) GHz WiMAX operations can be achieved. Details of the antenna design and experimental results are presented and analyzed.

2. ANTENNA STRUCTURE

The configuration of the proposed antenna and its detailed dimensions are shown in Figure 1. The overall dimensions of the antenna are $39\,(W) \times 39\,(W)\,\mathrm{mm}^2$. The antenna which locates in y-z plane and symmetrical with respect to the longitudinal direction (z-direction), is printed on a 1-mm-thick FR4 substrate with the dielectric constant (ε_r) of 4.6 and the loss tangent ($\tan\delta$) of 0.02. The basis of the antenna structure is a circular slot antenna. The radius of the circular slot is set to be R. A straight strip with the width of 1.7 mm and the length of L_1 is embedded in the circular slot. It can be proven that, due to the presence of the straight strip, two separate impedance bandwidths can be easily excited. To obtain the desired multi-band operation, two pairs of T-shaped slots are etched symmetrically along the center line

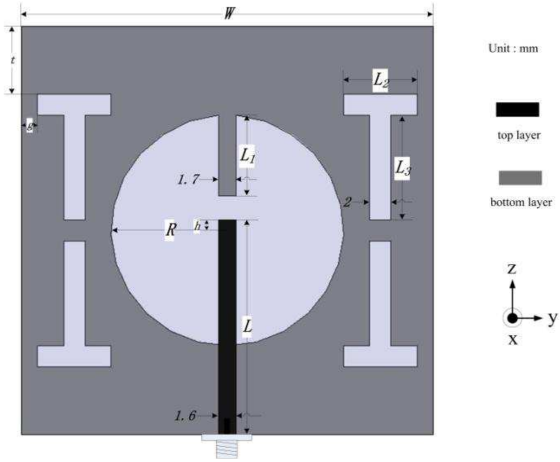

Figure 1. Antenna configuration and detailed dimensions (W = 39 mm, R = 11 mm, L = 20.5 mm, L_1 = 7.7 mm, L_2 = 7 mm, $L_3 = 10$ mm, $h = 1$ mm, $g = 1.5$ mm, $t = 6.5$ mm).

of the ground plane. The length of the horizontal slot is set to be L_2 with the width of 2 mm. The vertical slot with the length of L_3 has a significant effect on the higher resonant frequency. In addition, a 50 Ω microstrip line with a width of 1.6 mm, which is printed on the top side of the substrate, is used for feeding the antenna. The microstrip feed line is extended beyond the centre of the substrate by a length h for the tuning stub. With the aid of simulation by electromagnetic simulation software Ansoft HFSS, all geometrical parameters of the proposed antenna are optimized.

3. PARAMETRIC STUDY

Figure 2 presents the design evolution of the proposed antenna and its corresponding simulated frequency response of return losses. It begins with the design of Antenna I, which consists of a circular slot ground plane and a microstrip feed line. It can be seen from Figure 2(b) that there is only one operating band. By embedding a straight strip in the circular slot (Antenna II), the antenna can excite another resonant mode. As shown in Figure 2(b), two operating bands centered at 3.5 GHz and 5.5 GHz can be gained. It has been studied before that the structure of the ground plane also affects the characteristics of the antenna. In our design, two pairs of T-shaped slots are etched symmetrically along the center line of the ground plane. A new

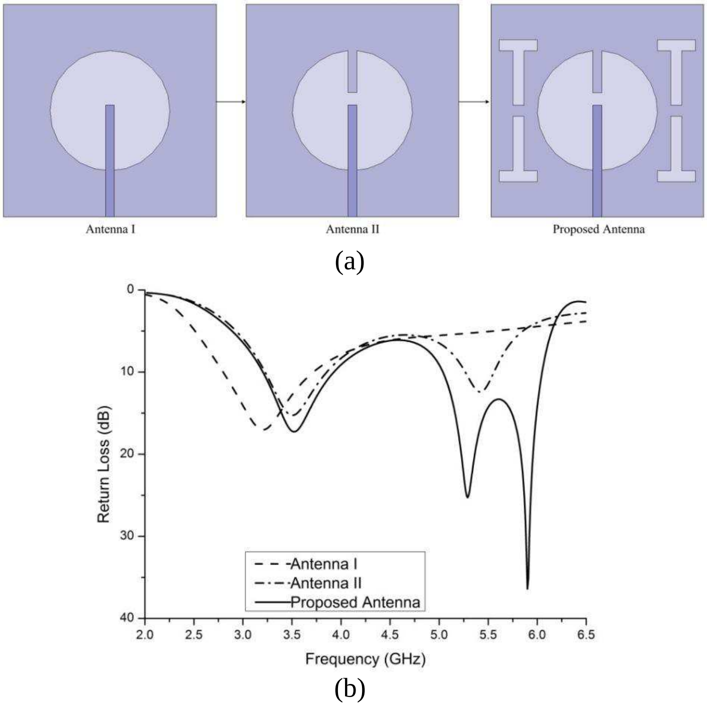

Figure 2. (a) Design evolution of the proposed antenna and (b) its corresponding simulated return loss results.

resonant frequency close to the higher operating band can be excited, and the higher impedance bandwidth is improved significantly. From Figure 2(b), it can be clearly seen that, due to the introduction of the straight strip and two pairs of T-shaped slots, the proposed antenna can satisfy the requirements for WLAN/WiMAX standards. The effects of the key structure parameters on the antenna performances are analyzed and presented.

3.1. Parameters for the Ground Plane: L_1, L_3

In this section, the functions of the straight strip and two pairs of T-shaped slots are studied. Figure 3(a) illustrates the simulated return loss characteristics of the proposed antenna for various L_1. As L_1 increases from 7.2 mm to 8.7 mm, it is observed that the first resonant frequency centered at 3.5 GHz shifts down dramatically, while the other resonant frequencies change slightly. This shows that the straight strip is used for the lower band operation. From the results shown in Figure 3(b), it can be seen that two pairs of T-shaped slots have a significant effect on the higher resonant frequency. The increasing of L_3 from 5 mm to 8 mm causes a lower resonant frequency in the higher band. The parametric study shows that by a proper choice of the parameters L_1 and L_3, the desired lower and higher center frequencies can be obtained.

3.2. Parameters for the Microstrip Feed Line: *L*

To demonstrate the effect of the tuning stub on the performance of the antenna, Figure 4 shows the return loss characteristics of the proposed antenna for various values of the length L. From the graph, it is clearly visible that when L increases from 18.5 mm to 21.5 mm, both the lower

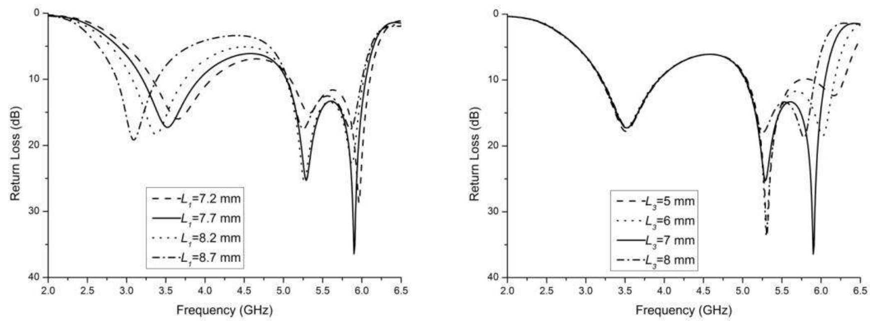

Figure 3. Effect of varying ground plane parameters on the antenna performance. (a) Length of the straight strip (L_1). (b) Length of the T-shaped slot (L_3).

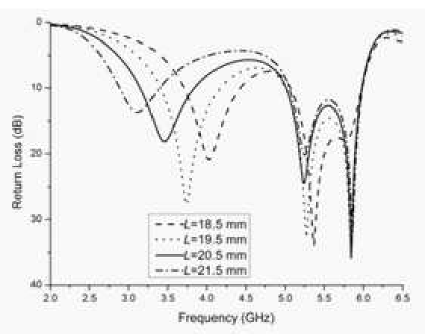

Figure 4. Simulated return loss for different values of L.

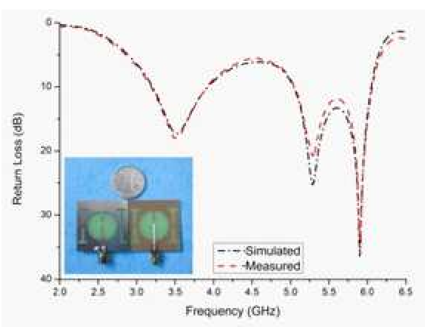

Figure 5. Simulated and Measured return losses of the antenna.

and middle resonant frequencies moves towards left, which means that the lower and middle resonant frequencies decreases with the increase of the feed line L. However, over increasing the length of the feed line will cause poorer impedance matching especially at lower band and a narrow impedance bandwidth. By carefully adjusting the length of the tuning stub and choosing the length of the feed line, the proposed antenna can meet the requirements for WLAN/WiMAX standards.

4. EXPERIMENTAL RESULTS AND DISCUSSION

The prototype of the proposed antenna is fabricated according to the optimum design results. The return loss of the proposed antenna is measured with WILTRON 37269A vector network analyzer. Figure 5 shows the simulated and measured return losses of the antenna. As can be seen, a reasonable agreement between simulated and measured results is obtained. The measured 10 dB return loss bandwidths of the proposed antenna are 760 MHz (3.18–3.94 GHz) and 1002 MHz (5.05–6.07 GHz), respectively, which makes it easy to cover the required bandwidths for both WLAN and WiMAX applications.

To further demonstrate the mechanism of the proposed antenna, the simulated current distribution on the whole antenna at the frequencies of 3.5 GHz, 5.3 GHz and 5.9 GHz are presented in Figure 6. It can be seen that the current has different distributions along the antenna at different resonant frequencies. For the excitation at 3.5 GHz, as shown in Figure 6(a), the current is flows along the circular slot, so that the lower impedance bandwidth for WiMAX (3.4–3.6 GHz) application can be gained. As depicted in Figure 6(b), the current is mainly concentrated at the straight strip and the microstrip feed line at 5.3 GHz, and therefore the middle resonant frequency can be adjusted by the length of the feed line. It is observed from Figure 6(c) that the

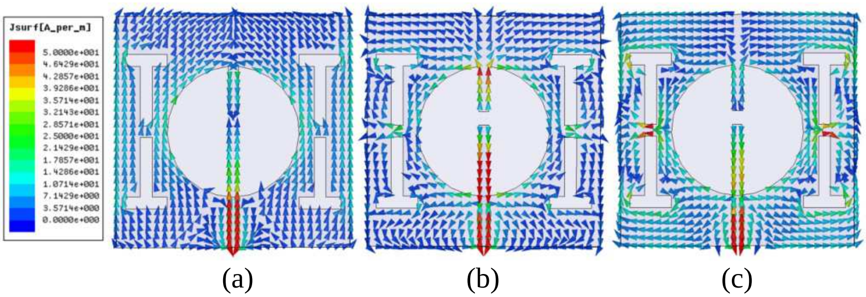

Figure 6. Simulated current distribution at (a) 3.5 GHz, (b) 5.3 GHz, (c) 5.9 GHz.

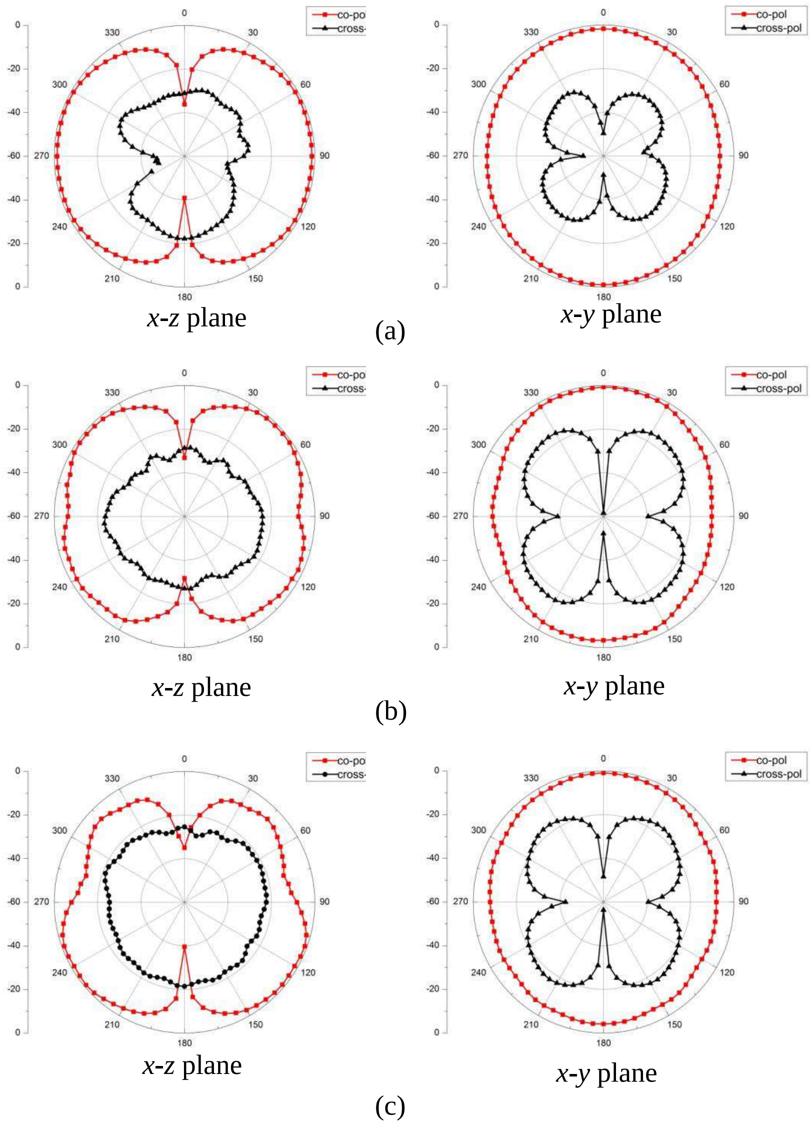

Figure 7. Radiation patterns at (a) 3.5 GHz, (b) 5.3 GHz, (c) 5.9 GHz.

current is mainly concentrated at the T-shaped slots edge at 5.9 GHz, so that the higher resonant mode is mainly affected by the length of the T-shaped slots.

Figure 7 shows the simulated normalized x-z plane (E-plane) and x-y plane (H-plane) radiation patterns of the proposed antenna at the resonant frequencies of 3.5 GHz, 5.3 GHz and 5.9 GHz, respectively.

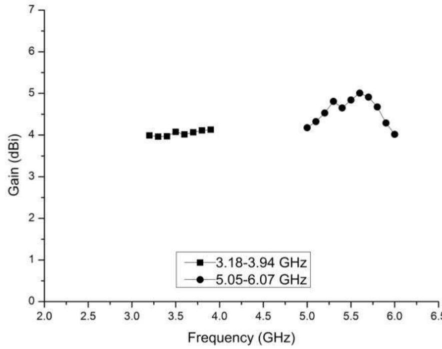

Figure 8. Gain of the proposed antenna.

It is observed that the radiation patterns are monopole-like in the x-z plane and omnidirectional in the x-y plane. In addition, the simulated antenna gains against frequency are shown in Figure 8. As can be seen, appreciable gains are obtained over the operating bands. Hence, the proposed antenna with dual bands property is suitable for WLAN/WiMAX applications.

5. CONCLUSION

In this paper, a novel circular slot antenna has been proposed for WLAN/WiMAX applications. Using a straight strip embedded in the circular slot, the antenna can generate two impedance bands. With the use of two pairs of T-shaped slots, the impedance bandwidth can be improved and meet the requirements for WLAN/WiMAX standards. The design evolution of the antenna is presented to provide information for designing and optimizing such an antenna. Effects of varying dimensions of key structure parameters on the antenna performance are studied. Moreover, the proposed antenna has the advantages of low cost, simple structure, and compact size. Accordingly, the proposed antenna with appreciable gain is expected to be an excellent candidate for WLAN/WiMAX wireless communication systems.

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