THE INTEGRATED AVIONICS UNIT – PERFORMANCE, INNOVATION AND APPLICATION

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ABSTRACT

To address the new demands of the microsatellite market, LuxSpace is developing the next generation of microsatellite platforms – Triton-X, which includes three microsatellite platform classes: Light (40kg), Medium (75kg) and Heavy (150-250kg). The three classes are based on a common core, ensuring non-recurring engineering costs associated to adaptation to different missions are minimized. This common core, namely the Integrated Avionics Unit (IAU), is the key-innovation which enables the implementation of the Triton-X product line.

This paper presents the IAU concept and explores approaches for IAU application beyond the mentioned "new space" microsatellite family.

The IAU, developed by LuxSpace and partners, combines a high number of functionalities, such as on-board computer, data and power interface, low-speed communication transceiver, high-speed communications downlink, payload data handling, mass memory storage and remote terminal element.

The integration density is maximized by implementing functions that are traditionally housed in separate units in individual physical boxes. This is achieved by using the high-performance processing capabilities of state-of-the-art System-on-Chip (SoC) technology. However, the SoC is a commercially available product (COTS) and special provision must be taken to assure reliability. The requirements of the space environment are met by protecting the SoC through selected space grade components. The verification of that concept is done by radiation testing on board-level and component level already during development. In fact, extensive testing, early in the development phase is a method which enables to take quick measures for remedy in case of anomalies.

In summary, the chosen concept allows for a large flexibility to scale the performance according to the mission requirements and to adapt easily to the spacecraft class. Nevertheless, due to its centralized concept the IAU can also be conceived as stand-alone unit outside the Triton-X product, e.g., for launchers, in-orbit-servicing drones, beyond-LEO applications.

Although the IAU concept emerged from the needs of the "New Space" market, there is an increasing demand for making the IAU compatible with the requirements of the traditional space market so that the latter can benefit from the key features and advantages of the IAU.

Over recent years a softening of the "traditional Space" way-of-thinking which is often conceived as rigid by "New Space" can be noticed and pragmatism may lead to a consolidation of both worlds depending on performance, willing of risk-taking, timeline and economics.

The IAU has the potential of applying that best of both worlds. This paper sketches the approach.

1 INTRODUCTION

LuxSpace is developing a next-generation Triton-X microsatellite platform to address the evolving needs of the market. The platform features a modular design that addresses the performance range needed for satellites ranging from 40 kg to 250 kg. Specifically, the core avionics and communication system is designed as a modular system with a wide range of interfaces, industry-leading on-board processing, and the ability to adapt to a broad range of missions. This capability forms the core of the Triton-X product line, which uses a catalogue approach and standardized interfaces to achieve diverse mission needs. The platform and avionics system can be deployed for single satellites or small constellations, in LEO and beyond, and even as part of third-party satellites or exploration systems. Featuring low-cost commercial-off-the-shelf (COTS) components with high-reliability supervisory systems and the benefits of modular and extensible designs, the Triton-X product line with the integrated avionics system provides a high-performance, cost-effective package that can be used for both “new space” and “traditional space” missions.

2 TRITON-X

Triton-X is a low-earth orbit, high-performance microsatellite product line under development by LuxSpace, providing three classes of satellites: Light, Medium, and Heavy (Table 1). The product line is built around a common core of components; different levels of performance are achieved by a catalogue approach, where components can be selected to meet mission needs (Figure 1). The Triton-X product line is designed for the high-performance microsatellite market, providing 5+ years of lifetime and high levels of power, data storage, data processing, and attitude and orbit control system (AOCS) performance.

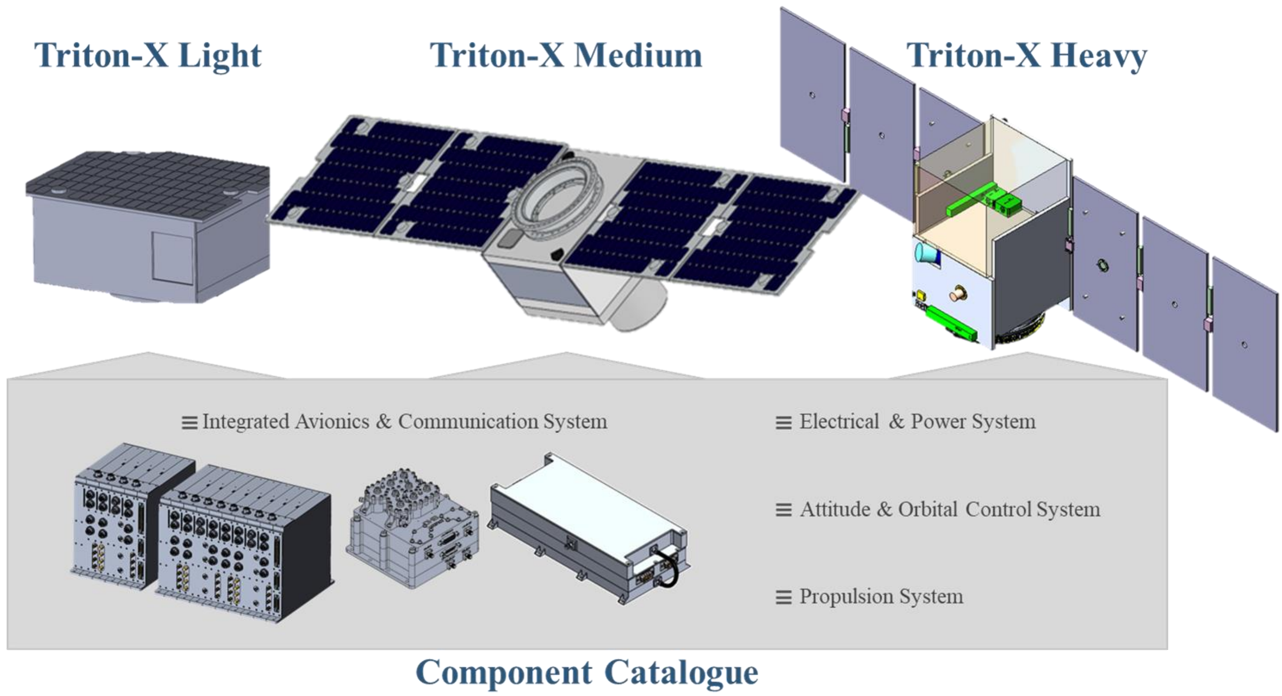

Figure 1. The Triton-X product line—comprised of Light, Medium, and Heavy classes—leverages a component catalogue approach for modularity, expansibility, and control of lifetime cost.

A modular approach controls the variation within the product line scope with the purpose of maximizing reusability between each instantiation. However, even with a modular approach, the Triton-X product line provides many opportunities for missionization, including on-board data processing, payload control systems, control of analogue and digital peripheral units, redundancy and reliability, and sizing to meet mission objectives. Altogether, this provides a high-performance system based on high quality elements that can meet a broad range of missions.

Table 1. The Triton-X product line supports three performance classes of satellites with a modular architecture and common core of components.

Parameter	**Triton-X Light**	**Triton-X Medium**	**Triton-X Heavy**
Key features	Low power, mass, and bandwidth; single string	Moderate power and mass; high bandwidth; single string	High power and mass; very high bandwidth; fully redundant
Payload			
Mass	Up to 15 kg	Up to 45 kg	Up to 90 kg
Stowed volume	Up to 12U	13-50U	50-280U
Orbit average power	10-90 W	45-180 W	120-310 W
Power bus	28 V unregulated	28 V unregulated	28 V unregulated
Data interfaces	CAN, RS-485, LVDS, SPI, Ethernet, SpaceWire	CAN, RS-485, LVDS, SPI, Ethernet, SpaceWire	CAN, RS-485, LVDS, SPI, Ethernet, SpaceWire
Platform			
Mass	40-50 kg	75-90 kg	130-160 kg
Peak power generation	288 W	576 W	864 W
Low-speed communication	S-band Up to 2 Mbps transmit 32 kbps receive	S-band Up to 2 Mbps transmit 32 kbps receive	S-band Up to 2 Mbps transmit, 32 kbps receive
High-speed communication	None	X-band >600 Mbps transmit	X-band >1.2 Gbps transmit
On-board processing	Dual-Core SoC	Dual-Core SoC	Dual-Core SoC
On-board data storage	128-512 GB	128-512 GB	128-1024 GB
Pointing accuracy	2-5 deg	0.007-0.10 deg	0.007-0.10 deg
Pointing knowledge	<0.017 deg	<0.017 deg	<0.017 deg
Position knowledge	10 m	10 m	10 m
Propulsion	None	Single	Dual
Redundancy	Single string	Single string	Fully redundant

2.1 Development Programme

Triton-X is a "new space" satellite platform with the quality and rigor of "traditional space." This is achieved by employing accelerated design reviews, leveraging commercial approaches, employing COTS components, and implementing agile methodologies, while maintaining rigorous oversight and guidance as well as adherence to traditional standards (such as European Space Agency standards). This places a high emphasis on quality and product assurance, which supports the targeted high-performance end of the microsatellite market.

Started in early 2021, the Triton-X program takes a phased development approach. Working with partners, LuxSpace is focused on advancing the maturity of all critical systems to a high TRL by the end of 2022, proving integrated performance, achieving flight heritage for core systems, and preparing to move into serial production.

2.2 Market

The Triton-X product line is designed to offer high performance microsatellite solutions for up to 90 kg payload mass and 310 W payload average power (Figure 2). This performance range is achieved by leveraging a product line approach, with reuse, modularity, and standardization.

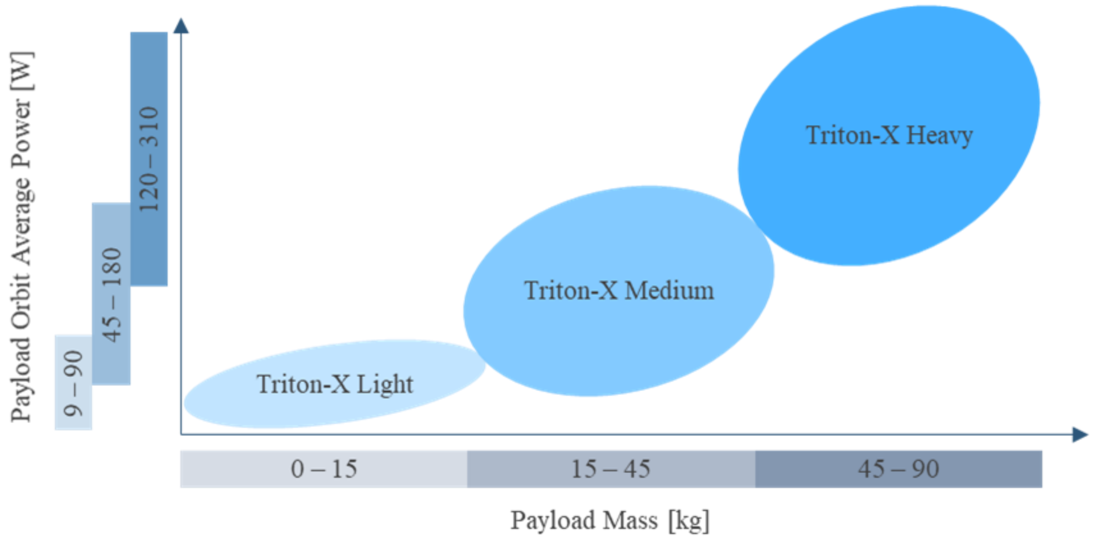

Figure 2. The Triton-X product line covers the complete range of performance from 0 to 90 kg payload mass and 9 to 310 W payload average power.

The core design mission is for small constellations of 2 to 12 satellites, which takes advantage of the reusability of missionization efforts. However, even within a constellation, satellite-specific customizations can be made due to the flexibility of the product line architecture.

2.3 Product Line Architecture

The Triton-X product line architecture uses a combination of reuse approaches: opportunistic reuse, reusable modules (or "building blocks"), and standardized interfaces (or "reference architecture") [1].

The thermal and structural systems are reused within each size class of Triton-X—each of the three configurations envelopes the performance variation within its own size class. A removable payload deck enables easy payload integration and provides the option to perform integration at the customer site. Additionally, key AOCS components—such as gyro or star tracker—may be mounted directly to the payload deck to provide tight alignment tolerances, especially with optical payloads.

Leveraging the modularity and defined interfaces of the core avionics systems, the Triton-X product line employs a catalogue approach for the power system and AOCS elements, selecting COTS components with interchangeable interfaces with the aim of reducing missionization cost and schedule.

The software is similarly modular, based on a library of features and mission-selectable interfaces, with parameterization reducing the amount of custom software for each mission.

To achieve the high level of adaptability while maintaining high performance capabilities, the in-house avionics and communications architecture is also modular and comprises the following:

- Modular and expandable integrated avionics unit (IAU)
- Modular and expandable Remote terminal unit (RTU)
- Low-speed communication (LSC) S-band transceiver with solid state power amplifier (SSPA) and low-noise amplifier (LNA) unit
- High-speed communication (HSC) transmitter with X-band up-converter (UC) and SSPA unit

The product line approach provides a large range of flexibility in performance and cost while maintaining high quality and reliability.

3 INTEGRATED AVIONICS SYSTEM ARCHITECTURE

LuxSpace is developing the Triton-X microsatellite platform to address the “New Space” market. The Triton-X product line is a next generation microsatellite platform designed to enable affordable regional and global LEO constellations to support multi-mission requirements while meeting the stringent in orbit delivery time needs of a competitive market. A key architectural enabler of the Triton-X product line is the IAU and RTU.

The IAU is the result of a system engineering paradigm change in the allocation of functions to hardware products. To meet the needs of the New Space Market, the IAU:

- Increases the integration density of functions
- Is based on function agnostic hardware
- Scales the performance and dependability

The integration density is maximized by combining functions that are traditionally housed in separate units into a single physical product. This is achieved by using the high-performance processing capabilities of state-of-the-art system-on-chip (SoC) technology. The requirements of the space environment are met by protecting the SoC through a few carefully selected space grade components.

The support of multi-mission profiles is achieved through complete reconfigurability of the IAU. The IAU can support on-board computer (OBC) functions, payload data handling unit (PDHU) functions, mass memory functions, RTU functions, telemetry and telecommand (TMTC) functions, as well as payload data download functions. This is the result of the smallest building block of the IAU being function agnostic.

The competitive aspect of the New Space market requires to solve the conflicting requirements of supporting different missions without the need to change the design or to requalify even a part of the platform. Furthermore, it is essential to scale the performance of the IAU to accurately meet the mission needs and maximize the compliance to cost ratio; in other words: not to charge the customer for excess performance. The Triton-X product line—and specifically the IAU—solves this constrained optimization problem through scalability. The IAU consists in a configurable number of identical building elements, which are called digital mother boards (DMBs). The performance and dependability are scaled in discrete steps. The IAU can be realized as single DMB, fulfilling only the most essential OBC and TMTC functions, or can comprise several DMBs implementing the full suite of functions.

The architecture of each unit of the avionics system is described in the following sections.

3.1 Integrated Avionics Unit

The IAU is an avionics system with a modular “blade” architecture, allowing quantized selection of features, interfaces, functions, and performance depending on mission needs. A single IAU may contain 4, 6, or 8 blades, where each blade uses a common DMB with the addition of specialized mezzanine boards (Figure 3). This architecture provides the following selection of blades:

- OBC – comprised of the common DMB and an optional interface mezzanine board
- OBC with LSC transceiver – comprised of the common DMB, an S-band transceiver mezzanine board, and an optional interface mezzanine board
- HSC transmitter – comprised of the common DMB, a high-speed communication transmitter, and an optional interface mezzanine board
- PDHU – comprised of the common DMB and 1 or 2 interface mezzanine boards to provide a full range of standard satellite interfaces
- Additional blades can be developed using the common DMB with the addition of custom mezzanine boards, such as additional mass memory, specific GPS interface, etc.

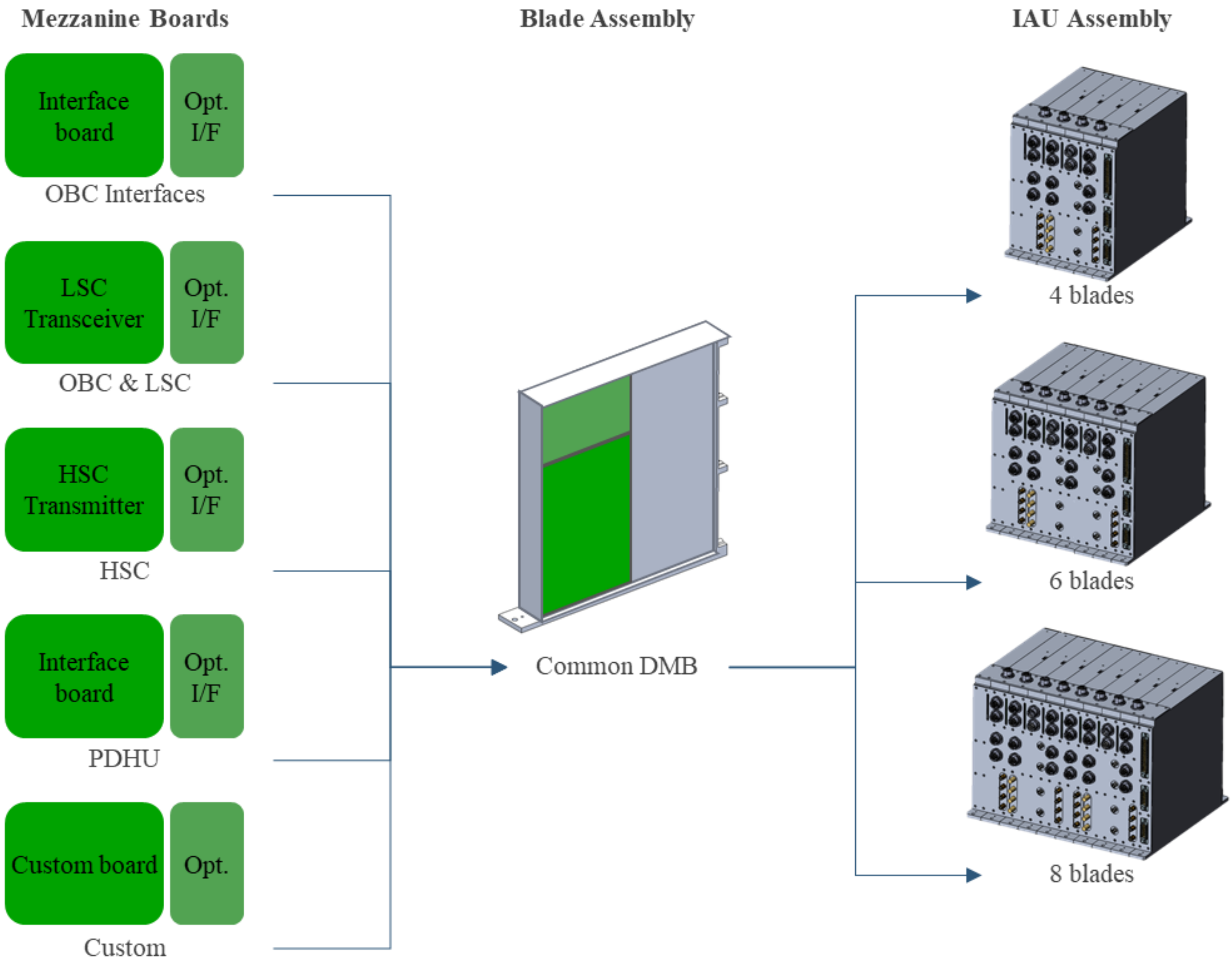

Figure 3. The IAU uses a modular architecture to provide the benefits of a common core with the flexibility of customizable boards.

With this approach, the IAU benefits from the reduced cost and complexity of common core software and hardware with built-in watchdog functions, while still allowing the adaptability to perform all necessary functions. Additionally, the common DMB architecture provides the opportunity for future evolution and addition of new or upgraded interfaces.

3.2 Remote Terminal Unit

The RTU also features a "blade" architecture using the remote terminal element (RTE) blades, providing a quantized selection of digital, analogue, and driver interfaces. A single RTU may contain 4, 6, or 8 blades (Figure 4); there are two specific RTE blades:

- RTE-Digital – to provide digital communication interfaces
- RTE-Analog/Driver – to provide analogue sensor interfaces and to drive mechanical devices and heaters

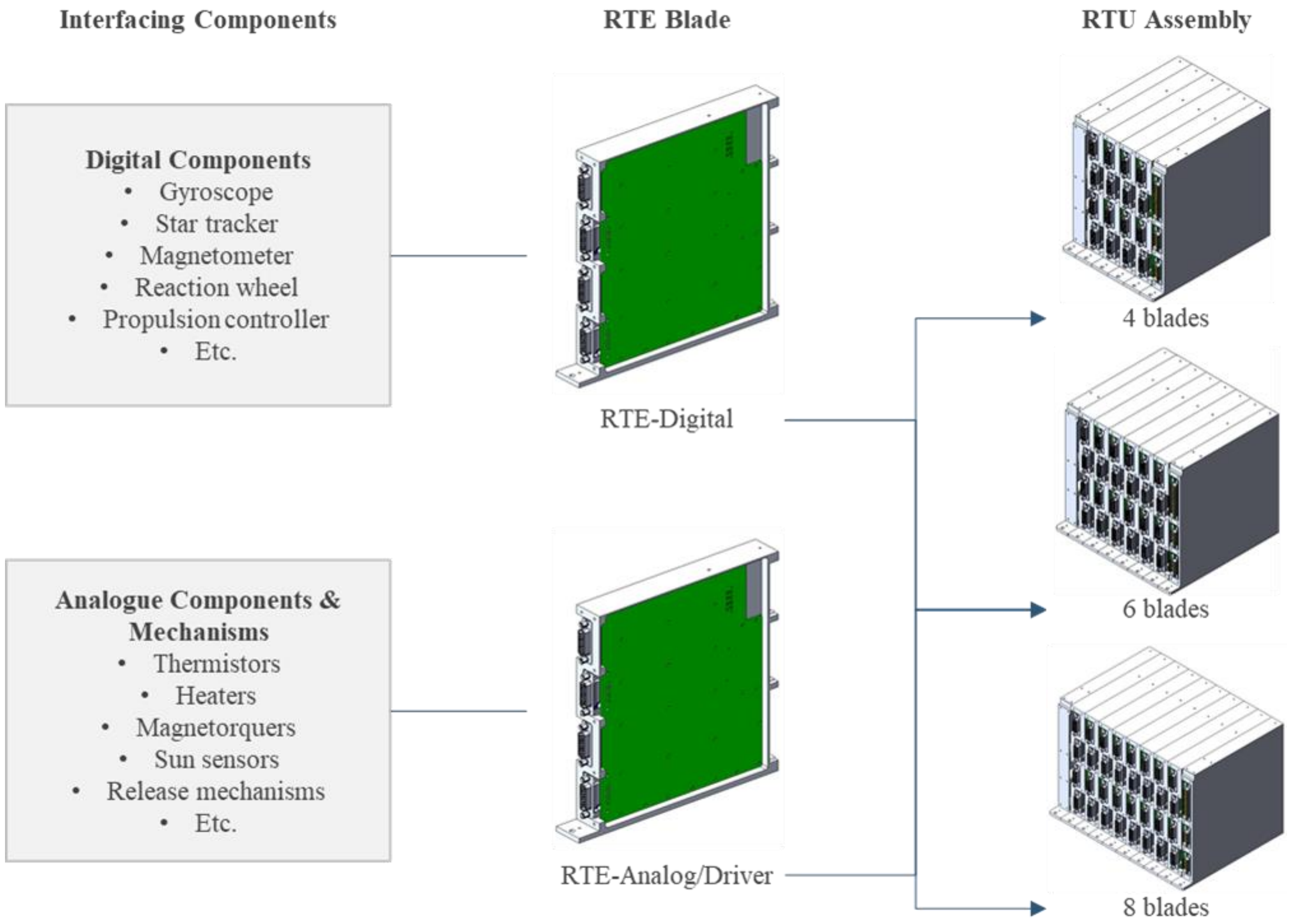

Figure 4. The IAU uses a modular architecture to provide the benefits of a common core with the flexibility of customizable boards.

The RTU supports both power control unit (PCU) and power distribution and control unit (PDCU) power architectures. When used with a PCU, the RTU is the primary method of power distribution.

3.3 Low-Speed Communications

The LSC chain includes the S-band transceiver of the IAU (above) and an S-band LNA SSPA with diplexer. The LSC chain supports the following configurations:

- Single OBC LSC with single LSC LNA SSPA
- Dual OBC LSC with dual LSC LNA SSPA

The flexibility supports a range of missions for both “traditional space” and “new space.”

3.4 High-Speed Communications

The HSC chain includes the high-speed transmitter of the IAU (above) and an X-band UC/SSPA unit. The HSC chain supports the following configurations:

- Single HSC DMB with single HSC UC/SSPA
- Dual HSC DMB with dual HSC UC/SSPA, without cross-strapping

These two configurations provide high bandwidth and very high bandwidth options, supporting up to 800 Mbps average downlink per pass (dependent upon link budget).

4 INTEGRATED AVIONICS SYSTEM PERFORMANCE

The following sections provide the detailed technical parameters of each blade of the IAU and RTU.

4.1 DMB OBC & LSC

The OBC blade provides on-board computing and control with an optional LSC transceiver for TMTC and low-volume data downlink. This blade interfaces with the LSC LNA SSPA. Refer to Table 2 for technical details.

Table 2. Technical parameters of each OBC, with the optional LSC transceiver.

Parameter	DMB OBC & LSC	Unit
DMB		
On-Board Processor	Dual-Core SoC	
Embedded Mass Storage	128	[GB]
LSC Transmitter		
Output Frequency, at output of the LSC Mezzanine	S-band 2200-2290	[MHz]
Output Modulation, configurable	BPSK, OQPSK	
Channel Coding	Convolutional encoding (r=1/2) concatenated with Reed-Solomon (255,223) with interleaving depth 5 and E=16	
Information Bit Rate, settable via telecommand	Up to 2	[Mbps]
Output Power of the LSC SSPA	Up to +33	[dBm]
LSC Receiver		
Receive Frequency, at input of the LSC Mezz	S-band 2025-2110	[MHz]
Uplink Modulation	BPSK	
Symbol Rate	32 and higher	[kSymbol per sec]
Port Noise Figure, at input of LSC LNA	<2	[dB]
Implementation Loss	<2	[dB]

4.2 HSC DMB

The HSC DMB blade provides an HSC transmitter for high-volume data downlink. This blade interfaces with the X-band UC/SSPA. A single HSC DMB can provide more than 600 Mbps information bit rate. Two HSC chains can be employed using left-hand and right-hand circular polarization to double the total downlink bandwidth. The transmitter can support X-band, C-band, Ka-band, and even optical. Refer to Table 3 for performance details.

Table 3. Technical parameters of each HSC board and transceiver.

Parameter	HSC DMB	Unit
DMB		
On-Board Processor	Dual-Core SoC	
Embedded Mass Storage	128	[GB]
High-Speed Communication Bus	Up to 4x high-speed links, point-to-point	
High-Speed Link Speed, each	1	[Gbps]
HSC Transmitter		
Channel Coding	Selectable, compliant with DVB-S2 & DVB-S2X ETSI standard	
Information Bit Rate	> 600	[Mbps]
Symbol Rates, settable via telecommand	25, 50, 100, or 200	[Msymbol per sec]
Output Power Range, at output of the HSC UC/SSPA, settable via telecommand	+20 to +40	[dBm]

4.3 DMB PDHU

The DMB PDHU blade interfaces with payloads. DMB PDHUs may be operated in single string configuration or with hot or cold redundancy. Refer to Table 4 for technical performance and interface capabilities.

Table 4. Technical parameters of each DMB PDHU.

Parameter	DMB PDHU	Unit
DMB		
On-Board Processor	Dual-Core SoC	
Embedded Mass Storage	128	[GB]
High-Speed Communication Bus	Up to 4x high-speed links, point-to-point	
High-Speed Link Speed, each	1	[Gbps]
Interfaces		
Main Interface	• 1x 28V unregulated power supply, 70W max • 1x PPS output • up to 4x SpaceWire (200 Mbps) • up to 4x Ethernet (5 Gbps) • up to 8x differential pairs for LVDS plus clock (up to 600 Mbps) • up to 8x SPI or UART	
Secondary Interface	• 1x 28V unregulated power supply, 10W max • 1x SPI or UART • 1x PPS output • 1x SpaceWire, or 1x Ethernet (1 or 3 Gbps), or 8x differential pairs for LVDS plus clock (up to 500 Mbps)	

4.4 Remote Terminal Elements

The RTU—comprised of RTE blades—provides power distribution and data interfaces to digital and analogue hardware units (e.g., magnetometers, reaction wheels, GPS, thermistors, heaters, release mechanisms). The RTU stack is selected to meet the mission needs, including the possible use of redundancy or cross-strapping. Due to its modularity, interfaces are available in quanta and are selected to meet mission needs; refer to Table 5 for details.

Table 5. Technical parameters of the RTU.

Parameter	RTU	Unit
Design Orbit	LEO	
Maturity	Available from end of 2022	
Lead Time from Order	6	[month]
Backplane	Power bus, Communication bus	
Interfaces		
RS-485 / RS-422	Scalable in quanta of 8x, configurable	
SPI	Scalable in quanta of 2x	
PPS	Scalable in quanta of 4x, configurable as input or output	
Power	Scalable in quanta of 8x, 28V unregulated, up to 2.5A each	
Thermistor	Scalable in quanta of 24x	
Sun Sensor	Scalable in quanta of 24x (6 sun sensors x 4 photodiodes each)	
Magnetorquer Driver	Scalable in quanta of 3x	
Mechanism / HDRM	Scalable in quanta of 3x, 4A across 1.5Ω each; arm, fire, and inhibit	
Heater Lines	Scalable in quanta of 12x, 28V unregulated, up to 3A per group of 4x lines	

5 INTEGRATED AVIONICS SYSTEM INNOVATIVE FEATURES

The integrated avionics system includes the following innovative features that enable the performance range of the Triton-X product line and address a wide range of missions in the microsatellite market.

5.1 High-Performance SoC

A primary feature of the IAU is the inclusion of an industry-leading SoC to provide in-orbit processing power. Every DMB features an off-the-shelf SoC, providing the FPGA fabric to be used by the payload. This enables mission-specific image and data processing, compression, high-speed communications, flexible payload control, and an unprecedented level of adaptability.

5.2 Specialized Mezzanine Boards

The use of mezzanine boards to specialize the common DMB is a key feature of the Triton-X avionics solution. The mezzanine boards implement the desired interfaces from the DMB to the front-end—SpaceWire, Ethernet, LVDS, UART, X-band RF, and S-band RF. Other functions performed by the mezzanines include data processing, packetizing, encryption, and keying.

The adaptable mezzanines also provide a path for future evolution of the IAU. Additional mezzanines may be developed in the future to meet mission-specific interface needs, to upgrade the offering, or to expand the number and types of interfaces currently available.

5.3 Adaptable Chassis and Backplane

The IAU and RTU each feature a common backplane architecture for inter-blade communication and power. The size of the backplane and chassis is easily adapted to the number of blades required by the mission.

5.4 Modular Software and Firmware

The DMB and RTE software architecture is a layer-based, modular design in which the core functionalities are encapsulated in reusable software modules (Figure 5). Data exchange between the modules is done via clearly defined interfaces, which include module dependency restrictions.

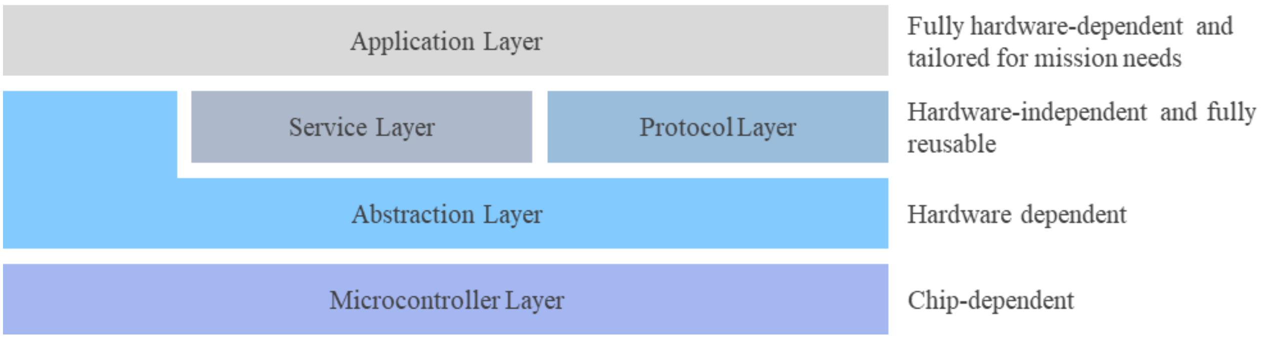

Figure 5. The IAU and RTU use a modular, layered software approach for adaptability to hardware changes and ease of missionization.

This flexible approach ensures independence of the software modules in case of hardware changes and allows customization and extensibility at the application level for mission needs.

5.5 Reliability and Quality

The IAU and RTU take advantage of recent advancements in commercial technology with regards to performance, cost, and availability, to provide high levels of flexibility and adaptability within "new space" cost and schedule expectations. However, this approach is inherently less reliable in a space environment; to overcome these limitations, two mitigations are used:

1. EEE parts screening
2. On-board supervisory system

The identical nature of the DMBs also allows to have flexible redundancy schemes, avoiding the need to duplicate every critical function implementation. Using a built-in supervisory system with a radiation-hardened microcontroller, a given DMB can be dynamically reconfigured to take over for a failing DMB. For the RTEs, primary and backup and/or cross-strapping schemes can be used; additionally, the RTEs have built-in redundancy of interfaces to further improve reliability. For both DMBs and RTEs, the supervisory system monitors for board faults and faulty incoming sensor data.

This combination of screened COTS components with a high-reliability supervisory system provides a highly tolerant system tailored to the cost and dependability needs of the market.

6 TRITON-X AND INTEGRATED AVIONICS SYSTEM APPLICATIONS

The Triton-X product line and the integrated avionics system are designed to be multi-mission capable. The basic design reference mission is for small LEO constellations, using the complete Triton-X product line with integrated avionics systems. However, the integrated avionics system can be used in other contexts, with or without the communications chain or the greater Triton-X satellite platform. Example use-cases are shown in Table 6; these range from single satellite missions to small constellations using the Triton-X product line, third-party LEO and beyond-LEO satellites with the integrated avionics system, and exploration missions (e.g., payload control for a lunar lander) with the IAU.

Table 6. The modular Triton-X product line and integrated avionics system are adaptable to a wide range of use-cases.

Use-Case	Key Benefits
Low-Earth Orbit Small constellations	Using Triton-X product line and/or Integrated Avionics System • Lead time and cost support “new space” missions • Procurement and manufacturing approach provide cost-effective batch builds and flight qualification • Standardized approach ensures cost-saving for multiple units • Mass memory and high performance SoC for customizable in-orbit processing • Modularity provides ability for tailoring to variation within the constellation • Layered software ensures ability to reuse modules in the face of hardware changes or evolution
Low-Earth Orbit Single satellite	Using Triton-X product line and/or Integrated Avionics System • Lead time and cost support “new space” missions • Reliability and development rigor support “traditional space” systems • Mass memory and high performance SoC for customizable in-orbit processing • Modularity provides selectable level of off-the-shelf performance • Extensibility provides flexibility for customized features
Third-party satellite or in-space tug Satellite control & RF communication system	Using the Triton-X Integrated Avionics System as standalone • On-board monitoring system and optional redundancy support beyond-LEO applications • Mass memory and high performance SoC for customizable in-orbit processing • Modularity provides selectable level of off-the-shelf performance • Extensibility provides flexibility for customized features • Flexible interfaces to communicate with payloads as well as the spacecraft control system or control units, and to transfer data for downlink • Agnostic of power system architecture (can be used with PCU or PDCU)

Use-Case	Key Benefits
Third-party satellite or in-space tug Payload data handling and control & RF communication system	Using the Triton-X IAU and optional RF communication system(s) as standalone • On-board monitoring system and optional redundancy support beyond-LEO applications • Mass memory and high performance SoC for customizable in-orbit processing • Modularity provides selectable level of off-the-shelf performance • Extensibility provides flexibility for customized features • Flexible interfaces to communicate with multiple payloads, communicate with the spacecraft control computer, and to transfer data for downlink • Optional HSC and LSC systems • On-board data storage and processing • Agnostic of power system architecture (can be used with PCU or PDCU)
Deep space & exploration mission (e.g., lunar surface) Payload data handling and control	Using the Triton-X IAU as standalone • On-board monitoring system and optional redundancy support beyond-LEO applications • Mass memory and high performance SoC for customizable in-orbit processing • Modularity provides selectable level of off-the-shelf performance • Extensibility provides flexibility for customized features • Flexible interfaces to communicate with multiple payloads and to transfer data for downlink • On-board data storage and processing • Agnostic of power system architecture (can be used with PCU or PDCU)
Launch system Control system & RF Communication System	Using the Triton-X IAU and optional RF communication system(s) as standalone • Mass memory and high performance SoC for customizable in-orbit processing • Modularity provides selectable level of off-the-shelf performance • Extensibility provides flexibility for customized features • Flexible interfaces to communicate with on-board payloads, communicate with the launcher control computer, and to transfer data for downlink • Optional communication system • Agnostic of power system architecture (can be used with PCU or PDCU)

The cost-effective Triton-X product line with the integrated avionics system are adaptable to a broad range of missions due to the built-in flexibility, extensibility, reliability, and performance range.

7 CONCLUSIONS

The Triton-X product line with the integrated avionics system concept allows for a large flexibility to scale the performance according to the mission requirements and to easily adapt to the spacecraft class. Although the IAU concept emerged from the needs of the “New Space” market, there is an increasing demand for making the IAU compatible with the requirements of the traditional space market so that the latter can benefit from the key features and advantages of the IAU—particularly the high processing power—which has the potential of applying the best of both worlds. Indeed, the IAU can also be conceived as a stand-alone unit outside the Triton-X product line, e.g., for launchers, in-orbit-servicing drones, and applications beyond LEO.

The system is expected to be ready for first commercial flights by the end of 2023.

8 REFERENCES

[1] *CESAM: CESAMES Systems Architecting Method, A Pocket Guide*, CESAM, Paris, France, 2017.