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Design of a FlatSat for the AlbaSat mission

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The man who moves a mountain
starts by moving small stones.
("Confucio")

ABSTRACT

This thesis presents the design of a FlatSat for the AlbaSat mission. AlbaSat is a 2U CubeSat with four mission objectives: (1) to collect in-situ measurements of the sub-mm space debris environment in LEO, (2) to study the micro-vibration environment on the satellite throughout different mission phases, (3) to do orbit determination through laser ranging; (4) to investigate alternative systems for possible Satellite Quantum Communication applications on nanosatellites.

Firstly, an overview of CubeSats state of art and of the AlbaSat mission is provided, illustrating the main mission objectives and the importance of testing, and verifying the satellite performance before launch using, for instance, a FlatSat. Subsequently, the objectives of the FlatSat in the AlbaSat mission are defined. These objectives include creating a test and verification platform to evaluate the satellite's functionalities, verifying the proper interaction between subsystems, and achieving performance and reliability requirements. The design of the FlatSat is described in detail, including component selection, functional architecture, subsystem arrangement, and interfaces between them. Aspects such as power supply, attitude control, data acquisition, and communication are considered. Special attention is given to subsystems integration to ensure proper connection and interaction. The tests programmed on the FlatSat are presented, including functional tests, integration tests, and communication tests.

The thesis is developed in the framework of the Alba CubeSat project, which participates to the European Space Agency’s (ESA) Fly Your Satellite! – design booster program. The thesis provides the guidelines to assembly, integrate, and test the FlatSat of AlbaSat, contributing to the development of the mission. The results and experiences gained from this research can be applied to future satellite development projects.

SOMMARIO

Questa tesi presenta il progetto di un FlatSat per la missione AlbaSat. AlbaSat è un CubeSat 2U con quattro obiettivi di missione: (1) raccogliere misure in-situ dell'ambiente dei detriti spaziali sub-mm in LEO, (2) studiare l'ambiente delle micro-vibrazioni sul satellite durante le diverse fasi della missione, (3) effettuare la determinazione dell'orbita attraverso il laser ranging; (4) studiare sistemi alternativi per possibili applicazioni di Comunicazione Quantistica Satellitare su nanosatelliti.

In primo luogo, viene fornita una panoramica dello stato dell'arte dei CubeSats e della missione AlbaSat, illustrando i principali obiettivi della missione e l'importanza di testare e verificare le prestazioni del satellite prima del lancio utilizzando, ad esempio, un FlatSat. Successivamente, vengono definiti gli obiettivi del FlatSat nella missione AlbaSat. Questi obiettivi includono la creazione di una piattaforma di test e verifica per valutare le funzionalità del satellite, la verifica della corretta interazione tra i sottosistemi e il raggiungimento dei requisiti di prestazione e affidabilità. Il progetto del FlatSat è descritto in dettaglio, compresa la selezione dei componenti, l'architettura funzionale, la disposizione dei sottosistemi e le interfacce tra di essi. Vengono presi in considerazione aspetti quali l'alimentazione, il controllo dell'assetto, l'acquisizione dei dati e la comunicazione. Particolare attenzione viene data all'integrazione dei sottosistemi per garantire una corretta connessione e interazione. Vengono presentati i test programmati sul FlatSat, compresi i test funzionali, i test di integrazione e i test di comunicazione.

La tesi è sviluppata nell'ambito del progetto Alba CubeSat, che partecipa al programma dell'Agenzia Spaziale Europea (ESA) Fly Your Satellite! - dell'Agenzia Spaziale Europea (ESA). La tesi fornisce le linee guida per assemblare, integrare e testare il FlatSat di AlbaSat, contribuendo allo sviluppo della missione. I risultati e le esperienze acquisite da questa ricerca possono essere applicati a futuri progetti di sviluppo di satelliti.

LIST OF ACRONYMS

ADCS	Attitude Determination and Control Subsystem
BBM	BreadBoard Model
CCR	Corner Cube Retroreflectors
CCEW	CubeSat Concurrent Engineering Workshop
COTS	Commercial Off The Shelf
EGSE	Electrical ground support equipment
EM	Engineering Model
ESA	European Space Agency
EPS	Electric Power Subsystem
FAR	Flight Acceptance Review
FFT	Full Functional Test
FM	Flight Model
FYS	Fly You Satellite!
IS	Impact Sensor
LEO	Low Earth Orbit
MDR	Mission Definition Review
MRR	Modulating Retro Reflector
MVS	Micro-Vibration Sensor
OBC	On Board Computer
OBDH	On Board Data Handling
OBSW	On Board Software
PCB	Printed Circuit Board
PFM	ProtoFlight Model
PRR	Preliminary Requirements Review
PSD	Power Spectral Density
QFP	Quantum Future Payload
RFT	Reduced Functional Test

SLR	Satellite Laser Ranging
SNR	Signal Noise Ratio
SOA	State of the Art
SPI	Serial Peripheral Interface
TRL	Technology Readiness Level
TTC	Telemetry, Tracking and Command
V&V	Validation and Verification

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Chapter 1

INTRODUCTION TO SMALL SATELLITE

Miniaturized satellites are satellites with reduced mass, usually below 500 kg. This type of satellite can be further divided as follows [1]:

- **Minisatellite**: Artificial satellites with a mass ranging from 100 kg to 500 kg, including propellant.
- **Microsatellite**: Artificial satellites with a mass ranging from 10 kg to 100 kg, including propellant.
- **Nanosatellite**: Artificial satellites with a mass ranging from 1 kg to 10 kg.
- **Picosatellite**: Artificial satellites with a mass ranging from 100 g to 1 kg.

CubeSats belong to the class of nanosatellites and have precise geometric dimensions. In fact, their basic unit, called "1U", is a cube with a side of 10 cm, and weight lower than 1.33 kg. Multiple units can be connected to form a satellite capable of hosting payloads with dimensions greater than one unit, such as CubeSat 2U, 3U, 6U, and 12U [2].

This technology proved to be a low-cost approach for developing space missions, in addition it is characterized by short development time. The strength of CubeSats lies in the use of "Commercial Off-The-Shelf" (COTS) components which, having a high TRL (Technology Readiness Level), often ensures that fewer tests can be carried out. Depending on the application for which a CubeSat mission is designed, its cost can range from tens of thousands to a few million dollars, with development times much shorter than typical space missions [3].

An example for low-cost CubeSat missions is “e-st@r” from the University of Turin, which with a budget of EUR 50,000 managed to complete the mission. The main objective of “e-st@r” CubeSat 1U was to demonstrate the capability of autonomous determination, control, and maneuver, through the development and test in orbit of an

Attitude Determination and Control Subsystem (ADCS) entirely designed and manufactured by students [4].

On the other hand, a mission with a budget of over EUR 2 million is ESA's OPS-SAT, which aims to demonstrate the improvements in mission control capabilities that will occur when satellites can fly with high performances on-board computers [5].

CubeSats emerged in the early 2000s at the California Polytechnic State University (Cal Poly) with the goal of developing academic projects that allow students to gain practical skills in the aerospace field [2].The first launch of CubeSats took place in 1998 [6]. The first CubeSat designed and developed by a university was AAU, launched in 2003 by Aalborg University in Denmark. However, the mission failed after two months of operations as it was no longer possible to re-establish a connection with the satellite [7]. Figure 1-1shows the numbers related to all nanosatellite and CubeSat missions from 1998 with a projection up to 2027 [6].

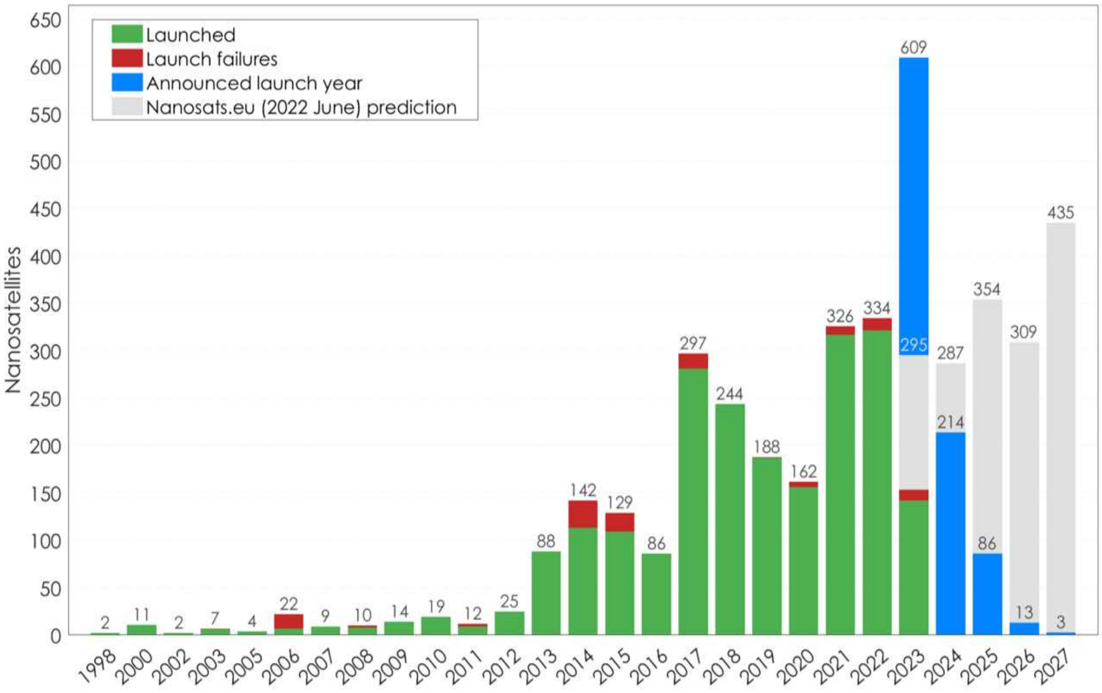


Figure 1-1: CubeSat mission launches from 1998 to 2027.

CubeSats are considered a competitive solution for space applications because they allow for a balance between essential elements of a space project, such as mission duration, reliability, development times, and costs [3]. Of course, with CubeSats it is not possible to achieve the performance that is possible with much larger satellites. For applications such as telescopes, for example, large satellites are preferred because they can accommodate instruments that are significantly more powerful than those that could be mounted on a CubeSat. Despite this, CubeSats have features that have enabled them to become very popular. For one thing, they have enabled small and medium sized companies to use this technology as it is available at more affordable prices. Moreover, whereas the development of a conventional satellite takes years, a CubeSat can be launched in a matter of months. This is thanks to a great deal of standardization of the components used in NanoSat production [8].

In fact, the International Organization for Standardization published the ISO 17770:2017 standard in 2017. This standard indicates the physical, mechanical, electrical, and operational requirements for CubeSats. It also provides instructions for the interface that connects CubeSat to the launch vehicle and lists the capabilities needed to survive the environmental conditions both during and after launch.

By using COTS, development time is reduced as well as costs and the tests that are carried out on the entire system may be reduced. However, this introduces possible risk factors for the mission. The choice of developing a CubeSat mission is a trade-off between reduced costs, short development time and increased risk in the design of the Nanosat [9].

Each subsystem uses printed circuit boards called PC104, which are made specifically to meet mission objectives. These boards have dimensions just under 10 cm so that they can fit inside a CubeSat unit. In addition, a specific connection, called “stack connector”, is used to connect the different subsystems. This is a male-female connector formed by two ports called H1 and H2 each formed by two rows of twenty-six pins each, for a total of one hundred and four pins. This connection allows the subsystems to be "stacked" on top of each other, ensuring connection between them but most importantly saving space [10].

A PC104 board is shown in Figure 1-2 by highlighting the female stack connector port.

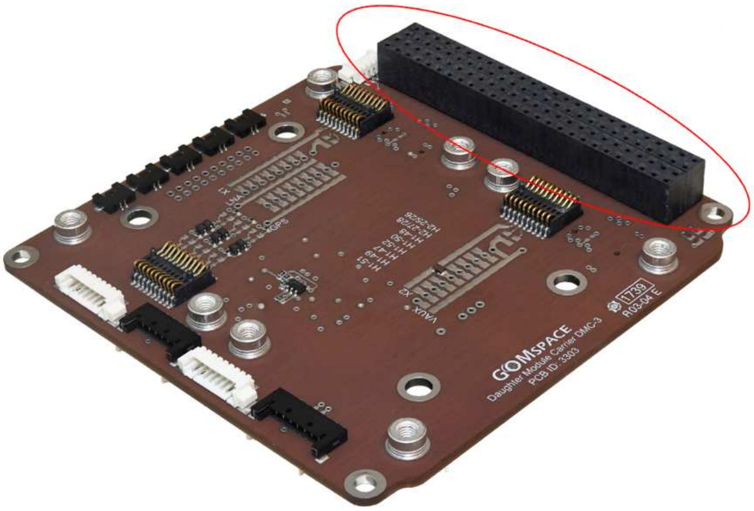


Figure 1-2: Example of a PC104 board.

In addition, this technology revolutionized the way satellites were launched. Initially, launches were carried out with only a few large satellites on board. However, with the development of CubeSats, it has become possible to carry out launches with many nanosatellites, forming constellations or containing completely independent scientific experiments. In addition, through the "piggyback" configuration, it is possible to fill the empty spaces left by large satellites inside a launcher with CubeSats. In this way the launch cost is reduced. Some piggyback configurations used by ESA during the 2019 launch of Vega are depicted Figure 1-3 [11].

Figure 1-3: Piggyback configuration used by ESA in 2019.

Thanks to these reasons, the use of this type of nanosatellite has expanded beyond the university sector, gaining interest from private companies and governmental institutions worldwide. An example is the DART mission that used a CubeSat, LICIA that flew by the asteroid "65803 Didymos" reaching a perigee of 51 km, and then continuing its journey in space, sending photos taken during the flyby back to earth [12].

The Figure 1-4 shows the number of CubeSats launched by different countries worldwide from 2000 to 2022, highlighting how this phenomenon is an innovation in the space field that is not limited to a specific geographical area but is widespread globally [6].

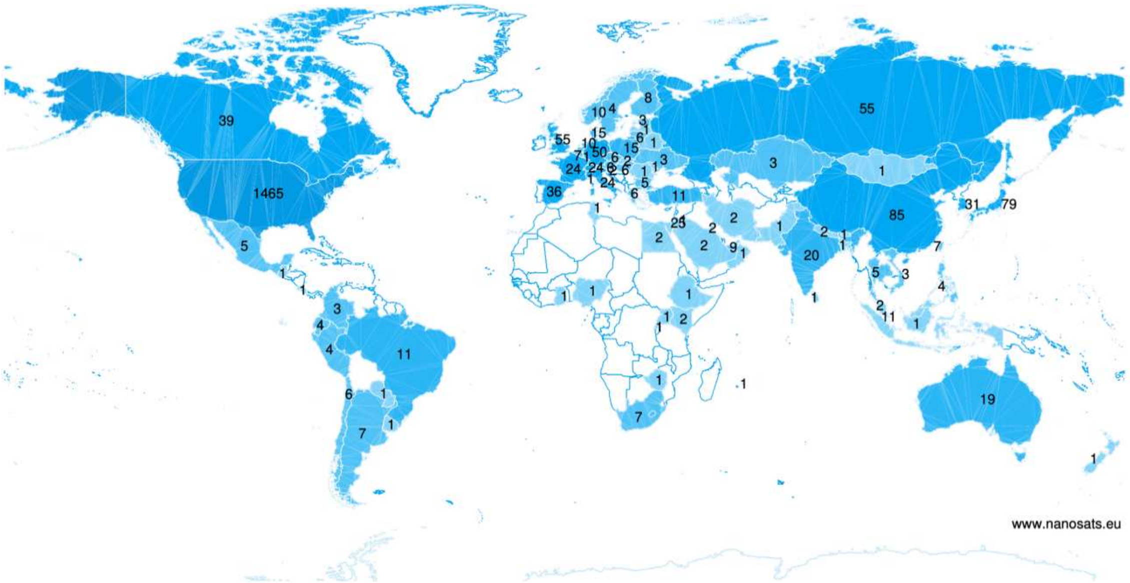


Figure 1-4: CubeSat launched for country from 2000 to 2023.

With the widespread use of CubeSats, it is interesting to show their distribution based on the application sector. Due to these factors, interest in using this kind of nanosatellite has spread beyond the academic community and into the business and governmental sectors around the globe, as seen in the accompanying graph [6].

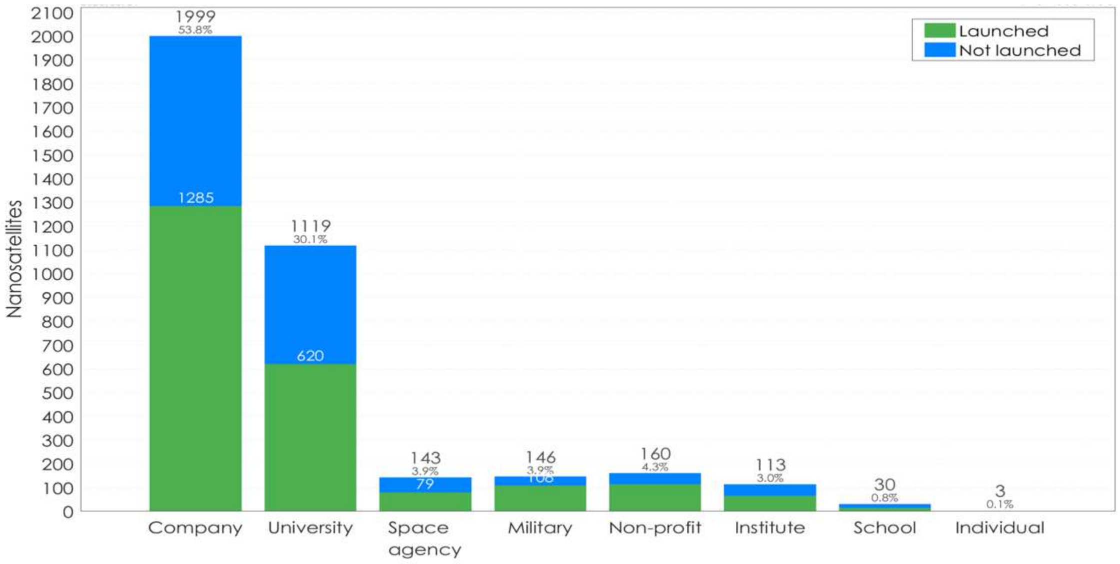


Figure 1-5: CubeSat launched by organization.

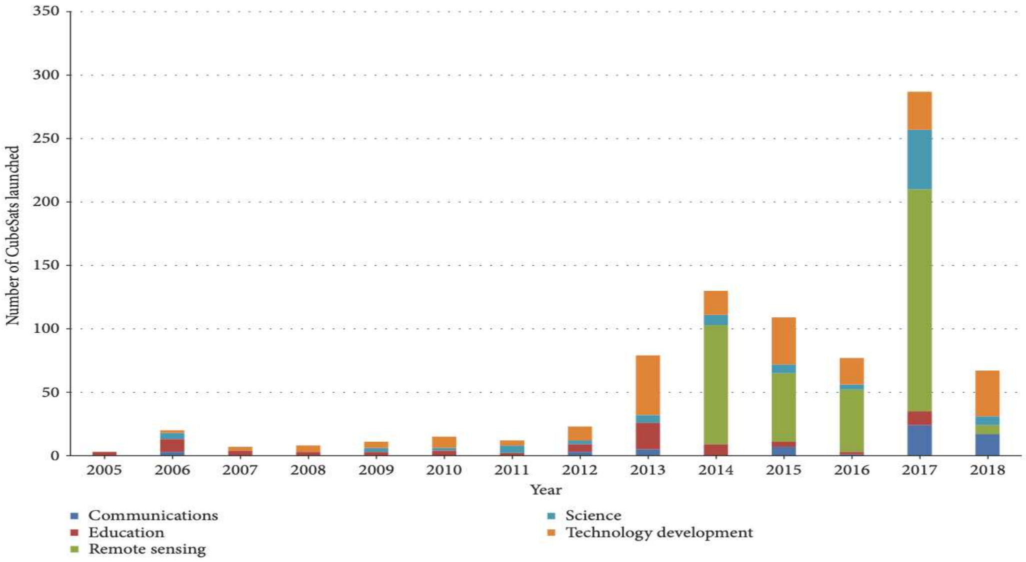


Figure 1-6: CubeSats launched per year and per application from 2005 to May 31, 2018.

Additionally, as observed from the Figure 1-6, the primary objective of missions that use this type of nanosatellite is Earth observation, followed by the development of new technologies and scientific applications, communication and, finally, educational purposes.

This once again highlights how CubeSats, originally designed mainly to provide universities with a cost-effective educational solution for space mission development, have evolved into much larger projects with applications in various fields, leading to significant technological advancements [2].

To achieve mission objectives, different CubeSat sizes can be used. The most common one, accounting for approximately 64% of the total number of nanosatellites launched, is the 3U, followed by the 1U at about 19%, the 2U at 8%, and the remaining percentage with other configurations such as 6U and 12U [3].

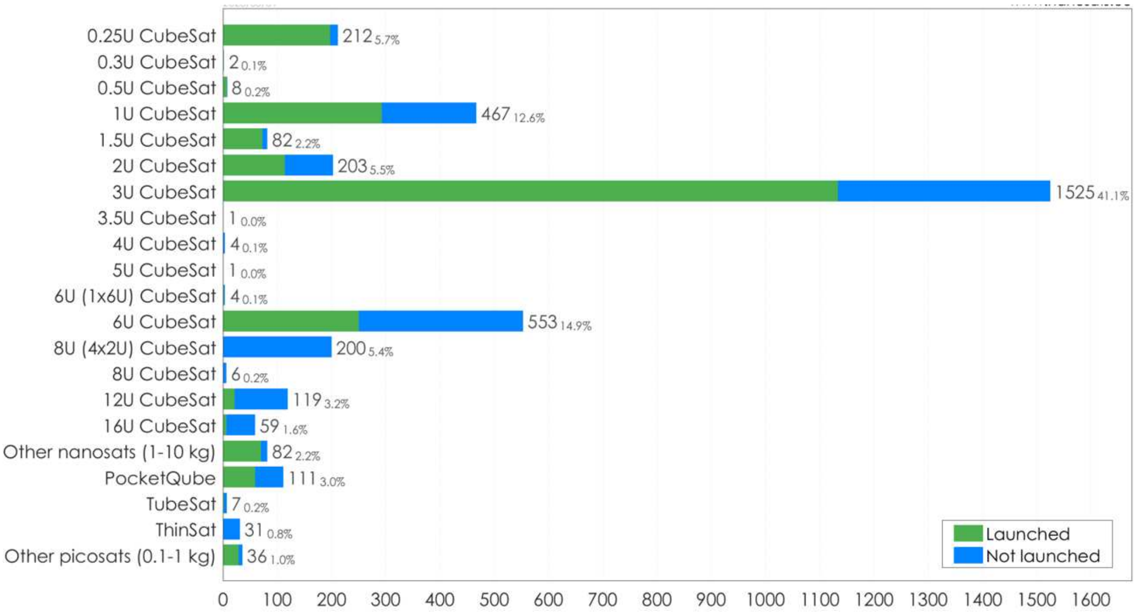


Figure 1-7: CubeSats type from 2000 to 2023.

One of the concerns regarding the use of CubeSats is their failure rate. As the technology has progressed, some companies have specialized in the production of specific components, ensuring higher levels of reliability thanks to the flight heritage accumulated over these two decades [13]. From the Figure 1-8, it can be inferred that a significant portion of the failures of missions using CubeSats is attributed to issues occurring during the launch phase. At the same time, mission failures due to CubeSat malfunctions have decreased over the years, as well as problems related to the launch. In fact, when analyzing missions from 2005 through 2012, the success rate is 48 %. On the other hand, looking at missions from 2005 to 2018, the same percentage rises to 61 percent thus demonstrating how over the years CubeSats are improving their reliability [6].

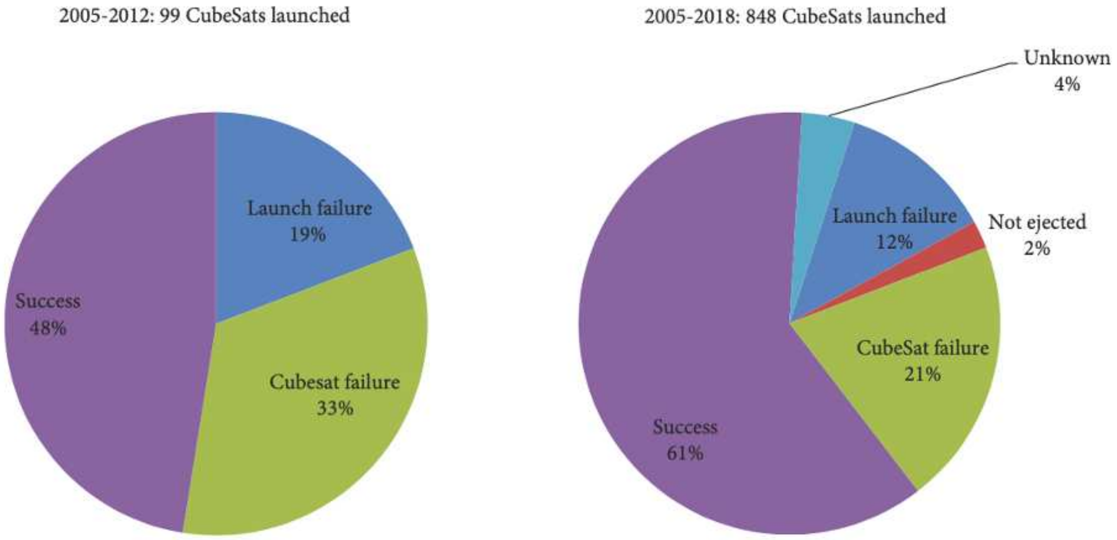


Figure 1-8: CubeSats mission status.

Another important data to consider for CubeSats missions is the infant mortality. This term refers to a failure that occurs during the early stages of the mission, excluding launch-related failures. From the Figure 1-9, it can be observed that over the years, the success rate of missions has reached approximately 75%.

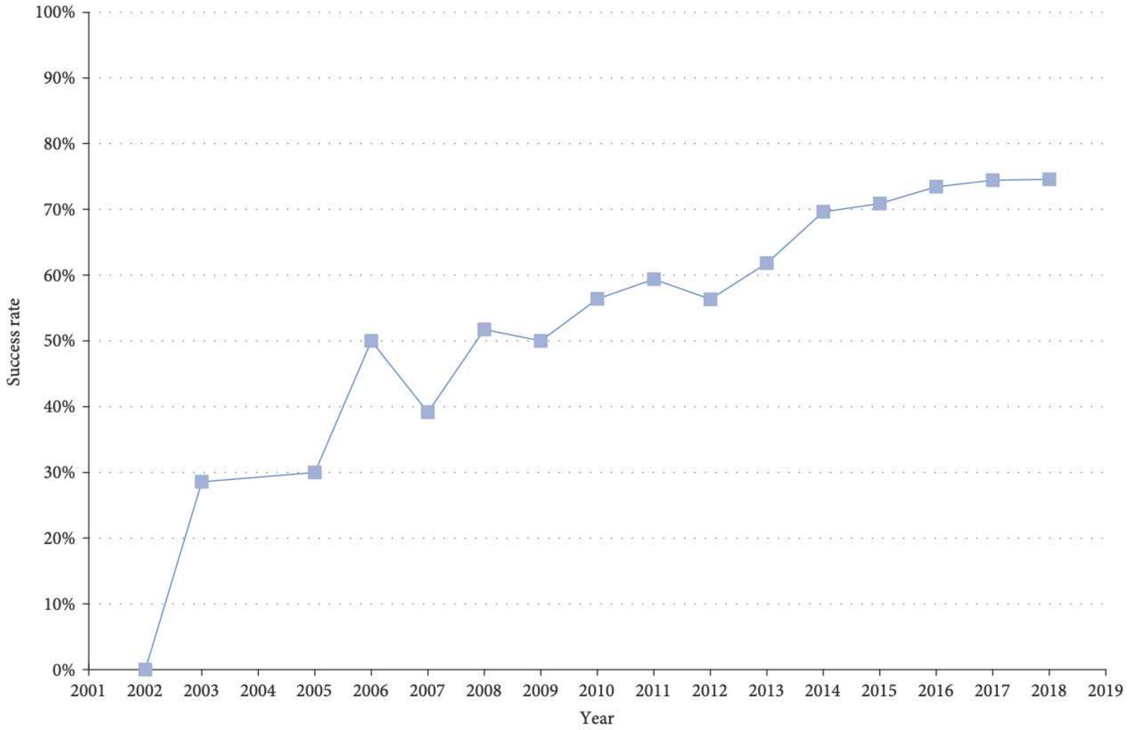


Figure 1-9: Success rate of CubeSat missions as a function of time.

The ISO 19683:2017(E) [14] standard was established with the goal of reducing the infant mortality of small spacecraft by establishing guidelines to be followed in the design and testing phases. In addition, the components developed for the construction of CubeSats will increasingly have a large flight heritage allowing these satellites to achieve high levels of reliability [15] [16].

1.1 The AlbaSat mission

AlbaSat is a mission developed by a group of university students from Padua. The team was founded in 2019, with the intention of allowing students to become familiar with the development of a CubeSat. The satellite under design is a 2U CubeSat which host four payloads.

The choice of mission objectives was focused on fields of study covered at the University of Padua, which are represented in the Table 1-1.

FIELDS OF STUDY	MISSION OBJECTIVES
Space debris	Collect in-situ measurements of the sub-mm space debris environment in LEO
Highly stable pointing mechanisms	Study the micro-vibration environment on the satellite throughout different mission phases
Pointing, acquisition and tracking of small satellites with laser payloads	Do precise orbit determination through laser ranging
Satellite Quantum Communication	Investigate alternative systems for possible Satellite Quantum Communication applications on nanosatellites

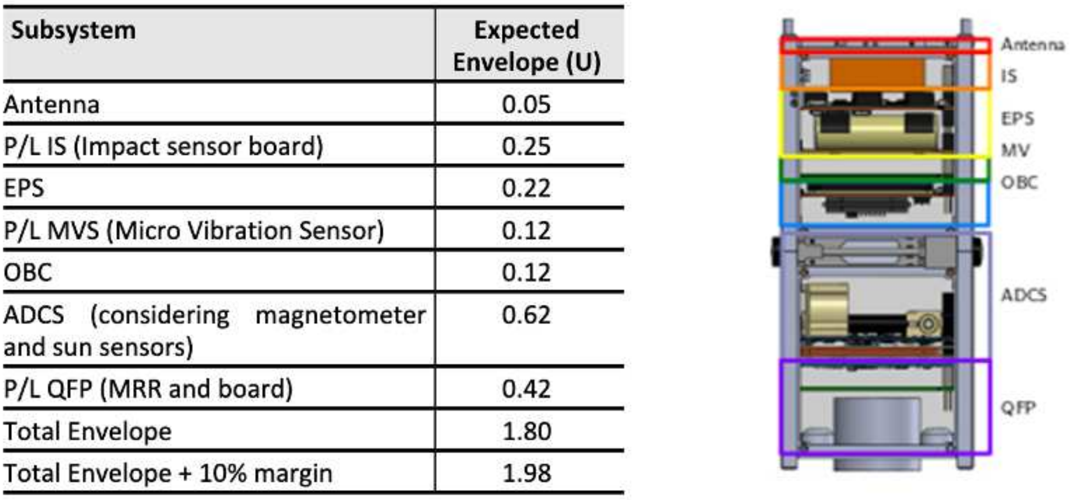
Table 1-1: Fields of study and related mission objectives of AlbaSat

Thanks to the definition of the mission objectives, it was possible to choose and define the payloads able to satisfy them. The four payloads that will be on board AlbaSat are the following:

- **Impact Sensor (IS)**: it will be able to count the number of sub-mm debris impacting on the satellite. It will be placed on the outer face that points towards the motion direction.
- **Micro Vibration Sensor (MVS):** it will consist of a COTS sensor that measures the micro-vibrations on board the satellite.

- **Corner Cube Retroreflectors (CCRs):** they will be employed to precisely evaluate the position using Satellite Laser Ranging (SLR) techniques.
- **Quantum Future Payload (QFP):** it will be used to test the optical receiver for quantum communication.

CCRs are mirrors that allow reflection of a laser beam irradiated toward the source, while the QFP is a CCR characterized by a deformable mirror that allows modulation of the reflected signal. COTS components will be extensively used in AlbaSat except for the payloads which will be in house designed and are currently still under development. Figure 1-10 reports a summary diagram of the subsystems and payloads present within the satellite with a summary table of the volume occupied by each component.



Subsystem	Expected Envelope (U)
Antenna	0.05
P/L IS (Impact sensor board)	0.25
EPS	0.22
P/L MVS (Micro Vibration Sensor)	0.12
OBC	0.12
ADCS (considering magnetometer and sun sensors)	0.62
P/L QFP (MRR and board)	0.42
Total Envelope	1.80
Total Envelope + 10% margin	1.98

Figure 1-10: Visual representation of the envelope of each subsystem.

The project follows typical space mission phases by adopting the ESA model. The definition of a space mission begins in phase 0 in which mission goals are defined. Objectives need a strong motivation, that is provided after a comprehensive review and analysis of the State Of the Art (SOA), the clear identification of shortcomings in the SOA, the definition of possible improvements with respect to the SOA, and the specification of the scientific, social, and technical impact of such improvements. Mission objectives must be qualitative and static, and this phase ends with the milestone of Mission Definition Review (MDR). For AlbaSat mission the Phase 0 of the mission was developed from 2019 to July 2020, during which qualitative and static, immutable objectives were defined.

Next, the mission enters phase A in which mission requirements are defined to meet the objectives along with alternative mission concepts and architectures. This phase ends with the Preliminary Requirements Review (PRR). For the AlbaSat mission, once Phase A began, some members of the group had the opportunity to participate in the CubeSat Concurrent Engineering Workshop (CCEW), which allowed them to acquire important knowledge about CubeSat design and mission management. In March 2022, the project entered Phase B, during which the design of the satellite has been consolidated based on mission requirements was developed.

On January 16, 2023, the AlbaSat project became part of the European Space Agency (ESA) Fly Your Satellite! (FYS) - Design Booster program, which enables university projects to leverage the knowledge and skills of ESA experts to accelerate the development of their CubeSat projects [17]. The program will support the AlbaSat group until May 2024, at the end of the program the team will produce a document called the Final Design Review (FDR).

Before the end of the FYS project, AlbaSat will enter phase C of detailed definition, in which all components of the satellite will be designed in detail. Currently, the project is in Phase B, and this thesis will focus on the preliminary design of a FlatSat, a platform necessary for testing on ground the subsystems aboard AlbaSat. Figure 1-11 shows a timeline of the mission, indicating the main milestones.

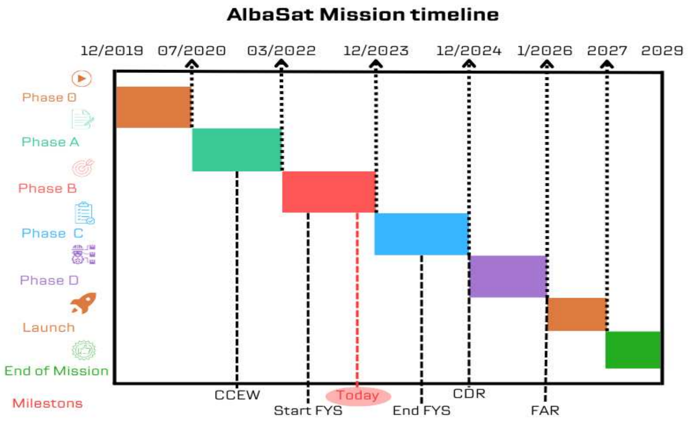


Figure 1-11: Timeline of AlbaSat Mission.

1.2 **Definition of FlatSat**

A FlatSat, short for "Flat Satellite", is a test system used in the development of CubeSats but also of larger satellites. The FlatSat provide an efficient and representative test platform that reduces the risks and uncertainties associated with low-cost space missions. Indeed, this system provides a representation of the flight system, allowing to test mission operations and to verify and validate the functions of the satellite subsystems before launch. The open structure of this test platform makes it easier to operate the FlatSat by allowing operators, in case of malfunctions, disconnections and damages to conveniently access the affected component [18].

There are significant advantages to adopting a FlatSat for a space mission. First, it allows the satellite to undergo rigorous testing and verification of its functionality and interactions in a controlled Earth environment, minimizing the risks associated with launch. This preliminary testing process helps to identify and resolve any problems or defects before the launch into space, ensuring greater reliability and a high probability of mission success. In addition, the use of a FlatSat provides a safe and cost-effective environment to perform iterative testing, making improvements to the satellite without the restrictions and complexities that characterize the flight models of the satellites. This allows for deeper refinement of the satellite and optimization of its performance [19].

Using a FlatSat it is possible to achieve the followings:

- **Subsystem integration**

  The FlatSat must allow the integration of the subsystems of the satellite, such as the power system, communication, attitude control and a number of sensors and actuators. This allows testing the interaction and compatibility between subsystems.

- **Functional test**

  The FlatSat must allow performing functional tests to verify the nominal functioning of the subsystems. These include power tests, communication tests, sensor and actuator tests, and thermal control tests.

- **Mission test**

  The FlatSat must allow the simulation of the mission scenarios to test the behavior of the satellite in realistic situations. This includes simulating orbital maneuvers, acquiring science data, executing control procedures, and managing communications.

- **Advanced diagnostics**

  The FlatSat must be equipped with advanced diagnostic tools that allow monitoring, logging, and analyzing data during the test campaign. This permits to identify any anomalies, diagnose problems and evaluate the performance of the satellite.

- **Test repeatability**

  The FlatSat must be designed to allow the repetition of the tests. This is essential for the verification and validation of the system and for the analysis of the data collected during the tests.

1.3 **Objectives of AlbaSat FlatSat**

The main objectives of the FlatSat for the AlbaSat mission are:

1. to test the operations.
2. to test the electrical components of the satellite.
3. to verify and test the communication protocols between the subsystems and the payloads.

Reaching these objectives is crucial to ensure the nominal function of the systems and to guarantee its reliability.

During the design of the FlatSat, particular attention shall be paid to electrical components that make up the satellite subsystems. An in-depth analysis of the technical specifications of the components shall be performed, together with an in-depth analysis of their operating parameters and nominal performance. Thorough tests will be scheduled to verify the correct integration of the subsystems and to ensure that they work nominally.

Another fundamental objective of the FlatSat is the verification and testing of the communication protocols between the subsystems of the satellite. Effective communication between subsystems is essential for the proper functioning and coordination of satellite activities. Hence, tests will be scheduled to evaluate the robustness and reliability of the communication protocols, as well as their ability to manage data transfer between subsystems efficiently and without data loss. Furthermore, the FlatSat will allow to examine in detail how the satellite subsystems communicate with the payloads.

The payloads are the instruments on-board AlbaSat that allow data collection to reach the scientific objectives of the mission. For this reason, tests will be scheduled to evaluate the correct communication between the subsystems and the payloads, verifying the data transmission between them. It will be important to ensure that the data collected by the payloads is reliably transmitted to the subsystems dedicated to the processing and transmission to the ground.

Chapter 2

FLATSAT COMPONENTS

In this chapter, the good-practices to follow when designing a FlatSat will be examined in detail. The basic principles and best practices that should guide the creation of an effective FlatSat test system will be explored. This will include not only the technical aspects of component selection and integration, but also the philosophy adopted in the design process. Through the analysis of components, methodologies and design philosophies, the goal is to provide the insight behind the design of a FlatSat for the AlbaSat mission to perform reliable pre-launch testing.

2.1 **Good practices for designing a FlatSat**

The design of FlatSats for small satellites such as CubeSats represents a crucial phase in their development. The design of FlatSats requires a deep understanding of the requirements of the system being tested. This involves a detailed definition of power, communication, and electronic interface requirements. Once these requirements have been identified, the design of a customized FlatSat for the analyzed CubeSat can proceed [20].

The approach to experimentation through FlatSat platforms reveals an inherently flexible and modular aspect. These facilities allow each mission to probe specific areas of interest, focusing on what is most relevant to the intended objective. This methodology offers the freedom to explore and test various components and functionalities in a controlled environment, thus helping to optimize desired performance. Consequently, the aim is to design a test platform that is representative of the CubeSat main subsystems, allowing for the study and verification of key FlatSat characteristics, such as power consumption, communication interfaces between different boards, and analysis of exchanged data.

Another important factor to be considered in FlatSat design is the integration of electronic components. CubeSats consist of multiple electronic boards, each representing a different subsystem, and these boards must properly be interconnected to ensure the CubeSat functioning. Therefore, FlatSat design requires meticulous wiring and interfaces design between the various components.

A crucial aspect in FlatSat design is the inclusion of testing and diagnostic tools. FlatSats must be able to monitor and record data during testing to evaluate the CubeSat performance. This necessitates the integration of sensors and diagnostic tools that provide detailed information on the CubeSat behavior during operational phase simulations.

2.2 **Design choices**

In addition to the technical aspect, the design of FlatSats also requires proper resource planning. FlatSats require a significant investment in terms of time and budget. Therefore, a careful project planning is necessary, considering the development timelines of the platform and costs of the tests to be conducted on it. For this reason, the correct choice of model philosophy for the FlatSat is of considerable importance.

The following philosophy was firstly selected for the development of AlbaSat, which includes the development of three models: BreadBoard Model (BBM), Engineering Model (EM) and ProtoFlight Model (PFM). This approach was chosen for three different reasons:

1. To allow students in the AlbaSat group to become familiar with the system.
2. To keep the development cost low
3. To allow fast development times

The students have never participated in a space mission firsthand. Therefore, when selecting the model philosophy, human errors must be considered as they may impact the system development's budget and timeline. The team must adhere to the deadlines imposed by participation in the "Fly Your Satellite! - Design Booster" program, and the amount of financial support that will be supplied by the university and sponsors is difficult to be precisely estimated.

As for the three payloads not being COTS components, a different model philosophy was chosen. For IS the DM+EQM+FM approach is employed, for the MVS is DM+QM+FM, for the QPL is DM+EQM+PFM and for the CCRs follows the model philosophy of the platform (BBM+EM+PFM).

It was initially decided for the development of FlatSat to follow the model philosophy chosen for the system (BBM+EM+PFM). In this way, two version of the FlatSat would be built.

This approach would have required “in-house” construction of each board, with meticulous attention to representing the subsystems being replicated. Additionally, this choice would have allowed the team to gain familiarity with the electrical design of the boards. However, it would not have facilitated the verification and validation of the components used in the PFM of the CubeSat. Consequently, the main objective of the FlatSat would not have been achieved, as the connections between subsystems and the communication between them would not have been tested.

Another crucial factor that led to the exclusion of using BBM components is the time required for the design, procurement, assembly, testing, and potential modifications of all components on each board intended for the FlatSat. Indeed, the estimated time required for the development of a single subsystem amount to several weeks of work.

Table 2-1 reports a summary of the pros and cons regarding the implementation of the platform with BBM components.

Version: BBM -EM	PROS	CONS
Long development times		X
Acquisition of skills related to the construction of electrical boards	X	
Costs related to design, procurement, assembly, and testing	X	
Difficulty in representing the chosen subsystem		X
Low reliability of components		X
Incomplete representation of flight components		X

Table 2-1: Pros and Cons of BBM-EQM version of the FlatSat.

For the reasons listed above, it was decided to change the model philosophy of the system in EM+PFM. This results in having to develop only the EM version of the FlatSat.

The components used for the main subsystems will be PFMs, while EMs will be used for the payloads. Since PFM components specifically selected for the CubeSat design will be used, the FlatSat will be representative of the design choices of the platform. This choice is significantly more resource-intensive in terms of costs, but it guarantees the development of more structured tests once the platform is integrated, reducing the construction time of various FlatSat components. In fact, by using COTS components, most of the time spent on FlatSat construction will be dedicated to the integration and connection of subsystems through interfaces and cables.

Like the previous case with BBM-EQM version, the pros, and cons for EM components are listed in the Table 2-2.

Version: EM	PROS	CONS
Reduction of development times for AlbaSat team	X	
Lack of acquisition of skills related to the construction of electrical boards		X
Costs related to the purchase of components		X
Perfect representation of the subsystems	X	
High reliability of components	X	
Complete representation of flight components	X	
Components already tested in different environmental conditions	X	
High Flight Heritage	X	

Table 2-2: Pros and Cons of EQM philosophy

As a result, the choice of using PFM components in an EM version of the system allows for a significant reduction in FlatSat development time, even though it incurs a substantial financial cost. This cost, in turn, is justified using components designed, manufactured, and tested by industry-leading companies, thereby reducing errors caused by inexperience and using unproven construction procedures.

Table 2-3 is a summary table outlining the cost estimates for the implementation of a FlatSat using BBM and PFM components.

	BBM		EM	
Components	**Cost [€]**	**Cost+ 20% Margin [€]**	**Cost [€]**	**Cost+ 20% Margin [€]**
EPS	190	228	70.000	84.000
ADCS	380	456	40.000	48.000
OBC	0	0	17.000	20.400
TTC	179	204	20.000	24.000
Cable	200	240	5.000	6.000
Total	949	1128	152.000	182.400

Table 2-3: Cost comparison.

As observed, the costs associated with components for the EM version are significantly higher than those of BBM version. However, as previously explained, this cost difference is justified by the reliability and representativeness of the CubeSat. The values shown for the BBM version are derived from the evaluation of the purchase of electrical and electronic components. It is important to note that the value for the realization of the OBC is EUR 0 as a PC in the laboratory would have performed this function allowing the platform to be progressed by the students of the AlbaSat project. For the development of the BBM-EM version of the platform, the two costs obtained would have to be added together; from this it can be seen that in economic terms this choice does not differ significantly from the option of realizing only an EM version of FlatSat. In conclusion, as there were no major differences in the cost of building the structure, the factor that influenced the choice was the development time for FlatSat.

The choice for the design of the FlatSat was to insert the following subsystems which will be analyzed individually in the following paragraphs:

- **ADCS** (Attitude Determination & Control System)
- **EPS** (Electrical Power System)
- **OBC** (On-Board Computer)

In addition to the latter subsystems, it is also possible to include the payloads, which, unlike the previous subsystems, will be developed using the model philosophy previously presented. Once the EQM is built, it will need to be tested within the FlatSat. The payloads that will be integrated into the platform are the followings:

- **IS**
- **MVS**
- **QPL**

Given the high level of complexity of the AlbaSat mission, with four "in-house" developed payloads and the lack of experience within the project development due to a team made of students, it is necessary to implement a robust verification approach. A similar philosophy, as in other student missions, like for EIRSAT-1 and ISTSAT-1, will be applied, subjecting a EQM of the system to rigorous planned test campaigns outlined in this document.

Test campaigns are planned for the FlatSat, including functional and mission tests. In addition, all hardware is first tested individually before system level integration. This approach aims to reduce risk and demonstrate, prior to launch, the system reliability in achieving its mission objectives [20] [21].

2.3 **Study of AlbaSat components**

The different components that will compose the FlatSat of the AlbaSat mission are the following and will be analyzed individually in the following paragraphs:

- **ADCS** (Attitude Determination & Control System)
- **EPS** (Electrical Power System)
- **OBC** (On-Board Computer)

These components work synergistically to ensure the mission operations, both during FlatSat testing and in space. The design and verification of these components are crucial to ensure adequate power supply, attitude control, data processing and communication, thus maximizing the chances of success of the space missions. The boards that will be presented have been chosen as they best meet the mission requirements.

Also, in the configuration of the OBC board chosen for the AlbaSat mission there is the possibility of mounting both the component on which the on-board software will be loaded and the transceiver. It should be noted that for this first version of FlatSat, the antenna will not be mounted to complete the telecommunication subsystem.

2.3.1 ***ADCS***

Figure 2-1: ADCS module.

The subsystem chosen for the attitude control is designed and built by CubeSpace and takes the name of "CubeADCS Y-momentum". CubeADCS consists of several CubeSpace components integrated, reported in Table 2-4 into a PBC with dimensions of 90.14mm x 88.10 mm [22].

Component	Number
Fine sun sensor	2
Coarse sun sensor	6
Rate sensor	3
Magnetometer	1
Redundant magnetometer	2
Magnetorquer rods	2
Coil	1
Momentum wheel	1

Table 2-4: Components of ADCS.

CubeADCS is provided with a dedicated software developed by CubeSpace already installed allowing the user to interface with the subsystem via one of the multiple communication buses. The ground support software is also supplied with CubeADCS, allowing the user to connect directly to the CubeADCS via a USB to UART cable using a PC. Figure 2-2 shows an illustrative diagram of the configuration used in the FlatSat.

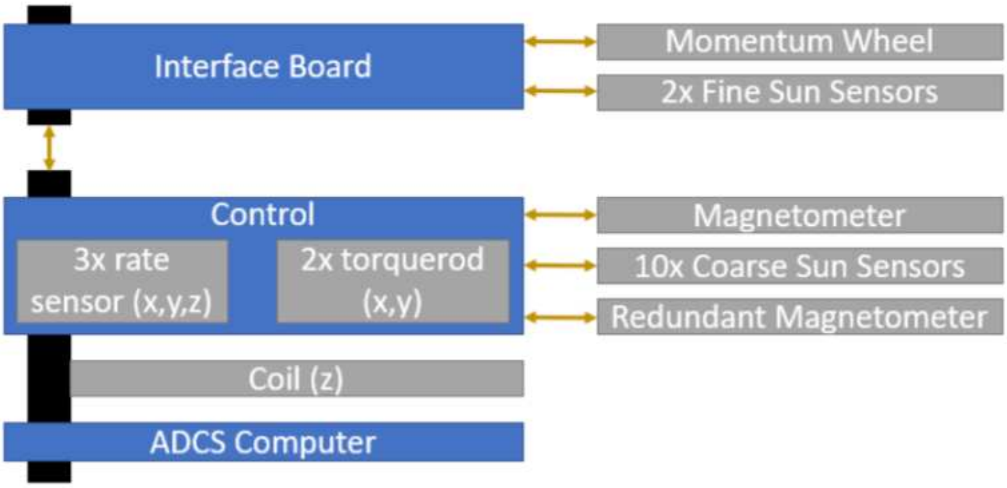
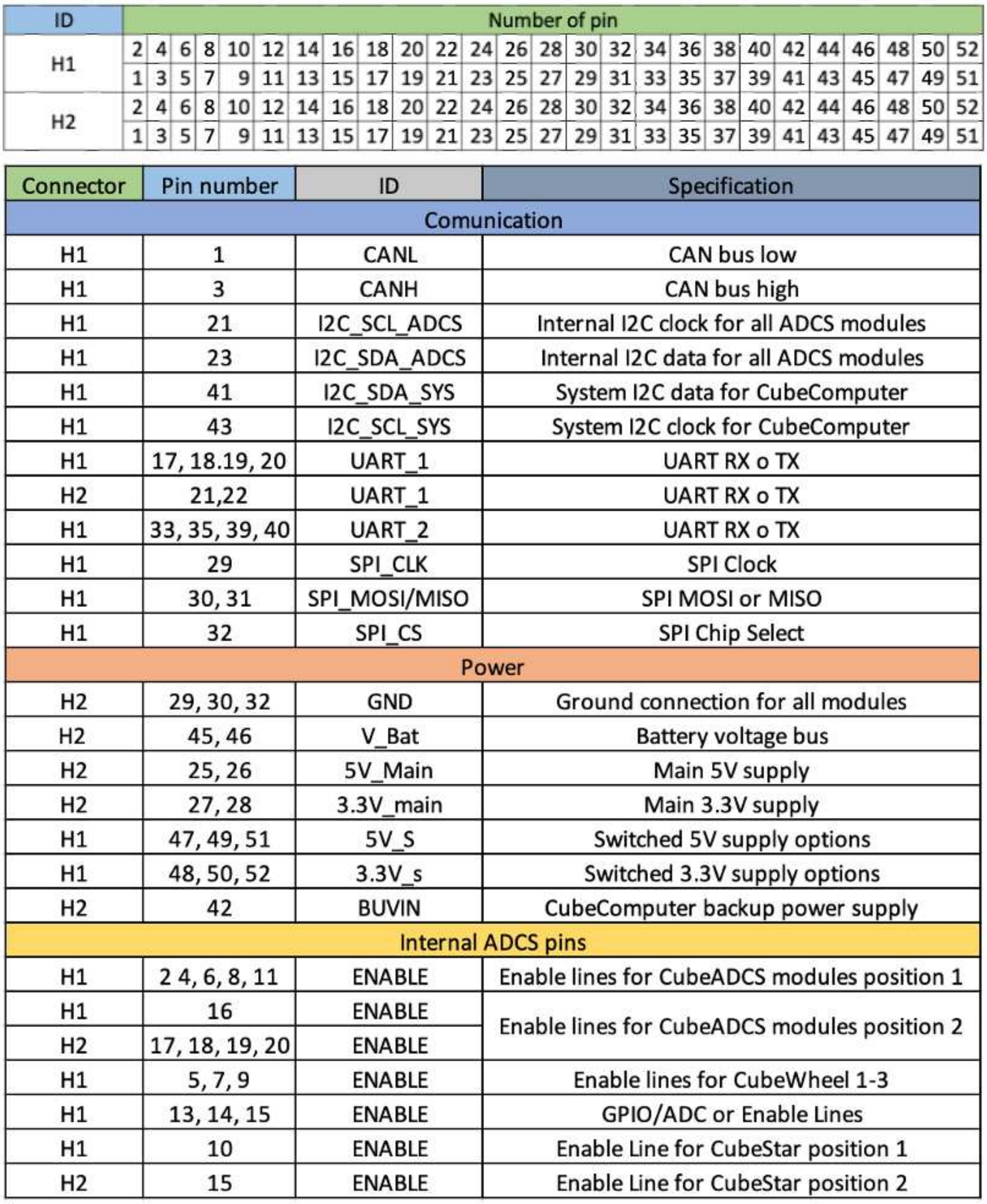


Figure 2-2: ADCS physical arcitecture.

The Y-Momentum CubeADCS configuration is chosen as the AlbaSat requires a 3-axis stabilized attitude with a pointing error lower than 15 deg. This configuration of CubeADCS provides the functionality maintain the Nadir-pointing attitude employing a Momentum Wheel (MW). In addition, it provides the possibility to perform pitching maneuvers in the orbital plane by controlling its speed. This is especially useful for tracking ground stations during mission operations. As regards the connection with the PC104 interfaces, the pin connections via the "stack connector" are described in the Table 2-5.



ID	Number of pin																									
H1	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52
	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51
H2	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52
	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51

Connector	Pin number	ID	Specification
Comunication			
H1	1	CANL	CAN bus low
H1	3	CANH	CAN bus high
H1	21	I2C_SCL_ADCS	Internal I2C clock for all ADCS modules
H1	23	I2C_SDA_ADCS	Internal I2C data for all ADCS modules
H1	41	I2C_SDA_SYS	System I2C data for CubeComputer
H1	43	I2C_SCL_SYS	System I2C clock for CubeComputer
H1	17, 18.19, 20	UART_1	UART RX o TX
H2	21,22	UART_1	UART RX o TX
H1	33, 35, 39, 40	UART_2	UART RX o TX
H1	29	SPI_CLK	SPI Clock
H1	30, 31	SPI_MOSI/MISO	SPI MOSI or MISO
H1	32	SPI_CS	SPI Chip Select
Power			
H2	29, 30, 32	GND	Ground connection for all modules
H2	45, 46	V_Bat	Battery voltage bus
H2	25, 26	5V_Main	Main 5V supply
H2	27, 28	3.3V_main	Main 3.3V supply
H1	47, 49, 51	5V_S	Switched 5V supply options
H1	48, 50, 52	3.3V_s	Switched 3.3V supply options
H2	42	BUVIN	CubeComputer backup power supply
Internal ADCS pins			
H1	2 4, 6, 8, 11	ENABLE	Enable lines for CubeADCS modules position 1
H1	16	ENABLE	Enable lines for CubeADCS modules position 2
H2	17, 18, 19, 20	ENABLE	
H1	5, 7, 9	ENABLE	Enable lines for CubeWheel 1-3
H1	13, 14, 15	ENABLE	GPIO/ADC or Enable Lines
H1	10	ENABLE	Enable Line for CubeStar position 1
H2	15	ENABLE	Enable Line for CubeStar position 2

Table 2-5: Pins identification of ADCS stack connector.

The ADCS subsystem must be powered with a regulated voltage of 3.3V and 5V.

The ADCS is optimized to limit the effect of inrush currents, as it has its own protection circuits. However, the power supply and the connection from the power supply to the CubeADCS can cause inrush current problems if not configured correctly. Therefore, it is important to ensure a power supply that does not exceed 1A with 8V when connecting the FlatSat, as this would cause the magnetometer to unfold, an instrument that you do not want to test in this first test campaign. In addition, the cables between the 3.3 V power supply and the ADCS must be less than 15 cm in length and more than 0.511 mm thick, which guarantees protection against inrush currents.

The ADCS has internal power switches for the various components, all controlled by the CubeComputer. Figure 2-3 shows the power switching connections. The switching states are available as telemetry.

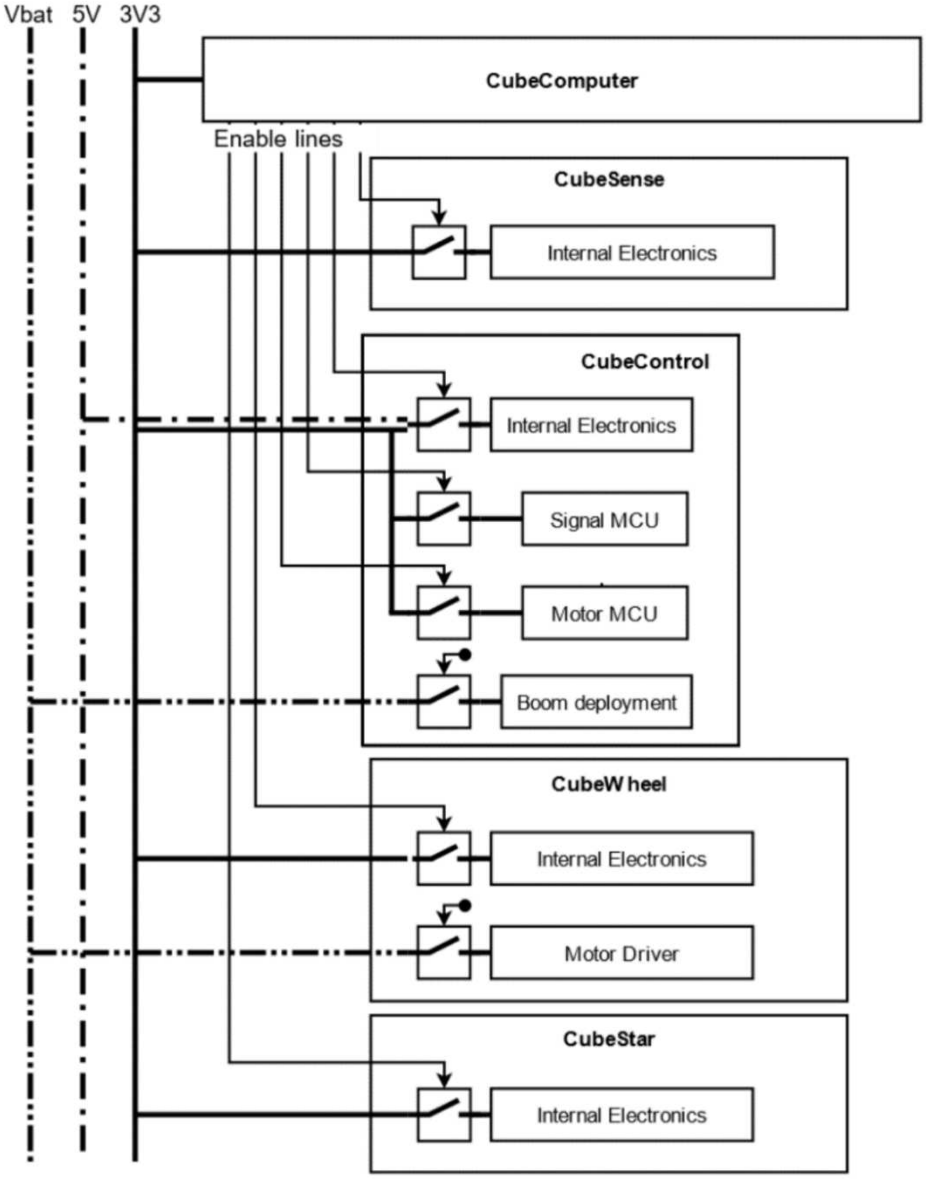


Figure 2-3: ADCS power switches connections.

The ADCS communicates with other subsystems using the I2C, UART and CAN protocols. The ADCS computer has a CAN interface that can be chosen by the buyer. The ADCS computer feature a CAN controller module and a CAN transceiver, which allow the ADCS to interact at CAN bus voltage levels of 3.3V or 5V [23] [24].

2.3.2 ***EPS***

The GomSpace NanoPower P31U device was chosen as the EPS, which is a solution capable of satisfying the power distribution within the AlbaSat mission's CubeSat.

The NanoPower P31U features a wide range of features, including voltage regulation, performance monitoring, surge protection, and a flexible platform for integrating solar panels. The chosen configuration uses the P31U device with the addition of a BP4 battery pack shown in Figure 2-4.

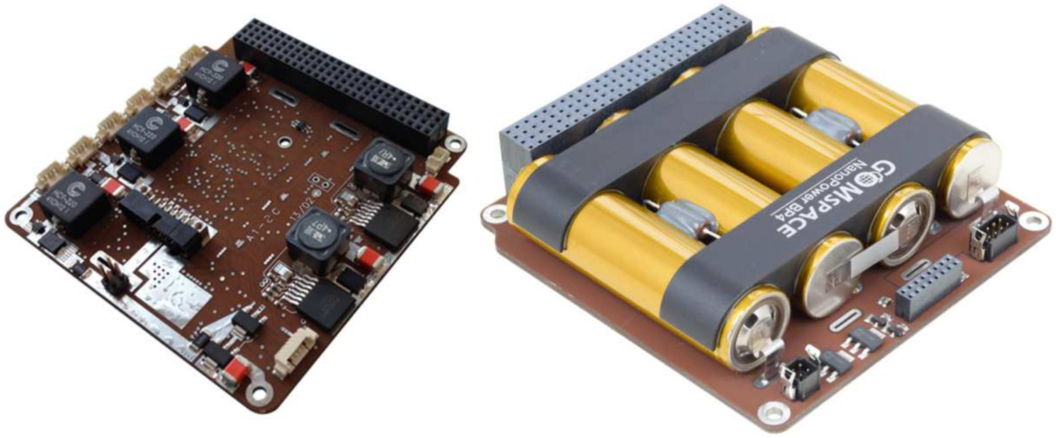


Figure 2-4: NanoPower P31U (left) and battery BP4 (right) from GomSpace.

In addition, Figure 2-5 represents the connections inside the NanoPower P31U board.

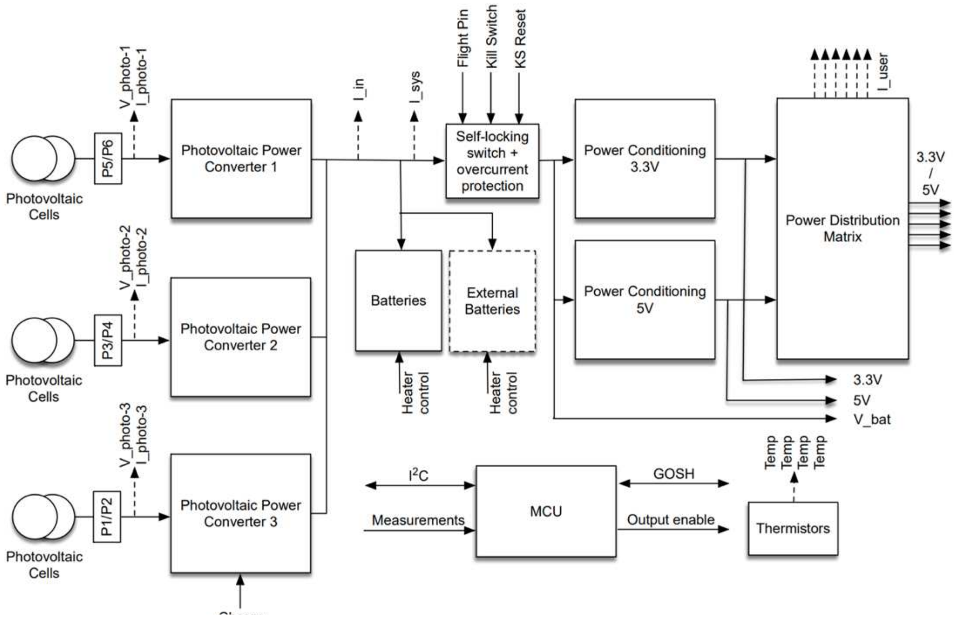
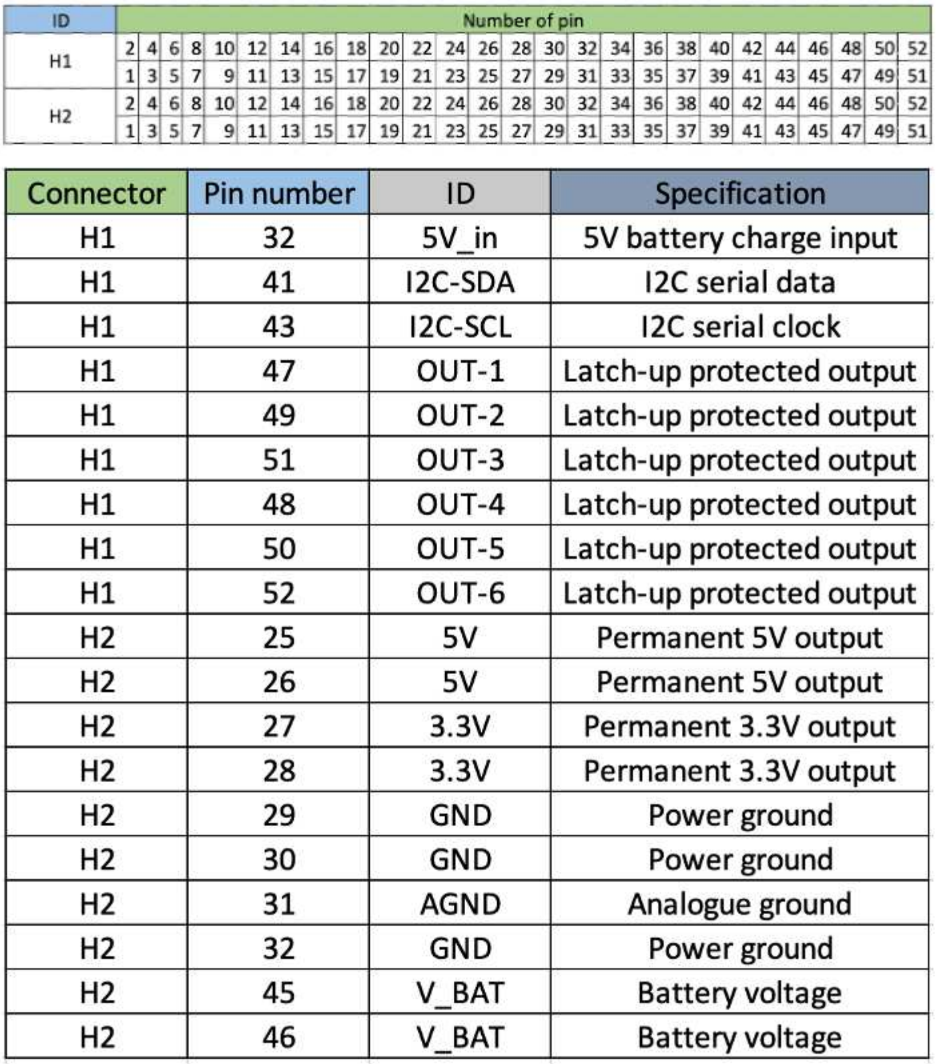


Figure 2-5: Block diagram of NanoPower P31U.

The P31U includes a microcontroller that offers user control, maximum power-point tracking (MPPT) functionality, and measures and tracks system voltages, currents, and temperatures. It is possible to read measurements, control the on/off status of the 3.3 V and 5 V busses, turn on/off the MPPT, and set/read several parameters via an I2C interface. The connections with the solar arrays are shown on the left of Figure 2-5, having their own power-point setting. The battery pack is replaced by a bench power supply connected to the P31U which ensure the correct distribution of power to all the connected subsystems. Table 2-6 describes the functions of the pins present in the "stack connectors".



ID	Number of pin																									
H1	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52
	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51
H2	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52
	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51

Connector	Pin number	ID	Specification
H1	32	5V_in	5V battery charge input
H1	41	I2C-SDA	I2C serial data
H1	43	I2C-SCL	I2C serial clock
H1	47	OUT-1	Latch-up protected output
H1	49	OUT-2	Latch-up protected output
H1	51	OUT-3	Latch-up protected output
H1	48	OUT-4	Latch-up protected output
H1	50	OUT-5	Latch-up protected output
H1	52	OUT-6	Latch-up protected output
H2	25	5V	Permanent 5V output
H2	26	5V	Permanent 5V output
H2	27	3.3V	Permanent 3.3V output
H2	28	3.3V	Permanent 3.3V output
H2	29	GND	Power ground
H2	30	GND	Power ground
H2	31	AGND	Analogue ground
H2	32	GND	Power ground
H2	45	V_BAT	Battery voltage
H2	46	V_BAT	Battery voltage

Table 2-6: Pins identification of EPS stack connector.

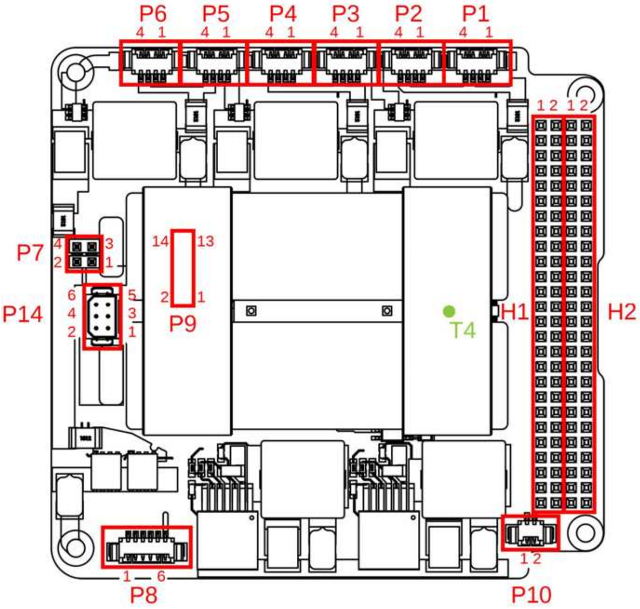


Figure 2-6: Upper face of NanoPower P31U board.

The ports "P1-P2-P3-P4-P5-P6" in the Figure 2-6 are dedicated to the connection with the solar panels, while the "P7" allows the connection with the bench generator.

The “P8” connector is prepared for connection to another GomSpace module called “Flight preparation panel”, which allows for some connections to the fully integrated satellite and is not used in the present case.

The “P9” connector allows the connection of the EPS module with a battery pack called BP4 which will not be used for the first test campaign.

Port “P10”, is the one dedicated to kill switches, which for the FlatSat test campaigns will not be physically present but will be simulated via software.

A kill switch is a system that allows a satellite to be switched off or shut down quickly and effectively. This system is useful in emergency situations when a satellite is malfunctioning or could cause damage to other satellites or the space environment.

The P14 connector is designed for optional battery grounding.

Lastly, "T1-T2-T3-T4" indicate the presence of sensors which provide the temperature of the P31U board, one is in the upper face of the board and the others are in the lower face.

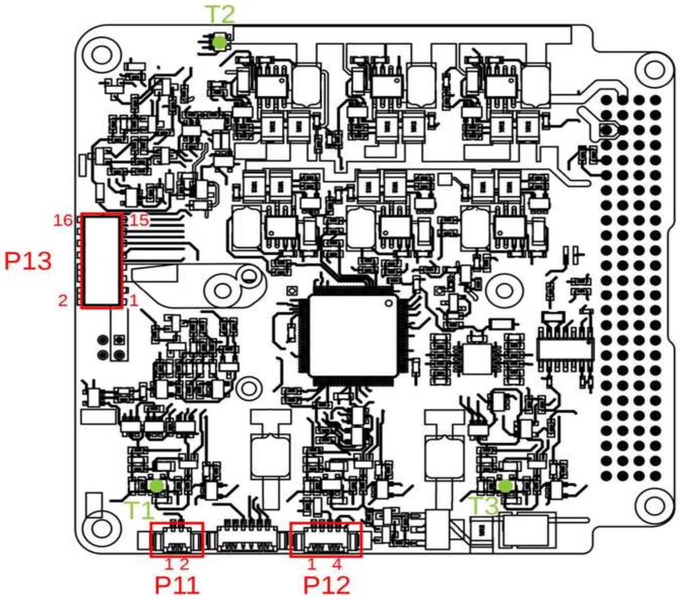


Figure 2-7: Lower face of the NanoPower P31U board.

“P11” and “P12” ports at the bottom of the board allow connection to other modules designed by GomSpace, which will not be used in the present case.

In the case of the configuration chosen for the AlbaSat mission, since there is an external battery pack BP4, this will be connected with the EPS module via the “P13” port.

As previously introduced, the EPS will be used in the FlatSat without connection to the batteries which will be replaced by a bench power supply and a power resistor. The power supply will be set to a voltage that matches the P31U battery voltage range specified in the **Chapter 4 FlatSat test**, based on the conditions you intend to simulate and test. The power resistor is used to absorb the current coming from the battery charge and must be suitably sized both in terms of resistive value and in terms of nominal power.

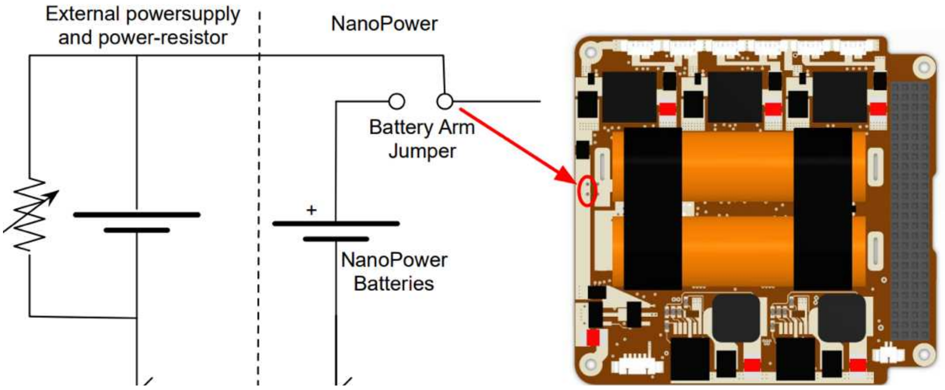


Figure 2-8: Connection with the bench power supply.

For example, if you intend to operate with a voltage of 7.4 V and a 5 Ω resistor, the simulated battery can draw 7.4 V/5 Ω = 1.48 A of current, and the resistor must be able to dissipate 7.4 V * 1.48 A = 10.9 W. These calculations are carried out independently by the bench power supply, which allows for the proper supply of power to the entire system.

The board has a mass of 100g distributed over the three dimensions of 89.3x92.9x15.3 mm.

2.3.3 *OBC & Transceiver*

The board chosen for housing the OBC is the NanoDock DMC-3, which allows a configuration, which will be used in the AlbaSat mission, capable of housing the board intended for the OBC NanoMind 3200 and another board with the role of transceiver, NanoCom AX100.

The configuration that will be used for the FlatSat is shown in Figure 2-9.

Figure 2-9: Configuration of the NanoDock DCM-3 with NanoMind 3200 and NanoCom AX100 boards.

The NanoDock DMC-3 is primarily a passive circuit board that provides a physical platform for the daughterboards and electrical connections to the stack connector. A “passive circuit board” refers to a PCB on which mainly passive components, such as resistors and capacitors, are mounted. In other words, there are no components such as transistors or amplifiers on the board; only components that passively influence the behavior of the electrical signal.

The only active electronic circuit is the USB-serial circuit on the underside of the PCB, which is powered by USB and provides a serial connection to the daughter boards.

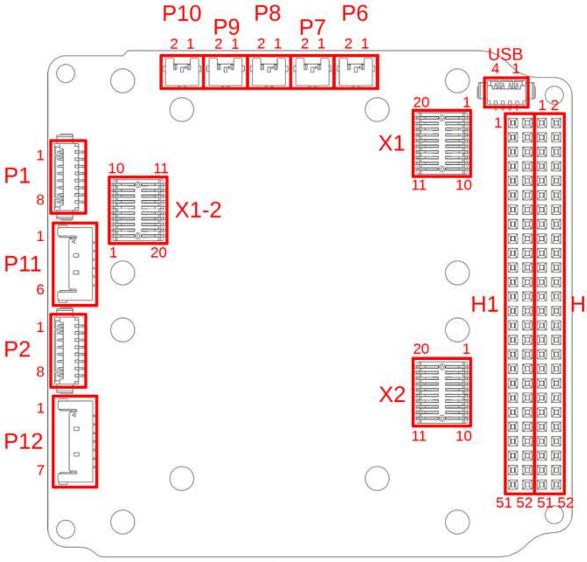
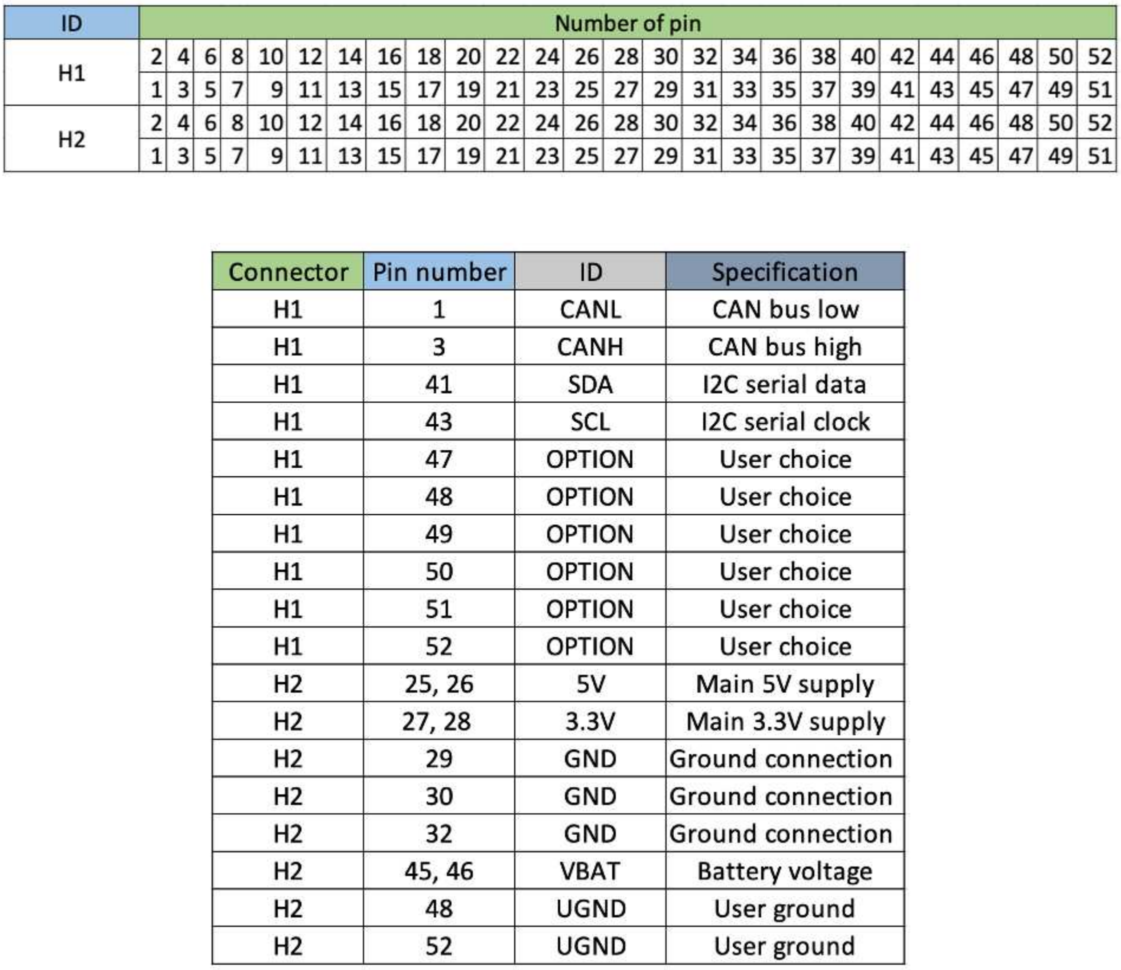


Figure 2-10: Upper face of the NanoDock DMC-3.

The H1/H2 stack connector connects the power supplies and daughter board interfaces to the PC104 CubeSat bus. Table 2-7 shows the pins used in the stack connector. GND, CAN, and I2C are permanently routed to each daughterboard connector. The characteristics of the doors shown in the Figure 2-10 are shown below:

- "P1, P2" - Breakout Connector. Each daughterboard connector is mapped to a correspondingly numbered breakout connector, so X1 is mated to P1, etc.
- "P6-P10" provide five individual ADC inputs directly to five of the ADC inputs found on the NanoMind A3200.
- "P11" provides a Serial Peripheral Interface (SPI) connection to the NanoMind A3200. SPI connection is a form of synchronous serial communication used to transfer data between electronic devices.
- "P12" – I2C and CAN, P12 provides an additional connection to the main I2C, and CAN buses present on the PC104 stack for peripheral payloads.
- "USB" connector provides the USB connection to the USB-serial circuit of the DMC-3.

- Ports X1, X2 and X1-2 allow the connection of the NanoDock to the other two above-mentioned boards, i.e., the NanoMind and NanoCom, that will be described in the following chapter.



ID	Number of pin																									
H1	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52
	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51
H2	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52
	1	3	5	7	9	11	13	15	17	19	21	23	25	27	29	31	33	35	37	39	41	43	45	47	49	51

Connector	Pin number	ID	Specification
H1	1	CANL	CAN bus low
H1	3	CANH	CAN bus high
H1	41	SDA	I2C serial data
H1	43	SCL	I2C serial clock
H1	47	OPTION	User choice
H1	48	OPTION	User choice
H1	49	OPTION	User choice
H1	50	OPTION	User choice
H1	51	OPTION	User choice
H1	52	OPTION	User choice
H2	25, 26	5V	Main 5V supply
H2	27, 28	3.3V	Main 3.3V supply
H2	29	GND	Ground connection
H2	30	GND	Ground connection
H2	32	GND	Ground connection
H2	45, 46	VBAT	Battery voltage
H2	48	UGND	User ground
H2	52	UGND	User ground

Table 2-7: Pins identification of NanoDock DMC-3 stack connector.

At the bottom of the board there are other ports, namely X3 and X4, which allow connection to additional boards produced by GomSpace that will not be used for the AlbaSat mission. The P3 and P4 connectors play the same role as the P1 and P2 ports at the top. Finally, the connection defined as GPS allows connection with the GomSpace GPS module, which will not be used in this first test campaign but may be integrated into future versions of FlatSat.

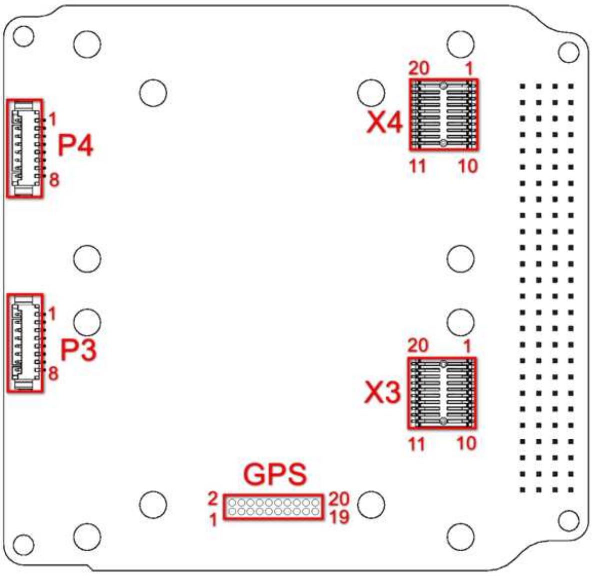


Table 2-8: Lower face of the NanoDock DMC-3.

2.3.4 *NanoMind A3200*

The first daughter board, indicated in Figure 2-9 with the abbreviation A3200, represents the OBC. Its block diagram is shown in Figure 2-11.

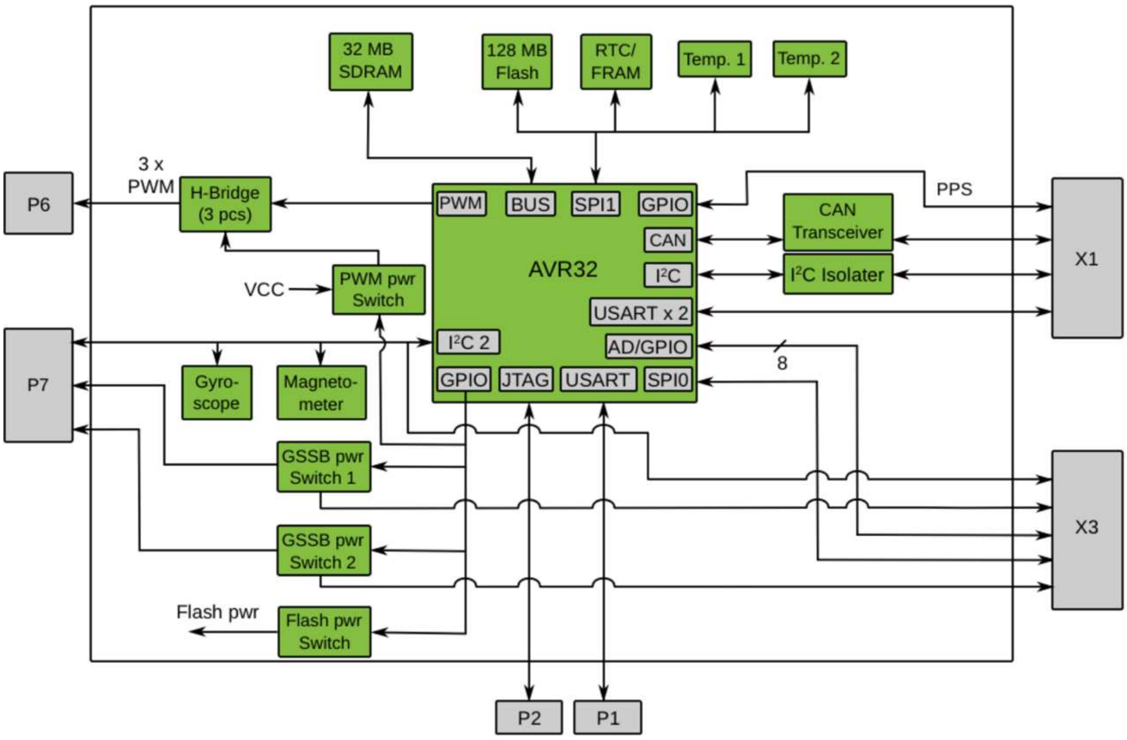


Figure 2-11: Block diagram of the NanoMind A3200.

The A3200 is based on an Atmel AT32UC3C Microcontroller Unit (MCU). There are two I2C buses that support bi-directional data transfer. Serial clock synchronization allows devices with different bit rates to communicate over a serial bus and is used as a “handshake” mechanism to suspend and resume the serial transfer. One of the NanoMind A3200 main interfaces for communicating with other subsystems is a CAN bus interface. The maximum bus speed is 1 Mbit/s. The possible connections are represented in the Figure 2-12 and reported also in the block diagram Figure 2-11.

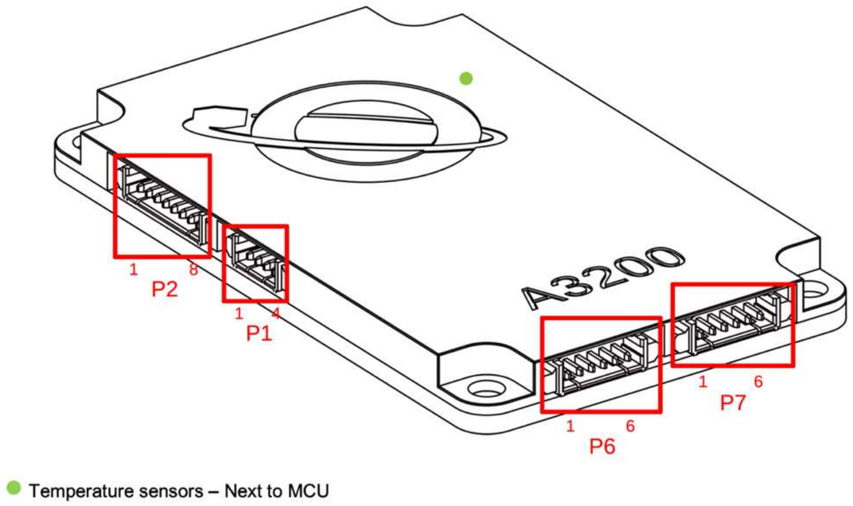


Figure 2-12: Upper face of the NanoMind A3200.

The functionality of the ports on the above-mentioned board is explained hereunder:

- "P1" - Picoblade USART (debug) Connector is designed for easy-access to the A3200 configuration and permits to do factory checkout of standalone modules without a motherboard.
- "P2" - Picoblade Connector for JTAG is used for software upload only.
- "P6" - Picoblade Connector with PWM outputs for driving magnet torques are in connector J6. The PWM drivers in the MCU control these outputs and they are setup by default. However, they can be configured differently in the SW.
- "P7" - Picoblade Connector with I2C and VBAT. In Figure 2-13, two ports are shown, which are used to enable connection with the NanoDock DMC-3 and they will be further explored in the **FlatSat integration** [25].

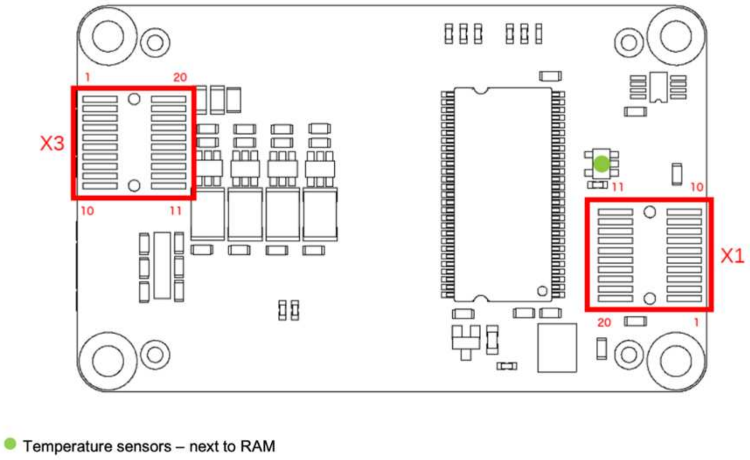


Figure 2-13: Lower face of the NanoMind A3200.

2.3.5 ***NanoCom AX100***

The second board in Figure 2-9 with the code AX100 represents the half-duplex transcription machine designed specifically for long-range transmissions (transceiver). The radio module supports full in-orbit reconfiguration of the frequency, bitrate, filter bandwidth and modulation type. The system provides a short satellite ping time, managing to remove the need for full-duplex radios, even for high-volume data downloads. This simplifies satellite design, because only one antenna is needed. The microcontroller, transmitter, receiver, LNA and power amplifier are integrated in a PCB of dimensions 65x40mm. Figure 2-14 shows the block diagram of the AX100 transceiver.

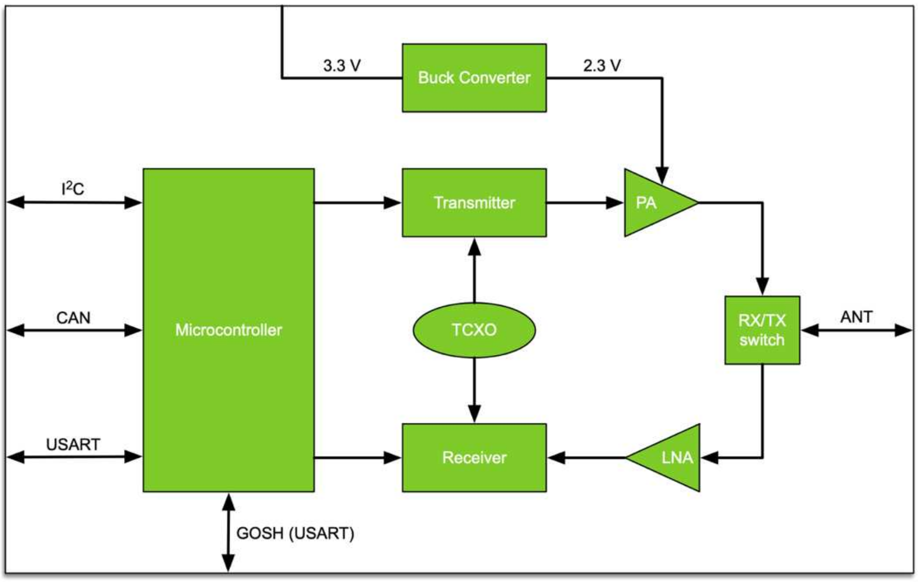


Figure 2-14: Block diagram of AX100

The Microcontroller has three satellite bus connections; it can use I2C, CAN-BUS or USART. Furthermore, it has a separate USART for the GOSH debugging console. Finally, the RF connector is a single SMA 50 Ω for both RX and TX. The possible connections are represented in Figure 2-15.

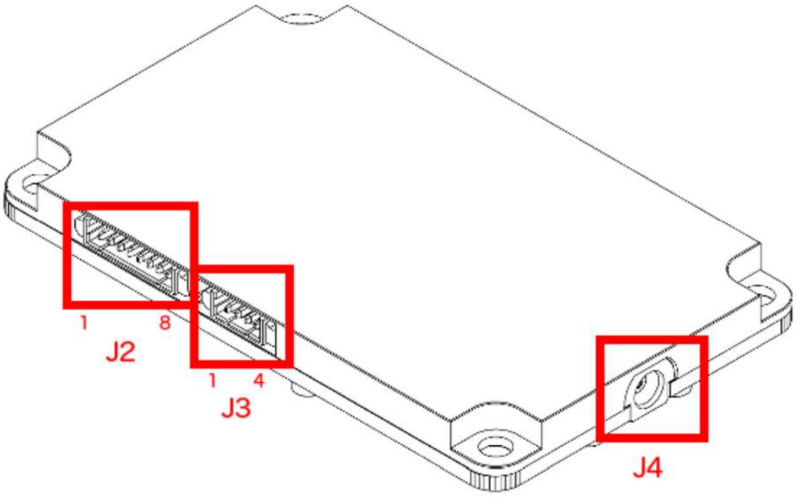


Figure 2-15: Connection of NanoCom AX100

The following are the connectors found on the NanoCom AX100:

- “J2” - Picoblade Connector is used for factory software upload only.
- “J3” - Picoblade USART (debug) Connector is designed for easy-access to the NanoCom AX100 configuration and makes it possible to do factory checkout of standalone modules.
- “J4” - MCX RF Connector that allows connection with the antenna.

At the bottom of the board there is a port named “J1” represented in Figure 2-16 which allows connection with NanoDock DMC-3.

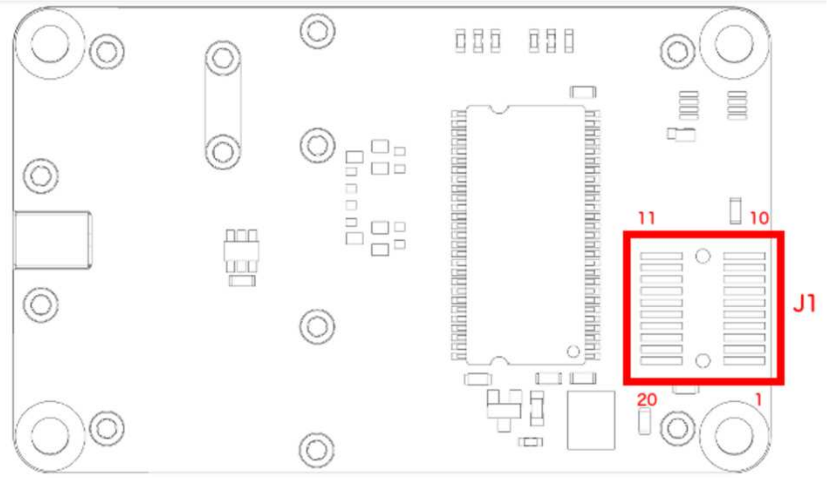


Figure 2-16: Lower face of the NanoCom AX100

Chapter 3

FLATSAT INTEGRATION

In this chapter, the process to be used for the successful integration of FlatSat will be illustrated, as well as the design choices applied to the design of the test support platform. There are various ways in which subsystems can be organized.

A first example for the development of the FlatSat is that of the ISTSat-1 mission, where the platform boards were connected via cables without the use of a support structure. In this way, the production cost of the platform was considerably reduced, but at the same time, the instability of the platform was significantly increased. In fact, by not anchoring all the boards to a single support structure, there is a risk of possible disconnection or breakage of the subsystems due to operator movements in the test environment.

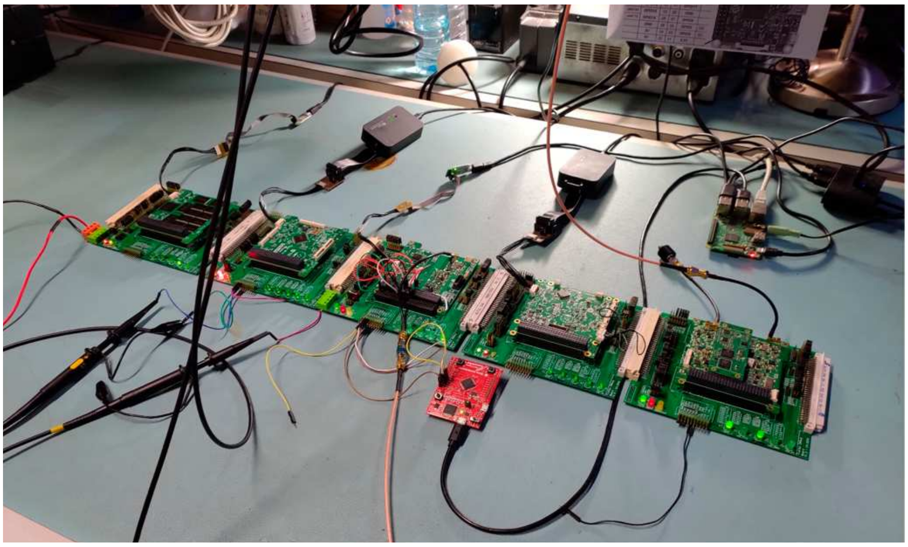


Figure 3-1: ISTSAT-1 FlatSat

In order to reduce this type of risk, it is therefore convenient to adopt a model similar to the one used for the EIRSAT-1 mission's FlatSat. For this platform, an aluminum structure was designed with special housings for boards and connections. This not only makes it more convenient to organize the cables within the FlatSat, but also reduces the risk of component breakage.

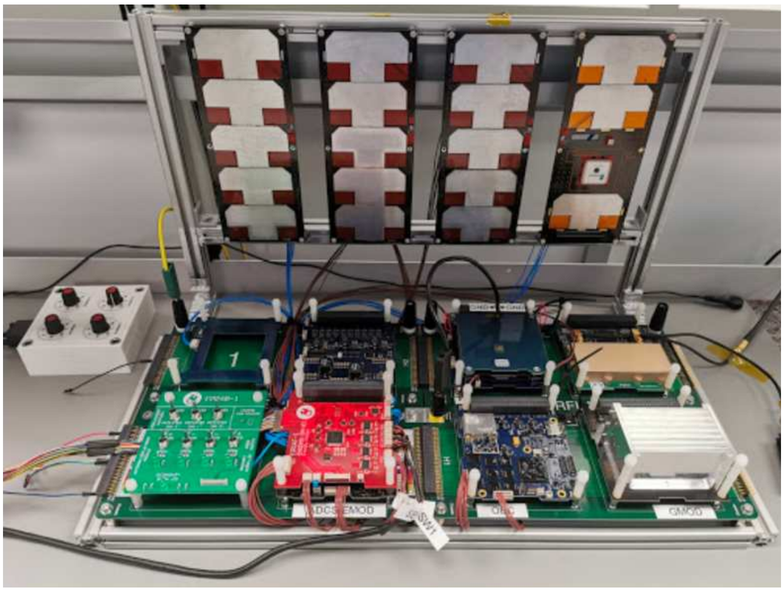


Figure 3-2: EIRSAT-1 FlatSat.

For the reasons listed above, it was decided to design a structure capable of housing the six PC104 type boards and allow the three main subsystems (EPS, OBC and ADCS) and the three payloads (IS, MVS and QPL) to be tested, with the possibility of also adding the battery pack, antenna, and solar panels in a second test campaign.

The base of the structure capable of housing the boards is a 3mm-thick aluminum plate measuring 500x500mm so that one board can be spaced at least 60mm apart. On the plate there are four 20-mm spacers for each board that allow anchoring to the structure by means of 3-mm-diameter and 10-mm-long screws.

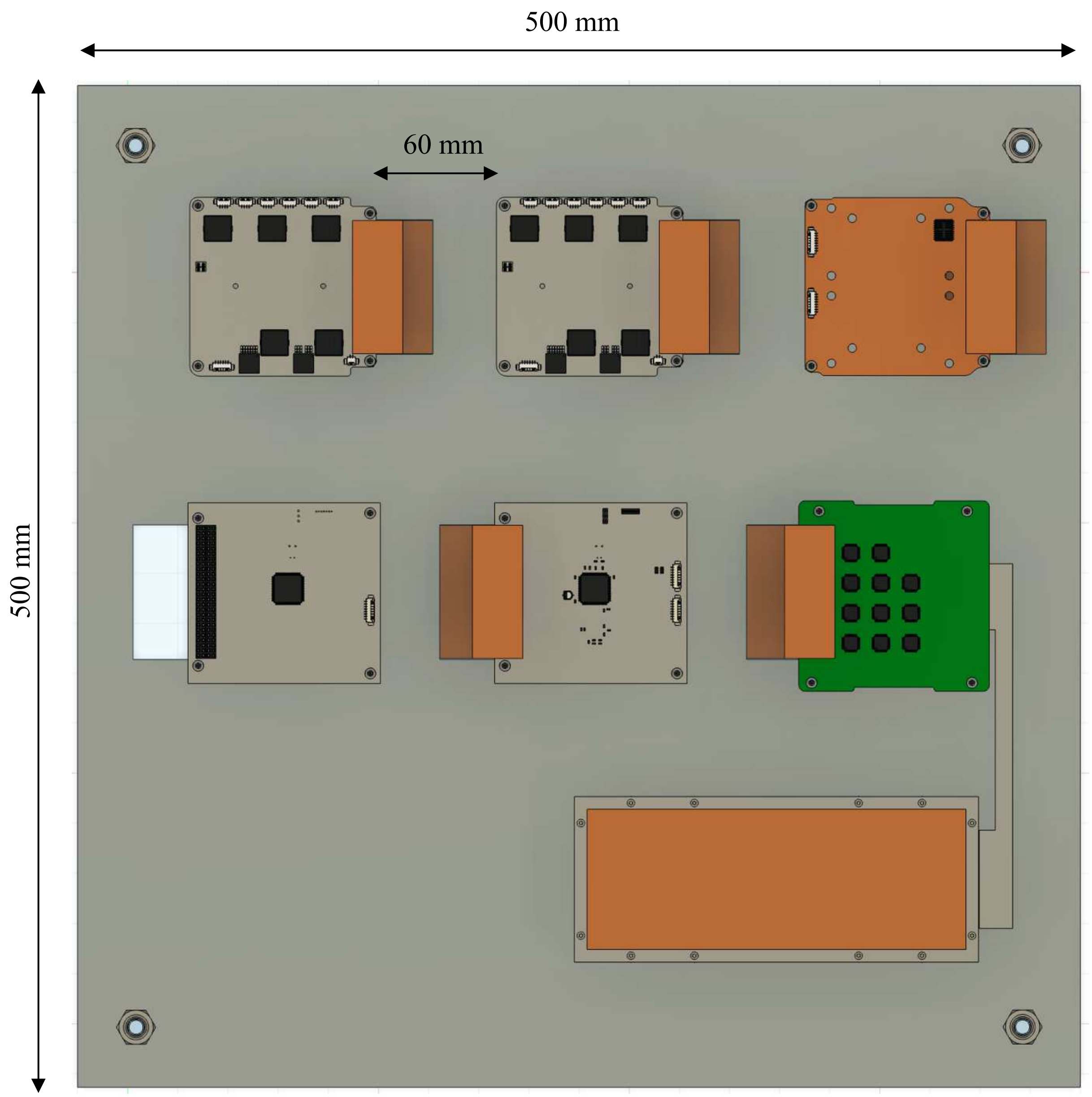


Figure 3-4: Top view of the FlatSat CAD.

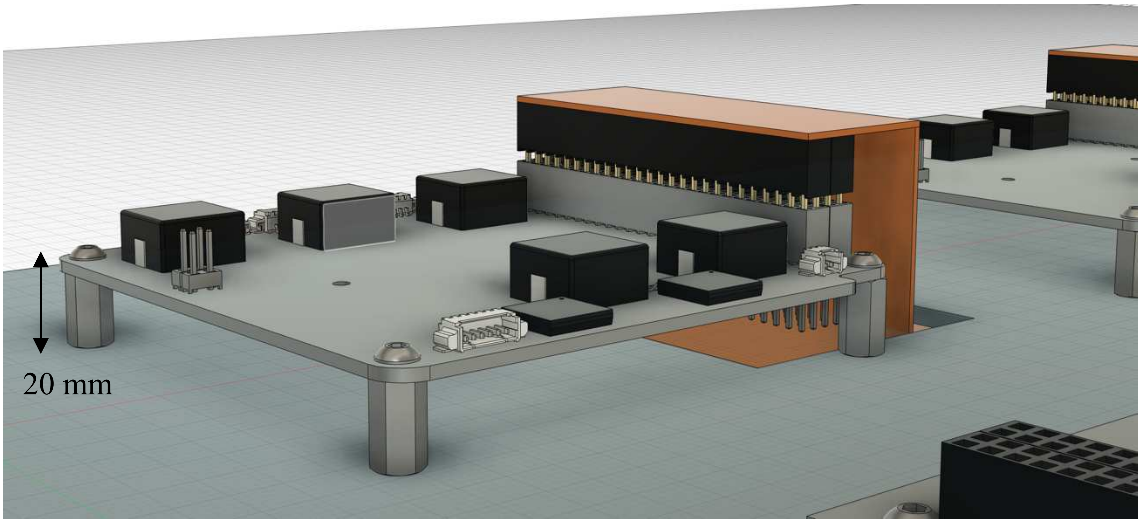


Figure 3-3: View of screws housing for a board.

In addition, the plate has 68x50mm openings below the stack connector of each board to allow it to be connected to the adjacent board. Usually, PC104 boards in flight configuration are stacked on top of each other to allow greater compactness of the entire system. In this case, however, since there are no constraints on the volume to be occupied, it is possible to take advantage of the various stack connectors to develop the connections in the lower part of the board. The boards will be connected via 104 pin male-female type ribbon cable, represented in orange in the Figure 3-5. The connections will take advantage of the aforementioned openings. In this way, it will be possible to place the male-type connector on the top of a board and by running the cable underneath the structure, through the 68x50mm slot it will be possible to connect the female-type connector to the stack connector of the next board.

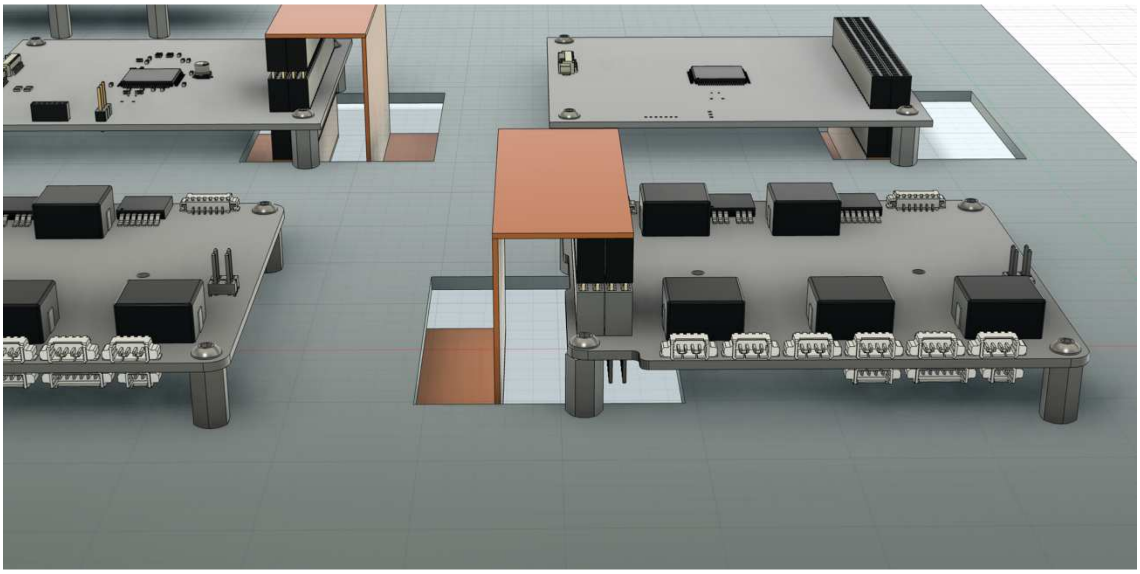


Figure 3-5: Top view of the opening to allow the connection of the boards made with Fusion 360.

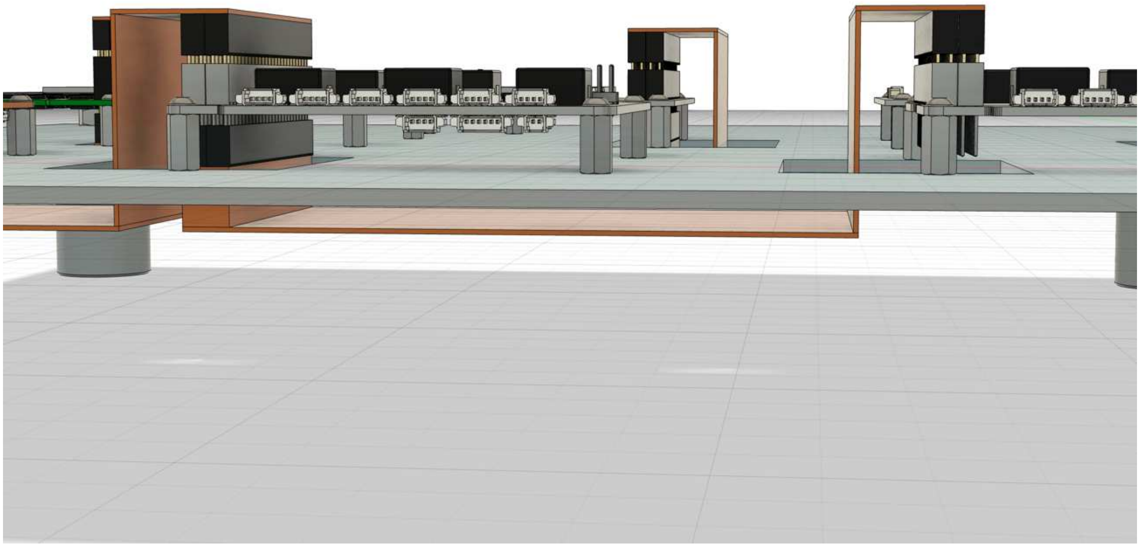


Figure 3-6: Lateral view of the opening to allow the connection of the boards.

It is necessary to remember that through the H1 and H2 ports of the stack connector the power supply, 5V or 3.3V and CAN protocol connections are made.

Finally, four 65-mm-high aluminum feet, manufactured by item Industrietechnik GmbH, were arranged to support the board housing plate, as shown in Figure 3-7 and anchored via the screw on the component. The height of the supports was chosen in order to protect the cables in the lower part of the structure and to avoid them touching the supporting plate.

Figure 3-7: CAD view of the aluminum foot of the structure.

Other types of connections between the boards will be described in Assembly and integration of FlatSat components in order to allow communication between the subsystems via other protocols such as SPI and UART, which are used by payloads.

The in-depth analysis of materials for the structure of a FlatSat represents an important research and selection phase, aimed at identifying the optimal material to meet the requirements of strength, weight, thermal conductivity and durability. Materials such as stainless steel, carbon fibers and titanium alloys were ruled out for the construction of the FlatSats structure because they were either too expensive or too heavy and therefore not suitable for using of the platform during testing. Ultimately, polycarbonate sheets were also excluded because, although they were designed to be perforated, their flexibility under distributed loads and poor thermal conductivity led to the exclusion of this type of material as well. Consequently, of the various options available, aluminum emerges as a particularly advantageous choice, as its intrinsic properties present an excellent balance between mechanical performance and lightness. Aluminum offers a combination of lightness and strength, which is essential to withstand the test campaigns. The structure of a FlatSat requires a solution that provides structural strength without placing an undue burden on it. In this respect, aluminum proves to be an excellent candidate due to its low density and great ability to withstand static loads.

In addition to its mechanical properties, the ability of aluminum to conduct heat efficiently is of significant importance. The dissipation of the heat generated by FlatSat components is essential for maintaining thermal stability and preventing overheating that could compromise the performance of the entire system. Aluminum, with its high thermal conductivity, facilitates heat management and helps maintain optimal operating conditions. An analysis of the components that will be mounted on the platform shows that the maximum expected temperature is 40 C°, which allows the structure to operate without thermal problems.

In addition, aluminum is inherently resistant to corrosion due to the spontaneous formation of an oxide layer on its surface, increasing the durability and reliability of the structure.

The machinability of aluminum is a further strength. The processing flexibility of this material allows the creation of the necessary holes, facilitating the integration of components and adaptation to specific design requirements. This feature translates into greater versatility and adaptability of the support structure.

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From an environmental point of view, aluminum demonstrates remarkable sustainability. Its recyclability contributes to reducing the environmental impact and adheres to the principles of sustainability that are increasingly relevant in space technology. The choice of aluminum as a structural material therefore reflects a responsible and conscious approach to spacecraft design and development.

In summary, the detailed material analysis revealed that aluminum is an optimal choice for the structure of a FlatSat. Its properties of lightness, strength, thermal conductivity, corrosion resistance and processability combine in a harmonious synergy, helping to ensure high system performance and reliability in demanding space environments [26] [27] [28].

3.1 **Assembly and integration of FlatSat components**

Once the structure has been built it will be possible to arrange the six boards chosen for test development. The arrangement of the subsystems has been carefully selected to facilitate the management of cables and connections outside the connector stack. In fact, as will be illustrated in this chapter Assembly and integration of FlatSat components, various connections will be arranged between the NanoDock board and the three payloads to allow communication but also to perform updates and transmit data acquired by the instruments.

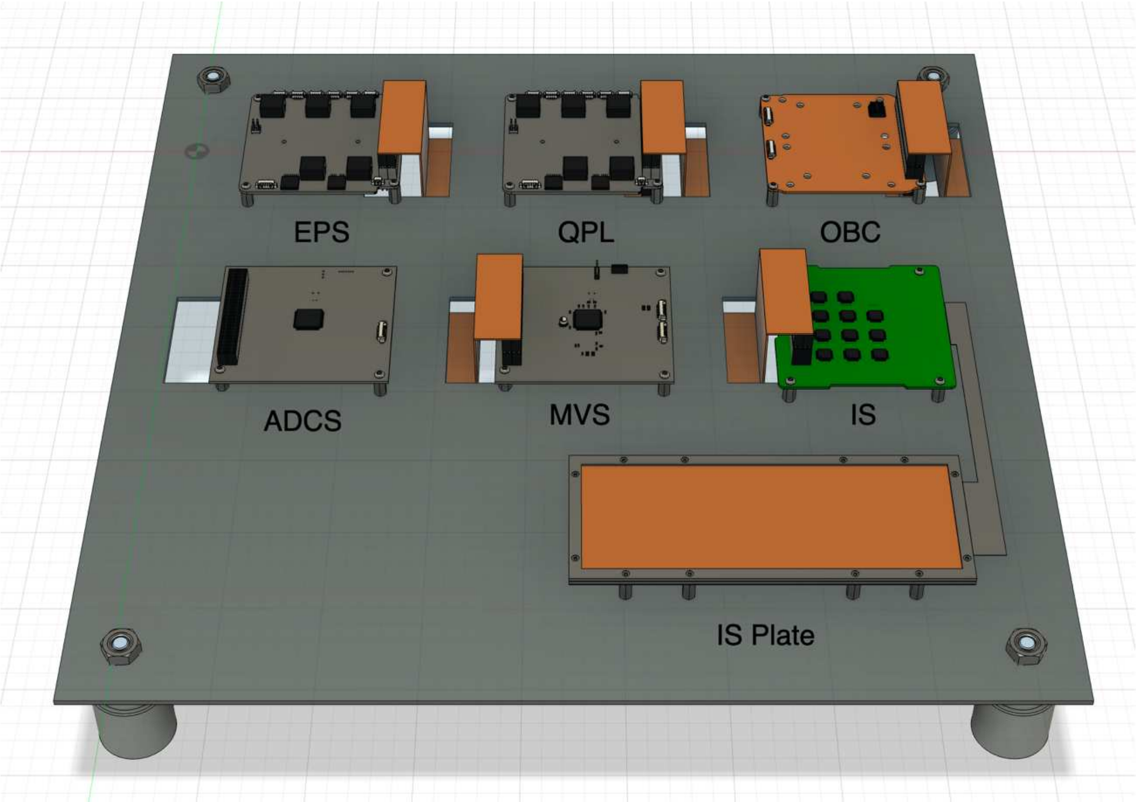

Figure 3-8: Arrangement of the subsystems in the FlatSat.

As shown in Figure 3-8, EPS is placed at the left end of the structure so that it can be connected to the bench power supply without creating clutter for the other subsystems. In addition, OBC is placed close to the three payloads to allow connection via cables of limited length.

As specified in **2.3.2 EPS** , the EPS board will be connected to the bench power supply via port P7, which has a four-pin male connection. Therefore, it will be necessary to use a power cable with a four-pin female connector at one end and the typical Molex connector used by bench power supplies at the other.

The NanoDock allows the housing of two additional boards, which in the case of the AlbaSat mission are, as already specified, NanoCom AX100 and NanoMind A3200. As far as the former is concerned, it is connected via the J1 port at the bottom of the NanoDock to the X2 port on the NanoDock. The connection is made by means of a push-pull connector that allows the two boards to interlock via the appropriate port. For the second board, on the other hand, the connection is made via ports X1 and X3 on the bottom of the NanoMind A3200 to ports X1 and X1-2 on the NanoDock.

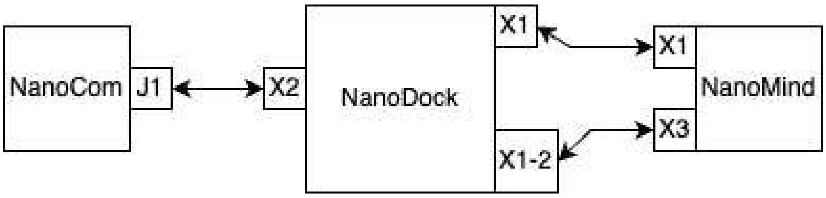

Figure 3-9: Connections between NanoDock, NanoMind and NanoCom.

These connections do not need any special wiring as all components involved are manufactured by the same company and consequently designed and manufactured to operate in the chosen configuration. Furthermore, for both boards, four screws are required to secure the NanoMind A3200 and AX100 to the NanoDock board. Finally, a USB port on the OBC main board will allow umbilical connection to the WorkStation (WS) during testing.

As far as the three payloads are concerned: QPL, IS and MVS not only have connections with through the stack connector but also others with the OBC subsystem.

The QPL connects with the NanoDock board through the P6 port with a 'Molex PicoLock 503763-029' type connector. This port allows the microprocessor to read data from the payload and also being of type 'Analog in /GPIO (General Purpose Input Output)' indicates that a has been configured to function as an analogue input, which means that it can detect variable voltages and convert them into usable digital data, via an analogue-to-digital converter (ADC). This is common in situations where it is necessary to acquire data from sensors or signals that produce continuous or time-varying voltages. The other connection of the QPL is directly to the NanoMind via the first two pins of the P6 port with a Molex PicoBlade 53261-0671 housing. This connection enables the movement of the actuators in the payload.

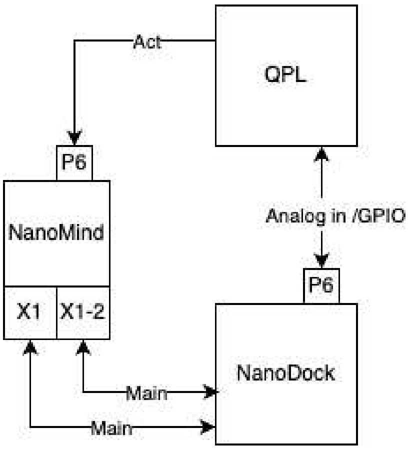

Figure 3-10: Connections between QPL, NanoDock and, NanoMind.

The IS, on the other hand, has only one further connection to the NanoDock board, which is via the first four pins of port P11 and allows the connection between the payload and OBC via the Serial Peripheral Interface (SPI) protocol. Which is a widely adopted serial communication method in embedded electronics and computing. This protocol establishes a synchronous connection between the two electronic devices, enabling them to exchange data efficiently and accurately.

Communication takes place via several signal lines, including one for the synchronization clock, one for the transmission of data from the master to the slave devices, and another for the transmission of data from the slave to the master.

As the IS, MVS is also connected to the NanoDock via a single connection, which is made via the first two pins of the NanoDock P1 port and allows the connection between the two boards using the UART (Universal Asynchronous Receiver-Transmitter) protocol. Which is a serial communication method that allows electronic devices to transmit and receive data asynchronously, i.e., without a dedicated synchronization clock signal. Instead, communication is based on a start and stop signal, together with the actual data transmitted in between. The UART protocol involves two main lines: one for data transmission (TX) and one for data reception (RX). This approach makes it suitable for communication between devices operating at different speeds or which may have varying timings.

Figure 3-11 shows all the connections in the FlatSat, the different colors represent their different types. In black are represented connections that are made without the use of cables but thanks to special ports X1, X1-2 of the NanoDock and X1, X3 of the NanoMind reported Figure 2-10, that allow two components to be connected by pressure.

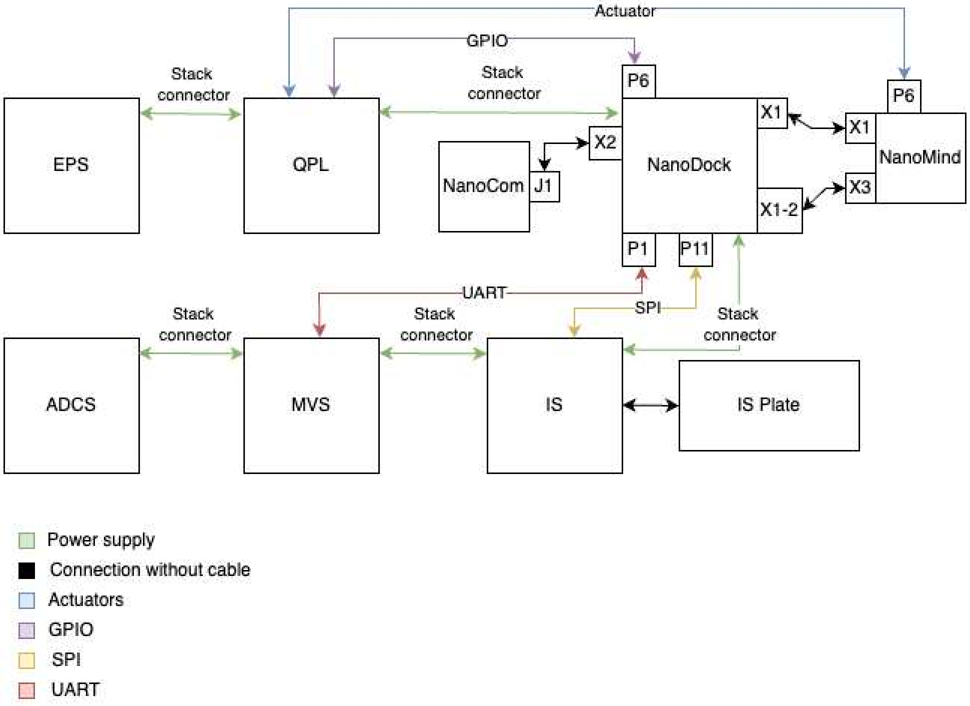

Figure 3-11: All connections in the FlatSat.

Chapter 4

FLATSAT TEST

This chapter aims to define the activities and subsequently the associated procedures that will be used to evaluate the functionality of FlatSat. Functional tests will be planned to examine that the platform is able to fulfil the objectives for which it is designed.

According to the ECSS standard ECSS-E-ST-10-03C [29], a Full Functional Test (FFT) is an extensive examination aimed at showcasing the flawless operation of all functions within the tested item, across all operational modes. Its primary objectives include validating the absence of design, manufacturing, and integration errors. The FFT assess the spacecraft capability to meet its technical specifications and to verify the overall functionality of the entire system. Consequently, a thorough and comprehensive functional test, complemented by mission, performance, or end-to-end testing, has the potential to enhance the mission chances of success and survival.

Space-related functional tests associated with the verification of a FlatSat are critical examinations aimed at assessing the proper functioning and interaction between the different subsystems by simulating their behavior in space.

During functional testing, the FlatSat undergoes a series of simulations and operating conditions to verify its performance and robustness. Control, communication, power, and other tests are performed on the FlatSat to ensure that all subsystems work properly and in synergy with each other.

The results of the functional tests provide an important assessment on the ground prior to the integration of the satellite, helping to reduce risks and ensuring the effective operation and success of the space mission. With regard to the subsystems within the FlatSat, an initial test campaign is planned, at the component level, before moving on to the system-level test campaign that will be outlined below. This is done because the first objective of FlatSat is to verify the communication capability between all subsystems and to check that each board performs the task for which it was chosen.

The technique that is implemented for the development of the test campaign is the Hardware in The Loop (HIL), which involves the integration of hardware components with a software simulation environment. Basically, the HIL technique involves linking a physical system (hardware) with a simulation model (software) that represents the behavior of other systems with which, the FlatSat in this case, it should interact. During HIL testing, the real physical system is subjected to simulated conditions in order to test its operation and responses in realistic situations. These simulations can include different operating scenarios, failures or extreme situations that might occur during the real mission. The main objective of the HIL technique is to validate and verify the operation of the hardware system in its context of use.

4.1 **Test objectives**

As previously mentioned, the objectives of the functional tests on the FlatSat are to verify the correct integration of the subsystems and the appropriate response of the system during operations. Consequently, all connections on the platform must be functional, enabling power and communication to be supplied to all the FlatSat boards. The platform will be connected via an umbilical connection to a computer (WS) in the laboratory where the tests will be carried out. The WS will be used to send commands to the FlatSat and will also allow the acquisition of simulation data, hence it will be provided with the necessary interfaces and software for communication with the platform.

In order to verify the correct integration and communication between the subsystems, the satellite modes and procedures will be verified, which will be explained **4.3 Mode analysis**. Once the FlatSat connections have been verified, the platform can be used to verify the functionality of the payloads once connected to the other subsystems. Next, it will be necessary to test the accuracy of the platform connections by assessing the energy consumption and data output for each configuration. These data will then be compared with those evaluated beforehand or those declared by the component/subsystem manufacturer in the case of COTS components. The data obtained will allow a valid comparison with those that are expected to be obtained in orbit following launch in the future.

The achievement of the test objectives will make it possible to confirm the validity of the FlatSat and the correctness of the connections between the subsystems. In addition, the absence of component defects will be demonstrated, confirming the ability of the components to achieve the mission objectives.

4.2 **Test conditions**

Test conditions are to be established according to documents drawn up by the 'European Co-operation for Space Standardization' using relevant terrestrial environments. Cleanliness and contamination control for test programmed shall be in accordance with ECSS-Q-ST-20-07 [30].

Electrical ground support equipment (EGSE) or other support systems for the test object shall:

- Not compromise the test results.
- Be immune to the signals used for sensitivity testing.
- Be designed to comply with applicable legislation, including safety regulations (e.g., EC Directives).

Therefore, it was decided to conduct the functional tests at the laboratory of the Department of Industrial Engineering of the University of Padua, which fulfils the necessary safety requirements for carrying out the tests. The following precautions are further imposed:

Tests are performed during hours that minimize potential sources of external noise, such as vibration or electromagnetic interference from the use of machinery in the laboratories with a preference to complete tests between 2pm and 4pm in the afternoon, hours usually less prone to these types of noise.

- The test area is thoroughly cleaned immediately before testing and must remain clean at all times.
- External electromagnetic sources not essential for testing are turned off in the vicinity of the test equipment.
- Tests are conducted in natural sunlight to eliminate potential background noise from artificial lighting.
- Air conditioning systems are turned off to limit the acoustic noise produced by such devices.

The test equipment, test levels and operating procedures shall not create conditions that could.

- Induce failures of the test object:
- Create dangerous situations.

The temperature recorded in the test area shall be between 15°C and 30°C, allowing both the described instrumentation to operate in its operating range and the selected personnel to perform the tests without requiring air conditioning measures.

4.3 **Mode analysis**

During its operational life, the satellite will encounter various conditions and, consequently it must be able to cope with all of them without incurring damage that could cause the mission to fail. For this reason, five modes have been selected that will allow the entire system to deal safely with all the scenarios envisaged during the design phase.

The selected modes are as follows:

- Off mode
- Activation sequence
- Safe mode
- Detumbling mode
- Nominal mode

Each time the satellite enters a different mode, the various subsystems also change their operating mode. Modes are associated with a "level" based on the complexity of procedures that are performed within it as depicted in Figure 4-1. The identification of

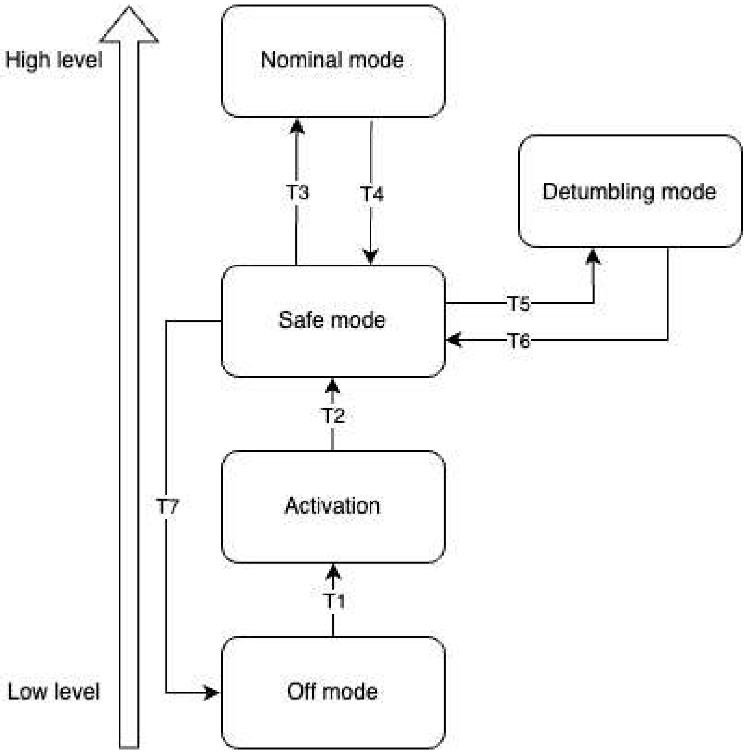

Figure 4-1: Modes graph.

levels allows the satellite to remain in a higher mode if the selected parameters remain in a nominal range. Otherwise, the system switches to a lower mode.

In Figure 4-1, the arrows indicate the transitions that can be made, also indicating the direction in which they can occur; some of them are bi-directional while others are mono-directional.

For the FlatSat to enter modes higher than Safe mode, a command must be sent from the WS to the FlatSat. As far as the transition from Off mode to Activation is concerned, this must take place autonomously as in the first mode there is no possibility of communicating with the entire system as all subsystems are switched off.

Each transition is associated with triggers and conditions, the former being events which, if only one of them is met, cause the transition to take place automatically while the latter are a set of requirements that must be met for the transition to take place. To switch from a higher to a lower mode, there are several triggers and no conditions. For the reverse transition, on the other hand, there are several conditions and only one trigger.

For proper test programming, it will be necessary to identify all the steps that must be monitored during the analysis of each individual mode. Accordingly, the modes will be briefly illustrated hereunder, specifying what will have to be analyzed during testing in order to assess the success of the campaign.

4.3.1 ***Off mode***

This is not a true operational mode of the satellite as all its subsystems are switched off. The system can be put into this mode from all other possible modes. Consequently, the test to verify this mode will consist of examining that all the subsystems are not powered; this can be done through the WS, which allows the visualization of the status of the various subsystems through the dedicated software.

4.3.2 ***Activation sequence***

This mode represents the transition between off mode and safe mode (T1). This sequence occurs whenever the entire system is rebooted or when it is activated for the first time. The main objective of the activation sequence is to initiate the necessary subsystems, i.e., EPS, OBC and deploy the antenna. In the case of first activation, the latter task will be done 30 min after the activation while the beacon is activated after an additional 15 min from the antenna deployment, for a total of 45 min.

Two conditions must be met to enter this mode:

- The battery voltage must be higher than 6.4 V.
- The kill switches must not be pressed.

The kill switches are devices for checking whether or not the satellite has been released from the launch vehicle. Instead, the trigger for the activation sequence is that all conditions are verified.

4.3.3 ***Safe mode***

This mode is necessary to allow the system to enter a stable state thus maximizing the chances of survival in potentially critical situations. When entering this mode, power consumption is minimized by shutting down all non-essential systems, leaving only the sensors and actuators required for power and attitude control active. During safe mode, the system continues to transmit a beacon signal with telemetry data (TM) until a command is sent from the WS or if the battery voltage drops below 6.5 V.

Entry into this mode can occur in several ways, which are summarized in Table 4-1 indicating the triggers and conditions required:

From	**Level**	**Triggers**	**Conditions**
Activation (T2)	Lower than safe	• OBC active • EPS active • 45 minute timer elapsed	Deployment done
Nominal (T4)	Higher than safe	• Battery voltage < 6.7 V • Rotational Velocity > TBD deg/s • Battery temperature > 50 °C (TBC) • No contact with ground for more than 2 days • Failure flag active	N.A.

		TC to enter safe mode recived	
Detumbling (T6)	Higher than safe	- Rotational velocity - ADCS not healthly - Battery voltage < 6.7 V - TC to enter safe mode received	N.A.

Table 4-1: Triggers and conditions for transitions to Safe mode.

In this mode, there are also four procedures that can be performed in parallel and are summarized below:

- **Safe Procedure 01 (SP01) - Beacon:** The beacon “heartbeat” signal is sent every 60 seconds (TBC) in order to improve the visibility of the spacecraft. The beacon can be switched off in response to a request from the ground control center and will remain in this state until it receives a dedicated command, even in the event of a complete system reset. It can also be switched off in situations where limited power is available.
- **Safe Procedure 02 (SP02) - Checks:** Allows telemetry to be acquired and the status of all subsystems to be checked, including parameters such as battery voltage and time of last communication with the WS.
- **Safe Procedure 03 (SP03) - ADCS:** Initializes the ADCS safe mode check and monitors whether the rotation speed exceeds a threshold TBD; if this condition is met, it triggers the transition to detumbling mode. In addition, there is a function to disable the ADCS via the 'safe to operate' flag, which allows it to be disabled in the event of a malfunction.
- **Safe Procedure 04 (SP04) - Exit:** Enables the implementation of the switch to nominal mode. This is done after conducting a check to ensure there are no active malfunction signals or parameters outside the limits, as well as receiving a specific command from the ground station.

4.3.4 ***Detumbling mode***

The detumbling mode allows the system to reduce the rotation speed and can be activated either by a command from the WS or from the safe mode (T5). In the latter case, for the transition to take place, the system's rotational speed must be greater than TBD deg/s.

The triggers, on the other hand, are as follows:

- Battery voltage > 7 V.
- ADCS healthly.

The detumbling mode is a higher level compared to the safe mode, as it requires more energy and uses a more refined attitude control architecture. Consequently, if events such as a power shortage or a failure in the detumbling process prevent this mode from being maintained, the system automatically returns to safe mode.

As in the previous mode, a number of procedures are performed in parallel and are explained below:

- **Detumbling Procedure 01 (DP01) - Beacon:** Sends the beacon heartbeat signal every 60 seconds (TBC) in order to increase the visibility of the spacecraft. The beacon function can be deactivated in response to a request from the ground control center and will remain deactivated until a specific command is received, even in the event of a system reset. In addition, the beacon can also be switched off in low power situations.
- **Detumbling Procedure 02 (DP02) - Checks:** Allows telemetry to be acquired and the status of all subsystems to be checked, including parameters such as battery voltage and time of last communication with the ground station (GS). In addition, there is an option to manually activate the exit from detumbling mode via a ground command in the event of any kind of malfunction in the ADCS subsystem.
- **Detumbling Procedure 03 (DP03) - ADCS:** Allows to check the spacecraft rotation speed against a predefined threshold, determining whether the system should switch to safe mode or continue with the detumbling process. In the second scenario, it is examined whether the ADCS is currently in detumbling mode; if not, this mode is activated along with the start of a specific timer. Next, the rate of speed increase is monitored, as an increase may be indicative of an ADCS malfunction, and the detumbling timer is checked. If one of these checks indicates an anomaly in the ADCS, the spacecraft re-enters safe mode. Otherwise, the detumbling process continues.

4.3.5 *Nominal mode*

This is the only mode in which the payloads are active since there are no specific modes dedicated to their operations. In nominal mode, the satellite maintains its pointing at Nadir and a beacon is transmitted every 60 s. In this mode there are seven main procedures that can be executed in parallel. They will be all tested.

Activation of the processes described below is governed by a set of operating procedures that include initial state checks (e.g., checking battery status and component temperature) and detailed instructions that operators must follow to safely activate certain components or perform tasks.

This is the mode in which the system will spend most of its time, there are seven procedures that will be carried out in parallel and are outlined below:

- **Nominal Procedure 01 (NP01) - Beacon:** Send the beacon beat signal every 60 seconds (TBC) in order to improve the visibility of the spacecraft. The beacon can be deactivated in response to a request from the ground and will remain inactive until it receives a specific command, even if the system is reset.
- **Nominal Procedure 02 (NP02) - Checks:** Allows monitoring of the status of all subsystems, including battery voltage and time of last contact with the ground station (GS). In case a parameter is detected outside the nominal values, the fault detection and repair (FDIR) systems are activated, which sets an error flag. The spacecraft can then transit in safe mode, aborting all other ongoing procedures and shutting down nonessential subsystems (NES).
- **Nominal Procedure 03 (NP03) - IS:** Allows the impact sensor to be activated or deactivated by a command from the ground (TC). It also monitors the status of the IS, detecting any impacts or anomalies e.g., overheating.
- **Nominal Procedure 04 (NP04) - QPL:** Provides a record of the operations of the modulating retro reflector (QPL), allowing it to be activated on demand, typically by a timed command, and deactivated after a period specified by the activation command. Modulation of the reflector is based on a signal in on-board memory, which can be modified from the ground. In the event that an error, which includes overheating, occurs during QPL operation, the On-Board Software (OBSW) will automatically deactivate it.
- **Nominal Procedure 05 (NP05) - MVS:** Allows the acquisition of Micro Vibrations (MV) data by activating the sensor when required, usually by a timed command, and deactivating it after a preset period (the default value is 4 seconds

but can be customized). Sampled data are recorded on board and subsequently downloaded as soon as the GS is visible.

- **Nominal Procedure 06 (NP06) -TTC:** Data transmission can be initiated by a direct command from the ground station (GS). The transmission has a maximum duration of 60 seconds, and if further data needs to be sent, an additional command is required to continue the transmission. During the data transfer process, the beacon transmission is interrupted. In addition, while the data is being transmitted, the OBSW will perform checks on the status of the components and terminate the procedure if an error is detected, which also includes monitoring the temperature of the transceiver.
- **Nominal Procedure 07 (NP07) -ADCS:** This procedure monitors the status of the ADCS subsystem, changes its secondary mode in response to commands from ground TC, or disables it completely in case of a failure in the ADCS. It also checks the spacecraft rotation speed and activates the safe mode if it exceeds a critical threshold. In case of fault detection while the ADCS is active, the transition to safe mode is initiated.

4.4 **Test planning**

Once all the modes and procedures in the Safe mode, Detumbling mode and Nominal mode have been analyzed, it is necessary to schedule tests to verify that both modes and procedures are occurring correctly. For this reason, through the use of the FlatSat, it will be possible to perform the correct satellite mode verifications. All the tests that will be explained below will be performed following the integration of the platform, the connection between all the boards that are part of it, and the connection of EPS with the bench power supply as explained in 2.3.2. In addition, it should also be mentioned that the WS plays a key role during these tests as it will allow the operators to visualize and analyze what is happening in the FlatSat by playing a similar role to that of the GS for the satellites in orbit. But at the same time, it will "cooperate" with OBC by allowing commands to be sent correctly to the entire platform.

4.4.1 ***FlatSat Test – Activation (FTA)***

The purpose of this test is to analyze the activation sequence and verify that all the steps described above have been carried out correctly.

1. Set the battery voltage of the bench power supply to 6.5 V.
2. Through the WS change the condition of the KSs from pressed to un-pressed.

These devices are not present in the FlatSat but thanks to the WS it is possible to simulate their condition from pressed to un-pressed through the dedicated Software interface on it.

3. Verification through the WS of the start of the 45 min timer.
4. After 30 min from the start of the timer, it is necessary to verify through the WS the sending by OBC of the command to deploy the antenna.

The antenna is not present in the FlatSat, but through the WS it will be possible the verification of the sending of the command by OBC.

5. At the end of the 45 min timer the FlatSat should be in safe mode. To verify the transition to this mode the WS will have to have received the command from OBC to send the Beacon every 60 s and also OBC and EPS will have to be active.

It will be possible to verify the status of OBC and EPS through the WS. By performing this test, it will be possible to verify both activation mode and T1 and T2 transitions.

4.4.2 *FlatSat Test – Safe mode*

To perform the following tests, it will be necessary to initially set the FlatSat in the safe mode. This process can be done either by running FT01 or through a direct command from the WS. The aim of the tests that will be illustrated in this section is to verify to verify the possible transitions that start from the safe mode and bring the system into the other modes, namely T3, T5 and T7. In addition to the transitions, it will be possible to verify that the whole system is in the chosen mode thanks to the WS.

4.4.2.1 *FlatSat Test - Safe mode - T3 (FTST3)*

T3 represents the transition of the system from safe mode to nominal mode. Consequently, since it is a transition that occurs from a lower-level mode to a higher one, a set of conditions must be met and there must be only one trigger reported in Table 4-2.

From	To	Conditions	Trigger
Safe	Nominal	Battery voltage > 7	TC to exit safe mode received
		No failure flag active	
		Parameters in nominal ranges	
		Battery temperature < 50°C (TBC)	

Table 4-2: Conditions and Trigger for T3.

Below are reported the steps to perform the test:

1. Set the battery voltage of the bench power supply to 7.1 V.
2. Verify via WS that there are no failure flags.
3. Verify through WS that the parameters are in the nominal ranges.
4. Set the battery temperature data to a lower value of 50 °C through WS.

As mentioned in **2.3.2 EPS** for this first test campaign, it was decided not to include the battery pack inside the FlatSat and consequently there is no possibility to evaluate the state of the batteries. To remedy this situation, it is possible to set through the WS a value for the battery data thus allowing its simulation.

5. Send the command to the FlatSat to exit the safe mode via WS.
6. Wait TBD s, to allow the system to perform the operation.
7. Verify via WS that the components shown in Table 4-3 are in the indicated state.

Subsystem	Component	Nominal mode
ADCS	Fine Sun Sensor	ON
	Coarse Sun Sensor	ON
	Rate Sensor	ON
	Magnetometer	ON
	Magnetorquers	ON
	Momentum Wheel	ON
	GPS	ON
OBC	OBC	ON
Payloads	IS	OFF
	MVS	OFF
	QPL	OFF
EPS	PCDU	ON
TTC	Tranciever	RX/Beacon/TX

Table 4-3: Components state after T3.

8. Verification via WS of the correct execution of **NP01** and **NP02**.

As it can be seen, both the transition and the state of the nominal mode components are verified in FTST3. The operability of the payloads and their associated procedures will be verified in specific tests which will be explained in Section XXX.

4.4.2.2 *FlatSat Test - Safe mode – T5 (FTST5)*

As with FTST3, the transition from safe mode to detumbling mode also takes place from a lower-level mode to a higher one, therefore a number of conditions must be fulfilled for T5 to occur with a single trigger reported in Table 4-4.

From	To	Conditions	Trigger
Safe	Detumbling	Battery voltage > 7	Rotational velocity > TBD deg/s
		ADCS healthy	

Table 4-4: Conditions and Trigger for T5.

Below are reported the steps to perform the test:

1. Set the battery voltage of the bench power supply to 7.1 V.
2. Verify via WS that ADCS is 'healthy'.
3. Set a rotation speed of TBD deg/s via WS

In this case, the FlatSat is unable to rotate because it is fixed on a workbench, so through WS it will also be possible to manage this parameter by setting a value to trigger T5.

4. Wait TBD s, to allow the system to perform the operation.
5. Check via WS that the components in Table 4-5 are in the state indicated.

Subsystem	Component	Nominal mode
ADCS	Fine Sun Sensor	OFF
	Coarse Sun Sensor	OFF
	Rate Sensor	ON
	Magnetometer	ON
	Magnetorquers	ON
	Momentum Wheel	IDLE
	GPS	ON

OBC	OBC	ON
Payloads	IS	OFF
	MVS	OFF
	QPL	OFF
EPS	PCDU	ON
TTC	Tranciever	RX/Beacon/TX

Table 4-5: Components state after T5.

6. Check through WS the rotation speed of the MW
7. Visual verification of MW rotation.
8. Verification via WS of the correct execution of **DP01, DP02** and **DP03**.

4.4.2.3 ***FlatSat Test - Safe mode – T7 (FTST7)***

For T7, i.e., the transition from safe mode to off mode, since it is a transition from a higher to a lower-level mode, it will occur following the fulfilment of a trigger. For the test campaign under analysis, three events were identified which correspond to the tests illustrated below.

4.4.2.3.1 FlatSat Test – Safe mode – T7 – 01 (FTST701)

The first trigger taken into consideration concerns the battery voltage condition. In fact, if this value falls below the 6V threshold, the system must be able to switch to off mode to protect its components.

Below are reported the steps to perform the test:

1. Set the battery voltage of the bench power supply to 5.9V.
2. Wait TBD s, to allow the system to perform the operation.
3. Check via WS that the components in Table 4-6 are switched off.

Subsystem	**Component**	**Nominal mode**
ADCS	Fine Sun Sensor	OFF
	Coarse Sun Sensor	OFF

	Rate Sensor	OFF
	Magnetometer	OFF
	Magnetorquers	OFF
	Momentum Wheel	OFF
	GPS	OFF
OBC	OBC	OFF
Payloads	IS	OFF
	MVS	OFF
	QPL	OFF
EPS	PCDU	OFF (TBC)
TTC	Tranciever	OFF

Table 4-6: Components state after FTST701.

4.4.2.3.2 FlatSat Test – Safe mode – T7 – 02 (FTST702)

The second trigger is such that T7 takes place in the event that the contact with the satellite is lost for more than five days. Therefore, in order to simulate this situation, it is possible to set a period of five days prior to the date on which the test is carried out as the date of last contact via WS. It will then be necessary to check via WS that the components listed in Table 4-6 are deactivated.

4.4.2.3.3 FlatSat Test – Safe mode – T7 – 03 (FTST703)

The last trigger selected for T7 is a command sent by WS; therefore, the following steps will be necessary to execute FTST703.

1. Send the command to the FlatSat to enter off mode via WS.
2. Wait for TBD s, to allow the system to perform the operation.
3. Check via WS that the components listed in Table 4-6 are off.

With the T7 tests it will be possible to verify both the correctness of the transition that brings the system into off mode, but also the mode itself.

4.4.2.4 *FlatSat Test – Detumbling mode – T6*

From Figure 4-1, it can be seen that the only transition to take the system from detumbling mode to safe mode is T6. As for T7, the transition is from a higher to a lower-level mode. In the following sections the tests for the triggers selected to perform T6 are reported. T6 can only be performed if the system is in safe mode.

4.4.2.4.1 *FlatSat Test – Detumbling Mode – T6 – 01 (FTDT601)*

The first trigger that is considered, takes into account the case where the rotation speed is below an established threshold as stated in the following points.

Below are reported the steps to perform the test:

1. Set a rotation speed of 0.4 deg/s via WS.
2. Wait TBD s for the system to perform the operation.
3. Check via WS that the components in the Table 4-7 are in the state indicated.

Subsystem	Component	Nominal mode
ADCS	Fine Sun Sensor	OFF
	Coarse Sun Sensor	OFF
	Rate Sensor	OFF
	Magnetometer	ON
	Magnetorquers	ON
	Momentum Wheel	OFF
	GPS	ON
OBC	OBC	ON
Payloads	IS	OFF
	MVS	OFF
	QPL	OFF
EPS	PCDU	ON
TTC	Tranciever	RX/Beacon

Table 4-7: Components state after FTDT601.

4.4.2.4.2 FlatSat Test – Detumbling Mode – T6 – 02 (FTDT602)

Another situation that could occur in orbit is when ADCS fails becoming unable to perform its functions. For this reason, it is necessary to return the satellite to safe mode in order to safeguard the entire system. The following points must be followed to verify this condition.

1. Set failure flags for ADCS via WS.
2. Wait TBD s, to allow the system to perform the operation.
3. Check via WS that the components listed in Table 4-7 are in the indicated state.

4.4.2.4.3 FlatSat Test – Detumbling Mode – T6 – 03 (FTDT603)

The third trigger considered to enable the transition from detumbling mode to safe mode is when the battery voltage falls below a threshold value. The following points must be followed to perform this test.

1. Set the battery voltage of the bench power supply to 6.6 V.
2. Wait TBD s, to allow the system to perform the operation.
3. Check via WS that the components shown in Table 4-7 are in the indicated state.

4.4.2.4.4 FlatSat Test – Detumbling Mode – T6 – 04 (FTDT604)

The last condition to be evaluated in this test campaign for T6 is when a command is sent via the WS.

1. Via WS send the command to the FlatSat to enter safe mode via T6.
2. Wait TBD s, to allow the system to perform the operation.
3. Check via WS that the components shown in Table 4-7 are in the state indicated.

4.4.3 ***FlatSat Test – Nominal mode***

The most substantial part of the test campaign is evaluating how the system behaves when in nominal mode. In this, which turns out to be the mode in which the satellite will spend most of the temple, there are several procedures and a transition to be tested. To perform these tests, it will be necessary to bring the entire system to the condition reached after FTST3. This can be done either by performing the nominal mode tests after the test presented in **4.4.2.1** ***FlatSat Test - Safe mode - T3 (FTST3)***or by setting the FlatSat to the mode of interest via WS. The methods for evaluating how the FlatSat behaves when in nominal mode will be explained below.

4.4.3.1 ***FlatSat Test – Nominal mode – T4***

As in the cases of T6 and T7, in order to carry out T4, it is not necessary for any condition to occur, but it is essential that the transition occurs as a result of a trigger. In this case a few have been identified and will be tested in this first test campaign.

4.4.3.1.1 FlatSat Test – Nominal mode – T4 – 01 (FTNT401)

Starting from nominal mode, the first trigger to switch the system to safe mode relates to the battery voltage value. In fact, in the event that the satellite is in nominal mode, but this value falls below a certain threshold, the system must be able to return to safe mode to preserve itself. To perform the test described above, the following points must be followed.

1. Set the battery voltage of the bench power supply to 6.6 V.
2. Wait TBD s, to allow the system to perform the operation.
3. Check via WS that the components shown in Table 4-8 are in the indicated state.

Subsystem	Component	Nominal mode
ADCS	Fine Sun Sensor	OFF
	Coarse Sun Sensor	OFF
	Rate Sensor	OFF
	Magnetometer	ON
	Magnetorquers	ON
	Momentum Wheel	OFF
	GPS	ON
OBC	OBC	ON
Payloads	IS	OFF
	MVS	OFF
	QPL	OFF
EPS	PCDU	ON
TTC	Tranciever	RX/Beacon

Table 4-8: Components state after FTNT401.

4.4.3.1.2 FlatSat Test – Nominal mode – T4 – 02 (FTNT402)

If the rotational speed value exceeds a certain threshold during nominal operations, the system must be able to return to safe mode and then possibly perform T5 to allow a reduction in rotational speed through detumbling mode. The following points must be followed to verify this process.

1. Set a rotational speed of TBD deg/s via WS.
2. Wait TBD s, to allow the system to perform the operation.
3. Check via WS that the components shown in Table 4-8 are in the state indicated.

4.4.3.1.3 FlatSat Test – Nominal mode – T4 – 03 (FTNT403)

The third trigger that is taken into account is the evaluation of the battery temperature. In fact, if this value exceeds a certain threshold, the system must be able to switch to safe mode to avoid damaging the EPS. This process is checked as follows.

1. Using WS, set the battery temperature value to a lower value of 50 °C.
2. Wait TBD s, to allow the system to perform the operation.
3. Check via WS that the components listed in Table 4-8 are in the indicated state.

4.4.3.1.4 FlatSat Test – Nominal mode – T4 – 04 (FTNT404)

A condition may also occur whereby the satellite in nominal mode is unable to contact GS for a period longer than 2 days. This requires the system to be able to enter safe mode. The test to verify the situation just described is shown below.

1. Via the WS, set the date of the last contact with the FlatSat to be two days before the test date.
2. Wait TBD s, to allow the system to perform the operation.
3. Verify via WS that the components listed in Table 4-8 are in the indicated state.

4.4.3.1.5 FlatSat Test – Nominal mode – T4 – 05 (FTNT405)

It is necessary to consider the case in which the satellite is in nominal mode and any failure flag occurs. The following test was programmed to verify this scenario.

1. Use the WS to set a failure flag.
2. Wait TBD s for the system to perform the operation.
3. Check via WS that the components listed in Table 4-8 are in the indicated state.

4.4.3.1.6 FlatSat Test – Nominal mode – T4 – 06 (FTNT406)

The last trigger analyzed in this section involves GS sending a command to bring the system from nominal mode to safe mode. The following points must be followed to verify the correct execution of this process.

1. Send the command to the FlatSat to enter safe mode via T4 via WS.
2. Wait TBD s, to allow the system to perform the operation.
3. Check via WS that the components shown in Table 4-8 are in the state indicated.

4.4.3.2 ***FlatSat Test – Nominal mode – Payload***

Because the payloads have a low level of operational complexity, there is no dedicated Payload mode. Instead, these payloads are activated directly from the Nominal mode through specific commands received from the WS. For this reason, it is necessary to schedule a test for each payload in order to test their operability. Consequently, for the development of the following tests, it is necessary for the entire system to be in nominal mode, and as mentioned above, this can take place either as a result of the tests FTST3 or via a direct command from the WS.

4.4.3.2.1 FlatSat Test – Nominal mode – IS (FTNIS)

The following points must be followed during the test.

1. Check that the system is in nominal mode.
2. Send via WS the command to activate IS.
3. Wait TBD s, to allow the system to perform the operation.
4. Check via WS that the components listed in Table 4-9 are in the state indicated.

Subsystem	Component	Nominal mode
ADCS	Fine Sun Sensor	ON
	Coarse Sun Sensor	ON
	Rate Sensor	ON
	Magnetometer	ON
	Magnetorquers	ON
	Momentum Wheel	ON
	GPS	ON
OBC	OBC	ON
Payloads	IS	ON
	MVS	OFF
	QPL	OFF
EPS	PCDU	ON
TTC	Tranciever	RX/Beacon

Table 4-9: Components state after FTNIS.

4.4.3.2.2 FlatSat Test – Nominal mode – MVS (FTNMVS)

The following points must be followed to perform the test.

1. Check that the system is in nominal mode.
2. Send the command to activate MVS via WS.
3. Wait TBD s, to allow the system to perform the operation.
4. Check via WS that the components listed in Table 4-10 are in the state indicated in Table 4-8.

Subsystem	Component	Nominal mode
ADCS	Fine Sun Sensor	ON
	Coarse Sun Sensor	ON
	Rate Sensor	ON
	Magnetometer	ON
	Magnetorquers	ON
	Momentum Wheel	ON

	GPS	ON
OBC	OBC	ON
Payloads	IS	OFF
	MVS	ON
	QPL	OFF
EPS	PCDU	ON
TTC	Tranciever	RX/Beacon

Table 4-10: Components state after FTNMVS.

4.4.3.2.3 FlatSat Test – Nominal mode – MVS (FTNQPL)

The procedure enumerated hereunder must be followed during the test.

1. Check that the system is in nominal mode.
2. Send the command to activate IS via WS.
3. Wait TBD s, to allow the system to perform the operation.
4. Check via WS that the components listed in Table 4-11 are in the state indicated.

Subsystem	Component	Nominal mode
ADCS	Fine Sun Sensor	ON
	Coarse Sun Sensor	ON
	Rate Sensor	ON
	Magnetometer	ON
	Magnetorquers	ON
	Momentum Wheel	ON
	GPS	ON
OBC	OBC	ON
Payloads	IS	OFF
	MVS	OFF
	QPL	ON
EPS	PCDU	ON
TTC	Tranciever	RX/Beacon

Table 4-11: Components state after FTNQPL.

4.4.4 ***FlatSat Test – Reset (FTR)***

A satellite reset is an operation performed for several technical and operational reasons. One of the main reasons lies in correcting anomalies or problems that may arise during the course of the space mission. These problems may involve the operation of on-board systems, control software or communication with the ground station. In addition, reset may be employed to apply updates or patch to the software on board the satellite in order to improve performance, introduce new features or resolve errors. In some circumstances, reset can also be used to optimize energy use by temporarily shutting down nonessential systems to conserve the satellite energy resources. Finally, reset can be an integral part of procedures for responding to commands sent from the ground station, helping to maintain or restore proper satellite operations in line with mission objectives. Planning and executing a reset require careful consideration of the satellite specific needs and operational implications to ensure the success of the space mission. For these reasons, the last test that is planned in this test campaign involves resetting the satellite from any operating mode.

The following directions must be followed to perform this test:

1. Set the battery voltage of the bench power supply to 6.5 V.
2. Through the WS set the condition of the un-pressed KS.
3. Send via WS the command to reset the system.
4. Wait TBD s, to allow the system to perform the operation.
5. Verify via WS that the 45 min timer has started.
6. At the end of the 45 min timer the FlatSat should be in safe mode. To verify the transition to this mode, the WS have to receive the command from OBC to send the Beacon every 60 s and OBC and EPS will be activated.
7. Check via WS that the components listed in Table 4-12 are in the state indicated.

Subsystem	Component	Nominal mode
ADCS	Fine Sun Sensor	OFF
	Coarse Sun Sensor	OFF
	Rate Sensor	OFF
	Magnetometer	ON
	Magnetorquers	ON
	Momentum Wheel	OFF
	GPS	ON
OBC	OBC	ON
Payloads	IS	OFF
	MVS	OFF
	QPL	OFF
EPS	PCDU	ON
TTC	Tranciever	Rx/Beacon

Table 4-12: Components state after FTR.

Figure 4-2 represents an exhaustive list of the tests that will be performed on the FlatSat in order to assess the ability of the subsystems to communicate with each other and to determine whether the system is able, by responding to triggers and conditions, to move to the desired operating mode. These tests are of crucial importance in ensuring the overall integrity and efficiency of the system. They make it possible to verify the synergetic functionality of the various FlatSat components, identifying any communication problems or malfunctions of individual subsystems. Furthermore, through the application of predefined triggers and conditions, these tests provide a critical assessment of the system ability to respond in a timely and accurate manner to desired operational situations, thus ensuring a high degree of reliability and performance.

Furthermore, the tests are subdivided according to the mode or transition to be tested, so that it will be possible to subdivide their scheduling as shown in the image by color. In this way, it will either be necessary to carry out the test linked via the arrow to the test of interest beforehand, or it will be possible to set the conditions for carrying it out via WS.

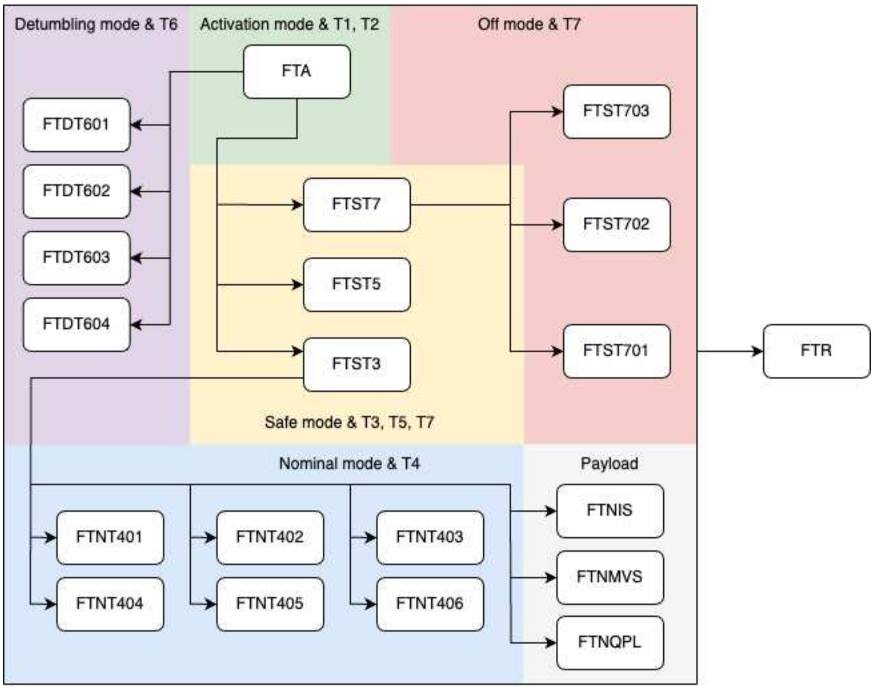

Figure 4-2: FlatSat Test graph.

Chapter 5
CONCLUSION

CubeSats are constructed by various entities to pursue a wide range of missions. It has been observed that the number of launches of this type of satellite shows no signs of decreasing in the near future, steadily expanding the size of this market. However, one of the initial purposes of CubeSats, i.e., the educational aspect, remains of paramount importance, as several universities and institutions engage students in the execution of these missions through dedicated students' projects. CubeSat projects often employs COTS components that allow a fast design of the system but still require testing after the assembly and integration of the system. However, the failure rate of these missions is significant. To perform the test campaign that permit to increase the reliability of the system, many CubeSat teams develop a FlatSat, a facility that allows the easy access to the components of the system.

In this context, this Master Thesis is developed within the framework of the AlbaSat mission at the University of Padua, which, starting from January 2023, has become part of the Fly Your Satellite – Design Booster program. The program enables university projects to leverage the knowledge and expertise of ESA experts to accelerate the development of CubeSat projects. Within this Master Thesis, the design of the FlatSat for the mission is developed, with its main objectives being the understanding of connections between the boards present in the satellite and the communication protocols between them.

To achieve this, all the components of the satellite have been deeply analyzed and their operations have been fully understanded through the study of the operational manuals of the selected boards. Subsequently, based on the characteristics of the COTS components for the mission, it was possible to evaluate the configuration of the FlatSat that would simplify the development of the payloads thanks to a flexible architecture. Furthermore, a physical platform capable of accommodating all the subsystems that will be present inside the CubeSat has been designed. Its fundamental feature is modularity; thanks to its specific configuration, it will allow the AlbaSat team to test both the single subsystems and their interaction. This will enable the development of various test campaigns that will provide a deep understanding of the components and how they interact with each other. Additionally, in case of damage or malfunctions, it will be possible, thanks to the physical configuration of the FlatSat, to promptly intervene on the individual damaged component without the need to work on the system fully integrated. Another fundamental part of this project is the programming of an initial test campaign, which will allow, once the development of all the necessary components for the complete integration of the platform is completed, to validate the operational modes of the satellite in a controlled environment.

This thesis has provided a detailed design for the realization of the FlatSat, which will be implemented in the upcoming phases of the AlbaSat mission. By including all the specifications necessary for the realization of the physical platform, the connections between the subsystems, and the procedures to follow to carry out the test campaign, it will increase the overall system reliability, thereby increasing the chances of mission success.

Chapter 6
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