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Small Form Factor Embedded Systems

New Technologies Drive Diverse Solutions

As sensor processing hardware like data converters, FPGAs and CPUs evolve to handle more channels with higher signal bandwidths, designers can develop powerful distributed signal acquisition and pre-processing subsystems in small form factor (SFF) enclosures located right next to the sensors. They connect to central processing or storage resources using wideband gigabit serial links, now often exploiting low cost, standardized optical cables and interfaces. Major benefits include high signal quality over long distance, improved maintainability, and easier insertion of new technology. Since these same benefits apply across many different applications and installations, SFF system vendors now offer a bewildering array of enclosures targeting the unique requirements of each customer.

Small form factor systems mounted up on the mast are extremely effective in handling digitized radar and communications signals to and from shipborne antennas by eliminating signal degradation through long RF cables. Digital optical links between the equipment room and the mast provide immunity to EMI from powerful transmitters and other noise sources commonly found on large ships.

What Are SFF Systems?

In the existential struggle to maintain military and aerospace superiority, embedded systems must constantly evolve to counter new threats, deal with new constraints, embrace the latest technologies, and develop new implementation strategies. Together, these mandates invariably steer systems engineers towards designs that deliver effective solutions. After early adoption and user validation, the best solutions survive to become industry standards.

Standard open architecture embedded systems such as VME, VPX, and CompactPCI, offer flexibility and modularity so that systems integrators can choose standard boards, backplanes and chassis from several different vendors to create each application. These benefits, along with easier system upgrades, new technology insertion, and simpler maintenance, are all fully consistent with the COTS philosophy.

However, a large, diverse, and growing class of highly-effective solutions, collectively, and often arbitrarily, dubbed “small form factor”, have largely foiled traditional standardization efforts. Although several VITA and PICMG standards have emerged, each is supported by only a small handful of different vendors, even after many years. Indeed, SFF system enclosures come in all shapes and sizes, with a variety of backplanes, interconnect schemes, circuit board definitions, and environmental specifications.

As a result, SFF systems are often proprietary architectures that satisfy a single, well-defined function with limited availability from multiple vendors. Compared to traditional open architecture systems, SFF systems are smaller, less expensive, lighter, lower power, easier to install, and capable of supporting tough operating environments – all significant and often critical advantages!

Gaining Popularity

Pentek Model 5973 3U OpenVPX FMC carrier with VITA 66.4 optical backplane interface supports 12 GBytes/sec of traffic in and out of the module over 24 optical fibre lanes to a remote SFF subsystem.

Customers are naturally attracted to SFF systems for two major reasons. Obviously, any embedded system with improved SWaP metrics opens up new application spaces and markets where those factors are critical. In addition, larger embedded systems are now being split up into smaller distributed sub-systems, each handling a portion of the system tasks. These two trends are gaining momentum and changing the landscape of embedded system offerings from traditional full size rack mount chassis.

For these distributed systems, several business factors drive make-or-buy decisions for each element:

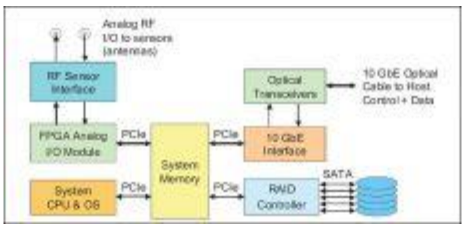
- If the required technology is outside the scope of the prime contractor's capabilities, he may not want to invest in developing internal engineering skills and expertise. A good example is a compact high-speed recording subsystem, capable of storing wideband analog or digital output signals from the signal processing system.
- Even if the prime contractor does have engineers capable of a complex or technically challenging sub-system, he may decide to purchase an SFF solution to reduce risk or time to market, even if the estimated cost to develop it himself might be a bit lower. An example might be a sensitive RF receiver small enough to fit within the confines of a UAV.
- Customers are increasingly willing to accept compact SFF enclosures and boards that do not follow embedded system standards. This is especially true for distributed systems if the vendor can successfully argue that the main portion of the system is a standards-based platform, while the SFF sub-systems are “just peripherals”.
- For larger distributed architectures, SFF sub-systems make it much easier for systems integrators to replace these SSF peripherals to easily accommodate new requirements for a similar system, but installed in a completely different platform with different sensors, topologies, and environments.

SFF and Optical Links

Apart from the business reasons above, SFF systems can significantly improve performance levels, simplify installations, and reduce maintenance costs. Whether for radar, communications, or telemetry, overall system performance is limited by the dominant source of noise or interference at any point in the signal path.

Embedded systems have traditionally used the same system chassis to house the processing boards and the sensor interface boards. Many of these must support analog I/O using RF circuitry and precision data converters to maintain the highest levels of signal fidelity and dynamic range. Isolating and shielding these sensor interfaces from conducted and radiated emissions from powerful signal processor boards, graphic processors, and switching power supplies operating at several hundreds of watts is extremely challenging. Analog signals flowing from remote antennas or sensors suffer degradation from cable losses and susceptibility to interference from transmitters and power generation equipment. These chronic problems can be largely eliminated using the latest SFF strategies.

Removing the sensor interfaces from the chassis by using a SFF subsystem to relocate them as close as possible to the sensors solves the first problem of system noise contamination. With sensitive RF circuitry and data converters inside the SFF enclosure, the link to the main system is now digital. This is a good first step, but digital copper cables still suffer from loss and interference, both of which only get worse over distance. New optical interfaces are often an excellent solution to this second problem.



Remote SFF system for communications or radar with real-time recording capability. Optical 10 GbE connection to host supports control, status and wideband data transfer. A well-defined API simplifies operation.

Based on existing industry standards for MT optical cables and connectors and new technology for optical transceivers, the embedded community has now standardized optical backplane I/O interfaces for VPX within the VITA 66 working group. Several flavors of the standard accommodate different mechanical arrangements, but VITA 66.4 defines housings and connectors for 24 lanes of optical I/O for 3U and 6U VPX modules and mating connectors for backplanes. Optical emitters and detectors located within the modules are connected to gigabit serial pins of an FPGA, which implements a suitable protocol for the required traffic. Figure 1 shows the VITA 66.4 optical backplane circuitry for a 3U VPX FMC carrier, capable of serving as the host interface to a remote SFF system connected by optical cable.

By incorporating this same optical technology within the SFF package, digital signals can be easily delivered through optical cables with baud rates exceeding 10 GHz over distances of hundreds of meters. These cables are completely immune to electromagnetic interference, so running them down the antenna mast of a large ship equipped with radar dishes poses no problem. Optical cables are smaller in diameter and much lighter in weight compared to copper, offering a significant advantage for aircraft and small unmanned vehicles.

Again, the message here is that the host can be a standards-based COTS system using OpenVPX and VITA 66.4, while a standard MT optical cable connects it to the MT optical interface of a remote SFF, which otherwise follows no open architecture standards.

SFF Systems - What's Inside?

Although they lack a common mechanical form factor, successful SFF embedded system implementations 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.

A typical SFF system contains a controller to manage its resources and to communicate with peripherals and the host system. Popular choices today are PC/104-Express, ComExpress, Mini-ITX and derivatives. These small PCs usually include an Intel 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. Windows and Linux are the most popular SFF operating systems, with Linux dominating in the smaller and simpler products.

Conduction cooled SFF recorder subsystem with A/D converters, digital down converters, and removable 15-TB SSD storage supports recording rates up to 4 GB/sec. Removable air cooling jackets are installed on each side for lab operation.

The SFF application drives requirements for the rest of the hardware. Specialized peripherals include A/D and D/A converters, RF tuners and upconverters, power amplifiers, GPS receivers, accelerometers, power meters, video adapters, high-speed Ethernet adapters, optical interfaces, RAID controllers, wireless network adapters, and a long list of many others.

Many of these peripherals are already equipped with standard system interfaces like PCIe and USB, ready for connection to the system controller. Others require custom circuitry to these interfaces, and FPGAs are a popular choice for implementation. Rounding out the system is the power supply, enclosure, mounting provisions, cooling structures, and suitable connectors, all designed for compliance with the deployed environment.

Figure 2 shows a remote SFF system for a communications transceiver or radar transponder, which incorporates RF circuitry and data converters, a system controller, a RAID controller and SSD array for recording, and a 10 GbE interface to the host. Located very close to the antennas, it eliminates signal degradation from long analog cables. All of the real-time operations take place within the sub-system, controlled by the host through the 10 Gb Ethernet link, which is also fast enough to support wideband data transfers.

Beating the Heat - A Major Challenge

Integrating the diverse collection of hardware above requires highly creative mechanical design, and one of the most difficult aspects is thermal management. In most SFF systems, fewer than ten components produce 90% of the heat. Various structures pull heat away from the hottest components to deliver it efficiently to internal airflow or the side wall of the chassis, but they also consume internal space and add metal and weight.

Heat pipes can be extremely effective at moving heat from otherwise inaccessible components to the side wall. Peltier effect thermoelectric devices extract heat from hot devices and deliver it elsewhere. Flex circuits allow repositioning of the boards for optimal cooling and easier assembly. As an added benefit, flex circuits can save weight and replace a maze of interconnecting cables not only between boards, but also to the I/O connectors on the chassis. Flex circuits and heat pipes require custom engineering and fabrication, but can yield large payoffs in environmental performance, assembly cost and reliability.

Several successful techniques serve the diverse range of applications and environments:

- Fan cooled, through chassis. Intake air flows around internal components, with finned heat sinks on the hottest ones. Internal baffles channel airflow to the exhaust vents.

- Fan-cooled, around chassis. Chassis is sealed and heat is conducted from internal components to the chassis wall using heat exchangers, metal structures, heat pipes, or thermal pads. External fan-cooled jacket forces air across external chassis wall.
- Convection-cooled, external fins. Chassis is sealed as above with heat removed through fins attached to the external case of the chassis by convective airflow.
- Liquid-cooled. Chassis is sealed as above with liquid pumped through internal or external chambers to remove heat to an external heat exchanger.
- Conduction-cooled. Chassis is sealed as above with heat removed by conduction from the external case by a metal cold plate or mounting surface.

Combinations and variations of these strategies will continue to evolve as SFF vendors pack more and more components with higher complexities in very cramped spaces.

Putting It All Together

Because of the many benefits they offer, SFF systems will continue to play an ever-increasing and important role in embedded systems. A high percentage of them are well served by topologies of distributed SFF sub-systems with local sensor interfaces, data converters, pre-processors, and high-speed digital ports to a remote host. This modular approach sustains itself by simplifying upgrades to boost performance by adding new capabilities, without having to replace an entire system. The absence of any dominant standard for SFF systems, while somewhat unsettling to some, is highly justifiable for the reasons discussed and will become more widely accepted as the multitude of benefits accrue.

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