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A NOVEL TRIBAND CIRCULAR RING PATCH ANTENNA WITH A SYMMETRICAL DOOR-SHAPED STRIP FOR WLAN/WiMAX APPLICATIONS

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Abstract—In this paper, a novel circular ring patch antenna with tri-band operation is proposed for satisfying WLAN and WiMAX applications simultaneously. The proposed antenna consists of a circular ring patch, a straight strip and a door-shaped strip, all of which are printed on the top side of the substrate. The straight strip embedded in the rectangular slot is aimed to obtain resonant mode at 5.5 GHz. With the use of a door-shaped strip symmetrically with the microstrip feed line, the proposed antenna can operate in three separate bands. The proposed antenna has been fabricated and tested. The numerical and experimental results exhibit the designed antenna operates over triple frequency ranges, and the 10 dB return loss bandwidths of the proposed antenna are 570 MHz (2.27–2.84 GHz), 470 MHz (3.35–3.82 GHz) and 1720 MHz (4.84–6.56 GHz), which can fulfill both the WLAN bands (2.4–2.484 GHz, 5.15–5.35 GHz, and 5.725–5.825 GHz) and the WiMAX bands (2.4–2.6 GHz, 3.4–3.6 GHz, and 5.25–5.85 GHz). In addition, a design evolution and a parametric study of the proposed antenna are presented to provide information for designing, modifying, and optimizing such an antenna. At last, the proposed antenna has an unusual advantage of omnidirectional radiation characteristics and stable gain over the whole operating bands.

1. INTRODUCTION

In recent years, with the rapid development of wireless local area network (WLAN) and worldwide interoperability for microwave access

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(WiMAX), more and more people pay attention to multiband antennas. Thus antennas with broadband characteristic are often required to cover several bands simultaneously. For this, various designs of multiband antenna have already been reported for WLAN/WiMAX applications, such as the slot antennas [1, 2], the monopole antennas [3, 4], the ring patch antennas [5–7]. Unfortunately, most of them are either complex in physical structure or large in overall size for practical applications. Some of them only can fulfill the requirement of the WLAN or WiMAX band [8]. Due to their advantages such as low profile, light weight, low cost and wide bandwidth, the printed planar monopole antennas are attractive for WLAN and WiMAX applications. A few these antennas have been designed to cover both the WLAN and WiMAX bands [9–11]. But the impedance is not well matched for all bands. The antennas proposed in [9, 10] can generate wide bands to cover both the WLAN and WiMAX bands, however, they have so large an impedance bandwidth that it causes a significant interference with other communication systems. In [11], by employing two T-shaped strips in the two circular slots, the antenna radiates more frequency bands, but it will make the structures of the antenna more complicated for practical engineering applications.

In this paper, a novel tri-band circular ring patch antenna consisting of a straight strip and a door-shaped strip on the radiation patch and a rectangular ground on the opposite side is proposed for WLAN/WiMAX applications. Unlike the tri-band antennas mentioned above, the proposed antenna has three separate operating bands. In the design, the main patch with rectangular slot is directly fed by microstrip line. The straight strip embedded in the rectangular slot is aimed to excite a high resonant frequency mode and combine with the former high frequency mode, thus the impedance bandwidth of the high band can be widened greatly. Additionally, by using the door-shaped strip, the middle resonant frequency can be created and the achieved impedance bandwidth can meet the bandwidth requirements for WLAN standards in the 2.4/5.2/5.8 GHz bands and WiMAX standards in the 2.5/3.5/5.5 GHz bands. The simulation software Ansoft HFSS is used in the design and simulation processes of the proposed antenna. Details of the antenna design are discussed in Section 2. Parameters of the antenna are studied in Section 3. Experimental results and discussion are provided in Section 4, and the conclusions are presented in Section 5.

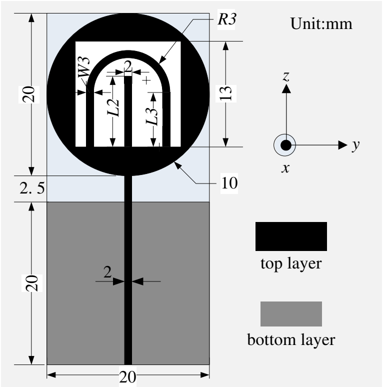


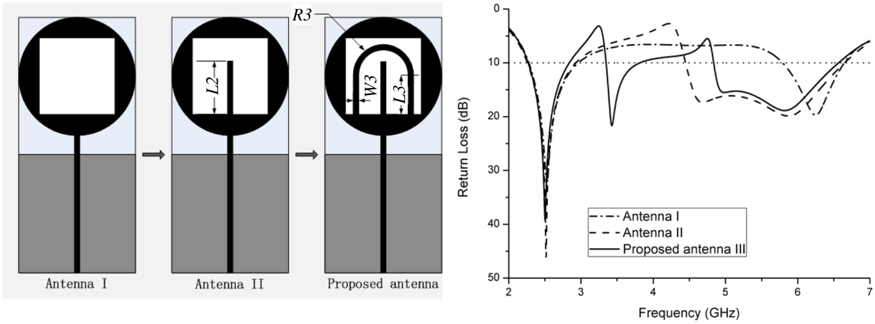
Figure 1. Geometry of the proposed tri-band antenna.

2. ANTENNA DESIGN

The geometry and dimensions of the proposed tri-band antenna are shown in Figure 1. The antenna is designed on a 1-mm-thick FR-4 substrate with the dielectric constant (ε_r) of 4.4 and loss tangent ($\tan\delta$) of 0.02. The overall dimensions of the proposed antenna are $42.5 \times 20\,\text{mm}^2$. The antenna locates in y-z plane and symmetrically with the z-direction. Based on a simple circular ring patch antenna, the radiating element of the proposed antenna consists of a straight strip and a door-shaped strip, all of which are placed symmetrically with the microstrip feed line. It can be proven that, due to the presence of the circular ring with an outer radius of 10 mm, two impedance bandwidths for WLAN/WiMAX applications can be easily excited. The radius of the circular ring controls the resonant mode at 2.5 GHz. By using a straight strip with a length of $L2$, the high frequency impedance bandwidth can be widened extremely. With the use of the door-shaped strip, the middle resonant frequency can be created. The length of the door-shaped strip ($L3$) has a significant effect on the characteristic of the middle resonant frequency mode, and thus three separate operating bands can be achieved. Additionally, a $50\,\Omega$ microstrip transmission line with a width of 2 mm is used for feeding the antenna.

3. PARAMETRIC STUDY

Figure 2 shows the design evolution of the proposed antenna and its corresponding simulated frequency response of return losses. The following analysis is based on the basic antenna structure (Antenna I) shown in Figure 2(a), which consists of a circular ring patch and a



(a) (b)

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

rectangular ground plane. As shown in Figure 2(b), a dual-resonant response is obtained by etching a rectangular slot in the circle patch. The impedance bandwidth of 690 MHz (2.27–2.96 GHz) centered at 2.52 GHz and 850 MHz (5.79–6.64 GHz) centered at 6.26 GHz are excited by the Antenna I. After adding a straight strip on the radiation patch (Antenna II), another resonant mode worked at 4.68 GHz can be excited and then the high frequency impedance bandwidth becomes 2200 MHz (4.45–6.65 GHz). With the use of the door-shaped strip (Antenna III), the impedance bandwidth of 440 MHz (3.35–3.79 GHz) with the resonant frequency excited at 3.43 GHz can be obtained. By adjusting the lengths of the straight strip and the door-shaped strip, the desired operation can be achieved. A parametric analysis is made to further illustrate the functions of the strips.

3.1. Parameters for the Straight Strip: $L2$

In this section, we will study the function of the straight strip added in the rectangle slot. The return loss characteristics of this antenna for varies $L2$ are given in Figure 3. It can be observed clearly that the straight strip affects the high frequency resonance mode greatly. So we can adjust the impedance bandwidth of the high frequency by the length of the straight strip ($L2$). As the length of the straight strip ($L2$) increases from 7 mm to 9 mm, the resonance frequency of high band shifts down obviously while the impedance bandwidth of the low frequency resonance mode changes slightly. By properly adjusting the length of the straight strip, the higher band which can fulfill the 5.2/5.8 GHz WLAN and 5.5 GHz WiMAX standards has been obtained. Therefore, it can be concluded that the main function of the straight strip is to improve the impedance bandwidth of the high band.

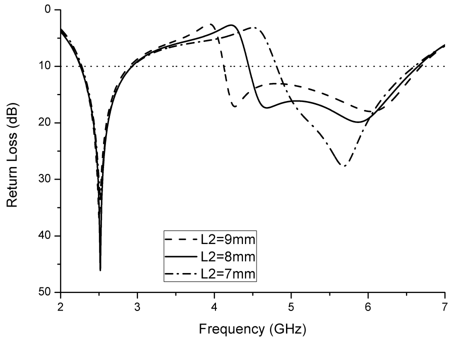


Figure 3. Simulated return loss variations for different values of $L2$.

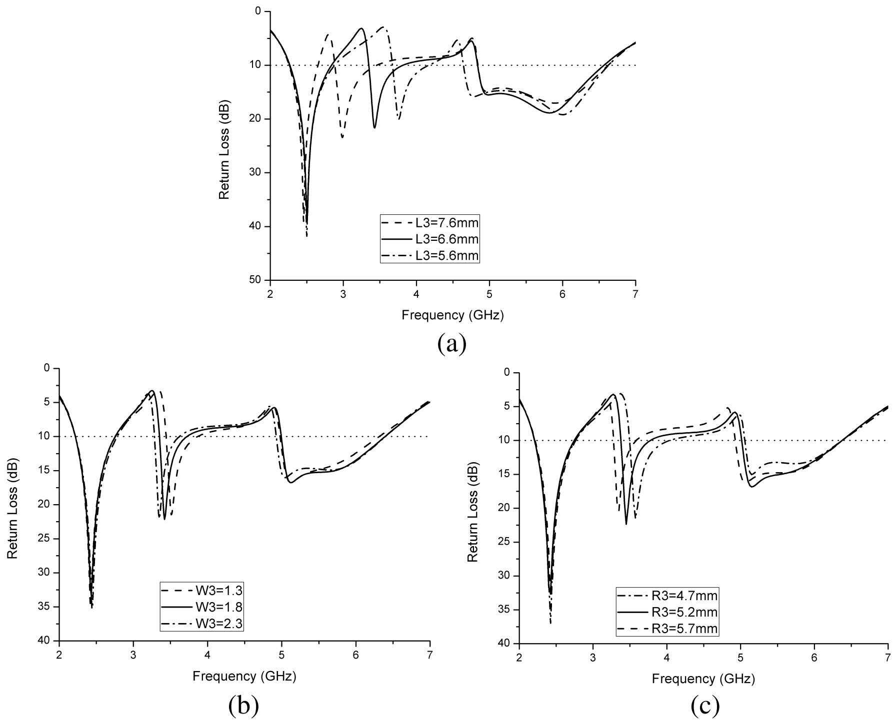


Figure 4. (a) Simulated return loss variations for different values of $L3$. (b) Simulated return loss variations for different values of $W3$. (c) Simulated return loss variations for different values of $R3$.

3.2. Parameters for the Door-shaped Strip: $L3$, $W3$ and $R3$

The door-shaped strip is made up of two straight strips and a semi-circular strip. To demonstrate the effect of the door-shaped strip,

Table 1. Parameters of the proposed antenna.

Parameters	$L2$	$L3$	$W3$	$R3$
Physical size (mm)	8	6.6	1.8	5.2

Figure 4 shows the return loss characteristics of the proposed antenna for different values of $L3$, $W3$ and $R3$. As the length of the door-shaped strip increases from 5.6 mm to 7.6 mm, the middle resonance frequency moves to the lower band. It can be seen clearly that the lower band resonance frequency is still around 2.5 GHz and its matching characteristic changes slightly. Though the high frequency resonance mode shifts a little, the high operating band still can cover the WLAN/WiMAX bands completely. It can be seen from Figure 4(b), when $W3$ is increased from 1.3 mm to 2.3 mm, the resonant frequency of the middle band shift down slowly. From the results shown in Figure 4(c), it is observed that the radius of the semi-circle has some effect on the middle, too. The increasing of the $R3$ from 4.7 mm to 5.7 mm makes the middle resonant frequency move towards left. So we can conclude that the middle resonant frequency decrease with the increasing of the $L3$, $R3$ and $W3$. By properly choosing the lengths of the straight strip and the door-shaped strip, three separate operating bands that fulfill the requirements of the WLAN/WiMAX standards are obtained. The optimal parameters of the proposed antenna are listed in Table 1.

4. EXPERIMENTAL RESULTS AND DISCUSSION

The tri-band circular ring patch antenna is simulated and optimized using the electromagnetic simulation software Ansoft HFSS, and a prototype of the proposed antenna has been constructed and experimentally studied. The return loss of the proposed antenna has been measured with Agilent E8358A vector network analyzer. Figure 5 shows the simulated and measured return losses of the proposed antenna. From the measured result, it can be seen that the 10 dB return loss bandwidths of the proposed antenna are 570 MHz (2.27–2.84 GHz), 470 MHz (3.35–3.82 GHz) and 1720 MHz (4.84–6.56 GHz), respectively, which makes it easy to cover the required bandwidths for WLAN bands (2.4–2.484 GHz, 5.15–5.35 GHz, and 5.725–5.825 GHz) and WiMAX bands (2.4–2.6 GHz, 3.4–3.6 GHz, and 5.25–5.85 GHz) applications. Reasonable agreement is obtained. The difference between measured and simulated responses may be attributed to the fabrication tolerance of the fabricated antenna prototype and the test environment.

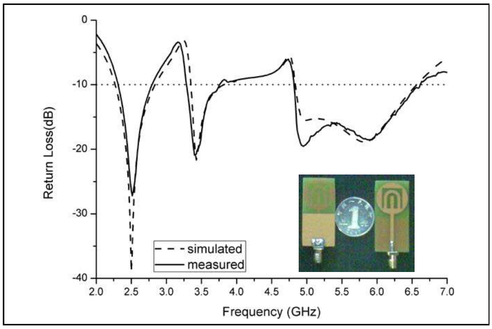


Figure 5. Simulated and measured return loss of the proposed antenna.

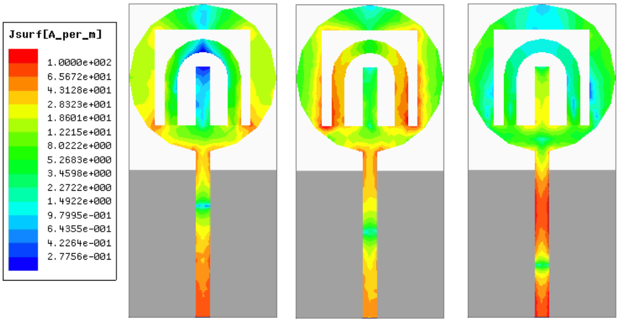


Figure 6. Simulated current distribution at (a) 2.5 GHz, (b) 3.5 GHz, (c) 5.5 GHz.

For better understanding the behavior of the proposed antenna, the simulated results of the surface current distributions on the whole proposed antenna at the frequencies of 2.5, 3.5 and 5.5 GHz are displayed in Figure 6. It can be clearly seen that the current has different distributions along the antenna at different frequencies. For the excitation at 2.5 GHz, as illustrated in Figure 6(a), the currents are forced to flow around the circular ring, so that a lower impedance bandwidth for WLAN (2.4–2.484 GHz) and WiMAX (2.4–2.6 GHz) applications can be gained. It can be seen from Figure 6(b) that the current distribution around the door-shaped strip is drastically increased and therefore the middle resonant mode at 3.5 GHz for WiMAX (3.4–3.6 GHz) operation can be excited. As can be seen in the Figure 6(c), the high resonant mode (5.5 GHz) is mostly affected by the straight strip, and thus the third impedance bandwidth for WLAN (5.15–5.35 GHz and 5.725–5.825 GHz) and WiMAX (5.25–5.85 GHz) operations can be achieved.

The simulated radiation patterns at the 2.5 GHz, 3.5 GHz, and 5.5 GHz, respectively, in the x-z plane (E-plane) and x-y plane (H-plane) are given in Figure 7. From the figure another

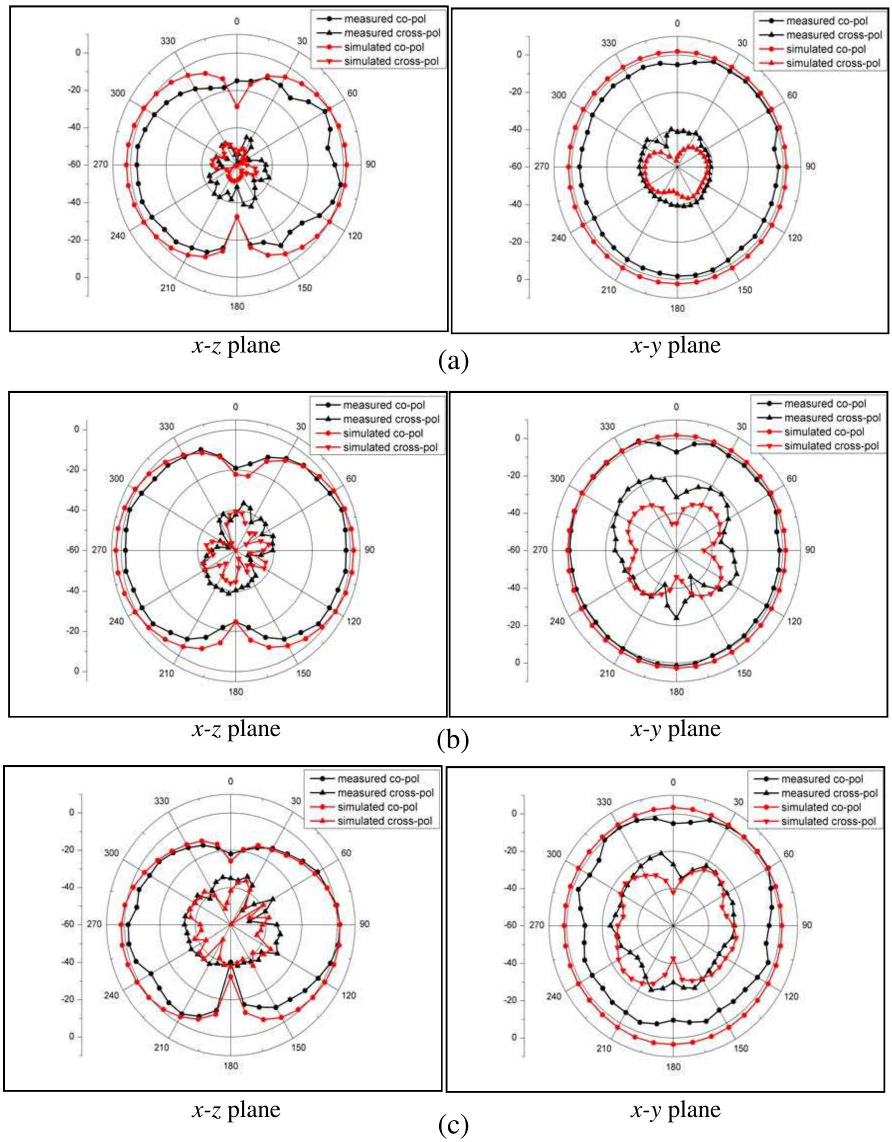


Figure 7. Measured and simulated radiation patterns, (a) 2.5 GHz, (b) 3.5 GHz, (c) 5.5 GHz.

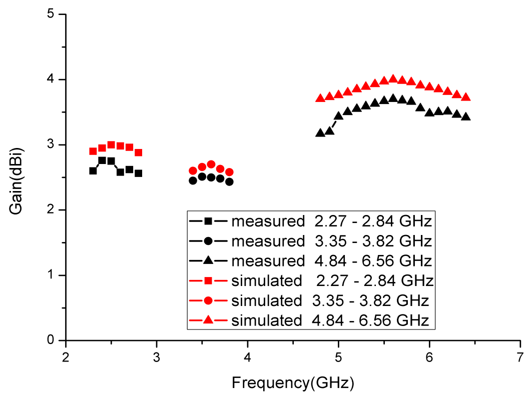


Figure 8. Measured and simulated gain of the proposed antenna.

uncommon advantage can be easily found that the proposed antenna is omnidirectional in the x-y plane and monopole-like in the x-z plane. Besides, Figure 8 shows the realized gain against frequency. And it can be clearly seen that appreciable gains are obtained over the operating bands. Therefore, the proposed antenna with tri-band property is suitable for WLAN/WiMAX applications.

5. CONCLUSION

In this paper, a novel circular ring patch antenna for WLAN/WiMAX applications haa been proposed, manufactured and verified with simulation and measurement successfully. With embedding a straight strip in the circular ring, two impedance bands are obtained. The middle frequency resonant mode is introduced by the door-shaped strip etching in the rectangular slot. Therefore, the three separate impedance bands which can meet the requirements for the WLAN/WiMAX standards are achieved. The designing evolution of the proposed antenna is presented to provide information for designing and optimizing such an antenna. The effects of varying dimensions of key structure parameters on the antenna performance are studied. Furthermore, the antenna shows a dipole-like radiation pattern in the E-plane and a nearly omnidirectional radiation pattern in the H-plane which almost no congeneric antenna can achieve.

Consequently, the proposed antenna with superior frequency characteristics and appreciable gain across the operation bands is expected to be an excellent candidate for WLAN/WiMAX wireless communication systems.

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