Research Article

The New C-Shaped Parasitic Strip for the Single-Feed Circularly Polarized (CP) Microstrip Antenna Design

Zhao-Lin Zhang, Kun Wei, Jian Xie, Jian-Ying Li, and Ling Wang

School of Electronics and Information, Northwestern Polytechnical University, Xi’an 710072, China

Correspondence should be addressed to Kun Wei; weikun916@163.com

Received 22 July 2019; Revised 29 September 2019; Accepted 19 October 2019; Published 11 November 2019

Academic Editor: N. Nasimuddin

Copyright © 2019 Zhao-Lin Zhang et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

A new single-feed circularly polarized (CP) microstrip antenna with the C-shaped parasitic strip is proposed in this paper. The proposed CP antenna is designed for the transmitting terminal in the Global Navigation Satellite System (GNSS). The square patch is surrounded by a C-shaped parasitic strip. By adjusting the parasitic strip dimension, the antenna CP operation is achieved. The main advantage of this method is that those two resonant modes for achieving the CP operation are independent from each other, which is liable to design and debug the proposed CP microstrip antenna. The designed CP microstrip antenna has the good impedance matching, the good CP radiation pattern, and the stable CP gain across the 3 dB AR (axial ratio) bandwidth.

1. Introduction

The CP antenna is extensively used in the Global Navigation Satellite System (GNSS) because of its advantages for improving the system sensitivity and reducing the polarization mismatch. There are many kinds of CP antennas, like microstrip antenna, horn antenna, and helix antenna. Microstrip antenna is widely used in both military and civil applications because of the following advantages: small size, low cost, easy to be manufactured, and convenient to expand into arrays [1]. For a square-radiated patch antenna, one easy way to achieve CP operation is feeding the patch at two orthogonal directions to excite two resonant modes. However, the dual-feeding mechanism enlarges the antenna dimension, increases the antenna geometry complexity, and leads to extra loss. To overcome the dual-feeding complexities, the square patch antenna with the single-feed port has been studied [2]. The single-feed microstrip antenna has the simplest structure for achieving the CP radiation.

With the development of the GNSS, various single-feed CP microstrip antennas achieved by adjusting the patch physical dimensions or etching the slots have been reported. A CP antenna for the GNSS application is presented in [3]. The antenna CP operation is achieved by feeding network. A novel low-profile CP microstrip antenna is proposed in [4]. The antenna consists of two circular eccentric rings for achieving the CP operation, which are simultaneously excited by an arc-shaped strip. The CP microstrip antennas based on the fractal boundary are proposed in [5, 6]. By replacing the sides of a square patch with asymmetrical prefractal curves, two orthogonal modes are excited for CP operation. A single-feed microstrip antenna with loading of shorting pins for CP radiation is proposed in [7]. After the optimal loading position is investigated for maximum directivity of the linear polarization, one pair of the inner pins is slightly shifted in an offset to properly separate the two degenerate modes, so that the CP radiation can be excited. An asymmetric-circular shaped slotted microstrip antenna with slits is proposed in [8] for the CP radiation. The single-feed configuration based asymmetric-circular shaped slotted square microstrip patches are adopted to realize the CP microstrip antenna. A compact CP-stacked patch antenna is investigated for BeiDou navigation satellite system in [9]. The bottom patch with symmetrical slant cornercuts and the top one with two rectangular stubs on the diagonal produce a pair of degenerated modes, achieving CP radiation.

A microstrip antenna with the CP radiation is proposed and investigated in [10]. The patch has an octagon-star shape
2. Antenna Geometries

The geometries of the proposed CP microstrip antenna, as well as the C-shaped parasitic strip are drawn in Figure 1. The designed CP antenna resonates at the center frequency 1.65 GHz. Both the square patch and the parasitic strip are printed on a substrate with the dielectric constant 10, height 3.18 mm, and loss tangent 0.0035. Antenna element has outline dimension 65 mm. The square patch is fed by a coaxial probe, which has the distance \( d \) away from the patch edge. The length of the square patch is \( l \). A C-shaped parasitic strip surrounds the radiated patch, which is applied for realizing the CP operation. The parasitic strip has width \( w \) and total length \( l = l_1 + l_2 + l_3 + l_4 \). The gap width between the radiated patch and the parasitic strip is \( g \).

To understand the antenna CP design principle, Figure 2 shows the surface current vector graphs at the frequency 1.65 GHz of the radiated patch with the C-shaped parasitic strip at different time phases (\( \omega t \)), from 0° to 270° with an interval of 90°. The current vectors at the frequency 1.65 GHz are only detected in the horizontal direction before adding the C-shaped parasitic strip. When adding the C-shaped parasitic strip, the new current vectors are detected in the vertical direction, as shown in subgraphs (a) and (c). It clearly shows that the second resonant mode is generated because of the asymmetric C-shaped parasitic strip structure, which helps to achieve the CP design. By adjusting the parasitic strip dimension, these two orthogonal resonant modes will have the approximately equal amplitude value and 90 deg time-phase difference, which contributes to achieve the CP operation. Moreover, the surface current vector rotation is counterclockwise, which means the proposed microstrip antenna is left-handed circularly polarized. By mirroring the parasitic strip along the \( y \)-axis, the antenna circular polarization can be transformed from LHCP to RHCP, as shown in the Figure 3.

By introducing a proper asymmetry in the structure, the degeneracy can be removed with one mode increasing with frequency, while the orthogonal mode will be decreasing with frequency by the same amount. Since the two modes will have slightly different frequencies, by proper design, the field of one mode can lead by 90 deg phase difference necessary for circular polarization. For the CP antenna in this paper, the asymmetry parasitic structure generates the second resonant mode, which has a slightly different frequency and the 90 deg phase difference with the original resonant mode. Due to that, the antenna CP radiation is realized.

3. Antenna Parametric Analysis

To better illustrate how the antenna CP operation is realized, the parameter studies of the C-shaped parasitic strip are
Table 1: Comparison of this work and previous published CP antennas.

| Ref. | Method to achieve the CP operation | Dielectric constant | Operating frequency | 10 dB BW | 3 dB AR BW | Antenna size | Network required | Independent resonant modes |
|------|-----------------------------------|---------------------|---------------------|----------|------------|--------------|------------------|--------------------------|
| [3]  | Feeding network                   | 2.33                | 1.575 GHz           | N.A.     | N.A.       | $\phi 0.61 \lambda_0 \times 0.008 \lambda_0$ | Yes | No |                      |
| [5]  | Fractal structure                 | 2.2                 | 2.54 GHz            | 6.4%     | 2%         | $0.35 \lambda_0 \times 0.35 \lambda_0 \times 0.027 \lambda_0$ | No | No |                      |
| [7]  | Metallic pins                     | 2.2                 | 2.53 GHz            | 4.3%     | 1.15%      | $1.26 \lambda_0 \times 1.26 \lambda_0 \times 0.027 \lambda_0$ | No | No |                      |
| [9]  | Rectangular stubs                 | 4.4                 | 1.615 GHz           | 9.1%     | 1%         | $0.38 \lambda_0 \times 0.38 \lambda_0 \times 0.024 \lambda_0$ | No | No |                      |
| [10] | Octagon-star shaped patch          | 2.164               | 1.575 GHz           | 2.5%     | 0.5%       | $0.42 \lambda_0 \times 0.016 \lambda_0$ | No | No |                      |
| [12] | Feeding network                   | 6                   | 1.35 GHz            | 32%      | 32%        | $0.2 \lambda_0 \times 0.2 \lambda_0 \times 0.005 \lambda_0$ | Yes | Yes |                      |
| [18] | DGS                               | 10                  | 1.575 GHz           | 1.9%     | 0.4%       | $0.24 \lambda_0 \times 0.24 \lambda_0 \times 0.017 \lambda_0$ | Yes | Yes |                      |
| [19] | Two parasitic strips              | 4.4                 | 925 MHz             | 5.4%     | 0.65%      | $0.22 \lambda_0 \times 0.22 \lambda_0 \times 0.005 \lambda_0$ | No | No |                      |
| This | Single C-shaped parasitic strip    | 10                  | 1.65 GHz            | 1.9%     | 0.61%      | $0.36 \lambda_0 \times 0.36 \lambda_0 \times 0.017 \lambda_0$ | No | Yes |                      |

Figures 6 and 7 show S11 and the axial ratio (AR) of the designed CP antenna when tuning the gap width $g$. Figure 5 clearly shows that the proposed CP antenna has two resonant modes. One of the resonant modes moves to the high-frequency region when increasing the gap width. Because there is no patch dimension change, the resonant mode in the $x$-axis is fixed in the high-frequency region. The other resonant mode is determined by the electric field $E_y$ in the $y$-direction, which is generated by the vertical current distributions. Figure 6 gives the proposed CP antenna AR against theta, when turning the gap width $g$. When the gap width $g$ equals to 1 mm, the proposed antenna has better CP performances. The 3 dB AR beamwidth is approximately 200 deg in the phi = 0 deg plane.

The C-shaped parasitic strip dimension optimization affects only one resonant mode, which indicates that those two resonant modes for achieving the antenna CP operation are independent from each other. This is the main advantage or novelty of the proposed CP antenna in this paper, which is liable to design and debug the proposed CP antenna.

4. The Optimized Simulation Results

The simulated antenna S11 with and without the C-shaped parasitic strip is drawn in Figure 8 for comparison. Before adding the C-shaped parasitic strip, the bandwidth of the linear polarized (LP) antenna is 20 MHz. When the parasitic strip is added, the antenna polarization is transformed from linear polarization to circular polarization. Moreover, the bandwidth of the CP antenna is expanded to 31 MHz (from 1.635 GHz to 1.666 GHz), which is wider than that of the antenna without the C-shaped parasitic strip. The existence of these two resonant modes results to expand the antenna bandwidth. This also leads to the double minimum in the matching frequency behavior.

Figure 9 shows the simulated radiation patterns in different planes of the designed CP microstrip antenna with the parasitic strip at 1.65 GHz. In both the phi = 0 deg and phi = 90 deg planes, it shows that the radiation patterns are in the domination position. The proposed CP antenna with the C-shaped parasitic strip has the peak gain 4.2 dBi and efficiency approximately 78%. When enlarging the ground plane to be 100 × 100 mm$^2$, the gain of the proposed CP
Figure 2: The surface current distribution on the LHCP antenna radiated patch at 1.65 GHz.

Figure 3: The surface current distribution showing RHCP behavior of the antenna with the mirrored parasitic strip at 1.65 GHz.
The antenna will be increased from 4.2 dBic to 5.3 dBic, and the backside radiation will be decreased.

Figure 10 illustrates the antenna AR against theta in different planes. The 3 dB AR beamwidth covers the angles from theta = −60deg to theta = 60deg. The minimum value of the AR is 0.7 dB at the center frequency (1.65 GHz), which indicates that the designed antenna has pure circular polarization. In the boresight direction, the AR value is approximately 1 dB. The 3 dB AR beamwidth is approximately 200deg, 190deg, 175deg, and 160deg in the phi = 0, 30, 60, and 90deg planes, respectively.

Figure 11 shows the antenna ARs against frequency with and without the C-shaped parasitic strip. Before adding the parasitic strip, the antenna is linear polarized. So the ARs of the antenna without the parasitic strip are much larger than those of the antenna with the parasitic strip.

5. The Simulation and Measurement Comparisons

The proposed CP microstrip antenna is fabricated based on the optimized parameters. As shown in Figure 12, both the antenna patch and the C-shaped parasitic strip are printed on the substrate with the dielectric constant 10, height 3.18 mm, and loss tangent 0.0035. The simulation and measurement S11 of the CP microstrip antenna are plotted in Figure 13. The measurement result agrees well with the simulation result. Both the simulation and measurement
results show that the bandwidth of the designed antenna is 30 MHz (1.8% with center frequency 1.65 GHz). The slight differences between the measurement and the simulation may be caused by the machine error of the fabricated CP microstrip antenna.

The simulated and measured radiation patterns of the proposed CP microstrip antenna on both the phi = 0° and phi = 90° planes are plotted in Figure 14. The results show that the simulated radiation patterns agree well with the measured ones. It also clearly shows that the proposed antenna presents good broadside radiation patterns. In the upper-sphere space, there are no significant main lobe pattern differences between the simulation and the measurement. The proposed CP microstrip antenna has the peak gain about 4.2 dBic, the 3 dB beamwidth about 90°, and the antenna efficiency about 78%. Moreover, the cross polarization level is less than −15 dB.

The simulated and measured ARs and CP gains in the boresight direction against frequency are plotted in Figure 15. A reasonable good agreement between the simulation and the measurement is achieved. The CP gain is relatively stable across the 3 dB AR band, and its value ranges from 4.0 dBic to 4.2 dBic. The 3 dB AR bandwidth is 10 MHz. The designed antenna has the peak gain at the frequency where the AR value is the lowest. The deteriorative antenna circular polarization performance will worsen the antenna gain. Although the measurement in general agrees well with the simulation as
**Figure 12:** The fabricated CP microstrip antenna with the C-shaped parasitic strip.

**Figure 13:** The simulated and measured S11 of the proposed CP microstrip antenna.

**Figure 14:** Measured and simulated antenna radiation patterns in the (a) phi = 0 deg and (b) phi = 90 deg planes.
6. Conclusions

A new single-feed CP microstrip antenna achieved by the C-shaped parasitic strip is proposed in this paper. The antenna CP characteristic is realized by adjusting the parasitic strip dimension. The microstrip antenna is fabricated based on the optimized parameter values. Bandwidth of the proposed CP antenna is approximately 30 MHz (1.8% with center frequency 1.65 GHz). The proposed CP microstrip antenna has approximately 4.2 dBi gain peak gain, 90deg 3 dB beamwidth, and 78% antenna efficiency. Moreover, the CP gain is relatively stable across the 3 dB AR band, and its value ranges from 4.0 dBi to 4.2 dBi. The main advantage and novelty of the designed CP antenna is that those two resonant modes for achieving the CP operation are independent from each other, which is convenient for the CP antenna design and debug.

Data Availability

The data used to support the findings of this study are currently under embargo while the research findings are commercialized. Requests for data, 12 months after publication of this article, will be considered by the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

This work was supported in part by the National Natural Science Foundation of China (nos. 61771404 and 61601372). This work was also supported by the China Postdoctoral Science Foundation (no. 2018M631258) and the Postdoctoral Innovative Talent Support Program (no. BX20180003).

References

[1] K. Wei and B.-C. Zhu, "The novel W parasitic strip for the circularly polarized microstrip antennas design and the mutual coupling reduction between them," *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 2, pp. 804–813, 2019.
[2] W.-J. Chen, H.-H. Chen, C.-H. Lee, and C.-I. G. Hsu, "Differentially fed wideband circularly polarized slot antenna," *IEEE Transactions on Antennas and Propagation*, vol. 67, no. 3, pp. 1941–1945, 2019.
[3] K. A. Yinusa, "A dual-band conformal antenna for GNSS applications in small cylindrical structures," *IEEE Antennas and Wireless Propagation Letters*, vol. 17, no. 6, pp. 1056–1059, 2018.
[4] Z.-X. Liang, D.-C. Yang, X.-C. Wei, and E.-P. Li, "Dual-band dual circularly polarized microstrip antenna with two eccentric rings and an arc-shaped conducting strip," *IEEE Antennas and Wireless Propagation Letters*, vol. 15, pp. 834–838, 2016.
[5] V. V. Reddy and N. V. S. N. Sarma, "Compact circularly polarized asymmetrical fractal boundary microstrip antenna for wireless applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 13, pp. 118–121, 2014.
[6] V. V. Reddy and N. V. S. N. Sarma, "Tri-band circularly polarized koch fractal boundary microstrip antenna," *IEEE Antennas and Wireless Propagation Letters*, vol. 13, pp. 1057–1060, 2014.
[7] X. Zhang and L. Zhu, "High-gain circularly polarized microstrip patch antenna with loading of shorting pins," *IEEE Transactions on Antennas and Propagation*, vol. 64, no. 6, pp. 2172–2178, 2016.
[8] Nasimuddin, N. C. Zhi, and Q. Xianming, “Asymmetric-circular shaped slotted microstrip antennas for circular polarization and RFID applications,” *IEEE Trans. Antennas Propag.*, vol. 58, no. 12, pp. 3821–3828, 2010.
[9] H. Yang, Y. Fan, and X. Liu, "A compact dual-band stacked patch antenna with dual circular polarizations for BeiDou navigation satellite systems," *IEEE Antennas and Wireless Propagation Letters*, vol. 18, no. 7, pp. 1472–1476, 2019.
[10] Y. Shi and J. Liu, "A circularly polarized octagon-star-shaped microstrip patch antenna with conical radiation pattern," *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 4, pp. 2073–2078, 2018.
[11] K. M. Mak, H. W. Lai, K. M. Luk, and K. L. Ho, "Polarization reconfigurable circular patch antenna with a C-shaped," *IEEE Transactions on Antennas and Propagation*, vol. 65, no. 3, pp. 1388–1392, 2017.
[12] C. Sun, Z. Wu, and B. Bai, "A novel compact wideband patch antenna for GNSS application," *IEEE Transactions on Antennas and Propagation*, vol. 65, no. 12, pp. 7334–7339, 2017.
[13] K.-K. Zheng and Q.-X. Chu, "A novel annular slotted center-fed BeiDou antenna with a stable phase center," *IEEE Antennas and Wireless Propagation Letters*, vol. 17, no. 3, pp. 364–367, 2018.
[14] K. Ding, C. Gao, D. Qu, and Q. Yin, "Compact broadband circularly polarized antenna with parasitic patches," *IEEE Transactions on Antennas and Propagation*, vol. 65, no. 9, pp. 4854–4857, 2017.
[15] Y.-Q. Zhang, X. Li, L. Yang, and S.-X. Gong, "Dual-band circularly polarized annular-ring microstrip antenna for...
GNSS applications,” *IEEE Antennas and Wireless Propagation Letters*, vol. 12, pp. 615–618, 2013.

[16] A. K. Gautam, A. Kunwar, and B. K. Kanaujia, “Circularly polarized arrowhead-shape slotted microstrip antenna,” *IEEE Antennas and Wireless Propagation Letters*, vol. 13, pp. 471–474, 2014.

[17] X. Bai, X. Liang, M. Li, B. Zhou, J. Geng, and R. Jin, “Dual-circularly polarized conical-beam microstrip antenna,” *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 482–485, 2015.

[18] K. Wei, J. Y. Li, L. Wang, R. Xu, and Z. J. Xing, “A new technique to design circularly polarized microstrip antenna by fractal defected ground structure,” *IEEE Transactions on Antennas and Propagation*, vol. 65, no. 7, pp. 3721–3725, 2017.

[19] H.-D. Chen, S.-H. Kuo, C.-Y.-D. Sim, and C.-H. Tsai, “Coupling-feed circularly polarized RFID tag antenna mountable on metallic surface,” *IEEE Transactions on Antennas and Propagation*, vol. 60, no. 5, pp. 2166–2174, 2012.

[20] G. Byun and H. Choo, “Antenna polarisation adjustment for microstrip patch antennas using parasitic elements,” *Electronics Letters*, vol. 51, no. 14, pp. 1046–1048, 2015.
