A Wideband Circularly-Polarized Spiral Antenna for CubeSat Application

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Abstract**—In this paper, a wideband circularly-polarized spiral antenna is proposed to be used for CubeSat application. The antenna covers two of CubeSat frequencies; the S-band (2.2 GHz) and X-band (8 GHz). The proposed antenna belongs to the wideband and frequency-independent antenna category, which are known to provide a constant radiation pattern, impedance and polarization throughout the whole bandwidth. The performance of the spiral is compared in two different conditions; in free space and above a ground plane with a separation distance of $\lambda/4$ at the operating frequency of 2.2 GHz and 8 GHz. The spiral above the ground plane exhibits a unidirectional radiation and higher gain with an increase of 26.6% (2.2 GHz) to 34.6% (8 GHz) than the free space spiral. Moreover, the return loss also managed to stay within the ideal limit of S_{11}<-10dB (-19.528 dB at 2.2 GHz, and -21.92 dB at 8 GHz) and exhibits circularly-polarized radiation with low axial ratio < 3 dB (0.78 dB at 2.2 GHz, and 0.89 dB at 8 GHz).**

Index Terms**—Circular Polarization; CubeSat; Frequency-Independent Antennas; Spiral Antennas; Wideband Antennas.**

I. INTRODUCTION

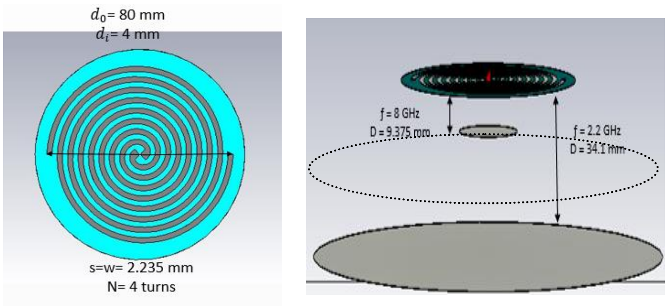
In order to maximize solar panel surface area, small satellite or microsatellite should be designed according to CubeSat standard in order to generate enough power to operate [1]. CubeSat is a mini satellite with a 10×10×10 cm^3 dimension and weighing a maximum of 1 kg [2]. There were several designs that have been proposed for CubeSat application such as wire antennas, deployable helical antennas, patch antennas and quadrifillar helix antennas [3]. To enable new communication capabilities, several characteristics such as wide bandwidth, circularly-polarized radiation and high gain has been opted for the use of CubeSat.

Spiral antennas radiate and receive circularly-(or elliptically-) polarized electromagnetic waves as a broadband travelling wave. These antennas belong to the frequency-independent antenna class which provides large bandwidth as high as 30:1, exhibiting a constant radiation pattern, impedance and polarization throughout the whole frequency band [4]. These antennas radiate on both side of the spiral plane (i.e. exhibit bi-directional circular-polarization) with equal gain in the upper and lower hemisphere. A uni-directional operation is practically needed for conformal mounting on a structure and to increase the gain of the antenna, which can be done by adding a cavity backing, such as conducting reflectors, electromagnetic absorbers and metamaterials [4–7].

In this paper, an Archimedean spiral antenna has been designed to be used for CubeSat application at 2.2 GHz and 8 GHz. The geometrical parameters of the proposed antenna can be seen in Section II. The simulated return loss, axial ratio at boresight (0^0), radiation pattern in both right-hand circular polarization (RHCP) and left-hand circular polarization (LHCP), and gain are shown in Section III. The spiral antenna is analyzed in two conditions; in free space (without a ground plane) and above a ground plane with a quarter-wavelength ($\lambda/4$) separation at each frequency.

II. DESIGN OF SPIRAL ANTENNA

A printed two-arm Archimedean spiral antenna has been designed and simulated using CST Microwave Studio (CST MWS) software for the use of CubeSat application. The antenna covers the S-band (2.2 GHz) and the X-band (8 GHz) of the CubeSat frequencies. The geometry design and parameters of the spiral is shown in Figure 1(a). The spiral was designed with an outer and inner diameter of 80 mm and 4 mm, respectively, which is compatible with a 3U CubeSat form factor (30×10×10 cm^3). Figure 1(b) shows the antenna above a ground plane with a quarter-wavelength ($\lambda/4$) separation distance at each frequency (i.e. $\lambda/4$ at 2.2 GHz = 34.1 mm, and $\lambda/4$ at 8 GHz = 9.375 mm).

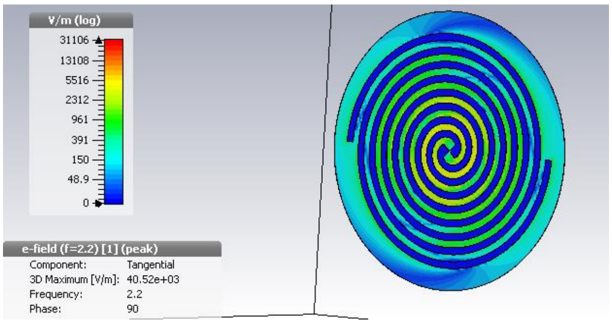


(a) (b)

Figure 1: (a) The geometrical parameters of the Archimedean spiral antenna; outer diameter d_o = 80 mm, inner diameter d_i = 4 mm, spacing s = 2.235 mm, width, w = 2.235 mm, number of turns N = 4, and (b) the Archimedean spiral antenna on a ground plane with a quarter-wavelength ($\lambda/4$) separation distance at each frequency

III. SIMULATION RESULTS

The simulated results (return loss, axial ratio at boresight, radiation pattern and gain) are analyzed at two CubeSat frequencies; 2.2 GHz and 8 GHz.



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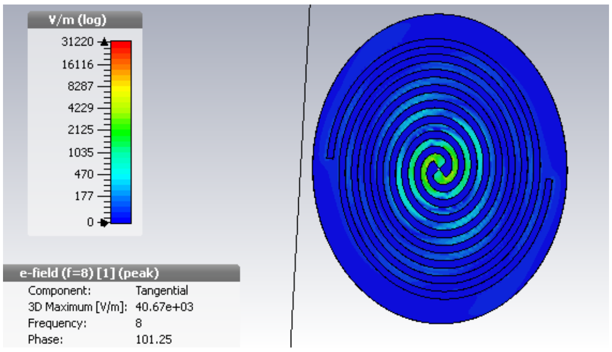

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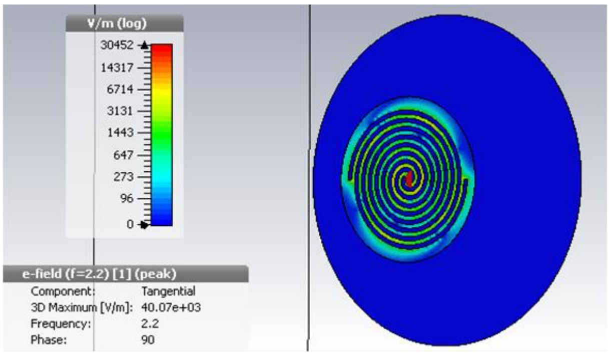
Figure 2: Simulated current distribution of the Archimedean spiral antenna in free space at (a) 2.2 GHz, and (b) 8 GHz, showing the active region



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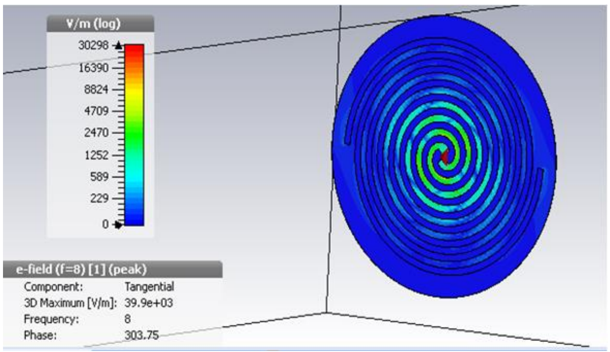


(b)

Figure 3: Simulated current distribution of the Archimedean spiral antenna on a ground plane with $\lambda/4$ separation distance at (a) 2.2 GHz, and (b) 8 GHz, showing the active region

Table 1 shows the location of the active region ($C = \lambda$) within the proposed spiral geometries and also the corresponding radius. The active region is the region where the spiral starts to radiate [8]. The spiral radius for the active region of frequency 2.2 GHz and 8 GHz is calculated to be 21.7 mm and 5.97 mm, respectively, and the circumference of the active region can be observed by the current distribution shown in Figures 2 and 3.

Table 1
The Circumference (mm) of the Active Region and the Corresponding Outer Radius (mm) of the Spiral at 2.2 GHz and 8 GHz

Frequency	Active Region $C = \lambda\ (mm)$	Outer Radius $C = r_\lambda$ (mm)
2.2 GHz	136.4	21.7
8 GHz	37.5	5.97

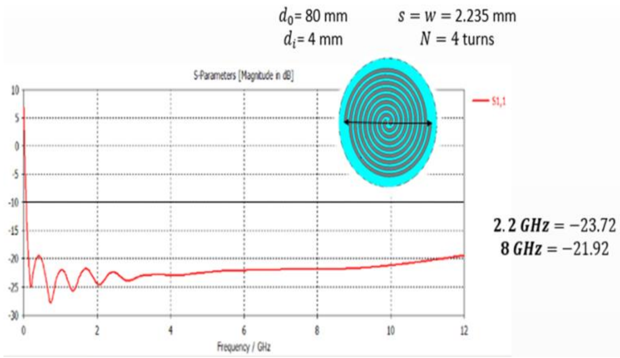
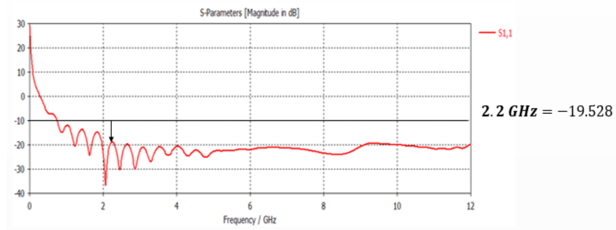


Figure 4: Simulated return loss (ideal S_{11} <-10 dB) of the Archimedean spiral antenna in free space; covering a wide bandwidth from 2.2 GHz to 8 GHz



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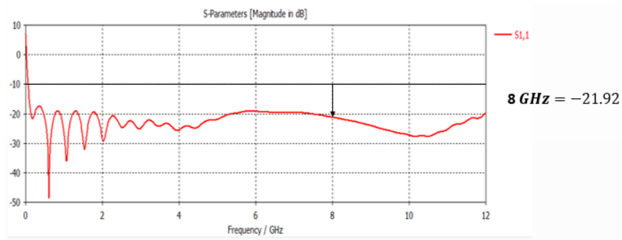
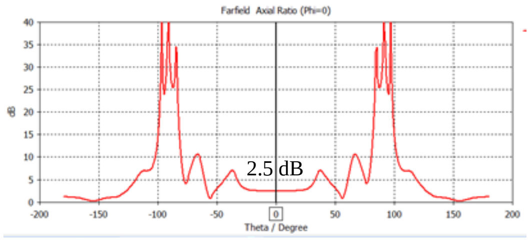


(b)

Figure 5: Simulated return loss (ideal S_{11} <-10 dB) of the Archimedean spiral antenna on a ground plane with $\lambda/4$ separation distance at (a) 2.2 GHz, and (b) 8 GHz

The return loss, S_{11} (ideal <-10 dB) for the Archimedean spiral antenna in free space and above a ground plane can be examined in Figures 4 and 5. From this figures, it can be observed that the spiral radiated perfectly as the S_{11} along the operating frequency range of 2.2 GHz and 8 GHz is below than -10 dB for both cases [5]. The S_{11} of the antenna in free space covers a wide bandwidth from 2.2 GHz (-23.72 dB) to 8 GHz (-21.92 dB). Next, a ground plane is inserted $\lambda/4$ below the spiral at each frequency of 2.2 GHz (34.1 mm) and 8 GHz (9.375 mm). This step is performed to provide a uni-directional radiation and to increase the gain of the antenna [5]. The antenna maintains a good impedance match even with the addition of the ground plane at 2.2 GHz and 8 GHz with a return loss of -19.528 dB and -21.92 dB, respectively.



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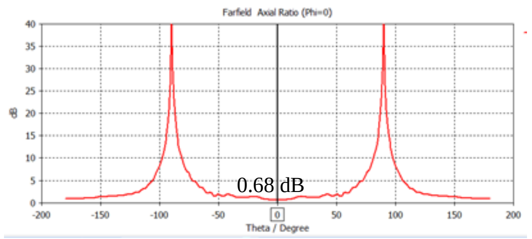
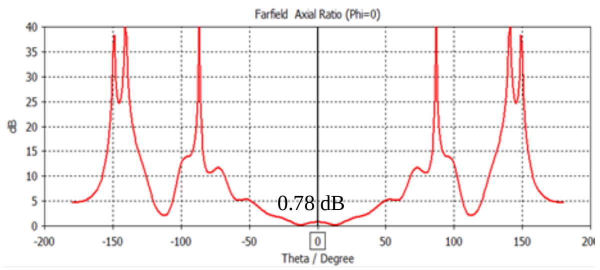


(b)

Figure 6: Simulated axial ratio at boresight (0^0) of the Archimedean spiral antenna in free space at (a) 2.2 GHz, and (b) 8 GHz



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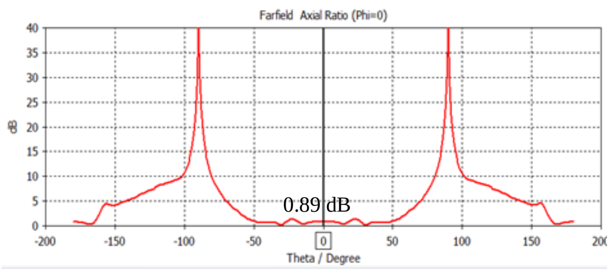

(b)

Figure 7: Simulated axial ratio at boresight (0^0) of the Archimedean spiral antenna on a ground plane with $\lambda/4$ separation distance at (a) 2.2 GHz, and (b) 8 GHz

Figures 6 and 7 depict the axial ratio at boresight (0^0) of the Archimedean spiral antenna in free space and on a ground plane at 2.2 GHz and 8 GHz. As stated by [8], an ideal circular polarization should provide an axial ratio less than 3 dB. Here, the axial ratio of the spiral antenna in free space is shown to be 2.5 dB (2.2 GHz) and 0.68 dB (8 GHz). With the addition of a ground plane, the axial ratio is 0.78 dB and 0.89 dB at 2.2 GHz and 8 GHz, respectively (which still maintain its ideal limit of less than 3 dB).

Table 2
Simulated Radiation Pattern (RHCP and LHCP) of the Archimedean Spiral Antenna in Free Space at 2.2 GHz and 8 GHz

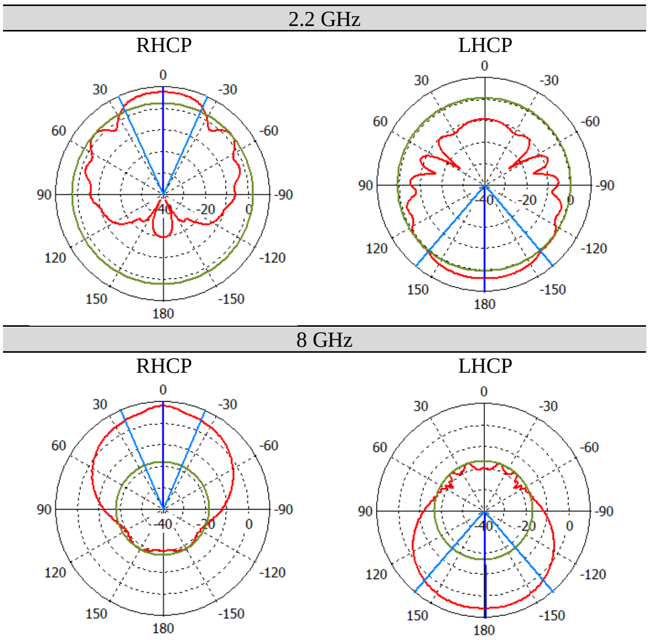

Table 3
Simulated Radiation Pattern (RHCP and LHCP) of the Archimedean Spiral Antenna on a Ground Plane with $\lambda/4$ Separation Distance at 2.2 GHz and 8 GHz

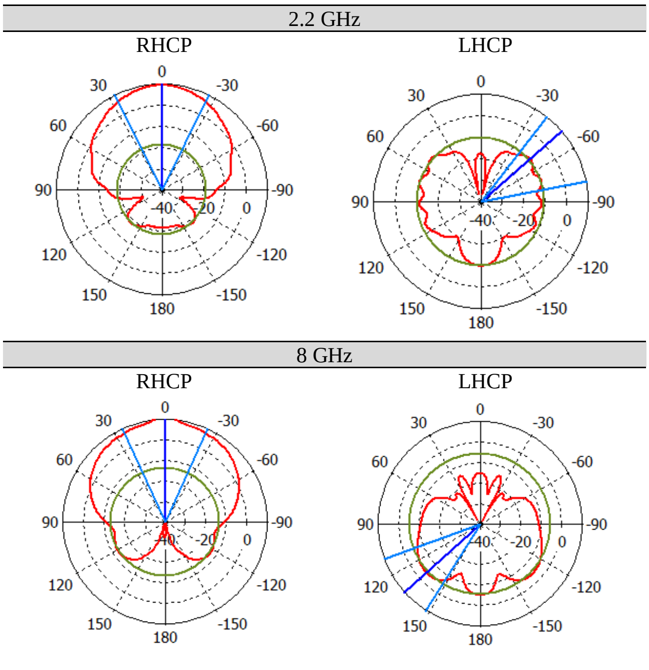

Table 2 shows the far-field radiation patterns of the designed antenna in free space at 2.2 GHz and 8 GHz. From this table, it can be observed that the spiral exhibits bi-directional radiation pattern with equal gain on the right-hand circular polarization (RHCP) and left-hand circular polarization (LHCP). In Table 3, the power in the lower hemisphere is reflected to the upper hemisphere with the addition of a ground plane to the back of the spiral, which provides a uni-directional radiation pattern. This step not just changes the direction from bi-directional to uni-directional, but also increases the gain and front-to-back ratio of the antenna.

Table 4 summarized the performance of the spiral antenna in terms of return loss S_{11}, axial ratio at boresight (0^0), radiation pattern and gain in free space and above a ground plane with $\lambda/4$ separation distance at each frequency. In free space, the gain of the spiral antenna is shown to be 7.43 dB (2.2 GHz) and 7.85 dB (8 GHz). After the addition of a ground plane, the gain increases to 9.41 dB (2.2 GHz) and 10.57 dB (8 GHz). This is about 26.6% (2.2 GHz) to 34.6% (8 GHz) increase from the antenna without the presence of a ground plane. Moreover, the polarization of the antenna changes from bi-directional to uni-directional, with high front-to-back ratio, which can also be observed in Table 3. The return loss and axial ratio of the spiral antenna above the ground plane also managed to stay within the ideal limit of S_{11}<-10dB and axial ratio < 3dB.

Table 4
Performance Summary of the Archimedean Spiral Antenna in Terms of Return Loss S_{11}, Axial Ratio at Boresight (0^0), Radiation Pattern and Gain in (a) Free Space, and (b) on a Ground Plane with $\lambda/4$ Separation Distance at 2.2 GHz and 8 GHz

Free space	Ideal	2.2 GHz	8 GHz
S_{11}	< -10 dB	-23.72 dB	-21.92 dB
Axial ratio	< 3 dB	2.5 dB	0.68 dB
Radiation pattern	Uni-directional	Bi-directional	Bi-directional
Gain	-	7.43 dB	7.85 dB

(a)

Ground plane	Ideal	2.2 GHz	8 GHz
S_{11}	< -10 dB	-19.528 dB	-21.92 dB
Axial ratio	< 3 dB	0.78 dB	0.89 dB
Radiation pattern	Uni-directional	Uni-directional	Uni-directional
Gain	-	9.41 dB	10.57 dB

(b)

IV. CONCLUSION

In this paper, a wideband circular-polarized Archimedean spiral antenna is proposed for the use of CubeSat application. The antenna covers two of the commonly used CubeSat frequencies, S-band (2.2 GHz) and X-band (8 GHz). The antenna performances such as return loss S_{11}, axial ratio at boresight (0^0), radiation pattern and gain has been studied and investigated. The proposed Archimedean spiral antenna belongs to the wideband and circular-polarized antenna category. The wideband characteristic can be observed by the S_{11} result where the antenna stays within the minimum limit of less than -10 dB, covering a wide bandwidth from 2.2 GHz to 8 GHz. The antenna also exhibits circularly-polarized radiation with an axial ratio below 3 dB at both 2.2 GHz and 8 GHz. The addition of a cavity backing helps to increase the gain and also change the bi-directional radiation to uni-directional. Moreover, the axial ratio and return loss of the antenna stays within the ideal limit even with the presence of the ground plane. The proposed antenna has met all the requirements set i.e. having a wide bandwidth covering 2.2 GHz to 8 GHz, radiate circular polarization with low axial ratio, and exhibit a uni-directional radiation pattern, and thus will be an excellent choice for a future CubeSat antenna.

ACKNOWLEDGMENT

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