THE PAVAROTTI PROJECT: IOV-IOD MISSION USING A 3U CUBESAT PLATFORM TO QUALIFY A WIDE RANGE OF NANOSATELLITES SERVICES AND PRODUCTS

Angela FRANCO-DAZA[(1)], Muriel BERNARD[(2)], Rafael MENDES-DUARTE[(2)], Nicolas WUYAM[(1)], Laurent DUSSEAU[(2,3)]

[(1)] Latécoère Interconnection Systems, 1080 Impasse des Bigos, 34470 Vendargues, France, +33 7 78 64 64 28, angela.franco@latecoere.aero

[(2)] University of Montpellier – University Space Center, 950 rue de St Priest – Bâtiment 6, 34090 Montpellier, France

[(3)] University of Montpellier – IES - UMR UM/CNRS 5214, 860 Rue de St Priest, Bat. 5, F-34095 Montpellier, France.

ABSTRACT

In 2021, the Van Allen Foundation (FVA) and the University Space Centre of Montpellier (CSUM) initiated the "P.A.V.A.R.O.T.T.I." tech demo CubeSat project aiming at demonstrating several technologies developed by the FVA founding members and partners. Latécoère Interconnection Systems (LIS), a European leader in the development and manufacturing of interconnection systems, on-board equipment and test benches for aeronautics, military and space, took the lead on the consortium. Since 2018, LIS has been actively extending their nanosatellites manufacturing capabilities in the frame of a strong partnership with the CSUM. Together, they aim at industrializing the versatile 3U to 12U CubeSat platforms developed at CSUM. The consortium is composed of nine partners and three subcontractors: LIS, 3D PLUS, Rakon, Nimesis, Expleo, Trad, SDR Technologies, Clix, Airbus Defence & Space, Mecanique Laurent, Anywaves and the CSUM. The PAVAROTTI project is currently in phases 0/A and the launch of the 3U satellite is scheduled for the end of 2023 in LEO. All innovative solutions developed by Latécoère and their partners, to provide an answer to the needs of small satellites developers in terms of affordable and robust solutions, will be described in this paper.

1 INTRODUCTION

The PAVAROTTI project gathers a consortium of 9 partners and 3 subcontractors belonging to the Foundation Van Allen (FVA). This Foundation was created in 2012 in order to support the activities of the University Space Centre of Montpellier (CSUM) and to provide a solid industrial governance. The FVA has, since its establishment, greatly contributed to the development of the Nanosatellites industry in France, by promoting the partnership between the FVA's founders and partners.

Since 2019, the FVA Executive Board requested to the CSUM to evaluate the feasibility of a technological demonstration mission. Using a CSUM 3U platform to put in orbit the payloads from R&D companies of the consortium, the in-flight test of these technologies would be possible. Each partner identified the needs of on orbit demonstration for their technology. As a result, all the members of the consortium has decided to create the PAVAROTTI project, which was presented in 2021 in the frame of a Call for proposals of the French Space Agency [1]. The name of the project,

PAVAROTTI, which in French stands for "***P**lateforme **A**pplicative pour **VA**lide**R** en **O**rbi**T**e des **T**echnologies **I**nnovantes*", means in English "Applicative Platform to Validate In Orbit the Innovative Technologies".

The aim of this paper is to present the new technologies developed by a consortium of companies gathered for the PAVAROTTI project. It will also be described the role of each partner in this project and the applicative mission consisting in tacking the debris in orbit.

In the present document, it will be described the nanosatellite proposed in the PAVAROTTI Project. In the second section of the paper, the platform used in this nanosatellite, which is a 3U Cubesat developed by the CSUM, will be presented. In the third section of the document, the missions proposed for this nanosatellite will be described. It will be also detailed the innovative technologies developed by the consortium partners and the specific characteristics of these equipment.

2 PLATFORM OVERVIEW

The platform used in the PAVAROTTI project is the Robusta-3U CubeSat, which has been developed by the University Space Centre of Montpellier (CSUM). The Robusta-3U platform was presented in a previous paper [2]. Latécoère Interconnection Systems (LIS) has been actively extending their nanosatellites manufacturing capabilities in partnership with the CSUM. Together, they aim at industrializing the versatile 3U CubeSat platform developed at CSUM.

The Robusta-3U platform is a 3 axis stabilized 3Units CubeSat. The platform is built around a modular and distributed architecture, which allows each sub-system to autonomously operate and perform specific tasks independently. The attitude and determination of the platform in orbit can be controlled from the ground by means of a set of precise algorithms implemented in its Attitude Determination and Control System (ADCS) subsystem. In terms of communications capabilities, an UHF transceiver is used for Telemetry and Telecommand functionalities, while a S-Band transceiver allows high data rate communications for payload data. In addition, the platform also performs internal temperature monitoring and control through a set of sensors and heaters. The main subsystems of the platform are described below:

- **Structure**: provide mechanical support and electrical connection to all subsystems along the missions' phases, deploy the necessary elements.
- **Attitude Determination and Control System (ADCS)**: changes the orientation of the satellite in space based on coordinates received from the Ground Segment.
- **Electrical Power System (EPS)**: harvests power from the Sun through the solar panels and distribute as necessary to other sub-system. The EPS is also responsible for activating the deployment sequences after launcher separation.
- **S-Band Transceiver**: Provides Uplink and downlink capabilities in the S-Band commercial frequency range at 2 Mbps (QPSK). This transceiver is used to transfer payload data to the ground segment. The transceiver can use the CCSDS protocols or a simple synchronization word structure to establish the communications link with the Ground Segment.
- **On-Board Data Handling**: Coordinates the action of all sub-system and payloads. Its main functions is to store housekeeping and mission data from other subsystems. It also implements safety mechanisms such as watchdog and reset sequences.
- **UHF Transceiver (TT&C)**: The telemetry, tracking, and control (TT&C) subsystem handles the communication of telemetry and telecommands between the Ground Segment and the satellite. It supports AFSK and GMSK modulation schemes of up to 38400 bps. The

transceiver uses a simple synchronization word protocol to implement the link layer of the radio communication.

- **Deployable solar panels**: The satellite has four sets of deployable solar panels which are used to harvest energy from the sun and recharge the satellite batteries through the EPS.

In the platform, a common CAN BUS connects all the subsystems on the platform, including its payloads. The data is exchanged between the subsystems on the main CAN BUS by taking advantage of the Cubesat Space Protocol (CSP). In this scenario, each subsystem is configured as a CSP node that be directly accessed from the Ground Segment for parameter configuration or data request. To handle the set of configuration parameters on the platform, each subsystem runs a custom protocol called the CSUM Protocol, which enables direct read and write routines of configuration parameters. In addition, the voltage lines of core components in each subsystem are protected against latch-up events at the hardware level, while the firmware layers implements safety and recovery routines to maximize the mission lifetime.

3 MISSION OVERVIEW

In order to demonstrate the on-board technologies in a real case scenario, it has been decided, in agreement between all the partners, to propose a mission that build on the payload technological capabilities. The main payload's tool/instrument, is a high resolution camera developed by the company 3D PLUS. It has been considered well adapted for the objects' trace detection in Low Earth Orbit, which presents a major interest. Space debris entail critical risks for current and future space missions. In order to reduce these risks, it is important to warn the operators and, if necessary, to perform avoidance manoeuvres. This mitigation strategy relies on the precise knowledge of orbits that are not possible to obtain by Two Line Elements. Whereas the biggest objects can be tracked by radar, the smallest ones (less than $2m^2$ of exposed surface) are harder to be detected. This support mission gives a supplementary meaning to the main technological demonstration mission.

The consortium is composed by nine partners and three subcontractors: Latécoère, 3D PLUS, Rakon, Nimesis, Expleo, Trad, SDR Technologies, Clix, Airbus Defence & Space, Mecanique Laurent, Anywaves and the University Space Centre of Montpellier (CSUM). The partners and their innovative technologies will be described in this section. The location in France of the partners and subcontractors of the PAVAROTTI project is presented here below.

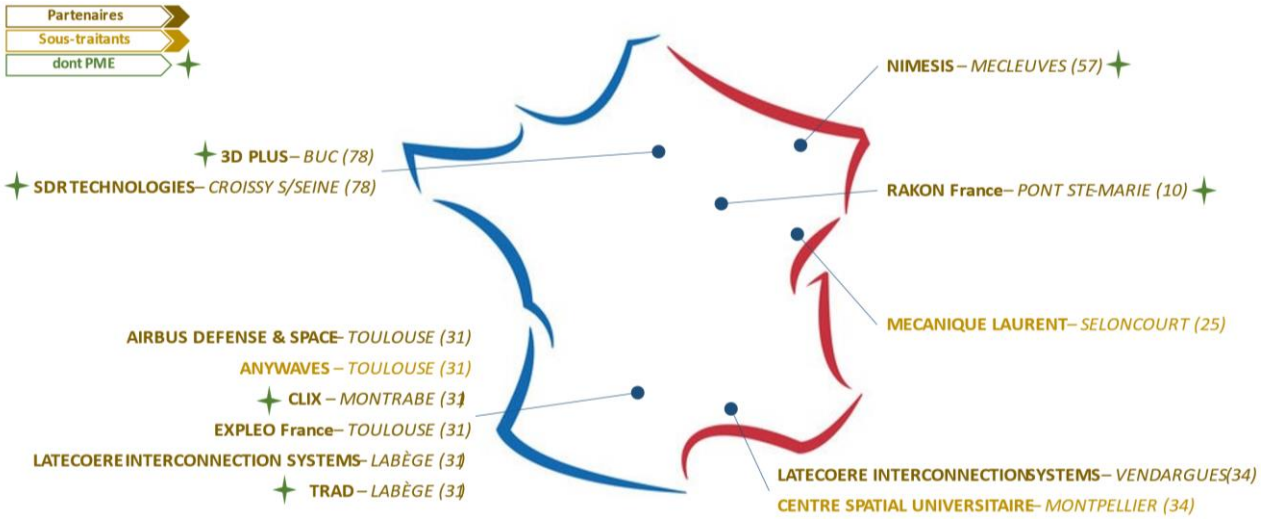


Figure 1. Partners of the consortium and subcontractors of the PAVAROTTI project

3.1 Main mission: Payload's new technologies demonstration

3.1.1 LATÉCOÈRE: LiFi space awareness

Latécoère is developing LiFi solutions for aeronautical and military needs. The challenge is to test the LiFi technology in the space domain to demonstrate it is a viable wireless data transmission technology [3].

The LiFi system is composed of 2 main boards:

- LiFi Board:

  This board is converting SGMII electrical signal into LiFi Light Signal.

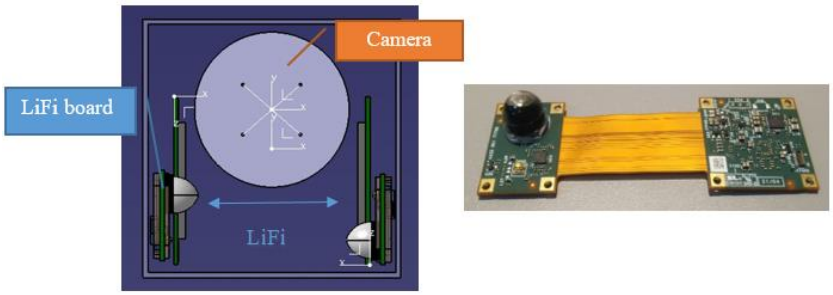


Figure 2. LiFi Board

- LVDS - SGMII conversion board:

  This board is converting LVDS Signal (Video format coming from the camera) to a SGMII electrical format (Ethernet link).

  This board is developed using a French FPGA in order to have alternative solutions of American components.

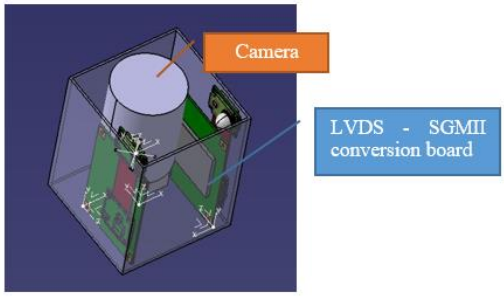


Figure 3. LVDS - SGMII

LiFi interest:

- Data Security
- Ease of integration
- Ease of wireless communication across multiple satellites among various mobile parts of the embedded systems
- Eliminate cabling risks in critical and/or mobile locations
- Mass reduction by less use of harnesses and cabling (fiber optics)

3.1.2 3D PLUS: Camera system based on innovative opto-electronic architecture and high performance lens

3D PLUS offers a space grade camera system [4] consisting of the following sub-systems:

Opto-electronic module: The 3DCM800 opto-electronic module uses a 4096x3000 global shutter CMOS image Sensor targeting visible spectral bandwidth. It is able to provide up to 68 full resolution frames per second, with several integrated modes available such as 8/10/12 bits pixel resolution, windowing/subsampling modes. The optoelectronic performances have been improved, with read noise below 3 electrons, and dark current below 20 electrons per seconds.

The camera's architecture is designed around a high performance 500K logic cells FPGA Core and its processing and storage memories allowing control of the sensor and interfacing of the microcameras, as well as integrated image processing such as compression, binning, or specific algorithms depending on the application. The design integrates all needed power supplies using only one 5V input power supply. PGA array are provided for a flex-rigid connector to be assembled to insure the TM/TC and data link to the system and able to cover a wide range of interfaces, such as SpaceWire, CameraLink, or simple single-ended or differential signals, depending on the FPGA code.

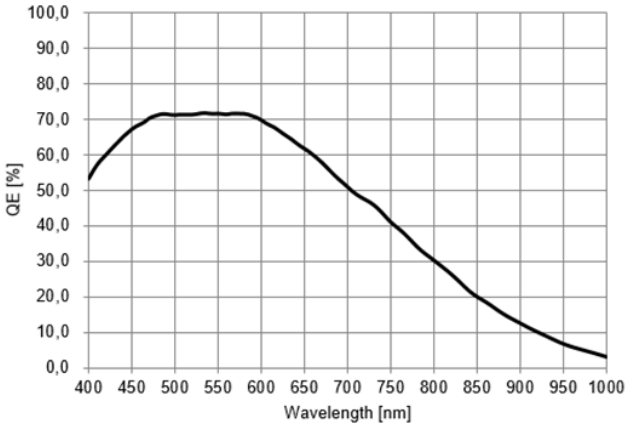


Figure 5. Quantum efficiency of the sensor

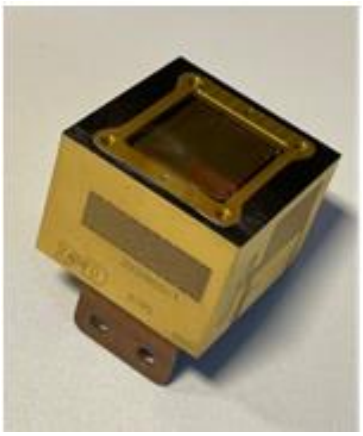


Figure 4. Opto-electronic module

Optics: the proposed optics is an objective of 50mm focal length, based on a 54 lenses assembly. First frontal lenses are made with radhard glass. It allows to reach an angular resolution of <0.1 mrads over a 11° field of view, with very low distortion on the angles. The casing is made of titanium for increased thermal stability.

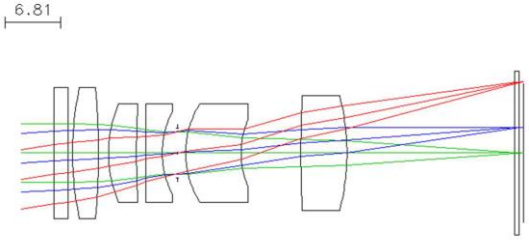


Figure 6. Optical design

3.1.3 RAKON: NewSpace GNSS receiver and S-band transceiver

NewSpace GNSS Receivers

The Rakon NewSpace GNSS Receiver is an easy to customize multi-Constellation multi-Frequency and multi antenna GNSS receiver [5]. It is off-the-shelf compliant with the Galileo and GPS signals and its design can be adjusted to take into account new constellations or new signals on request (Beidou, Glonass, SBAS, GBAS, DGPS, QZSS). It can easily be configured and customized and makes it a high performance GNSS receiver of choice for smallsats. It is part of the NewSpace Equipment series and is available in two variants, for short missions (<5 years) and long missions (>5 years).

Table 1. Key Features, Configuration and Options

▪ Multi-Constellation, Multi Frequency ▪ Multi-Antenna (active or passive) ▪ Warm/cold TTFF: <10s / < 100s ▪ Position accuracy (800km): <1m ▪ Up to 48 channels ▪ 1PPS signal output ▪ Power consumption: up to 5W ▪ Supply voltage: 5 V	▪ Short or long mission ▪ Internal LNA or supply to external LNA ▪ Can be provided with customized card sizes and standards

Table 2. Accuracy in LEO (800 km altitude)

Signals	Position (m) Real time 1-sigma per axis	Velocity (cm/s) Real time 1-sigma per axis	Timing (ns) Real time 1-sigma per axis
L1C/A	2.45	8.8	5.6
L1C/A, E1	0.93	4.2	2.6
L1C/A, E1, E5a	0.82	3.6	2.4
L1C/A, E1, E5a, L5	0.80	3.3	2.3

Table 3. TTFF (independent)

Parameter	LEO (s)
L1C/A	42
E1	72
E5a	93
L5	71

NewSpace S-band Transceivers

The Rakon NewSpace S-band Transceiver is a low SWaP (Size, Weight and Power) full-duplex transceiver designed for TT&C and high data rate communication between satellites (inter-satellite links) or between satellites and Ground stations [5]. The S-band transceiver operates over commercial frequency ranges and only needs a passive external antenna to be fully operational. It is highly configurable and is offering the flexibility of changing data rates and frequencies on-orbit. It is part of the NewSpace Transceivers series and is available in two variants, for short (>1 year) and long missions (>5 years).

Table 4. Key Features and Configuration

▪ Full duplex communication ▪ In-flight re-configurable frequency range (Tx/Rx) ▪ In-flight re-configurable data rate ▪ Triple safety watchdog ▪ Low power consumption (<12W on Tx) ▪ Max. Tx & Rx baud rate: 5 Mbps ▪ CAN-bus and RS-422 interfaces to on-board systems ▪ RF output power of up to 33 dBm (2W) ▪ Supply voltage range: 5-28 VDC	▪ Short or long mission ▪ Receiver/Transmitter operating frequency ▪ Downlink data rate ▪ Transmitter power, modulation ▪ RF connector type, position and orientation

Table 5. Interface specifications

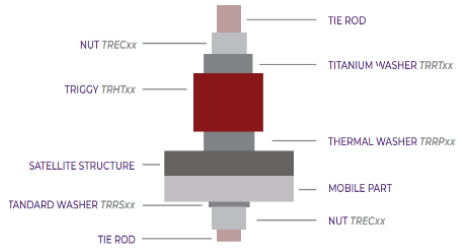
Parameter	Condition / Remarks	Short missions	Long missions
CAN			
Maximum data rate		1 Mbps	
Protocol		CSP	
Connectors		Molex or Harwin	Harwin
RS 485			
Maximum data rate		5 Mbps	
Connectors		Molex or Harwin	Harwin
RF			
Maximum Tx data rate	Transfer frame level	5 Mbps	
Maximum Rx data rate	Transfer frame level	5 Mbps	
Supported protocols		CSP + Sync. word CCSDS USLP AX. 25	
Channel encoding options	For CSP or CCSDS protocols	RS + Convolutional LDPC	
Connectors		SMA or MMCX	SMA

3.1.4 NIMESIS: Shape memory alloys based actuators for space systems

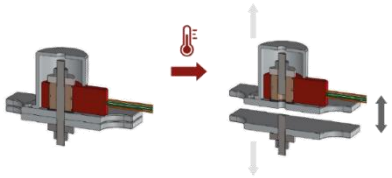
Nimesis is the only company in Europe that designs, manufactures, and markets intelligent actuators for the space domain. These intelligent actuators are based on the technology of Shape Memory Alloys (SMA) which Nimesis have mastered for many years, two actuators will be deployed for the project PAVAROTTI: TRIGGY and HECTOR [6].

TRIGGY is the optimal actuator for deploying, locking, unlocking, releasing, or dismantling space mechanisms. The operating principle of TRIGGY is based on the change of shape of a shape memory alloy component from an initially selected temperature. This change in shape generates a displacement and a force capable of moving, pulling, or pushing any action generating mechanism, in a reduced space and with a higher reliability than any other mechanism (motor, cylinder, etc.).

Figure 7. TRIGGY



Typical integration



Actuation scheme

	TRHT02	TRHT03	TRHT04	TRHT05	TRHT06	TRHT08	TRHT10	TRHT12
Material	CN-250X	CN-250X	CN-250X	CN-250X	CN-250X	CN-250X	CN-250X	CN-250X
Screw size	M2	M3	M4	M5	M6	M8	M10	M12
Max. axial preload (N)*	1265	3165	5482	8973	12659	23237	37002	53954
Fracture load (N)	1800	4600	8100	13200	18700	34400	54800	79900
Outer diameter (mm)	16,4	19,2	21,8	24,7	28,3	33,9	39,6	45,5
Elongation (mm)	0,82	0,90	1,13	1,39	1,71	2,20	2,74	3,33
Armed length (mm)	9,22	10,10	12,67	15,51	19,14	24,65	30,66	37,27
Fired length	10,04	11,00	13,80	16,90	20,85	26,85	33,40	40,60
Weight (g)**	4	8	14	22	37	80	164	271

Features:

- SMA component (Shape Memory Alloy)
- Redundant heater
- 2 temperature sensors Pt1000 (COTS or ESCC)
- Customizable fastener
- Triggering temperature: 150°
- Miniaturized concept
- Preload up to 60 kN

Figure 8. TRIGGY's features

	HECTOR (SINGLE)	HES190	HES118	HES290	HES218	HES390	HES318
Dimensions	Total length (mm)	90		180		270	
	Fasteners length (mm)	2 x 10	2 x 5	2 x 15	2 x 10	2 x 25	2 x 15
	Operational length (mm)	70	80	150	160	220	240
	Diameter (mm)	12.8	9.7	21.1	13.8	28.4	18.0
Rotation	Nominal deployment angle (°)	90	180	90	180	90	180
	Maximal deployment angle (°)	110	220	110	220	110	220
	Deployment accuracy[1] (°)	2	4	2	5	2	4
	Reproductibility (°)	1	2	1	2	1	2
Mechanical	Maximal torque (N.m)	6	1	56	8	118	29
	Torsional stiffness (hot) (Nm/°)	1,7	0,2	17	1,2	53	4,3
	Torsional stiffness (cold) (Nm/°)	0,2-1,7	0,02-0,2	1,8-17	0,1-1,2	5,8-53	0,5-4,3
	Mass (g)	32	11	292	82	941	280
Electrical	Power (W)	32	11	145	41	469	140
	Nominal voltage[2] (V)	8	8	16	16	110	28
	Nominal current (A)	4	1,5	9	2,5	4,5	5
	Actuation duration (s)	300	300	600	600	600	600

Features:

- 90° and 180° deployment
- High torque: up to 120N.m
- Operational temperature range in orbit: -120°C to +80°C
- Shock-free: progressive deployment

Figure 9. HECTOR's features

The **HECTOR** rotary actuator is a simple, unique, and effective solution for the deployment and rotation of space mechanisms. Its joints are designed for the deployment of solar panels, antennas, and other mechanisms. The HECTOR is divided to two sub series:

- Simple with a high torque and facility to install
- Double with good mechanical stability, low volume, and power requirement

Nimesis is developing a series of actuators that meet the needs of the space industry in terms of locking, unlocking, deployment and dismantling of space mechanisms. Its vision is to setup its own catalogue of innovative products.

3.1.5 EXPLEO: Platform Interface Board for Payloads

Expleo is positioning itself as a payload integrator for Nanosatellites [7]. Our team provides a payload interface board solution compatible with the CSUM 1U and 3U platforms. This solution enables fast and reliable development of payloads and facilitates the integration into nanosatellites by providing a standardized module onto which the payloads are connected.

The interface board contains the external connections necessary to power and communicate with a payload and it handles all communication with the CSUM platforms. In addition, the board contains temperature sensors and attitude sensors. The technology is already implemented on two nanosatellites, Expleo's ENSO and Djibouti's HYDROSAT. A satellite IoT solution using the interface board is currently being developed with our industrial partners.

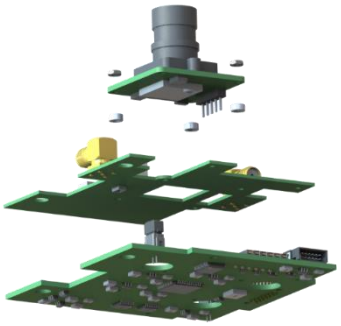


Figure 10. RF payload and camera payload assembly on interface board

<u>Technology</u>

The interface board meets the following technical specifications:

- Receive the primary power supply voltage from the satellite platform and distribute secondary power supplies for on-board payloads through OV/OC protection units.
- Communicate with the platform to manage TM/TC requirements for on-board payloads.
- Communicate with the payload to complete the specified mission.

The interface board architecture adapts to the needs of the payload:

- Multiple communication protocols (SPI, UART, CAN, etc.).
- Control of output/input signals (enable, PWM, etc.).
- Analog measurements.
- Multiple power supply voltages (3.3V, 5.0V, …).

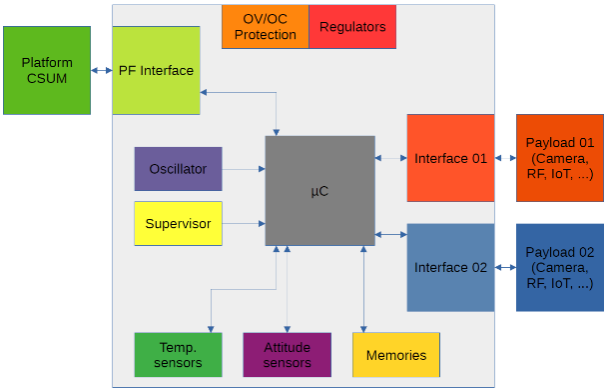
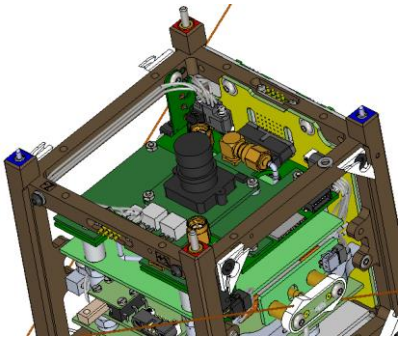


Figure 11. System Synoptic



<u>Technical Specifications</u>

- Weight: 30 g (interface board only)
- Dimensions: 78 x 76.5 mm
- Operating temperature: -40°C to +85°C
- Power consumption: 30 mA at 6.0V

Figure 12. Interface board integrated into the CSUM 1U platform

3.1.6 TRAD: HIRCOM© UHF transceiver for cubesats

For more than 25 years, TRAD Tests & Radiations is recognized for its unique expertise on radiation effects [8]. On a daily basis, we assist companies wishing to better predict and minimize radiation effects on their products. We offer a complete range of services and products allowing us to meet all requirements of the radiation process or applicable standards.

Technical description:

- High reliable Half duplex system for communication
- Compatible with Cubesat standard kit PC104 and M80 -5401442.
- Modulation: GMS K / A F S K
- Dimensions: 8 0mmx 80mmx 10mm
- 52 g with the shield
- High-Reliable Half-Duplex sub-system for communications link UHF band between space/ground segments
- Fully Configurable Frequency range (Tx/Rx): 400 to 438 MHz
- Modulations: GMSK/AFSK
- Data rate in the air: up to 76.8 kbps
- Triple watchdog system (dedicated IC, internal HW WD, internal SW WD)
- Low Power Consumption (< 5W on TX)
- HDLC, AX.25, CSP and CCSDS Protocol support
- Ultra-reliable Processing Unit based on LockStep Execution and SafeTI™ Compliance
- Fully compliant with ECSS (PUS) and CCSDS standards and recommendations
- CAN-BUS and SPI interfaces to the on-board systems
- RF output power of up to 33 dBm
- Connection: Plug and Play

Figure 13. HIRCOM© UHF Transceiver for Cubesat

Associated Services:

- User Document
- Technical assistance 5 hours

TRAD Offer:

- Radiation environment definition / analysis of RHA & other specification documents
- Part sensitivity evaluation: SEE error prediction, applicable radiation test data research & procurement R2COTS©
- Radiation-oriented 3D modeling: shielding optimization, design validation, etc.
- Radiation software editor in the space, nuclear FASTRAD ©, RAYXPERT©
- Analysis and solutions: mitigation solution, derating recommendation, etc.
- Electronic component testing: test bench development and test campaigns (TID, TNID, SEE)
- Material testing and characterization: thermal cycling, irradiation campaign, electrical test, etc.
- Sourcing & radiation qualification of electronic components
- Complete and tailored training courses at TRAD or at client's premises
- R&D activities, partnerships with academic entities and agencies

3.1.7 SDR Technologies: Devices for RF hardware engineering, embedded software, signal processing and integration

SDR-Technologies has developed a product line dedicated to distributed radiocommunication systems [9]. This technology is particularly well suited to build a network of satellite ground-stations interconnected through the internet to maintain an operational datalink with non-geostationary satellites.

Considering the costs to build and maintain such a network, the technology enables multi-satellite tracking and multi-channel communication from each ground-station.

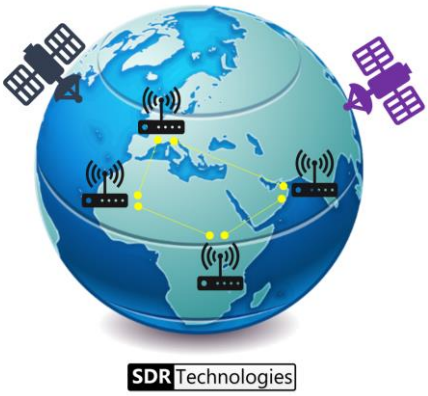


Figure 14. SDR-Technologies

The software can drive multiple radio interfaces and multiple antenna systems (fixed or adjustable antennas) to dynamically allocate radio channels to communicate with traveling satellites.

The radio protocol can be dynamically changed remotely when required (satellite embedded firmware updates, enhancements …).

Each station includes internet connectivity to retrieve orbital elements or update remote dashboards.

SDR-Technologies develops the different modules required for this application: custom Linux-based software running on embedded GPU processors, custom radio transceivers with high dynamic range (typically better than 90 dB), custom front-ends for the different radio bands, custom RF power amplifiers and rotator drivers.

Our current R&D is focused on multi-channel radio front-ends to enable dynamic beamforming, first for receive-only stations, to remove the need of adjustable antennas for radio links.

3.1.8 CLIX Industries: Bonding solutions

The company has its expertise in the definition and the realisation of bonding solutions and has developed several components for the New Space, based on different bonding technologies [10].

We propose to participate to the PAVAROTTI project with the supply of the whole photovoltaic panels' deployment system. It consists in a set of a Composite Hinge and a HDRM mechanism per panel. These mechanisms are flying on the EYESAT program lead by the CNES. CLIX is also able to bond subassemblies of a nanosatellite like the PV cells on the panels or other components.

Figure 15. Composite Hinge

Composite Hinge

Product description: Composite Hinge based on 2 elastic flanges and a flexible middle part. The CLIX Hinge provides a spring function for self-deployment and locks itself in the open end-position.

Benefits: Self-deploying, self-locking, compact, lightweight, accurate rotation, friction free, no need for external energy.

HDRM (Hold-Down and Release Mechanism)

Figure 16. HDRM

Product description: Two clamps, installed on two leaf springs, are attached to each other using a polymer tie. The clamps hold a sphere fixed to the mobile structure. The ball joint isostatic locking system allows the angular alignment, prohibiting sideways movements in particular during launch vibrations. Relaxation is done by a thermal knife that melts the polymer tie.

Benefits: This resettable mechanism is light, small, low shock and low cost. The release is done without motor or pyrotechnical devices.

CLIX has also developed other components for the space industry. Hereafter three examples, they all take advantage of bonding technologies developed at CLIX.

Composite mast

Product description: Mast is based on several hinges. CLIX Mast is very light. It provides a spring function for self-deployment and locks itself in the open end-position.

Benefits: Several segments can be assembled, compact when folded, deployment ratio 1:10, no need for external energy, light weight.

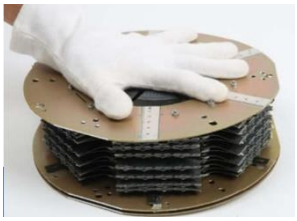


Figure 17. Composite mast

Flexible Pivot

Product description: Mechanism based on orthogonal blades deformation around a virtual rotation axis. Our production process gives a great design freedom and material choice for the blades and the pivot body. As it is friction free, there is no need for lubrification.

Benefits: High precision rotation without any free play, friction free, no lubrification needed, high durability, great design freedom.

Figure 18. Flexible Pivot

Magnetic laminar stack

Product description: The bonded magnetic laminar stack proposes a full insulation between every single sheet. This process decreases Eddy currents, Joule effects and iron losses for electrical stator/rotor. Structural bonding permits high resistance strength of magnetic stacks and higher electromagnetic performances.

Benefits: Reach higher motor frequencies and speed, high magnetic yield, lower the motor Temperature class, and increase life cycles.

Figure 19. Magnetic laminar stack

3.1.9 AIRBUS DEFENCE & SPACE

Nowadays the cost of solar panels for satellite applications is extremely high. Typical solar cells used in space arrive to the cost of 100€/W, with typical efficiency at the beginning of life of 28-30% (depending on technology). Airbus is currently working on low-cost solar panel technology for newspace missions [11].

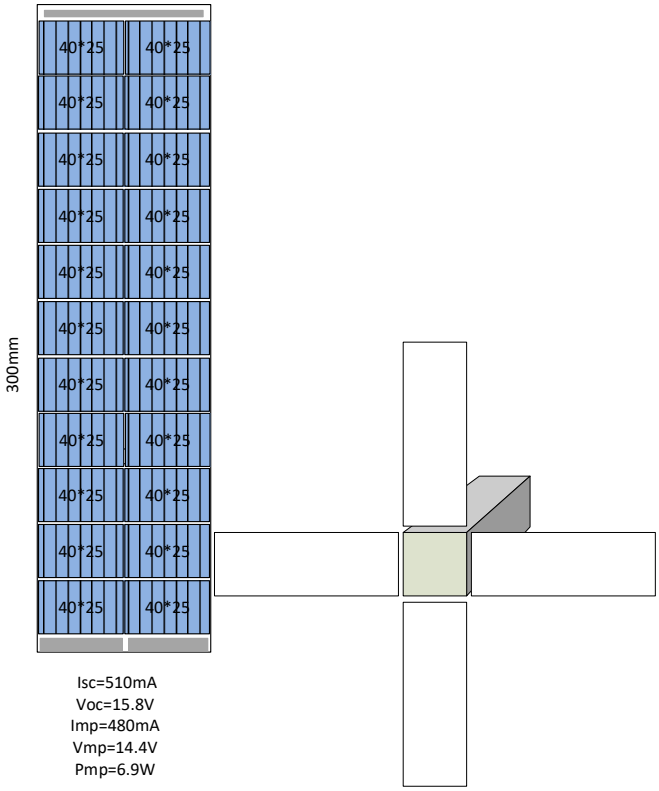


Figure 20. Solar Panel Technology

As a part of PAVAROTTI project, our mission is to deliver three low cost solar panels, made with silicon technology with appropriate front side protection. The efficiency of these cells at BOL is a little bit lower (19-22%) however the target PVA cost is about 20€/W.

Today, these solar panels were tested only in simulated environment. The examples of tests are following:

- Radiation for cells, cover glass, adhesive up to 1015 e/cm² 1MeV e-fluence
- Thermo-mechanic behavior of the PVA (cells, interconnections, substrate) during 2000 cycles for +/-140°C
- UV characterizations (4000ESH), for optical properties validation

Those tests allowed to achieve equivalent of TRL6 for this technology.

Role of the solar panels in this project is to be compatible with the electrical system and to bring the necessary power to the nanosatellite. The behavior of SA will be followed during the whole mission due to interfaces which allow to measure the temperature, current and voltage. The validation of TRL9 will be possible, if the degradation of solar arrays performance will be less 5% during 2 years.

3.1.10 MECANIQUE LAURENT: Structure and Other Mechanical Components for Nanosatellites by Robert LAURENT SARL

Laurent SARL is a supplier of rigid mechanical solutions for the satellite constellation market [12]. In addition to its reactivity and its good understanding of the requirements of this sector, our company has the experience of machining alloys of various grades, and can support you in the development of all your mechanical components with surface coating.

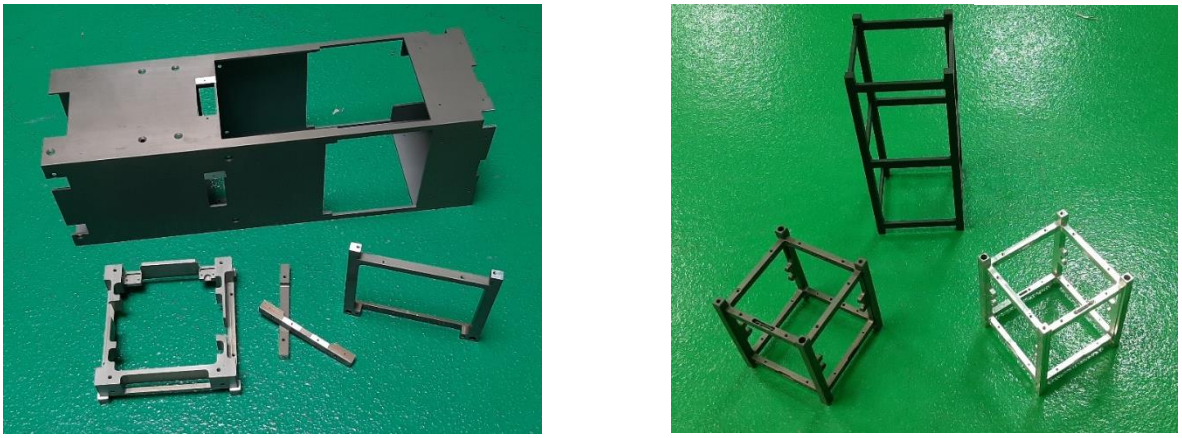


Figure 21. Structures and Mechanical Components for Nanosatellites

3.1.11 ANYWAVES: Antennas for the satellite constellations market

Founded in 2017 by Nicolas CAPET, former antenna expert at CNES (the French Space agency), ANYWAVES develops revolutionary antennas for the satellite constellations market [13]. Based on a breakthrough technology and an expert team, ANYWAVES designs and manufactures according to space standards a new generation of high-quality antennas, on demand or off-the-shelf.

ANYWAVES' technologies now includes 4 qualified COTS antennas, shown below:

Figure 22. S-band TT&C antenna

Figure 23. X-band Payload Telemetry antenna

Figure 24. GNSS All-Bands antenna

Figure 25. GNSS L1/E1 band antenna

S-Band TT&C and X-Band Payload Telemetry antennas benefit from a technological transfer from the CNES ("CNESAdvance" label). The GNSS All-Bands and GNSS E1/L1-Band antennas are the latest addition to the COTS offer, with a successful qualification in 2020.

This last antenna is based on a patented breakthrough technology implementing 3D printed ceramic part. By managing the structuration of the 3D lattice, we can adapt on demand the dielectric permittivity of the substrate in order to optimize the performance and miniaturization level of the antenna.

In addition to off-the-shelf products, ANYWAVES develops antennas for specific customer needs, including payload antennas. Specific developments can rely on various patented technologies, such as on-demand 3D printed ceramic substrates or self-deployable masts for helix antennas.

3.1.12 University Space Centre of Montpellier: Platform and ground segment infrastructure

The University Space Centre of Montpellier (CSUM) is a subcontractor in the PAVAROTTI project. The CSUM is in charge of the mission, systems and operations activities, in addition to the platform development, integration and test activities [14].

The ground segment facilities which are available in the CSUM are:

- UHF station, which is operational and operated by the CSUM team. It was validated during the 1U Cubesat development, and it has been end-to-end tested in a real mission. It is a multi-mission UHF station.
- S-band station, composed by a complete system (2.4m of parabolic antenna, connectivity, ground station and data decoding), which has been donated by Zodiac Data Systems (ZDS). The whole station is operated by the CSUM team, which has been trained by ZDS. This station will be validated during the flight of Robusta3A, a CSUM's nanosatellite which will be launched at the beginning of 2023.

3.2 Support mission: Space debris tracking

The aim of this secondary mission is to ensure the tracking of space debris using optical tools in the Low Earth Orbit, in order to estimate the trajectory of the debris.

Using the technologies developed by the partners of the PAVAROTTI project, which are going to be tested in the frame of the on-orbit demonstration proposed as first mission, the secondary mission represents a real case scenario.

On request from the ground station, the satellite will switch into detection mode and it will be capable of acquire a set of high-resolution images which will provide the estimation of the object's trajectory after on-ground data post-processing. The estimated size for the tracked objects is smaller than 2 m^2, with an accuracy of 10 m, in a distance of 100 km.

4 CONCLUSION

The PAVAROTTI Project proposes the in-flight demonstration of innovative technologies developed by a consortium comprise of 9 partners and 3 subcontractor. This consortium will also provide the expertise in assembly, integration and test activities, system engineering, launch and operations. The platform used to put in orbit the technologies will be a 3 axis stabilized 3-Units CubeSat.

In addition to the main mission, a support mission is proposed in order to implement the technological demonstration in a real case scenario. It consists in tracking the small spatial debris using a high resolution camera. Both missions, the on-orbit demonstration of technologies and the space tracking, have a huge interest for the development of new applications in the space industry.

5 ACKNOWLEDGMENTS

The authors would like to thank the Van Allen foundation for its financial support on this work. The authors would also like to thank CNES for co-founding the ROBUSTA-3A project in the frame of the Nanolab Academy program. They also would like to thank the Occitanie region and the French National Research Agency (ANR) for their support. The authors would like to thank all the partners of the PAVAROTTI project.

6 REFERENCES

[1] Latecoere Interconnection Systems. “Plan nanosatellites – Accélération des validations en vol (IoD/IoV). Projet PAVAROTTI”. *Plan de Relance (CNES)*, 2021, France.

[2] V. Muravyev, L. Dusseau. “Investigation and Design of Cubesat of Robusta–3 in Project Mediterrannee”. *Small Satellite Services and Systems Symposium (ESA/CNES)*, 2014, Mallorca, Spain. Hal–01934485.

[3] https://www.latecoere.aero

[4] https://www.3d-plus.com

[5] https://www.rakon.com

[6] https://www.nimesis.com

[7] https://expleo.com/global/en

[8] https://www.trad.fr/en

[9] https://www.sdrtechnologies.fr

[10] https://clix-industries.com

[11] https://www.airbus.com

[12] https://www.mecanique-laurent.com

[13] https://anywaves.eu

[14] https://csum.umontpellier.fr/en/home