The SpaceVNX+ Standard for Small Form-Factor, Modular Electronics for Space Applications

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Abstract— **SpaceVNX+ is a small form-factor standard for space flight electronic units, which aims to provide high-performance, high reliability, flexibility, modularity, scalability and interoperability. SpaceVNX+ modules plug into slots in a backplane in a unit. The electrical, mechanical and thermal interfaces of those modules are defined. The backplane and unit design is up to the user, giving considerable architectural flexibility while realizing the cost advantage of standard modules. Of course, standard backplanes and units are also possible. This paper introduces SpaceVNX+, describes a redundant SpaceVNX+ architecture, outlines the module profiles (signals on the backplane connector) and then describes a couple more example architectures.**

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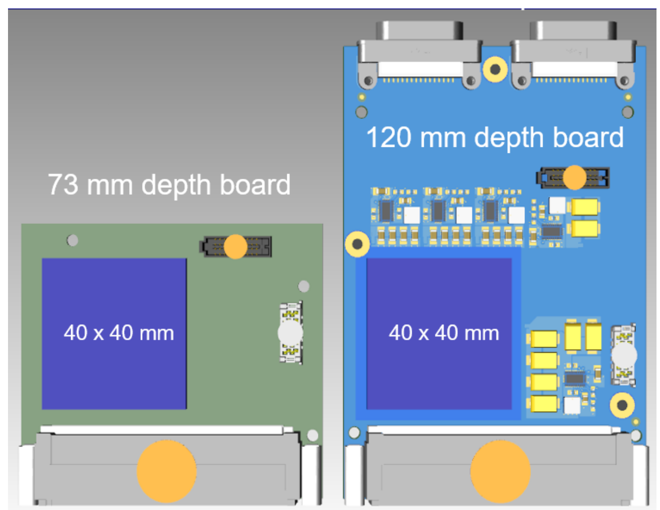
1. INTRODUCTION

SpaceVNX+ [1] is a standard for small form factor equipment modules and units which is being designed specifically for space applications. SpaceVNX+ is a development of the military/aerospace standard VNX+ [2] which is an emerging VITA [3] standard for small form factor systems based on the earlier VNX standard. VNX is widely used in aerospace and military terrestrial applications. The ANSI/VITA standard for VNX+ is expected to be published in 2025.

VNX+ has a very small form factor: a board size of 84 x 73 mm, however, spaceflight components are significantly larger than commercial, industrial and automotive components, so a larger board is required. The SpaceVNX+ board has the same width as a VNX+ board (84 mm) but a depth of 120 mm, see Figure 1. This almost doubles the board area and permitted power consumption (thanks to a longer thermal interface) of a SpaceVNX+ module compared to a VNX+ module. The backplane connectors used on the SpaceVNX+ are Samtec SEARAY™ connectors [4][1], which are low-outgassing, high-speed and have 400 pins available in the 8-row version, shown in Figure 1.



VNX+ Size Board SpaceVNX+ Extended Board

Figure 1. SpaceVNX+ Board Sizes

SpaceVNX+ provides a standard platform for the implementation of the entire range of avionics applications on-board a spacecraft, from simple remote terminal units to high-performance payload data-handling units. SpaceVNX+ is intended to be complementary to larger form factor standards such as VITA SpaceVPX [5] and ESA's ADHA [6].

To support a complete range of space applications SpaceVNX+ will support various forms of redundancy. Single-string units, which efficiently support both spacecraft-level redundancy and cross-strapped unit-level redundancy, will be facilitated. Redundancy inside a unit will also be supported, allowing dual-redundant modules and 1-of-M redundant units inside a unit. SpaceVNX+ provides high-performance interconnect between modules which can carry SpaceWire [7], SpaceFibre [8], Ethernet (Base-X) and/or PCIe.

The principle drivers for SpaceVNX+ are: the space environment, small form factor, modularity, scalability both within and outside units, versatility, performance and availability supported by fault tolerance [1].

This paper introduces SpaceVNX+, describes the SpaceVNX+ modules, and the types of system that can be constructed with those modules.

2. SPACEVNX+ ARCHITECTURE

A SpaceVNX+ architecture which provides dual redundancy for most of its modules is shown in Figure 2. In the center there are two power supply modules, default and redundant (PSUD and PSUR respectively) together with associated power switch modules (PSXD and PSXR). The active PSU takes in external power, normally at 28 V, and converts this to 3.3V and 12V. These power rails are passed to the associated PSX. The PSX then distributes these power rails to each of the System Controller modules (SCD and SCR) and each of the Payload modules (PMxx). A microcontroller on the PSU controls the power switches for the System Controllers (purple GPIO lines in Figure 2). The active System Controller controls the power switches for the power modules. I2C links between the PSU microcontrollers and the System Controller modules (pink lines) provides chassis management support. Similarly, I2C links between the System Controllers and each Payload module provide chassis management support for the Payload modules. The System Controllers also distribute two clock signals to the Payload modules, REFCLK and AUXCLK. A high performance network routing switch is provided on each System Controller. This provides redundancy in a dual-redundant system when one System Controller is powered at a time, or two parallel networks for increase bandwidth when both System Controllers are powered. Each network connects to all the Payload modules and both System Controllers.

The Payload modules work together to provide the functionality required by the application. Example functions of a Payload module include sensor interfacing and control, data compression, data storage, data encryption, data fusion and down link encoder. The PSUs, PSXs and System Controllers all provide support services to the Payload modules. The Payload module functionality can be expanded by an Expansion module (EXP). An Expansion module is in an adjacent slot to its associated Payload module and they are connected together via the backplane. An Expansion module is similar in concept to a daughterboard except that it is connected via the backplane.

In Figure 2, there are nominal and redundant PSUs, PSXs, and System Controllers. PM1 and PM2 are dual redundant but PM3 and PM4 are single-string. PM1, both default and redundant copies, have an associated Expansion module.

Power, GPIO and data link connections to the SpaceVNX+ unit are either through dedicated connectors on the various modules, or via the backplane to chassis mounted connectors.

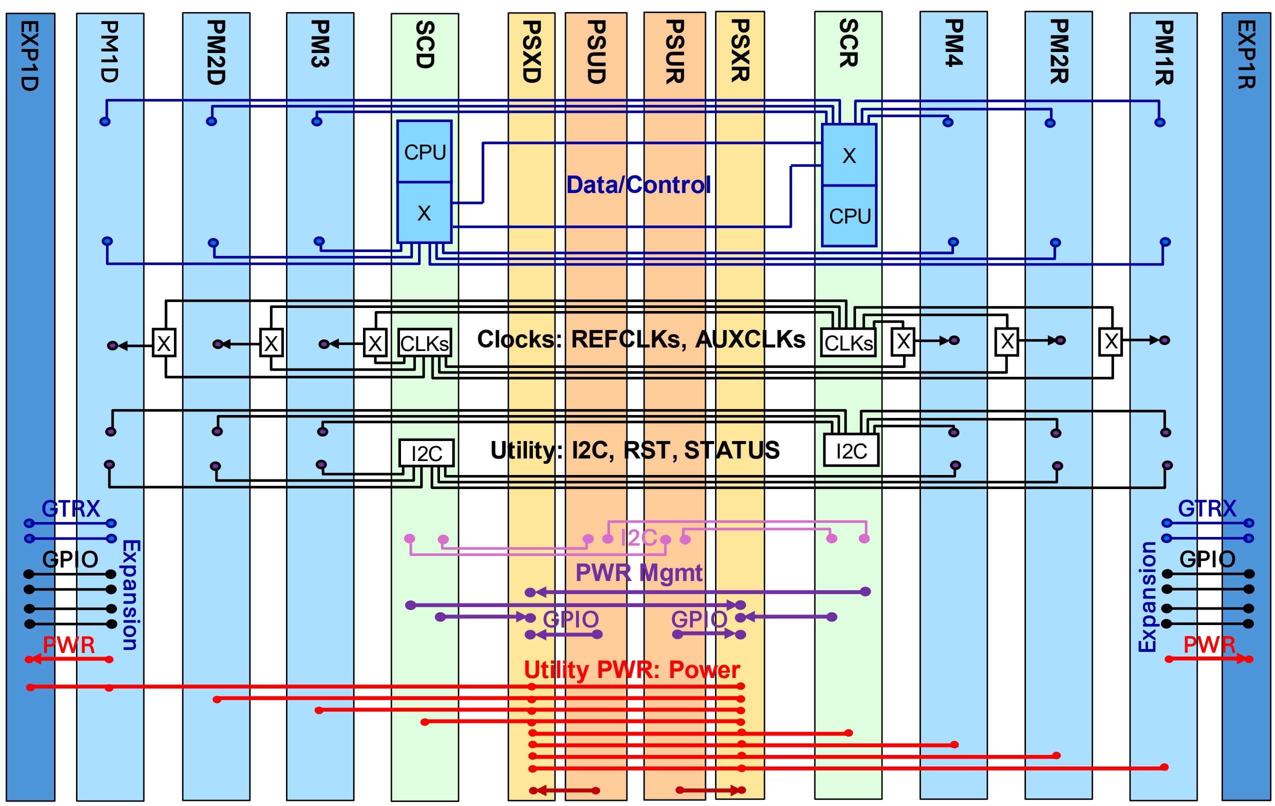


Figure 2. SpaceVNX+ Architecture with Redundancy

3. SpaceVNX+ Modules

SpaceVNX+ specifies a series of modules types, defining their electrical, protocol, mechanical and thermal interfaces. The design of the backplane is up to the user. This means that SpaceVNX+ can support many different system architectures tuned to the requirements of specific applications. For example, SpaceVNX+ modules can be used in a single-string architecture or in a dual-redundant architecture. The module when used in a single-string architecture carries little overhead to support its use in the dual-redundant architecture. SpaceVNX+ modules are designed to be both interoperable and flexible through the use of defined signal overlays and chassis management. Signal overlays are alternative signal allocations to specific sets of connector pins. Chassis management makes sure that before a module is fully powered and the overlay signals activated, the right module is in the right slot with the right overlays.

The various types of module and the signals on their backplane connectors will now be considered.

Power Supply (PSU)

The Power Supply (PSU) module is responsible for providing power to all the other modules in a SpaceVNX+ unit. The front panel and backplane connections of the Power Supply module are illustrated in Figure 3. Two modules are shown: the PSU module and a combined PSU and Power Switch module (PSU/PSX).

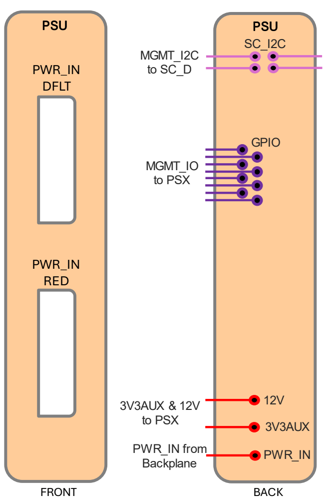


Figure 3. Power Supply Unit (PSU) module signals

The PSU module takes input power either from a front panel connector or from the backplane. The input voltage is typically 28V nominal, but other input voltages are permitted to suit the application. The front panel connectors may support default/redundant power interfaces. The PSU converts the input power to 3.3 V and 12 V for the 3V3AUX and 12V power rails, respectively. 3V3AUX is used to power auxiliary circuitry related to chassis management. 12V is used for the principal power rail to the System Controller (SC), Payload (PM) and Expansion (EXP) modules. The PSU provides 3V3AUX and 12V via the backplane connector to the power switch (PSX) module.

The PSU and PSX boards work closely together in a pair, effectively forming a single unit from the redundancy perspective.

The PSU module provides control signals to its PSX module via the backplane to control some of the power switches. The PSU board has a pair of I2C interfaces on the backplane for communicating with the default and redundant System Controller (SCD and SCR respectively). Note that in Figure 3, the signals are normally shown on left hand side of the module. If there are signals to/from default and redundant modules, the signals connected to a default module are shown on the left and those connected to a redundant module are shown on the right. This is the case for the pair of I2C interfaces.

Power Switch (PSX)

The Power Switch (PSX) module is responsible for switching regulated power from the PSU module to the other modules in a SpaceVNX+ unit. The front panel and backplane connections of the Power Switch module are illustrated in Figure 4.

The PSX module receives 3V3AUX and 12V power from its related PSU. Each of these supply rails are fed to a set of 10 power switches, a total of 20 power switches. The outputs of the power switches supply the two System Controller slots and the eight Payload Module slots, individually over the backplane. To control these switches there are discrete control signals (MGMT_IO) from the PSU (for first stage chassis management) and from the SC (for second stage chassis management) which are routed via the backplane, see Figure 4. Discrete control lines are used rather than I2C, to speed up the response to a fault. Chassis management is described later. There are normally no front panel connections on the PSX module.

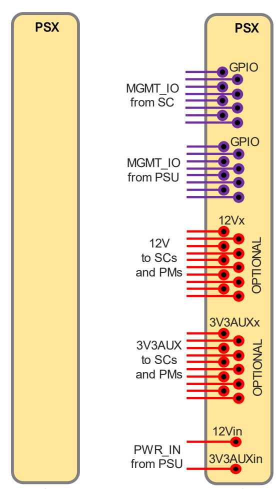


Figure 4. Power Switch (PSX) module signals

Combined Power Supply and Power Switch (PSU/PSX)

The possibility of a combined PSU/PSX module is also being considered. The combined PSU/PSX module is responsible for providing and switching power to all the other modules in a SpaceVNX+ unit.

A combined PSU/PSX module is illustrated in Figure 5. It takes power (PWR_IN) from an external source via a front panel connector or via the backplane. This is converted to 3V3AUX and 12V power rails which connect to the power switches. Up to 10 switched 3V3AUX power outputs and up to 10 switched 12V power outputs are connected to the backplane for routing to the SC and PM modules in the SpaceVNX+ unit. The necessary discrete control signals to control the switches for the power rails to the SC come from the microcontroller in the PSU/PSX module. The switch control signals for the PM modules, come from the SC modules. Management I2C signals (MGMT_I2C) go from the PSU/PSX module for first stage chassis management purposes. If there are default and redundant SC modules, the PSU/PSX has two sets of MGMT_I2C and MGMT_IO signals connected via the backplane.

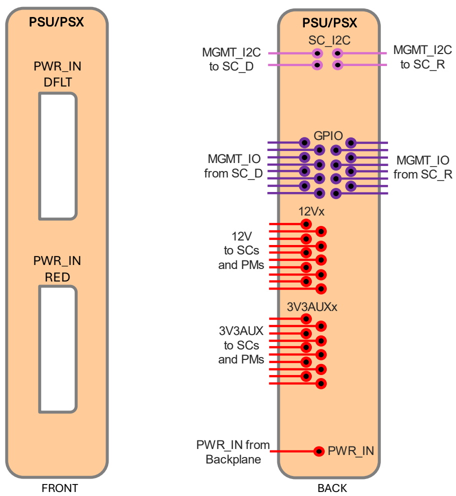


Figure 5. Combined PSU/PSX module signals

System Controller (SC)

The System Controller (SC) module is responsible for providing key services to the Payload modules, including data communication network, reference and auxiliary clock distribution, 3V3AUX and 12V power rail switch control, reset, status monitoring and second-level chassis management.

The interfaces on the System Controller needed to provide these services are shown in Figure 6. The System Controller receives 3V3AUX and 12V power from the PSX modules. The power switches for 3V3AUX and 12V power to each of the Payload Modules are controlled by the System Controller so there are 16 management output signals (MGMT_IO) which go to each PSX module, a total of 32 signals. There are two I2C interfaces that are used for either the default or redundant PSU to talk to the SC during power up. An I2C interface and some GPIO management signals (UTIL_I2C and UTIL_IO) are provided on the SC to manage each PM. A reference clock (REFCLK), which is normally 100 MHz, and an auxiliary clock (AUXCLK), which is normally a 1 pulse per second (PPS) signal, connect to each PM. When a data network is required in the SpaceVNX+ unit to provide data communication between the PMs and the SC, the SC incorporates a data routing-switch and has a single or dual-lane link to each PM. The permits communication from the SC to each PM and between the PMs.

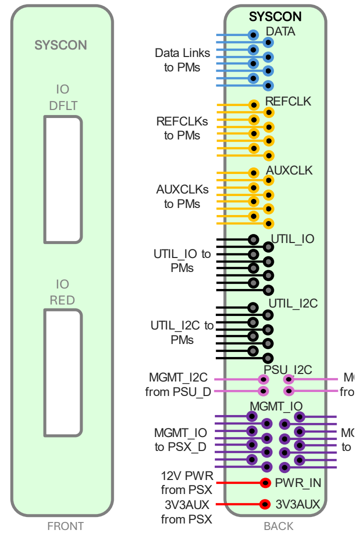


Figure 6. System Controller (SC) module signals

Payload Module (PM)

The Payload Module is responsible for providing part or all of the application services that the SpaceVNX+ unit is to deliver. Together the one or more PMs in a unit provide the capabilities required by the application. The PSU, PSX and SC all provide support services to the PMs.

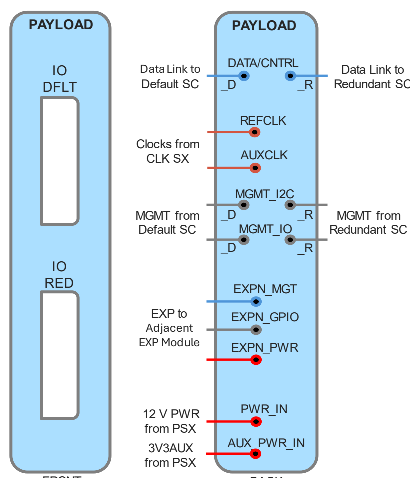


Figure 7. Payload (PM) module signals

The interfaces of the PM are shown in Figure 7. The PM receives 3V3AUX and 12V power from the PSX modules. It has management I2C (MGMT_I2C) and GPIO signals (MGMT_IO) from each of the System Controllers. Inputs for the REFCLK and AUXCLK signals are provided. Should a PM need to communicate with one or more other PMs, it will do so via data links that are typically connected to a data switch in the System Controller. It is also possible for the data links available on a PM to be directly connected to other PMs. Two dual-lane data links are provided on the PM, normally one going to the switch on the default SC and the other to the redundant SC. In addition there is a set of power, GPIO and multi-Gigabit transceivers (MGTs) on the PM, which are used, when required, for connection to an adjacent Expansion module.

Expansion Module

The Expansion Module (EXP) is responsible for expanding the functional and/or IO capabilities of a Payload Module.

The Expansion Module is a companion module to a Payload Module. In essence it is like a daughterboard on a PM, except that the connections between the PM and the EXP modules are via the backplane connector. This approach avoids the need for daughterboard connectors which would take up valuable space on the PM board and daughterboard. It also provides another wedgelock to take heat from the EXP module, whereas a daughterboard would share a wedgelock with the PM board. In a unit, the EXP board is adjacent to its PM board. The backplane connections between the PM board and the EXP board include regulated power, GPIO, Multi-Gbit/s transceivers (MGTs) and reference voltages for the GPIO. The EXP board interface contains signals that are very much like those of an FMC daughterboard. From the system perspective the EXP board is an expansion of the PM and it is connected only to the signals from the PM, except for 3V3AUX and 12V power which, if required, can be provided from the same power connections as for the associated PM. It is also possible, for example, for the EXP board to be a COTs processor under control of and reporting to the PM it is attached to.

The signals on the Expansion Module are illustrated in Figure 8.

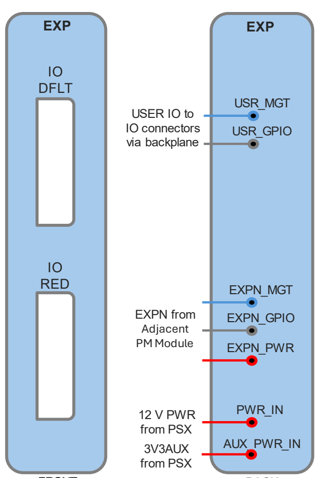


Figure 8. Expansion module signals

4. CHASSIS MANAGEMENT

Chassis management is responsible for ensuring that a module is not powered up fully until it has been confirmed that the correct module is in a slot and configured as expected. This prevents damage in the event of the wrong module or wrongly configured module being place in a slot. It also supports rapid integration.

First-Stage Chassis Management

When the PSU module is provided with input power, a microcontroller on the PSU module is enabled first. This microcontroller provides first-stage chassis management (first-stage chassis manager) as well as controlling the power supply and related power switches. The microcontroller confirms that the PSU module is in the correct slot of the SpaceVPX+ rack using the slot's geographic address, that the input power is at an acceptable voltage, and that the 3V3AUX and 12V regulators are operating correctly. It then provides 3V3AUX and 12V to the Power Switch module (see the bottom arrow in Figure 2).

3V3AUX and 12V power switches on the PSX module that provide power to the SC. These switches are operated by the first-stage chassis manager on the PSU using discrete control lines. Once the PSU module has provided 3V3AUX and 12V power to the Power Switch module, the first-stage chassis manager switches on 3V3AUX to the System Controller. The first-stage chassis manager then talks to the SC over an I2C link to confirm that it is a SC module in the SC slot on the backplane. If all is well, the first-stage chassis manager switches on 12V power to the System Controller.

Second-Stage Chassis Management

When a System Controller receives its 12V power from the power switch, the system controller will start the second-stage chassis management. The System Controller controls the PSX to provide 3V3AUX power to one PM module. The SC then talks to that PM over its I2C link to confirm that it is a PM in the slot and if it is configured appropriately. It will then do the same for all the other PMs in turn. If all PMs are okay, the SC is at liberty to switch on the 12V power to the PMs, when required by the application, by sending appropriate control signals to the PSX. When a PM receives its 12V power, status signals from the PM to the SC indicate whether it is working properly or there is a fault. There is a reset signal from the SC to each PM, should a reset be necessary at any time.

Normally the default SC will be operating. If it has a failure, the redundant SC will operate in its place. It is also possible to run both SCs at the same time. They can be in a dual-redundant configuration or the second SC can provide additional communication resources.

5. SINGLE-STRING ARCHITECTURE

SpaceVNX+ modules are designed to support both single-string architectures and architectures which have redundant modules. Figure 9 shows a single-string architecture. It provides the same functionality as the dual-redundant architecture of Figure 2, except there is only one of each type of module. Modules PM1, PM2, PM3 and PM4 are all providing different functions.

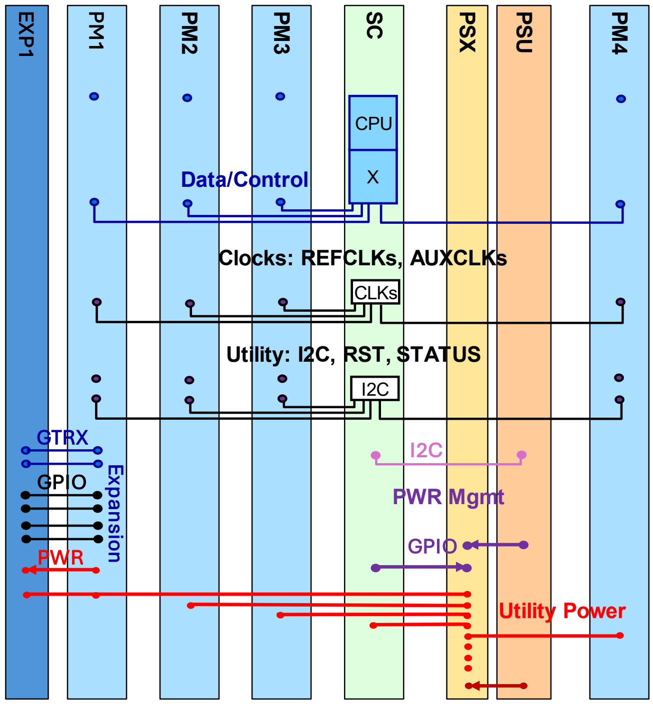


Figure 9. SpaceVNX+ Single-String Architecture

The module profiles for all the modules in the single-string architecture are identical to those of the dual-redundant architecture. The amount of overhead that the module carries when designed to support dual redundancy and used in a single-string architecture is small.

In the single-string architecture, the number of data network connections on each PM has been halved, because the PMs do not need to talk to a redundant system controller. The additional data connection has to be retained to support dual redundancy, so is a possible overhead. In practice this is a small and usable overhead. The data network connections are likely to go to an FPGA in which case the extra data connection are a few more MGTs on the FPGA. These extra data connections are still available for other purposes in single-string applications – either for point-to-point connections between PMs or for external connections via the backplane.

6. Instrument Control Architecture

SpaceVNX+ is adaptable to very simple architectures. An example is an instrument control unit which provides the communication and control functions required by some instrument. It requires power, some application specific processing capability, perhaps motor control electronics, and communications interfaces. An example architecture is shown in Figure 10, comprising :

- A PSU module and associated PSX, which could be combined into a single PSU/PSX module;
- A Payload module which provides the required processing capability, GPIO, and communications interfaces; and
- An Expansion module which provides additional specific functions for the Payload module, for example the motor control functions, ADCs, etc.

The goal of SpaceVNX+ is to provide a high level of architectural flexibility with common standard modules which are small but powerful.

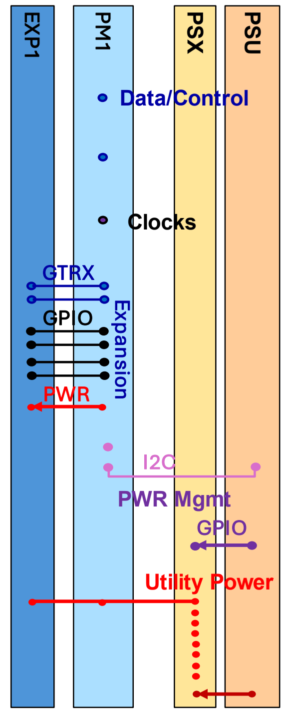


Figure 10. SpaceVNX+ Instrument Control Architecture

7. Conclusions

The requirements, rationale and design trade-offs driving SpaceVNX+ are detailed in [1].

The principal results of the work reported in this paper are the SpaceVNX+ reference architectures that are being used to evaluate different possible designs, the emerging module profiles, and the chassis management approach.

SpaceVNX+ is a small form-factor electronic equipment unit and module specification designed for space flight applications. It supports a range of different architectures using modules with standard interfaces both electrical, mechanical and thermal.

SpaceVNX+ is taking shape, and being tested with vigorous discussion in the VITA SpaceVNX+ working group meetings. Further discussions will take place until the end of 2025 and then work will start on the drafting of the standard.

ACKNOWLEDGEMENTS

The discussions with the members of the VITA 90.5 working group have been very helpful in focusing the work on SpaceVNX+. The VITA 90.5 working group is open to VITA members.

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BIOGRAPHY

Steve Parkes *received a BSc. and MSc. in Applied Physics and Electronics from Lancaster University, and a PhD from University College Cardiff. He is a Fellow of the Royal Academy of Engineering. He worked on Underwater Acoustic Systems for six years and at BAE Space Systems for seven years, before moving to Academia. He worked at Dundee University for 24 years where he became Professor of Spacecraft Electronic Systems carrying out research on spacecraft onboard networks, vision-based navigation and related planet surface simulation, and signal processing. He is the author of the widely used ECSS SpaceWire and SpaceFibre standards, with inputs from international engineers. In 2002 he founded STAR-Dundee which supports industry and space agencies using SpaceWire and SpaceFibre technology and where he is now Chief Technology Officer.*

David Givens *is Vice President of Industry Standards at Samtec Inc., a global leader in interconnection technology. His career spans 38 years, focused on high-reliability and high-performance cable and connector systems used across a wide range of industries. Global experience in Application Engineering, Product Management, and Product Development led to directing Industry Standards, most of which define modern embedded computing architectures. The last 20 years have required heightened system integration practices, due to ever-rising transmission protocol functions combined with the need to compress PCB-based sub-assemblies into new higher-density confines. During this proliferation in rugged embedded computing applications, David chaired many mezzanine Standards in VITA, a leader in mission-critical Mil/Aerospace rack systems. This resulted in joining their Board of Directors to best-support the creation of a new Small Form Factor ecosystem known as VNX. Its next generation, VNX+, is currently on the path to global publication as an Open Standard. A highly configurable nano-backplane system, VNX+ is uniquely aligned with the needs of traditional Mil/Aero platforms, plus emerging uncrewed space-constrained applications. It was also intentionally designed to fit Cube-Sat and Small-Sat hardware envelopes, with reliability-optimized definitions coming in the SpaceVNX+ Standard in 2026. David currently chairs the six foundational VNX+ hardware committees.*