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A Compact Triband ACS-Fed Monopole Antenna Employing Inverted-L Branches for WLAN/WiMAX Applications

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Abstract—A compact triband asymmetric coplanar strip (ACS)-fed monopole antenna for WLAN/WiMAX applications is proposed and investigated in this paper. The proposed antenna is composed of an ACS-fed folded monopole and two inverted-L branches, which occupies a very compact size of $26.5 \times 12\,\text{mm}^2$ including the ground plane. By carefully adjusting the lengths and positions of these branches, three desired resonant frequencies can be achieved and adjusted independently. The antenna exhibits three resonances covering the 2.4/5.8 GHz WLAN bands and 3.5 GHz WiMAX band. Details of the antenna design, simulation, and experimental results are presented and discussed. The proposed antenna shows nearly omnidirectional radiation characteristics and moderate gains in the operating bands. The compactness, simple feeding technique and uniplanar design make it easy to be integrated within the portable device for wireless communication.

1. INTRODUCTION

In recent years, many engineers focus their interests on how to design multiband antennas that can be integrated in a portable wireless communication device for several communication standards, especially for the WLAN (2.4–2.48, 5.15–5.35, and 5.72–5.85 GHz) and the WiMAX (2.5–2.69, 3.40–3.69, and 5.25–5.85 GHz) in wireless communication. Thus, different types of multiband antennas have been proposed to cater various user requirements, such as [1–12]. For example, a dual-band coplanar patch antenna integrated with an electromagnetic bandgap substrate is reported in [1], a dual-wideband printed T-shaped monopole antenna is proposed for WLAN and WiMAX applications [2], a compact ring monopole antenna with double meander lines is proposed for WLAN applications [3], a couple dual-U-shaped antenna is presented for WiMAX triband operation [4]. However, there are only two bands involved in [1–3], and only triple WiMAX band is reported in [4], which limited the number of working bands in portable devices. A compact triband planar monopole antenna suitable for WLAN and WiMAX is presented [5], the antenna consists of a L-shaped microstrip feedline and open-ended slot on the ground plane is proposed for WLAN/WiMAX applications [6], miniature triband CPW-fed monopole antenna embedded with dual U-shaped slot is reported in [7], the antenna with simply shaped radiator element for multi-operating bands of the wireless communication systems is studied in [8]. Furthermore, some compact antennas for WLAN/WiMAX applications have been presented in [9–12]. However, the antennas mentioned above have either complex structure or large size, which are not suitable for the portable wireless terminals with limited space. A coplanar-waveguide (CPW)-fed single-band antenna, loaded with a reactive termination has been proposed to reduce the size of an antenna [13], but it still has a large size.

In order to further minimize the overall size of an antenna, the asymmetric coplanar strip (ACS)-fed structure is introduced. The overall size of this antenna can be reduced to about one half of the common coplanar waveguide (CPW)-fed monopole antennas. An ACS-fed monopole antenna has been proposed

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to reduce the size of the antenna for lower band WLAN application [14]. However, the proposed antenna still has a large size. Another ACS-fed F-shaped antenna has been investigated for dual-band WLAN applications [15]. However, the proposed F-shaped antenna is still large than our antenna.

In this paper, the inverted-L branches are used in a compact ACS-fed printed monopole antenna for WLAN and WiMAX applications. Triple operating band is generated by adding two inverted-L branches to the ACS-fed folded monopole antenna. The process of the inverted-L branches in generating working bands are given in detail, and the effects of the key parameters including the lengths and positions are also simulated and analyzed. The measured −10 dB impedance bandwidths are 210 MHz (2.32–2.53 GHz), 420 MHz (3.22–3.64 GHz), and 450 MHz (5.53–5.98 GHz), which can be used for the 2.4/5.8 GHz WLAN bands and 3.5 GHz WiMAX band. Compare to the ACS-fed antennas mentioned above, the proposed antenna exhibits a very compact size. Details of the design and experimental results are presented and discussed. Moreover, the antenna has good radiation pattern performance and stable gains in the three operating bands. Good agreement between the simulated and measured results demonstrates that the antenna is a good candidate for WLAN and WiMAX applications.

2. ANTENNA DESIGN AND PARAMETRIC STUDY

The geometry of the triband ACS-fed monopole antenna is shown in Figure 1. The antenna is designed on a 1.6-mm-thick FR-4 substrate with relative permittivity of 4.4, and the overall dimensions are only $26.5 \times 12\,\mathrm{mm}^2$. The ACS feedline has a signal strip width of 2.9 mm and gap distance of 0.1 mm between the signal strip and the coplanar ground plane, corresponding to the 50-Ω characteristic impedance. This feeding mechanism is analogous to the CPW-fed except that the ACS-fed has a single lateral ground strip compared to the twin lateral ground strips in the CPW-fed. Furthermore, the ACS-fed antenna exhibits similar radiation patterns as CPW-fed antenna. Therefore, the antenna constructed using the ACS-fed exhibits all the advantages of the CPW-fed antenna together with more compactness. The two inverted-L branches are added to the ACS-fed folded monopole, by adjusting the lengths and positions of these branches, three desired resonant frequencies can be achieved and adjusted independently. The dimensions of the proposed antenna are optimized and shown in Table 1. Additionally, the length of each inverted-L strip is found to be nearly equal to half of the dielectric wavelength calculated at the

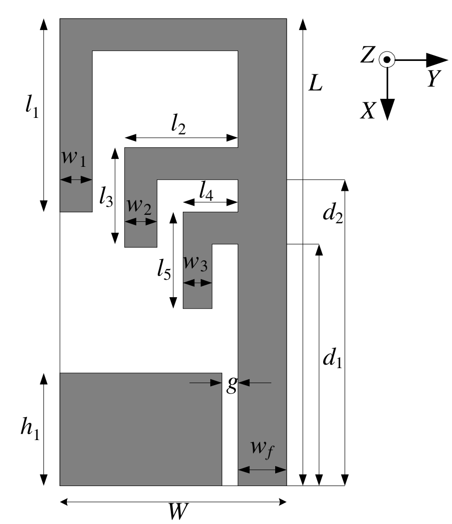


Figure 1. Geometry of the proposed ACS-fed monopole antenna.

Table 1. Parameters of the proposed antenna (see Figure 1).

Parameter	W	L	h_1	w_f	g	d_1	d_2	w_1	w_2	w_3	l_1	l_2	l_3	l_4	l_5
Value (mm)	12	26.5	6.5	2.9	0.1	14.5	18.5	1.8	2	2	9.8	6	6	3	5.6

desired resonant frequency. The dielectric wavelength λ_d is defined as follows:

$$\lambda_d = \frac{c}{\sqrt{\varepsilon_{eff}} f} \tag{1}$$

$$\varepsilon_{eff} \approx \frac{(\varepsilon_r + 1)}{2} \tag{2}$$

where c is the speed of light, f is the desired resonant frequency, and ε_{eff} is the effective relative permittivity.

The electromagnetic simulation software Ansoft HFSS V13 is used to perform the design. Figure 2 shows the evolution of the proposed antenna and corresponding simulated return losses. Antenna 1 in Figure 2(a) is the original ACS-fed monopole, which consists of an ACS-fed structure and a monopole. The monopole is folded to reduce the size, it looks like an inverted-L branch. As illustrated in Figure 2(b), the first resonant mode at about 2.52 GHz is generated by antenna 1 and it covers the operating band from 2.46–2.60 GHz. Meanwhile, the harmonic locates at about 5.45 GHz. Then an inverted-L branch is added to the monopole (antenna 2) to generate the second resonant mode at about 3.41 GHz. It can be seen that after introducing the second resonant mode, the performance of the first resonant mode is improved (the S_{11} at the first resonant frequency changes from −12.6 dB to −16 dB and the first resonant frequency shifts from 2.52 GHz to 2.42 GHz). Antenna 2 has impedance bandwidths of 2.34–2.51 GHz and 3.29–3.59 GHz. Moreover, the harmonic is generated from antenna 1 has been suppressed. By adding another inverted-L branch to the monopole (antenna 3), the third resonant mode at about 5.75 GHz can be achieved. Therefore, the triband antenna for WLAN/WiMAX applications is obtained. It is found that the performances of the former two working bands are almost not affected by the appearance of the third working band.

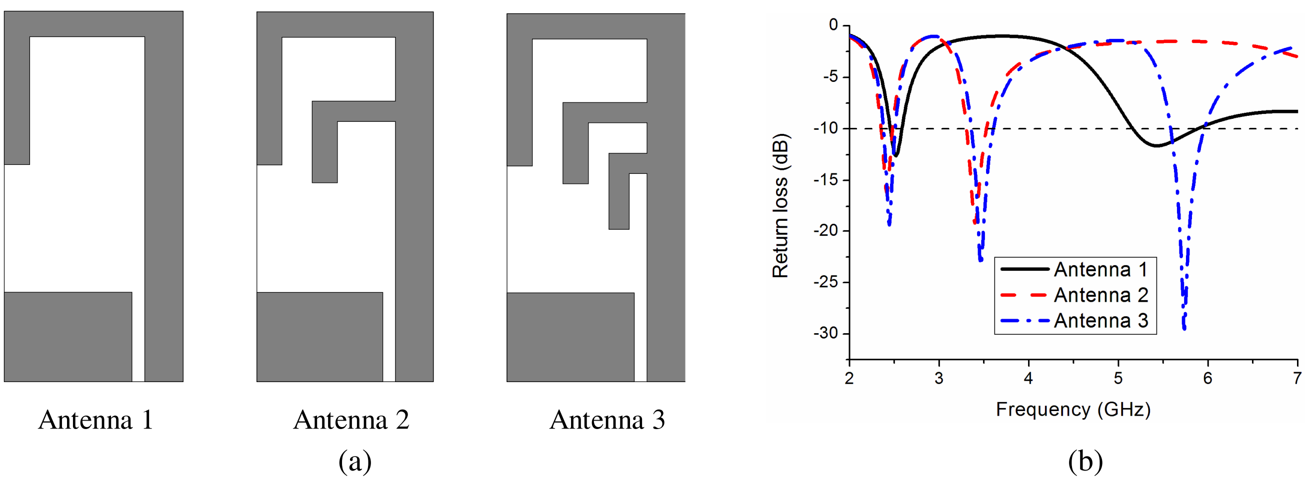


Figure 2. (a) Evolution of the proposed triband ACS-fed monopole antenna. (b) Its corresponding simulated return loss curves.

The performance of the antenna is affected by several key parameters. Therefore, effects of the key parameters, including the lengths of the invert-L branches and ground plane, are simulated and shown in Figure 3. Figure 3(a) shows the simulated return losses when the length of the branch l_1 is varying. It is found that the first band is affected by the variation in l_1 and shift to lower frequencies as l_1 is increasing, and this may be due to the fact that the length of folded monopole determining the resonant frequency of the antenna. The change of l_1 has small effects on the second band and the third band. Figure 3(b) plots the simulated return losses by changing the length of the inverted-L branch l_3. It shows that the second band shifts to lower frequencies as l_3 is increasing, and this may be attributed to the fact that the length of inverted-L branch determining the resonant frequency of the antenna. The first band is nearly not affected. The third band shifts to higher frequencies as l_3 is increasing, which is possibly due to the changing coupling between the two inverted-L branches. Figure 3(c) describes

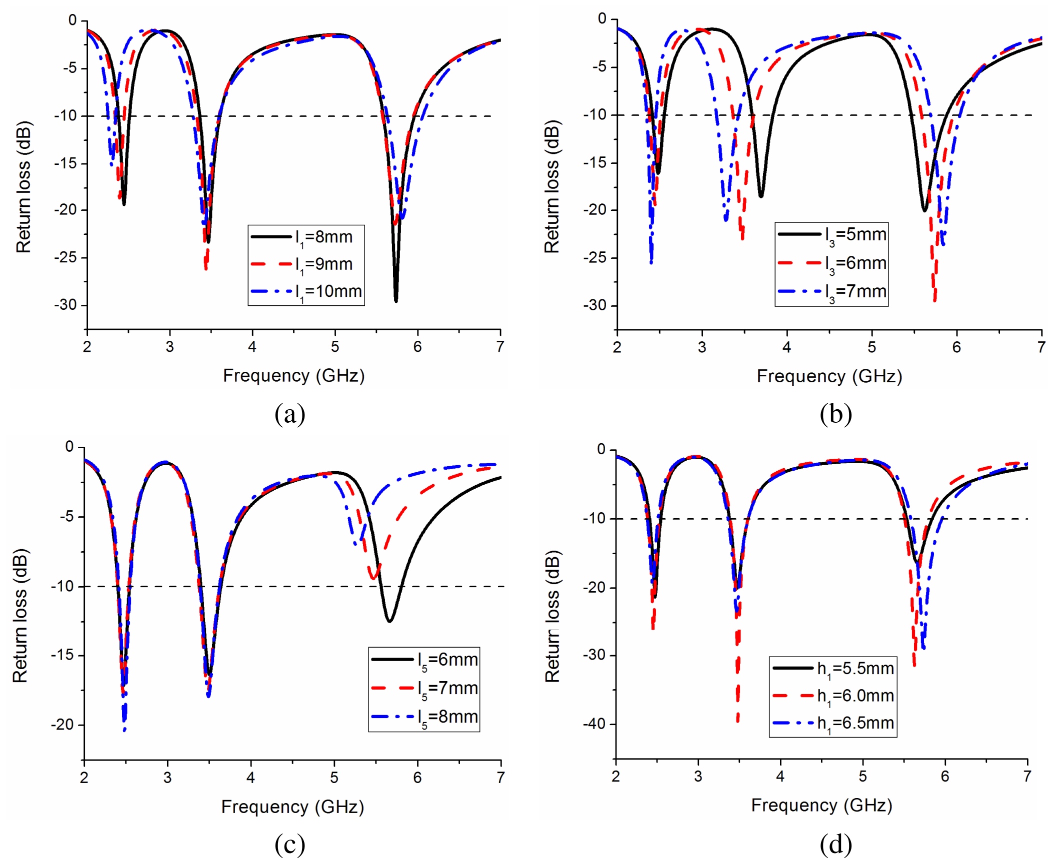


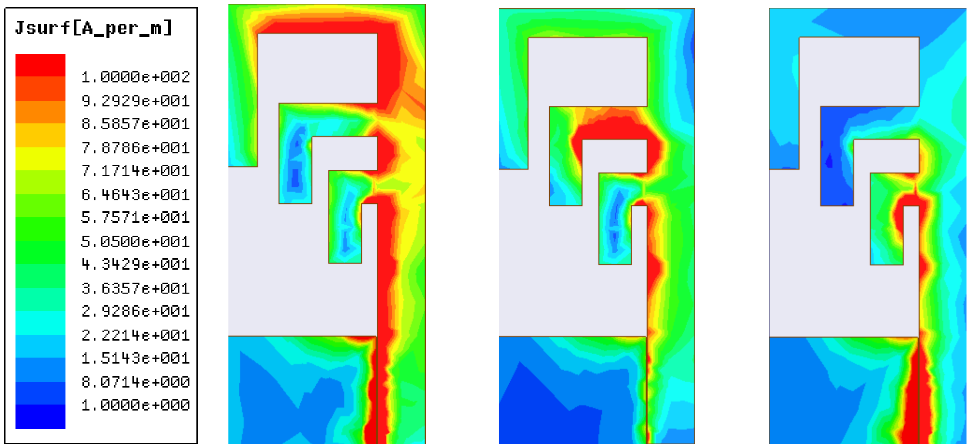
Figure 3. Simulated return losses of the proposed antenna. (a) When l_1 is varying. (b) When l_3 is varying. (c) When l_5 is varying. (d) When h_1 is varying.

the simulated return losses when the length of the inverted-L branch l_5 varies from 6 mm to 8 mm. It can be seen that with the increase of l_5, the third band shifts to lower frequencies (the reason is same as l_3) while the first band and the second band are almost not influenced. The third resonant mode is gradual disappear as l_5 is increasing. Figure 3(d) illustrates the simulated return losses for different value of h_1. From the figure, it can be concluded that with the increase of h_1, the impedance bandwidth of the third band is improved while the first band and the second band are nearly not changed. The results discussed above indicate that the three resonant frequencies and impedance bandwidth can be controlled effectively and tuned independently by adjusting the dimensions l_1, l_3, l_5, h_1.

The simulated surface current distribution of the proposed antenna at 2.4, 3.5, and 5.8 GHz carried out by HFSS V13 is given in Figure 4. 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 is mainly concentrate along the inner side of the folded monopole, whereas for the second resonant frequency at 3.5 GHz, the current distribution is observed along the inverted-L branch which consists of l_2 and l_3. For the third resonant frequency at 5.8 GHz, the surface current distribute along the inner side of another inverted-L branch which consists of l_4 and l_5. Furthermore, they have a common feature that the surface current is mainly concentrate along the inner side of the folded monopole or inverted-L branch. It is indicated that the folded monopole and two inverted-L branches generate three resonant frequencies independently.

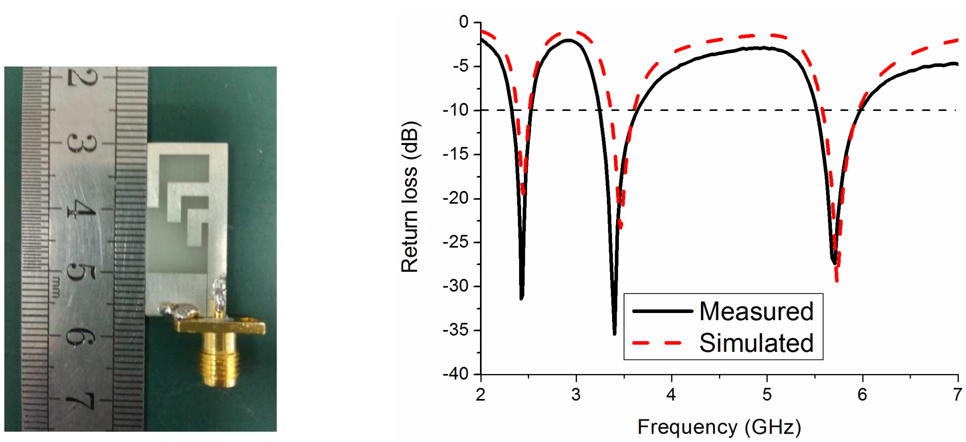
3. RESULTS AND DISCUSSION

A prototype of the proposed triband antenna is fabricated and measured, and its photograph is shown in Figure 5(a). The return loss of the triband antenna is measured by Agilent E8363B vector network



(a) (b) (c)

Figure 4. Simulated surface current distribution of the proposed antenna. (a) 2.4 GHz. (b) 3.5 GHz. (c) 5.8 GHz.



(a) (b)

Figure 5. (a) Photograph of the fabricated triband ACS-fed monopole antenna. (b) Simulated and measured return losses against frequency.

Table 2. Comparisons of antenna size among proposed antenna and other compact antennas.

Published literature	Antenna purpose	Size comparison (proposed/literature)
Ref. [9]	Triple band	27.9%
Ref. [10]	Triple band	30.3%
Ref. [11]	Triple band	35.5%
Ref. [12]	Triple band	35.5%
Ref. [14]	Triple band	37.9%
Ref. [15]	Dual band	79.7%

analyzer (VNA). The simulated and measured return losses against frequency of this antenna are given in Figure 5(b). It can be seen that the simulated and measured results show reasonable agreement and the three resonant frequencies at about 2.4, 3.5, and 5.8 GHz are achieved. The fabrication tolerance is cause of the differences between measures and simulated results. The measured impedance bandwidths for $S_{11} \leqslant -10$ dB are about 210 MHz (2.32–2.53 GHz) resonated at 2.43 GHz, 420 MHz (3.22–3.64 GHz)

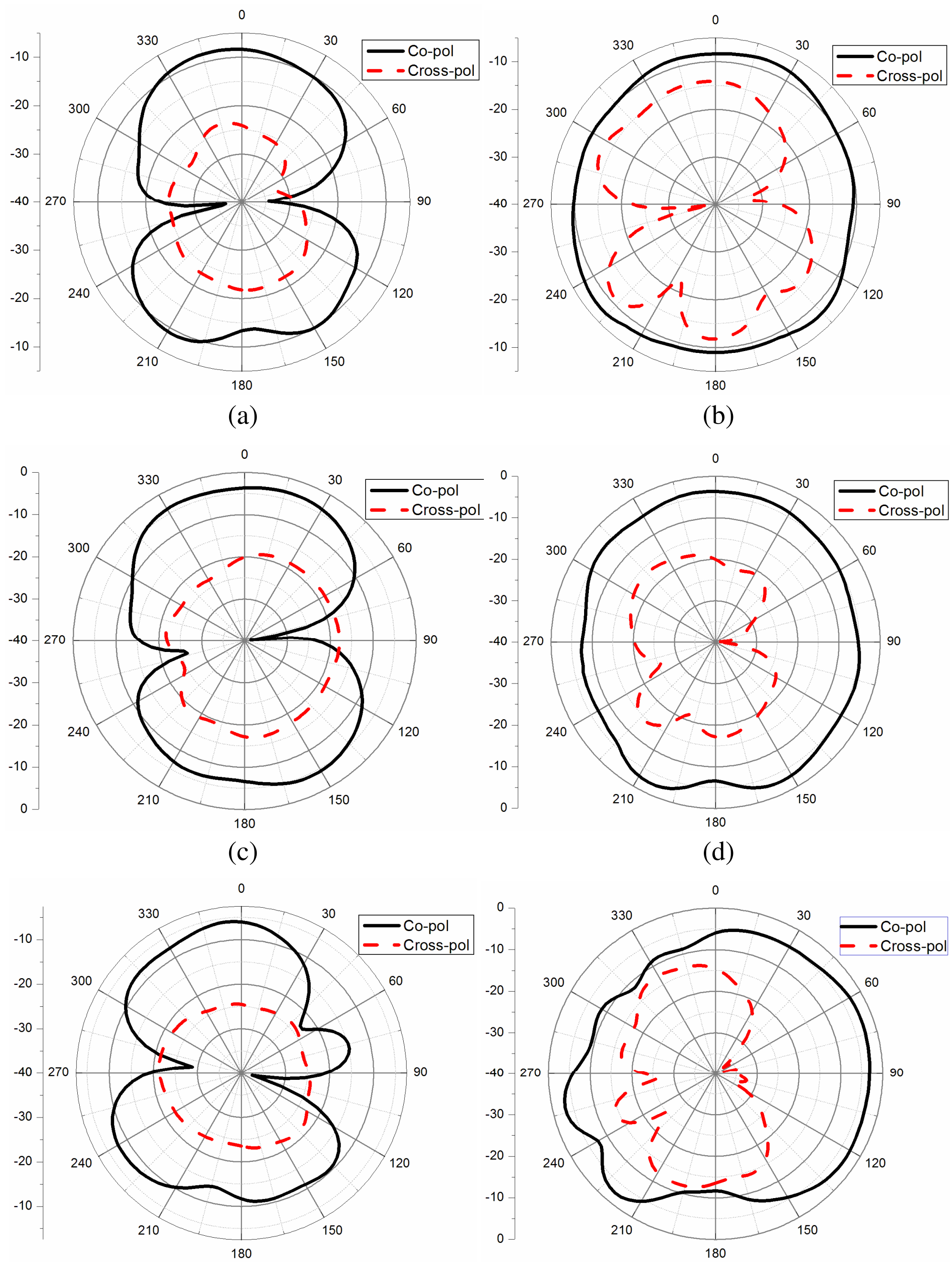


Figure 6. Measured radiation patterns of the proposed antenna. (a) E-plane radiation patterns at 2.4 GHz. (b) H-plane radiation patterns at 2.4 GHz. (c) E-plane radiation patterns at 3.5 GHz. (d) H-plane radiation patterns at 3.5 GHz. (e) E-plane radiation patterns at 5.8 GHz. (f) H-plane radiation patterns at 5.8 GHz.

resonated at 3.45 GHz, and 450 MHz (5.53–5.98 GHz) resonated at 5.75 GHz, which can be used for the 2.4/5.8 GHz WLAN bands and 3.5 GHz WiMAX band. In Table 2, comparisons of the proposed antenna with those presented in [9–12] and [14–15] on antenna dimensions are given. Significant reduction in size has been achieved with our antenna design.

The measured far field radiation patterns in E-plane (XZ-plane) and H-plane (YZ-plane) at 2.4, 3.5, and 5.8 GHz are shown in Figure 6. Nearly omnidirectional patterns in H-plane are obtained over the desired operating bands. It can be seen that the radiation pattern deteriorates slightly at the higher resonant frequency, and this may be attributed to the fact that the asymmetric ground plane of the present design is half of the CPW-fed antennas. The measured peak gains against frequency are shown in Figure 7. The measured average gains are about 1.73 dBi, 1.93 dBi, and 2.39 dBi for the 2.4 GHz, 3.5 GHz, and 5.8 GHz bands, respectively. It can be seen that the antenna exhibits stable gain in the working bands, which makes it is suitable for practical applications.

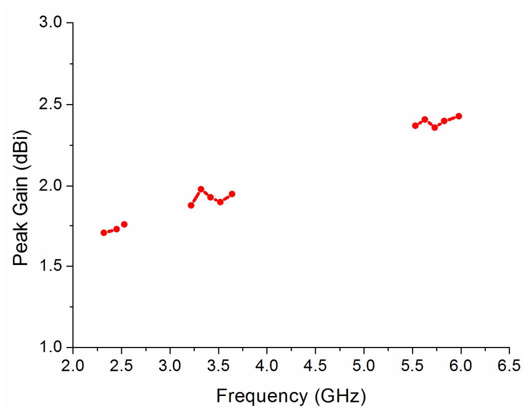


Figure 7. Measured peak gains of the proposed antenna.

4. CONCLUSION

A compact ACS-fed monopole antenna with inverted-L branches for wireless communication is proposed, fabricated, and measured. The antenna has a simple structure and compact size of $26.5 \times 12\,\text{mm}^2$. The three resonant frequencies are realized by adding two inverted-L branches to the ACS-fed folded monopole. The key parameters of the inverted-L branches in achieving resonant frequencies are discussed in detail. Measured results demonstrate that the antenna can achieve three desired working bands, good omnidirectional radiation characteristics, and reasonable gains. Consequently, the proposed antenna, which has advantage of compact size, is suitable for WLAN and WiMAX applications.

REFERENCES

1. Zhu, S. and R. Langley, "Dual-band wearable antennas over EBG substrate," *Electron. Lett.*, Vol. 43, No. 3, 141–142, 2007.
2. Kang, L., Y.-Z. Yin, H. Li, W.-J. Huang, and S.-F. Zheng, "Dual-wideband symmetrical G-shaped slotted monopole antenna for WLAN/WiMAX applications," *Progress In Electromagnetics Research Letters*, Vol. 17, 55–65, 2010.
3. Zhao, G., F.-S. Zhang, Y. Song, Z.-B. Weng, and Y.-C. Jiao, "Compact ring monopole antenna with double meander lines for 2.4/5 GHz dual-band operation," *Progress In Electromagnetics Research*, Vol. 72, 187–194, 2007.
4. Koo, T.-W., D. Kim, J.-I. Ryu, J.-C. Kim, and J.-G. Yook, "A coupled dual-U-shaped monopole antenna for WiMAX triple-band operation," *Microwave Opt. Technol. Lett.*, Vol. 53, No. 4, 745–748, 2011.

5. Liu, Z.-Y., Y.-Z. Yin, S.-F. Zheng, W. Hu, and L.-H. Wen, "A compact CPW-fed monopole antenna with a U-shaped strip and a pair of L-slits ground for WLAN and WiMAX applications," *Progress In Electromagnetics Research Letters*, Vol. 16, 11–19, 2010.
6. Ren, F.-C., F.-S. Zhang, J.-H. Bao, B. Chen, and Y.-C. Jiao, "Compact triple-frequency slot antenna for WLAN/WiMAX operations," *Progress In Electromagnetics Research Letters*, Vol. 26, 21–30, 2011.
7. Zhang, X.-Q., Y.-C. Jiao, and W.-H. Wang, "Miniature triple-band CPW-fed monopole antenna for WLAN/WiMAX applications," *Progress In Electromagnetics Research Letters*, Vol. 31, 97–105, 2012.
8. Lee, Y.-C. and J.-S. Sun, "A new printed antenna for multiband wireless applications," *IEEE Antennas Wireless Propag. Lett.*, Vol. 8, 402–405, 2009.
9. Thomas, K.-G. and M. Sreenivasan, "Compact triple band antenna for WLAN/WiMAX applications," *Electron. Lett.*, Vol. 45, No. 16, 811–813, 2009.
10. Dang, L., Z.-Y. Lei, Y.-J. Xie, G.-L. Ning, and J. Fan, "A compact microstrip slot triple-band antenna for WLAN/WiMAX applications," *IEEE Antennas Wireless Propag. Lett.*, Vol. 9, 1178–1181, 2010.
11. Hu, W., Y.-Z. Yin, P. Fei, and X. Yang, "Compact triband square-slot antenna with symmetrical L-strips for WLAN/WiMAX applications," *IEEE Antennas Wireless Propag. Lett.*, Vol. 10, 462–465, 2011.
12. Ren, X.-S., Y.-Z. Yin, W. Hu, and Y.-Q. Wei, "Compact tri-band rectangular ring patch antenna with asymmetrical strips for WLAN/WiMAX applications," *Journal of Electromagnetic Waves and Applications*, Vol. 24, No. 13, 1829–1838, 2010.
13. Lai, C.-P., S.-C. Chiu, and S.-Y. Chen, "Miniaturization of CPW-fed slot antennas using reactive terminations and truncated bilateral ground plane," *IEEE Antennas Wireless Propag. Lett.*, Vol. 11, 1072–1075, 2012.
14. Deepu, V., R.-K. Raj, M. Joseph, M.-N. Suma, and P. Mohanan, "Compact asymmetric coplanar strip fed monopole antenna for multiband applications," *IEEE Trans. Antennas Propag.*, Vol. 55, 2351–2357, 2007.
15. Deepu, V., R. Sujith, S. Mridula, C.-K. Aanandan, K. Vasudevan, and P. Mohanan, "ACS fed printed F-shaped uniplanar antenna for dual band WLAN applications," *Microwave Opt. Technol. Lett.*, Vol. 51, 1852–1856, 2009.