UDAN: A Compact Deployable UHF Antenna Enabling High-Gain Links for CubeSats

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***Abstract*—The miniaturization of satellite platforms has imposed severe constraints on antenna systems, particularly for UHF links requiring high gain and polarization robustness. To address these challenges, this contribution introduces UDAN, a deployable UHF antenna concept designed to significantly enhance communication capabilities of CubeSats and other small spacecraft while remaining compliant with standard launch and deployment interfaces.**

UDAN is based on a deployable quadrifilar helix architecture with an integrated ground plane, tailored for operation around 430 MHz and supporting a wide operational range from 400 to 460 MHz. The antenna is fully stowed within a 1.5U CubeSat volume and relies on a hold-down and release mechanism that enables autonomous deployment without motors or active actuators. Once deployed, the structure expands to approximately 1 m in diameter and 0.5 m in height, providing the electrical aperture required for high-performance radiation characteristics.

Electromagnetic simulations and experimental validation on multiple breadboard models demonstrate that the antenna provides circular polarization with a realized gain above 10 dBi across the target band. Measured results confirm excellent impedance matching near the center frequency and a high level of polarization purity, validating the beam-forming and feeding approach adopted in the design. Repeated deployment tests show consistent mechanical behavior and reliable release performance.

The proposed antenna is well suited for UHF TT&C and IoT-oriented CubeSat missions, enabling improved link margins and reducing dependency on complex ground infrastructure. The concept is also applicable to microsatellites, amateur radio payloads, and low-data-rate Earth-observation missions. UDAN demonstrates that high-gain, circularly polarized UHF antennas can be successfully integrated into nanosatellite platforms through innovative deployable solutions.

Keywords—Deployable ; CubeSat ; UHF ; Quadrifilar ; TT&C ; Antenna

I. INTRODUCTION

The rapid expansion of small satellite constellations is redefining the architecture of space communications. CubeSats and microsatellites are increasingly being deployed for Earth observation, maritime tracking, asset monitoring, scientific missions, and machine-to-machine connectivity [1]. While payload capabilities have evolved significantly over the past decade, communication subsystems continue to represent one of the principal bottlenecks for nanosatellite missions, particularly when reliable long-range links are required under strict power and volume constraints.

This challenge becomes especially severe in lower frequency bands such as VHF and UHF. These frequencies remain highly attractive for telemetry, tracking and command (TT&C), Internet-of-Things (IoT) relay services, emergency communications, and low-data-rate mission architectures due to their favorable propagation characteristics, reduced atmospheric attenuation, and comparatively low power requirements [2]. However, achieving high antenna gain at these frequencies remains difficult for CubeSat-class spacecraft. Since antenna dimensions scale directly with wavelength, systems operating below 1 GHz typically require large radiating apertures that are fundamentally incompatible with the limited internal volume of standard nanosatellite platforms. As a result, most currently available CubeSat antennas in the UHF domain rely on monopoles, dipoles, or patch configurations that provide modest gain levels, often forcing operators to compensate through larger ground infrastructure or reduced mission flexibility [3].

To address this technological gap, a new deployable antenna architecture has been developed: UDAN (UHF Deployable Antenna for Nanosatellites). The system introduces a compact high-gain communication solution specifically engineered for CubeSat and small satellite platforms operating in the UHF spectrum. In its launch configuration, the antenna occupies only 1.5U, allowing compatibility with conventional CubeSat deployment envelopes. Once released in orbit, the structure autonomously deploys into a large-aperture quadrifilar helix configuration with an approximate deployed diameter of 1 meter and a height of 0.5 meters, enabling performance levels traditionally unattainable in nanosatellite platforms operating at these frequencies [4].

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The antenna architecture combines four helical radiating elements with an integrated deployable ground plane and a passive deployment mechanism based on stored elastic strain energy [5]. The resulting system provides greater than 10 dBi gain, circular polarization, and operational coverage across the 400–460 MHz band, centered at 430 MHz, making it suitable for both commercial and institutional missions [6].

This paper presents the updated development status of UDAN, including its mechanical architecture, deployment strategy, RF performance validation, and pathway toward in-orbit demonstration [7]. The work highlights how deployable low-frequency antennas may become a key enabling technology for the next generation of high-performance small satellite missions [8].

II. TECHNOLOGY DESCRIPTION

A. Main Features

UDAN has been conceived as a compact deployable communication payload intended to overcome the volumetric limitations traditionally associated with low-frequency satellite antennas. The system has been specifically optimized for CubeSat and small satellite missions requiring high-gain communications in UHF bands without sacrificing valuable onboard volume. The antenna operates nominally at 430 MHz, while maintaining operational capability across the broader 400–460 MHz frequency range, allowing compatibility with multiple mission profiles including TT&C links, IoT relay services, scientific payload communications, and governmental communication architectures. With minor geometric adaptations, the design philosophy can also be extended to adjacent VHF and lower UHF bands. The architecture is based on a deployable quadrifilar helix antenna (QHA) configuration composed of four radiating helices arranged around a central axis. This topology was selected due to its ability to generate circular polarization while maintaining strong radiation efficiency at low frequencies. A deployable ground plane is integrated into the architecture to improve radiation efficiency. Once deployed, the antenna reaches an approximate operational envelope of 1 meter in diameter and 0.5 meter in height. This large effective aperture enables the system to achieve antenna gain levels above 10 dBi, which remains highly uncommon for CubeSat-compatible UHF systems. During launch, the complete antenna remains packaged within a highly compact volume of only 10 cm × 10 cm × 15 cm.

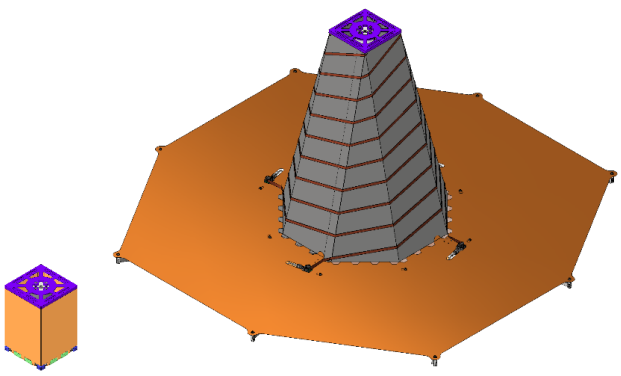


Fig. 1. UDAN in stowed (left) and in deployed (right) configuration.

This allows integration within standard CubeSat dispensers while minimizing the impact on spacecraft payload allocation. One of the most relevant design drivers was the elimination of mechanically complex deployment systems. Instead of using motors, articulated joints, or active actuators, UDAN stores elastic strain energy while in its stowed configuration.

Once released, this energy enables autonomous deployment with reduced failure points and lower overall system complexity. Key system characteristics include:

- 10 dBi antenna gain.
- Circular polarization.
- 400–460 MHz operational bandwidth.
- Autonomous deployment.
- Passive deployment actuation.
- CubeSat-compatible form factor.
- Low mass architecture.
- High deployment repeatability.
- Scalability toward broader small satellite platforms.

This combination makes UDAN particularly attractive for missions where communication performance must be maximized under severe SWaP constraints (Size, Weight and Power).

B. Deployment Sequence

Since deployment events remain one of the most critical single-point failures in small satellite missions, minimizing the number of active mechanisms was considered essential during the design phase.

The deployment process begins after orbital insertion, once the spacecraft verifies nominal attitude conditions and sends the release command to the antenna subsystem. Upon command execution, the primary release line is activated, the redundant release line remains available as backup and the mechanical constraints are removed.

After previous action has been performed, the deployable ground plane unfolds, creating the required electromagnetic reference surface for nominal antenna operation. This step is critical because proper planar deployment directly affects radiation efficiency and beam stability. Therefore, ground plane deployment was one of the earliest subsystems validated during prototype testing campaigns due to its importance in overall RF performance. At the same time of the ground plane stabilization, the four helical radiating elements expand outward and upward into their final geometry.

This process is fully passive and driven by previously stored elastic energy. No motors or active deployment devices are required. The final deployed geometry creates the large effective aperture required for high-gain operation. The complete deployment process requires approximately 10–12 seconds. This timing can be intentionally slowed down for missions requiring reduced shock transmission to sensitive spacecraft payloads.



Fig. 2. Ambient deployment sequence of UDAN.

C. Customer Interfaces

To simplify spacecraft integration, UDAN has been designed with a standardized interface architecture that minimizes adaptation effort for satellite manufacturers and mission integrators. The antenna subsystem includes three primary customer interfaces:

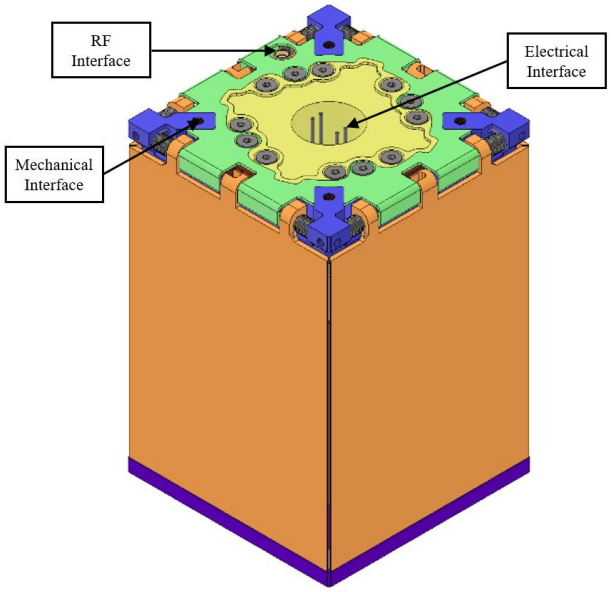


Fig. 3. Interfaces from customer side.

- Electrical Deployment Interface

This interface manages deployment initiation. It includes two primary electrical release lines and two redundant electrical release lines. This dual-redundant architecture ensures deployment can still be executed even in the event of electrical failure in the primary trigger path. The interface can be integrated directly into the spacecraft EPS or deployment controller architecture.

- RF Interface

The communication payload interfaces with the spacecraft transceiver through a standard SMA coaxial connector. This enables straightforward integration with commercially available CubeSat radios and UHF communication modules.

- Mechanical Interface

Mechanical integration is performed through four M4 threaded mounting points located at the base structure of the antenna assembly. Depending on mission requirements, the antenna can either be mounted directly on an external spacecraft panel or be housed internally with an additional release stage.

III. ENVIRONMENTAL PERFORMANCE

A. Structural Performance

One of the primary engineering challenges during the development of UDAN was ensuring structural robustness while preserving the extremely low mass required for deployable UHF architectures. Large deployable antennas typically suffer from low natural frequencies due to the

presence of slender structural members, which can create undesirable coupling with the satellite's attitude determination and control system (ADCS). This issue becomes particularly critical in CubeSat and small satellite missions, where even small structural oscillations can introduce pointing disturbances. To mitigate these risks, the UDAN development process included multiple structural optimization iterations focused on reducing mass concentration in the most flexible structural elements.

- Stowed Configuration Performance

Finite element simulations show that the first natural frequency of UDAN in stowed configuration reaches 223 Hz.

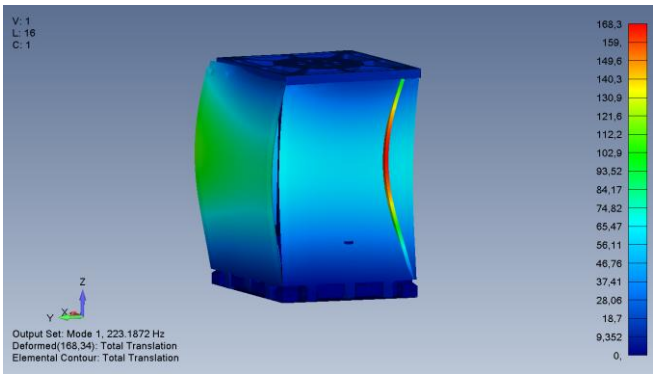


Fig. 4. First structural mode at 223 Hz in stowed configuration.

This value is significantly above the minimum qualification threshold typically required by commercial spacecraft integrators, which commonly establish minimum first-mode requirements around 100 Hz for payload equipment.

- Deployed Configuration Performance

Once deployed in orbit, the antenna transitions into a significantly larger geometry optimized for RF performance. As expected for ultra-light deployable systems, the first structural mode shifts toward lower frequencies due to the increased deployed span. The first deployed mode was identified at 3.3 Hz. This mode is primarily associated with localized oscillations of the deployable ground plane. Although this frequency is relatively low, its impact on spacecraft stability remains limited because the structural elements involved in this vibration mode possess low mass.

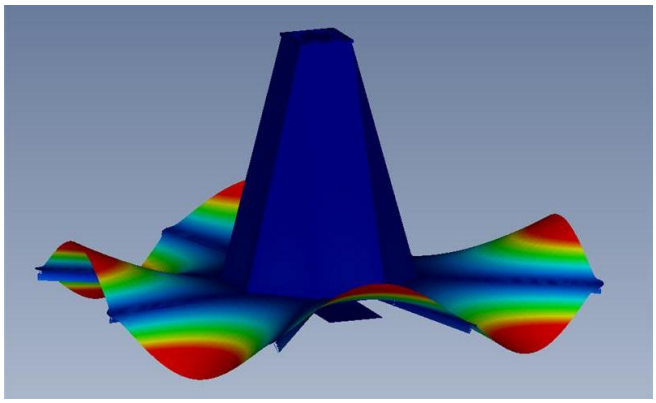


Fig. 5. First structural mode at 3.3 Hz in deployed configuration.

B. Thermal Performance

In addition to mechanical survivability, the antenna must maintain structural integrity under extreme thermal cycling conditions encountered during orbital operations. Materials used in UDAN were selected to withstand prolonged exposure to the thermal conditions typically experienced in Low Earth Orbit (LEO), including repeated transitions between solar illumination and eclipse phases. The system has been designed to operate within a temperature envelope of -40°C to +150°C. Additionally, and to evaluate the risk of thermal expansion mismatches which can generate localized stresses, thermo-mechanical simulations were performed to quantify stress concentrations generated across the operational temperature envelope.

Particular attention was given to the antenna support structure where the helical radiators are mounted, as this region represents one of the most critical mechanical interfaces in the system. The results confirmed that thermal stresses remain within acceptable structural margins, ensuring that repeated orbital thermal cycling does not compromise antenna functionality over mission lifetime.

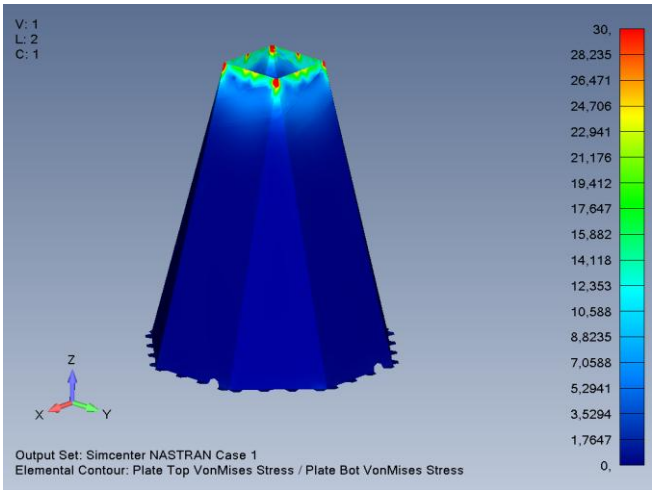


Fig. 6. Von Mises stress distribution on antenna support structure.

IV. RF PERFORMANCE

A. Nominal Radiation Performance

Under its fully deployed geometry, UDAN demonstrates strong radiation performance across the target UHF band, operating at a nominal center frequency of 430 MHz with functional coverage between 400 MHz and 460 MHz.

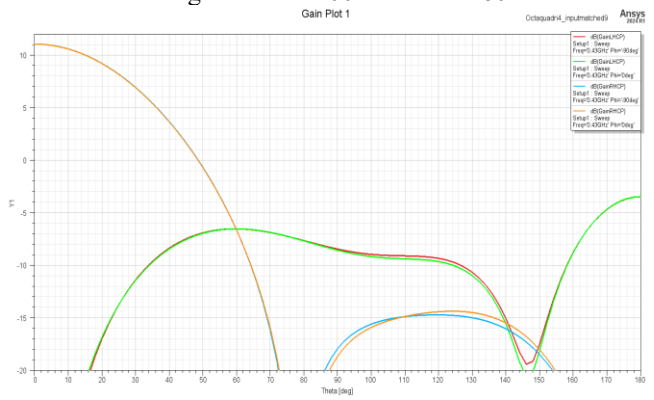


Fig. 7. Octa-quadri helix antenna pattern cuts at 430 MHz.

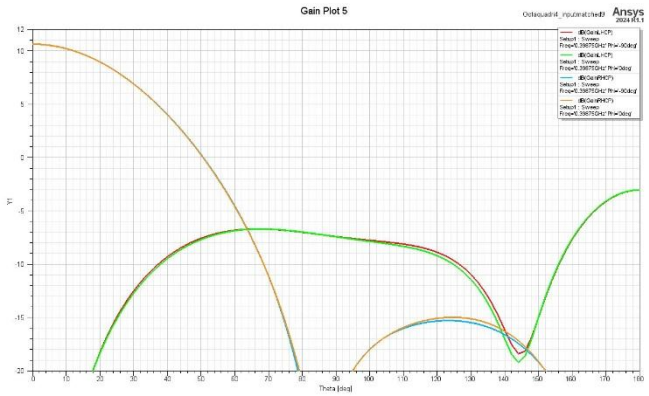


Fig. 8. Octa-quadri helix antenna pattern cuts at 400 MHz.

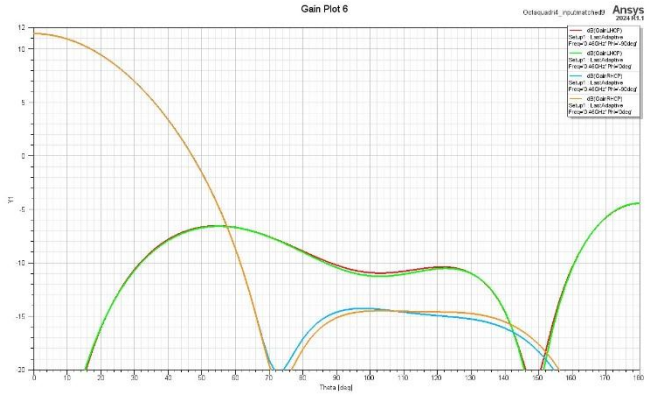


Fig. 9. Octa-quadri helix antenna pattern cuts at 460 MHz.

Simulation results show that the antenna achieves:

- Peak gain exceeding 10 dBi.
- Circular polarization.
- Stable radiation pattern symmetry.
- High forward directivity.
- Low sidelobe levels.

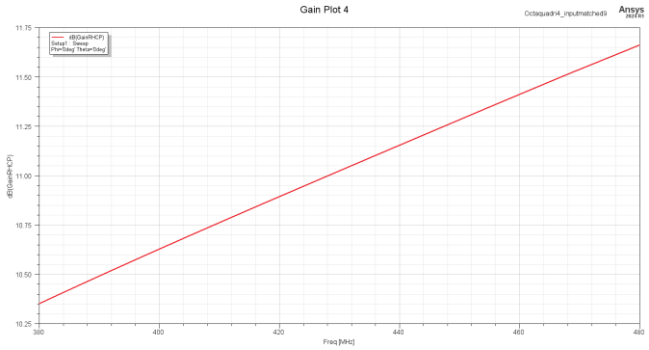


Fig. 10. Octa-quadri helix antenna Peak gain frequency sweep.

These characteristics make the system particularly suitable for long-distance telemetry links where maintaining link margin is critical. Unlike traditional monopole-based CubeSat antennas, which typically operate in the 0-3 dBi range, the significantly higher gain offered by UDAN enables:

- Reduced ground station aperture requirements.
- Lower transmission power demand.
- Increased communication range.
- Improved link availability.

B. Impedance Matching and Bandwidth Performance

The antenna was optimized to maintain strong matching performance around its target operational frequency. Simulation results indicate:

- Return loss around 25 dB at 430 MHz.
- Commercially acceptable impedance behavior across the operational bandwidth.
- Minimal reflected power losses.

This level of matching ensures that most transmitted power is effectively radiated rather than reflected back toward the communication subsystem.

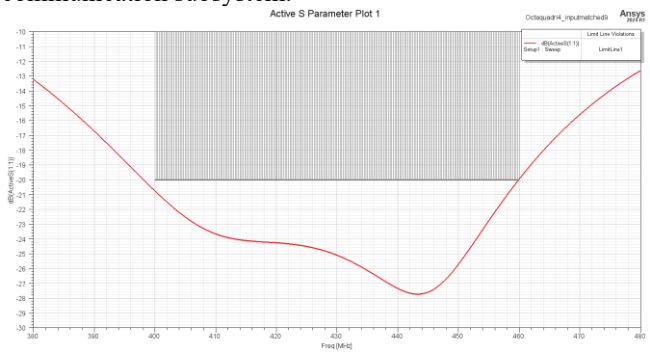


Fig. 11. Octa-quadri antenna active return loss.

V. TEST PLAN

A. Test Plan Description

The qualification campaign for UDAN followed a structured test plan designed to robustness under representative mission conditions. As illustrated in the test flow chart, the campaign begins with baseline geometry accuracy measurements. This is followed by an initial S-parameters assessment and radiation pattern testing. Once RF behavior is validated, the campaign transitions into environmental testing, including vibration (modal, quasi-static, sine, and random loads) and shock testing, replicating launch conditions and separation events. A dedicated deployment shock test is also performed to evaluate the mechanical impact of antenna release at spacecraft level. After these mechanical stresses, RF performance is reassessed through a second S-parameter measurement to identify any degradation. The antenna is then subjected to thermal vacuum (TVAC) cycling and TVAC deployment. Finally, the campaign concludes with a repeat of geometry verification and RF characterization.

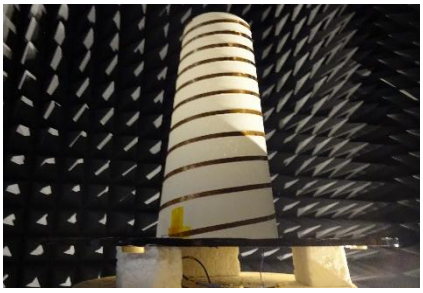


Fig. 12. RF test of the breadboard of UDAN.

B. Test Plan Chart

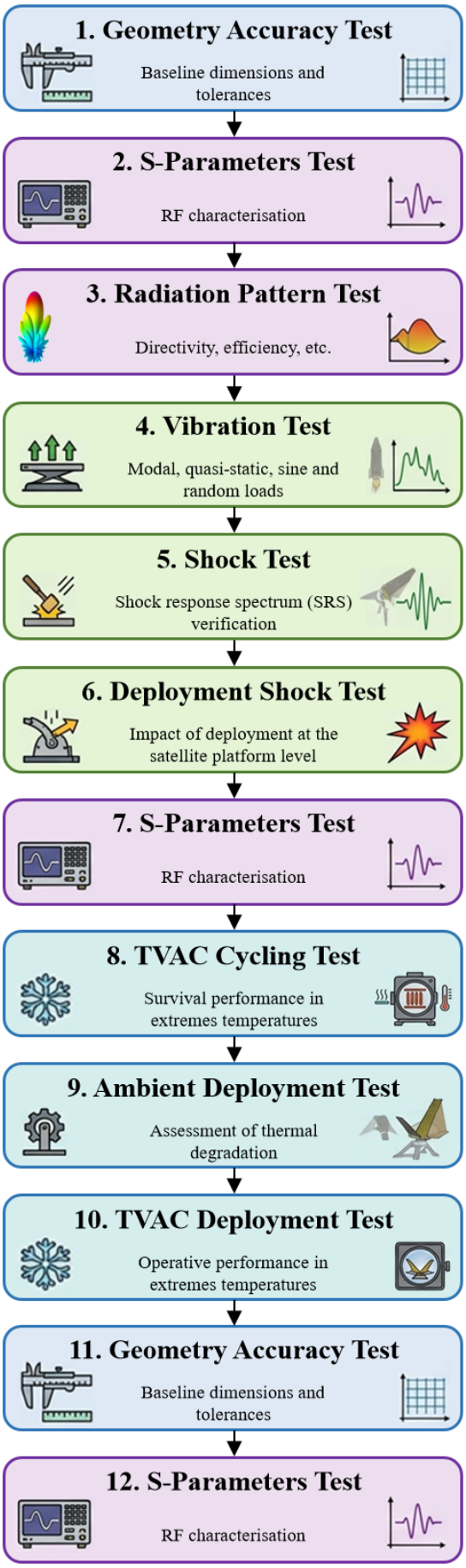


Fig. 13. Test plan chart.

VI. CONCLUSIONS

The development of the UDAN antenna demonstrate that high-performance communication systems in the UHF band can be successfully integrated within the strict volumetric constraints of CubeSat platforms. By combining a compact stowed configuration with a large deployable aperture, the system effectively overcomes one of the most persistent limitations in low-frequency small satellite communications: the trade-off between antenna size and achievable gain. The results presented throughout this work confirm that UDAN achieves a consistent RF performance exceeding 10 dBi with circular polarization, while maintaining stable behavior under manufacturing tolerances, thermal deformation, and repeated deployment conditions. Additionally, test results will be correlated with the modelling, to also confirm the simulated gain and directivity performance at end of the test campaign. Beyond its technical performance, UDAN introduces a scalable and reliable approach to deployable antenna design, based on passive actuation and reduced system complexity. This not only enhances robustness but also supports cost-effective manufacturing and integration, which are critical factors for emerging constellation-based missions. Overall, UDAN represents a significant step forward in enabling advanced communication capabilities for small satellites operating at low frequencies. Its successful in-orbit demonstration as part of a planned future development will further consolidate its role as a key technology for next-generation CubeSat missions.

VII. ACKNOWLEDGEMENTS

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