

A CPW-Fed Dual-Band Slot Antenna with Circular Polarization

Yonghao Xin, Quanyuan Feng^{*}, and Jun Tao

Abstract—In this paper, a coplanar waveguide (CPW)-fed dual-band slot antenna with circular polarization (CP) is presented. In order to achieve CP characteristic, an asymmetric slot and F-shaped end patch are introduced to a conventional rectangular slot antenna. Moreover, by cutting a T-shaped notch on the ground plane, the axial ratio (AR) bandwidth (ARBW) can be extended. The antenna shows left-hand CP (LHCP) radiation in the boresight direction (i.e., +Z direction) at both ARBW. The proposed antenna is fabricated and measured. The measured results have a good agreement with the simulated ones. The measured impedance bandwidths ($|S_{11}| < -10$ dB) are 1.08 GHz (2.02 to 3.10 GHz, 40% at 2.70 GHz) and 2.31 GHz (4.57 to 6.88 GHz, 39.8% at 5.8 GHz). The two measured ARBW are 600 MHz (2.60 to 3.20 GHz, 22.2% at 2.70 GHz) and at least 1.15 GHz (4.85 to 6.0 GHz, 19.8% at 5.8 GHz) at the lower and upper bands, respectively.

1. INTRODUCTION

With the rapid development of wireless communication technology, circularly polarized antennas attract more research interest due to the characteristics of immunity to multi-fading, better weather penetration and more mobility than linearly polarized antenna. Because of the wide-band, simple structure and low profile characteristics, slot antenna becomes a good candidate for designing CP antenna. In order to achieve circularly polarized characteristic, two orthogonal modes with equal amplitude and a phase difference (PD) of 90° must be excited. Several CP slot antennas have been introduced [1–17]. Open slot antenna have been presented and discussed in [1–3]. In [4], a microstrip to CPW-fed structure was introduced to the slot antenna to excite the even and odd modes of circularly polarized operation. Several techniques were introduced to achieve CP characteristic such as stair-shaped slot [5–7], utilizing of asymmetric tuning stub [8, 9], embedding a pair of invert L-shaped strips [10] or circular arc [11] in the opposite corner of the rectangular slot. L-shaped, C-shaped and T-shaped stubs have also been utilized to achieve 3-dB ARBW [12–14]. By feeding an asymmetric T-shaped patch with a coplanar waveguide (CPW) and introducing a grounded strip and an L-shaped strip in the slot, a 3-dB axial ratio bandwidth of 50% can be achieved [13]. The antennas mentioned above have only one ARBW. A dual-band CP was achieved by using an L-shaped radiating patch in which one end was connected to the ground plane, and one corner truncated slot in the ground plane [15]. An antenna with two ARBW, which consists of a stair-like slot, a C-shaped strip on the ground and a tuning stub with a rectangular strip is presented [16]. However, one of the ARBW is narrow. In [17], dual-ARBW was achieved by a simple structure. The antenna was constructed by an L-shaped strip and a U-shaped parasitic strip on the slot near the bottom right corner. By tuning the inverted L-shaped strip and the asymmetric U-shaped strip, the CP radiation characteristic can be achieved.

In this paper, a CPW-fed CP slot antenna with two impedance bandwidths ($|S_{11}| < -10$ dB) and two 3-dB ARBW is proposed. The proposed antenna consists of an asymmetric slot and F-shaped end patch. By tuning the patch, the antenna provides a 3-dB ARBW at the lower band and improves the impedance match at the two operating bands. By cutting a T-shaped notch on the ground plane, the 3-dB ARBW at the upper band can be extended.

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2. ANTENNA DESIGN

The structure of the proposed antenna is illustrated in Fig. 1. The antenna is printed on an FR4 substrate with thickness of 1.6 mm and relative permittivity of 4.4. The antenna is fed by a 50 Ohm coplanar waveguide (CPW) structure with a central strip of $W_f = 2.4$ mm, and the gap between the strip and ground plane is $g = 0.3$ mm. In order to improve the impedance match, two rectangular notches with a length of 2 mm are cut on the CPW structure. The overall dimension of the antenna is $40 \times 46 \times 1.6$ mm³. The proposed antenna was simulated and optimized by the software Ansoft HFSS 13.0.

The design evolution of the antenna is depicted in Fig. 2. The prototype is a conventional rectangular slot antenna. The CPW feeding structure is located in the left bottom of the ground plane with an L-shaped strip connecting to the CPW central strip referring to [17]. An extra stub is added in the middle of the L-shaped strip, which turns it into an F-shaped end patch (type A). Thus, the -10 dB impedance bandwidth at the upper band can be obtained. Fig. 3 depicts the simulated results of different types of the antenna. By modifying the F-shaped end patch, we can not only improve the impedance match at the two operating bands, but also reduce the axial ratio. However, the AR at the operating bands is still greater than 3 dB, and the impedance match at the lower band is not good enough. For further improving the performance, a rectangular notch is introduced on the left side of the ground plane, and two rectangular patches are added to the two right corners of the slot, which makes the slot become asymmetric (type B). The asymmetric slot can provide perturbation to the

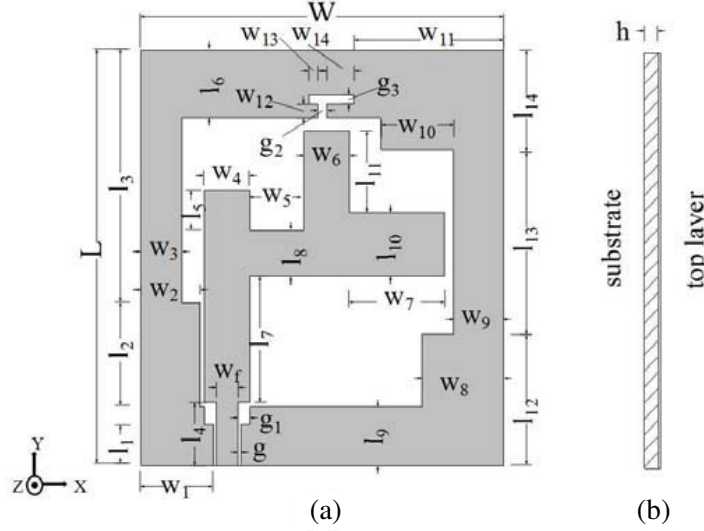


Figure 1. Structure of the proposed antenna.

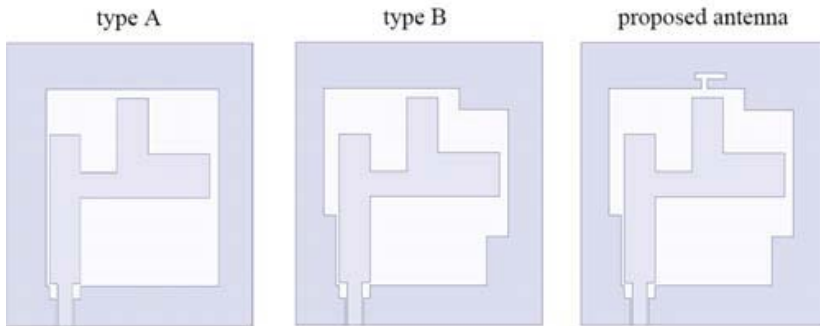


Figure 2. Design evolution of the antenna.

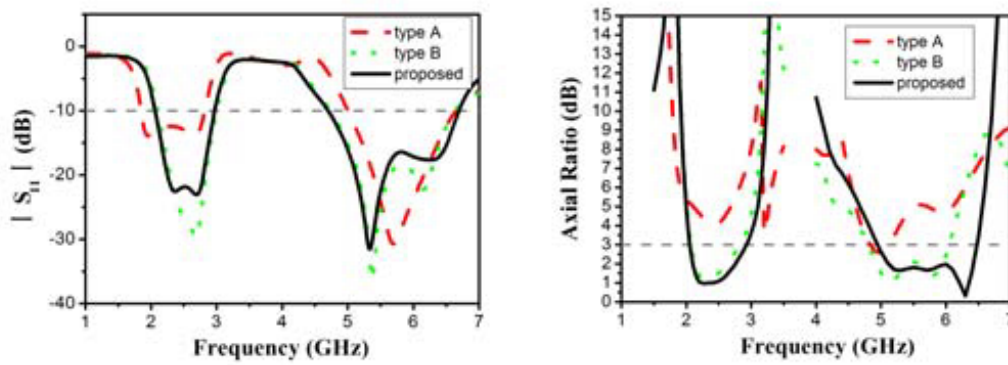


Figure 3. Simulated $|S_{11}|$ and AR for three types of antenna.

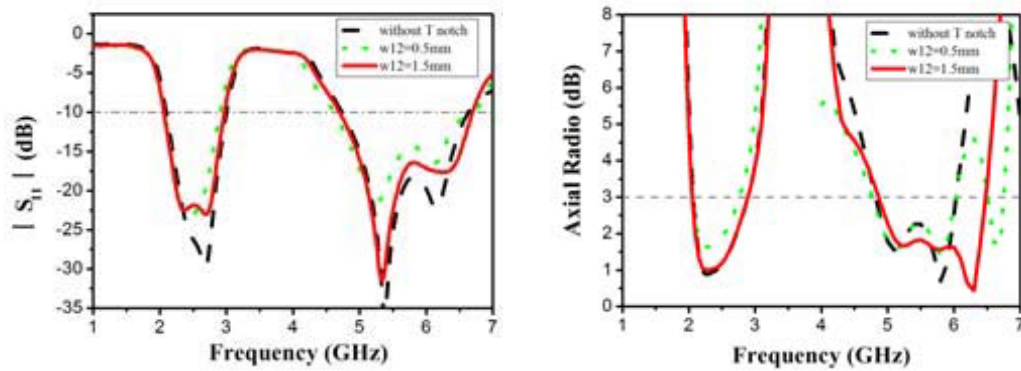


Figure 4. Simulated $|S_{11}|$ and AR for different values of w_{12} .

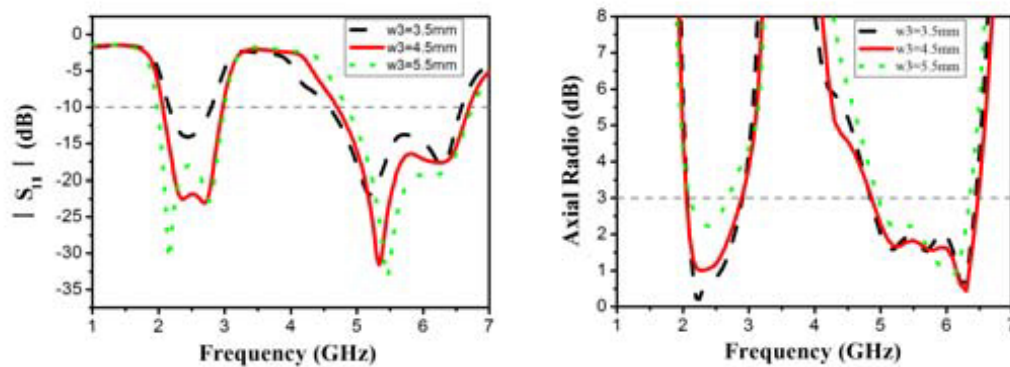
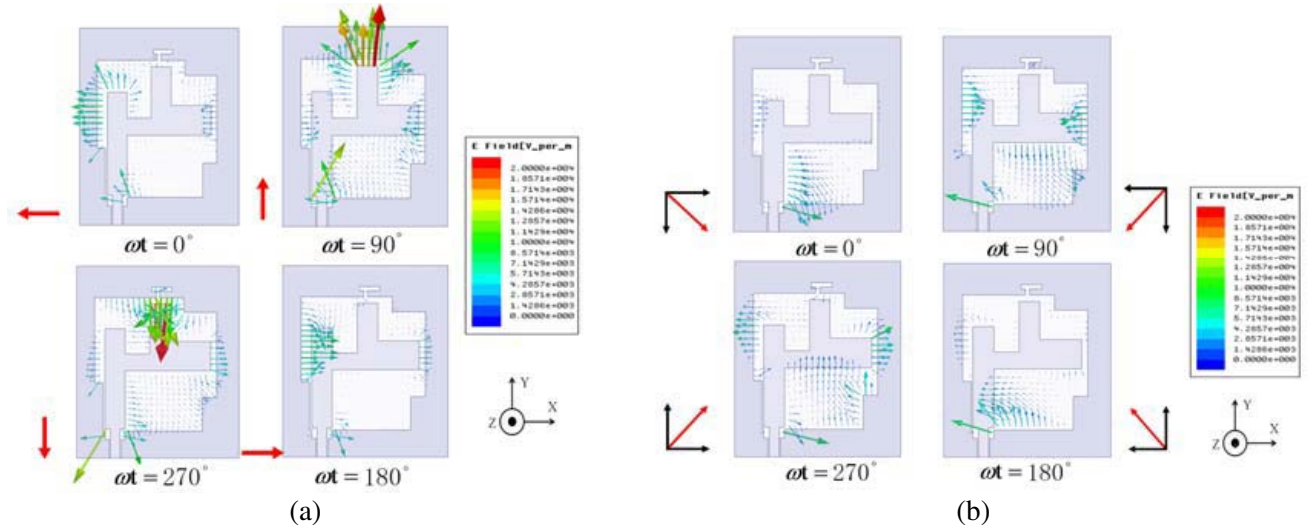


Figure 5. Simulated $|S_{11}|$ and AR for different values of w_3 .

magnetic current distribution, which generates circularly polarized wave. Besides, we can also improve the impedance match by modifying the asymmetric slot. For further expanding the 3-dB ARBW, a T-shaped notch is cut on the ground plane (proposed antenna), which provides perturbation of the current distribution at higher frequencies (around 6.3 GHz). This procedure can effectively reduce the AR at higher frequencies while it has small influence on the performance at the other band. Furthermore, w_{12} is varied in the simulation to reveal the influence of the T-shaped notch. According to the simulated

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

l_1	l_2	l_3	l_4	l_5	l_6	l_7	l_8	l_9
4.5	11.5	28	7	6	7.5	14	4	6.5
l_{10}	l_{11}	l_{12}	l_{13}	l_{14}	w_1	w_2	w_3	w_4
7	9	14.5	20.5	11	8	6.5	4.5	5
w_5	w_6	w_7	w_8	w_9	w_{10}	w_{11}	w_{12}	w_{13}
6	5	10	9	5.5	8	16.5	1.5	1
w_{14}	w_f	g	g_1	g_2	g_3	h	W	L
3	2.4	0.3	1.3	1	1	1.6	40	46

**Figure 6.** E -field distribution of (a) 2.70 GHz, (b) 5.8 GHz.

results shown in Fig. 4, when w_{12} increases from 0.5 mm to 1.5 mm, the ARBW is expanded thanks to the two upper 3-dB ARBW's merged with each other. However, when w_{12} is greater than 1.5 mm, the ARBW becomes narrower. So the value of w_{12} is selected to be 1.5 mm in this design.

For the proposed antenna, parameters w_3 mainly dominate the left part of the slot. Fig. 5 gives the influence of w_3 on $|S_{11}|$ and AR. When w_3 increases from 3.5 mm to 5.5 mm, the gap between ground plane and the F-shaped strip becomes narrower. The AR at the lower band deteriorates. On the contrary, the impedance match becomes better due to the changed capacitance between the patch and ground plane. Hence, the value of w_3 is selected to be 4.5 mm in this design with a tradeoff between lower AR and better impedance match. Finally, a thorough analysis has been performed, and the optimal value of each parameter is selected (listed in Table 1).

In order to analyze the mechanism of circular polarization, the simulated E -field distributions on the slot at different times ($\omega t = 0^\circ, 90^\circ, 180^\circ, 270^\circ$) of 2.70 GHz and 5.8 GHz are given in Fig. 6, respectively. From Fig. 6(a), we can observe that the E -field distribution concentrates on the left gap between the F-shaped patch and ground plane at $\omega t = 0^\circ$ and $\omega t = 180^\circ$. At $\omega t = 0^\circ$, the E -field direction is along $-X$ axis, and it is in the opposite direction ($+X$) at $\omega t = 180^\circ$. At $\omega t = 90^\circ$ and $\omega t = 270^\circ$, the E -field distribution concentrates on the top gap between the F-shaped patch and ground plane. The E -field direction is along $+Y$ axis at $\omega t = 90^\circ$ and $-Y$ axis at $\omega t = 270^\circ$. Hence, the direction of predominant E -field rotates clockwise by time at 2.7 GHz, which describes left-hand circular polarization (LHCP) radiation in the boresight direction (i.e., $+Z$ direction). The E -field distribution is more even at 5.8 GHz than that of 2.7 GHz, which can be observed in Fig. 6(b). Since the predominant

E -field is not in one direction, we observe the composite E -field. At $\omega t = 0^\circ$, there are two directions of the E -field. One is along $+X$ axis and the other along $-Z$ axis. Thus, the composite direction is orientated in about $\varphi = -45^\circ$ relative to the $+X$ axis. Composite directions of E -field at different times are depicted in Fig. 6(b), which also rotates clockwise. It depicts the behavior of LHCP radiation in the boresight direction.

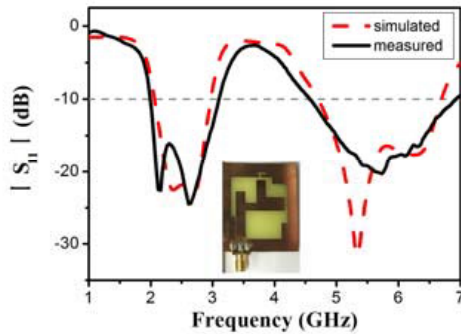


Figure 7. Measured and simulated results of $|S_{11}|$.

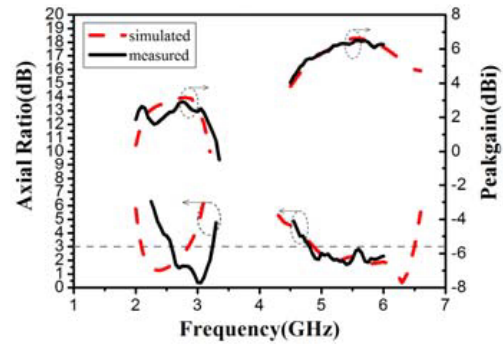


Figure 8. Measured and simulated results of AR and peak gain.

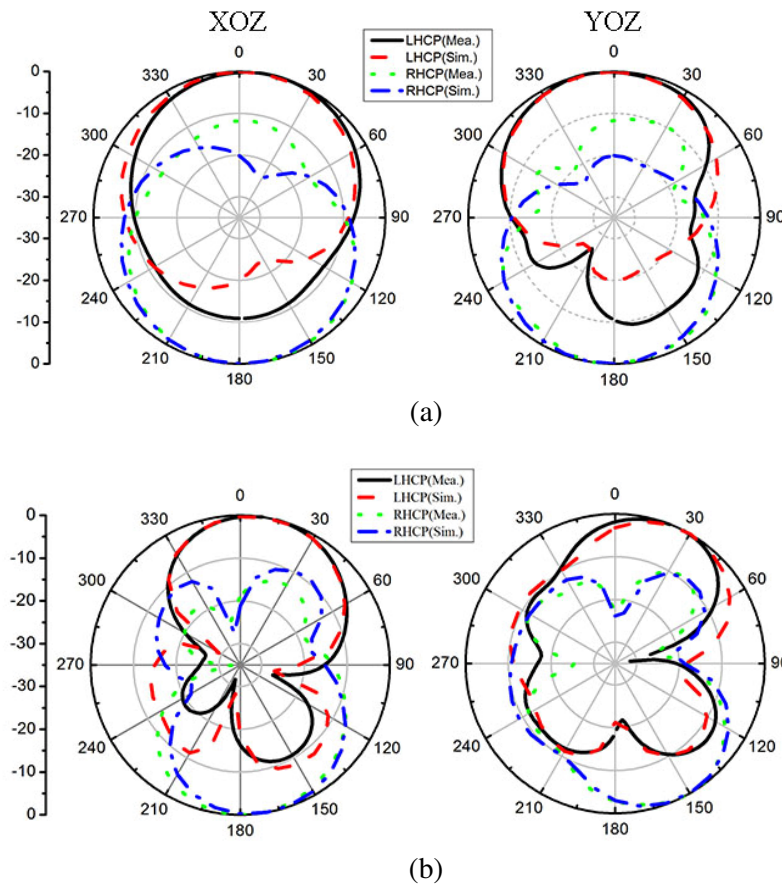


Figure 9. Measured and simulated LHCP and RHCP radiation patterns of the proposed antenna in XOZ and YOZ plane, (a) 2.7 GHz, (b) 5.8 GHz.

3. EXPERIMENT RESULTS

The proposed antenna was fabricated and measured, and the reflection coefficient was measured by using the Agilent vector network analyzer (VNA) E5071C. The measured result is depicted in Fig. 7. The measured impedance bandwidths ($|S_{11}| < -10$ dB) are 1.08 GHz (2.02 to 3.10 GHz, 40% at 2.70 GHz) and 2.31 GHz (4.57 to 6.88 GHz, 39.8% at 5.8 GHz), respectively, which can cover the ISM (Industrial, Scientific, Medical) 2.4 and 5.8 GHz bands, WLAN 2.4 and 5.2/5.8 GHz bands and the radio frequency identification (RFID) 2.45 and 5.8 GHz bands.

Figure 8 depicts the simulated axial ratio and peak gain of the proposed antenna. The measured results have a good agreement with the simulated ones, except that the measured AR at the lower band shifts to higher frequency with about 500 MHz deviation (2.60 to 3.20 GHz, 22.2% at 2.70 GHz). The discrepancy can be attributed to the rough connection between the SMA connector and the fabrication error. It should be noted that the frequency of far-field measurement can only reach 6.0 GHz due to the limitation of testing equipment. Since the AR is lower than 3 dB at 6.0 GHz, we consider that the ARBW is at least 1.15 GHz (4.85 to 6.0 GHz, 19.8% at 5.8 GHz) at the upper band. The measured peak gain of the proposed antenna is around 1.8 dBi and 5.5 dBi at the lower and upper bands, respectively.

The measured and simulated LHCP and RHCP radiation patterns in the XOZ - and YOZ -planes at the frequencies of 2.7 GHz and 5.8 GHz are depicted in Fig. 9. As we can observe, the measured results have a reasonable agreement with the simulated ones. The results indicate that the proposed antenna radiates LHCP wave in the boresight direction at both ARBW.

4. CONCLUSION

In this paper, a coplanar waveguide (CPW)-fed dual-band slot antenna with circular polarization (CP) is presented. In order to achieve CP characteristic, an asymmetric slot and an F-shaped end patch are introduced. According to the measured results, the proposed antenna has two wide impedance bands and two wide ARBW. It also radiates LHCP wave in the boresight direction. These characteristics make the proposed antenna a good candidate for modern wireless communication systems.

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REFERENCES

1. Chen, L.-T., C.-M. Lin, and C.-J. Wang, "Broadband cross-slot antennas with CPW feeding structure," *2012 Asia-Pacific Microwave Conference Proceedings (APMC)*, 316–318, 2012.
2. Wang, C. J., M. H. Shih, and L. T. Chen, "A wideband open-slot antenna with dual-band circular polarization," *IEEE Antennas and Wireless Propagation Letters*, Vol. 14, 1306–1309, 2015.
3. Jan, J.-Y., C.-Y. Pan, K.-Y. Chiu, and H.-M. Chen, "Broadband CPW-fed circularly-polarized slot antenna with an open slot," *IEEE Transactions on Antennas and Propagation*, Vol. 61, 1418–1422, 2013.
4. Xue, H., X. Yang, and Z. Ma, "A novel microstrip-CPW fed planar slot antenna with broadband and circular polarization," *IEEE Antennas and Wireless Propagation Letters*, 1-1, 2015.
5. Nasimuddin, Z. Chen, and X. Qing, "Symmetric-aperture antenna for broadband circular polarization," *IEEE Transactions on Antennas and Propagation*, Vol. 59, 3932–3936, 2011.
6. Gosaltvit, J., C. Mahatthanajatuphat, and P. Akkaraekthalin, "A wideband circular polarization antenna with tuning rectangular slot fed by CPW," *2012 9th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON)*, 1–4, 2012.

7. Li, G., H. Zhai, T. Li, L. Li, and C. Liang, "CPW-fed S-shaped slot antenna for broadband circular polarization," *IEEE Antennas and Wireless Propagation Letters*, Vol. 12, 619–622, 2013.
8. Mao, J.-J., L. Zhang, and Y.-C. Jiao, "Broadband circularly-polarized square slot antenna fed by coplanar waveguide," *2014 3rd Asia-Pacific Conference on Antennas and Propagation (APCAP)*, 463–465, 2014.
9. Mohammadi, S., J. Nourinia, C. Ghobadi, J. Pourahmadazar, and M. Shokri, "Compact broadband circularly polarized slot antenna using two linked elliptical slots for C-band applications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 12, 1094–1097, 2013.
10. Krishna, R. V. S. R. and R. Kumar, "A CPW fed rectangular slot antenna for wideband circular polarization," *2014 IEEE Radio and Wireless Symposium (RWS)*, 94–96, 2014.
11. Saini, R. K. and S. Dwari, "CPW-fed broadband circularly polarized microstrip rectangular slot antenna with circular shaped tuning stub," *2013 International Conference on Microwave and Photonics (ICMAP)*, 1–5, 2013.
12. Rezaeieh, S. A. and A. Abbosh, "Broadband CPW-fed slot antenna with circular polarization for on-body applications at ISM band," *2012 Asia-Pacific Microwave Conference Proceedings (APMC)*, 1184–1186, 2012.
13. Pan, S.-P. and J.-Y. Sze, "A new design for CPW-fed broadband circularly polarized square slot antenna," *2012 Asia-Pacific Microwave Conference Proceedings (APMC)*, 791–793, 2012.
14. Chen, T.-H., D.-Y. Wang, and W.-H. Tu, "Broadband CPW-fed circularly polarized square slot antenna with combining C-shaped strip and asymmetry ground plane," *2013 Asia-Pacific Microwave Conference Proceedings (APMC)*, 1073–1075, 2013.
15. Kushwaha, N. and R. Kumar, "Design of a dual band circular polarized antenna for ZigBee, WLAN and DSRC applications," *2015 IEEE MTT-S International Conference on Microwaves for Intelligent Mobility (ICMIM)*, 1–4, 2015.
16. Chen, Y.-Y., Y.-C. Jiao, G. Zhao, F. Zhang, Z.-L. Liao, and Y. Tian, "Dual-band dual-sense circularly polarized slot antenna with a C-shaped grounded strip," *IEEE Antennas and Wireless Propagation Letters*, Vol. 10, 915–918, 2011.
17. Weng, W. C., J. Y. Sze, and C. F. Chen, "A dual-broadband circularly polarized slot antenna for WLAN applications," *IEEE Transactions on Antennas and Propagation*, Vol. 62, 2837–2841, 2014.