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FloripaSat-2 Documentation

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SpaceLab, Universidade Federal de Santa Catarina, Florianópolis - Brazil

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Project Chief:
Eduardo Augusto Bezerra

Authors:
Gabriel Mariano Marcelino
André Martins Pio de Mattos
Yan Castro de Azeredo

Contributing Authors:
Eduardo Augusto Bezerra
Edemar Morsch Filho

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Nomenclature

FEC	*Forward Error Correction.*
ACS	*Attitude Control System.*
AEB	*Agência Espacial Brasileira.*
AIT	*Assembly, Integration and Test.*
CDS	*CubeSat Design Specification.*
CG	*Center of Gravity.*
CI	*Continuos Integration.*
EDC	*Environmental Data Collection.*
EPS	*Electrical Power System.*
FPGA	*Field-Programmable Gate Array.*
GMAT	*General Mission Analysis Tool.*
GOLDS	*Global Open Collecting Data System*
HIL	*Hardware-In-the-Loop.*
INPE	*Instituto Nacional de Pesquisas Espaciais.*
LIT	*Laboratório de Integração e Testes.*
LNA	*Low Noise Amplifier.*
MPPT	*Maximum Power Point Tracking.*
OBDH	*On-Board Data Handling.*
PA	*Power Amplifier*
PCB	*Printed Circuit Board.*
PCD	*"Plataforma de Coleta de Dados", or Data Collection Platform*
SBCD	*Sistema Brasileiro de Coleta de Dados.*
SDRAM	*Synchronous Dynamic Random-Access Memory.*

SDR *Software Defined Radio.*

SNR *Signal To Noise Ratio*

SoC *System-On-a-Chip.*

TLE *Two-Line Element.*

TTC *Telemetry, Tracking and Command Module.*

Contents

CHAPTER 1

Introduction

The FloripaSat-2 is a satellite project of a 2U CubeSat (10×10×22,70 cm). This nanosatellite is the sequence project of the FloripaSat-1 CubeSat [1], both developed by SpaceLab [2]. This second project is being developed in partneship with INPE (*Instituto Nacional de Pesquisas Espaciais*), who is supplying the main payload of the mission: The EDC board (*Environmental Data Collection*) [3]. This project is part of the "GOLDS" constellation ("Global Open Collecting Data System"), a collaborative CubeSat constellation for environmental data collection planned as part of the Brazilian space program [4].

This project started just after the launch of FloripaSat-I (first half of 2020) and is planned to be launched in 2022. Most of the embedded electronics is partially or totally based on the FloripaSat-I satellite, with the same and/or improved versions of the modules. In other words, this project has at some level a flight heritage.

1.1 Mission Description

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1.2 Mission Objectives

The main objectives of this mission are enumerated below:

1. To serve as a host platform for the EDC payload.
2. Validate the EDC payload in orbit.
3. Validate EDC functionality in orbit.
4. Validate core-satellite functions in orbit.
5. Evaluate the behavior of the core modules in a 2U mission.
6. Perform experiments on radiation effects in electronic components in orbit.
7. Serve as relay for amateur radio communications, as a contribution to the amateur radio community.

1.3 Project Members

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

A list with the current members directly related to the project (2021/02/08) can be seen in Table 1.1.

Name	Title	Position	Institution
Anderson Wedderhoff Spengler	Ph.D.	Professor	UFSC
Eduardo Augusto Bezerra	Ph.D.	Professor	UFSC
Richard Demo Souza	Ph.D.	Professor	UFSC
Laio Oriel Seman	Ph.D	Researcher	UFSC
Manoel Jozeane Mafra de Carvalho	Ph.D.	Researcher	INPE
José Marcelo Duarte	Ph.D.	Researcher	INPE
Rodrigo Leonardi	Ph.D.	Researcher	AEB
Cezar Antônio Rigo	M.Sc.	Ph.D. Student	UFSC
Edemar Morsch Filho	M.Sc.	Ph.D. Student	UFSC
Gabriel Mariano Marcelino	M.Sc.	Ph.D. Student	UFSC
Thiago Martins	M.Sc.	Ph.D. Student	UFSC
Vinicius Pimenta Bernardo	B.Eng.	Master's Student	UFSC
Amanda Medeiros	-	Undergraduate Student	UFSC
André Martins Pio de Mattos	-	Undergraduate Student	UFSC
Augusto Cezar Boldori Vassoler	-	Undergraduate Student	UFSC
Daniel Baron	-	Undergraduate Student	UFSC
João Cláudio Elsen Barcellos	-	Undergraduate Student	UFSC
Lorenzo Maturano	-	Undergraduate Student	UFSC
Matheus Wagner	-	Undergraduate Student	UFSC
Maurício Sinigaglia	-	Undergraduate Student	UFSC
Tatiane dal Ross	-	Undergraduate Student	UFSC
Victor Noster	-	Undergratuate Student	UFSC
Yan Castro de Azeredo	-	Undergraduate Student	UFSC

Table 1.1: Project members (2021/02/08).

All the used modules and methods used in this project are based in a lot of past works, most of it being the FloripaSat-I and the EDC projects. The list with the indirectly involved people is much bigger.

1.4 Mission Patch

The mission patch of the FloripaSat-2 can be seen in Figure 1.1, it is inspired by the FloripaSat-I patch [1] because it uses the flight heritage from its core modules (EPS, OBDH, TTC) from the past mission, these were improved in hardware and/or in software to achive the new requirements. The patch shows Brazil, the country of the mission's origin, and grey orbits representing a constellation of CubeSats. The yellow was originally thought of a "gold" like color because of the mission participation on the GOLDS constellation.

Figure 1.1: FloripaSat-2 mission patch.

CHAPTER 2

Mission Requirements

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

CHAPTER 3

Mission Schedule

	Month (2021)											
Activity	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dez
1	■	■	■	■								
2	■	■	■	■								
3	■	■	■	■	■	■	■	■	■			
4	■	■	■	■	■	■						
5				■	■	■	■	■	■	■		
6					■	■	■	■	■	■	■	
7								■	■	■		
8								■	■	■	■	
9									■	■	■	■
10										■	■	
11										■	■	
12											■	
13									■	■	■	■
14											■	■

Table 3.1: Mission schedule.

Each activity of Table 3.1 is decribed below:

1. Acquisition and manufacturing of critical elements and components for the solo platform.
2. Acquisition and manufacture of elements and components critical to the payload.
3. Acquisition and manufacturing of critical elements and components for the solo segment.
4. Compatibility tests between platform and payload in SpaceLab UFSC.
5. Integration of the engineering model in SpaceLab UFSC.
6. Preparation and suitability of the ground segment.
7. Verification and validation of the engineering model at SpaceLab UFSC.
8. Verification and validation of the flight model at SpaceLab UFSC.

9. Data collection platforms installation.
10. Verification and validation tests of Engineering Model compatibility with EMMN in the INPE / CRN in Natal.
11. Environmental tests at the Integration and Testing Laboratory (LIT/INPE).
12. Flight model acceptance and ground segment review.
13. Ground segment delivery.
14. Flight model delivery.

CHAPTER 4

Technical Budgets and Mission Analysis

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

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

4.1 Orbit Parameters and Analysis

To define the orbit parameters and simulate the behaviour of the satellite during its operation, the GMAT software was used [5]. The orbit parameters was based on the FloripaSat-I TLE, but with a lower altitude. These parameters can be seen in Table 4.1.

Parameters	Value	Unit
Altitude	550	km
Eccentricity	0,0015051	°
Inclination	97,9750	°
RAAN	85,5100	°
Arg. of Perigee (AOP)	194,87	°
TA	99,8877	°

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

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

- Force model for gravitational field: "*Earth Gravitational Model 1996 (EGM96)*"
- Propagator: "*PrinceDorman78*"
- Drag coefficient: 2,2
- Drag atmosphere model: "*Mass Spectrometry and Incoherent Scatter (MSISE90)*"
- Epoch: 01 Jan 2022 11:59:28.000

The Figure 4.1 shows the 3D representation of the FloripaSat-2 orbit simulation, Figure 4.2 shows the ground track of the first day of operation.

The next sections present some analysis based on the results obtained on the simulations executed on GMAT.

The source files of the GMAT simulation are available in [7].

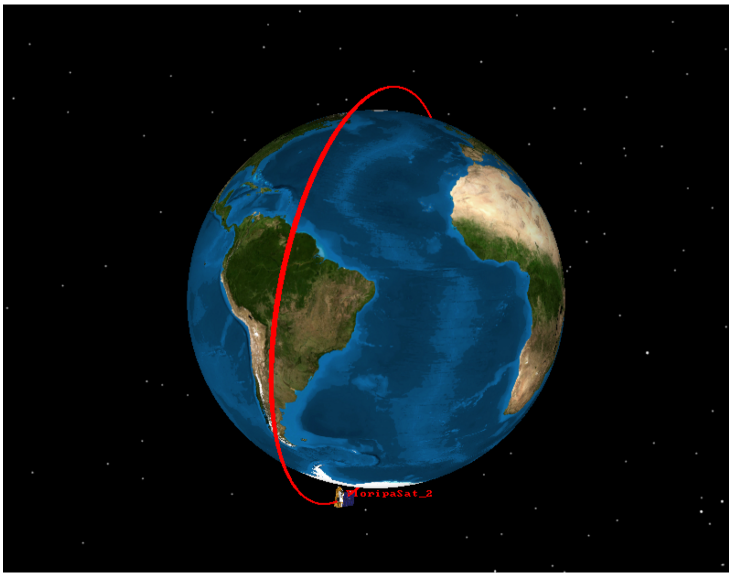

Figure 4.1: FloripaSat-2 orbit simulation on GMAT.

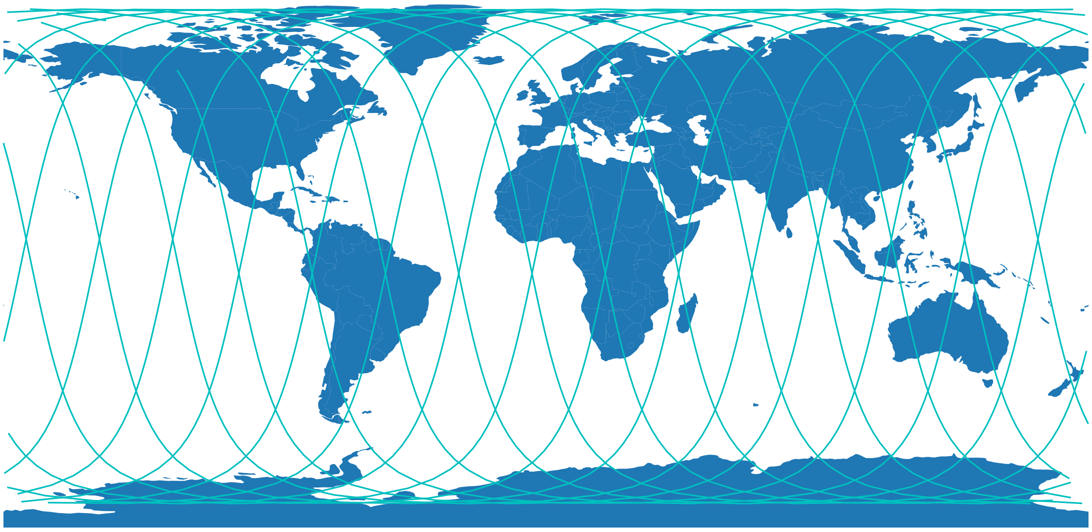

Figure 4.2: FloripaSat-2 simulated groundtrack.

4.1.1 Lifetime Analysis

Considering the same parameters of FloripaSat-I, but with an initial altitude of 550 km, the simulations on GMAT showed that the satellite decays approximately in 2000 days ($\cong$ 5 years), as can be seen in Figure 4.3.

4.1.2 Ground Station Passes and Data Transfer Analysis

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

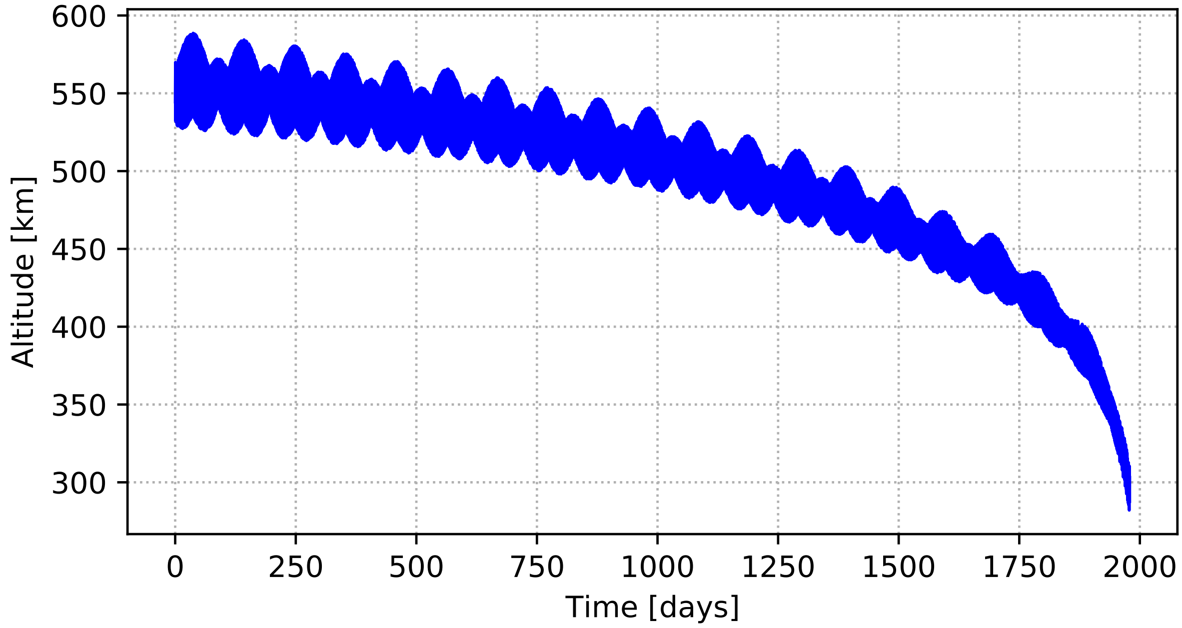

Figure 4.3: Lifetime analysis on GMAT.

achieved during the simulations on GMAT (Table 4.2).

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

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

As can be seen from Table 4.2, during the first 60 days of operation, considering the two main ground stations that will contact the satellite, the total contact period is 80599 seconds (43394 + 37205). With the data rate of the downlink/uplink as 4800 bps, this time period will allow a data transfer of 48359400 bytes (or 46,12 M_iB) between FloripaSat-2 and the Earth. Using the lifetime of the satellite from the previous analysis (2000 days), and an average data transfer per day of 805990 bits, the total theoretical raw data transfer during the whole operation of the satellite will be approximately 1,5 G_iB.

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

4.2 Mass Budget

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

Subsystem	Model	Mass [g]
OBDH	SpaceLab OBDH 2.0	TBD
TTC	SpaceLab TTC 2.0	TBD
EPS	SpaceLab EPS 2.0	TBD
Battery	SpaceLab Battery Module 4C	TBD
Antenna	ISISpace AntS	89
ACS	SpaceLab Passive ACS 2U	TBD
Payload	INPE-RN EDC	TBD
Payload	SpaceLab Payload X	TBD
Payload	SpaceLab Payload Harsh	TBD
Interface	SpaceLab Interface Boards	40
Solar Panel	Orbital Custom Solar Panel	266
Structure	Usiped Custom 2U Structure	206
Cables	-	TBD
Others	-	TBD
Total	-	**601**

Table 4.3: Mass budget of the satellite.

According to the CubeSat standard [8], the maximum mass of each unit must be 1,33 kg. As the FloripaSat-2 is a 2U CubeSat, the maximum allowed mass of the project is 2,66 kg. Considering the weight of each subsystem presented in Table 4.3, the current total mass of the object is below the maximum allowed.

4.3 Power Budget

According to section 10.3 of [9], the power budget of satellite can be determined through three steps:

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

4.3.1 Input Power

A simulation of the energy input to the solar panels along some orbits can be seen in the Figure 4.4 graph. From this simulation, the following results were obtained:

- Peak power $\cong$ 8759,5 mW
- Average (orbit) $\cong$ 2744,9 mW
- Average (sun light) $\cong$ 4315,6 mW
- Orbit period $\cong$ 6018 sec
- Sun light period $\cong$ 3712 sec

- Eclipse period $\cong$ 2124 sec

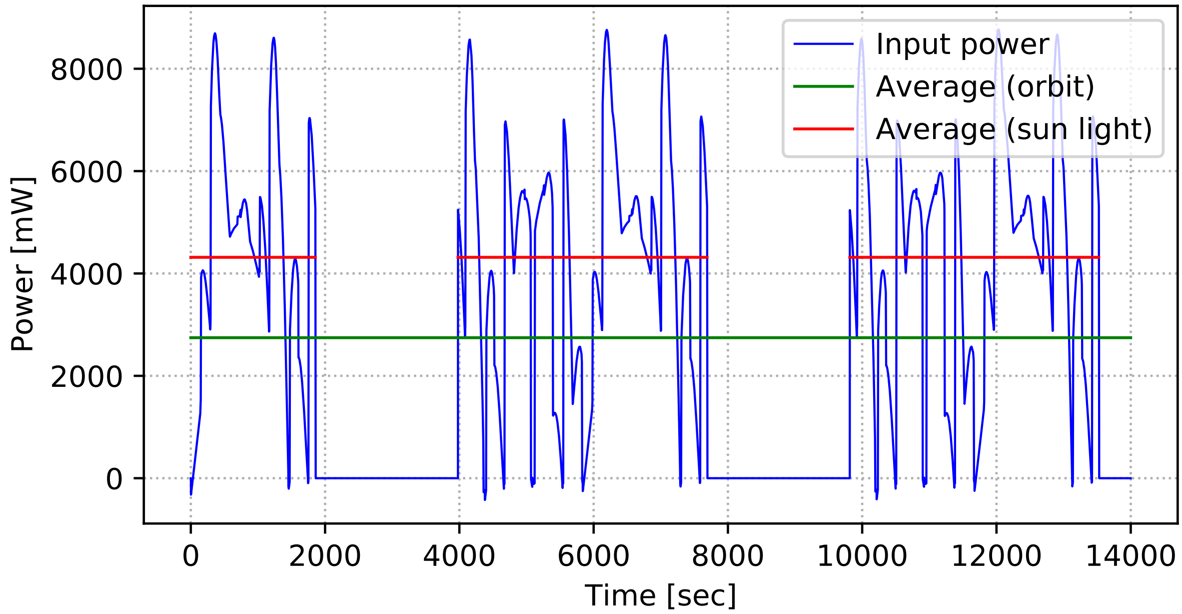

Figure 4.4: Silumated input power of the solar panels.

4.3.2 Operating Power Budget

Typical operating voltages, and current and power ranges consumed by each satellite subsystem are presented in Table 4.4.

Module	**Voltage** [V]	**Current** [mA]		**Power** [mW]	
		Min.	**Max.**	**Min.**	**Max.**
OBDH	3,3	TBD	TBD	TBD	TBD
TTC (μC)	3,3	TBD	TBD	TBD	TBD
TTC (radio module)	5	TBD	650	TBD	3250
EPS (digital part)	7,4	TBD	40	TBD	TBD
EPS (heater)	3,3	TBD	TBD	TBD	TBD
Antenna module	3,3	TBD	TBD	TBD	TBD
Payload EDC	5	250	250	1250	1250
Payload-X	5	TBD	TBD	TBD	TBD
Payload Harsh	3,3	TBD	TBD	TBD	TBD

Table 4.4: Power requirements of the subsystems and payloads of the satellite.

Using the information presented in Table 4.4, and the activation periods defined for each module, we arrive at the average satellite consumption present in Table 4.5.

The duty cycles of Table 4.5 were defined according to the following assumptions:

- One of the EDC payload is always off (cold redundancy).

Module	**Duty Cycle [%]**	**Power [mW]**
OBDH	100	115
TTC (radio 1 RX)	95	65
TTC (radio 1 TX)	5	3250
TTC (radio 2 RX)	95	65
TTC (radio 2 TX)	5	3250
EPS	100	320
BAT (idle)	90	0
BAT (heater full)	10	5000
Antenna (deployment)	0	1800
Antenna (deployed)	100	35
Payload EDC	100	1250
Payload Harsh	0	330
Payload-X	0	1000
	$\cong$ 2668	

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

- The Payload-X and the Harsh payload are turned on just during limited periods and only with telecommands.

4.3.3 Battery Sizing

4.3.4 Power Degradation Over Mission Life

- Solar panels degradation
- Battery degradation

4.4 Link Budget

The link budget of all radio links of the satellite is available in Table 4.6.

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

All equations and steps used to obtain the results of Table 4.6 are available in Appendix A.

[1] Without FEC.

Variable	Beacon	Downlink	Uplink	Uplink (Payload)	Unit
Altitude	550	550	550	550	km
Elevation	0	0	0	0	°
Frequency	437	462,5	462,5	401,635	MHz
Modulation	GMSK	GMSK	GMSK	BPSK	-
Protocol	NGHam	NGHam	NGHam	SBCD	-
Transmit power	30	30	44	30	dBm
Transmitter antenna gain	0	0	12	3	dBi
Receiver antenna gain	12	12	0	0	dBi
FSPL	153,9	154,4	154,4	153,2	dB
Power at receiver	-116,9	-117,4	-103,4	-125,2	dBm
Receiver sensibility	-134	-134	-126	-128	dBm
System losses	5	5	5	5	dB
Receiver noise temp.	361,7	361,7	361,7	361,7	K
Antenna noise temp.	300	300	300	300	K
System noise temp.	661,7	661,7	661,7	661,7	K
Data rate	4800	9600	9600	400	bps
Received SNR	16,68	13,17	27,17	19,20	dB
SNR required for 10^{-5} BER[1]	9,6	9,6	9,6	9,6	dB
Link margin	$\geq$ 7,077	$\geq$ 3,574	$\geq$ 17,57	$\geq$ 9,601	dB

Table 4.6: Link budget results.

CHAPTER 5

Overall Description

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5.1 General Diagrams

The CubeSat's subsystems are positioned in the 2U physical structure as exemplified in Figure 5.1. An exploded 3D view of the satellite is showed in Figure 6.1.

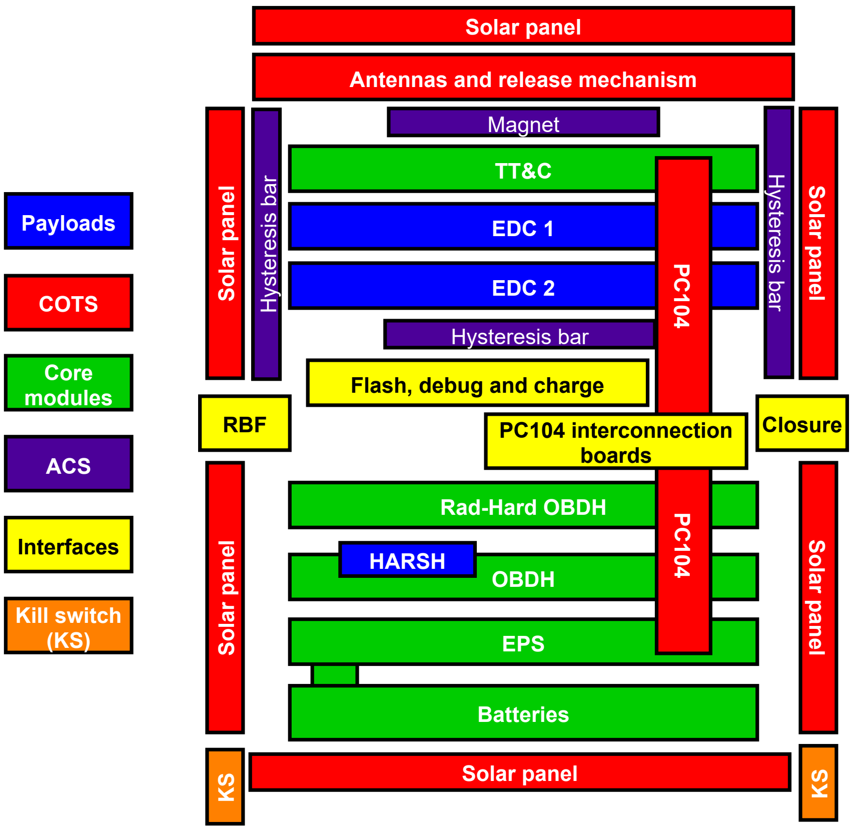

Figure 5.1: Subsystems positioning.

5.1.1 Power Diagram

In Figure 5.2 is presented a block diagram showing the satellite's power buses. The EPS module distributes these buses and have the hability to turn on and off some subsystems, while other modules also have direct control over some dc regulators[10]. The bus used for the antenna module is only active during its deployment. The current values showed are the maximum capability and not the nominal operating values, these are determined by the variable power generation of the solar panels as well the loads present in a given time of the satellite's operation.

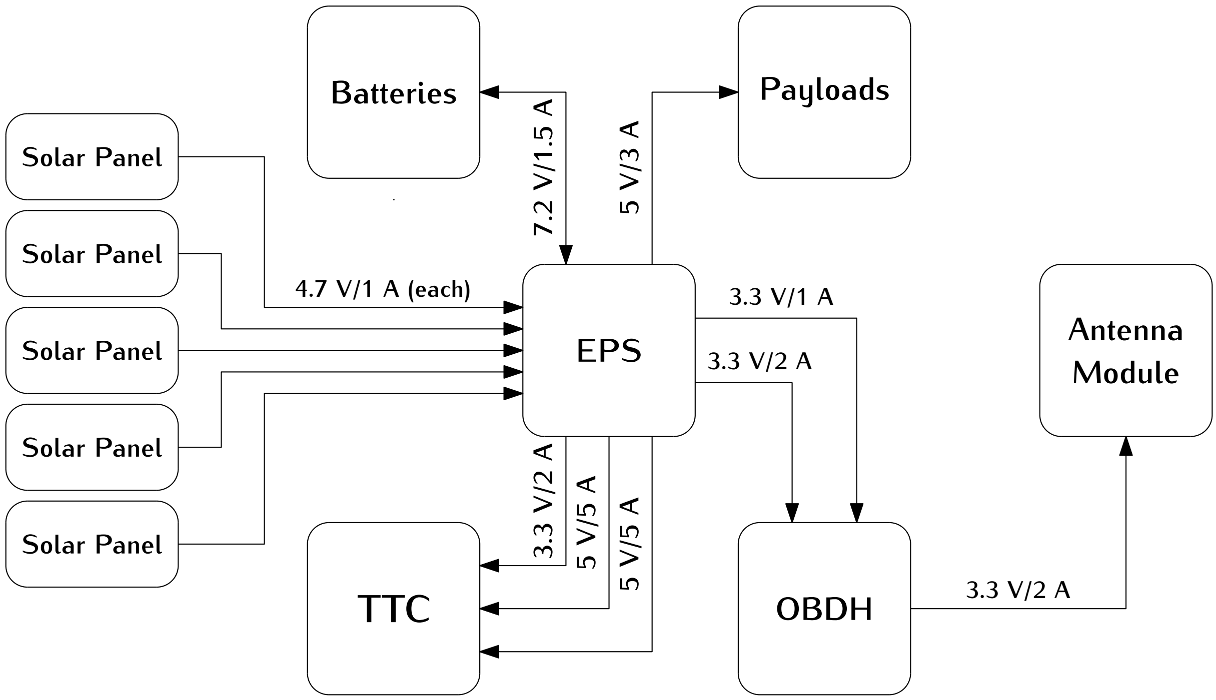

Figure 5.2: Power diagram.

5.1.2 Data Path Diagram

5.1.3 Deployment Sequence

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

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

As the OBDH and the TTC have access to the antenna module, both subsystem can control the deployment of the antennas. Following the CDS specifications [8], all CubeSats must wait 30 minutes to deploy the antennas and 45 minutes to transmit any RF signal. This way, the OBDH waits 45 minutes to send the deployment command to the antenna module. As redundancy, the TTC waits 55 minutes to execute the same operation.

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

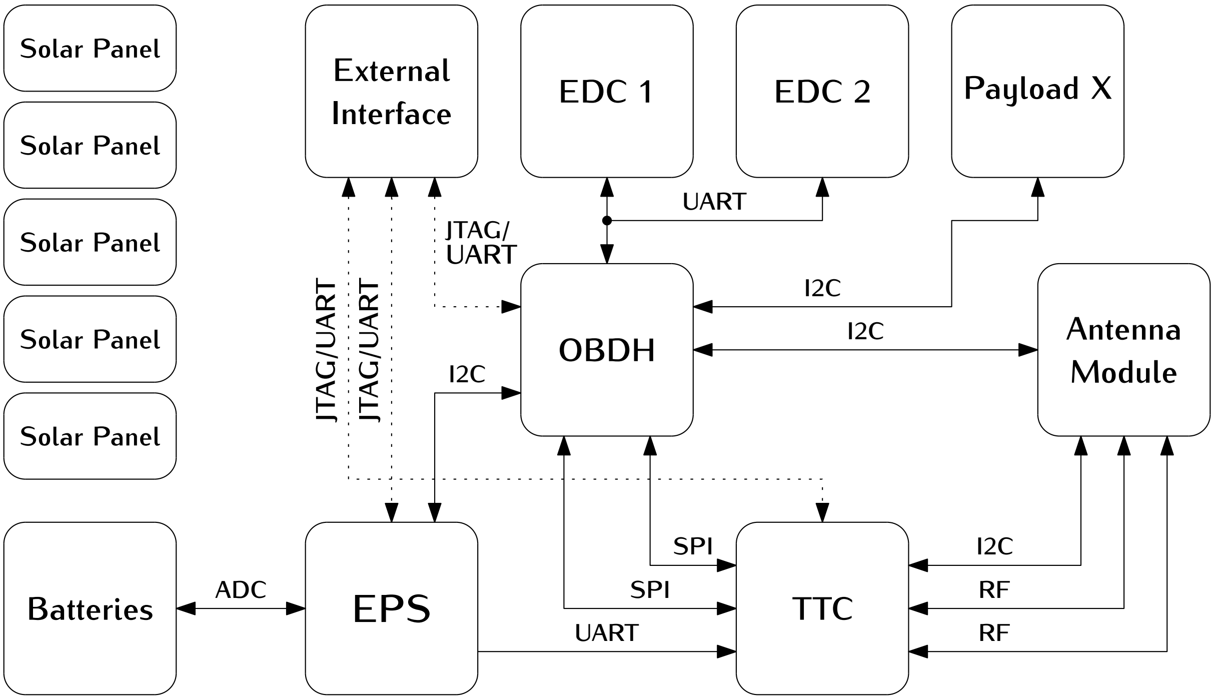

Figure 5.3: Data path diagram.

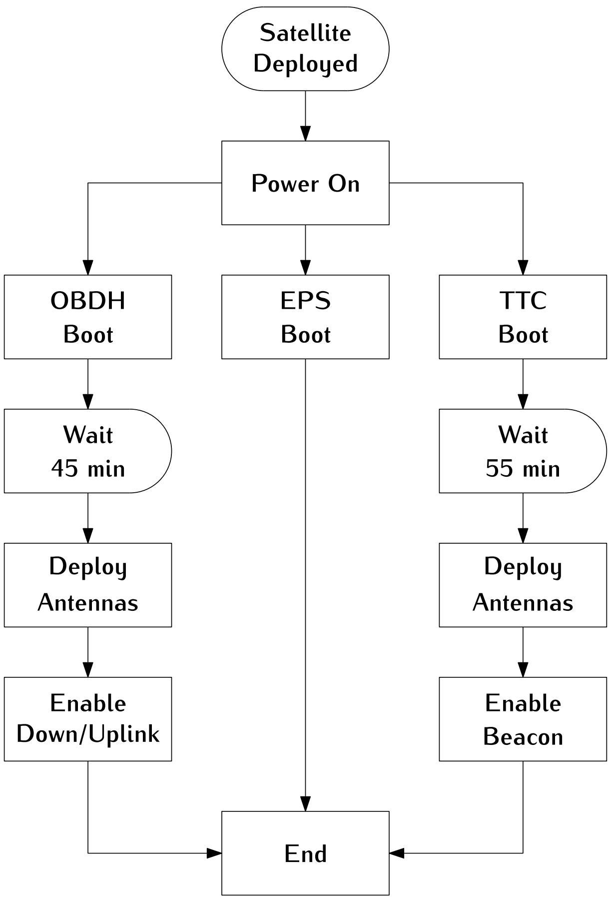

Figure 5.4: Flowchart of the deployment sequence.

5.1.4 Beacon Operation

After the boot sequence of the beacon microcontroller, the operation of the beacon starts. The normal operation consist on reading the data from the EPS and the TTC modules, transmit the valid data (EPS or TTC package, in this order of priority), wait 60 seconds and repeat this sequence. The Figure 5.5 has a flowchart of this behaviour.

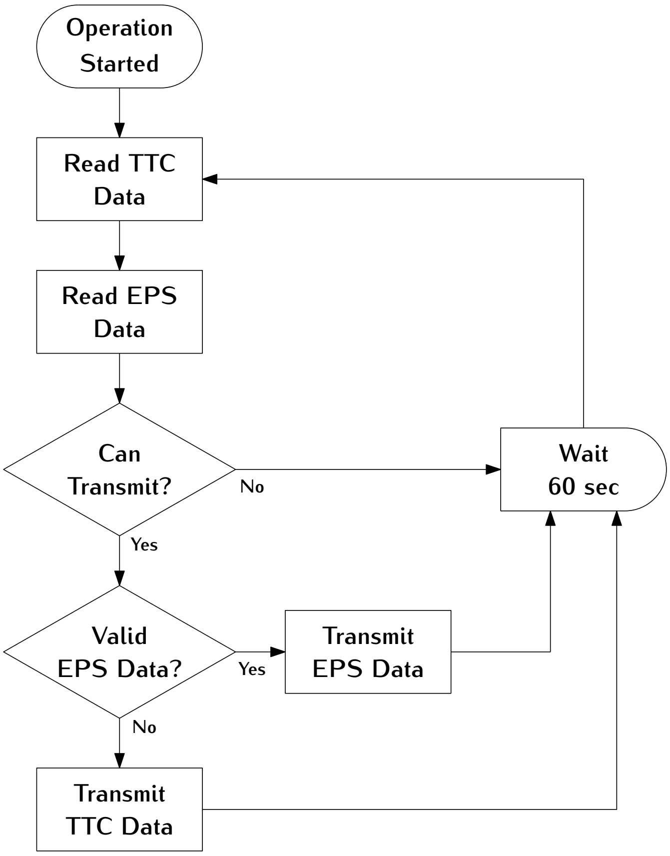

Figure 5.5: Flowchart of the normal beacon operation.

5.1.5 OBDH Operation

After the boot sequence of the OBDH microcontroller, the operation of the OBDH starts. The normal operation consist on reading the housekeeping data from the EPS, TTC, payloads, antenna module and the OBDH (its own housekeeping data), save the read data on the non-volatile memory and transmit the housekeeping data of the satellite as a beacon. After that, it waits 60 seconds and check if a new telecommand was received, if true process the telecommand, if not, does nothing. After this sequence, these steps start again. The Figure 5.6 has a flowchart of this behaviour.

5.1.5.1 Telecommand Processing

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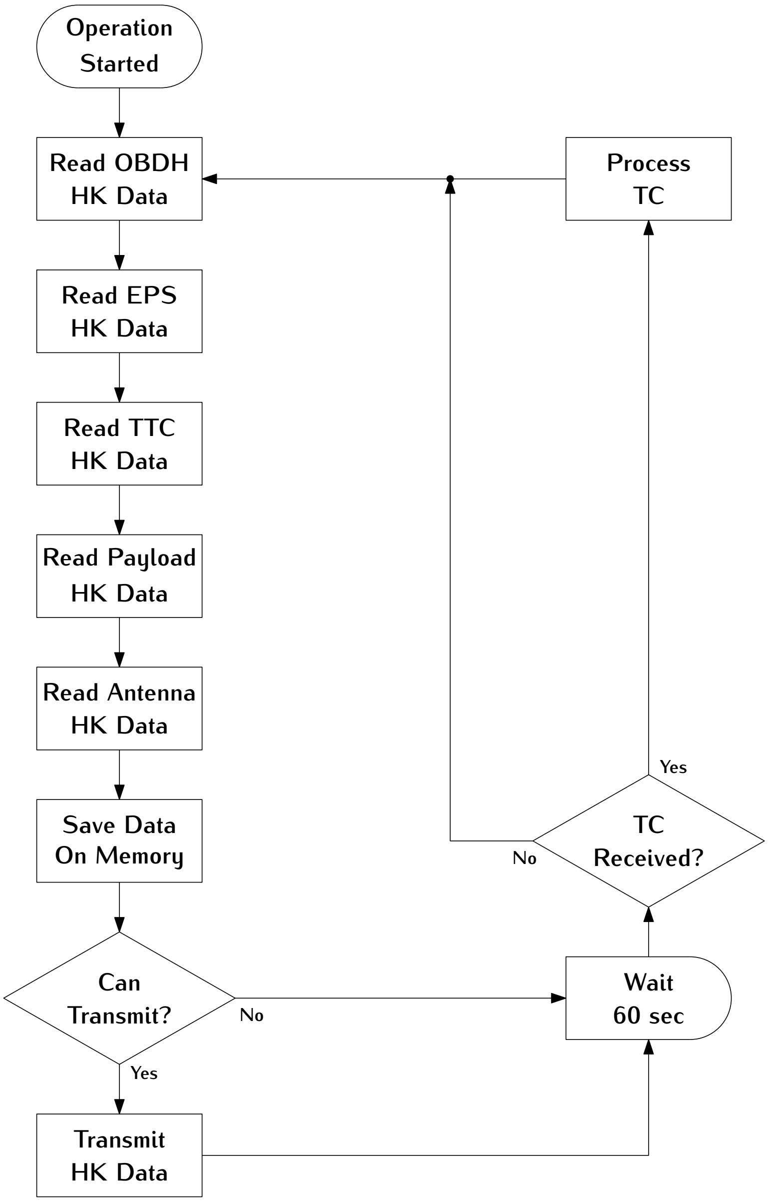

Figure 5.6: Flowchart of the normal OBDH operation.

5.1.6 EPS Operation

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

5.2 General Behaviour

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5.3 PC-104 Bus

5.3.1 Interface

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

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

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

Table 5.1: PC-104 bus pinout.

The distribution pattern of pins adopted in this project is a mix of multiple different patterns from CubeSat modules manufacturers, like GomSpace, ISIS and Endurosat. Some pins are positioned to attend specific project requirements, and it is possible that the adopted pattern is not totally compatible to some commercial modules.

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

5.3.2 Form Factor

The form factor follows a similar specification of the PC-104 standard[11]. The connector used for the interface differs given the module, the isolation heigth and presence of pin or receptable are definied from the overall stack up of the subystems inside the CubeSat 2U structure. The core modules have smoothed edges and some linear mounting hole distances different from the standard, these are according to fit in a CubeSat form factor. The PC-104 form factor used can be seen in Figure 5.10.

5.4 Telecommunication

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

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

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

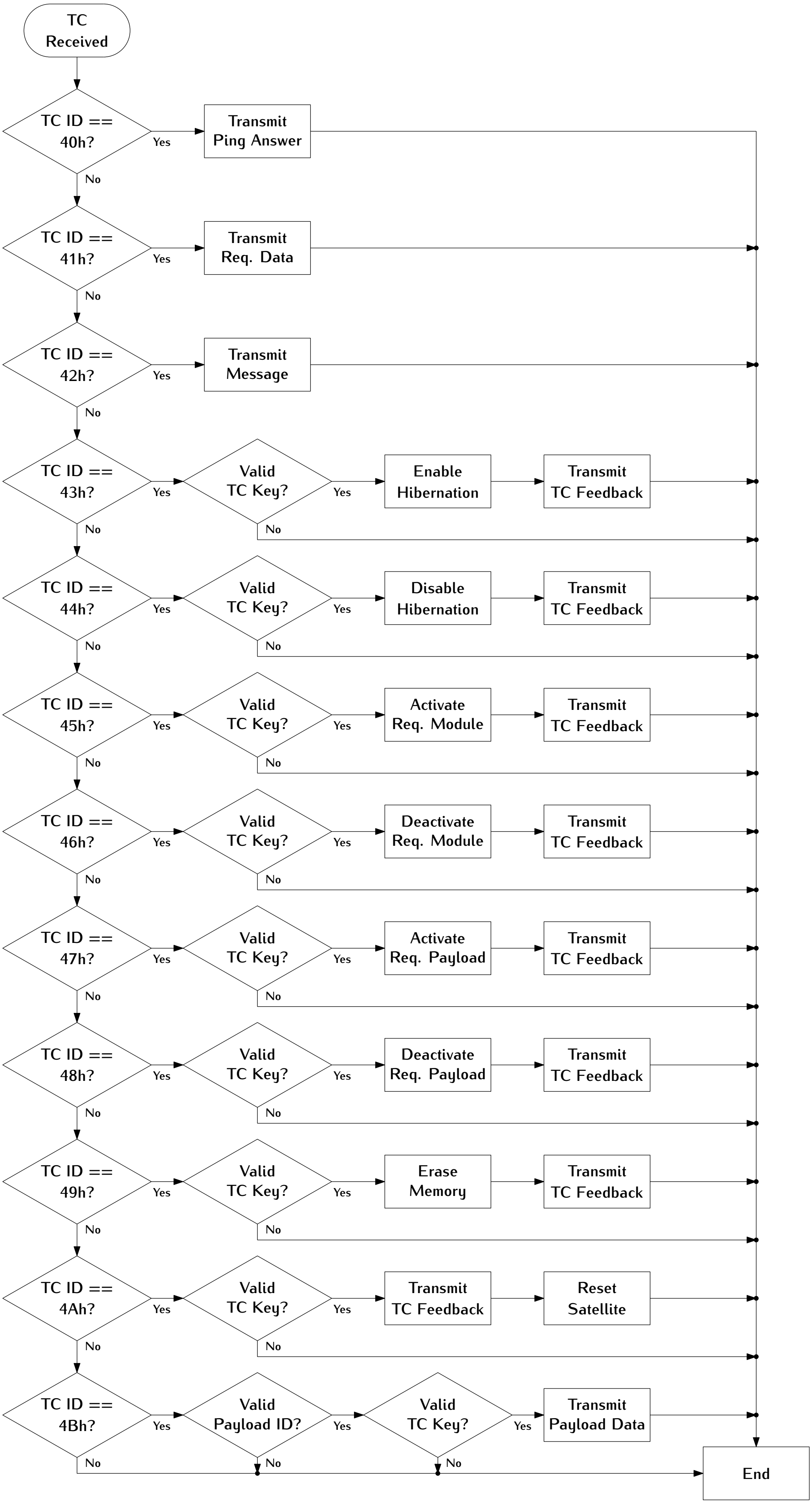

Figure 5.7: Flowchart of telecommand processing.

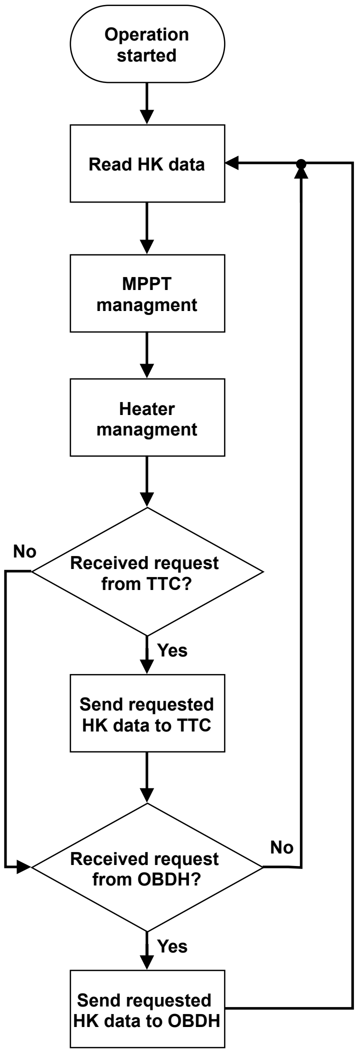

Figure 5.8: Flowchart of the normal EPS operation.

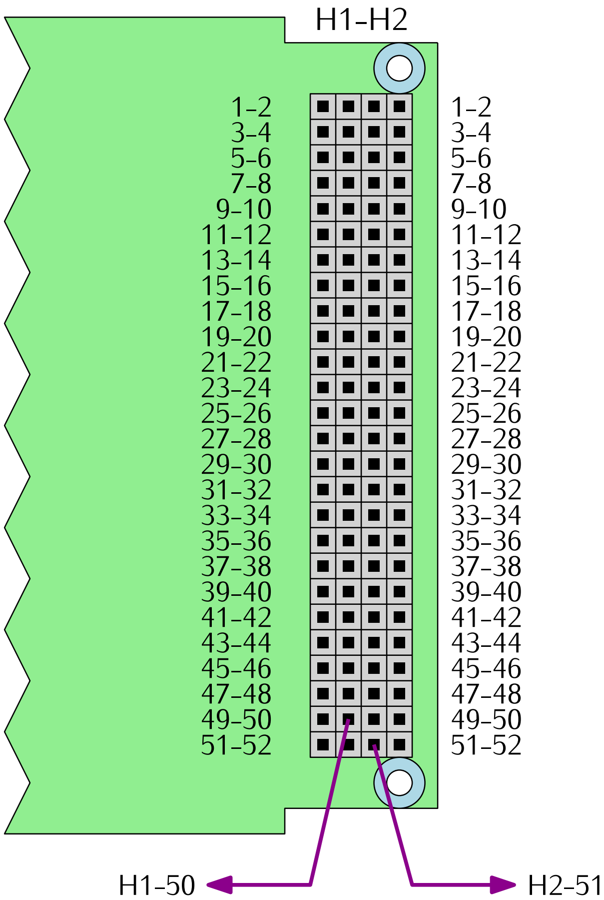

Figure 5.9: Reference diagram of the PC-104 bus (top view of a generic module).

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

Table 5.2: PC-104 bus signal description.

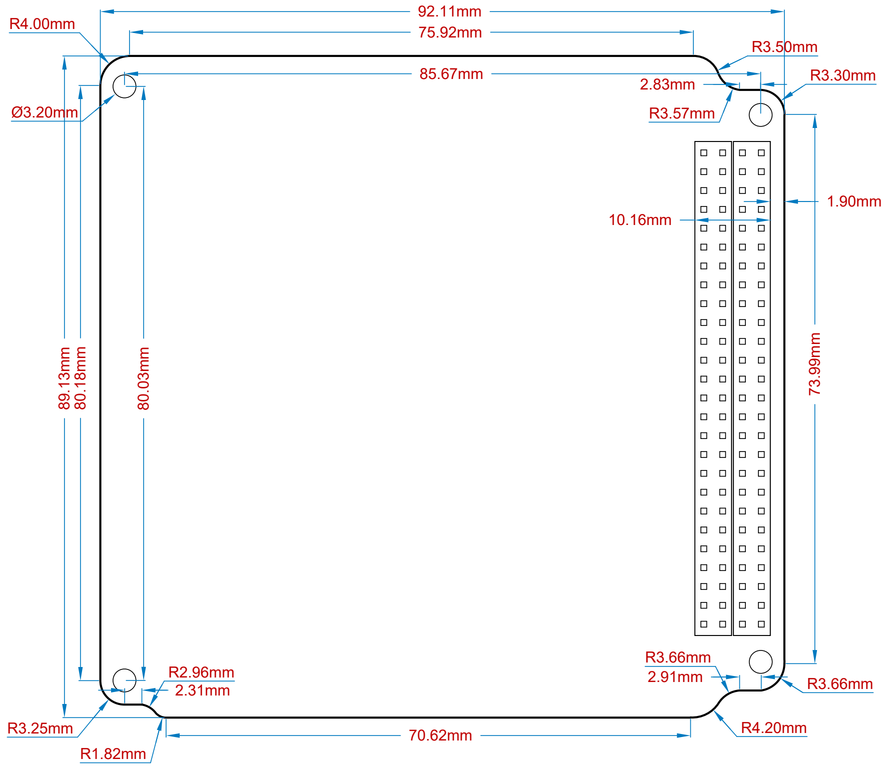

Figure 5.10: PC-104 Form Factor.

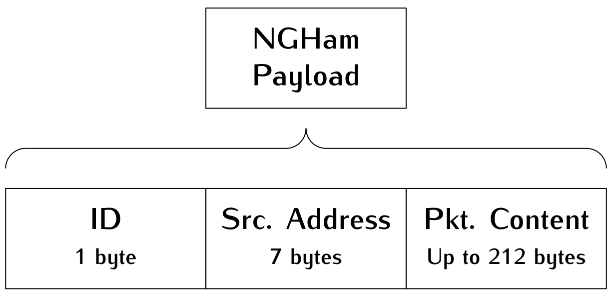

Figure 5.11: Payload structure of the FloripaSat-2 packets.

Link	Packet Name	Payload				Access
		ID	Source Callsign	Data (up to 220 bytes)	Size (bytes)	
Beacon	EPS data	00h	“ ” + “PY0EFS”	EPS data	58	Public
	TTC Data	01h		TTC data	18	Public
Downlink	General telemetry	20h	“ ” + “PY0EFS”	OBDH/EPS data	75	Public
	Ping answer	21h		Requester callsign	15	Public
	Data request answer	22h		Requester callsign + data	15 to 155	Public
	Message broadcast	23h		Requester + dst. callsign + message	22 to 60	Public
	Payload data	24h		Payload ID + payload data	9 to 220	Public
	TC feedback	25h		Req. callsign + TC packet ID + timestamp	13	Public
Uplink	Ping request	40h	Any Callsign	None	8	Public
	Data request	41h		Data flags + count + origin + offset	16	Public
	Broadcast Message	42h		Dst. callsign + message	15 to 46	Public
	Enter hibernation	43h		Req. callsign + hibernation in hours + key	29	Private
	Leave hibernation	44h		TC key	16	Private
	Activate module	45h		Module ID + TC key	17	Private
	Deactivate module	46h		Module ID + TC key	17	Private
	Activate payload	47h		Payload ID + TC key	17	Private
	Deactivate payload	48h		Payload ID + TC key	17	Private
	Erase memory	49h		TC key	16	Private
	Force reset	4Ah		TC key	16	Private
	Get payload data	4Bh		Payload ID + TC key + payload args.	17 to 28	Private

Table 5.3: Telecommunication packets and their content.

The ID of the modules that can be activated or deactivated are available in Table 5.4.

Module	ID Number
Battery heater	1
Beacon	2
Periodic telemetry	3

Table 5.4: IDs of the modules that can be activated or deactivated.

The ID of the payloads, to be used in the activate/deactivate telecommands, are available in Table 5.5.

Payload	ID Number
EDC 1	1
EDC 2	2
Payload-X	3
Radiation monitor	4

Table 5.5: IDs of the payloads.

5.4.1 Operation Licenses

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CHAPTER 6

Subsystems

This chapter presents a description of all subsystems of the space segment of the mission, which can be seen in the exploded view of the satellite, available in Figure 6.1.

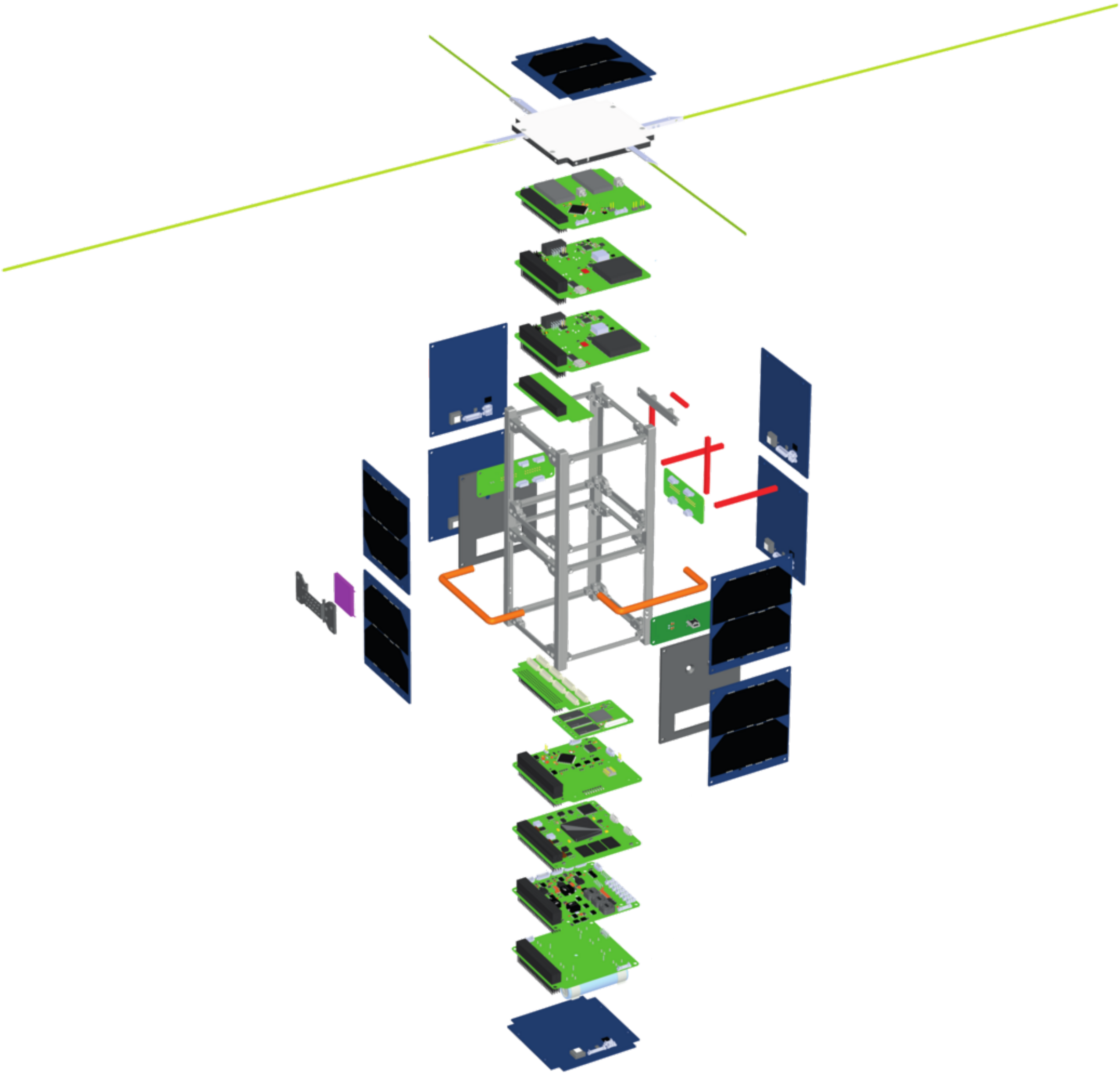

Figure 6.1: Exploded view of the FloripaSat-2 satellite.

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

6.1 On-Board Data Handling

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

The module is a direct upgrade from the OBDH of FloripaSat-1 [1], which grants a flight heritage rating. The improvements focus on providing a cleaner and more generic implementation in comparison with the previous version, more reliability in software and hardware implementations, and adaptations for the new mission requirements. The board of the module can be seen in Figure 6.2.

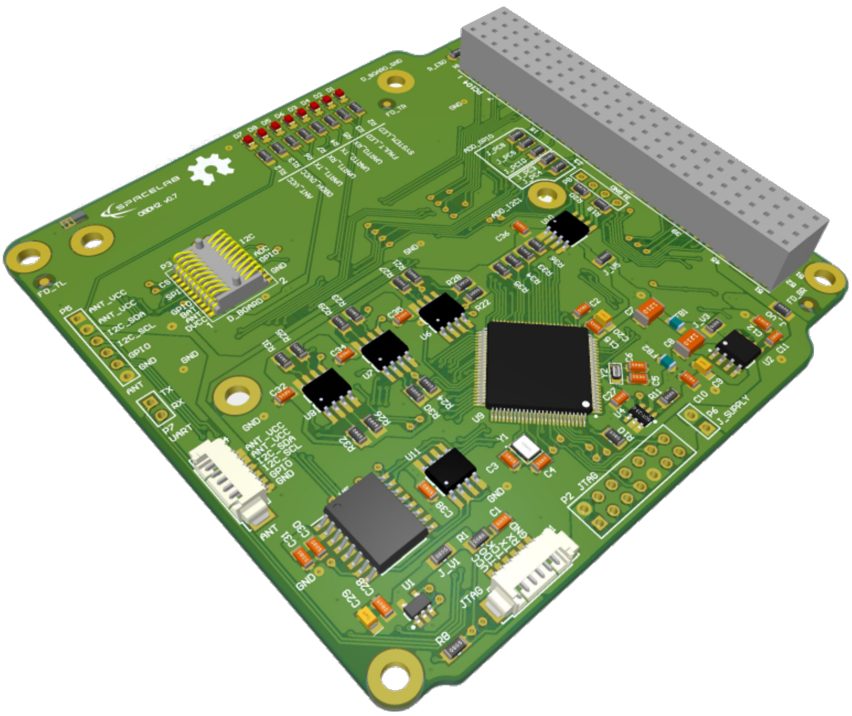

Figure 6.2: OBDH module.

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

6.2 Telemetry, Tracking and Command Module

The TTC (or TT&C) is responsible to make the communication between the earth (a ground station) and the satellite, and is divided in two sub-modules: Beacon and downlink/uplink. The beacon is a independent sub-module who transmits a periodic signal containing an identification data (ID) of the satellite and some basic telemetry data. The downlink/uplink sub-module is the main communication device. It has a bidirectional data link to receive telecommands from the earth and transmit all available data back to Earth. The board of the module can be seen in Figure 6.3.

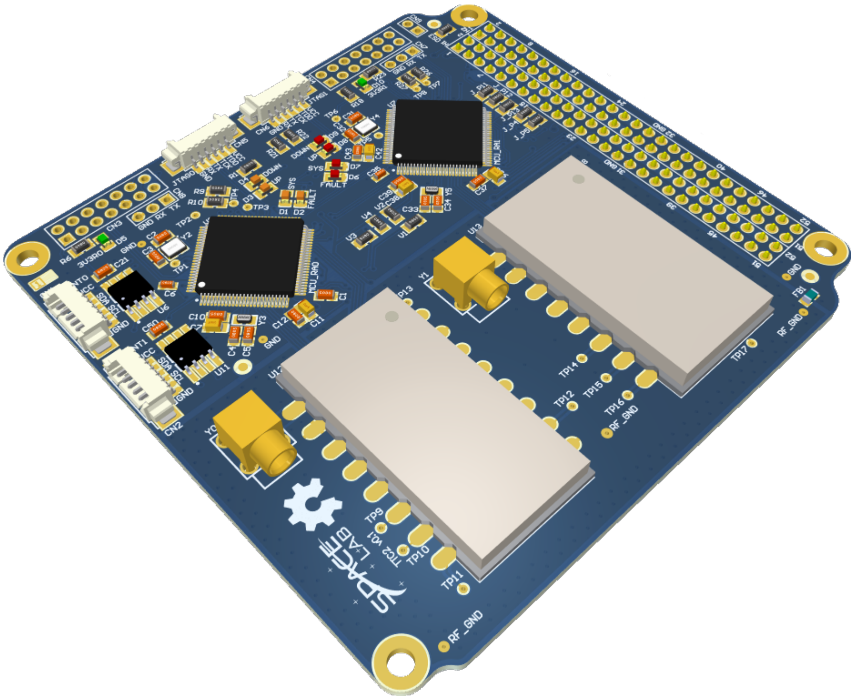

Figure 6.3: TTC module.

More information about this module can be found in [13].

6.2.1 Antenna Module

The used antenna module is the CubeSat deployable VHF and UHF antenna from ISISpace [14]. It is a four monopole antenna built with tape strings (up to 55 cm) and compliant with the CubeSat standard (dipole or turnstile options are also available). The deployment method is the burning wire and it can be controlled digitally through a I^2C interface. To allow redundancy, there are two independent deployment controllers that can be activated separately. Also, the construction of this module allows the installation of a solar panel at the top side. The RF gain is about 0 dBi.

A picture of the antenna module (with all antennas released) can be seen in Figure 6.4.

The chosen configuration for this mission can be seen below (using Figure 6.5 as reference):

- Configuration: 4 monopoles (1x VHF + 3x UHF)
  - Antenna 1: VHF - 145,97 MHz (beacon)

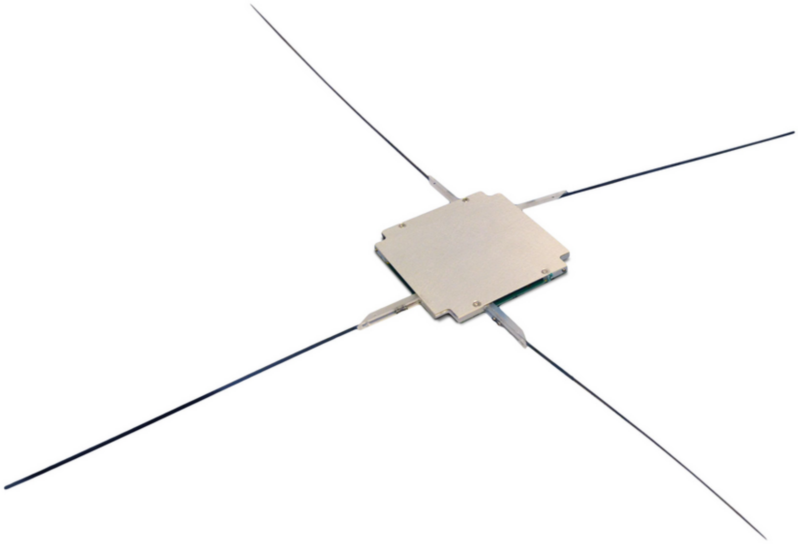

Figure 6.4: Antenna module from ISISpace.

  - Antenna 2: UHF - 401,635 MHz (EDC)
  - Antenna 3: UHF - 436,9 MHz (downlink/uplink)
  - Antenna 4: UHF - 401,635 MHz (redundant EDC)

- Tuning structure size: 2U
- Mounting position: Top
- Supply voltage: 3,3 V
- I^2C control type: Dual bus
  - Primary I^2C address: 31h (7-bit address)
  - Redundant I^2C address: 32h (7-bit address)
- I^2C watchdog: Enabled with a time out of 60 seconds.

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

6.3 Electrical Power System

The EPS is the module designed to harvest, store and distribute energy for the satellite. The energy harvesting system is based on solar energy conversion through te solar panels attached to the CubeSat structure. The EPS is designed to operate the solar panels at their maximum power point (MPPT). The board also measures the solar panels current, voltage and the temperature of the batteries. The harvested solar energy is stored in a

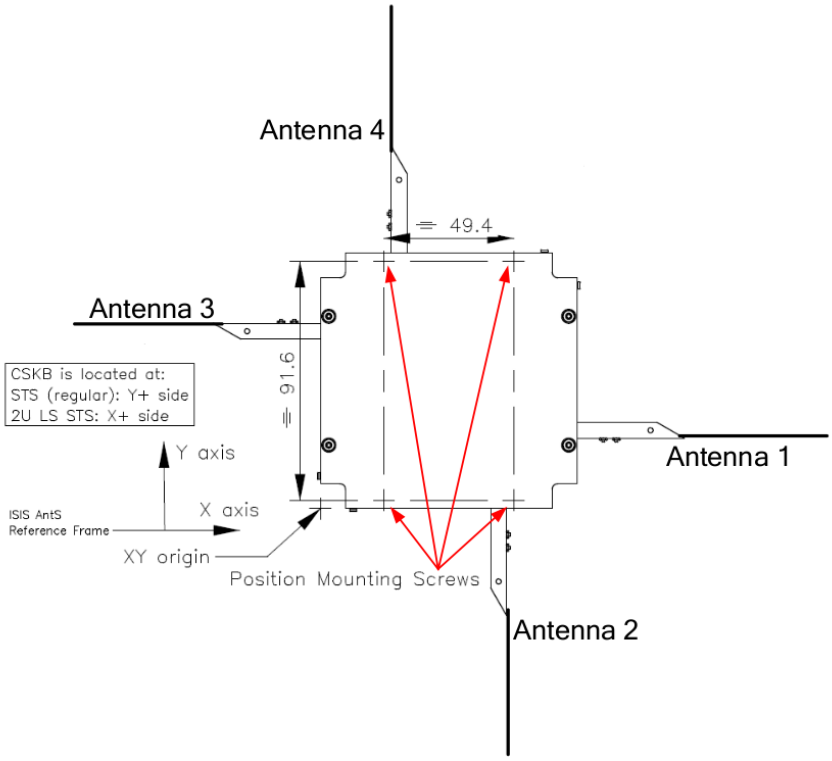

Figure 6.5: Configuration reference of the antenna module.

battery module connected to the EPS. The energy distribution is done by several integrated buck DC-DC converters. The full EPS system is composed of the solar panels, the EPS PCB and the battery module. A general view of the EPS board can be seen in Figure 6.6.

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

More information about this module can be found in [10].

6.3.1 Battery Module

The used battery module is the "*Battery Module 4C*", that is a separate battery module from the EPS board and composed by four lithium-ion 18650 cells. Besides the cells, the board has connectors for interfacing signals and power lines with the EPS module, 2 power resistors to operate as heaters to maintain the cell's temperature during eclipse periods, and 4 temperature sensors. The batteries used are the ICR18650-30B lithium-ion cells from Samsung [15], which are connected in series and parallel (two sets of two parallel cells in series) to supply the required voltage and current. Each cell is fixed with 18650 metal holders and between the pairs there is the power resistor attached with a thermal element in the middle. A mechanical mount is placed over the batteries and screwed to the board, providing better stress resistance. Also, there are PC-104 through hole pads present on the board for a connector that could be used for making mechanical integration with the EPS, or with future improvements a interface for power, data or control signals. The board is a direct improvement from the first battery board used in the FloripaSat-1

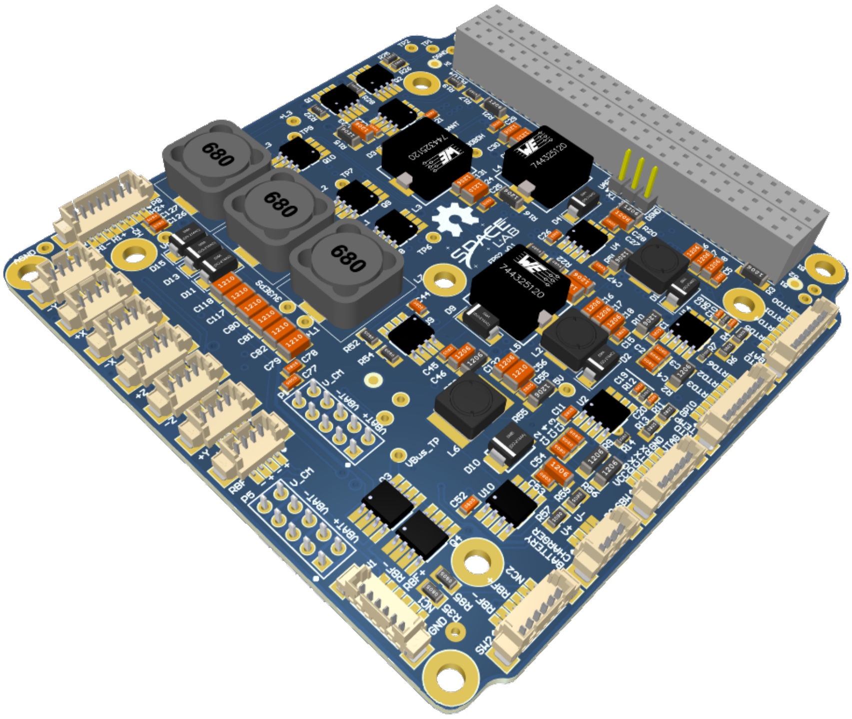

Figure 6.6: EPS module.

mission [1].

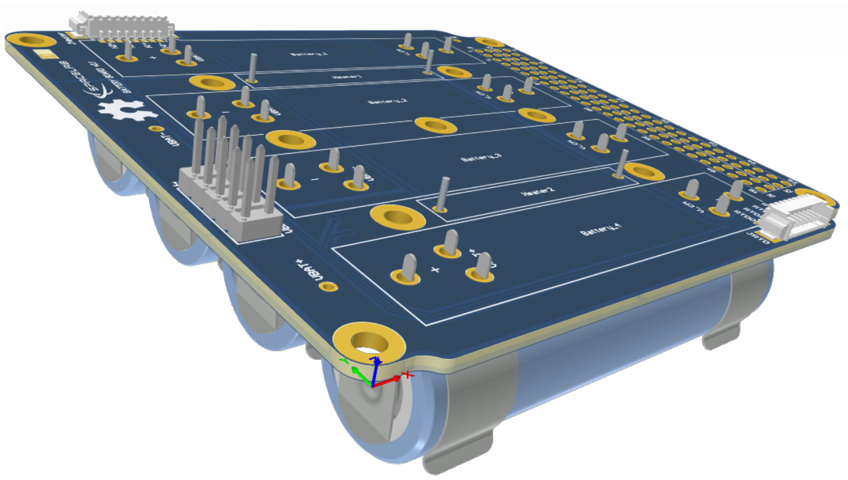

Figure 6.7: Battery module board.

More information about the battery module can be found in [16].

6.3.2 Solar Panels

The solar panels are a set of 5 custom made panels manufactured by ORBITAL, a Brazilian company, and a single panel from ISISpace. The panels features protection diodes and high-efficiency solar cells, which are the CESI's CTJ-30 [17] with dimensions 6,9 × 3,9 cm (area 26,5 cm^2). This cell is qualified for space use by ESA with an efficiency of 29,5 %

(AM0, BOL). The panels do not include magnetorquers, sensors and others devices. The top solar panel is a model from ISISpace to ensure mechanical compatibility with the antenna module (also from ISISpace). These two types of solar panels can be seen in Figures 6.8 and 6.9.

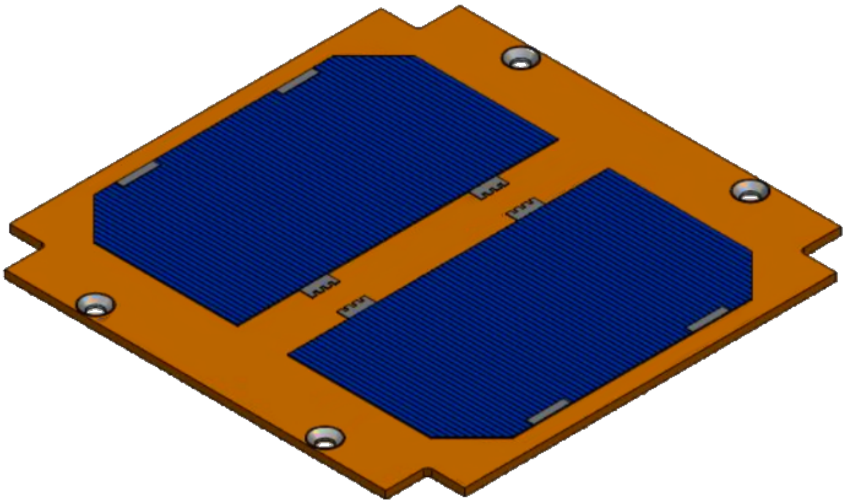

Figure 6.8: Conceptual solar panel from ORBITAL.

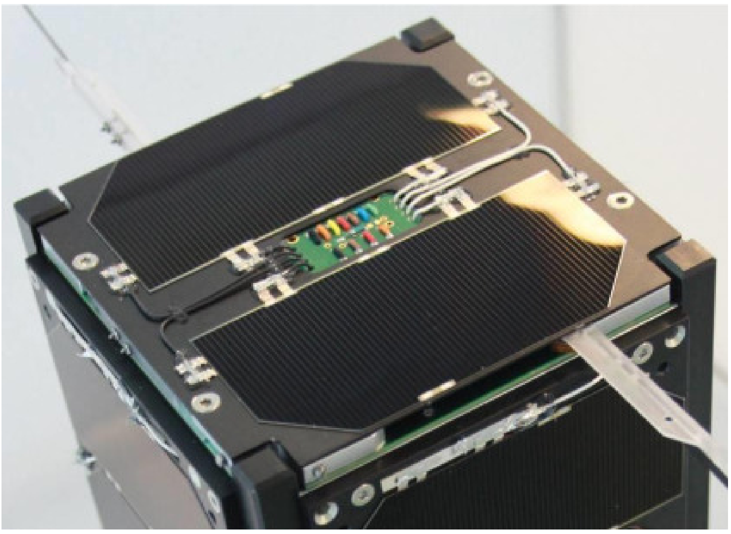

Figure 6.9: Top solar panel from ISISpace.

6.3.3 Kill-Switches and RBF

Two electronic switches have been implemented into the design as to allow for the (redundant) deployment detection of the CubeSat when it is deployed from the POD. This electronic microswitch can be used to prevent the satellite from starting up during launch as is required for all CubeSat launches and hence acts as a Kill-Switch. The Kill-Switch is the Panasonic AV4 microswitch (AV402461), as can be seen in Figure 6.10.

Figure 6.10: Panasonic AV402461 Microswitch.

The Kill-Switch mechanism in the mechanical structure has combined the function of providing deployment and detection (Figure 6.11). The travel of the actual switch of the Kill-Switch itself is so short that the Kill-Switch could "detect deployment" of the CubeSat from the launch adapter simply due to launch vibrations. To overcome this issue the Kill-Switch has been rotated so that there is a positive obstruction in front of the switch which needs 8 mm of deployment before deployment can be detected with the Kill-Switch. In Figure 6.11 the Kill-Switch parts are highlighted and the stowed and deployed configuration is shown.

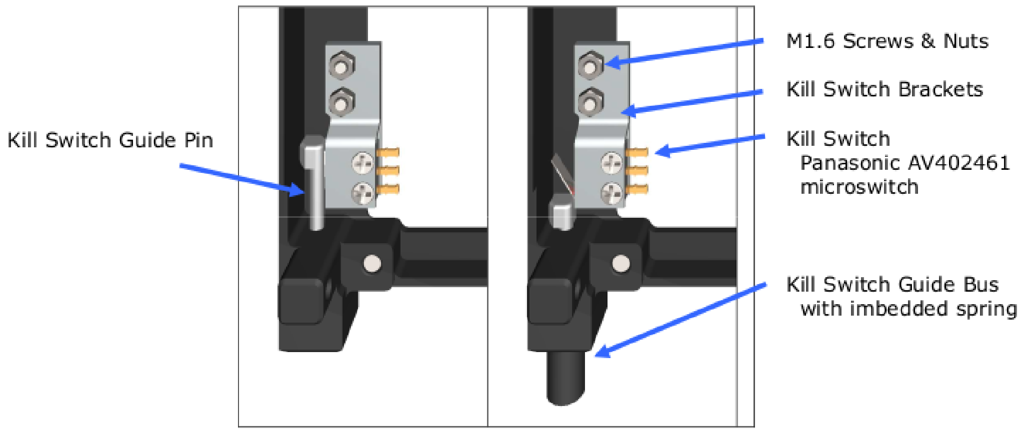

Figure 6.11: Kill-Switches installed in the mechanical structure.

The contact arrangement of the microswitch and the current rating are detailed in Figure 6.12 and Table 6.1.

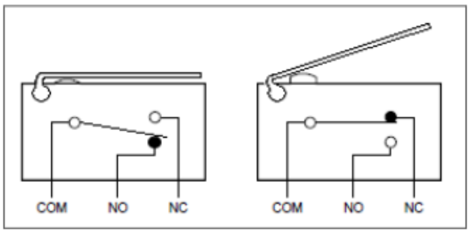

Figure 6.12: The contact arrangement of the microswitch.

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

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

6.4 Attitude Control System

The Attitude Control System (ACS) is a passive attitude control system, which depends on the Earth's magnetic field to rotate and stabilize the satellite [18, 19]. The system is composed of one permanent magnet to create a force to align the magnet with the Earth's magnetic field and four hysteresis bars to damp the cube oscillations and achieve stabilization.

When equilibrium is achieved, the permanent magnet aligns itself to the Earth's field lines. The hysteresis bars convert oscillation and rotation energy into heat, maintaining the alignment through magnetic moment. The components are placed in positions as to minimize the magnet's interaction with the hysteresis bars, which limits the magnetic moment of the magnet [20]. Figure 6.13 shows the mounting of the hysteresis bars (green) and the permanent magnet (red) on the mechanical structure. The whole passive ACS was implemented according to [20].

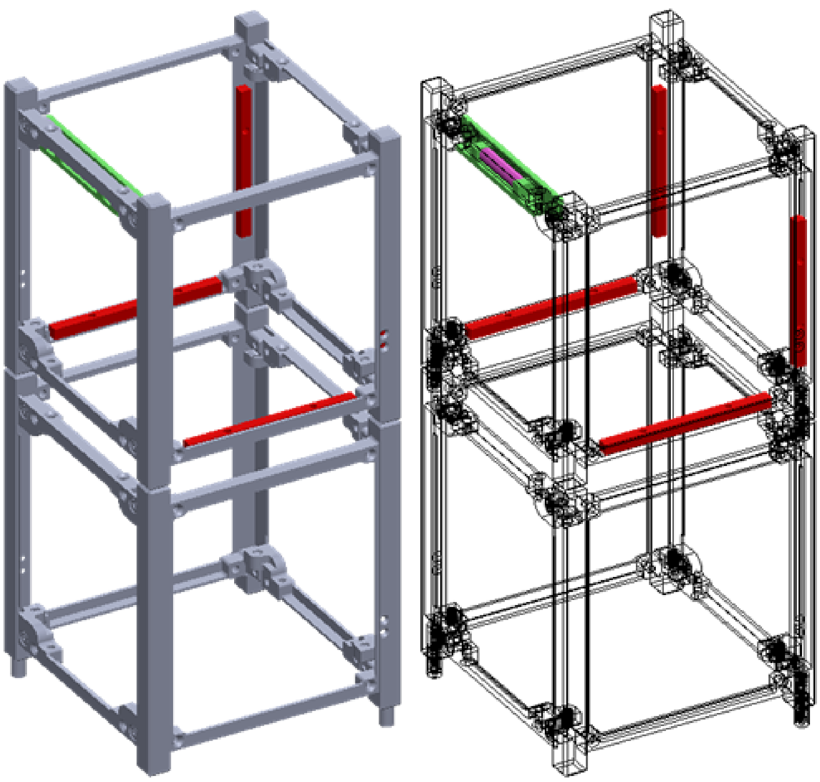

Figure 6.13: ACS subsytem. Rare earth magnet (pink) and hysteresis bars (red) installed in the structure.

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

Many conditions impact on the detumbling time, which is the time required for the satellite to stabilize. Magnetic passive attitude stabilization systems such as the one developed for this mission achieve the equilibrium state within a few weeks of operation [18].

The FloripaSat-2 satellite does not feature an orbit control subsystem.

6.5 Mechanical Structure

The USIPED 2-Unit CubeSat structure is developed as a generic, modular satellite structure based upon the CubeSat standard. The modular chassis allows for up to two 1-Unit stack of PCBs, or other modules, to be mounted inside the chassis, using the PC-104 standard and spacers attached to the structure. In addition, there are 4 slots in the middle section, providing space for the interface boards and the ACS. The solar panels and antennas are externally mounted, providing a complete mechanical solution. A picture of this structure can be seen in Figure 6.14.

Figure 6.14: 2U CubeSat structure from Usiped.

6.6 Interconnection Modules

6.6.1 PC-104 Interconnection Boards

The PC-104 interconnection boards are intended to be used as an interconnection of the two PC-104 bus segments of the 2U structure (top and bottom units). This interconnection is made with a set of PicoBlade cables between the top and bottom boards. The set of two boards can be seen in Figure 6.15.

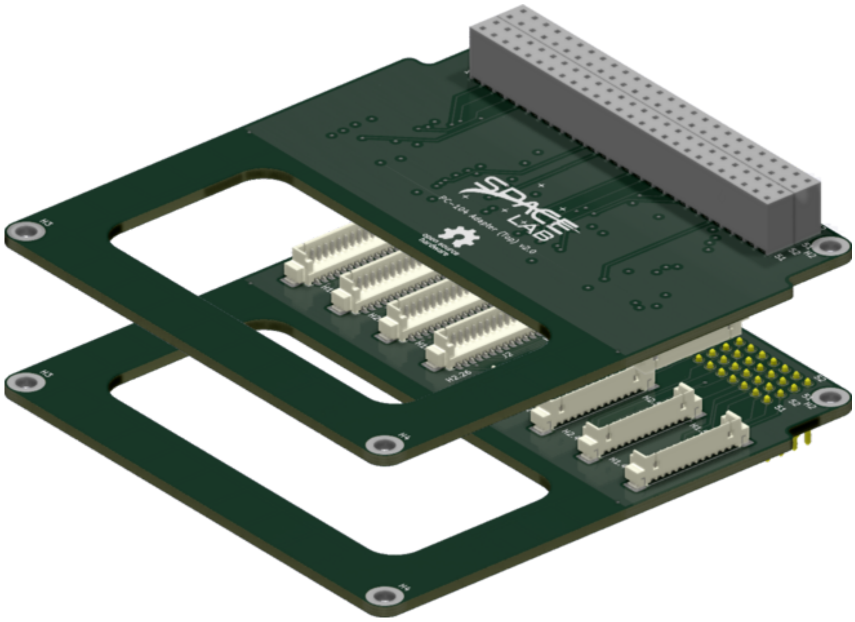

Figure 6.15: PC-104 adapter boards (top and bottom).

More information about these boards can be found in [21].

6.6.2 External Connection Boards

The Interstage Interface Panels (IIP) are three vertical internally mounted PCBs designed to give external access up to four modules inside of a 2U CubeSat during final assembly, integration and testing (AIT) before launch. The complete set of the boards allow the nanosatellite to be charged, programed and debugged. The usage of this hardware platform is taking into account the use of a MSP-FET: MSP430 Flash Emulation Tool from Texas Instruments for JTAG programing and debugging, UART debugging through a mini USB type B port interfacing the FT4232H USB bridge IC from FTDI, a JST XH header for charging internal batteries and a Remove Before Flight (RBF) pin header. The boards can seen in Figure 6.16.

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

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

6.7 Payloads

The FloripaSat-2 satellite is planned to carry three different payloads on-board: "*EDC*", "*Payload-X*" and the "*Harsh Payload*". Each one of these payloads are presented next.

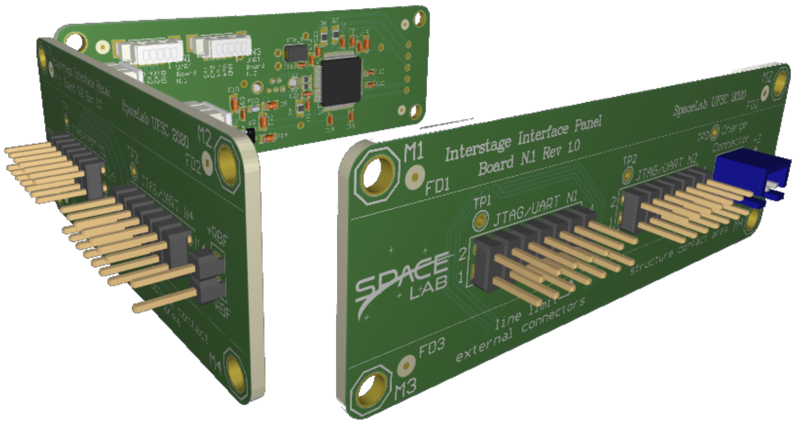

Figure 6.16: Set of external connection boards.

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

Table 6.2: IIP JTAG connectors usage.

6.7.1 Environmental Data Collection

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

The main featues of this payload are listed below, a 3D model of the EDC board can be seen in Figure 6.17.

- Reception/decoding of SBCD and Argos-2 signals on the 401.635 MHz ± 30 kHz frequency range.
- Can decode up to 12 PTT signals simultaneously.
- Attaches a header to decoded messages with frequency, time, and signal strength information.
- Full speed I^{2}C interface (400 kbit/s) for the OBC communication.
- Full-duplex RS-485 interface with fail-safe for the OBC communication.
- 5 V power supply.
- Memory capable of storing up to 64 decoded user messages.
- Generates housekeeping information including current supply, board temperature, digitized signal RMS level, front-end PLL synchronism state and overcurrent events.

- Can capture a 2048 samples sequence (16 ms window) from the received signal upon request.

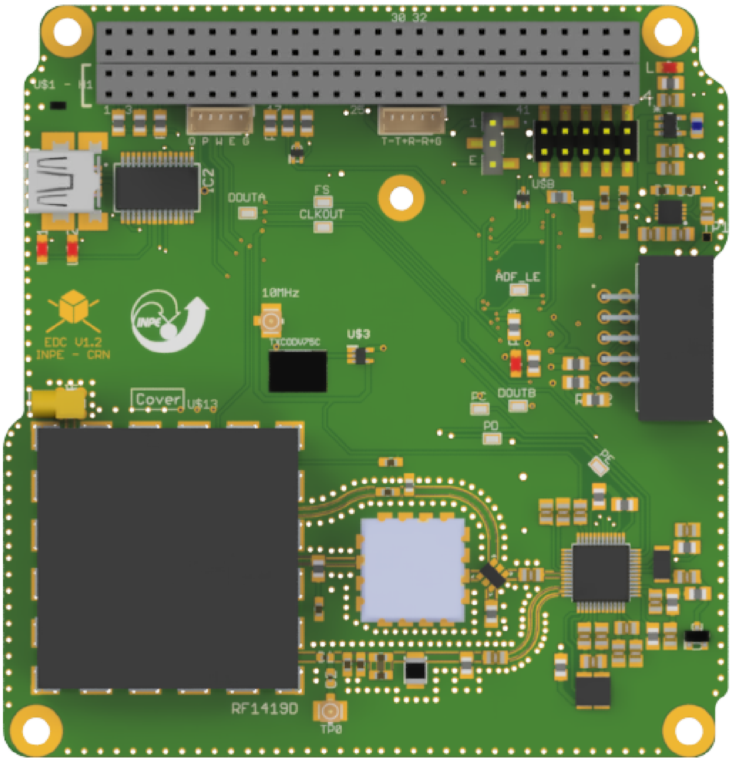

Figure 6.17: EDC board.

As can be seen in Figure 6.1, for this mission, two identical EDC boards will be used, in a cold redundancy configuration. More information about this payload can be found in [3].

6.7.2 Redundant OBDH (Payload-X)

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

More information about this payload can be found in [23].

6.7.3 Radiation Monitor (Harsh Payload)

The Radiation Monitor (or Harsh Payload) is a payload capable of evaluate the radiation effects on three SDRAM memories with different manufacturing nodes. This payload will test this chips in the real harsh space environment by flying aboard of FloripaSat-2 CubeSat mission. These particular SDRAM memories were previous characterized on laboratory experiments, then by exposing them to the real environments and executing the same tests routines will not only generate more results for analysis, but also provide an opportunity to assess the test methodologies themselves. Also, after collecting sufficient data to be analysed, this payload could be used to provide a meaningful health status, concerning the radiation doses which the satellite were exposed, to the entire satellite

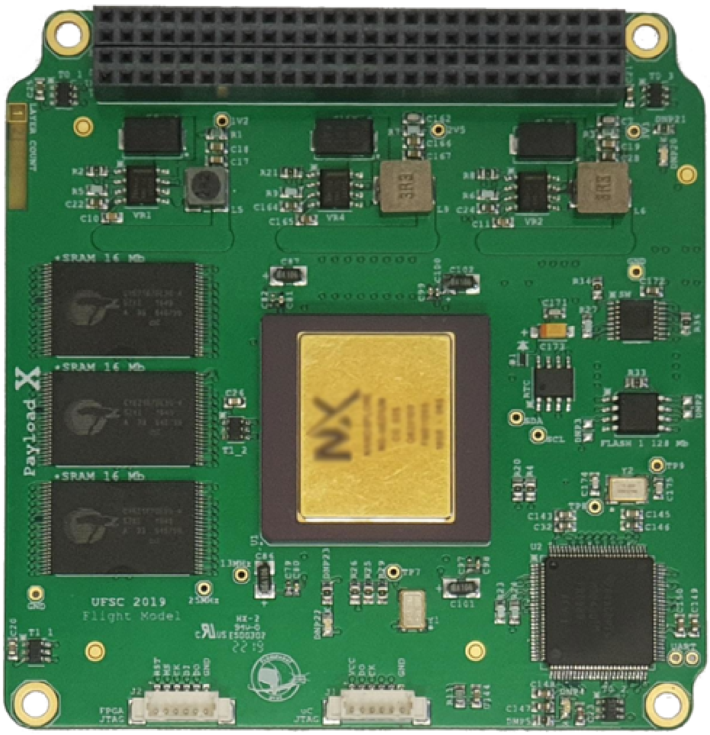

Figure 6.18: Payload-X board.

subsystems and further missions. A picture of the harsh payload board is available in Figure 6.19.

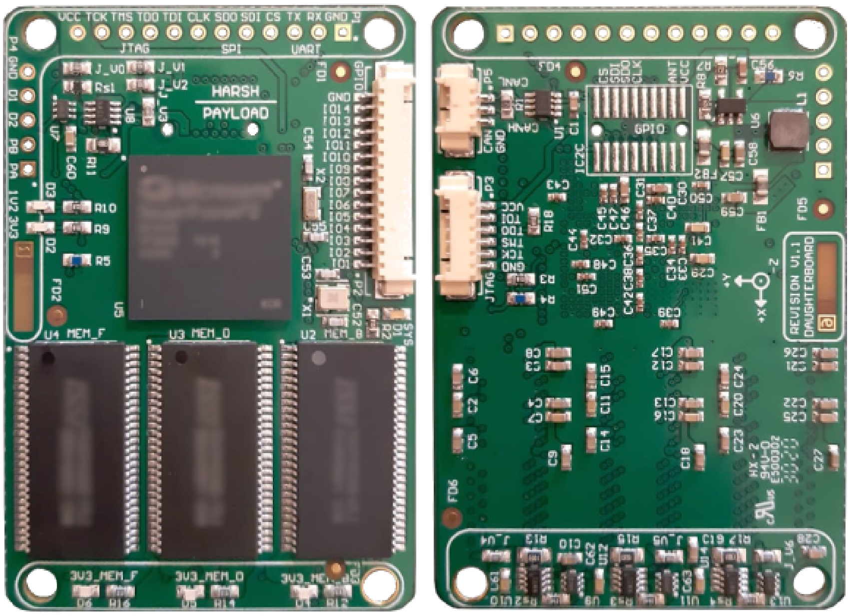

Figure 6.19: Radiation monitor board. Top (left) and bottom (right) sides.

In order to accomplish this objectives, the payload is designed to follow the OBDH DaughterBoard standard of SpaceLab, which defines the connectors, shape and size of the board. This standard allows the utilization of the module throughout future SpaceLab core missions in reason of its low space occupation inside the CubeSat, being considered further as an expansion module instead of a payload experiment. A picture of the exploded view of the harsh payload and the OBDH can be seen in Figure 6.20.

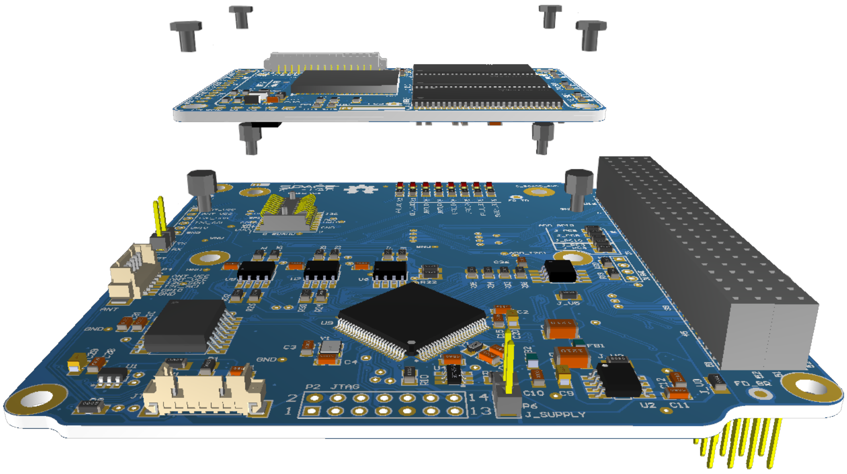

Figure 6.20: Integration of the radiation monitor payload in the OBDH.

Also, due to the mission limited power budget, the developed board should consider reduce power consumption and define clever power management strategies. In addition, methods for anti latch-up, a type of short circuit which can occur inside an IC, are considered in the design. Therefore, combining all these requirements, the payload architecture consists of the following modules: a control and management subsystem, operated by a System-On-a-Chip (SoC) solution with an integrated FPGA, power converters for properly voltage level supply, anti latch-up circuitry, communication and interface buses, debug module and the SDRAM memory chips.

CHAPTER 7

Ground Segment

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

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

7.1 UFSC Ground Station

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

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

7.1.1 Hardware

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

7.1.1.1 Antennas

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

More information about the VHF and UHF antennas can be found in [24] and [25] respectively.

7.1.1.1.1 Surge Protector

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

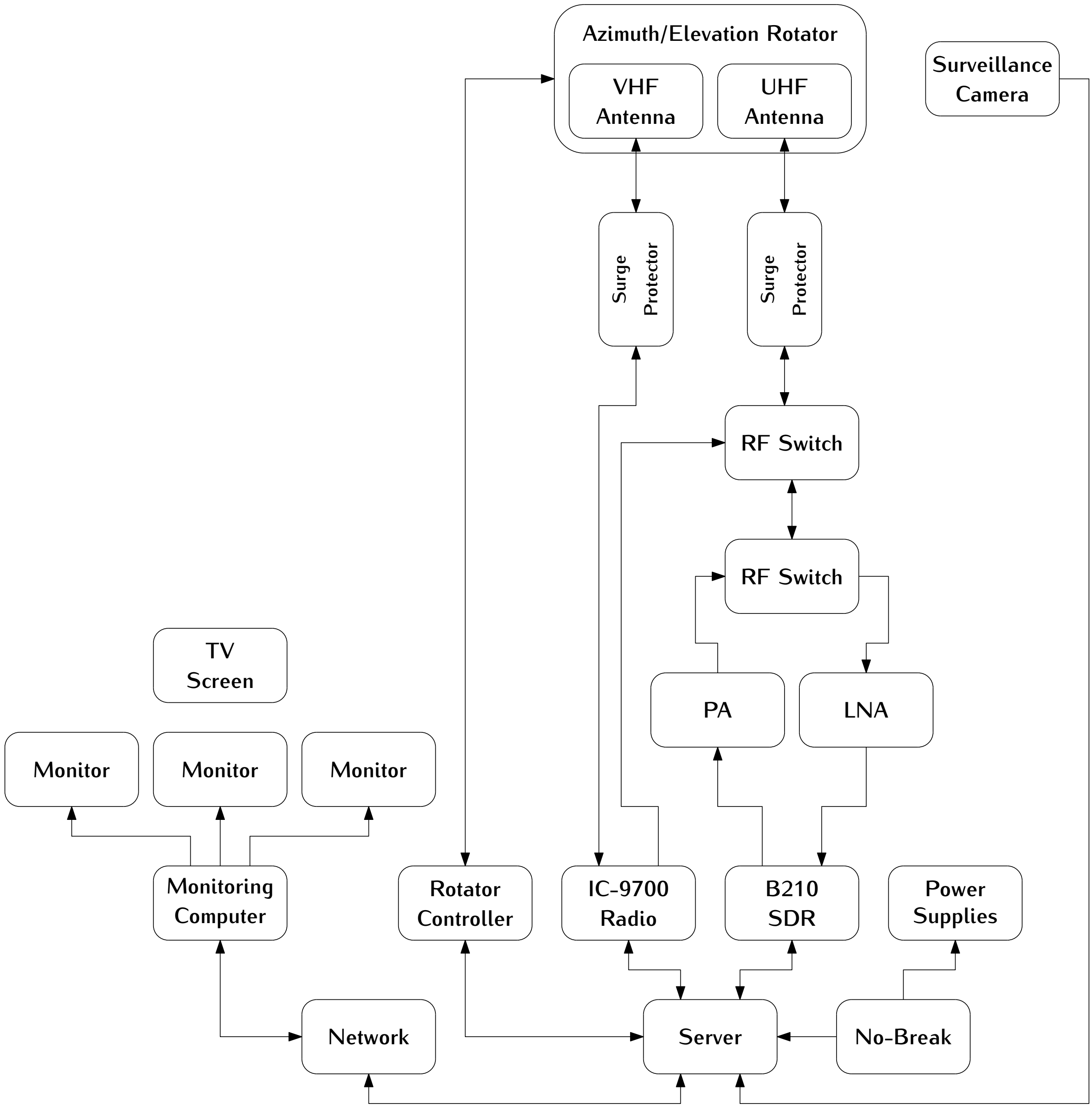

Figure 7.1: Block diagram of the ground segment.

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

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

7.1.1.2 Rotators

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

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

Characteristic	VHF Antenna	UHF Antenna	Unit
Brand	M^2	Cushcraft	-
Model	2MCP14	A719B	-
Type	Yagi	Yagi	-
Number of elements	14	19	-
Frequency range	143-148	430-450	MHz
Gain	12,34	15,5	dBi
Power rating	1500	2000	W
Boom length	3,2	4,1	m
Longest element	1,02	0,34	m
Weight	2,72	2,55	kg

Table 7.1: Main characteristics of the ground segment antennas.

Figure 7.2: MFJ-270N surge protector.

Figure 7.3: Yaesu G-5500 rotator and controller.

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

Table 7.2: Main characteristics of antennas' rotators.

More information about the ground station rotator can be found in [26].

7.1.1.3 Amplifiers

7.1.1.3.1 Power Amplifier

PA...

A picture of the power amplifier can be seen in Figure 7.4, the main characteristics are available in Table 7.3.

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

7.1.1.3.2 Low Noise Amplifiers

LNA...

Characteristic	Value	Unit
Brand	Mini-Circuits	-
Model	ZHL-50W-52-S+	-
Frequency range	50-500	MHz
Gain	47-52	dB
Noise figure	4,5-7,0	dB
DC supply voltage	24-25	V
Max. supply current	9,3	A

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

7.1.1.4 Radios

The Icom IC-9700 [27] is an RF direct sampling receiver for 2 m and 70 cm. The IF receiver consists of a single, down conversion for 23 cm that is between 311 and 371 MHz. The PA provides 100 W on 2 m, 75 W on 70 cm, and 10 W on 23 cm.

In addition to band specific memory channels, the IC-9700 allows band specific receiver and transmitter settings. For transmit, users can make adjustments to RF power, TX power Limit, Limit Power, and TX Delay by band. Basic receiver settings, like the Noise Blanker, Noise Reduction, and others can be tweaked by band with a dynamic Notch and Filter setup by band/mode.

A picture of the IC-9700 radio can be seen in Figure 7.5.

Figure 7.5: Icom IC-9700 radio transceiver.

7.1.1.4.1 Software Defined Radio

As presented in Figure 7.1, the ground segment also has an SDR (Software Defined Radio) as transceiver. The used model is the USRP B210, from Ettus Research [28], which is a fully integrated, single-board SDR with continuous frequency coverage from 70 MHz to 6 GHz. It combines the AD9361 RFIC direct-conversion transceiver providing up to 56 MHz of real-time bandwidth, an open and reprogrammable Spartan6 FPGA, and USB 3.0 connectivity. Also, a full support for the USRP Hardware Driver (UHD) software allows the use with the GNURadio framework.

A picture of the USRP B210 SDR (with enclosure) can be seen in Figure 7.6.

Figure 7.6: Ettus USRP B210 SDR.

7.1.1.5 Processing and Control

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7.1.2 Satellite Tracking

To track the satellite and for orbit prediction, the GPredict software [29] will be used. Gpredict is a real-time satellite tracking and orbit prediction application. It can track a large number of satellites and display their position and other data in lists, tables, maps, and polar plots (radar view). Gpredict can also predict the time of future passes for a satellite, and provide you with detailed information about each pass. Gpredict is free software licensed under the GNU General Public License. A picture of the main window of GPredict can be seen in Figure 7.7.

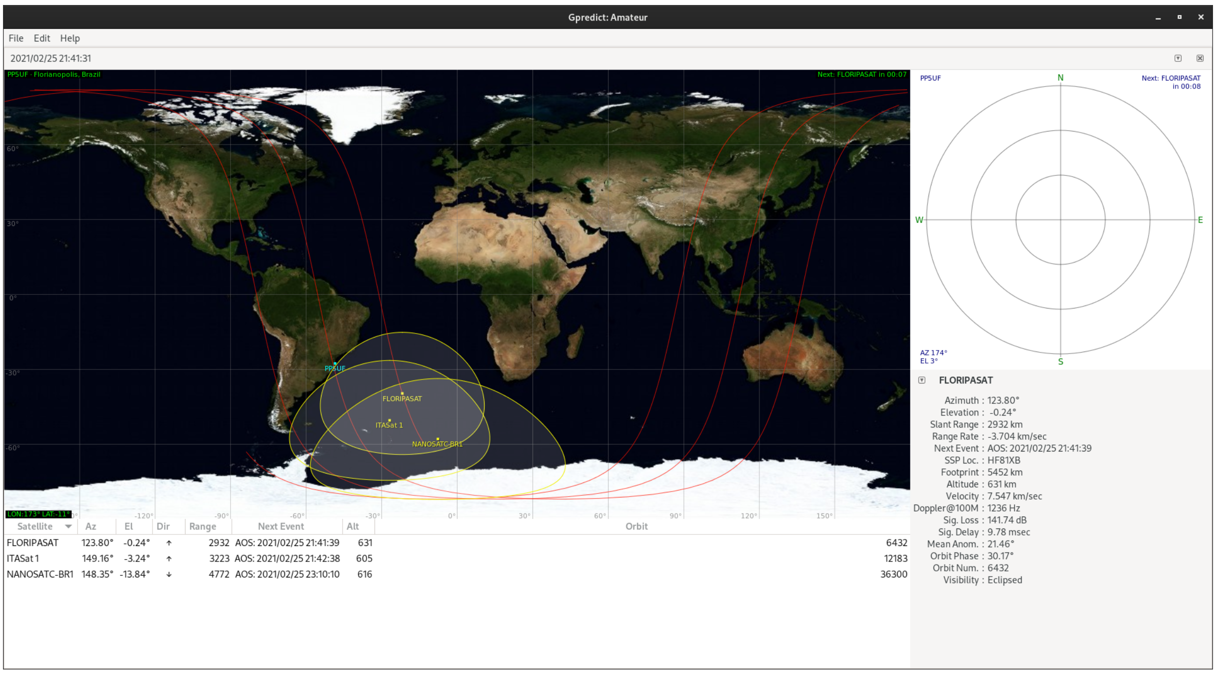

Figure 7.7: Main window of GPredict.

7.1.3 Packet Decoding

[30]

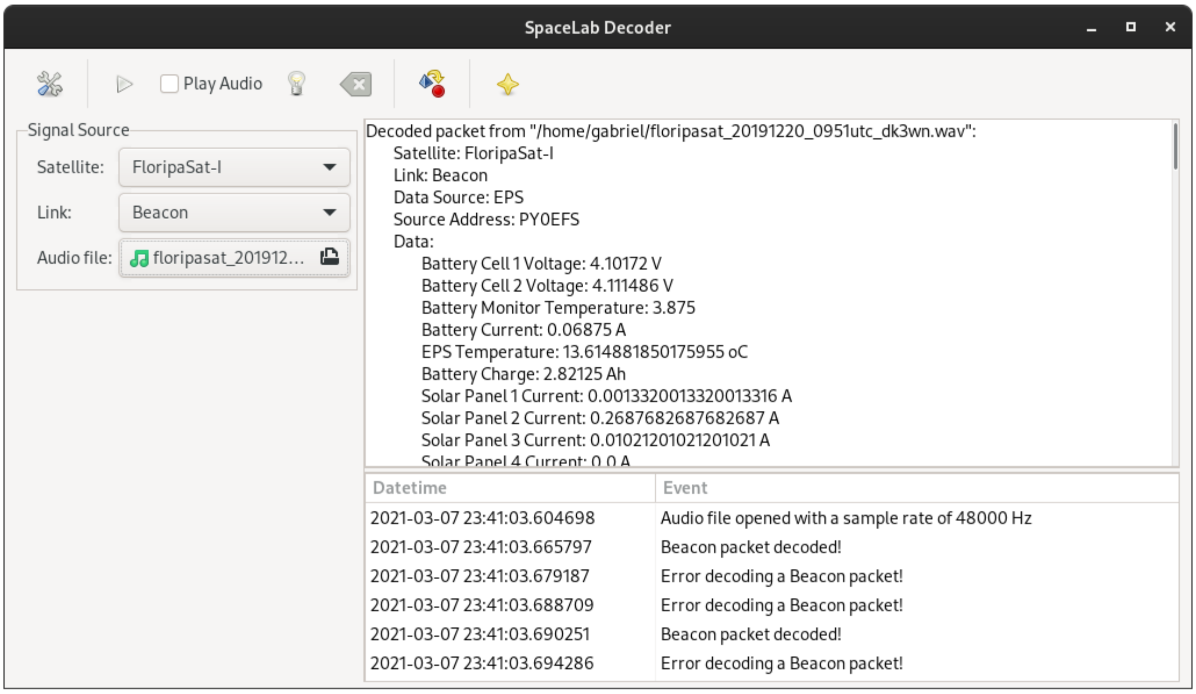

Figure 7.8: Main window of the SpaceLab Decoder application.

7.2 INPE-RN Ground Station

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7.3 Data Collection Platforms (PCDs)

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CHAPTER 8

Test Plan and Results

The FloripaSat-2 test plan is structured into four phases: Module tests, FlatSat, Engineering integration, and Flight integration. This plan is summarized in the Table 8.1 and includes the components under test for each phase.

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

Table 8.1: Test plan phases and tested components.

This section focus on providing an overview of the planned testing workflow and a description of the strategies approached to accomplish the mission objectives. The module tests focus on the individual modules operation and behavior, in which a general template is provided in this document and each module applies it for their needs. The FlatSat phase is the first modules integration in a debug platform to validate the system from a development perspective (described with more details in [31]). Finally, the engineering integration is the final development campaign aiming to validate the system from a mission perspective and the flight integration is the actual CubeSat assembly using the flight components and final assessments to prepare the satellite for launch. The integration details, procedures and qualification proccess are described with more depth in the chapter 9.

8.1 Module tests

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

8.1.1 Workflow

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

8.1.1.1 Visual Inspection

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

8.1.1.2 Mechanical Inspection

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

8.1.1.3 Integration Inspection

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

8.1.1.4 Electrical Inspection

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

8.1.1.5 Electrical Testing

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

8.1.1.6 Functional Testing

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

8.1.1.7 Module Testing

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

8.1.2 Continuos Integration

In order to detect errors and bugs in the early stages of development, a continuos integration workflow was setup for automated firmware tests focusing in small scope verfications (i.e., unit tests). Instead of executing the code in the target processor, the tests are executed remotely in a host computer through the usage of an unit testing framework, called "cmocka" [32]. This tool allows to abstract the inherent hardware dependencies of embedded systems to enable firmware tests without errors introduced by hardware problems (exection in a consolidated platform, the computer), which provides an optimal behavioral assessment of the code implementations. This approach not only support remote testing, but promote continuos test execution, which is essencial to detect erros and architectural issues. The integration of these procedures is powered by "GitHub Actions" [33], which provides a host machine and a dashboard inside the same environment of the already used version control, source distribution and management tool.

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

8.1.3 Hardware-In-the-Loop

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

8.2 Flatsat

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

Besides the hardware platform itself, during the FlatSat phase, a setup is used with the same structure as the hardware-in-the-loop strategy herein mentioned. Instead of using logs of one board, the analysis is performed from the perspective of all modules under test, which provides an evaluation of a complete system (satellite). More information about the Flatsat hardware platform and procedure details can be found in [31].

8.3 Engineering integration

The engineering model integration is the final development campaign since it connects the satellite design in the actual CubeSat form factor, allowing the assessment not only of the system from a behavioral perspective (as performed in the FlatSat), but also from the application and mission point of view. This is achieved due to additional elements

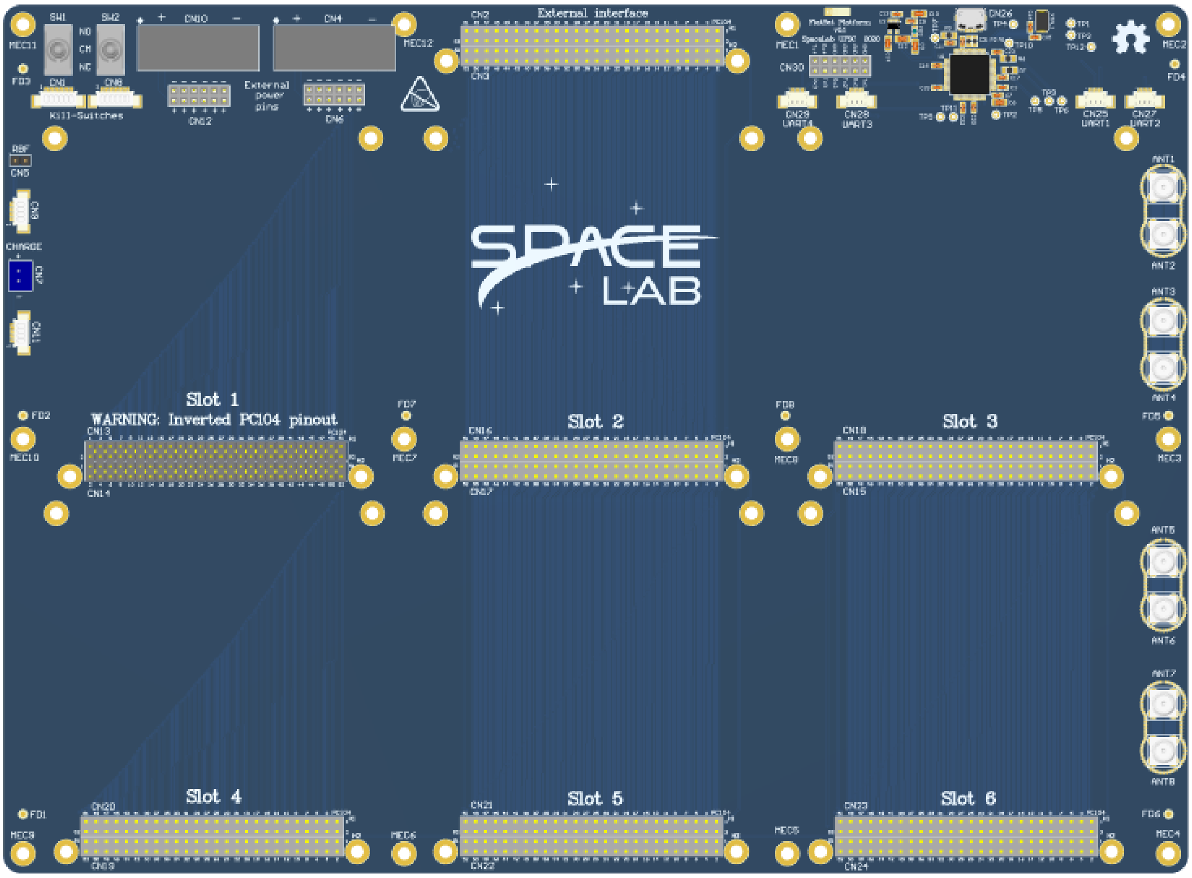


Figure 8.1: Top view of the flatsat board.

(e.g., actual mechanical frame), environmental tests and execution of use cases. Also, it is possible to early evaluate electrical, mechanical and behavioral compliance fulfillment.

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

8.4 Flight integration

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

LIT

[34]

8.5 Preliminary Results

8.5.0.1 Output Power of the Radio Modules

The output power of the radio modules can be measured using a spectrum analyzer, as can be seen in the picture of Figure 8.2.

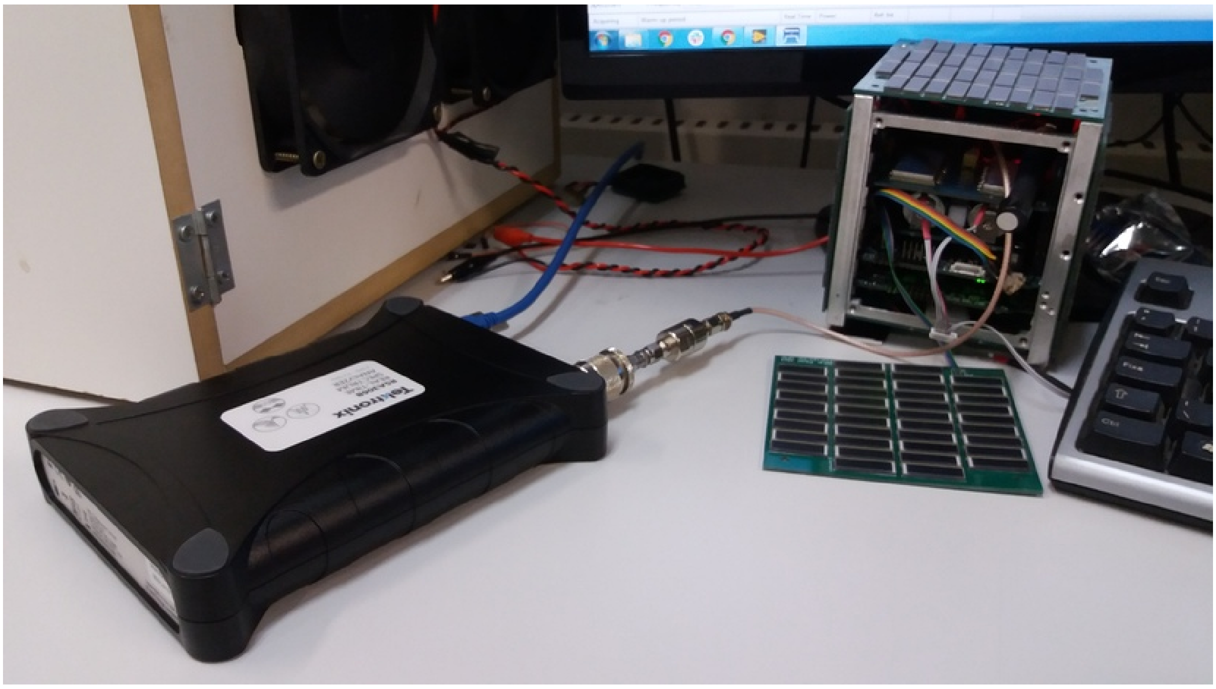


Figure 8.2: RF output power test with the radio modules connected to a spectrum analyzer.

The measured values for the beacon and downlink transmitters are available in Figures 8.3 and 8.4 respectively.

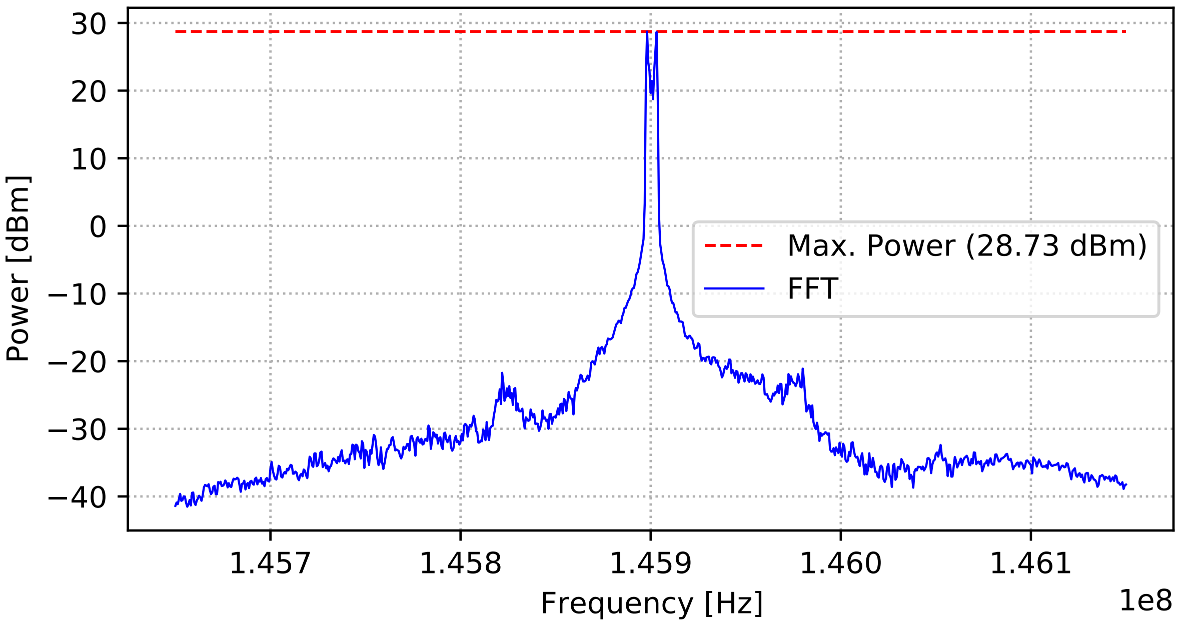


Figure 8.3: Output power of the beacon radio.

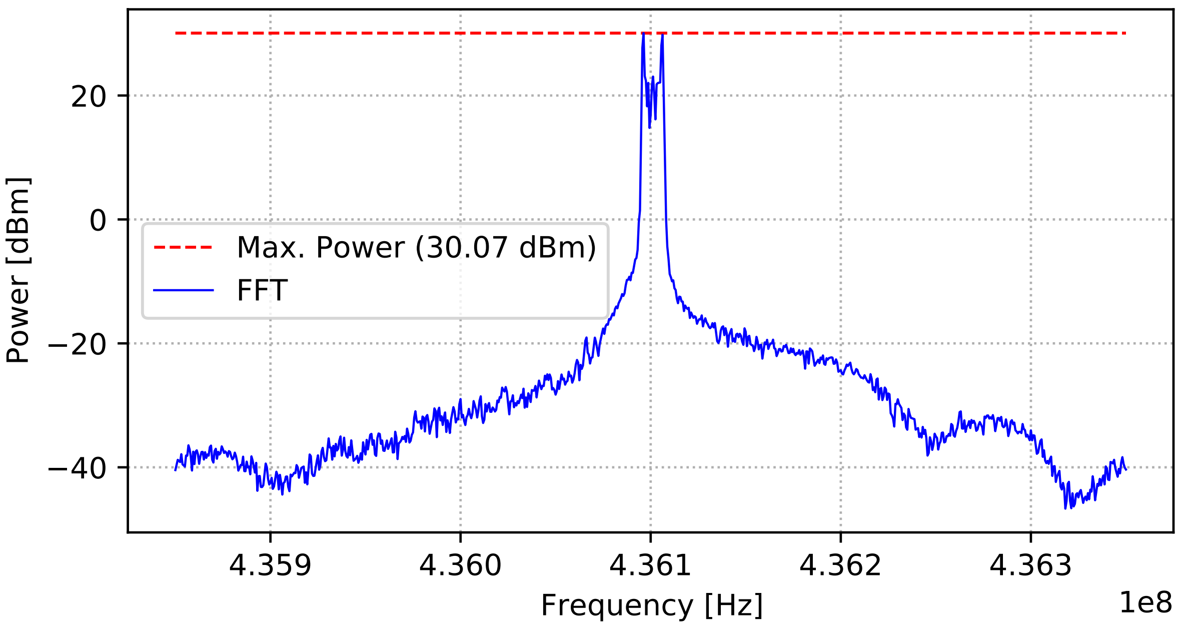


Figure 8.4: Output power of the downlink radio.

CHAPTER 9

Assembly, Integration and Test

AIT...

9.1 Assembly Instructions

9.1.1 Preparation and Required Material

- .
- .

9.1.2 Assembly Steps

1. .
2. .

9.2 Environmental Testing

- Mass verification
- Dimensions verification (fit check)
- Center of gravity (CG) verification
- Vibration test
- Thermal test
- Bake out test

9.2.1 Mass, Center of Gravity and Fit Check

9.2.1.1 Mass Verification

This test checks the total mass of the satellite (without RBF tag), which must be less than 2,66 kg [8]. The verification is made with a precision balance. Figure 9.1 examplifies this process with FloripaSat-I total mass.

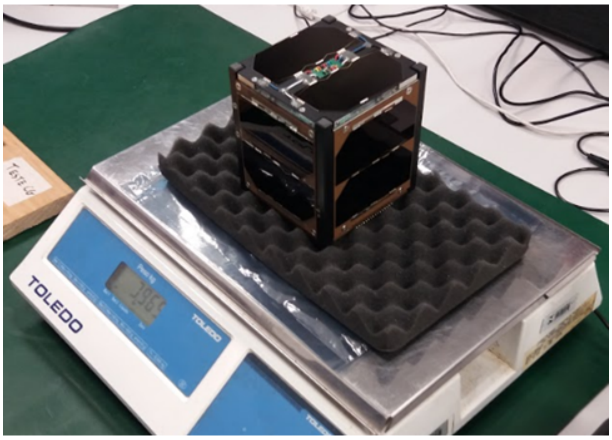
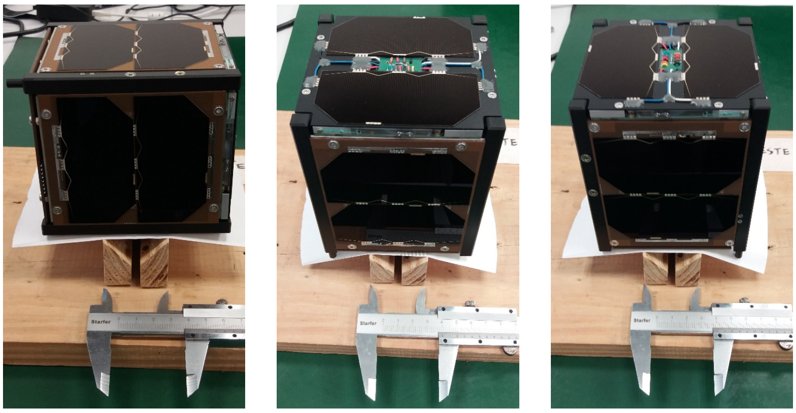


Figure 9.1: Mass verificatiton of FloripaSat-I.

9.2.1.2 Center of Gravity

This test checks the center of gravity (CG) of the satellite, which must be less than 2 cm from the geometric center (see Figure 9.2) [8]. To perform this test, a simple test-bench based on two parallel bars fixed on a plate (4 cm from each other) can be used. The geometric center of the satellite is put in the middle of the bars and, if the satellite does not fall, the CG is within the radius of 2 cm. This strategy does not measure the location of CG, however, it does prove if the satellite follows the requirement.



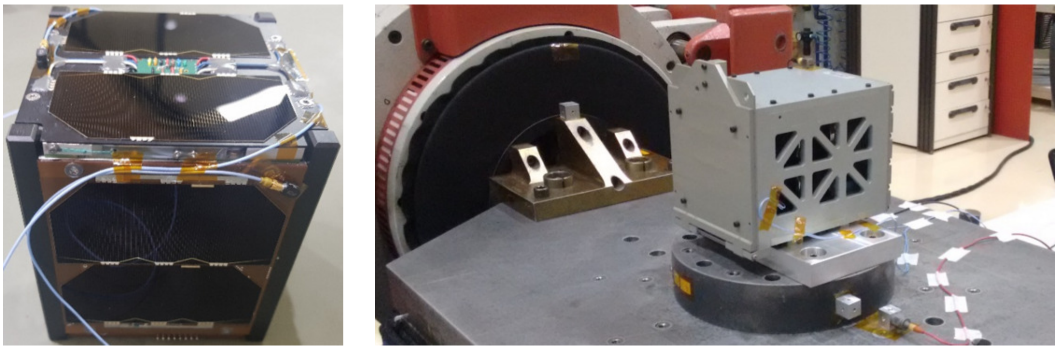
(a) X axis. (b) Y axis. (c) Z axis.

Figure 9.2: Center of gravity of FloripaSat-I within 2 cm from geometric center.

9.2.1.3 Fit Check

9.2.2 Vibration Test

To measure and control the acceleration profile during the dynamic tests, accelerometers should be positioned on three external surfaces of the satellite, one on each axis, over areas without solar cells. The satellite should be fixed on a shaker. Figure 9.3(a) shows some of the accelerometers and Figure 9.3(b) shows the satellite during a vibration test.



(a) Position of the accelerometers.

(b) Shaker.

Figure 9.3: Vibration test.

The CubeSat should be tested entirely off, with RBF pin removed but with the Kill-Switches pressed, in a 2U Test POD, simulating the normal launching condition. The set of vibration tests follows Figure 9.4.

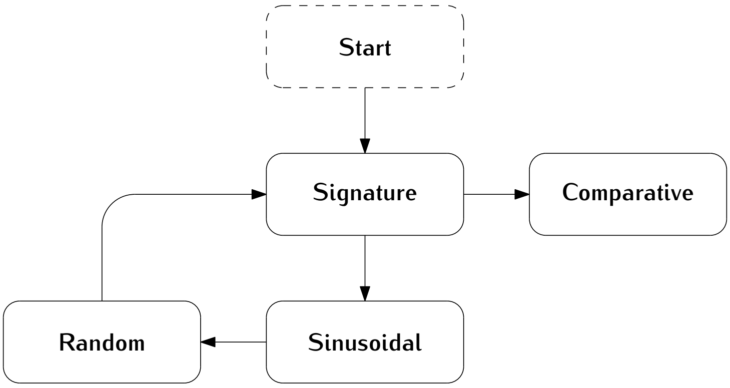


Figure 9.4: Sequence of dynamic tests.

A signature testing should be conducted before and after the tests (sinusoidal and random vibration), in order to identify the presence of significant variations in the dynamic response, a condition that may represent mechanical failures. For the signature task, Table 9.1 presents the specifications.

Name	Parameter
Test method	Sinusoidal sweep testing
Frequency range	5 - 2000 Hz
Vibration level	0,25 g
Sweep rate	2 octaves per minute
Number of sweeps	1 (5 - 2000 Hz)
Test axes	3 (X, Y, Z)

Table 9.1: Resonance survey test (signature).

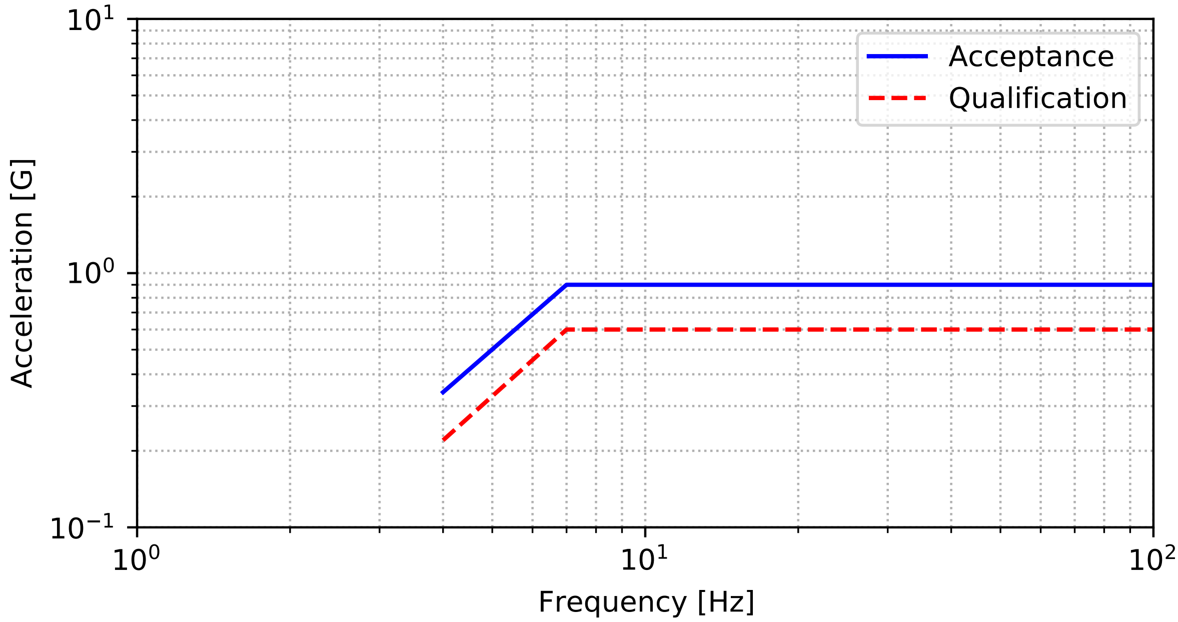


Figure 9.5: Sinusoidal sweeping vibration curve.

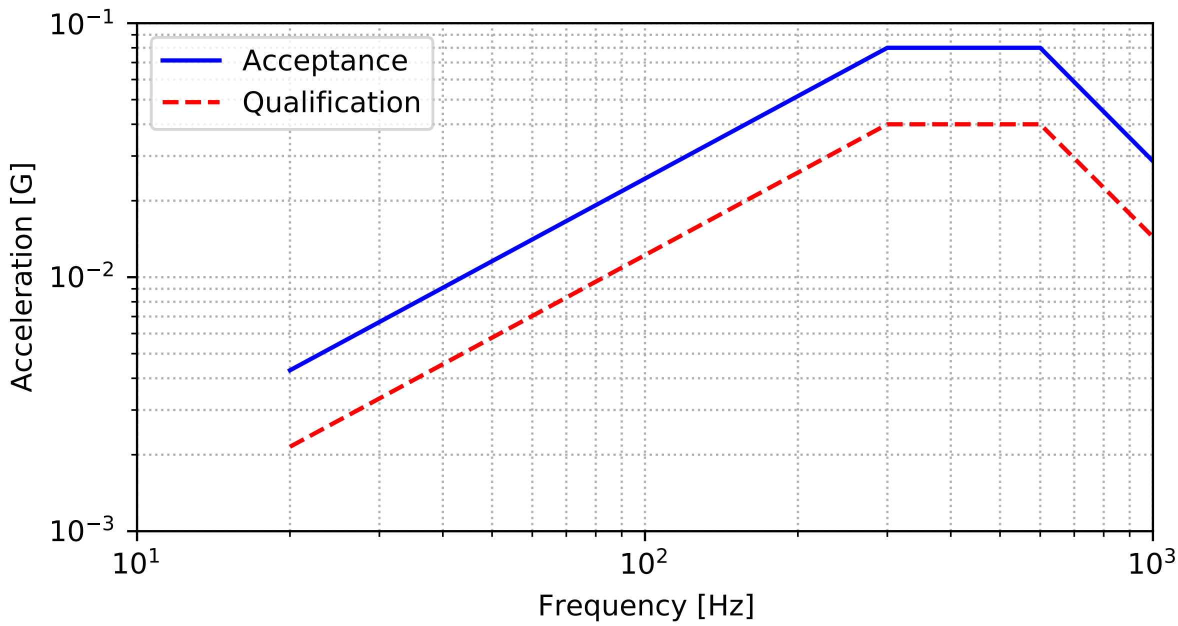


Figure 9.6: Random vibration curve.

9.2.3 Thermal Cycling

For the thermal tests, thermocouples should be attached on different points on the surface of the satellite, including over the solar panels and structure. As an example, **??** shows FloripaSat-I ready for thermal tests. The parameters of the tests are indicated in Table 9.2.

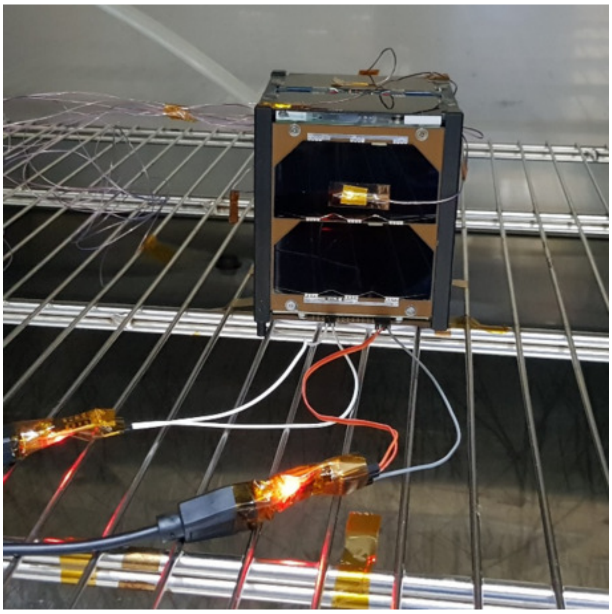


Figure 9.7: FloripaSat-I during the thermal cycling (with thermocouples).

Thermal cycle		**Bake out**	
Parameter	**Value**	**Parameter**	**Value**
Number of cycles	2	Part 1	
Min. temp. (T_{min})	-15 °C	Pressure	<1×10^{-4} mbar
Max. temp. (T_{max})	+50 °C	Temperature	23 °C
Duration in T_{min}	30 min	Duration	12 hours
Duration in T_{max}	60 min	Part 2	
Heating rate	5.5 °C/min	Pressure	<1×10^{-4} mbar
Cooling rate	3.5 °C/min	Temperature	60 °C
Stabilization criteria	1 °C/10 min	Duration	6 hours

Table 9.2: Parameters for the bake out and thermal cycling.

9.2.4 Bake Out

1. .

2. .

9.3 Pre-launch Preparation

1. .

2. .

9.3.1 Keys of the Telecommands

1. .
2. .

9.3.2 Firmware Upload

1. .
2. .

9.3.3 Memory Reset

1. .
2. .

9.4 Transport to Launch

9.4.1 Packing the Satellite

1. .
2. .

9.4.2 Unpacking the Satellite

1. .
2. .

CHAPTER 10

Operation Planning

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APPENDIX A

Link Budget Calculation

This appendix shows the link budget calculation of all the satellite links (including the radio links of the payloads). The used method was taken from [9] (section 13.3).

A.1 Distance to Satellite at Horizon

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

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

Where:

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

So, the distance to satellite at horizon is:

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

A.2 Free-Space Path Loss

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

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

Where:

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

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

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

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

A.2.1 Beacon

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

$$FSPL^{dB}_{min} = 32,45 + 20\log\left(\frac{550}{1\ km}\right) + 20\log\left(\frac{437}{1\ MHz}\right) = \mathbf{140,1\ dB} \tag{A.5}$$

$$FSPL^{dB}_{max} = 32,45 + 20\log\left(\frac{2705}{1\ km}\right) + 20\log\left(\frac{437}{1\ MHz}\right) = \mathbf{153,9\ dB} \tag{A.6}$$

$$\mathbf{140,1 \leq FSPL^{dB} \leq 153,9\ dB} \tag{A.7}$$

A.2.2 Downlink/Uplink

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

$$FSPL_{min} = 32,45 + 20\log\left(\frac{550}{1\ km}\right) + 20\log\left(\frac{462,5}{1\ MHz}\right) = \mathbf{140,6\ dB} \tag{A.8}$$

$$FSPL_{max} = 32,45 + 20\log\left(\frac{2705}{1\ km}\right) + 20\log\left(\frac{462,5}{1\ MHz}\right) = \mathbf{154,4\ dB} \tag{A.9}$$

$$\mathbf{140,6 \leq FSPL^{dB} \leq 154,4\ dB} \tag{A.10}$$

A.2.3 Uplink (Payload)

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

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

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

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

A.3 Power at Receiver

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

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

Where:

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

A.3.1 Beacon

$$P_r = 30 + 0 + 12 - 153,9 - 5 = -116,9 \ dBm \tag{A.15}$$

$$\mathbf{P_r \geq -116,9 \ dBm} \tag{A.16}$$

A.3.2 Downlink (UHF)

$$P_r = 30 + 0 + 12 - 154,4 - 5 = -117,4 \ dBm \tag{A.17}$$

$$\mathbf{P_r \geq -117,4 \ dBm} \tag{A.18}$$

A.3.3 Uplink (UHF)

$$P_r = 44 + 12 + 0 - 154,4 - 5 = -103,4 \ dBm \tag{A.19}$$

$$\mathbf{P_r \geq -103,4 \ dBm} \tag{A.20}$$

A.3.4 Uplink (Payload)

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

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

A.4 Signal-to-Noise-Ratio

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

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

Where:

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

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

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

with:

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

and:

$$F = 1 + \frac{T_r}{T_0} = 1 + \frac{323}{290} = 2,114 \tag{A.26}$$

The SNR value in decibels can be calculated using the Equation A.27:

$$\begin{aligned} SNR^{dB} &= 10\log_{10}\left(\frac{E_b}{N_0}\right) = 10\log_{10}\left(\frac{P_t G_t G_r}{k T_s R L_p}\right) \\ &= P_t^{dBm} - 30 + G_t^{dBi} + G_r^{dBi} - L_p^{dB} - 10\log k - 10\log T_s - 10\log R \end{aligned} \tag{A.27}$$

Considering other losses in the system (L_s) (cable and connection losses as example), the Equation A.27 can be corrected as presented in Equation A.28.

$$SNR^{dB} = P_t^{dBm} - 30 + G_t^{dBi} + G_r^{dBi} - L_p^{dB} - L_s^{dB} - 10\log k - 10\log T_s - 10\log R \tag{A.28}$$

A.4.1 Beacon

Using Equations A.28 and A.24, with:

- $P_t = 30\ dBm$
- $G_t = 0\ dBi$
- $G_r = 12\ dBi$
- $L_p = 153,9\ dB$
- $L_s = 5\ dB$
- $R = 4800\ bps$
- $T_0 = 290\ K$
- $T_r = 290\ K$
- $T_{ant} = 300\ K$
- $F = 2\ dB$
- $L_r = 0,89\ (0,5\ dB)$

$$T_s = 300 + \left(\frac{290(1-0,89)}{0,89}\right) + \left(\frac{290(2-1)}{0,89}\right) = 661,7\ K \tag{A.29}$$

$$SNR^{dB} = 30 - 30 + 0 + 12 - 144,8 - 5 + 228,6 - 30,64 - 30,79 = 16,68\ dB \tag{A.30}$$

$$\mathbf{SNR^{dB} \geq 16,68\ dB} \tag{A.31}$$

A.4.2 Downlink

Using Equations A.28 and A.24, with:

- $P_t = 30\ dBm$
- $G_t = 0\ dBi$
- $G_r = 12\ dBi$
- $L_p = 154,4\ dB$
- $L_s = 5\ dB$
- $R = 9600\ bps$
- $T_0 = 290\ K$
- $T_r = 290\ K$

- $T_{ant} = 300\ K$
- $F = 2\ dB$
- $L_r = 0,89\ (0,5\ dB)$

$$SNR^{dB} = 30 - 30 + 0 + 15.5 - 154,3 - 5 + 228,6 - 30,64 - 36,81 = 13,17\ dB \tag{A.32}$$

$$\mathbf{SNR^{dB} \geq 13,17\ dB} \tag{A.33}$$

A.4.3 Uplink

Using Equations A.28 and A.24, with:

- $P_t = 44\ dBm$
- $G_t = 12\ dBi$
- $G_r = 0\ dBi$
- $L_p = 154,4\ dB$
- $L_s = 5\ dB$
- $R = 9600\ bps$
- $T_0 = 290\ K$
- $T_r = 290\ K$
- $T_{ant} = 300\ K$
- $F = 2\ dB$
- $L_r = 0,89\ (0,5\ dB)$

$$SNR^{dB} = 44 - 30 + 15.5 + 0 - 154,3 - 7 + 228,6 - 31,39 - 36,81 = 27,17\ dB \tag{A.34}$$

$$\mathbf{SNR^{dB} \geq 27,17\ dB} \tag{A.35}$$

A.4.4 Uplink (Payload)

Using Equations A.28 and A.24, with:

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

$$SNR^{dB} = 30 - 30 + 3 + 0 - 153,9 - 5 + 228,6 - 28,21 - 26,02 = 19,20\ dB \quad \text{(A.36)}$$

$$\mathbf{SNR^{dB} \geq 19,20\ dB} \quad \text{(A.37)}$$

A.5 Link Margin

From [9], the minimum SNR value at the received considering a 10^{-5} bit error rate is:

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

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

- Beacon: $-9,6 = \mathbf{7,077\ dB}$
- Downlink: $-9,6 = \mathbf{3,574\ dB}$
- Uplink: $-9,6 = \mathbf{17,57\ dB}$
- Uplink (payload): $-9,6 = \mathbf{9,601\ dB}$

APPENDIX B

Telecommunication Packets

B.1 Beacon

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

15	Temperature of the beacon radio in K	2
		19

Table B.1: Beacon packets.

B.2 Downlink

Packet	Position	Content	Length [bytes]
General telemetry	0	Packet ID (20h)	1
	1	Source callsign (" PY0EFS")	7
	8	Time counter in milliseconds	4
	12	Temperature of the OBDH μC in Kelvin	2
	14	Input current of the OBDH in mA	2
	16	Input voltage of the OBDH in mV	2
	18	Last reset cause of the OBDH	1
	19	Reset counter of the OBDH	2
	21	Last valid telecommand (uplink packet ID)	1
	22	Temperature of the radio in Kelvin	2
	24	RSSI of the last valid telecommand	2
	26	Temperature of the antenna in Kelvin	2
	28	Antenna status	2
	30	Payloads status	1
	31	Temperature of the EPS μC in K	2
	33	EPS circuitry and Beacon MCU current in mA	2
	35	Last reset cause of the EPS	1
	36	Reset counter (EPS)	2
	38	-Y and +X sides solar panel voltage in mV	2
	40	-X and +Z sides solar panel voltage in mV	2
	42	-Z and +Y sides solar panel voltage in mV	2
	44	-Y side solar panel current in mA	2
	46	+Y side solar panel current in mA	2
	48	-X side solar panel current in mA	2
	50	+X side solar panel current in mA	2
	52	-Z side solar panel current in mA	2
	54	+Z side solar panel current in mA	2
	55	MPPT 1 duty cycle in %	1
	56	MPPT 2 duty cycle in %	1
	57	MPPT 3 duty cycle in %	1
	59	Main power bus voltage in mV	2

	61	Batteries voltage in mV	2
	63	Batteries current in mA	2
	65	Batteries average current in mA	2
	67	Batteries accumulated current in mA	2
	69	Batteries charge in mAh	2
	71	Battery monitor IC temperature in K	2
	73	Battery heater 1 duty cycle in %	1
	74	Battery heater 2 duty cycle in %	1
	75	Payload EDC status (00h=none, 01h=EDC_1, 02h=EDC_2, 03h=Both)	1
	76	Payload-X status (00h=OFF,01h=ON)	1
	77	Radiation monitor status (00h=OFF,01h=ON)	1
			78
	0	Packet ID (21h)	1
Ping answer	1	Source callsign (" PY0EFS")	7
	8	Requester callsign	7
			15
	0	Packet ID (22h)	1
Data request answer	1	Source callsign (" PY0EFS")	7
	8	Requester callsign	7
			15
	0	Packet ID (23h)	1
	1	Source callsign (" PY0EFS")	7
Message broadcast	8	Requester callsign	7
	15	Destination callsign	7
	22	Message	up to 38
			22 to 60
	0	Packet ID (24h)	1
	1	Source callsign (" PY0EFS")	7
	8	Payload ID (01h or 02h)	1
	9	PTT signal receiving time	4
	13	Error code	1
	14	Carrier frequency	2
	16	Carrier amplitude at ADC interface output	2
	18	User message length in bytes	1
	19	ARGOS-2 PTT-A2 user message	35
	54	Current time since J2000 epoch	4
	58	Elapsed time since last reset	4
Payload data	62	System current supply in mA	2
(EDC info)	64	System voltage supply in mV	2
	65	EDC board temperature	1

	66	RF front end LO	1
	67	RMS level at front-end output	2
	69	Generated PTT packages since last initialization	1
	70	Max	1
	71	Memory error count	1
	72	Current time	4
	76	Number of PTT package available for reading	1
	77	PTT decoder task status	1
	78	ADC sampler state	1
			79
Payload data (EDC samples)	0	Packet ID (24h)	1
	1	Source callsign (“ PY0EFS”)	7
	8	Payload ID (01h or 02h)	1
	9	Elapsed time since J2000 epoch	4
	13	ADC sample packet number	1
	14	First ADC I-sample	2
	16	First ADC Q-sample	2
	...	...	...
	214	N ADC I-sample	2
	216	N ADC Q-sample	2
			218
TC feedback	0	Packet ID (25h)	1
	1	Source callsign (“ PY0EFS”)	7
	8	Requester callsign	7
	15	TC packet ID	1
	16	Timestamp	4
			20

Table B.2: Downlink packets.

B.3 Uplink

Packet	**Position**	**Content**	**Length [bytes]**
Ping request	0	Packet ID (40h)	1
	1	Ground station callsign	7
			8
Data request	0	Packet ID (41h)	1
	1	Ground station callsign	7
			8
Broadcast message	0	Packet ID (42h)	1
	1	Ground station callsign	7
	8	Destination callsign	7
	15	Message	up to 38

			up to 53
Enter hibernation	0	Packet ID (43h)	1
	1	Ground station callsign	7
	8	Hibernation in hours	2
	10	TC key	8
			18
Leave hibernation	0	Packet ID (44h)	1
	1	Ground station callsign	7
	8	TC key	8
			16
Activate module	0	Packet ID (45h)	1
	1	Ground station callsign	7
	8	Module ID	1
	9	TC key (one for each module)	8
			17
Deactivate module	0	Packet ID (46h)	1
	1	Ground station callsign	7
	8	Module ID	1
	9	TC key (one for each module)	8
			17
Activate payload	0	Packet ID (47h)	1
	1	Ground station callsign	7
	8	Payload ID	1
	9	TC key (one for each payload)	8
			17
Deactivate payload	0	Packet ID (48h)	1
	1	Ground station callsign	7
	8	Payload ID	1
	9	TC key (one for each payload)	8
			17
Erase memory	0	Packet ID (49h)	1
	1	Ground station callsign	7
	8	TC key	8
			16
Force reset	0	Packet ID (4Ah)	1
	1	Ground station callsign	7
	8	TC key	8
			16
Get payload data	0	Packet ID (4Bh)	1
	1	Ground station callsign	7
	8	Payload ID	1
	9	TC key (one for each payload)	8
	17	Payload arguments	up to 11

	16

Table B.3: Uplink packets.