AEROSPACE & DEFENSE TECHNOLOGY
The Engineer's Guide to Design & Manufacturing Advances

September 1, 2021

Migrating Advanced Signal Processing Technology to Rugged SFF Platforms

Modern radar, communications, interception, and electronic counter-measure systems now rely on phased-array antennas for steering receive and transmit signal beam patterns.

The latest data acquisition and signal processing devices are critical for capturing and manipulating wideband sensor signals for real-time radar, electronic countermeasures, EW, and SIGINT systems. These include new data converter technology and advanced FPGA designs, including the RFSoC (radio frequency system-on-chip).

To maintain strategic superiority for military and aerospace platforms, embedded systems must constantly evolve to embrace the latest technologies, counter new threats, and deal with new constraints. To meet these objectives, systems engineers must exploit new architectures that deliver effective solutions.

Strong mandates to move systems closer to the antenna are driven by the need to preserve signal integrity and minimize latency while shrinking the size and weight of the enclosures. As a result, these SFF (small form factor) systems must often be capable of withstanding extreme environmental conditions during operation, forcing designers to develop new packaging and thermal management techniques to overcome these tough requirements.

Because of the many different applications and installation platforms, each SFF enclosure must conform to a unique set of SWaP constraints. As a result, SFF system vendors now address these requirements with an extensive array of enclosures, which are often not compatible with open-standard system architectures.

NEW TECHNOLOGY ENHANCES SFF CAPABILITIES

Figure 1. Example of RFSoC-base SFF Ruggedized Sub-System. Provides 8-channels of remote data acquisition and generation, local ARM processor system controller, FPGA fabric for DSP, and dual 100 GbE optical interfaces with VITA-49 data protocol.

Traditional military embedded systems often consist of sensors (e.g., antennas) mounted in locations to best capture signals (e.g., antenna masts) with coaxial cables carrying signals to and from the equipment bay. There, a common chassis often houses both the digital signal processors and the sensor interfaces, which require analog RF I/O circuitry and precision data converters to maintain the highest levels of signal fidelity and dynamic range.

It is difficult to shield and isolate these sections from conducted and radiated emissions from adjacent digital signal processing boards, graphic processors, and switching power supplies operating at several hundreds of watts. To make matters worse, analog signals flowing from remote antennas or sensors suffer signal degradation from cable losses and susceptibility to interference from powerful antenna transmit signals, inter-channel crosstalk, and power generation equipment.

Modern radar, communications, interception, and electronic counter-measure systems now rely on phased-array antennas for steering receive and transmit signal beam patterns. These antennas are usually linear or two-dimensional flat arrays that can contain dozens of elements, each requiring separate signal processing for precisely shifting the phase to attain the desired directionality. Unfortunately, with traditional architectures, this dramatically boosts the required number of coaxial RF cables.

Removing the sensor interfaces from the equipment room chassis by relocating them as close as possible to the sensors solves the first problem of system noise contamination. New, highly integrated monolithic devices like the Xilinx Zynq UltraScale+ RFSoC family are rapidly turning the tables on traditional architectures. Because they contain 8 or 16 RF signal data converters (ADCs and DACs), FPGA resources for DSP, and multi-core ARM processors for system management, they can perform essential functions that previously required large multi-board chassis.

Now, compact SFF enclosures holding RF circuitry to convert antenna signal frequencies to-and-from L-band and the RFSoC devices for data conversion and initial signal processing are small enough to be mounted next to, or even behind, the antenna array. The FPGA resources in the RFSoC can locally apply the required phase shifts to the elements for all receive and transmit signals. Depending on the application, additional front end processing tasks can include target tracking and identification, modulation/demodulation, or encryption/decryption. Not only do these operations deliver low latency performance, they also significantly off-load backend processing tasks. With sensitive RF circuitry and data converters inside the SFF enclosure, the link to the main system is now digital, thereby eliminating analog RF cables.

Multi-gigabit Ethernet has become one of the most popular interconnect standards between embedded system elements. The latest VITA interfaces now define 10-, 40- and 100-gigabit Ethernet across copper backplane links between system boards, and over copper or optical cables between chassis. These are implemented by using either single transceiver lanes, or four bonded lanes, each operating at 10 or 25 gbaud to achieve the higher channel rates. Multi-mode fiber optical transceivers and cables can deliver these rates across distances of 100 meters.

Each 100 GbE link connecting SFF systems to back-end processors carries bidirectional digitized receive and transmit signals with data payload rates up to 12 GB/sec in each direction. This strategy not only eliminates the signal degradation and EMI susceptibility associated with long RF coaxial cables, but also saves weight, vital to aircraft systems and smaller platforms like UAVs. Optical cables are also less expensive, require less maintenance, and for added security, are highly resistant to eavesdropping.

VITA 49 Radio Transport Protocol defines how digitized RF and IF signals are packetized for Ethernet using standardized fields for channel identification, signal parameters, time and location stamps, and payload data. In this way, the same digitized signal stream can be distributed across network links to support many different applications. The latest incarnation, VITA 49.2, adds control and status protocols for both receive and transmit functions, representing powerful new levels of standardized system management and data connectivity.

SFF SYSTEMS INFLUENCE NEW EMBEDDED SYSTEM OPEN STANDARDS

SOSA (Sensor Open Systems Architecture), a significant DoD inspired system initiative, will define future MIL-AERO requirements. The SOSA Technical Standard, expected to be released in mid-2021, draws heavily on OpenVPX to define cards, backplanes, and system inter-connections. But, many participants in the SOSA community recognize that 3U and 6U OpenVPX system enclosures exceed the size constraints of many important applications.

Over the last decade, well before SOSA came on the scene, many embedded system SFF proposals have been slowly moving through the standardization process at VITA. Now, SOSA is evaluating these architectures to determine if one or more of them can be adopted to support smaller SOSA systems.

Figure 2. VITA 74 VNX SFF Modules, showing both the 12.5 mm and 19 mm widths with two and four rows of backplane contacts, respectively. Courtesy Wolf Advanced Technologies.

One of the main contenders is VITA 74, also called VNX, which offers small boards (89 mm × 78 mm) and two widths (12.5 and 19 mm) as shown in Figure 2. High-speed, high-density backplane connectors carry the same signals as VITA 46 (VPX). VNX boards can carry ComExpress

Mini and Mini PCIe mezzanines defined by PICMG. Extensions support optical and RF backplane I/O.

The second main contender is Short VPX, a new SFF initiative that preserves 3U and 6U OpenVPX backplane connectors and signals, except it shortens the length of the VPX board from 160 mm to 100 mm. Although Short VPX is too short to support PMC or XMC mezzanine modules, it can accommodate FMCs. To make up for the smaller board area, the module spacing (pitch) increases to 1.2 inches to allow taller mezzanine components. Optical and RF backplane I/O is automatically inherited from the many new OpenVPX standards in VITA 66 and VITA 67. Transitioning to Short VPX will be easier than VNX for current OpenVPX and SOSA-aligned product vendors because it uses the same backplane.

SFF PRODUCTS AND MODULAR ARCHITECTURES

Despite the availability of these standards-based SFF enclosures, they will exceed the SWaP or cost constraints of many applications. To satisfy the growing trend towards modular, distributed system architectures, SFF products are often proprietary subsystems that satisfy a single, well-defined application. To make it easier, these products can take full advantage of the growing shift towards gigabit Ethernet connectivity within and between embedded systems. For this reason, distributed architectures scale extremely well to support a wide range of platforms from small UAVs to large naval ships.

Other tangible benefits of modular systems include easier upgradability and insertion of new technology. For example, replacing an older SFF sub-system peripheral with a more advanced one may be far easier if both share common Ethernet and VITA 49 protocol connections to the host. The same argument applies for a major upgrade to a host radar system, where expensive antenna systems are often retained to save costs. In this way, defense embedded platforms can more quickly adapt to new threats.

SFF SYSTEMS: WHAT’S INSIDE?

Regardless of the mechanical form factor, successful SFF embedded systems draw upon the latest silicon devices, system links and interfaces, industry standard software tools and protocols, all integrated with proven packaging and thermal management strategies. Resources typically found in high-performance embedded system SFFs are listed below:

- **System Controller:** A CPU handles local management of host communication, control, status, and health monitoring. This is usually an Intel, ARM or AMD processor with SDRAM and FLASH memory, and a limited collection of standard peripheral interfaces including PCIe, USB, Ethernet, SATA, parallel, and serial ports. Some SFF controllers use FPGAs with embedded ARM processors or soft processor IP cores built from FPGA fabric. Linux is the dominant CPU operating system, especially in the smaller and simpler products.

- **Specialized Peripheral Interfaces:** These are application-specific sensor interfaces including ADCs and DACs, RF tuners and upconverters, power amplifiers, GPS receivers, accelerometers, power meters, and video adapters, RAID controllers, and wireless network adapters. Some of these are provided by the system controller CPU or an FPGA.
- **Signal Processor:** Unlike the system controller, this section handles realtime DSP tasks required for the digitized sensor signals. These tasks are often locally controlled and monitored by the system controller in response to commands from the host system.
- **Wideband Data Interfaces:** Multi-gigabit serial interfaces move real-time payload data to and from the SFF enclosure, often using optical transceivers to assure signal integrity over long distances.
- **Packaging and Power:** Rounding out the SFF system is the power supply, enclosure, mounting provisions, cooling structures, and suitable connectors, all designed for compliance with the deployed environment.

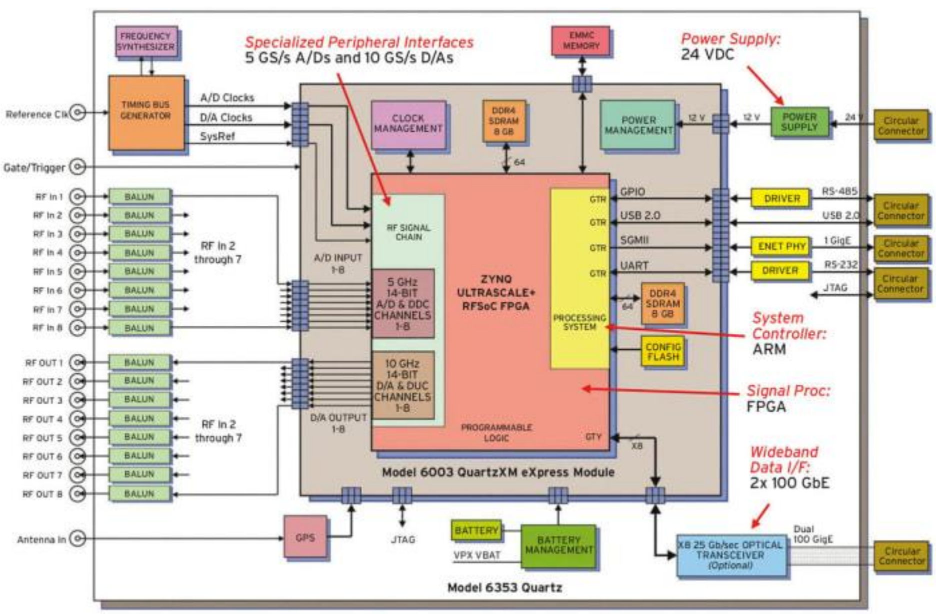

Figure 3. Model 6353 RFSoC SFF Processor Block Diagram. Eight 5 GS/s A/Ds and 10 GS/s, D/As, DDCs and DUCs, ARM system controller with I/O, Powerful Xilinx Zynq UltraScale+, Gen3 FPGA, and dual 100 GbE Optical ports.

GOING FORWARD

By enabling distributed system architectures, SFF systems and subsystems solve many of the toughest problems facing embedded system designers. The strong shift towards Ethernet connectivity between elements helps preserve software and firmware development efforts when repartitioning sections of a system to optimize specific applications.

Additionally, this modular approach often boosts performance, especially for SFFs with local sensor interfaces, data converters, pre-processors, and highspeed Ethernet links to a remote host. Consistent with many objectives of SOSA, SFF products help improve reusability of hardware and software, facilitate new technology insertion, foster innovation and multi-vendor competition, shorten system development cycles, and reduce acquisition costs. SFF products will continue to play increasingly critical roles in future military embedded systems.

This article was written by Rodger Hosking, Vice President, Pentek, Inc. (Upper Saddle River, NJ). For more information, visit here .