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Compact ACS-Fed Circular-ARC-Shaped Stepped Monopole Antenna for Tri-Band WLAN/WiMAX Applications

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Abstract—In this paper, a compact asymmetric coplanar strip (ACS)-fed printed monopole antenna for tri-band WLAN/WiMAX applications is presented. The proposed antenna is composed of a circular-arc-shaped stepped monopole with dual operating frequencies at 2.4/5.7 GHz and a simple circular-arc-shaped strip with the third operating frequency at 3.5 GHz. The three resonant frequencies of the antenna can be controlled by adjusting the geometries and the sizes of the stepped monopole, the strip and the ground plane. The antenna occupies a very compact size of $22.1 \times 12\,\mathrm{mm}^2$ including the ground plane, has nearly omnidirectional radiation characteristics and reasonable gain in the operating bands. The simple feeding structure, compactness and uniplanar design make it easy to be integrated within the portable device for wireless communications.

1. INTRODUCTION

Recently, because wireless local area network (WLAN: 2.4–2.48, 5.15–5.35, and 5.72–5.85 GHz) and worldwide interoperability for microwave access (WiMAX: 3.40–3.69, and 5.25–5.85 GHz) have been widely applied to mobile devices such as handheld computers and smart phones, the multiband antennas have become one of the most important circuit elements and attracted significant attentions. However, many engineers only focus their interest on WLAN or WiMAX antennas, such as [1–3]. Hence, it is highly desirable to design a multiband antenna which can meet both the WLAN and WiMAX bands. Therefore, different types of multiband antennas have been proposed to cater the multiband requirement, such as [4–9]. For example, a tri-band monopole antenna with double coupled C-shaped strips for WLAN/WiMAX applications is presented [4], open L-slot antenna with a slit and a strip for WLAN/WiMAX triband operation [5, 6] presented a tri-band design of a circular slot patch antenna for WLAN/WiMAX applications. However, the antennas mentioned above have either complex structure or large size, which are not suitable for the portable wireless terminals with limited space. Therefore, in order to design miniaturized antenna, a coplanar waveguide (CPW)-fed is presented Miniature tri-band CPW-fed monopole antenna embedded with dual U-shaped slot is reported [7]. In literature [8], a compact CPW-fed planar monopole antenna with triband for WLAN and WiMAX operations by inserting two I-shaped notched slots and an open-ended U-shaped slot on the edge of the radiation patch is presented.

In order to further minimize the overall size of antennas, literature [9] presented an effective feeding (asymmetric coplanar strip (ACS) feeding) technique. Unlike the traditional antennas using a larger ground plane or a coaxial line feed, the ACS-fed structure only has half a ground plane. The asymmetric coplanar strip feed used here has all the advantages of a uniplanar feed along with compactness, and the feeding mechanism can be analogized to the coplanar wave guide feed. However, the proposed antenna in [9] still has a large size and only covers one band, namely for WLAN applications. Another ACS-fed dual-band antenna for 2.4/5.8 GHz WLAN applications has been studied in [10], the proposed antenna

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uses loaded capacitance terminations to reduce the size, but it has a complex structure and is hard to design. Recently, a tri-band ACS-fed monopole antenna for WLAN and WiMAX applications has been presented in [11], which consists of a monopole and two slots. Compared with our design, it is still larger than ours.

In this paper, inspired by the planar antenna with only a stepped monopole can generate two desired operating bands [12], we successfully design a novel circular-arc-shaped stepped monopole with dual operating frequencies, then add a simple circular-arc-shaped strip with the third operating frequency in the monopole to generate three desired operating bands of 2.37–2.53 GHz, 3.37–3.71 GHz, and 4.93–6.35 GHz for 2.4/5.2/5.8 GHz WLAN and 3.5/5.5 GHz WiMAX applications. The circular-arc-shaped structure can immensely reduce the overall size of the proposed antenna. Furthermore, the principles and processes of generating the operating bands are given in detail. The effects of the key parameters are simulated and analyzed, and the experimental results are presented and discussed. Measured results indicate that the antenna is a good candidate for WLAN and WiMAX applications.

2. ANTENNA DESIGN AND PARAMETRIC STUDY

Figure 1 shows the geometry of the tri-band ACS-fed monopole antenna. The antenna is printed on the FR-4 substrate with dielectric constant of 4.4 and a thickness of 1.6 mm, and the overall dimensions are only $22.1 \times 12\,\mathrm{mm}^2$. In order to correspond to the 50-Ω characteristic impedance, the ACS-fed structure has a signal strip width of W_1 (= 3.8 mm) and a gap distance g (= 0.2 mm) between the signal strip and the coplanar ground plane. Details of the design procedure are as follows.

The electromagnetic simulation software Ansoft HFSS V13 is used to quicken the design. Figure 2 shows the evolution of the proposed antenna and corresponding simulated reflection coefficient curves. Antenna 1 in Figure 2(a) is the original ACS-fed monopole antenna, which consists of an ACS-fed structure and a circular-arc-shaped stepped monopole. In comparison to the conventional monopole, it indicates not only the electrical length, but also the characteristic impedance of the stepped monopole controls the resonant frequencies [12], which means that the frequency ratio of the resonant frequencies is more flexible, and it is very useful for multiband applications. Therefore, by adjusting the length and width of the stepped monopole, two resonant frequencies can be controlled flexibly. It can be seen from Figure 2(b) that Antenna 1 generates two resonant modes at about 2.45 GHz (first resonant mode) and 5.56 GHz (second resonant mode), covering the operating bands 2.40–2.49 GHz and 4.51–6.57 GHz. Then a circular-arc-shaped strip is added in the monopole (antenna 2) to generate the third resonant mode at about 3.56 GHz. Different from the traditional half-wavelength trip, the length of the trip is about a quarter of the guided wavelength calculated at the centre frequency, and the guided wavelength

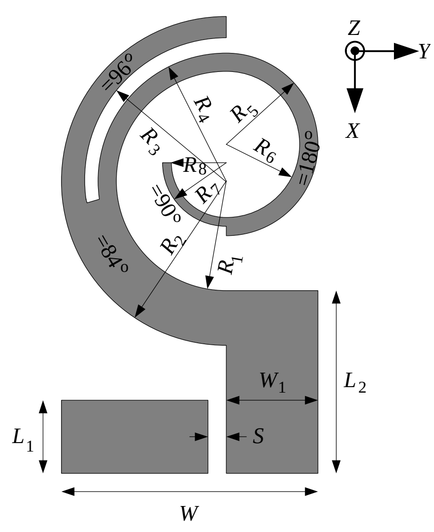


Figure 1. Geometry of the proposed ACS-fed monopole antenna.

$\lambda_g = \lambda_0/\mathrm{sqrt}\ (\varepsilon_{eff})$, where $\varepsilon_{eff} \approx (\varepsilon_r + 1)/2$ and λ_0 is the free-space wavelength. As illustrated in Figure 2(b), Antenna 2 has three separate operating bands of 2.39–2.48 GHz, 3.38–3.69 GHz, and 5.05–6.51 GHz. It can be seen that introducing the third resonant mode makes the performance of the

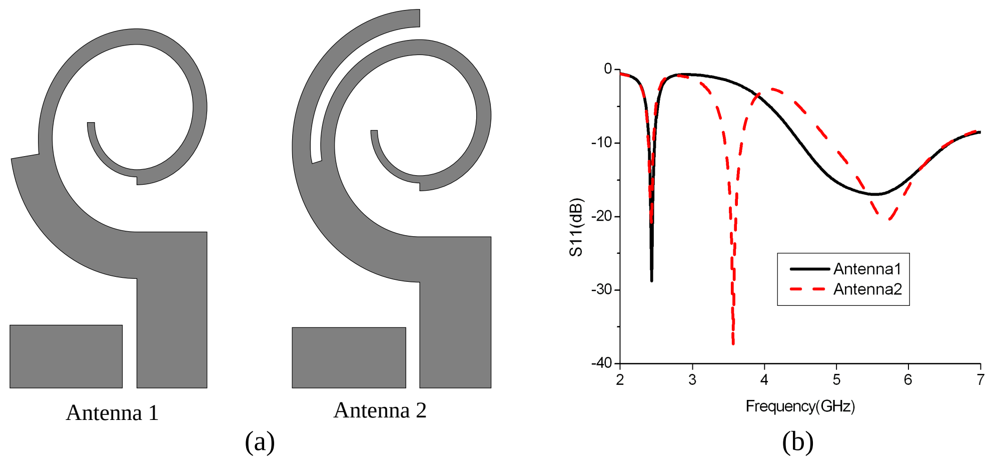


Figure 2. (a) Evolution of the proposed tri-band ACS-fed monopole antenna. (b) The corresponding simulated reflection coefficient curves.

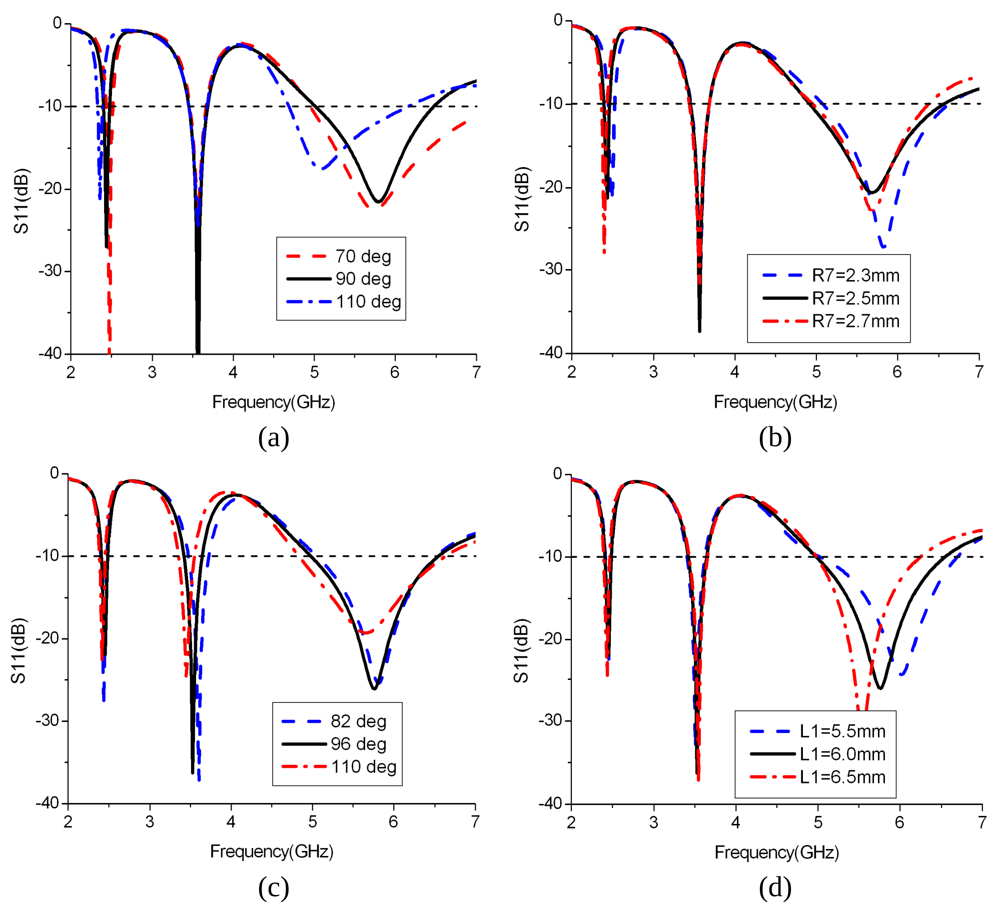


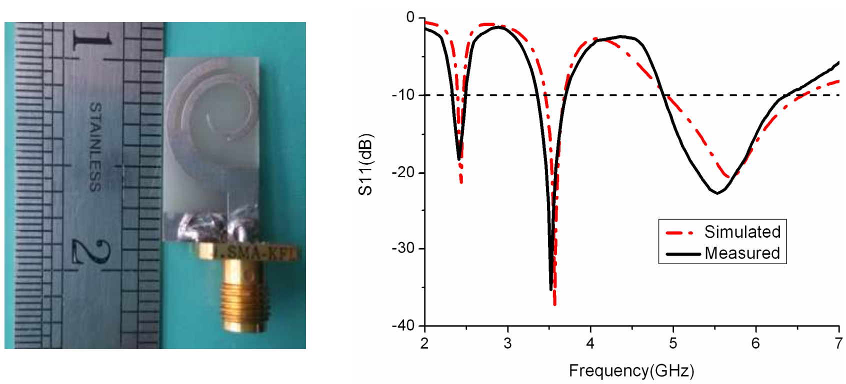
Figure 3. Simulated reflection coefficient of the proposed antenna. (a) When the central angle of φ changes. (b) When the length of R_7 changes. (c) When the central angle of β changes. (d) When the length of L_1 changes.

second resonant mode change, the centre frequency shifts from 5.56 GHz to 5.76 GHz and the impedance bandwidth changes from 4.51–6.57 GHz to 5.05–6.51 GHz, while the effect on the first resonant mode at about 2.45 GHz can be neglected. Therefore, the tri-band antenna for WLAN/WiMAX applications is obtained.

In the design, the performance of the ACS-fed antenna is affected by several key parameters, includng the length of the monopole (φ), impedance ratio of the stepped monopole (R_7), length of the strip (β), and size of the ground plane (L_1). Figure 3(a) shows the simulated reflection coefficient when the central angle of φ changes with $\theta = 180$ deg (equal to changing the total length of monopole). It is found that the low and high bands all shift to the lower frequencies with an increase of φ, while the effect on the middle band can be neglected, and finally find $\varphi = 90$ deg approximately satisfy the size for the working frequencies. Figure 3(b) plots the simulated reflection coefficient by changing the value of R_7, equal to changing the impedance ratio of the stepped monopole. It is shown that the low and high bands can be controlled flexibly by adjusting the impedance ratio, while the middle band is nearly not influenced. Figure 3(c) describes the simulated reflection coefficient when the central angle of β varies from 82 deg to 110 deg. It can be seen that with the increase of β, the middle band shifts to

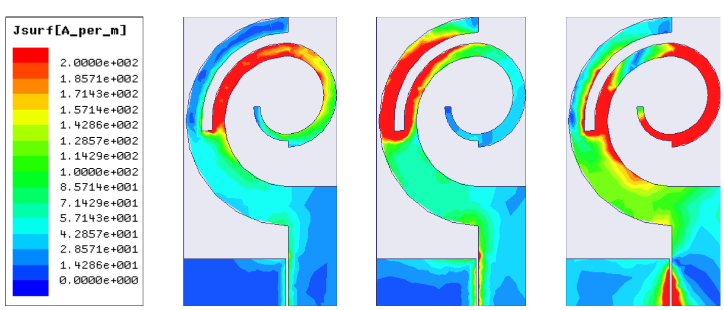
Table 1. Parameters of the proposed antenna.

Parameter	W	W_1	L_1	L_2	S	R_1	R_2	R_3	R_4	R_5	R_6	R_7	R_8
Value (mm)	12	3.8	4.1	9.1	0.2	5.0	8.0	6.8	6.0	4.0	3.0	2.5	2.0



(a) (b)

Figure 4. (a) Photograph of the fabricated tri-band ACS-fed monopole antenna. (b) Simulated and measured reflection coefficient against frequency.



(a) (b) (c)

Figure 5. Simulated surface current distribution of the proposed ACS-fed antenna at about (a) 2.4 GHz, (b) 3.5 GHz, (c) 5.7 GHz.

the lower frequency while the low and high bands are almost not affected, and finally find $\beta = 96\,\text{deg}$ approximately satisfy the size quarter of the guided wavelength for the working frequency. Figure 3(d) illustrates the simulated reflection coefficient for different values of L_1. It can be concluded that with the increase of L_1, the high operating frequency shifts to the lower band, while the low and middle bands are nearly not changed, which means that the size of ground pane has great effect on the high resonant frequency. The results discussed above indicate that the three resonant frequencies can be controlled effectively and tuned independently by adjusting the dimensions φ, R_7, β, L_1. The final dimensions of the proposed antenna are optimized and shown in Table 1.

3. RESULTS AND DISCUSSION

The proposed antenna is fabricated and measured. A photograph is shown in Figure 4(a), the simulated and measured reflection coefficients are given in Figure 4(b). The proposed antenna is fed with a $50\,\Omega$ SMA connector, and the reflection coefficient is measured by the Agilent E8363B vector network analyzer. From the figure, it can be seen that the simulated and measured results show reasonable

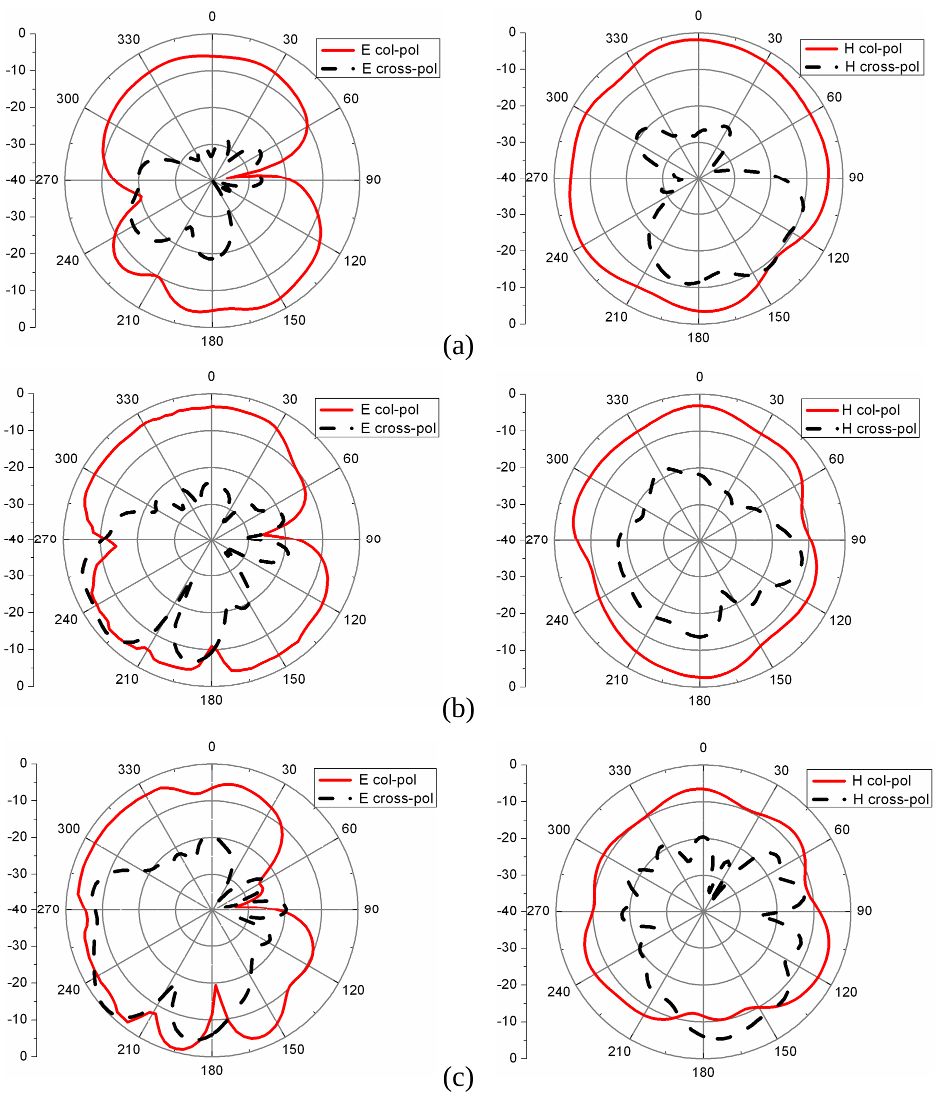


Figure 6. Measured radiation patterns of the proposed ACS-fed antenna at about (a) 2.4 GHz, (b) 3.5 GHz, (c) 5.7 GHz.

agreement, and the antenna generates three resonant frequencies at about 2.44 (simulated at 2.45), 3.53 (simulated at 3.56), and 5.56 (simulated at 5.76) GHz. The differences between the measured and simulated results are probably due to the fabrication error. The measured −10 dB impedance bandwidths are about 160 MHz (2.37–2.53 GHz) resonating at 2.44 GHz, 340 MHz (3.37–3.71 GHz) resonating at 3.53 GHz, and 1420 MHz (4.93–6.35 GHz) resonating at 5.56 GHz, which can be used for the 2.4/5.2/5.8 GHz WLAN bands and the 3.5/5.5 GHz WiMAX bands.

In order to clearly observe the effects of the three different resonant modes, the simulated current distributions of the proposed antenna at about 2.4, 3.5 and 5.7 GHz are shown in Figure 5. It can be seen that the current distributions at three resonant frequencies are different. For the first resonant frequency at 2.4 GHz, the surface current mainly concentrates along the middle of the inner circular-arc-shaped monopole, whereas for the second resonant frequency at 3.5 GHz, large surface current is observed along the outer circular-arc-shaped strip. For the third resonant frequency at 5.7 GHz, the surface current mainly distributes along the end of the inner monopole. It is indicated that the stepped monopole and strip generate three resonant frequencies independently.

The measured radiation patterns in E- (XZ-) and H- (YZ-) planes at about 2.4, 3.5, and 5.7 GHz are shown in Figures 6(a)–(c). Nearly omnidirectional patterns in H-plane and figure-eight radiation patterns in E-plane are obtained over the desired operating bands. It is found that the obtained radiation patterns correspond well with the conventional printed monopole antennas. While the radiation patterns worsen slightly at the higher resonant frequency, which may be because the designed structure of asymmetric ground plane has little influence on the high resonant frequency. Figure 7 shows the measured peak gains against frequencies. According to the measurements, the average gains are about 1.79, 2.12, and 2.43 dBi for the 2.4, 3.5, and 5.7-GHz bands, respectively. The gains of the proposed antenna are a little lower than those CPW-fed antennas in [7, 8], which are mainly due to the single lateral ground plane structure and the compact size. However, the gains are still reasonable, which makes it suitable for the practical applications.

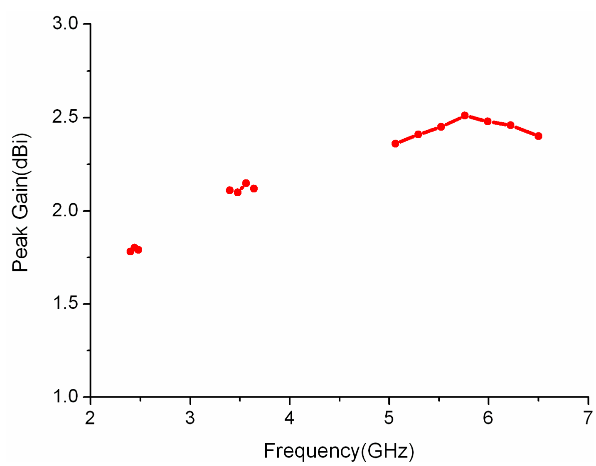


Figure 7. Measured peak gains of the proposed ACS-fed antenna.

4. CONCLUSION

A compact ACS-fed circular-arc-shaped stepped monopole antenna for WLAN/WiMAX applications is designed, fabricated, and measured. The proposed antenna has a simple structure and compact size of 22.1 × 12 mm^2. By adding a circular-arc-shaped strip in the stepped monopole, three desired resonant frequencies have been achieved. The key parameters of the stepped monopole, the strip and the ground plane in generating resonant frequencies are discussed in detail. Measured results demonstrate that the proposed antenna can achieve three desired operating bands, good omnidirectional radiation characteristics, and reasonable gains. Therefore, the proposed antenna is suitable for WLAN and WiMAX applications.

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