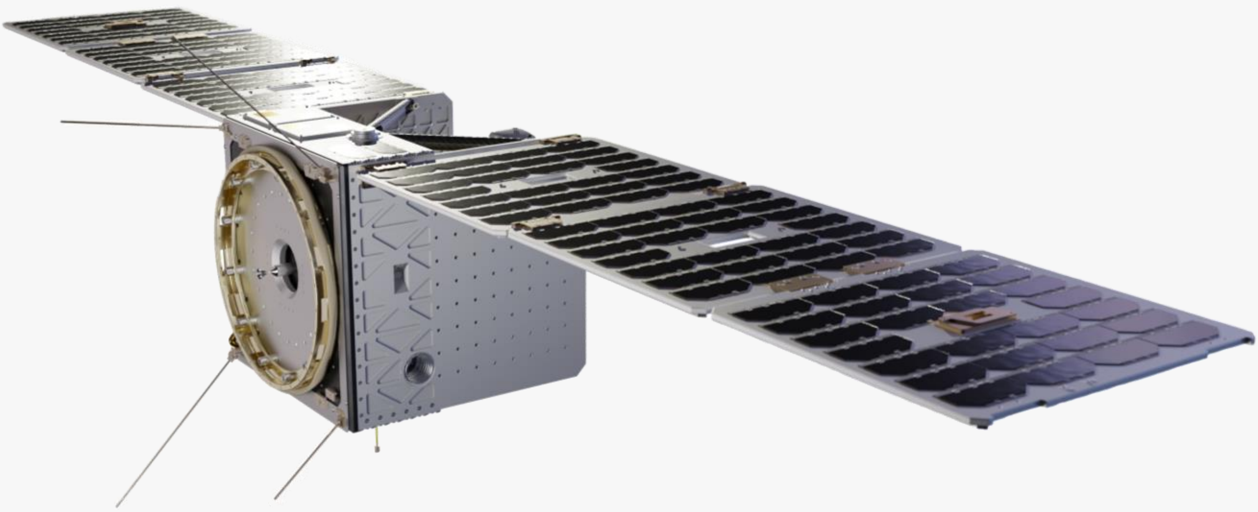

Microsatellite Bus MP42

Technical Information Summary

NA-MP42-G0-R0

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1 Microsatellite Bus MP42 Introduction

Hardware and software of NanoAvionics satellite bus MP42, as well as mission operations infrastructure, are established on baseline architecture and mission-specific "building blocks" for flexible, time & cost-efficient integration, resulting in wide applicability, reliability, repeatability and manufacturability.

MP42 buses are highly versatile – their performance capabilities are optimized for remote sensing, high data throughput & complex communications missions, emergency communications, and fundamental research missions. All requiring minimal reconfiguration.

All of the MP42 subsystems have been flight-proven during these different types of missions. Latest technological developments have been implemented to ensure the practical reliability of the platform. Critical systems such as the Flight Computer, Payload Controller, Electric Power System, and all others are 20krad radiation-tolerant and have an expected lifetime of 5 years in LEO. MP42 enables high payload data downlink speed – up to 1 Gbps downlink on the X-Band, while intersatellite link ensures uninterrupted real-time communications (LEO-LEO and LEO-GEO options available).

MP42 buses can include a propulsion system that enables the satellite to perform high-impulse maneuvers such as: orbital deployment, orbit maintenance, precision flight in formations, orbit synchronization, and atmospheric drag compensation. It results in extended satellite orbital lifetime uncovered new opportunities for the unique customer missions and significant savings on constellation maintenance costs.

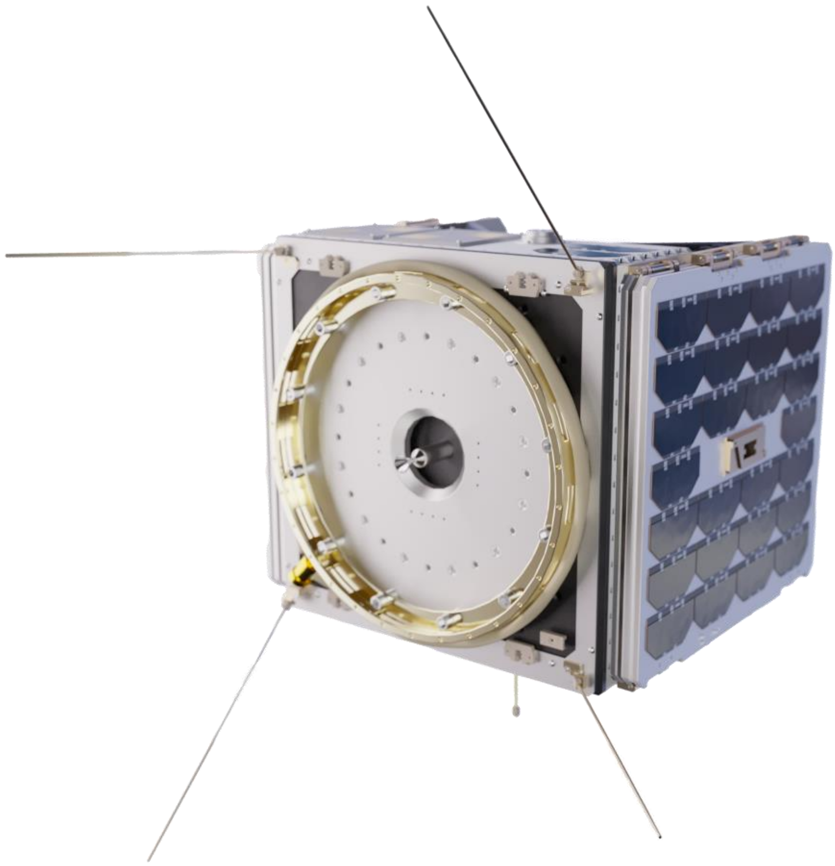

Figure 1. Microsatellite Bus MP42

2 MP42 Bus Features

Subsystem	MP42 Bus Specifications
General Features	• Total Empty Bus Mass: from 30 kg (depends on configuration). • Payload Envelope: 480 mm x 480 mm x 320* mm (*payload height is highly adjustable to customers payload requirements). • MP42 Bus is already pre-integrated (mechanically, electrically and functionally tested) and pre-qualified to be ready for instant payload integration. Therefore, final flight acceptance and flight readiness procedures are minimized for the Customer. • Default operation of MP42 Bus during satellite mission is implemented at command level by execution of uploaded scripts. • A sophisticated mission code can be prepared by the NanoAvionics team according to separately agreed terms and conditions.
Command, Control and Telemetry NanoAvionics “SatCOM UHF”	• ARM 32-bit Cortex™ M4 CPU with clock speed up to 72 MHz (configurable); • Modulations: GFSK2; • Receiver sensitivity (GFSK2, 2400 bps): -122 dBm; • RF output power: up to 3 W; • UHF beacon allows payload housekeeping data fragments to be included into the data packets; • TRL9.
Satlab S-Band Full-duplex Transceiver SRS-4 (Default)	• Receive frequency range: 2025-2110 MHz; • Transmit frequency range: 2200-2290 MHz; • Data rate TX: up to 10 Mbps; • Data rate RX: 128 kbps; • Transmit & Receive Modulation: BPSK, QPSK, 8PSK (only transmit); • Transmit power: adjustable 20-30 dB; • TRL9.
Satlab S-Band Full-duplex Transceiver SRS-3 (Optional)	• Receiver frequency range: 2025-2110 MHz; • Transmitter frequency range: 2200-2290 MHz; • Data rate TX: 500 kbps (without FEC); • Data rate RX: 128 kbps; • Modulation: GMSK; • Output Power: up to 30 dBm; • TRL9.
X-Band Transceiver (Optional)	• Frequency Uplink: 8025-8400 MHz; • Frequency Downlink: 7145-7250 MHz; • Transmit Modulation: BPSK, QPSK, 8PSK; • Linear RF output power: up to +30dBm; • Data rate Satellite to Ground: 25 Mbps+; • TRL9.
X-Band Transmitter (Optional)	• Bitrate: 3-50 Mb/s in Flight Configurable or 100 Mb/s Fixed; • Frequency Downlink: 8025-8450 MHz; • Modulation: OQPSK or QPSK; • Output Power: 30-33 dBm; • Contains LVDS Interface; • TRL9.
X-Band Transmitter (Optional)	• Carrier frequency (factory settable): 8100 - 8500 MHz; • Output power: 8 W (max T, EOL); • Modulation: QPSK, 8PSK, 16APSK, 32APSK; • Symbol rate (customizable): 200 Msymb/s; • Throughput: up to 1Gbps; • TRL9.

Large bus’s housekeeping data packets can be requested also as well as other high-speed S-band, X-band, Ka-band radio equipment options.

Subsystem	MP42 Bus Specifications
Payload Controller 2.0 (Default)	• Dual ARM A9 CPU running Linux; • 1 GB DDR3L or 512 MB DDR3L ECC protected volatile memory; • 3 x 4 Mbit FRAM high reliability storage; • 2 x 16 MB NAND storage; • 4 x microSD 32GB to 128 GB interfaces 2 x (1+1); • 22 LVDS pairs for flexible high bandwidth IO applications; • Over 40 GPIO for low-speed IO; • 4 x RS422 transceivers (up to 1 Mbps + 3x up to 10 Mbps); • 2 x I2C lines; • 2 x CAN (1 Mbps); • 2 x SPI interfaces; • 2 x 1 Gbps Ethernet; • USB 2.0 controller (accessible via expander board); • Flexible PCIe, SATA, USB 3.0 interfaces for high bandwidth applications (accessible via expander interface); • GPIOS, LVDS pairs and power supplies available at expansion interface; • 2 Load Switches for external power control; • Power input: 4.5 V to 15.5 V; • PC104 form factor; • Shield option available; • High capacity and high-speed storage with NAND Flash expansion board available; • TLR9.

Payload Controller 1.5 (Optional)	• ARM 32-bit Cortex™ M7 CPU with clock speed up to 400 MHz (configurable);
	• 1 MB of internal RAM;
	• MB of internal FLASH memory;
	• 512 kB of FMC-connected FRAM memory;
	• MB FMC-connected SRAM;
	• 256 MB of external NOR-FLASH for data storage (2 x two die (64 MB each) chips, QSPI);
	• 2×512 kB of FRAM (SPI) for frequently changing data storage;
	• Integrated TRC;
	• microSD NAND Memory support (up to 2 x 32 GB);
	• Three On-Board PWM Controlled H-Bridges;
	• PWM Outputs;
	• FreeRTOS;
	• In-Orbit firmware update;
	• Firmware Power-on-check and Restore;
	• RFS – Redundant Record-based File System;
	• A number of Payload dedicated interfaces:
	    • 100BASE-TX Ethernet port;
	    • CAN Interface;
	    • 2 x RS422 (on request interchangeable with 2 x RS485);
	    • 3 x buffered SPI;
	    • 2 x USART/UART;
	    • 2 x I2C;
	• CSP Support;
	• PC104 form factor;
	• TRL9.

Subsystem	MP42 Bus Specifications
NanoAvionics Electrical Power Supply "EPS" 2.0	• Input MPPT converters efficiency: up to 97 %; • Output converter efficiency: up to 97 %; • Power consumption: 650 mW; • Eight regulated voltage rails: 2x3.3V; 2x5V and four custom 3.3…42 V converters; • Unregulated voltage rail: 12-16.6 V (4S) to 24-33.2 V (8S); • TRL9; Outputs: • 20 output channels in default, up to 60 output channels in extended output version (configurable voltage rail); • Typical output channel current: 3A (configurable); • Max 3.3 V Output converter power: 40 W; • Max 5 V Output converter power: 50 W; • Max 3-18 V Output converter power: 50 W; • Max unregulated output power with default battery back (4S1P configuration): 50 W; • Max unregulated output power with extended battery pack (8S7P configuration): 600 W; Inputs: • Eight MPPT converters (16 solar panel input channels) with integrated ideal blocking diodes; • Solar panel voltage range: 5.2 – 42 V; • Max input power per MPPT converter: 50 W; • Max charging power with default battery back (4S1P configuration): 20 W; • Max charging power with extended battery pack (8S7P configuration) and extended input converters: 270 W.
Solar Panels (GaAs)	• Triple junction GaInP/GaInAs/Ge epitaxial structure Solar Cells; • Up to 30 % efficiency; • NASA-qualified low out gassing Solar Cell adhesive; • Magnetically clean circuit design without current loops to avoid spontaneous satellite spin up due to parasitic magnetic dipole effects; • Silicone applied over solder joints for atomic oxygen protection; • Integrated magnetometers and temperature sensors; • TRL9.

Subsystem	MP42 Bus Specifications
Flight Computer (Including ADCS functionality) NanoAvionics "SatBus 3C2"	• ARM 32-bit Cortex™ M7 CPU with clock speed up to 400 MHz (configurable); • Double-Precision FPU; • 1 MB of Internal RAM; • MB of Internal FLASH memory; • 2×512 KB of FMC-connected FRAM; • 256 MB of External NOR-FLASH for data storage; • 2×512 KB of FRAM (SPI) for frequently changing data storage; • Integrated RTC; • microSD NAND memory up to 32 GB; • On-board Magnetorquers Drivers; • PWM Outputs; • FreeRTOS; • In-orbit Firmware Update; • Firmware Power-on-check and Restore; • RFS – redundant record-based file system; • CSP Support; • Self-Diagnostics; • Dynamic CPU frequency control; • User-friendly console; • Mission Planner with time-scheduled script/task execution support; • Telemetry Logging; • TRL9; ADCS Sensors: • High precision Inertial Measurement Unit (IMU); • Magnetic Sensors System; • Albedo-free Fine Sun Sensors; • Star Trackers; Actuators: • Reaction Wheels System; • Integrated Magnetorquers; • Attitude Control type: 3-axis stabilization; Attitude pointing accuracy ranges (pointing/knowledge) depends on the final bus parameters: • Up to 0.05° / up to 0.01°; Attitude maneuver ability (Slew rate): • Up to 5°/s; Operational modes: • Sun pointing mode; • Nadir pointing mode; • Velocity pointing mode; • Ground geodetic coordinate pointing mode; • Client defined pointing mode.

Subsystem	MP42 Bus Specifications
Reaction Wheels System	Momentum: • 1.0 Nms (Nominal); Torque: • ±100 mNm at 0.8 Nms; Power Consumption: • 1.4 W @ 0.2 Nms (steady state); • 45 W @ 1.0 Nms (+60 mNm torque); • TRL9.
NanoAvionics Magnetorquers “SatBus MTQ”	• Nominal magnetic dipole strength of X, Y and Z axis magnetorquer coils @ 5 V: 1.0 Am^2; • TRL9.
GPS System Receiver	• Position accuracy: ± 2.5 m; • Velocity accuracy: ± 0.1 m/s; • Time Accuracy: ± 10 ns (if pulse-per-second signal is used); • TRL9.
Propulsion System NanoAvionics “EPSS C2“ (Default)*	• Thrust per Thruster: 1N BOL to 0,22N EOL; • Total Impulse: 1650 Ns; • Specific Impulse: 214 s; • Propellant mass: 0,8 kg; • TRL9.
Electrical Propulsion System (Optional)*	• Total Impulse: >5000 Ns; • System Mass (wet): 1,000 g; • System Volume: 0,6 dm^3; • TRL9.
Umbilical Connector	Umbilical connector is surface-mounted therefore shall be placed according to deployer specifics, to be accessible in case there is a requirement for the final check after integration. It contains the following interfaces through 16-pin connector: • Main Satellite CAN Bus; • Payload CAN Bus; • Battery Charging; • EPS Kill Switch Reset (KSR) – must be shorted to ground to reset; • EPS Kill Switch Override (KS) – must be shorted to ground to engage; Note: the same umbilical connector is being used to interface through the test chambers used by NanoAvionics.

*Other propulsion equipment options can be requested.

2.1 MP42 Architecture Diagram

The interaction between subsystems comprising the MP42 bus is described in Figure 2:

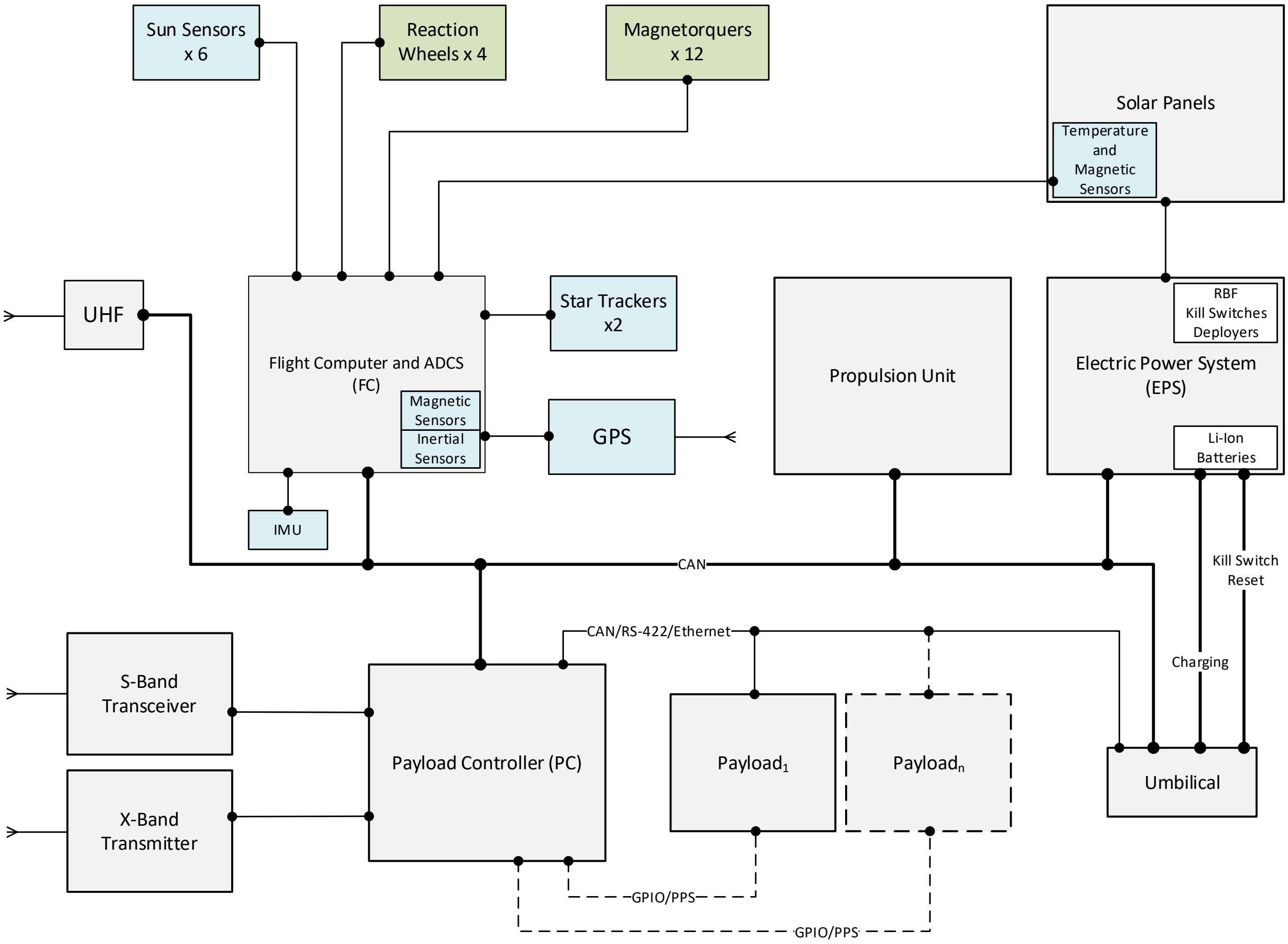

Figure 2. MP42 Architecture Diagram (may vary according to the final Customer's requirements)

3 MP42 Bus Power Configurations

The configuration of solar panels is fully dependent on mission requirements. Therefore, for the configuration estimation the Customer shall provide NanoAvionics with inputs such as:

- Desired orbit parameters;
- Payload specifications (power and duty cycle);
- Payload thermal requirements;
- Preliminary information on ground/orbital objects pointing (if any);
- Other critical data which could have an impact on power and thermal configuration.

Example power options available to practically handle thermal loads through excess heat dissipation are within the following ranges:

- **Example 1**: No Deployable Panels Configuration Giving up to 55 W OAP in SSO with Continuous Sun Tracking in dawn/dusk orbit;
- **Example 2**: High Power Single Deployable Panel Configurations Giving up to 160 W OAP in SSO with Continuous Sun Tracking in dawn/dusk orbit;
- **Example 3**: High Power Double Deployable Panel Configurations Giving up to 260 W OAP in SSO with Continuous Sun Tracking in dawn/dusk orbit;
- **Example 4**: High Power Triple Deployable Panel Configurations Giving up to 360 W OAP in SSO with Continuous Sun Tracking in dawn/dusk orbit.

It should be noted that the average power available for payload is **highly dependent** on the Satellite orbit and Customer mission requirements.

Figure 3. MP42 High Power Triple Deployable Panel Configuration

4 MP42 Payload Installation

The MP42 bus allows easy and fast integration of the payload through baseline electrical, data, software, mechanical and thermal interfaces as well as extensive documentation and professional Customer support. NanoAvionics engineers can also perform the Payload integration in order to ensure smooth and reliable operation throughout the entire mission's lifetime.

The mechanical brackets and harness needed to accommodate the payload instruments are provided by NanoAvionics to ensure mechanical rigidity and stability of the payload allocation. Thermal control, power and data interfaces are connected under the guidance or recommendations of the NanoAvionics team.

Additional qualification, EM compatibility or functional testing might be performed if required by the Customer or launch provider for safety or flight acceptance reasons.

5 Payload Interfaces

5.1 Payload Interfaces – Mechanical Layout

NanoAvionics microsatellite buses offer flexible envelopes for the Customer's payload, thus significantly reducing mechanical constraints for payload integration. The bus package also includes all required harnesses (wires and connectors) to connect the payload and prepare the flight software through programming, debugging and umbilical interfaces which allows software upload and charging of the satellite when fully integrated.

NanoAvionics provides extensive documentation and excellent Customer support, allowing smooth and quick payload integration. If needed, Customer can request the Payload integration to be performed by NanoAvionics.

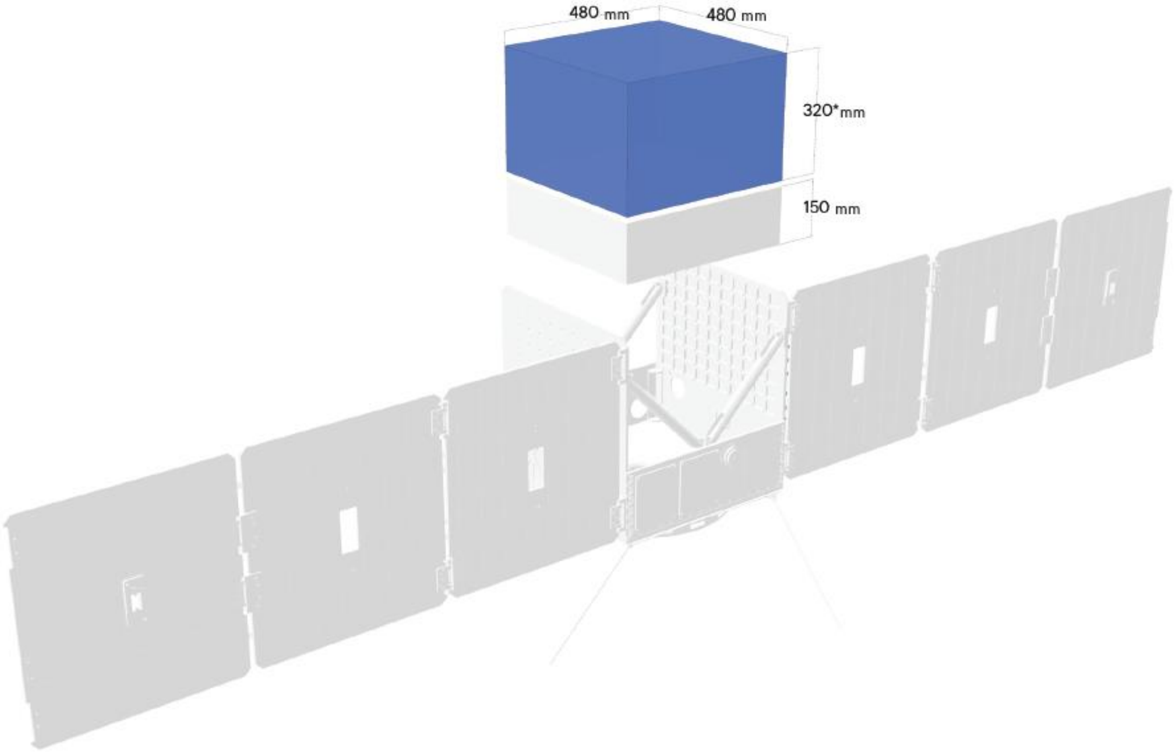

Figure 4. MP42 mechanical layout (blue color marks the payload volume)

*Adjustable according to customer's payload requirements.

5.2 Data and Power

All signals and power channels are available on Molex Pico-Lock type connectors. Power is connected directly to the EPS and Data is connected to the Payload Controller.

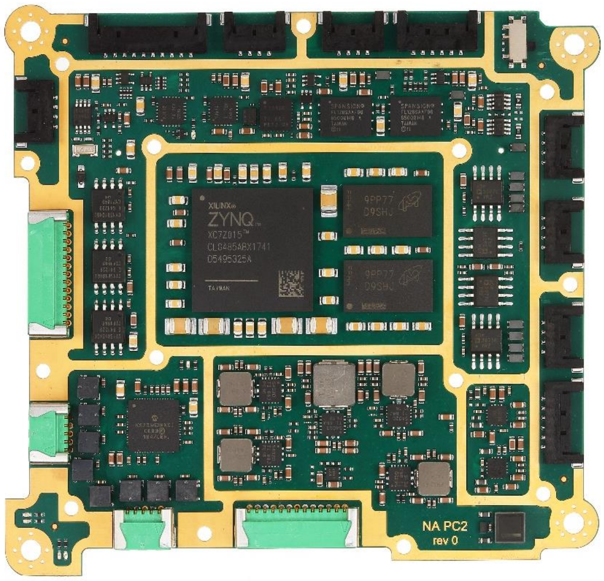

Figure 5. Payload Controller 2.0

Table 1. Payload Interface Options

Default	Optional
• I2C x2; • SPI x2; • CAN x2; • RS-422 x4; • LVDS (22 pairs); • Ethernet (1 Gbps) x2.	• 4 UART interfaces; • 44 GPIO pins; • 24 LVDS pairs (48 GPIO pins) available on expansion board; • PCIE x2, SATA, USB 3.0, SpaceWire interfaces available on the expansion board.

6 Payload Development Continuous Integration for Testing

The Customer can fully integrate the Payload development and testing process with the MP42 bus employing MP42 FlatSat without waiting for the MP42 bus engineering or flight module delivery. Access to the FlatSat is granted right after contract signature. MP42 FlatSat accelerates Payload development, integration and the testing cycle as well as enabling simulation of the entire satellite mission. Access to the FlatSat will be provided by employing a TCP/IP connection that can be used as a link for CSP or other protocol packets, giving the ability to access the main MP42 CSP network or other MP42 software remotely.

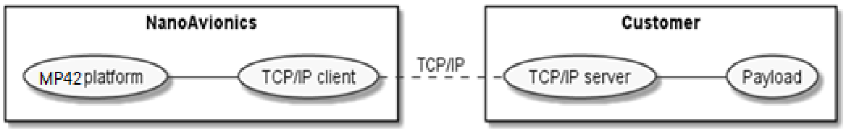

Figure 6. Payload Integration into MP42 bus During Software Development and Testing Phase

NanoAvionics provides software tools to remotely connect to the Flat-Sat over TCP/IP link using NNG protocol and the established connection is used for command-and-control CSP packets. CSP packet encapsulation in NNG messages is described in CSP Bridge software interface control document.

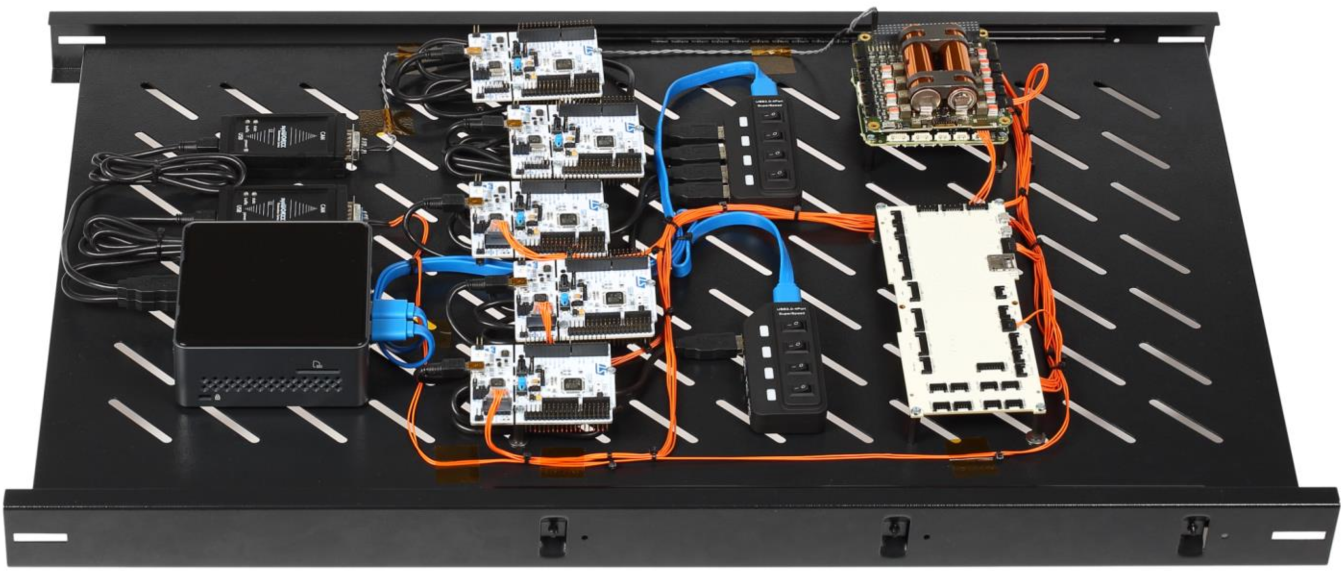

Figure 7. M6P “FlatSat” – Simulator Accessible by Internet for Remote Payload Development Purposes (Photo Credit: NanoAvionics)

7 Qualified Design

MP42 bus and its comprising electronic and mechanical subsystems have been designed based on the requirements of EUROPEAN COOPERATION FOR SPACE STANDARDIZATION (ESA ECSS) of European Space Agency document TEC-SY/128/2013/SPD/RW '*Tailored ECSS Engineering Standards for In-Orbit Demonstration CubeSat Projects*'. Overall, our design is based on these ECSS standards and handbooks:

- ECSS-E-ST-10-02C Verification;
- ECSS-E-ST-10-03C Testing;
- ECSS-E-ST-10-04C Space environment;
- ECSS-E-ST-20C Electrical and electronic;
- ECSS-E-ST-20-08C rev.1 Photovoltaic assemblies and components;
- ECSS-E-ST-31C Thermal control general requirements;
- ECSS-E-ST-32C Rev.1 Structural general requirements;
- ECSS-E-ST-32-01C Rev.1 Fracture control;
- ECSS-E-ST-32-02C Rev.1 Structural design and verification of pressurized hardware;
- ECSS-E-ST-32-08C Materials;
- ECSS-E-ST-33-01C Mechanisms;
- ECSS-E-ST-35-01C Liquid and electric propulsion for spacecraft;
- ECSS-E-ST-50C Communications;
- ECSS-E-ST-50-05C Radiofrequency and modulation;
- ECSS-E-ST-60-30C Satellite attitude and orbit control system (AOCS) requirements;
- ECSS-E-ST-35-06C - Cleanliness requirements for spacecraft propulsion hardware;
- ECSS-E-ST-32-02C - Structural design and verification of pressurized hardware;
- ECSS-E-HB-32-25A - Mechanical shock design and verification handbook;
- ECSS-E-HB-32-26A - Spacecraft mechanical loads analysis handbook (edited);
- ECSS-E-ST-35C Rev 1. - Propulsion general requirements;
- ECSS-E-ST-35-01C – Liquid and electric propulsion for spacecraft;
- ECSS-Q-ST-70-08C, Manual soldering of high-reliability electrical connections;
- ECSS-Q-ST-70-38C Rev.1 – High-reliability soldering for surface-mount and mixed technology;
- ECSS-Q-ST-70-28C – Repair and modification of printed circuit board assemblies for space use;
- ECSS-Q-ST-70-26C Rev.1 – Crimping of high-reliability electrical connections.

NanoAvionics also follows IPC-A-610 class 3 standards. Design of each subsystem of the MP42 bus has been qualified by thermal vacuum cycling, vibration and shock testing following the National Aeronautics and Space Administration GENERAL ENVIRONMENTAL VERIFICATION STANDARD (NASA GEVS GSFC-STD-7000A) levels.

Electromagnetic Compatibility (EMC) testing at the bus level has been performed qualifying robustness against adverse effects of electromagnetic interference from external sources, internal subsystems or the electromagnetic environment of the space.

To ensure 7 years operational lifetime in LEO all subsystems of MP42 have been radiation tested under 20 kRad Total Ionizing Dose (TID) which recreate total accumulated radiation dose in space environment in SSO up to 800 km over 7 years period at peaks of the Solar activity (i.e., worst case). Additionally, mechanically complex subsystems such as reaction wheels and propulsion units have been tested by accelerated lifetime tests to qualify proper functionality for at least 7 years period.

Design qualification testing reports of MP42 can be disclosed to the Customer if requires.

The most importantly all of the hardware provided by NanoAvionics has been flight proven in space during the numerous missions.

8 Quality Control Features

High industrial standards and procedures are applied to control the quality of NanoAvionics electronics, mechanical systems and software.

Electronic subsystems assembled and qualified in accordance to the IPC-A-610 class 3 by IPC certified specialists applying the requirements for each individual electronic component containing the systems. 3 dimensional Automatic Optical and X-Ray inspection is performed for each of the assembly.

Mechanical components are subject to measurement checks for tolerance control. Incoming and outgoing items inspection is performed at NanoAvionics to minimize the risk of faults and failures due to the discrepancy of the components.

For traceability purposes each system has a unique number indicated, where the serial number refers to a unique item list and the technical documentation of the product. Incoming/outgoing inspection documentation can be released to the Customer if required.

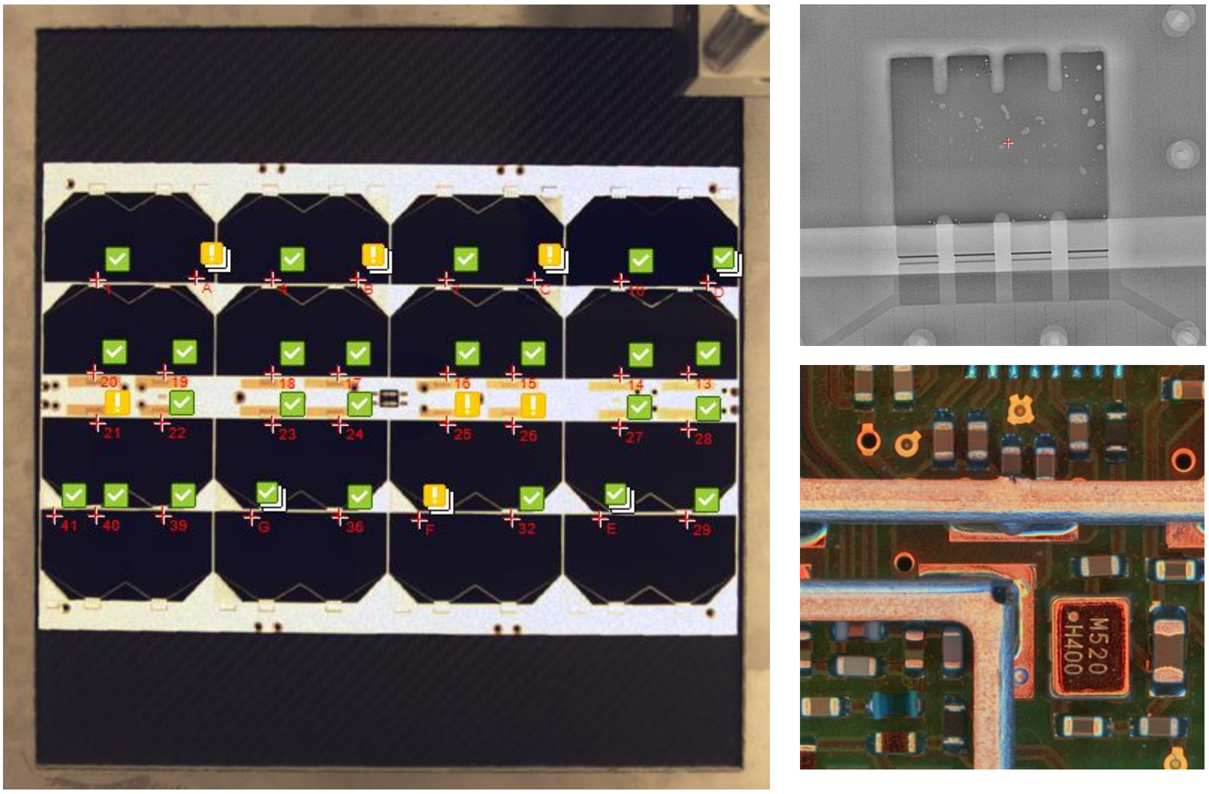

Figure 8. Optical and X-Ray inspection of electronic components and soldering quality

Final MP42 bus assembly is conducted following the predefined assembly plan, standard and customized component list, customized configuration sheets. Internal subsystems are assembled and integrated into the frame structure sequentially, verifying their functionality as per designed parameters and mechanical properties. After complete assembly MP42 bus undergoes functional testing which is being performed following European Space Agency EUROPEAN COOPERATION FOR SPACE STANDARDIZATION (ESA ECSS) guidance. NanoAvionics also follows the documentation list and content suggested by ECSS standard for nano and micro satellites development.

Finally, NanoAvionics follows quality control procedures by ISO 9001. The company is certified since 2018.

9 Ground Station and Mission Operations

NanoAvionics has extensive experience in operating satellites in an optimal manner, taking into account data and power constraints, while using payload instruments on-board the satellite. The company's satellite operations center offers cost-effective support for satellite operations, while ensuring the highest standards of data security. To meet demanding customers' missions' requirements, NanoAvionics have developed powerful mission control software which is capable of handling multiple satellite missions.

The company provides global coverage using its extensive ground stations network, which includes NanoAvionics owned ground stations in Denmark, Lithuania and the USA, as well as commercial partners' ground stations in over 200 locations around the globe (KSAT, LeafSpace, AWS and others).

Figure 9. NanoAvionics used Ground Station network

Mission Control Software (MCS) provided by NanoAvionics is compatible to any of above-mentioned options. Customer's access MCS and controls the Ground Station or access the external ground station networks through a defined Application Programming Interface (API). The Graphical User Interface (GUI) is to be developed by the Customer itself. If required, NanoAvionics may provide a mission specific interface under the separate agreement. All satellite operations are carried out through the established internet (TCP/IP) connection, ensuring confidentiality of the Customer data.

For more technical details on Mission Control Software (MCS), Application Programming Interface (API) and NanoAvionics Ground Station hardware please refer to the following document:

- NanoAvionics MCS API Description;
- NanoAvionics Ground Station Hardware Description.

10 Disclaimer

The information in this document is subject to change without notice and should not be construed as a commitment by NanoAvionics, Corp. NanoAvionics assumes no responsibility for any errors that may appear in this document.