# LISAT-01: Design and Implementation of a Student-Built CubeSat for Maritime Domain Awareness


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***Abstract*—Portugal's vast maritime jurisdiction, which encompasses a 1.7 million $km^2$ Exclusive Economic Zone (EEZ) and a 5.75 million $km^2$ Search and Rescue (SAR) region, demands persistent, wide-area surveillance that current assets cannot fully provide. Coastal sensors reach only approximately 24 nautical miles, satellite revisits are intermittent, and naval and air patrol assets are constrained by limited defense budgets, leaving critical blind spots across the North Atlantic. This paper presents LISAT-01, a 1U CubeSat mission conceived and developed by a student team at Instituto Superior Técnico (Lisbon, Portugal), designed to complement existing maritime surveillance infrastructure by collecting Automatic Identification System (AIS) signals from orbit. The mission demonstrates that a low-cost nanosatellite can extend near-real-time vessel detection across Portugal's EEZ and SAR region, bridging coverage gaps without dependence on shared international assets.**



***Index Terms*—CubeSat, maritime surveillance, AIS, nanosatellite, Exclusive Economic Zone, Portugal**


## I. Introduction

Portugal's relationship with the ocean is foundational to its national identity, economy, and security. Its EEZ of approximately 1.7 million $km^2$ [2], roughly 18 times its land area, grants sovereign rights over resources around the mainland, Azores, and Madeira, while its SAR region of approximately 5.75 million $km^2$ [2] obliges Portugal to coordinate maritime assistance across a vast stretch of the North Atlantic. Together, these spaces place Portugal among the custodians of one of the Atlantic's most strategically significant corridors, demanding robust and continuous maritime situational awareness.

*a) :* Portugal's current surveillance architecture is layered and multi-agency. The Navy conducts surface patrols coordinated through the Maritime Operations Center around Portugal, with reach extending to the island territories. The Air Force provides long-range surveillance and SAR response through maritime patrol aircraft and helicopters. Along the coast, the GNR's SIVICC network of fixed and mobile radars and cameras, complemented by port VTS systems and coastal AIS receivers, tracks vessel traffic out to approximately 24 nautical miles. Beyond that range, Portugal relies on EU-level capabilities, including EMSA satellite-AIS feeds and Copernicus Sentinel-1 radar [3], to monitor illegal fishing, pollution events, and vessel anomalies.

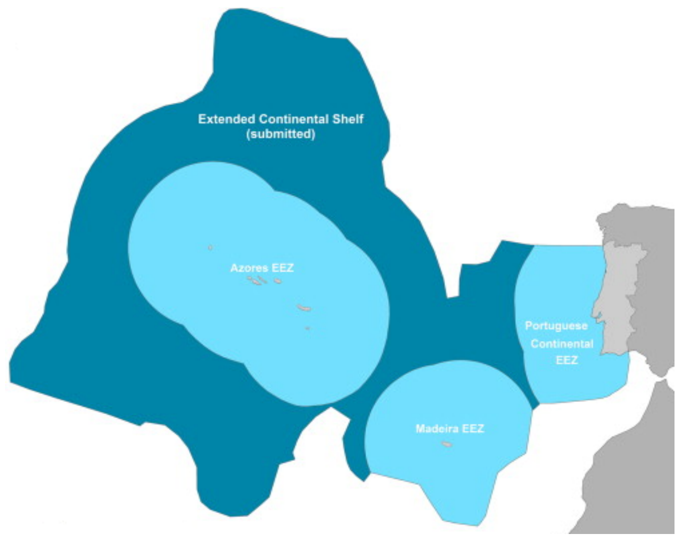


Fig. 1. Portugal's Exclusive Economic Zone, encompassing the continental shelf, Azores EEZ, and Madeira EEZ.

*b) :* Despite these foundations, significant gaps remain. Coastal sensors provide coverage only to 24 nautical miles, satellite revisit times are insufficient for continuous monitoring far offshore, and the naval and air assets available are costly and limited in number. The result is non-continuous awareness across these areas and reduced capacity to respond to fast-moving or covert threats.

*c) :* Addressing this gap requires a surveillance layer that is persistent, scalable, and cost-effective. The LISAT-01 mission, developed by the student-led LISAT team at Instituto Superior Técnico, proposes exactly this. LISAT-01 is a 1U CubeSat designed to collect AIS signals from orbit. Signals broadcast by vessels on two VHF frequencies (161.975 MHz and 162.025 MHz) using GMSK modulation at 9600 bps, providing a complementary detection capability across Portugal's EEZ and SAR region. The mission does not aim to replace existing patrol assets but rather to enhance them, demonstrating that a compact, low-cost nanosatellite developed by a student team can contribute meaningfully to national maritime awareness and serve as a proof of concept with broader global applicability.

## II. Mission Objectives

LISAT-01 is a student-driven technology demonstrator designed to prove that a low-cost, compact nanosatellite can meaningfully contribute to maritime situational awareness over Portugal's EEZ and SAR regions. The mission's primary objective is to receive, process, and store AIS signals from orbiting altitude, transforming raw vessel broadcasts into a structured database delivered to a dedicated web-based interface for the Portuguese Navy, enabling real-time vessel tracking and position monitoring across the North Atlantic.

*a) :* Primary objectives include establishing reliable bidirectional communication with the Taguspark Ground Station (Lisbon, Portugal) and demonstrating end-to-end AIS data collection, on-board processing, and downlink to the ground segment.

*b) :* Secondary objectives encompass the demonstration of internal developed , SRAD hardware: including custom solar panels with embedded magnetorquers and a student-designed OBC, as well as the implementation of secure command authentication between the satellite and ground station, Sun pointing with a minimum precision of 20°, and TLE refinement through the ground station network. An educational objective also underpins the mission, providing the LISAT team with hands-on experience across all phases of satellite design, integration, and operations.

*c) :* To be considered successful, LISAT-01 must remain operational for a minimum of 30 days, during which it must complete the full AIS data pipeline. The mission is designed to operate for 5 years in orbit.

## III. Spacecraft Overview

LISAT-01 is a 1U CubeSat with a total mass of 1.3 kg. The spacecraft is composed of the following subsystems: an Electrical Power System (EPS), responsible for power generation, storage, and distribution; two On-Board Computers (OBC), one commercial off-the-shelf (COTS) unit for primary operations and one Student Research and Development (SRAD) unit developed in-house; a Telemetry, Tracking and Command (TTC) subsystem handling all communication with the ground segment; a deployable antenna supporting both the TTC link and AIS signal reception; the PIAIS AIS decoder payload, responsible for receiving and decoding VHF vessel broadcasts on 161.975 MHz and 162.025 MHz [1]; and an Attitude Determination and Control System (ADCS), achieved through magnetorquers embedded in the SRAD solar panels and an additional dedicated PCB.

The solar panels are semi-custom: commercial solar cells are procured and assembled in-house onto SRAD panels that also embed the magnetorquer coils, serving a dual structural and attitude control function. With the exception of these panels and the SRAD OBC, all remaining components are COTS, keeping development and integration risk manageable.

## IV. Flight Operations and Coverage

LISAT-01 operates in low Earth orbit at approximately 462–473 km altitude, completing 16 orbits per day with an orbital period of 94 minutes. Three orbit families are considered: mid inclination (37°–53°), high inclination (54°–70°), and near-polar (71°–100°), with mid-inclination orbits preferred for maximising coverage time over Portugal's regions of interest.

*a) :* Operations are organised around two key geographic regions. Over the EEZ and SAR region, the satellite collects and stores AIS messages from vessels operating in Portuguese waters. Over the Ground Station region, it downlinks the processed AIS data alongside operational telemetry, receives commands, and updates its TLE. A third operational state - no contacts - covers the remainder of each orbit, during which the satellite performs housekeeping, attitude control, and pre-processing tasks.

*b) :* Collected AIS data is processed on board and downlinked to the Taguspark Ground Station, from where it feeds into a web-based platform providing the Portuguese Navy with real-time vessel tracking, position data, and a structured vessel database.

## V. Mission Phases

LISAT-01's mission is segmented into five distinct phases: Launch and Early Operations Phase (LEOP), In-orbit Commissioning, Operational Phase, End of Life, and Post Mission.

TABLE I
LISAT-01 Mission Phases, Objectives, and Key Events

| Phase | Objective | Key Events |
|---|---|---|
| LEOP | Establish communication with Ground Station (GS) | Detumbling and antenna deployment; ground efforts focus on locating and contacting the satellite. |
| In-Orbit Commissioning | Activate and test subsystems | Review LEOP; sequential subsystem activation, enable Attitude Determination and Control System (ADCS), and start Automatic Identification System (AIS) payload. |
| Operational | Continuous AIS monitoring and data transmission | Perform housekeeping; downlink AIS and telemetry to the GS. |
| End of Life | Controlled system deactivation | Execute passivation and shut down all systems, ceasing communication. |
| Post Mission | Track until atmospheric re-entry | Ground-based tracking using Two-Line Element Set (TLE) data until complete decay. |

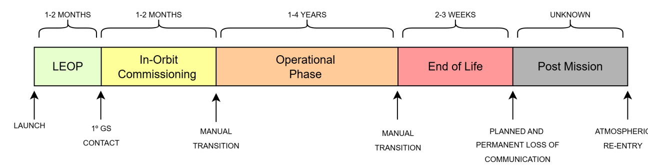


Fig. 2. Mission phases and duration.

*Note: In case of an unplanned and permanent loss of communication during the Operational Phase, the End of Life phase is bypassed.*

## VI. AIS Payload Design

The satellite's payload is responsible for receiving AIS messages broadcast by vessels operating within Portugal's EEZ, filtering and processing them on board, and transforming raw, potentially overlapped signals into structured data for downlink to the ground segment. The chosen component for this purpose is the piAIS CubeSat AIS Receiver, developed by SkyFox Labs.

### A. Antenna

AIS messages are first captured by the onboard antenna system, which consists of two deployable dipoles: one in the VHF band and one in the UHF band. The VHF dipole is responsible for receiving AIS signals and forwarding them to the piAIS receiver. Due to the near-omnidirectional radiation pattern of the dipole, attitude pointing is not required for AIS reception, simplifying operations and reducing dependence on the ADCS during data collection passes.

### B. Receiver Architecture

The piAIS is a fully autonomous dual-channel AIS receiver, simultaneously monitoring both standard AIS channels: 87B at 161.975 MHz and 88B at 162.025 MHz, using GMSK modulation at 9600 bps [1] with 25 kHz channel bandwidth. The module is designed to handle the signal environment expected from low Earth orbit, where transmissions from multiple vessels arrive simultaneously. To address this, the piAIS incorporates a 16-bit CRC filter applied at the data processing core, which discards invalid messages and maximises the yield of the data stream capture in the presence of overlapping or colliding transmissions.

The internal message processing pipeline from signal reception to UART output consists of the following sequential stages: demodulation, NRZI decoding, bit destuffing, deframing, and CRC validation. Valid messages are then encoded into human-readable HEX ASCII datagrams with start, delimiter, and stop characters, terminated with CR+LF, before being transmitted to the OBC.

### C. Message Types and Data Output

The piAIS produces two distinct output message types. The first is a telemetry message, identifiable by the "TLM" identifier after the start byte, which reports payload health parameters including input bus voltage, input bus current, temperature, unit uptime, message counter, and noise floor on both channels A and B, as illustrated in Fig. 3.

```
*TLM,3.22V,065.0mA,+27°C,000006E8,0000279C,-115.5,-116.0;⇐↵
```

Fig. 3. Example of piAIS telemetry output message.

The second output type is the AIS data message, which carries the decoded vessel broadcast payload in hexadecimal format alongside the channel source and RSSI value, as shown in Fig. 4.

```
*87B,-081.0,000006EF,1000A54F107E940C09A41073D26729FA6BC00808CA;⇐↵
```

Fig. 4. Example of piAIS AIS data output message.

The piAIS supports AIS message types ranging from 72 to 424 bits. Of these, LISAT-01 targets message types 1, 2, 3, and 5, which are the operationally relevant types for maritime situational awareness. Message types 1, 2, and 3 are 256-bit messages with a 168-bit payload, carrying dynamic vessel information such as position, speed, and heading. Message type 5 is a 424-bit message carrying static and voyage-related vessel data.

### D. On-Board Data Processing

The piAIS communicates with the OBC via UART at 115200 bps, with 8 data bits, no parity, and 1 stop bit. Upon receiving a message, the OBC executes the following processing sequence: start and end characters are read to delimit the message frame and then discarded; the channel source field is used to increment per-channel message counters, after which it is discarded; the RSSI value is logged internally but not downlinked directly; the message counter field is processed and discarded; and CR+LF bits are stripped.

The AIS message payload is subsequently stored in SRAM. The OBC uses the first six bits of each message, which encode the AIS message type, to filter incoming packets, retaining only messages of types 1, 2, 3, and 5. To optimise memory usage, messages received from the same vessel have their individual overhead removed and are aggregated into a single record containing the combined payload information from all transmissions received from that vessel during the pass.

## VII. Ground Segment

The LISAT-01 ground segment is centred on the Taguspark Ground Station, located in Oeiras, Lisbon (latitude 38.7371361°N, longitude 9.3026679°W). The station is designed for full satellite tracking capability, ensuring reliable uplink and downlink communication throughout each pass. It currently serves as the primary ground station for ISTSat-1, a 1U CubeSat developed by IST students and engineers [4], managed by AMRAD and licensed by ANACOM as a common-use amateur radio station. This operational heritage provides LISAT-01 with a proven infrastructure for mission control.

The ground station provides the essential interfaces for all uplink and downlink operations: transmission of telecommands to the satellite, reception of AIS and vessel-related messages, continuous downlink of telemetry data, and real-time visualisation of the frequency spectrum and decoded telemetry on monitoring displays.

### A. Hardware Components

The Taguspark Ground Station RF chain is composed of the following hardware: a crossed Yagi UHF antenna with a gain of 15.25 dBi (WiMo model); an AlfaSpid AZ/EL RAS antenna rotator for automated satellite tracking; a UHF Low Noise Amplifier (LNA), model SSB SP 70, on the downlink chain; and a 500 W UHF power amplifier, model Microset RU, on the uplink chain. The radio subsystem consists of two Software Defined Radios: an Ettus B210, used as the primary signal processing unit, and an ADALM-Pluto SDR, used for signal checking and testing.

### B. Signal Processing Pipeline

The main signal processing chain relies on Gpredict [6] for real-time orbit propagation. Gpredict computes the satellite's position and forwards pointing data to the antenna rotator, ensuring accurate antenna alignment throughout the pass. It also applies real-time Doppler shift correction to dynamically adjust the reception frequency on the SDR hardware.

The received signal is amplified by the LNA and passed to GNU Radio [5], which performs the full demodulation and decoding sequence in seven steps: SDR source capture and IQ signal reconstruction; low-pass filtering to remove out-of-band noise and improve SNR; GMSK demodulation to recover the binary bit stream; clock recovery and binary slicing to convert the analogue bit stream into digital bits; custom framer and sync block to detect the payload frame using predefined protocol flags; payload extraction to isolate the data section of the frame; and external parser to interpret the telemetry at the application layer.

The decoded byte stream is passed to a telemetry parser, which interprets the data according to the protocol's application layer and outputs structured telemetry. This data is stored in a database, from which Grafana retrieves and displays real-time telemetry in dashboards, graphs, and tables. In parallel, the PlutoSDR captures RF signals independently, with GNU Radio providing waterfall plots and spectrum analysis tools for signal evaluation and monitoring.

### C. Automation

Although certain operations, such as transmitting telecommands and launching the satellite tracking software, currently require manual initiation, several subsystems operate continuously and autonomously. The antenna system, autonomously pointed using the rotator controller, and the supporting hardware remain active at all times, consistently receiving and decoding incoming RF signals. This includes both satellite telemetry and vessel-related transmissions, which are processed through the GNU Radio decoding pipeline and passed to the telemetry parser. The interpreted data is automatically stored in the database, making it available for real-time visualisation through Grafana.

### D. Link Budget

The downlink link budget was assessed across three hardware scenarios: non-favourable, nominal, and favourable. The key parameters for each case are summarised in Table II.

TABLE II
LINK BUDGET PARAMETERS FOR NON-FAVOURABLE, NOMINAL, AND FAVOURABLE CASES

| **Parameter** | **Non-Fav.** | **Nominal** | **Favourable** |
|---|---|---|---|
| Antenna Gain (dBi) | 14.1 | 14.1 | 14.1 |
| Transmit Power (W) | 5 | 500 | 500 |
| LNA Gain (dB) | 17.5 | 18.0 | 18.0 |
| Bandpass Filter Loss (dB) | 1.0 | 0.7 | 0.65 |
| Pointing Loss (dB) | 1.7 (15°) | 0.2 (5°) | 0.0 |
| Feedline Loss (dB) | 0.10 | 0.08 | 0.08 |

## CONCLUSION

LISAT-01 represents a meaningful step forward in low-cost, student-driven satellite development for maritime domain awareness. By demonstrating that a low-cost 1U CubeSat can receive, process, and downlink AIS data to a dedicated naval interface, the mission proves that compact nanosatellites can serve as viable complements to traditional maritime surveillance infrastructure, extending coverage across Portugal's EEZ and SAR region without reliance on costly shared international assets.

What makes LISAT-01 particularly significant is the context in which it was built. The mission was conceived, designed, and developed entirely by university students, all of them began the project with no prior knowledge of satellite engineering. Every subsystem, from the SRAD solar panels with embedded magnetorquers to the custom OBC and ground station pipeline, was learned, designed, and validated from the ground up. This is not a trivial achievement. It reflects an extraordinary collective effort and demonstrates that, given the right environment and determination, student teams can deliver real space hardware.

At the time of writing, LISAT-01 is in the Integration, Verification and Testing phase, in conformance with the MAIVT schedule. All PCB manufacturing and assembly steps have been successfully completed, with all electronic boards and the Electrical Ground Support Equipment (EGSE) fully integrated. The team is currently focused on the development and validation of the FlatSat, expected to be completed by May 2026, after which mission testing will begin. Involving continuous FlatSat operation with commands issued from a remote ground station to validate end-to-end system performance and operational robustness. Launch is targeted for mid-2027.

Beyond the mission itself, LISAT-01 is intended as the first in a series. The LISAT team's long-term ambition is to establish itself as a sustained, student-led satellite development organisation. One capable of designing, building, and operating successive missions with increasing complexity and capability. The approach demonstrated here, a low-cost CubeSat delivering operationally relevant data to national authorities, is directly transferable to other nations facing similar challenges: large maritime jurisdictions, limited defence budgets, and a need for persistent, independent surveillance capability.

LISAT-01 is not just a satellite. It is a proof of concept for what students can build, and a foundation for what's to come.

## ACKNOWLEDGMENT

The author wishes to express the deepest gratitude to every current member, alumni, and mentor of the LISAT team. LISAT-01 exists because of the extraordinary dedication, competence, and grit of the students who built it. Leading this team has been an honour, one made effortless by the exceptional people who comprise it, and who have long surpassed the conventional definition of a team. The author also gratefully acknowledges the support of IST NanosatLab, MEO, Oeiras Valley, Thales Portugal, and the Portuguese Navy whose technical expertise, infrastructure, and mentorship were instrumental to the mission. May this work stand as the first chapter of a long and ambitious story.

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