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# Compact Tri-Band Planar Monopole Antenna with ACS-Fed Structure

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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 simple monopole with the high resonant mode at 5.8 GHz, an open-ended slot embedded on the ground plane with the low resonant mode at 2.4 GHz, and a meander trip shorted to the ground with the middle resonant mode at 3.5 GHz. The three resonance frequencies of the antenna can be controlled by adjusting the geometries and the sizes of the monopole, the slot and the strip. The antenna occupies a very compact size of $22 \times 12\,\mathrm{mm}^2$ 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 communication.

## 1. INTRODUCTION

Recently, as wireless local area network (WLAN) and worldwide interoperability for microwave access (WiMAX) have been widely applied in people's daily life and work designing simple in feed, small in size, low in profile and light in weight antennas have become a challenging problem. Therefore, a considerable amount of research and approach have been devoted to achieve WLAN and WiMAX applications [1–12]. For example, a three strips monopole antenna [1], a L-slot antenna with a slit and a strip [2], a defected ground structure (DGS) antenna [3], a inverted-F antenna [4], and a printed omni-directional antenna [5]. However, the antennas mentioned above have either complex structure or large size, which are not suitable for the portable wireless terminals with limited space. The coplanar waveguide (CPW)-fed antennas appear more promising owing to their many attractive characteristics [6–8]. However, the CPW-fed antenna occupies a large ground plane, which possibly limits the integration level of the future wireless communication system. In order to further minimize the overall size of antenna, the asymmetric coplanar strip (ACS)-fed structure is introduced and several ACS-fed antennas have been proposed [9–12] such as ACS-fed inverted-C-shaped monopole antenna [9], ACS-fed F-shaped antenna [10], ACS-fed open-ended slots antenna [11], and triband ACS-fed circulararc-shaped stepped monopole [12]. Compared with the CPW-fed antenna the ACS-fed antenna has more compact structure, wider impedance matching, better integration level and only has single lateral ground plane which means the overall size could be reduced to about one half.

In this paper, differs from our previous work [12], the proposed ACS-fed antenna makes use full of the ground plane by embedding slot and adding stub on the ground to realize the low resonant mode of 2.4 GHz and the middle resonant mode of 3.5 GHz. The open-ended slot embedded on the ground plane generates the low operating band of 2.38–2.48 GHz resonating at 2.4 GHz, the meander trip shorted to the ground generates the middle operating band of 3.37–3.68 GHz resonating at 3.5 GHz. The simple

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monopole generates the high operating band of 5.48–6.12 GHz resonating at 5.8 GHz. The bandwidth over different frequency bands can be controlled independently by adjusting the geometries and the sizes of the monopole, the slot and the strip. Meanwhile, compared with the ACS-fed antennas mentioned above [9–11], the proposed antenna has one more operating band of WiMAX (3.5 GHz) and achieves much simpler structure. Furthermore, the processes of generating the operating bands are given in detail, the effects of the key parameters are also simulated and analyzed, and the experimental results are presented and discussed.

## 2. ANTENNA DESIGN AND PARAMETRIC STUDY

The electromagnetic simulation software Ansoft HFSS 13 is used to quicken the design. Figure 1(a) shows the geometry of the proposed antenna, and the photograph is shown in Figure 1(b). The proposed antenna is printed on a 1.6-mm-thick FR-4 substrate with relative permittivity of 4.4, and the overall size is only $22 \times 12\,\text{mm}^2$. In order to correspond to the 50-$\Omega$ characteristic impedance, the ACS-fed structure has a signal strip width of $W_1$ ($= 3.0$ mm) and a gap distance of $g$ ($= 0.3$ mm) between the signal strip and the coplanar ground plane.

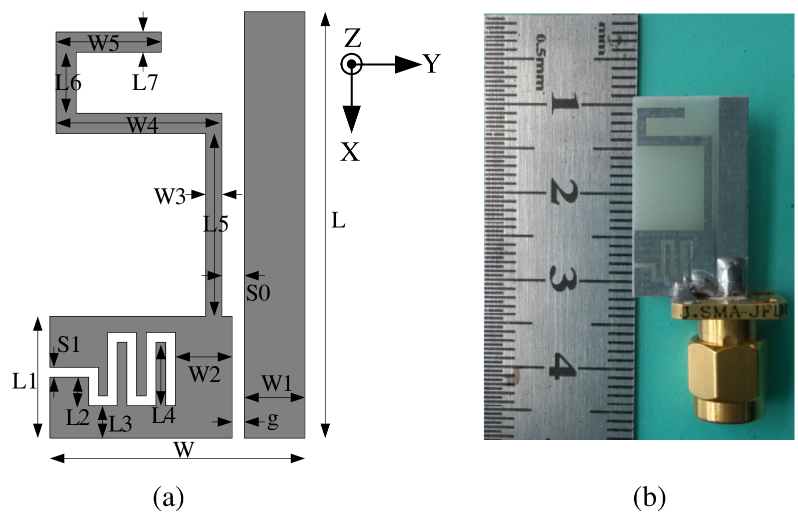


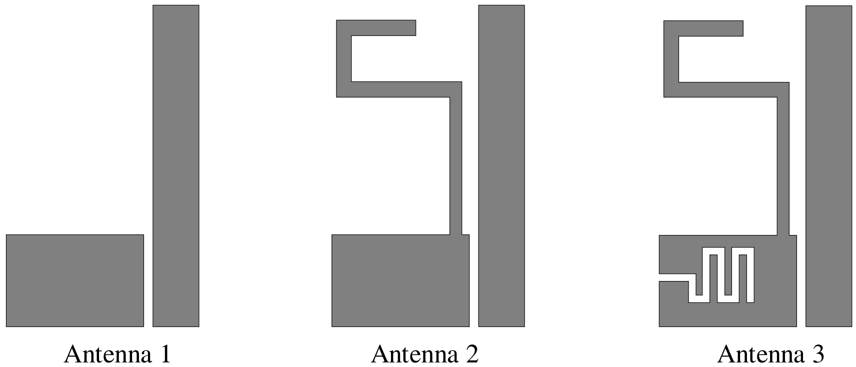

**Figure 1.** (a) Geometry of the proposed ACS-fed antenna. (b) Fabricated photograph of the proposed ACS-fed antenna.

Furthermore, the resonance frequency ($f_S$) of the half wavelength resonator is given by Eq. (1).

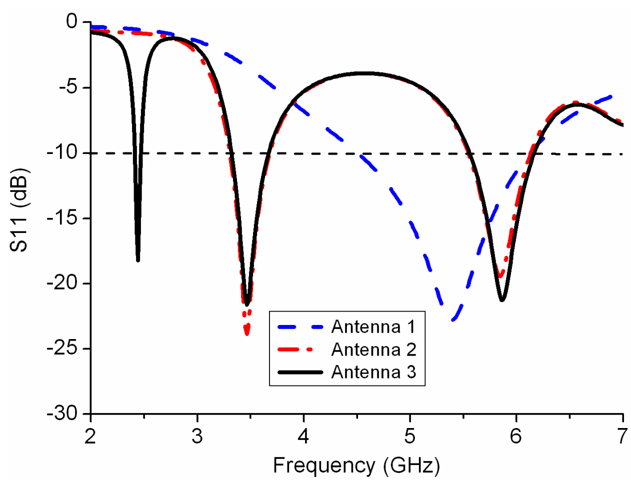
$$f_S \approx \frac{c}{2l_S\sqrt{\dfrac{\varepsilon_r + 1}{2}}} \tag{1}$$

where $c$ is the speed of light, $l_S$ the length of the strip or slot, and $\varepsilon_r$ the dielectric constant.

Figure 2 shows the evolution of the proposed ACS-fed antenna and corresponding simulated $S_{11}$ curves. Antenna 1 in Figure 2(a) is the original ACS-fed monopole antenna, which consists of an asymmetric ground plane and a simple monopole. It can be seen from Figure 2(b) that antenna 1 generates the first resonant mode at about 5.4 GHz, covering the operating band 4.51–6.13 GHz. Then a meander trip is shorted to the ground plane (antenna 2) to generate the second resonant mode at about 3.5 GHz. Antenna 2 has two separate operating bands of 3.29–3.68 and 5.55–6.12 GHz. It is found that introducing the second resonant mode makes the performance of the first resonant mode change, the centre frequency shifts from 5.4 GHz to 5.8 GHz and the impedance bandwidth changes from 4.51–6.13 GHz to 5.55–6.12 GHz. It is because the two radiation elements are close to each other, and some currents on the simple monopole will couple to the meander trip to lead the centre frequency




(a)




(b)

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

shift slightly. Finally, an open-ended slot is embedded on the ground plane (antenna 3) to generate the third resonant mode at about 2.4 GHz, which has three desired operating bands of 2.40–2.47 GHz, 3.32–3.67 GHz, and 5.56–6.16 GHz. It can be seen that introducing the third resonant mode has nearly no effect on the former two resonant modes. Therefore, the tri-band antenna for WLAN/WiMAX applications is obtained.

In our design, the performance of the ACS-fed antenna is affected by several key parameters, which include the length of the monopole ($L$), length of the strip ($W_5$), length of the slot ($L_2$), and gap distance ($g$). Figure 3(a) shows the simulated reflection coefficient when the length of $L$ changes. It can be seen that the high resonant frequency shifts to the lower frequency as the length of $L$ increases, while effect on the low and middle resonant frequencies can be neglected. Figure 3(b) plots the simulated reflection coefficient when $W_5$ varies from 4 to 6 mm. It can be seen that the middle resonant frequency shifts to the lower frequency, while the low and high resonant frequencies change slightly. Figure 3(c) describes the simulated reflection coefficient with the increase of $L_2$. It can be seen that the low resonant frequency shifts to the lower frequency while the middle and high resonant frequencies are almost not affected. Figure 3(d) illustrates the simulated reflection coefficient for different value of $g$. It can be concluded that the low and high resonant frequencies are sensitive to the gap distance between the signal strip and the coplanar ground plane while the middle resonant frequency is nearly not changed. The results discussed above indicate that the three resonant frequencies can be controlled effectively and tuned independently by adjusting the value of $L$, $W_5$, $L_2$, $g$. The final dimensions of the proposed antenna are optimized and shown in Table 1.

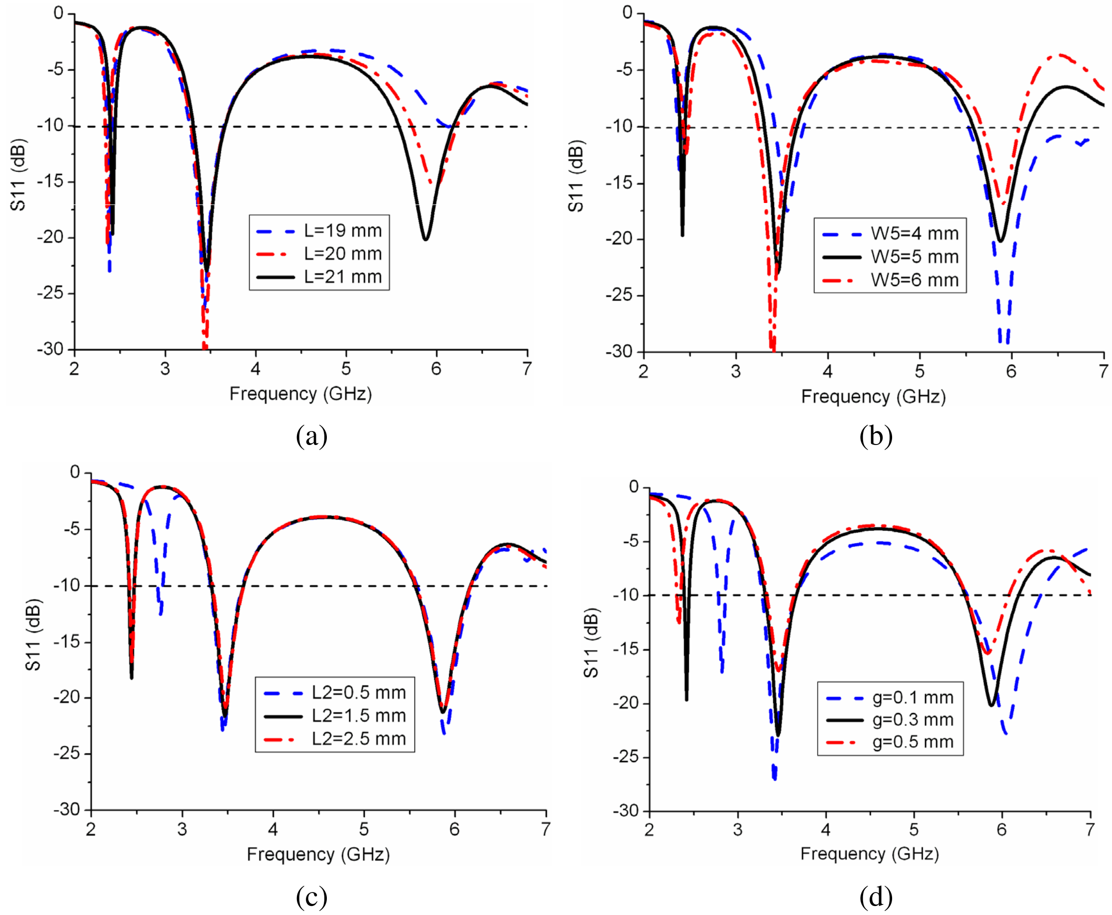



**Figure 3.** Simulated reflection coefficient of the proposed ACS-fed antenna. (a) When the length of $L$ changes. (b) When the length of $W_5$ changes. (c) When the length of $L_2$ changes. (d) When the gap distance of $g$ changes.

**Table 1.** Dimensions of the proposed antenna (unit: mm).

| $L$ | $L_1$ | $L_2$ | $L_3$ | $L_4$ | $L_5$ | $L_6$ | $L_7$ | $g$ |
|---|---|---|---|---|---|---|---|---|
| 22 | 7.0 | 1.5 | 1.5 | 4.0 | 9.0 | 2.0 | 1.0 | 0.3 |
| $W$ | $W_1$ | $W_2$ | $W_3$ | $W_4$ | $W_5$ | $S_0$ | $S_1$ | |
| 12 | 3.0 | 2.4 | 0.8 | 8.0 | 5.0 | 0.7 | 0.5 | |

## 3. RESULTS AND DISCUSSION

The proposed antenna is fed with a 50-Ω SMA connector, and the reflection coefficient is measured by the Agilent E8363B vector network analyzer. It can be seen from Figure 4 that the simulated and measured results show good agreements, but still there are some differences. Except the fabrication error, the tin solder distribute uneven may be another factor. The measured $-10$ dB impedance bandwidths are about 100 MHz (2.38–2.48 GHz) resonated at 2.44 GHz, 310 MHz (3.37–3.68 GHz) resonated at 3.52 GHz, and 640 MHz (5.48–6.12 GHz) resonated at 5.77 GHz, which can be used for the 2.4/5.8 GHz WLAN bands and the 3.5 GHz WiMAX band.

In order to clearly observe the effects of the three different resonant modes, the simulated current distributions of the proposed antenna at 2.4, 3.5 and 5.8 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

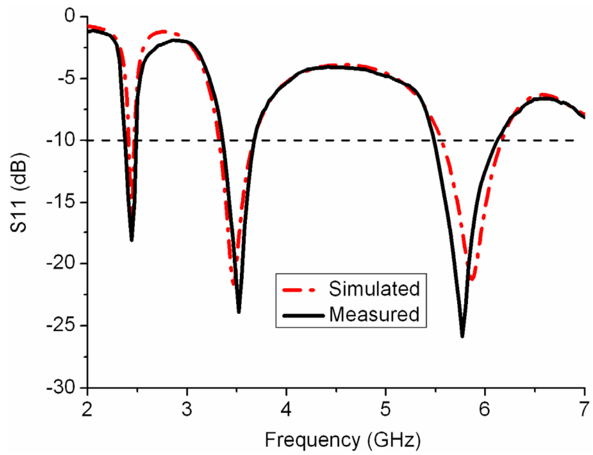
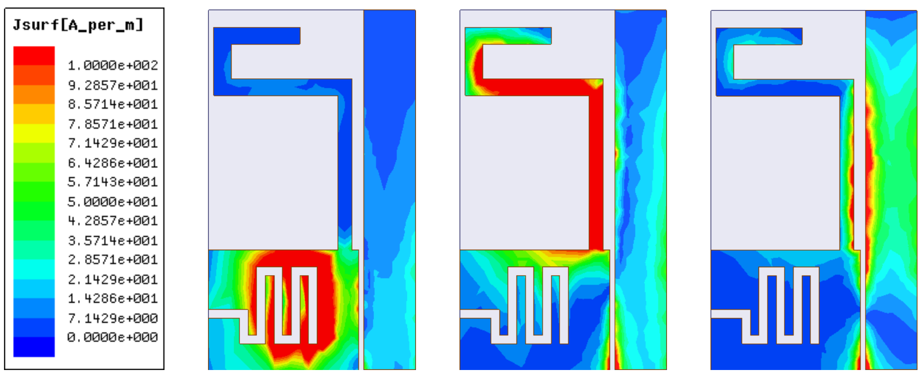


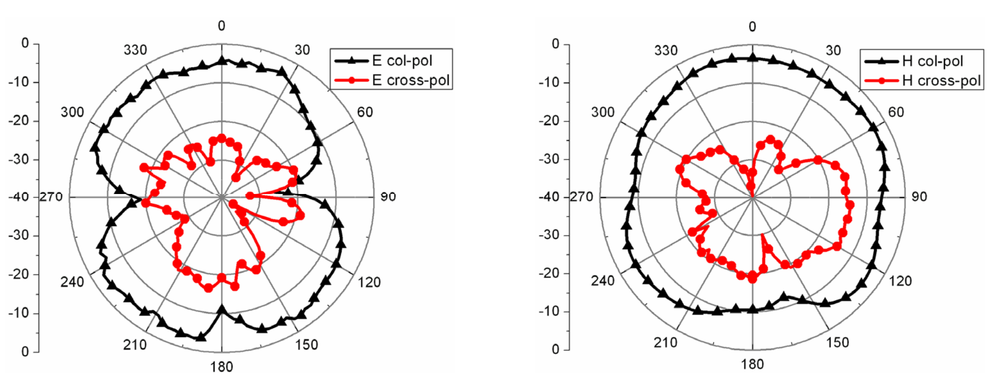

**Figure 4.** Simulated and measured reflection coefficient against frequency.



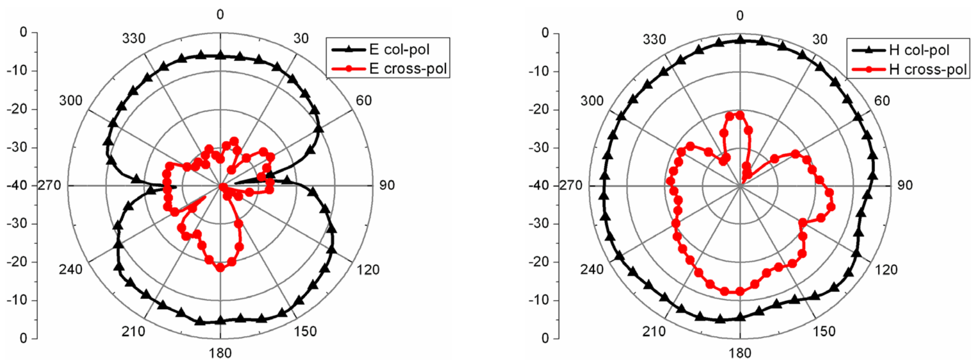

(a) (b) (c)

**Figure 5.** Simulated surface current distributions of the proposed ACS-fed antenna at (a) 2.4 GHz. (b) 3.5 GHz. (c) 5.8 GHz.

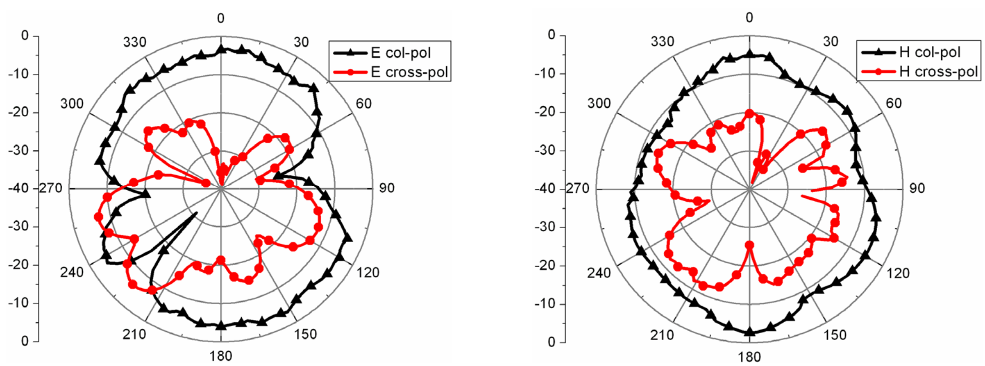
2.4 GHz, the surface current mainly concentrate along the embedding open-ended slot on the ground plane, whereas for the second resonant frequency at 3.5 GHz, large surface current is observed along the shorted meander strip, but for the third resonant frequency at 5.8 GHz, the surface current mainly distributes along the monopole. It is indicated that the slot, the strip and the monopole generate three resonant frequencies independently.




(a)




(b)




(c)

**Figure 6.** Measured radiation patterns of the proposed ACS-fed antenna at (a) 2.4 GHz, (b) 3.5 GHz, (c) 5.8 GHz.

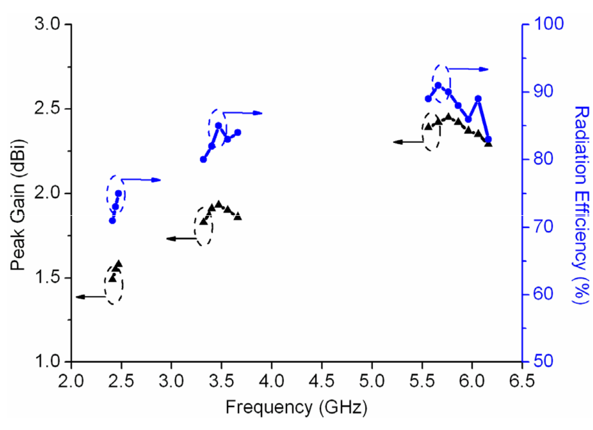



**Figure 7.** Measured peak gain and radiation efficiency of the proposed ACS-fed antenna.

Figure 6 shows the measured far field radiation patterns at 2.4, 3.5, and 5.8 GHz, respectively. Nearly omnidirectional patterns in $H$- ($YZ$-) plane and figure-eight radiation patterns in $E$- ($XZ$-) plane are obtained over the desired operating bands. Figure 7 shows the measured peak gain and radiation efficiency against frequencies. According to the measurements, the average gains are about 1.54 dBi for 2.4 GHz band, 1.92 dBi for 3.5 GHz band, and 2.38 dBi for 5.8 GHz band, respectively. The gains of the proposed antenna are a little lower than those CPW-fed antennas in [6–8], 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. The measured radiation efficiency is also depicted in Figure 7, and it can be seen that the radiation efficiency is higher than 70% in the three bands.

## 4. CONCLUSION

A compact ACS-fed planar monopole antenna for WLAN/WiMAX applications is designed, fabricated, and measured. The proposed antenna has a simple structure and a very compact size of $22 \times 12\,\mathrm{mm}^2$. Three desired resonant frequencies have been achieved by three different radiation elements. The evolution and key parameters of the slot, strip and monopole in generating resonant frequencies are discussed in detail. Measured results show that the proposed antenna displays three adequate impedance bandwidths, good omnidirectional radiation characteristics, and reasonable gains in the desired operating bands. Therefore, it is very suitable for multiband practical applications.

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