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Spiral Square Single Feed Circularly Polarized Compact Slot Antenna for CubeSat Applications

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Abstract-*The demand for compact and efficient antennas for CubeSat applications has been growing steadily with the increasing popularity of small satellite missions. In this paper, we propose a novel design of a Spiral Square Single Feed Circularly Polarized Compact Slot Antenna (SSSF-CP-CSA) tailored specifically for CubeSat communication systems. The antenna design offers several advantages, including a compact form factor, circular polarization, and wideband operation suitable for various CubeSat missions. The SSSF-CP-CSA is designed using a square-shaped substrate with a spiral slot etched on its surface. By strategically placing a single feed at the centre of the spiral, circular polarization is achieved. The spiral geometry contributes to broadband characteristics, enabling the antenna to cover a wide frequency range suitable for CubeSat communication bands. Furthermore, the compact size and lightweight nature of the antenna make it particularly suitable for integration into CubeSat platforms where space and weight constraints are critical considerations. The proposed antenna design offers a practical solution for CubeSat missions requiring reliable communication systems while minimizing payload volume and mass.. Capacitive loading is used in the construction of the slot to achieve wideband properties in a small package. The proposed antenna design functions over a large frequency range from 360 MHz to 900 MHz, as confirmed by the simulated and measured results. The entire board size of the fabricated design is 50 x 50 x 1.52 mm^3.*

Index Terms—*CubeSat, slot antenna, circular polarization, compact antenna, spiral geometry.*

I. INTRODUCTION

In order to progress the technology for satellite missions and low-Earth orbit satellite communications in the future, cube sats have emerged as a crucial answer. A single unit CubeSat typically measures 10×10×10 cm3 [1], [2]. Additionally, a circular polarized (CP) antenna with a broad impedance matching bandwidth is needed for CubeSats. In many wireless communication applications, such as satellites, 5G millimetre-wave, and radio frequency identification, the CP antenna provides greater orientation freedom and matching than linear polarized [3], [4]. However, the construction of CP antennas is always difficult, particularly when they need to be broad and small in size [5] in the UHF spectrum—two essentials for CubeSat communication. The CP antenna offers more orientation flexibility and matching compared to linear polarized in many wireless communication applications including satellites, 5G millimetre-wave and radio frequency identification. Nevertheless, the CP antenna is always challenging to built especially with wideband and compact size characteristics at UHF spectrum, which are the core requirements in CubeSat communication[6][7]. Due to physical and structure requirements by CubeSat, electrically small antennas with CP and wideband character istics are good candidates. At its core, this antenna design features a unique spiral square geometry, meticulously engineered to optimize both size and performance. By strategically arranging slots in a spiral pattern within a square aperture, the antenna achieves efficient radiation characteristics while occupying minimal space—a critical consideration for CubeSat missions where size and weight constraints are paramount.

In order to progress the technology for satellite missions and low-Earth orbit satellite communications in the future, CubeSats have emerged as a crucial answer. The demand for compact and efficient antennas for CubeSat applications has been growing steadily with the increasing popularity of small satellite missions[8]. In this paper, we propose a novel design of a Spiral Square Single Feed Circularly Polarized Compact Slot Antenna (SSSF-CP-CSA) tailored specifically for CubeSat communication systems. The antenna design offers several advantages, including a compact form factor, circular polarization, and wideband operation suitable for various CubeSat missions.

The SSSF-CP-CSA is designed using a square-shaped substrate with a spiral slot etched on its surface. By strategically placing a single feed at the centre of the spiral, circular polarization is achieved. The spiral geometry contributes to broadband characteristics, enabling the antenna to cover a wide frequency range suitable for CubeSat communication bands. Overall, the SSSF-CP-CSA offers a promising solution for CubeSat communication systems, combining compactness, circular polarization, and performance efficiency. The next sections will delve into the design methodology, simulation results, and discussions regarding the practical implications of the proposed antenna for CubeSat applications[9]. Electromagnetic simulations are conducted to assess the antenna's performance in terms of return loss, axial ratio, and radiation patterns across the desired frequency range. The results demonstrate the effectiveness of the proposed antenna design in meeting the communication requirements of CubeSat missions.

II. METHODOLOGY

The design methodology of the Spiral Square Single Feed Circularly Polarized Compact Slot Antenna (SSSF-CP-CSA) for CubeSat applications involves several key steps aimed at achieving the desired performance characteristics within the constraints of CubeSat platforms. This section outlines the design approach adopted for the development of the proposed antenna. Requirement Analysis: The design process begins with a thorough analysis of the requirements specific to CubeSat communication systems. This includes understanding the desired operating frequency bands, polarization requirements, space limitations, and other mission-specific constraints.

Geometry Selection: The choice of antenna geometry is crucial in achieving the desired performance within the confined space of CubeSat platforms. The square-shaped substrate is selected as the base geometry for the antenna, ensuring compatibility with CubeSat structural elements. Slot Geometry Design: The spiral slot geometry is carefully designed to achieve circular polarization and wideband operation. The dimensions of the spiral are optimized to cover the desired frequency range while maintaining compactness and efficiency.

Feed Placement Optimization: A single feed is positioned at the center of the spiral slot to excite the antenna structure. The placement of the feed is optimized to ensure proper impedance matching and circular polarization characteristics across the operating frequency bands.

Simulation and Analysis: Electromagnetic simulations using software tools such as HFSS (High-Frequency Structural Simulator) or CST Microwave Studio are employed to analyze the antenna's performance. Parameters such as return loss, axial ratio, radiation patterns, and efficiency are evaluated across the desired frequency range.

Parameter Tuning and Optimization: The antenna design parameters, including slot dimensions, feed position, and substrate properties, are iteratively tuned and optimized to achieve the desired performance metrics while adhering to CubeSat size and weight constraints.

Fabrication and Testing: Once the design is finalized through simulation, a prototype of the antenna is fabricated using suitable manufacturing techniques such as printed circuit board (PCB) fabrication or additive manufacturing. The fabricated prototype is then subjected to experimental testing to validate its performance under real-world conditions.

Iterative Refinement: The design process may involve iterative refinement based on experimental results and feedback from testing. This iterative approach helps to fine-tune the antenna design for optimal performance and reliability in CubeSat applications.

By following this systematic design methodology, the Spiral Square Single Feed Circularly Polarized Compact Slot Antenna (SSSF-CP-CSA) is developed to meet the communication requirements of CubeSat missions while addressing the challenges posed by space, weight, and performance constraints. The subsequent sections will delve into the detailed design parameters, simulation results, and performance analysis of the proposed antenna.

III. PROPOSED CIRCULARLY POLARIZED ANTENNA

The Spiral Square Single Feed Circularly Polarized Compact Slot Antenna (SSSF-CP-CSA) presented in this study offers a compact and efficient solution tailored specifically for CubeSat communication applications[10][12]. This section provides a detailed description of the proposed antenna, including its geometric configuration, feeding mechanism, and operational principles. The demand for compact and efficient antennas suitable for CubeSat communication systems has led to the development of innovative designs. In this context, we propose a Circularly Polarized Slot Antenna (CPSA) tailored specifically for CubeSat applications. The CPSA offers advantages in terms of compactness, circular polarization, and wideband operation, making it an ideal candidate for CubeSat communication systems. The CPSA design comprises a square-shaped substrate with a spiral slot etched onto its surface. This spiral geometry is instrumental in achieving circular polarization and broadband characteristics necessary for CubeSat missions[13].fig 1 shows the structure of the antenna. A single feed is strategically placed at the center of the spiral slot to excite the antenna structure, ensuring balanced radiation patterns and efficient energy transfer.

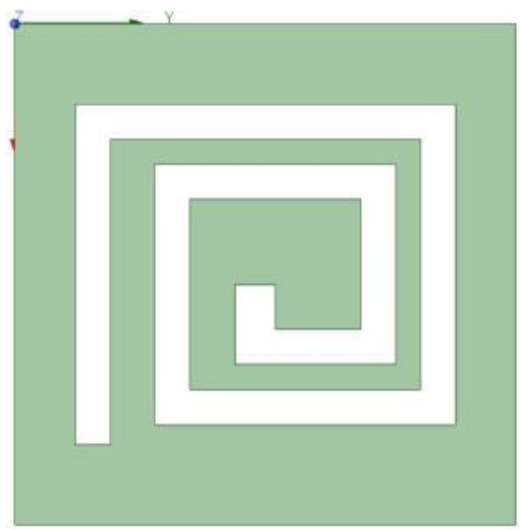


fig 1:design of antenna

IV. SINGLE FEED SLOT ANTENNA

A single feed slot antenna refers to an antenna design in which a single feed element is used to excite a single slot in the transmitter, causing electromagnetic waves to be radiated[14][15]. This configuration is often preferred in mobile antenna designs for its simplicity and efficiency, making it suitable for CubeSat applications where space and weight constraints are critical. Proposed Spiral Field Single Feed Circularly Polarized Compact Field Antenna (SSSF-CP-CSA) Single feed field antenna architecture for CubeSat applications plays a key role in achieving circular polarization and broadband characteristics while maintaining compactness[16]. space provides balanced excitation and symmetrical radiation patterns. The feed position is optimized to achieve the correct impedance matching and circular polarization characteristics in the required frequency band. A feed conductor serves as a source of electromagnetic energy coupled to a hole in the ground. When food is excited by an appropriate RF signal, a current is generated in the current and causes electromagnetic waves. Oter is a radioactive element that emits radiation into space.

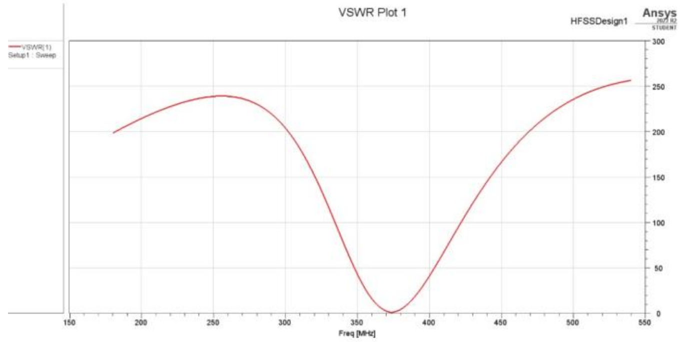


fig 2: the VSWR plot

The fig 2 shows the VSWR plot. Voltage Standing Wave Ratio (VSWR) is a critical parameter in the world of radio frequency (RF) engineering. VSWR is closely related to return loss and quantifies the same phenomenon. It expresses the efficiency of power transmission from a source to a load. It is a dimensionless ratio (without measurement units) that indicates how much energy is reflected back to the transmitter when a signal is transmitted through an antenna.

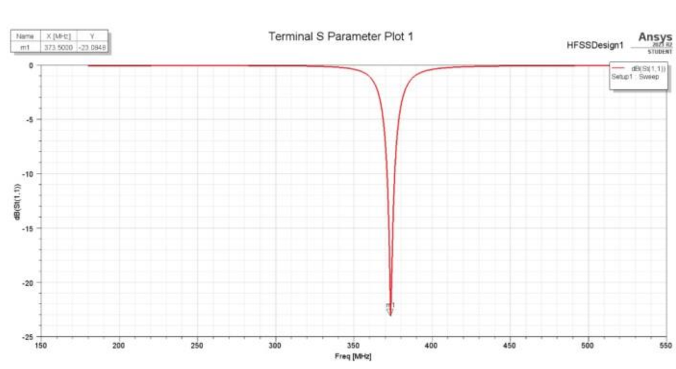


fig 3: Terminal S Parameter Plot

here the above figure 3 shows the terminal s planar plot, Terminal S-parameter plots play a crucial role in radio frequency (RF) engineering and antenna design. S-parameters describe the input-output relationship between ports (or terminals) in an electrical system. For instance, if we have two ports (intelligently called Port 1 and Port 2), then S12 represents the power transferred from Port 2 to Port 1, while S21 represents the power transferred from Port 1 to Port 21. These parameters are essential for understanding how energy flows within a network, especially in RF circuits and components here we got the frequency of 374 MHz.

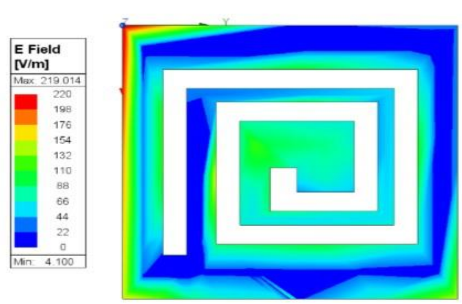


fig 4(a): E Field

above figure 4(a) shows the E(electric) field. The electric field is a fundamental concept in electromagnetism. It arises due to the presence of electric charges.(max=219,min=4.1)The electric field at a point in space represents the force experienced by a positive test charge placed at that point. The electric field points away from positive charges and toward negative charges. units: Measured in volts per meter (V/m).

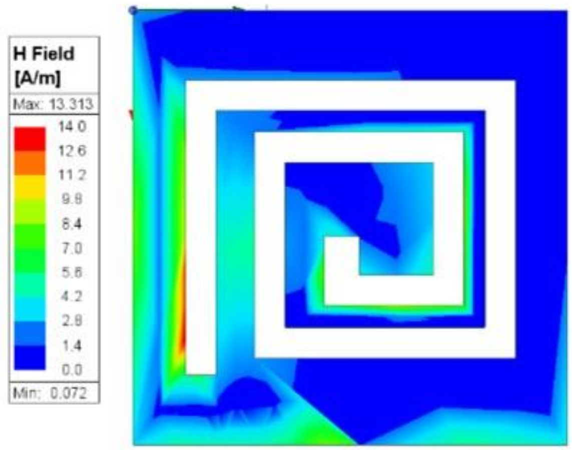
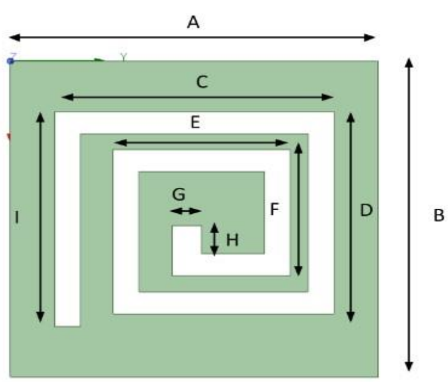


fig 4(b): H Field

above figure 4(b) shows the (magnetic) field is another essential component of electromagnetism. It arises due to moving charges (currents) or changing electric fields. The magnetic field at a point represents the force experienced by a moving charge (like an electron) placed at that point. The magnetic field forms closed loops around current-carrying conductors. Units: Measured in amperes per meter (A/m).



S.NO	PARAMETERS	VALUES
1	A	50
2	B	50
3	C	38
4	D	38
5	E	24
6	F	24
7	G	3.8
8	H	16
9	I	25

fig:5(a) fig:5(b)

The above figures 5(a) and 5(b) shows the parameters and values of the antenna.

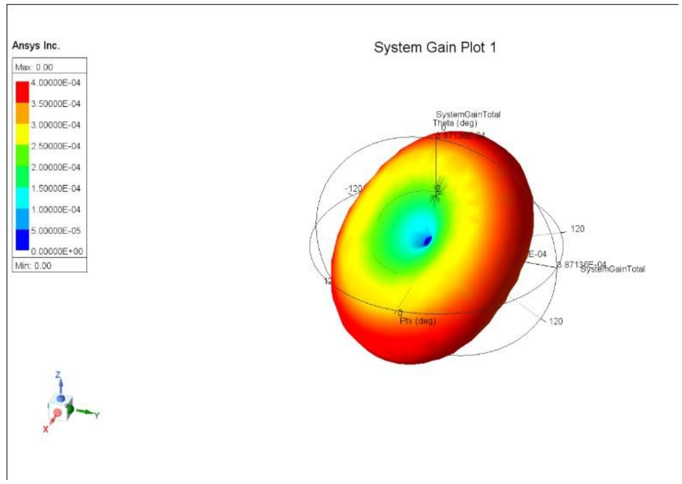


fig 6: system gain plot

The above figure 6 shows the system gain plot. A system gain plot, often seen in control systems and signal processing, displays the gain of a system as a function of frequency. The gain typically refers to the amplification or attenuation applied to a signal passing through the system at different frequencies. In a system gain plot, the x-axis represents frequency, usually in logarithmic scale (commonly in units of Hertz or radians per second), while the y-axis represents the gain or magnitude of the system's response, often measured in decibels (dB) or as a linear scale. These plots are crucial for understanding how a system responds to different frequencies. They help engineers and researchers analyse the behaviour of systems such as filters, amplifiers, and control systems, and can provide insights into stability, bandwidth, and frequency response characteristics.

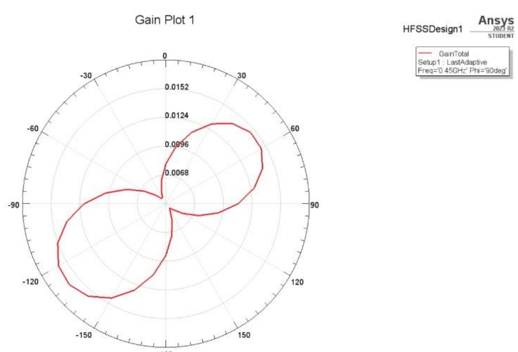


fig 7: gain plot

The gain plot of an antenna shows how its gain varies with frequency or directionality. Antenna gain is a measure of the ability of the antenna to direct or concentrate radio frequency energy in a particular direction compared to an isotropic radiator. Gain plots of antennas are essential for antenna design, selection, and performance evaluation in various applications such as telecommunications, radar systems, satellite communication, and wireless networking. They help engineers understand how well an antenna will perform in different scenarios and environments.

V. CONCLUSION

Spiral square single-feed CP antenna presents a viable solution for CubeSat communication systems, offering advantages in terms of circular polarization, compactness, wideband performance, and reliability. Continued research and development in this area are crucial for advancing CubeSat technology and enabling future space exploration missions.

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