

# A transparent robust quasi-isotropic circularly polarized antenna for Cub-Sat and outdoor wireless

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## Abstract

In this article, a highly robust antenna is proposed for omnidirectional circular polarized communications in harsh environments at 2.45 GHz industrial, scientific, and medical frequency band. Circular polarization is realized by utilizing a combination of two magnetic and electric dipoles. The proposed antenna is based on a transparent structure and covered by a quarter wavelength thick layer of plexiglass to achieve desired robustness and visible light transparency. Meanwhile, because of the high transparency of the glass, it can integrate with solar cells to simultaneously propagate signals and harvest energy. The average gain and bandwidth of the antenna are 1.7 dBic and 300 MHz, respectively. The antenna's axial ratio is achieved less than 3 dB within the bandwidth, showing circular polarization behavior. The proposed compact antenna is numerically and experimentally analyzed and the results have a great agreement. In another viewpoint, the structure delivers promising possibilities to improve the propagating and radiating properties, which bring in significant advantages for real-world multifunctional applications.

## KEYWORDS

electromagnetics, circularly polarized antennas, dipole, omnidirectional, transparent, quasiisotropic

## 1 | INTRODUCTION

Circularly polarized (CP) antennas have interesting features such as mitigating the multipath interference, easing the alignment for transmitting and receiving antennas as polarization matching, overcoming the phasing issues, and being weather resistant. An omnidirectional CP radiation results in 360° coverage, desired for multipurpose wireless communication applications that are relatively insensitive to transmitter and receiver orientations. Various omnidirectional CP antennas with conical radiation patterns have been designed over years, such as dielectric resonator antenna,<sup>1</sup> based on tilted dipoles,<sup>2</sup> tightly coupled array mechanism,<sup>3</sup> multiple-input multiple-output form,<sup>4</sup> planar metamaterial structures,<sup>5,6</sup> and fractal formation.<sup>7</sup> Utilizing two electric and magnetic dipoles is a prevalent way to realize orthogonal quadrature fields leading an omnidirectional CP radiation.<sup>1,7</sup> In order to realize a CP omnidirectional antenna, a combination design of electric and magnetic dipole antennas is needed. A loop antenna has been proposed by Alford and Kandoian in the 1950s to realize a horizontally polarized magnetic dipole. Their method was an inspiration for more

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designs of omnidirectional CP antennas.<sup>8,9</sup> In addition, the design of some electric dipole and monopole antennas are discussed in References 10-12.

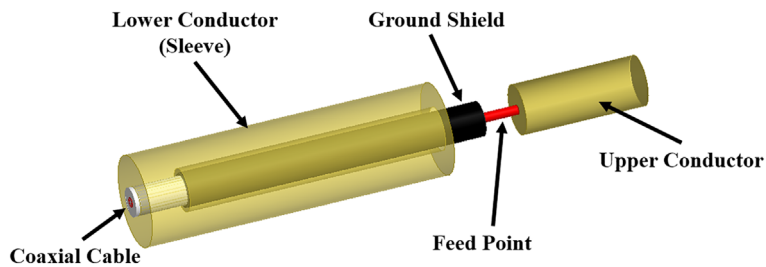
The advantage of using omnidirectional CP antennas is that specific orientations between the transmitter and the load terminal are not required for operation anymore. Hence, it can be expected that omnidirectional CP antennas find great applications for the WLAN band. A novel omnidirectional CP antenna with a transparent multi-purpose structure is proposed here. In this manuscript, this robust omnidirectional CP antenna targets outdoor wireless communications at industrial, scientific, and medical (ISM) 2.45 GHz band. The design is developed based on the Alford loop (magnetic dipole) and the electric dipole antennas. The main findings of the designed antenna are omnidirectional CP, relatively high bandwidth, considering harsh surrounding environments, and multidisciplinary structure for energy harvesting capabilities. The antenna has a multifunctional purpose: it simultaneously functions as an antenna and exploits a possible feature of implementing the solar cell due to the use of transparent material. In the following sections, the antenna design and its performance are discussed.

## 2 | ANTENNA DESIGN

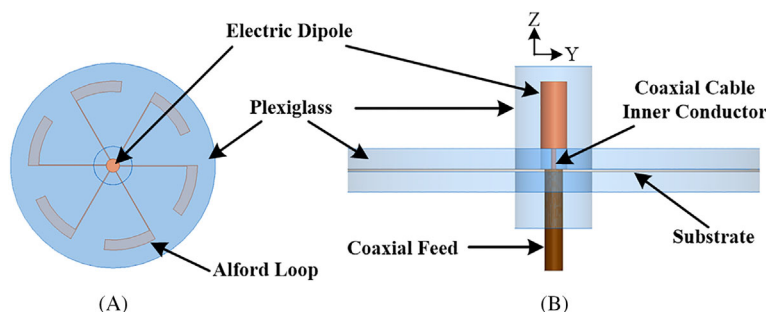
The proposed omnidirectional CP antenna is designed based on electric and magnetic dipole antennas. A half wavelength electric dipole is connected to the inner conductor of the common coaxial cable feed. The electric dipole antenna consists of two arms (radiation element). The upper arm is a coaxial copper cylinder and the lower arm has two parts including the copper sleeve-shape cylinder and the inner coaxial feeding line. The feed semirigid coaxial cable is fixed through the lower arm and is connected between these two upper and lower (sleeve) arms.<sup>10</sup> Figure 1 clarifies the structure of this electric sleeve dipole antenna.

The Alford loop structure is attached to the outer conductor of the coaxial feed, and acts as a magnetic dipole antenna. This magnetic loop antenna behaves electrically as a coil and couples to the magnetic field of the wave, in contrast to the electric dipole antenna which couples to the electric field of the wave. An arrangement with six arc dipoles is selected to obtain a broadband performance. Arc dipoles are excited by a coaxial feeding cable and create a circular loop with an omnidirectional pattern in horizontal plane. Each arc dipole has a length of about a half wavelength of the center frequency. The inner conductor of the feed is a quarter wavelength longer at the center frequency to impose a 90° phase shift between the electric and magnetic dipoles. The coaxial feed line is placed at the center of the circular structure to achieve the omnidirectional radiation pattern and symmetrical axial ratio (AR). Figure 2 shows the structure of the proposed antenna with the identification of electric and magnetic dipoles.

The two electric and magnetic dipoles are predicted because the electric and magnetic vectors are rotating in a CP antenna. The antenna is covered by a transparent quarter wavelength thick layer of plexiglass on the top and bottom

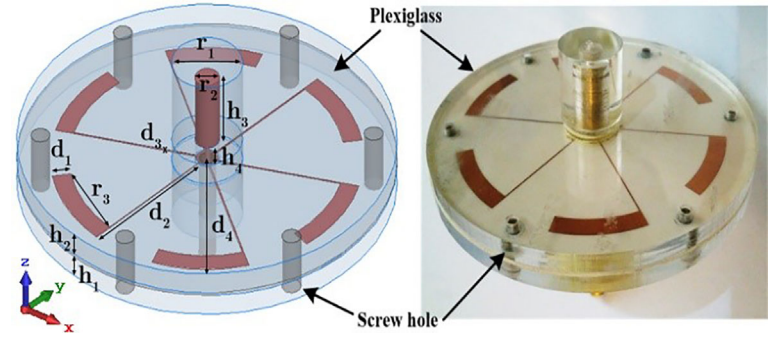


**FIGURE 1** The structure of the electric sleeve dipole antenna with an inner feed line



**FIGURE 2** The structure of the proposed omnidirectional CP antenna, A, top view and B, side view. CP, circularly polarized

**FIGURE 3** Three-dimensional views of the simulated and fabricated versions of the proposed antenna. Parameters are;  $d_1 = 4$ ,  $d_2 = 30.7$ ,  $d_3 = 0.3$ ,  $d_4 = 40$ ,  $h_1 = 4$ ,  $h_2 = 4$ ,  $h_3 = 13$ ,  $h_4 = 4$ ,  $r_1 = 15$ ,  $r_2 = 5.2$ , and  $r_3 = 17.92$  (unit: mm)

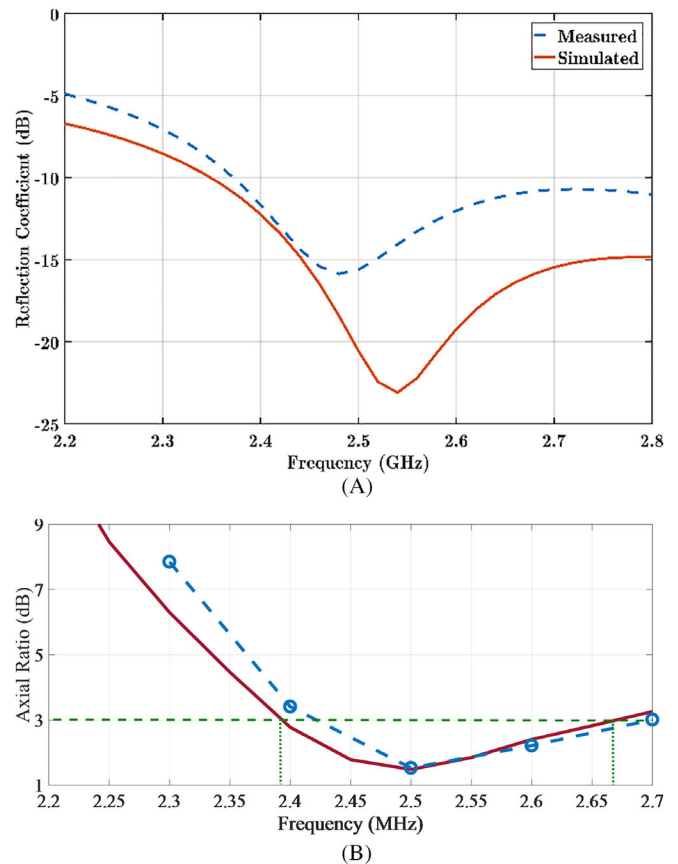


providing resistance to the harsh environment and as the employment of the potential energy-saving mechanism.<sup>14,15</sup> The relative permittivity of plexiglass is calculated about  $\epsilon_r = 5.2$  from the microwave interferometry measurement. This method of electromagnetic wave interferometry for calculating the constitutive parameters of a material is reported in.<sup>13</sup> Three-dimensional (3D) views of the simulated and fabricated versions of the antenna are illustrated in Figure 2. Each one of the plexiglass layers has a thickness of 4 mm. The metallic parts of the Alford loop are photos plotted on the glass of the bottom layer with copper material.

As shown in Figure 3, the antenna is fabricated and tested on a plexiglass substrate to validate the omnidirectional radiation pattern, CP property, and the benefit of transparency to the visible light. To geometrically describe the structure in detail, the coordinate axes is shown and the geometrical parameters are given in the caption of Figure 3.

### 3 | RESULTS AND DISCUSSION

The simulated and measured results are presented in Figure 4, in which the blue dashed line is from measurement while the red line represents the results from the HFSS software. Given Figure 4A, the reflection coefficient, also known as



**FIGURE 4** Measured and simulated results for; A, reflection coefficient ( $S_{11}$ ), and B, axial ratio of the proposed antenna vs frequency ( $\theta = 90^\circ$ )

the impedance bandwidth ( $|S_{11}| < -10$  dB), shows the operating frequency range of the antenna is from 2.35 to 2.8 GHz, corresponding to a fractional bandwidth of about 18%.

The AR is determined as the ratio between the minor and major axes of the polarization ellipse and in practice, the AR of a CP antenna is defined less than 3 dB. One dual CP receiving reference antenna is used to measure the AR of the proposed antenna in an anechoic chamber. The analysis of the maximum and minimum values of crosspolarization isolation, mixed with the corresponding electrical phase, between the test antenna's co- and cross-polarized ports, provides the necessary information to determine the proper ARs of the antenna. The designed antenna has excellent circular polarization (AR < 3 dB) in the 2400 to 2700 MHz frequency band according to Figure 4B, and it is fully matched to the 10-dB bandwidth.

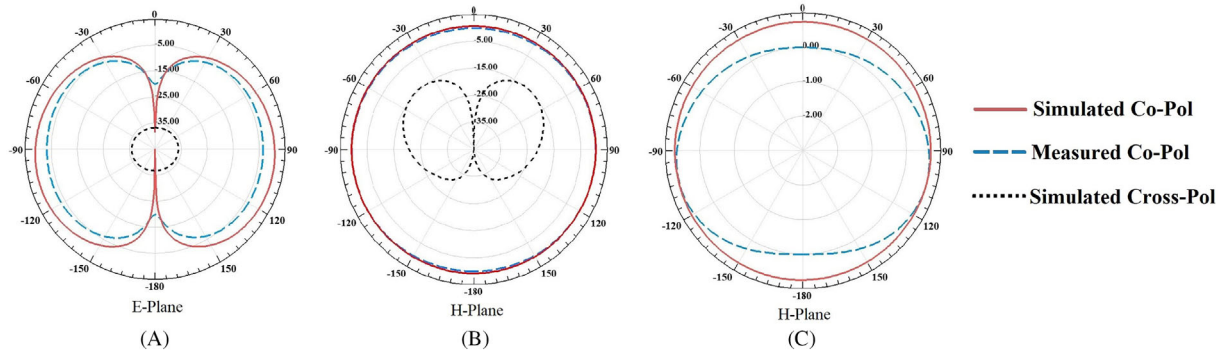
Figure 5 shows the simulated magnetic current vector behavior on arc dipoles of the proposed antenna related to the phase at 2.45 GHz. It is illustrated the surface current at 60°, 120°, 180°, 240°, 300°, and 360° phases are rotating clockwise and it makes use of polarization on the left side (Left hand circular polarized [LHCP] antenna).

The fabricated antenna is located inside the anechoic chamber, far enough from the reference antenna and in its far-field region to guarantee plane wave impingement and measurement results. Co- and cross-polarization of E- and H-plane radiation patterns of the studied antenna are presented in Figure 6A,B. In the elevation plane, the copolarized (LHCP) field is at least 15 dB greater than the related crosspolarized (RHCP) counterpart. In the anechoic chamber, a single-axis rotational pattern is used to measure antenna patterns. The proposed antenna is placed on a rotational positioner and rotated about the azimuth to make a two-dimensional polar pattern. This method is usually done for the two major axes of the antenna to provide the beam width in both the E and H planes. Simulations and measurements show a quasiperfect omnidirectional radiation. From the results, an average antenna gain of 1.7 dBic is indicated. Because of overlapping and very little difference between the simulation and measurement results of the H-plane radiation pattern in a 10 dB scale, the same results are depicted in Figure 6C with a 1 dB scale for more detail. The solid red chart represents simulation of copolarization, the dashed blue is the result of copolarization measurement and the small dashed black line illustrates copolarization simulation, as given in Figure 6. The attained results corroborate with each other.

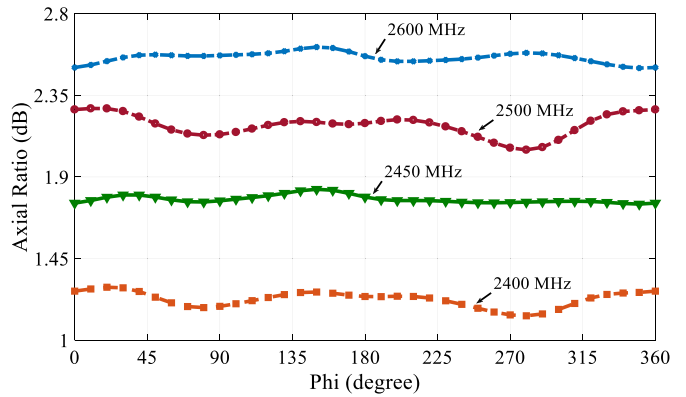
In addition, the AR of the antenna in  $xy$ -plane vs  $\phi$  angle is presented Figure 7, and it is less than 3 dB for all  $\phi$  angles. It means the antenna has a proper omnidirectional CP radiation. The four charts are from four different frequencies of 2.4, 2.45, 2.5, and 2.6 GHz. These results make the presented antenna a great candidate for isotropic CP wave radiations. The simulated 3D directivity of the antenna is shown and plotted in Figure 8 that a good omnidirectional pattern is observed. The CP radiation pattern is identical to the whole  $xy$ -plane.



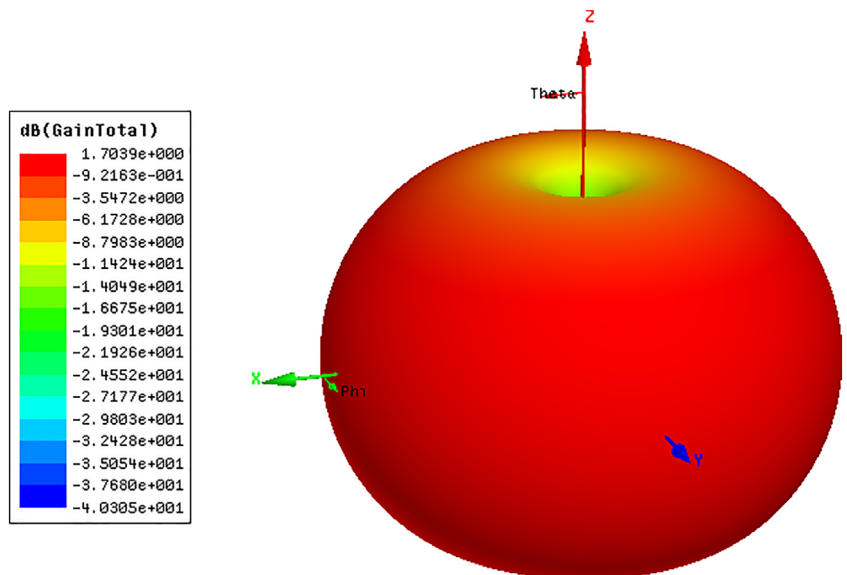
**FIGURE 5** Simulated current vector distribution on arc dipoles of the presented antenna with phase-shifting at 2.45 GHz



**FIGURE 6** Co- and cross-polarized radiation patterns of (A) E-, (B) H-plane in 10 dB scale, and (C) H-plane in 1 dB scale of the proposed antenna at 2.45 GHz



**FIGURE 7** The simulated AR of the proposed antenna in  $xy$ -plane (vs the  $\phi$  angle) for four different frequencies. AR, axial ratio



**FIGURE 8** The simulated three-dimensional radiation pattern of the proposed antenna at 2.45 GHz



**TABLE 1** Performance comparison

Design	CP BW [GHz] (Fractional BW)	Impedance BW [GHz] (Fractional BW)	Gain (dBic)	Size (mm <sup>3</sup> )	Complexity/ Robustness
This Work	2.39-2.68 (11.44%)	2.35-2.80 (17.48%)	1.70	70 × 70 × 55	Medium/High
1	2.39-2.51 (4.90%)	2.39-2.51 (4.90%)	1.12	50 × 50 × 20	Complex/Moderate
16	2.32-2.61 (11.76%)	2.32-2.54 (9.05%)	1.20	33 × 33 × 20	Medium/Low
17	2.46-2.48 (0.81%)	2.40-2.51 (4.48%)	1.90	80 × 46 × 6	Medium/Medium
18	2.25-2.73 (19.27%)	2.27-2.77 (19.84%)	3.75	180 × 180 × 3	Medium/Medium
19	2.39-2.57 (7.26%)	2.30-2.94 (24.42%)	0.91	39 × 39 × 33	Complex/Medium
20	2.37-2.56 (7.71%)	2.37-2.63 (10.4%)	1.56	53 × 53 × 20	Complex/Low
21	2.40-2.60 (8.0%)	2.35-2.57 (8.94%)	2.07	52 × 52 × 56	Complex/Low

Abbreviation: CP, circularly polarized.

The overall dimension of the fabricated antenna is 70 mm × 70 mm × 55 mm, including the coaxial cable and the SMA connector. For comparison of the different parameters, the similar CP omnidirectional antennas operating the ISM frequency band of 2.4 to 2.484 GHz are listed in Table 1. The proposed antenna has striking advantages like an acceptable fractional bandwidth for both CP and impedance matching features, a similar gain to the standard dipole antenna, a single probe-fed antenna, and no need for feeding network. In addition, the antenna is easy to fabricate, robust, and sturdy enough for harsh weather and outdoor environment.

## 4 | CONCLUSION

A new design of multifunctional robust omnidirectional CP antenna based on transparent material has been proposed for outdoor wireless communications at 2.45 GHz ISM band. The CP is obtained by utilizing two electric and magnetic dipole structures based on the plexiglass material covering. The printed metallic arcs present a magnetic dipole function. The antenna is covered by layers of plexiglass for the robustness and potential capability of integration with the solar cells performing as an energy harvesting mechanism. Therefore, the proposed antenna acts as a CP omnidirectional antenna and energy harvesting device simultaneously. Achieving the average radiation gain of the antenna about 1.7 dBic confirms the quasiisotropic behavior. In addition, the AR for CP from 2.4 to 2.7 GHz is measured less than 3 dB. The radiation pattern of the antenna shows a perfect symmetric omnidirectional pattern around its axis in the azimuthal xy-plane. Due to multidisciplinary and multifunction capacities, omnidirectional coverage and CP properties, the proposed antenna is a supreme fit for RF transceiver applications such as cube-sat and flying target systems.

## CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

## AUTHOR CONTRIBUTIONS

**Mansoor Dashti Ardakani:** Conceptualization-Equal; Formal analysis-Equal; Funding acquisition-Equal; Investigation-Lead; Project administration-Lead; Software-Lead; Supervision-Lead; Writing-original draft-Equal.  
**Marzie Tabatabaefar:** Formal analysis-Equal; Methodology-Equal; Software-Equal; Writing-original draft-Equal.

## PEER REVIEW INFORMATION

*Engineering Reports* thanks Giuseppe Torrisi and other anonymous reviewers for their contribution to the peer review of this work.

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**How to cite this article:** Dashti Ardakani M, Tabatabaeifar M. A transparent robust quasi-isotropic circularly polarized antenna for Cub-Sat and outdoor wireless. *Engineering Reports.* 2020;e12224.  
<https://doi.org/10.1002/eng2.12224>