Regular Article

A Very Wideband Circularly Polarized Crossed Straight Dipole Antenna with Cavity Reflector and Single Parasitic Element

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Abstract– **A very wideband circularly polarized (CP) crossed dipole antenna is presented in this paper. The primary radiating element of the antenna consists of two straight dipoles arranged orthogonally through double printed rings. To further enhance the axial ratio bandwidth, a cavity with proper size and single parasitic element are employed to generate two additional bands. The use of cavity reflector is investigated thoroughly, providing a solid framework for designing this type of antennas. The final design with an overall size of $0.92\lambda_0 \times 0.92\lambda_0 \times 0.32\lambda_0$ at the center CP frequency yields a measured -10 dB-impedance bandwidth of 75.2% and 3 dB-axial ratio bandwidth of 67.7%. The proposed antenna exhibits right-handed circular polarization and an average broadside gain of about 8.3 dBi over the CP operating bandwidth.**

Keywords– **circularly polarized, wideband, crossed dipole, parasitic element, cavity reflector.**

1 Introduction

Circularly polarized (CP) antennas have been used extensively in wireless communication due to their capabilities of reducing polarization mismatch and their natural aid against multipath interferences [1]. Demands for low-complex-configuration CP antennas with wideband operation are extremely desired following the trend of high-speed transmission in wireless technology in recent years. In particular, crossed dipole antennas have been demonstrated to produce wideband CP operation without a complicated feeding structure [2, 3]. The methods of using parasitic elements [4], crossed bowtie antennas [5, 6], combination of magnetic and electric dipoles [7, 8], single dipole backed by an elliptical cavity [9], and additional circular and straight strips [10] have been presented to achieve wide axial ratio (AR) bandwidth. Other approaches using an artificial magnetic conductor as a ground plane have also been presented in [11, 12]. However, these antennas so far have limited CP bandwidths (typically around $30 - 40\%$ and up to 51% in [6]), and/or complex configurations that may require complicated fabrication process.

In this paper, a simple design of a CP crossed straight dipole antenna with bandwidth enhancement is presented. The main principle is to produce three adjacent CP bands. One of them is excited by the original crossed dipole while the others are generated by a cavity with an appropriate size and a single parasitic element, respectively. To clarify, the main contribution of the paper is the principle of using two additional CP bands to achieve a significantly enhanced CP bandwidth. Additionally, the use of cavity reflector is also systematically investigated, providing a solid framework for designing this type of antennas. It is noted that although the design in [13] might show a higher operation performance, these features have not been considered or completely discussed. The final prototype of the antenna, with an overall size of $90 \times 90 \times 31$ mm^3 ($0.92\lambda_0 \times 0.92\lambda_0 \times 0.32\lambda_0$ at the center CP frequency 3.1 GHz), has been fabricated and measured to validate the proposed methods. The measurement results indicate that the proposed antenna achieves an impedance bandwidth for $|S11| \leq -10$ dB of 75.2% ($1.95 - 4.31$ GHz) and $3-$dB AR bandwidth of 67.7% ($2.05 - 4.15$ GHz). Furthermore, the antenna exhibits stable broadside radiation patterns which yield an average gain of approximately 8.3 dBi over the entire CP band.

2 Antenna Design and Characteristics

As demonstrated comprehensively in [4, 8], the straight dipoles, which are crossed through double printed rings, can only produce a minimum AR at a single frequency. To achieve better AR bandwidth, multiple parasitic elements [4] or magneto electric dipoles [7, 8] have been employed. However, these approaches do not only complicate the fabrication process but also produce low CP performance. Different configurations

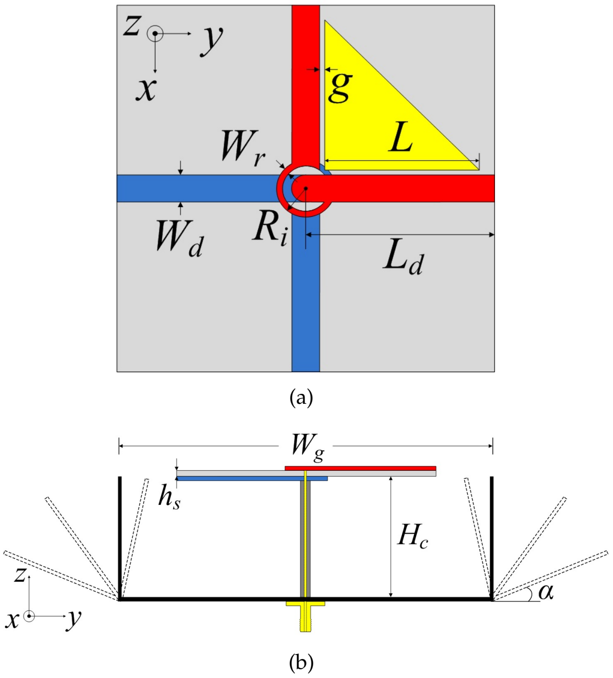


Figure 1. Antenna geometry: (a) top view of the radiator and (b) cross-section of the antenna.

of the radiating elements, such as bow-tie or elliptical shape, have also been proposed which require further optimization and/or additional matching technique [6, 13]. In this paper, straight dipoles with a cavity reflector and a single parasitic element are utilized for an ultimately simple design while still producing a very wide CP bandwidth.

The geometry of the proposed antenna is illustrated in Figure 1. The primary radiator is constructed by two straight dipoles arranged orthogonally and their lengths are chosen so that the real part of their input admittances were equal and the angle of the input admittances differed by 90^o at the desired frequency [2]. The cavity is placed behind the radiator at a proper distance and its size needs to be chosen appropriately to improve the 3−dB AR bandwidth and broadside gain. To further enhance CP operation bandwidth, a single parasitic element is employed to produce one more CP band [14]. The proposed design is printed on both sides of a 0.8128 mm-thick Rogers RO4003 substrate ($\varepsilon_r = 3.38$ and $\tan\delta = 0.0027$) and excited directly by a $50-\Omega$ coaxial cable. The antenna structure has been simulated using a commercially available electromagnetic simulation software (CST MWS) [15] with the frequency-domain solver type. The optimized parameters of the antenna are as follows: $R_i = 3.2$, $W_r = 0.3$, $W_d = 3.8$, $L_d = 26.2$, $L = 21.6$, $h_s = 0.828$, $H_c = 31$, $W_g = 90$ (unit: mm).

For a better understanding of the antenna operational principle, the characteristics of the crossed dipole backed by a cavity are considered first. Figure 2 presents the AR performance of the crossed straight dipole with a planar perfect electric conductor (PEC) as a reflector. The distance from this ground plane to the radiating element is a quarter-wavelength at the center CP frequency. Here the parameter W_g is chosen large enough (90 mm) so that the reflector has minimal effect on the antenna characteristics. As expected, only one AR minimum is observed at 2.2 GHz. Next, the antenna radiation performance is investigated when the reflector is surrounded by four conducting walls. The effects of varying the angle between the cavity wall and the bottom plane, denoted as α, on CP performance are shown in Figure 2(a). Notably, an additional CP band is produced when increasing α and the largest AR bandwidth occurs when $\alpha = 90^o$. Therefore, the overall 3−dB AR bandwidth of the antenna is enhanced substantially to 51.8% (2.0 − 3.4 GHz). Figure 2(b) also demonstrates that the antenna broadside gain improves with the increase of α, especially at the higher frequency band. The variation of the impedance bandwidth with α is insignificant and not shown here for brevity. It can be concluded that apart from better focusing the radiation towards one side of the antenna compared to a planar reflector, the cavity also interacts with the main radiator to generate an additional CP resonance. This feature can be further observed and confirmed

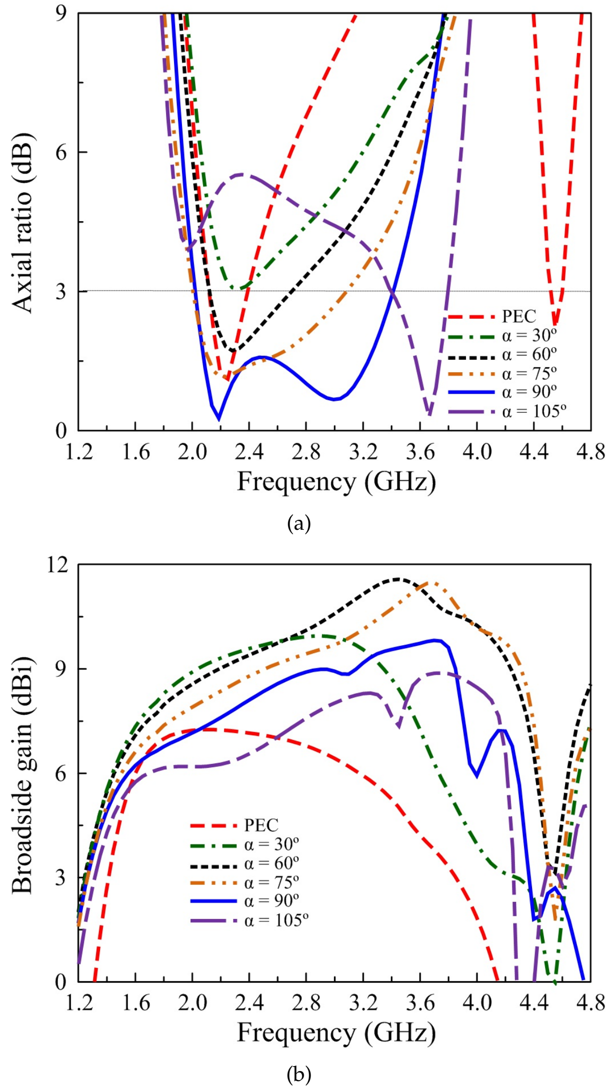


Figure 2. Simulated (a) |S11| and (b) AR of the antenna in different configurations of ground plane.

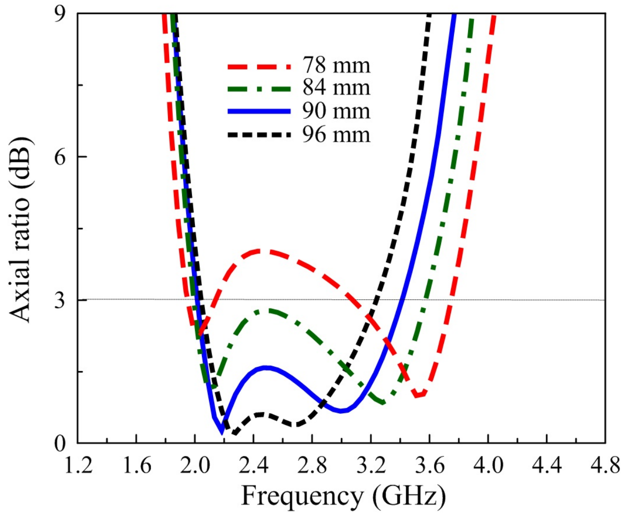
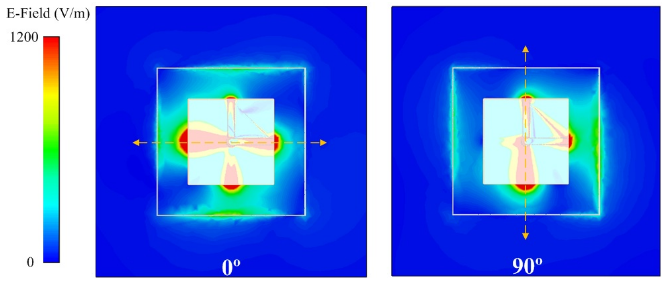
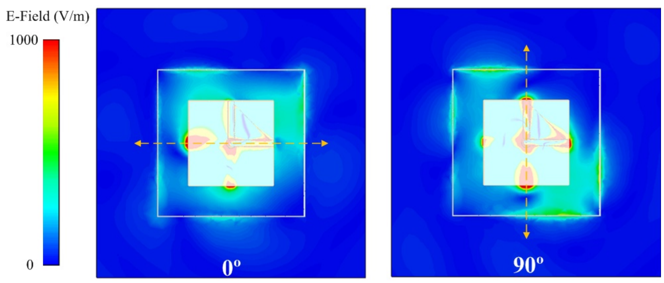


Figure 3. AR characteristic of the antenna against the variation of W_g.



(a)



(b)

Figure 4. Simulated E-field distribution of the antenna (for the case W_g = 78 mm) at (a) 2.0 GHz and (b) 3.6 GHz.

in Figure 3, which shows the impacts of the cavity aperture size (W_g) on the radiation characteristic. The results indicate that the additional CP band moves towards higher frequency with the decrease of the aperture size. Besides, increasing W_g causes the lower CP resonance to slightly increase. The results also show an interesting trade-off between the axial ratio bandwidth and the absolute axial ratio. As a demonstration for the CP excitation sources in the antenna, the E-filed distributions at 2.0 GHz and 3.6 GHz for the case $W_g = 78$ mm are shown in Figure 4. As can be seen from the figure, at both frequencies, the E-field at phase 0^o and phase 90^o are orthogonal. At 2.0 GHz, the field only concentrates at the dipoles, which means only dipole mode is excited, while at 3.6 GHz, the fields are stronger in between the dipole and the cavity, showing that both of them are excited.

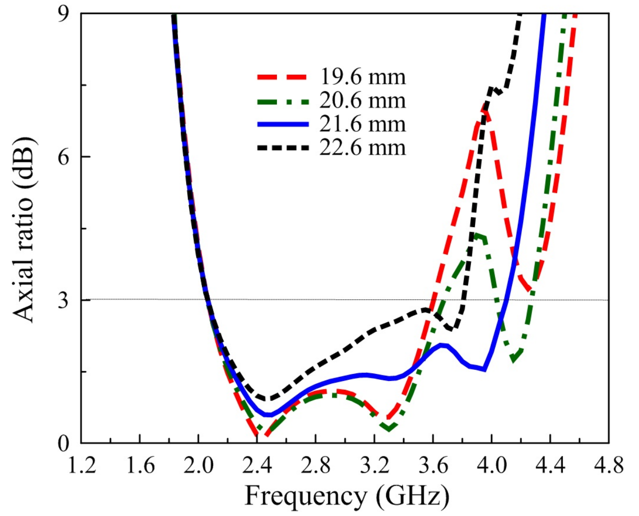


Figure 5. Simulated AR characteristic of the antenna against the variation of parasitic element length L.

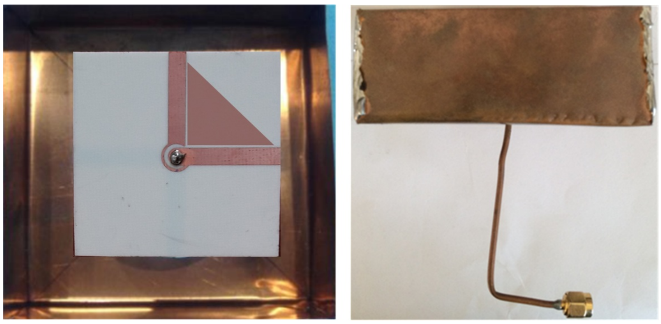
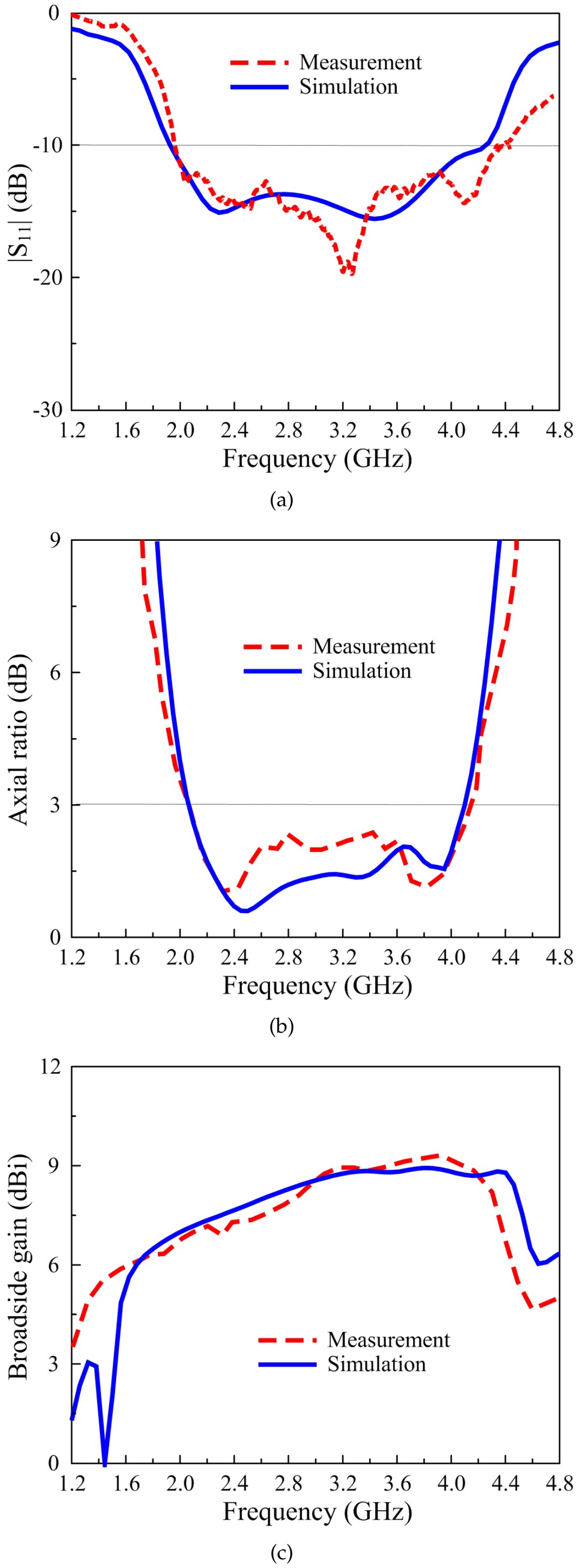


Figure 6. Photograph of the fabricated antenna with top view and side view.

To further enhance the CP radiation, the technique of using a single parasitic element [14] is employed and briefly demonstrated here. The parasitic element is placed adjacent to the top radiating element of the antenna (Figure 1). The simulated AR curves versus the parasitic element's length (L) are shown in Figure 5. It can be seen that the AR performance of the antenna is significantly influenced by the parasitic element size, particularly at higher frequency band. In fact, the parasitic element creates an additional CP band. As L increases, the third CP band is shifted towards the lower frequencies with the decrease of AR. As a compromise between the bandwidth and the AR, parameter L is chosen as 22 mm and a very wide 3−dB AR bandwidth of 66.7% ranging from 2.05 − 4.1GHz is obtained.

3 Measurement Results

The proposed wideband antenna has been fabricated, seen in Figure 6, and validated experimentally. Figure 7(a) shows the measured and simulated $|S11|$ of the proposed antenna. The simulated impedance bandwidth for $|S11| < -10$ dB is 75.4% (1.9 − 4.2 GHz) while the measurement result is 75.2% (1.95 − 4.31GHz). Figure 7(b) presents the measured and simulated ARs versus frequency in the broadside direction (z-direction).

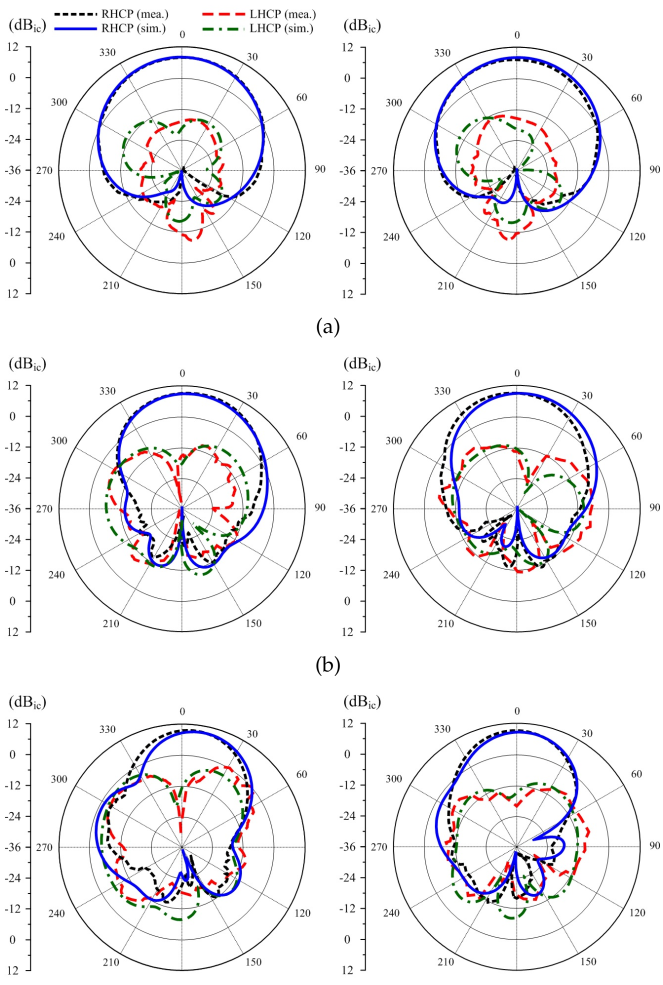


(a)

(b)

(c)

Figure 7. Simulated and measured results of the proposed antenna; (a) $|S11|$, (b) Axial Ratio, and (c) broadside gain.



(a)

(b)

(c)

Figure 8. Simulated and measured gain patterns of the proposed antenna at (a) 2.4 GHz, (b) 3.2 GHz and (c) 4.0 GHz. Left-hand and Right-hand columns plot for $x-z$ plane and $y-z$ plane, respectively.

The figures for measurement and simulation AR are approximately of 67.7% (2.05 − 4.15 GHz) and 66.7% (2.05 − 4.1 GHz), respectively. Figure 7(c) shows that the measured broadside gain varies from 6.8 to 9.5 dBi within the 3−dB AR bandwidth with an average gain of 8.3 dBi. These figures are reasonably matched with the simulation results.

The antenna radiation patterns at three selected frequencies along the operating bandwidth, i.e., 2.4 GHz, 3.2 GHz and 4.0 GHz, in the two principal planes ($\varphi = 0^o$ and $\varphi = 90^o$) are plotted in Figure 8. The measured radiation patterns yield antenna gains of 7.6 dBi, 9.1 dBi, and 9.3 dBi and half-power beamwidths (3 dB beamwidth) approximately of 40^o, 36^o, and 31^o at 2.4 GHz, 3.2 GHz, and 4.0 GHz, respectively. An average front-to-back ratio of more than 15.7 dB over the CP operating bandwidth is obtained. Finally, a measured radiation efficiency of greater than 87% within the CP operation bandwidth is achieved; this is slightly less than the simulated value (> 93%).

A performance comparison among recently reported wideband CP dipole antennas and this work are summarized and given in Table I. It is noted that the antenna's size is defined according to the wavelength at the CP center frequency. It can be seen that the proposed antenna exhibits a large CP operation BW with a simple structure, in comparison with the antennas reported in [16, 17]. Although the $|S11|$ and AR BWs of the antennas reported in [18, 19] are better than those of the proposed antenna, their average gains within the CP band are lower than ours.

Table I
Performance Comparison with Reported Wideband CP Dipole Antennas

Ref.	Method	Antenna size (λ_0^3)	S_{11} BW (%)	AR BW (%)	Average gain (dBi)
[16]	Ground plane and parasitic elements	$1.1 \times 1.1 \times 0.4$	93.1	90.9	5.1
[17]	Dual cavity	$0.86 \times 0.86 \times 0.36$	79.4	66.7	8.5
[18]	Ground plane	$2.06 \times 2.06 \times 0.13$	66.9	55.1	10.4
[19]	Ground plane and vertical plates	$0.63 \times 0.63 \times 0.2$	115.2	106.1	5.0
Prop.	Cavity and parasitic element	$0.93 \times 0.93 \times 0.33$	75.2	67.7	8.3

λ_0 is the wavelength at the CP center frequency.

4 Conclusions

In this paper, a very wideband CP crossed dipole antenna with a cavity reflector and a single parasitic element has been investigated. The study has shown that the performance of the crossed straight dipoles can be improved considerably by properly choosing the size of the cavity and the parasitic element. The antenna exhibits a very wide measured 3−dB AR bandwidth of 67.7% ($2.0 - 4.15$ GHz) and impedance bandwidth of 75.2% ($1.95 - 4.31$ GHz), which show significant improvements compared to existing designs in the literature utilizing similar techniques. Finally, it is also noted that the techniques used in this paper keep the antenna design simple, and therefore do not require extensive optimizations as well as complex fabrication process.

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References

[1] T. S. Rappaport and D. A. Hawbaker, "Wide-band microwave propagation parameters using circular and linear polarized antennas for indoor wireless channels," *IEEE Transactions on Communications*, vol. 40, no. 2, pp. 240–245, 1992.

[2] M. F. Bolster, "A new type of circular polarizer using crossed dipoles," *IRE Transactions on Microwave Theory and Techniques*, vol. 9, no. 5, pp. 385–388, 1961.

[3] S. X. Ta, I. Park, and R. W. Ziolkowski, "Crossed dipole antennas: A review." *IEEE Antennas and Propagation Magazine*, vol. 57, no. 5, pp. 107–122, 2015.

[4] J.-W. Baik, T.-H. Lee, S. Pyo, S.-M. Han, J. Jeong, and Y.-S. Kim, "Broadband circularly polarized crossed dipole with parasitic loop resonators and its arrays," *IEEE Transactions on Antennas and Propagation*, vol. 59, no. 1, pp. 80–88, 2011.

[5] S.-W. Qu, C. H. Chan, and Q. Xue, "Wideband and high-gain composite cavity-backed crossed triangular bowtie dipoles for circularly polarized radiation," *IEEE Transactions on Antennas and Propagation*, vol. 58, no. 10, pp. 3157–3164, 2010.

[6] H. H. Tran and I. Park, "Wideband circularly polarized cavity-backed asymmetric crossed bowtie dipole antenna," *IEEE Antennas and Wireless Propagation Letters*, vol. 15, pp. 358–361, 2016.

[7] M. Li and K.-M. Luk, "A wideband circularly polarized antenna for microwave and millimeter-wave applications," *IEEE Transactions on Antennas and Propagation*, vol. 62, no. 4, pp. 1872–1879, 2014.

[8] S. X. Ta and I. Park, "Crossed dipole loaded with magneto-electric dipole for wideband and wide-beam circularly polarized radiation," *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 358–361, 2015.

[9] X. Bai and S.-W. Qu, "Wideband millimeter-wave elliptical cavity-backed antenna for circularly polarized radiation," *IEEE Antennas and Wireless Propagation Letters*, vol. 15, pp. 572–575, 2016.

[10] R. Xu, J.-Y. Li, and W. Kun, "A broadband circularly polarized crossed-dipole antenna," *IEEE Transactions on Antennas and Propagation*, vol. 64, no. 10, pp. 4509–4513, 2016.

[11] J. Yeo and D. Kim, "Design of a wideband artificial magnetic conductor (amc) ground plane for low-profile antennas," *Journal of Electromagnetic Waves and Applications*, vol. 22, no. 16, pp. 2125–2134, 2008.

[12] H. H. Tran and I. Park, "Wideband circularly polarized low-profile antenna using artificial magnetic conductor," *Journal of Electromagnetic Waves and Applications*, vol. 30, no. 7, pp. 889–897, 2016.

[13] L. Zhang, S. Gao, Q. Luo, P. R. Young, Q. Li, Y.-L. Geng, and R. A. Abd-Alhameed, "Single-feed ultra-wideband circularly polarized antenna with enhanced front-to-back ratio," *IEEE Transactions on Antennas and Propagation*, vol. 64, no. 1, pp. 355–360, 2016.

[14] H. H. Tran, I. Park, and T. K. Nguyen, "Circularly polarized bandwidth-enhanced crossed dipole antenna with a simple single parasitic element," *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 1776–1779, 2017.

[15] CST Microwave Studio, "CST GmbH," *http://www.cst.com*, 2016.

[16] T. K. Nguyen, H. H. Tran, and N. Nguyen-Trong, "A wideband dual-cavity-backed circularly polarized crossed dipole antenna," *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 3135–3138, 2017.

[17] W. Yang, Y. Pan, S. Zheng, and P. Hu, "A low-profile wideband circularly polarized crossed-dipole antenna," *IEEE Antennas and Wireless Propagation Letters*, vol. 16, pp. 2126–2129, 2017.

[18] G. Feng, L. Chen, X. Wang, X. Xue, and X. Shi, "Broadband circularly polarized crossed bowtie dipole antenna loaded with parasitic elements," *IEEE Antennas and Wireless Propagation Letters*, vol. 17, no. 1, pp. 114–117, 2018.

[19] Y. M. Pan, W. J. Yang, S. Y. Zheng, and P. F. Hu, "Design of wideband circularly polarized antenna using coupled rotated vertical metallic plates," *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 1, pp. 42–49, 2018.

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