A Wideband Circularly Polarized Cross-Dipole Antenna

Yejun He, *Senior Member, IEEE*, Wei He, and Hang Wong, *Senior Member, IEEE*

***Abstract*—This letter introduces a wideband circularly polarized (CP) cross-dipole antenna fabricated on a double-layered printed circuit board (PCB) substrate for 2.45-GHz ISM band wireless communications. Unlike conventional cross-dipole antennas, the proposed cross dipole is designed with wide open ends such that both impedance and axial-ratio (AR) bandwidths are enhanced. In addition, to excite the CP radiation effectively, a curved-delay line providing an orthogonal phase difference among the cross-dipole elements is attached at the corners of the sequentially rotated elements. By choosing a proper radius of the curved-delay line, a wide input impedance of the antenna can be realized. The antenna is center-fed by a 50-Ω coaxial cable and is placed above a square reflector to obtain a directional CP radiation pattern. With the advantage of centered feed, symmetric CP radiation patterns can be achieved across the entire operating bandwidth. Simulated and measured results confirm the proposed antenna produced good CP characteristics. An impedance bandwidth (for $\mathrm{VSWR} \leq 2$) of about 50.2% (1.99–3.22 GHz) and the 3-dB AR bandwidth of about 27% (2.30–2.9 GHz) around the center frequency of 2.45 GHz were measured. The antenna has an average CP gain of 6.2 dBic across the operating bandwidth and the maximum gain of 6.8 dBic at the center frequency. The size of antenna is $0.45\lambda \times 0.45\lambda \times 0.24\lambda$.**

***Index Terms*—Circularly polarized, cross-dipole, wideband antenna.**

I. Introduction

CIRCULARLY polarized (CP) antennas are widely used in various modern wireless communications, such as satellite communication [1], radio frequency identification (RFID) [2], wireless local network (WLAN) [3], and the Global Positioning System (GPS) [4] because CP can reduce multipath effects and improve system sensitivities between transmitting antennas and receiving antennas. With the trend of high-speed transmission in wireless communications, requirements for CP antennas with wide impedance bandwidth and wide axial-ratio (AR) bandwidth are highly preferred. Various techniques for wideband CP antenna designs have been reported such as an auxiliary radiator [5], a hybrid dielectric resonator [6], a pyramidal ground structure with a partially enclosed flat conducting wall [7], a microstrip monopole combination [8], a quadrature 3-dB branch line hybrid coupler placed below the ground plane [9], and a lighter-weight slot dipole antenna [10]. However, these antennas have several shortcomings such as complex structure, large size, and low gain. Recently, applying a cross dipole to enhance the AR bandwidth has attracted much attention. A simple cross-dipole CP antenna with a broad AR bandwidth of 15.6% has been proposed in [11]; it uses a sequentially rotated configuration in itself. The antenna in [12] has the 3-dB AR bandwidth of 28.6% by adding four parasitic loops to the simple cross dipole, but the size of these cross-dipole antennas is still large.

In this letter, we propose a new cross-dipole CP antenna. Its size is only 46% of the cross-dipole antenna proposed in [11] and [12], and unlike the conventional cross-dipole antennas, the proposed antenna is designed with wide open ends such that both impedance and AR bandwidths are enhanced. It has an impedance bandwidth (for $\mathrm{VSWR} \leq 2$) of about 48.9% (2.01–3.2 GHz) and a 3-dB AR bandwidth of about 30.6% (2.30–3.05 GHz) around the center frequency of 2.45 GHz. Details of the antenna design are introduced in Section II. The simulation and measurement results are presented in Section III. Section IV is the conclusion.

Manuscript received September 04, 2013; revised November 08, 2013 and November 27, 2013; accepted December 16, 2013. Date of publication January 09, 2014; date of current version January 23, 2014. This work was supported in part by the Fundamental Research Program of Shenzhen City under Grants No. JCYJ20120817163755061, No. JCYJ20120618140206431, and No. JC201105201054A and the National Natural Science Foundation of China under Grant No. 61372077.

Y. He is with the College of Information Engineering, Shenzhen University, Shenzhen 518060, China (e-mail: heyejun@126.com).

W. He is with the Information and Communication Technology Centre, Shenzhen Research Institute, City University of Hong Kong, Hong Kong, and also with the College of Information Engineering, Shenzhen University, Shenzhen 518060, China.

H. Wong is with the State Key Laboratory of Millimeter-wave, City University of Hong Kong, Hong Kong, and also with the Information and Communication Technology Centre, Shenzhen Research Institute, City University of Hong Kong, Hong Kong (e-mail: hang.wong@cityu.edu.hk).

Color versions of one or more of the figures in this letter are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/LAWP.2013.2296324

II. Antenna Design and Parametric Discussion

The geometry of the proposed CP antenna is shown in Fig. 1. The printed cross-dipole antenna is fabricated on both sides of a 55×55-mm^2 FR4 substrate with a thickness of 1.6 mm, a relative permittivity of 4.4, and a loss tangent of 0.02. As illustrated in Fig. 1, the antenna comprises two printed dipoles with wide open ends, a reflector, a curved-delay line, and a semi-rigid coaxial cable. The structures of two printed dipoles are same. One printed dipole with wide open ends is printed on the upper side of the substrate, while the other dipole is on the lower side. The dipole on the bottom is rotated 180° related to the dipole on the upper. The resonant frequency is determined by the value of $w_4 + L_1$. To excite the CP radiation effectively, a curved-delay line providing an orthogonal phase difference among the cross-dipole elements is attached at the corners of the sequentially rotated elements. By choosing a proper radius of the curved-delay line, a wide input impedance of the antenna can be realized. In addition, unlike conventional cross-dipole

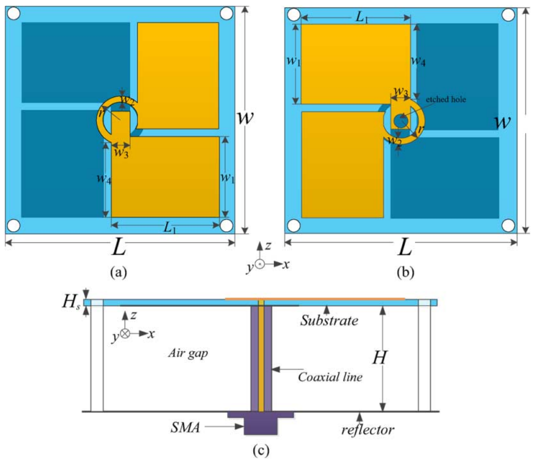

Fig. 1. Geometry of the proposed antenna. (a) Top view, (b) bottom view, and (c) side view of the antenna ($L = 55$ mm, $L_1 = 25.5$ mm, $w = 55$ mm, $w_1 = 19.4$ mm, $w_2 = 1.5$ mm, $w_3 = 4.5$ mm, $w_4 = 18.3$ mm, $r = 5.7$ mm, $H = 28$ mm, $H_s = 1.6$ mm).

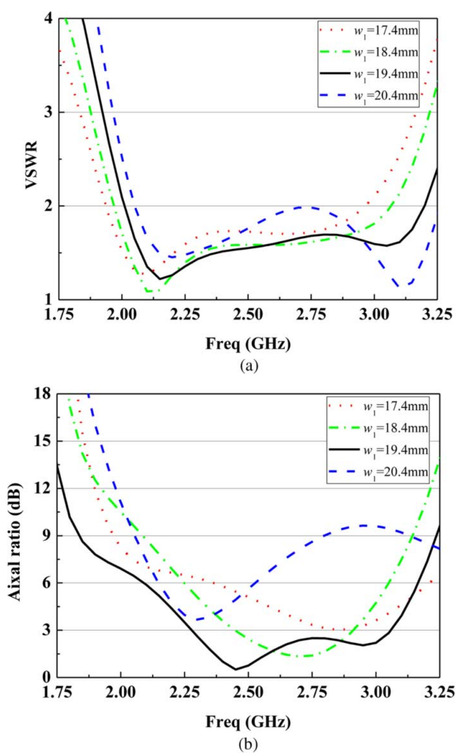

Fig. 2. (a) VSWR and (b) AR as a function of frequency for different widths (w) of the dipole arm.

antennas, both the impedance and AR bandwidths of the proposed cross dipole are enhanced by the wide open ends controlled by the value of w_1. The antenna is center-fed by a 50-Ω coaxial cable and is placed a quarter-wavelength above a square reflector to obtain a directional CP radiation pattern. With the advantage of being center-fed, symmetric CP radiation patterns can be achieved across the entire operating bandwidth. Since the cross dipole is used to generate a circularly polarized wave, the antenna results in a left-hand CP at the broadside direction and obtains a right-hand CP (RHCP) at the back direction due to the bidirectional radiation characteristics of the dipole.

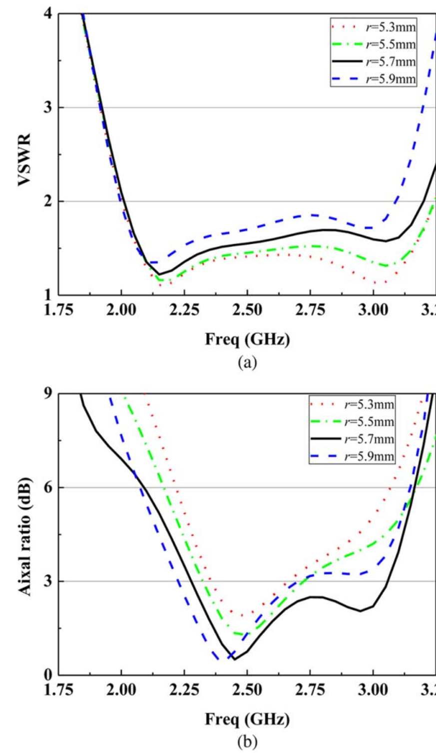

Fig. 3. (a) VSWR and (b) AR as a function of frequency for different radii (r) of the printed ring.

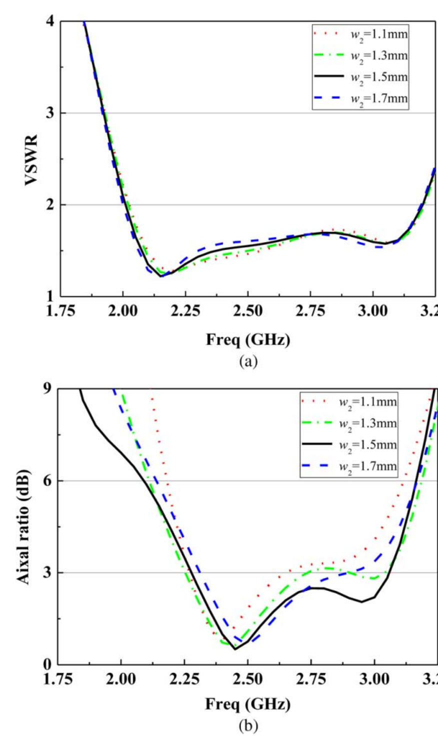

Fig. 4. (a) VSWR and (b) AR as a function of frequency for different widths $(w1)$ of the printed ring.

The design and development of the proposed antenna was achieved by using the commercial electromagnetic (EM) software HFSS. The curved delay provides a 90° phase difference to the dipole arms such that the CP radiation can be generated.

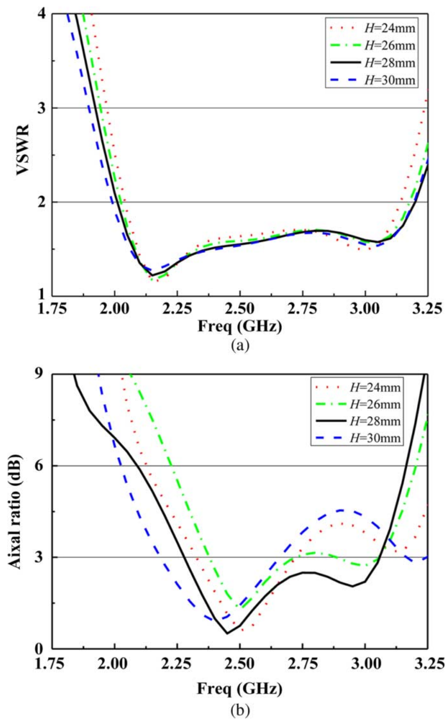

Fig. 5. (a) VSWR and (b) AR as a function of frequency for different heights (H).

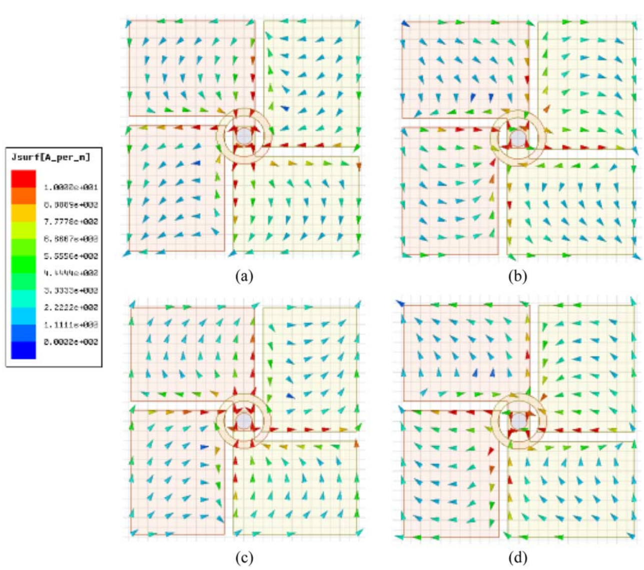

Fig. 6. Simulated current distributions on the proposed antenna at 2.45 GHz. At four phase angles: (a) 0°, (b) 90°, (c) 180°, (d) 270°.

In addition, this method of sequential-rotated excitation obtains a wide impedance bandwidth as well. The simulated VSWR and AR of the antenna as a function of frequency for different widths (w_1) of the dipole arm and different radii (r) and widths (w_2) of the curved-delay line are shown in Figs. 2–4.

All parameters were kept constant except w_1. As shown in Fig. 2, w_1 has a significant influence both on VSWR and AR. The reason for this result is that the width of the open ends would affect not only the input impedance of the proposed antenna but also the phase difference between two orthogonal currents. When $w_1 = 19.4$ mm, the optimal results were obtained in terms of wide impedance and AR bandwidths. Moreover, Fig. 3(a) illustrates that increasing the radius (r) of the curved-delay line causes the impedance bandwidth to reduce slightly. When $r = 5.7$ mm, the optimal result was obtained. Fig. 4 indicates that the parameter w_2 has a considerable influence on AR, but little influence on VSWR. When $w_2 = 1.5$ mm, the optimal result of CP bandwidth was obtained. Fig. 5 illustrates the simulated VSWR and AR of the antenna as a function of frequency for different heights (H) of the antenna. As H varied from 24 to 30 mm in increments of 2 mm and the other parameters were kept constant, the impedance bandwidth slightly varied, but the wide impedance bandwidth characteristics still could be obtained for $\mathrm{VSWR} \leq 2$. For AR response, the optimal AR bandwidth was obtained when $H = 28$ mm. Further changing the value of H, a reduction of AR bandwidth would result. The simulated current distribution of the proposed antenna at 2.45 GHz is shown in Fig. 6. It is observed that the current

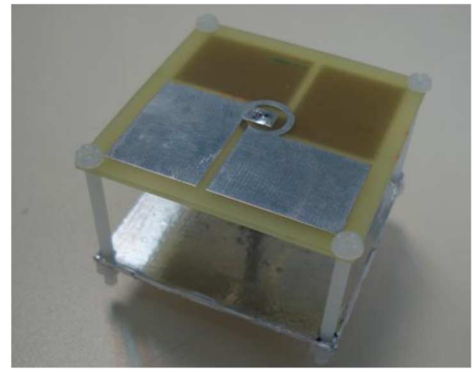

Fig. 7. Prototype of the proposed antenna.

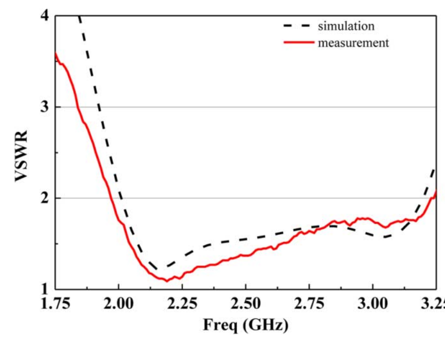

Fig. 8. Measured and simulated VSWR.

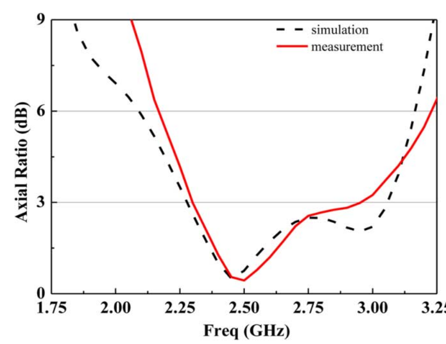

Fig. 9. Measured and simulated axial ratio.

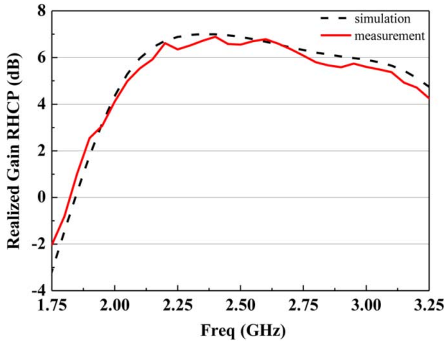

Fig. 10. Measured and simulated gains.

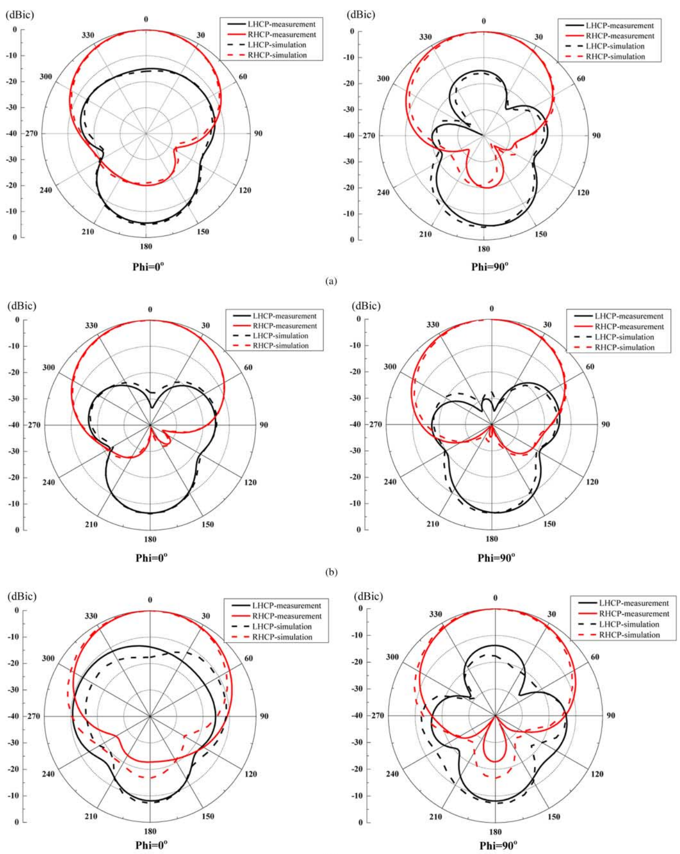

Fig. 11. Radiation patterns of the antenna at (a) 2.30, (b) 2.45, and (c) 2.90 GHz.

flows in a counterclockwise direction, which will contribute to an RHCP.

III. Experimental Results

The top layer of the antenna has been fabricated on a double-sided FR4 substrate, which has a copper thickness of 20 μm. A prototype of the antenna is shown in Fig. 7. The VSWR was measured using an Agilent N5230A vector network analyzer. The axial ratio, gain, and radiation pattern of the prototype were measured by a Satimo StarLab system. Fig. 8 shows the measured and simulated VSWR for the proposed antenna. The measured impedance bandwidth is 50.2% for $\mathrm{VSWR} \leq 2$, ranging from 1.99 to 3.22 GHz, which is consistent with the HFSS simulated results (2.1–3.2 GHz). Measured and simulated ARs are presented in Fig. 9. The measured 3-dB AR bandwidth is about 27%, from 2.3 to 2.9 GHz, and has a discrepancy of 3% with the HFSS simulated. The measured and simulated gains are shown in Fig. 10, which illustrates that the measurement agrees reasonably with the simulation. The peak gain is 6.8 dBic at 2.45 GHz. Fig. 11 shows the radiation patterns at 2.3, 2.45, and 2.9 GHz. The antenna yields stable radiation pattern in both $phi = 0^\circ$ and $phi = 90^\circ$ planes across the operating frequency. The 3-dB AR beamwidth is 88° for both $phi = 0^\circ$ and $phi = 90^\circ$ planes at center frequency of 2.45 GHz. The front-to-back ratio of the directional dipole depends on the size of the ground reflector. In our proposed design, the size of our reflector is identical to the size of the dipole area as shown in Fig. 7. Therefore, the small value in the front-to-back ratio is expected. The back radiation can be enhanced when a larger ground reflector is used.

IV. Conclusion

This letter demonstrated a wideband circularly polarized cross dipole by employing a sequential-rotated excitation in a single coaxial feed. The proposed antenna has a cutting-quarter printed ring that can provide a wide orthogonal phase difference to dipole arms such that it enhances the bandwidths of impedance and axial ratio. The proposed antenna has an impedance bandwidth of about 50.2% and a 3-dB AR bandwidth of about 27%. It has the maximum gain of 6.8 dBic at the broadside direction.

References

[1] E. Arnieri, L. Boccia, G. Amendola, and G. D. Massa, “A compact high gain antenna for small satellite applications,” *IEEE Trans. Antennas Propag.*, vol. 55, no. 2, pp. 277–282, Feb. 2007.

[2] H. L. Chung, X. Qing, and Z. Ning, “Broadband circularly polarized stacked patch antenna for UHF RFID applications,” in *IEEE Antennas Propag. Soc. Int. Symp. Dig.*, Honolulu, HI, USA, Jun. 2007, pp. 1189–1192.

[3] K. L. Wong, F. R. Hsiao, and C. L. Tang, “A low-profile omnidirectional circularly polarized antenna for WLAN access point,” in *IEEE Antennas Propag. Soc. Int. Symp. Dig.*, Monterey, CA, USA, Jun. 2004, pp. 2580–2583.

[4] X. L. Bao, G. Ruvio, M. J. Ammann, and M. John, “A novel GPS patch antenna on a fractal hi-impedance surface substrate,” *IEEE Antennas Wireless Propag. Lett.*, vol. 5, pp. 323–326, 2006.

[5] Z. Chen, W. Toh, and X. Qing, “A microstrip patch antenna with broadened beamwidth,” *Microw. Opt. Technol. Lett.*, vol. 50, no. 7, pp. 1885–1888, Jul. 2008.

[6] G. Massie, M. Caillet, M. Clenet, and Y. M. M. Antar, “A new wideband circularly polarized hybrid dielectric resonator antenna,” *IEEE Antennas Wireless Propag. Lett.*, vol. 9, pp. 347–350, 2010.

[7] C. W. Su, S. K. Huang, and C. H. Lee, “CP microstrip antenna with wide beamwidth for GPS band application,” *Electron. Lett.*, vol. 43, no. 20, pp. 1062–1063, Sep. 2007.

[8] C. Wu, L. Han, F. Yang, L. Wang, and P. Yang, “Broad beamwidth circular polarization antenna: Microstrip-monopole antenna,” *Electron. Lett.*, vol. 48, no. 19, pp. 1176–1178, Sep. 2012.

[9] E. Mireles and S. K. Sharma, “A novel wideband circularly polarized antenna for worldwide UHF band RFID reader applications,” *Prog. Electromagn. Res. B*, vol. 42, pp. 23–44, Jun. 2012.

[10] T. Kumar and A. R. Harish, “Dipole excited wideband circularly polarized slot antenna,” in *IEEE Antennas Propag. Soc. Int. Symp. Dig.*, Chicago, IL, USA, Jul. 2012, pp. 8–14.

[11] J. W. Baik, K. J. Lee, W. S. Yoon, T. H. Lee, and Y. S. Kim, “Circularly polarised printed crossed dipole antennas with broadband axial ratio,” *Electron. Lett.*, vol. 44, no. 13, pp. 785–786, Jun. 2008.

[12] J. W. Baik, T. H. Lee, K. J. 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 Trans. Antennas Propag.*, vol. 59, no. 1, pp. 80–88, Jan. 2011.