A Compact CPW-Fed Circularly Polarized Planar Monopole Antenna for IoT Applications

Abu Horaira Hridhon and Tutku Karacolak
School of Engineering and Computer Science, Washington State University Vancouver, Vancouver, Washington, USA
(*Email: abuhoraira.hridhon@wsu.edu)

***Abstract*—A flexible, compact C-shaped coplanar waveguide-fed (CPW-fed) circularly polarized (CP) antenna is proposed for Internet of Things (IoT) applications. The antenna is designed on a polyethylene terephthalate (PET) substrate, enabling flexibility and the potential for conformal integration. The design achieves a wide 3-dB axial ratio bandwidth (ARBW) of 5.66 GHz (79.94%) from 4.25 GHz to 9.91 GHz, demonstrating excellent CP performance. Additionally, the antenna exhibits a broad 10-dB return loss bandwidth (RLBW) of 7.67 GHz (99.55%) spanning 3.87 GHz to 11.54 GHz, fully encompassing the ARBW. The antenna maintains a peak gain over 3.5 dB and radiation efficiency over 95% within the ARBW. This wide operational range makes the antenna suitable for a variety of wireless communication systems, including WiFi, WiMAX, and emerging 5G technologies.**

I. Introduction

In recent years, flexible antennas have emerged as a vital component in the evolution of wireless communication, particularly in wearable technologies and biomedical applications. Their ability to conform to non-planar surfaces allows for seamless integration with the human body and other curved structures, making them ideal for unobtrusive devices that require flexibility [1]. This adaptability is further enhanced by circularly polarized (CP) antennas, which offer orientation independence, reduce multipath interference, and ensure consistent signal strength, providing reliable communication despite varying transmitter and receiver positions. Together, the flexibility of substrates and the orientation versatility of CP antennas create an optimal solution for applications in dynamic environments, such as the Internet of Things (IoT), where devices must operate reliably across various orientations and surfaces [2]. Among the various monopole structures used in CP antenna design, such as circular, rectangular, and elliptical shapes [3], C-shaped monopoles have shown notable performance [4], [5]. These designs have reported significant bandwidths, including 87.7% for 10-dB return loss and 65.2% for 3-dB axial ratio [4], and 70% and 82.2%, respectively, in modified versions [5]. However, these antennas were designed on rigid substrates, limiting their applicability in flexible and conformal environments needed for IoT technologies. To address this limitation, coplanar waveguide-fed (CPW-fed) techniques allow the radiator and ground to be on the same plane, facilitating the fabrication of flexible antennas through methods like inkjet printing [2]. In this paper, we propose a C-shaped CPW-fed circularly polarized antenna on a polyethylene terephthalate (PET) substrate, achieving a wide 3-dB axial ratio bandwidth (ARBW) of 5.66 GHz (79.94%) from 4.25 GHz to 9.91 GHz, along with a broad 10-dB return loss bandwidth (RLBW) of 7.67 GHz (99.55%) from 3.87 GHz to 11.54 GHz, fully covering the ARBW. This work aims to leverage the advantages of CP antennas on flexible materials, paving the way for developing conformable antennas for IoT applications.

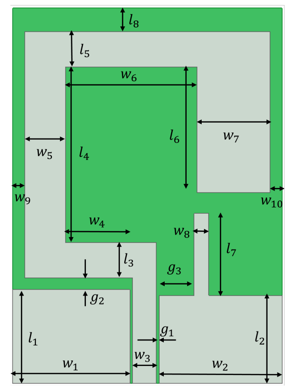

Fig. 1. Design of the proposed antenna. Values of design parameters: l_1 = 8, l_2 = 7.5, l_3 = 3, l_4 = 15, l_5 = 3, l_6 = 10.75, l_7 = 7, l_8 = 2, w_1 = 10, w_2 = 10.5, w_3 = 2, w_4 = 5.75, w_5 = 3.5, w_6 = 11.25, w_7 = 6.25, w_8 = 1.25, w_{10} = 1, g_1 = 0.25, g_2 = 1, g_3 = 3. All dimensions are in mm.

II. Antenna Design

The proposed antenna is designed on a PET paper substrate with a thickness of 0.135 mm, a dielectric constant of 3.2, and a loss tangent of 0.022. The overall dimensions of the antenna are 23 mm × 32 mm × 0.135 mm. The design features a modified C-shaped radiating patch excited by a 50Ω CPW feedline, as illustrated in Figure 1. Initial design is modified by adding a stub to the ground and introducing asymmetry between two ground planes for enhancing the 10-dB RLBW and the 3-dB ARBW. The antenna structure is designed and optimized using Ansys HFSS, with final dimensions determined through parametric analysis to ensure optimal performance within substrate constraints.

III. Simulated Results

Figures 2 and 3 illustrate the S_{11} parameter and axial ratio (AR) of the proposed antenna at each design stage, respectively. Initially, the antenna exhibits a 10-dB RLBW of 6.68 GHz, with resonance frequencies at around 6 GHz, 8 GHz, and 10 GHz. The initial AR curve shows lower resonance points at 4.71 GHz and 6.24 GHz with an ARBW of 2.23 GHz (Fig. 3). After the addition of a ground stub, the lower resonance frequencies are shifted in the S_{11} curve to

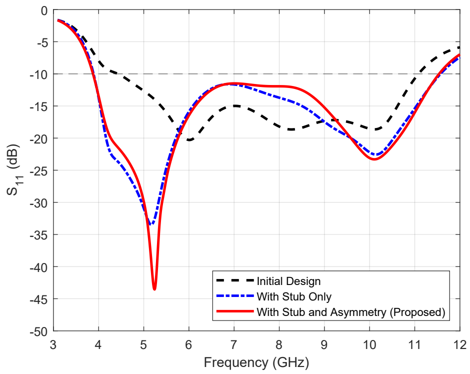

Fig. 2. S_{11} parameter of the proposed antenna.

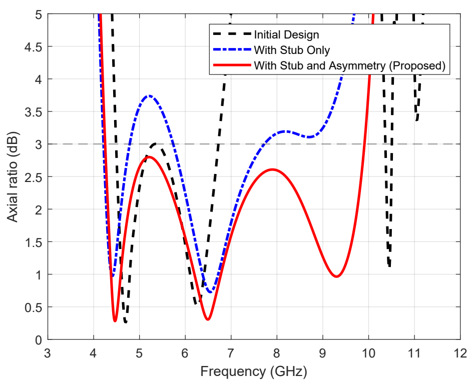

Fig. 3. Axial ratio of the proposed antenna.

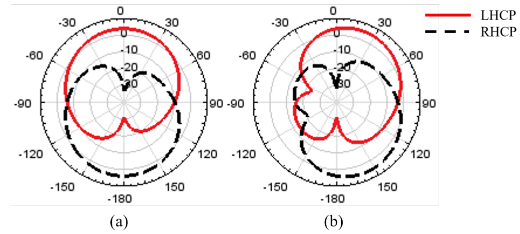

Fig. 4. Radiation pattern of the antenna at 6.51 GHz, where (a) $\phi = 0°$, and (b) $\phi = 90°$.

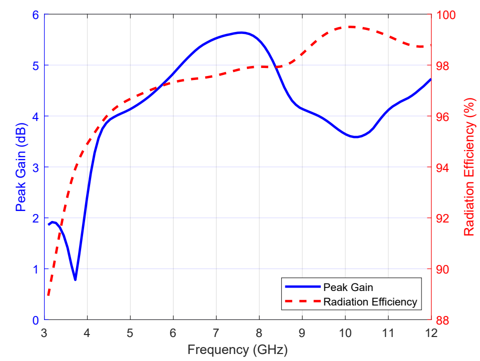

Fig. 5. Peak gain and radiation frequency of the proposed antenna.

4.26 GHz and 5.16 GHz, while the upper resonance frequency remains relatively unchanged, resulting in an increased 10-dB RLBW of 7.67 GHz. This modification also introduces a new upper resonant point at around 9 GHz in the AR curve, although the AR value at this point exceeds 3 dB. Finally, asymmetry between the ground planes is introduced, and the vertical extension of the C-shaped patch is modified. While the increased 10-dB RLBW is maintained, the AR at the new resonance point decreases below 3 dB, significantly enhancing the ARBW to 5.66 GHz. Figure 4 presents the simulated radiation patterns for left-hand circular polarization (LHCP) and right-hand circular polarization (RHCP) in both the XZ plane ($\phi = 0°$) and YZ plane ($\phi = 90°$). The significant separation between LHCP and RHCP patterns in the broadside direction clearly indicates that the antenna exhibits LHCP characteristics. Figure 5 illustrates the peak gain and radiation efficiency of the proposed antenna. Throughout the ARBW, the antenna maintains a peak gain exceeding 3.5 dB while simultaneously achieving a remarkably high radiation efficiency of over 95%. These results demonstrate the antenna's excellent performance across its operational bandwidth.

IV. Conclusion

This paper presents a flexible wideband CP antenna that covers multiple frequency bands, including the C-band (4-8 GHz), portions of the X-band (8-12 GHz), the 5.8 GHz ISM band, and the 5 GHz Wi-Fi band. Utilizing a CPW-feeding mechanism simplifies fabrication and facilitates integration with other circuits, while the flexible PET substrate allows for seamless incorporation into IoT devices. Future work will explore multiple-input multiple-output (MIMO) technology and analyze the antenna's performance under bending. The antenna will be fabricated using inkjet printing technology, with measured results compared to simulations to validate performance.

Acknowledgement

This work was supported by the National Science Foundation (NSF) under Grant No. ECCS-2104513.

References

[1] S. G. Kirtania, A. W. Elger, M. R. Hasan, A. Wisniewska, K. Sekhar, T. Karacolak, and P. K. Sekhar, "Flexible antennas: A review," *Micromachines*, vol. 11, no. 9, p. 847, Sep. 2020.

[2] A. R. Hossain, M. S. I. Sagar, A. A. Mertvyy, P. K. Sekhar and T. Karacolak, "Inkjet Printed Flexible Dual-Band Dual-Sense Circularly Polarized Patch Antenna," in *IEEE Access*, vol. 12, pp. 55424-55433, 2024.

[3] S. Kumar, G. H. Lee, D. H. Kim, H. C. Choi, and K. W. Kim, "Dual circularly polarized planar four-port MIMO antenna with wide axial-ratio bandwidth," *Sensors*, vol. 20, no. 19, p. 5610, Oct. 2020.

[4] K. Ding, C. Gao, T. Yu and D. Qu, "Broadband C-Shaped Circularly Polarized Monopole Antenna," in *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 2, pp. 785-790, Feb. 2015.

[5] F. M. Alnahwi, Y. I. A. Al-Yasir, N. T. Ali, I. Gharbia, C. H. See and R. A. Abd-Alhameed, "A Compact Wideband Circularly Polarized Planar Monopole Antenna With Axial Ratio Bandwidth Entirely Encompassing the Antenna Bandwidth," in *IEEE Access*, vol. 10, pp. 81828-81835, 2022.