HIGH-PERFORMANCE 2U-CUBESAT FOR EARTH OBSERVATION WITHIN THE NANOFF-MISSION

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ABSTRACT

The Chair of Space Technology at TU Berlin has a long heritage in satellite development. Starting in 1985, the first satellite was launched in June 1991. In 2005, six years after the CubeSat standard was presented, the 1U-CubeSat mission BEESAT-1 kicked off with a focus on miniaturization, redundancy and the implementation of single-failure tolerant technology. BEESAT-1 was followed by several missions, based on the same satellite bus with an increasing density within the payload system: BEESAT-2 (Camera with PDH); BEESAT-4 (Camera, GPS-receiver); BEESAT-9 (Camera, GNSS-receiver, pFDA).

The miniaturization accumulated in the project PiNaSys I/II, where the satellites B5-8 were developed, launched and are now operated in space since March 2021. The satellites are fully redundant 0.25U-CubeSats, featuring a camera, GNSS receivers, laser reflectors, UHF- and X-Band communication systems, a CAN-bus and 40 antennas per CubeSat unit.

Based on these satellites with their verified technologies, a high-performance 2U CubeSat bus was developed. All subsystems are integrated into a volume of 0.7U, including COM, OBC, EPS and AOCS. There are two different communication systems included, a UHF and an S-Band system, both redundant and for Up- and Downlink. The onboard computer will control the redundant CAN-bus, has an extensive storage for telemetry and several software images. All major electronic subsystems will be integrated on two electronic circuit boards.

The attitude and orbit control system consists of several sensors and actuators. For attitude determination arrays of eight gyroscopes, eight magnetic field sensors, ten sun sensors, three star trackers and four accelerometers are integrated, providing an accuracy of up to one arc minute. Four reaction wheels in a tetrahedral configuration and six magnetic coils control the attitude of the satellite. The navigation and orbit control is based on four GNSS receivers with antennas on different side panels.

The NanoFF satellite bus will be complemented with AQUAJET, a resistojet propulsion system (0.6U) and a multispectral camera system (0.7U). The AQUAJET will provide a delta v of 15 m/s for each of the two 2U satellites. The camera system has four narrowband spectral channels. It will be radiometrically calibrated, providing a broad bandwidth of scientific data with a ground pixel resolution of 30m and a swath width of more than 160 km from a 550 km SSO.

1 INTRODUCTION

In 2018 the formation flight mission NanoFF – Nanosatellites in formation flight kicked off. The mission objectives demand a high-performance satellite bus in nearly all subsystems. Igniting a thruster requires an electrical power system that can provide sufficient energy to the satellite bus, including AOCS actuators as well as the propulsion system simultaneously. Furthermore, the AOCS system needs to be highly accurate to ensure the thrust vector points in the right direction. This includes a sophisticated combination of several attitude sensors for a reliable determination, powerful actuators with the long-term capability of three-axis stabilization and GNSS receivers for time synchronization and position and velocity determination, especially during close formation flight maneuvers.

As a payload a camera system with four spectral channels is used. Additionally to the AOCS requirements, which are met due to the formation flight, a high data rate downlink capability is necessary. It was included to the satellite bus, as well as the payload compartment for the download of Earth observation data, also being able to downlink big amounts of telemetry compared to the UHF transceiver.

The satellite bus development is based on the experience gained within the former TU Berlin satellite mission. Nevertheless, the level of miniaturization and complexity of the mission demanded new solutions to integrate all obligatory components, meet the redundancy requirements and fulfill all the mission objectives.

2 SYSTEM OVERVIEW

The NanoFF satellite bus is a fully redundant and nearly single-fault tolerant system. Its core are two PCBs, which contain several subsystems. As seen in Figure 1 the red dotted lines show the components that belong to each electronic board. Two communication system in the frequency bands of UHF and S-Band are put together with the On-Board Computer, the GNSS receivers and the formation flight computers for autonomous maneuvering. On the other hand, there is a board which features the AOCS nodes and sensors as well as the PCU and other parts of the EPS. Seven solar panels with a series of four solar cells are the primary energy source. In a stored state three sides of the satellite integrate one panel, which ensures sufficient energy production for LEOP and Commissioning. After the deployment all panels face one direction for an efficient Sun Pointing Mode. Two battery packs of four cells each store additional energy for operations during Eclipse and peak consumption times. The subsystems communicate via a redundant CAN-bus with each other. Furthermore, the propulsion unit, the PDH and the Star Trackers are directly connected to this main communication bus system. Additional interfaces connect the Sun Sensors and the two actuators of the AOCS. Four reaction wheels and six Magnetorquers enable a three-axes stabilization as well as highly accurate pointing maneuvers. The camera system is directly connected to the PDH and has its own downlink channel in X-Band.

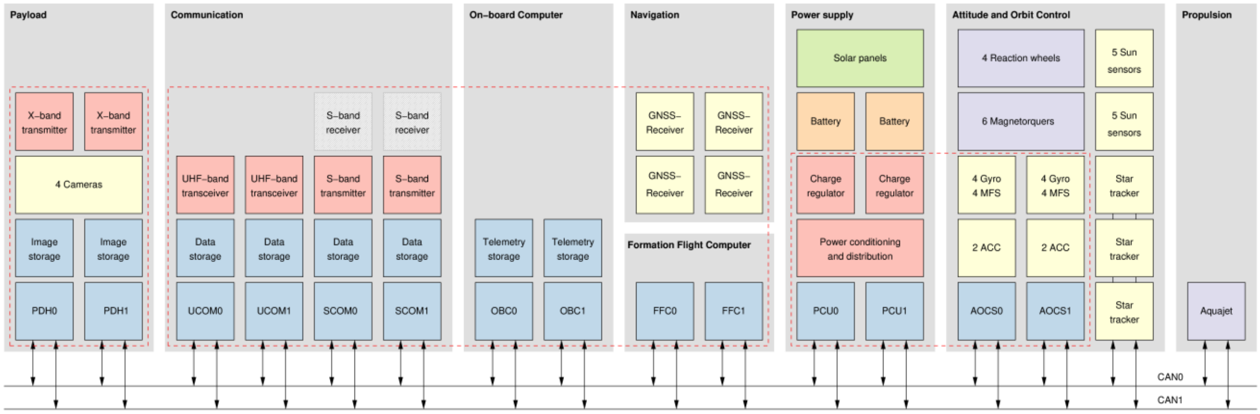


Figure 1: System Overview of NanoFF

The satellite is subdivided into three parts. Each part is also integrated individually and can be tested before being assembled with the other blocks. In Figure 2 the compartments can be seen. On the right side the propulsion system AQUAJET with a size of 0.6U. In the center the entire satellite bus with a size of 0.7U is placed. It includes the battery pack with a battery management system, the four reaction wheels, the PCU/AOCS board and the OBC/COM board. Between the two boards, the redundant magnetorquers are situated for one axis. The left side features the Star Trackers, two PCBs for the PDH and the X-Band transmitters and the camera system with its four spectral channels.

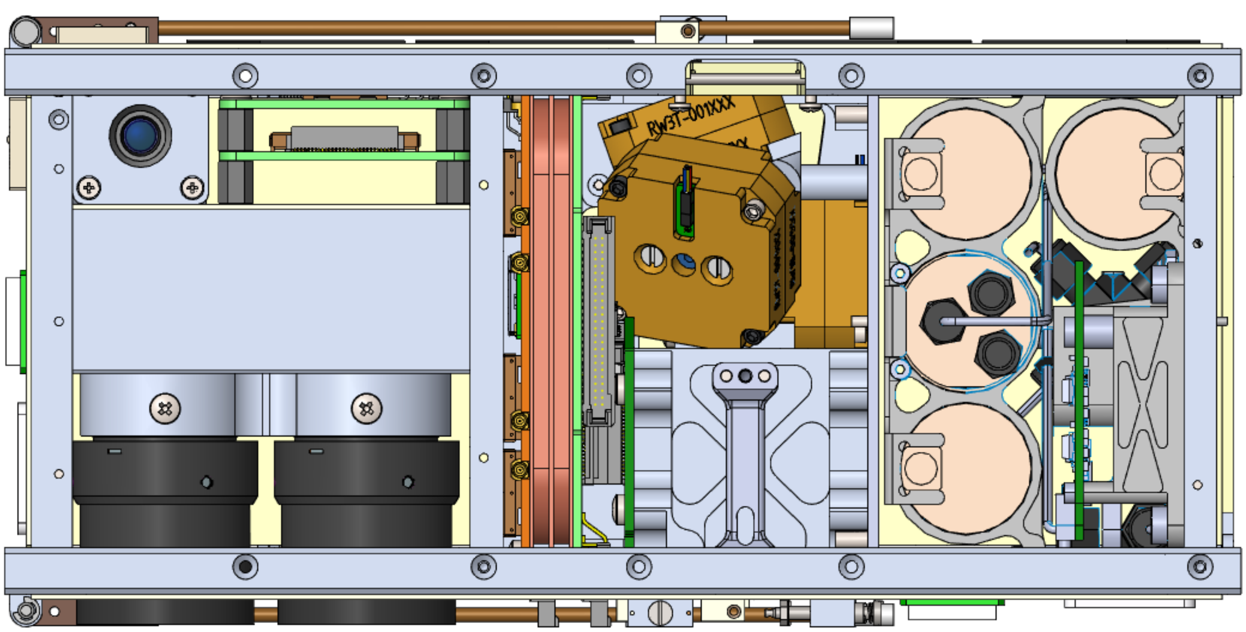


Figure 2: Subdivision of components

The satellite features mainly miniaturized components and subsystem, which are grouped to use the available space most efficiently. Nevertheless, the performance is comparable or better within the available satellite platforms. In Table 1 the main parameters can be seen. Additionally, an updated 3U version is planned. Most of the subsystems can be reused.

Table 1: Key parameters of NanoFF satellite bus

	2U NanoFF	3U NanoOOV
Communication		
Downlink UHF	Up to 9.6 kbit/s	Up to 9.6 kbit/s
Downlink S/X-band	Up to 4 Mbit/s	Up to 4 Mbit/s
Uplink UHF	Up to 9.6 kbit/s	Up to 9.6 kbit/s
Uplink S-Band	Up to 1 Mbit/s	Up to 1 Mbit/s
Electrical Power System		
Solarpower	36 W	55 W
Storage	47 Wh	47 Wh
AOCS		
Determination	30 arcsec	30 arcsec
Pointing	0.5°	0.5°
Position	5 m	1 m
Velocity	0.1 m/s	0.01 m/s
Propulsion	~ 15 m/s	~ 11 m/s
Payload Volume	0.7U (1.3U w/o propulsion)	1.6U (2.2U w/o propulsion)

3 STRUCTURE AND MECHNANISMS

A total of seven primary structural parts assure the integrity of the satellite during launch (see Figure 3). The bottom plate (4) integrates the propulsion system and feature a hole for the nozzle. Furthermore, there is a plate between the bus section and the payload compartment (2), which supports the rigidity of the entire system. Side elements (3,5) integrate the solar panel hinges and are used for the integration of the satellite bus subsystems. The top plate (7) completes the satellite and features interfaces for antennas and a Star Tracker. All these parts are connected with the rail structures (1,6).

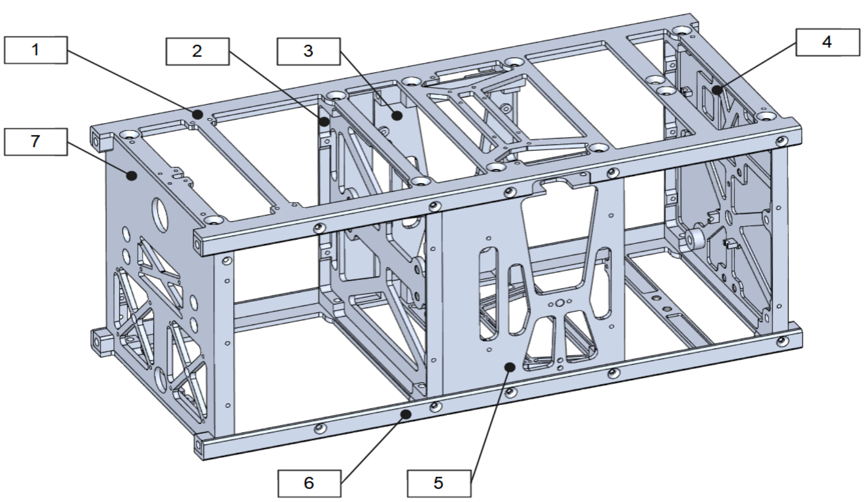


Figure 3: Primary Structural Parts

As mentioned above, the satellite bus is an independent block and can be integrated and tested separately. In Figure 4 an explosion view can be seen. It consists of a base plate (3), the two side elements (1,4) and a structure to support the reaction wheels and batteries (2,5). Furthermore, the main PCBs include interfaces to the rest of the satellite and to the EGSE. The PCU has connections to the side panels, which are used as a back plane to gather measurements from several sensors, connect the propulsion system and provide further subsystems with energy and communication lines. The OBC features connections to the EGSE to support software debugging and programming of all subsystems with a fully integrated satellite.

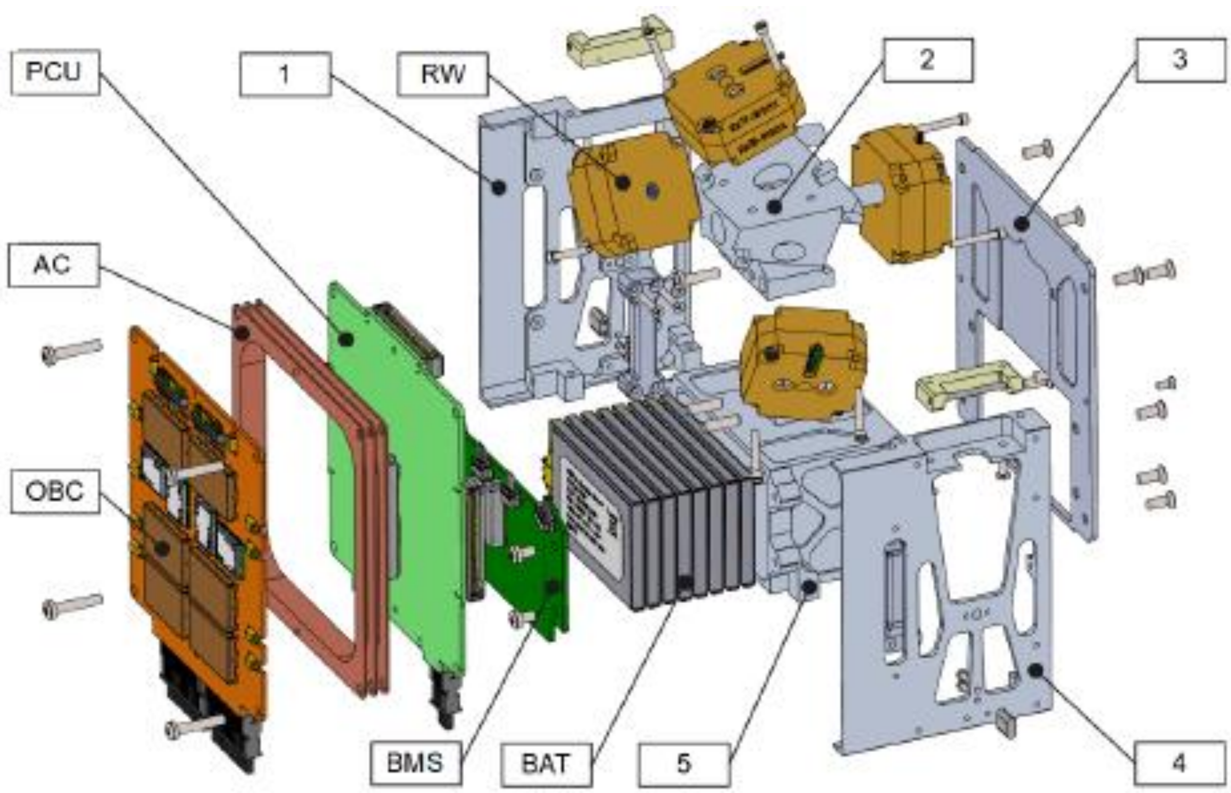


Figure 4: Explosion view of satellite bus

For the deployment of the UHF antennas as well as the solar panels a mechanism was implemented, which was used and updated throughout the satellite missions of TU Berlin, starting with BEESAT-1 in 2009. The last redundant design derived from the S-Net mission is was miniaturized for NanoFF to fit into the deployer. In Figure 5 all the elements of the mechanisms and features of the solar panels can be seen. This side of the satellite includes the mechanism for one UHF antenna and for both solar panels. A redundant heater (1) cuts the Nylon wire (2), which is guided through openings (3,6) and steering to hold the panels and the antennas. Furthermore, a pin (4) maintains the position of the solar panel during launch. An opening in the side panel (5) can be seen to include the temperature sensor (7) of the side panel. All the energy from the solar panel is wired from connector (8) to connector (10).

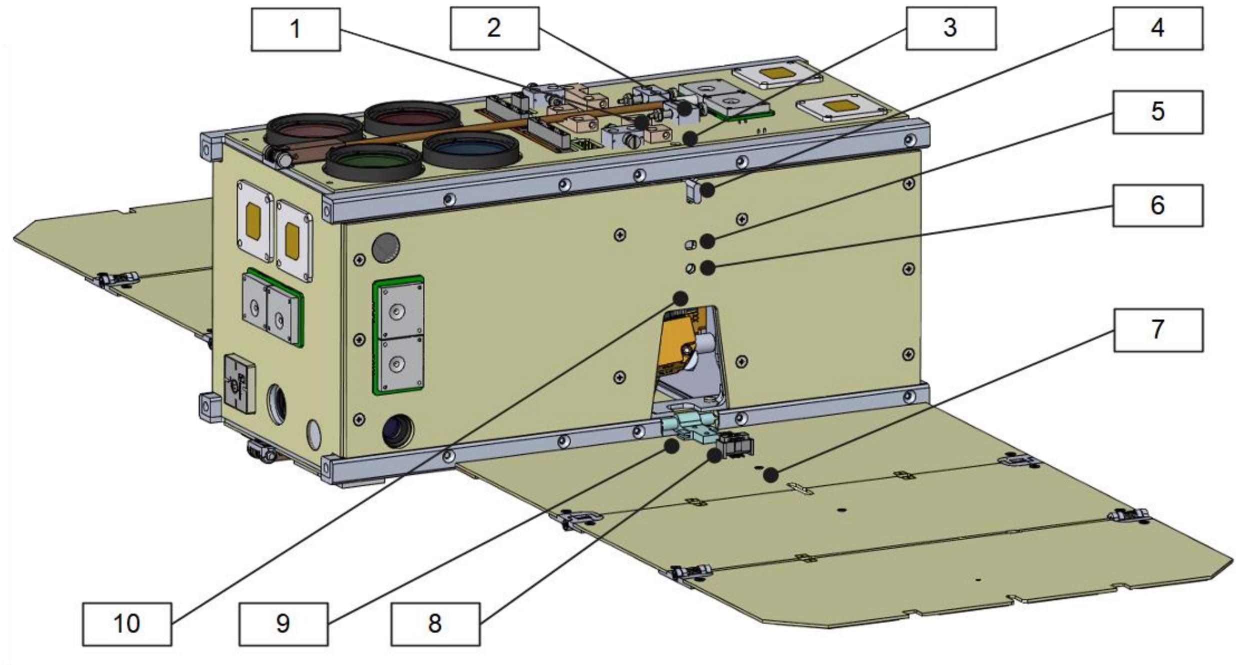


Figure 5: Mechanisms and connectors

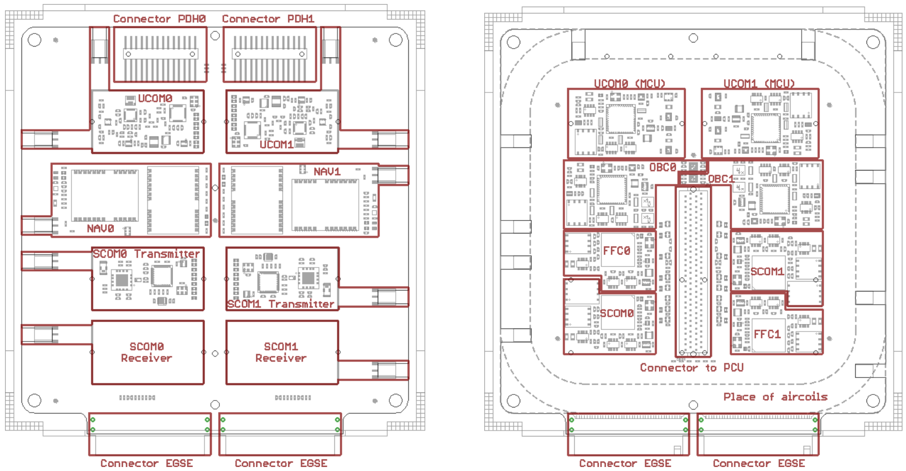
4 SATELLITE BUS ELECTRONICS

The electronics for the satellite bus compartment as shown in Figure 4 are implemented as two PCBs, the OBC/COM and PCU/ADCS, described in the following subsections. Each PCB contains two identical copies of the subsystems it contains, to achieve single-fault tolerant redundancy. Due to the high complexity and limited space, they are manufactured using 8 layer High-Density Interconnect (HDI) technology.

As shown in Figure 4, a redundant air coil (AC) which provides magnetic actuation in the X axis of the satellite is placed between the two boards.

4.1 ON-BOARD COMPUTER AND COM BOARD

The communication systems in UHF- and S-band (UCOM, SCOM), on-board computers (OBC), formation flight computers (FFC) and navigation receivers (NAV) are integrated together in a printed circuit board (see Figure 6). This board provides connectors to the power subsystem, to the payload and to the PDH as well as to several antennas.



(Top) *(Bottom)*

Figure 6: Multifunctional printed circuit board

4.2 Power Control Unit and Attitude Determination and Control Subsystem Board

The Electrical Power Subsystem (EPS) and Attitude and Orbit Control Subsystem (AOCS) are implemented in the PCU/AOCS board. Each redundant side of the AOCS consists of a microcontroller and two sensor packages, which are themselves redundant. Each sensor package contains an accelerometer, two gyroscopes and two magnetic field sensors. In total, there are eight gyroscopes, eight magnetic field sensors and four accelerometers. Figure 7 shows the board.

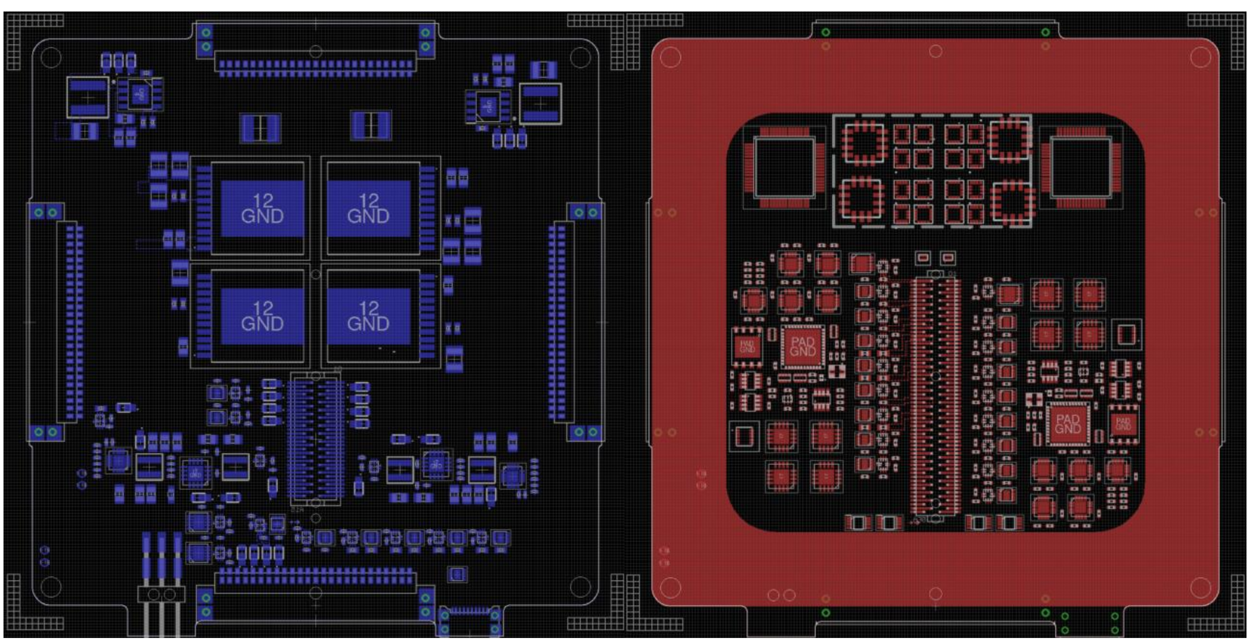


Figure 7: PCU and AOCS board

The EPS has three main functional blocks: solar energy conversion and battery charging, power conditioning, and power distribution and monitoring.

The low voltage from the solar cell strings (5-15V open circuit) is converted to an intermediate high voltage (20V) that is then regulated using the CC-CV method to charge the batteries. From the battery voltage, three bus voltages are made available: 12V (for the propulsion system), 5V (for the communications systems) and 3.3V (for the microcontrollers of all subsystems, and all deployment mechanisms).

The bus voltages are distributed through a series of power switches that are controlled by the Power Control Unit. The current flowing through each supply path is measured using current sense amplifiers and an array of analog-to-digital converters.

The solar panel arrangement used in NanoFF consists of seven strings of four high-efficiency multi-junction solar cells in series. Each panel of the deployable solar array wings contains three such strings (as shown in Figure 8), and an additional string is placed on one of the satellite's side panels (not shown in the figure).

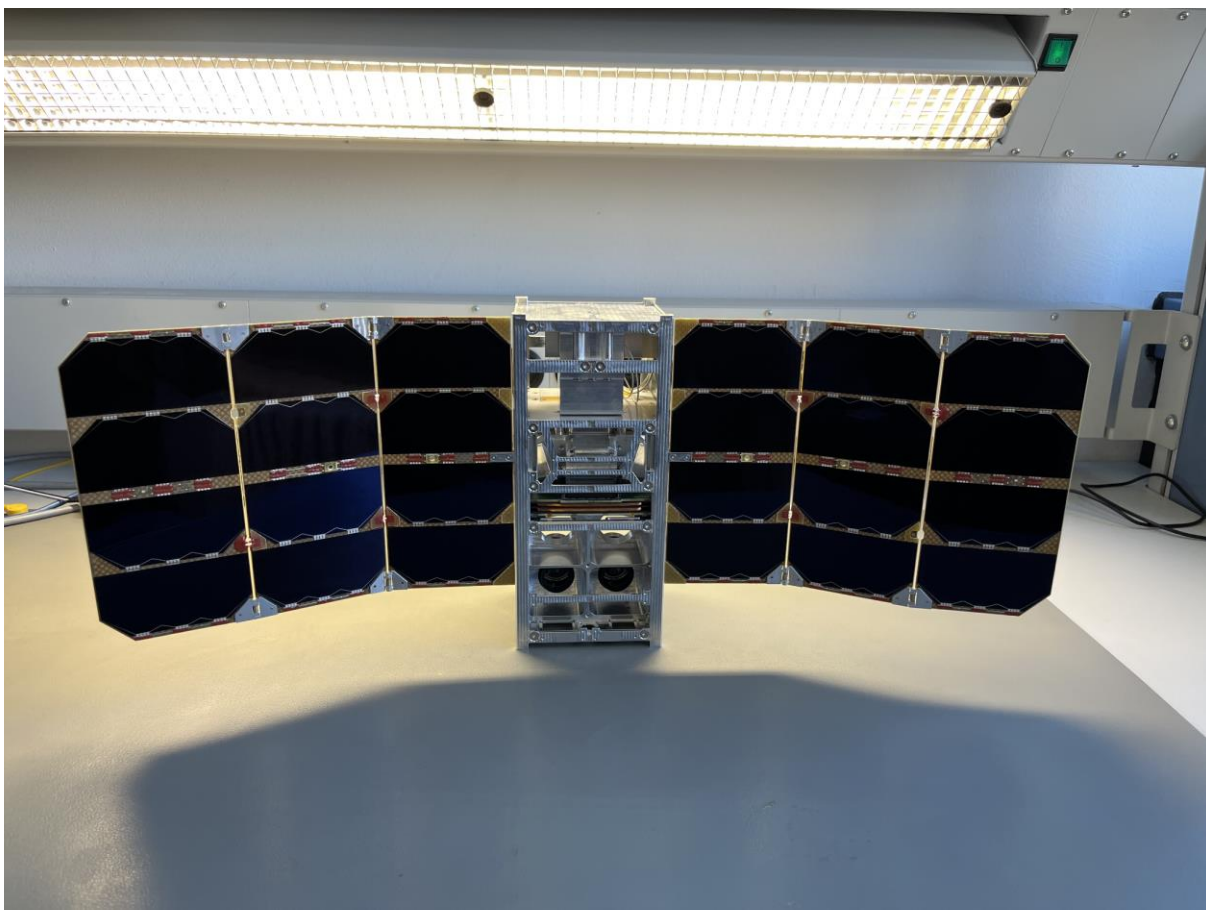


Figure 8: Satellite model with deplyed solar panels

The battery pack consists of two parallel strings of four Lithium-Ion cells in series (4s2p). Each battery cell (shown in Figure 9, left panel) is individually protected by a built in cell protection circuit that disconnects the battery when an under- or over-voltage condition is present. It can be reset by providing a trickle charge current. Additionally, a Battery Management board (shown in Figure 9, right panel) provides pack-level over- and under-discharge protection, as well as a cell balancing function.

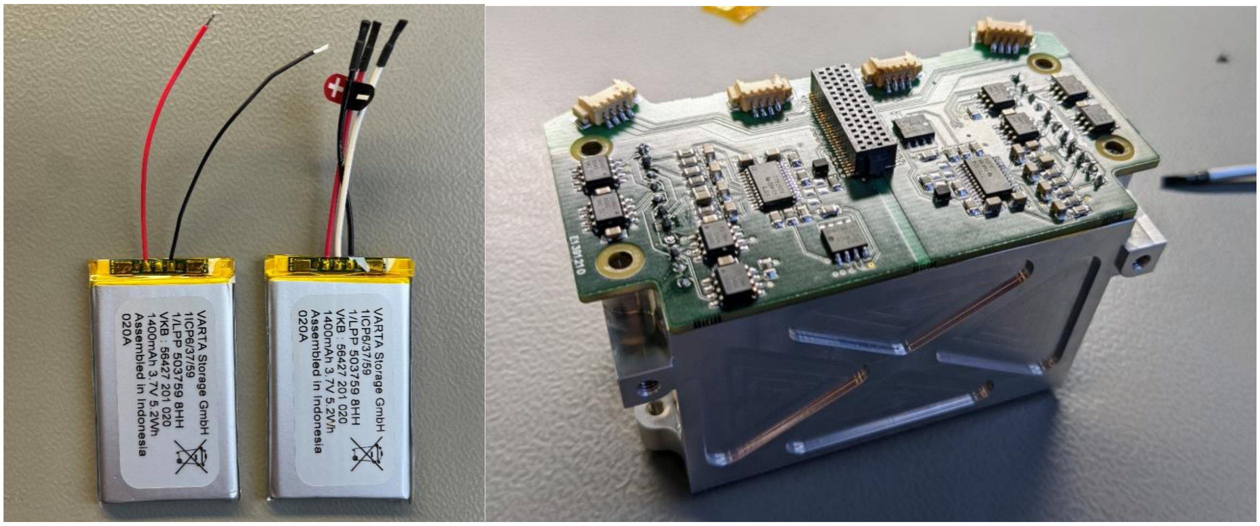


Figure 9: Battery cells and integrated battery compartment

6 PROPULSION SYSTEM AQUAJET

For the main objectives of the NanoFF mission, the formation flight in different relative orbits, the propulsion system AQUAJET was adapted, measured and integrated. It was verified in orbit within the TET-1 mission in 2012. It is an electro-thermical propulsion system. Due to its non-toxic propellant, water with anti-freeze add-on, low power consumption and high thrust, it is well suited for its usage within a small CubeSat. In Figure 10 the four integrated propulsion systems for the EQM, two FMs and the FS are shown.

Figure 10: Flight models of AQUAJET

The required electrical and data interfaces are provided by the satellite bus. The system itself is adapted to the CubeSat form factor to be integrated most efficiently. The main parameters of AQUAJET are shown in table Table 2

Table 2: Key Parameters of AQUAJET

Dimensions	94*x*94*x*59mm3 (without connectors and cables)
Mass	ca. 580*g* (incl. electronics, without connectors and cables)
Propellant mass	ca. 80*g*
Working fluid	Water and antifreeze
Pressure (MEOP)	ca. 5.8 *bar*
Vcc (nominal)	12*V* / 5*V* / 3.3*V*
Electric power	Max. 7*W*
Isp	up to 700*m/s*
Thrust	up to 4*mN*
Remark: Incl. electronics, 4 tanks with PMD, pressure transducers and temperature sensors, number of connecting fixation points: up to 14	

7 CAMERA SYSTEM FOR EARTH OBSERVATION

A multispectral camera system for Earth observation is the main payload of the NanoFF mission. With a ground resolution of around 30 m from the desired SSO at 525km altitude, it is comparable to the ESA mission Sentinel 2A and the NASA mission LANDSAT-8. Commercial-of-the-shelf optics and filters are used to achieve an MTF of around 0.4 over most of the image area. In Figure 11 the main components of the payload can be seen. The camera sensor features an FPGA to transfer the image data to the DRAM and finally to the flash storage on the PDH.

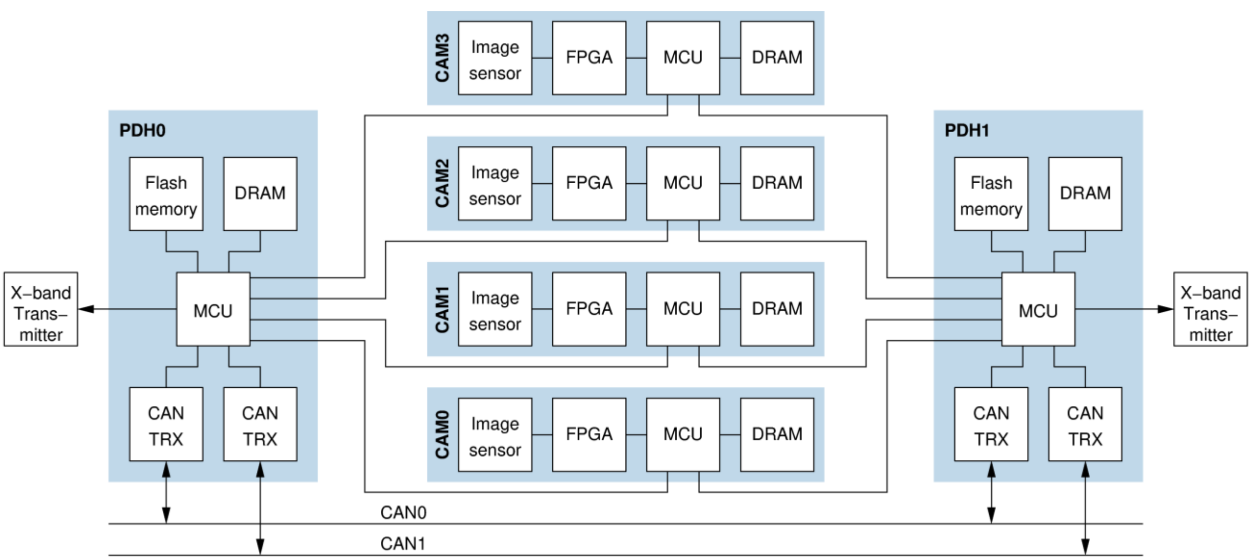


Figure 11: Block diagram of camera system and PDH

In Figure 12 a test image is shown. The two magnified cornes provide an illustration of the resolving power of the system. The CMOS global shutter image Sensor has a diagonal of 14 mm, a resolution of 12 million pixels at 2.74µm pixel size. The depth will be chosen at 12bit. With the mentioned altitude a swath width of 131km and an image height of 96km. The entire camera system shall be capable of capturing consecutive pictures to stich them flawlessly.

Figure 12: Test image of camera system

8 CONCLUSION

During the NanoFF mission a highly miniaturized and performant satellite bus has been developed. It meets all the requirements to accomplish the mission objectives. Furthermore, the core satellite bus can be used as a 3U CubeSat form factor as well. All key subsystems enable the integration of complex payloads in relation to downlink capabilities, energy consumption or pointing accuracy.

Within the operations of the two satellites during the NanoFF mission, the camera system with its four spectral channels will make use of all these subsystems as well as the formation of the satellites to experiment with possible Earth observation applications.