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Design of Tri-Band Quasi-Self-Complementary Antenna for WLAN and WiMAX Applications

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Abstract—In this article, a novel printed quasi-self-complementary antenna with tri-band characteristic is presented for WLAN and WiMAX applications. A triangular quasi-self-complementary structure, which consists of a radiating patch and its counterpart slot on the ground, is employed to produce two operating bands centered at about 2.5 and 5.2 GHz. Then, by introducing a rectangular slit cut from the patch and its complementary mirror image strip inserted into the slot, an additional resonance at 3.5 GHz is excited and tri-band operation can be realized. A prototype of the proposed antenna has been successfully fabricated and measured. Both the simulated and measured results are obtained to demonstrate the promising performance required for practical applications. Based on the results, it is shown that 10-dB impedance bandwidths of the proposed antenna are 510 MHz (2.25–2.76 GHz), 330 MHz (3.38–3.71 GHz), and 770 MHz (5.1–5.87 GHz), respectively. Also, nearly omnidirectional radiation patterns and acceptable antenna gains can be achieved over the three operating bands.

1. INTRODUCTION

Since the modern wireless communication systems have been widely used, there is an increasing demand for multiband antennas that can satisfy the different wireless standards such as Wireless Local Area Network (WLAN) and Worldwide Interoperability for Microwave Access (WiMAX). Owing to the advantages of low profile, small size and easy integration, several types of printed antennas have been reported recently. Various techniques such as the single-loop resonator (SLR) [1], complementary split-ring resonators (CSRRs) [2], defected ground structure (DGS) [3], and hybrid strips [4] have been adopted to generate multiple resonant modes. Despite multiband operation can be obtained, these antennas fail to provide the sufficient coverage of both 2.4/5.2/5.8 GHz WLAN and 2.5/3.5/5.5 GHz WiMAX standards.

In order to overcome the drawback of inherent narrow bandwidths of small antennas, the self-complementary structures can be a promising choice. The self-complementary antennas (SCAs) are characterized by wide impedance bandwidth due to the constant input impedance independent of the source frequency [5, 6]. Recently, many efforts have been devoted to the wideband and multiband applications of the SCAs and quasi-self-complementary antennas (QSCAs). Different types of quasi-self-complementary structures [7–9] have been presented to widen the operating bandwidth. The antenna with an arrow-shaped self-complementary configuration [9] yields a broad bandwidth for 2.5/3.5/5 GHz multiband applications, yet the wide band may easily cause interference with other communication systems. Unlike the conventional wideband QSCAs, the antenna with the acute pie-shaped notch and stub [10] achieves dual-band performance. And the rectangular QSCA [11] also exhibits two separate impedance bandwidths. However, both the antennas [10, 11] are only adequate for WLAN operation.

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In this article, a tri-band printed QSCA is presented for WLAN/WiMAX applications. To enhance the impedance matching of the antenna, a triangular quasi-self-complementary structure is used. The quasi-self-complementary structure is composed of a triangular radiating patch and a counterpart triangular slot on the ground. By etching a rectangular slit on the patch and inserting its complementary mirror image strip into the slot, tri-band resonant characteristic is achieved without increasing the antenna size. In addition, the proposed antenna produces good dipole-like radiation patterns and acceptable gains over the desired frequency bands. Details of the antenna design and both the simulated and measured results are presented and discussed.

2. ANTENNA DESIGN AND DISCUSSION

Figure 1 shows the configuration of the proposed antenna with a quasi-self-complementary structure. The QSCA is designed on a 1 mm-thick FR4 substrate with a relative permittivity of 4.4 and a loss tangent of 0.02. An isosceles triangular radiating patch, which is fed by a microstrip transmission line, is printed on one side of the substrate. The ground plane is located on the other side of the substrate and etched with a slot with the complement of the triangular patch. Besides, a rectangular slit is cut from the patch and a rectangular strip is connected to the ground. The slit and the strip are complementary mirror images of each other.

The evolution process of the proposed tri-band antenna is depicted in Figure 2, and the simulated return losses of various antennas involved are shown in Figure 3. It is found that the printed monopole antenna with a triangular patch (denoted as Ant.1) can provide two resonances near 2.5 and 5.6 GHz. Then the complementary counterpart of the triangular patch is formed by etching a triangular open slot on the extend ground. By using the triangular quasi-self-complementary structure, the impedance matching of Ant.2 can be effectively improved. The impedance bandwidth for 10-dB return loss of the lower band is enhanced from 280 to 650 MHz, and the upper resonant frequency is shifted to 5.2 GHz with an impedance bandwidth of 1030 MHz. Moreover, the quasi-self-complementary structure is modified by introducing a rectangular slit on the patch and a rectangular strip into the slot. Then an additional resonant mode at 3.5 GHz is excited and tri-band operation can be realized by Ant.3. By appropriately adjusting the dimensions of Ant.3, the bandwidth requirements for WLAN (2.4–2.484, 5.15–5.35, and 5.725–5.825 GHz) and WiMAX (2.5–2.69, 3.4–3.69, and 5.25–5.85 GHz) standards can be satisfied simultaneously. The numerical analysis and geometry refinement of the antenna structure have been carried out by using Ansoft's High Frequency Structure Simulator (HFSS). 50-Ω SMA connector was included in the simulated model to improve the simulation precision. The optimal parameters of the proposed antenna are recorded as follows: $W = 29$ mm, $L = 40$ mm, $L_1 = 5.6$ mm, $W_1 = 14.5$ mm,

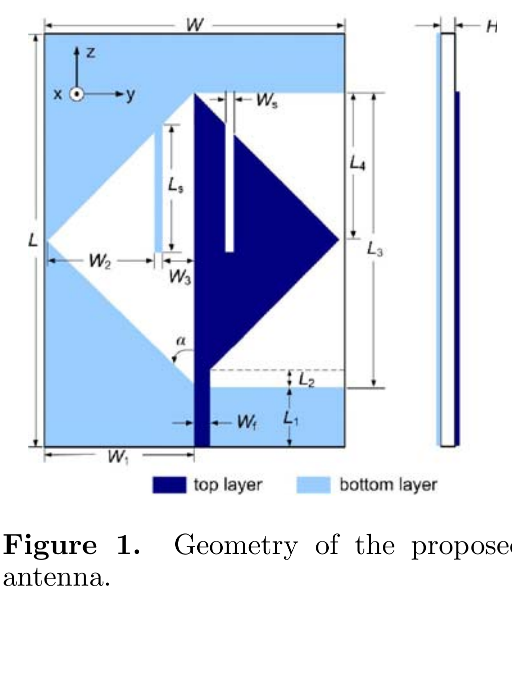


Figure 1. Geometry of the proposed antenna.

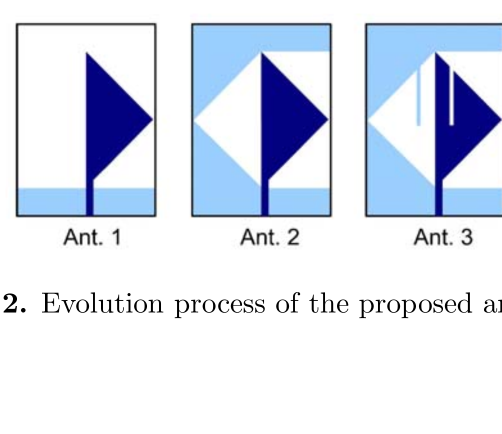


Figure 2. Evolution process of the proposed antenna.

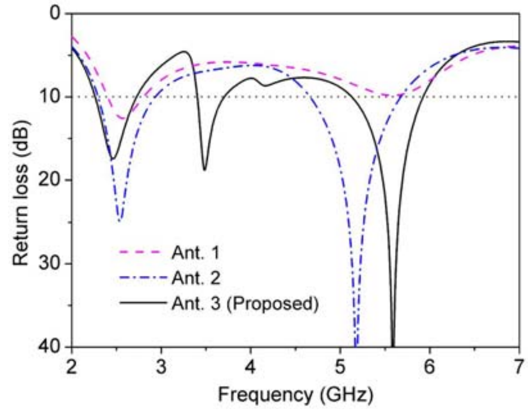
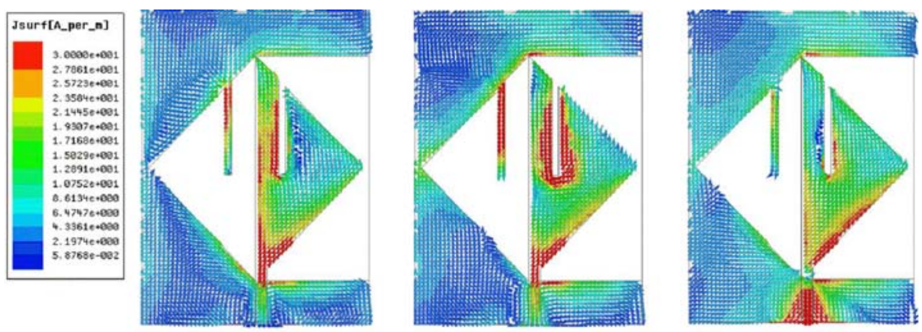


Figure 3. Simulated return losses of various antennas involved in the evolution process.



(a) (b) (c)

Figure 4. Simulated current distributions of the proposed antenna at (a) 2.5, (b) 3.5, and (c) 5.5 GHz.

$L_2 = 1.6$ mm, $W_2 = 9.9$ mm, $L_3 = 28.8$ mm, $L_4 = 14.4$ mm, $W_3 = 3$ mm, $W_f = 1.5$ mm, $W_s = 0.8$ mm, $L_s = 12.2$ mm, and $\alpha = 43.5°$.

To further investigate the working mechanism of the proposed antenna, the simulated current distributions of proposed antenna at 2.5, 3.5, and 5.5 GHz are shown in Figure 4. It can be seen from Figure 4(a) that larger surface currents are concentrated along the left edge of the triangular patch at the lower resonant frequency. The resonant length of the current patch (L_3) equals about $0.60\lambda_g$ at 2.5 GHz. As shown in Figure 4(c), most surface currents are distributed along the bottom edge of the patch. The upper resonant frequency is mainly controlled by the total length of the current patch ($L_2 + (L_3 - L_4) * \sec(\alpha)$), which is approximately $0.57\lambda_g$ at 5.6 GHz. At 3.5 GHz, strong currents flow both around the slit on the patch and along the strip extended from the ground. It is also noted that the slit and the strip have the identical dimensions with a width of W_s and a length of L_s. And L_s is taken as 12.2 mm, which approximately equals a quarter of the guided wavelength at 3.5 GHz. Hence, it is demonstrated that both the slit and the strip contribute to the additional resonance.

3. MEASURED RESULTS

Based on the detailed dimensions given in Figure 1, a prototype of the proposed antenna was fabricated and measured with an Agilent N5230A vector network analyzer. Figure 5 shows the simulated and measured return losses against frequency. It can be seen that the measured and simulated results are in good agreement. The measured impedance bandwidths for 10-dB return loss are 510 MHz (2.25–2.76 GHz), 330 MHz (3.38–3.71 GHz), and 770 MHz (5.1–5.87 GHz). Therefore, the proposed antenna suffices to cover both WLAN (2.4/5.2/5.8 GHz) and WiMAX (2.5/3.5/5.5 GHz) working bands.

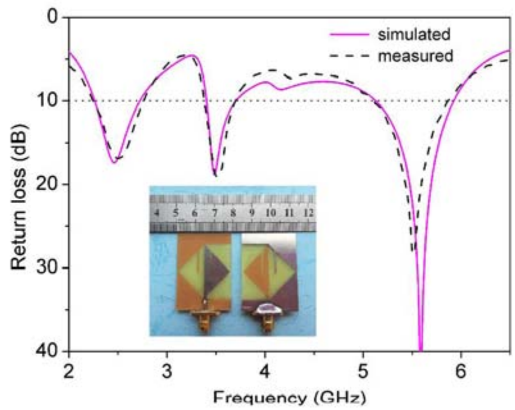


Figure 5. Simulated and measured return losses of the proposed antenna.

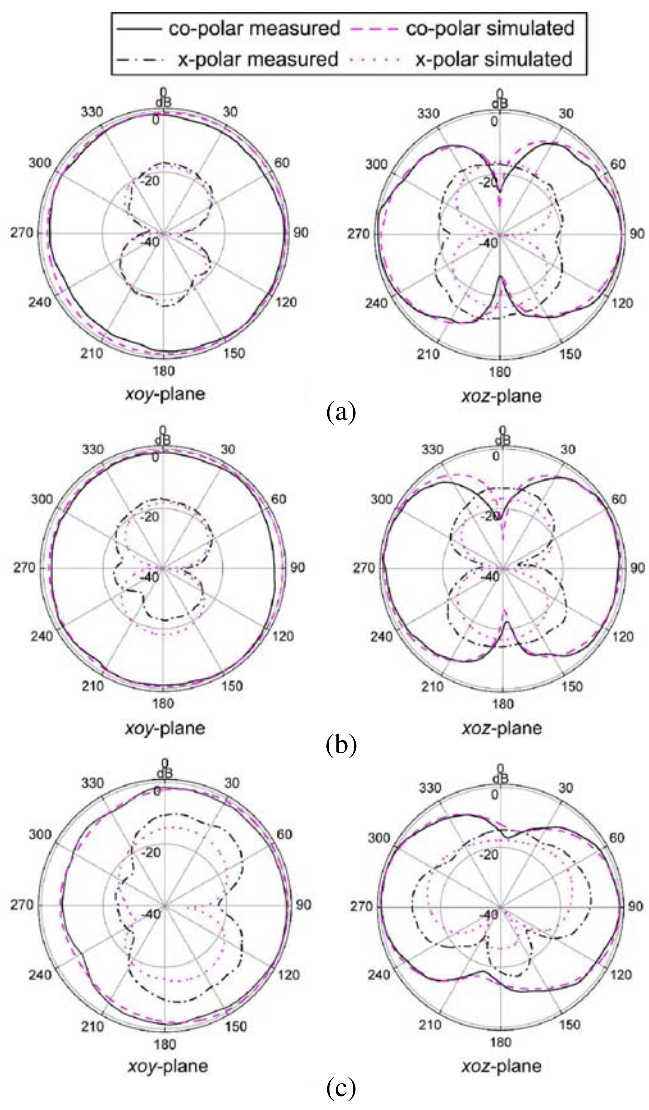


Figure 6. Simulated and measured radiation patterns of the proposed antenna: (a) 2.5, (b) 3.5, and (c) 5.5 GHz.

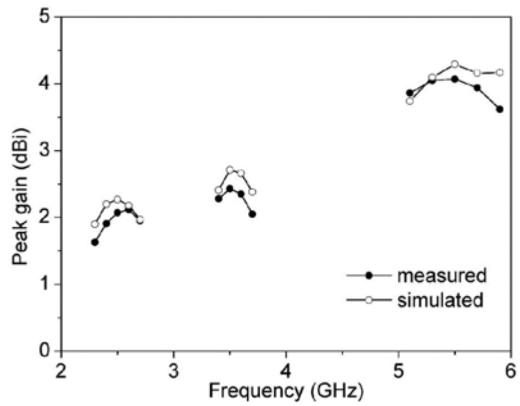


Figure 7. Simulated and measured gains of the proposed antenna.

Radiation characteristics, including radiation patterns and peak gains of the antenna prototype, have also been measured. The simulated and measured radiation patterns of the fabricated prototype at 2.5, 3.5, and 5.5 GHz are plotted in Figure 6, respectively. It can be observed that the antenna exhibits nearly omnidirectional H-plane (xoy-plane) and bidirectional E-plane (xoz-plane) patterns over the desired operating bands. Thus, the radiating performance of the proposed QSCA is stable and similar to that of a simple dipole antenna. However, at the upper resonant frequency of 5.5 GHz, the patterns in the H-plane (xoy-plane) are slightly less omnidirectional. It is found in Figure 4(c) that a large portion of surface currents can be observed along the bottom edge of the triangular patch. Thus, stronger currents are generated towards the $+y$ direction, which leads to the relatively high out-of-roundness in xoy-plane at 5.5 GHz. The measured and simulated gains across the three operating bands are shown in Figure 7. As can be seen, the measured gains vary from 1.63 to 2.12 dBi, 2.05 to 2.43 dBi, and 3.62 to 4.07 dBi for the lower, middle and upper bands, respectively. Obviously, small gain variations of less than 1 dB can be obtained for each operating band.

4. CONCLUSION

A printed QSCA antenna for multiband applications has been designed, fabricated and tested. With a triangular quasi-self-complementary structure and a pair of complementary mirror image structures, the proposed antenna not only produces tri-band resonances to cover the desired frequency bands but also maintains the merits of small size and simple structure. Experimental results also indicate stable radiation patterns and acceptable gains over the operating bands. Therefore, the proposed antenna could be a potential candidate for multiband wireless applications.

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