SPACE EXPLORATION NEEDS NEW MPUs

The RAD750 processor, which has been NASA's de facto choice for space computing, debuted 20 years ago. It has been utilized in a variety of groundbreaking missions, including those involving NASA's Deep Impact spacecraft and the Curiosity Mars rover. Today's much larger and more diverse public- and private-sector space industry has significantly broader and rapidly expanding computational requirements. System developers need a new, more capable space-grade microprocessor (MPU).

In 2022, NASA selected Microchip to build its new PIC64 High Performance SpaceFlight Processor (HPSC) MPU that will help propel space avionics and payload innovation for decades to come. PIC64-HPSC MPUs meet the needs of a space hardware and service industry that the World Economic Forum projected will grow at a CAGR of 7% from 2023's $330 billion to $755 billion by 2035. Theyare designed to solve space computing challenges as part of a new advanced computing development ecosystem that will leverage many of the same widely adopted standards and technologies that have driven commercial and industrial innovations worldwide.

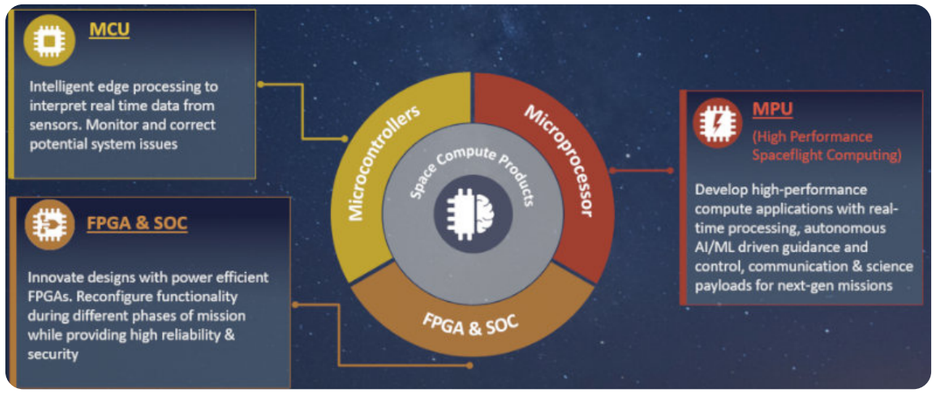

Figure 1: Microchip's triad of space computing solutions.

The HPSC Vision

A space-grade MPU for the next chapter of spaceflight had to meet two very different sets of requirements for long-duration deep-space missions and shorter-duration commercial Low-Earth Orbit (LEO) missions. At the same time, the MPUs had to better facilitate innovation by moving beyond yesterday's purpose-built and obsolescence-prone architectures to support open standards and open-source software while integrating many of the same scalable and extensible technologies that are simultaneously transforming everything from the data center to e-mobility.

The first two members of Microchip's PIC64-HPSC MPU family illustrate the path to achieving this vision. The radiation-hardened (RH) PIC64-HPSC-RH MPU gives autonomous missions the local processing power for such real-time tasks as rover hazard avoidance on the Moon's surface, plus the low-power consumption and radiation protection for deep-space missions. For Low Earth Orbit (LEO) missions, , the radiation-tolerant (RT) PIC64-HPSC-RT MPU provides system developers a cost-optimized solution with the necessary fault tolerance and radiation performance.

New Capabilities

Among the most significant space-grade MPU innovations is the integration of widely adopted RISC-V® CPUs augmented with vector-processing instruction extensions that support AI/ML applications. These MPUs also include industry-standard interfaces and protocols that were not previously available for space applications.

Other key capabilities include:

1. A space-grade 64-bit MPU architecture. The inclusion of eight SiFive RISC-V® X280 64-bit CPU cores support virtualization and real-time operation. Vector extensions deliver up to 2 TOPS (int8) or 1 TFLOPS (bfloat 16) of vector performance for implementing AI/ML for autonomous missions.

2. High-speed network connectivity. Supports multiple high-speed connectivity options including a) up to 10GbE Time-Sensitive Networking (TSN) Ethernet; b) a 240 Gbps TSN Ethernet switch; c) scalable and extensible PCIe® gen 3 and Compute Express Link™ (CXL™) 2.0 connectivity with x4 or x8 configurations; and d) RMAP-

compatible SpaceWire ports featuring internal routers.

3. Low-latency data transfers. The MPUs maximize compute capabilities by bringing data from remote sensors close to the CPU. This is done through Remote Direct Memory Access (RDMA) over Converged Ethernet (RoCEv2) hardware accelerators.

4. Platform-level defense-grade security. The MPUs' defense-in-depth security supports post-quantum cryptography and anti-tamper features.

5. High fault-tolerance capabilities. The MPUs support Dual-Core Lockstep (DCLS) operation, use a WorldGuard hardware architecture for end-to-end partitioning and isolation, and have an onboard System Controller for fault monitoring and mitigation.

6. Flexible power tuning. Multiple controls enable the MPUs to meet computational demands across the multiple phases of space missions while also offering the tailored activation of functions and interfaces.

A New Innovation Ecosystem

These new MPUs for high-performance computing are part of a triad of space-grade processing solutions within a new innovation ecosystem. This triad also includes microcontrollers for intelligent edge processing and FPGAs and SoCs to provide reconfigurable functionality during different mission phases along with high reliability and security (see Figure 1).

The PIC64-HPSC MPUs' larger ecosystem of space-grade products and third-party software that will collectively expedite the development of system-level integrated solutions. In addition to Microchip's evaluation platform consisting of the MPU, expansion card and a variety of peripheral daughter cards, the ecosystem features flight-capable single board computers (SBCs) that implement common commercial form factors and industry standards. The first ecosystem members providing resources and expertise include SiFive, Moog®, IDEAS-TEK, Ibeos, 3D PLUS, Micropac, Wind River®, Linux Foundation, RTEMS, Xen, Lauterbach®, Entrust® and many more. For information about these MPU ecosystem partners click here.

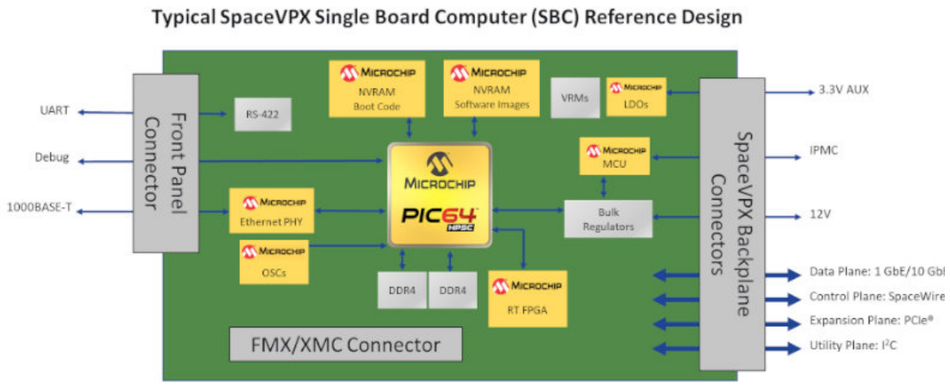

Figure 2: Modern space systems need a variety of space-grade peripherals including clock and timing solutions, memory, discretes, and more. Multiple ecosystem partners will be providing off-the-shelf Single Board Computers (SBCs) like the one above that adhere to the standards set forth by organizations like VITA, SOSA or PICMG. This will enable an HPSC SBC from one vendor to seamlessly interoperate with plug-in cards from various other vendors within a unified chassis.

The ecosystem also includes space-grade companion components with proven flight heritage. These components are designed and qualified to deliver the necessary reliability for withstanding the rigors of the harsh environments found in space. Figure 2 shows how these components will be used in a popular SpaceVPX form factor single board computer to help accelerate development of system-level integrated spaceflight avionics and payload solutions.

Diverging Space Computing Needs

Accelerating system development through a comprehensive ecosystem is critical for fueling a "New Space" era. In contrast to "Traditional Space" where space programs and technological development were primarily driven by government agencies and public funding, this new space era is characterized by significant private sector participation and an entrepreneurial approach to space endeavors. New Space advocates for more economical and accessible approaches of spaceflight development, particularly for Low-Earth Orbit (LEO) constellations. These constellations exhibit unique characteristics, such as reduced radiation intensity, shorter mission durations, different fault tolerance requirements, and a higher frequency of satellite replacement.

The processor needs of traditional and "New" space reflect these differences:

- Traditional space: Radiation-hardened processors must be engineered to survive the extreme conditions found in Medium-Earth Orbit (MEO), Geosynchronous-Earth Orbit (GEO), deep space, and planetary missions. They must operate in environments where electronics are exposed to intense radiation levels.

- New Space: Radiation-tolerant processors must be tailored to meet the requirements of Low Earth Orbit (LEO) constellations. The optimal solution supports missions where lower radiation levels allow for a more cost-effective approach.

These differences can be bridged from a development perspective if there is processor pin- and software-compatibility so users can create customized solutions for both Low Earth Orbit (LEO) and deep space missions with a single development effort. Such compatibility between the radiation-hardened PIC64-HPSC-RH MPUs and the radiation-tolerant PIC64-HPSC-RT MPUs facilitates a streamlined design process, reduces development costs, and accelerates the deployment of space technologies across various orbital regimes.

A Growing Role for 64-Bit Embedded MPUs

In addition to modernizing space computers, 64-bit embedded MPUs are also coming to a new generation of AI-enabled edge computing and other high-performance embedded processing applications here on Earth. They are joining 8-, 16- and 32-bit microcontrollers and processors, as well as FPGAs and SoCs, that are all supported by a common development tool ecosystem. This will give developers the flexibility and reusability they need to solve difficult computing challenges across a diverse array of markets and applications and transform how embedded systems are designed and operate whether at the edge of Earth-bound networks or in space. ETN