2.5 Payload subsystem

1 Introduction

In recent decades, satellite communications have become central in multiple domains, from weather forecasts and telecommunication to navigation and internet services. Launching a satellite into orbit has become cheaper throughout the years and many companies are shifting their infrastructure from terrestrial to orbital, as demonstrated by programs such as Starlink, Project Kuiper and IRIS2. The integration of satellite communications into aerospace systems opens new opportunities, allowing data exchange from aircraft and launchers even under critical operating conditions. Notable examples include the use of the Iridium NEXT constellation for civil aviation, operating in the L-Band range and Starlink for the video feed of Starship's reentry.

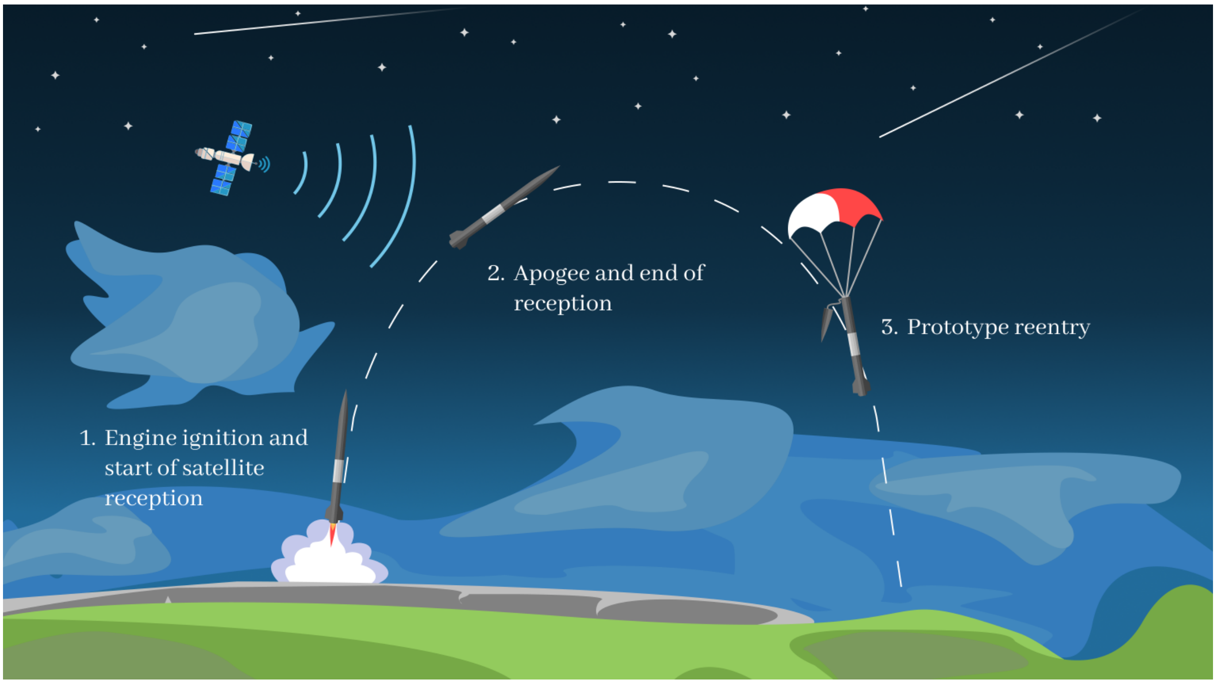


Fig. 2.28: The mission concept of Nemesis' scientific payload

Historically, receiving a satellite signal required specific demodulator that allows to decode the particular signal, therefore a receiving station could only decode the signals its demodulator was intended to. Today, with the introduction of a Software-Defined Radio, it's possible to digitalize the signal first and then use software based application to decode the signal present in the saved baseband.While this technology has been broadly used by amateur radio amateurs, its applicability into the aerospace sector is still being tested. Some of the possible applications of an SDR include calculating real-time measurement of a rocket's flight direction using the signal transmitted by multiple ground stations, which has already been tested by the Indonesian Space Agency (LAPAN) using GNU-radio for signal acquisition and MATLAB for processing the signals [4]. The same tracking system can also be applied to estimate the rocket's trajectory through the Doppler effect of the signals received from multiple satellites (i.e., the Iridium constellation), as described in the following conference by Orabi, Khalife, and Kassas (2021) [5].

Developing a system capable of doing such real-time signal analysis and calculations mid flight isn't simple; being a new team at EuRoC, we believe that delivering a system capable of the inflight signal processing, such as the one developed by LAPAN, as our first ever payload would be out of our capabilities. Instead, we developed Aether, a proof-of-concept CubeSat which includes all the satcom required hardware. The main objective of the experiment is saving the received baseband of the geostationary satellites during the ascension phase of the rocket flight, to allow a post-flight analysis of the data collected to develop the next payload's iterations. The mission concept is illustrated in Figure 2.28. While the Iridium constellation would be more interesting for our experiment, the Inmarsat geostationary satellites have been chosen instead due for obvious reasons related to the reception windows and the possibility to legally decode their signals.

2 Form factor & structure

Aether is a non-deployable, 1U payload, capable of receiving and saving the baseband of L-band satellites, from the Inmarsat constellation of geostationary satellites, distant more than 35000 km from Earth's surface. The payload is located in the ogive, between two 3D printed supports, that have been topologically optimized to remove part of the unnecessary mass. The payload assembly is visible in Figure 2.29. The total weight of the CubeSat is little more than 1 Kg. The outer structure is made of ABS plastic while the inside is composed of different layers separated by brass spacers. The first layer host the batteries, the second one the PCB and the last the receiver equipment, connected to the patch antenna on the top.

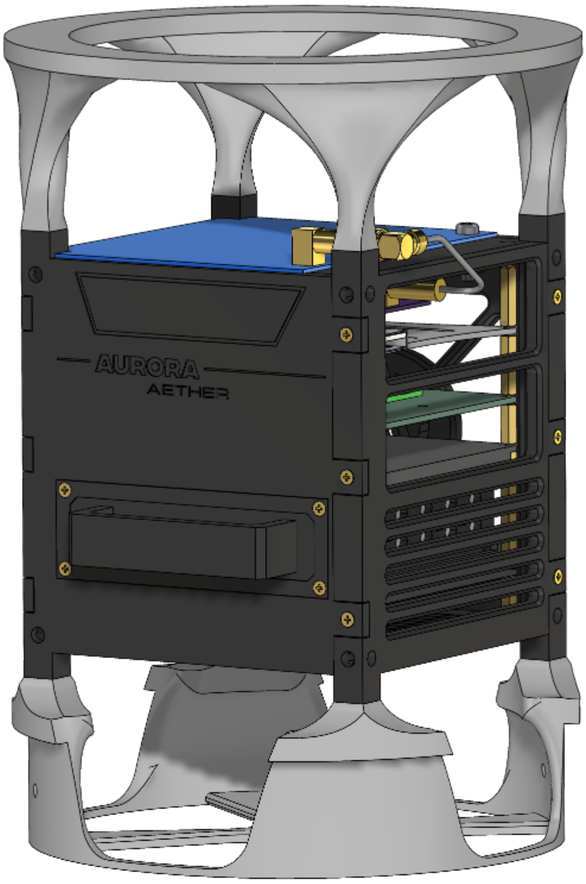


Fig. 2.29: The payload final assembly

The CubeSat can be easilily removed by unscrewing the nosecone to the flange, and removing the top support. The batteries are replaceable without a total disassembly, thanks to the handle on front, which locks the batteries inside their pack.

The experiment main objective is a good reception of Inmarsat satellites' data during the ascension phase through the use of a SDR. The inmarsat constellation provides a vast range of services, including Aeronautinautical (Aero), involving packet data of ACARS and ADS, and Inmarsat-C (or STD-C or EGC messages), for global maritime distress and safety. With the help of softwares such as SatDump and Jaero, it is possible to decode the signals and get the packets. An example of a packet of the Inmarsat-C service, decoded with Aether, can be seen in Figure 2.30.

```
Type                      Timestamp  Contents
EGC double header, part : 13:39:50
                                     BSNL CSAT  29-JUL-2025 13:33:10 209743NAVAREA VIII 666.
                                     BAY OF BENGAL AND INDIAN OCEAN.
                                     SRIHARIKOTA.
                                     CHARTS IN 33 7071 7073 7707 INT 71.
                                     1. ROCKET LAUNCH FROM 13-43.2N 080-13.8E SCHEDULED 30 JUL TO 01 AUG 25 FROM
                                     1130 TO 1530 UTC
                                     2. DANGER ZONE AS FOLLOWS .
                                      ZONE-1: CIRCLE OF 10 NM AROUND LAUNCH POINT
                                      ZONE-2: DANGER AREA BOUNDED BY 10-25N 082-40E, 10-50N 083-05E, 08-45N
                                     084-50E, 08-20N 084-25E
                                      ZONE-3: DANGER AREA BOUNDED BY 03-00S 084-00E, 03-00S 086-00E, 08-00S
                                     086-00E, 08-00S 084-00E
                                     3. WIDE BERTH FROM AREA ADVISED  .
                                     4. CANCEL THIS MSG 011630 UTC AUG 25 .
                                     +++
```

Fig. 2.30: EGC message decoded with SatDump

All these services are transmitted trough signals in the L-Band, around 1545.123 MHz for the Aero packets and 1537.10 MHz for STD-C packets. The exact frequencies varies depending on which of the four main geostationary satellites the signal is transmitted from. To work, Aether needs electronics devices that receive, digitalize and decode the satellite's signal. The signal processing chain is shown in Figure 2.31.

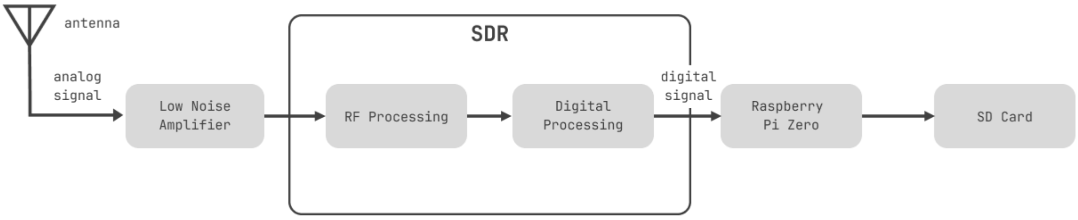


Fig. 2.31: Signal processing chain for satellite communication

Following is a description of each component of the chain:

A **Satcom Antenna** is needed for receiving the signal. The receiver dimensions are strictly correlated to the frequency of the signal, by the equation:

$$\lambda = \frac{c}{f} \tag{2.16}$$

It is clear how the dimension of the antenna increases the lower the frequency gets. Most of the antennas are designed to work with a fraction of the wavelength. In the case of a patch antenna, we have an effective length of the side equal to:

$$L \approx L_{\text{eff}} = \frac{\lambda_0}{2\sqrt{\varepsilon_{\text{eff}}}} \approx \frac{\lambda_0}{2\sqrt{\varepsilon_r}} \tag{2.17}$$

Where ε_{eff} is the relative permittivity of the material. Assuming FR4 Glass Epoxy as the material, with a dielectric constant of 4.36, and a height of the substrate of 1.5 mm, we get a length of approximately 4.65 mm, which is compatible with the dimensions constraints of the payload.

Instead of developing our own antenna, we decided to use a COTS one. The 1550 MHz Inmarsat antenna from Nooelec has been chosen due to its dimensions and low profile. The antenna is located on top of the payload and it's locked through one nylon screw.

A **Low Noise Amplifier** plays a fundamental role in SDR systems. This component amplifies the analog signal before it reaches the SDR's RF tuner and is subsequently digitized. Since input signals are often very weak, it is crucial that an LNA introduces as little noise as possible, maximizing the signal-to-noise ratio (SNR). The amplifier is placed very close to the antenna in order to avoid amplifying the noise introduced by the coaxial cable or other connections. The operating principle is shown in Figure 2.32.

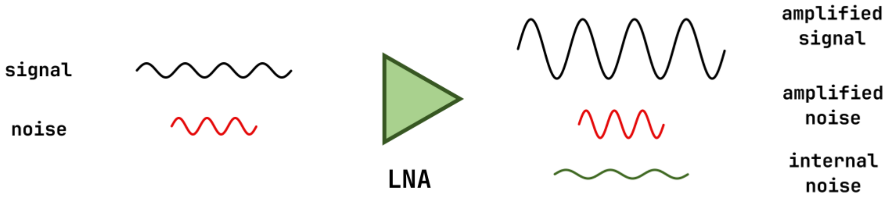


Fig. 2.32: Functionality of a Low Noise Amplifier

The LNA needs to be powered in order to work. The energy can be delivered through a dedicated system, using a micro usb cable for example, or by using the same RF cable connected to the SDR. This last method is called *bias-tee*, and is the one adopted in our configuration.

A *bias-tee* is a system consisting of a capacitor and an inductor, capable of supplying DC current over the coaxial cable to the amplifier. The capacitor is connected along the RF signal path and serves to block DC current, allowing only the high-frequency signal to pass through to the SDR. The inductor, on the other hand, is placed between the power source and the coaxial line: it allows the DC current needed to power the LNA to pass, while preventing the RF signal from flowing back to the power supply. In this way, the signal and the power travel over the same cable but remain electrically separated within the circuit.d

The manufacturer has not specified the power consumption of the amplifier integrated in the antenna; however, the consumption of a similar LNA (Nooelec SAWbird IR) can be used as a reference.

A **Software-Defined Radio** is a communication system that replaces many traditional hardware components with software. It operates through three main elements: the RF tuner, which isolates a specific frequency received by the antenna and shifts it to an intermediate frequency or baseband; the ADC, which converts the analog signal into a digital format suitable for computer processing; and the interface, typically USB, which transfers the digitized signal to the computer for demodulation and analysis.

When selecting an SDR, several factors must be considered. For our application, the most important ones are the supported frequency range, the availability of bias-tee, to power the amplifier through the RF cable, and the overall power consumption. A model that meets all these requirements is the Nooelec SMArTee v2 SDR. It operates with a DC supply of 4.5V at 250mA and supports bias-tee powering. Since the device uses a USB interface, an adapter will be required to connect it to the onboard computer. Finally, the supported frequency range is 25-1750 MHz, which covers the Inmarsat L-Band.

In our design, the LNA and the SDR are located in the third layer of the cubesat, as visible in Figure 2.33, inside a custom printed support.

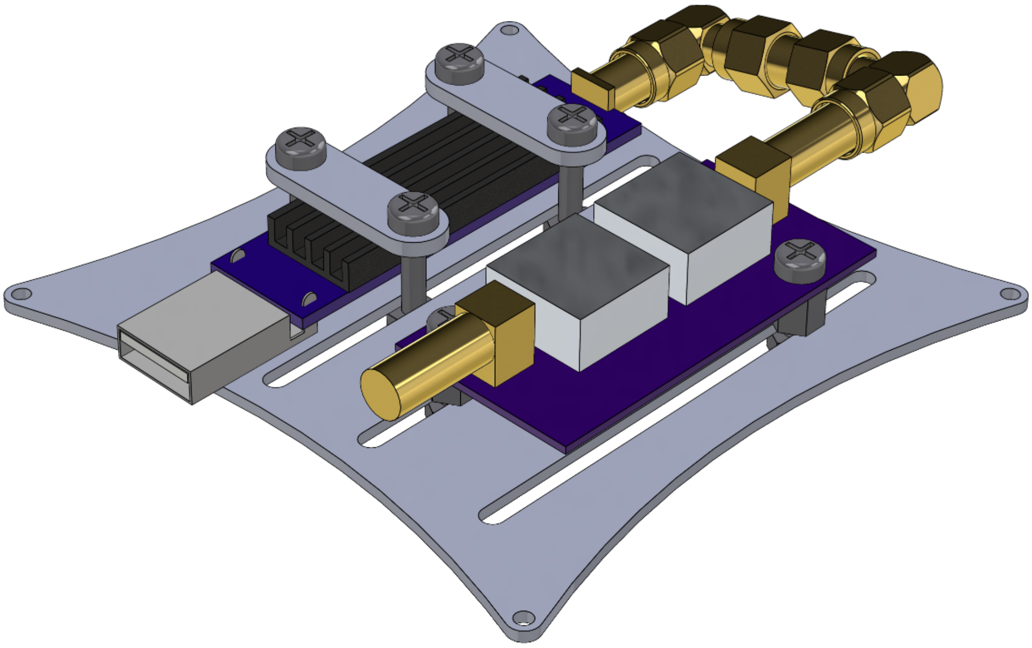


Fig. 2.33: Third layer of the Cubesat, with the SDR and LNA

For SDR data processing, a simple microcontroller is not sufficient. A Single Board Comouter is required to handle real-time data acquisition from the receiver and process it through software, often running on Linux. The **Raspberry Pi Zero 2 W** is a suitable choice. It is a compact board (65 mm × 30 mm) with a quad-core processor and wireless connectivity, allowing remote access even when installed on the launch vehicle through SSH. It supports Linux and a wide range of open-source SDR software, and its micro-USB port enables direct connection to receivers such as the Nooelec SMArTee via an adapter. Power consumption is very low, from about 120 mA in idle up to 450 mA peak at 5 V. At the end of the chain, the Raspberry Pi saves the baseband on a different Micro SD card.

4 Power & Energy

The various components of the telecommunication system and the onboard computer have been defined. It is therefore possible to proceed with sizing the electrical system. Table 2.4 shows the nominal power consumption of each component. For the Raspberry Pi Zero 2 W, the idle current consumption is considered, since it can be activated remotely before launch through the IMU sensor. The maximum consumption is reached only during ascent (about 20-30 seconds) and can be neglected compared to the hours spent on the launch pad.

Table 2.4: Required Power

Component	Power Consumption		
	Voltage [V]	Current [mA]	Power [W]
LNA	4.5	30	0.135
SDR	4.5	250	1.125
Raspberry Pi Zero 2 W	5	~ 120	0.6
Total			1.86W

A maximum required power consumption of 1.86 W is therefore obtained. Considering the mission requirement of 6 hours of autonomy, the necessary energy is

$$E_{\text{tot}} = P.t = 11.16 \text{ Wh} \tag{2.18}$$

It is therefore necessary to select a battery pack capable of powering our system. The student team already owns, from a previous project, LiFePo_4 batteries, which, as specified in the mission requirements, are allowed by the regulations and do not require particular precautions. These have a capacity of 1.5 Ah at 6.4 V, i.e., 9.6 Wh. Considering a transmission efficiency η equal to 90% and a depth of discharge DoD equal to 100%:

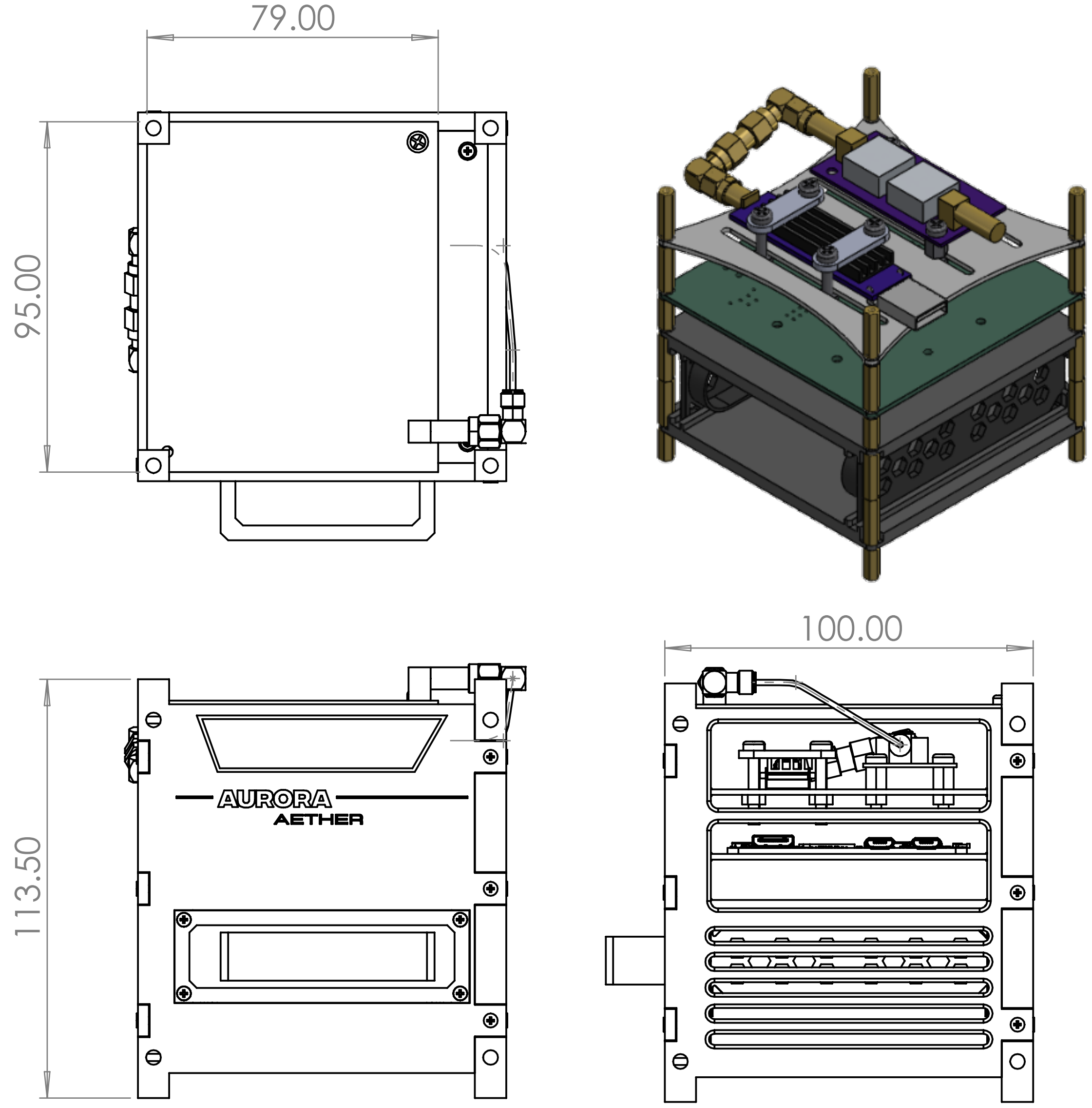
$$E_{\text{tot}} = \text{DoD } \eta \text{ N}C_b \tag{2.19}$$

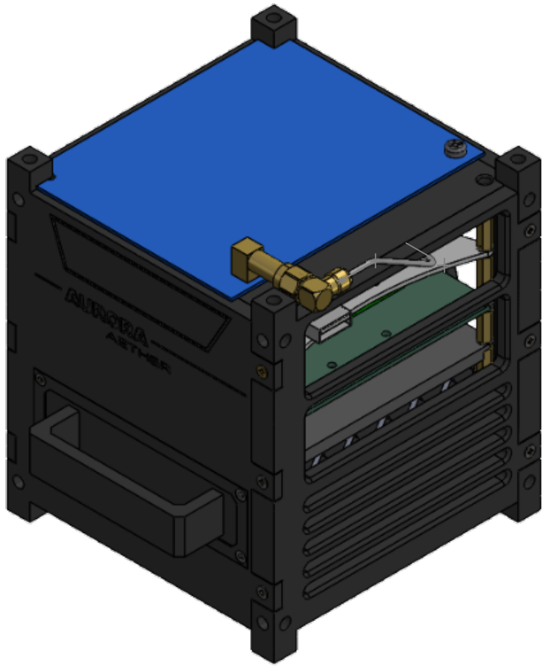
$$\text{N} = \frac{E_{\text{tot}}}{\text{DoD } \eta C_b} \approx 1.3 \tag{2.20}$$

It is therefore possible to proceed with two batteries, ensuring a good safety margin for possible thermal losses and additional power draws from extra components, such as the buck step-down converter, necessary to step down from 6.4 V of the batteries to 5 V for the Raspberry Pi Zero 2 W. The SDR will then be powered via a USB cable connected to the Raspberry Pi.

5 Data output

The data expected to be received is a raw recording of the baseband at 1545.123 MHz through the use of the open-source software SatDump. Portugal is in the coverage of both Inmarsat-4 4F1 and Inmarsat-3 F5, so the baseband will contain both the signals. We opted for the Aero packets instead of STD-C due to a stronger reception during our testing. We aim to study the later received signals to develop a Matlab algorithm to calculate the rocket heading in real-time for next generations.





Project Payload	Created by Nicolò Basso	Approved by Nicolò Basso
AURORA ROCKETRY	Document Type Assembly	Status APPROVED
	Title S-PLD-AET	Scale A4 1:2
		Rev 1 · Date of issue · Sheet 1/1