

Miniaturized, Dual-Polarized Corner-Fed Microstrip Antenna with Cylindrical Cavity Enclosure Working in L-Band

Peizhuo Yang, Lizhong Song*, and Yuanyuan Zhang

Abstract—In this article, a miniaturized, dual-polarized corner-fed microstrip antenna is designed and fabricated at 1.43 GHz for Low Earth Orbit (LEO) Satellite applications. The antenna adopts a Complementary Split-Ring Resonator (CSRR)-inspired structure and slotted patch to achieve miniaturization. This reduces the patch size by 39.4%. Meandered impedance-transforming lines are placed for impedance tuning, and its benefit is demonstrated by both simulated and measured S_{11} curves reaching lower than -20 dB. Feeding at corner increases its isolation to -25 dB over the whole bandwidth of 40 MHz and reaches lower than -33 dB at the resonant frequency. The antenna is fabricated and tested. Measured results are generally in good agreement with simulations.

1. INTRODUCTION

Nowadays, Low Earth Orbit (LEO) satellite communications provide location/time information as well as data/voice services, which has greatly facilitated various applications for civil, commercial, and military purposes. Contrary to normal antennas on the ground, several requirements are imposed to the antennas for such satellite communication/navigation system. FR4 and Rogers series are commonly used as PCB dielectric materials. However, these materials' mechanical and thermal properties face severe challenges in the harsh environment of the outer space, which is avoided by all-metal antenna. As a member of the all-metal antenna family, microstrip antenna with air substrate gains popularity for its compactness and light weight.

Miniaturization is widely demanded in the world of modern LEO communication system to alleviate weight and cost issues. In recent years, techniques for antenna miniaturization have been constantly emerging, including slotted patch [1], fractal [2], and metamaterials [3].

Dual-polarized antennas have been widely employed to mitigate multipath fading and increase channel capacity. To realize dual polarizations, most of the feeding networks adopt orthogonal coupling mode and use two ports [4]. In terms of choice of polarization, many dual Circular-Polarized (CP) microstrip antennas work in dual bands in literature, e.g., LHCP in lower frequency and RHCP in upper frequency [5, 6]. The realization of a single band dual CP patch antenna requires more complicated structures, for example, branch line coupler [7] and linear series-fed array [8], which adds to the weight and volume of the system. For antennas working in L band, miniaturization is by all means an efficient way to reduce weight and cost, thus linear polarization is adopted in this work.

As for feeding method, we used corner-feed, which is less frequently seen in literature than normally edge-fed antenna. However, when putting into dual-polarized design, the former enjoys better isolation as well as reduced cross polarization level [9]. In this paper, the proposed antenna is a combination of aforementioned technologies. It not only achieves dual-polarization when being fed at corner, obtaining better isolation, but also achieves miniaturization with air substrate.

Received 7 March 2022, Accepted 8 April 2022, Scheduled 20 April 2022

* Corresponding author: Lizhong Song (songlizhong@hitwh.edu.cn).

The authors are with the School of Information Science and Technology, Harbin Institute of Technology, Weihai 264200, China.

2. ANTENNA STRUCTURE AND DESIGN

In this letter, the proposed antenna is intended to be compact enough to be encompassed by a cylindrical metal wall with radius equaling 76 mm and height equaling 30 mm, which is a common design setting in applications with fixed mechanical structures. The proposed antenna is miniaturized by cutting slots on the patch as well as the application of double Complementary Split-Ring Resonators (CSRRs) on the ground layer. Two ports are placed to realize dual polarizations.

The distance between adjacent rings stays the same, thus the size of the annular slot is determined by the radius of the first ring and the distance between neighbouring ones. Moreover, the widths of all the slots remain the same, no matter on the top or bottom. Corner-feed is used in order to increase isolation between two ports as two ports are physically placed further with each other compared to its edge-fed counterpart. Corner fed patch antenna is generally less used partly due to its nature of high input impedance [10]. Therefore, a quarter-wave impedance transformer is adopted at the feed point for input impedance tuning of the port. The transformer is made zigzag so that the patch size is reduced.

SMA connectors are mounted below the end of the transformer, where bottom feed is applied. A cylindrical cavity enclosing the patch is mounted, adding to the robustness of the mechanical structure and narrowing down the main lobe thus increasing gain.

The geometry of the proposed antenna is shown in Figure 1(a), followed by Figure 1(b) and Figure 1(c) which show details and parameters of the top and bottom layers, respectively.

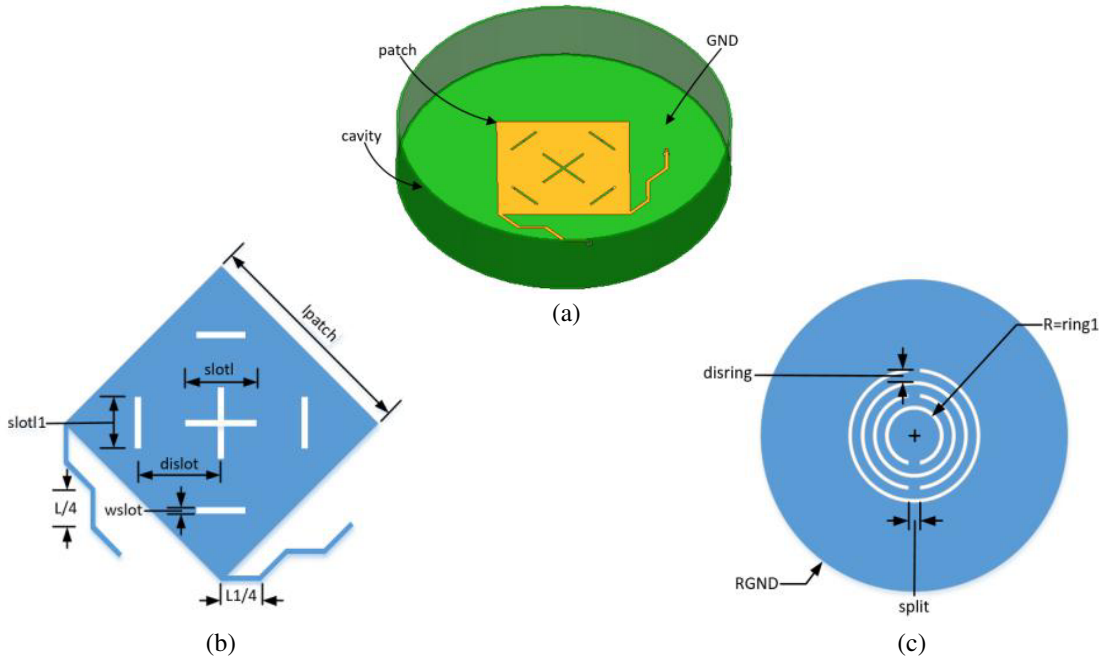


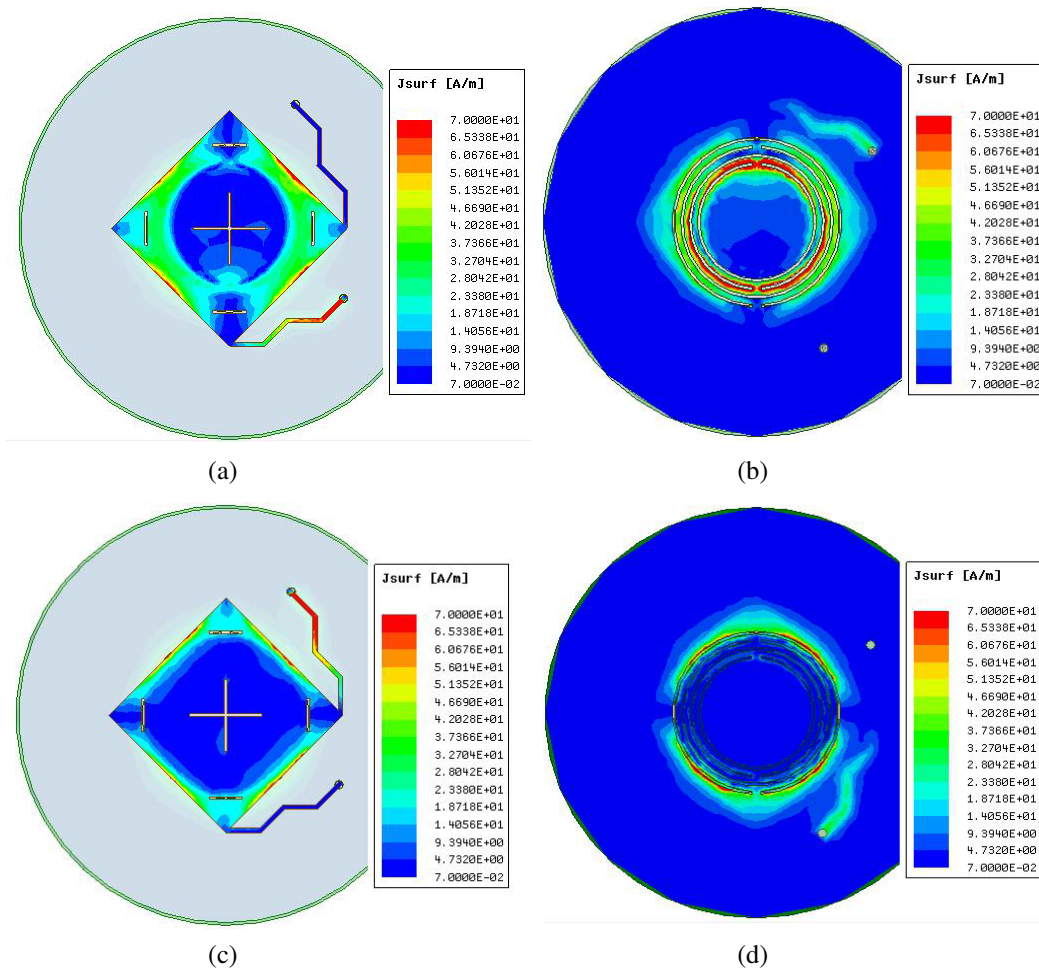
Figure 1. Geometry of the proposed antenna: (a) Isometric view, (b) Patch and (c) GND.

An air substrate with thickness $h = 2$ mm is used in this design. Parameter studies have been carried out, and the ultimate parameters of the antenna are listed below in Table 1. During parameter studies, a trade-off between back lobe and miniaturization rate has been detected, which is directly related to the radius of the first CSSR (ring1). As ring1 increases, the back lobe becomes bigger as there is less obstacle for radiating backwards. However, more effective miniaturization is achieved meanwhile. Finally, as back lobe is nearly inevitable if bottom slots are cut, more advantage is given to miniaturization.

The current distribution when Port 1 is excited at 1.43 GHz is shown in Figure 2(a) and Figure 2(b). Note that two ports are numbered arbitrarily. As shown in Figure 2(a), the high current levels at the patch edges indicate good radiation. In Figure 2(b), the CSRR currents show high levels beneath the

Table 1. Dimensions of the antenna.

Parameters	Dimension (mm)
lpatch	60
RGND	76
ring1	20.2
split	3
disring	3
dislot	30
slot1	13
slot11	6
wslot	1
L	51
L1	55

**Figure 2.** Current distribution when excited at different ports, namely (a) Top, Port 1, (b) Bottom, Port 1, (c) Top, Port 2, (d) Bottom, Port 2.

radiating patches at the resonant frequency. Note that current distribution of Port 2 shows pronounced symmetry and is presented in Figure 2(c) and Figure 2(d).

3. FABRICATION AND MEASUREMENT

The proposed antenna is firstly designed and tuned in Ansys HFSS 2019, and then experimentally fabricated and measured for validating feasibility of the design. Four foam posts are placed at each corner to support the patch 2 mm above the GND, and the enclosing cavity is backed up by foam as well. The patch, GND, and cavity are made of copper. Slots and shapes are cut by a laser cutting machine. The fabricated antenna is shown in Figure 3.

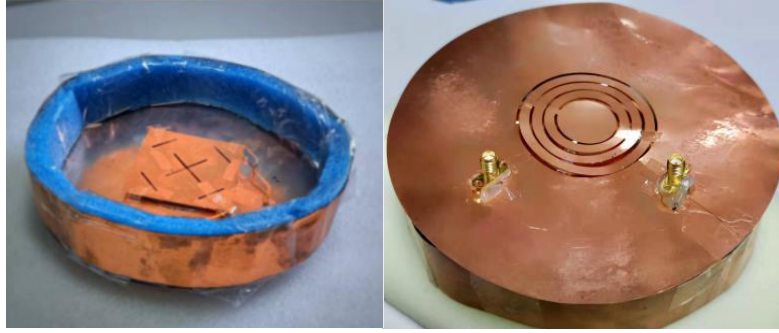


Figure 3. Fabricated cavity-enclosing patch antenna.

Figure 4(a) shows the return loss curve of the two ports, and Figure 4(b) shows the isolation curve between two ports, both with measured and simulated results. The antenna resonates at 1.43 GHz with a -10 dB bandwidth of approximately 40 MHz. As shown in Figure 4(b), though there exists certain difference between simulated and measured isolations, both reach lower than -30 dB at 1.43 GHz, which demonstrates the isolation-improvement nature of corner-fed method.

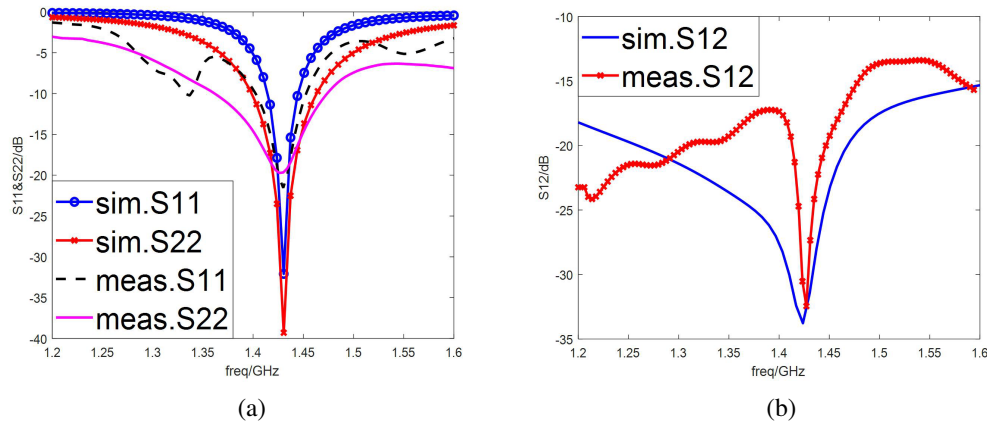


Figure 4. S parameter both simulated and measured, respectively (a) S_{11} , S_{22} and (b) S_{21} .

Figure 5(a) and Figure 5(b) illustrate the simulated and measured radiation patterns at 1.43 GHz of Port 1 in E plane and H plane, with co- and cross-polarized curves, respectively. Figure 5(c) and Figure 5(d) depict the same curves of Port 2. As shown in Figure 5, simulated gain reaches 6.3 dBi while measured one shows a slight dip by approximately 0.3 dBi. Simulated results put cross polarization lower

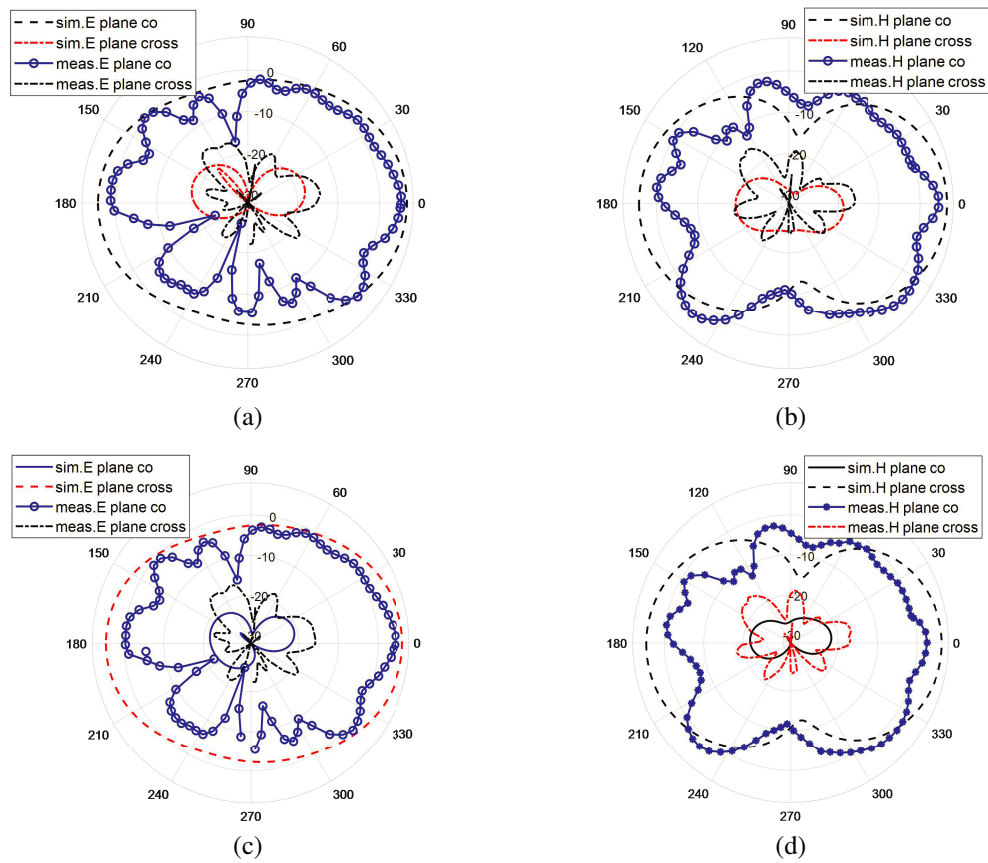


Figure 5. Co- and Cross-polarization of E plane and H plane respectively when each port is excited: (a) Port 1 E plane, (b) Port 1 H plane, (c) Port 2 E plane, (d) Port 2 H plane.

than -27 dB, while measured ones show -23 dB. Two ports exhibit high level of similarity as for far-field properties. Although great attention was paid while soldering the SMA connectors to the antenna arms, one can never achieve absolute accuracy while soldering by hand; this might also be a possible reason for the difference between the measured and simulated values.

The performances of the proposed antenna and similarly published works are compared in Table 2. Here, λ_0 represents the wavelength of the lower operating frequency in free space. Comparing this work with [6] and [10], it is shown that the proposed antenna enjoys better port isolation while maintaining similar miniaturization level and cross polarization. Comparing this work with [10], the designed antenna has weaker cross polarization but achieves better miniaturization. From the comparison, it can be concluded that the proposed antenna achieves good performance in isolation, miniaturization, as well as cross polarization.

Table 2. Comparison of the proposed antenna with prior arts.

Reference	Operating Frequency (GHz)	Port Isolation (dB)	Patch Dimensions	Cross polarization
[6]	1.6	-6	$0.21\lambda_0 \times 0.21\lambda_0$	-
[7]	0.9	-	$0.42\lambda_0 \times 0.42\lambda_0$	-27 dB
[10]	14.25	-	$0.29\lambda_0 \times 0.29\lambda_0$	-24.5 dB
This work	1.43	-25	$0.29\lambda_0 \times 0.29\lambda_0$	-23 dB

4. CONCLUSION

In this paper, a compact and robust dual-polarized patch antenna for LEO satellite applications has been presented. The antenna operates from 1.41 GHz to 1.45 GHz with a return loss less than -10 dB. The adoption of slots and double CSRRs greatly reduces the size of the antenna to $60 \times 60 \text{ mm}^2$, which is $0.29\lambda_0 \times 0.29\lambda_0$ (λ_0 is the wavelength at 1.43 GHz in free space). Corner-fed method is adopted to improve port isolation to lower than -25 dB, and a pair of meandered $\lambda/4$ transformer helps tune the input impedance.

ACKNOWLEDGMENT

This work is sponsored by the Research Project on Civil Aerospace Technology In advance (D040301), the National Natural Science Foundation of China (Grant No. 61971157), the Foundation of the Key Laboratory of Science and Technology for National Defence (Grant No. 6142401200401) and the Science Foundation of Aeronautics of China (Grant No. 201901077005).

REFERENCES

1. Ghosh, C. K., et al., "Slotted microstrip antenna for miniaturization," *2020 National Conference on Emerging Trends on Sustainable Technology and Engineering Applications (NCETSTEA)*, 1–4, 2020, doi: 10.1109/NCETSTEA48365.2020.9119935.
2. Verma, R. and S. Kumar, "Design and analysis of fractal geometry loaded microstrip patch antenna," *2020 IEEE 5th International Conference on Computing Communication and Automation (ICCCA)*, 243–247, 2020, doi: 10.1109/ICCCA49541.2020.9250848.
3. Vani, H. R., M. A. Goutham, and Paramesha, "Comparative study of square and circular split ring resonator metamaterial for patch antenna miniaturization for C-band wireless applications," *2019 International Conference on Recent Advances in Energy-efficient Computing and Communication (ICRAECC)*, 1–2, 2019, doi: 10.1109/ICRAECC43874.2019.8995105.
4. Nawaz, H. and I. Tekin, "Three ports microstrip patch antenna with dual linear and linear co-polarisation characteristics," *Electron. Lett.*, Vol. 53, No. 8, 518–520, 2017.
5. Yang, H., 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, 1472–1476, July 2019, doi: 10.1109/LAWP.2019.2920265.
6. Long, J. and D. F. Sievenpiper, "A compact broadband dual-polarized patch antenna for satellite communication/navigation applications," *IEEE Antennas and Wireless Propagation Letters*, Vol. 14, 273–276, 2015, doi: 10.1109/LAWP.2014.2362125.
7. Yang, X., Q. Feng, D. Tian, and Z. Zheng, "A wide-band dual circular polarization UHF RFID reader antenna based on miniaturized branch line coupler," *2018 Progress in Electromagnetics Research Symposium (PIERS-Toyama)*, 1290–1294, Toyama, Japan, Aug. 1–4, 2018.
8. Chen, S. J., W. Withayachumnankul, Y. Monnai, and C. Fumeaux, "Linear series-fed patch array with dual circular polarization or arbitrary linear polarization," *2019 International Conference on Electromagnetics in Advanced Applications (ICEAA)*, 0365–0369, 2019, doi: 10.1109/ICEAA.2019.8879041.
9. Chopra, R., G. Kumar, and R. Lakhmani, "Corner fed microstrip antenna array with reduced cross polarization and side lobe level," *2016 Asia-Pacific Microwave Conference (APMC)*, 1–4, 2016, doi: 10.1109/APMC.2016.7931473.
10. Wang, H., X. B. Huang, and D. G. Fang, "A novel corner-fed patch to reduce cross-polarization for a microstrip antenna array," *2008 Asia-Pacific Microwave Conference*, 1–4, 2008, doi: 10.1109/APMC.2008.4957951.