

A Compact Circularly Polarized Microstrip Antenna with Bandwidth Enhancement

Lumei Li¹, Jianxing Li^{1, 2, *}, Bin He¹, Songlin Zhang¹, and Anxue Zhang^{1, 3}

Abstract—A novel compact circularly polarized microstrip antenna (CPMA) with bandwidth enhancement is proposed and studied. By employing capacitive loading and inductive loading, the size miniaturization is achieved. The cross-shaped aperture in the ground plane is able to excite two orthogonal modes. The near-equal amplitudes and 90° phase difference between these two modes are realized by properly designing the feed network, i.e., a 0° – 90° hybrid comprising a 3-dB Wilkinson power divider cascaded with a 90° phase shifter. The proposed antenna exhibits a global bandwidth of 11.5% ranging from 1.88 GHz to 2.11 GHz with an overall size $50\text{ mm} \times 50\text{ mm} \times 6.8\text{ mm}$ ($0.33\lambda_0 \times 0.33\lambda_0 \times 0.045\lambda_0$). The global bandwidth is defined where return loss is larger than 10 dB, broadside axial ratio (AR) smaller than 3 dB, and gain above 0 dBic.

1. INTRODUCTION

Microstrip antennas have been widely employed due to their obvious advantages such as low profile, light weight, and relatively low manufacturing cost. Likewise, circular polarization (CP) possesses some significant features, such as reduction of the effects of multipath signals and resistance to bad weather conditions [1–4]. Circularly polarized microstrip antennas (CPMAs) combine the advantages of both microstrip antenna and circular polarization, thus have aroused extensive interest in the research field.

The realization of CP patch antenna through coupling slots in the ground plane demonstrates several outstanding advantages, hence has been reported numerous times [5–11]. Firstly, since the feed network has no direct contact with the radiating patch, the radiation pattern can avoid being interfered and low cross-polarization is generated. Secondly, the antenna substrate can be different from the feed substrate which facilitates the broadband realization. Last but not least, the complicated feed network can be designed and employed to improve the performance of the CP antenna since one ground plane separates it from the radiating patch [12]. Generally, to increase the bandwidth of the antenna, a thick substrate with low permittivity is required for the radiating patch. In this case, a large coupling slot is indispensable to achieve impedance matching. As a result, the back radiation pattern of the antenna is increased and the antenna performance is degraded [13]. So it is important to balance the coupling strength through the aperture and the deterioration of the front-to-back ratio by choosing appropriately the size of the slot.

The CP patch antenna with single feed usually has the advantage of miniaturization because of its simple structure, whereas exhibits narrow bandwidth performance [14–16]. In addition, for many applications like portable global navigation satellite systems (GNSS), compactness is becoming an increasingly important requirement. One method has been proposed to realize miniaturization, but only for linear polarization application [17].

Received 13 May 2016, Accepted 7 July 2016, Scheduled 15 July 2016

* Corresponding author: Jianxing Li (jianxingli.china@gmail.com).

¹ School of Electronic and Information Engineering, Xi'an Jiaotong University, Xi'an, Shaanxi 710049, China. ² Department of Electrical and Computer Engineering, Duke University, Durham, NC 27708, USA. ³ Beijing Center for Mathematics and Information Interdisciplinary Science (BCMIIIS), Beijing 100048, China.

In this paper, a novel design of a single-feed compact cross-aperture coupled CPMA with bandwidth enhancement is presented. The capacitive loading offered by the shorting strips and the radiating patch are combined with the inductive loading offered by the shorting pins to miniaturize the antenna. A 0° – 90° hybrid served as the feed network is aimed to improve the global bandwidth.

2. ANTENNA DESIGN

The proposed single-feed compact CPMA, presented in Fig. 1, is composed of two-layer printed circuit boards (PCBs). The square radiating patch is printed on the top side of the upper layer (RO4003C, $\epsilon_{r1} = 3.38$ and $\tan \delta = 0.0027$). The ground plane with cross-shaped aperture etched is printed on the top side of the lower layer (Taconic CER-10, $\epsilon_{r2} = 10$ and $\tan \delta = 0.0035$). And the 0° – 90° hybrid is printed on the bottom side of the lower layer. These two layers are connected by four arrays of three shorting pins. Each array is placed under each shorting strip which is printed on the bottom side of the upper layer and aligned with the edge of the radiating patch. The optimized geometrical parameters of the proposed antenna are finally determined as follows (unit: mm): $h_1 = 1.524$, $h_2 = 3.8$, $h_3 = 1.524$, $L_g = 50$, $L_s = 22$, $L_t = 6$, $L_r = 29.6$, $L_p = 19$, $W_s = 1.5$, $W_p = 3.1$, $W_1 = 1.4$, $W_2 = 0.6$, $R_v = 0.6$, and $D_v = 4.8$. The parameter R_v corresponds to the radius of the pins. Therefore, the pin diameter is 1.2 mm. During the implementation, the metal wire of radius R_v has been truncated with equal length h_2 and taken as the pins.

The model is built and simulated at the center frequency 2 GHz by using High Frequency Structure Simulator (HFSS). Fig. 2 shows the current distribution on the radiating patch by time. The red arrow shows the current rotates clockwise with time which indicates that the antenna is a right-handed circularly polarized (RHCP) antenna. The reason why CP can be generated is mainly because the cross-shaped aperture is able to excite two orthogonal modes with a phase difference of 90° . The shorting strips and the radiating patch constitute capacitive loading while the shorting pins can be regarded as inductive loading. Thus, the antenna size is reduced as a result of the extension of the equivalent surface current path which distributes on the radiating patch and the vertical pins.

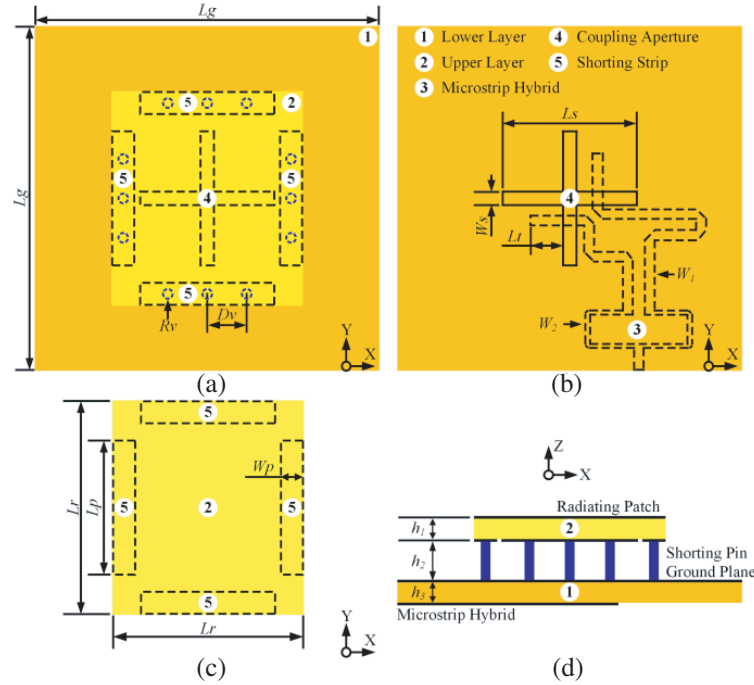


Figure 1. Geometry of the single-feed compact cross-aperture coupled CPMA. (a) Top view. (b) Lower layer. (c) Upper layer. (d) Side view.

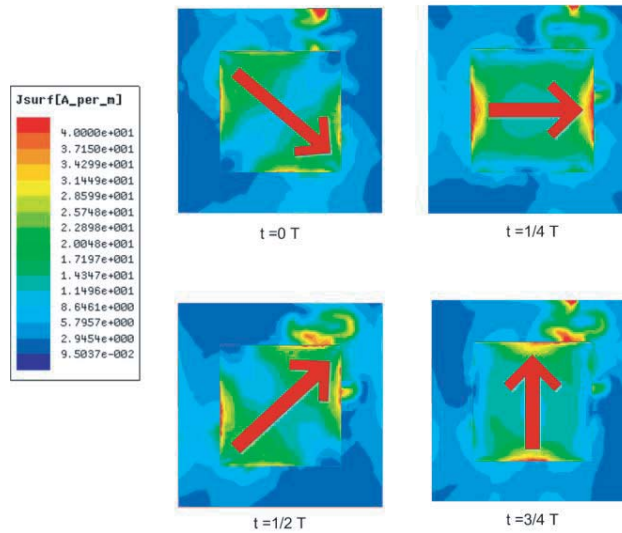


Figure 2. Equivalent current distribution with time.

3. RESULTS AND DISCUSSIONS

The proposed single-feed compact cross-aperture coupled CPMA has been implemented as shown in Fig. 3. The simulated and measured return loss and broadside AR against frequency for the proposed antenna are shown in Fig. 4. And Fig. 5 indicates the simulated and measured RHCP gain in the broadside direction.

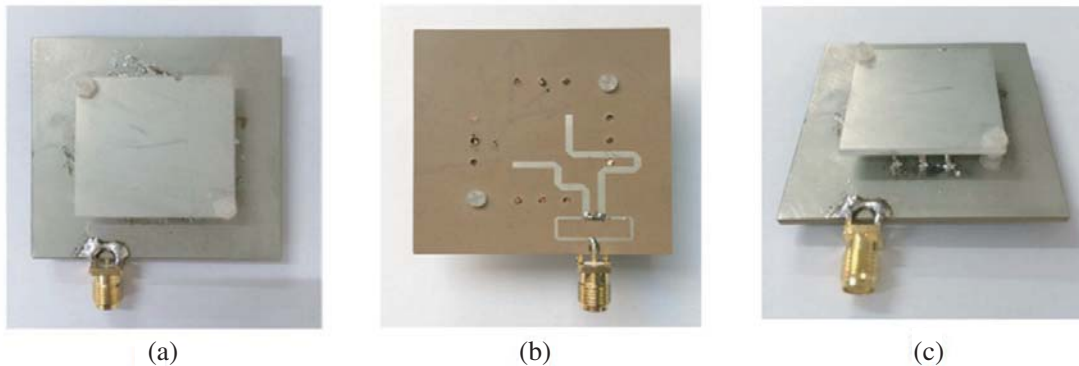


Figure 3. Photograph of proposed antenna. (a) Top view. (b) Back view. (c) Side view..

In Fig. 4, simulated results show that the global bandwidth is 11.8% ranging from 1.862 GHz to 2.096 GHz. The corresponding 10-dB return loss bandwidth, 3-dB AR bandwidth, 0 dBic gain bandwidth are 18.1% from 1.767 GHz to 2.119 GHz, 26.4% from 1.666 GHz to 2.172 GHz, 11.8% from 1.862 GHz to 2.096 GHz respectively. By comparison, the global bandwidth has been improved by over eight times for almost the same antenna size owing to the employment of a 0° – 90° hybrid rather than the microstrip line feed positioned along the 45° diagonal line direction [10]. In addition, we should note that the 0 dBic gain bandwidth is totally included in the 10-dB return loss bandwidth and the 3-dB AR bandwidth, therefore the global bandwidth has the potential to be extended by some other gain-bandwidth-widen methods.

Concerning the measured results, the 10-dB return loss bandwidth, 3-dB AR bandwidth, 0 dBic

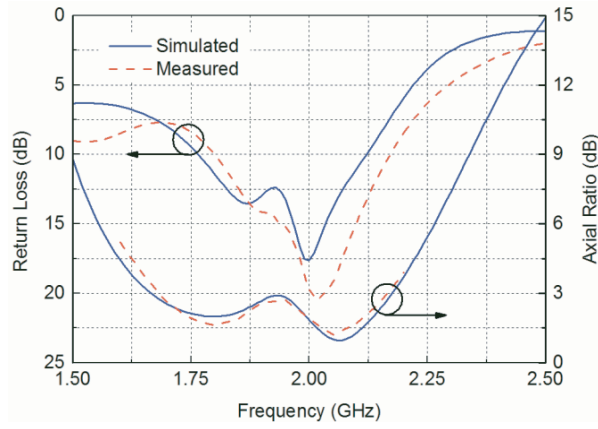


Figure 4. Simulated and measured return loss and broadside AR of the proposed CPMA.

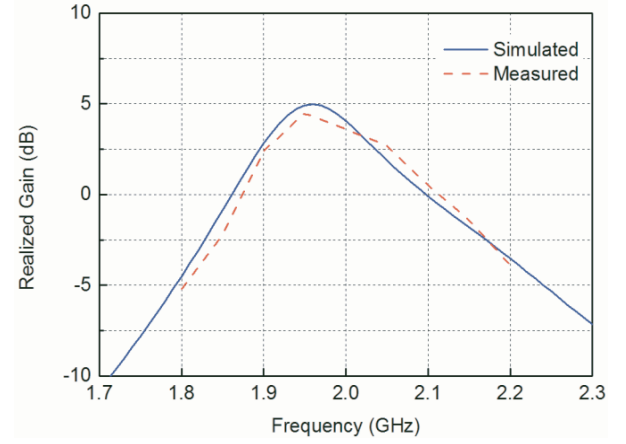


Figure 5. Simulated and measured RHCP gain in the broadside direction.

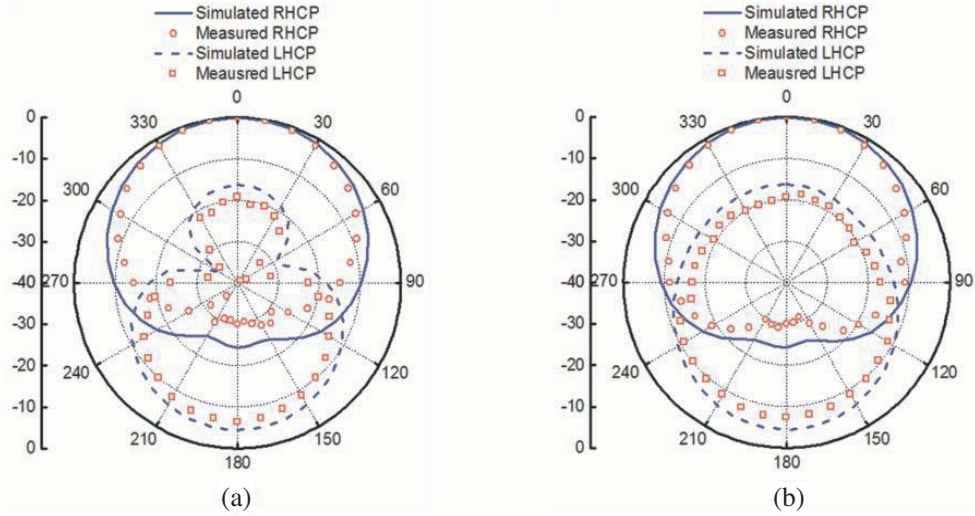


Figure 6. Simulated and measured far-field radiation patterns in the x - z and y - z planes. (a) x - z plane. (b) y - z plane.

gain bandwidth are 18% from 1.811 GHz to 2.17 GHz, 25% from 1.688 GHz to 2.17 GHz, and 11.5% from 1.88 GHz to 2.11 GHz, respectively. The realized peak gain is around 4.8 dB at 1.95 GHz, and the global bandwidth is 11.5% from 1.88 GHz to 2.11 GHz. These figures indicate that the measured results reasonably agree with the simulated ones.

The simulated and measured results for the normalized radiation patterns at 2 GHz in the x - z and y - z planes are presented in Fig. 6. Again, the measured results agree perfectly with the simulated ones, and we can observe that the antenna has good sky coverage in the upper hemisphere.

4. CONCLUSION

A novel design of a single-feed compact cross-aperture coupled CPMA with bandwidth enhancement is presented and experimentally studied. The size miniaturization is achieved by the capacitive and inductive loading. And the global bandwidth is improved by more than eight times using a 0° - 90° hybrid combining a Wilkinson 3-dB power divider and a 90° phase shifter.

REFERENCES

1. Bahl, I. J. and P. Bhartia, *Microstrip Antennas*, Artech House, Dedham, MA, 1980.
2. James, J. R., P. S. Hall, and C. Wood, *Microstrip Antenna Theory and Design*, Peter Peregrinus, London, U.K., 1981.
3. Carver, K. R. and J. W. Mink, "Microstrip antenna technology," *IEEE Trans. Antennas Propag.*, Vol. 29, No. 1, 2–24, 1981.
4. Pozar, D. M., "Microstrip antennas," *Proceedings of the IEEE*, Vol. 80, No. 1, 79–91, 1992.
5. Targonski, S. D. and D. M. Pozar, "Design of wide-band circularly polarized aperture coupled microstrip antenna," *IEEE Trans. Antennas Propag.*, Vol. 41, No. 2, 214–220, 1993.
6. Gardiol, F. E. and J. F. Zuercher, "Broad-band patch antennas — A SSFIP update," *IEEE AP-S Int. Symp. Dig.*, 2–5, 1996.
7. Aksun, M. I., S. L. Chuang, and Y. T. Lo, "On slot-coupled microstrip antennas and their applications to CP operation — Theory and experiment," *IEEE Trans. Antennas Propag.*, Vol. 38, No. 8, 1224–1230, 1990.
8. Oliver, M. B., Y. M. M. Antar, R. K. Mongia, and A. Ittipiboon, "Circularly polarized rectangular dielectric resonator antenna," *Electron. Lett.*, Vol. 31, No. 6, 418–419, 1995.
9. Esselle, K. P., "Circularly polarized higher-order rectangular dielectric resonator antenna," *Electron. Lett.*, Vol. 32, No. 3, 150–151, 1996.
10. Li, J. X., J. Y. Guo, A. X. Zhang, W. T. Joines, and Q. H. Liu, "Miniaturized single-feed cross-aperture coupled circularly polarized microstrip patch antenna," *Progress In Electromagnetics Research C*, Vol. 63, 183–191, 2016.
11. Vlasits, T., E. Korolkiewicz, A. Sambell, and B. Robinson, "Performance of a cross-aperture coupled single feed circularly polarized patch antenna," *Electron. Lett.*, Vol. 32, No. 7, 612–613, 1996.
12. Huang, C. Y., J. Y. Wu, and K. L. Wong, "Cross-slot-coupled microstrip antenna and dielectric resonator antenna for circular polarization," *IEEE Trans. Antennas Propag.*, Vol. 47, No. 4, 605–609, 1999.
13. Wong, K. L. and T. W. Chiou, "Broad-band single-patch circularly polarized microstrip antenna with dual capacitively coupled feeds," *IEEE Trans. Antennas Propag.*, Vol. 49, No. 1, 41–44, 2001.
14. James, J. R. and P. S. Hall, *Handbook of Microstrip Antennas*, Peter Peregrinus, London, U.K., 1989.
15. Lu, J. H. and C. L. Tang, "Circular polarization design of a single-feed equilateral-triangular microstrip antenna," *Electron. Lett.*, Vol. 34, No. 4, 319–321, 1998.
16. Wong, K. L. and J. Y. Wu, "Single-feed small circularly polarized square microstrip antenna," *Electron. Lett.*, Vol. 33, No. 22, 1833–1834, 1997.
17. Yang, M., Z. N. Chen, P. Y. Lau, X. Qing, and X. Yin, "Miniaturized patch antenna with grounded strips," *IEEE Trans. Antennas Propag.*, Vol. 63, No. 2, 843–848, 2015.