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A WIDEBAND TWIN-DIAMOND-SHAPED CIRCULARLY POLARIZED PATCH ANTENNA WITH GAP-COUPLED FEED

Xuehui Li*, Xueshi Ren, Yingzeng Yin, Lu Chen, and Zedong Wang

National Laboratory of Science and Technology on Antennas and Microwaves, Xidian University, Xi'an, Shaanxi 710071, P. R. China

Abstract—A novel twin-diamond-shaped antenna is presented for wideband circularly polarized (CP) radiation. By introducing a twin-diamond-shaped patch and a gap-coupled feed structure, a left-handed circularly polarized (LHCP) antenna in bore-sight direction is obtained. The gap-coupled feed structure consists of a horizontal microstrip arm of approximately $0.285\lambda_0$ at the centre frequency and two small diamonds, which greatly contributes to wideband characteristics. The experimental bandwidths of 10-dB return loss and 3-dB axial ratio (AR) for the antenna prototype are about 20% and 9.2%, respectively. The measured gain is more than 6.8 dBi over the entire bandwidth.

1. INTRODUCTION

Radio frequency identification (RFID) systems generally composed of a reader and a tag which are widely used in a number of industries, such as purchasing and distribution logistics, parking management systems, and manufacturing companies [1]. This reader transmits a carrier signal to a tag and receives a backscattered signal from the tag by an antenna, and this antenna is an indispensable component in the process of transmitting and receiving data. Circularly polarized (CP) antennas have been a hot topic for the applications of RFID readers, mobile communication and navigational systems [2–5] because they allow flexible orientation of the transmitter and the receiver.

In generally, conventional CP microstrip patch antenna can be realized by either using a square patch with truncated sides or

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* Corresponding author: Xuehui Li (lixuehui1220@126.com).

employing dual-feed network for RFID applications requiring circular polarizations. In the past few decades, various kinds of feed networks have been proposed to realize CP antennas. A series feed configuration with an L-shaped strip for a narrow square-ring slot antenna has been applied to achieve 3 dB AR bandwidth of more than 6% [6], but the capacitance value between the bent strip and ground is very critical to obtain a low axial ratio and good impedance matching [7]. Though the CPW-feed can present 3-dB AR bandwidth (68%) and 10-dB return loss bandwidth (107%) [8], its measured bore-sight gain is only 3.0 dBic over the CP bandwidth. A wideband single-fed circularly polarized patch antenna and a wideband circularly polarized antenna with suspended candy-like patch were introduced [9, 10], which obtained a wide impedance and polarization bandwidth but made use of two or three layers substrates leading to difficulty of fabrication and adjustment. Besides that, a suspended patch antenna with indented edge and gap-coupled feed has been presented to realise circular polarization [11]. A proper feed network has become a major challenge for wideband CP antennas [12–20].

In this letter, a single-feed CP antenna is proposed for 2.4 GHz RFID reader applications. Two linked diamond patches with a thick FR4 substrate is fed by a vertical coaxial probe combined with a microstrip line and two relatively small diamonds, which result in excellent circular polarisation behaviour over the entire bandwidth. We achieve favourable impedance bandwidth by optimising the dimensions of the microstrip line and the radiating patch using simulation software. Details of the antenna prototype design and both simulated and measured results are presented and discussed as follows.

2. ANTENNA DESIGN AND DISCUSSIONS

Figure 1 illustrates the configuration of the proposed single-feed CP patch antenna. The radiating patch, microstrip line and two small diamonds are etched on a 0.8 mm-thick FR4 substrate with relative dielectric permittivity of 4.4 and dielectric loss tangent of 0.02. A 105 mm × 105 mm aluminium ground is a height of 14.2 mm (about $0.114\lambda_0$ of centre frequency of the operation frequencies) below the substrate. The air-substrate between the ground and the substrate is conducive to experimental adjustments and reduces the dielectric loss. The parameters of two diagonal lines of a radiating patch with two partially overlapping diamonds are b and $b \times d$. The d is the scale factor of the long side and the short side of a rhombus. The feed network involves a probe fed driving patch1, a microstrip line and a driving patch2. These two driving patches are coupled with the radiating patch by a gap and the microstrip line realises 90° phase difference similar to the function of $\lambda/4$ microstrip transmission line, which realize good LHCP characteristics. However, when the driving patch2 is fed by the probe, the right-handed circularly polarized (RHCP) will be achieved.

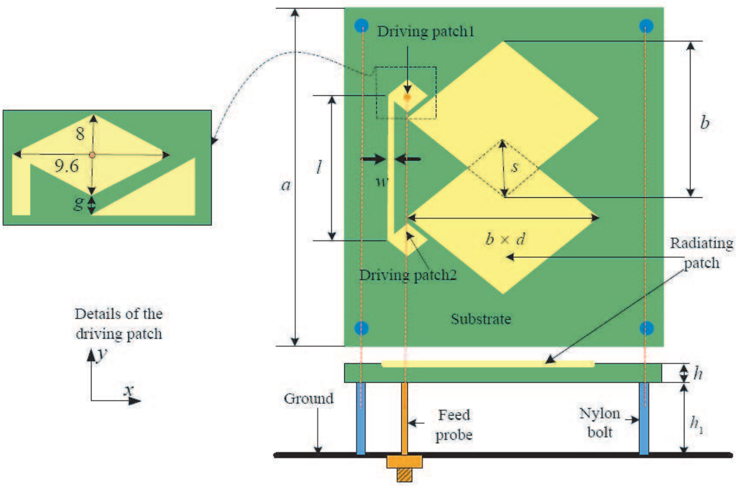

Figure 1. Geometry of the proposed antenna (unit: mm).

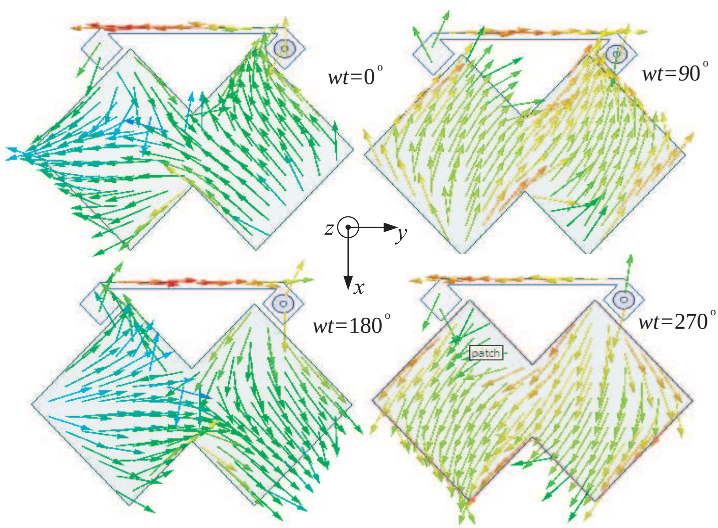

Figure 2. Current distribution of proposed antenna.

The principal parameters including h_1, s and g determine impedance bandwidth and polarization performances. Parameter g is the inclined width of the gap between the radiating patch and the driving patch, which not only decides the coupling strength, but also influences the current distributions on the radiating patch. Time varying current distributions are generated in Fig. 2 at $wt = 0°$, $90°$, $180°$, $270°$. The current amplitude at $wt = 0°$ is almost as same as that at $wt = 180°$, however, their directions are opposite. It is obvious that the current flows from the y-axis into the x-axis, generating a LHCP radiation from the presented antenna. The utilization of the four nylon bolts connects and fixes the metallic ground and the substrate. A prototype of the mentioned CP antenna is depicted in Fig. 1, and the optimized parameters are $a = 75$ mm, $b = 38$ mm, $s = 6.8$ mm, $w = 1.5$ mm, $l = 35.6$ mm, $g = 1.6$ mm, $h_1 = 14.2$ mm, $d = 1.2$.

The proposed antenna has been simulated using the high frequency structure simulator (HFSS) software. The diagonal line of overlapping small diamond s, the distance g and the height h_1 between the substrate and the ground has an obvious effect on CP characteristics. Parameter s determines the centre frequency of the shown antenna and the simulated results are shown in Fig. 3. The centre frequency of the 10-dB working band will move to higher frequency and the impedance match will be better by increasing g, the corresponding reflection coefficients and axial ratios for different g values are given in Fig. 4 and Fig. 5. However, the centre frequency of the S_{11}s will move to lower frequency and the impedance match will be worse by increasing h_1 as depicted in Fig. 6. The axial ratios for different h_1 values are plotted in Fig. 7. The optimal dimensions will be $s = 6.8$ mm, $g = 1.6$ mm, $h_1 = 14.2$ mm due to the resonance at 2.4 GHz for RFID applications.

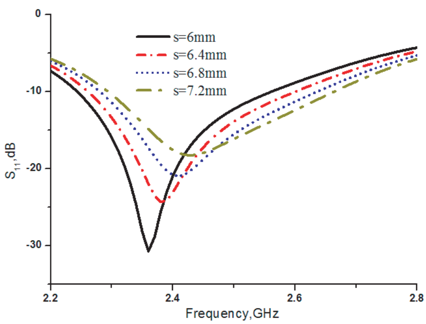

Figure 3. S_{11}s for different s values (while $g = 1.6$ mm, $h_1 = 14.2$ mm).

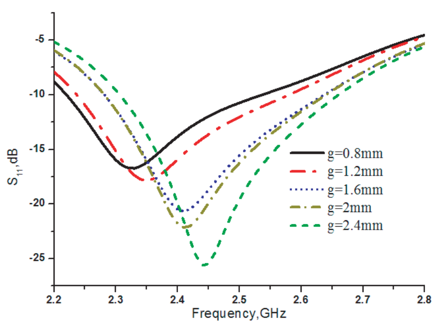

Figure 4. S_{11}s for different g values (while $s = 6.8$ mm, $h_1 = 14.2$ mm).

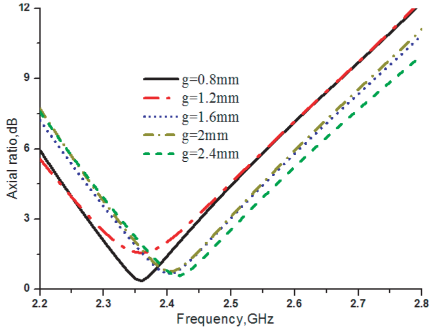

Figure 5. Axial ratios for different g values (while $s = 6.8\,\text{mm}$, $h_1 = 14.2\,\text{mm}$).

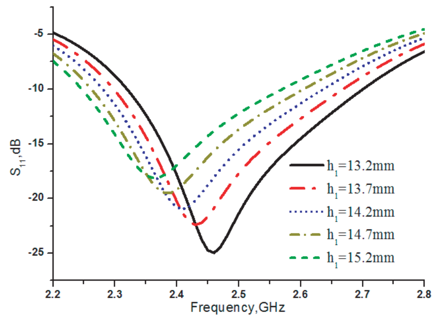

Figure 6. S_{11}s for different h_1 values (while $s = 6.8\,\text{mm}$, $g = 1.6\,\text{mm}$).

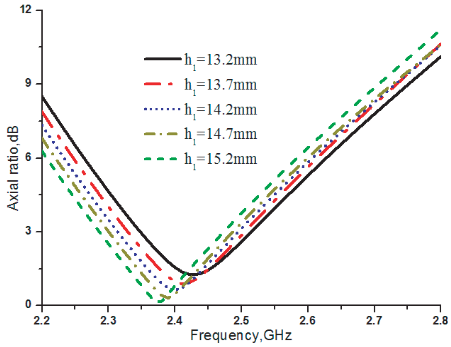

Figure 7. Axial ratios for different h_1 values (while $s = 6.8\,\text{mm}$, $g = 14.2\,\text{mm}$).

3. MEASUREMENT RESULTS

The antenna model has been fabricated and its photographs are shown in Fig. 8. The antenna was measured in anechoic chamber using Agilent E8357A vector network analyzer. Fig. 9 compares the simulated and measured return loss and axial ratio of the designed antenna. The simulated and measured bandwidths of 10-dB return loss are around 15% (2.28–2.64 GHz) and 20% (2.15–2.62 GHz), and those of axial ratio are 7.5% (2.32–2.49 GHz) and 9.2% (2.31–2.53 GHz). The discrepancies between the measured results and the simulated results might be attributed to the fact that the response of the antennas is sensitive to the exact location of the gap-coupled feed, which is subject to fabrication tolerances in the fabrication process. Positional errors of assembling and soldering may give rise to the differences of the simulated and the measured curves. The measured and simulated x-z plane and y-z plane radiation patterns at 2.4 GHz (the frequency of the least AR in simulation) and 2.47 GHz (the frequency of the least AR in measurement) are shown in Fig. 10 and Fig. 11. The measured results show a good agreement with the simulated results which validates the design strategy practically. The measured maximum gain in bore-sight direction is 8.0 dBi at 2.43 GHz as shown in Fig. 12. Measured bore-sight gain is more than 6.8 dBi over the 3-dB AR bandwidth.

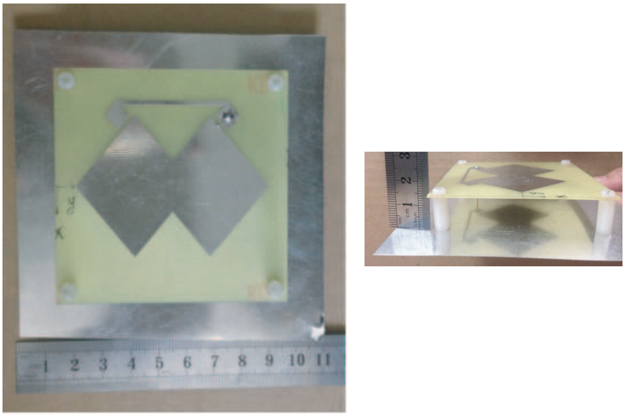

Figure 8. Photographs of the fabricated antenna.

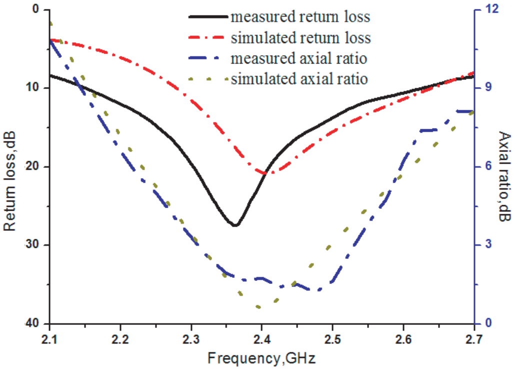

Figure 9. Measured and simulated return loss and axial ratio.

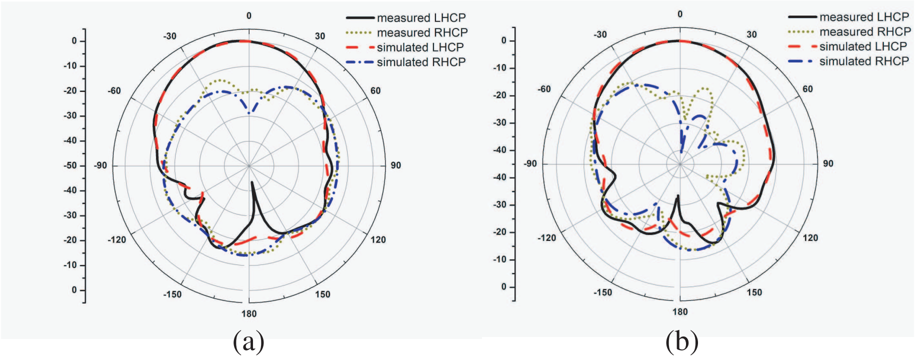

Figure 10. Measured and simulate radiation patterns at 2.4 GHz. (a) x-z plane; (b) y-z plane.

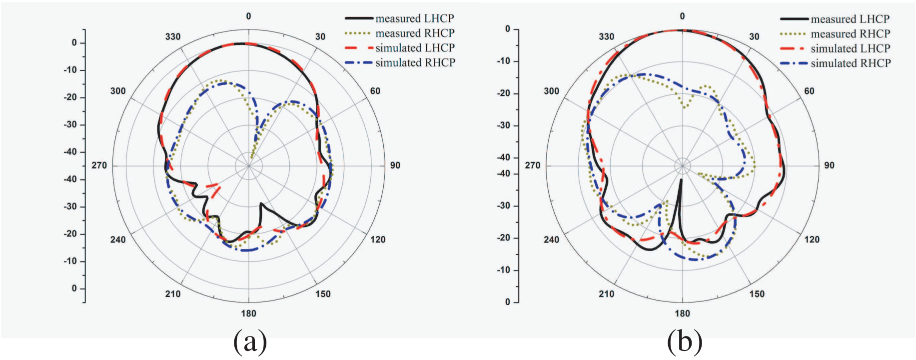

Figure 11. Measured and simulate radiation patterns at 2.47 GHz. (a) x-z plane; (b) y-z plane.

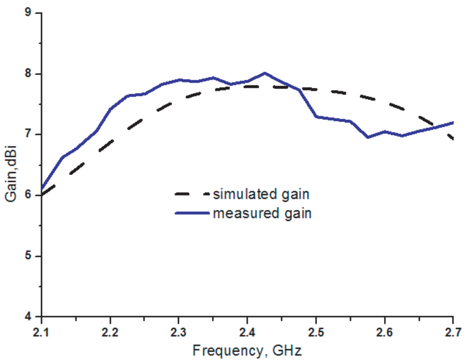

Figure 12. Simulated and measured gain.

4. CONCLUSION

A novel LHCP antenna structure with gap-coupled feed has been investigated in this paper. By a probe feed network containing two small diamonds and a microstrip line in the horizontal direction, a 2.4 GHz LHCP RFID reader antenna with wideband operation is acquired. The measured results cover 20% 10-dB impedance bandwidth ranging from 2.15 GHz to 2.62 GHz and 9.2% 3-dB axial ratio bandwidth from 2.31 GHz to 2.53 GHz. The broad impedance bandwidth and good CP radiation characteristic prove it is a proper candidate for 2.4 GHz reader antenna.

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REFERENCES

1. Finkenzeller, K., *RFID Handbook*, 2nd edition, Wiley, New York, 2004.
2. Tiang, J.-J., M. T. Islam, N. Misran, and J. S. Mandeep, "Circular microstrip slot antenna for dual-frequency RFID application," *Progress In Electromagnetics Research*, Vol. 120, 499–512, 2011.
3. Wang, P., G. Wen, J. Li, Y. Huang, L. Yang, and Q. Zhang, "Wideband circularly polarized UHF RFID reader antenna with high gain and wide axial ratio beamwidths," *Progress In Electromagnetics Research*, Vol. 129, 365–385, 2012.
4. Rezaeieh, S. A. and M. Kartal, "A new triple band circularly polarized square slot antenna design with crooked T and F-shape strips for wireless applications," *Progress In Electromagnetics Research*, Vol. 121, 1–18, 2011.
5. Exposito-Dominguez, G., J.-M. Fernandez Gonzalez, P. Padilla de la Torre, and M. Sierra-Castaner, "Dual circular polarized steering antenna for satellite communications in X band," *Progress In Electromagnetics Research*, Vol. 122, 61–76, 2012.
6. Row, J.-S., "The design of a squarer-ring slot antenna for circular polarization," *IEEE Trans. Antennas Propag.*, Vol. 53, No. 6, 1967–1972, Jun. 2005.
7. Tseng, L.-Y. and T.-Y. Han, "Circular polarization square-slot antenna for dual-band operation," *Microwave and Optical Technology Letters,* Vol. 50, No. 9, 2307–2309, Sep. 2008.

8. Nasimuddin, Z. N. Chen, and X. Qing, "Symmetric-aperture antenna for broadband circular polarization," *IEEE Trans. Antennas Propag.*, Vol. 59, No. 1, 3932–3936, Jan. 2011.
9. Sun, L., Y.-H. Huang, J.-Y. Li, and Q.-Z. Liu, "A wideband circularly polarized candy-like patch antenna," *Journal of Electromagnetic Waves and Applications*, Vol. 25, Nos. 8–9, 1113–1121, 2011.
10. Sudha, T., T. S. Vedavathy, and N. Bhat, "Wideband single-fed circularly polarized patch antenna," *Electron Lett.*, Vol. 40, No. 11, 648–649, 2004.
11. Deng, J.-Y., L.-X. Guo, T.-Q. Fan, Z.-S. Wu, Y.-J. Hu, and J. H. Yang, "Wideband circularly polarized suspended patch antenna with indented edge and gap-coupled feed," *Progress In Electromagnetics Research*, Vol. 135, 151–159, 2013.
12. Yang, S. S., K.-F. Lee, A. A. Kishk, and K.-M. Luk, "Design and study of wideband single feed circularly polarized microstrip antennas," *Progress In Electromagnetics Research*, Vol. 80, 45–61, 2008.
13. Chang, T. N. and J.-H. Jiang, "Enhance gain and bandwidth of circularly polarized microstrip patch antenna using gap-coupled method," *Progress In Electromagnetics Research,* Vol. 96, 127–139, 2009.
14. Joseph, R. and T. Fukusako, "Circularly polarized broadband antenna with circular slot on circular groundplane," *Progress In Electromagnetics Research C*, Vol. 26, 205–217, 2012.
15. Tsai, C.-L., "A coplanar-strip dipole antenna for broadband circular polarization operation," *Progress In Electromagnetics Research*, Vol. 121, 141–157, 2011.
16. Wu, G.-L., W. Mu, G. Zhao, and Y.-C. Jiao, "A novel design of dual circularly polarized antenna fed by L-strip," *Progress In Electromagnetics Research*, Vol. 79, 39–46, 2008.
17. Sze, J.-Y. and S.-P. Pan, "Design of broadband circularly polarized square slot antenna with a compact size," *Progress In Electromagnetics Research*, Vol. 120, 513–533, 2011.
18. Xu, F., X.-S. Ren, Y.-Z. Yin, and S.-T. Fan, "Broadband single-fed single-patch circularly polarized microstrip antenna," *Progress In Electromagnetics Research C,* Vol. 34, 203–213, 2013.
19. Wang, C.-J. and C.-H. Lin, "A circularly polarized quasi-loop antenna," *Progress In Electromagnetics Research,* Vol. 84, 333–348, 2008.

20. Li, J.-F., B.-H. Sun, H.-J. Zhou, and Q.-Z. Liu, "Miniaturized circularly-polarized antenna using tapered meander-line structure," *Progress In Electromagnetics Research,* Vol. 78, 321–328, 2008.