



GOLDS-UFSC Documentation

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SpaceLab, Universidade Federal de Santa Catarina, Florianópolis - Brazil

GOLDS-UFSC Documentation
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List of Figures

| | |
|--|----|
| 1.1 GOLDS-UFSC mission patch. | 2 |
| 4.1 Reference diagram of the PC-104 bus. | 8 |
| 5.1 Exploded view of the GOLDS-UFSC satellite. | 13 |
| 5.2 OBDH module. | 14 |
| 5.3 TTC module. | 15 |
| 5.4 Antenna module from ISISpace. | 16 |
| 5.5 Configuration reference of the antenna module. | 16 |
| 5.6 EPS module. | 17 |
| 5.7 Battery module board. | 18 |
| 5.8 Conceptual solar panel from ORBITAL. | 19 |
| 5.9 Top solar panel from ISISpace. | 19 |
| 5.10 Panasonic AV402461 Microswitch. | 19 |
| 5.11 Kill-Switches installed in the mechanical structure. | 20 |
| 5.12 The contact arrangement of the microswitch. | 20 |
| 5.13 ACS subsystem. Rare earth magnet (pink) and hysteresis bars (red) installed in the structure. | 21 |
| 5.14 PC-104 adapter boards (top and bottom). | 22 |
| 5.15 Set of external connection boards. | 23 |
| 5.16 EDC board. | 24 |
| 5.17 Payload-X board. | 25 |
| 5.18 Radiation monitor board. | 25 |
| 5.19 Integration of the radiation monitor payload in the OBDH. | 26 |
| 6.1 Top view of the flatsat board. | 29 |

List of Tables

| | | |
|-----|---|----|
| 3.1 | Mission schedule. | 5 |
| 4.1 | Link budget results. | 8 |
| 4.2 | PC-104 bus pinout. | 9 |
| 4.3 | PC-104 bus signal description. | 10 |
| 4.4 | Telecommunication packets and their content. | 11 |
| 5.1 | Kill-Switch current rating and voltage range. | 20 |

Nomenclature

| | |
|--------------|---|
| ACS | <i>Attitude Control System.</i> |
| EDC | <i>Environmental Data Collection.</i> |
| EPS | <i>Electrical Power System.</i> |
| GOLDS | <i>Global Open Collecting Data System</i> |
| INPE | <i>Instituto Nacional de Pesquisas Espaciais.</i> |
| LIT | <i>Laboratório de Integração e Testes.</i> |
| MPPT | <i>Maximum Power Point Tracking.</i> |
| OBDH | <i>On-Board Data Handling.</i> |
| PCB | <i>Printed Circuit Board.</i> |
| SBCD | <i>Sistema Brasileiro de Coleta de Dados.</i> |
| SNR | <i>Signal To Noise Ratio</i> |
| TTC | <i>Telemetry, Tracking and Command Module.</i> |

Contents

| | |
|--|-----|
| List of Figures | v |
| List of Tables | vii |
| Nomenclature | ix |
| 1 Introduction | 1 |
| 1.1 Mission Description | 1 |
| 1.2 Mission Objectives | 1 |
| 1.3 Mission Patch | 1 |
| 2 Mission Requirements | 3 |
| 3 Mission Schedule | 5 |
| 4 Overall Description | 7 |
| 4.1 General Diagrams | 7 |
| 4.2 General Behaviour | 7 |
| 4.3 Orbit Parameters | 7 |
| 4.4 Power Budget | 7 |
| 4.5 Link Budget | 7 |
| 4.6 PC-104 Bus | 7 |
| 4.7 Telecommunication | 7 |
| 5 Subsystems | 13 |
| 5.1 On-Board Data Handling | 13 |
| 5.2 Telemetry, Tracking and Command Module | 14 |
| 5.2.1 Antenna Module | 15 |
| 5.3 Electrical Power System | 17 |
| 5.3.1 Battery Module | 17 |
| 5.3.2 Solar Panels | 18 |
| 5.3.3 Kill-Switches and RBF | 18 |
| 5.4 Attitude Control System | 20 |
| 5.5 Mechanical Structure | 22 |
| 5.6 Interconnection Modules | 22 |
| 5.6.1 PC-104 Interconnection Boards | 22 |
| 5.6.2 External Connection Boards | 22 |
| 5.7 Payloads | 23 |
| 5.7.1 Environmental Data Collection | 23 |

Contents

| | | |
|-------------------|---|-----------|
| 5.7.2 | Redundant OBDH (Payload-X) | 24 |
| 5.7.3 | Radiation Monitor (Harsh Payload) | 24 |
| 6 | Test Plan and Results | 27 |
| 6.1 | Test Procedure | 27 |
| 6.1.1 | Hardware | 27 |
| 6.1.2 | Software | 27 |
| 6.1.3 | Flatsat | 28 |
| 6.2 | Preliminary Results | 28 |
| 7 | Ground Segment | 31 |
| 8 | Operation Planning | 33 |
| References | | 36 |
| Appendices | | 37 |
| A | Link Budget Calculation | 37 |
| A.1 | Distance to Satellite at Horizon | 37 |
| A.2 | Free-Space Path Loss | 37 |
| A.2.1 | Beacon | 38 |
| A.2.2 | Downlink/Uplink | 38 |
| A.2.3 | Uplink (Payload) | 38 |
| A.3 | Signal-to-Noise-Ratio | 39 |
| A.3.1 | Beacon | 40 |
| A.3.2 | Downlink | 40 |
| A.3.3 | Uplink | 41 |
| A.3.4 | Uplink (Payload) | 41 |
| A.4 | Link Margin | 42 |

CHAPTER 1

Introduction

GOLDS stands for Global Open Collecting Data System...

INPE
LIT
PCB

1.1 Mission Description

1.2 Mission Objectives

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.
6. Perform experiments on radiation effects in electronic components in orbit.
7. Serve as relay for amateur radio communications.

1.3 Mission Patch

The mission patch of the GOLDS-UFSC can be seen in Figure 1.1, it is inspired by the FloripaSat-I patch [1].



Figure 1.1: GOLDS-UFSC 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 GOLDS-UFSC 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. GOLDS-UFSC 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. GOLDS-UFSC 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 GOLDS-UFSC.

CHAPTER 3

Mission Schedule

| Activity | Month (2021) | | | | | | | | | | | |
|----------|--------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| | 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 described 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

Overall Description

4.1 General Diagrams

4.2 General Behaviour

4.3 Orbit Parameters

4.4 Power Budget

4.5 Link Budget

The link budget of all radio links of the satellite is available in Table 4.1.

All equations and steps used to obtain the results of Table 4.1 are available in Appendix A.

4.6 PC-104 Bus

4.7 Telecommunication

| Variable | Beacon | Downlink | Uplink | Uplink (Payload) | Unit |
|---------------------------------|--------------|-------------|-----------|------------------|------|
| Frequency | 145,97 | 436,9 | 436,9 | 401,635 | MHz |
| Modulation | MSK | MSK | MSK | BPSK | - |
| Protocol | NGHam | NGHam | NGHam | SBCD | - |
| Transmit power | 30 | 30 | 47 | ?? | dBm |
| FSPL | 144,8 | 154,3 | 154,3 | ?? | dB |
| Other losses | 5 | 5 | 7 | 5 | dB |
| Receive antenna gain | 12 | 15,5 | 0 | 0 | dBi |
| Receiver noise temp. | | | | | K |
| Antenna noise temp. | | | | | K |
| System noise temp. | | | | | K |
| Data rate | 1200 | 4800 | 4800 | 400 | bps |
| Received SNR | 30,87 | 17,35 | 31,60 | ?? | dB |
| SNR required for 10^{-5} BER* | 9,6 | 9,6 | 9,6 | 9,6 | dB |
| Link margin | $\leq 21,27$ | $\leq 7,75$ | ≤ 22 | $\leq ??$ | dB |

Table 4.1: Link budget results.

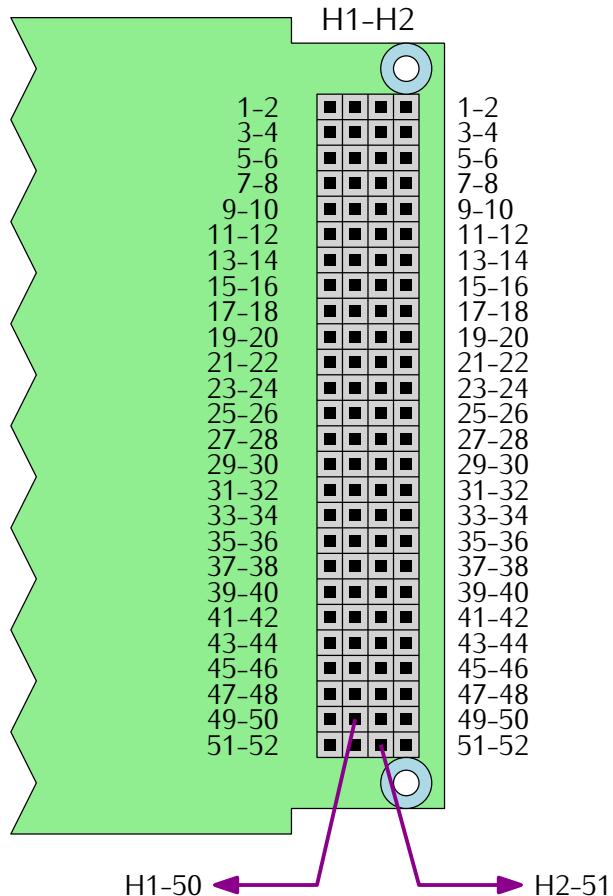


Figure 4.1: Reference diagram of the PC-104 bus.

| 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 4.2: PC-104 bus pinout.

| 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_RX/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 4.3: PC-104 bus signal description.

| <i>Link</i> | <i>Packet Name</i> | <i>Payload</i> | | | |
|-------------|----------------------|----------------|------------------------|--|---------------------|
| | | <i>ID</i> | <i>Source Callsign</i> | <i>Data (up to 220 bytes)</i> | <i>Size (bytes)</i> |
| Beacon | EPS Data | 00h | "0" + "PY0EGU" | EPS + TTC data | 58 |
| | TTC Data | 01h | | TTC data | 18 |
| | EPS Data | 02h | | EPS + TTC data | 39 |
| | TTC Data | 03h | | TTC data | 18 |
| Downlink | Telemetry | 10h | "0" + "PY0EGU" | Flags + OBDH/EPS data | 220 |
| | Ping Answer | 11h | | Requester callsign | 15 |
| | Data Request Answer | 12h | | Req. callsign + data | 15 to 155 |
| | Hibernation Feedback | 13h | | Req. callsign + hibernation in hours | 17 |
| | Message Broadcast | 14h | | Req. + dst. callsign + message | 22 to 60 |
| Uplink | Ping Request | 20h | Any Callsign | None | 8 |
| | Data Request | 21h | | Data flags + count + origin + offset | 16 |
| | Hibernation Request | 22h | | Req. callsign + hibernation in hours + key | 29 |
| | Broadcast Message | 23h | | Dst. callsign + message | 15 to 46 |

Table 4.4: Telecommunication packets and their content.

CHAPTER 5

Subsystems

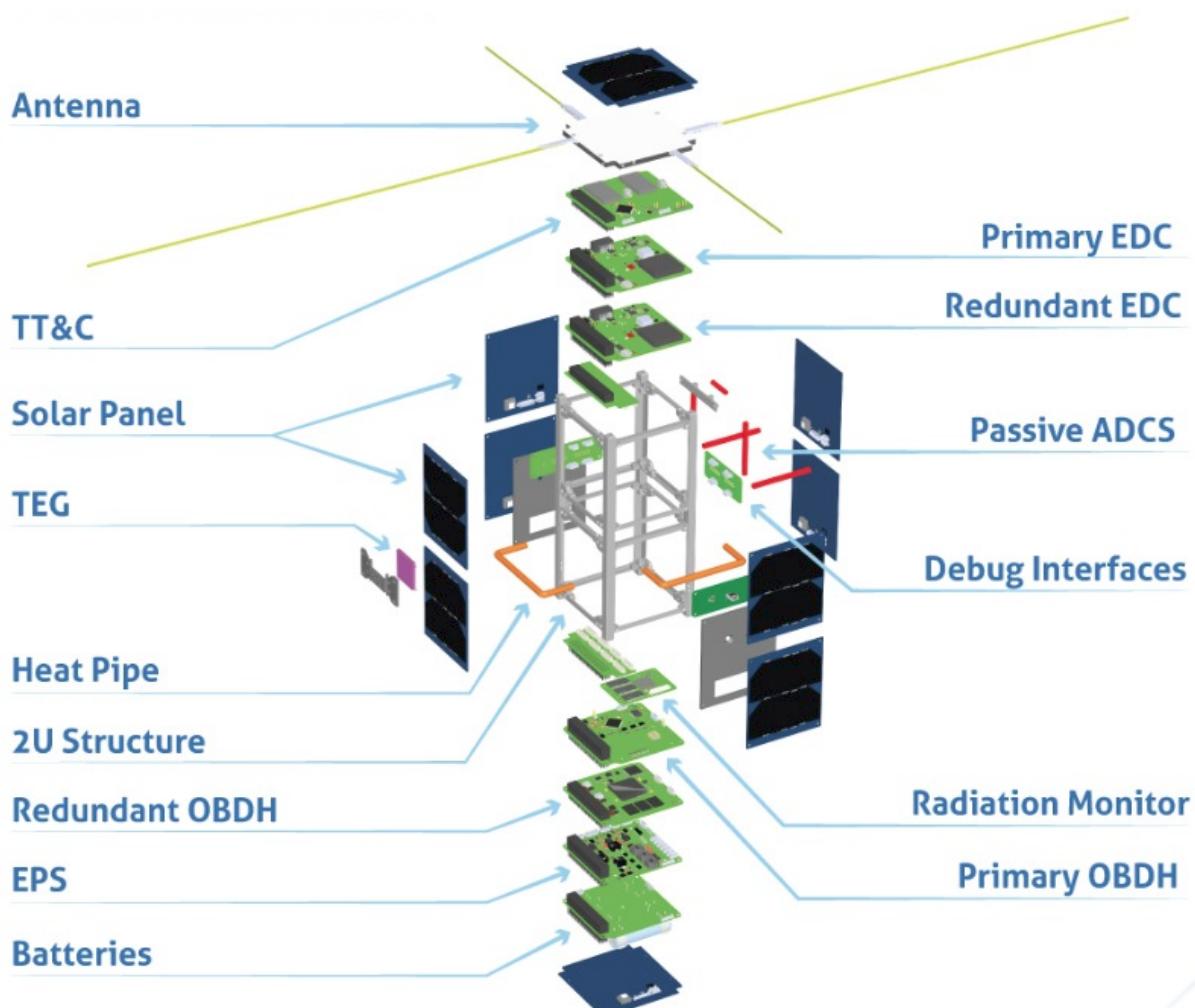


Figure 5.1: Exploded view of the GOLDS-UFSC satellite.

5.1 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 5.2.

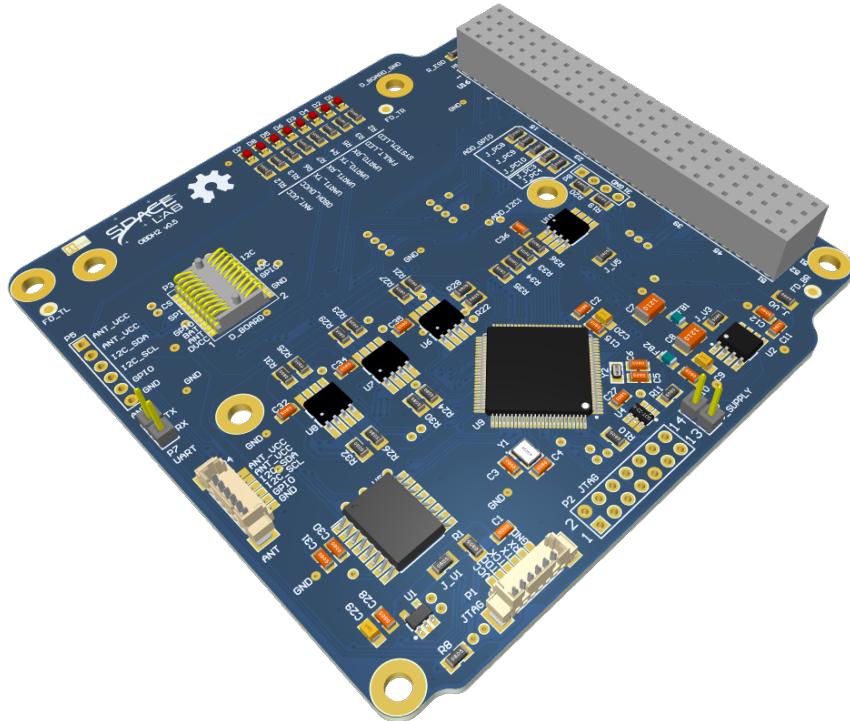


Figure 5.2: OBDH module.

More information about this module can be found in [2].

5.2 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 5.3.

More information about this module can be found in [3].

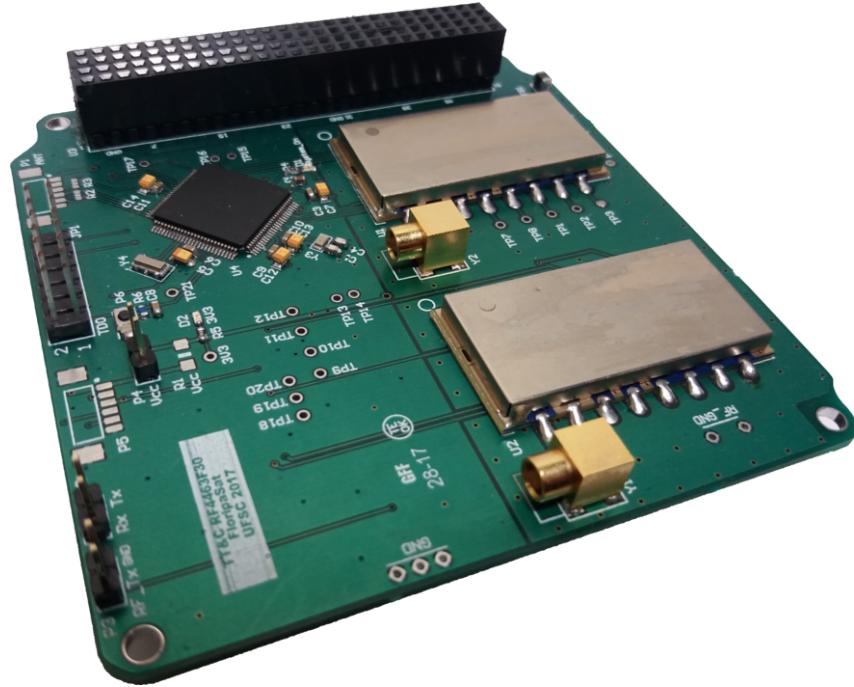


Figure 5.3: TTC module.

5.2.1 Antenna Module

The used antenna module is the CubeSat deployable VHF and UHF antenna from ISISpace [4]. 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 I²C 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 5.4.

The chosen configuration for this mission can be seen below (using Figure 5.5 as reference):

- Configuration: 4 monopoles (1x VHF + 3x UHF)
 - Antenna 1: VHF - 145,97 MHz (beacon)
 - 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
- I²C control type: Dual bus
 - Primary I²C address: 31h (7-bit address)

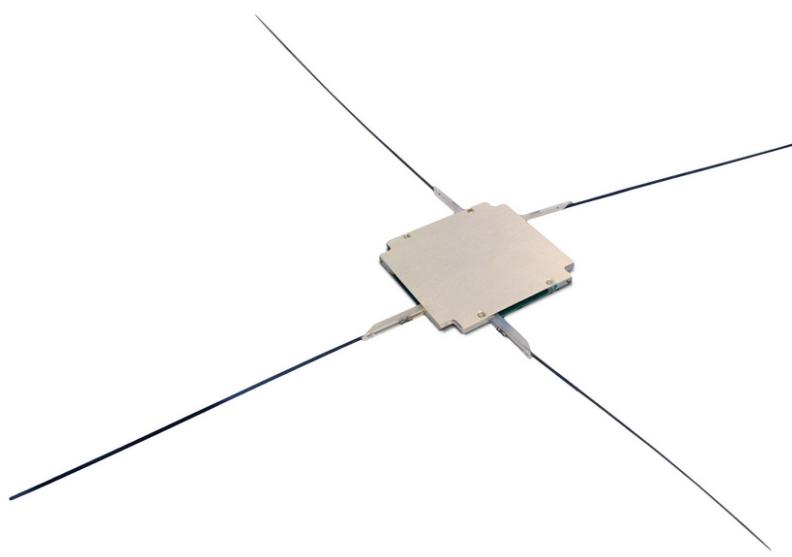


Figure 5.4: Antenna module from ISISpace.

- Redundant I²C address: 32h (7-bit address)
- I²C watchdog: Enabled with a time out of 60 seconds.

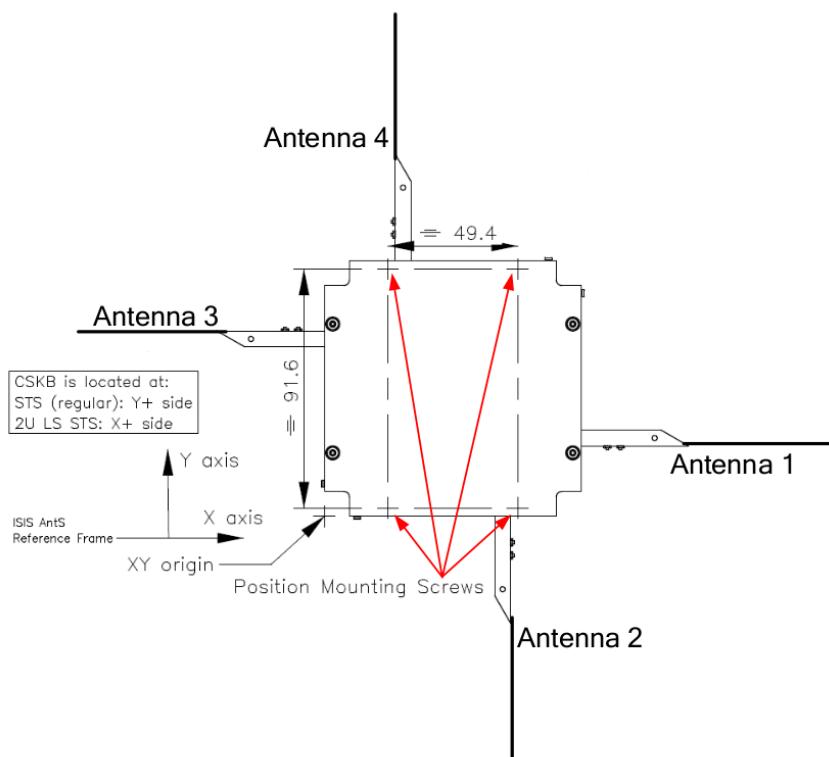


Figure 5.5: Configuration reference of the antenna module.

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.

5.3 Electrical Power System

The EPS is the module designed to harvest, store and distribute energy for the satellite. The energy harvesting system is based on solar energy conversion through the solar panels attached to the CubeSat structure. The EPS is designed to operate the solar panels at their maximum power point (MPPT). The board also measures the solar panels current, voltage and the temperature of the batteries. The harvested solar energy is stored in a 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 5.6.

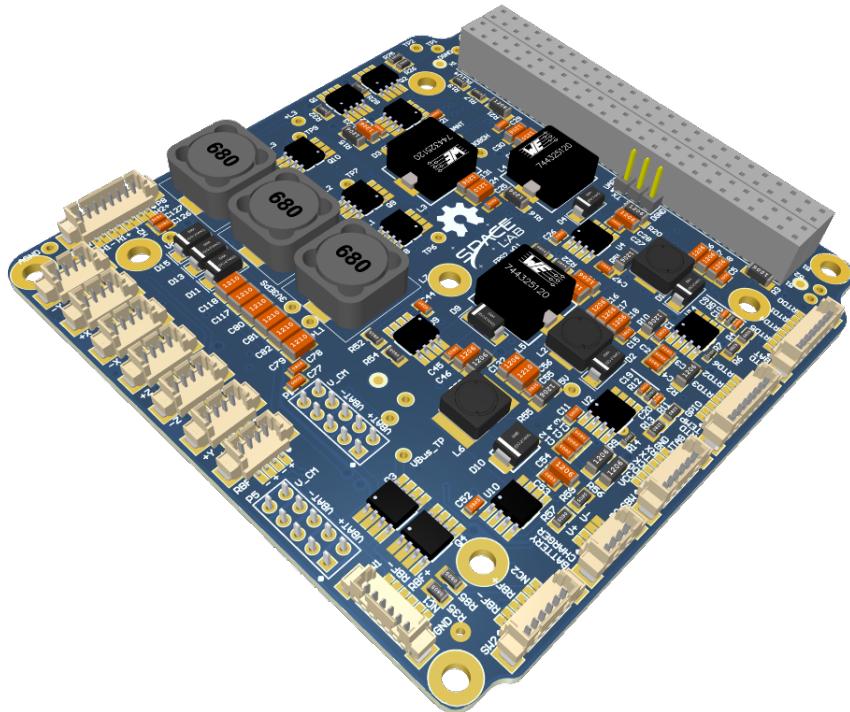


Figure 5.6: EPS module.

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 [5].

5.3.1 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 [6], 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 mission [1].

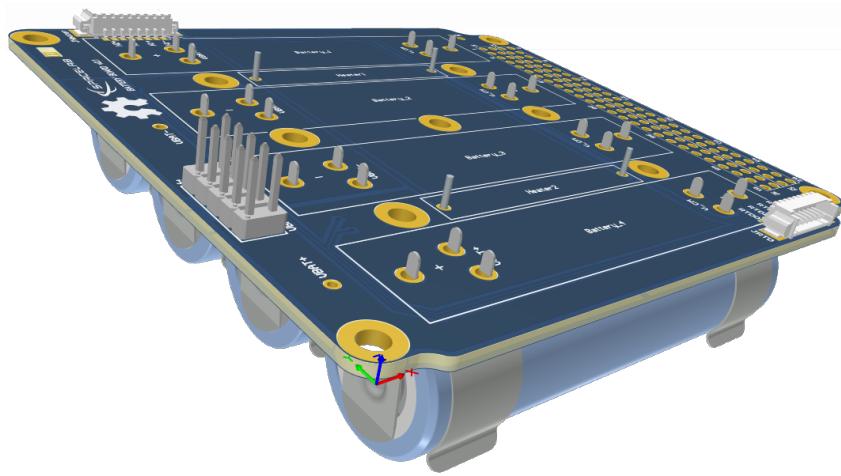


Figure 5.7: Battery module board.

More information about the battery module can be found in [7].

5.3.2 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 [8] with dimensions $6,9 \times 3,9$ cm (area $26,5 \text{ cm}^2$). 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 5.8 and 5.9.

5.3.3 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 5.10.

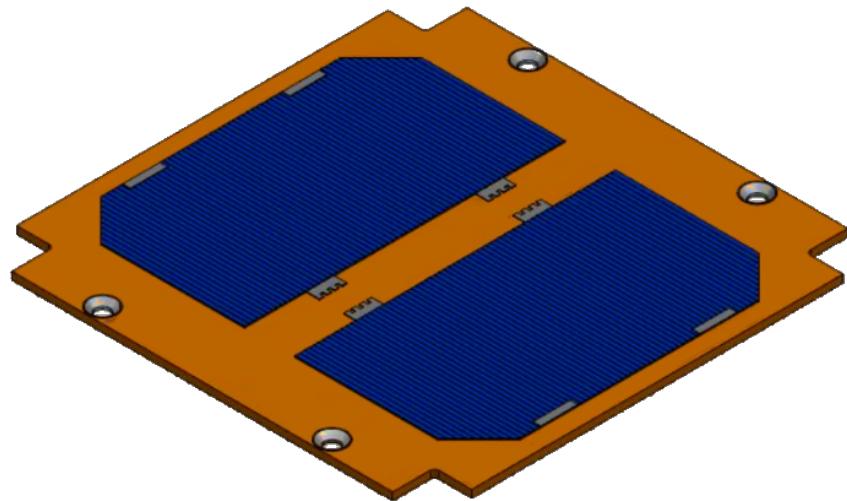


Figure 5.8: Conceptual solar panel from ORBITAL.

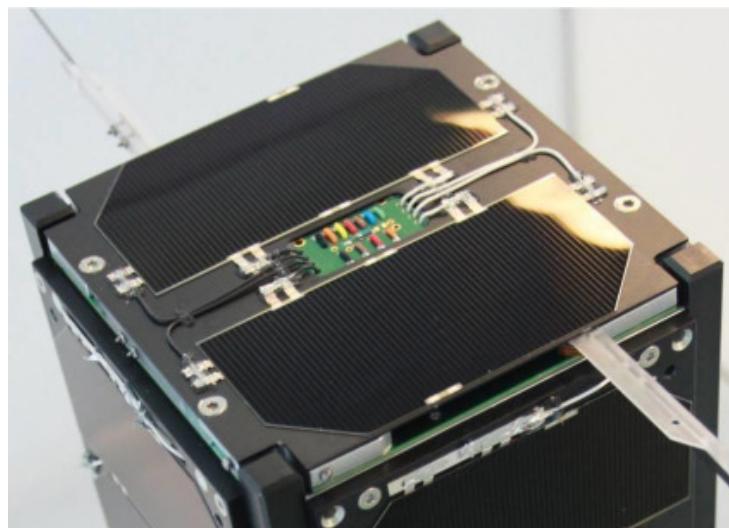


Figure 5.9: Top solar panel from ISISpace.



Figure 5.10: Panasonic AV402461 Microswitch.

The Kill-Switch mechanism in the mechanical structure has combined the function of providing deployment and detection (Figure 5.11). 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 5.11 the Kill-Switch parts are highlighted and the stowed and deployed configuration is shown.

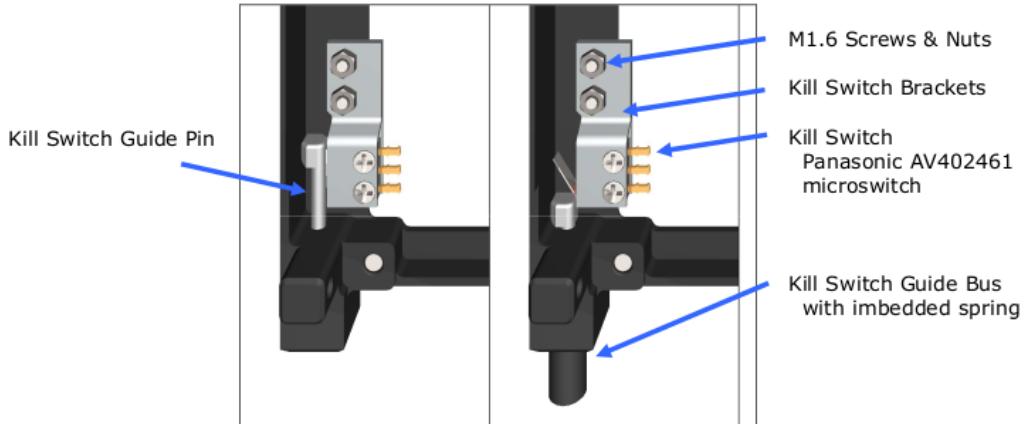


Figure 5.11: Kill-Switches installed in the mechanical structure.

The contact arrangement of the microswitch and the current rating are detailed in Figure 5.12 and Table 5.1.

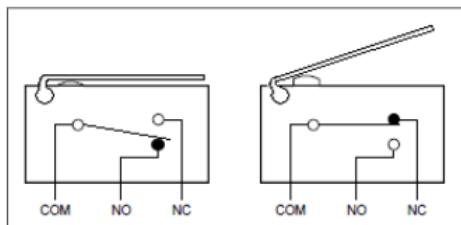


Figure 5.12: The contact arrangement of the microswitch.

| 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 5.1: Kill-Switch current rating and voltage range.

5.4 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 [9, 10]. 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 [11]. Figure 5.13 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 [11].

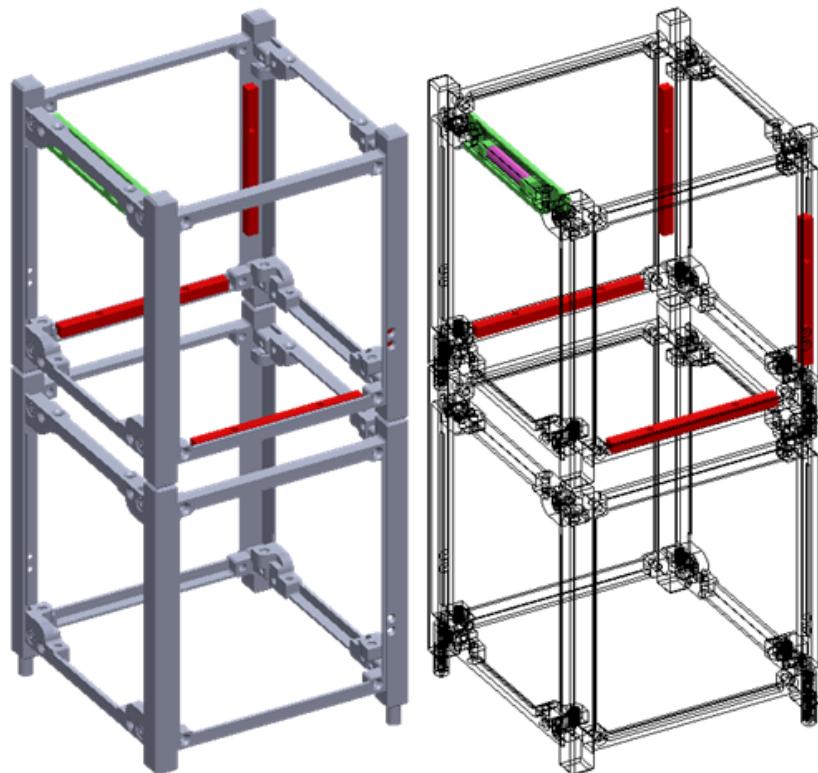


Figure 5.13: ACS subsystem. Rare earth magnet (pink) and hysteresis bars (red) installed in the structure.

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 [9].

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

5.5 Mechanical Structure

5.6 Interconnection Modules

5.6.1 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 5.14.

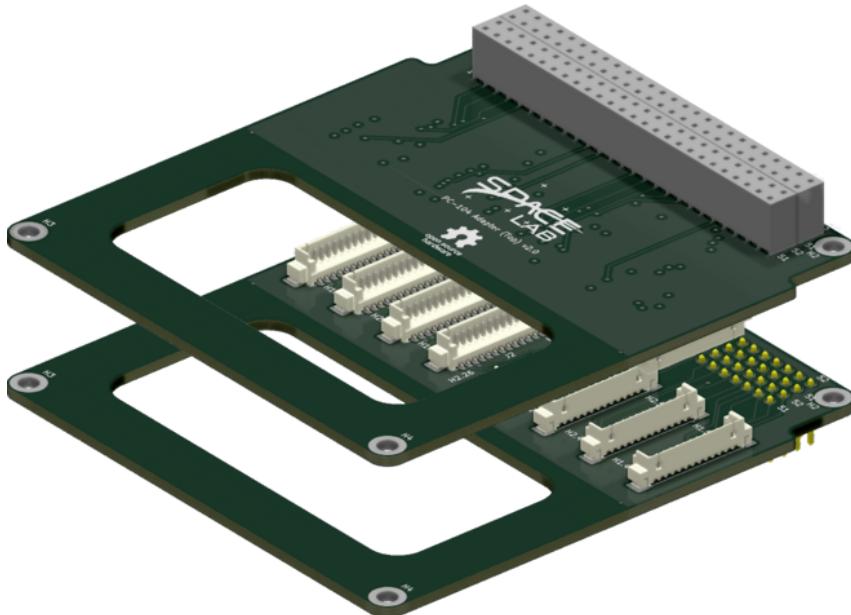


Figure 5.14: PC-104 adapter boards (top and bottom).

More information about these boards can be found in [12].

5.6.2 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, programmed 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 programming and debugging, UART debugging through a mini USB type B port interfacing the FT4232H USB bridge IC from FTDI, a JST XH header for charging internal batteries and a Remove Before Flight (RBF) pin header. The boards can be seen in Figure 5.15.

More information about these boards can be found in [13].

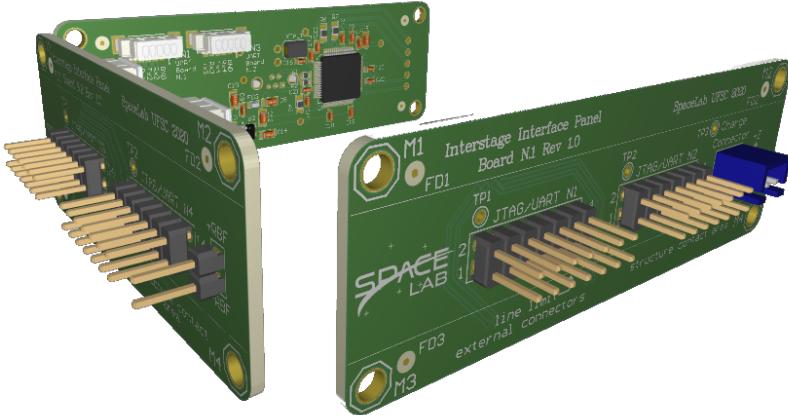


Figure 5.15: Set of external connection boards.

5.7 Payloads

The GOLDS-UFSC 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.

5.7.1 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 GOLDS-UFSC mission.

The main features of this payload are listed below, a 3D model of the EDC board can be seen in Figure 5.16.

- Reception/decoding of SBCD and Argos-2 signals on the $401.635 \text{ MHz} \pm 30 \text{ kHz}$ 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 I²C 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.

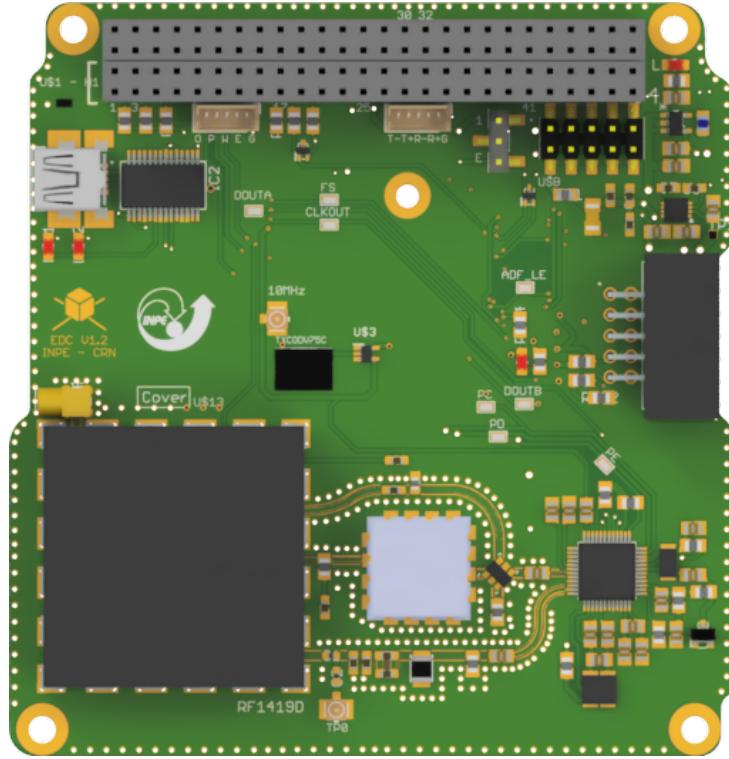


Figure 5.16: EDC board.

As can be seen in Figure 5.1, for this mission, two identical EDC boards will be used, in a cold redundancy configuration. More information about this payload can be found in [14].

5.7.2 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 [15].

5.7.3 Radiation Monitor (Harsh Payload)

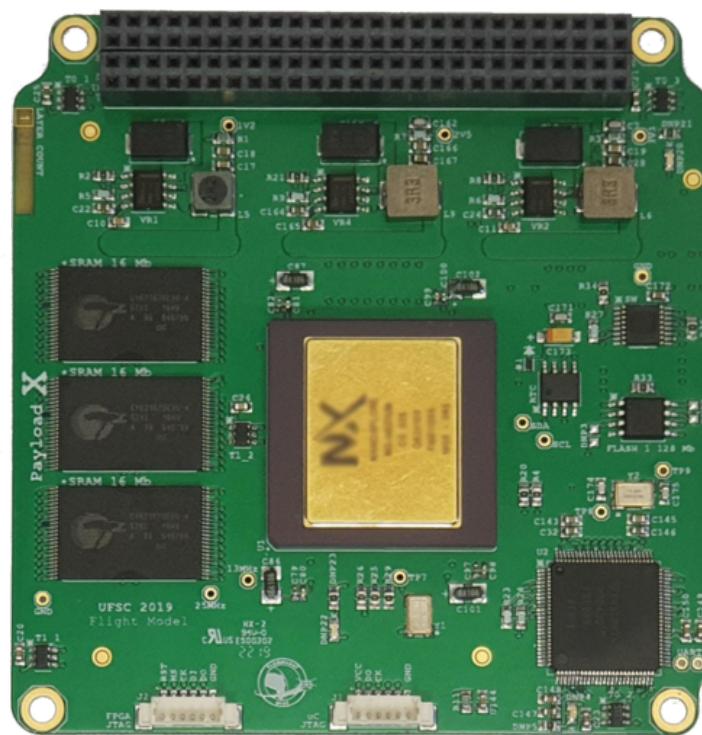


Figure 5.17: Payload-X board.

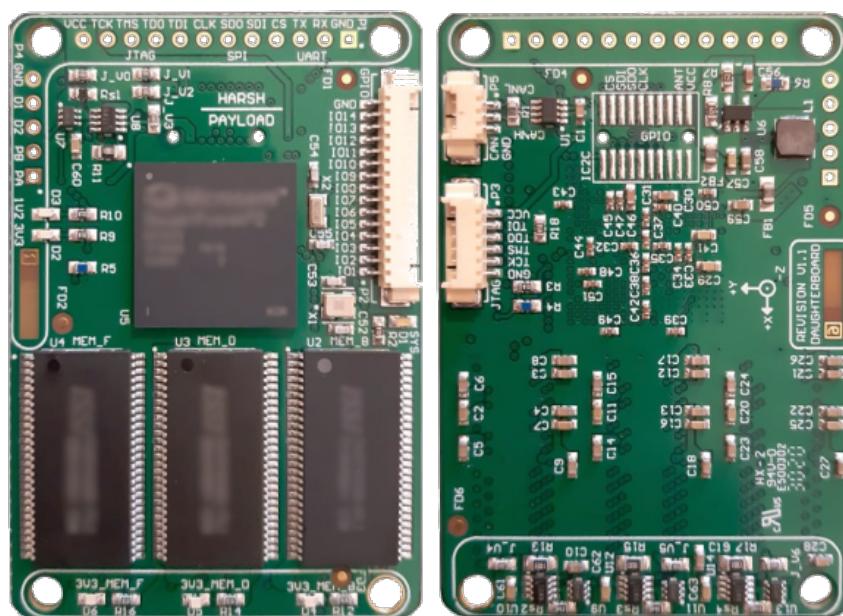


Figure 5.18: Radiation monitor board.

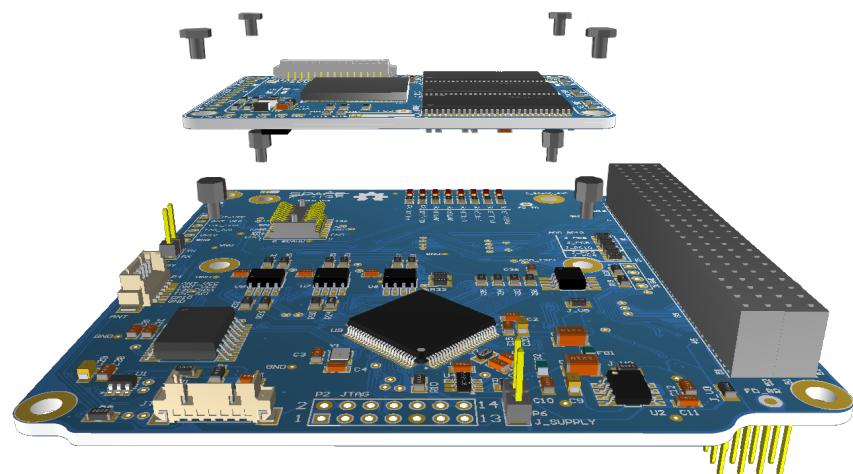


Figure 5.19: Integration of the radiation monitor payload in the OBDH.

CHAPTER 6

Test Plan and Results

6.1 Test Procedure

6.1.1 Hardware

6.1.2 Software

Unit Tests

- Hardware checks (might require mock circuitry).
- Driver operation checks: not extensive, might use loopback and fake sensor data schemes for hardware checks.
- Device operation checks: one test file for each device implemented, more extensive than driver checks, but should avoid development overhead.
- Standalone application checks: evaluate the application logic (masking or faking operating system calls, such as waiting for queue or a delay). It should be implemented without the operating system, in other words, evaluate inputs/outputs in dedicated main file.

Integration Tests

- Operating system initialization: assert memory allocation (RAM, stack, heap), hooks and etc;
- Boot sequence (as similar to the actual procedure as possible).
- Operating system task/queue/interrupts priority, constraints, size, depth and delay checks: use dummy task/queue/interrupts (same config as actual system).
- Short-term system check: after 1 hour, exit without error logs.
- Mid-term system check: after 1 day, exit without error logs.
- Long-term system check (used in flatsat): after 1 week, exit without flatsat/integration error logs.

Workflow

- Always it is a build->flash->test, change main and repeat.
- It must have a test folder containing subfolders (hardware, drivers, devices, app, integration) and a json file (with name, path and type).
- Inside the workflow is called a python script that read this json and setup variables to allow running multiple main file swaps for each test type.
- There are 5 different workflows, one for each test type: hardware, drivers, devices, app, integration;
- The workflow, tests and scripts must be reviewed before each release.
- Idea: for short/mid/long-term tests, the workflow should evaluate the log messages offline instead of real time, in which a job is scheduled to run just after this period and “a script” will read the log file and search for the test criteria, giving the actual CI result.
- Idea: Inside the code, using the log message approach, we might create our ultra lightweight framework that consists of only log types (colors) and log messages (specific strings). This way we do not modify our current workflow and we can add a simple scheme to access the flight code.
- Unit Tests = Tests performed per firmware unit.
- Integration Tests = Tests performed per firmware component (several units abstracted).

6.1.3 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 subsystems 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 taken into account. One PC-104 has inverted pinout, the board also makes it possible to have two separate power supplies, a UART to USB converter for 4 modules, kill-switches activation through 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 6.1.

More information about the Flatsat Platform can be found in [16].

6.2 Preliminary Results

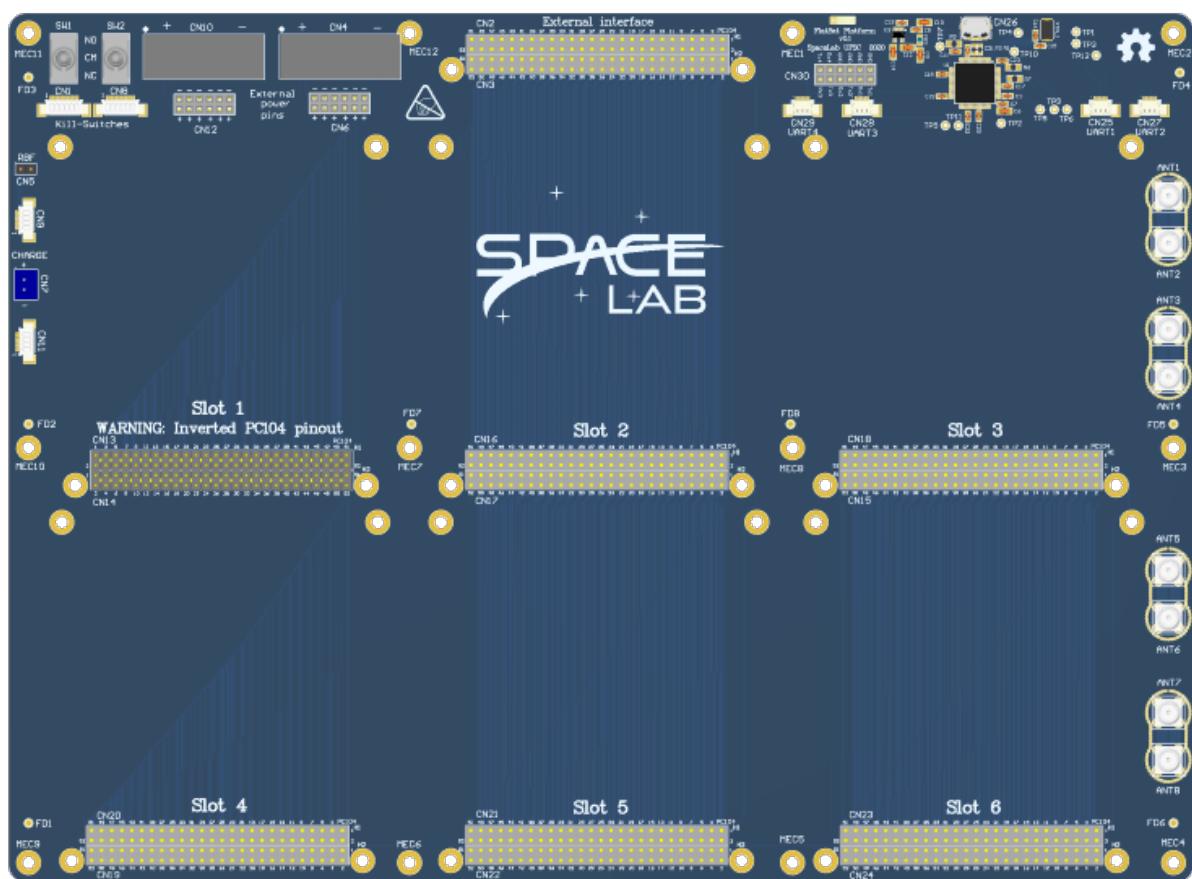


Figure 6.1: Top view of the flatsat board.

CHAPTER 7

Ground Segment

CHAPTER 8

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 [17] (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.

$$d = \sqrt{2 \cdot R_e \cdot h + h^2} \quad (\text{A.1})$$

Where:

- R_e = Earth radius = 6378 km
- h = Satellite altitude = 600 km
- d = Distance to satellite at horizon

So, the distance to satellite at horizon is:

$$d = \sqrt{2 \cdot 6378 \cdot 600 + 600^2} = 2830 \text{ km} \quad (\text{A.2})$$

A.2 Free-Space Path Loss

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

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

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.

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

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 145,97 MHz, the minimum and maximum FSBL is:

$$FSPL_{max}^{dB} = 32,45 + 20 \log \left(\frac{2830}{1 \text{ km}} \right) + 20 \log \left(\frac{145,97}{1 \text{ MHz}} \right) = 144,8 \text{ dB} \quad (\text{A.5})$$

$$FSPL_{min}^{dB} = 32,45 + 20 \log \left(\frac{600}{1 \text{ km}} \right) + 20 \log \left(\frac{145,97}{1 \text{ MHz}} \right) = 131,3 \text{ dB} \quad (\text{A.6})$$

$$131,3 \leq FSPL^{dB} \leq 144,8 \text{ dB} \quad (\text{A.7})$$

A.2.2 Downlink/Uplink

Considering the frequency of the downlink/uplink as 436,9 MHz, the minimum and maximum FSBL is:

$$FSPL_{max} = 32,45 + 20 \log \left(\frac{2830}{1 \text{ km}} \right) + 20 \log \left(\frac{436,9}{1 \text{ MHz}} \right) = 154,3 \text{ dB} \quad (\text{A.8})$$

$$FSPL_{min} = 32,45 + 20 \log \left(\frac{600}{1 \text{ km}} \right) + 20 \log \left(\frac{436,9}{1 \text{ MHz}} \right) = 140,8 \text{ dB} \quad (\text{A.9})$$

$$140,8 \leq FSPL^{dB} \leq 154,3 \text{ dB} \quad (\text{A.10})$$

A.2.3 Uplink (Payload)

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

$$FSPL_{max} = 32,45 + 20 \log \left(\frac{2830}{1 \text{ km}} \right) + 20 \log \left(\frac{401,635}{1 \text{ MHz}} \right) = 153,6 \text{ dB} \quad (\text{A.11})$$

$$FSPL_{min} = 32,45 + 20 \log \left(\frac{600}{1 \text{ km}} \right) + 20 \log \left(\frac{401,635}{1 \text{ MHz}} \right) = 140,1 \text{ dB} \quad (\text{A.12})$$

$$140,1 \leq FSPL^{dB} \leq 153,6 \text{ dB} \quad (\text{A.13})$$

A.3 Signal-to-Noise-Ratio

The Signal-to-Noise-Ratio (SNR) of a transmitted signal at the receiver can be expressed using Equation A.14:

$$SNR = \frac{E_b}{N_0} = \frac{P_t G_t G_r}{k T_s R L_p} \quad (\text{A.14})$$

Where:

- P_t = Transmitter power
- G_t = Transmitter gain
- G_r = Receiver gain
- k = Boltzmann's constant ($\approx 1,3806 \times 10^{-23} \text{ J/K}$)
- 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.15.

$$T_s = T_{ant} + T_r \quad (\text{A.15})$$

with:

$$T_r = \frac{T_0}{L_r}(F - L_r) \quad (\text{A.16})$$

and:

$$F = 1 + \frac{T_r}{T_0} = 1 + \frac{323}{290} = 2,114 \quad (\text{A.17})$$

The SNR value in decibels can be calculated using the Equation A.18:

$$\begin{aligned} SNR^{dB} &= 10 \log_{10} \left(\frac{E_b}{N_0} \right) = 10 \log_{10} \left(\frac{P_t G_t G_r}{k T_s R L_p} \right) \\ &= P_t^{dBm} - 30 + G_t^{dBi} + G_r^{dBi} - L_p^{dB} - 10 \log k - 10 \log T_s - 10 \log R \end{aligned} \quad (\text{A.18})$$

Considering other losses in the system (L_s) (cable and connection losses as example), the Equation A.18 can be corrected as presented in Equation A.19.

$$SNR^{dB} = P_t^{dBm} - 30 + G_t^{dBi} + G_r^{dBi} - L_p^{dB} - L_s^{dB} - 10 \log k - 10 \log T_s - 10 \log R \quad (\text{A.19})$$

A.3.1 Beacon

Using Equations A.19 and A.15, with:

- $P_t = 30 \text{ dBm}$

- $G_t = 0 \text{ dBi}$

- $G_r = 12 \text{ dBi}$

- $L_p = 144,8 \text{ dB}$

- $L_s = 5 \text{ dB}$

- $R = 1200 \text{ bps}$

- $T_0 = 290 \text{ K}$

- $T_r = 323 \text{ K}$

- $T_{ant} = K$

$$F = 1 + \frac{T_r}{T_0} = 1 + \frac{323}{290} = 2,114 \quad (\text{A.20})$$

$$T_r = \frac{T_0}{L_r}(F - L_r) = \frac{290}{L_r}(2,114 - L_r) = K \quad (\text{A.21})$$

$$T_s = T_{ant} + T_r == K \quad (\text{A.22})$$

$$SNR^{dB} = 30 - 30 + 0 + 12 - 144,8 - 5 + 228,6 - 30,64 - 30,79 = 30,37 \text{ dB} \quad (\text{A.23})$$

$$\text{SNR}^{\text{dB}} \geq 30,87 \text{ dB} \quad (\text{A.24})$$

A.3.2 Downlink

Using Equations A.19 and A.15, with:

- $P_t = 30 \text{ dBm}$

- $G_t = 0 \text{ dBi}$

- $G_r = 15 \text{ dBi}$

- $L_p = 154,3 \text{ dB}$

- $L_s = 5 \text{ dB}$

- $R = 4800 \text{ bps}$

- $T_0 = 290 \text{ K}$

- $T_r = K$
- $T_{ant} = K$

$$SNR^{dB} = 30 - 30 + 0 + 15.5 - 154, 3 - 5 + 228, 6 - 30, 64 - 36, 81 = 17, 35 \text{ dB} \quad (\text{A.25})$$

$$\mathbf{SNR^{dB} \geq 17, 35 \text{ dB}} \quad (\text{A.26})$$

A.3.3 Uplink

Using Equations A.19 and A.15, with:

- $P_t = 30 \text{ dBm}$
- $G_t = 15 \text{ dBi}$
- $G_r = 0 \text{ dBi}$
- $L_p = 154, 3 \text{ dB}$
- $L_s = 7 \text{ dB}$
- $R = 4800 \text{ bps}$
- $T_0 = 290 \text{ K}$
- $T_r = K$
- $T_{ant} = K$

$$SNR^{dB} = 47 - 30 + 15.5 + 0 - 154, 3 - 7 + 228, 6 - 31, 39 - 36, 81 = 31, 60 \text{ dB} \quad (\text{A.27})$$

$$\mathbf{SNR^{dB} \geq 31, 60 \text{ dB}} \quad (\text{A.28})$$

A.3.4 Uplink (Payload)

TBD

A.4 Link Margin

From [17], the minimum SNR value at the received considering a 10^{-5} bit error rate is:

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

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: $30,87 - 9,6 = 21,27 \text{ dB}$
- Downlink: $17,35 - 9,6 = 7,75 \text{ dB}$
- Uplink: $31,60 - 9,6 = 22 \text{ dB}$
- Uplink (payload): $X - X = XX \text{ dB}$