SpaceLab.DMO.2020.06.001 rev C

GOLDS-UFSC Design and Mission Overview

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June 2023

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June, 2023

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Revision Control:

Version	Author	Changes	Date
0.0	G. M. Marcelino	Document creation	2020/06/05
0.1	G. M. Marcelino	First release	2021/05/30
0.2	G. M. Marcelino, L. O. Seman, B. F. Ribeiro, E. M. Filho, C. S. M. Gomes, V. B. Bianchin	CDR release	2022/11/04
0.3	G. M. Marcelino, L. O. Seman	TBD	TBD

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Nomenclature

FEC	*Forward Error Correction.*
ACS	*Attitude Control System.*
AEB	*Agência Espacial Brasileira.*
CDS	*CubeSat Design Specification.*
CI	*Continuos Integration.*
COTS	*Commercial Off-The-Shelf.*
DoD	*Depth of Discharge.*
EDC	*Environmental Data Collection.*
EMMN	*Estação Mutlimissão de Natal.*
EPS	*Electrical Power System.*
FPGA	*Field-Programmable Gate Array.*
GMAT	*General Mission Analysis Tool.*
GOLDS	*Global Open Collecting Data System.*
HIL	*Hardware-In-the-Loop.*
HMAC	*Hash-based Message Authenticaion Code.*
INPE	*Instituto Nacional de Pesquisas Espaciais.*
MPPT	*Maximum Power Point Tracking.*
OBDH	*On-Board Data Handling.*
PCB	*Printed Circuit Board.*
PCD	*"Plataforma de Coleta de Dados", or Data Collection Platform*
SBCD	*Sistema Brasileiro de Coleta de Dados.*
SDR	*Software Defined Radio.*
SHA-1	*Secure Hash Algorithm 1.*

SINDA *Sistema Integrado de Dados Ambientais.*

SNR *Signal To Noise Ratio*

TLE *Two-Line Element.*

TTC *Telemetry, Tracking and Command Module.*

WBS *Work Breakdown Structure.*

WP *Work Package.*

Contents

CHAPTER 1

Introduction

GOLDS-UFSC is a 2U CubeSat (10×10×22.70 cm), and it is a follow up of FloripaSat-1 mission [2]. Both FloripaSat-1 and GOLDS-UFSC are developed by SpaceLab/UFSC [3]. GOLDS-UFSC main payload is the EDC board (*Environmental Data Collection*) [4], developed by INPE. The mission is part of the "GOLDS" constellation ("Global Open Collecting Data System"), a collaborative CubeSat constellation for environmental data collection planned as part of the Brazilian Space Program [5].

The project started just after the launch of FloripaSat-1 (first half of 2020) and is planned to be launched in 2023. Most of the embedded electronics is partially or totally based on the FloripaSat-1 satellite, with the same and/or improved versions of the modules. In other words, this project has, at some level, a flight heritage.

A conceptual image of the GOLDS-UFSC satellite is shown in Figure 1.1.

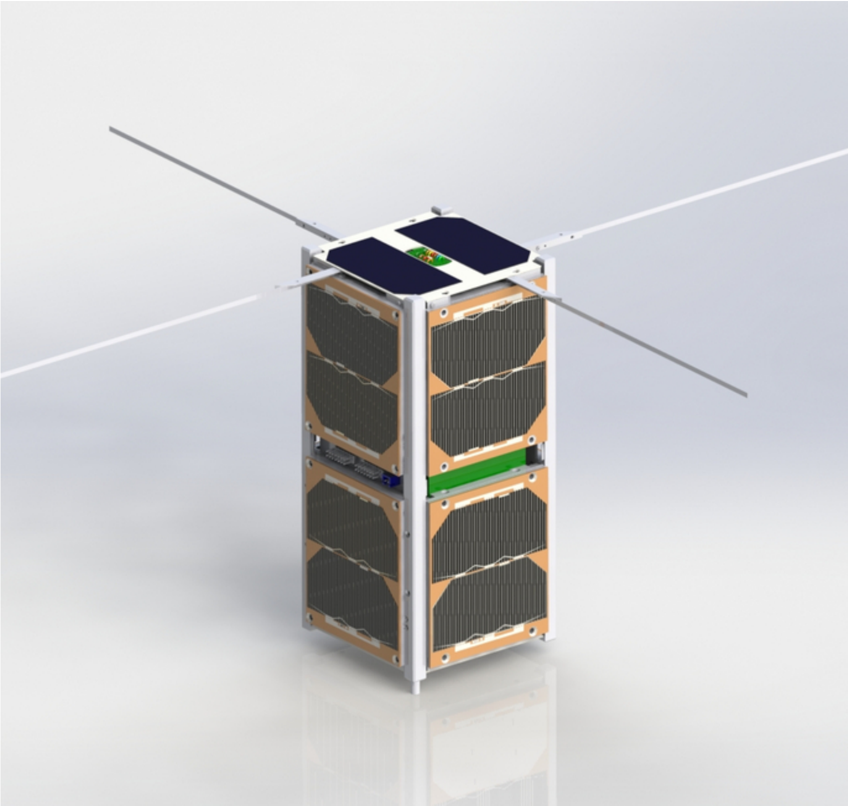


Figure 1.1: GOLDS-UFSC 3D renderization.

1.1 Mission Description

The mission's main objective is the In-Orbit Validation (IoV) of INPE's EDC payload, using a service module based on FloripaSat-1 bus. The EDC payload is a module developed for CubeSats and capable of receiving data from data collection stations (Plataformas de Coleta de Dados, PCDs) of the Brazilian Data Collection System (*Sistema Brasileiro de Coleta de Dados*, SBCD) installed along the Brazilian territory. The received data is forwarded to the ground segment through the main communication link offered by the satellite service module. A scientific contribution of the mission is the evaluation of radiation effects on electronic devices, as both EDC and the service platform are based on COTS. The radiation effects evaluation will be performed by the Radiation instrument, which has also been developed for the FloripaSat-1 mission. The mission provides also a relay service to the amateur radio community.

1.2 Mission Objectives

The main objectives of the mission are as follows:

1. In-Orbit Validation (IoV) of INPE's EDC payload.
2. Provide a flight model for the satellite's service platform, based on FloripaSat-1 bus.
3. Set up the ground segment for the mission operation.
4. Receive environmental data from ground (from EDC stations), and forward the collected data to the ground station.
5. Validate core-satellite functions in orbit.
6. Perform experiments on radiation effects in electronic components in orbit, evaluating the radiation levels affecting EDC and the service platform modules.
7. Serve as a relay for amateur radio communications, contributing to the amateur radio community.

1.3 Project Members

All people involved in the project are students, professors and researchers from Federal University of Santa Catarina (UFSC), the National Institute for Space Research (INPE) and the Brazilian Space Agency (AEB).

A list with the current members directly related to the project (2022/10/24) can be seen in Table 1.1.

All the modules and methods used in this project are based in past works, mainly the FloripaSat-1 and the EDC projects. The list with the indirectly involved people is much bigger.

Name	Title	Position	Institution
Anderson Wedderhoff Spengler	Dr.	Professor	UFSC
Eduardo Augusto Bezerra	Ph.D.	Professor	UFSC
Richard Demo Souza	Dr.	Professor	UFSC
Xisto Lucas Travassos	Dr.	Professor	UFSC
Laio Oriel Seman	Dr.	Researcher	UFSC
Rodrigo Leonardi	Dr.	Researcher	AEB
José Marcelo Duarte	Dr.	Researcher	INPE
Manoel Jozeane Mafra de Carvalho	M.Sc.	Researcher	INPE
Gabriel Mariano Marcelino	M.Sc.	Doctoral Student	UFSC
Brenda Fernandes Ribeiro	M.Sc.	Doctoral Student	UFSC
André Martins Pio de Mattos	B.Eng.	Doctoral Student	UFSC
Edilberto Costa Neto	B.Eng.	Master Student	UFSC
Vinicius Pimenta Bernardo	B.Eng.	Master Student	UFSC
Augusto Cezar Boldori Vassoler	B.Eng.	Master Student	UFSC
Bruno Benedetti	-	Undergraduate Student	UFSC
Caique Sales Miranda Gomes	-	Undergraduate Student	UFSC
João Cláudio Elsen Barcellos	-	Undergraduate Student	UFSC
Lucas Zacchi	-	Undergraduate Student	UFSC
Matheus Wagner	-	Undergraduate Student	UFSC
Miguel Böing	-	Undergraduate Student	UFSC
Ramon de Araújo Borba	-	Undergraduate Student	UFSC
Rebecca Quintino do O	-	Undergraduate Student	UFSC
Vitória Beatriz Bianchin	-	Undergraduate Student	UFSC

Table 1.1: Project members (2022/10/24).

1.4 Mission Patch

The mission patch of the GOLDS-UFSC can be seen in Figure 1.2; it is inspired by the FloripaSat-1 patch [2] as it uses the flight heritage from its core modules (EPS, OBDH, TTC), which have been improved at hardware and/or software levels, to achieve the new requirements. The patch shows Brazil, the country of the mission's origin, gray orbits representing a constellation of CubeSats, and the yellow circles representing the "gold" color as a reference to the GOLDS constellation.

Figure 1.2: GOLDS-UFSC mission patch.

CHAPTER 2

Mission Management

This chapter presents the main aspects of the general management of the project, like the mission schedule, product tree, and so on.

2.1 Schedule

The current schedule of the project is available in Table 2.1.

Activity	**Month** Nov 22	Dez 22	Jan 23	Feb 23	Mar 23	Apr 23	May 23	Jun 23
1	■	■						
2	■	■	■	■				
3	■	■	■					
4				■	■			
5					■			
6			■	■				
7					■			
8					■	■		
9						■	■	
10							■	■
11		■						
12			■					

Table 2.1: Mission schedule (updated on 2022/10/24).

Each activity of Table 2.1 is described below:

1. Integration of the engineering model in SpaceLab UFSC.
2. Preparation and suitability of the ground segment.
3. Verification and validation of the engineering model.
4. Integration and verification with data collection platforms.
5. Verification and validation tests of Engineering Model compatibility with EMMN in the INPE / CRN in Natal.

6. Verification and validation of the flight model.
7. Environmental tests at the Integration and Testing Laboratory (LIT/INPE).
8. Flight model acceptance and ground segment review.
9. Ground segment delivery.
10. Flight model delivery.
11. Purchase (flight model).
12. Delivery of purchased items (flight model).

2.2 Product Tree

The product tree of the GOLDS-UFSC mission is the project breakdown into successive levels of hardware and software products (or elements). The product tree of the project can be seen in the diagram of Figure 2.1. As shown, the satellite was divided into eight segments.

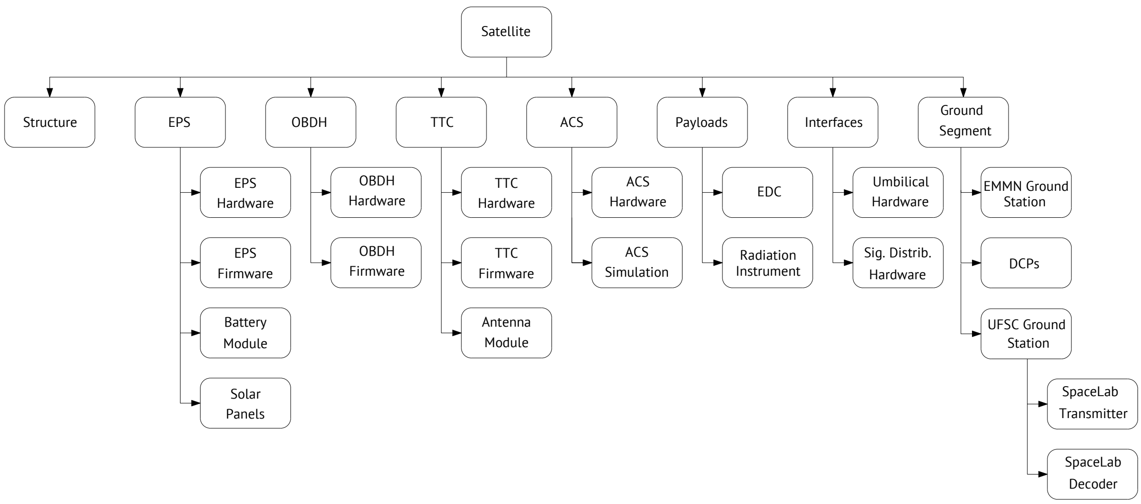


Figure 2.1: Product tree of the satellite.

The responsibility of each segment of the product tree is described next:

- **Structure**: UFSC (COTS).
- **EPS**: UFSC (developed in-house, with COTS solar panels).
- **OBDH**: UFSC (developed in-house).
- **TTC**: UFSC (developed in-house).
- **ACS**: UFSC (developed in-house).
- **Payload EDC**: INPE

- **Radiation instrument**: UFSC (developed in-house).
- **Interfaces**: UFSC (developed in-house).
- **Ground segment**:
  - **EMMN ground station**: INPE
  - **DCPs**: INPE/SINDA and other institutions
  - **UFSC ground station**: UFSC

2.2.1 Work Breakdown Structure

The Work Breakdown Structure (WBS) is presented as a diagram in Figure 2.2. The WBS is divided into work packages (WP) as can be seen in the diagram. The description of each WP is detailed below.

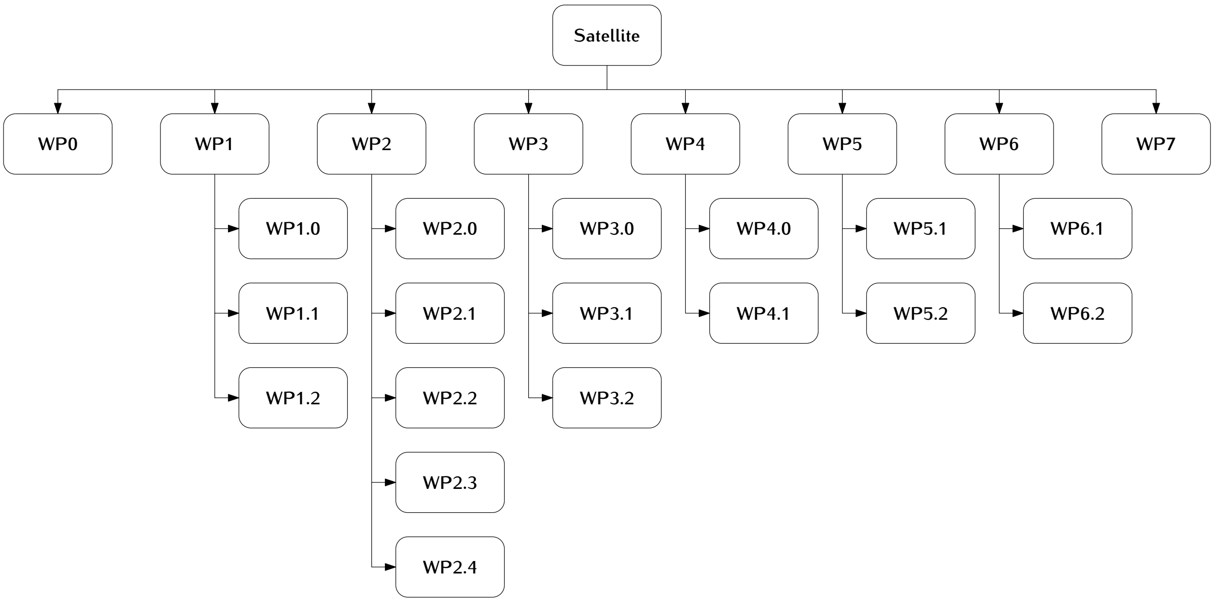


Figure 2.2: WBS diagram.

- **WP0**: Management and preparation.
- **WP1**: Architecture study and specification.
  - **WP1.0**: Operation scenario definition.
  - **WP1.1**: Architecture definition.
  - **WP1.2**: Requirements definition.
- **WP2**: Engineering and flight models definition
  - **WP2.0**: Application design.
  - **WP2.1**: Platform design.
  - **WP2.2**: Application implementation.

  - **WP2.3**: Platform implementation.
  - **WP2.4**: Decoder implementation (EGSE).

- **WP3**: Engineering model integration.
  - **WP3.0**: Subsystems integration and tests.
  - **WP3.1**: Engineering model satellite integration.
  - **WP3.2**: Integration and tests with decoder.

- **WP4**: Engineering model validation.
  - **WP4.0**: Validation scenarios specification.
  - **WP4.1**: Project validation.

- **WP5**: Fligth model integration.
  - **WP5.0**: Subsystems integration and tests.
  - **WP5.1**: Fligth model satellite integration.

- **WP6**: Fligth model validation.
  - **WP6.0**: Validation scenarios specification.
  - **WP6.1**: Project validation.

- **WP7**: Evaluation and dissemination.

2.3 Risk Management

A risk is an event that threatens the project's success, even if partially. Therefore, this plan aims to help identifying adverse events at an early stage, handle them, and mitigate.

The development of this project will be based on a qualitative risk analysis standard. This depends on crossing two metrics: the probability of risk occurrence and the impact of risk occurrence. Table 2.2 shows definitions of the probability of occurrence categorization.

Likelihood	**Likelihood of occurrence**
Expected	Almost certain occurrence. Very likely event to occur.
Probable	Occurs frequently, relatively recurrent observations. Event with considerable chances of occurring.
Improbable	Occurs occasionally, it is not a rare event. Event with a significant but small chance of occurring.
Rare	Occurs rarely, rare observations. Very unlikely event to occur.
Very rare	It almost never occurs, very rare occurrences, or never occurred. An almost impossible event to occur.

Table 2.2: Likelihood categorization.

Five levels of impact define the occurrence impact metric:

- **5 (Catastrophic):** In general, these are risks that, if materialized, make the Subject or Activity unfeasible or end. Some examples of the description by feature:
  - *Financial Resources:* Significant increase in expenses that makes the continuation of the project or activity unfeasible or causes its termination;
  - *Material Resources:* loss of materials that makes the continuation of the project or activity unfeasible or causes its termination;
  - *Temporal Resources:* delay that makes the continuation of the project or activity unfeasible or causes its termination;
  - *Human Resources:* Death of one or more people. Evasion of more than 95% of those involved; and
  - *Organizational Image Resources:* Loss of total institutional credibility.
- **4 (Critical):** Overall, these are risks that, if materialized, make it very difficult to complete or progress the Subject/Activity and may raise considerations of finishing the Subject or Activity. Some examples of the description by resource:
  - *Financial Resources:* Increase of over 50% in expenses;
  - *Material Resources:* Material loss that cannot be replaced in a timely manner and that causes a significant loss of permanent performance of the system;
  - *Temporal Resources:* delay of more than 80% in the estimated time in the conclusion of the Subject/Activity;
  - *Human Resources:* Permanent disability of one or more people. Evasion between 70% and 95% of those involved; and
  - *Organizational Image Resources:* Very strong loss of institutional credibility.
- **3 (Major):** Overall, these are risks that, if materialized, make it difficult to complete or progress the Subject/Activity but do not usually raise considerations about ending the Subject or Activity. Some examples of the description by resource:
  - *Financial Resources:* Increase in subject/activity expenses between 15% and 50%;
  - *Material Resources:* Material loss capable of being replaced in a timely manner, but causing significant temporary system loss;
  - *Temporal Resources:* delay between 40% and 80% in the estimated time in the conclusion of the Subject/Activity;
  - *Human Resources:* Temporary disability of one or more people. Evasion between 40% and 70% of those involved; and
  - *Organizational Image Resources:* Loss of significant institutional credibility.
- **2 (Minor):** Overall, these are risks that, if materialized, significantly hamper the completion or progress of the Subject/Activity, but definitely do not raise the consideration of termination. Some examples of the description by feature:
  - *Financial Resources:* Increase in subject/activity expenses between 5% and 15%;
  - *Material Resources:* Material loss capable of being replaced in a timely manner and causing a temporary loss of system performance;

  - *Temporal Resources:* delay between 10% and 20% in the estimated time for completion of the Subject/Activity;

  - *Human Resources:* Minor injuries to one or more people. Evasion between 25% and 40% of those involved; and

  - *Organizational Image Resources:* Some loss of institutional credibility.

- **1 (Insignificant):** Overall, these are risks that, if materialized, make it a little difficult to complete or progress the Subject/Activity. Some examples of the description by resource:

  - *Financial Resources:* Increase in subject/activity expenses by up to 5%;

  - *Material Resources:* Loss of material that does not cause temporary loss of performance;

  - *Temporal Resources:* delay of up to 10% in the estimated time in the conclusion of the Subject/Activity;

  - *Human Resources:* Minor injuries to one or more people. Evasion of less than 25% of those involved; and

  - *Organizational Image Resources:* Little loss of institutional credibility.

2.3.1 Risks identification

The identified risks are displayed in Table 2.3, classified by context (mission or system), likelihood (Very Rare-Expected), and by level of impact (1-5).

ID	Risk	Context	Likelihood	Impact
RSK-1	Unable to obtain additional financial resources to complete the mission	Mission	Improbable	5
RSK-2	Lack of components on the market	Mission	Probable	2
RSK-3	High turnover of the development team	Mission	Improbable	2
RSK-4	Significant rise in the dollar (may not have enough resources to acquire systems)	Mission	Probable	3
RSK-5	Satellite commissioning failure	Mission	Improbable	5
RSK-6	Satellite does not survive launch	Mission	Rare	5
RSK-7	Ground Station failure	Mission	Improbable	5
RSK-8	LIT not available for satellite qualification tests	Mission	Improbable	2
RSK-9	Operational licensing not available on launch time	Mission	Improbable	3
RSK-10	EPS Software operation failure	System	Improbable	5
RSK-11	OBDH software operation failure	System	Improbable	5
RSK-12	Radiation instrument operation failure	System	Improbable	1
RSK-13	GSE software operation failure	System	Improbable	4
RSK-14	EDC does not comply with requirements	System	Rare	4
RSK-15	Materials resources not sufficient for preliminary tests	System	Probable	2
RSK-16	Fail on vibration tests impacting on delays	System	Rare	3
RSK-17	Non compliant metrological requirements impacting on delays	System	Probable	2
RSK-18	Kill switch mechanism fail, and satellite does not power on	System	Very rare	5
RSK-19	COTS systems not available in market	System	Rare	3

Table 2.3: Mission and space systems risks.

CHAPTER 3

Concept of Operations

3.1 Introduction

This chapter describes the operational concept of the In-Orbit Validation (IoV) mission of the EDC payload of INPE. The mission is focused on the use of a service module based on the FloripaSat-1 platform for the in-orbit validation of the EDC, a module developed for CubeSats capable of receiving data from the data collection stations (Data Collection Platforms, DCPs) of the Brazilian Data Collection System (SBCD) installed throughout the Brazilian territory.

The document defines the mission's structure, the operational mode of the EDC payload and the service module, as well as outlining the operational expectations and responsibilities of the stakeholders.

3.1.1 Mission description

The main task of this mission is the In-Orbit Validation (IoV) of the EDC payload of INPE. The EDC is a module specifically developed for CubeSats, designed to receive data from data collection stations (DCPs) of the Brazilian Data Collection System (SBCD) distributed throughout the Brazilian territory.

The service module is based on the FloripaSat-1 platform and its primary function is to transmit the received data to the ground segment through the main communication link provided by the satellite.

A crucial scientific component of the mission is the assessment of radiation effects on electronic devices. Both the EDC and the service platform are based on Commercial Off-The-Shelf (COTS) components, and the evaluation of radiation effects will be carried out by the Radiation instrument, also developed for the FloripaSat-1 mission.

Additionally, the mission will also provide a relay service for the amateur radio community.

3.1.2 Mission objectives

The main objective of the mission is to validate the functionality and performance of the INPE's EDC payload in orbit. The mission will seek to achieve this objective through the following activities:

- Receive data from DCP stations of the SBCD installed in Brazilian territory.

- Transmit the received data to the ground segment through the satellite's main communication link.

- Evaluate the effects of radiation on COTS electronic devices.

- Provide a relay service for the amateur radio community.

In the next section, we will describe in detail the operational environment and the execution plan to achieve these objectives.

3.2 Mission structure

The mission architecture is designed to achieve the objectives set for the satellite mission. It defines the layout of the satellite system, including the different payload modules, the satellite platform, the ground segment, and the communication protocols.

3.2.1 Satellite platform

The satellite platform is based on the FloripaSat-1 bus, which has a proven track record of reliability and performance. It provides the necessary environment to host and operate the payload modules, as well as the essential systems of the satellite, such as attitude control, power generation, and communications.

3.2.2 Payload modules

The satellite carries two EDC modules, developed for CubeSats, that are capable of receiving data from the Data Collection Platforms (DCPs) of the Brazilian Data Collection System (SBCD). One of the EDCs acts as a backup for the other, providing redundancy and ensuring mission continuity in the event of a failure.

Also onboard is the Radiation Instrument, developed to assess the effects of radiation on COTS electronic devices. This instrument will be activated when the satellite is out of range of the DCPs in Brazil.

3.2.3 Ground segment

The ground segment consists of the Data Collection Platforms (DCPs) installed throughout the Brazilian territory and the INPE's Information System (SINDA). The DCPs transmit data that is received by the EDC modules on the satellite and sent back to SINDA for processing and distribution.

3.2.4 Mission control

The mission control will be carried out by the Federal University of Santa Catarina (UFSC), which will monitor the health and performance of the satellite, execute flight control commands, and plan mission activities.

3.2.5 Communication protocols

The mission uses a reliable communication protocol to ensure the transmission of data between the satellite and the ground segment. The protocol ensures that all transmitted data is received correctly and in order, and allows for error correction in transmission.

Together, the mission architecture ensures that all functions and objectives of the mission can be fulfilled efficiently and effectively.

3.3 Mission operation modes

3.3.1 Deployment mode

The Launch Mode is the first phase of the mission, during which the satellite is launched into space. During this phase, all satellite functions are disabled to protect the system from any potential mechanical or thermal stress during launch. After a successful launch and separation from the launch vehicle, the satellite automatically enters the Initialization Mode.

3.3.2 Initialization mode

In the Initialization Mode, the satellite will automatically power up, going through the system boot process. During this process, the onboard computer of the satellite will initialize all satellite subsystems in a specific sequence to check their status and functionality.

This mode also involves the initial acquisition of satellite orientation (attitude) and the establishment of a communication link with the ground station. Once the communication link has been established and all systems are operating as expected, the satellite transitions to the Nominal Operation Mode.

3.3.3 Nominal operation mode

This is the default operational state of the satellite. In the Nominal Operation Mode, the satellite will perform all its intended functions, including receiving data from the DCP stations, transmitting data to the ground segment, evaluating the effects of radiation on COTS electronic devices, and providing relay services for the amateur radio community.

The Nominal Operation Mode also involves maintaining satellite attitude and managing power consumption, ensuring that all systems operate optimally. The satellite will remain in this mode as long as all functions are operating as expected.

3.3.3.1 EDC activated

This is the default operational state of the satellite when it is flying over Brazilian territory. During this period, the EDC is activated to receive and store data from the Data Collection Platforms (DCPs). Additionally, the satellite performs attitude maintenance and power consumption management tasks.

The EDC payload, crucial for receiving data from the DCP stations, is a critical part of the mission. However, to optimize power usage and maximize operational efficiency, the EDC will only be activated when the satellite is passing over Brazilian territory. This will allow the EDC to collect data from the DCPs more effectively and transmit them to the ground segment while conserving energy when data collection is not possible.

The decision of when to activate and deactivate the EDC will be based on the satellite's orbit propagation, which will be calculated using regularly updated Two-Line Elements (TLEs). TLEs are widely used format for describing a satellite's orbit. It consists of two lines of textual data that contain information about the orbital element epoch, inclination, right ascension of the ascending node, eccentricity, argument of perigee, mean anomaly, and mean motion of the satellite.

The satellite's TLEs will be received periodically from the ground segment. The mission control team will calculate the satellite's future position based on the TLEs and determine the period when the satellite will be over Brazil. During this period, the EDC will be activated and begin collecting data from the DCPs. Once the satellite exits the coverage area, the EDC will be deactivated until the next pass over Brazil.

This approach of operating the EDC based on orbit propagation allows for efficient utilization of satellite resources while maximizing the amount of data collected and transmitted to the ground segment.

In addition to data collection, the satellite continues to provide relay services for the amateur radio community. However, priority is given to the operation of the EDC and data collection from the DCPs during this period.

3.3.3.2 EDC deactivated

When the satellite is out of reach of Brazil, the EDC is deactivated to save energy. During this period, the focus is on the operation of the radiation measurement instrument, which assesses the effects of radiation on COTS electronic devices.

While the EDC is deactivated, the radiation measurement instrument is activated and begins collecting data. This data is essential for evaluating the effectiveness of COTS electronic devices in radiation environments, providing valuable insights for the future development of satellites.

Additionally, the satellite continues to maintain its attitude and manage its power consumption. It also continues to provide relay services for the amateur radio community, although these may be limited to prioritize radiation data collection.

In both modes, the health and performance of the satellite are continuously monitored by the mission control team to ensure that all operations are being executed as planned. If any issues arise, the satellite can be put into an alternative operational mode for diagnosis and troubleshooting.

3.3.4 Contingency mode

The Contingency Mode is an operational state that the satellite enters if there is a failure in one of the critical systems or if an anomaly is detected. This includes the failure of one of the Data Collection Payload Modules (EDCs). The mission was designed with two EDCs onboard the satellite to provide redundancy. This means that if one EDC fails, the other can be activated to ensure the continuity of the mission.

3.3.4.1 EDC failure

In the event of a failure in the primary EDC, the system will automatically switch to the secondary EDC. This backup EDC has the same functionality as the primary EDC and can receive data from the Data Collection Platforms (DCPs) and transmit them to the ground segment. The switch to the backup EDC will be made without interruption in data collection and transmission, ensuring the continuity of the mission.

3.3.4.2 Recovery procedure

In case of a failure, the mission control team at the Universidade Federal de Santa Catarina (UFSC) will work to identify the cause of the failure and implement a recovery procedure. This may involve resetting the primary EDC, performing a software update, or executing maneuvers to change the satellite's attitude.

The goal of the Contingency Mode is to ensure the continuity of the mission in the presence of failures or anomalies, minimizing any interruption in data collection and transmission. Thanks to the redundancy of the EDC, the mission is capable of adapting and responding to failures, ensuring that data continues to be collected and transmitted to the ground segment.

3.3.5 Decommissioning mode

The Decommissioning Mode is activated at the end of the satellite's lifespan when it is no longer capable of performing its functions or when an irreparable problem is detected. In this mode, all satellite functions are permanently shut down, and the satellite is moved to an orbit where it poses no threat to other objects in space.

3.4 Ground segment

The ground segment is an essential component of the mission and includes all the terrestrial infrastructure that will be used to communicate with the satellite, receive data from the EDC payload, and monitor the health and performance of the satellite.

3.4.1 Data collection platforms

The DCPs are ground stations distributed throughout the Brazilian territory. They are responsible for collecting environmental data and other scientific information. Each DCP collects data locally and transmits it to the satellite when it passes over it.

The EDC on board the satellite is designed to receive these data transmitted by the DCPs. When the satellite is passing over Brazil and the EDC is activated, it will receive the data from the DCPs and store them for later transmission to the ground segment.

3.4.2 Environmental data integrated system

The Enviromental Data Integrated System (SINDA, *Sistema Integrado de Dados Ambientais* in portuguese) is the main data reception center of INPE. It is responsible for receiving the data transmitted by the satellite, processing it, and distributing it to end users. SINDA also plays an important role in monitoring the health and performance of the satellite.

When the satellite is passing over SINDA and the communication link is established, the data collected by the EDC will be transmitted to SINDA. Upon receipt, SINDA will process this data and make it available to end users.

Additionally, SINDA will regularly receive telemetry from the satellite, allowing the mission control team to monitor the health and performance of the satellite and make operational decisions based on this information.

3.4.3 Control and coordination

The coordination and control of the ground segment will be carried out by the mission control team, which is responsible for ensuring that all parts of the ground segment are functioning correctly and for resolving any issues that may arise. They will also be responsible for determining when and where the EDC should be activated based on the TLEs and the orbit propagation of the satellite.

In summary, the ground segment is a vital part of the mission. It enables data collection and transmission, satellite monitoring and control, and facilitates the interaction between the satellite and the DCPs, ensuring the success of the mission.

3.5 Mission control

Mission control will be carried out by the UFSC. UFSC has a pass involvement in satellite development, providing a wide range of skills and expertise to manage the satellite operation.

3.5.1 Mission control station

UFSC will establish a dedicated mission control station for this purpose. This station will be responsible for the continuous monitoring of the satellite's health and performance, as well as the execution of flight control commands, such as attitude maneuvers, software updates, and anomaly resolution.

3.5.2 Mission control team

The mission control team will be composed of students and professors from UFSC who have been trained to operate the satellite system. The team will be responsible for monitoring the satellite's telemetry, identifying and resolving issues, and interfacing with other stakeholders, such as the teams responsible for the ground segment.

3.5.3 Mission planning

The UFSC mission control team will also be responsible for planning and executing mission activities. This includes preparing detailed mission plans that define the activities to be performed by the satellite, such as activating the EDC and collecting data from the DCPs. These mission plans will be based on the propagation of the satellite's orbit, which is calculated using the TLEs.

3.5.4 Coordination with external entities

As part of mission control, UFSC will also coordinate with other entities involved in the mission, such as INPE and the ground stations for data reception. This includes coordinating the upload of TLEs and the transmission of received data to INPE's SINDA for processing and distribution.

In summary, UFSC will have a central role in mission control, ensuring that the satellite operates efficiently and performs its tasks as planned. UFSC's extensive experience in mission operations will be a significant advantage for the success of this mission.

3.6 Schedule

Experiment	**Start**	**End**	**Observations**
DCPs data reception	Day 2	End of lifespan	Continuous operation, subject to the availability of the DCPs.
Data transmission	Day 2	End of lifespan	Data transmission will be performed as data is received from the DCPs.
Radiation effects evaluation	Day 2	End of lifespan	This experiment takes place continuously during the mission, collecting and sending data periodically.
Retransmission service	Day 7	End of lifespan	The relay service will be available to the amateur radio community, with restrictions to avoid interfering with the satellite's primary operation.

Table 3.1: Steps of operation.

CHAPTER 4

Technical Budgets and Mission Analysis

This chapter presents a general analysis of the mission, such as a preliminary analysis of the satellite's estimated orbit, estimated lifetime, and the amount of data exchanged along its operation.

Another type of analysis presented is the satellite budgets, such as the power and link budgets.

4.1 Requirements

The mission requirements are listed next:

1. The power system must be able to harvest solar energy.
2. The power system must be able to store energy for use when GOLDS-UFSC is eclipsed.
3. The power system must supply energy to all other modules.
4. The data handling system must communicate with the other modules and store their data.
5. The communications system must send a beacon signal periodically using VHF radio.
6. The communications system must send the CubeSat telemetry using UHF radio.
7. The communications system must be able to receive telecommands and respond to them accordingly.
8. The attitude system must be able to perform a 1-axis stabilization of the CubeSat.
9. GOLDS-UFSC must be able to receive and execute a shutdown telecommand, therefore ceasing all transmissions.
10. The downlink transmissions must be done once at a time, either telemetry or beacon.
11. The ground station must operate under the proper radio frequency communication licenses.
12. GOLDS-UFSC must comply with international and Brazilian radio license agreements and restrictions.

13. The team must build and operate a ground station for full communication with GOLDS-UFSC.
14. GOLDS-UFSC must be capable of sustaining the primary payload (EDC) operation.
15. The service module and payload must employ materials and components that do not compromise or damage LIT/INPE test facilities.
16. The satellite must reenter the Earth's atmosphere within 25 years.
17. It is recommended that the satellite be placed in an orbit up to 500 km.

4.2 Orbit Parameters and Analysis

To simulate the behavior of the satellite during its operation, the software SimCube developed at the SpaceLab was used. It is important to emphasize that the results presented in this chapter are preliminary, since the actual orbit parameters are yet to be defined and are subject to market availability.

The orbit parameters were based on the FloripaSat-1 TLE, but with a lower altitude. These parameters can be seen in Table 4.1.

Parameters	**Value**	**Unit**
Apogee	550	km
Eccentricity	0.0015051	-
Inclination	97.9750	°
RAAN	85.5100	°
Arg. of Perigee	194.87	°

Table 4.1: Initial orbit parameters (adapted from FloripaSat-1).

The parameters of the simulation were based on [6] and can be seen below:

- Force model for gravitational field: "*Earth Gravitational Model 1996 (EGM96)*"
- Drag coefficient: 2.2
- Drag atmosphere model: "*NRLMSISE-00*"
- Epoch: 01 Jan 2022 11:59:28.000

The Figure 4.1 shows the 3D representation of the GOLDS-UFSC orbit simulation, while Figure 4.2 shows the ground track of a regular orbit obtained with the GMAT software [7].

The next sections present some analysis based on the results obtained from the simulations performed with SimCube.

4.2.1 Lifetime Analysis

Considering the same parameters of FloripaSat-1, but with an initial altitude of 550 km, the simulations on SimCube showed that the satellite decays approximately in 2183 days ($\cong$ 6 years), as can be seen in Figure 4.3.

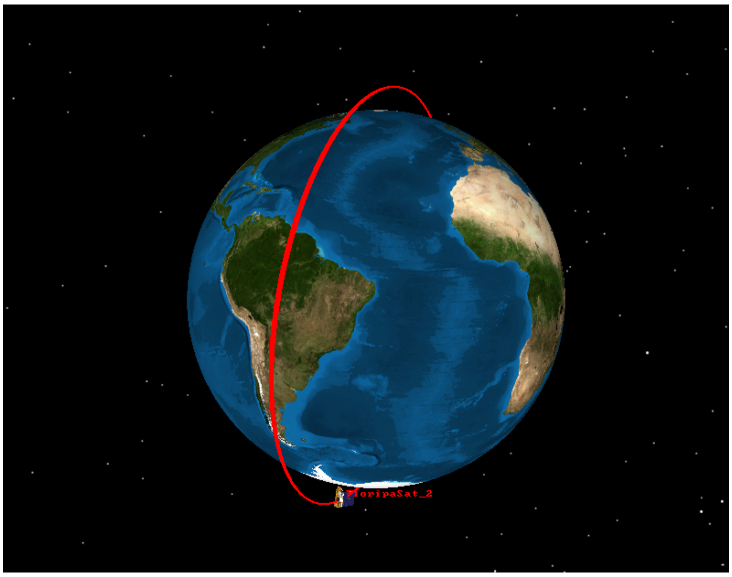


Figure 4.1: GOLDS-UFSC orbit simulation on GMAT.

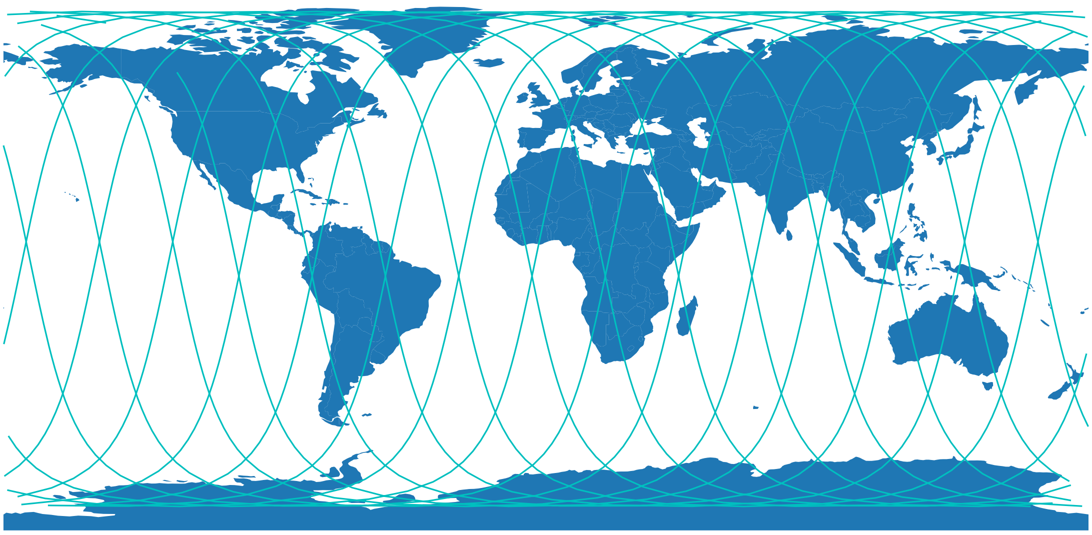


Figure 4.2: GOLDS-UFSC simulated groundtrack.

4.2.2 Ground Station Passes and Data Transfer Analysis

Considering two ground stations, one at the SpaceLab installations in Florianópolis (27° 36′ 00.9" S, 48° 31′ 03.2" W) and other at the INPE/CRN installations in Natal (5° 50′ 10.1" S, 35° 12′ 27.5" W), both with a minimum elevation of 15°, the results in Table 4.2) were achieved.

As seen from Table 4.2, during the first 60 days of operation, considering the two main ground stations that will contact the satellite, the total contact period is 80599 seconds (43394 + 37205). With the data rate of the downlink/uplink as 4800 bps, this period will allow a data transfer of 48359400 bytes (or 46.12 M$_i$B) between GOLDS-UFSC and the Earth. Using the satellite's lifetime from the previous analysis (2000 days), and an

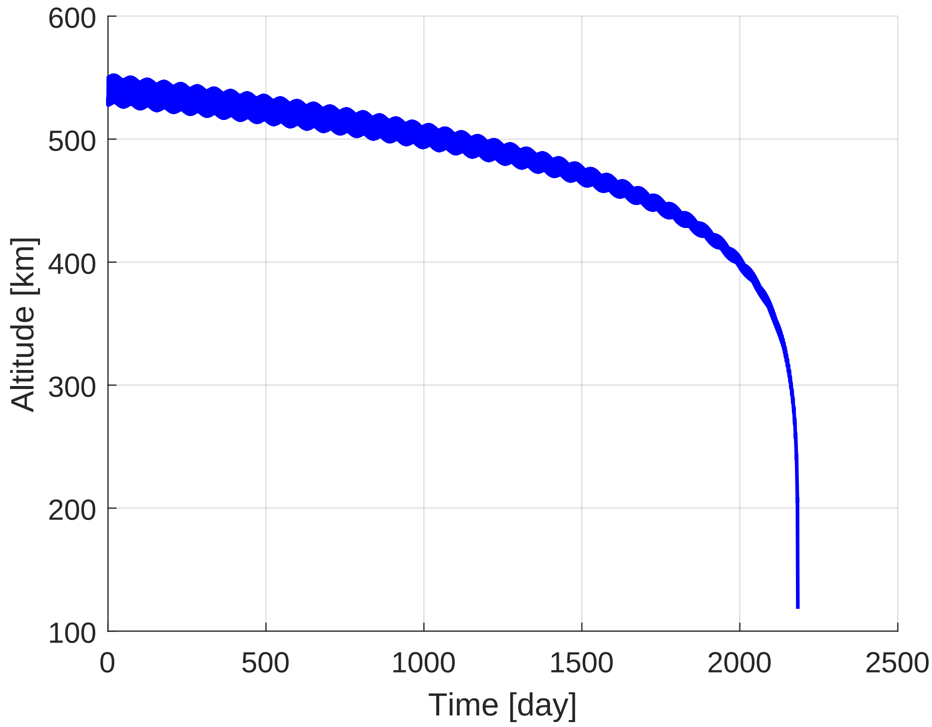


Figure 4.3: Lifetime analysis.

Parameter	UFSC Station	INPE-RN Station	Unit
Minimum elevation to a valid contact	15	15	°
Number of contacts	143	125	-
Minimum contract period	24	34	sec
Maximum contact period	395	394	sec
Average contact period	303	298	sec
Total contact period	43394	37205	sec

Table 4.2: Ground station contacts analysis during the first 60 days of operation.

average data transfer per day of 805990 bits, the total theoretical raw data transfer during the whole operation of the satellite will be approximately 1.5 G_iB.

These values can be even more significant if a smaller minimum elevation is considered, or with more ground stations in other locations.

4.3 Mass Budget

The mass budget of the satellite can be seen in Table 4.3.

According to the CubeSat standard [1], the maximum mass of each unit must be 1.33 kg. As the GOLDS-UFSC is a 2U CubeSat, the maximum allowed mass of the project is 2.66 kg. Considering the weight of each subsystem presented in Table 4.3, the current total mass of the object is below the maximum allowed, with a margin of 16 %.

Subsystem	Model	Mass [g]
OBDH	SpaceLab OBDH 2.0	53
TTC	SpaceLab TTC 2.0	52
EPS	SpaceLab EPS 2.0	80
Battery	SpaceLab Battery Module 4C	235
Antenna	ISISpace AntS	89
ACS	SpaceLab Passive ACS 2U	100 (TBC)
Payload	INPE-RN EDC	75 ($\times$2)
Radiation instrument	SpaceLab Payload X	75 (TBC)
Interface	SpaceLab Interface Boards	40
PC-104 Adapter	SpaceLab PC-104 Adapter	50 (TBC)
Solar Panel	Orbital Custom Solar Panel	266
Shields	3 mm aluminum sheets	590 (TBC)
Structure	Usiped Custom 2U Structure	206
Cables	-	200
Others	-	100
Total	-	**2211**
Max. CubeSat 2U	-	2666
Margin	-	455

Table 4.3: Mass budget of the satellite.

4.4 Power Budget

According to section 10.3 of [8], the power budget of a satellite can be determined through three steps:

1. Prepare operating power budget
2. Size the battery
3. Estimate power degradation over mission life

4.4.1 Input Power

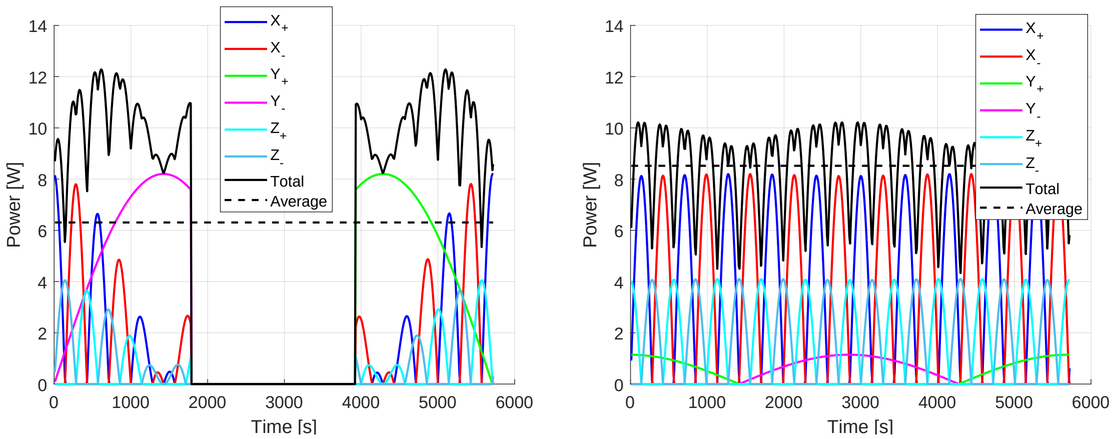
Simulations of the energy input to the solar panels along some orbits can be seen in the Figure 4.4 graph. Two extreme orbit scenarios, without and with maximum eclipse, were tested. The figures show the power generated on each side of the CubeSat, as well the total and average values.

From these simulations, the results in Table 4.4 were obtained:

4.4.2 Operating Power Budget

Typical operating voltages and current and power ranges consumed by each satellite subsystem are presented in Table 4.5.

Using the information presented in Table 4.5, and the activation periods defined for each module (the duty cycle), we arrive at the average satellite consumption present in Table 4.6.



(a) Maximum eclipse.

(b) Without eclipse.

Figure 4.4: Simulated input power of the solar panels.

Parameter	Maximum eclipse	Without eclipse
Peak power	12282.7 mW	10217.2 mW
Average power (total orbit)	6306.9 mW	8519.6 mW
Average (sunlight)	10048.9 mW	8519.6 mW
Orbit period	5720 s	5720 s
Sun light period	3590 s	5720 s
Eclipse period	2130 s	0 s

Table 4.4: Results for the power input.

Module	Voltage [V]	Current [mA]		Power [mW]	
		Min.	Max.	Min.	Max.
OBDH	3.3	35	200	115	660
TTC (μC)	3.3	40	40	132	132
TTC (radio module)	5	10	650	33	3250
EPS (digital part)	7.4	50	260	165	858
EPS (heater)	7.4	675	675	5000	5000
Antenna module	3.3	60	550	200	1800
Payload EDC	5	250	250	1250	1250
Radiation instrument	5	TBD	TBD	TBD	TBD

Table 4.5: Power requirements of the subsystems and payloads of the satellite.

The duty cycles of Table 4.6 were defined according to the following assumptions:

- One of the EDC payload is always off (cold redundancy).
- The Radiation instrument is turned on just during limited periods and only with telecommands.

As can be seen from Figure 4.4 and Table 4.6, there is a slight positive margin of **76.9 mW** in the power budget.

Module	Duty Cycle [%]	Power [mW]
OBDH	100	115
TTC (radio 1 RX)	95	65
TTC (radio 1 TX)	5	3250
TTC (radio 2 RX)	95	65
TTC (radio 2 TX)	5	3250
EPS	100	320
BAT (idle)	90	0
BAT (heater full)	10	5000
Antenna (deployment)	0	1800
Antenna (deployed)	100	35
Payload EDC	100	1250
Radiation instrument	0	1000
Satellite	$\cong$ 2668	

Table 4.6: Power consumption of the subsystems and payloads of the satellite.

4.4.3 Battery Sizing

As described in [8], the battery sizing of a satellite can be made by following the steps below:

1. Estimate power level that the battery must supply
2. Compute discharge cycle duration, charge cycle duration, and numbers of charge-discharge cycles
3. Select depth of discharge
4. Select charge rate
5. Compute battery recharge power

The power level that the battery must supply is the total power consumption of the satellite and is available in Table 4.6.

The discharge and charge cycle duration can be obtained from Figure 4.4. The discharge duration is approximately 35.3 min (or 0.5889 h), and the charge cycle duration is 61.83 min (or 1.031 h). This is considering a single complete orbit.

The depth of discharge (DoD) can be obtained using the Equation 4.1.

$$DoD = \frac{D_i \cdot D_t}{C} \cdot 100\ \% \tag{4.1}$$

Where:

- D_i: Discharge rate
- D_t: Discharge period
- C: Battery capacity

As the battery cells are already selected (5000 mAh in total, as described in subsection 6.3.1), the current DoD is computed in Equation 4.2.

$$DoD = \frac{2668\ mW \cdot 0.5889\ h}{18500\ mWh} \cdot 100 \cong \mathbf{8.5}\ \% \tag{4.2}$$

The charge rate can be estimated from the power input of the solar panels when the satellite is in sunlight. As presented before, the simulation results estimate the power input as 4315.6 mW. Considering the charge time as 61.83 min (or 1.031 h), the input energy is 4450 mWh. From Table 4.6, the power consumption of the satellite at sunlight is 2169 mW (or 2236 mWh considering the sunlight period). This way, energy input at sunlight is obtained in Equation 4.3.

$$4450 - 2236 = 2214\ mWh \tag{4.3}$$

From the DoD calculation, the energy consumption during the eclipse is 1571 mWh. This way, the energy margin of the battery becomes positive ($2214 - 1571 = 643mWh$), as expected from the power budget results.

All results from the battery sizing are available in Table 4.7.

Parameter	**Value**	**Unit**
Battery capacity	18500	mWh
Energy consumption on sunlight	2169	mWh
Energy consumption on eclipse	1571	mWh
Sunlight duration	1.031	h
Eclipse duration	0.5889	h
Depth of Discharge (DoD)	8.5	%
Total battery energy margin	643	mWh

Table 4.7: Battery sizing results.

From the results, the battery sizing is well suited for the current satellite configuration and the planned behavior.

4.4.4 Power Degradation Over Mission Life

Two major events along the satellite operation should be considered in the power degradation analysis:

1. Solar panels degradation
2. Battery degradation

From [8], 5 % per year is a usual number for the solar panels' degradation, in other words, the general efficiency of the solar panels decays at a rate of 5 % per year of operation.

Variable	Beacon	Downlink	Uplink	Uplink (Payload)	Unit
Altitude	550	550	550	550	km
Elevation	0	0	0	0	°
Frequency	146	450	450	401.635	MHz
Modulation	GMSK	GMSK	GMSK	BPSK	-
Protocol	NGHam	NGHam	NGHam	SBCD	-
Transmit power	30	30	44	30	dBm
Transmitter antenna gain	0	0	12	3	dBi
Receiver antenna gain	12	12	0	0	dBi
FSPL	144.4	154.2	154.2	153.2	dB
Power at receiver	-107.4	-117.2	-103.16	-125.2	dBm
Receiver sensibility	-134	-134	-126	-128	dBm
System losses	5	5	5	5	dB
Receiver noise temp.	361.7	361.7	361.7	361.7	K
Antenna noise temp.	300	300	300	300	K
System noise temp.	661.7	661.7	661.7	661.7	K
Data rate	1200	9600	9600	400	bps
Received SNR	32.22	13.41	27.41	19.17	dB
SNR required for 10^{-5} BER[1]	9.6	9.6	9.6	9.6	dB
Link margin	≥ 22.62	≥ 3.812	≥ 17.81	≥ 9.57	dB

Table 4.8: Link budget results.

4.5 Link Budget

The link budget of all satellite radio links is available in Table 4.8.

As can be seen, considering the worst case for the estimated orbit, that is, with the satellite on the horizon and with an elevation of zero degrees, the margin of all links is positive with a considerable balance.

All equations and steps used to obtain the results of Table 4.8 are available in Appendix A.

[1]Without FEC.

CHAPTER 5

Service Module Overview

This section presents the design description of GOLDS-UFSC.

5.1 General Diagrams

The CubeSat's subsystems are positioned in the 2U physical structure as exemplified in Figure 5.1.

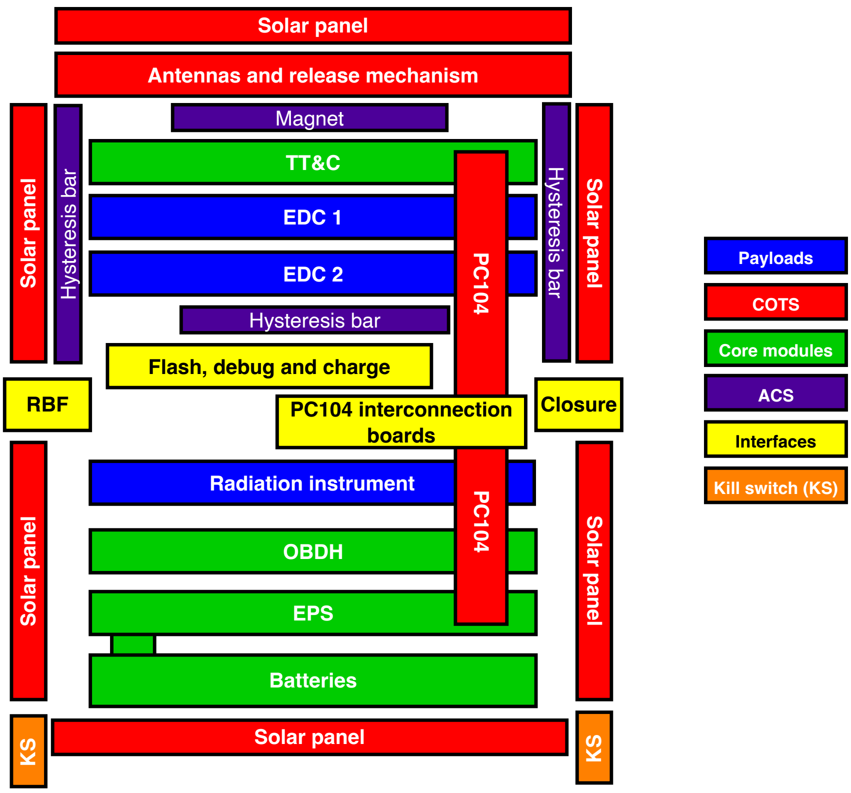


Figure 5.1: Subsystems positioning.

5.1.1 Power Diagram

In Figure 5.2 is presented a block diagram showing the satellite's power buses. The EPS module distributes these buses and has the ability to turn on and off some subsystems, while other modules also have direct control over some dc regulators[9]. The bus used for the antenna module is only active during its deployment. The current values shown are the maximum capability and not the nominal operating values; these are determined by the variable power generation of the solar panels as well as the loads present at a given time of the satellite's operation.

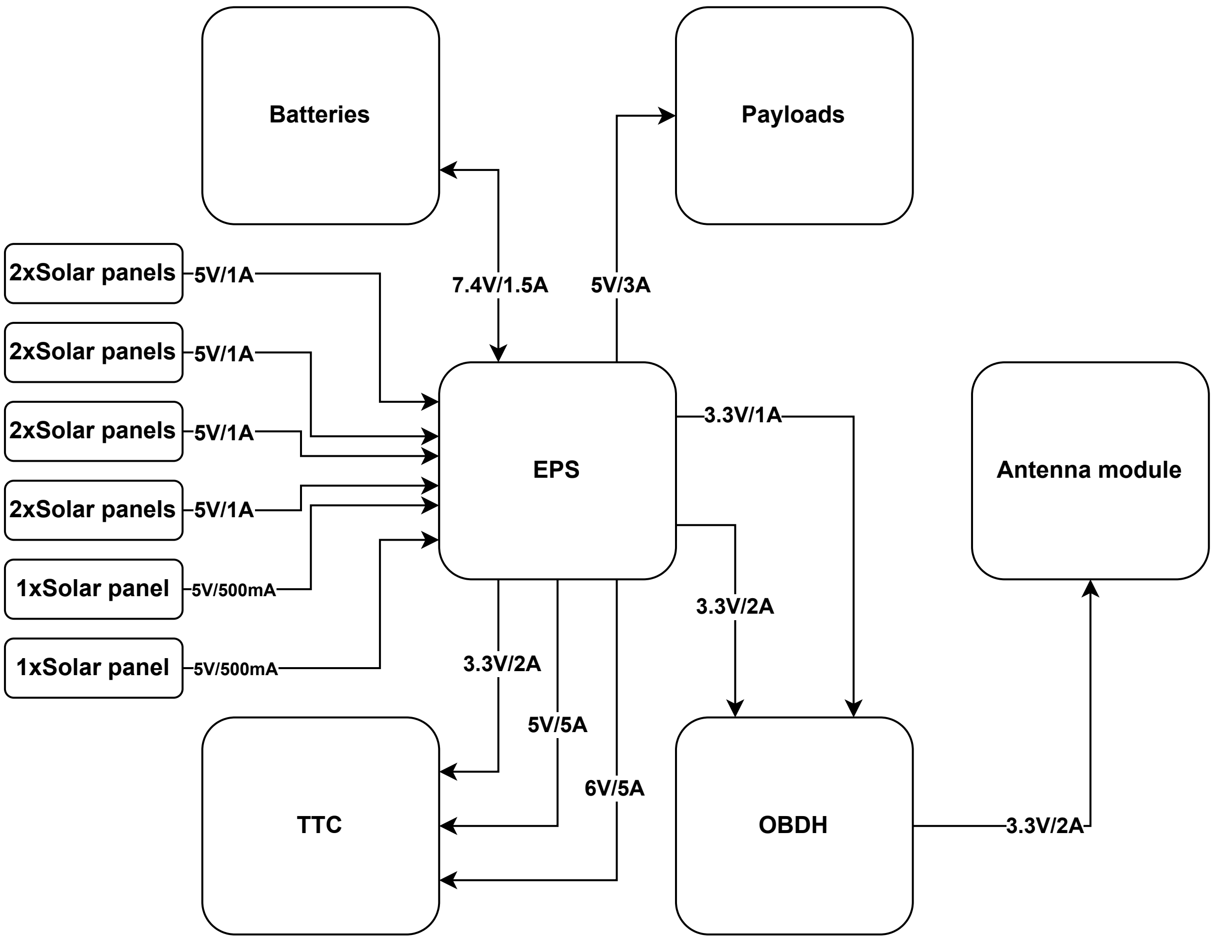


Figure 5.2: Power diagram.

5.1.2 Data Path Diagram

The data path diagram is shown in Figure 5.3.

5.1.3 Deployment Sequence

The deployment sequence of the satellite is the routine to be executed just after the launch. The main objective of this operation is to deploy the antennas and prepare the satellite to start its normal operation.

After the satellite is ejected from the deployer, the kill switches enable the electric power and the three core modules to execute the boot sequence (EPS, OBDH and TTC). The EPS module is ready to operate when the boot finishes. The OBDH and the TTC modules waits for a determined period before starting the normal execution.

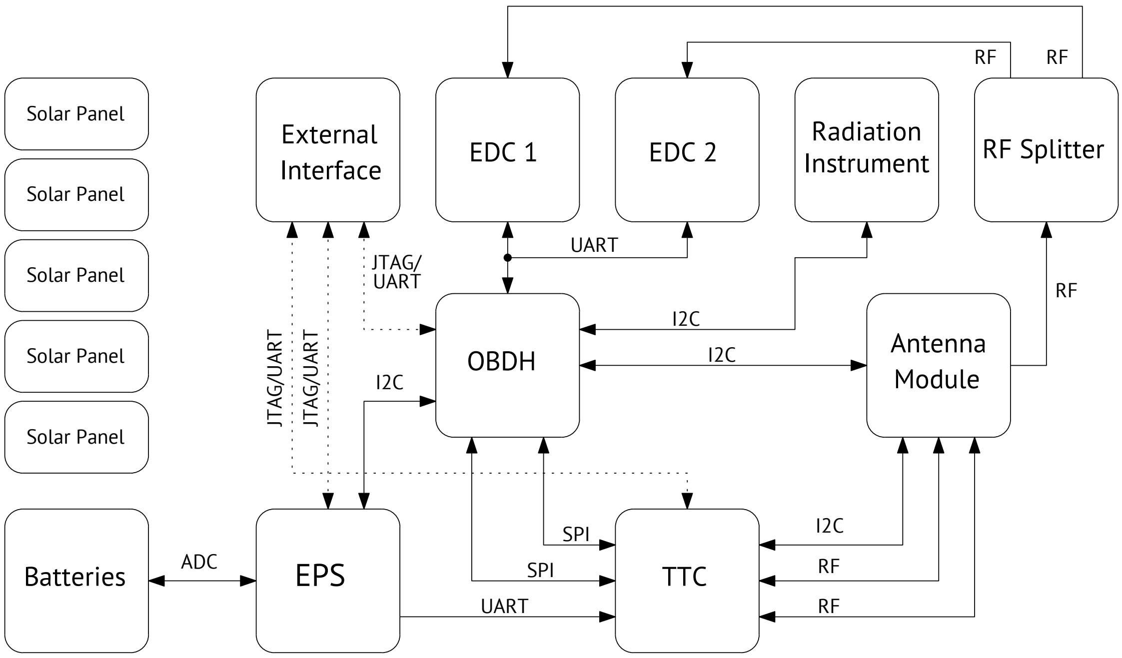


Figure 5.3: Data path diagram.

As the OBDH and the TTC have access to the antenna module, both subsystems can control the deployment of the antennas. Following the CDS specifications [1], all CubeSats must wait 30 minutes to deploy the antennas and 45 minutes to transmit any RF signal. This way, the OBDH waits 45 minutes to send the deployment command to the antenna module. As redundancy, the TTC waits 55 minutes to execute the same operation.

The Figure 5.4 has a flowchart that illustrates the deployment sequence of the service modules.

5.1.4 Beacon Operation

After the beacon microcontroller's boot sequence, the beacon's operation starts. The normal operation consists of reading the data from the EPS and the TTC modules, transmitting the valid data (EPS or TTC package, in this order of priority), waiting 60 seconds, and repeating this sequence. The Figure 5.5 has a flowchart of this behavior.

5.1.5 OBDH Operation

After the boot sequence of the OBDH microcontroller, the operation of the OBDH starts. The regular operation consists of reading the housekeeping data from the EPS, TTC, payloads, antenna module, and the OBDH (its own housekeeping data), saving the read data on the non-volatile memory, and transmitting the housekeeping data of the satellite as a beacon. After that, it waits 60 seconds and checks if a new telecommand was received; if true, it processes the telecommand; if not, it does nothing. After this sequence, these steps start again. The Figure 5.6 has a flowchart of this behavior.

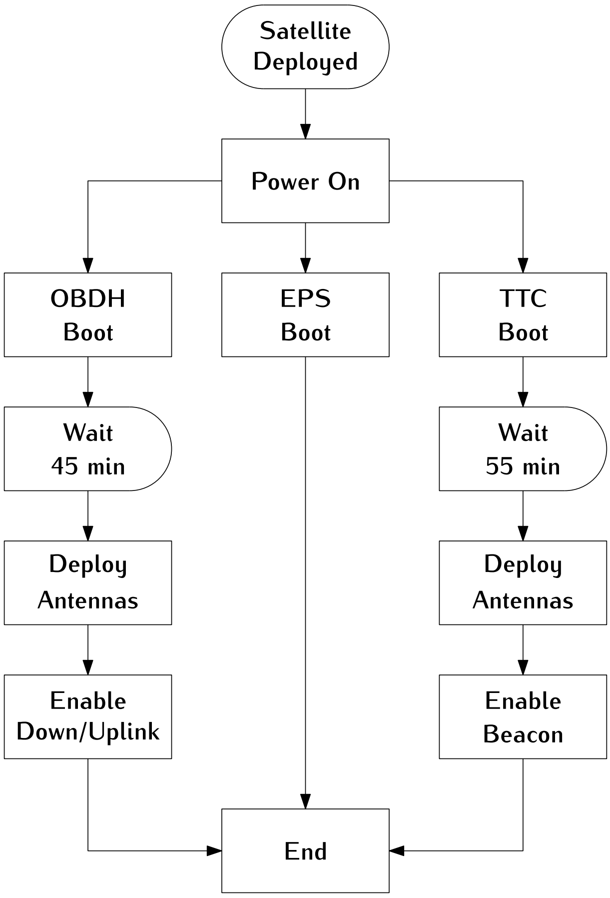


Figure 5.4: Flowchart of the deployment sequence.

5.1.5.1 Telecommand Processing

Figure Figure 5.7 shows the telecommand processing flow.

5.1.6 EPS Operation

The operation of the EPS microcontroller starts shortly after the release of the CubeSat in its orbit by the deployer. In the first 60 minutes, the module operation consists of reading the housekeeping data from its sensors and managing the duty cycles of the MPPT and heaters. When operational, the TTC and OBDH modules send separate periodic requests to the EPS for forwarding, the housekeeping data acquired. The TTC receives a simplified version, while the OBDH receives a complete version of the data. The Figure 5.8 has a flowchart of this behavior.

5.2 Interface Data Sheet (IDS)

5.2.1 Interface

To electrically connect all the satellite modules, a PC-104 bus standard is being used. This bus is composed by 104 lines disposed by four rows of 26 pins each (with a vertical and horizontal pitch of 2,54 mm).

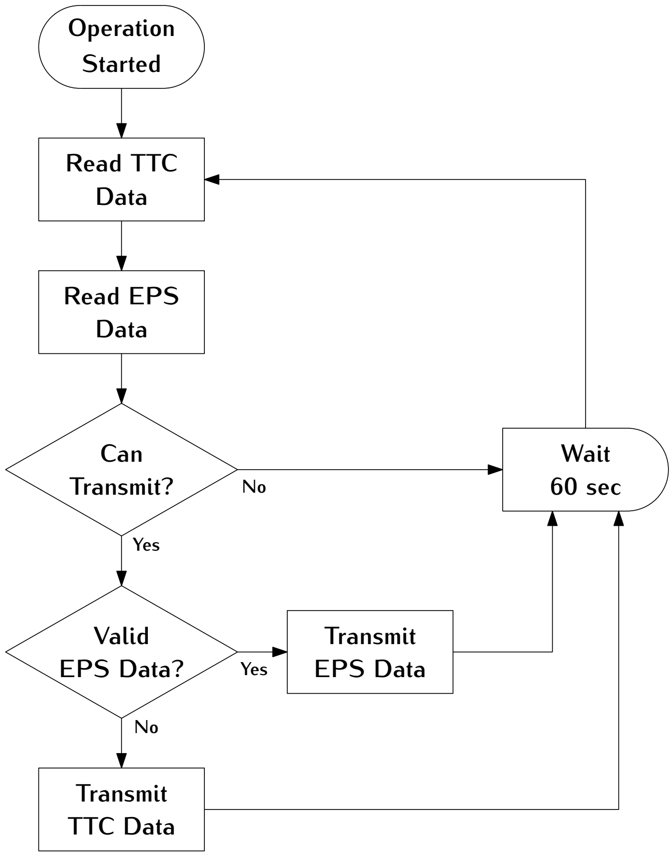


Figure 5.5: Flowchart of the normal beacon operation.

Using the Figure 5.9 as reference, all used positions and signals of the PC-104 bus are presented in Table 5.1. The Table 5.2 describes each signal and which modules are connected to them.

This project's distribution pattern of pins is a mix of multiple patterns from CubeSat module manufacturers, like GomSpace, ISIS, and Endurosat. Some pins are positioned to meet specific project requirements, and the adopted pattern may only be partially compatible with some commercial modules.

Beyond the PC-104 bus, some signals are connected directly by wires and cables, like the control and power pins of the antenna module, the battery charger, and the programming ports.

5.2.2 Form Factor

The form factor follows a similar specification of the PC-104 standard[10]. The connector used for the interface differs given the module; the isolation height and presence of a pin or receptacle are defined from the overall stack up of the subsystems inside the CubeSat 2U structure. The core modules have smoothed edges, and some linear mounting hole distances are different from the standard; these are according to fit in a CubeSat form factor. The PC-104 form factor used can be seen in Figure 5.10.

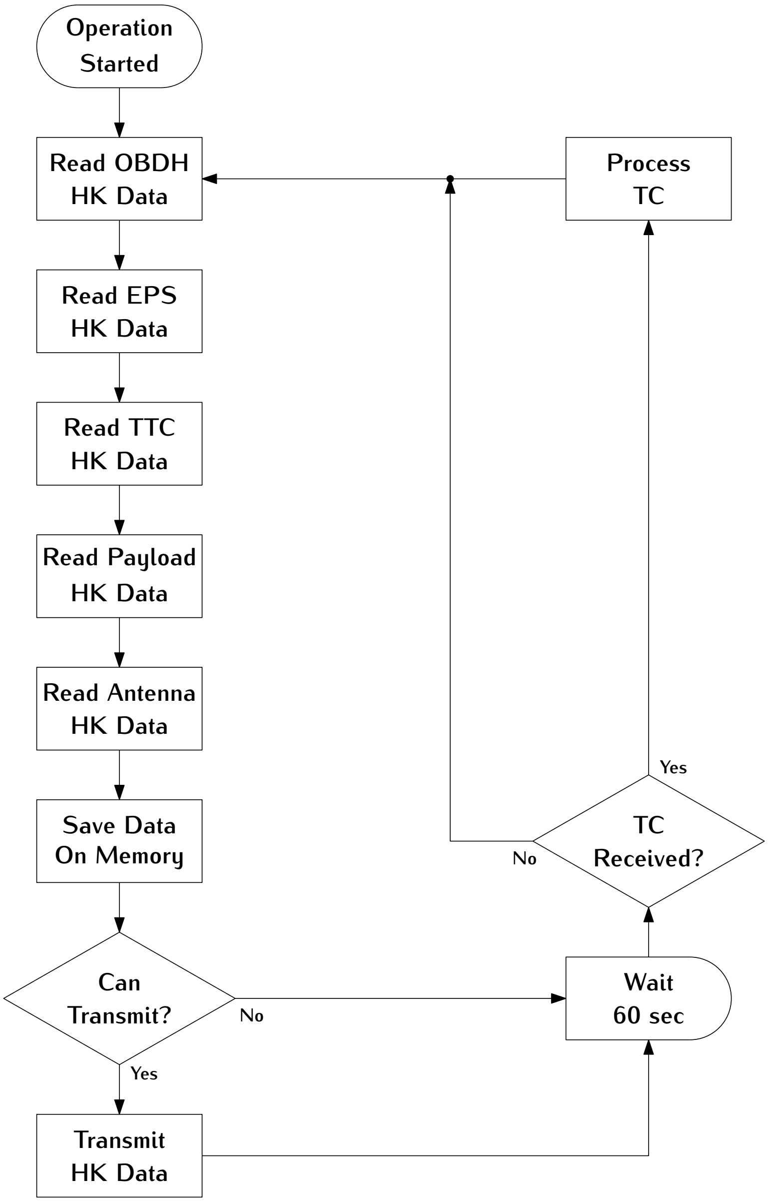


Figure 5.6: Flowchart of the normal OBDH operation.

5.3 Telecommunication

This section describes the configuration and behavior of the telecommunication subsystems of the satellite. There are three types of links available in the CubeSat: beacon, downlink, and uplink. The beacon link is a periodic transmission of packets with basic telemetry data of the satellite (containing data from the EPS or TTC subsystems). The downlink is the link used to receive all data from the satellite, including the results of all experiments, telemetry data, and telecommands feedback. Moreover, the uplink sends telecommands from a ground station to the satellite.

The payload of all packets follows the same structure, with an ID number, the source address (callsign), and the packet's content (variable according to each type of packet). Following the NGHam protocol characteristics, the maximum packet length, including the ID and the source address, is 220 bytes. The Figure 5.11 illustrates this packet structure.

Pin Row	H1 Odd	H1 Even	H2 Odd	H2 Even
1-2	-	-	-	-
3-4	-	-	EDC_1_EN	EDC_2_EN
5-6	-	-	BE_UART_RX	-
7-8	RA_GPIO_0	RA_GPIO_1	BE_UART_TX	GPIO_0
9-10	RA_GPIO_2	BE_EN	-	-
11-12	RA_RESET	RA_EN	BE_SPI_MOSI	BE_SPI_CLK
13-14	-	-	BE_SPI_CS	BE_SPI_MISO
15-16	-	-	-	-
17-18	EDC_UART_RX/TX	PLX_EN	-	GPIO_1
19-20	EDC_UART_TX/RX	GPIO_2	-	GPIO_3
21-22	-	-	-	GPIO_4
23-24	-	-	-	-
25-26	-	-	PL_VCC	PL_VCC
27-28	-	-	TTC_VCC	TTC_VCC
29-30	GND	GND	GND	GND
31-32	GND	GND	GND	GND
33-34	-	-	-	-
35-36	RA_SPI_CLK	-	ANT_VCC	ANT_VCC
37-38	RA_SPI_MISO	-	-	-
39-40	RA_SPI_MOSI	RA_SPI_CS	-	-
41-42	PL_I2C_SDA	-	-	GPIO_5
43-44	PL_I2C_SCL	-	-	-
45-46	OBDH_VCC	OBDH_VCC	BAT_VCC	BAT_VCC
47-48	PL_VCC	PL_VCC	-	-
49-50	RA_VCC	RA_VCC	EPS_I2C_SDA	-
51-52	BE_VCC	BE_VCC	EPS_I2C_SCL	-

Table 5.1: PC-104 bus pinout.

The Table 5.3 summarizes all types of packets transmitted or received by satellite, with the ID number, structure and length, and access type of each packet.

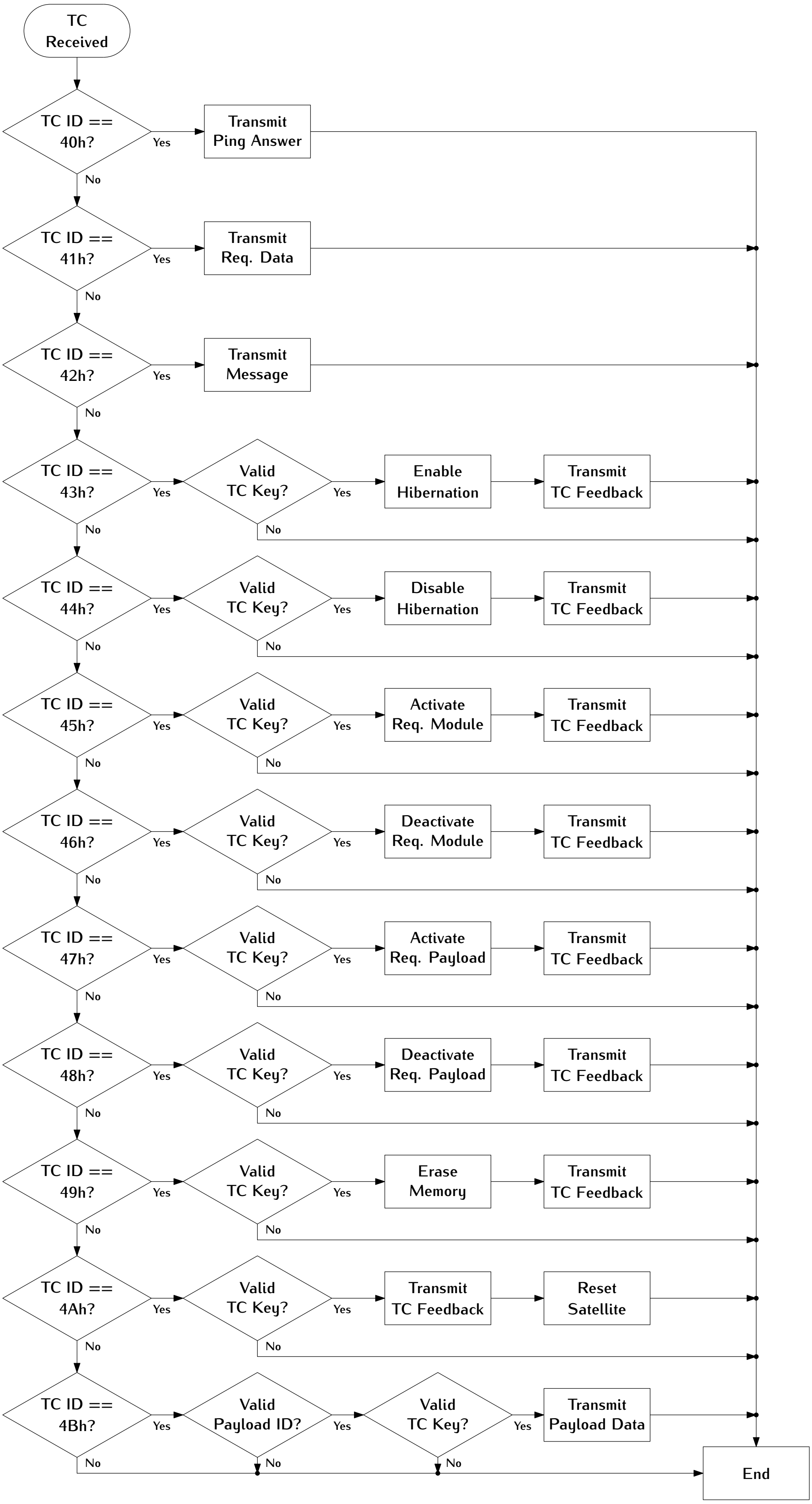


Figure 5.7: Flowchart of telecommand processing.

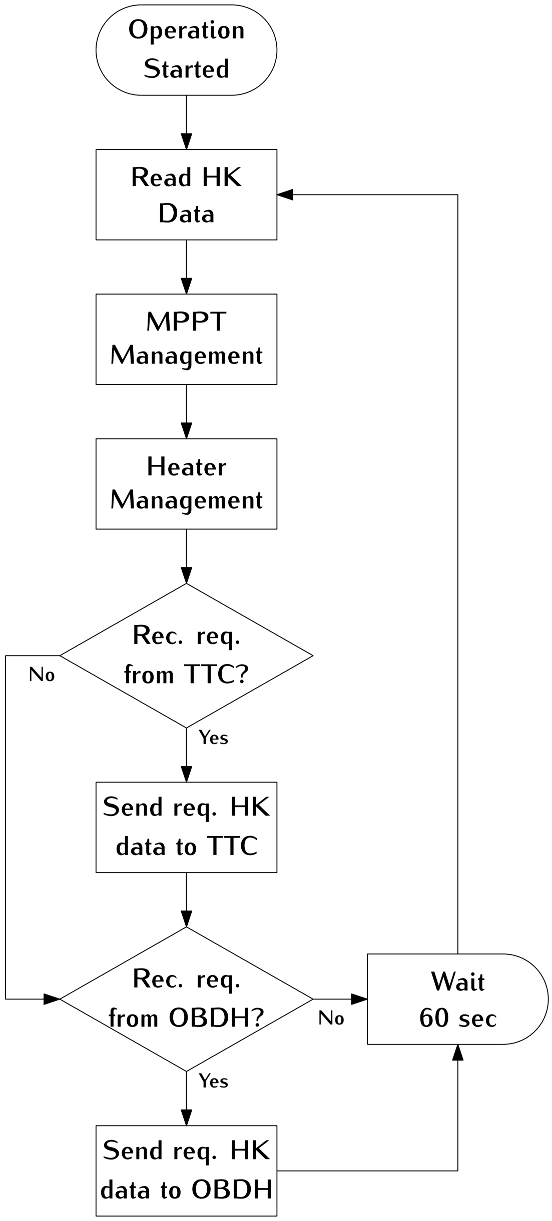


Figure 5.8: Flowchart of the normal EPS operation.

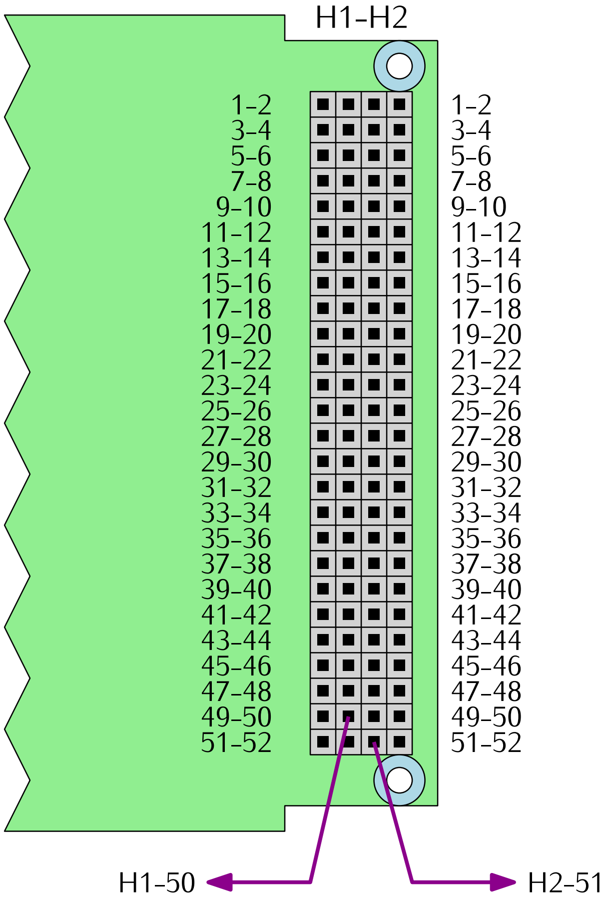


Figure 5.9: Reference diagram of the PC-104 bus (top view of a generic module).

Signal	Pin(s)	Used By	Description
GND	H1-29/30/31/32, H2-29/30/31/32	All	Ground reference
BAT_VCC	H2-45, H2-46	EPS	Battery terminals (+)
ANT_VCC	H2-35, H2-36	EPS, ANT	Antenna power supply (3.3 V)
OBDH_VCC	H1-45, H1-46	EPS, OBDH	OBDH power supply (3.3 V)
TTC_VCC	H2-27, H2-28	EPS, TTC	TTC power supply (3.3 V)
PL_VCC	H1-47/48, H2-25/26	EPS, EDC 1/2, Radiation instrument	Payloads power supply (5 V)
RA_VCC	H1-49, H1-50	EPS, TTC	Main radio power supply (5 V)
BE_VCC	H1-51, H1-52	EPS, TTC	Beacon power supply (6 V)
RA_SPI_CLK	H1-35	OBDH, TTC	CLK signal of the main radio SPI bus
RA_SPI_MISO	H1-37	OBDH, TTC	MISO signal of the main radio SPI bus
RA_SPI_MOSI	H1-39	OBDH, TTC	MOS signal of the main radio SPI bus
RA_SPI_CS	H1-40	OBDH, TTC	CS signal of the main radio SPI bus
EPS_I2C_SDA	H2-49	OBDH, EPS	SDA signal of the EPS I2C bus
EPS_I2C_SCL	H2-51	OBDH, EPS	SCL signal of the EPS I2C bus
BE_UART_RX	H2-5	EPS, TTC	EPS TX, Beacon RX (UART bus)
BE_UART_TX	H2-7	EPS, TTC	EPS RX, Beacon TX (UART bus)
EDC_UART_TX/RX	H1-25	OBDH, EDC 1/2	OBDH TX, EDCs RX (UART bus)
EDC_UART_RX/TX	H1-27	OBDH, EDC 1/2	OBDH RX, EDCs TX (UART bus)
BE_EN	H1-10	EPS, TTC	Beacon radio power enable
RA_EN	H1-12	EPS, OBDH	Main radio power enable
EDC_1_EN	H2-3	OBDH, EDC 1	EDC 1 enable signal
EDC_2_EN	H2-4	OBDH, EDC 2	EDC 2 enable signal
PLX_EN	H1-18	OBDH, Radiation instrument	Radiation instrument enable (GPIO)
PL_I2C_SDA	H1-41	OBDH, Radiation instrument	SDA signal of the payload I2C bus
PL_I2C_SCL	H1-43	OBDH, Radiation instrument	SCL signal of the payload I2C bus
GPIO_N	H1-20, H2-8/18/20/22/42	OBDH	GPIO pin (not used)

Table 5.2: PC-104 bus signal description.

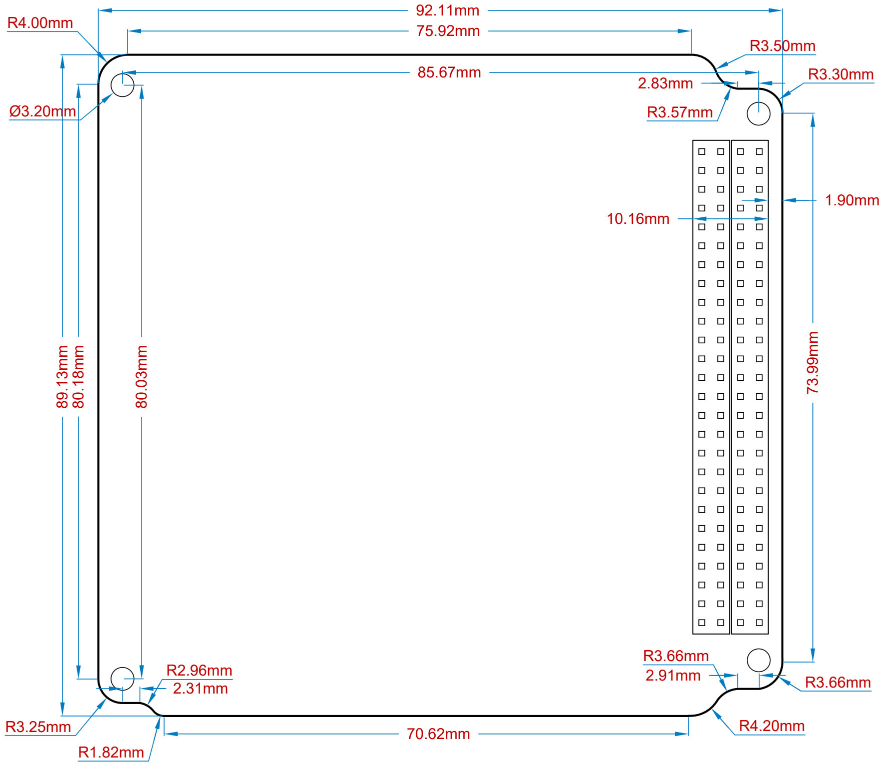


Figure 5.10: PC-104 Form Factor.

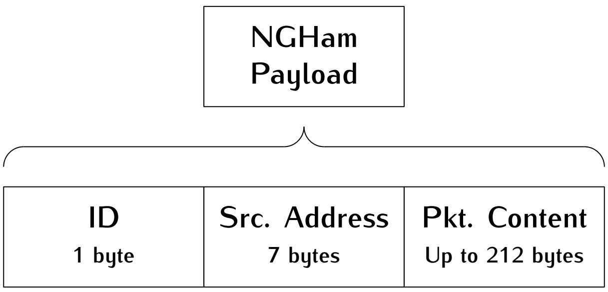


Figure 5.11: Payload structure of the GOLDS-UFSC packets.

Link	Packet Name	Payload				Access
		ID	Source Callsign	Data (up to 220 bytes)	Size (bytes)	
Beacon	EPS data	00h	“ ” + “PY0EFS”	EPS data	46	Public
	TTC Data	01h		TTC data	19	Public
Downlink	General telemetry	20h	“ ” + “PY0EFS”	OBDH/EPS data	78	Public
	Ping answer	21h		Requester callsign	15	Public
	Data request answer	22h		Requester callsign + data ID + ts. + data	20 to 220	Public
	Message broadcast	23h		Requester + dst. callsign + message	22 to 60	Public
	Payload data	24h		Payload ID + payload data	9 to 220	Public
	TC feedback	25h		Req. callsign + TC packet ID + timestamp	20	Public
	Parameter value	26h		Req. callsign + Sub. ID + Param. ID + Param. Val.	21	Public
Uplink	Ping request	40h	Any Callsign	None	8	Public
	Data request	41h		Data ID + Start ts. + End ts. + Hash	37	Private
	Broadcast Message	42h		Dst. callsign + message	15 to 53	Public
	Enter hibernation	43h		Hibernation in hours + Hash	30	Private
	Leave hibernation	44h		Hash	28	Private
	Activate module	45h		Module ID + Hash	29	Private
	Deactivate module	46h		Module ID + Hash	29	Private
	Activate payload	47h		Payload ID + Hash	29	Private
	Deactivate payload	48h		Payload ID + Hash	29	Private
	Erase memory	49h		Hash	28	Private
	Force reset	4Ah		Hash	28	Private
	Get payload data	4Bh		Payload ID + Args. + Hash	41	Private
	Set parameter	4Ch		Subsystem ID + Param. ID + Param. value + Hash	34	Private
	Get parameter	4Dh		Subsystem ID + Parameter ID + Hash	30	Private

Table 5.3: Telecommunication packets and their content.

The ID of the subsystems, modules, and payloads are available in Table 5.4.

Type	ID Number	Description
Subsystem	0	OBDH
	1	TTC 1
	2	TTC 2
	3	EPS
Module	1	Battery heater
	2	Beacon
	3	Periodic telemetry
Payload	1	EDC 1
	2	EDC 2
	3	Radiation instrument

Table 5.4: IDs of the satellite.

5.3.1 Authentication

All the telecommands classified as private use an HMAC authentication scheme. Every type of private telecommand has a unique 16-digit ASCII character key that with the telecommand sequence (or message) generates an 160-bits (20-bytes) hash sequence to be transmitted together with the packet payload. The used hash algorithm is the SHA-1. The Figure 5.12 illustrates this authentication method.

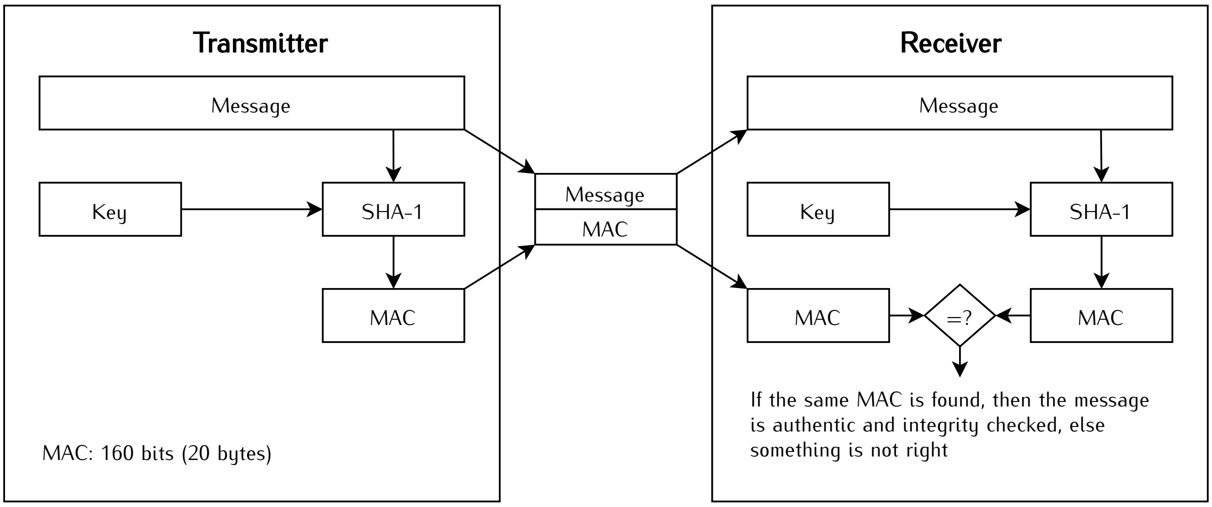


Figure 5.12: Diagram of the used HMAC scheme.

5.3.2 Operation Licenses

Regarding the non-amateur radios frequencies, Resolution 685, of October 9, 2017 from ANATEL establishes that:

Art. 9. Assign to the Private Limited Service (SLP), for use by systems for capturing and transmitting scientific data related to space operation, on a secondary basis, the following sub-ranges (related to this project):

- 400.15 MHz to 401 MHz;
- 449.75 MHz to 450.25 MHz.

Art. 17. The allocation of all radio frequency bands dealt with in this Resolution follows the restrictions imposed by the respective allocation.

Single paragraph. Those interested in the use of the radio frequency bands object of this Resolution must provide in their projects, until specific regulations are issued on the conditions of use of these bands, criteria for harmonious coexistence with the existing systems in these bands, maintaining specific coordination, when necessary, of such so that incoming systems do not cause harmful interference to existing systems.

Thus, a process must be carried out for radio 1 (146 MHz) in the amateur radio band, and another process for the radios with 401 MHz and 450 MHz. Since the last two radios must be a secondary service SLP where a preliminary study is necessary on the harmonic coexistence with the existing systems in these bands.

CHAPTER 6

Subsystems

This chapter describes all subsystems of the space segment of the mission. Most subsystems presented here have their own technical documentation with a more profound description. When available, there is a reference to the respective document. This chapter is intended to show an overview of each subsystem in a macro context of the mission.

6.1 On-Board Data Handling

The OBDH 2.0 is an On-Board Computer (OBC) module designed for nanosatellites. The module is responsible for synchronizing actions and the data flow between other modules (i.e., power module, communication module, payloads) and the Earth segment. It packs the generated data into data frames and transmits back to Earth through a communication module or stores it on non-volatile memory for later retrieval. Commands sent from Earth segment to the CubeSat are received by radio transceivers in the communication module and redirected to the OBDH, which takes the appropriate action or forward the commands to the target module.

The module is a direct upgrade from the OBDH of FloripaSat-1 [2], which grants a flight heritage rating. The improvements focus on providing a cleaner and more generic implementation than the previous version, more reliability in software and hardware implementations, and adaptations for the new mission requirements. The module board can be seen in Figure 6.1.

More information about this module can be found in [11].

6.2 Telemetry, Tracking and Command Module

The TTC (or TT&C) is responsible for making the communication between the Earth (a ground station) and the satellite and is divided into two sub-modules: Beacon and downlink/uplink. The beacon is an independent sub-module that transmits a periodic signal containing satellite identification data (ID) and some basic telemetry data. The downlink/uplink sub-module is the primary communication device. It has a bidirectional data link to receive telecommands from the Earth and transmit all available data back to Earth. The module board can be seen in Figure 6.2.

More information about this module can be found in [12].

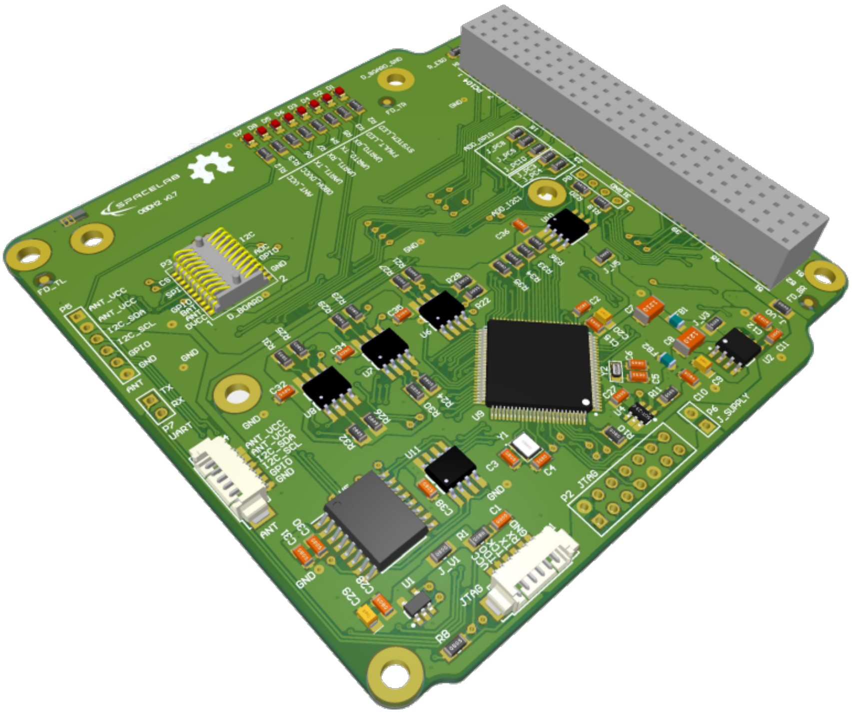


Figure 6.1: OBDH module.

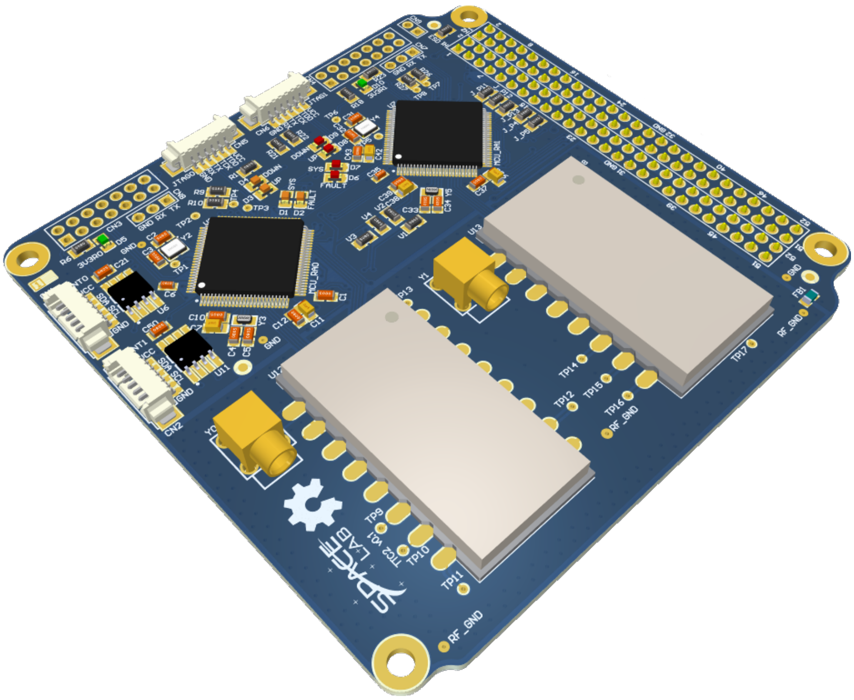


Figure 6.2: TTC module.

6.2.1 Antenna Module

The used antenna module is the CubeSat deployable VHF and UHF antenna from ISISpace [13]. It is a four monopole antenna built with tape strings (up to 55 cm) and compliant with the CubeSat standard (dipole or turnstile options are also available). The deployment method is the burning wire, which can be controlled digitally through a I^{2}C interface. To allow redundancy, two independent deployment controllers can be activated separately. Also, the construction of this module allows the installation of a solar panel at the top side. The RF gain is about 0 dBi.

A picture of the antenna module (with all antennas released) can be seen in Figure 6.3.

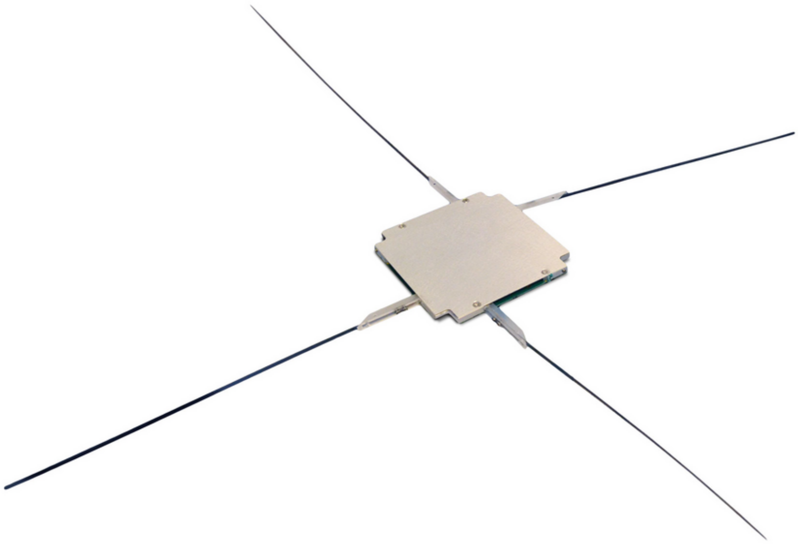


Figure 6.3: Antenna module from ISISpace.

The chosen configuration for this mission can be seen below (using Figure 6.4 as reference):

- Configuration: 2 monopoles (UHF) + 1 dipole (VHF)
  - Antenna 1: UHF - 450 MHz (downlink/uplink)
  - Antenna 2: UHF - 401.635 MHz (both EDCs)
  - Antenna 3 and 4: VHF - 145.97 MHz (beacon)
- Tuning structure size: 2U
- Mounting position: Top
- Supply voltage: 3.3 V
- I^{2}C control type: Dual bus
  - Primary I^{2}C address: 31h (7-bit address)
  - Redundant I^{2}C address: 32h (7-bit address)
- I^{2}C watchdog: Enabled with a time out of 60 seconds.

A temperature sensor and the state of four deployment switches (1 per monopole) are also available in the digital interface. These switches indicate if a monopole is released or not, and can be used as feedback of the deployment process.

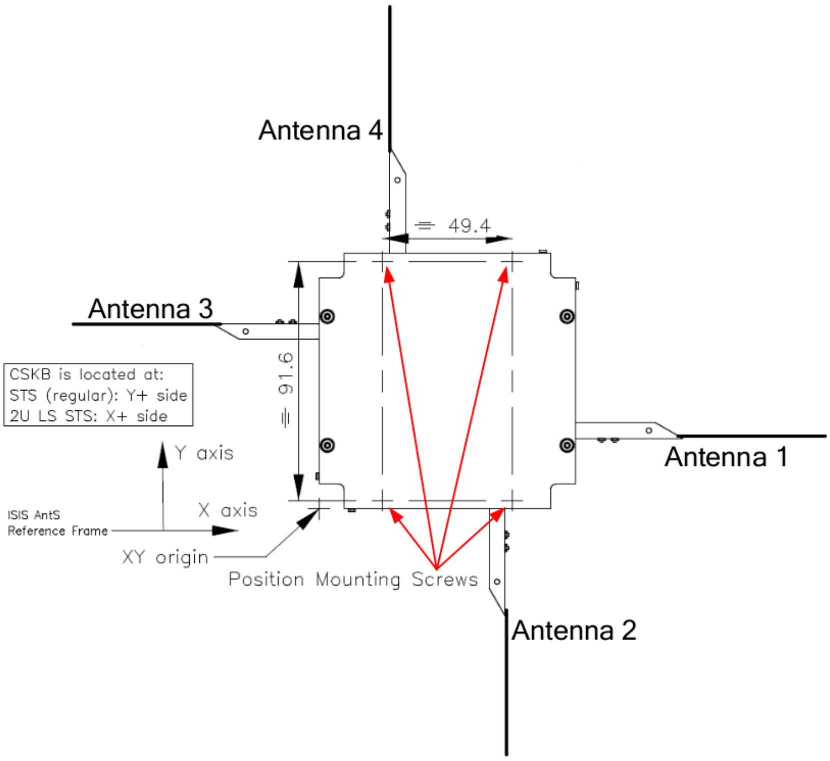


Figure 6.4: Configuration reference of the antenna module.

6.2.1.1 RF Splitter

As the satellite has two EDCs (in a cold redundancy scheme) and just one dedicated antenna (antenna 2, UHF monopole), a RF splitter is also being used. This way, the received signal from a single monopole can be processed by both EDCs. The used model is the Z99SC-62-S+ from Mini-Circuits [14]. A picture of this device is available in Figure 6.5.

Figure 6.5: Mini-Circuits Z99SC-62-S+ RF splitter.

To mechanically install the Z99SC-62-S+ device in the satellite, a board in the PC-

104 form factor is being used, as can be seen in Figure 6.6. More information about the RF splitter module is available in [15].

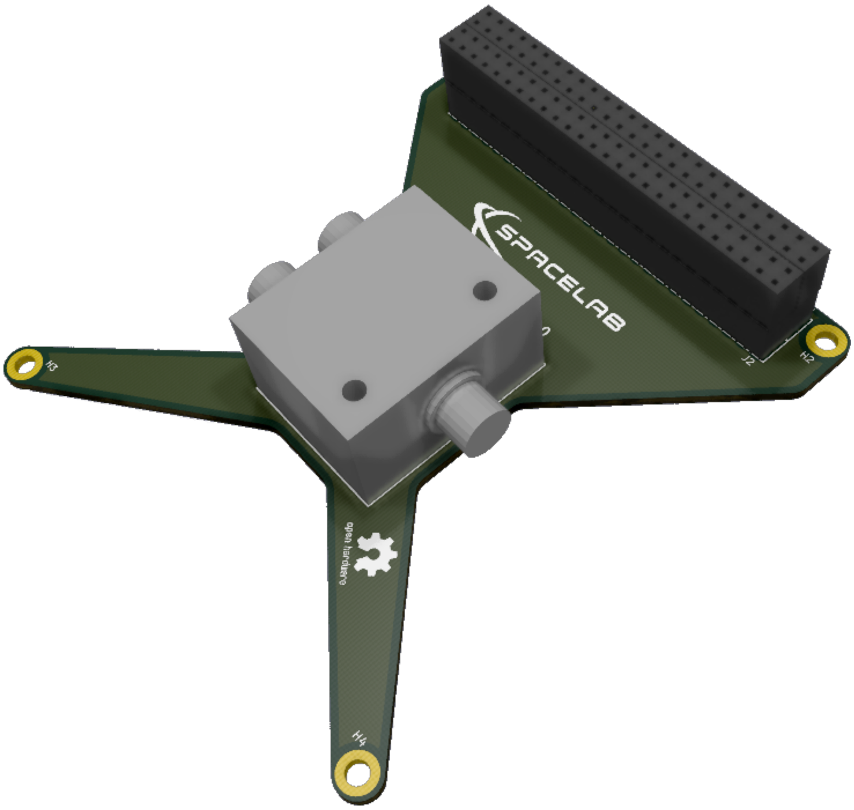


Figure 6.6: RF splitter module.

6.3 Electrical Power System

The EPS is the module designed to harvest, store and distribute energy for the satellite. The energy harvesting system is based on solar energy conversion through the solar panels attached to the CubeSat structure. The EPS is designed to operate the solar panels at their maximum power point (MPPT). The board also measures the solar panels current, voltage and temperature of the batteries. The harvested solar energy is stored in a battery module connected to the EPS. Several integrated buck DC-DC converters do the energy distribution. The full EPS system is composed of the solar panels, the EPS PCB and the battery module. A general view of the EPS board can be seen in Figure 6.7.

The module is a direct upgrade from the EPS of FloripaSat-1 [2], which grants a flight heritage rating. The improvements focus on providing a cleaner and more generic implementation compared to the previous version, more reliability in software, and adaptations for the new mission requirements.

More information about this module can be found in [9].

6.3.1 Battery Module

The used battery module is the "*Battery Module 4C*", which is a separate battery module from the EPS board and composed by four lithium-ion 18650 cells. Besides the cells,

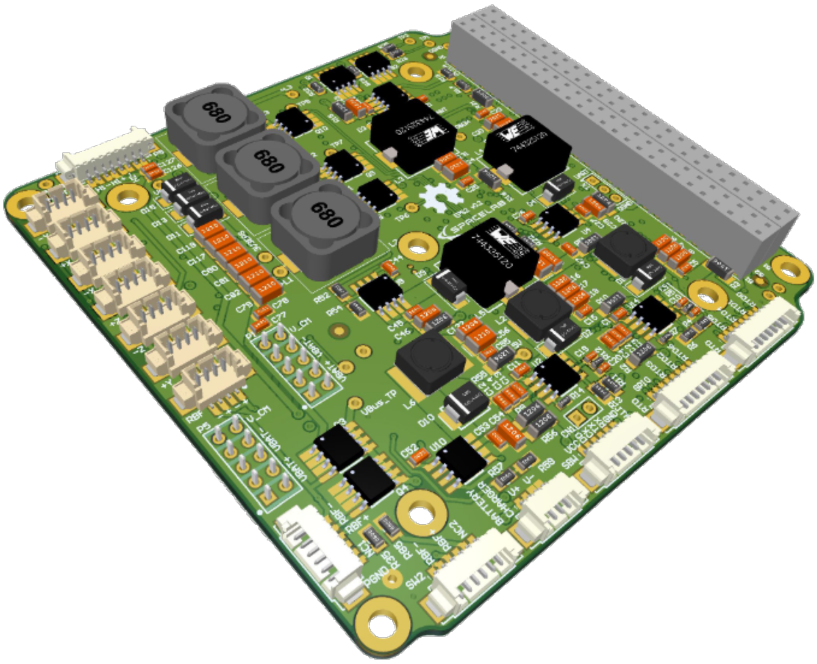


Figure 6.7: EPS module.

the board has connectors for interfacing signals and power lines with the EPS module, 2 power resistors to operate as heaters to maintain the cell's temperature during eclipse periods, and 4 temperature sensors. The batteries used are the ICR18650-30B lithium-ion cells from Samsung [16], which are connected in series and parallel (two sets of two parallel cells in series) to supply the required voltage and current. Each cell is fixed with 18650 metal holders, and between the pairs, the power resistor is attached with a thermal element in the middle. A mechanical mount is placed over the batteries and screwed to the board, providing better stress resistance. Also, PC-104 through-hole pads are present on the board for a connector that could be used for mechanical integration with the EPS, or, with future improvements, an interface for power, data or control signals. The board is a direct improvement from the first battery board used in the FloripaSat-1 mission [2].

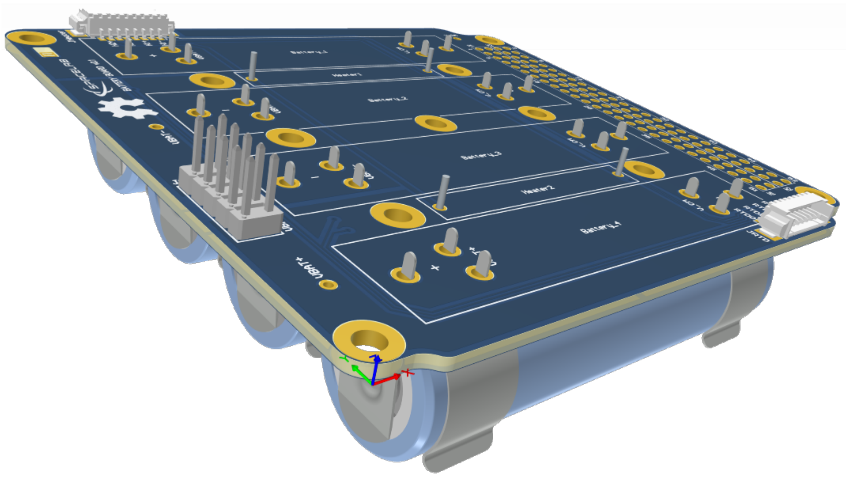


Figure 6.8: Battery module board.

More information about the battery module can be found in [17].

6.3.2 Solar Panels

The solar panels are a set of 5 custom-made panels manufactured by ORBITAL, a Brazilian company, and a single panel from ISISpace. The panels feature protection diodes and high-efficiency solar cells, which are the CESI's CTJ-30 [18] with dimensions 6.9 × 3.9 cm (area 26.5 cm^2). This cell is qualified for space use by ESA with an efficiency of 29.5 % (AM0, BOL). The panels do not include magnetometers, sensors, and other devices. The top solar panel is a model from ISISpace to ensure mechanical compatibility with the antenna module (also from ISISpace). These two types of solar panels can be seen in Figures 6.9 and 6.10.

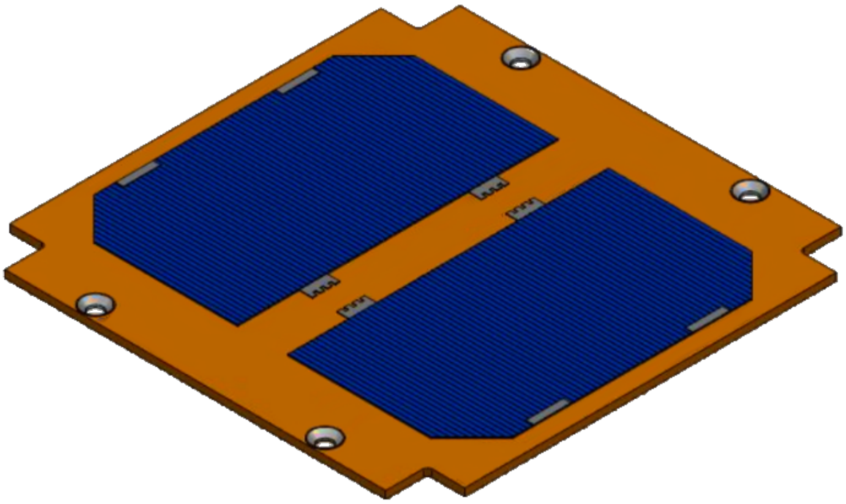


Figure 6.9: Conceptual solar panel from ORBITAL.

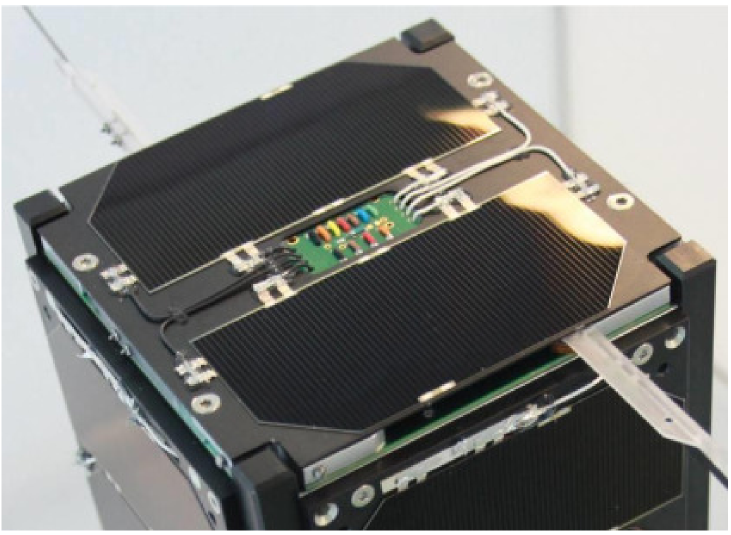


Figure 6.10: Top solar panel from ISISpace.

6.3.3 Kill-Switches and RBF

Two electronic switches have been implemented into the design to allow for the (redundant) deployment detection of the CubeSat when deployed from the POD. This electronic micro switch can be used to prevent the satellite from starting up during launch, as is required for all CubeSat launches and hence acts as a Kill-Switch. The Kill-Switch is the Panasonic AV4 microswitch (AV402461), as seen in Figure 6.11.

Figure 6.11: Panasonic AV402461 Microswitch.

The Kill-Switch mechanism in the mechanical structure has combined the function of providing deployment and detection (Figure 6.12). The travel of the actual switch of the Kill-Switch itself is so short that the Kill-Switch could "detect deployment" of the CubeSat from the launch adapter simply due to launch vibrations. To overcome this issue the Kill-Switch has been rotated so that there is a positive obstruction in front of the switch which needs 8 mm of deployment before deployment can be detected with the Kill-Switch. In Figure 6.12 the Kill-Switch parts are highlighted, and the stowed and deployed configuration is shown.

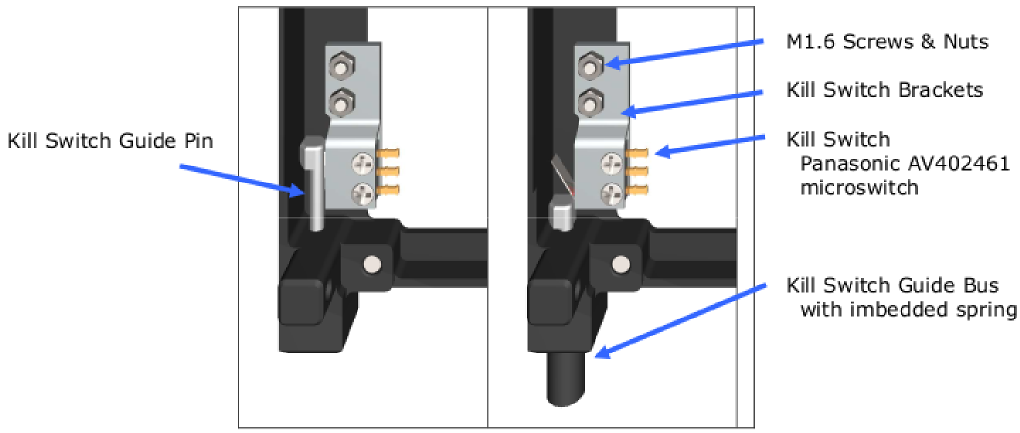


Figure 6.12: Kill-Switches installed in the mechanical structure.

The contact arrangement of the microswitch and the current rating are detailed in Figure 6.13 and Table 6.1.

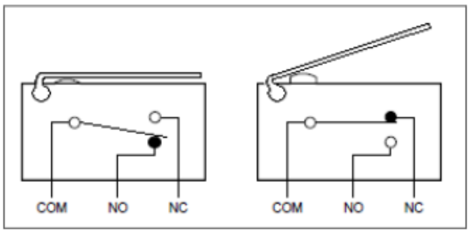


Figure 6.13: The contact arrangement of the microswitch.

Characteristic	Minimum	Typical	Maximum	Unit
Switch Current	2	50	100	mA
DC Voltage across switch contacts	n/a	n/a	30	V
Contact resistance microswitch	n/a	n/a	200	mΩ

Table 6.1: Kill-Switch current rating and voltage range.

6.4 Attitude Control System

The Attitude Control System (ACS) is a passive attitude control system, which depends on the Earth's magnetic field to rotate and stabilize the satellite [19, 20]. The system is composed of one permanent magnet to create a force to align the magnet with the Earth's magnetic field and four hysteresis bars to dampen the cube oscillations and achieve stabilization.

When equilibrium is achieved, the permanent magnet aligns with the Earth's field lines. The hysteresis bars convert oscillation and rotation energy into heat, maintaining the alignment through the magnetic moment. The components are placed in positions to minimize the magnet's interaction with the hysteresis bars, which limits the magnetic moment of the magnet [21]. Figure 6.14 shows the mounting of the hysteresis bars (green) and the permanent magnet (red) on the mechanical structure. The whole passive ACS was implemented according to [21].

As a passive magnetic attitude control system is used, it is possible to stabilize only one axis. So, the CubeSat will still slowly (due to hysteresis bars) rotate around this axis, even after stabilized. A N45 neodymium magnet and 4 hysteresis bars of Permanorm 5000 H2 are used (courtesy of Vacuumschmelze GmbH & Co. KG). The hysteresis bar's material is shaped to maximize stabilization, which is the most critical part of attitude control.

Many conditions impact the detumbling time, which is the time required for the satellite to stabilize. Magnetic passive attitude stabilization systems such as the one developed for this mission achieve the equilibrium state within a few weeks of operation [19].

The GOLDS-UFSC satellite does not feature an orbit control subsystem.

6.5 Thermal control

An active control gives the thermal control: two resistors (24 Ω) to protect the batteries against low temperatures and two RTDs to monitor the temperature. The control is an ON/OFF control.

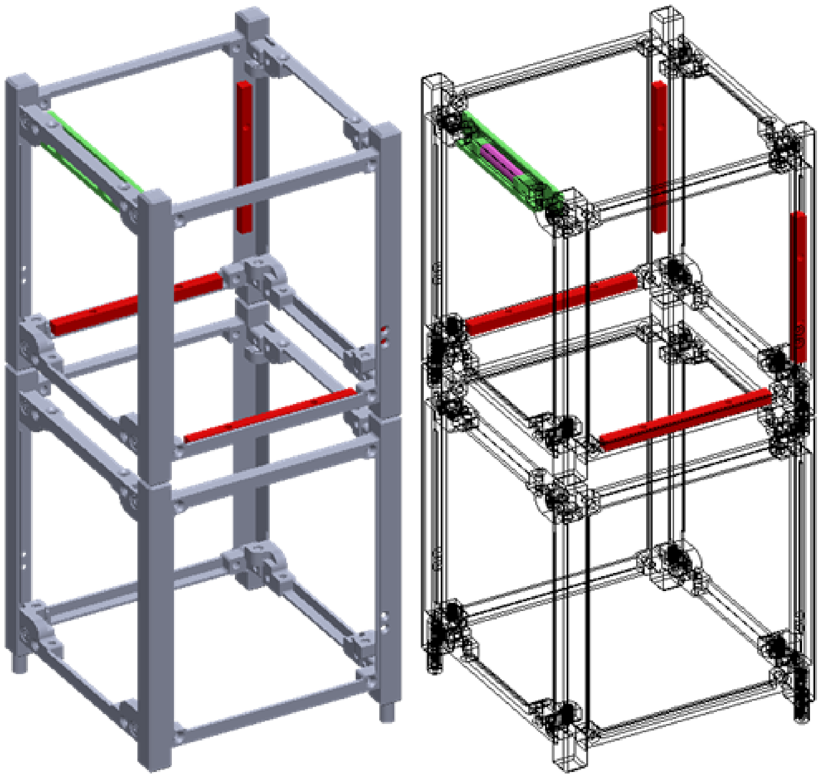


Figure 6.14: ACS subsytem. Rare earth magnet (pink) and hysteresis bars (red) installed in the structure.

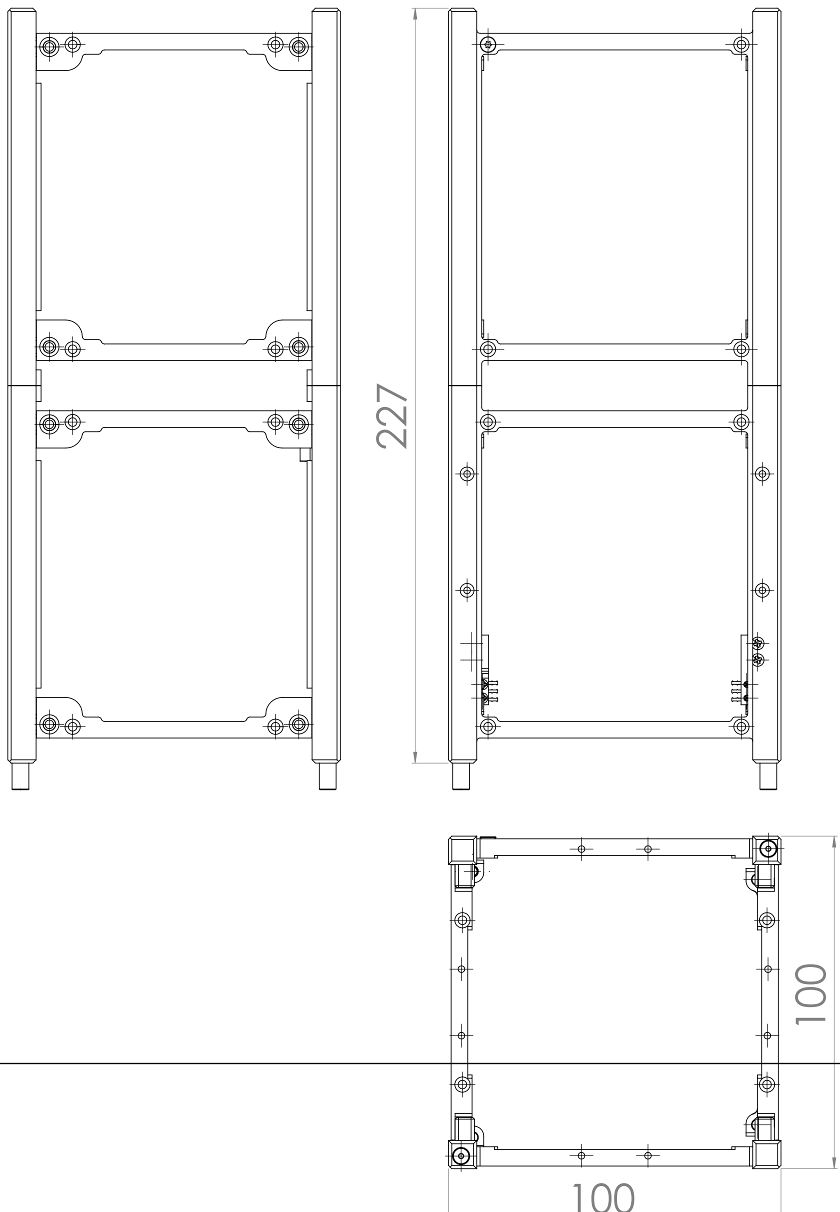
6.6 Mechanical Structure

The USIPED 2-Unit CubeSat structure is developed as a generic, modular satellite structure based on the CubeSat standard. The modular chassis allows up to two 1-Unit stack of PCBs, or other modules, to be mounted inside the chassis, using the PC-104 standard and spacers attached to the structure. In addition, there are 4 slots in the middle section, providing space for the interface boards and the ACS. The solar panels and antennas are externally mounted, providing a complete mechanical solution. A picture of this structure can be seen in Figure 6.15.

The structure will support the loads and vibration along the entire life cycle of the satellite, which includes every phase prior to the launch, the launch itself, and the operation of the CubeSat in space. In addition, the structure must keep all the parts of the CubeSat fastened at the proper position during the launch and operation, provide a conductive thermal path for heat transfer, and provide access for assembly, integration, and verification.

The material of all its parts is aluminum T6065, except for the bolts and thread. This material presents good mechanical properties for space application, such as weight, strength, fracture and fatigue resistance, thermal expansion, and ease of manufacturing. The surfaces of the CubeSat in contact with the deployer are anodized and grounded for proper and smooth ejection. The main views of the assembled structure is presented in Figure 6.16, as well as its main dimensions.

Figure 6.15: 2U CubeSat structure from Usiped.



6.7 Interconnection Modules

6.7.1 PC-104 Interconnection Boards

The PC-104 interconnection boards are intended to be used as an interconnection of the two PC-104 bus segments of the 2U structure (top and bottom units). This interconnection is made with a set of PicoBlade cables between the top and bottom boards. The set of two boards can be seen in Figure 6.17.

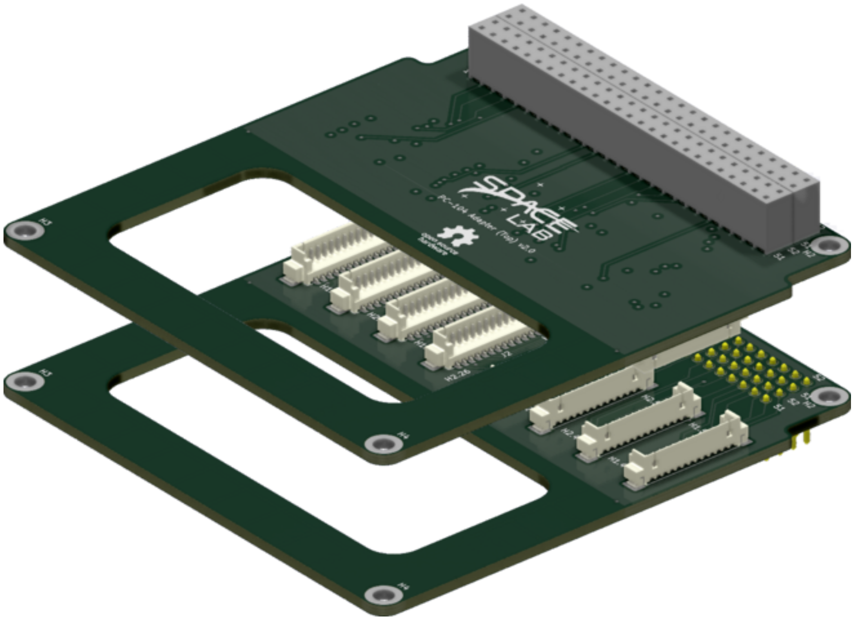


Figure 6.17: PC-104 adapter boards (top and bottom).

More information about these boards can be found in [22].

6.7.2 External Connection Boards

The Interstage Interface Panels (IIP) are three vertical internally mounted PCBs designed to give external access to up to four modules inside of a 2U CubeSat during final assembly, integration, and testing (AIT) before launch. The complete set of boards allows the nanosatellite to be charged, programmed, and debugged. The usage of this hardware platform takes into account the use of a MSP-FET: MSP430 Flash Emulation Tool from Texas Instruments for JTAG programming and debugging, UART debugging through a mini USB type B port interfacing the FT4232H USB bridge IC from FTDI, a JST XH header for charging internal batteries and a Remove Before Flight (RBF) pin header. The boards can be seen in Figure 6.18.

For this mission, the four JTAG connectors are being used as described in Table 6.2.

More information about these boards can be found in [23].

6.8 Payloads

The GOLDS-UFSC satellite is planned to carry the "*EDC*" as the primary and main payload. Moreover, in order to asses the radiation levels present in the satellite, an

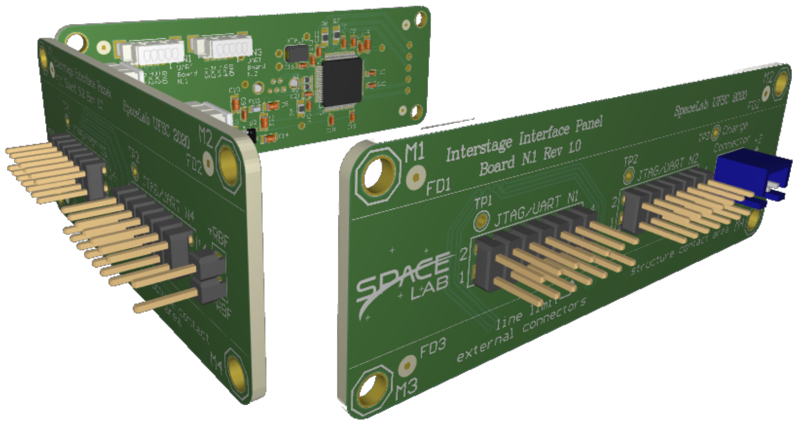


Figure 6.18: Set of external connection boards.

JTAG Connector	Connected Module
JTAG/UART N1	OBDH
JTAG/UART N2	EPS
JTAG/UART N3	TTC
JTAG/UART N4	None

Table 6.2: IIP JTAG connectors usage.

additional scientific experiment is planned in the form of a Radiation instrument. Each one of these payloads are presented next.

6.8.1 Environmental Data Collection

The Environmental Data Collector (EDC) is a CubeSat-compatible payload that decodes signals from Platform Transmitter Terminals (PTTs) belonging to the Brazilian Environmental Data Collection System (SBCD) and the Argos-2 System. It is the main payload of the GOLDS-UFSC mission.

The main features of this payload are listed below, a 3D model of the EDC board can be seen in Figure 6.19.

- Reception/decoding of SBCD and Argos-2 signals on the 401.635 MHz ± 30 kHz frequency range.
- Can decode up to 12 PTT signals simultaneously.
- Attaches a header to decoded messages with frequency, time, and signal strength information.
- Full speed I^2C interface (400 kbit/s) for the OBC communication.
- Full-duplex RS-485 interface with fail-safe for the OBC communication.
- 5 V power supply.
- Memory capable of storing up to 64 decoded user messages.

- Generates housekeeping information, including current supply, board temperature, digitized signal RMS level, front-end PLL synchronism state, and overcurrent events.
- Can capture a 2048 sample sequence (16 ms window) from the received signal upon request.

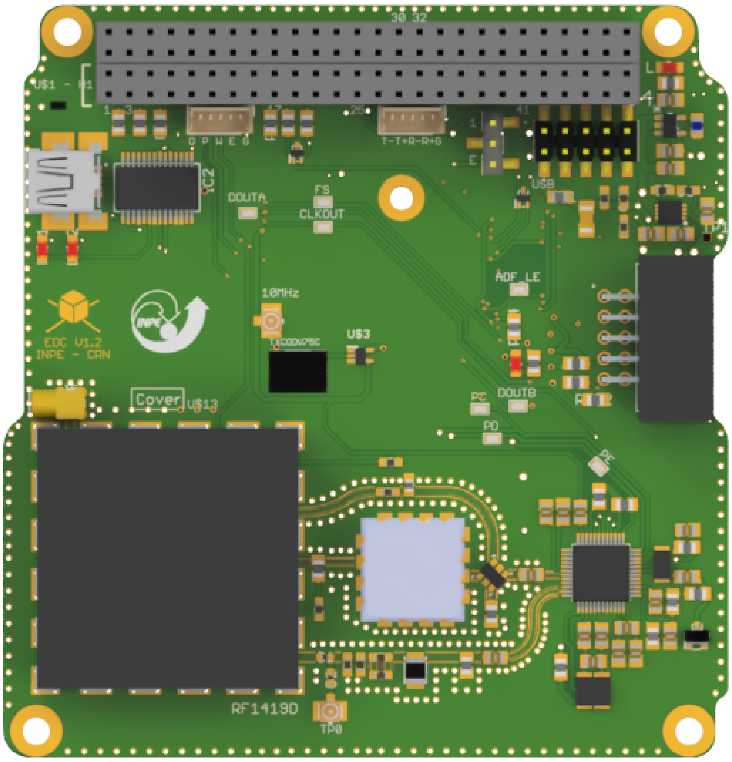


Figure 6.19: EDC board.

Two identical EDC boards will be used in a cold redundancy configuration for this mission. More information about this payload can be found in [4].

6.9 Radiation instrument

The Radiation instrument is a radiation-hardened reconfigurable hardware platform designed for a radioactive environment, having as the main feature the possibility to change the hardware configuration of the FPGA through remote uplink of its bitstream.

More information about this payload can be found in [24].

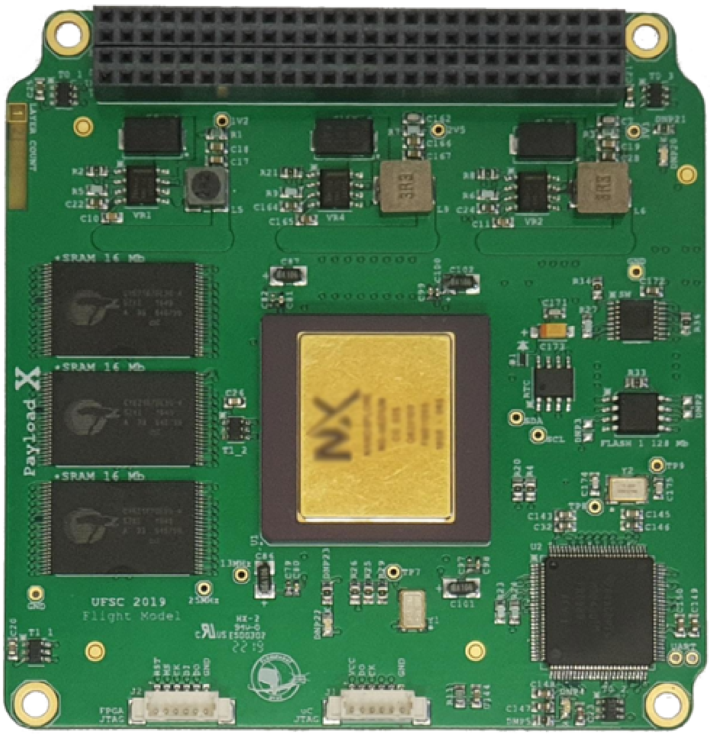


Figure 6.20: Radiation instrument board.

CHAPTER 7

Ground Segment

This chapter describes the ground segment of the mission. It is composed of two ground stations (one at the INPE-RN installations and the other at the SpaceLab installations) and many data collection platforms (PCD, or *"Plataforma de Coleta de Dados"*), installed at a variety of locations on the Brazilian territory.

The control of the mission and the reception of the collected data will be performed mainly at these two ground stations, but if necessary, other stations can execute this task. Any station in the world can use the amateur radio link since having the required equipment to it.

7.1 UFSC Ground Station

The UFSC ground station is currently being developed and prepared for this mission. This section presents the project of this station. A general block diagram can be seen in Figure 7.1.

In the following sections, a description of the main components of the station will be presented.

7.1.1 Hardware

This part describes the hardware side of the UFSC ground station and details the main peripherals that will be used in this project. Most of the components described here are represented in Figure 7.1.

7.1.1.1 Antennas

There are two antennas in the ground station: One for VHF and one for the UHF band. The main characteristics of these antennas can be seen in Table 7.1

More information about the VHF and UHF antennas can be found in [25] and [26] respectively.

7.1.1.1.1 Surge Protector

Two surge protectors will be used to protect the ground station electronics of possible atmospheric discharges in the outside components (one for each antenna). The gas surge protectors safely discharge/deflect up to 5000 A of peak current to earth without causing

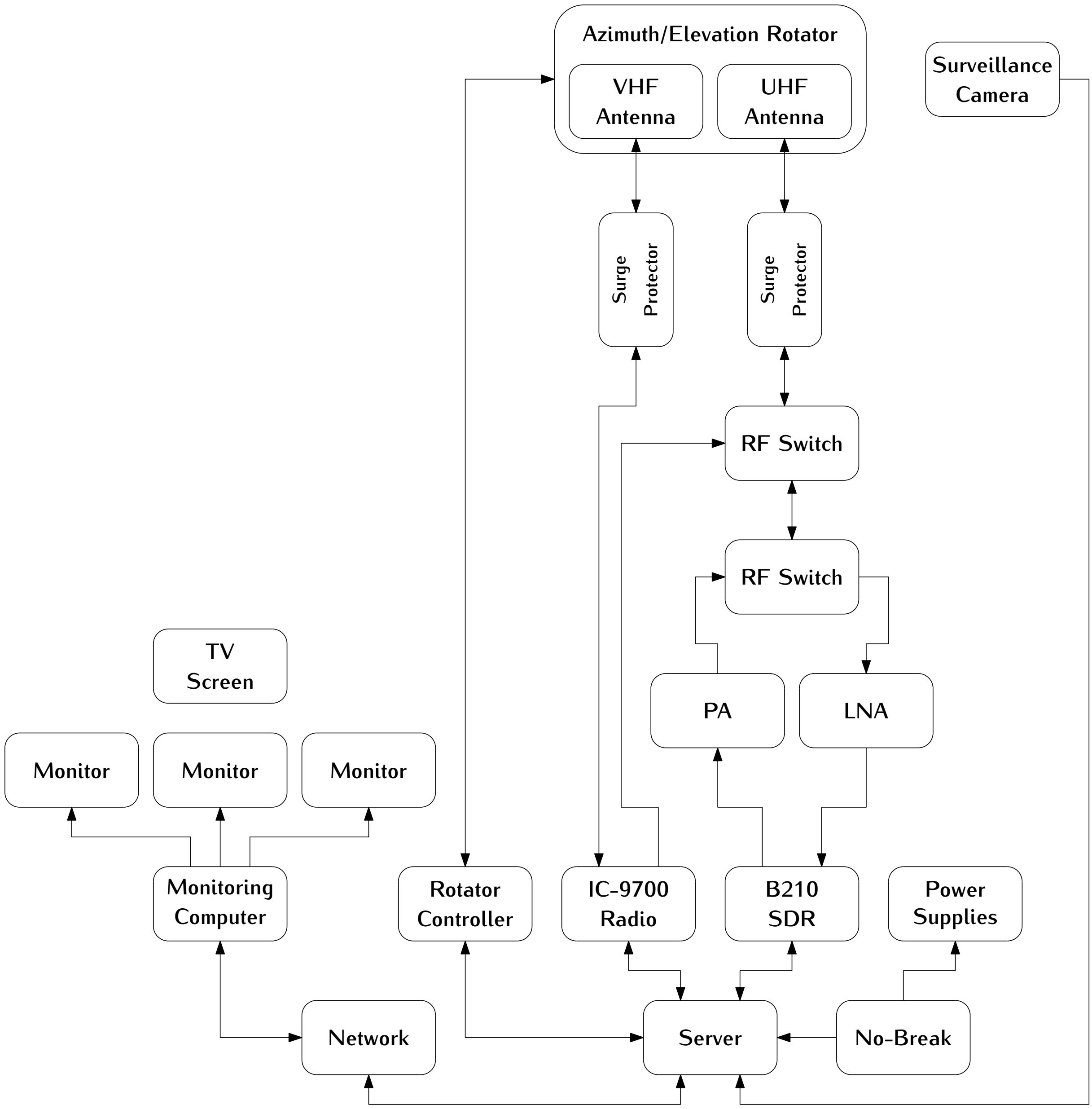


Figure 7.1: Block diagram of the ground segment (UFSC ground station).

damage to an independent ground. This device is installed near the antennas, in cascade with the RF cables.

For this project, the model MFJ-270N will be used, and a picture of it can be seen in Figure 7.2.

7.1.1.2 Rotators

Both antennas (VHF and UHF) track the satellite through a two axis rotator (azimuth and elevation). The used model is the Yaesu G-5500, which provides 450° azimuth and 180° elevation control of medium and large size unidirectional satellite antenna arrays under remote control from station operation position.

A picture of the G-5500 rotator (and controller) can be seen in Figure 7.3; the main characteristics can be found in Table 7.2.

Characteristic	VHF Antenna	UHF Antenna	Unit
Brand	M^2	Cushcraft	-
Model	2MCP14	A719B	-
Type	Yagi	Yagi	-
Number of elements	14	19	-
Frequency range	143-148	430-450	MHz
Gain	12.34	15.5	dBi
Power rating	1500	2000	W
Boom length	3.2	4.1	m
Longest element	1.02	0.34	m
Weight	2.72	2.55	kg

Table 7.1: Main characteristics of the ground segment antennas.

Figure 7.2: MFJ-270N surge protector.

Figure 7.3: Yaesu G-5500 rotator and controller.

Characteristic	Value	Unit
Brand	Yaesu	-
Model	G-5500	-
Voltage requirement	110-120 or 200-240	V_{AC}
Motor voltage	24	V_{AC}
Rotation time (elevation, 180°)	67	s
Rotation time (azimuth, 360°)	58	s
Maximum continuous operation	5	min
Rotation torque (elevation)	14	kg-m
Rotation torque (azimuth)	6	kg-m
Braking torque (elevation and azimuth)	40	kg-m
Vertical load	200	kg
Pointing accuracy	$\pm$ 4	%
Wind surface area	1	m^2
Weight (rotator)	9	kg
Weight (controller)	3	kg

Table 7.2: Main characteristics of antennas' rotators.

More information about the ground station rotator can be found in [27].

7.1.1.3 Amplifiers

There are two dedicated amplifiers in the UFSC ground station: one power amplifier (PA) for transmitting telecommands with a high power signal, and a low noise amplifier (LNA), for amplify the received signals from the satellite. Both are presented next.

7.1.1.3.1 Power Amplifier

The power amplifier is used to add a gain to the generated signals of the transmitter. The used model is the Mini-Circuits ZHL-50W-52-S+ [28]. A picture of this power amplifier can be seen in Figure 7.4, the main characteristics are available in Table 7.3.

Figure 7.4: Mini-Circuits ZHL-50W-52-S+ power amplifier.

Characteristic	Value	Unit
Brand	Mini-Circuits	-
Model	ZHL-50W-52-S+	-
Frequency range	50-500	MHz
Gain	47-52	dB
Noise figure	4.5-7.0	dB
DC supply voltage	24-25	V
Max. supply current	9.3	A

Table 7.3: Main characteristics of the ZHL-50W-52-S+ power amplifier.

7.1.1.3.2 Low Noise Amplifiers

As LNA, the model ZFL-500LN+ from Mini-Circuits [29] is being used. This amplifier will be used just after the antennas to add a gain to the incoming telemetry signals transmitted by the satellite. A picture of the low noise amplifier can be seen in Figure 7.5, the main characteristics are available in Table 7.4.

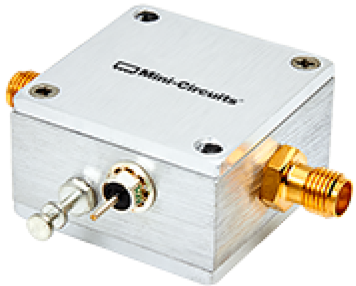


Figure 7.5: Mini-Circuits ZFL-500LN+ low noise amplifier.

Characteristic	Value	Unit
Brand	Mini-Circuits	-
Model	ZFL-500LN+	-
Frequency range	0.1-500	MHz
Gain	24-28	dB
DC supply voltage	15	V
Max. supply current	60	mA

Table 7.4: Main characteristics of the ZFL-500LN+ low noise amplifier.

7.1.1.4 Radios

Besides the SDR solution presented in the block diagram of the Figure 7.1, there is also a amateur radio transceiver with a standalone solution for the amateur radio link with the satellite. The used model is the Icom IC-9700 [30], that is an RF direct sampling receiver for 2 m and 70 cm. The IF receiver consists of a single down conversion for 23 cm that is between 311 and 371 MHz. The PA provides 100 W on 2 m, 75 W on 70 cm, and 10 W on 23 cm.

In addition to band-specific memory channels, the IC-9700 allows the band-specific receiver and transmitter settings. For transmission, users can adjust RF power, TX power Limit, Limit Power, and TX Delay by the band. Basic receiver settings, like the Noise Blanker, Noise Reduction, and others, can be tweaked by the band with a dynamic Notch and Filter setup by band/mode. A picture of the IC-9700 radio can be seen in Figure 7.6.

Figure 7.6: Icom IC-9700 radio transceiver.

7.1.1.4.1 Software Defined Radio

As presented in Figure 7.1, the ground segment also has an SDR (Software Defined Radio) as a transceiver. The used model is the USRP B210, from Ettus Research [31], a fully integrated, single-board SDR with continuous frequency coverage from 70 MHz to 6 GHz. It combines the AD9361 RFIC direct-conversion transceiver providing up to 56 MHz of real-time bandwidth, an open and reprogrammable Spartan6 FPGA, and USB 3.0 connectivity. Also, full support for the USRP Hardware Driver (UHD) software allows the use of the GNURadio framework. A picture of the USRP B210 SDR (with enclosure) can be seen in Figure 7.7.

Figure 7.7: Ettus USRP B210 SDR.

7.1.1.5 Processing and Control

The ground station control room shall have two monitors and a dedicated computer alongside most of the previously presented hardware. It will work as a monitoring room with a nobreak to protect the equipment from power grid fluctuations.

The antennas and rotator will also be monitored with outside cameras. And the room will count with a server so that the transmission and decoding can be done remotely and at any time.

In the Figure 7.8 can be seen a picture of the used server, and in Table 7.5 are presented the main characteristics of the it.

Characteristic	**Value**
Brand	Dell
Model	PowerEdge R240
Processor	Intel Xeon E-2244G 3.8 GHz 4C/8T
RAM Memory	16 GB DDR4 ECC
Storage	1 TB HD

Table 7.5: Main characteristics of the Dell PowerEdge R240 server.

Figure 7.8: Dell PowerEdge R240 server.

7.1.2 Satellite Tracking

To track the satellite and for orbit prediction, the GPredict software [32] will be used. Gpredict is a real-time satellite tracking and orbit prediction application. It can track many satellites and display their position and other data in lists, tables, maps, and polar plots (radar view). Gpredict can also predict the time of future passes for a satellite and provide detailed information about each pass. Gpredict is free software licensed under the GNU General Public License. A picture of the main window of GPredict can be seen in Figure 7.9.

7.1.3 Packet Transmission

The packet generation and transmission to GOLDS-UFSC satellite can be done with the SpaceLab-Transmitter software [33], which was written in Python with the interface developed using the GTK framework. It has a USRP Handler made with Ettus libraries to work with Ettus USRP B210 as shown in Figure 7.7. The supported modulation is the

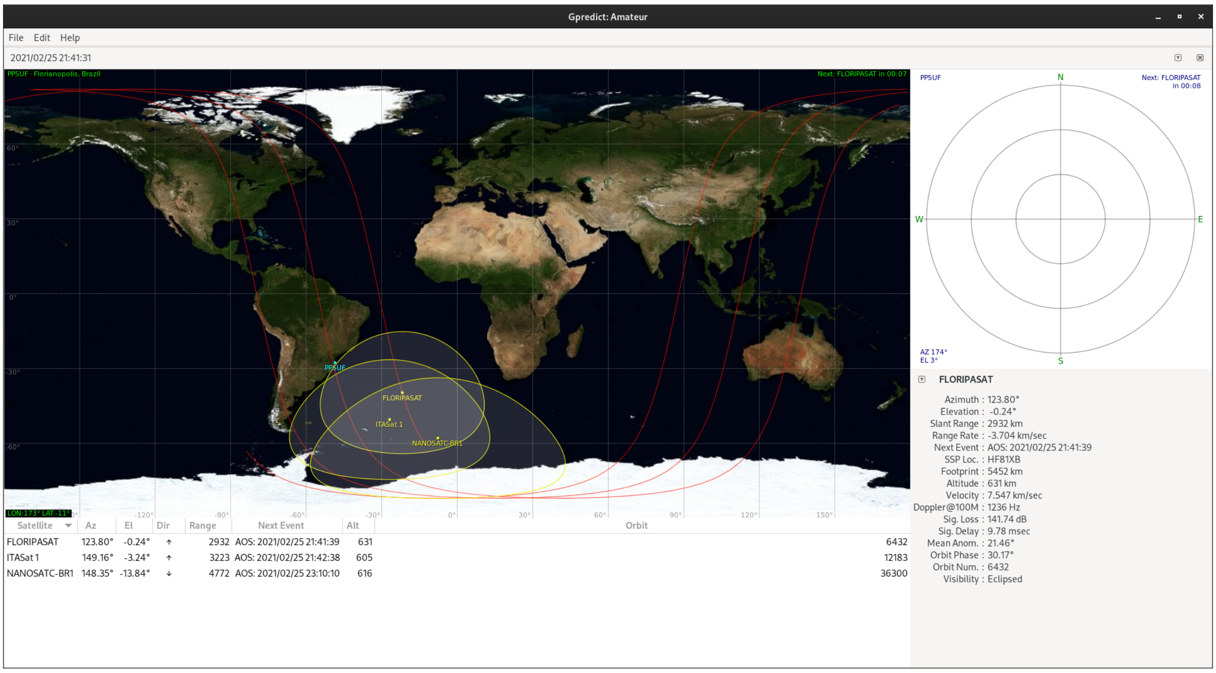


Figure 7.9: Main window of GPredict.

Gaussian Minimum Shift Keying (GMSK). Furthermore, the software also has unit tests for the main modules and a logging system to record events such as an initialization or a successfully transmitted telecommand.

In the Figure 7.10 is shown the product tree of the software, which contains its main elements of it, and in the Figure 7.11 is shown the main window of it.

7.1.4 Packet Decoding

The packet decoding of GOLDS-UFSC satellites telemetry can be done using the SpaceLab-Decoder [34] software using a .wav file or through a real time reception. The decoded telemetry will appear in a dialog within the main window. The software was written in Python, and the interface was developed using GTK framework. Furthermore, the software also has unit tests for the main modules and a logging system to record events.

The Figure 7.12 is showing the product tree of the software, which contains its main elements, and in the Figure 7.11 is shown the main window of it.

7.2 EMMN Ground Station

The EMMN (*Estação Multimissão de Natal* in portuguese) ground station [35] was designed to operate in VHF, UHF and S-Band frequency bands, receiving payload and telemetry data and transmitting telecommands from and to satellites operating in low orbits.

The station's radio frequency systems use Software Defined Radios (SDRs), which offer the flexibility to quickly reconfigure parameters such as modulation type, encoding, datarate, etc. Most commonly used modulation schemes and encoding methods are already implemented, and any customization requests can be requested.

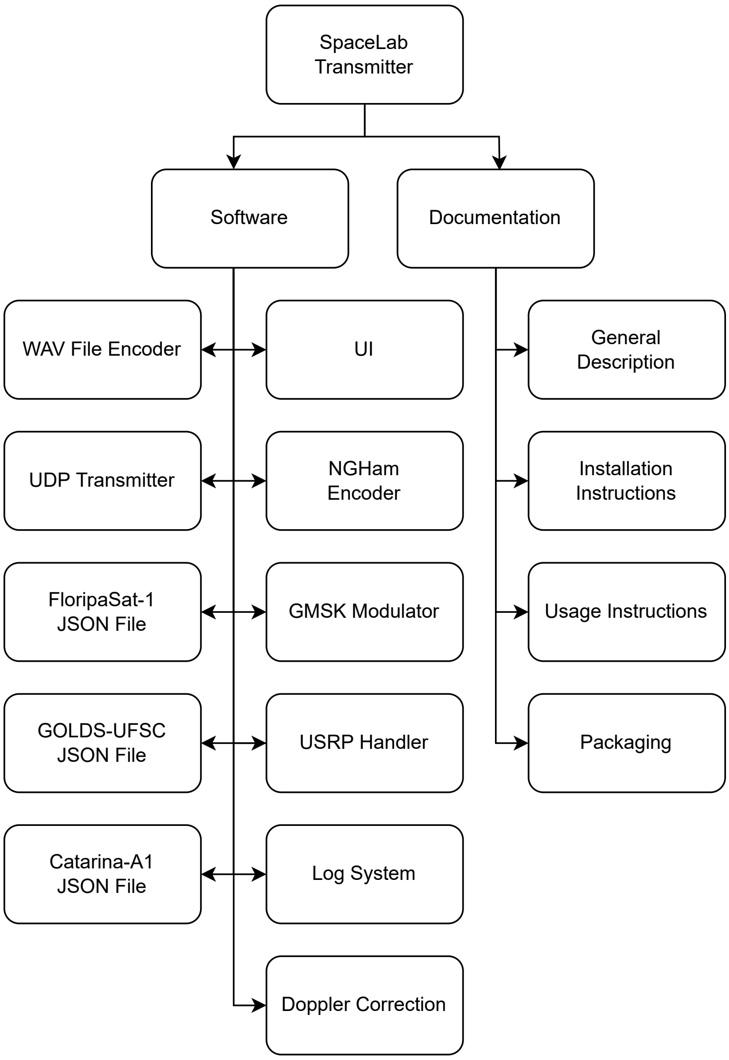


Figure 7.10: SpaceLab-Transmitter product tree.

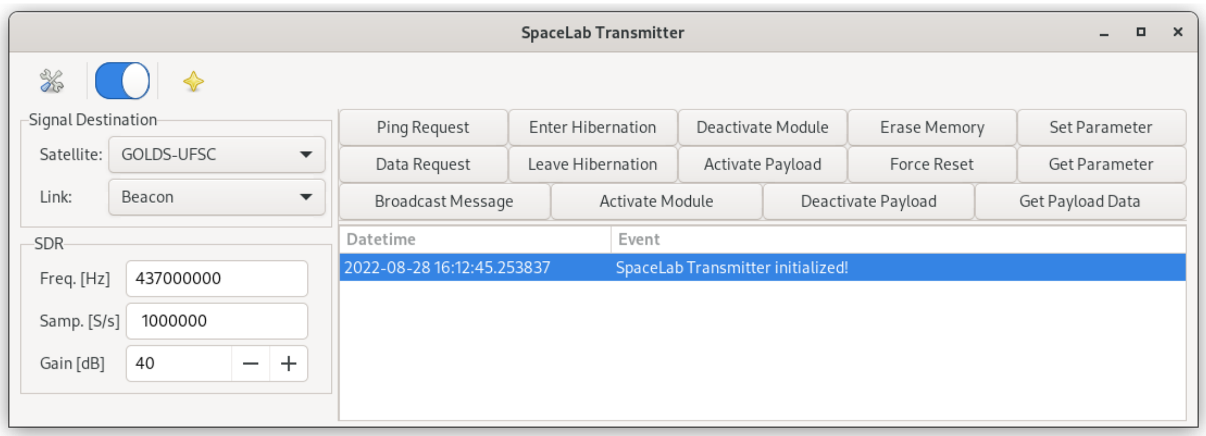


Figure 7.11: Main window of the SpaceLab-Transmitter application.

The station performs autonomous tracking of several satellites according to a previous schedule and a scale of priorities. A Client-Server network design allows station users to

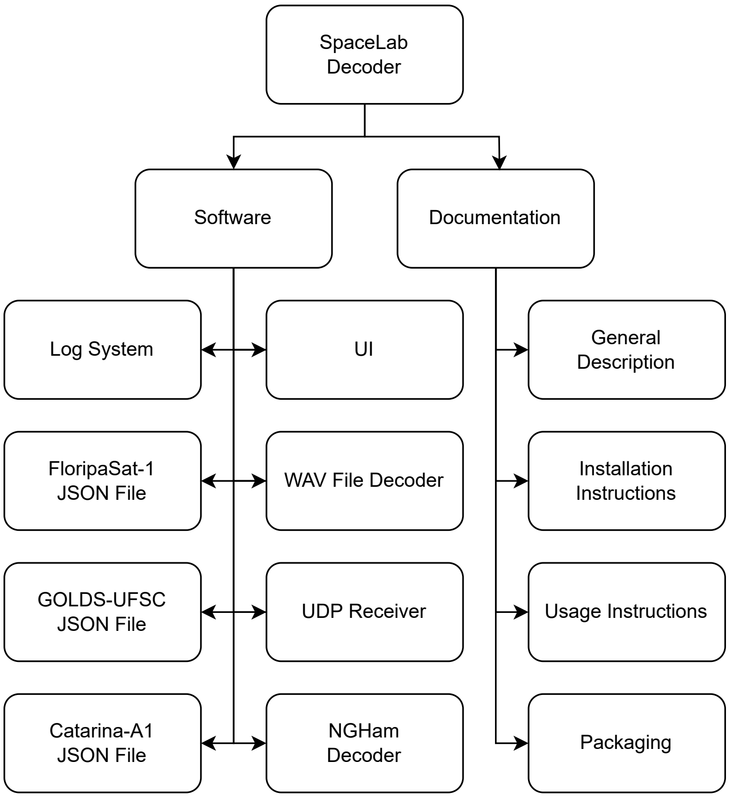


Figure 7.12: SpaceLab-Decoder product tree.

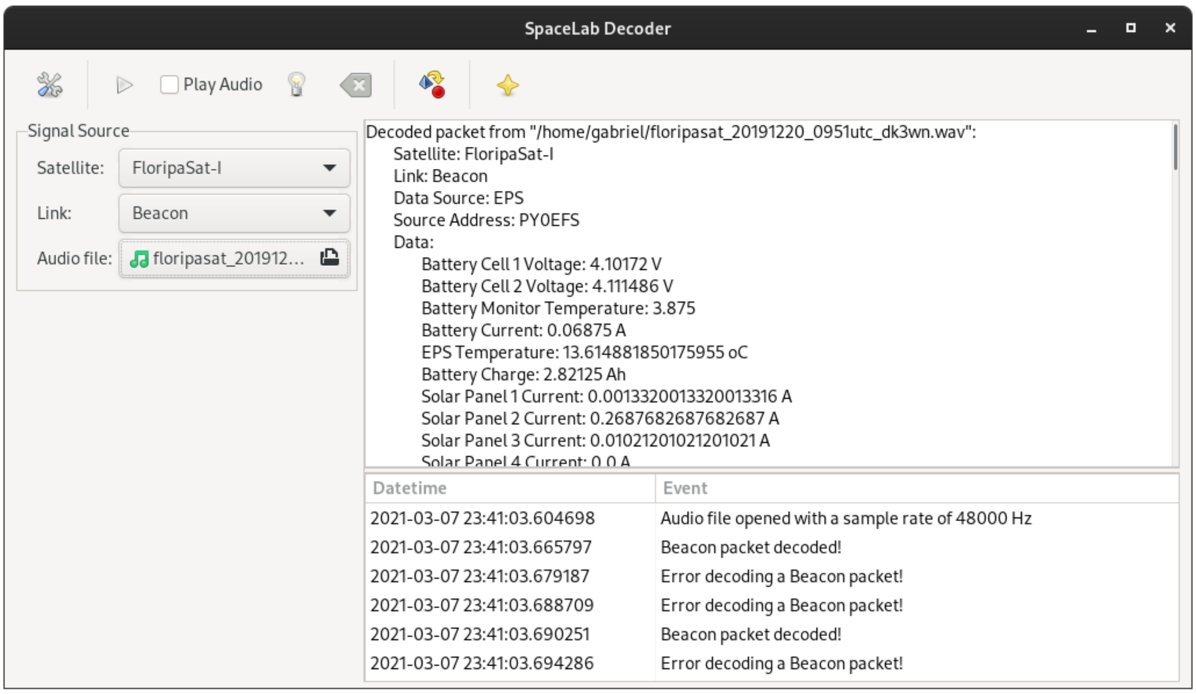


Figure 7.13: Main window of the SpaceLab-Decoder application.

send and receive data remotely.

A general block diagram of the EMMN hardware is available in Figure 7.14.

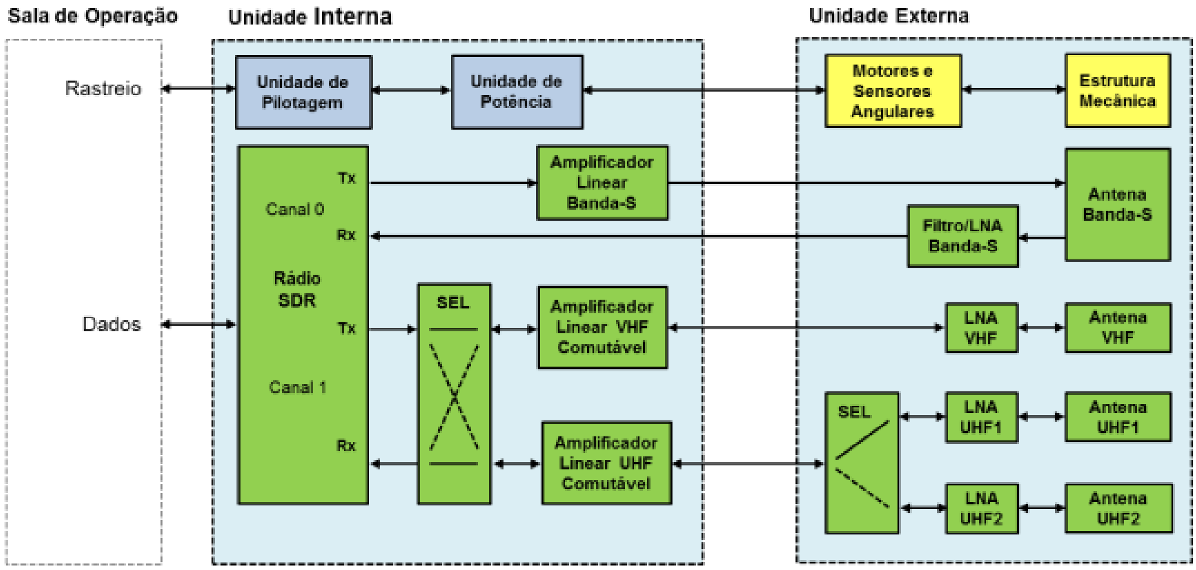


Figure 7.14: General block diagram of the EMMN.

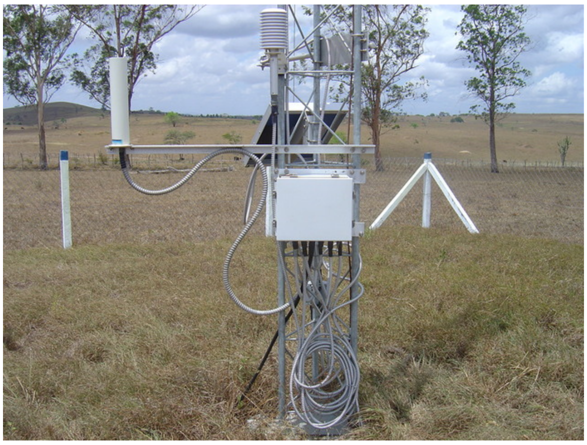
Parameter	Value
Grid locator	HI24JD59CI
Coordinates	-5.835238, -35.209285
Altitude	51 m
Antennas	Yagi and parabolic
Bands	VHF, UHF and S-Band
Frequencies	144-146 MHz (VHF), 395-405 and 432-440 MHz (UHF) 2200-3300 MHz (S-Band)

Table 7.6: EMMN specs.

Figure 7.15: Multimission station of Natal-RN.

7.3 Data Collection Platforms

Data Collection Platforms (DCPs) are part of the Integrated System of Environmental Data (*Sistema Integrado de Dados Ambientais, SINDA* [36], in Portuguese), which collects the data and by satellites, it is retransmitted to be received in the ground station so that it can be sent to SINDA to be processed. The data is shown online sometime after the receiving. Examples of DCPs can be seen in Figure 7.16.



(a)

(b)

(c)

Figure 7.16: Examples of data collection platforms (DCPs).

CHAPTER 8

Test Plan and Procedures

The GOLDS-UFSC test plan is structured into four phases: Module tests, FlatSat, Engineering integration, and Flight integration. This plan is summarized in the Table 8.1 and includes the components under test for each phase.

Phase	**Components**
Module tests	OBDH module EPS module TTC module BATC4 board IIP boards PC104-ADPT boards ACS components (simulation) Mechanical (CAD assessment)
FlatSat	Satellite core (OBDH+EPS+TTC+BATC4) Satellite core + GRS Satellite core + Payloads Satellite core + Payloads + GRS Satellite (long-term evaluation)
Engineering integration (clean room preferable)	Mechanical assembly (repeated when required) Satellite core + Payloads + GRS Satellite (long-term evaluation) Satellite + Solar Panels Preliminary environmental tests
Flight integration (clean room mandatory)	Mechanical assembly (flight components) Satellite (short-term evaluation) Satellite + Antenna (deployment) Mechanical reassembly for flight Satellite (long-term evaluation) Qualification environmental tests

Table 8.1: Test plan phases and tested components.

This section provides an overview of the planned testing workflow and a description of the strategies to accomplish the mission objectives. The module tests focus on the individual module's operation and behavior, in which a general template is provided in this document, and each module applies it for its needs. The FlatSat phase is the first module integration in a debug platform to validate the system from a development perspective (described with more details in [37]). Finally, the engineering integration is the final development campaign aiming to validate the system from a mission perspective. The flight integration is the actual CubeSat assembly using the flight components and final assessments to prepare the satellite for launch. The integration details, procedures, and qualification process are described with more depth in the chapter 9.

8.1 Module tests

The first phase is the foundation for the satellite, consolidating the base design for each subsystem and shaping their relations. Therefore, several techniques were employed to ensure a solid test strategy: several inspections of the boards' design and manufacturing quality; manual experimental assessments of various hardware, electrical, mechanical, and behavioral parameters; remotely automated tests using a continuous integration (CI) approach; semi-automated tests using a hardware-in-the-loop (HIL) strategy; simulations; and CAD models assessment.

8.1.1 Workflow

The following topics list the template workflow used to create the procedures for each subsystem. Each module documentation has its test chapter describing the process in detail, from procedures to success criteria.

8.1.1.1 Visual Inspection

1. Packaging quality assessment
2. Board manufacturing and assembly quality
3. 3D model comparison
4. Layers marker
5. Labels (schematics comparison)
6. High resolution photos for documentation

8.1.1.2 Mechanical Inspection

1. Board dimensions and mounting holes positioning
2. Board weight measurement

8.1.1.3 Integration Inspection

1. Check connectors pinout against the documentation (not schematics)
2. Check connectors positioning (if applicable)

8.1.1.4 Electrical Inspection

1. Solder shorts
2. Missing components
3. Lifted pins
4. Poor soldering
5. Swapped components
6. Components part number
7. Components polarity (schematic comparison)
8. Components defined to not be soldered (DNP)

8.1.1.5 Electrical Testing

1. Continuity test
2. Power up procedures (check LEDs and test points)
3. Average input power consumption measurement
4. Average output power source measurement (if applicable)
5. Power tracks temperature (if applicable)
6. Simple signal integrity (if applicable)

8.1.1.6 Functional Testing

1. Run a simple test code (if applicable)
2. Run the system code (if applicable and available)
3. Check the system hardware self-test flags (if applicable and available)
4. Monitor basic LEDs behavior (if applicable)
5. Monitor the debug serial port logs (if applicable)

8.1.1.7 Module Testing

1. Run simulations and review results (if applicable)
2. Review operation behavior against the documentation (if applicable)
3. Review features and requirements fulfillment
4. Review communication buses configuration and protocol (if applicable)
5. Review data packages, power buses, and control signals
6. Review and evaluate operation edge cases
7. Run remote automated code tests (if applicable)
8. Run system test codes in the board (if applicable)
9. Run the latest stable code version, monitor logs, and qualify behavior (if applicable)

8.1.2 Continuos Integration

In order to detect errors and bugs in the early stages of development, a continuous integration workflow was set up for automated firmware tests focusing on small-scope verifications (i.e., unit tests). Instead of executing the code in the target processor, the tests are executed remotely in a host computer using a unit testing framework called "cmocka" [38]. This tool allows abstracting the inherent hardware dependencies of embedded systems to enable firmware tests without errors introduced by hardware problems (execution in a consolidated platform, the computer), which provides an optimal behavioral assessment of the code implementations. This approach supports remote testing and promotes continuous test execution, which is essential for detecting errors and architectural issues. "GitHub Actions" drive the integration of these procedures [39], which provides a host machine and a dashboard inside the same environment of the already used version control, source distribution, and management tool.

The unit tests follow a layered structure accordingly to the firmware layers. This is used alongside mockups (i.e., interfaces that abstract what the layer receive as input without having to implement the underlying functionality), which allows independency between the layers and abstract the actual hardware dependencies with an emulated behavior.

8.1.3 Hardware-In-the-Loop

In the context of embedded systems, many errors are caused by hardware issues and limitations. Then, it is important to assess the system operating in the existing hardware platform. The hardware-in-the-loop strategy brings these elements into a more controlled and automated test environment. The idea is to execute the firmware in the board with an emphasis on evaluating the general behavior and operation flow since several log messages are used to report the system's current status or action across the execution.

8.2 Flatsat

To test all modules during the development of the projet, a flatsat platform was developed. The FlatSat Platform is a testbed for CubeSat PCB modules. FlatSats enable a more straightforward, faster, and secure method for independently testing subsystems while being integrated in a flat design before integrating on a CubeSat form factor. The PCB can support up to 7 modules; all PC-104 pins are interconnected to flexibilize its use; only the particularity connection between modules needs to be taken into account. One PC-104 has an inverted pinout; the board also makes it possible to have two separate power supplies, a UART to USB converter for 4 modules, kill-switches activation though SPDTs, Remove Before Flight (RBF) pin header, a connector for charging batteries and SMA connectors for antennas. A picture of the flatsat board can be seen in Figure 8.1. In Figure 8.2 there is a picture of the flatsat, including the core modules and the payloads.

Besides the hardware platform itself, during the FlatSat phase, a setup is used with the same structure as the hardware-in-the-loop strategy herein mentioned. Instead of using logs of one board, the analysis is performed from the perspective of all modules under test, which provides an evaluation of a complete system (satellite). More information about the Flatsat hardware platform and procedure details can be found in [37].

8.3 Engineering integration

The engineering model integration is the final development campaign since it connects the satellite design in the actual CubeSat form factor, allowing the assessment not only of the system from a behavioral perspective (as performed in the FlatSat), but also from the application and mission point of view. This is achieved due to additional elements (e.g., actual mechanical frame), environmental tests and execution of use cases. Also, it is possible to evaluate electrical, mechanical and behavioral compliance fulfillment early.

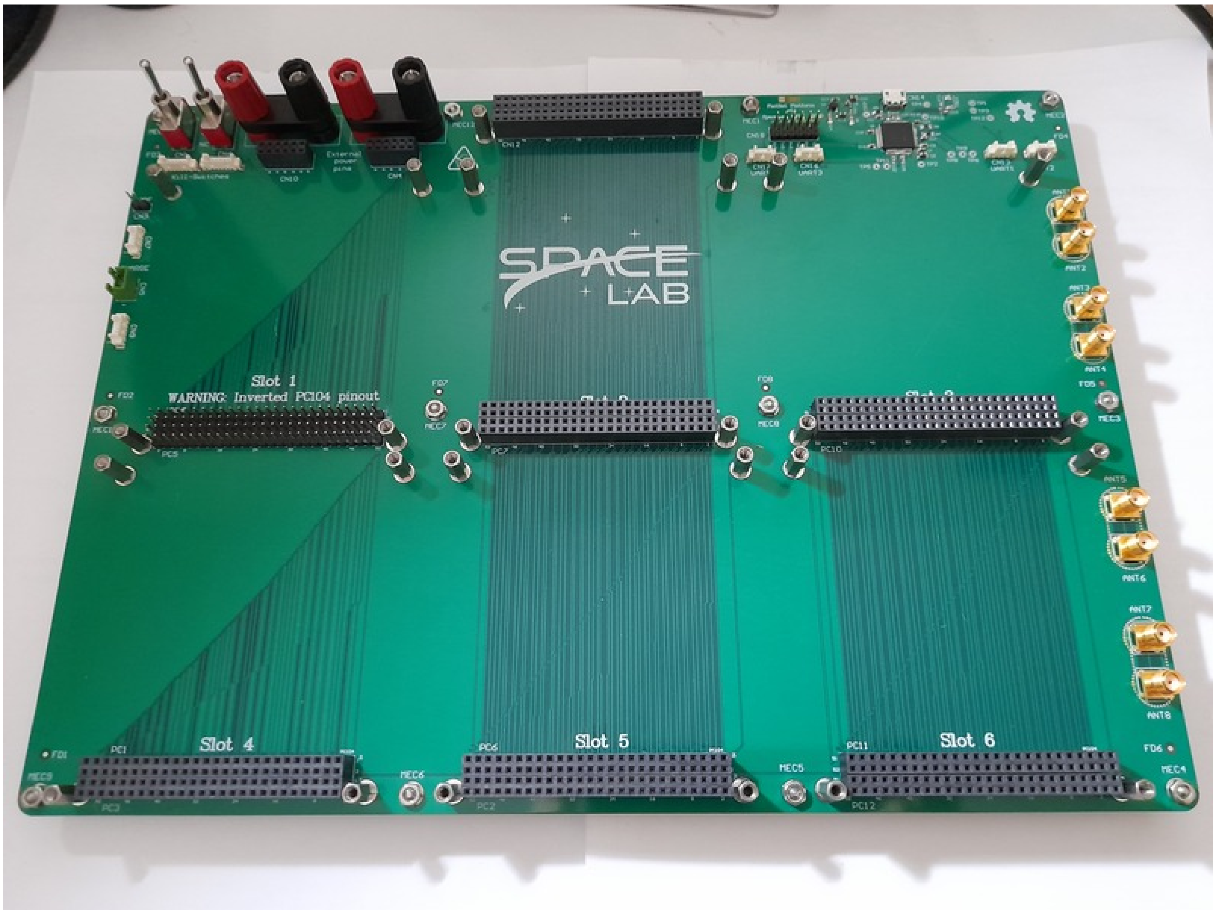


Figure 8.1: Top view of the flatsat board.

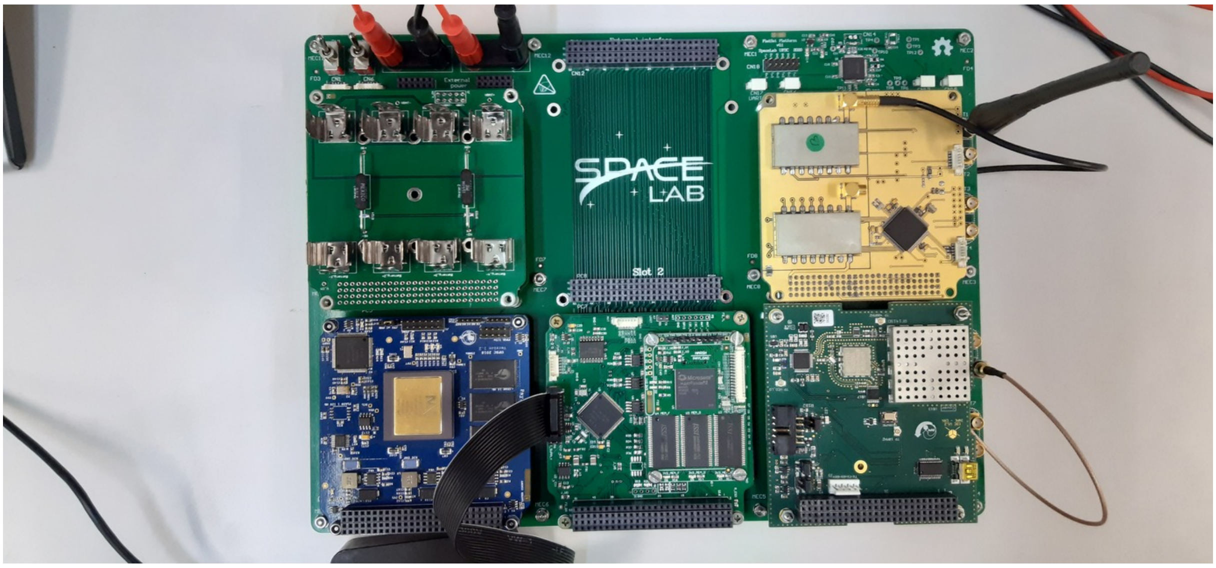


Figure 8.2: Flatsat of the GOLDS-UFSC.

During this phase, the FlatSat process and test methodology are repeated in a condensed manner since the system was already tested and some preliminary procedures can be skipped. The mechanical assembly is performed several times until the design and the related documentation are settled. The environmental tests are a simplified version of the final process for qualification but open opportunities for early assessments and more destructive procedures. Also, long-term testing provides a comprehensive knowledge of the satellite's reliability and robustness. Further details are provided in the chapter 9 section.

8.4 Flight integration

The flight model integration performs the final arrangements before launch in a clean room, including evaluation assembly with all final parts; the last test campaign, the same as executed in the engineering integration; reassembly with definitive parts, placement, and resin; environmental qualification tests; and flight-ready procedures (packaging, transport and pre-launch) [40].

CHAPTER 9

Assembly, Integration and Test

The following activities refer to the Flight Model, so after the execution of this AIT the CubeSat will not suffer any modification in its hardware, software, and firmware. The only acceptable interference is the recharge of batteries, which is made through an external umbilical cable.

In Figure 9.1 there is a general view of the sequential steps to the entire AIT campaign, where I refers to integration activities and T is used for testing activities.

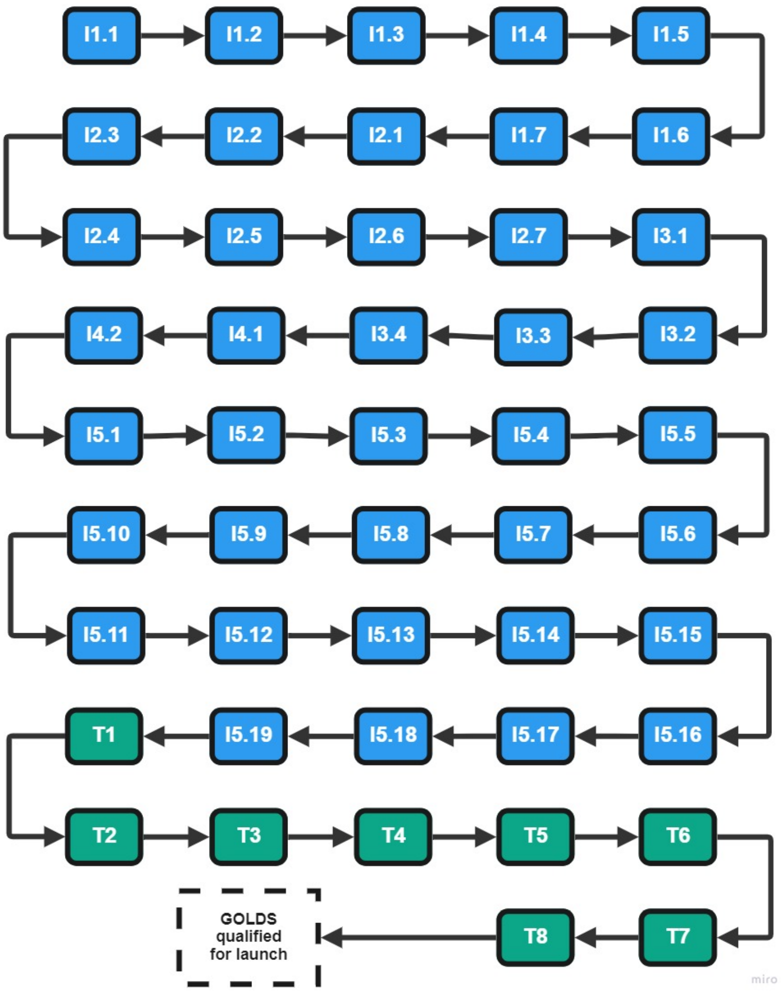


Figure 9.1: Sequence of activities of AIT plan.

9.1 Assembly Instructions

Each task in the Integration segment of the AIT campaign is listed in Table 9.1 together with a label for the block, name and section with further details.

Block	Name	Section
I1.2	I1.2: To pre-mount battery+case and EPS	I1
I1.3	I1.3: I1.2+Bottom structure	I1
I1.4	I1.4: I1.3+Primary OBDH	I1
I1.5	I1.5: I1.4+Radiation Monitor	I1
I1.6	I1.6: I1.5+Interface Module	I1
I1.7	I1.7: I1.6+Top structure	I1
I2.1	I2.1: To pre-mount upper (U) modules	I2
I2.2	I2.2: Interface Module+Bottom structure	I2
I2.3	I2.3: I2.2+Redudant EDC	I2
I2.4	I2.4: I2.3+Primary EDC	I2
I2.5	I2.5: I2.4+Radiation instrument	I2
I2.6	I2.6: I2.5+TT&C	I2
I2.7	I2.7: I2.6+Top structure	I2
I3.1	I3.1: Debug interface (-X and +X)+Lateral structure	I3
I3.2	I3.2: I3.1+ADCS+Lateral structure	I3
I3.3	I3.3: I1.7+ADCS	I3
I3.4	I3.4: I2.7+Magnet+upper(U) top structure	I3
I4.1	I4.1: I1.7+I2.7+I3.5	I4
I1.1	I1.1: To pre-mount lower (U) modules	I4
I4.2	I4.2: I4.1 and I4.2+Debug interface (-Y and +Y)+Lateral structure	I4
I5.1	I5.1: I4.2+Shield (-Z)	I5
I5.2	I5.2: I5.1+Shield (Z0;X0)	I5
I5.3	I5.3: I5.2+Shield (Z0;X1)	I5
I5.4	I5.4: I5.3+Shield (Z0;Y0)	I5
I5.5	I5.5: I5.4+Shield (Z0;Y1)	I5
I5.6	I5.6: I5.5+Shield (Z1;X0)	I5
I5.7	I5.7: I5.6+Shield (Z1;X1)	I5
I5.8	I5.8: I5.7+Shield (Z1;Y0)	I5
I5.9	I5.9: I5.8+Shield (Z1;Y1)	I5
I5.10	I5.10: I5.9+Antenna+SP(+Z)	I5
I5.11	I5.11: I5.10+SP (-Z)	I5
I5.12	I5.12: I5.11+SP (Z0;X0)	I5
I5.13	I5.13: I5.12+SP (Z0;X1)	I5
I5.14	I5.14: I5.13+SP (Z0;Y0)	I5
I5.15	I5.15: I5.14+SP (Z0;Y1)	I5
I5.16	I5.16: I5.15+SP (Z1;X0)	I5
I5.17	I5.17: I5.16+SP (Z1;X1)	I5
I5.18	I5.18: I5.17+SP (Z1;Y0)	I5
I5.19	I5.19: I5.18+SP (Z1;Y1)	I5

Table 9.1: List of integration activities.

9.2 Environmental Testing

After the integration, the tests that will be executed in the AIT campaign to qualify GOLDS-UFSC for launch are in Table 9.2. Each of these tests receives the letter T and a number for identification.

Block	Name	Criteria
T1	Dimensions	Dimensions of 100.0 × 100.0 × 227.0 mm ±0.1 mm in the X, Y, and Z axis
T2	Fit check	Absence of interference and a smooth sliding through the deployer
T3	Mass	Total CubeSat mass below or equal to 4.00 kg
T4	Center of gravity	It must be within ±2.0 cm from the geometric center on the X-Axis and Y-Axis, and less than ±4.5 cm in Z-axis
T5	Vibration	To be defined by the launch vehicle
T6	Thermal cycling	To be defined by the launch vehicle
T7	Thermal Vacuum Bake-out	To be defined by the launch vehicle
T8	EMC testing	To be defined by the launch vehicle

Table 9.2: List of qualifying tests and simulations.

The sequence of these tests is summarized in Fig. 9.2.

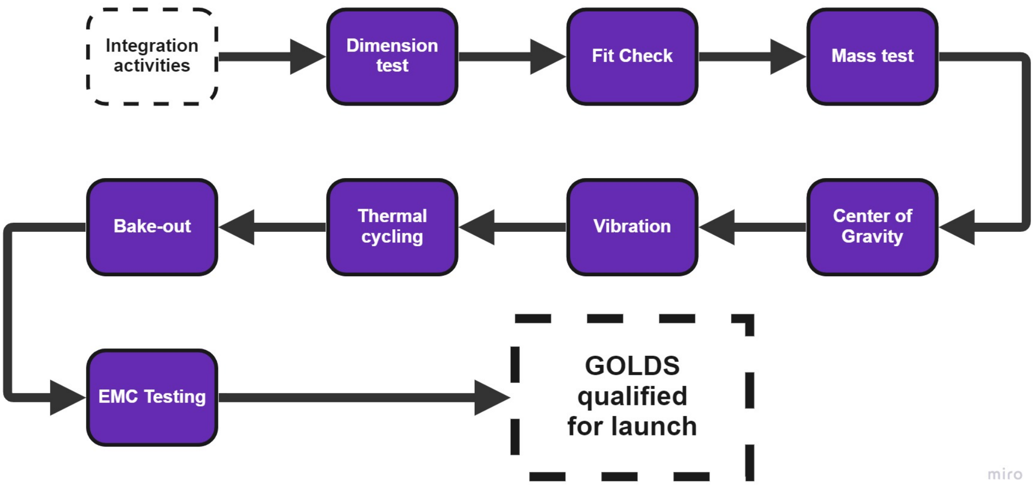


Figure 9.2: Test sequence for GOLDS-UFSC.

In the following sections, these tests are described.

9.2.1 Dimensions

This test checks the main external dimensions of GOLDS-UFSC and aims to prove that its dimensions are appropriate for integration in a standard 2U CubeSat deployer. The dimensional test is validated by measuring with a caliper or micrometer the main external dimensions of GOLDS-UFSC, according to Figure 9.3. The tolerance is ±0.1 mm in the

X, Y, and Z axis. Any measurement out of this range means the CubeSat is not ready for launch.

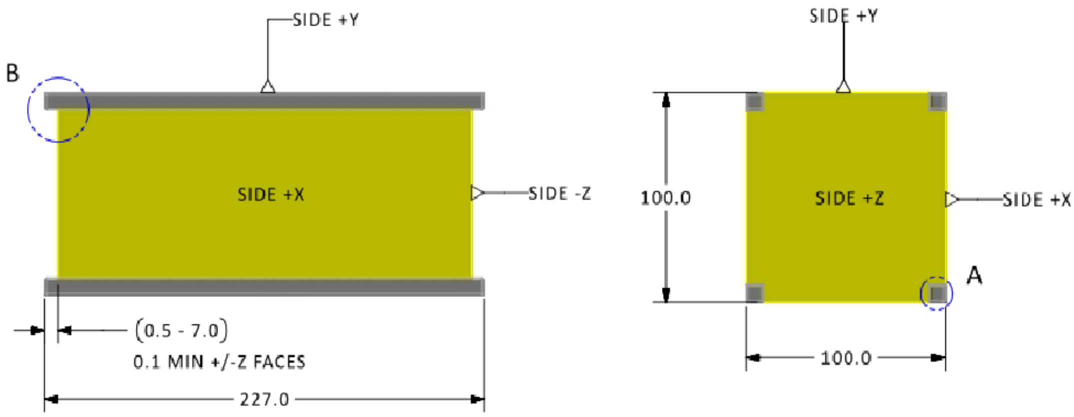


Figure 9.3: Dimensional validation. Adapted from [1].

9.2.2 Fit check

To assure a proper integration and deployment of the CubeSat, a similar 2U deployer used by the launch is fundamental to verify any additional mechanical interference between these interfaces, as illustrated in Figure 9.4. A smooth sliding through the deployer, the absence of interference, and proper pressing of kill-switches are required for qualification.

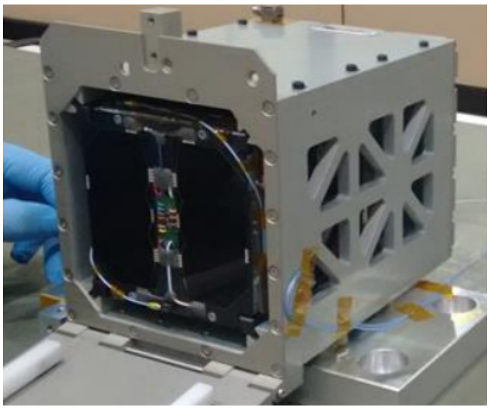


Figure 9.4: FloripaSat-1 fit check.

Therefore, this activity lacks a better definition until the launch vehicle and its mandatory deployer are confirmed.

9.2.3 Mass

This test checks the satellite's total mass (without RBF tag), which must be less than 4.00 kg for a 2U CubeSat [1]. The verification is made with a precision balance. Figure 9.5 exemplifies this process with the CubeSat 1U FloripaSat-1.

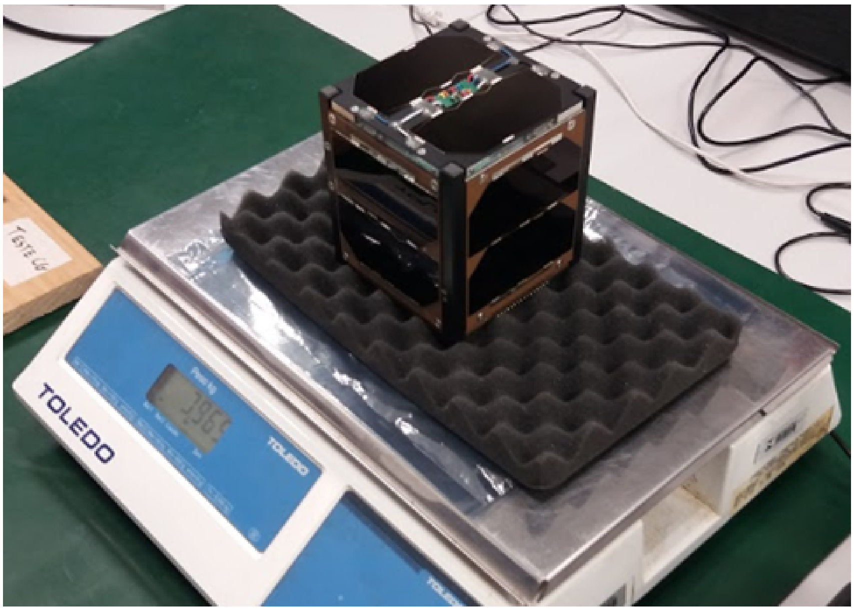
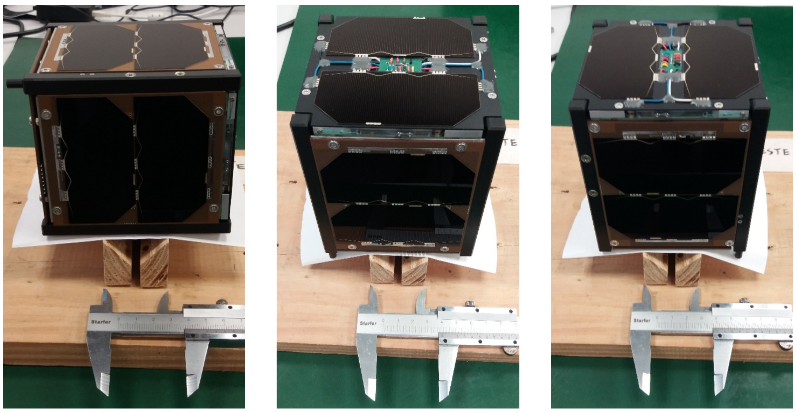


Figure 9.5: Mass verification of FloripaSat-1.

9.2.3.1 Center of Gravity

This test checks the Center of Gravity (CG) of the satellite and proves if it is within the acceptable range. The CG must be within ±2.0 cm from the geometric center on the X-Axis and Y-Axis, and within ±4.5 cm from the geometric center on the Z-Axis [1]. To perform this test, a simple test bench with parallel bars is used. To perform the test, the bars are 4.0 cm apart (to test in the X and Y-axis) or 9.0 cm apart (to test the Z-axis), the geometric center of CubeSat is positioned above them, right between the bars. The CubeSat is not going to tip if the CG is within the range. This strategy does not measure the location of CG; however, it does prove that the satellite follows the requirement.

This test was already validated with FloripaSat-1, as illustrated in Figure 9.6, where a caliper is used to verify that the distance between the bars are 4.0 cm.

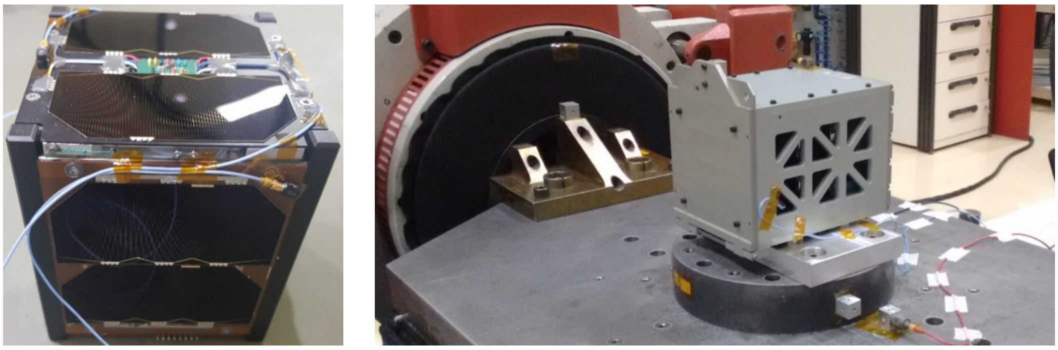


(a) X axis. (b) Y axis. (c) Z axis.

Figure 9.6: Center of gravity of FloripaSat-1 within ±2.0 cm from the geometric center.

9.2.4 Vibration

During the launch phase, a significant level of vibration is expected, which can cause failures in the CubeSat. To determine if the CubeSat supports those loads, vibration test are performed. To measure and control the acceleration profile during the dynamic tests, accelerometers are positioned on three external surfaces of the satellite, one on each axis, over areas without solar cells to avoid any damage to them, as illustrated for the case of FloripaSat-1 in 9.7(a). After that, the satellite is integrated into a 2U test deployer, and then the deployer is fixed on a shaker, as seen in 9.7(a).



(a) Position of the accelerometers.

(b) Shaker.

Figure 9.7: Vibration test.

The CubeSat is tested entirely off, with RBF pin removed, but with the Kill-Switches pressed by the 2U Test POD, simulating the normal launching condition. The envelope of vibration is determined by the launch vehicle, therefore, this activity lacks a better definition until the launch vehicle is confirmed.

Nevertheless, this test is usually executed for most of the CubeSat missions, so a preliminary set of vibration tests is anticipated in Figure 9.8. This process will be followed until further information from the launch vehicle is provided.

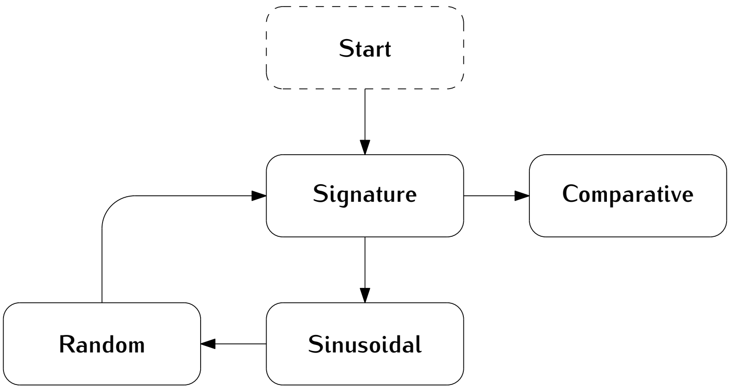


Figure 9.8: Sequence of dynamic tests.

A signature testing should be conducted before and after the tests (sinusoidal and random vibration), in order to identify the presence of significant variations in the dynamic response of the CubeSat, a condition that may represent internal mechanical failures that are non-visible from outside.

For the signature task, Table 9.3 presents the specifications.

Name	**Parameter**
Test method	Sinusoidal sweep testing
Frequency range	5 - 2000 Hz
Vibration level	0.25 g
Sweep rate	2 octaves per minute
Number of sweeps	1 (5 - 2000 Hz)
Test axes	3 (X, Y, Z)

Table 9.3: Resonance survey test (signature).

9.2.4.1 Sinusoidal vibration test

The sinusoidal vibration test should simulate low-frequency quasi-harmonic excitation of the launch in the order of 5 to 100 Hz. The level of sine sweeping vibration test is listed in Fig. 9.9 and Table 9.4.

Acceptance Test		**Qualification Test**	
Frequency Range (Hz)	Vibration Amplitude	Frequency Range (Hz)	Vibration Amplitude
5∼8	2.33mm(0-p)	5∼8	3.49mm(0-p)
8∼100	0.6g	8∼100	0.9g

Table 9.4: Sinusoidal Sweeping Vibration Test Condition.

The sweeping rates of the acceptance test and qualification tests are 4oct/min and 2oct/min, respectively. The test directions are along three orthogonal axes, and the levels along the three directions are the same. Input amplitude errors do not exceed ±10% while frequency error is ±2% when frequency $>$ 25 Hz or ±0.5 Hz when frequency $\leq$ 25 Hz.

9.2.4.2 Random vibration

This test follows the NASA-STD-7001B standard. This test profile is specified in Figure 9.10 and illustrated in Figure 9.11. The random vibration is performed by 2 minutes, along each of three orthogonal axes.

9.2.5 Thermal Cycling

For the thermal tests, thermocouples are attached to different points on the surface of the satellite, including over the solar panels and structure. For example, Figure 9.12 shows FloripaSat-1 ready for thermal tests. This test may ruled by the launch vehicle requirements, but until there is no further information about it, the parameters of the tests are summarized in Table 9.5.

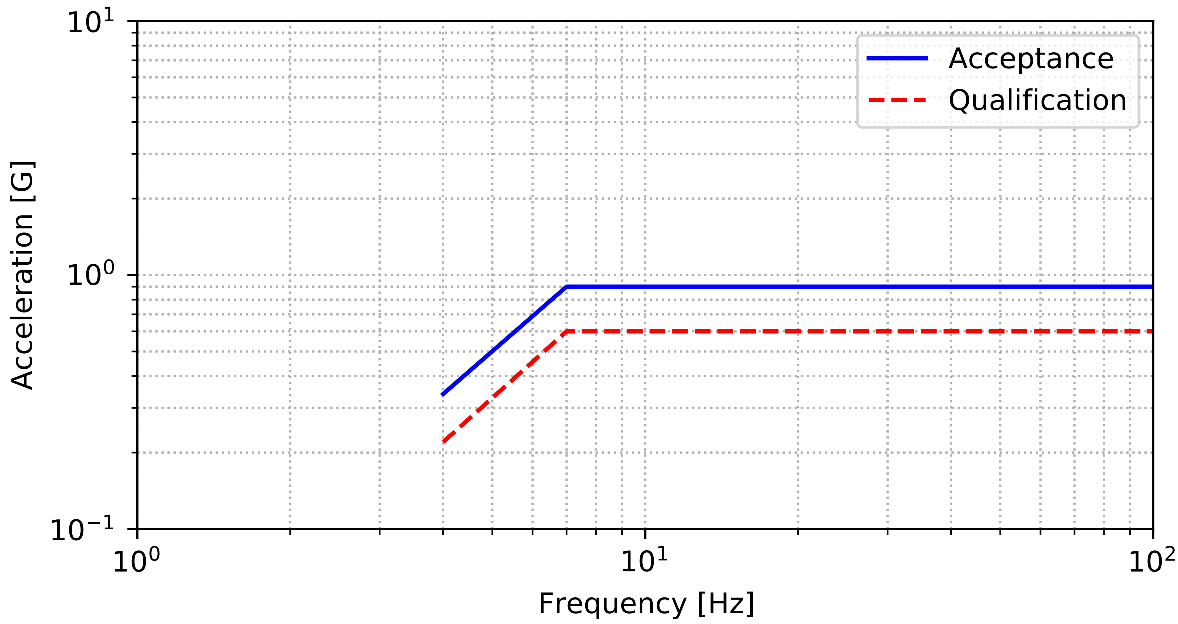


Figure 9.9: Sinusoidal sweeping vibration curve.

20 Hz	@	0.01 g^2/Hz
20 to 80 Hz	@	+3 dB/oct
80 to 500 Hz	@	0.04 g^2/Hz
500 to 2000 Hz	@	-3 dB/oct
2000 Hz	@	0.01 g^2/Hz
Overall Level	=	6.8 grms

Figure 9.10: Component Minimum Workmanship Random Vibration Test Levels.

Parameter	Value
Number of cycles	6
Minimum temperature	$T_{min} = -15°C$
Maximum temperature	$T_{max} = +50°C$
Duration in T_{min}	30 min
Duration in T_{max}	60 min
Heating rate	5.5 °C/min
Cooling rate	3.5°C/min
Stabilization criteria	1°C/10 min

Table 9.5: Parameters for the thermal cycling.

9.2.6 Bake Out

Here the CubeSat is exposed to a high temperature in a high vacuum environment during a determined time to stimulate their outgassing to fulfill a requirement established to launch.

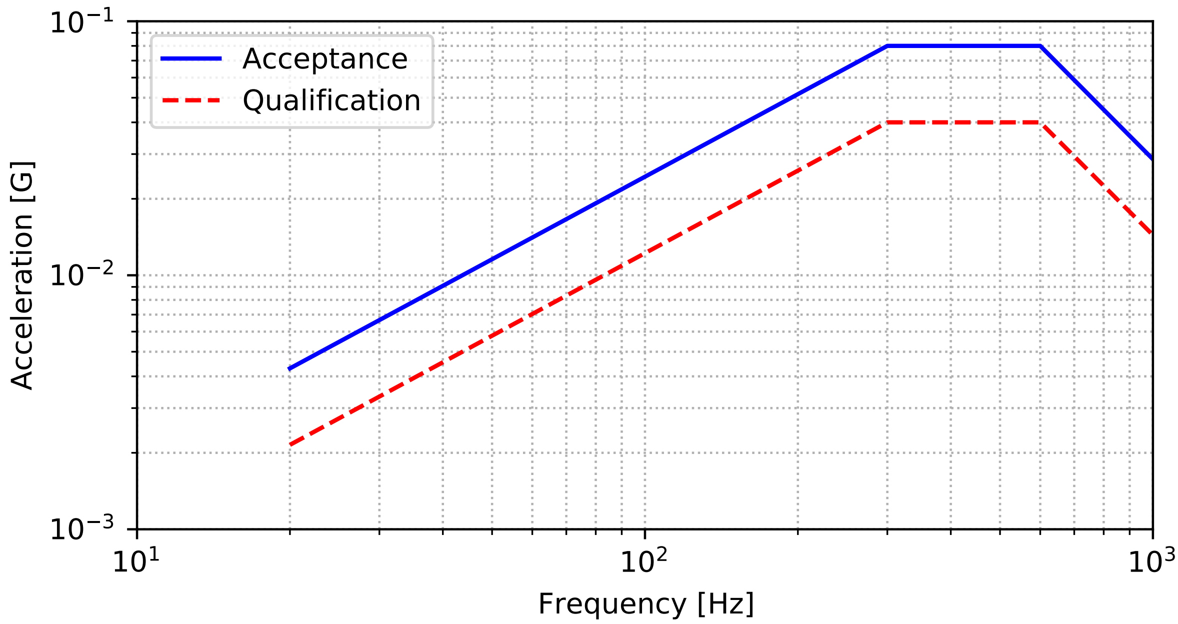


Figure 9.11: Random vibration test.

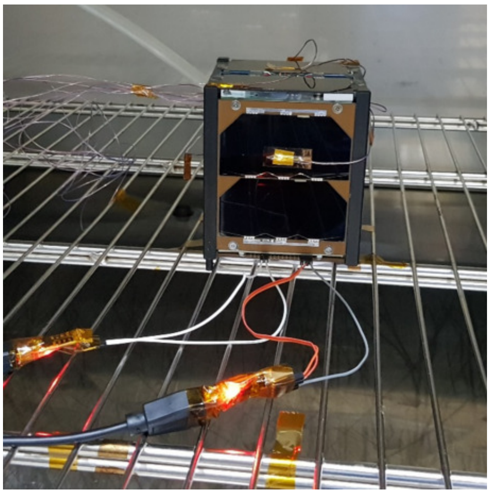


Figure 9.12: FloripaSat-1 during the thermal cycling (with thermocouples).

The Bake-out test requirements usually come from the launch provider, but in the absence of this information, the plan is summarized in Table 9.6.

9.2.7 EMC Testing

9.2.7.1 EMC: Radiation Emission(RE)

For EMC Radiation Emission test, refer to ECSS-E-ST-20-07C clause 5.4.6. The levels can be found at ECSS-E-ST-20-07C Annex A. The number of applications shall be one.

Parameter	Value
Part 1	
Pressure	$<1\times10^{-4}$ mbar
Temperature	23 °C
Duration	12 hours
Part 2	
Pressure	$<1\times10^{-4}$ mbar
Temperature	60 °C
Duration	6 hours

Table 9.6: Parameters for the bake out.

9.2.7.2 EMC: Conducted Emission (CE)

For EMC Conducted Emission test, refer to ECSS-E-ST-20-07C clause 5.4.2 The levels can be found at ECSS-E-ST-20-07C Annex A. The number of applications shall be one.

9.2.7.3 EMC: Radiation Susceptibility (RS)

For EMC Radiation Susceptibility test, refer to ECSS-E-ST-20-07C clause 5.4.11 The levels can be found at ECSS-E-ST-20-07C Annex A. The number of applications shall be one.

9.2.7.4 EMC: Conducted Susceptibility (CS)

For EMC Conducted Susceptibility test, refer to ECSS-E-ST-20-07C clause 5.4.7 The levels can be found at ECSS-E-ST-20-07C Annex A. The number of applications shall be one.

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APPENDIX A

Link Budget Calculation

This appendix shows the link budget calculation of all the satellite links (including the radio links of the payloads). The method used was taken from [8] (section 13.3).

A.1 Distance to Satellite at Horizon

The distance to the satellite at the horizon (the maximum theoretical distance between the satellite and a ground station) can be calculated using Equation A.1.

$$d = \sqrt{2 \cdot R_e \cdot h + h^2} \tag{A.1}$$

Where:

- R_e = Earth radius = 6378 km
- h = Satellite altitude = 550 km
- d = Distance to the satellite at the horizon

So, the distance to the satellite at the horizon is:

$$d = \sqrt{2 \cdot 6378 \cdot 550 + 550^2} = \mathbf{2705\ km} \tag{A.2}$$

A.2 Free-Space Path Loss

The free-space path loss ($FSPL$) can be calculated using Equation A.3.

$$FSPL = \left(\frac{4\pi d f}{c}\right)^2 \tag{A.3}$$

Where:

- d = Distance between the satellite and the ground station
- f = Radiofrequency
- c = Speed of light

The FSPL value in decibels can be calculated with Equation A.4.

$$\begin{aligned} FSPL^{dB} &= 20\log\left(\frac{4\pi}{c}\right) + 20\log(d) + 20\log(f) \\ &= 32,45 + 20\log\left(\frac{d}{1\ km}\right) + 20\log\left(\frac{f}{1\ MHz}\right) \end{aligned} \tag{A.4}$$

The minimum distance between the satellite and a ground station is the satellite altitude, in this case: 600 km. The maximum distance is the distance at the horizon, defined by Equation A.2.

A.2.1 Beacon

Considering the frequency of the beacon as 437 MHz, the minimum and maximum FSBL is:

$$FSPL^{dB}_{min} = 32,45 + 20\log\left(\frac{550}{1\ km}\right) + 20\log\left(\frac{146}{1\ MHz}\right) = \mathbf{130,5\ dB} \tag{A.5}$$

$$FSPL^{dB}_{max} = 32,45 + 20\log\left(\frac{2705}{1\ km}\right) + 20\log\left(\frac{146}{1\ MHz}\right) = \mathbf{144,4\ dB} \tag{A.6}$$

$$\mathbf{130,5 \leq FSPL^{dB} \leq 144,4\ dB} \tag{A.7}$$

A.2.2 Downlink/Uplink

Considering the frequency of the downlink/uplink as 462,5 MHz, the minimum and maximum FSBL is:

$$FSPL^{dB}_{min} = 32,45 + 20\log\left(\frac{550}{1\ km}\right) + 20\log\left(\frac{450}{1\ MHz}\right) = \mathbf{140,3\ dB} \tag{A.8}$$

$$FSPL^{dB}_{max} = 32,45 + 20\log\left(\frac{2705}{1\ km}\right) + 20\log\left(\frac{450}{1\ MHz}\right) = \mathbf{154,2\ dB} \tag{A.9}$$

$$\mathbf{140,3 \leq FSPL^{dB} \leq 154,2\ dB} \tag{A.10}$$

A.2.3 Uplink (Payload)

Considering the frequency of the payload's uplink is 401,635 MHz, the minimum and maximum FSBL is:

$$FSPL^{dB}_{min} = 32,45 + 20\log\left(\frac{550}{1\ km}\right) + 20\log\left(\frac{401,635}{1\ MHz}\right) = \mathbf{139,3\ dB} \tag{A.11}$$

$$FSPL^{dB}_{max} = 32,45 + 20\log\left(\frac{2705}{1\ km}\right) + 20\log\left(\frac{401,635}{1\ MHz}\right) = \mathbf{153,2\ dB} \tag{A.12}$$

$$\mathbf{139,3 \leq FSPL^{dB} \leq 153,2\ dB} \tag{A.13}$$

A.3 Power at Receiver

The power of the signal at the receiver can be estimated using Equation A.14.

$$P_r = P_t + G_t + G_r - L_p - L_s \tag{A.14}$$

Where:

- P_r = Power at the receiver
- P_t = Transmitter power
- G_t = Antenna gain of the transmitter
- G_r = Antenna gain of the receiver
- L_p = FSPL (Free-Space Path Loss)
- L_s = Other losses in the system

Considering the worst scenario with the maximum possible distance between the satellite and a ground station, the power at the receiver for each link is calculated below.

A.3.1 Beacon

$$P_r = 30 + 0 + 12 - 144,4 - 5 = -107,4 \ dBm \tag{A.15}$$

$$\mathbf{P_r \geq -107,4\ dBm} \tag{A.16}$$

A.3.2 Downlink (UHF)

$$P_r = 30 + 0 + 12 - 154,2 - 5 = -117,2 \ dBm \tag{A.17}$$

$$\mathbf{P_r \geq -117,2\ dBm} \tag{A.18}$$

A.3.3 Uplink (UHF)

$$P_r = 44 + 12 + 0 - 154,2 - 5 = -103,2 \ dBm \tag{A.19}$$

$$\mathbf{P_r \geq -103,2\ dBm} \tag{A.20}$$

A.3.4 Uplink (Payload)

$$P_r = 30 + 3 + 0 - 153,2 - 5 = -125,2 \ dBm \tag{A.21}$$

$$\mathbf{P_r \geq -125,2\ dBm} \tag{A.22}$$

A.4 Signal-to-Noise-Ratio

The Signal-to-Noise-Ratio (SNR) of a transmitted signal at the receiver can be expressed using Equation A.23:

$$SNR = \frac{E_b}{N_0} = \frac{P_t G_t G_r}{k T_s R L_p} \tag{A.23}$$

Where:

- P_t = Transmitter power
- G_t = Antenna gain of the transmitter
- G_r = Receiver gain
- k = Boltzmann's constant ($\cong 1,3806 \times 10^{-23}\ J/K$)
- T_s = System noise temperature
- R = Data rate in bits per second (bps)
- L_p = Free-Space Path Loss (FSPL)

The system noise temperature (T_s) can be defined using Equation A.24.

$$T_s = T_{ant} + T_r \tag{A.24}$$

with:

$$T_r = \frac{T_0}{L_r}(F - L_r) \tag{A.25}$$

and:

$$F = 1 + \frac{T_r}{T_0} \tag{A.26}$$

Combining Equations A.24, A.25 and A.26:

$$T_s = T_{ant} + \left(\frac{T_0(1 - L_r)}{L_r}\right) + \left(\frac{T_0(F - 1)}{L_r}\right) \tag{A.27}$$

Where:

- T_{ant} = Antenna noise temperature
- T_0 = Reference temperature (usually 290 K)
- L_r = Line loss between the antenna and the receiver
- F = Noise figure of the receiver
- T_r = Noise temperature of the receiver

The SNR value in decibels can be calculated using the Equation A.28:

$$\begin{aligned} SNR^{dB} &= 10\log_{10}\left(\frac{E_b}{N_0}\right) = 10\log_{10}\left(\frac{P_tG_tG_r}{kT_sRL_p}\right) \\ &= P_t^{dBm} - 30 + G_t^{dB} + G_r^{dB} - L_p^{dB} - 10\log k - 10\log T_s - 10\log R \end{aligned} \tag{A.28}$$

Considering other losses in the system (L_s) (cable and connection losses as an example), the Equation A.28 can be corrected as presented in Equation A.29.

$$SNR^{dB} = P_t^{dBm} - 30 + G_t^{dB} + G_r^{dB} - L_p^{dB} - L_s^{dB} - 10\log k - 10\log T_s - 10\log R \tag{A.29}$$

A.4.1 Beacon

Using Equations A.29 and A.24, with:

- $P_t = 30\ dBm$
- $G_t = 0\ dBi$
- $G_r = 12\ dBi$
- $L_p = 144,4\ dB$
- $L_s = 5\ dB$
- $R = 1200\ bps$
- $T_0 = 290\ K$
- $T_r = 290\ K$
- $T_{ant} = 300\ K$
- $F = 2\ dB$
- $L_r = 0,89\ (0,5\ dB)$

$$T_s = 300 + \left(\frac{290(1-0,89)}{0,89}\right) + \left(\frac{290(2-1)}{0,89}\right) = 661,7\ K \tag{A.30}$$

$$SNR^{dB} = 30 - 30 + 0 + 12 - 144,4 - 5 + 228,6 - 28,21 - 30,79 = 32,22\ dB \tag{A.31}$$

$$\mathbf{SNR^{dB} \geq 32,22\ dB} \tag{A.32}$$

A.4.2 Downlink

Using Equations A.29 and A.24, with:

- $P_t = 30\ dBm$
- $G_t = 0\ dBi$
- $G_r = 12\ dBi$
- $L_p = 154,2\ dB$
- $L_s = 5\ dB$
- $R = 9600\ bps$
- $T_0 = 290\ K$
- $T_r = 290\ K$
- $T_{ant} = 300\ K$
- $F = 2\ dB$
- $L_r = 0,89\ (0,5\ dB)$

$$SNR^{dB} = 30 - 30 + 0 + 12 - 154,2 - 5 + 228,6 - 28,21 - 39,82 = 13,41\ dB \quad \text{(A.33)}$$

$$\mathbf{SNR^{dB} \geq 13,41\ dB} \quad \text{(A.34)}$$

A.4.3 Uplink

Using Equations A.29 and A.24, with:

- $P_t = 44\ dBm$
- $G_t = 12\ dBi$
- $G_r = 0\ dBi$
- $L_p = 154,2\ dB$
- $L_s = 5\ dB$
- $R = 9600\ bps$
- $T_0 = 290\ K$
- $T_r = 290\ K$
- $T_{ant} = 300\ K$
- $F = 2\ dB$

- $L_r = 0,89\ (0,5\ dB)$

$$SNR^{dB} = 44 - 30 + 12 + 0 - 154,2 - 5 + 228,6 - 28,21 - 39,82 = 27,41\ dB \quad (A.35)$$

$$\mathbf{SNR^{dB} \geq 27,41\ dB} \quad (A.36)$$

A.4.4 Uplink (Payload)

Using Equations A.29 and A.24, with:

- $P_t = 30\ dBm$
- $G_t = 3\ dBi$
- $G_r = 0\ dBi$
- $L_p = 153,2\ dB$
- $L_s = 5\ dB$
- $R = 400\ bps$
- $T_0 = 290\ K$
- $T_r = 290\ K$
- $T_{ant} = 300\ K$
- $F = 2\ dB$
- $L_r = 0,89\ (0,5\ dB)$

$$SNR^{dB} = 30 - 30 + 3 + 0 - 153,2 - 5 + 228,6 - 28,21 - 26,02 = 19,17\ dB \quad (A.37)$$

$$\mathbf{SNR^{dB} \geq 19,17\ dB} \quad (A.38)$$

A.5 Link Margin

From [8], the minimum SNR value at the received considering a 10^{-5} bit error rate is:

- Beacon: $SNR^{dB} \geq 9,6\ dB$
- Downlink/Uplink: $SNR^{dB} \geq 9,6\ dB$
- Uplink (payload): $SNR^{dB} \geq 9,6\ dB$

And considering the link margin as the SNR of the link minus the SNR threshold for a given bit error, the link margin of the radio links of the satellite are:

- Beacon: $32,22 - 9,6 = \mathbf{22,62}$ **dB**
- Downlink: $13,41 - 9,6 = \mathbf{3,812}$ **dB**
- Uplink: $27,41 - 9,6 = \mathbf{17,81}$ **dB**
- Uplink (payload): $19,17 - 9,6 = \mathbf{9,57}$ **dB**

APPENDIX B

Telecommunication Packets

This appendix lists all the packets used by the RF links of the satellite: Beacon, downlink, and uplink. The fields and length of each type of packet is also presented.

B.1 Beacon

The Table B.1 presents the content of the beacon packets.

Packet	Position	Content	Length [bytes]
	0	Packet ID (00h)	1
	1	Source callsign (" PY0EFS")	7
	8	Timestamp in ms	4
	12	Battery cell 1 voltage in mV	2
	14	Battery cell 2 voltage in mV	2
	16	Battery current in mA	2
	18	Battery charge in mAh	2
	20	Battery cell 1 temperature in K	2
	22	Battery cell 2 temperature in K	2
	24	Battery monitor temperature in K	2
EPS data	26	Solar panel voltage in mV (-Y and +X)	2
	28	Solar panel voltage in mV (-X and +Z)	2
	30	Solar panel voltage in mV (-Z and +Y)	2
	32	Solar panel current in mA (-Y)	2
	34	Solar panel current in mA (+Y)	2
	36	Solar panel current in mA (-X)	2
	38	Solar panel current in mA (+X)	2
	40	Solar panel current in mA (-Z)	2
	42	Solar panel current in mA (+Z)	2
	44	Temperature of the EPS μC in K	2
			46
	0	Packet ID (01h)	1
TTC data	1	Source callsign (" PY0EFS")	7

8	Timestamp in ms	4
12	Temperature of the TTC μC in K	2
14	Reset counter	2
16	Last reset cause	1
15	Temperature of the beacon radio in K	2
		19

Table B.1: Beacon packets.

B.2 Downlink

In Table B.2 the content of the downlink packets is available.

Packet	**Position**	**Content**	**Length [bytes]**
	0	Packet ID (20h)	1
	1	Source callsign (" PY0EFS")	7
	8	Time counter in milliseconds	4
	12	Temperature of the OBDH μC in Kelvin	2
	14	Input current of the OBDH in mA	2
	16	Input voltage of the OBDH in mV	2
	18	Last reset cause of the OBDH	1
	19	Reset counter of the OBDH	2
	21	Last valid telecommand (uplink packet ID)	1
	22	Temperature of the radio in Kelvin	2
	24	RSSI of the last valid telecommand	2
	26	Temperature of the antenna in Kelvin	2
	28	Antenna status	2
	30	Payloads status	1
	31	Temperature of the EPS μC in K	2
	33	EPS circuitry and Beacon MCU current in mA	2
General telemetry	35	Last reset cause of the EPS	1
	36	Reset counter (EPS)	2
	38	-Y and +X sides solar panel voltage in mV	2
	40	-X and +Z sides solar panel voltage in mV	2
	42	-Z and +Y sides solar panel voltage in mV	2
	44	-Y side solar panel current in mA	2
	46	+Y side solar panel current in mA	2
	48	-X side solar panel current in mA	2
	50	+X side solar panel current in mA	2

	52	-Z side solar panel current in mA	2
	54	+Z side solar panel current in mA	2
	55	MPPT 1 duty cycle in %	1
	56	MPPT 2 duty cycle in %	1
	57	MPPT 3 duty cycle in %	1
	59	Main power bus voltage in mV	2
	61	Batteries voltage in mV	2
	63	Batteries current in mA	2
	65	Batteries average current in mA	2
	67	Batteries accumulated current in mA	2
	69	Batteries charge in mAh	2
	71	Battery monitor IC temperature in K	2
	73	Battery heater 1 duty cycle in %	1
	74	Battery heater 2 duty cycle in %	1
	75	Payload EDC status (00h=none, 01h=EDC_1, 02h=EDC_2, 03h=Both)	1
	76	Radiation instrument status (00h=OFF,01h=ON)	1
	77	Radiation monitor status (00h=OFF,01h=ON)	1
			78
Ping answer	0	Packet ID (21h)	1
	1	Source callsign (“ PY0EFS”)	7
	8	Requester callsign	7
			15
Data request answer	0	Packet ID (22h)	1
	1	Source callsign (“ PY0EFS”)	7
	8	Requester callsign	7
	15	Data type ID	1
	16	Timestamp	4
	20	Data	Var.
			20 (min.)
Message broadcast	0	Packet ID (23h)	1
	1	Source callsign (“ PY0EFS”)	7
	8	Requester callsign	7
	15	Destination callsign	7
	22	Message	up to 38
			22 to 60
	0	Packet ID (24h)	1
	1	Source callsign (“ PY0EFS”)	7
	8	Payload ID (01h or 02h)	1
	9	PTT signal receiving time	4
	13	Error code	1
	14	Carrier frequency	2

	16	Carrier amplitude at ADC interface output	2
	18	User message length in bytes	1
	19	ARGOS-2 PTT-A2 user message	35
	54	Current time since J2000 epoch	4
	58	Elapsed time since last reset	4
Payload data (EDC info)	62	System current supply in mA	2
	64	System voltage supply in mV	2
	65	EDC board temperature	1
	66	RF front end LO	1
	67	RMS level at front-end output	2
	69	Generated PTT packages since last initialization	1
	70	Max	1
	71	Memory error count	1
	72	Current time	4
	76	Number of PTT package available for reading	1
	77	PTT decoder task status	1
	78	ADC sampler state	1
			79
	0	Packet ID (24h)	1
	1	Source callsign (“ PY0EFS”)	7
	8	Payload ID (01h or 02h)	1
	9	Elapsed time since J2000 epoch	4
Payload data (EDC samples)	13	ADC sample packet number	1
	14	First ADC I-sample	2
	16	First ADC Q-sample	2
	...	...	...
	214	N ADC I-sample	2
	216	N ADC Q-sample	2
			218
	0	Packet ID (25h)	1
	1	Source callsign (“ PY0EFS”)	7
TC feedback	8	Requester callsign	7
	15	TC packet ID	1
	16	Timestamp	4
			20
	0	Packet ID (26h)	1
	1	Source callsign (“ PY0EFS”)	7
Parameter value	8	Requester callsign	7
	15	Subsystem ID	1
	16	Parameter ID	1
	17	Parameter value	4
			21

Table B.2: Downlink packets.

B.3 Uplink

As shown in Table 5.3, there are 14 supported telecommands. Below there is a description of each one.

- **Ping Request:** It is a simple command to test the communication with the satellite. When the satellite receives a ping packet, it will respond with another ping packet (with another packet ID, as defined in the downlink packets list). There are no additional parameters in the ping packet, just the packet ID and the source callsign (or address). It is also a public telecommand, anyone can send a ping request telecommand to a satellite.

- **Data Request:** It is a command to download data from the satellite. This command allows a ground station to get specific parameters from a given period (stored in the non-volatile memory of the onboard computer of the satellite). The list of possible parameters varies according to the satellite. The required fields of this telecommand are the parameter ID (1 byte), the start period in milliseconds (epoch, 4 bytes), and the end period in milliseconds (epoch, 4 bytes). This is a private telecommand, and a key is required to send it.

- **Bloadcast Message:** The "broadcast message" is another public telecommand, no authentication or key is required to send this telecommand to a satellite. This command has the purpose of making a satellite transmit a custom message back to Earth. This can be useful for communication tasks, like a station sending data to another. There are two parameters in this telecommand: the destination callsign (or address), and the content of the message, which can be any sequence of ASCII characters or any byte value. There is a limit of 38 characters in the message field.

- **Enter Hibernation:** This telecommand activates the hibernation mode in a satellite. During the hibernation mode, no transmissions are made by the satellite; it keeps just listening for new incoming packets (reception). The satellite will stay in hibernation mode for a custom period (1 to 65536 minutes), or until a "Leave Hibernation" mode is received. This is a private telecommand, a key is required to send it. Beyond the packet ID and the source callsign (or address), the number o minutes (2 bytes long) is also transmitted.

- **Leave Hibernation:** This telecommand complements the "enter hibernation" telecommand by deactivating the hibernation mode in the satellite. When a satellite receives this telecommand, it enables the transmission again immediately. This is also a private telecommand; a specific key is required to send it. There is no additional content to this telecommand packet, just the packet ID and the source callsign (or address).

- **Activate Module:** It activates an internal module of the satellite. Each module has a unique ID that is passed as an argument of this telecommand's packet. The module Battery heater's ID is 1, Beacon's ID is 2 and Periodic telemetry has ID number 3.

- **Activate Payload:** This one is similar to the telecommand "Activate Module", but in this case is used for activating payloads of the satellite. Each satellite will have a list of IDs of the set of payloads. This is also a private telecommand, and a key is required to transmit it.

- **Deactivate Payload:** It is the same as the "Deactivate Module" telecommand, but for payloads.
- **Erase Memory:** It erases all the content presented in the non-volatile memories of the onboard computer of a satellite. This is a private command, and a key is required to send it. No additional content is required in a erase memory telecommand packet, just the packet ID and the source callsign (or address).
- **Force Reset:** It performs a general reset of the satellite. When received, the satellite reset all subsystems. This is a private telecommand, and a key is required to send this command to a satellite. There is no additional content in this packet, just the packet ID and the source callsign (or address).
- **Get Payload Data:** It allows a ground station to download data from a specific payload of the satellite. The required fields are the payload ID, and optionally, arguments to be passed to the payload. The IDs and arguments vary according to the satellite. This is a private telecommand, and a key is required to send it.
- **Set Parameter:** It allows the configuration of specific parameters of a given subsystem of the satellite. The required fields are the ID of the subsystem to set (1 byte), the ID of the parameter to set (1 byte), and the new value of the parameter (4 bytes long). The possible IDs (subsystem and parameter) vary according to the satellite. This is a private telecommand, and a key is required to send it.
- **Get Parameter:** This telecommand complements the "Set Parameter" telecommand. It has the purpose of reading specific parameters of a given subsystem. The required fields are the subsystem's ID (1 byte) and the parameter ID (1 byte). The possible IDs (subsystem and parameter) vary according to the satellite. This is a private telecommand, and a key is required to send it.

The Table B.3 presents the content of the uplink packets.

Packet	Position	Content	Length [bytes]
Ping request	0	Packet ID (40h)	1
	1	Ground station callsign	7
			8
Data request	0	Packet ID (41h)	1
	1	Ground station callsign	7
	8	Data type ID	1
	9	Start timestamp	4
	13	End timestamp	4
	17	HMAC hash	20
			37
Broadcast message	0	Packet ID (42h)	1
	1	Ground station callsign	7
	8	Destination callsign	7
	15	Message	up to 38
			up to 53
Enter hibernation	0	Packet ID (43h)	1

	1	Ground station callsign	7
	8	Hibernation in hours	2
	10	HMAC hash	20
			30
Leave hibernation	0	Packet ID (44h)	1
	1	Ground station callsign	7
	8	HMAC hash	20
			28
Activate module	0	Packet ID (45h)	1
	1	Ground station callsign	7
	8	Module ID	1
	9	HMAC hash	20
			29
Deactivate module	0	Packet ID (46h)	1
	1	Ground station callsign	7
	8	Module ID	1
	9	HMAC hash	20
			29
Activate payload	0	Packet ID (47h)	1
	1	Ground station callsign	7
	8	Payload ID	1
	9	HMAC hash	20
			29
Deactivate payload	0	Packet ID (48h)	1
	1	Ground station callsign	7
	8	Payload ID	1
	9	HMAC hash	20
			29
Erase memory	0	Packet ID (49h)	1
	1	Ground station callsign	7
	8	HMAC hash	20
			28
Force reset	0	Packet ID (4Ah)	1
	1	Ground station callsign	7
	8	HMAC hash	20
			28
Get payload data	0	Packet ID (4Bh)	1
	1	Ground station callsign	7
	8	Payload ID	1
	9	Payload arguments	12
	21	HMAC hash	20
			41
Set parameter	0	Packet ID (4Ch)	1
	1	Ground station callsign	7
	8	Subsystem ID	1

	9	Parameter ID	1
	10	Parameter value	4
	14	HMAC hash	20
			34
Get parameter	0	Packet ID (4Dh)	1
	1	Ground station callsign	7
	8	Subsystem ID	1
	9	Parameter ID	1
	10	HMAC hash	20
			30

Table B.3: Uplink packets.

APPENDIX C

EDC Test Report

This appendix is a test report of the EDC board. The purpose of this test is to characterize the main functionalities of the EDC module. The main information about the test is available below:

- **Date**: From 2022/03/03 to 2022/03/14
- **Testers**: Bruno Benedetti, Gabriel M. Marcelino, Laio O. Seman

A picture of the boards used during the tests can be seen in Figure C.1.

This test is divided into two parts: the command interface test and RF chain test. Both are described below.

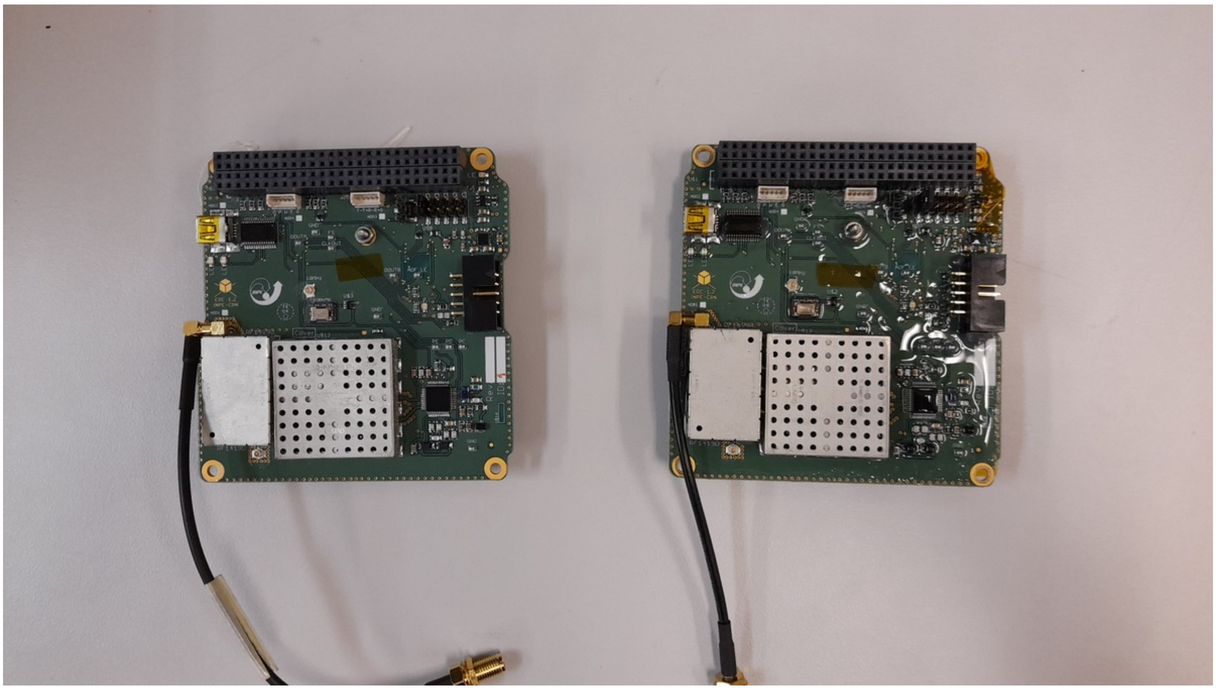
C.1 Command interface test

The command interface test aims to test the UART command interface available in the PC-104 bus of the module. All available commands were tested in this test.

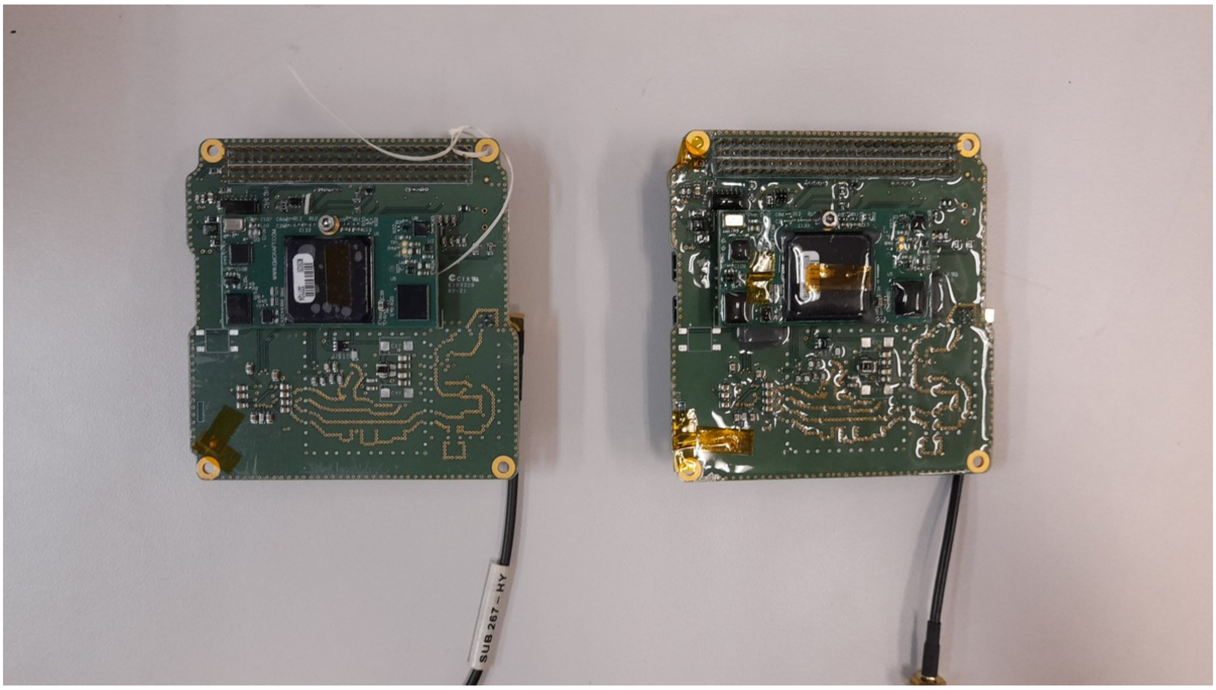
C.1.1 Used material

The used material is listed below:

- EDC boards
- USB-UART converter
- Saleae Logic Analyzer
- Protoboard
- Desktop computer
- Logic 2 software
- Cutecom software
- USB cables
- Pin header wires
- EDC documentation



(a) Top side.



(b) Bottom side.

Figure C.1: Tested EDC boards.

C.1.2 Setup

The test setup can be seen in Figure C.2. As seen in the picture, the USB-UART converter connects the UART interface of the EDC directly to a computer. The EDC board is powered directly by its USB debug interface.

To confirm and visualize the transmitted and received data, a logic analyzer is connected

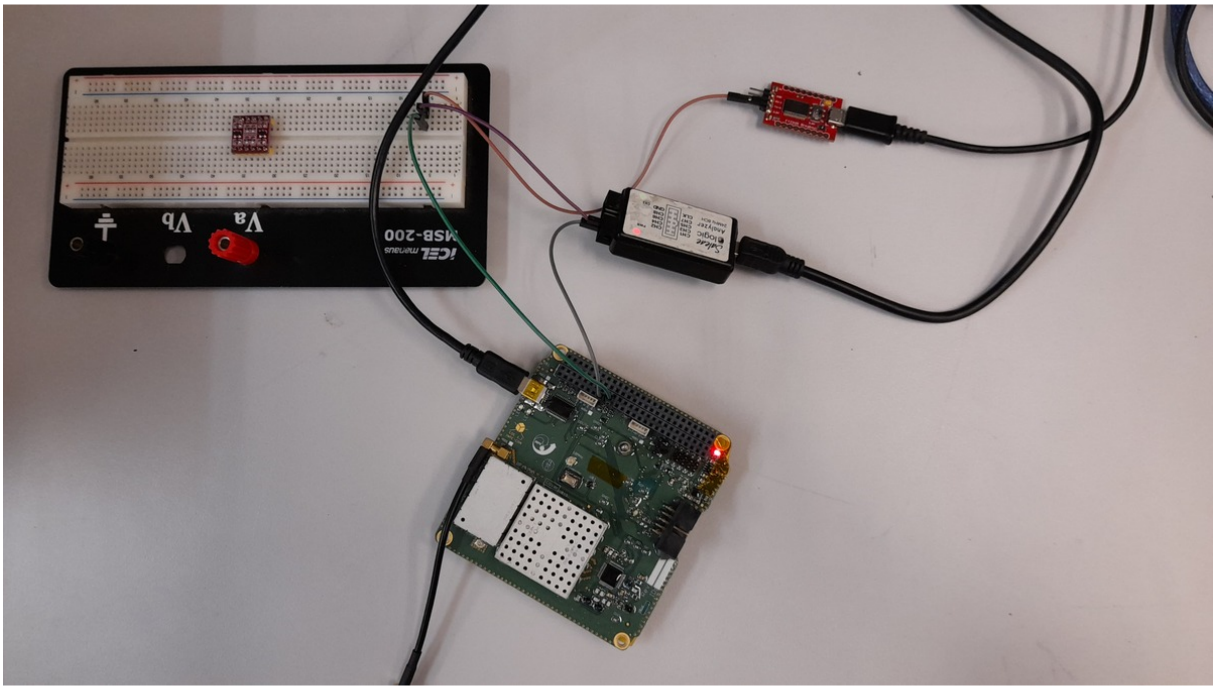


Figure C.2: Setup of the EDC's command interface test.

to the pins of the UART interface (TX and RX).

C.1.3 Results

During the first attempts to perform this test, no responses were received from both boards, considering all the available commands. After further investigation with the module developers (INPE-CRN), the issue was found. As can be seen in autoreffig:edc-cmd-issue, the voltage of the RX pin when in a low state is higher than expected, making all bits be interpreted as ones.

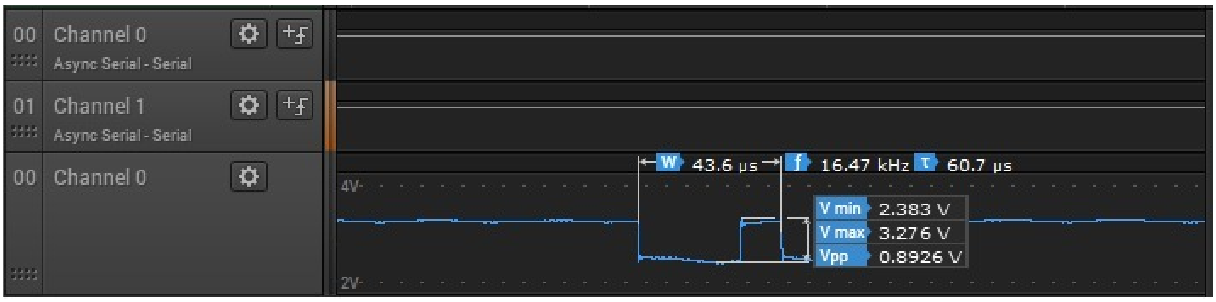


Figure C.3: Command interface issue.

The hypothesis for the cause of this problem is the RS-485 transceiver. As seen in Figure C.4, the RS-485 transceiver and the UART interfaces share the same UART port of the microcontroller. This way, the RS-485 transceiver can cause interference on the RX pin of the UART interface, forcing its state to be high all the time.

A solution to this problem is to disable the RS-485 transceiver by removing it from the board or putting the enable pin on a disabled state. As it would be difficult to remove

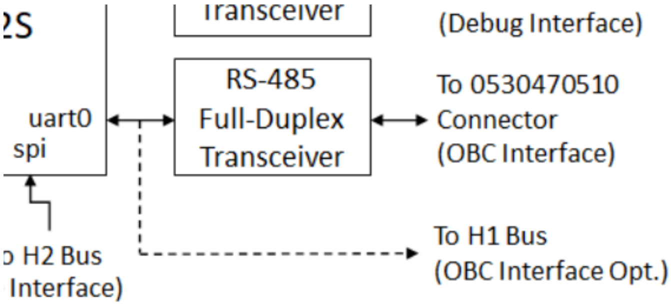


Figure C.4: UART and RS-485 interfaces of the EDC.

this component from the boards safely, the second option was chosen. With a modification in the firmware, the RS-485 transceiver was disabled. After this modification, the UART command interface started to work as expected, as can be seen in Figure C.5 ("echo" command).

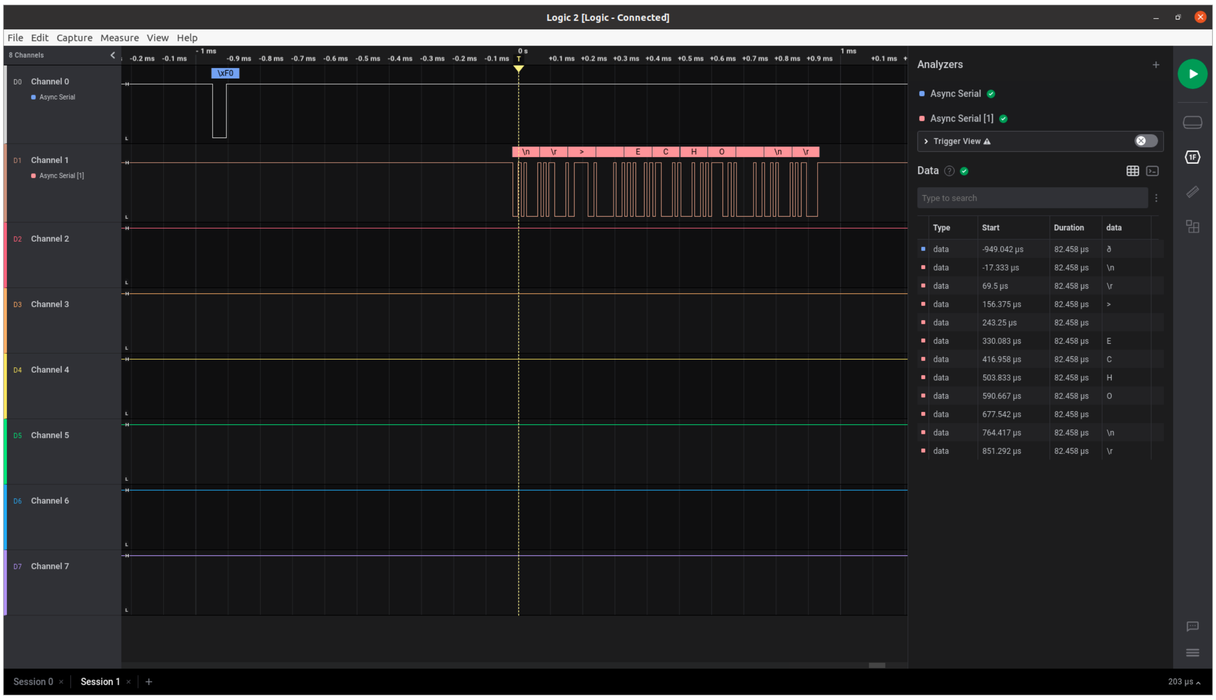


Figure C.5: "Echo" command demonstration.

C.2 RF chain test

This test simulates a signal transmitted by a DCP directly to the RF input of the EDC module. To emulate the DCP signal, a GNURadio flow generates the packets, and an SDR transmitter transmits the packet to the EDC. This test is divided into two steps: in the first step, we check the transmitted signal by the USRP, and in the second step, the EDC reception and decoding are verified.

C.2.1 Used material

The used material is listed below:

- EDC boards
- USB-UART converter
- Ettus USRP B210 SDR
- Desktop computer
- GNURadio v3.9
- Cutecom software
- USB cables
- Pin header wires
- SMA coaxial cable
- 30 dB attenuator
- RTL-SDR v3
- EDC documentation

C.2.2 Setup

This test is divided in two steps. The setup of the first step can be seen in Figure C.6. As can be seen in the picture, the SDR transmitter is connected directly to an SDR receiver through a 30 dB attenuator.

C.2.3 Results

The transmitted signal by the USRP SDR can be seen in Figure C.9.

The received and decoded packets by the EDC during the tests are available in Figure C.10. Each color line is a different decoded packet. The last byte sequence indicates the number of available packets in the queue (zero in this case, after reading all packets).

C.3 Conclusion

As presented in this report, an issue with the UART interface was found. A temporary solution was achieved by modifying the current version of the firmware and disabling the RS-485 transceiver by software. However, a better solution should be considered for the flight version of the boards; for example, the RS-485 CI can be unconsidered from the board assembly or disabled by hardware (with a jumper).

As for the RF chain test, no issues were identified so far, using the available stimulus signal, all packages are received and decoded as expected. The commands regarding the package reception also work as planned.

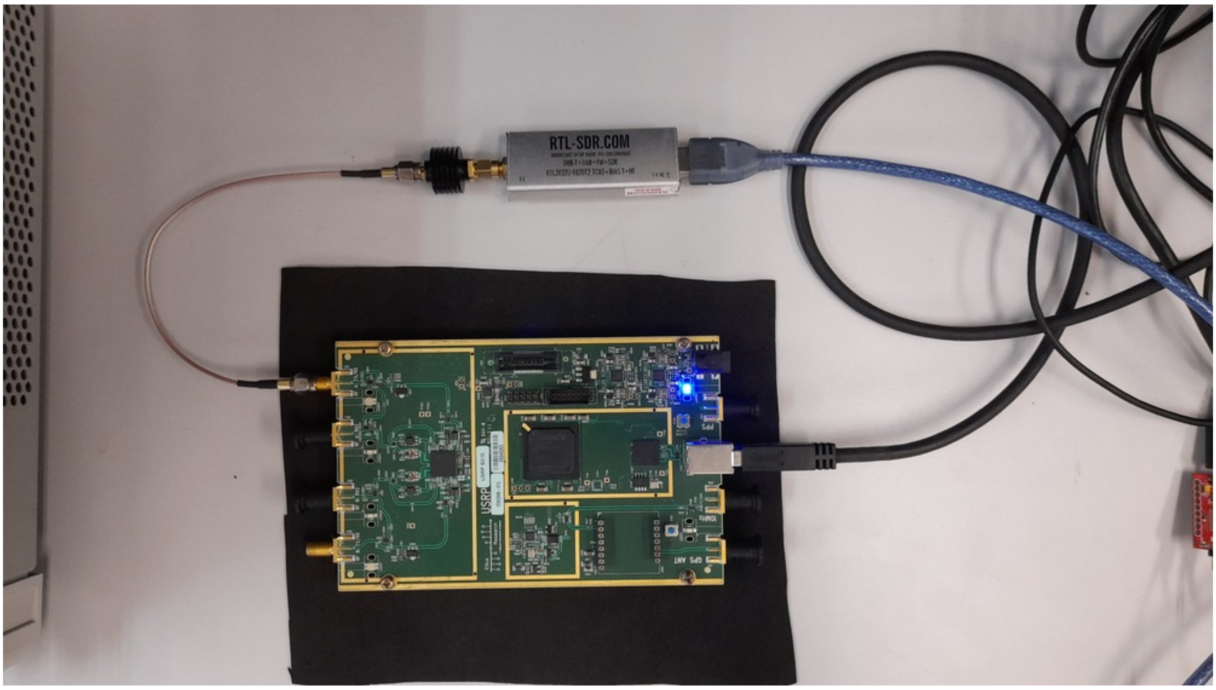


Figure C.6: Setup of the signal generator test.

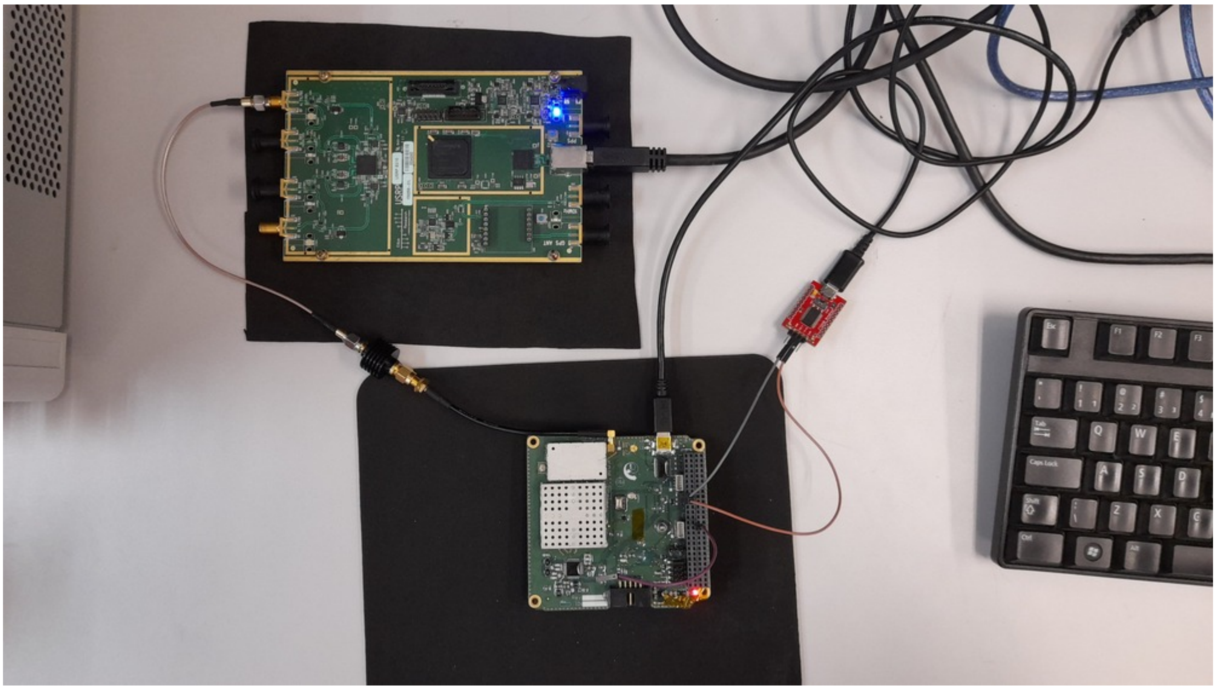


Figure C.7: Setup of the EDC's RF chain test.

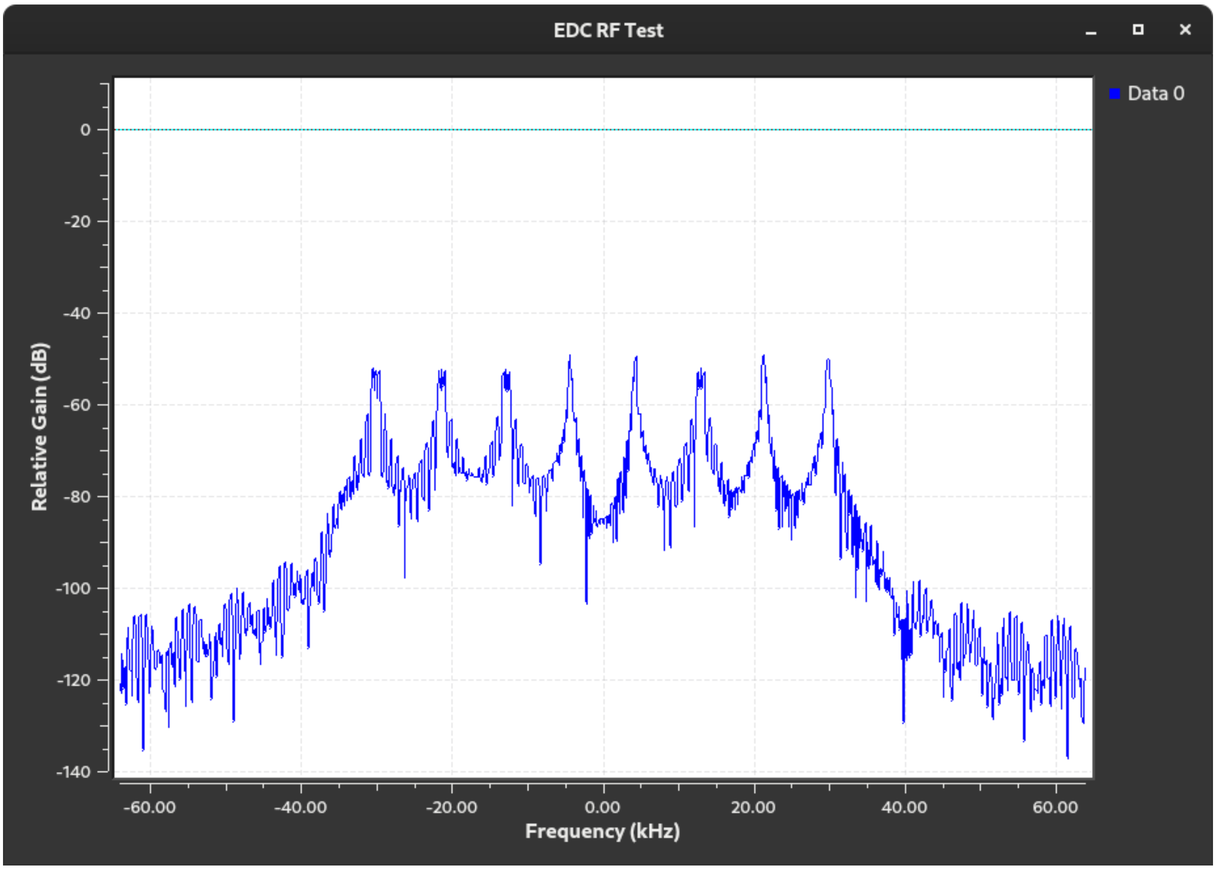


Figure C.8: Generated signal used in the RF chain test.

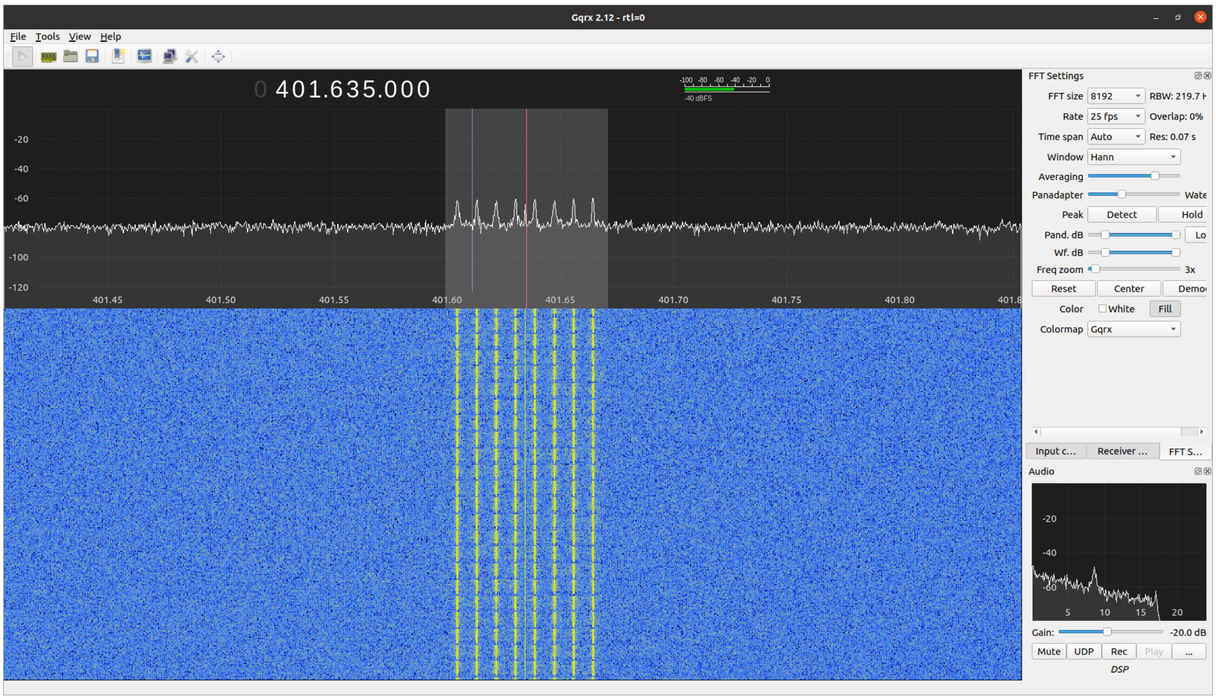


Figure C.9: Received signal from the EDC stimulus application.

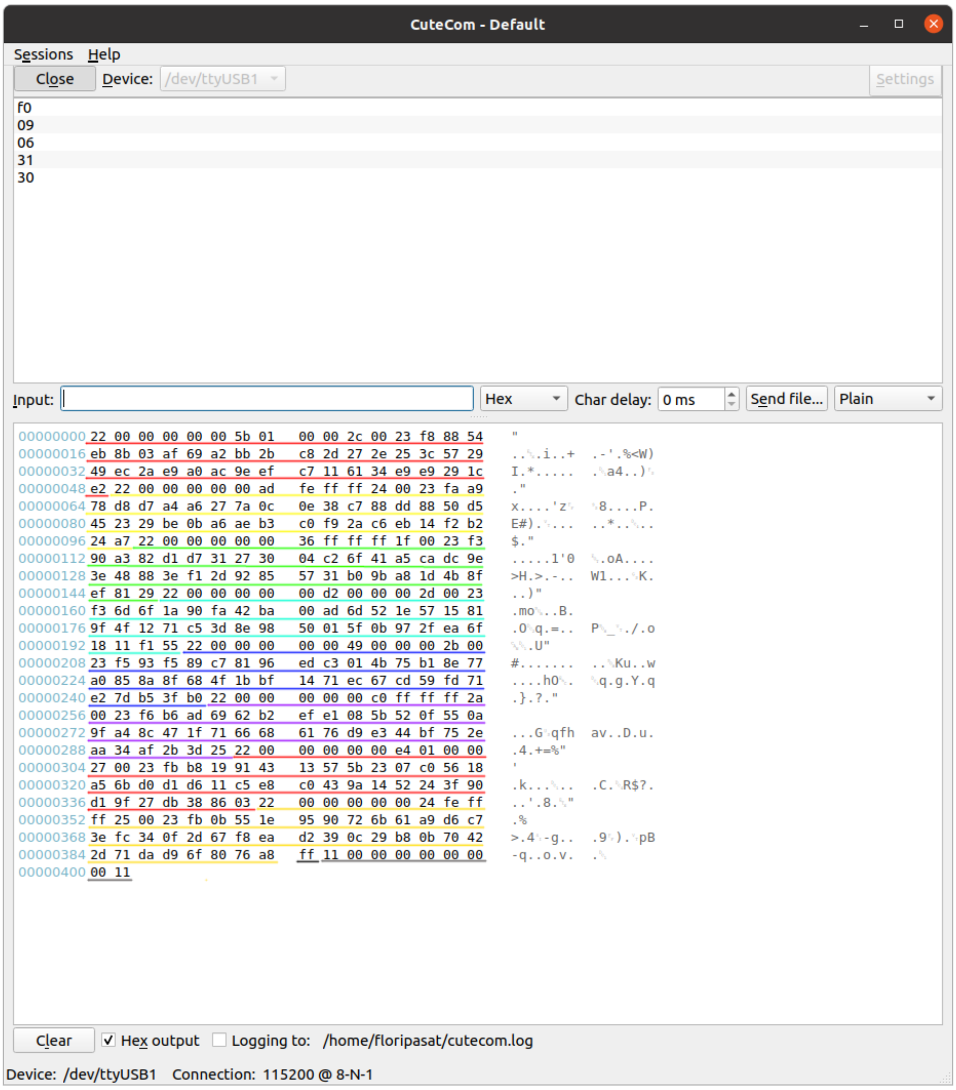


Figure C.10: Received PTT packages (colorful lines).