POQUITO: THE FIRST SATELLITE MISSION OF THE UNIVERSITY OF LUXEMBOURG

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ABSTRACT

This work details the mission and system of POQUITO, the PocketQube for In-Orbit Technology Operations, that is the first satellite mission of the University of Luxembourg. POQUITO will be deployed in a Sun-synchronous orbit in Q3 2024 by a PocketQube deployer onboard a SpaceX Transporter mission. POQUITO is the first PocketQube mission to host an independent ChipSat onboard and is intended to be a modular platform for future missions. The platform is a 5x5x5 cm PocketQube (1P), while the payload is a 5x5x0.2 cm ChipSat. POQUITO will test the communication between the PocketQube and the ChipSat through visible-light link. The ChipSat payload serves as a demonstration for both inter- and intra-satellite links: (1) between the ChipSat and POQUITO; and (2) within the ChipSat. The ChipSat is assembled on a printed circuit board with its own solar cells, sensors, and data management system, which are independent from the main platform. POQUITO is also equipped with a deployable UHF antenna and an experimental ADCS with 3 magnetorquers developed at the University of Luxembourg which are placed on the back side of the solar cells. The overall space system fits within a 5 cm edge cube and weighs less than 250 g. Several challenges encountered in the development of the POQUITO mission, encompassing diverse areas such as technical development, launch opportunities, and non-technical matters as insurance coverage for pico-satellites are also detailed in the paper, providing useful lessons learnt for teams aiming to work in the PocketQubes and sub-CubeSat area.

1 INTRODUCTION

The frequent rideshare opportunities enabled by the reusability of rocket launchers have determined an increase in the number of satellites in space. Nowadays, several constellations have been deployed, with more than 25 000 satellites planned to orbit Earth by 2030. The miniaturization of components allowed small players such as universities to launch their own satellite, after the CubeSat invention at CalPoly [1]. CubeSats are modular satellites made of units, or U, which is a box with a 10 cm edge. The first CubeSats were launched in 2003 [2-4] and, since then, CubeSats have also been devised for lunar missions (e.g. CAPSTONE [5], ArgoMoon [6], LUMIO [7]), martian fly-by (MarCo [8]), and asteroid missions (e.g. LiciaCube [9], M-ARGO [10], Milani [11], Juventas [12], NEA-Scout [13]). Soon after the CubeSat invention, PocketQubes were devised in 2009 to further miniaturize space missions [14]. PocketQubes are modular satellites made of PocketQube units, or P, which is a box with a 5 cm edge. While a CubeSat unit typically weighs 1.3 kg, a PocketQube unit typically weighs 250 g. PocketQubes have been launched since 2013 [15-19] by universities and small companies. PocketQubes introduce additional challenges when compared to CubeSats due to their small size and limited budgets. As an example, star trackers and propulsion systems for PocketQubes are still challenging owing to the miniaturisation of components [20, 21]. The ChipSats are another class of

miniaturized space systems, which are planar satellites made up of a printed circuit board with a typical edge of 3 cm to 7 cm and a thickness of a few millimetres [22].
This work details the mission and system design of the PocketQube for In-Orbit Technology Operations, or POQUITO, which is the first satellite mission of the University of Luxembourg and the first PocketQube mission to host an electrically independent ChipSat onboard as a payload. POQUITO is a 1P PocketQube weighing 185 g. POQUITO will test for the first time an intrasatellite link between the PocketQube platform and the ChipSat payload. The paper is structured as follows. Section 2 details the POQUITO mission, Section 3 presents the system design of the PocketQube and the ChipSat, and Section 4 summarizes the findings of this work.

2 THE POQUITO MISSION

The POQUITO satellite will be deployed in a sun-synchronous orbit (SSO) through a SpaceX rideshare Transporter mission for the planned launch date October 1st, 2024. POQUITO will be inserted into a PocketQube deployer from Alba Orbital, that will be inserted in the ION Orbit Transfer Vehicle (OTV) from D-Orbit. The OTV will be released by the Falcon 9 SpaceX launcher, and then POQUITO will be released by the OTV in a SSO with an altitude of 525 km, inclination 97.5 deg, and a longitude of descending node (LTDN) of 23:00.

The selected PocketQube deployer is the AlbaPod from AlbaOrbital which will be mounted in the ION Orbit Transfer Vehicle. The D-Orbit OTV, which includes the Alba Orbital deployer and the POQUITO PocketQube, will be put in orbit by the SpaceX Falcon 9 launcher. The Concept of Operations of the POQUITO mission is shown in Figure 1.

The launch is scheduled for October 1st 2024. The D-Orbit OTV will be injected into low Earth orbit and the POQUITO satellite will be deployed in a window spanning from 7 to 14 days after the D-Orbit OTV separation from the launcher into the 525 km altitude SSO orbit.

Type	Altitude	Inclination	LTDN	Period	Lifetime	Launch
SSO	525 km	97.5 deg	23:00	94 minutes	2.8 years	1st October 2024

Table 1: POQUITO satellite orbital characteristics.

POQUITO will perform in-orbit operations for a nominal duration of 2.8 years and will re-enter and burn in atmosphere due to natural decay dynamics and the increased solar activity foreseen in the window 2024 - 2027. The overall lifetime of the mission from orbit injection to disposal amounts to up to 3 years (margined). During the mission lifetime, the ground station at University of Luxembourg will be used to communicate with the satellite in the UHF frequency band (both uplink/downlink), and the mission control center placed at University of Luxembourg will be used to control the mission.

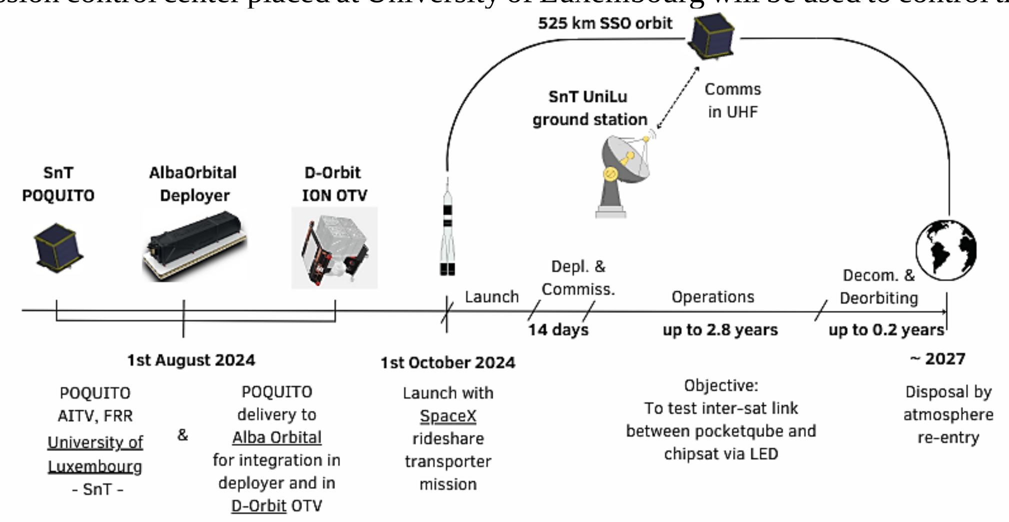

Figure 1: POQUITO mission Concept of Operations.

3 THE POQUITO SATELLITE

Being a picosatellite mission, one of the main driver for POQUITO is to adopt integrated cycles for design, development, and testing activities for the subsystems. In this way, the output of the testing activities can be critically analyzed to provide feedback on the new cycle, that will start with a delta-design activity, increasing the robustness of the mission with real laboratory testing. Then, two system level integrated tests for mechanical, thermal, and emissions qualification and acceptance are scheduled. This paradigm will increase the robustness of the satellite system and ensure working functionalities at subsystem and system levels. This section details the satellite system including the POQUITO phases and modes, the technical budgets, the design, and development activities.

3.1 Phases and modes

The mission timeline includes the phases described in Table 2.

Table 2: POQUITO mission phases.

Phase	Duration	Description
Deployment and Commissioning	14 days	• Deployment of antenna elements • Communications • Detumbling • Subsystems ON • ChipSat Payload power ON
Nominal Operations	< 2.8 years	• Power generation • Periodic beacon transmission • Data downlink/command uplink from Ground Station • ChipSat payload operation
Decommissioning	< 2 months	• ChipSat payload power OFF • Passivation of radio emissions • Microcontrollers OFF
Disposal	< 1 month	Disposal by natural atmospheric re-entry

The POQUITO system supports the modes described in Table 3.

Table 3: POQUITO system modes.

Mode	Description
OFF	System is disabled due to persisted telecommand, or deployment kill switches actuated. This mode is automatically active inside the Alba Orbital deployer due to the kill switches.
TESTING	System debugging and testing (not used in flight).
DEPLOYMENT	System is periodically attempting to deploy antenna elements until they are detected to be deployed by on-board switches.
NOMINAL	System checks and actuates detumbling, transmits periodic beacons, and receives light data from the ChipSat payload.
COMMUNICATIONS	System is broadcasting, transmitting or receiving from the Ground Station.
POWER SAVE	Subsystems (except comms) are put to low power modes. This is also a safe mode.

3.2 Budgets

This section presents the technical budgets of the satellite for what regard the mass, the power, and the communications. The satellite mass budget is shown in Table 4, the satellite power budget is shown in Table 5, and the satellite link budget is shown in Table 6. Note that these budgets are compliant with the system requirements, assuring an overall mass lower than the maximum available mass for a 1P PocketQube platform, a power positive scenario for the mission, and a link budget that is closed with positive margin for communications.

Table 4: POQUITO mass budget.

Subsystem	Component	Unitary Mass (g)	Quantity	Total mass + 10% margin (g)
Structures	Baseplate	14	1	15.4
	Bottom plate	9	1	9.9
	Top plate	10	1	11
	Truss M2.5 L60	1.70	4	7.5
	Spacer	0.4	24	10.5
Electric Power System	Side Solar Panel PCB	8	4	35.2
	Solar Cells	2.2	12	29
	Battery	25	1	27.5
	Power Management PCB	15	1	16.5
Attitude Determ. and Control	ADCS PCB + Mag + sun sensors	20	1	22
Communications	Comms PCB	15	1	16.5
	Antenna + mount	14	1	15.4
Payload	Chipsat PCB	10	1	11
Harness & Cables	Harness & Cables	10	1	11
TOTAL				**238.4**

Table 5: POQUITO power budget.

Orbital period	94 min		Min Sunlight duration	60 min	
Battery capacity	4.5 Wh (16200 J)		Max Eclipse duration	34 min	
Power generated	410 mW		Energy gen. in 1 orbit	1476 J	
Systems and margins		Operative Modes			
Subsystem	Margin	DEPL.	NOMINAL	COMMS	P. SAVE
ADCS	10 %	378 mW	33 mW	33 mW	33 mW
OBDH	10 %	13 mW	13 mW	13 mW	6 mW
COMMS	10 %	37 mW	37 mW	2800 mW	33 mW
TOTAL	+ 20 %	513 mW	99.6 mW	3415 mW	86.4 mW
Duration of mode in 1 orbit	-	Not repetitive (use battery)	91.4 minutes	156 sec (5 sec every 3 min)	Contingency
Energy consumed in 1 orbit	-	-	543 J	532.7 J	-
Energy consumed	20 % incl.	1075.7 J in 1 orbit			
Energy generated	-	1476 J in 1 orbit			
Energy positive?		-	Yes	Yes	Yes

Table 6: Link Budget.

POQUITO - **Link Budget Analysis**	
TTC Antenna gain [dBi]	21.0
Transmission Losses [dB]	159.2
EIRP GS [dBW]	27.4
EIRP S/C [dBW]	0.2
Path loss [dB]	148.6
Slant Range (a = 6903.1 km, δ = 15.0 0) [km]	1463.3
Atmospheric Loss [dB]	1.1
Demodulation Method	BPSK
POQUITO – **Uplink**	
Uplink Frequency [MHz]	437.50
Uplink Transmitter Power (GS) [W]	10.0
Uplink Transmitter Power (GS) [dBm]	40.0
Uplink Total Line Losses [dB]	3.62
Uplink Polarization Loss [dB]	0.23
Uplink SNR [dB]	39.3
Uplink SNR Minimum [dB]	24.9
Uplink Margin [dB]	**26.9**
POQUITO – **Downlink**	
Downlink Frequency [MHz]	437.45
Downlink Transmitter Power (S/C) [W]	1.0
Downlink Transmitter Power (S/C) [dBm]	30.00
Downlink Total Line Losses [dB]	1.99
Downlink Polarization Loss [dB]	4.11
Downlink SNR [dB]	14.5
Downlink SNR Minimum [dB]	-2.1
Downlink Margin [dB]	**9.9**

3.3 Satellite design and development

The POQUITO satellite is made up of the following subsystems:

- Structures (STR)
- Electric Power System (EPS)
- Communications (COMM) and Onboard Data Handling (OBDH)
- Attitude Determination and Control (ADCS)
- Payload (PLD)

A detailed description of these subsystems is presented in the following.

Structures.

The structural configuration of POQUITO is constituted by an internal truss structure that links an internal base-plate to an internal top-plate, creating an internal rigid box supporting the satellite. This is complemented by the external lateral panels, the external top panel (where there is the payload), and the external baseplate, which is the main interface with the PocketQube deployer from Alba Orbital. The supporting structure of POQUITO is shown in Figure 2. This comprehends:

- An external baseplate, produced as a PCB, which presents the slots for the antenna mounting, the kill switches to assure that no power is flowing in when inside the PocketQube deployer, and a size compatible with the deployer rails. Testing with the deployer brackets has shown compliance with the deployer.
- An internal baseplate made of anodized aluminum and squared shape is mounted on top of the external baseplate to provide support to the satellite.
- Four long screws acting as truss structure, made up of aluminum, and coaxially covered with spacers, to support the satellite and provide space among the different subsystems on PCBs
- An internal top plate, specular of the internal baseplate
- An external top plate, which is the payload
- Four side plates with two structural pins on top side and one on bottom side complete the structural configuration of the satellite, providing support to the solar cells and being clamped by the internal top-plate and internal baseplate.

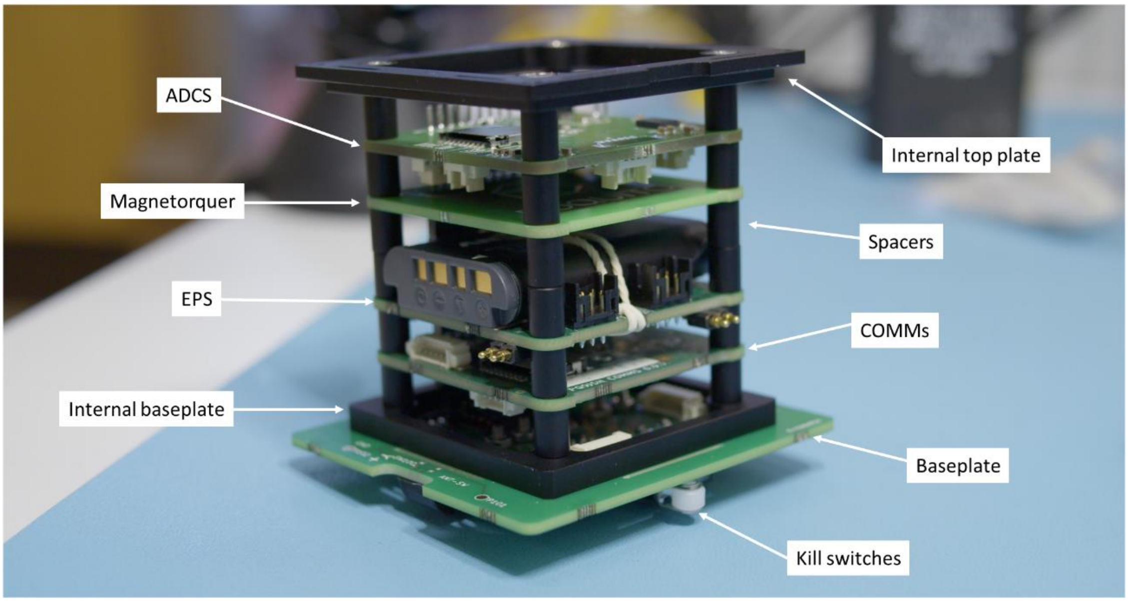

Figure 2: Structures of POQUITO.

<u>Electric Power System</u>.

The EPS has been designed in view of the power consumption throughout the mission lifetime and its capability of providing power for peak power consumption events. The EPS is constituted by a central power management control unit on a printed circuits board. This is connected to a battery for energy storage (Sony NP-BX1) and to the solar cells (SM141K04LV) attached to the lateral panels. This is achieved through pogo pins that link the EPS PCB to the lateral panels. Figure 3 shows the EPS central board and one solar panel. Note that 4 solar panels cover the lateral sides of the spacecraft with 12 solar cells overall, generating an overall 0.4 W of power when in sunlight. The battery (shown in Figure 2) has a capacity of 4.5 Wh and supplies power when the satellite is in eclipse.

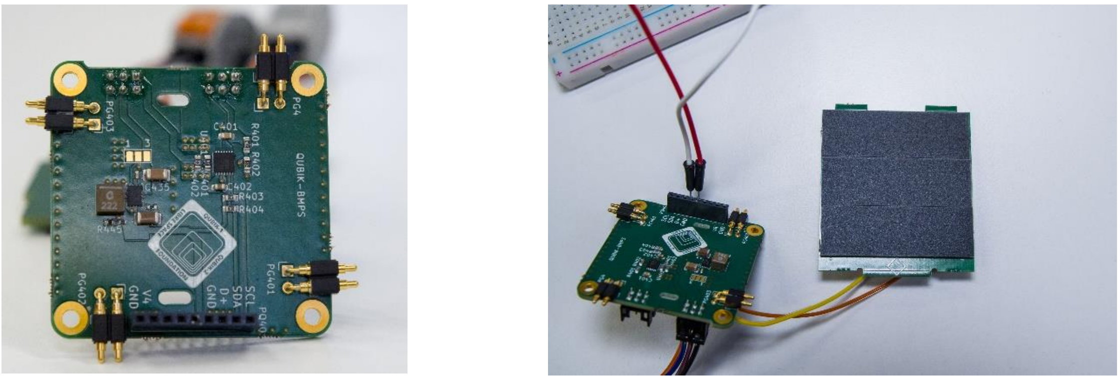

Figure 3: POQUITO EPS board (left), EPS board connected to the lateral solar πανελ

<u>Communications and on-board data handling.</u>

The communications subsystem of the satellite is based on the TRL 9 QUBIK satellite. The onboard software is responsible for ensuring the proper functioning of the POQUITO satellite. It is responsible for communications to the ground station and operating the satellite. Each subsystem includes its own automated control loops to function. The communication board interfaces with the ADCS and the Chipsat to provide the data to be transmitted to the ground. The software is run on a Cortex®-M4 based processor (STM32L4 microcontroller). The system has a high degree of autonomy, yet manual control is possible. The satellite implements both autonomous modes transition and manual modes transition controlled from the ground station. Data collected throughout the experiment is downlinked to the ground station through the UHF link provided by the deployed antenna. The software, which is running on the communication processor, reads from the sensors through the digital I2C and UART interfaces. The sensors provide housekeeping telemetry such as the internal temperatures, the battery temperature, the electrical power, the battery health, the antenna deployment status, and the data status. The communication software control with telecommands the power supply to the satellite, which will set to turn off when reaching the OFF mode, by turning off the MCU. Watchdog timers are implemented as electronic countdown timer that causes an interrupt when the timer reaches 0, avoiding failures due to freezing problems in the software. During normal operations, the software sets flags when done with the different tasks. When all the tasks are done, all the flags have been set, the watchdog resets. If any task fails to set the flag before the watchdog elapses, the system resets. POQUITO transmits telemetry for a configurable amount of seconds every 3 minutes, as a beacon broadcast. It can also transmit telemetry on-demand after a telecommand. The receiver is always ON in all operational modes and can execute received telecommands at any time.

<u>Attitude Determination and Control system.</u>

The ADCS is constituted by an internally developed ADCS board with 3x magnetorquers, a magnetometer, 9-axis MEMS IMU, and 4x sun sensors to achieve detumbling of the satellite and angular rate control exploiting the Earth magnetic field. Note that the magnetorquer are perpendicular each other, one being printed on a PCB and mounted in the stack sequence, while the others are printed in the internal layers of the solar panels, providing magnetic dipole along the three axes. The ADCS performances have been simulated through a Model-In-the-Loop (MIL) simulation which includes a state machine for the control modes, the flight dynamics model, the space environment disturbances, and the set of sensors and actuators available onboard. Based on the mission requirements and ADCS performance, the components listed in Table 7 have been selected for POQUITO.

Table 7: List of main ADCS components

Component	Model	Info
Processor	ARM Cortex M4 (STM23L476)	• Input voltage: 1.7-3.6 V • Ultra Low Power • Number of I/O ports: Up to 114 fast I/O, 5V-tolerant • 20 interfaces (I2C, USART, CAN, SPI, USB) • Dimension: 13x13 mm^2
Sensors	9-axis orientation sensor (BNO055)	• 3-axis accelerometer, 3-axis gyro, 3-axis mag • Low power, Input voltage: 2.4-3.6 V • Mag resolution~0.3μT • Digital interface: I2C-UART • Dimension: 3.8x5.2 mm^2
	3-axis Magnetometer (LIS3MDL)	• Sense range: ±400 μT to ±1600 μT • Ultra Low Power, Input voltage: 1.9-3.6 V • Digital Interface: I2C-SPI • Dimension: 2x2 mm^2
	Sun Sensor (Ambient Light Sensor, BH1682FVC)	• Input voltage: 2.3-5.5 V • Dimension: 1.6x1.6 mm^2 • Detection range: 55klx
Actuator	Magnetorquers (PCB integrated coils)	• Three-axis angular rate control • Three 4-layer PCBs (two with solar panels) • Coil Dimension~ 32x32 mm^2

The three magnetorquers, which have been printed as PCBs, can achieve an exceptionally low-power attitude control. The whole ADCS system has an average consumption of 30 mW and a peak of 375 mW for off-nominal conditions. The designed ADCS can control angular rates during nominal in-orbit operations, during the satellite orbit injection and detumbling, and even during the antenna deployment, which adds an instantaneous torque to the satellite. The ADCS PCB board unit and magnetorquers (before integration) are shown in Figure 4.

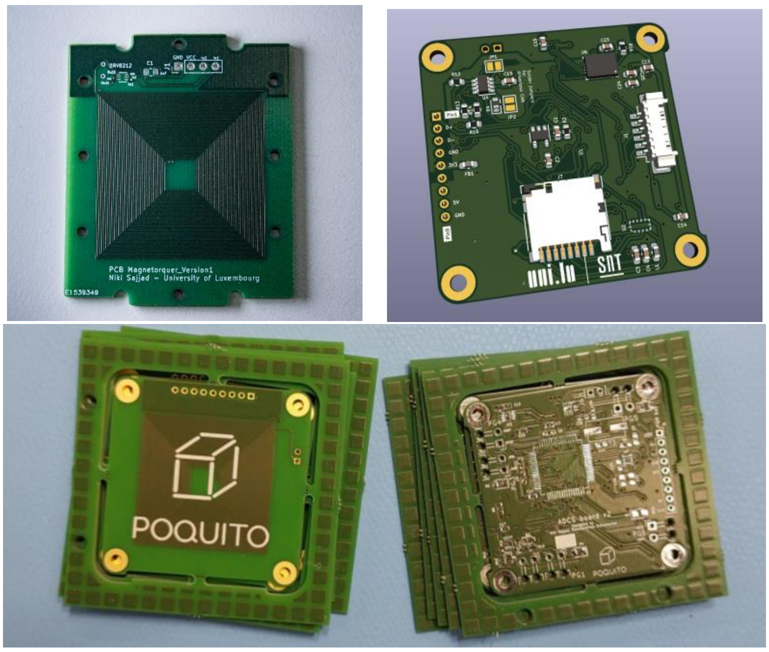

Figure 4: ADCS PCB and printed coils (top left and bottom left: magnetorquer, top right and top left: ADCS board).

No thrusters or propulsion systems are foreseen for POQUITO. This is still compliant with space debris mitigation requirements, as the maximum allowed time for satellites without propulsion in LEO amount to 5 years, and POQUITO decays after three years of deployment.

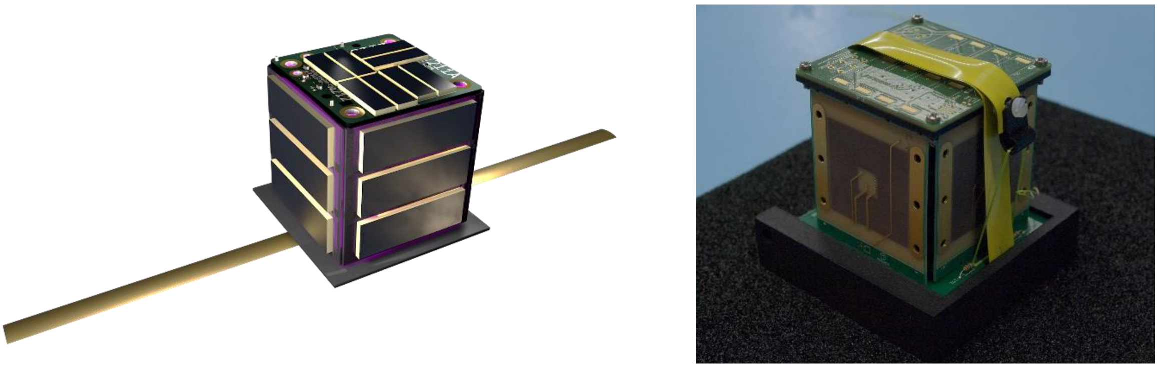

Figure 5: External views of POQUITO (left: CAD model, right: Engineering Model).

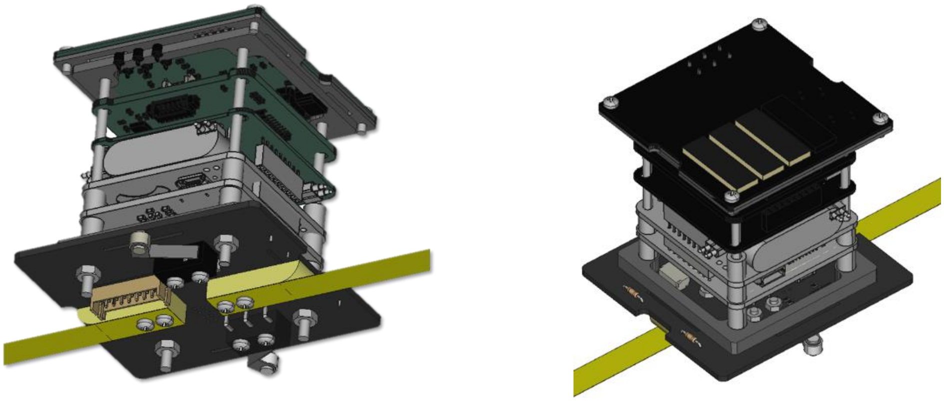

Figure 6: POQUITO CAD internal views.

3.4 Payload

The POQUITO payload is a single PCB named ChipSat-2.0, which is mounted on the top side of the PocketQube. This payload board measures 5 cm × 5 cm × 0.3 cm. The outer layer of the ChipSat-2.0 PCB is equipped with an array of solar cells, a light sensor, and two infrared light (IR) sensors which would be exposed to the space environment. The inner layer, which faces the PocketQube, includes a LED, a Gyroscope, and a Power Supply and Energy Storage system. The communications between the ChipSat-2.0 and the PocketQube is facilitated through the LED link, demonstrating optical communication between two electrically separated satellites. ChipSat-2.0 operates with its own power generation and data management systems, completely independent of the PocketQube. The IR Sensors on the ChipSat-2.0 will be used for temperature measurements and an array of eight solar cells will generate electricity for the ChipSat independently by the PocketQube.

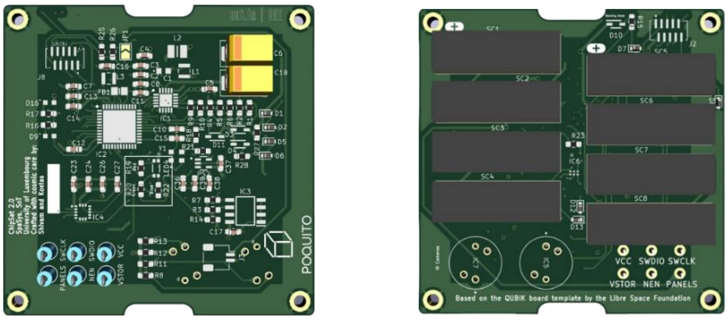

Figure 7: The POQUITO payload (ChipSat-2.0) bottom layer (left) and top layer (right).

4 CONCLUSIONS

This paper detailed the mission and the system design of the POQUITO PocketQube platform developed by the University of Luxembourg. The POQUITO satellite has been designed, tested, and qualified within a 1 year time frame through an iterative design-development-test approach. Novel technologies for pico-satellite communication and attitude control have been detailed, showing potential for a continuous technological development in the field. A novel ChipSat design has been introduced which comprehends independent power management, communication, and data handling with respect to the PocketQube.

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