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DESIGN OF AN EDGE-FED QUAD-BAND SLOT ANTENNA FOR GPS/WIMAX/WLAN APPLICATIONS

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Abstract—In this letter, a novel compact quad-band microstrip circular slot antenna using edge-feeding is proposed to support the four wireless communication bands of GPS1.575 (1.525–1.625 GHz), WIMAX3.5 (3.3–3.6 GHz), WLAN2.45 (2.4–2.485 MHz)and WLAN5.2/5.8 (5.15–5.825 GHz). To expand the bandwidth of the GPS band and induce the WIMAX/WLAN band to support quad-band applications without affecting the compactness of the proposed antenna, a good method of implanting two T copper slices at the inner boundary of the two circular slots respectively is adopted. By adjusting the diameter of the two circular slots and the size of the T-shaped patch, resonant frequencies and bandwidth of the antenna are controlled and the multiple operating bands are achieved. In order to further reduce the size of the antenna that an edge-fed technology is used. This antenna has a simpler structure for realizing quad-band characteristics. Then, a prototype of the proposed antenna was successfully implemented, and good radiation performance is observed in all desired bands.

1. INTRODUCTION

With the development of the modern wireless communication technology, one of the hot research topics is multi-band technology in recent years. Global positioning satellite (GPS), Worldwide Interoperability for Microwave Access (WIMAX) and Wireless local area network (WLAN) have been widely applied in mobile devices such as intelligent phones and portable computers. In order to satisfy the various wireless communication protocol systems demands, the future communication terminal antennas must not only be with a multi-band operation, but also have a simple structure, compact size and easy

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integration with the circuit. For the sake of achieving multi-band operation, the traditional approach is to use multi-branched strips [1–6], which generally leads to a large size or requires a large ground-plane. PIFA usually has a compact size, but its bandwidth is relatively narrow and a sufficient height from the ground plane has to be kept to achieve the acceptable performances. The planar wire antenna exhibits a much wider bandwidth, but their external configurations make it less practicable in the modern wireless communication applications. The planar monopole antennas proposed in [7–10] generally possess compact size, sufficient bandwidth and satisfying radiation patterns. However, their structures are all 3-dimensional instead of 2-dimensional, increasing the manufacture difficulty and cost.

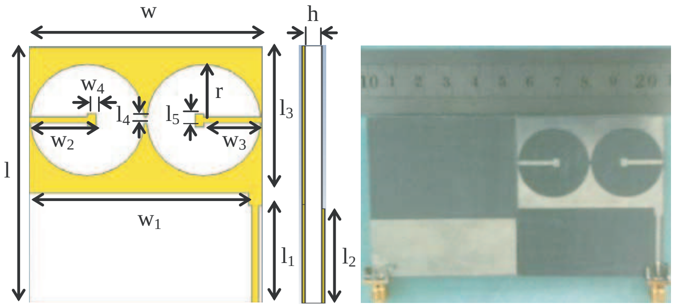
In [11, 12], a compact tri-band monopole antenna is proposed using reactive loading, that was inspired by previous TL-MTM work and a defected ground-plane, but the antenna structure increased difficulties of complicated processing. Alternatively, the concept of the frequency-reconfigurable multi-band antenna [13] has been proposed to develop multi-band monopole antennas for wireless communication system applications, however, variable frequency range is limited [14]. In [15, 16], a novel compact printed planar monopole antenna for mobile handset applications is proposed. By simply loading two narrow slits and a back coupling parasitic strip onto the radiating patch, multiple resonances can be obtained easily. Despite the advantages of the above methods proposed, high manufacturing costs and difficulty in fabricating such big ground plane structured antennas are major considerations for antenna engineers.

In this letter, a compact planar quad-band circular slot monopole antenna with 2-dimensional structure is introduced. Both the structure and the parameters are carefully adjusted to achieve multi-resonances, sufficient bandwidths and convenient profile. The antenna consists of a rectangle-shaped radiator patch which two simple circular slots are etched, two T-shaped patches, a microstrip edge-fed line, a substrate and a defected ground plane. By simply loading two circular slots and a small concave slot onto the radiating patch, four resonating modes centered at 1.575, 2.45, 3.5 and 5.5 GHz are excited and capable to operate within the GPS/WIMAX/WLAN bands with desirable impedance bandwidth measured at S_{11} $-10\,\mathrm{dB}$. The two circular slots are able to achieve two frequencies and also provide a broadband operation at high frequency. The additional two resonant modes are excited with opening a concave slot in the rectangular patch and two T-shaped patches. Compared to the antennas in [1–9], the proposed antenna in this letter not only achieves quadruple bands meanwhile, but also has a rather simple structure that is easy to fabricate. To further reduce the size of the antenna, edge-fed technologies which can increase the antenna resonant length are utilized. The prototype antenna with the compact total size of 53 mm × 34 mm × 1.6 mm which has been fabricated and tested. The design is accomplished with the aid of CST Microwave Studio that was used to verify the measured results of the fabricated antenna. The simulated S-parameters, the radiation patterns and a good antenna gain are given and discussed.

2. DESIGE OF THE ANTENNA

Geometry and fabrication photograph of the proposed antenna is shown in Figure 1. It is designed and fabricated on a dielectric substrate with relative permittivity $\varepsilon_r = 2.7$, a loss tangent of 0.02. It can be seen from Figure 1 that two circular slots were opened in the rectangular patch and each slot contains a T-shaped patch. Without loss of generality, a microstrip-feed line is adopted for marginally feeding the antenna in the side of edge the substrate. This ground plane was selected to be 22 × 53 mm in the experiment, which can further reduce the size of the antenna than the ground plane of [17].

Figure 2 presents the design flow of this proposed antenna, it can be seen that two circular grooves play an important role for frequency point 3.5 GHz and 5.5 GHz. T-shaped patch is mainly used for tuning frequency point here. By loading a T-shaped patch in the two circular slots respectively, an additional upper resonant frequency at around 2.45 GHz is excited due to the 1/2 wavelength current distribution along circular slot and T-shaped patch. Finally a single lower resonant frequency of around 1.575 GHz is produced by the middle of the small



(a) (b) (c)

Figure 1. The configuration of quad-band microstrip antenna: (a) Top view. (b) Side view. (c) Fabrication photograph.

concave slot.

From the Figure 2, it is easy to know that the lower resonance frequency point ($f = 1.575\,\mathrm{GHz}$) can be produced by the middle of the small concave slot. Resonance in the frequency point 2.45 GHz is influenced by the length of the T-shaped patch. That show in Figure 3. From the Figure 4, we can see that the radius size of the two circular grooves play an important role for frequency point 3.5 GHz and 5.5 GHz. T-shaped patches is mainly used for tuning frequency point here. Simultaneously, it should be noted that the defected ground structure can't only play a significant role in improving two the highest resonant mode impedance matching across the desired

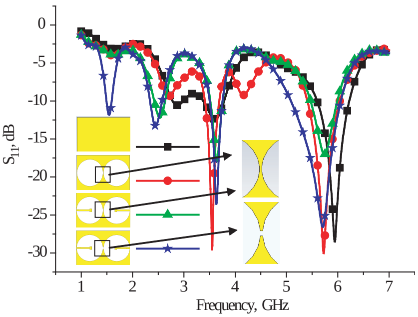


Figure 2. Reflection coefficients for various configurations of the antenna.

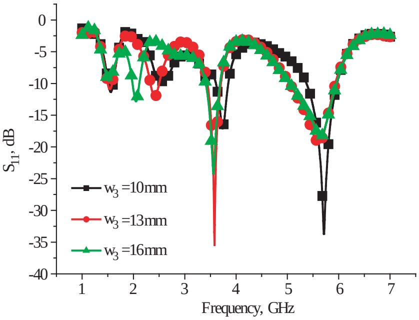


Figure 3. Simulated reflection coefficients S_{11} corresponding to the variation parameters of the length of the T-shaped patch.

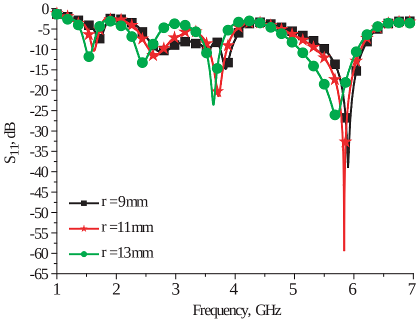


Figure 4. Simulated reflection coefficients S_{11} corresponding to the variation parameters of the two circular grooves radius size.

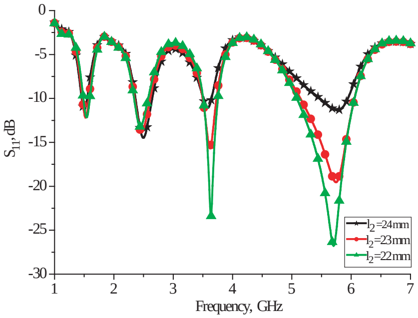


Figure 5. Simulated reflection coefficients S_{11} corresponding to the variation parameters of ground plane size.

operating bands, but also the actual ground plane dimensions can be minimized as far as possible to acquire broadside and bidirectional radiation patterns. The effect of the ground plane was investigated by checking the variations in the reflection coefficient against the size of the ground plane. The S_{11}-parameters of the different ground structures in the antenna design is shown in Figure 5, which clearly clarifies the impedance matching explanation of the proposed antenna.

By adjusting optimum parameters of the proposed antenna, good impedance matching through the operating bands for the GPS, WLAN and WIMAX applications is achieved by gradient impedance edge-fed line and the T-shaped patch. The parameters of the proposed antenna shown in Figure 1 are: $w = 53\,\text{mm}$, $l = 60\,\text{mm}$, $w_1 = 49\,\text{mm}$, $w_2 = 15.25\,\text{mm}$, $w_3 = 13.25\,\text{mm}$, $w_4 = 2\,\text{mm}$,$r = 13\,\text{mm}$, $l_1 = 23\,\text{mm}$, $l_2 = 22\,\text{mm}$, $l_3 = 34\,\text{mm}$, $l_4 = 1.5\,\text{mm}$, $l_5 = 3\,\text{mm}$, $h = 0.8\,\text{mm}$.

3. RESULTS OF THE ANTENNA

The resonant frequency of the proposed antenna was measured by an HPE8362B network analyzer and the simulation was performed by CST MWS. The measured and simulated S_{11}-parameter of the proposed antenna is shown in Figure 6. Obviously, the lower resonant band with 110 MHz (1.515–1.625 GHz) bandwidth is wide enough to cover the GPS (1.525–1.625 GHz) bands, the higher resonant bands with 280 MHz (3.42–3.7 GHz) bandwidths cover the 3.5 GHz WIMAX (3.4–3.6 GHZ) bands, 163 MHz (2.332–2.495 GHz) and 890 MHz (5.05–5.94 GHz) bandwidths cover the 2.45, 5.2 and 5.8 GHz WLAN (2.4–2.485 GHz, 5.15–5.35 GHz and 5.725–5.825 GHz) bands, respectively, which show approximate agreement with the simulated results.

The longer path starts from the feed point and follows the circular

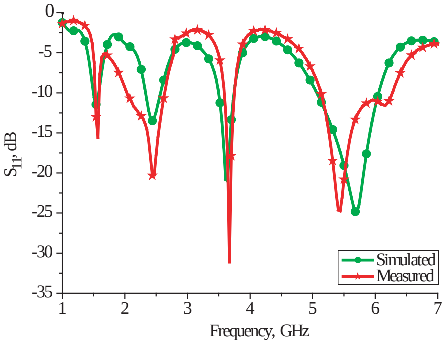
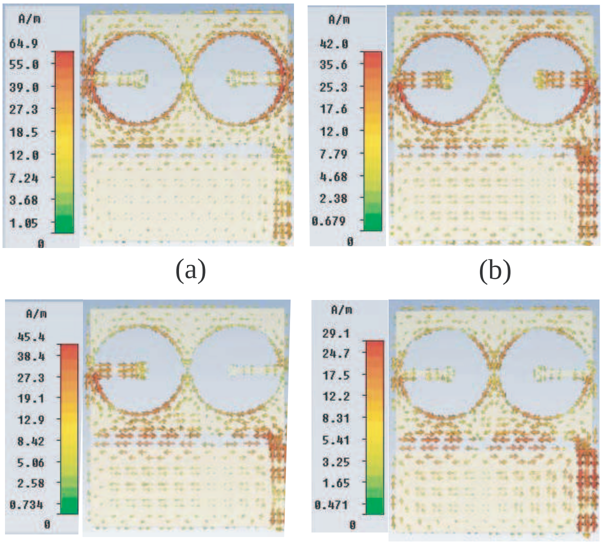


Figure 6. Measured and simulated reflection coefficients S-parameter.



(a) (b)

(c) (d)

Figure 7. Current distribution of the proposed antenna. (a) 1.575 GHz. (b) 2.45 GHz. (c) 3.5 GHz. (d) 5.5 GHz.

slot and the T-shaped patch, while the shorter one is from the feed point to the end of the inner circular slot. It can be seen that the length of the longer path is much greater than the length of the rectangular patch, which makes the fundamental resonant frequency of the proposed antenna greatly lowered. In the proposed design shown in Figure 6, this length is about 54 mm, which is slightly less than half-wavelength of the operating frequency at 2.45 GHz. This difference is largely due to the effect of the supporting FR4 substrate, which reduces the resonant length of the radiating element.

On the other hand, the length of the shorter path in the proposed design is about 18 mm, which makes it possible for the excitation of a quarter-wavelength resonant mode at about 5.5 GHz. This resonant mode incorporating the second-higher (half-wavelength) resonant mode of the longer path, which is expected to be at about 5.5 GHz, forms a wide impedance bandwidth covering the bandwidths of the 5.2-, 5.5-, and 5.8-GHz bands for the proposed antenna. The differences may be due to the effect of the SMA connector and mismatching tolerance.

Figure 7 illustrates the current distribution of the proposed antenna at different frequencies. As frequency increases, currents are major located in a smaller region of the two circular slots. As shown

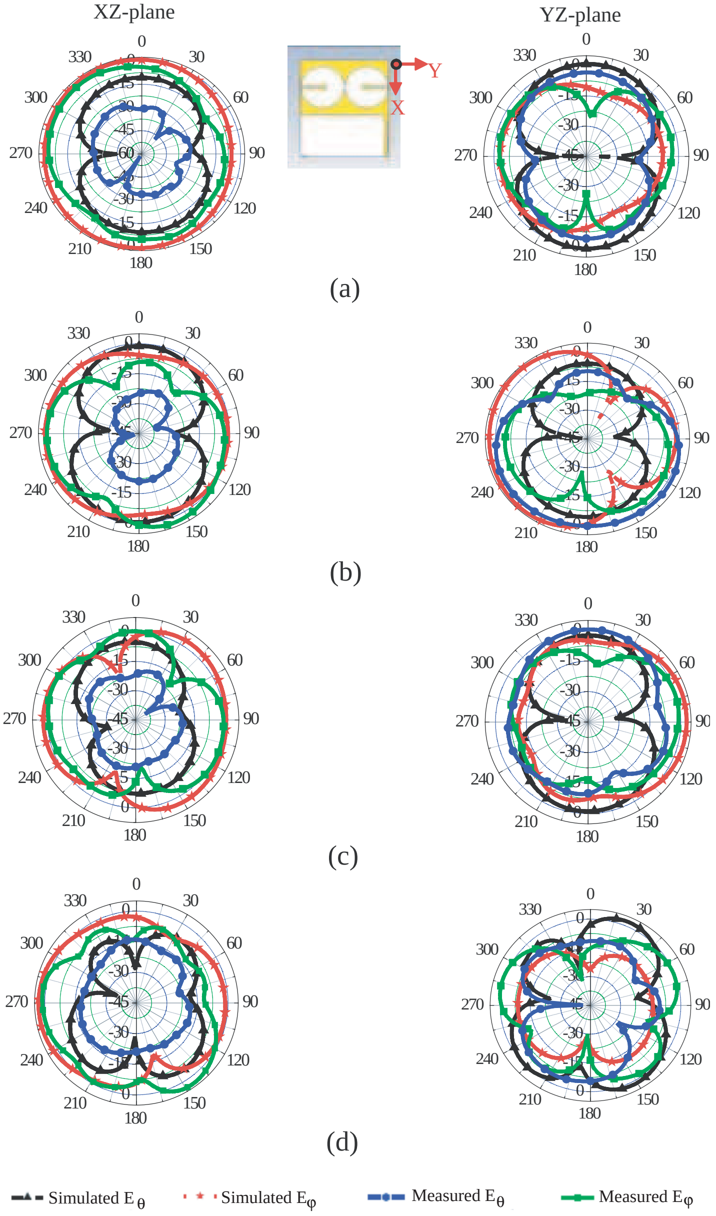


Figure 8. Radiation patterns of the proposed antenna at different frequencies. (a) 1.575 GHz. (b) 2.45 GHz. (c) 3.5 GHz. (d) 5.5 GHz.

in Figure 7(a), the current flows mainly along the outer edge of the circular slot. It justifies that the lowest resonant frequency is generated by etching the small concave slot on the rectangular copper patch. In Figure 7(b), the current flows along the edge of the circular slot upward to the two T-shaped copper strips. Therefore, the embedded strips in the slot mainly generate the middle frequency.

In Figure 7(c), the current centralizes in the lower half region nearby the circular slot upward to the left T-shaped copper strips that generates the first highest frequency. Similarly in the Figure 7(d), strong surface current distributions around the bottom of the small concave slot both sides and along the inside edge of the circular slot, which demonstrates that the second highest resonant mode is excited. It exists electromagnetic coupling that are the major factors for the proposed antenna at the 5.5 GHz band.

The measured and simulated radiation patterns of the proposed antenna in the xz-plane and yz-plane for four different frequencies 1.575 GHz, 2.45 GHz, 3.5 GHz and 5.5 GHz are shown in Figure 8. We found a relatively good agreement between the measured and simulated ones, especially the co-polarized components of the electric field. It is clearly seen that the antenna presents good broadside and bidirectional radiation patterns at 1.575, 2.45, 3.5 and 5.5 GHz in the xz-plane and yz-plane, which well-behaving nulls are observed as expected. Increased level of the cross-polar components is due to the circular slot in the antenna structure. It is still acceptable because in mobile communications, the orientation of the handset is not fixed and the incoming signals are depolarized due to multiple reflections and scattering in the propagation channel. It is, therefore, important that the handset antenna should be capable of receiving both the co-polar and cross-polar components. The simulated and measured peak gain values at all of the frequencies are given in Figure 9.

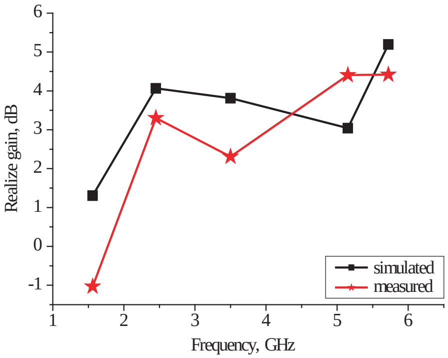


Figure 9. Measured and simulated peak gains of the proposed antenna.

4. CONCLUSIONS

The compact planar circular slot antenna which fed by way of the edge for the GPS, WIMAX and WLAN systems operation with two T-shaped patches has been studied and discussed in detail. The diameter of the two circular slots and the size of the T-shaped patch play an important role in controlling resonant frequencies, bandwidth of the antenna and achieving the multiple-resonant operations. Moreover, as the resonant frequencies have definite connections with certain parts of the antennas, the resonant frequencies can be controlled easily with broad frequency tuning ability. The proposed antenna can provide sufficient impedance bandwidths, good radiation patterns and along with moderate gain for GPS, WIMAX and WLAN bands. Finally, the performances of the proposed antenna prove it is suitable for multi-band wireless communication applications.

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