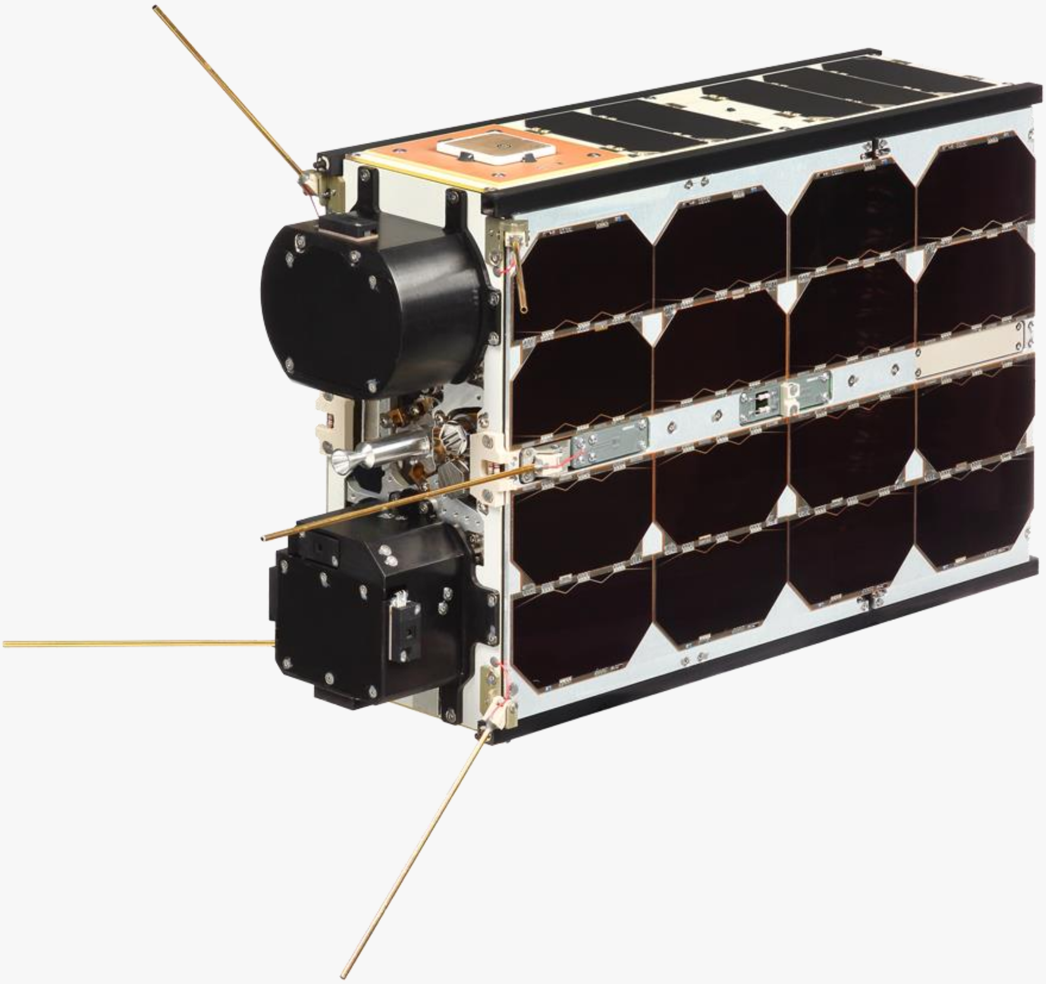

Multi-Purpose 6U Satellite Bus

Technical Overview

NA-M6P-TO-R000

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1 M6P (Multi-purpose 6U Bus) Introduction

The standard configuration of the bus is optimized for IoT, M2M, ADS-B, AIS and other commercial and emergency communication applications as well as scientific missions. Also, as an option - M6P configuration for Earth Observation (EO) missions are available. The M6P hardware layout allows for the maximization of volume available for the payload. The layout also ensures robust power properties and thermal control for sensitive payloads, such as measurement and sensing instruments. To ensure the practical reliability of the bus, radiation-resistant components and design implementation have been incorporated in critical systems such as the Flight Computer, Payload Controller, Electric Power System and Communication System.

The M6P bus has implemented intersatellite link system via GEO satellites and integration with KSAT ground station network for constant connectivity eliminating data and tasking delay challenges critically important for professional service applications.

The M6P bus includes a propulsion system capable of performing high-impulse manoeuvres such as orbital deployment, orbit maintenance, precision flight in formations, orbit synchronization and atmospheric drag compensation, resulting in new opportunities for unique Customer missions and significant savings on constellation maintenance costs. The propulsion unit also provides satellites with decommissioning capability at the end of mission, meeting the space debris mitigation requirements of ESA and NASA.

Each of M6P users is provided with an access to M6P *FlatSat* which helps to accelerate development process, payload integration and testing cycle as well as enable simulation of the entire satellite mission.

NanoAvionics also provides M6P-optimized launch integration services for PSLV (India). The Company also has access to Rocket Lab Electron (New Zealand), SpaceX Falcon 9, Soyuz, Vega, Long March, Orbital Sciences Antares and Atlas V launch vehicles. Launch integration services cover programmatic aspects including securing the specific launch slot, coordination of logistics, arrangement of mission-specific documents and technical aspects related to flight preparation and integration of the spacecraft with the deployer.

Figure 1. Multi-Purpose 6U Bus (M6P)

2 M6P Bus Features

Subsystem	M6P Bus Specifications
General Features	• Total Empty Bus Mass: 4,500 g / 5,500 g • Payload Volume: up to 5U • M6P 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 M6P 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. • A payload integration service can be performed by the NanoAvionics team according to separately agreed terms and conditions. • Inter-satellite link for regular connectivity.

Payload Controller (PC)	Payload Controller 1.5 (default):
	• ARM 32-bit Cortex™ M7 CPU with clock speed up to 400 MHz (configurable)
	• 1 MB of internal RAM
	• 2 MB of internal FLASH memory
	• 512 kB of FMC-connected FRAM memory
	• 4 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

NanoAvionics Electrical Power Supply “EPS”	• Input, Output Converter Efficiency: up to 96 % • Battery Cells Balancing • Configurable Thermal Control System • Supported Data Interfaces: CAN with CSP protocol support, UART for configuration • Integrated RTC with Backup Power Supply • Fail-safe Design: in case of total microcontroller malfunction EPS will go to emergency mode and selected emergency channels will keep satellite operational Outputs (Over-current protected): • 4 regulated Voltage Rails: 3.3 V; 5 V; 3 V – 18V configurable • Unregulated Battery Voltage (Switchable): 6.0 V - 8.4 V • Up to 18 Regulated Configurable – 3.3 V / 5 V / 3 - 18 V • Typical Output Channel Current: 3.13 A • Consistent 3.3 V Rail Output: 20 W • Consistent 5 V Rail Output: 20 W • Consistent 3 - 18 V Rail Output: 20 W • Consistent Unregulated (V_{Bat}) Output: up to 175 W

	Inputs: • 4 MPPT Converters (8 channels) with Integrated Ideal Blocking Diodes • Voltage: 2.6 - 18 V • Max Input Power per Converter: 25 W • Max Charging Power: up to 70 W Batteries: • 8 cells; 7.4 V; 13,600 mAh; 92 Wh
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 • 2 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 ADCS Sensors: • High precision Inertial Measurement Unit (IMU) • Magnetic Sensors System • Fine Sun Sensors • Star Tracker 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 0.1° / up to 0.05° Stability accuracy (Jitter): • ± 0.004°/s (at f > 4 Hz) 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

2.1 M6P Architecture Diagram

The interaction between subsystems comprising the M6P bus is described in Figure 2.

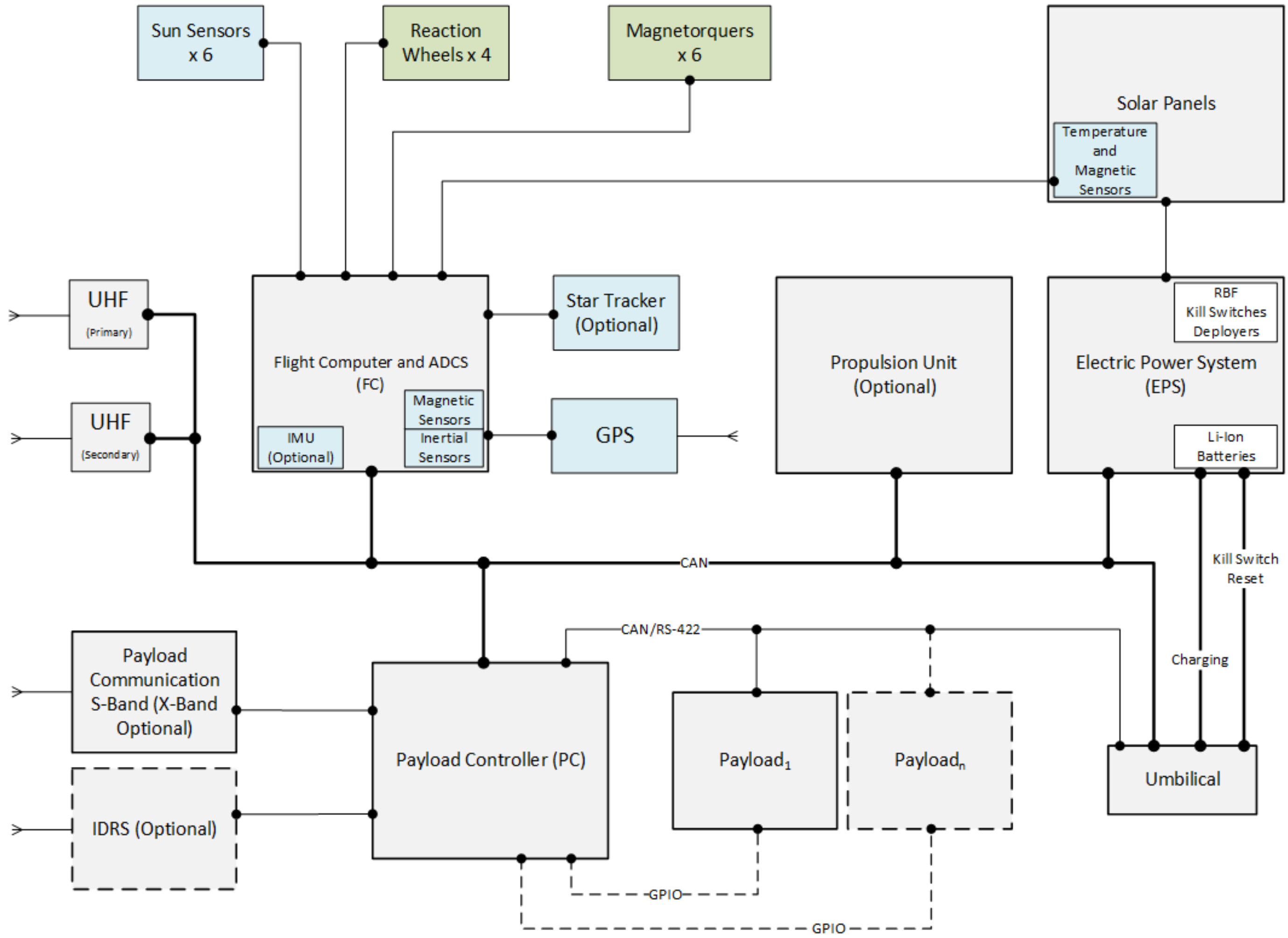

Figure 2. M6P Architecture Diagram (may vary according to the final Customer's requirements)

3 Propulsion System EPSS C1.5

The Enabling Propulsion System for Small Satellites (EPSS) C1.5 is a versatile system allowing nano-satellites to perform:

- Constellation deployment and formation flights;
- Drag compensation and orbit maintenance;
- Orbital maneuvering, including Hohmann transfer;
- Synchronization and positioning of communication equipment and payload instruments;
- De-orbiting at the end of the mission and other functions.

The EPSS system runs on an ADN-based mono-propellant blend which has up to a 6 % higher specific impulse and 24 % higher energy density compared to rival hydrazine employed systems, permitting significant levels of thrust impulse to be performed within a relatively small propellant storage volume.

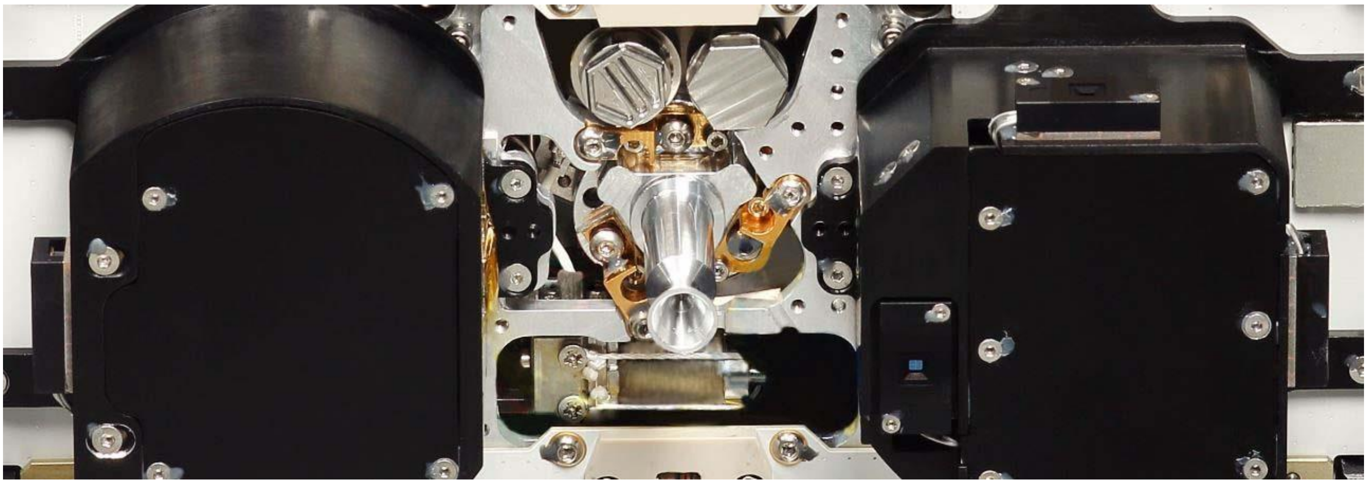

Figure 3. EPSS C1.5 on M6P Satellite Platform (Photo Credit: NanoAvionics)

4 Qualified Design

The M6P bus and its comprising electronic and mechanical subsystems have been designed following the requirements of EUROPEAN COOPERATION FOR SPACE STANDARDIZATION (ESA ECSS) of European Space Agency and IPC-A-610 class 3 standards.

NanoAvionics follows the protoflight model philosophy as described in ECSS-E-HB-10-02A to qualify the design.

This approach is applied to projects whose characteristics are:

a. no critical technology is employed in the design,
b. qualified products are extensively used, and
c. compromise is permitted to reduce cost by accepting a moderate level of risk.

The pure protoflight approach is based on a single model (protoflight model: see Figure 4) to be flown after it has been subjected to a protoflight qualification and acceptance test.

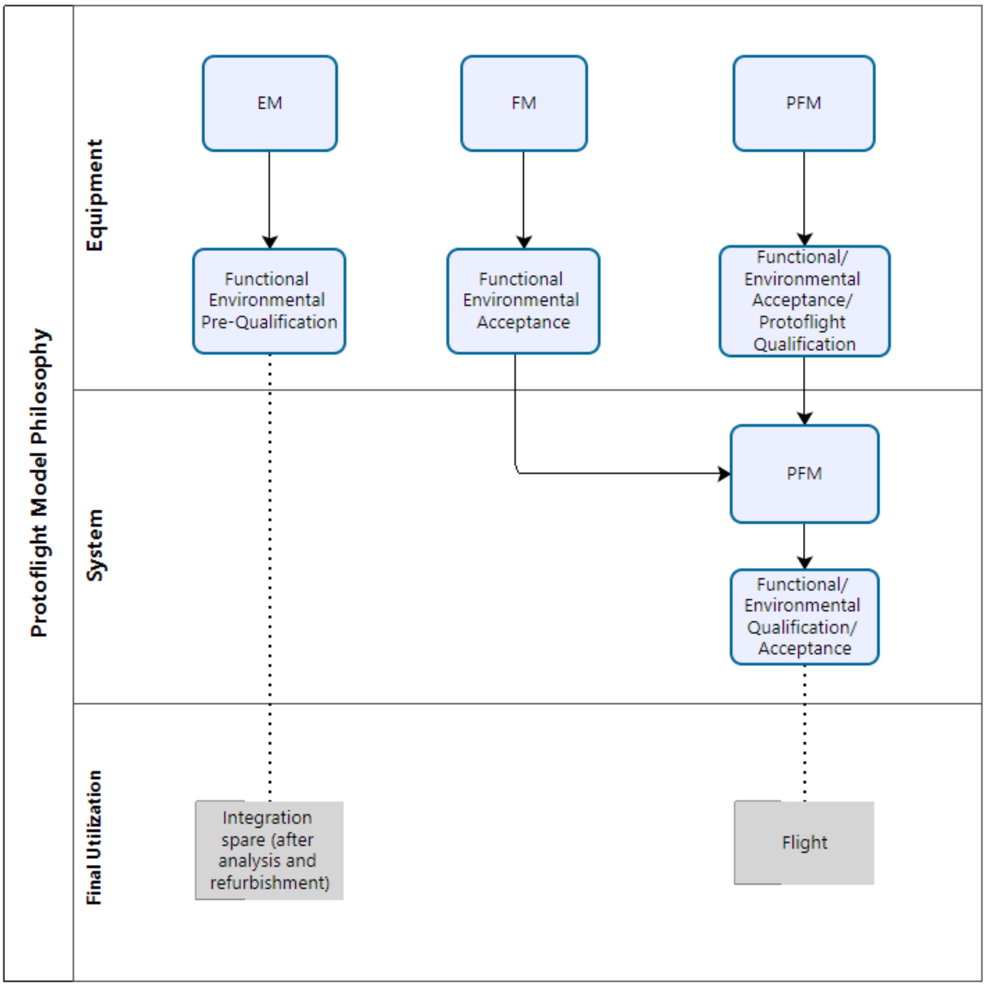

Figure 4. Protoflight model philosophy

Design of each subsystem of the bus has been qualified by thermal vacuum cycling, vibration and shock testing following National Aeronautics and Space Administration GENERAL ENVIRONMENTAL VERIFICATION STANDARD (NASA GEVS GSFC-STD-7000A) levels. Overall, our design is based on these ECSS standards and handbooks:

- ECSS-E-ST-10-02C Verification
- ECSS-E-ST-10-03C Space Engineering: Testing
- ECSS-E-ST-10-04C Rev.1 Space environment
- ECSS-E-ST-20C Rev.1 Electrical and electronic
- ECSS-E-ST-20-08C Rev.1 Photovoltaic assemblies and components
- ECSS-E-ST-31C Thermal control
- 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 pressurised hardware
- ECSS-E-ST-32-08C Rev.1 Materials
- ECSS-E-ST-33-01C Rev.2 Mechanisms
- ECSS-E-ST-35-01C Liquid and electric propulsion for spacecraft
- ECSS-E-ST-50C Communications
- ECSS-E-ST-50-05C Rev.2 Radiofrequency and modulation
- ECSS-E-ST-60-30C Satellite attitude and orbit control system (AOCS) requirements
- ECSS-E-ST-35-06C Rev.2 Cleanliness requirements for spacecraft propulsion hardware
- ECSS-E-ST-32-02C Rev.1 Structural design and verification of pressurised hardware
- ECSS-E-HB-10-02A Verification
- 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-20C Quality assurance
- ECSS-Q-ST-10C Rev.1 – Product assurance management
- ECSS-Q-ST-70-08C Manual soldering of high-reliability electrical connections
- ECSS-Q-ST-70-38C Rev.1 Corrigendum1 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

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 space.

All subsystems of proposed satellite bus have been radiation tested under 20 kRad Total Ionizing Dose (TID). Additionally, mechanically complex subsystems such as reaction wheels have been tested by accelerated lifetime tests to qualify proper functionality.

Design qualification testing reports of M6P 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.

5 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.

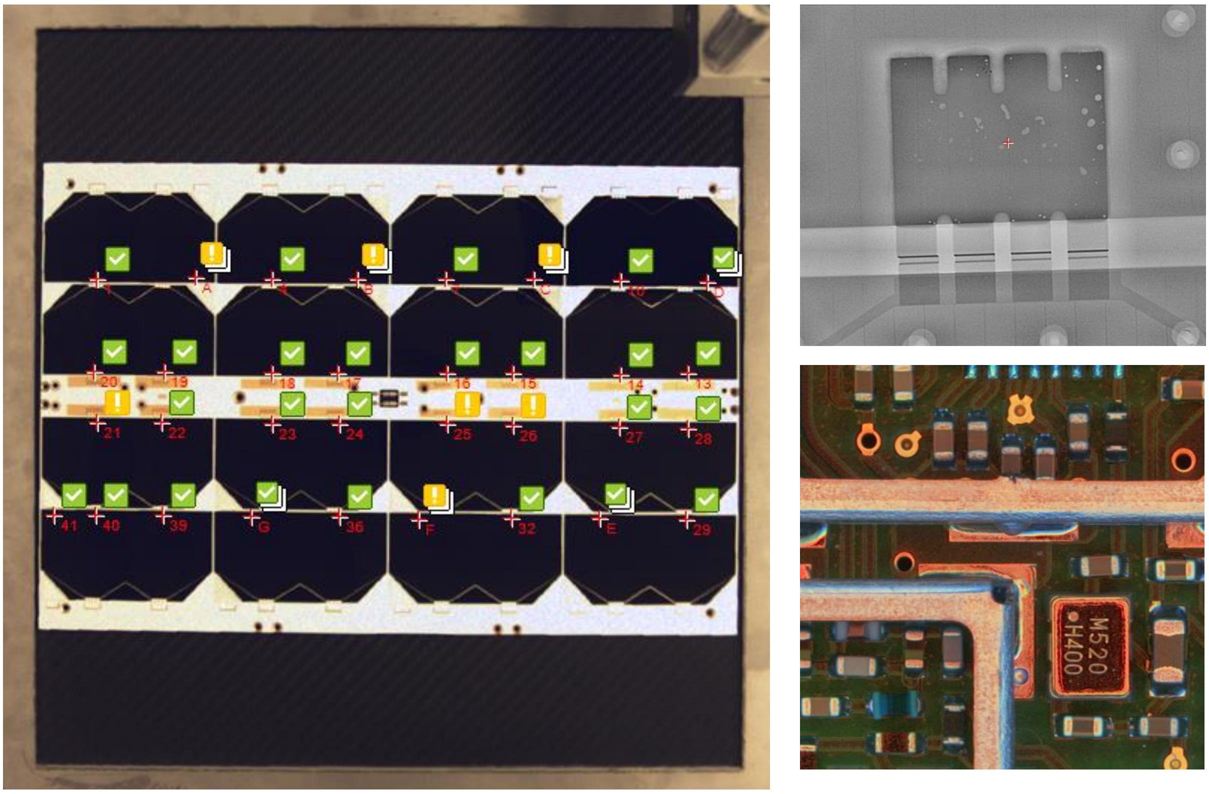

Figure 5. Optical and X-Ray inspection of electronic components and soldering quality

Final M6P 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 M6P 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.

6 Launch and Logistics

NanoAvionics offers a piggyback-launch opportunity to Low Earth Orbit (LEO) with Vega / Vega C (Arianespace), PSLV / SSLV (New Space India Limited), Falcon 9 (SpaceX), Electron (Rocket Lab), Antares (Northrop Grumman) launch vehicles. NanoAvionics' service includes a complete launch package taking care of all aspects related to launch, logistics of the satellite, and satellite-deployer-launch vehicle integration. The complete launch package service contains:

- Securing the launch opportunity on one of the suitable upcoming launches with a possibility to switch the launch time 6 months before agreed time with no additional charges
- Arrangement of launch deployer
- Technical interface control (ICD) – arrangement and coordination of technical interfaces, equipment, and documentation required for the launch acceptance
- Logistics coordination and support – coordination of Satellite and Ground Support Equipment logistics to the launch site and facilitating travel of personnel to and from integration facilities from Chennai airport as well as equipment re-export if needed
- Launch vehicle integration – final satellite flight preparation campaign and, if required, satellite fueling operations. Final checkout of the satellite and integration with the launch vehicle at the launch site
- Provision of the satellite orbit and attitude data at injection and commissioning support.

7 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 6. 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.

8 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.