ES: Executive Summary

Prepared by:	Rareș Apostol, Claudiu Cherciu, Marius Trușculescu, Alexandru Pandele, Claudiu Drăgășanu	
Approved by:	Alexandru Pandele	
Authorized by:	Marius Trușculescu	

Table of Contents

1. Document information

1.1. Revision History

Issue	Date	Section	Change Description
1.0	05/11/2020	All	Document Created

1.2. Acronyms

ADC - Analog-Digital Converter
AHB - Advanced High-performance Bus
AMBA - Advanced Microcontroller Bus Architecture
COTS - Components Off The Shelf
DAC - Digital-Analog Converter
DSP - Digital Signal Processing
DUT - Device Under Test
EEE - Electrical, Electronic & Electromechanical
FPU - Floating Point Unit
HAS - (Galileo) High Accuracy Service
LET - Linear Energy Transfer
LVDS - Low-voltage differential signalling
MCP - Multi-Chip Package
MCU - Microcontroller Unit
MIL - Military
MMU - Memory Management Unit
NVM - Non Volatile Memory
POD - Precise Orbit Determination
PPP - Precise Point Positioning
RAM - Random Access Memory
RPE - Reference Performance Evaluation
SEE - Single Event Effects
SRAM - Static RAM
TDP - Time Distribution Protocol
TID - Total Ionizing Dose
TTFF - Time to first fix
TVAC - Thermal Vacuum

2. Introduction

2.1. Purpose and Scope

The present document summarizes the work performed and the results obtained for the de-risk activity targeting the preliminary design of the OrbFIX GNSS receiver for space.

2.2. Background

Space grade GNSS receivers, with varying degrees of functionality have been available on the micro and small satellite market for several years. The demand for such systems is firstly derived from the most sought application of these satellite classes: precise formation flying and PVT correlated measurements in a spatially distributed network. Furthermore, the IOD potential of these satellites, makes them the ideal target for experimental missions testing for close orbital manoeuvres, for collision avoidance as safety procedures and even for docking.

The risky nature of all these types of missions needs to be mitigated with numerous complementary, fault tolerant technologies that need to gracefully degrade and reliably fall back to collision free safe modes. In this context, we propose the use of OrbFIX, a low-cost COTS-based, Precise Point Positioning, multi-constellation, multi-frequency GNSS receiver for micro and small satellites, allowing ≤10 cm positioning accuracy on a low Earth orbit.

3. Product and Architecture Definition

The OrbFIX development started with setting the requirements as derived from its desired accuracy and flown down from the target mission class: CubeSats and small satellites on LEO. OrbFIX is firstly a low-cost precise positioning device integrating a COTS receiver with high reliability components resulting a high availability, radiation tolerant device suitable to being integrated even in the CubeSat form factor.

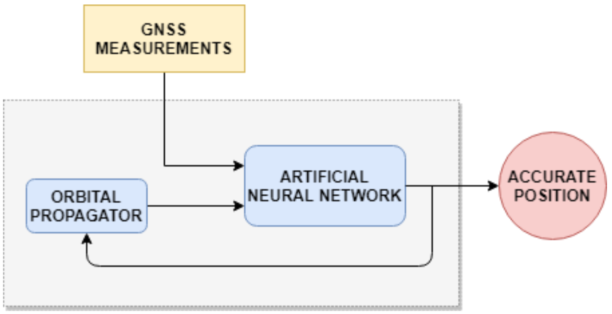

Figure 1 ANN augmentation of the position accuracy

Besides a precise positioning mode, the devices is capable to conserve energy and operate at lower power levels. In this modes, intermittent operations of the GNSS receiver are augmented by the use of ANN algorithms in order to improve the accuracy of the positionin when the receiver is not operated.

3.1. System architecture

Two main architectures were traded off for the implementation. The first one was based on using a dedicated RF front-end for receiving and demodulating the PPP corrections, decoupling the GNSS receiver from the corrections channel. In this case, the PPP corrections provider needs to be involved in the definition of the RF Front-End, the SDR and the MCU PPP library, which maximizes compatibility and minimize implementation risks. On the other hand, this architecture is more complex, with direct impact on robustness and power consumption.

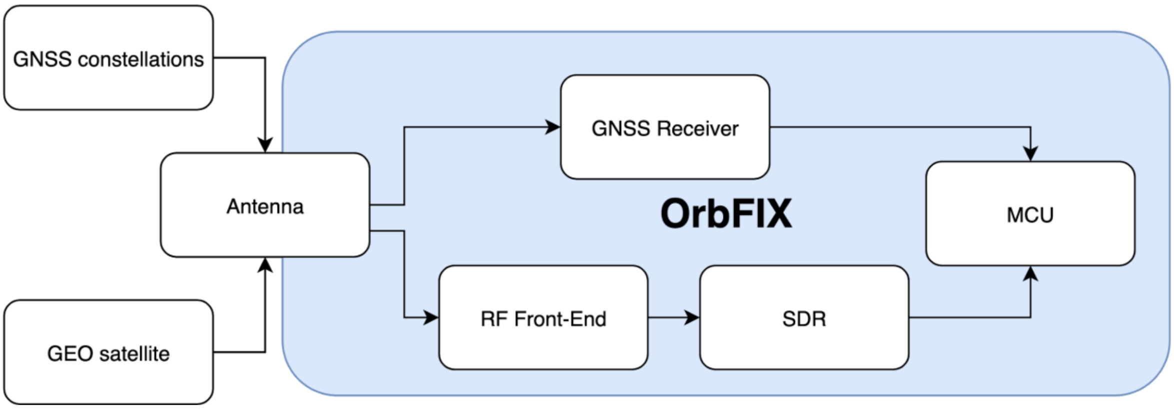

Figure 2 Architecture for independent correction delivery

For the more straight-forward option, the PPP corrections delivered via a geostationary satellite shall be decoded directly by the GNSS receiver, which shall in turn provide a PPP solution. The corresponding architecture is presented below.

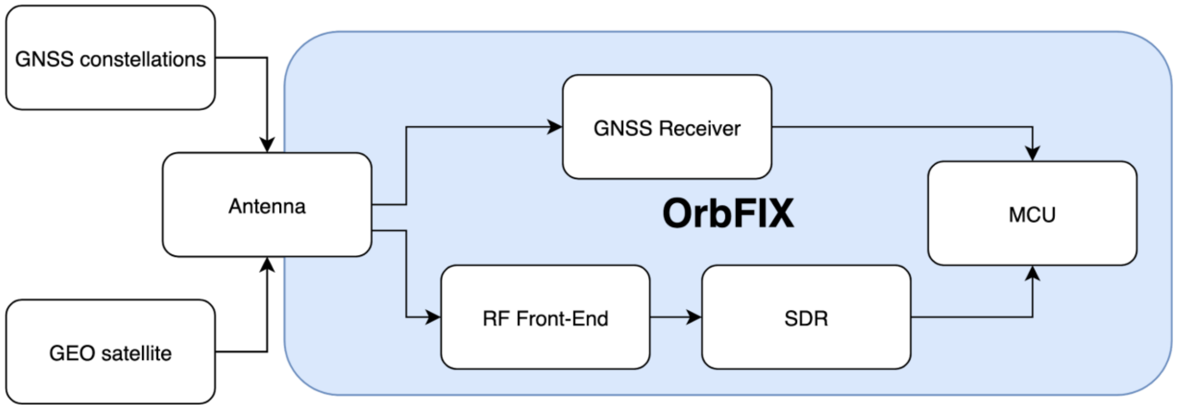

Figure 3 Architecture for receiver dependent corrections delivery

The main drawback of this architecture is the fact that the GNSS receiver shall be responsible to track, de-modulate and use PPP corrections dedicated to space users. There is no such receiver available as COTS. However, there are very capable COTS receivers that include PPP algorithms and that require only firmware updates in order to be able to work in space. This implies a risk for OrbFIX, a risk that is mitigated by including the option for the host satellite to forward PPP corrections obtained via ground communication and by including Galileo HAS. Together, these features should achieve the availability and positioning accuracy requirements.

Besides the GNSS receiver, OrbFIX includes several major components: microcontroller (MCU), external flash memory, SDR . The selection of each of these components was traded-off as part of the preliminary design phase.

4. OrbFIX Preliminary Hardware Testing

The use of COTS components for a high availability and reliability product needs to be validated by an extensive testing campaign. The de-risk activity focused on providing confidence by conducting preliminary validation in the reference environment: irradiation and vacuum.

4.1.1. GNSS receiver TID Test

For giving a RHA (Radiation Hardness Assurance) at the component level, only the receiver was subjected to the initial irradiation testing. The rest of major components are selected to comply with the radiation hardness requirements and the generic product compliance to radiation requirements will be assessed as part of the OrbFIX product qualification campaign. Two different tests were foreseen, one for observing the components behaviour under a certain radiation dose (the TID test) and one regarding the Single Event Effects (SEE) that could affect the EEE behaviour.

TVAC Tests

4.1.2.TVAC Test

The COTS receiver’s datasheet does not indicate its performance under vacuum conditions. A preliminary thermal vacuum verification was performed to mitigate potential underperformance in the expected temperature and pressure range. As part of the test, the device was taken to the extremes of the storage and functional thermal range while in a vacuum installation (i.e. pressure bellow 10^{-4} mbar). The expected storage temperature domain to be demonstrated is -40 °C to + 70 °C, while the corresponding operational domain is -30 °C to +60 °C.

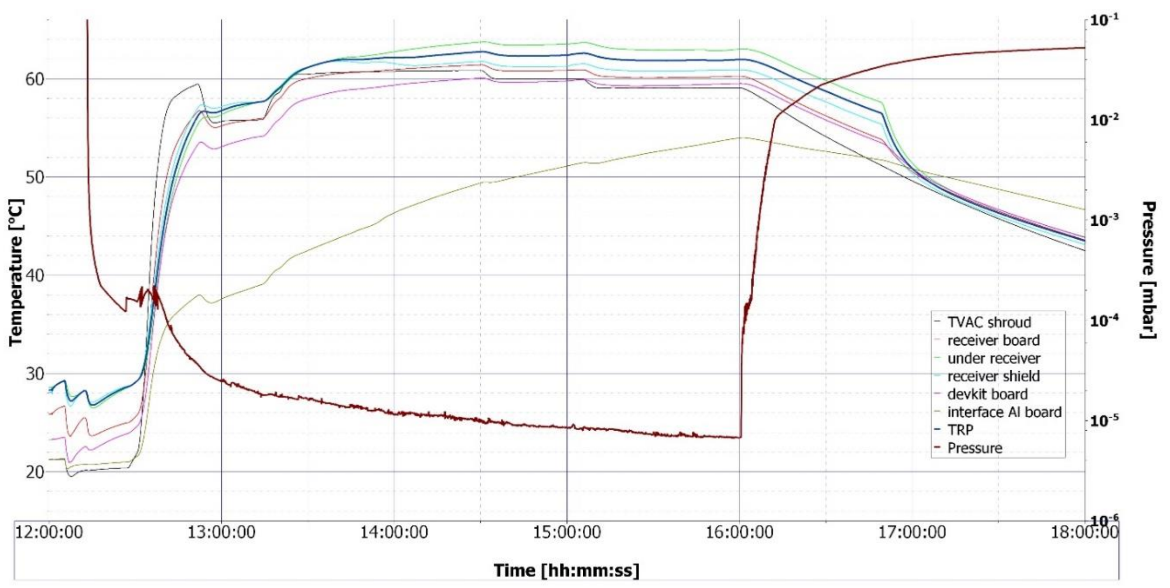

Figure 4 Temperature and pressure evolution during the receiver high temperature TVAC test

The receiver was heated and cooled in a thermal vacuum installations to both the storage and operational thermal extremes. The test confirmed no issue with operating under vacuum conditions

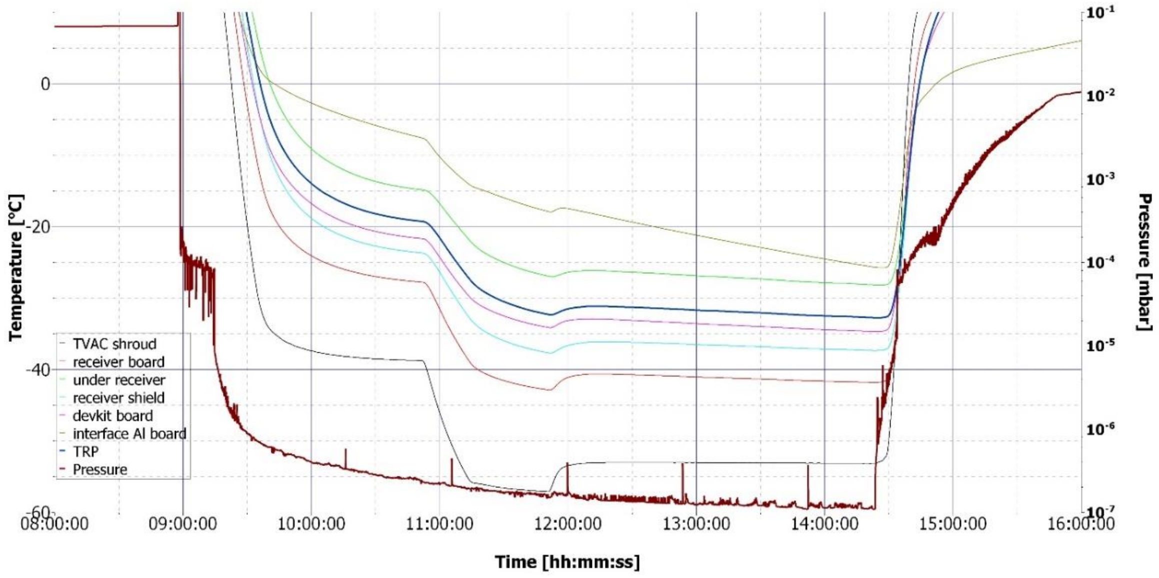

Figure 5 Temperature and pressure evolution during the receiver low temperature TVAC test

4.1.3. Balloon Test

The testing campaign of the COTS receiver included a planned in-flight verification on a high-altitude balloon. The balloon test aimed at testing the receiver in conditions as close as possible to a satellite, outside the laboratory. A stratospheric balloon could reach 34 km of altitude, with the pressure going as low as 50 mbar. Moreover, the receiver is operated on a battery.

During the flight, the payload section separated from the balloon and the parachute before reaching the maximum altitude, resulting in a rapid fall. **Error! Reference source not found.** shows the altitude profile reported by the onboard telemetry and the linear data fits corresponding to the climb and fall rates. The initial fall rate is higher than 30 m/s and the final vertical velocity at impact was higher than 20 m/s. The payload was recovered after the flight.

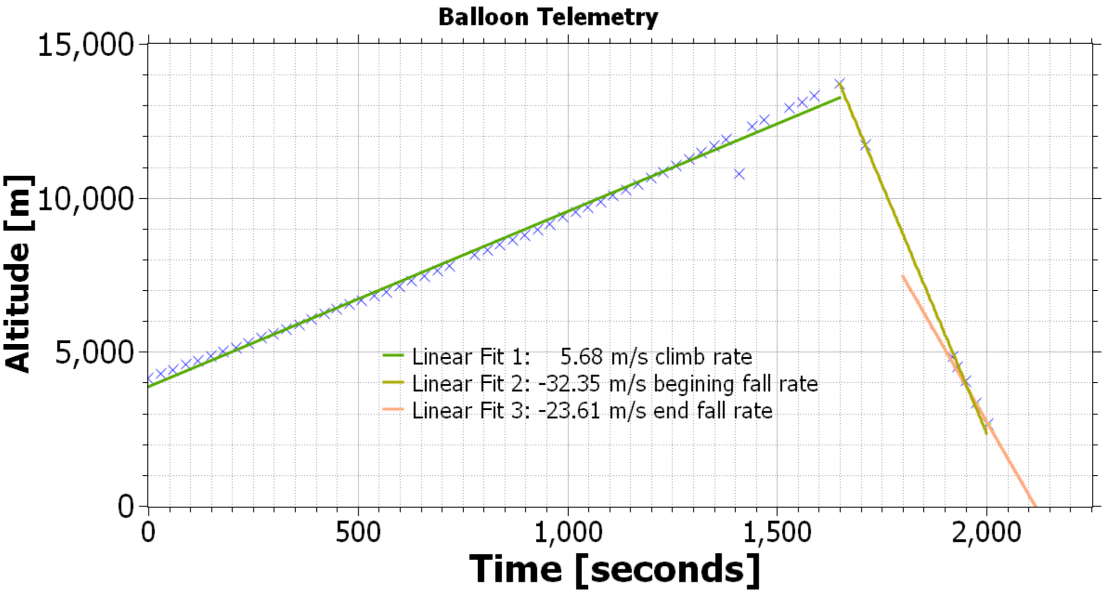

Figure 6 Balloon flight altitude fit

Upon recovery, the SD cards logging the data were found operational after the shock of the crash and after a rain. Data recorded by the payload confirms the balloon telemetry. Furthermore, it confirmed that the receiver continued to operate even after impact, until the batteries were depleted. Unfortunately, exposure to water made the receiver un-operational.

5. Preliminary Design

Following a hardware selection process that involved market research and compatibility check with system requirements, a preliminary set of hardware components was retained for the OrbFIX design.

5.1. Software Architecture

OrbFIX software architecture, driven by the system requirements, is summarized in Figure 7. The software shall be implemented on the LEON3 based, controller. A real time operating system shall ensure timely execution of the implemented functions and facilitate the integration. The OrbFIX controller interfaces both with the receiver and an external “client”, typically the satellite on-board computer. The Receiver Interface allows the receiver configuration through the Receiver Management. It is also the channel through which receiver measurements, either low level (pseudoranges) or high level (PVT), reach the Mode Manager. The Mode Manager switches between the three positioning modes:

- Low-power (orbit propagator and ANN)
- Nominal (GNSS + PPP corrections)

- Simple (standalone GNSS)

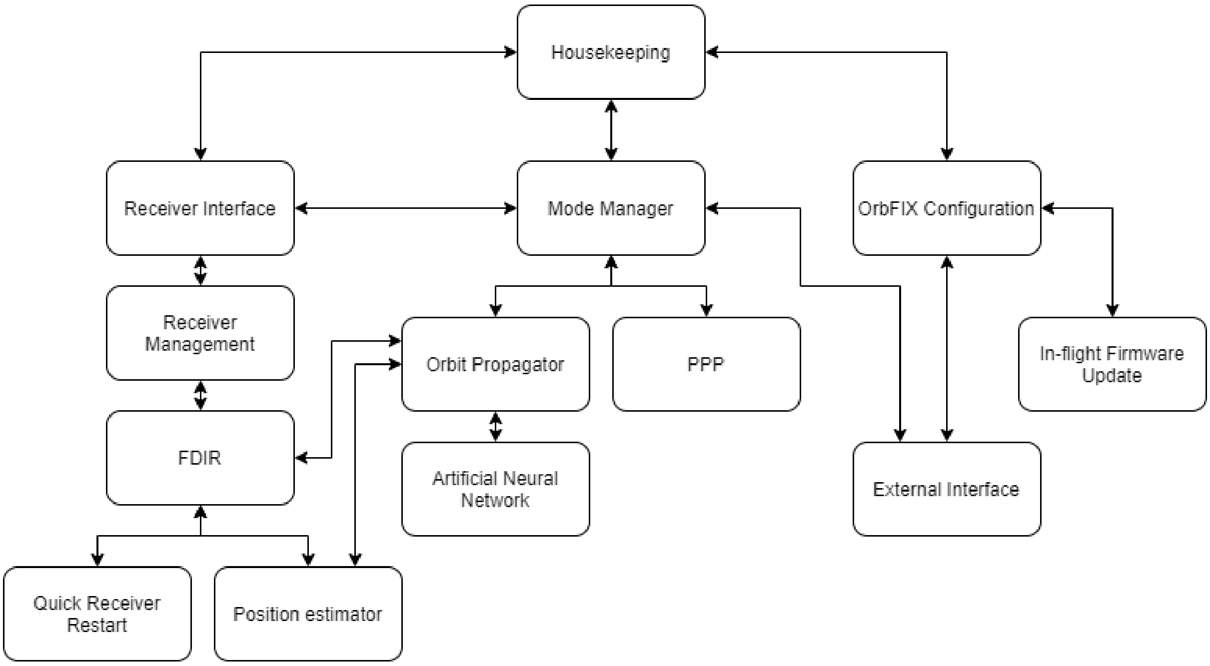

Figure 7 OrbFIX Software Architecture

The Mode Manager is providing the computed PVT as an output on the External Interface, based on the current mode of operation. Besides the PVT solutions, the External Interface allows the “client” to configure the OrbFIX operation. That should include at least mode changing, constellations and frequency selection, masking angles, orbit and clock corrections source, ANN coefficients. Moreover, the External Interface shall allow the client to provide orbit and clocks corrections using a ground communications interface. In order to increase receiver availability, a Quick Receiver Restart function is included. The function takes advantage of the available receiver firmware functions that allow creating a snapshot of the receiver status. This shall improve the restart time in case of a receiver SEE. Another module improving flexibility and robustness is the In-Flight Firmware Update. This shall allow updating both the OrbFIX firmware and the reciever firmware during the mission.

5.2. Preliminary Electronic Design

The OrbFIX electronic architecture is proposed in Figure 8. It includes the a LEON MCU and the GNSS receiver, an interface to the standard CubeSat PC104 BUS, an antenna connector and a current monitor. The MCU also requires an external RAM and FLASH memories. The components require special care in the routing of signals in order to avoid interference. This is done with the help of grounding planes and frequent vias connecting the planes and insulating sensitive signal traces such as the antenna signal. Soldering of the receiver is done using a reflow process and following a temperature curve recommended by the manufacturer.

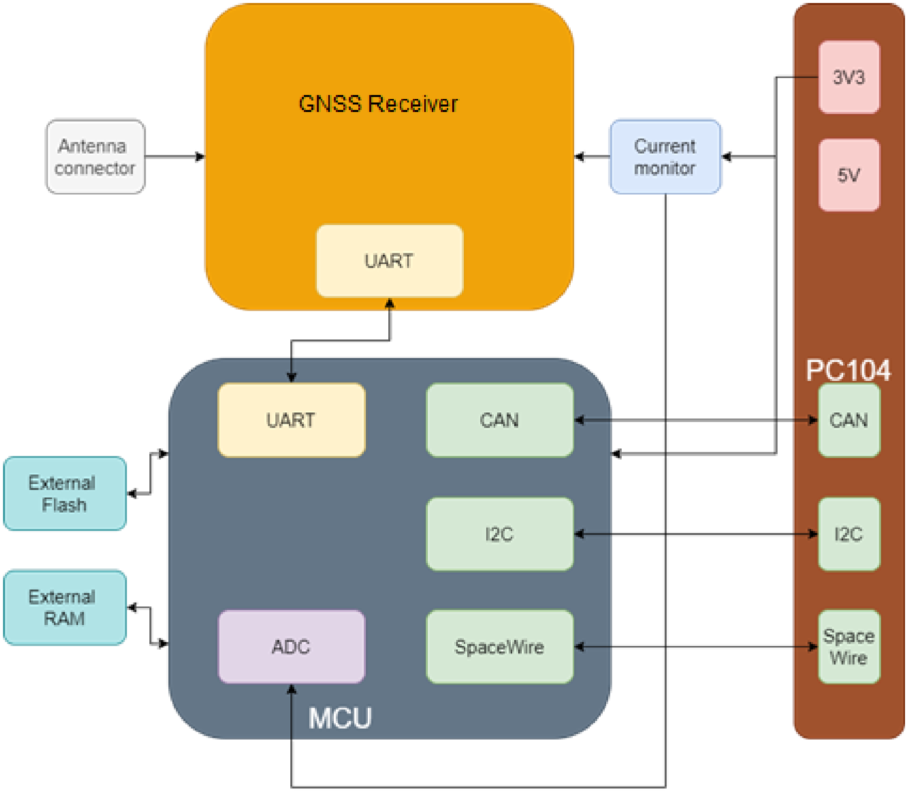

Figure 8 OrbFIX electronic architecture

Although the CubeSat specification does not feature a standardized electrical interface between the boards, we will implement a de facto interface, commonly used by the manufacturers of commercial subsystems. This is done in order to reduce cost, delivery time and it can easily interface with other CubeSat standard modules. It also ensures compatibility with developers of small satellites that expect to integrate CubeSat subsystem.

The CubeSat PC104 connector BUS provides power to the OrbFIX board, via the 5V and 3V3 power output pins. It also features the communication interfaces, such as SPI, I2C, SpaceWire and CAN.

5.3. Preliminary Mechanical Design

The layout implementation of the electric diagram is presented in the image below:

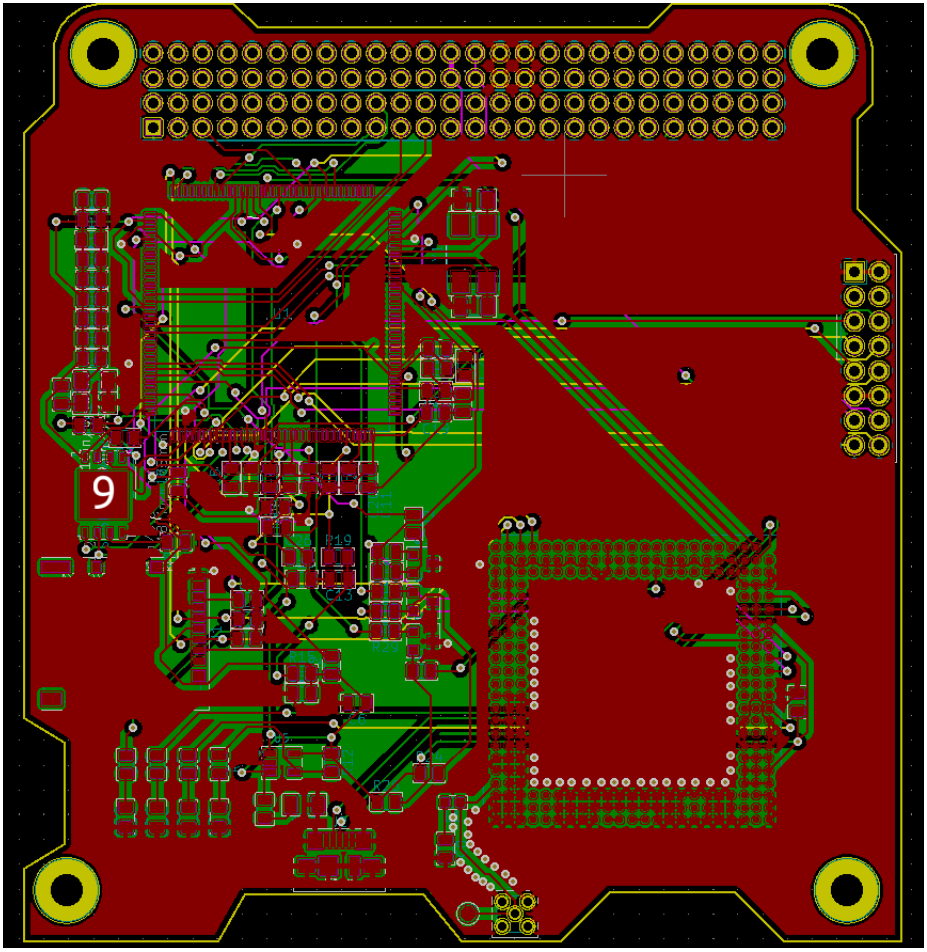

Figure 9 Ground planes view of the OrbFIX PCB (red – Top, green – Bottom)

The layout fits the mechanical constraints imposed by the CubeSat standard. It was built while taking into account the possibility of integrating a complementary receiver.. A four-layer PCB shall be used, with top and bottom grounding planes. Vias stitching is employed around the antenna signal route in order to limit RF interference.

The PC/104 board features an aluminium case to provide radiation protection. With 1.5 mm thickness it adds an estimated of less than 60 g to the overall mass.

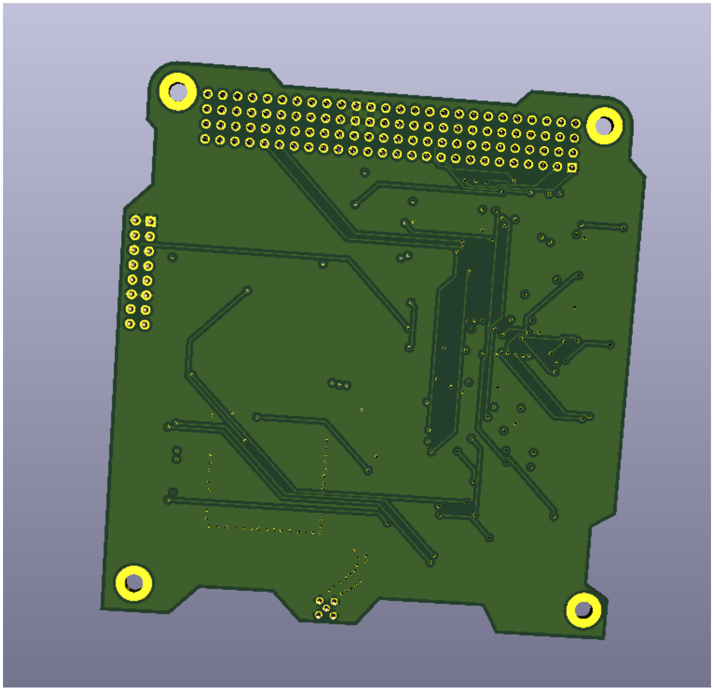

Figure 10 OrbFIX PCB Bottom render

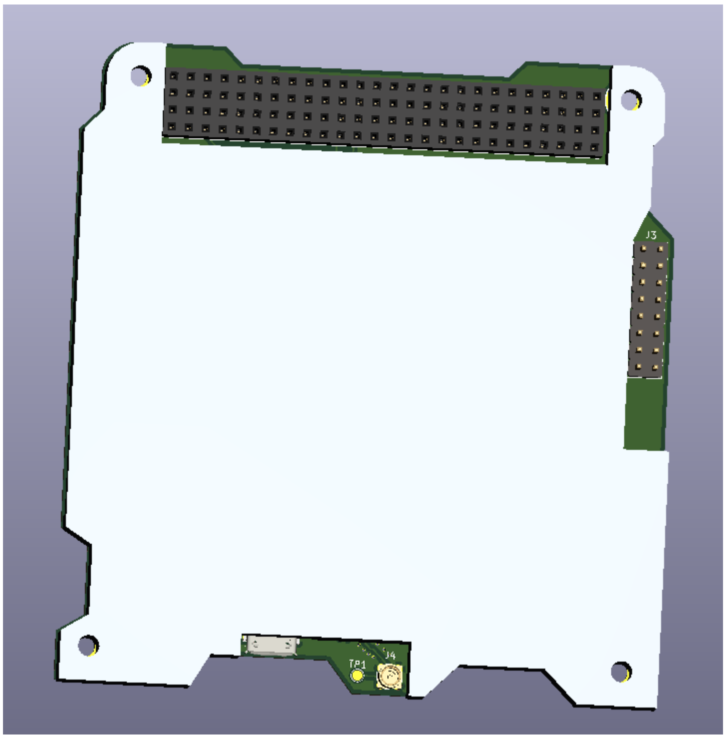

Figure 11 OrbFIX PCB with 1.5 mm aluminium shield