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A NOVEL LOOP-LIKE MONOPOLE ANTENNA WITH DUAL-BAND CIRCULAR POLARIZATION

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Abstract—A novel loop-like monopole antenna with dual-band circular polarization (CP) for the reception of WiMAX and WLAN is designed and implemented in this paper. The antenna consists of a radiating patch which is composed of an annular-ring linked by a square ring over the corner and a ground plane with embedded rectangular slit. The broad impedance bandwidth is achieved based on a novel monopole structure which is the combination of two perturbed loops and the perturbation causes the generation of right-hand circular polarization (RHCP) at 3.52 GHz and left-hand circular polarization (LHCP) at 5.75 GHz. In addition, by embedding a rectangular slit on the ground, the impedance bandwidth can be greatly enhanced. The measured results show that the proposed monopole antenna has an impedance bandwidth of 3.65 GHz from 2.65 to 6.3 GHz, reaching the particularly broad bandwidth of 81.6%. Furthermore, the measured 3-dB axial ratio (AR) bandwidths are about 440 MHz at the lower band (3.52 GHz) and 220 MHz at the upper band (5.75 GHz). The radiation characteristics of the implemented antenna are also presented.

1. INTRODUCTION

Recently, printed monopole antennas have been widely used due to their many attractive features, such as wide impedance bandwidth, omnidirectional radiation patterns, light weight, easy of fabrication and low cost [1–3]. Moreover, monopole antennas are compatible with wireless communication integrated circuitry due to their simple feed methods. However, most of the monopole antennas designs are based on linearly polarized (LP). The use of circularly polarized (CP) is

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advantageous as it can launch and receive CP electromagnetic waves and is relatively less sensitive to their respective orientations. The CP is often generated by exciting two near degenerated orthogonal resonant modes of equal amplitude and 90° phase difference. The CP monopole antenna can be widely used in many aspects such as radar, navigation, electronic countermeasure system and medical application. Therefore, if the monopole antenna can generate CP radiation waves, the applications of monopole antenna will be greatly enhanced.

There are various techniques for the design of CP antennas on the patch antenna [4], slot antenna [5], dielectric resonator antenna (DRA) [6], and array antenna [7], but the reports on monopole antenna for CP are much fewer than the other antennas. By using a rectangular dual-loop topology, Wang proposed an asymmetrically feeding monopole antenna to possess CP [8]. A coplanar waveguide (CPW)-fed monopole antenna with a shorting sleeve strip was used to excite a CP mode by the coupling effect between the monopole antenna and sleeve [9]. In addition, a printed CP omnidirectional Y-shaped monopole antenna was also presented in [10]. However, the CP monopole antennas mentioned above are focused on the single-band operation and the radiated fields of these previous designs are RHCP or LHCP. In the recent decade, there are numerous ways to obtain polarization diversity by implementing shorting pin diodes on the antenna structures to switch the far-field polarization, as described in [11]. On the other hand, antennas of these kinds can hardly radiate dual-sense CP waves at the same time. Utilizing an antenna with orthogonally CP at two discrete working frequencies has been proved to be an efficient way to obtain higher transmission capacity. This is simply because a LHCP antenna can normally receive incoming waves of any polarization except the one of RHCP, and vice versa. As a result, the antenna working frequency can thus be reused to enlarge the overall capacity in the wireless transmission. Therefore, dual-band dual-sense circularly polarized antennas have become a hot study in this research area during the last few years. Recently, monopole antennas in [12–14] were designed for dual-sense CP application. Although the design with a spiral structure [12] has the advantage of dual-sense CP operation, the 10-dB impedance bandwidth and the 3-dB axial-ratio (AR) bandwidth for the low and upper bands are relatively narrow. Another design of exciting CP was to utilize a ground plane embedded with an inverted-L slit [13], which was capable of exciting two orthogonal electric fields with equal amplitude and phase difference of 90°. Besides, the complementary SIR radiator can be controlled to obtain the dual-band CP characteristics [14]. But the mentioned antennas have disadvantages of narrow impedance bandwidth [13] and bulky volume [14].

In this paper, a novel microstrip-fed monopole antenna is proposed to achieve dual-band CP. By combining two loops in a unique way, the monopole antenna generates CP wave because each loop can be considered as a perturbation at the corner. In addition, by embedding a rectangular slit on the ground plane, the impedance bandwidth is greatly enhanced. The proposed antenna is particularly simple in manufacturing because of its single layer and monopole structure without additional feeding parts. The measured results show that this antenna excites a broad impedance bandwidth of 81.6% at a centre frequency of 4.475 GHz and the dual-band CP radiation waves of 12.5% RHCP at the center frequency of 3.52 GHz (lower band) and 3.8% LHCP at the center frequency of 5.75 GHz. The presented design can be applied to the practical engineering frequency bands, such as WiMAX and WLAN operations.

2. ANTENNA DESIGN

The geometry of the presented antenna is shown in Fig. 1. It is composed of a dual-loop radiator structure and a ground plane with an embedded rectangular slit. The antenna is fabricated on an FR-4 substrate with a relative permittivity $\varepsilon_r = 4.4$ and loss tangent $\tan\delta = 0.02$. The overall dimensions of the antenna are $55 \times 55 \times 1.6\,\text{mm}^3$. As Fig. 1(a) shows, the $50\,\Omega$ feed line of length L_f and width W_f is connected to an impedance transformer. The dual-loop monopole antenna consists of an annular ring which is combined at its left corner with a square ring. Both rings have the same width W_s. Due to the outer circumferences of the two rings are different, we can tune 10-dB return loss bandwidth to cover a wide operational range. Instead of a multifed structure, the antenna is based on a dual-loop monopole structure without additional feeding parts for a 90° phase difference between two orthogonal polarized modes. Through the antenna's performance analysis, the radiator structure can be viewed as a combination of two perturbed rings. As a result, the perturbation causes the radiating of CP wave at desired band. From the Fig. 1(b) we can see an $L \times G$ ground plane is etched at the bottom side of this antenna an $a \times b$ rectangular slit is embedded on the ground plane to improve the impedance matching. Detailed dimensions are listed in Table 1.

In order to better understand the excitation behavior and why the dual-band CP can be generated by the proposed antenna. Fig. 2 shows the simulated surface current distributions of 0° and 90° at the lower (3.52 GHz) and upper (5.75 GHz) frequencies. It can be

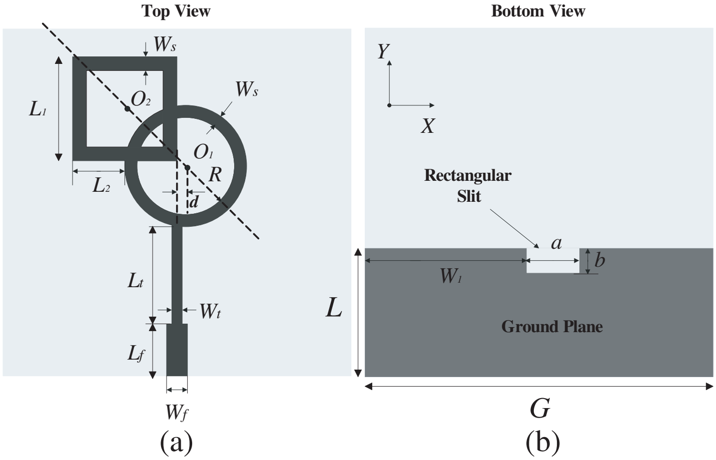


Figure 1. Configurations of the proposed antenna. (a) Top view; (b) Bottom view.

Table 1. Dimensions of the proposed antenna (mm).

parameter	value	parameter	value	parameter	value
G	55	$L_{\rm f}$	8.6	a	8
L	20	$W_{\rm s}$	1.8	b	3
L_1	14.3	W_t	1.8	R	7.9
L_2	6.4	$W_{\rm f}$	3	d	1.4
$L_{\rm t}$	13.4	W_1	23.7		

observed that the annular-ring and square ring are introduced as perturbed segments for generating two orthogonal modes with 90° phase difference and equal amplitude. For the lower band, the maximum current distributions are localized mainly in the annular-ring and a small part of the square ring to radiate RHCP waves. At 5.75 GHz, the square ring and annular-ring both contribute to generate opposite-sense CP waves. Therefore, we can conclude that the proposed antenna radiates RHCP waves at the lower (3.52 GHz) and LHCP waves at the upper (5.75 GHz) frequencies, respectively.

3. MEASUREMENT RESULTS AND DISCUSSIONS

The proposed antenna is fabricated and tested. Fig. 3 shows the fabricated prototype of it. All radiation characteristics of the antenna

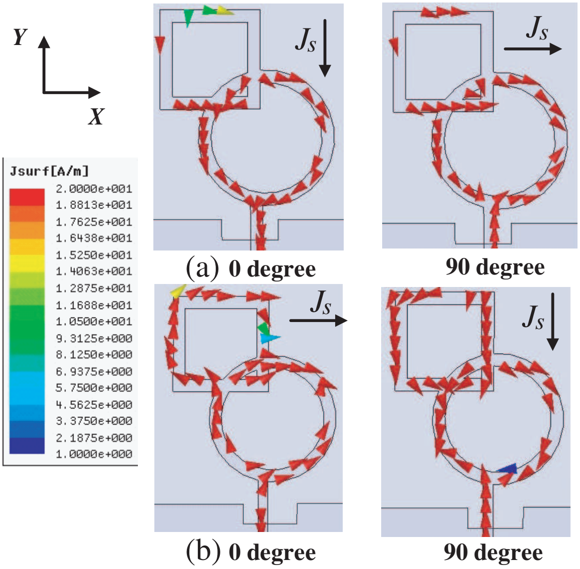


Figure 2. Simulated current distributions: (a) 3.52 GHz and (b) 5.75 GHz.

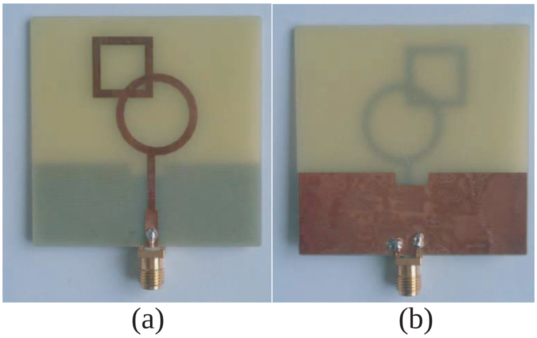


Figure 3. Photographs of the fabricated antenna. (a) Top view; (b) Bottom view.

are measured in an anechoic chamber, and the reflection coefficients are measured using the Agilent N5230C vector network analyzer. There are three subsections: A) Studying the impedance bandwidth and resonant modes. The simulated and measured return losses of the proposed antenna are discussed. B) Analyzing axial ratios. C) Illustrating the measured radiation patterns and gains.

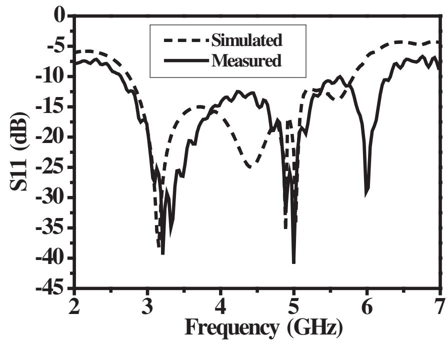


Figure 4. Measured and simulated return losses of the proposed antenna.

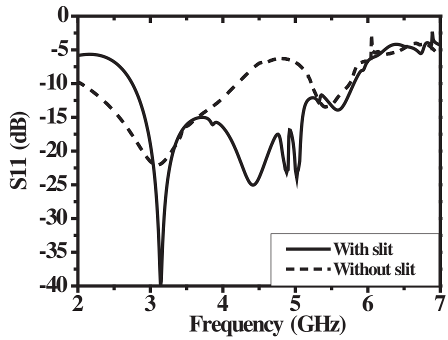


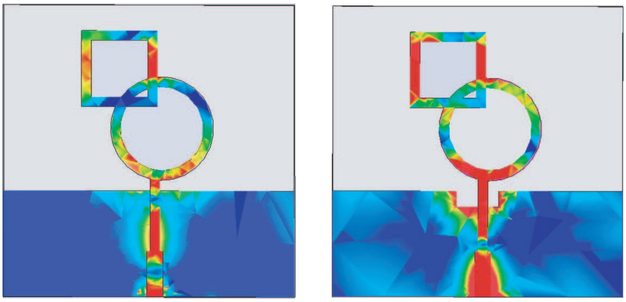
Figure 5. Comparison the S_{11} of the proposed antenna with and without the slit.

3.1. Return Loss and Resonant Modes

Figure 4 shows the measured and simulated return losses of the presented antenna. The 10-dB impedance bandwidth of the measured return loss reaches 3.65 GHz, which covers the range from 2.65 to 6.3 GHz, or approximately 81.6% with respect to the centre frequency of 4.475 GHz, suitable for WiMAX band and the higher WLAN band. Good agreement is found between simulated and measured results except a small frequency shift. The tolerance's fabrication errors and loss tangent of the substrate probably lead to the difference between theoretical value and measured value.

Figure 5 illustrates the comparisons of the simulated return loss of the proposed antenna with and without the rectangular slit. With the presence of the rectangular slit a resonant mode at the center frequencies of 4.4 GHz can be yielded to increase the impedance-bandwidth. According to Fig. 5, the proposed antenna performs a wide bandwidth due to the three resonant modes which are influenced and excited by the rectangular slit. The three resonant modes are: the two resonant modes of dual-loop monopole antenna at the center frequencies of 3.15 and 5.6 GHz, and one resonant mode of the ground plane at the center frequency of 4.4 GHz.

In Fig. 6 the simulated surface current distributions at 4.4 GHz are presented. It is shown that the most surface current distributions are formed along the rectangular slit and a part of the dual-loop patch. In other words, the ground embedded with rectangular slit and the patch can be used to excite extra resonant mode, which provides extended bandwidth.



(a) (b)

Figure 6. Current distributions of the proposed antenna at 4.4 GHz. (a) Without slit; (b) With slit.

3.2. Axial Ratios

The simulated and measured AR results for the broadside direction versus frequency are plotted in Fig. 7. The measured 3-dB AR bandwidths reach 440 MHz from 3.3 to 3.74 GHz (lower band) or about 12.5% with respect to the center frequency at 3.5 GHz, and 220 MHz from 5.64 to 5.86 GHz (upper band) or about 3.8% with respect to the center frequency at 5.75 GHz. Although there is a slight shift in the simulated and measured ranges of the 3-dB axial-ratio bandwidth, the antenna is still suitable for the WiMAX and WLAN applications.

3.3. Radiation Patterns and Gains

The measured normalized RHCP and LHCP radiation patterns in the XOZ-plane and YOZ-plane for frequencies of 3.5 and 5.75 GHz are

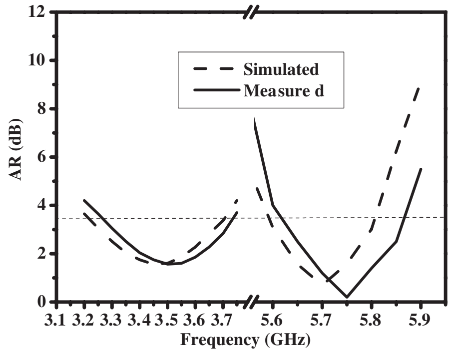


Figure 7. Measured and simulated AR of the proposed antenna.

shown in Fig. 8 respectively. It is noted that the radiation patterns are not omnidirectional because the dual-loop structure of the proposed antenna is not symmetrical and the radiation patterns are influenced by slit. In addition, the antenna enjoys the favorable characteristics of good CP wave and stable radiation patterns. A standard linearly polarized horn antenna is used to measure the total gain characteristics of proposed design. The measured gain for the broadside direction versus frequency is also shown in Fig. 9. In the 3.5-GHz band, the peak gain is about 2.3 dBi, and the maximum gain is at 3.5 GHz. In the 5.8-GHz band, the peak gain is about 2.4 dBi with the gain variation less than 0.5 dBi at the working band. It can fulfill the requirements of the indoor wireless applications.

4. PARAMETRIC STUDIES

In this section, the vital parameters of the antenna are investigated to find their impacts on the antenna. By Ansoft High Frequency Structure Simulator software (Ansoft HFSS ver. 10.0) [15], the square loop, rectangular slit are especially examined and compared to find the influences on the antenna performance.

In Fig. 10, when the size of the square loop increases, the center frequency of AR has a downward shift in WiMAX band, whereas AR frequency centers are affected slightly in WLAN band when the size of the square loop increases to some extent. As a result, we can conclude that the 3.5 GHz band is tunable by the size of the square loop.

Figures 11 and 12 also show the effects of the size of the rectangular slit on the AR in the broadside direction. The finding clearly illustrates that the AR is affected by the size of rectangular slit especially for

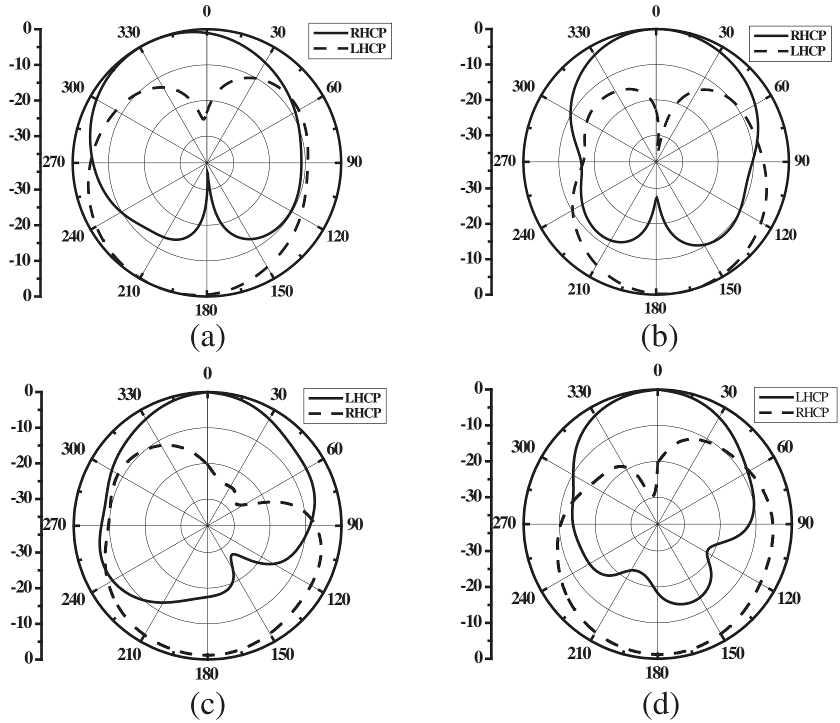


Figure 8. Measured radiation patterns of the proposed dual-band CP antenna. (a) 3.5 GHz at $\varphi = 0°$; (b) 3.5 GHz at $\varphi = 90°$; (c) 5.75 GHz at $\varphi = 0°$; (d) 5.75 GHz at $\varphi = 90°$.

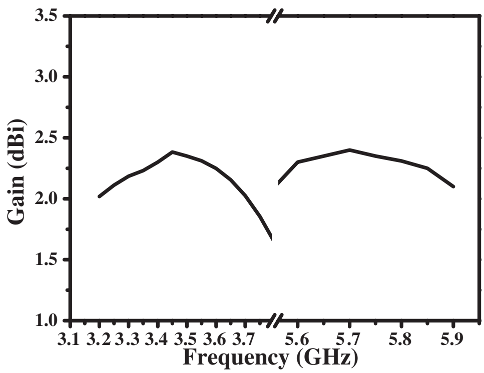


Figure 9. Measured gain of the proposed antenna.

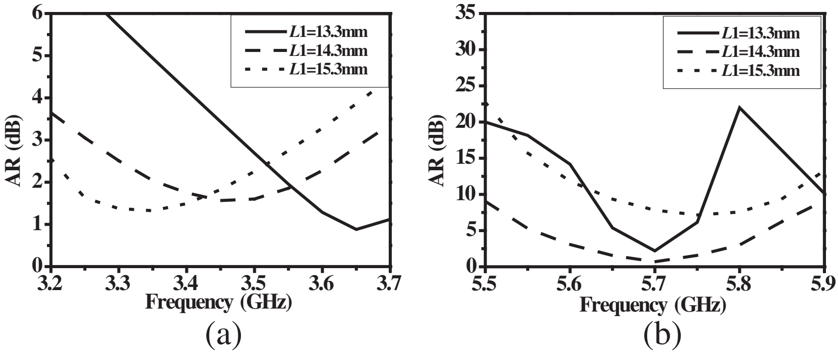


Figure 10. Simulated AR with different square loop size.

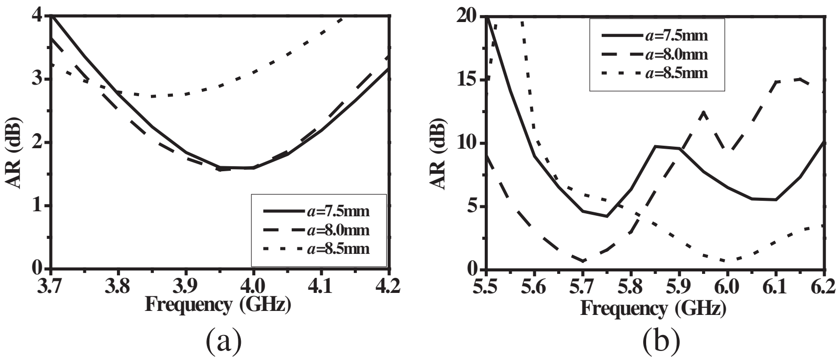


Figure 11. Simulated AR with different slit length.

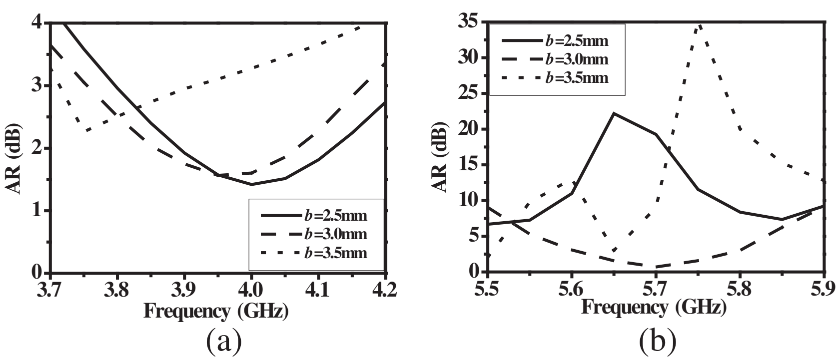


Figure 12. Simulated AR with different slit height.

upper band. However, when the size of the slit increases, it has little effect on the CP performance at lower band. At last, the size of the rectangular slit is set by $8 \times 3\,\text{mm}^2$.

5. CONCLUSION

In this paper, we designed a novel monopole antenna that is capable of realizing a broad impedance bandwidth and dual-band CP performance. The antenna has a structure of two combined loops and a ground plane embedded with a rectangular slit. Owing to the dual-loop structure which can be considered to be a combination of two perturbed rings, dual-band CP radiation wave is generated. In addition, by embedding a rectangular slit on the ground plane the impedance bandwidth is greatly improved. The impedance bandwidth achieved measured results of 81.6% from 2.65 to 6.3 GHz, and the 3-dB AR bandwidths of dual-band CP wave are about 12.5% for RHCP at the lower band and 3.8% for LHCP at the upper band. The proposed antenna would provide many advantages such as low weight, simple structure, easy fabrication, low production cost, broad impedance bandwidth, and CP radiation pattern, which demonstrate that it is very suitable for WiMAX, WLAN, and other broadband commutation system.

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REFERENCES

1. Ren, W., J. Y. Deng, and K. S. Chen, "Compact PCB monopole antenna for UWB applications," *Journal of Electromagnetic Waves and Applications*, Vol. 21, No. 10, 1411–1420, 2007.
2. Gopikrishna, M., D. D. Krishna, A. R. Chandran, and C. K. Aanandan, "Square monopole antenna for ultra wide band communication applications," *Journal of Electromagnetic Waves and Applications*, Vol. 21, No. 11, 1525–1537, 2007.
3. Zhang, H. T., Y. Z. Yin, and X. Yang, "A wideband monopole with G type structure," *Progress In Electromagnetics Research*, Vol. 76, 229–236, 2007.
4. Heidari, A. A., M. Heyrani, and M. Nakhkash, "A dual-band circularly polarized stub loaded microstrip patch antenna for GPS

applications," *Progress In Electromagnetics Research*, Vol. 92, 195–208, 2009.

5. Chen J., G. Fu, G. D. Wu, and S. X. Gong, "A novel broadband circularly polarized irregular slot antenna," *Journal of Electromagnetic Waves and Applications* Vol. 24, Nos. 2–3, 413–421, 2010.
6. Pan, Y. M. and K. W. Leung, "Wideband circularly polarized trapezoidal dielectric resonator antenna," *IEEE Antennas and Wireless Propagat. Lett.*, Vol. 9, 588–591, 2011.
7. Li, X., Y.-J. Yang, X. Tao, L. Yang, S.-X. Gong, Y. Gao, K. Ma, and X.-L. Liu, "A novel design of wideband circular polarization antenna array with high gain characteristic," *Journal of Electromagnetic Waves and Applications*, Vol. 24, No. 7, 951–958, 2010.
8. Wang, C. J., "A wideband loop-like monopole antenna with circular polarization," *Microwave Opt. Technol. Lett.*, Vol. 53, No. 11, 2556–2560, 2012.
9. Wang, C. J. and Y. C. Lin, "New CPW-fed monopole antennas with both linear and circular polarisations," *IET Microwave, Antennas and Propagation* Vol. 2, No. 5, 466–472, 2008.
10. Ghobadi, A. and D. Dehmollaian, "A printed circularly polarized Y-shaped monopole antenna," *IEEE Antennas and Wireless Propagat. Lett.*, Vol. 11, 22–25, 2012.
11. Shynu, S. V., G. Augustin, C. K. Aanandan, P. Mohanan, and K. Vasudevan, "Design of compact reconfigurable dual frequency microstrip antennas using varactor diodes," *Progress In Electromagnetics Research*, Vol. 60, 197–205, 2006.
12. Huang, C. R., J. H. Huang, and C. F. Jou, "Dual-band circularly polarized slotted monopole antenna," *Microwave Conference Proceedings (APMC)*, 1866–1869, 2011.
13. Li, W. M., Y.-C. Jiao, L. Zhou, and T. Ni, "Compact dual-band circularly polarized monopole antenna," *Journal of Electromagnetic Waves and Applications,* Vol. 25, Nos. 14–15, 2130–2137, 2011.
14. Liu, J. C., S. H. Chiu, K. D. Yeh, B. H. Zeng, H.-C. Wu, and T.-F. Hung, "CPW-fed sleeve monopole antenna with complementary SIR radiators for DTV signal reception and circularly polarized applications," *Progress In Electromagnetics Research C*, Vol. 14, 23–31, 2010.
15. High Frequency Structure Simulator (HFSS), Version 10.0, Ansoft Corporation, USA, 2005.