# *CubeSat Project* - Report

*IIT Indore*

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**Abstract**

CubeSats are miniature satellites designed to provide a cost-effective and accessible platform for space-based research and hands-on engineering experience. This project aimed to develop a CubeSat prototype capable of monitoring weather patterns by measuring temperature and humidity, facilitating the study of climate change and environmental anomalies. The primary objectives included designing and integrating a payload with various sensors, developing a Graphical User Interface (GUI) for real-time data visualization, and optimizing the CubeSat's structural design. The methodology involved selecting and calibrating environmental and orientation sensors, establishing a communication system using an RF transmitter-receiver module, and implementing a user-friendly GUI to display collected data. Structural analysis was performed to ensure the resilience and functionality of the CubeSat under expected conditions. Key findings include successful sensor integration for environmental data collection, efficient real-time data transmission via RF communication, and an optimized structural design that balances weight, strength, and functionality. The developed GUI provided an interactive platform for data visualization, enhancing usability. In conclusion, the project successfully demonstrated the feasibility of a compact, sensor-equipped CubeSat for atmospheric data collection. The insights gained from this work contribute to the advancement of small satellite technology and serve as a foundation for future space-based environmental monitoring missions.

**Keywords:** *CubeSat, Sensor Integration, Structural Analysis, Sensors, Graphical User Interface (GUI), Data Visualization*

## 1. Introduction

Satellites play a pivotal role in Earth observation, communication, and scientific research. However, traditional satellites come with high costs and long development cycles, limiting accessibility for educational institutions and small research teams. CubeSats, a class of miniature satellites standardized to 10 $cm^3$ units, offer a cost-effective alternative that allows students and researchers to actively participate in space technology development. These small satellites have become instrumental in various fields, from remote sensing to technology demonstrations.

One of the key applications of CubeSats is environmental monitoring. With climate change accelerating, tracking weather patterns and atmospheric anomalies has become more crucial than ever. Gathering real-time data on temperature and humidity allows for better understanding of climate fluctuations, helping scientists refine meteorological models and assess environmental trends. CubeSats, due to their compact size and adaptability, provide an efficient platform for this type of research. By equipping a CubeSat with appropriate sensors, valuable atmospheric data can be collected, analyzed, and used for further studies.

This project focuses on the development of a CubeSat prototype designed to collect and analyze environmental data, specifically temperature and humidity. The initiative is significant in multiple ways: it provides an opportunity for hands-on learning in aerospace engineering, sensor integration, and data processing while also contributing to the broader field of small satellite applications. The growing reliance on CubeSats for research purposes demonstrates their relevance in modern space missions, disaster management, and climate monitoring.

By successfully designing, analyzing, and implementing this CubeSat, the project showcases the potential of small satellites for scientific purposes. The insights gained from sensor data can aid in climate studies and serve as a foundation for future advancements in CubeSat missions. Additionally, the project fosters interdisciplinary collaboration, integrating mechanical design, electronics, and software development, making it a valuable educational experience.

The project aimed to develop a CubeSat capable of real-time atmospheric data collection and transmission. The key objectives included:

Payload Development: Integration of various sensors to measure environmental parameters such as temperature and humidity. Structural and Thermal Optimization: Ensuring that the CubeSat's mechanical design is robust enough to withstand expected operating conditions while maintaining minimal weight. Graphical User Interface (GUI) Implementation: Development of a real-time data visualization platform for user-friendly interaction with the collected information. The scope of the project included designing, fabricating, and testing a CubeSat prototype. While the current phase focused on ground-based testing, the long-term vision includes potential high-altitude testing or an eventual launch. The project serves as a stepping stone for future improvements, such as incorporating additional sensors, refining power management, or integrating advanced communication systems.

To efficiently manage the CubeSat's development, the team was divided into three specialized domains:

- **Design & Analysis:** This team was responsible for conducting structural, thermal, and modal analyses to ensure that the CubeSat could withstand operational conditions. Key tasks included stress analysis for load-bearing capacity, thermal simulations for temperature regulation, and modal analysis to evaluate vibrational behavior. These steps were critical in ensuring the satellite's durability and functionality.
- **Hardware:** The hardware team managed the physical construction of the CubeSat, focusing on sensor integration, PCB design, and 3D printing of the structural components. Sensor calibration and testing were essential to ensure accurate data collection. Additionally, assembling and validating the payload components played a crucial role in the CubeSat's overall performance.
- **GUI Development:** The software team was responsible for designing and implementing a graphical user interface (GUI) to facilitate real-time data visualization. This involved integrating sensor outputs into a user-friendly display, enabling easy interpretation of the collected data. The GUI ensured that the data from the CubeSat could be monitored efficiently, making it a crucial component for usability.

By structuring the project into these domains, the team ensured a systematic and collaborative approach, balancing mechanical design, electronics, and software development. Each domain played a crucial role in achieving the project's objectives, ultimately leading to a functional and optimized CubeSat prototype.

## 2. Methodology

To efficiently develop the CubeSat, the team was divided into three specialized domains: Design & Analysis, Hardware, and GUI Development. This structured approach allowed simultaneous progress across different aspects of the project, ensuring smooth integration of mechanical, electronic, and software components.

The Design & Analysis team was responsible for structural, thermal, and modal analyses. They optimized the CubeSat's frame for strength and weight efficiency, ensuring its resilience under operational conditions. The Hardware team focused on selecting and integrating sensors, designing the PCB, and fabricating the CubeSat structure using 3D printing for prototyping rather than flight-ready materials. Finally, the GUI Development team worked on real-time data visualization, creating an interactive interface to display sensor readings effectively.

Throughout the project, an iterative design process was followed. Initial simulations guided structural modifications, while sensor testing led to adjustments in hardware integration. Certain constraints, such as the use of 3D printing for model fabrication instead of aerospace-grade materials, shaped design decisions to ensure structural feasibility within available resources. Additionally, sensor calibration and optimizing real-time data transmission required continuous refinement. Frequent collaboration between teams ensured that design changes were compatible with hardware constraints and software functionality.

Key lessons learned include understanding structural optimization trade-offs, overcoming sensor interfacing difficulties, and refining real-time data visualization techniques. This systematic approach not only ensured a functional CubeSat prototype but also provided valuable hands-on experience in multidisciplinary engineering.

## 3. Design & Analysis

### 3.1. Structural Design

The CubeSat was designed as a 1U unit ($10 \times 10 \times 10$ cm) with a modular structure to ensure easy integration of hardware components. The frame follows an "X" design, consisting of six interconnected frames, which not only provide balanced stress distribution but also enhance structural integrity. This configuration allows for mechanical stability while maximizing the available space for the payloads and electronics. The central hole, strategically integrated into the design, optimizes weight distribution and facilitates thermal management by improving airflow or accommodating thermal straps/heat pipes. Its circular shape minimizes stress concentrations, which reduces the risk of cracks or structural failures under mechanical loads.

The CubeSat's base incorporates eight square platforms, increasing its stability and serving as a secure mechanism for spring-based deployment. The optimization goals were clear: minimize weight while maintaining robustness, maximize internal volume for hardware and payload integration, and ensure even stress distribution to prevent any weak points in the structure.

### 3.2. Structural Analysis

To validate the CubeSat's design, Finite Element Analysis (FEA) was carried out, simulating the expected launch conditions. The CubeSat must withstand various forces during deployment, including launch acceleration (3g), spring force ( 60N), and impulse loads (7N). The FEA results showed that the maximum stress observed was 15.45 MPa, with a maximum deformation of just 0.12 mm. These values were well within the material's limits, confirming the design's reliability under the predicted conditions. A Factor of Safety (FoS) of 1.4 was applied to account for potential uncertainties in load estimation, further reinforcing the CubeSat's resilience. The results assured that the CubeSat frame could effectively withstand launch conditions without structural failure.

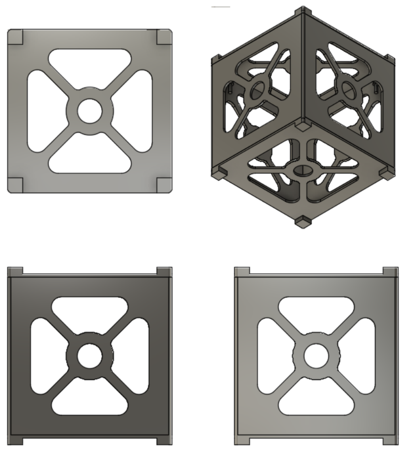
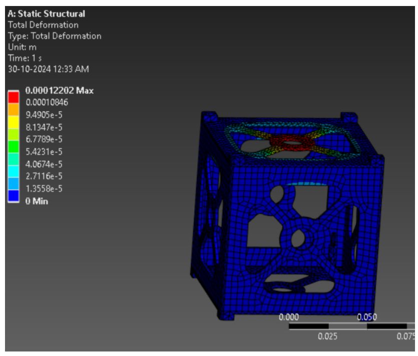
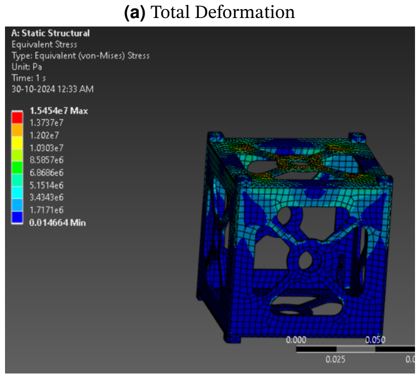


**Figure 1.** Design

The use of the "X" frame configuration proved effective in distributing stress, which enhanced the overall mechanical strength of the CubeSat. The integration of a central hole and circular edges reduced weight while maintaining the structure's integrity. Conducting FEA early in the design process allowed for iterative improvements, where stress and deformation results guided design refinements. Modal analysis further emphasized the importance of carefully considering natural frequencies to prevent potential resonance during launch. These analyses confirmed that the CubeSat was designed to withstand real-world operational conditions, providing a robust foundation for the project's continued development.




**(a)** Total Deformation




**(b)** Equivalent Stresses

**Figure 2.** Structural analysis

### 3.3. Modal Analysis

Beyond ensuring structural integrity, modal analysis was conducted to assess the CubeSat's natural frequencies and ensure it would not resonate with launch vibrations. The first natural frequency was found to be 1157.6 Hz, significantly higher than the critical frequency range of 100 Hz, which minimizes the risk of resonance-induced failures. This finding highlights the importance of avoiding natural frequencies within the operational vibration spectrum, ensuring the CubeSat remains stable and intact throughout its mission.

Tabular Data

| | Mode | Frequency [Hz] |
|---|---|---|
| 1 | 1. | 1157.6 |
| 2 | 2. | 1160.1 |
| 3 | 3. | 1205.8 |
| 4 | 4. | 1206.6 |
| 5 | 5. | 1216.3 |
| 6 | 6. | 1362.7 |
| 7 | 7. | 2026.5 |
| 8 | 8. | 2034.3 |
| 9 | 9. | 2368.4 |
| 10 | 10. | 2613.7 |

**Figure 3.** Natural Frequencies

## 4. Hardware

The CubeSat's hardware design incorporates multiple sensors to monitor environmental conditions, track its orientation, and ensure proper functioning throughout the mission. These sensors work together to gather essential data, which is then processed and transmitted to the ground station for analysis. Each sensor was carefully chosen based on its functionality, accuracy, and ease of integration with the CubeSat's system.

Sensors and Their Functions

1. BMP180 (Pressure & Altitude Sensor): This sensor measures atmospheric pressure, temperature, and altitude. It plays a critical role in monitoring environmental conditions in real-time. The data from BMP180 helps assess changes in atmospheric pressure and altitude, which are crucial during different phases of the CubeSat's mission.
2. GY-271 (Magnetic Sensor): The GY-271 is used to detect the CubeSat's orientation in space with respect to Earth's magnetic field. This magnetic sensor aids in attitude determination, ensuring that the CubeSat can adjust its orientation as needed, which is particularly important for tasks such as maintaining communication with the ground station or aligning solar panels.
3. GY-521 (Accelerometer-Gyroscope): The GY-521 sensor is a combination of an accelerometer and a gyroscope, allowing the CubeSat to measure acceleration and angular velocity. This sensor is essential for tracking the CubeSat's motion during launch and its orientation in space, enabling it to respond to forces and maintain proper attitude control.
4. DHT11 (Temperature-Humidity Sensor): The DHT11 sensor measures both temperature and humidity, providing important data for environmental monitoring. This sensor is used to ensure that the CubeSat's payload and electronics remain within operational temperature and humidity ranges throughout its mission.
5. GY-NEO6MV2 (GPS Module): This GPS module provides real-time location tracking, crucial for determining the CubeSat's precise position in orbit. It also helps during ground testing to track the CubeSat's movements and ensure that the system is functioning as expected.

Hardware Integration All sensors—BMP180, GY-271, GY-521, GPS, and DHT11—are connected to an Arduino UNO, which serves as the primary data acquisition unit. The Arduino collects data from each sensor, processes it, and sends it to the Raspberry Pi for more advanced processing, storage, and control of the GUI. The RF Transmitter-Receiver Module is used for wireless communication to the ground station, allowing real-time data transmission.

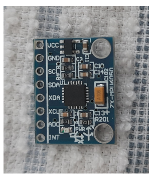
Testing and Validation To ensure the system worked as intended, each sensor module was validated individually before being integrated into the overall setup. After integration, the complete data flow was tested to confirm that the sensors were correctly transmitting data to the Raspberry Pi, which then relayed the information to the RF module. This end-to-end test ensured that data from the sensors flowed smoothly to the ground station.

Additionally, the GUI interface on the Raspberry Pi was tested for real-time visualization of the data, ensuring that users could monitor the CubeSat's environmental conditions and status. By performing these comprehensive tests, we ensured that the integrated sensor system would function reliably throughout the CubeSat's mission, providing critical information back to the ground station.

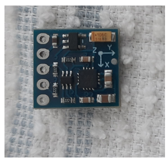
The PCB for the CubeSat's sensor integration was designed using EasyEDA software, which provided a user-friendly platform for creating the schematic and layout. This software allowed for precise placement of components and optimized routing for efficient signal flow and minimal interference. Once the design was finalized, the PCB was fabricated in the Makerspace laboratory at IIT Indore. The fabrication process involved transferring the design to a physical board, ensuring proper layer alignment, and etching the copper traces. After fabrication, the PCB was tested for connectivity and functionality, ensuring that all components were properly integrated

**(a)** BMP180 (Pressure & Altitude Sensor)

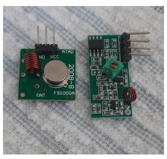
**(b)** Raspberry Pi



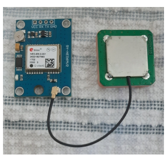
**(c)** GY-521 (Accelerometer-Gyroscope)



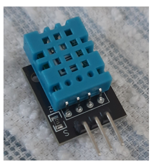
**(d)** GY-271 (Magnetic Sensor)



**(e)** RF Transmitter-Receiver Module



**(f)** GY-NEO6MV2 (GPS Module)



**(g)** DHT11 (Temperature-Humidity Sensor)

**(h)** Arduino UNO

**Figure 4.** Hardware Sensors & Components

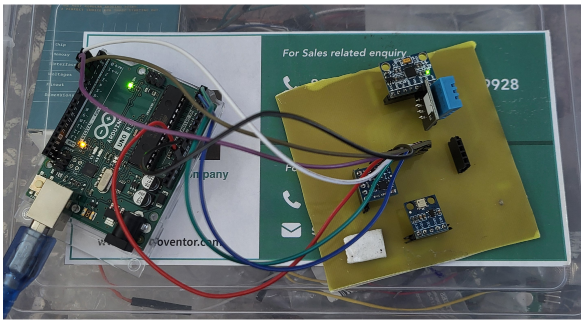



**Figure 5.** Integrated Cicuit

and the circuit was ready for sensor connections and system integration. This hands-on approach in the Makerspace allowed for quick iterations and immediate troubleshooting, ensuring the board met the necessary specifications for the CubeSat's mission.

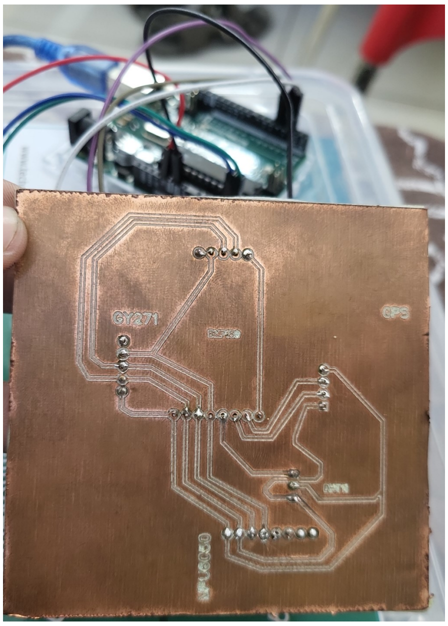


**Figure 6.** PCB

## 5. GUI Development

The Graphical User Interface (GUI) for the CubeSat was designed to provide an intuitive and efficient way to visualize and interpret sensor data in real time. The main objective was to ensure seamless user interaction with the CubeSat's hardware, allowing users to monitor its performance, analyze environmental conditions, and manage the system's operations from a central interface. Software Design and Programming Structure The GUI was developed using Python, with a combination of libraries tailored for ease of development and powerful functionality. The primary library used for the interface was Tkinter, which is a standard Python library for creating simple and effective graphical interfaces. Tkinter provided the foundation for creating windows, buttons, and labels, allowing the user to interact with the CubeSat system in a visual and intuitive manner. To handle more advanced graphical elements, such as plotting sensor data in real-time, the matplotlib library was employed. Matplotlib is highly versatile, enabling the creation of dynamic and interactive plots that allow users to visualize trends in data, such as temperature, humidity, pressure, and orientation, in real time. For image handling and displaying graphical elements like sensor icons or background images, Pillow, a powerful image-processing library, was used. It enabled smooth rendering of images and icons within the GUI,

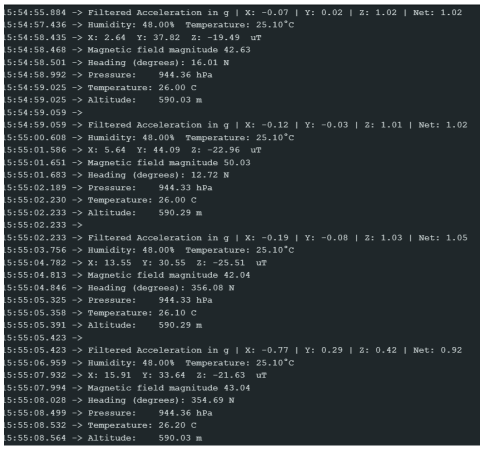



**Figure 7.** Validating the data from sensors

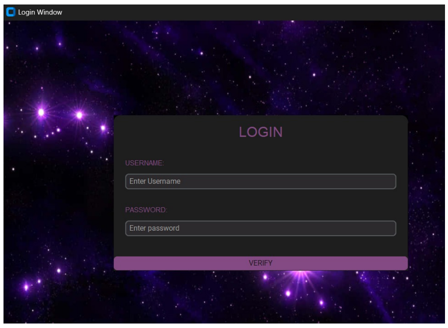



**Figure 8.** Login Window

enhancing the overall visual experience. Additionally, Pygame, a library often used for creating games, was used to manage animations and transitions, providing dynamic features like updating visual data representations as the CubeSat collects more information from its sensors. One of the key features of the CubeSat's GUI was real-time data visualization. As the CubeSat collected sensor data during its mission, the GUI displayed this information in easily interpretable graphs and charts. Using matplotlib, the GUI presented data in the form of dynamic, real-time line graphs for parameters like temperature, humidity, atmospheric pressure, and the CubeSat's orientation and motion. These graphs updated continuously, allowing the user to track sensor readings and trends over time, offering a comprehensive view of the CubeSat's operational status. The visualization also incorporated 3D projection capabilities, offering a more interactive and detailed view of sensor data, particularly useful for orientation and motion analysis. The 3D projection allowed users to view the CubeSat's movement and rotation in space, enhancing the understanding of its behavior during various mission phases.

Ensuring ease of access and usability was a key priority in the GUI design process. The interface was structured to be simple and intuitive, providing easy navigation between different data points and system controls. Buttons for sensor data control, system status checks, and real-time updates were clearly labeled, while interactive features like zooming and panning allowed users to dive deeper into specific data sets.

Moreover, the GUI's layout was designed to minimize user confusion, with each section clearly delineated to provide a logical flow from one task to another. This design ensured that users could efficiently interact with the CubeSat system, monitor its health, and make decisions based on the data presented. Ultimately, the goal was to make the user experience as seamless as possible, with real-time data visualization and clear, accessible controls that support efficient decision-making and CubeSat management.


**Figure 9.** GUI Main Page

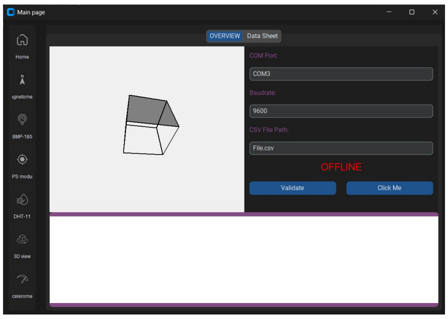



**Figure 10.** Home Page of GUI

## 6. Conclusion

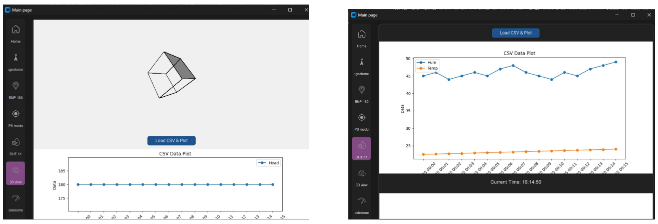
The CubeSat project successfully integrated hardware and software components to create a functional system capable of monitoring environmental conditions and providing real-time data to a ground station. The design of the CubeSat focused on structural integrity, ensuring that the frame could withstand the stresses of launch and space conditions while maximizing internal space for payloads and electronics. The integration of key sensors, including the BMP180, GY-271, GY-521, DHT11, and GPS, allowed for comprehensive environmental monitoring and attitude determination, providing vital information about the CubeSat's operational status.

The development of the Graphical User Interface (GUI) was a pivotal aspect of the project. Using libraries like Tkinter, matplotlib, and Pygame, the GUI enabled seamless data visualization and user interaction, allowing real-time tracking of sensor data and CubeSat performance. The system's ability to process and display sensor information in an intuitive and accessible manner was a major achievement, ensuring that users could easily interpret the CubeSat's behavior during its mission.

Throughout the project, several lessons were learned, including the importance of sensor calibration, the challenge of optimizing hardware within constrained space, and the need for a user-friendly interface to simplify complex data visualization. The iterative testing and validation of each component, from the sensors to the PCB and GUI, ensured the system's reliability and robustness.

Looking ahead, further improvements could be made to enhance the CubeSat's capabilities, such as integrating additional sensors for more comprehensive environmental monitoring or optimizing the communication systems for faster data transfer. Additionally, refining the GUI for more advanced features and expanding its data analysis capabilities could further improve the user experience.

In conclusion, the CubeSat project has provided valuable insights into the design, integration, and testing of space-bound systems, laying a strong foundation for future space missions and satellite development. The work accomplished in this project demonstrates the importance of interdisciplinary collaboration, combining mechanical design, hardware integration, and software development to create a successful and functional CubeSat system.



**(a)** Orientation **(b)** Sample graph

**Figure 11.** Visualizing the data

## 7. Future Aspects

Looking forward, several key developments are planned to enhance the CubeSat project. One of the primary objectives is to design and implement an antenna deployment mechanism. Currently, the CubeSat relies on manual antenna deployment, but this is not optimal for operational deployment in space. By developing an automated antenna deployment system, we can ensure reliable communication with the ground station once the CubeSat reaches its intended orbit. This mechanism would be designed to deploy the antennas once the CubeSat has been deployed from its launch vehicle and is stabilized in space, improving data transmission and overall mission performance.

Additionally, the Graphical User Interface (GUI) will be further refined and optimized. The current GUI relies on various libraries (Tkinter, matplotlib, Pygame) to provide real-time data visualization and user interaction. In the future, the goal is to consolidate these libraries into a single, self-contained software application by creating a standalone executable (.exe) file. This will simplify the user experience by removing the need for multiple library dependencies, improving performance, and ensuring that the system is easier to deploy and use. The executable GUI will also have a more streamlined, professional interface, allowing for smoother interaction and faster data processing.

Moreover, future work will focus on expanding the CubeSat's capabilities by adding additional sensors for more detailed environmental monitoring or improving the existing systems for enhanced accuracy. Optimizing the CubeSat's communication system to handle faster data transmission or integrating more advanced payloads will be key for future missions.

These improvements will significantly increase the CubeSat's functionality, reliability, and usability, paving the way for more advanced space missions and contributing to the development of efficient, low-cost satellite systems.