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A Novel Design of Dual-Band Circularly Polarized Antenna Based on Patches Having Rotation Angles

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Abstract—In this paper, a dual-band circularly polarized (CP) patch antenna with left-hand circular polarization (LHCP) in the lower band and right-hand circular polarization (RHCP) in the higher band is proposed. On the basis of aperture coupled feed, the dual-band circular polarizations are achieved by adopting two rectangular patches with different rotation angles on the front and back of a substrate. A good agreement between the simulated and measured results is obtained. The 10-dB impedance bandwidths and 3 dB Axial Ratio (AR) bandwidths are 18.4% (1.93–2.32 GHz) and 3.2% (2.14–2.21 GHz) in the lower band and 12.4% (2.58–2.92 GHz) and 1.7% (2.84–2.89 GHz) in the higher band, respectively. The proposed antenna with its simple structure, compact size and excellent performance provides a reference for communication system applications.

1. INTRODUCTION

With the rapid development of wireless communication systems, multiband application ranging from personal wireless communication to space-based applications plays a great role for terminal devices [1]. Meanwhile, CP antenna is widely used owing to its merits of ability to provide more flexibility in the orientation angle between the transmitter and receiver antennas than linearly polarized radiation [2, 3]. Therefore, increasing attention has been paid to the research of dual-band CP antennas.

Various dual-band CP antenna designs have been reported in literature [4–9]. In [4], dual-band circular polarization based on a single-layer and single-feed configuration has been obtained by introducing slots at the sides of the rectangular patch. In [5], a two-way Wilkinson power divider with a high different phase is employed to feed to doubled-layer U-slot for dual-band CP operation. The perturbation method also can be adopted in [6]. The antenna with four T-shaped elements at edges of the patch corners is operated at two resonant frequencies of TM_{10} and TM_{30} modes. However, most designs of dual-band CP antenna exhibit the same circular polarization, namely LHCP in both bands or RHCP in both bands. Dual-band CP antenna with different circular polarizations in both bands can be widely used to advance the development of new wireless communications. Some antennas have been proposed in previous researches. In [7], dual H-shaped slots have been placed in orthogonal direction and excited by 3-dB branch-line coupler to obtain both RHCP and LHCP. As presented in [8], the RHCP radiation and LHCP radiation are obtained by the currents flowing on the patch with eight curved slots. In [9], two circularly polarizations excited by the modified feeding line were achieved with a well-designed meta-surface placed atop a slot antenna. However, those antennas are either complicated in structure or relative narrow in impedance and circular polarization bandwidth.

In this paper, a novel design of simple structure dual-band CP antenna with different circular polarizations in both bands is proposed. Based on aperture coupled feed, the CP operation of the proposed antenna is achieved by adopting two rotated rectangular patches with different angles. The

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simulated $-10\,\text{dB}$ reflection coefficient bandwidths are 18.88% (1.90–2.30 GHz) and 14.97% (2.54–2.96 GHz). Meanwhile, the ARs at two center frequencies are about 0.31 and 1.66 dB, respectively. Thus, for its low profile, compact size and excellent performance, the proposed antenna is expected to be a good candidate for various communication system applications.

2. ANTENNA DESIGN

The schematic configuration of the proposed antenna is shown in Figure 1. It consists of two substrate layers, two rotated rectangular patches, a microstrip line and a slotted ground. Two layers of an FR4 substrate with relative permittivity $\varepsilon_r = 4.4$ and $\tan\delta = 0.02$ have the same thickness of 1 mm, which are separated by an air gap of thickness H. The sizes of upper and lower patches are $L_1 \times W_1$ and $L_2 \times W_2$ with rotated angles of α and β from y-axis, respectively. Two patches are positioned on the front and back of the upper substrate. CP operation can be obtained only by a dipole with angle [10]. In [11], a rectangular patch instead of a thin dipole can be put to use in order to widen the AR bandwidth. Excited at the edges of the patch, two orthogonal modes can be introduced. The additional one-wavelength mode appears along the edge of the patch when the current is excited. Also, the sense of antenna polarization depends on the direction of patch rotation [12]. LHCP in the lower band and RHCP in the higher band can be generated by upper and lower patches with different angles (α and β), respectively.

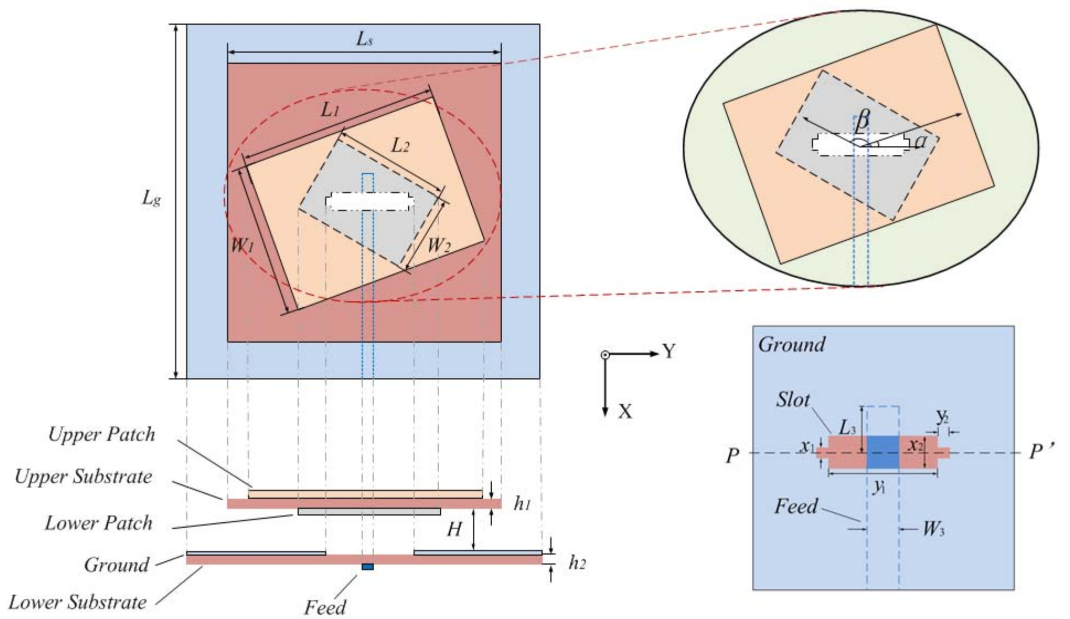

Figure 1. Schematic configuration of the proposed antenna.

Table 1. Detailed parameters of proposed antenna (Unit: mm).

Parameters	*Size*	*Parameters*	*Size*	*Parameters*	*Size*
L_g	100	L_s	80	L_1	50
W_1	41	L_2	30	W_3	25
L_3	6.5	W_3	1.5	H	7
h_1	1	h_2	1	α	32°
β	135°	x_1	5	x_2	8
y_1	31	y_2	4		

Generally, aperture coupled microstrip antennas offer a wider bandwidth and more robust design [13], which is adopted in the proposed antenna. It is noticed in Figure 1 that two patches are fed from an aperture etched on the ground plane. The offset part of the microstrip feeding line on the back of the lower substrate is at distance L_3 from the center of the slot. In fact, determined only by four parameters x_1, x_2, y_1 and y_2, the slot has transformed from H-shaped slot.

The proper dimensions and results are optimized with the aid of the 3D Electromagnetic tools ANSYS HFSS. The detailed parameters of proposed antenna are listed in Table 1.

3. PARAMETRIC ANALYSIS

To better understand the working principle of the antenna, some representative parameters will be analyzed. In [10, 14], it was found that the phase of circular polarization φ is linearly dependent on the dipole angle while it is independent of the slot angle, length and offset which only determine the impedance matching.

Firstly, the effect of rotation angle on the polarization is investigated. Based on the proposed antenna feeding structure, one rectangular patch with different rotation angles is adopted. The simulated radiation patterns with different rotation angles of patch at 2.4 GHz are illustrated in Figure 2. Comparing Figure 2(a) with Figure 2(b), it can be found that the polarization apparently presents a trend of LHCP in the interval $30° \leq \alpha \leq 60°$ and a trend of RHCP in the interval $120° \leq \alpha \leq 150°$, respectively. Two angles in Figure 2 can be used to illustrate that the gain of LHCP is approximately 14 dB higher than the gain of RHCP when $\alpha = 60°$, and the gain of RHCP is 15 dB higher than the gain

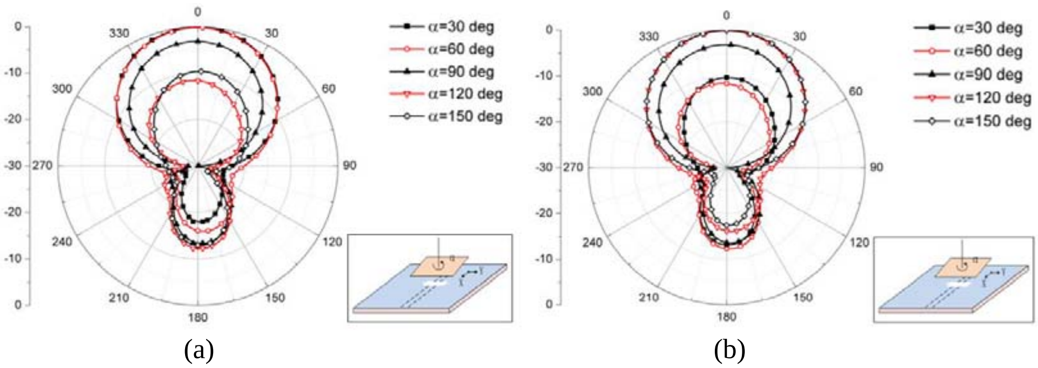

Figure 2. Simulated radiation patterns with different rotation angles of patches at 2.4 GHz: (a) LHCP at phi = 0°, (b) RHCP at phi = 0°.

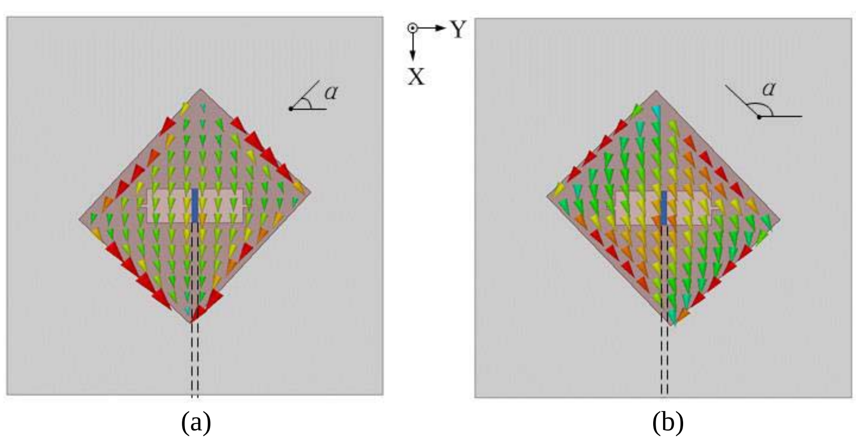

Figure 3. Surface current distributions on rotated patch at 2.4 GHz: (a) α=47°, (b) α=134°.

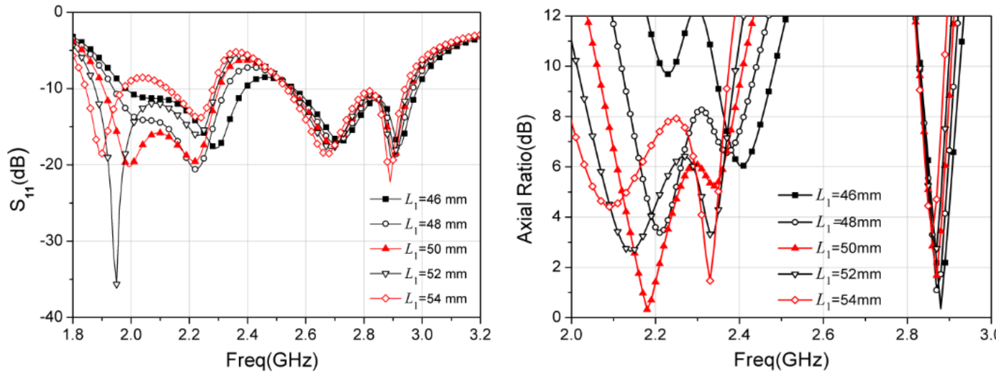

Figure 4. Simulated reflection coefficient and AR of proposed antenna with respect to various L_1.

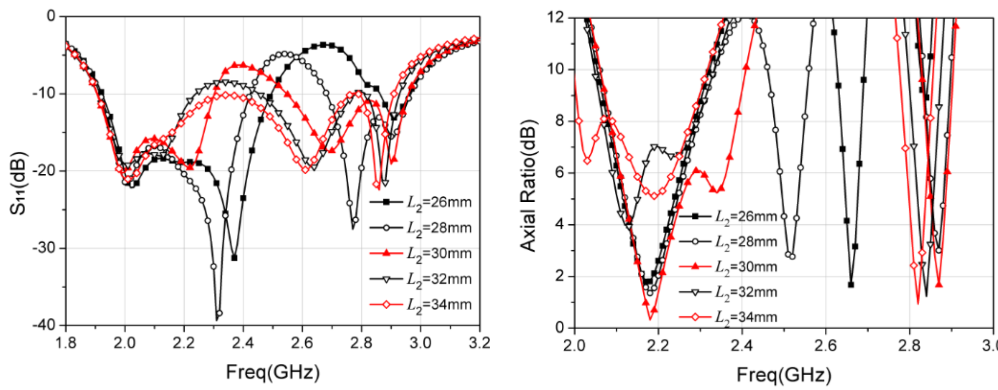

Figure 5. Simulated reflection coefficient and AR of proposed antenna with respect to various L_2.

of LHCP when $\alpha = 120°$, respectively. The characteristics of LHCP and RHCP are shown apparently by two examples above.

Figure 3 shows the surface current distributions of the antenna at two rotation angles. From Figure 3(a), when the rotation angle is equal to 47°, the current of the patch owns two perpendicular components at the edges. Meanwhile, the two components have almost the same amplitude and a phase difference of 90°, which leads to left-handed CP wave. Similarly, a right-handed CP wave is obtained from Figure 3(b) when the rotation angle is equal to 134°. From the analysis above, it is clear that two rectangular patches with different rotation angles can be used to obtain dual-band CP operation.

Furthermore, the length of the patch has a very obvious effect on both S_{11} and AR bandwidth of the antenna. A parameter study is conducted in Figure 4 and Figure 5, which shows reflection coefficient and AR with respect to various L_1 and L_2, respectively. In Figure 4, L_1 has a more drastic effect on both reflection coefficient and AR in the lower band, but almost little effect in the higher band. It is presented from the above results that the circular polarization in the lower band is mainly generated by the upper patch. Also, it is clear from Figure 5 that L_2 has a great influence on reflection coefficient and AR of both bands because of a small frequency ratio of 1.31 and the coupling between the upper patch and the lower patch. It is clear that the length of the patch has a great effect on the resonant frequency. The resonant frequency needed can be met by an adjustment of the patch size. Therefore, the dual CP operating bands can be tuned separately.

4. EXPERIMENTAL RESULTS

Based on the optimal parameters, a prototype antenna was fabricated as presented in Figure 6. The simulated and measured reflection coefficients and ARs of the proposed antenna are depicted

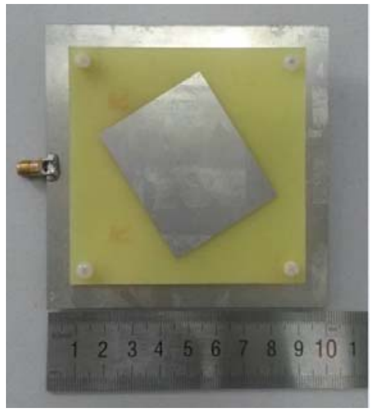

Figure 6. Photograph of the fabricated antenna.

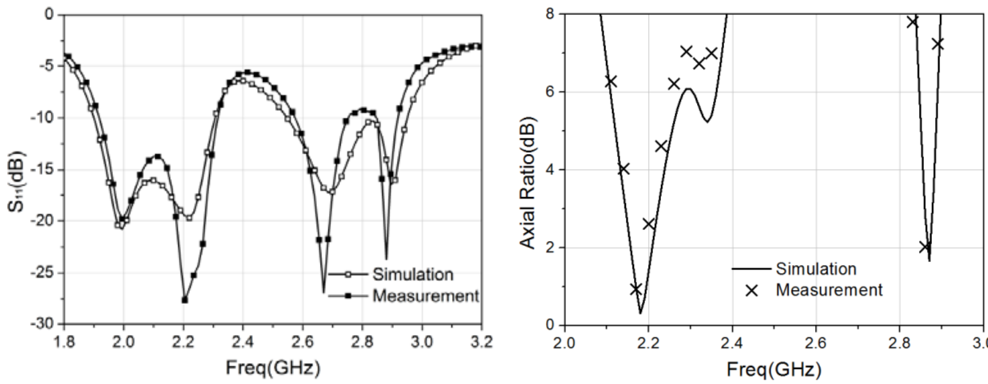

Figure 7. Measured reflection coefficient and AR of the proposed antenna.

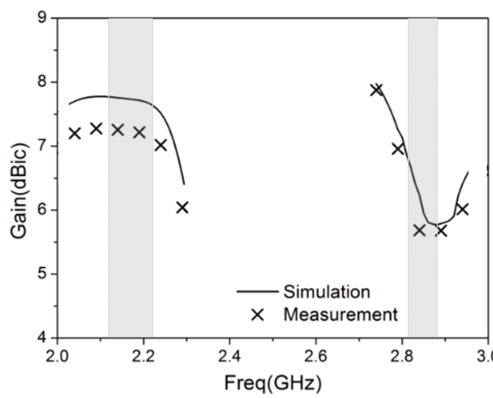

Figure 8. Measured gain of the proposed antenna.

in Figure 7. It is illustrated that the simulated -10 dB reflection coefficient bandwidths are 397 MHz (1.9049–2.3016 GHz) at the lower band and 412 MHz (2.5468–2.9591 GHz) at the higher band, while the simulated 3 dB AR bandwidths are 82 MHz (2.1430–2.2245 GHz) at the lower band and 44 MHz (2.8451–2.8892 GHz) at the higher band, respectively. A good agreement between the simulated and measured results is exhibited. With reference to the figure, the measured 10-dB impedance bandwidths and 3 dB AR bandwidths are 18.4% (1.93–2.32 GHz) and 3.21% (2.14–2.21 GHz) at the lower frequency band and 12.4% (2.58–2.92 GHz) and 1.7% (2.84–2.89 GHz) at the higher frequency band. The measured gain

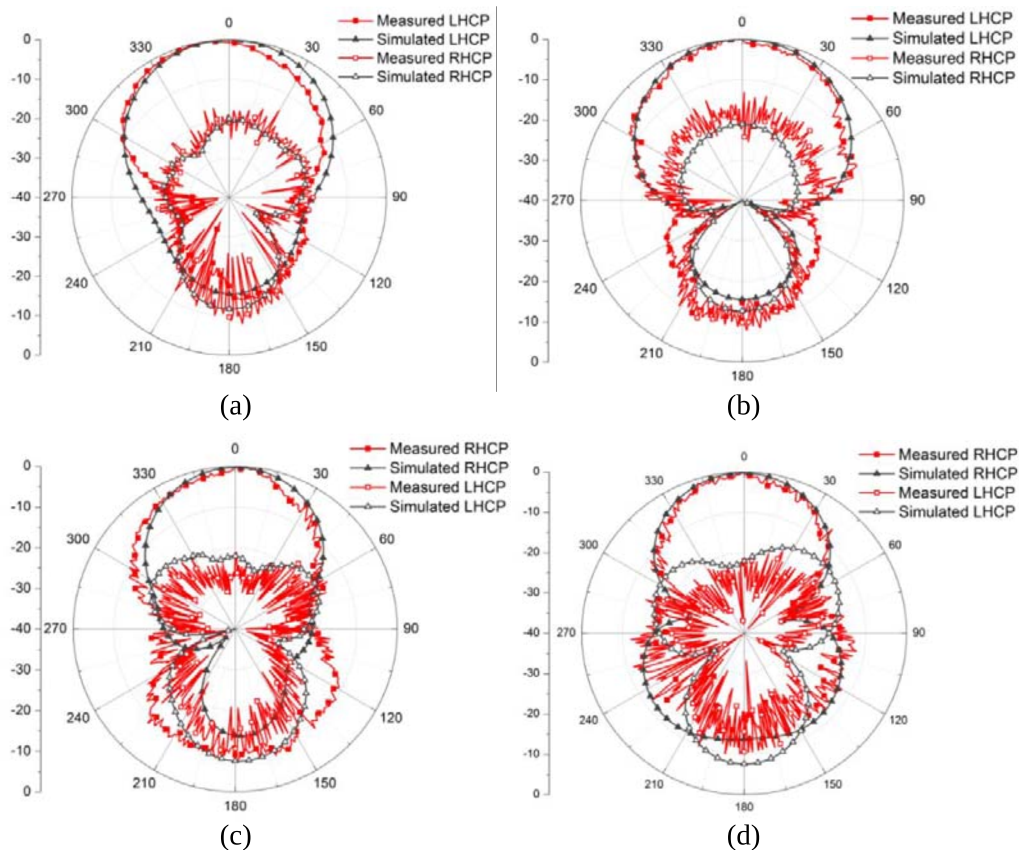

Figure 9. Simulated and measured normalized radiation patterns: (a) 2.18 GHz at xz-plane; (b) 2.18 GHz at yz-plane; (c) 2.87 GHz at xz-plane; (d) 2.87 GHz at yz-plane.

is higher than 7 dBic in the lower band and 5.5 dBic in the higher band, which is noticed in Figure 8. It is noted that a relative low gain at the high band is because the larger patch that determines the lower band is over the small one that determines the higher band, and the radiation characteristic of the antenna at high band is greatly affected. The measured normalized radiation patterns at 2.18 GHz and 2.87 GHz in xz-plane and yz-plane is shown in Figure 9.

5. CONCLUSION

A dual-band CP patch antenna with LHCP in the lower band and RHCP in the higher band is presented in this paper. Different from other antennas with complex structure and narrow impedance and circular polarization bandwidth, the dual-band circular polarizations based on aperture coupled feed are achieved by adopting two rotated rectangular patches with different angles. The measured 10-dB impedance bandwidths and 3 dB AR bandwidths are 18.4% and 3.21% in the lower band and 12.4% and 1.7% in the higher band, respectively. Due to its simple structure, compact size and excellent performance, the antenna is expected to be applied to wireless communications.

REFERENCES

1. 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.
2. Hsu, S. H. and K. Chang, "A novel reconfigurable microstrip antenna with switchable circular polarization," *IEEE Antennas Wireless Propagation Letters*, Vol. 6, 160–162, 2007.

3. Dorsey, W. M. and A. I. Zaghloul, "Dual-band, dual-circularly polarized antenna element," *IET Microwaves, Antennas & Propagation*, Vol. 7, 283–290, 2013.
4. Ramya, R. and T. R. Rao, "Circularly polarized dual band micro strip patch antenna for vehicular wireless network communications," *IEEE International Conference on Advanced Networks and Telecommuncations Systems (ANTS)*, 1–4, 2014.
5. Zhou, P. Y., X. H. Ye, and M. He, "A dual-band U-slot microstrip antenna with dual-feed and double-layer," *IEEE International Conference on Microwave Technology & Computational Electromagnetics (ICMTCE)*, 146–148, 2013.
6. Yang, K. P. and K. L. Wong, "Dual-band circularly-polarized rectangular microstrip antenna," *IEEE Trans. Antennas Propag.*, Vol. 49, 377–382, 2001.
7. Zhu, W., S. Q. Xiao, R. Yuan, and M. C. Tang, "Broadband and dual circularly polarized patch antenna with H-shaped aperture," *IEEE International Symposium on Antennas and Propagation (ISAP)*, 549–550, 2014.
8. Yu, D., S. X. Gong, Y. T. Wan, and W. F. Chen, "Omnidirectional dual-band dual circularly polarized microstrip antenna using TM_{01} and TM_{02} modes," *IEEE Antennas Wireless Propagation Letters*, Vol. 13, 1104–1107, 2014.
9. Li, K., L. Li, Y. M. Cai, C. Zhu, and C. H. Liang, "A novel design of low-profile dual-band circularly polarized antenna with meta-surface," *IEEE Antennas Wireless Propagation Letters*, No. 99, 1, 2015.
10. Min, K. S., J. Hirokawa, K. Sakurai, and M. Ando, "Phase control of circularly polarized waves from a parasitic dipole mounted above a slot," *Proc. IEEE Antennas and Propagation Society International Symposium*, Vol. 2, 1348–1351, 1997.
11. Li, Y., Z. N. Chen, X. Qing, Z. Zhang, J. Xu, and Z. Feng, "Axial ratio bandwidth enhancement of 60-GHz substrate integrated waveguide circularly polarized LTCC antenna array," *IEEE Trans. Antennas Propag.*, Vol. 60, 4619–4626, 2012.
12. Oraizi, H. and R. Pazoki, "Wideband circularly polarized aperture-fed rotated stacked patch antenna," *IEEE Trans. Antennas Propag.*, Vol. 61, 1048–1054, 2013.
13. Pozar, D. M. and S. M. Duffy, "A dual-band circularly polarized aperture coupled stacked microstrip antenna for global positioning satellite," *IEEE Trans. Antennas Propag.*, Vol. 45, 1618–1625, 1997.
14. Min, K. S., J. Hirokawa, K. Sakurai, M. Ando, and N. Goto, "Single-layer dipole array for linear-to-circular polarization conversion of slotted waveguide array," *Microwaves, Antennas and Propagation, IEE Proceedings*, Vol. 143, 211–216, 1996.