



UNICO I+D Project
6G-INTEGRATION-01

6G-INTEGRATION-01-E11

Antenna Design

Abstract

This document presents the initial system design of the 6G-INTEGRATION-01 antenna design. It defines the main entities and building blocks present in the system architecture. This deliverable focuses in defining the demonstrator that will allow to connect to a LEO satellite constellation in Ku band.

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List of Acronyms

AC: Alternating Current

ACU: Antenna Control Unit

AP: Access Point

DC: Direct Current

ESA: Electronic Steerable Antenna

G/T: Gain over Temperature

IC: Integrated Circuit

LEO: Low Earth Orbit

LHCP: Left-Hand Circular Polarization

PCB: Printed Circuit Board

RCM: RF Converter Module

RF: Radiofrequency

RHCP: Right-Hand Circular Polarization

RX: Reception

SLL: Side Lobe Level

TX: Transmission

RX: Reception

Resumen Ejecutivo

El presente trabajo consiste en la investigación y prediseño de una antena orientable electrónicamente para el segmento terrestre, con una gestión mejorada del haz para el apuntamiento dinámico de los satélites LEO que contiene los siguientes módulos:

- Diseño electromagnético, electrónico, mecánico.
- Diseño del elemento radiante.
- Integración en array y de la red de alimentación.

Los principales resultados descritos en el presente son los siguientes:

- Proporcionar servicios de comunicación de alto rendimiento en áreas sin infraestructura terrestre, facilitando la transformación digital en zonas rurales.
- Ofrecer cobertura global, alta capacidad y mínima latencia, mejorando significativamente las aplicaciones exigentes.
- Demostrar experimentalmente la validez de las técnicas propuestas con resultados aceptables, usando un banco de pruebas apto.
- Brindar soporte técnico para la ejecución de las pruebas.

Executive Summary

His Work Package consists of the investigation and pre-design of an electronically steerable ground segment antenna with improved beam management for dynamic pointing of LEO satellites which contains the following modules.

- Electromagnetic, electronic, mechanical design.
- Design of radiating elements.
- Array and powered network integration.

The main results described within the deliverable are:

- Provide high-performance communication services in areas without terrestrial infrastructure, facilitating digital transformation in rural areas.
- Offer global coverage, high capacity, and minimum latency, significantly improving demanding applications.
- Demonstrate experimentally the validity of the proposed techniques with acceptable results, using a suitable test-bend.
- Provide technical support for the execution of the tests.

1. Introduction

This deliverable aims to describe the integration of a new type of satellite antenna. As part of this, the research and pre-design of an electronically steerable ground segment antenna with improved beam management for dynamic pointing of LEO satellites is presented.

The overall architecture of a demonstrator capable of establishing communication with a LEO constellation is explained, composed by the following elements:

- Apertures
- ACU (Antenna Control Unit)
- PSU (Power Supply Unit)
- Synchronism Module
- RCM (RF-IF, IF-RF Converter)
- Modem
- Switch

One of the most important parts of the document is the design of the antenna aperture, which is the main element of the terminal. Its correct design and efficiency determine not only the final size and weight of the terminal, but also the compliance with all satellite regulations necessary to obtain the certificate of conformity.

Additionally, this document explains the mechanical design, i.e. the physical structure of the system. The required design drawings and reference tables are attached for this section. Moreover, the manufacturing and testing procedures are included in the present work.

2. General system architecture demonstrator

The solution offered by INSTER will feature one of its SATCOM terminals, compatible with a LEO low orbit LEO constellation.

It is essential to highlight that the technologies and functional blocks of INSTER's user terminals are consistent across various products in the portfolio. They are configured according to market priorities and use cases. The terminals to be supplied in the project will adhere to the specified functional and environmental technical characteristics outlined in this Technical Report.

Within the scope of this project, a demonstrator will be designed to establish communication with a LEO constellation. The demonstrator will consist of all the necessary elements to carry out this functionality, as illustrated in the continuous diagram system:

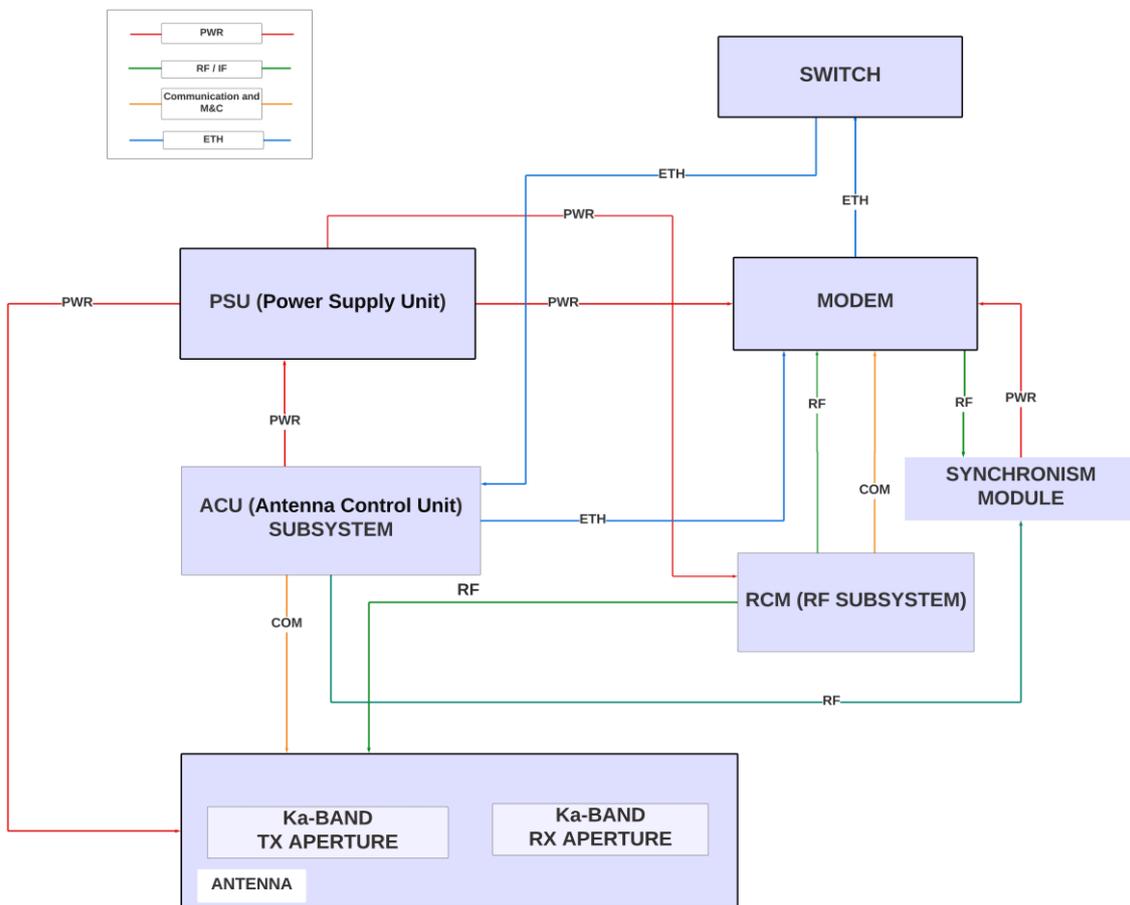


FIGURE 1 SYSTEM DIAGRAM

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- **Baseband (modem)**

The Synchronization Unit is the responsible for tasks such as synchronizing the transmitter and receiver, ensuring the proper timing of signal transmission, positioning the signal within a specified time frame, and providing a reference for both ends of the communication link. This also includes an External GNSS Receiver (EGR) for synchronism, positioning, and signal reference purposes.

- **RF (Reception and Transmission subsystems)**

This is formed by the RF Converter Module (RCM), which is responsible of performing the up and down conversion between the RF and IF (Intermediate Frequency) bands, and signal conditioning.

- **Apertures in Ku-band**

The TX and RX Ku-band radiating apertures are two independent RF Printed Circuit Boards (PCB). Each PCB contains the Ku-band radiating aperture itself, as well as the RF distribution network and the beamforming Integrated Circuits (ICs).

- **GPS antennas**

The GPS antennas will allow the demonstrator to have dual GNSS signal. This will help the system to know the position and orientation of the terminal.

- **ACU (Antenna Control Unit)**

The Antenna Control Unit is a critical element of the system, as all the demonstrator capabilities are implemented on this module. It manages the communication and synchronization between all the modules in the demonstrator, allowing the system to get into network with the LEO constellation.

- **PSU (Power Supply unit)**

This module provides the required power supply to the demonstrator HW and apertures. Its specifications will be detailed in the PSU description section.

- **Synchronism Module**

It is the responsible for the precise synchronization between the Modem and the Antenna control Unit (ACU), using the Global Navigation Satellite System time signal for synchronization.

- **Switch Ethernet**

The Ethernet switch will enable Ethernet communication between the ACU and Modem. It will also provide user access to the ACU and modem.

3. RF hardware and power supply design

Design of the radio frequency front-end (RF – IF and IF-RF conversion), encompassing frequency conversion blocks from baseband to satellite bands, including BUC (Block Up-Converter) and BDC (Block Down-Converter), amplifiers, signal conditioning circuits, and other interfaces essential for modem functionality. The design of the antenna feeding system is also a part of this task.

3.1. Demonstrator subsystems description

The INSTER LEO Terminal is composed of the following subsystems:

- Antenna Aperture subsystem and GPS antennas: located in the higher layer.

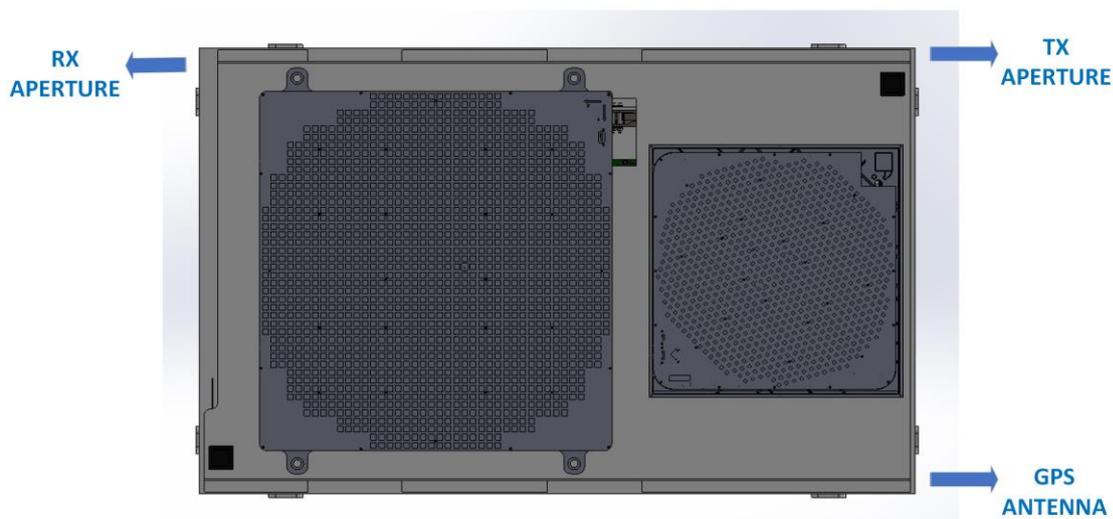


FIGURE 2 ANTENNA APERTURE SUBSYSTEM

- Rest of the HW: allocated in the bottom layer with the following distribution.

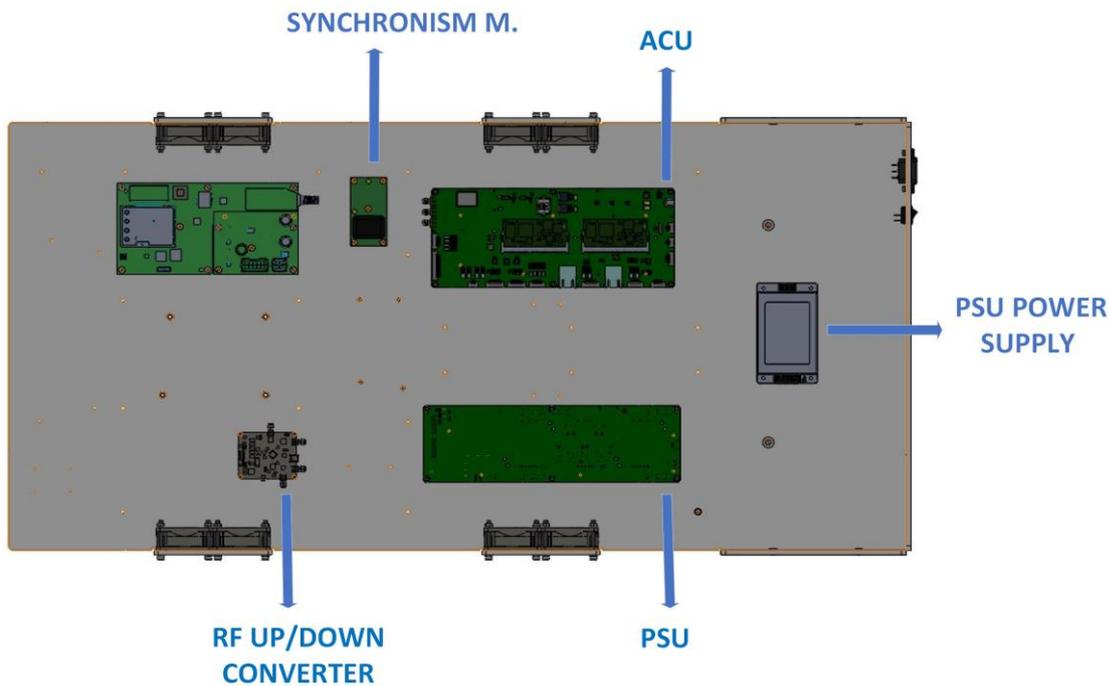


FIGURE 3 PHYSICAL LAYOUT OF THE HARDWARE

3.1.1. Antenna Aperture Subsystem

The TX and RX Ku-band radiating apertures are the main components of this subsystem. They oversee radiating signals in the transmission path and receiving radio-signals in the reception path. In addition, they perform the real-time electronic beam steering, both in TX and RX, through beamforming ICs.

The aperture location in the demonstrator is the following. Both apertures need to be installed aligned in order to optimize the demonstrator satellite tracking.

The aperture is composed of the following modules:

- Radiating element
- Analog beamforming module
- Aperture thermal dissipation
- RF distribution network
- Radome

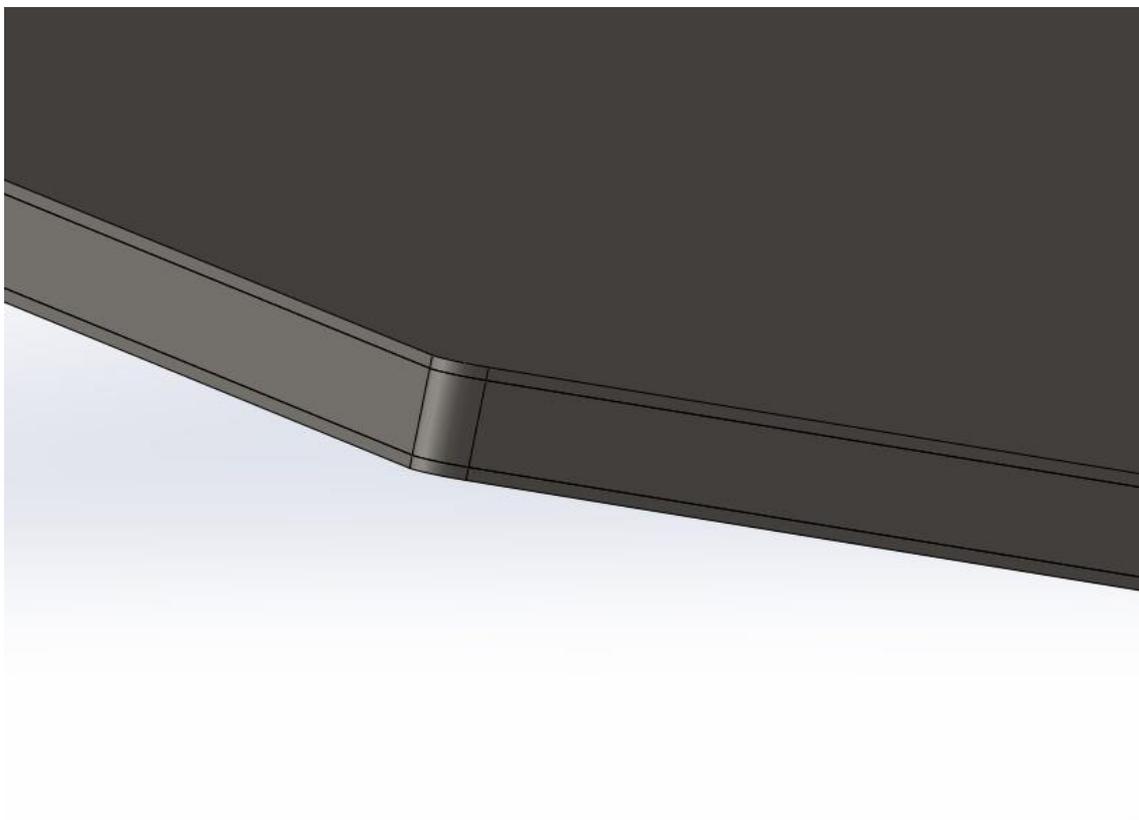
The radiating element, analog beamforming module, aperture thermal dissipation and RF distribution network description is available in 6G-INTEGRATION-01-E10- EBBM design document.

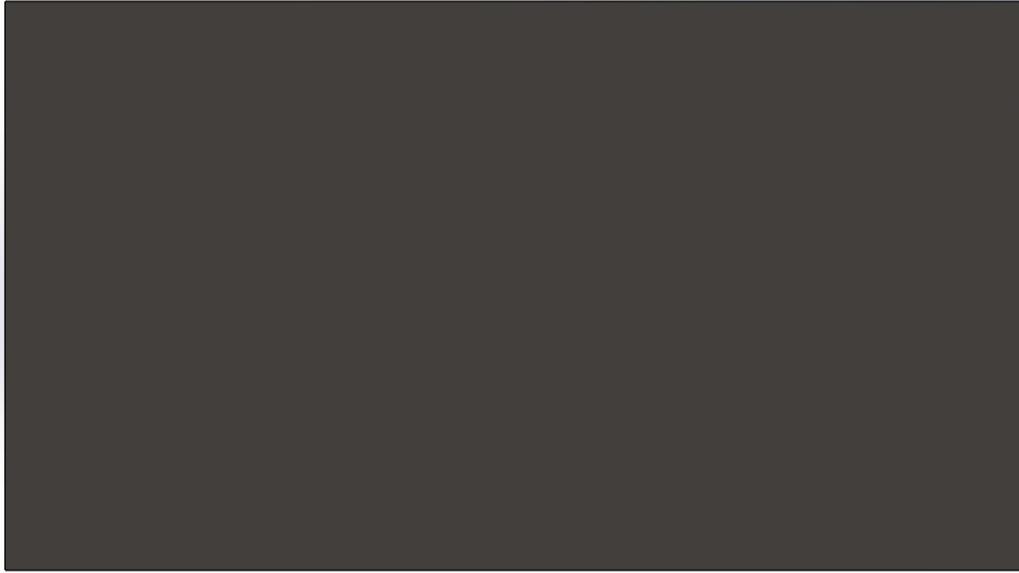
a. Radome

A Radome is a protective cover designed to shield antennas and other electronic devices from the effects of weather and other environmental elements.

It acts as a physical barrier that protects the antenna from rain, snow, hail, and other adverse weather conditions. This is essential to ensure consistent performance of the antenna in various meteorological conditions.

The material is robust and durable, capable of withstanding adverse environmental conditions over time without significant deterioration. This ensures continuous and reliable protection.



**FIGURE 4 RADOME**

3.1.2. ACU (Antenna Control Unit)

The Antenna Control Unit (ACU) is a crucial component of the terminal, enabling automatic LEO tracking. It obtains position and orientation data from GNSS receivers and accelerometers, employing optimal algorithms for precise searching. This ensures highly efficient pointing and smooth tracking. The ACU is time-synchronized with the modem to effectively command the terminal's actions, such as beam steering and frequency changes. Additionally, it monitors module and sensor statuses, controlling panel LEDs for comprehensive control and management of the Antenna Aperture and RF.

The ACU Subsystem serves as the terminal's intelligence hub.

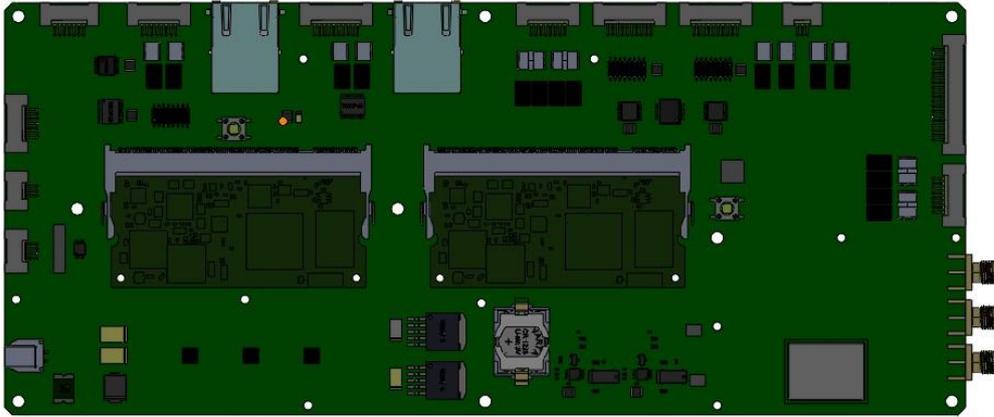
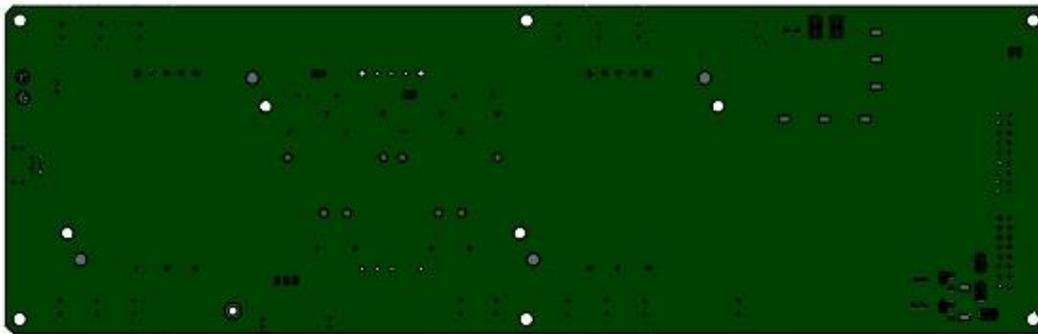


FIGURE 5 ACU (ANTENNA CONTROL UNIT)

3.1.3. PSU (Power Supply Unit)

The Power Supply Subsystem is responsible of powering all the subsystems. This includes the power conversion from the input power to every subsystem required power, and the power distribution throughout the terminal. This subsystem is mainly composed of INSTER Power Supply Unit (PSU), and an external AC/DC converter.



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FIGURE 6 PSU IMAGE

The main specifications of the PSU are listed below.

| PSU SPECIFICATIONS | |
|------------------------|------------------|
| Parameter | Value |
| Input Voltage | 18 – 36 VDC |
| Output voltage | +5, +12, +28 VDC |
| Max Continuously Power | 190 W |
| Operation Temperature | -40° to +85 °C |

TABLE 1: PSU SPECIFICATIONS

3.1.4. Synchronism Module

The synchronism module, which stands for External GNSS Receiver, handles synchronization and signal reference purposes. This module is required to provide the required synchronization to the ACU and SSM in order to execute all the required commands on time to work in the LEO constellation.

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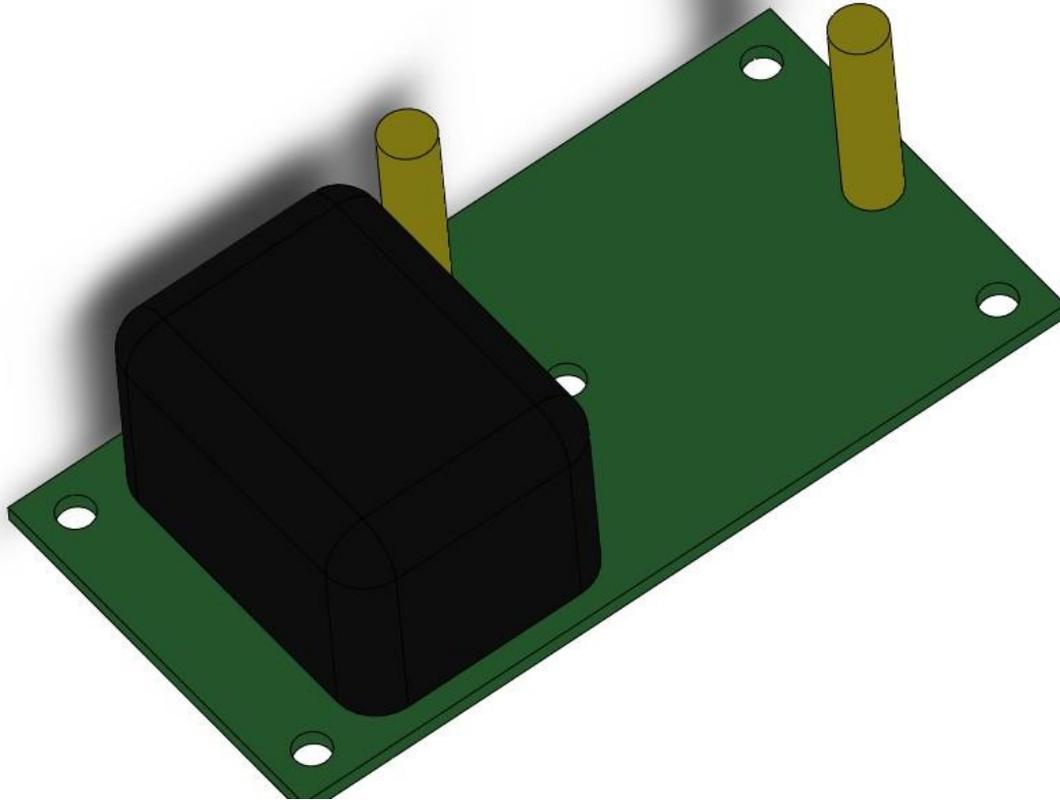


FIGURE 7 SYNCHRONISM MODULE

| SYNCHRONISM MODULE SPECIFICATIONS | |
|-----------------------------------|-------------------------------|
| Parameter | Value |
| Multi GNSS | GPS, GLONASS, Galileo, BeiDou |
| Communication | RS422 |
| Operating Temperature | -40° to +80°C |
| Power Supply | 5.5V +/-0.3V |
| Power Consumption | < 8W |
| Dimensions | 76 x 38 mm |

TABLE 2 SYNCHRONISM MODULE ESPECIFICACIONES

3.1.5. RCM (Radio Converter Module)

The RF Subsystem oversees RF and IF signal conditioning and performing the required up and down conversions between the RF and IF frequency bands.

The main specifications of the Radio Converter Module (RCM) are listed below.

| RCM UP CONVERTER SPECIFICATIONS | |
|--|-----------------|
| Parameter | Value |
| RF Frequency | 14.0 – 14.5 GHz |
| IF Frequency | MHz |
| Gain | 13 – 17 dB |

TABLE 3 UP CONVERTER SPECIFICATIONS

| RCM DOWN CONVERTER SPECIFICATIONS | |
|--|-----------------|
| Parameter | Value |
| RF Frequency | 10.7 – 12.7 GHz |
| IF Frequency | GHz |
| Gain | 21 – 27 dB |

TABLE 4 DOWN CONVERTER SPECIFICATIONS

3.1.6. Modem

The modem provides two-way communication between the user and the satellite. It features an Ethernet connection and IP protocol for network integration.

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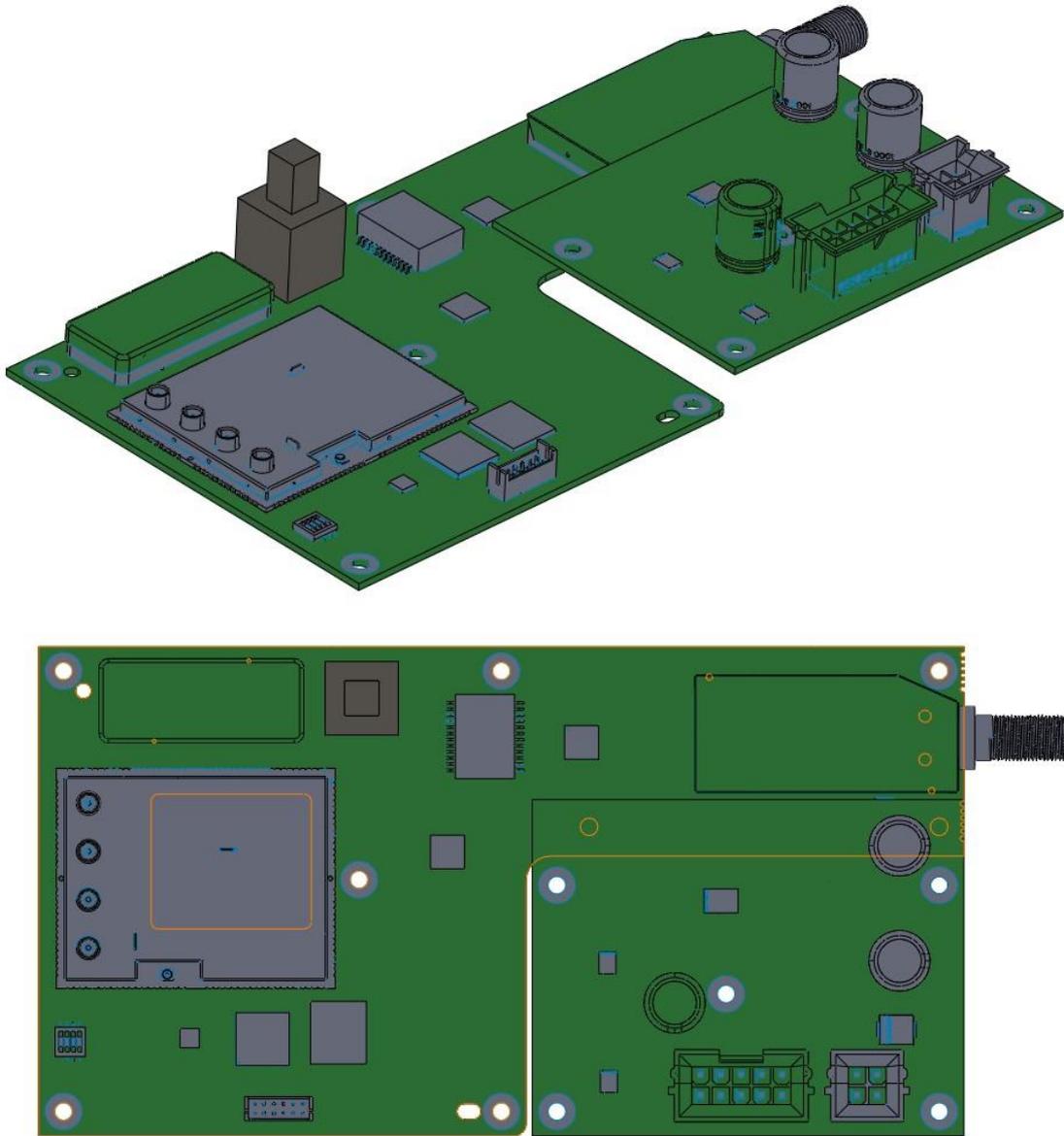


FIGURE 8 MODEM

3.2. Power Consumption

Next, a table with the consumption of the main modules in the terminal:

| POWER CONSUMPTION | |
|--|------------------------|
| Module | Consumption (W) |
| Rx Antenna | 35 |
| Tx Antenna | 56 |
| RCM | 6 |
| <i>Efficiency DC/DC 24VDC to 12VDC</i> | 90% |
| <i>Partial consumption</i> | 107.8 |
| PSU | 5 |
| ACU | 12 |
| Switch Ethernet | 15 |
| Fans | 20 |
| <i>Efficiency DC/DC 24VDC to 28VDC</i> | 90% |
| <i>Partial consumption</i> | 80.3 |
| TOTAL CONSUMPTION | 188.1 |

TABLE 5 DEMONSTRATOR CONSUMPTION

3.3. Interfaces

The INSTER LEO Terminal interfaces connection diagram is presented in the following table:

| Connector Panel Interfaces: |
|---|
| 1x Power Supply Connector |
| 1x Ethernet Communication Connector (Traffic) |
| 1x Ethernet ACU M&C |
| 12x Switches (Power ON/OFF, Wi-Fi) |
| RCM Interfaces: |
| RCM comms interface connector |
| RCM Rx IF connector |
| ACU Interfaces |

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| |
|----------------------|
| PWR IN connector |
| PWM Fans connector |
| Antenna Tx interface |
| Antenna Rx interface |
| RCM interface |
| Ethernet interface |
| PSU interface |
| GPS RF Rx interface |
| GPS RF Rx interface |
| GPS RF Rx interface |
| GPS RF Rx interface |
| Accelerometer |

| |
|----------------------------|
| Baseband Subsystem: |
| PWR enable connector. |
| PWR in connector |
| ACU connector |
| PSU Interfaces |
| PWR IN connector |
| PWR enable connector. |
| ACU connector |
| 12V interface |
| 28V interface |
| ACU power output connector |

| |
|------------------------------------|
| External Interfaces Cables: |
| Ethernet cable: RJ45 |

TABLE 6 INTERFACES

4. Mechanical Design

The assembly proceeds in a bottom-up fashion. The first layer to attach is the hardware by using the screws from table 7 to adjust the large PCB to the bottom panel.

Here the ACU and PSU are mounted on a shield (a mechanical part like the heatsink of the manpack) which is screwed to the board. The EGR and the RF converter are screwed into the sheet metal itself.

After that the apertures panel needs to be attached to its metal chassis by tightening the screws and then the assembled panel must be fitted into the previous layers, whose characteristics are indicated in the table 7.

Later, the radome must be fitted into its hollow chassis. Finally, the assembled radome with chassis must be tightened into the previous layers by using the screws with the same characteristics as the ones previously used.

ELECTRONIC FASTENERS

| Parameter | SCREWS |
|---------------|--|
| ACU | 6 screws DIN912 M3x6 + washer DIN125 M3 + washer DIN127 M3 |
| PSU | 6 screws DIN912 M3x6 + washer DIN125 M3 + washer DIN127 M3 |
| Shielding ACU | 6 screws DIN912 M2.5x8 + washer DIN125 M2.5 + washer DIN127 M2.5 |
| Shielding PSU | 6 screws DIN912 M2.5x8 + washer DIN125 M2.5 + washer DIN127 M2.5 |
| EGR | 5 screws DIN912 M3x8 + washer DIN125 M3 + washer DIN127 M3 |
| RF Converter | 4 screws DIN912 M3 + washer DIN912 M3 + washer DIN912 M3 + washer AET M3 |

TABLE 7 ELECTRONIC FASTENERS

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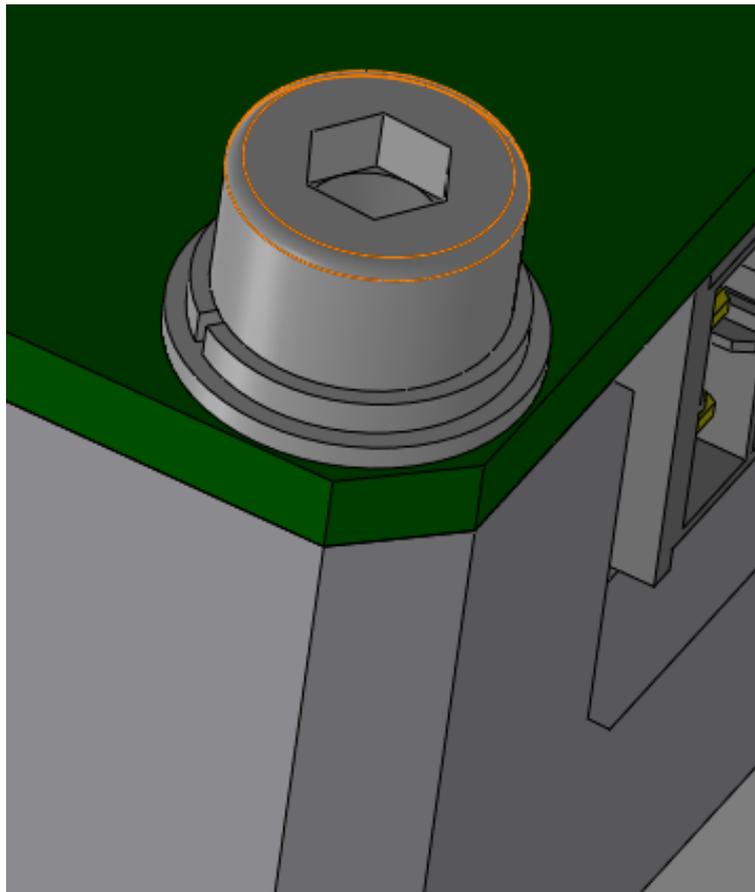


FIGURE 9 SCREWS DIN912 M3X6

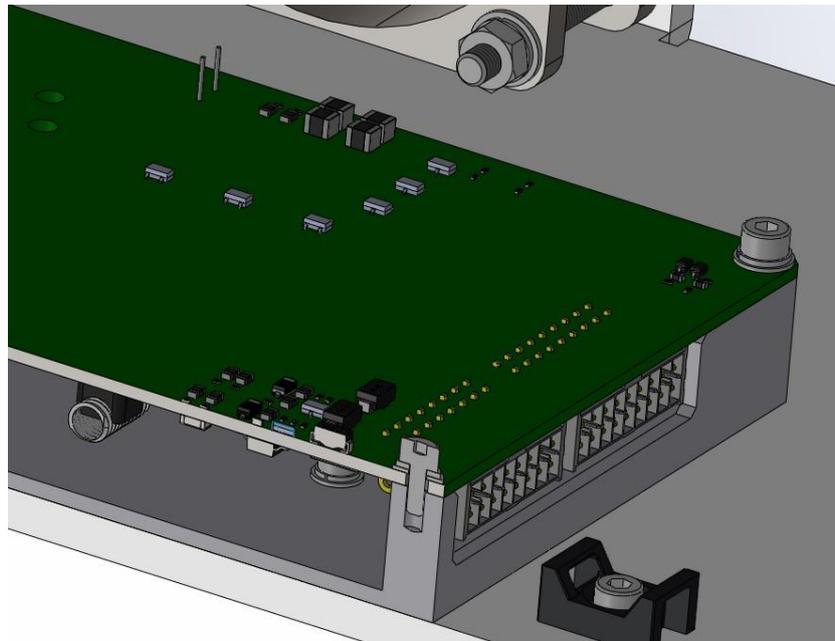


FIGURE 10 SCREW INSTALLATION

4.1. Dimensions and mechanical plans

The demonstrator dimensions are 1050,2 cm x 678,2 cm x 125,9 cm (L x W x H).

These sub-assemblies are shown in the following figures:

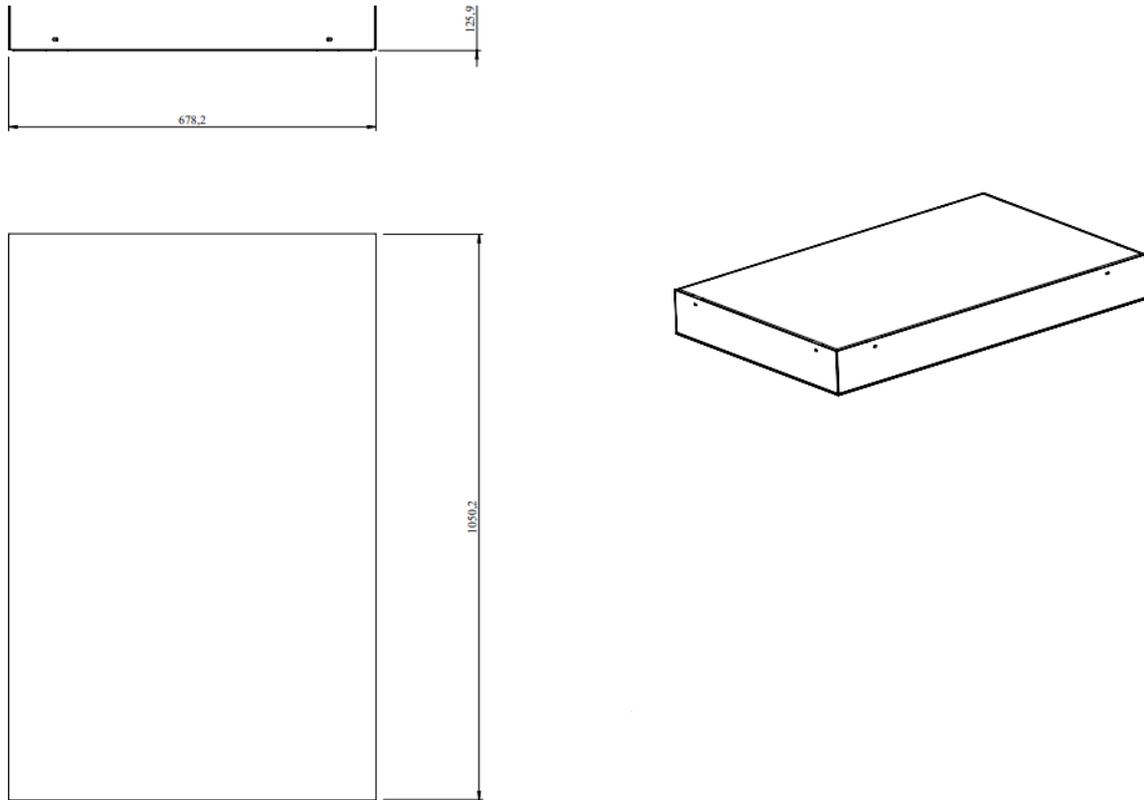


FIGURE 11 MECHANICAL DESIGN

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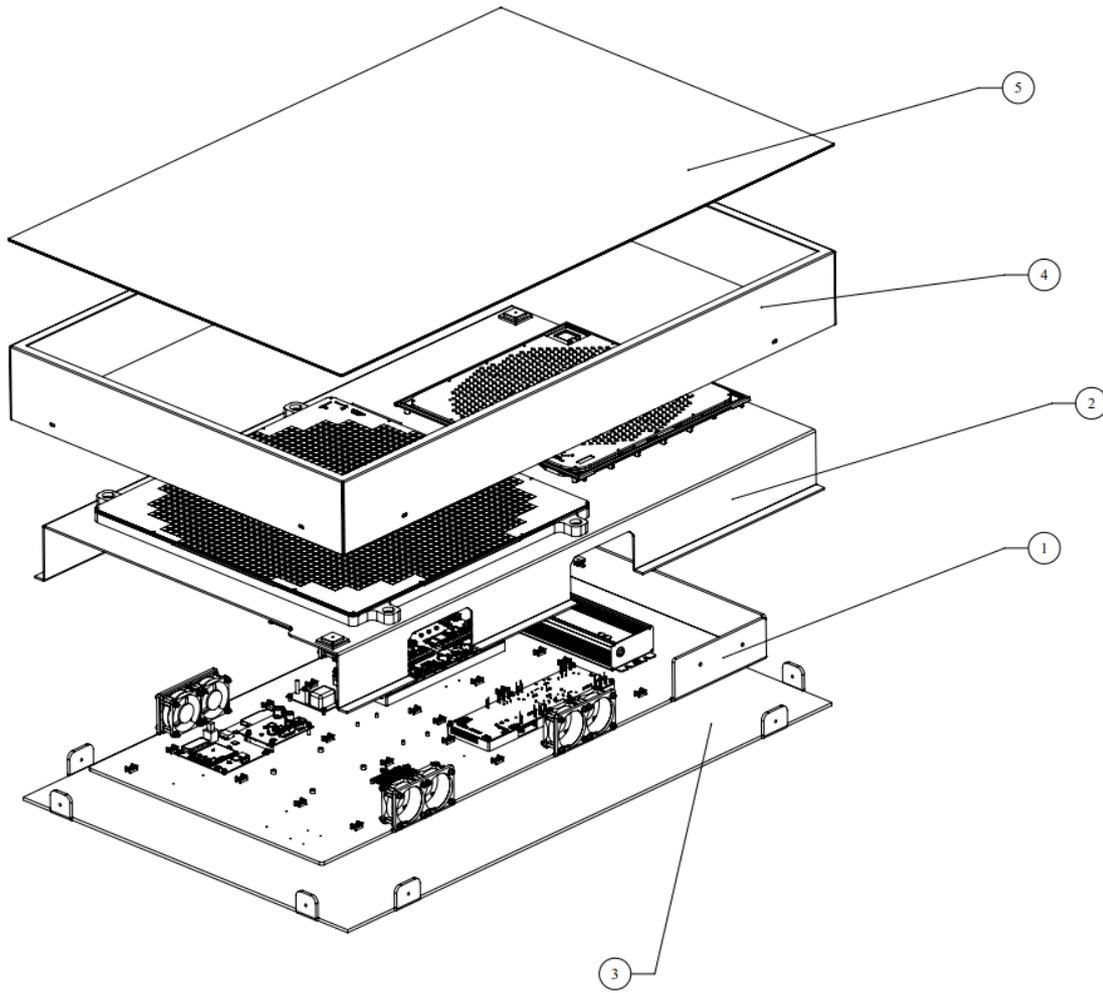


FIGURE 12 ARCHITECTURE DEMONSTRATOR

| Nº | DENOM./DESCRIPT. |
|----|-----------------------------|
| 1 | Interface |
| 2 | Aperture support |
| 3 | Bottom mechanical interface |
| 4 | Second layer structure |
| 5 | Radome |

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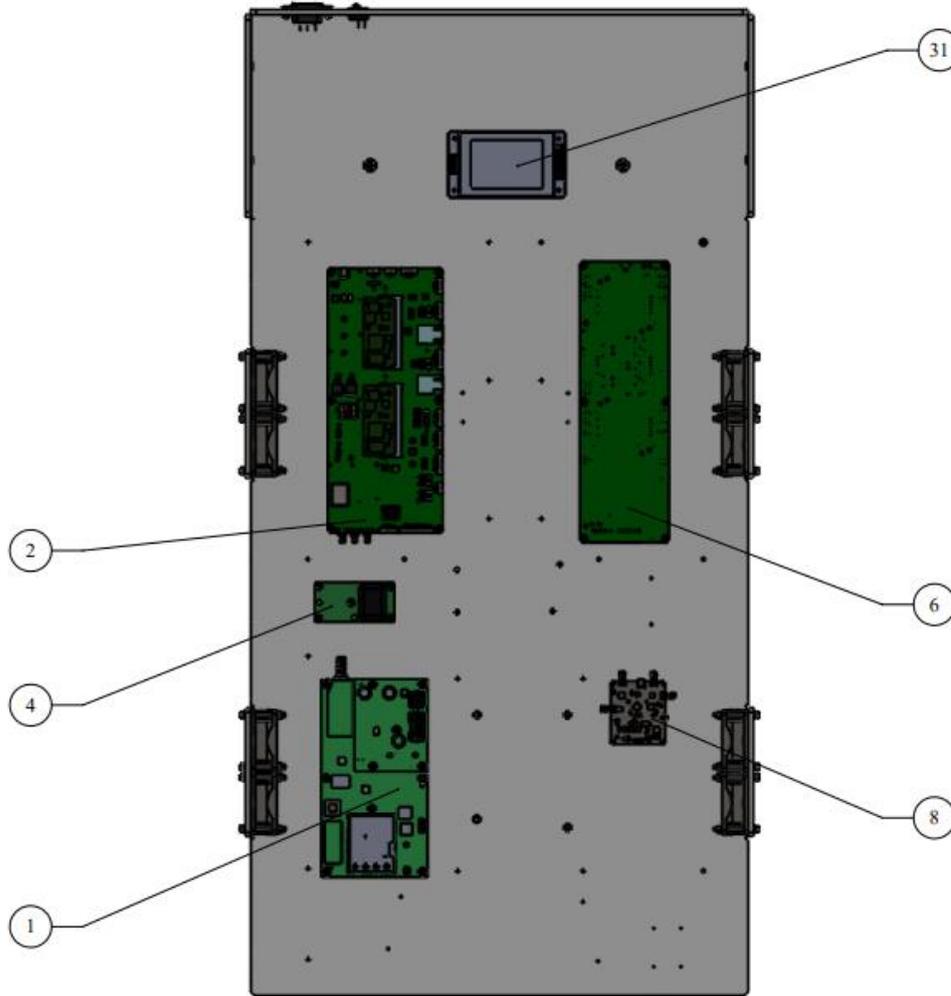


FIGURE 13 HADWARE DEMONSTRATOR

| Nº | DENOM./DESCRIPT. |
|----|------------------|
| 1 | Modem |
| 2 | ACU |
| 4 | Sync Module |
| 6 | PSU |
| 8 | RCM |
| 31 | DC/DC |

5. Design of the ACU

Design of the Antenna Control Unit, responsible for communicating with the modem and configuring the electromagnetic apertures to perform tracking of LEO satellites, as well as executing the satellite change process (handover). Synchronization between the ACU and modem is critical for the proper functioning of the antenna within the LEO network.

The Antenna Control Unit Subsystem main tasks are the following:

Communication with Base Band Subsystem

- The Antenna Control Unit (ACU) establishes a two-way link with the modem facilitating the exchange of HTTP messages containing various commands between subsystems. Precise time synchronization, managed by the ACU, is crucial for commanding actions (e.g., beam steering, frequency changes) of the Terminal to align with the time reference from the Baseband Subsystem.

Position and Orientation

- This task consists in receiving and processing data from the dual GNSS and accelerometers, for positioning and orientation obtainment. The position and orientation system is based on the GNSS antennas, GNSS receiver modules and accelerometer measurement to get all the required information.

Perform tracking and beamforming algorithms.

- The ACU calculates the optimal antenna pointing direction and determines the configuration to establish in the antenna apertures by means of tracking and beamforming algorithms, using the terminal position and orientation obtained through the accelerometer sensor and the dual GNSS, and the satellite trajectory received from the modem. Fine searching tracking algorithms become available when Signal to Noise Ratio (SNR) feedback from the modem is sent to the ACU.

Monitor and control

The ACU also contains the software related to the M&C Subsystem.

- The modules temperature is monitored to avoid any damage due to high or low temperatures.
- The Reception and Transmission status are also monitored to know if the system tracking status is safe.

- The communication between different modules is also monitored, to detect any type of communication issued that could affect the system operation.

6. Manufacturing and testing

6.1. Validation and assembly process

The following process is carried out in order to verify and assembly the demonstrator.

- The PCBs are verified in the laboratory, performing some FQT (Formal Qualification Tests)
- The PCBs are allocated in the demonstrator regarding the mechanical plans.
- The modules are connected to the PSU one by one to verify that the PSU is able to turn on every PCB in the demonstrator.
- The communication between different modules is verified step by step and module by module.
- The HW and apertures communication is also verified.
- Some validations are performed to check that the power levels are the correct ones, and that the FW is able to command/receive information to/from all the modules.

6.1.1. FQT tests

The following Factory tests will be performed to validate the PCBs and subsystems:

| Nº | Module | Test | Description | Verification Method |
|----|--------------------|--------|----------------------------------|---------------------|
| 1 | Modem | TEST1 | Modem consumption | T |
| 2 | Modem | TEST2 | ACU – Modem communication | T |
| 3 | Modem | TEST3 | Sync signal reception | T |
| 4 | Modem | TEST4 | Modem communication traffic port | T |
| 5 | Synchronism M. | TEST5 | Sync signal delivery | T |
| 6 | GPS antenna | TEST6 | Dual GPS reception | T |
| 7 | PSU | TEST7 | Power consumption | T |
| 8 | PSU | TEST8 | Operation voltage | T |
| 9 | ACU | TEST9 | GNSS–ACU communication | T |
| 10 | ACU | TEST10 | Verify Ethernet ports | T |
| 11 | ACU | TEST11 | Verify SPI protocol | T |
| 12 | RCM – up converter | TEST12 | Transmission frequency band | T |
| 13 | RCM – up converter | TEST13 | IF frequency band | T |

| Nº | Module | Test | Description | Verification Method |
|----|-------------------------|--------|--------------------------------------|---------------------|
| 14 | RCM – up converter | TEST14 | Verify Tx IF port | T |
| 15 | RCM – up converter | TEST15 | Verify Tx RF port | T |
| 16 | RCM – down converter | TEST16 | Reception RF frequency band | T |
| 17 | RCM – down converter | TEST16 | Reception IF frequency band | T |
| 18 | RCM – down converter | TEST14 | Verify Tx IF port | T |
| 19 | RCM – down converter | TEST15 | Verify Tx RF port | T |
| 20 | Aperture Tx | TEST16 | Aperture transmission frequency band | T |
| 21 | Aperture Tx | TEST16 | Transmission Polarization | T |
| 22 | Aperture Tx | TEST17 | Transmission gain | T |
| 23 | Aperture Tx | TEST18 | Transmission axial ratio | T |
| 24 | Aperture Tx | TEST19 | EIRP | T |
| 25 | Aperture Rx | TEST20 | Reception frequency band | T |
| 26 | Aperture Rx | TEST21 | Reception polarization | T |
| 27 | Aperture Rx | TEST22 | Verify – Rx Gain | T |
| 28 | Aperture Rx | TEST23 | Reception axial ratio | T |
| 29 | Aperture Rx | TEST24 | G/T | T |
| 30 | Demonstrator | TEST25 | Dimensions verification | T |

TABLE 8 VERIFICATION PLAN

6.1.2. Assembly

The demonstrator is allocated in a mechanical structure that allows the user to test the prototype. The system HW is allocated in the bottom layer of the demonstrator and the apertures and GPS antennas are allocated in the high layer with the radome over them.

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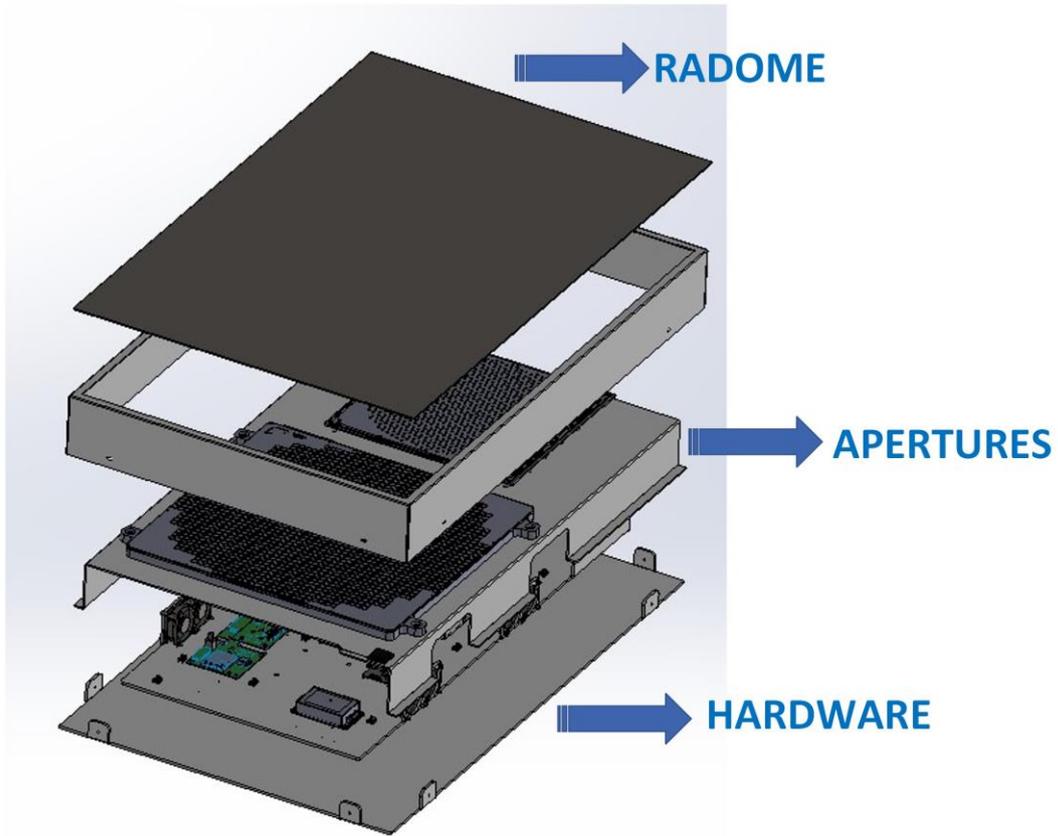


FIGURE 14 TERMINAL DEMONSTRATOR

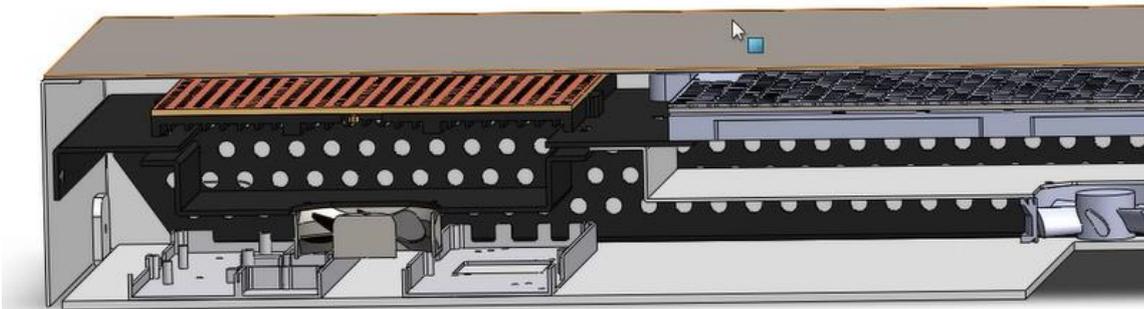


FIGURE 15 BACK PART TERMINAL DEMONSTRATOR

All the RF modules are installed in this mechanical structure as shown in the previous figures and the mechanical design description.

7. Summary and Conclusions

The research has focused on providing innovative solutions for satellite user terminals, the solutions have been adapted to the characteristics of emerging low orbit satellite constellations. The study has allowed to identify each of the functional and interface requirements that lead to the implementation of the electronic pointing LEO antenna.

The technology used by the PCBs (compact and low cost) is the most appropriate for the implementation of low profile and low weight antennas. Its scalability can also be emphasized by allowing the easy creation of periodically distributed multi-patch structures (array of patches), thus improving the RF performance of the antenna.