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A COMPACT CPW-FED MONOPOLE ANTENNA WITH TRIPLE BANDS FOR WLAN/WiMAX APPLICATIONS

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Abstract—A novel compact coplanar waveguide (CPW)-fed printed antenna with triple bands for WLAN and WiMAX applications is presented. By using a parasitic circular patch, a pair of symmetrical inverted-L strips and a 50-Ω transformer, the antenna can effectively provide a good input impedance matching. The tuning effects of the ground size, the parasitic circular patch and the symmetrical inverted-L strips to the resonance and matching condition are then examined, and the prototype of the proposed antenna is further fabricated and measured. The experimental and numerical results exhibit that the antenna has impedance bandwidth with 10 dB return loss 2.32–2.80 GHz, 3.06–4.13 GHz and 5.03–6.04 GHz, which can cover both the WLAN 2.4/5.2/5.8 GHz bands and the WiMAX 2.5/3.5/5.5 GHz bands. Also, a stable monopole-like radiation pattern and an average antenna gain of 3.06 dBi across the operating bands have been obtained.

1. INTRODUCTION

In recent years, with the rapid development of wireless communication systems, the multiple bands antenna with simple structure, compact size, higher performance and easy integration with the circuit has been studied intensively in order to satisfy the IEEE 802.11 wireless local area network (WLAN) standards in the 2.4/5.2/5.8 GHz (2400–2484/5150–5350/5725–5825 MHz) operating bands and the worldwide interoperability for microwave access (WiMAX) 2.5/3.5/5.5 GHz (2500–2690/3400–3690/5250–5850 MHz) bands.

For these applications, several promising dual or multiband planar antennas for the WLAN/WiMAX applications have already been

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proposed in [1–12]. In [1–3], by employing different shapes of monopole such as T-shaped monopole, double-T monopole or modified inverted-L monopole, the antennas can achieve dual-band operations and are simple in structure, but none of the above designs can achieve a dual-band bandwidth so large to cover the whole WLAN/WiMAX bands. So to further address this issue, some other various antennas such as a rectangular patch monopole with a π-shaped slot [4], a novel microstrip-fed monopole [5], a CPW-fed antenna with triangular split-ring resonator [6] and a pentagonal monopole with two bent slots [7] are proposed. Unfortunately, although the above designs achieve bandwidth enhancement, most of them have a relatively large overall size and occupy too much of the device space. In addition, several other types of compact antennas with multiband have been found in recent literatures, including a quadband antenna with three L-shaped slots and a rectangular slot [8], a koch fractal printed slot antenna [9], an elliptical slot antenna with "T"- and "L"-shaped slots and three quarter-wavelength stubs [10], a rectangular patch with dual U-shaped slot [11] and a dual rectangular ring with open-end [12]. But they are all complicated in configurations to reduce the antenna's application.

In this letter, considering a slotted patch antenna fed by a CPW structure can exhibit broad bandwidth, a novel compact CPW-fed printed monopole antenna consisting of a parasitic circular patch, a 50-Ω transformer and a pair of symmetrical inverted-L strips attached to the rectangular slot is proposed. By properly selecting shapes and dimensions of the patch and inverted-L strips, good triple bands impedance bandwidths, dipole-like radiation characteristics and moderate gain over the operating bands can be achieved in this design. An experimental prototype of the proposed antenna design was fabricated and measured, verifying the design concept. The measurements show agreement between the simulated and measured results, all of which make the designed antenna suitable for the WLAN/WiMAX application.

2. ANTENNA DESIGN AND DISCUSSIONS

Figure 1 exhibits the configuration of the proposed planar slot antenna for triple bands operation. The basic antenna structure is a rectangle patch with dimensions of $L \times W$ fabricated on one side of a single-layer low-cost and easy-acquirement FR4 epoxy substrate with relative permittivity (ε_r) 4.4, substrate thickness (h) 0.8 mm, and loss tangent of 0.02. The proposed antenna is excited by a 50-Ω CPW feeding line with a signal strip width of W_1 and a gap distance of d between the strip and the coplanar ground plane. The rectangle monopole element

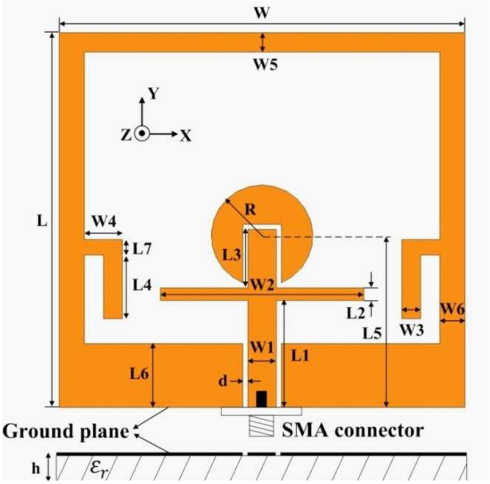


Figure 1. Geometry of the proposed CPW-fed monopole antenna with triple bands.

connected to a 50-Ω SMA connector is parasitically loaded with a circular patch having a radius of R and a gap distance of d to the strip. In order to improve the triple bands impedance matching, a 50-Ω transformer is introduced and connected to the rectangle monopole element. Moreover, for generating a resonance at the upper band for WLAN/WiMAX application, a pair of inverted-L strips is attached to the rectangular slot symmetrically in the proposed antenna. On the other hand, in designing the reference rectangular slot, the second operating frequency f_s can be empirically approximated by

$$f_s = \frac{c}{\sqrt{\varepsilon_{\mathit{eff}}} \cdot \lambda_g} = \frac{c}{2\sqrt{\varepsilon_{\mathit{eff}}} \cdot (0.5 \cdot W + L - L_6)} \tag{1}$$

$$\sqrt{\varepsilon_{\mathit{eff}}} \approx \frac{\varepsilon_r + 1}{2} \tag{2}$$

where c and $\varepsilon_{\mathit{eff}}$ are the speed of light at free space and the approximated effective dielectric constant, respectively. The half circumference along the rectangular slot is the estimated longest current path. However, the design (1) and (2) are only suitable for the single rectangular slot, without considering the mutual coupling between the rectangular slot and the symmetrical inverted-L strips. Therefore, the above formulas can be used to design the initial dimension of the antenna. Furthermore, accurate design for the proposed antenna needed to be adjusted and optimized using electromagnetic simulation software Ansoft HFSS 13 [13]. By finetuning the geometry parameters of these parts independently, a triple bands antenna suitable for WLAN/WiMAX operation is achieved. The optimal parameters for the antenna are listed in Table 1.

Table 1. Optimal parameters of the proposed antenna.

Parameter	L	L_1	L_2	L_3	L_4	L_5	L_6	L_7	d
Unit (mm)	29.5	8.4	1	4.6	5	13.5	5	1.2	0.4
Parameter	W	W_1	W_2	W_3	W_4	W_5	W_6	h	R
Unit (mm)	32	2.2	16	1.5	3	1.5	2	0.8	4

Figure 2 shows the simulated return loss against frequency for the proposed antenna, denoted as Ant. 3. The analyzed impedance bandwidths for -10 dB return loss of the three individual operating bands are about 520 MHz (2.31–2.83 GHz), 1000 MHz (3.05–4.05 GHz), and 1070 MHz (4.97–6.04 GHz), covering simultaneously the required bandwidths of the 2.4/5.2/5.8-GHz WLAN and 2.5/3.5/5.5-GHz WiMAX standards. To illustrate the evolution process of the antenna, the results for the cases of without both the symmetrical inverted-L strips and the 50-Ω transformer and without the 50-Ω transformer only, which were denoted as Ant. 1 and 2, respectively, were also studied and shown in Figure 2. Obviously, the design of Ant. 1 parasitically loaded with a circular patch to the CPW-fed rectangle monopole can excite three resonant modes at around 2.6 GHz, 4.6 GHz and 8.5 GHz. Then, a pair of symmetrical inverted-L strips is embedded in the rectangular slot to lengthen the effective current paths of the second and third modes and improve the matching conditions as shown in Ant. 2. We can see that for Ant. 2, the second and third resonant modes at 4.6 GHz and 8.5 GHz were therefore moved toward the lower frequency. Finally, based on Ant. 2, much improvement on impedance matching condition of the overall three bands was achieved through adding a 50-Ω transformer with the length W_2 and width L_2 into the rectangle monopole element, shown in Ant. 3. To further investigate the effect of 50-Ω transformer to the proposed antenna's impedance matching, the input resistance and reactance for the three antennas were also analyzed, shown in Figure 3. Comparing Ant. 2 and Ant. 3, it is noted that the 50-Ω transformer is successfully employed to improve the impedance matching through increasing the inductance at around 2.6 GHz. The result indicates that the transformer can be considered as a series inductor for impedance matching.

To further study the effects of each part to the antenna, in Figure 4, the simulated surface current distributions of the proposed antenna are illustrated at the resonant frequencies of 2.5, 3.9,

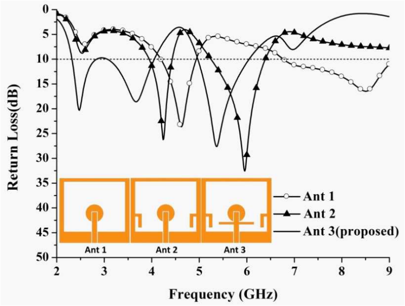


Figure 2. Geometry and simulated return loss of various antennas.

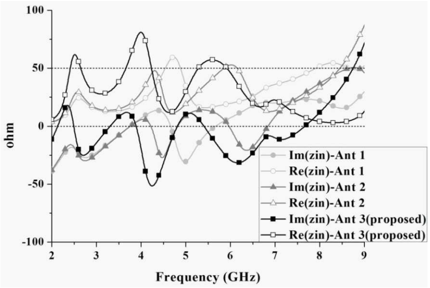
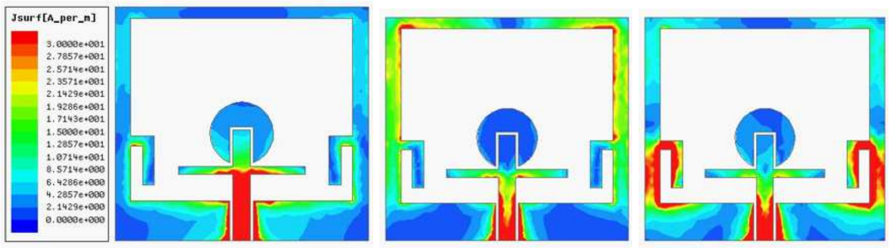


Figure 3. Effects of the 50-Ω transformer to the antenna's impedance matching.



(a) (b) (c)

Figure 4. Simulated surface current distributions of the proposed antenna at (a) 2.5, (b) 3.9, and (c) 5.1 GHz.

and 5.1 GHz, respectively. As expected, at the first resonance (2.5 GHz) the most current density distributes mainly along the rectangular monopole strip and the parasitic circular patch, as shown in Figure 4(a). This indicates that the rectangular monopole strip parasitically loaded with the parasitic circular patch acts as a resonator to generate the lowest resonance. However, at the second resonance (3.9 GHz) most of the surface currents shown in Figure 4(b) is concentrated along the rectangular slot, thus demonstrated that this structure generates the middle resonance. Figure 4(c) shows the current distributions at 5.1 GHz. It can be clearly seen that the currents are mainly around the symmetrical inverted-L strips, and thus the upper resonant mode is excited.

The important effects of the parameters W and L of the ground plane on the impedance matching for the proposed antenna are indicated in Figures 5 and 6. The results show that the lower and upper

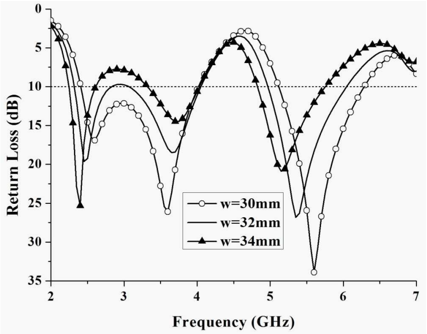


Figure 5. Simulated return losses for the proposed antenna with varying the parameter W of the ground plane.

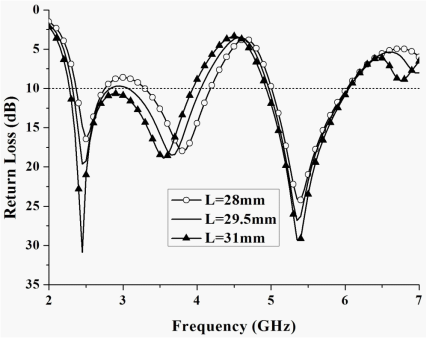


Figure 6. Simulated return losses for the proposed antenna with varying the parameter L of the ground plane.

operation bands are shifted toward the higher frequencies whereas the impedance bandwidth for the middle band is also improved when W decreases. However, varying L from 28 to 31 mm with an increment of 1.5 mm, it is seen that the middle resonant mode, occurring at around 3.65 GHz, move toward the lower frequency and the impedance matching condition for the lower band can be improved whereas the higher resonance is slightly affected by this parameter. The main reason for L to significantly affect the middle operating band, is due to the length of the rectangular slot, which appropriately provide the electric current path for the middle resonance as we discussed before, and is changed by varying L.

Effects of the symmetrical inverted-L strip's length L_4 and the 50-Ω transformer's length W_2 on impedance matching are also studied. In Figure 7, the result for L_4 varied from 4 to 6 mm is shown. In this case, effects of the length of the symmetrical inverted-L strip on the impedance matching of the third resonant mode are seen to be larger than that on the first and second resonant modes. The third resonant mode is shifted to higher frequencies with decrease in L_4 as the result of the decreasing of the electric current path generated by the symmetrical inverted-L strips. Figure 8 presents the tuning effect of the 50-Ω transformer's length on the proposed antenna's impedance matching by varying W_2 from 14 to 18 mm. Obviously, with an increase in W_2, the second and third resonant modes are shifted to lower frequencies and the impedance bandwidth for the lower band is enhanced. Finally, an overall good bandwidth has been obtained in case of $L_4 = 5$ mm and $W_2 = 16$ mm.

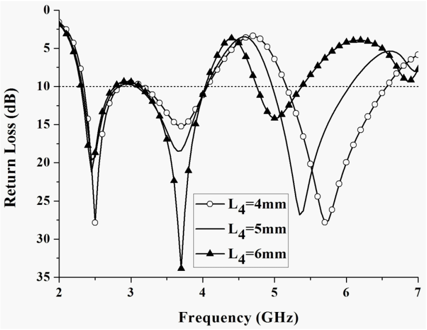


Figure 7. Simulated return losses for the proposed antenna with varying the parameter L_4 of the symmetrical inverted-L strip's length.

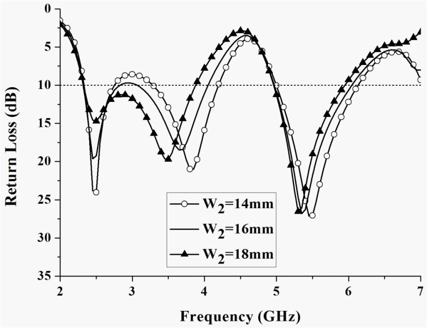


Figure 8. Simulated return losses for the proposed antenna with varying the parameter W_2 of the 50-Ω transformer's length.

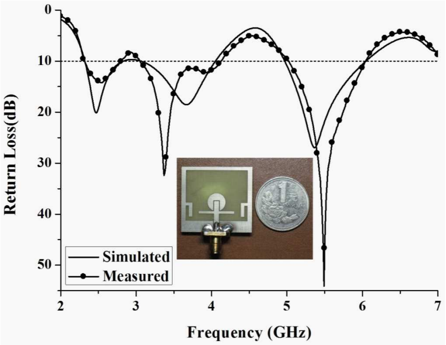


Figure 9. Measured and simulated return losses of the proposed antenna.

3. EXPERIMENTAL RESULTS

Based on the values of the proposed model, the prototype of the triple bands antenna, as depicted in Figure 1, was constructed and experimentally investigated by using the Agilent E8363B vector network analyzer. Figure 9 presents the measured return loss against the frequency for this antenna. For comparison, the simulated results, as Ant. 3 shown in Figure 1, were also plotted in this figure. Obviously, the agreement between simulation and measurement seems very good. Three distinct operating bands with 10 dB return loss are about 2.32–2.80, 3.06–4.13, and 5.03–6.04 GHz, corresponding to 18.8%, 29.8%,

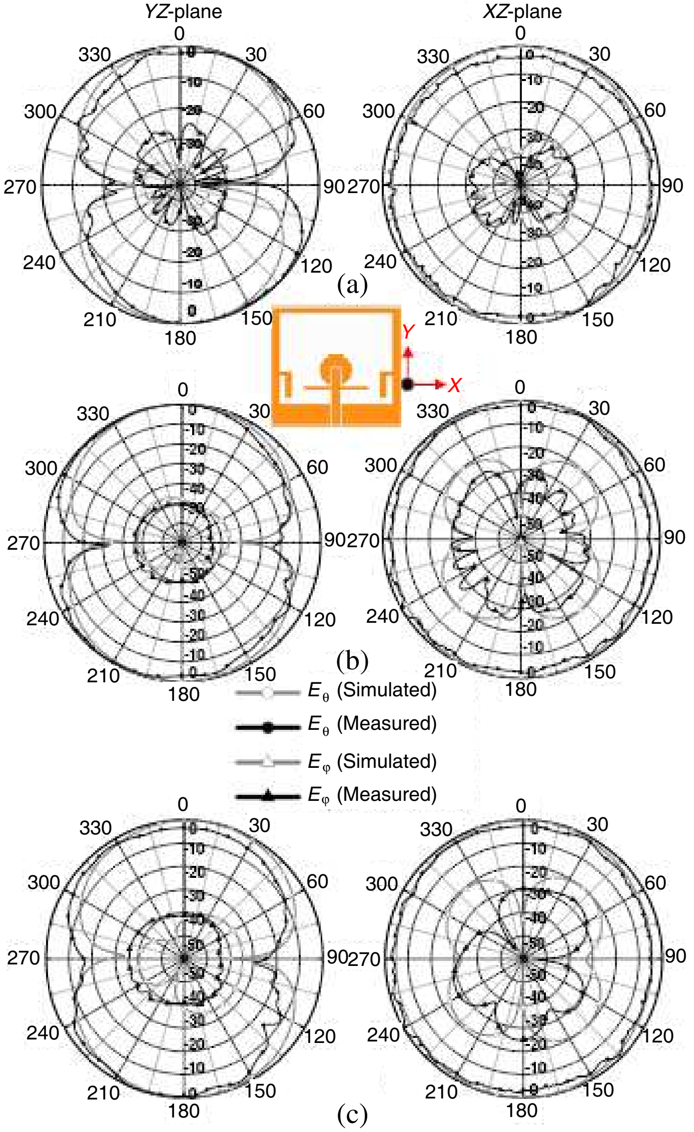


Figure 10. Radiation patterns of the proposed antenna at (a) 2.5, (b) 3.5, and (c) 5.5 GHz.

and 18.2%, respectively, making the antenna satisfy not only the WLAN bands of 2.4/5.2/5.8 GHz, but also the WiMAX bands of 2.5/3.5/5.5 GHz.

The far-field radiation characteristics at operating frequencies of 2.5, 3.5, and 5.5 GHz for the proposed antenna have also been studied. Figure 10 exhibits simulated and measured far-field radiation patterns of the co- and cross-polarizations in the E-plane (y-z plane) and H-plane (x-z plane). The results indicate that this antenna has a stable monopole-like radiation pattern with bidirectional radiations in the E-plane and a nearly omnidirectional pattern in the H-plane.

Finally, the measured peak gains for the proposed antenna at various frequencies across the three operating bands were measured and are shown in Figure 11. For the lower operating band of 2.32–2.80 GHz, the antenna gain varies from 2.80 to 3.11 dBi. Results in the medium band of 3.06–4.13 GHz describe that the gain variation is from 3.16 to 3.36 dBi for the antenna. The measured gain in the highest operating band of 5.03–6.04 GHz is also stable, which varies from 2.60 to 3.52 dBi. The obtained average gains are about 2.95, 3.26, and 3.06 dBi for the 2.32-2.80, 3.06–4.13, and 5.03–6.04 bands, respectively. Hence, these radiation characteristics reveal that the proposed antenna is well suited to be embedded inside the portable devices for application in WLAN/WiMAX systems.

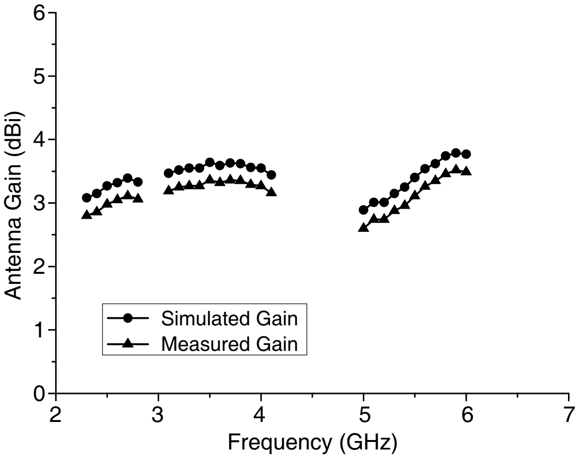


Figure 11. Measured and simulated antenna gain for the proposed antenna.

4. CONCLUSION

A novel compact CPW-fed monopole antenna has been successfully designed with theoretical and experimental results. With the use of a parasitic circular patch, a pair of symmetrical inverted-L strips and a 50-Ω transformer, the proposed antenna effectively excites three resonances and achieves a good input impedance matching which is suitable for the WLAN 2.4/5.2/5.8 GHz and WiMAX 2.5/3.5/5.5 GHz operations. The effects of existences of the symmetrical inverted-L strips and the 50-Ω transformer on both the antenna's resonance and matching condition have also been investigated. In addition, the antenna shows good dipole-like radiation pattern performance with relatively stable gains over the operating bands, which are attractive for wireless communication applications.

REFERENCES

1. Chen, S.-B., Y.-C. Jiao, W. Wang, and F.-S. Zhang, "Modified T-shaped planar monopole antennas for multiband operation," *IEEE Trans. Microwave Theory Tech.*, Vol. 54, 3267–3270, 2006.
2. Kuo, Y.-L. and K.-L. Wong, "Printed double-T monopole antenna for 2.4/5.2 GHz dual-band WLAN operations," *IEEE Trans. Antennas Propag.*, Vol. 51, 2187–2192, 2003.
3. Chen, H.-D., J.-S. Chen, and Y.-T. Cheng, "Modified inverted-L monopole antenna for 2.4/5 GHz dual-band operations," *Electron. Lett.*, Vol. 30, 1567–1568, 2003.
4. Li, B., Y.-Z. Yin, Y. Zhao, and Y. Ding, "A CPW-fed triple-band antenna with a π-shaped slot for WLAN and WiMAX applications," *Cross Strait Quad-regional Radio Science and Wireless Technology Conference*, 393–396, 2011.
5. Bicer, M. B. and A. Akdagli, "A novel microstrip-fed monopole antenna for WLAN/WiMAX applications," *Journal of Electromagnetic Waves and Applications*, Vol. 26, No. 7, 904–913, 2012.
6. Yang, K., H. Wang, Z. Lei, Y. Xie, and H. Lai, "CPW-fed slot antenna with triangular SRR terminated feed line for WLAN WiMAX applications," *Electron. Lett.*, Vol. 47, 685–686, 2011.
7. Liu, H.-W., C.-H. Ku, and C.-F. Yang, "Novel CPW-fed planar monopole antenna for WiMAX WLAN applications," *IEEE Antennas Wireless Propag. Lett.*, Vol. 9, 240–243, 2010.
8. Sun, X., G. Zeng, H.-C. Yang, and Y. Li, "A compact quadband

CPW-fed slot antenna for M-WiMAX/WLAN applications," *IEEE Antennas Wireless Propag. Lett.*, Vol. 11, 395–398, 2012.

9. Krishna, D. D., M. Gopikrishna, C. K. Anandan, P. Mohanan, and K. Vasudevan, "CPW-fed Koch fractal slot antenna for WLAN WiMAX applications," *IEEE Antennas Wireless Propag. Lett.*, Vol. 7, 389–392, 2008.
10. Rahanandeh, M., A. S. N. Amin, M. Hosseinzadeh, P. Rezai, and M. S. Rostami, "A compact elliptical slot antenna for covering bluetooth/WiMAX/WLAN/ITU," *IEEE Antennas Wireless Propag. Lett.*, Vol. 11, 857–860, 2012.
11. 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.
12. Li, B., Z.-H. Yan, and C. Wang, "Dual rectangular ring with open-ended CPW-FED monopole antenna for WLAN/WiMAX applications," *Progress In Electromagnetics Research Letters*, Vol. 25, 101–107, 2011.
13. Ansoft Corporation, Ansoft High Frequency Structure Simulator (HFSS) Version 13.0, Ansoft Corporation, 2011.