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Quadrupole Antennas for Cubesats: Radiation Characteristics in Different Configurations and Initial Results

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Abstract

In a CubeSat design, analyzing the antenna radiation diagram is vital for the study of the link budget and the pointing budget. Quadrupole antennas are widely used in CubeSats, and their radiation patterns change depending on the array configuration and CubeSat structure variations. Although manufacturers adjust antennas relative to the CubeSat structure, understanding the radiation characteristics of quadrupole arrays can facilitate initial mission planning. This paper describes initial studies of radiation characteristics in CubeSats with quadrupole antennas, including monopole, dipole, v-dipole, and turnstile configurations. Simulations were performed using HFSS software, and measurements were made in an anechoic chamber. A 2U CubeSat structure was used for the study, as it was the one available for testing. All quadrupole configurations were simulated, from which radiation patterns were obtained. Initially, the simulation results were compared with real measurements of the antenna when it was in a monopole configuration, and both methods showed a correlation. Future tests will extend this to other quadrupole configurations and CubeSat structures of varying sizes.

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1 Introduction

CubeSats have revolutionized space exploration by offering compact and low-cost satellite solutions. Among the main subsystems of a CubeSat, the communication module is essential to ensure data transmission and reception, which is directly related to the radiation characteristics of the antenna. Quadripole antennas, in particular, can be arranged in different configurations, mainly monopole, dipole, v-dipole and turnstile, and are adopted due to their simplicity and efficiency [1]. However, the radiation pattern can vary significantly depending on the array configuration and the CubeSat design [1] [2] [3].

Understanding radiation properties is crucial for effective mission planning, specifically for optimizing link and pointing parameters. Although antenna manufacturers often adapt their designs to fit CubeSat form factors, more knowledge about radiation characteristics in various configurations would be very useful in preliminary mission planning. In this sense, this work presents a preliminary study of the radiation of the quadripolar antenna in various configurations, both by simulation and by measurement in an anechoic chamber.

1.1 Quadrupole Antenna for CubeSats

Quadripole antennas, especially in monopole, dipole, v-dipole and turnstile configurations, are the majority in applications in CubeSats for operation in the VHF and UHF frequency regions; this can be attributed to their simple design characteristics, cost-effective nature and operational efficiency [1]. These types of antennas are considered particularly suitable for communication missions initiated in low Earth orbit (LEO), which is an area with the highest demand for durable long-range communication capabilities. According to sources such as [4], it is evident that the majority of CubeSat missions operate within the VHF and UHF frequency bands, a finding that is corroborated by a comprehensive review of the state of the art in 2023 [5], which highlights the dominance of these antennas in CubeSat applications. Some CubeSats utilize an orthogonal dipole (v-dipole) configuration that demonstrates characteristics similar to the turnstile and circularly polarized configuration, although with certain modifications in the radiation pattern predominantly attributed to the CubeSat structure [6].

The interaction between the antenna and the CubeSat structure has a major influence on the radiation characteristics. Previous studies, such as [2] [6] [7], have identified that the structural arrangement in the CubeSat influences the radiation pattern, and this sensitivity to the structure is one of the main drawbacks related to quadrupole antennas.

In addition, the antenna positioning on the CubeSat significantly influences its radiation pattern and coverage area. Investigating multiple antenna positioning configurations on different CubeSat designs may be impractical due to the vast number of possibilities, most of which rarely occur in reality. Therefore, this study focuses on a quadrupole antenna mounted on top of the standard 2U CubeSat structure. The goal of this approach is to provide detailed radiation performance of the antenna and provide input data that can be useful for a wider range of CubeSat missions.

2 Antenna Configurations

This study, focus on one quadrupole with four diferents configurations, resulting in four different radiation characteristics:

1. Monopole Antenna Configuration: A monopole antenna consists of a single radiating element that is perpendicular to the CubeSat structure.

2. Dipole Antenna Configuration: The dipole antenna comprises two opposing monopoles.

3. V-Dipole Array Configuration: In this configuration, two monopoles are arranged orthogonally on the CubeSat body.

4. Turnstile Antenna Configuration: The turnstile antenna is formed by crossing two dipoles, providing circular polarization.

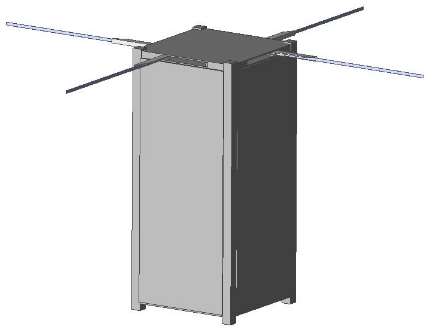

Figure 1: Simulation model of the antenna and 2U cubesat

3 Simulation Setup and Results

The simulation setup utilized a simplified model of a 2U CubeSat structure [8] and an antenna, as shown in Figure 1.

The material chosen for the structure and some parts of the antenna was aluminum, for the PCB it was copper, for the monopole supports it was nylon, and for the monopoles it was steel.

The software selected for the simulations was HFSS, to generate radiation patterns for each quadrupole configuration, maintaining a standard in the presentation of the results to avoid perspective errors.

In the context of HFSS, the Driven Solution Setup was created for an automatic configuration, while the frequency was set at 402 MHz and with a maximum of 20 steps. Furthermore, there was a *Maximum Delta D* set at 0.02. This therefore enabled the optimization of the four monopoles to operate at 402 MHz. For each of the monopoles, a *Wave Port* was assigned coupled with *Dembed* and impedance of 50 ohms. To replicate the four configurations, HFSS offers the functionality to independently activate or deactivate the feed for every port.

3.1 Simulation Results monopole configuration

In this subsection, the simulation results for the monopole configuration are presented. The antenna was analyzed in different planes to evaluate its performance in a 2U CubeSat simulation model. The gain diagrams illustrate the radiation pattern and the behavior of the antenna in the x, y, and z planes.

Figure 2 shows the gain diagram for the x

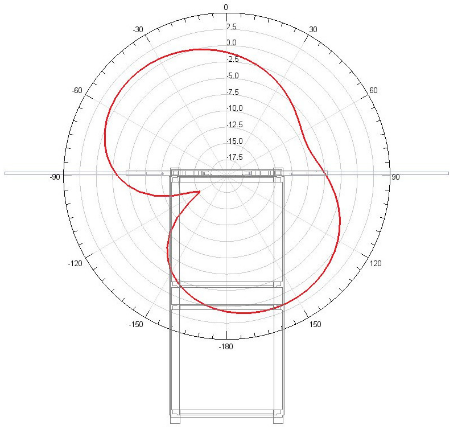

Figure 2: Gain diagram of the antenna in monopole configuration for the 2U CubeSat simulation model in the x plane

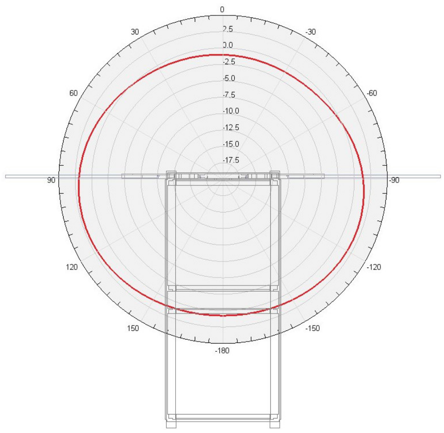

Figure 3: Gain diagram of the antenna in monopole configuration for the 2U CubeSat simulation model in the y plane

plane. This antenna configuration shows a maximum gain of 3.5 dB. It is important to note the low gain part that shows the antenna at 120 degrees, where its -15 dB.

The antenna gain diagrams shown in Figure 3 and Figure 4 show a maximum gain of 3.5 dB, with the radiation being quite homogeneous at all angles, with the exception of the -90 and 90 degree angles in plane z, where the gain

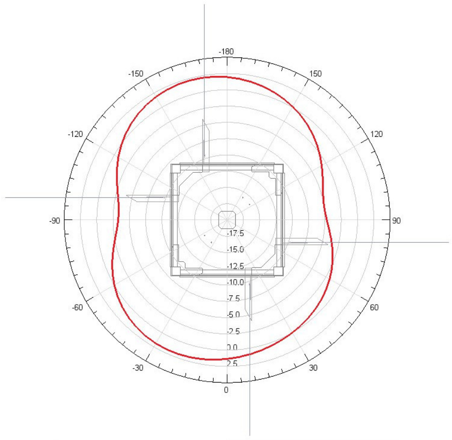

Figure 4: Gain diagram of the antenna in monopole configuration for the 2U CubeSat simulation model in the z plane

can reach -5 dB.

3.2 Simulation Results dipole configuration

The following figures show the simulation results for the dipole configuration, where the antenna's radiation patterns are evaluated in the x, y, and z planes.

Figure 5 illustrates the gain in the x plane. Here we can see that at angles -90 and 90 degrees the gain drops below -10 dB. The maximum gain is found at angles of 0 and 180 degrees, where it is approximately 2.5 dB.

Figure 6 shows the gain in the y plane. A homogeneous radiation diagram with a gain of approximately 2.5 dB is observed.

Finally, Figure 7 provides the gain diagram for the z plane. Similar to the x plane here we observe a radiation diagram with -10 dB gain for angles -90 and 90 degrees. and maximum gain is found at angles of 0 and 180 degrees, where it is approximately 2.5 dB.

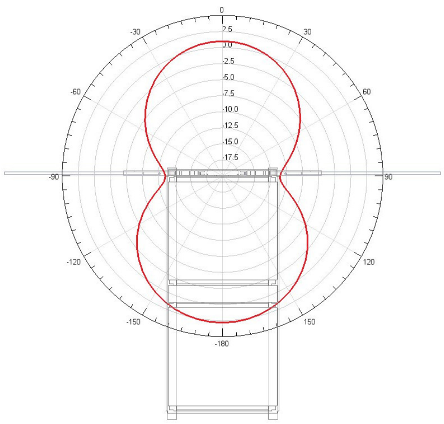

Figure 5: Gain diagram of the antenna in dipole configuration for the 2U CubeSat simulation model in the x plane

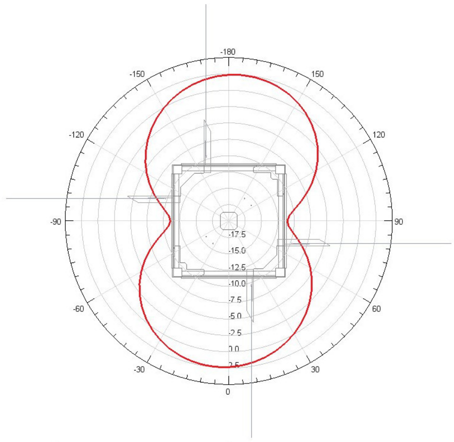

Figure 7: Gain diagram of the antenna in dipole configuration for the 2U CubeSat simulation model in the z plane

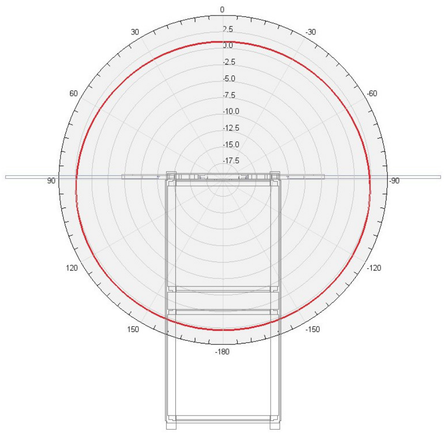

Figure 6: Gain diagram of the antenna in dipole configuration for the 2U CubeSat simulation model in the y plane

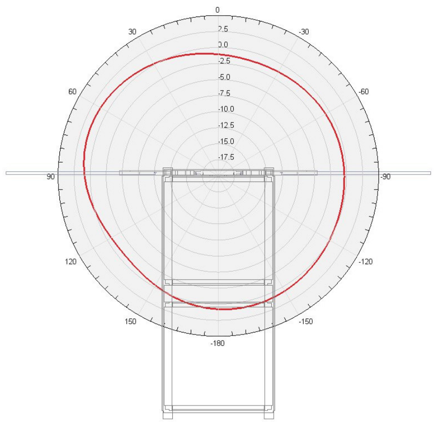

Figure 8: Gain diagram of the antenna in V-dipole configuration for the 2U CubeSat simulation model in the x plane

3.3 Simulation Results V-dipole configuration

In the V-dipole configuration, the antenna's radiation pattern in the x, y, and z planes is analyzed and illustrated in the following figures.

As can be seen in Figure 8, Figure 9 and Figure 10, the v-dipole configuration shows a radiation diagram with a homogeneous gain in all planes. The maximum gain is found between the angles of 120 and 150 degrees in the z plane, being approximately 2.5 dB, and the minimum gain is found in the same plane at the angle between the angles -30 and -60 degrees.

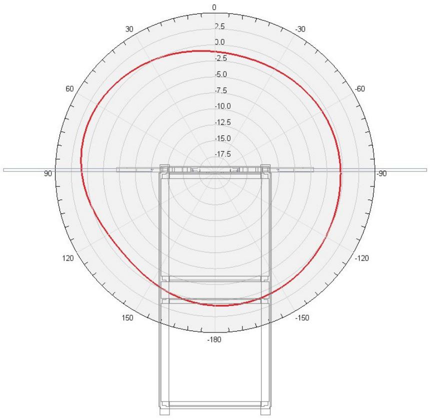

Figure 9: Gain diagram of the antenna in V-dipole configuration for the 2U CubeSat simulation model in the y plane

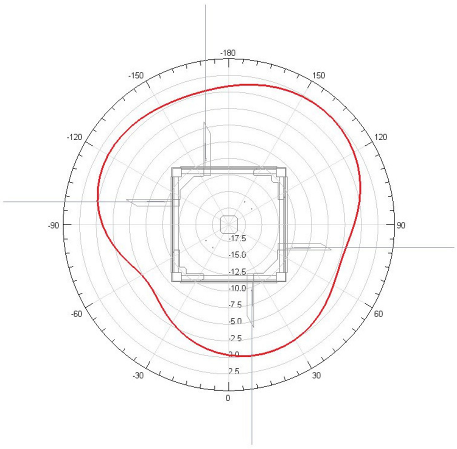

Figure 10: Gain diagram of the antenna in V-dipole configuration for the 2U CubeSat simulation model in the z plane

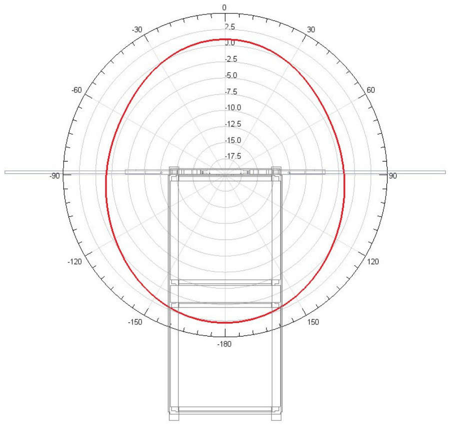

Figure 11: Gain diagram of the antenna in turnstile configuration for the 2U CubeSat simulation model in the x plane

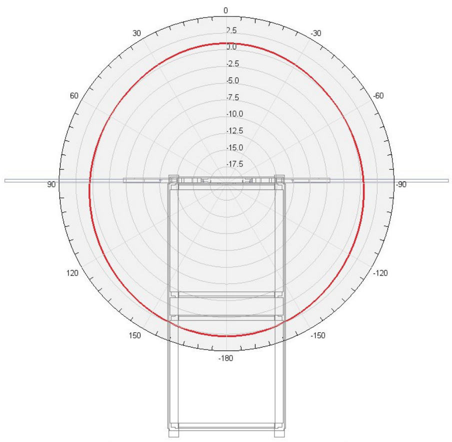

Figure 12: Gain diagram of the antenna in turnstile configuration for the 2U CubeSat simulation model in the y plane

3.4 Simulation Results turnstile configuration

The turnstile configuration is analyzed in the x, y, and z planes, with the corresponding gain diagrams displayed below.

As observed in Figure 8, Figure 9 and Figure 10, the turnstile configuration shows a radiation diagram with a very homogeneous gain in all planes. The maximum gain is found at the 180 degree angle in the x and y planes, being approximately 2.5 dB, and the minimum gain in this case is the lowest of all the analyzed configurations, being -2.5 dB and is found in the same z plane at the angles 60 and -120 degrees.

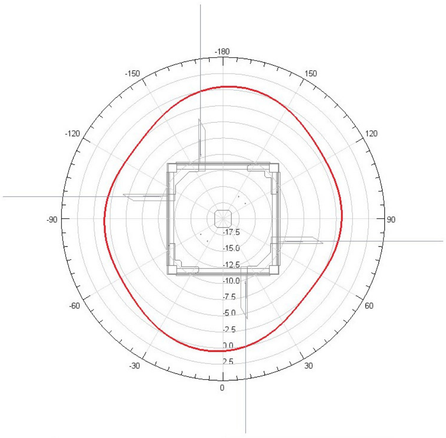

Figure 13: Gain diagram of the antenna in turnstile configuration for the 2U CubeSat simulation model in the z plane

4 Anechoic Chamber Setup and Results

Due to its simple design and frequent use in CubeSats, the monopole antenna configuration was selected for preliminary experimental verification. A semi-anechoic chamber, which has walls with high absorbance properties, reducing reflections and making the configuration controlled for accurate radiation pattern measurements, was used.

4.1 Experimental Setup

The cubesat model and antenna were fixed to a rotating platform inside the anechoic chamber, shown in Figure 14. For the monopole, two separate measurement series were made, placing the antenna in y and z panes in the current reference frame, and 72 measurements were made per measurement series, providing a resolution of 5 degrees for each plane. The receiving antenna used was a herringbone antenna located 1 meter away from the satellite and at an altitude of 1.6 meters.

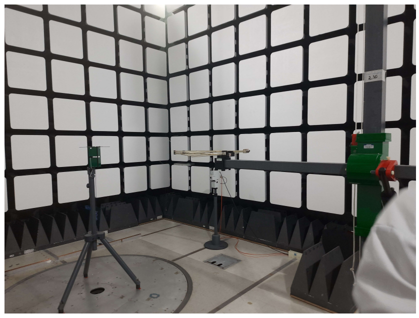

Figure 14: Anechoic chamber setup for monopole antenna measurement

During the test, a signal at a frequency of 402 MHz and 30 dBm of power was placed on the CubeSat antenna, in transmitter function, combined with a 30 dB attenuator. To minimize the measurement error, the configuration was calibrated before the tests. This calibration allows the loss in the coaxial cable and the properties of the receiving antenna to be disregarded during the measurement execution, thus ensuring greater accuracy of the results.

4.2 Preliminary Experimental Results

The received signal was measured using the *ESU EMI Test Receiver*, and the values were recorded in tables. These values were then normalized and plotted on the polar plots shown in Figure in the figures below 15 and Figure 16. The polar plots provide a visual representation of the antenna gain distribution over 360 degrees, allowing an analysis of the antenna radiation characteristics.

Figure 15 shows the measurements made on the antenna in the y plane. The measured

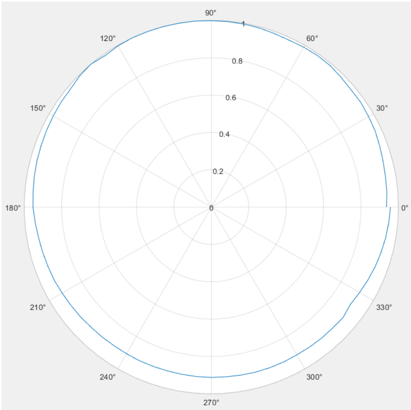

Figure 15: Normalized radiation diagram obtained in the tests for the y plane.

values indicate a homogeneous distribution along the 360 degrees, showing a similarity with the result obtained with the y plane of the simulated monopole.

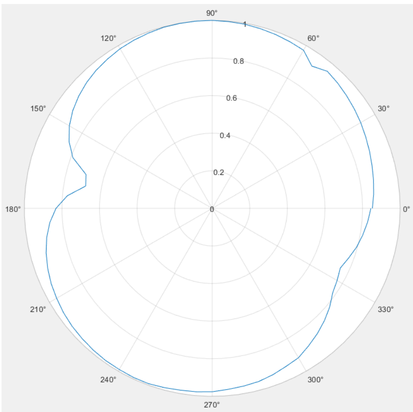

Figure 16: Normalized radiation diagram obtained in the tests for the z plane.

Finally, Figure 16 presents the measurements made for the z plane, illustrating the antenna performance in 360 degrees. In this case, some points of minimum gain are observed that stand out in relation to the maximum gain, similar to what happens with the simulated monopole z plane.

5 Conclusion

This paper presents a first study of radiation characteristics for quadrupole antennas on CubeSats in monopole, dipole, V-dipole, and turnstile configurations.

The distinctive trait in the design of the monopole is its simplicity, having only a coaxial cable feed for each monopole.

Dipoles and V-dipoles present similar complexity, needing a previous circuit. However, for a CubeSat application, the V-dipole would be preferable due to its circular polarization, with a more uniform radiation pattern.

The turnstile configuration is very desirable for CubeSats without attitude control, as it provides circular polarization and a highly uniform radiation pattern. However, this is at the expense of increased implementation complexity: whereas the linear antenna only requires two monopoles, the turnstile requires four, which reduces the number of radios that can be directly connected.

The monopole configuration is thus the easiest to realize. From dipole and V-dipole, V-dipole would, hence, become the most desirable configuration once circular polarization and absence of attitude control are favored. Finally, the turnstile antenna, due to its highly uniform radiation pattern, offers more reliable communications for a CubeSat with no attitude control, thus becoming the best choice for more stable links.

5.1 Future Work

A hardware will be designed for dipole, V-dipole and turnstile configurations to further this research. Experiments will then be performed in the anechoic chamber to verify the radiation patterns for these configurations using CubeSat arrays of various sizes.

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