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"Three popular mezzanine standards dominate the market: PMC, XMC, and FMC. These mezzanines support all popular industry architectures. Each mezzanine standard presents a unique set of advantages and disadvantages, which are discussed in this article."

Rodger Hosking, Pentek Vice President and Co-founder

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Choosing the Right Mezzanine Module for Embedded Systems

by Rodger Hosking, Pentek, Inc.

Open architecture embedded systems for military/aerospace applications have always relied on mezzanine or daughter cards to provide flexibility and modularity because they are very effective in handling the large breadth of I/O functions required. Thanks to widespread adoption of industry standards defining these mezzanine products, carrier boards are able to accept mezzanine boards from a wide range of vendors, each specializing in niche technologies and interfaces.

Today, three popular mezzanine standards dominate the embedded market:

■ **PMC** (PCI Mezzanine Card)

■ **XMC** (Switched Mezzanine Card)

■ **FMC** (FPGA Mezzanine Card).

These mezzanines support all popular industry architectures including VME, VXS, VPX, AMC, CompactPCI®, and CompactPCI Serial for both 3U and 6U form factors, and across a range of cooling techniques and ruggedization levels – especially important for MIL/AERO electronics. Each of these three mezzanine standards presents a unique set of advantages and disadvantages, which are discussed in this article.

Mezzanine Module Standards

Defined under the IEEE 1386.1 standard more than 15 years ago, PMC uses the mechanical dimensions of the CMC (Common Mezzanine Card) from IEEE 1386 with the addition of up to four 64-pin connectors to implement a 32- or 64-bit PCI bus as well as user I/O. ➢

Pentek's FlexorSets: the Model 3312 FMC on Model 5973 (VPX) and 7070 (PCIe) carriers

Two connectors, **P11** and **P12** (see **Figure 1**), handle a 32-bit PCI bus, expandable to 64 bits with the addition of the **P13** connector. Operating at PCI bus clock speeds of 33 or 66 MHz, the 32-bit interface delivers a peak transfer rate of 132 or 264 MB/sec, respectively, and twice that for a 64-bit interface.

A later extension, called PCI-X, boosts the clock rate to 100 or 133 MHz for a peak transfer rate of 800 or 1000 MB/sec for 64-bit implementations. The optional P14 connector supports 64 bits of user-defined I/O. As interconnect technology for mass-market PCs began shifting away from parallel PCI buses towards the faster PCIe (PCI Express) gigabit serial links, the need for a similar migration for mezzanine modules became apparent.

XMC modules are defined under VITA 42 as the switched fabric extension of the PMC module. It requires either one or two multi-pin connectors called the primary (**P15**) and secondary (**P16**) XMC connectors shown in **Figure 1**. Each connector can handle eight bidirectional serial lanes, using a differential pair of pins for each direction. The VITA 42.3 sub-specification defines pin assignments for PCIe, while VITA 42.2 covers SRIO (SerialRapidIO).

Typically, each XMC connector is used as a single x8 logical link or as two x4 links, although other configurations are also defined. Data transfer rates for XMC modules depend on the gigabit serial protocol and number of lanes per logical link. **Table 1** shows the peak rates for different configurations and protocols, which compare favorably with peak PMC rates.

FMC modules are defined in the VITA 57 specification and are intended as I/O modules for FPGAs. They depart from the CMC form factor, with less than half the real estate, as shown in the top right of **Figure 1**. Two different connectors are supported: a low pin-count (LPC) connector with 160 contacts and a high pin-count (HPC) connector with 400 contacts. Connector pins are generically defined for power, data, control and status with specific implementation depending on the design.

FMC modules rely on the carrier board FPGA to provide the necessary interfaces to the FMC components. These can be single-ended or differential parallel data buses, gigabit serial links, clocks and control signals for initialization, timing, triggering, gating, and synchronization. For data, the high-density FMC connector provides 80 differential pairs or 160 single-ended lines. It also has 10 high-speed ➢

Figure 1. Single PMC, XMC, FMC, and FMC+ Module Outline Dimensions & Connectors (drawn to scale, for comparison)
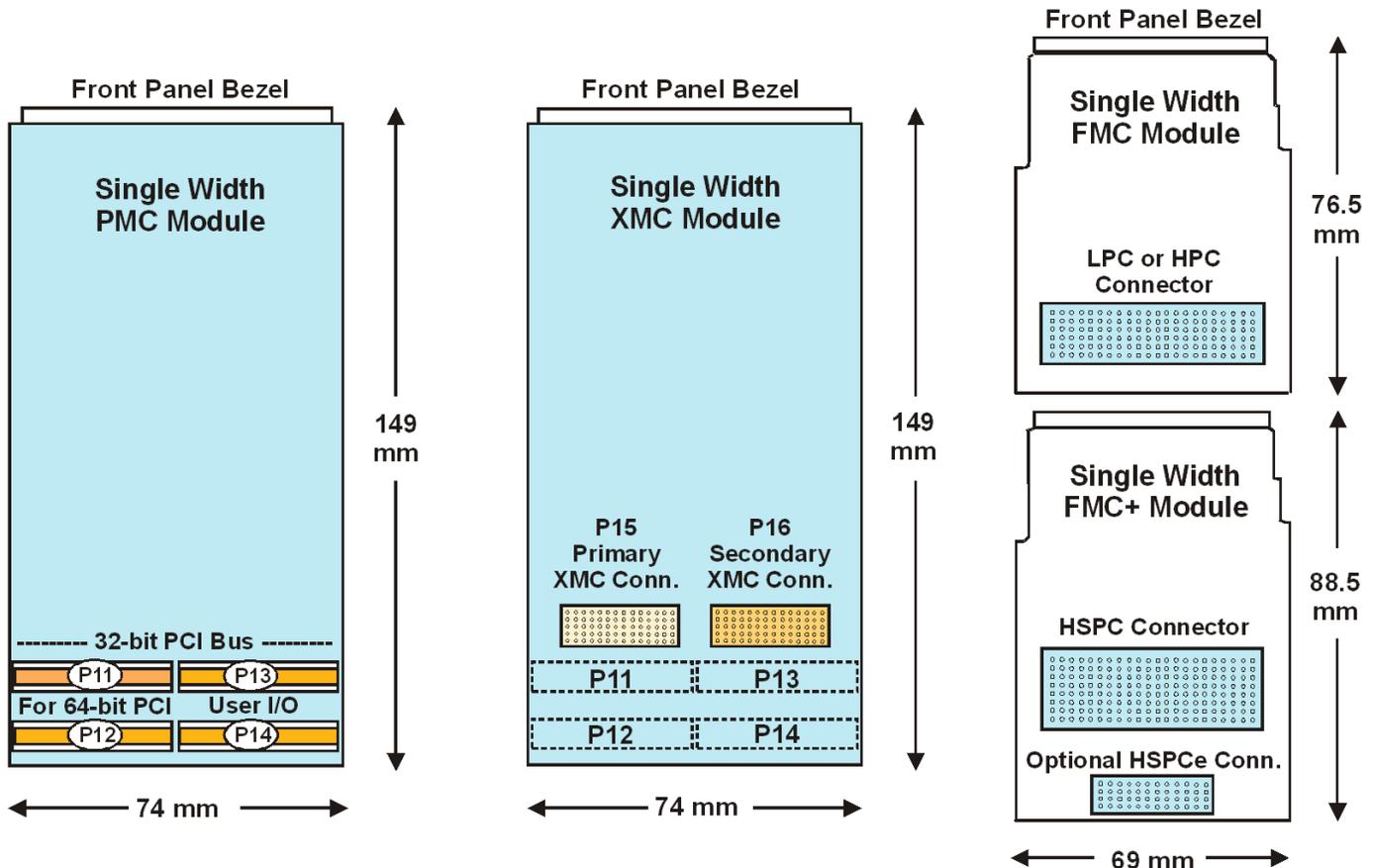
Table 1: Peak Data Transfer Rates for Various XMC Serial Link Configurations and Protocols

	Total Lanes	Duplex Mode	PCIe 1.0	SRIO 1.0	SRIO 2.0 PCIe 2.0	SRIO 2.0	PCIe 3.0
Clock (GHz)			2.5	3.125	5.0	6.25	8.0
Peak Data Transfer Rates (GB/sec)	x4	Half	1.0	1.25	2.0	2.5	4.0
		Full	2.0	2.5	4.0	5.0	8.0
	x8	Half	2.0	2.5	4.0	5.0	8.0
		Full	4.0	5.0	8.0	10.0	16.0
	x16	Half	4.0	5.0	8.0	10.0	16.0
		Full	8.0	10.0	16.0	20.0	32.0

gigabit serial lanes, with differential pairs for each direction.

In order to support the new class of data converter devices that use JESD204B gigabit serial interfaces instead of parallel LVDS, the FMC specification has been enhanced to FMC+. Defined in VITA 57.4, it increases the number of gigabit serial lanes from 10 to 24 through a new, higher-speed version of the HPC connector with four more rows of pins. The new connector for FMC+ is rated for data rates up to 28 Gbits/sec.

VITA 57.4 optionally adds 8 more gigabit serial lanes to the FMC+ module by extending the length of the original FMC module by 12 mm to support a new 40-pin connector, as shown in the bottom right of **Figure 1**. This boosts the total number of full-duplex gigabit serial lanes to 32 when maximum I/O data rates are required.

It should be noted that all three of these mezzanines are also available in double-width versions, fully defined in the specifications. This provides additional real estate for more components. However, the vast majority of mezzanines available in the marketplace today are single-width designs.

Lastly, all three specifications (PMC, FMC, and FMC) include complete specifications for rugged and conduction-cooled

versions of these mezzanine products so they can be deployed in extreme MIL/AERO environments.

Data Transfer Capabilities

Regarding the data transfer rates, PMC and XMC modules are well determined by the interface standard installed. Nevertheless, these rates are often affected by the carrier board in several ways. A shared PCI bus supporting other traffic will effectively block all transfers to a PMC until it is granted use of the bus. For example, this problem occurs on dual PMC SBCs (single board computers) where the two PMCs often share the same local PCI bus.

Also, when PMCs are installed on simple 3U CompactPCI carriers, the common PCI backplane must be shared across all boards installed in the card cage. Lastly, a carrier card or adapter that presents a lower speed PCI bus to the PMC module will force the module to operate its interface at that lower speed.

XMCs have an inherent data rate advantage over PMCs because they use fast gigabit serial links. Even the slowest x4 PCIe 1.0 interface still matches the fastest PCI-X 64-bit bus at 133 MHz. However, a major system level implication for the gigabit serial interfaces is that they are

dedicated point-to-point links and are not subject to the sharing penalty of parallel buses. **Table 1** (above) shows the peak data transfer rates for PCIe and SRIO for different width gigabit serial links.

Ultimately, any system will have CPU and memory bandwidth limitations, but new multi-core processors and chip sets feature more than 40 PCIe Gen3 lanes, each handling 1 GB/sec, and four DDR3 memory banks, each delivering transfer rates of 12.8 GB/sec. In these systems, a dedicated x8 PCIe link between the XMC and the system supports a respectable transfer rate of 8 GB/sec.

Unlike PMCs and XMCs, FMCs do not use industry standard interfaces like PCI or PCIe. Instead, each FMC has a unique set of control lines and data paths, each one differing in signal levels, quantity, bit widths, and speed. At a 1 GHz data clock rate, the 80 differential data lines can deliver 10 GB/sec, although the new FMC+ specification doubles these rates.

The original FMC specification set a design goal of 10 Gbits/sec for each of the ten serial lanes, delivering peak aggregate data rates of 10 GB/sec. The new FMC+ specification of 28 Gbits/sec for a maximum of 32 serial lanes, boosts this aggregate peak data rate to nearly 90 GB/sec. ➤

Real Estate and Power Considerations

FMC modules are less than half the size of PMCs and XMCs, and less real estate means less freedom to strategically place components for shielding, isolation and heat dissipation. For example, A/D converters are extremely sensitive to spurious signal pickup from power supplies, voltage planes, and adjacent copper traces. Often, the required power supply lines must be re-regulated and filtered locally on the same board as the A/D converters for best results, rather than on the carrier board. Arranging this circuitry on a small

FMC module can be challenging. Even though XMC modules have more components, they can often be rearranged more easily because of the larger board size.

FMCs require the FPGA to reside on the carrier board, while FPGA-based XMC modules include the FPGA on the mezzanine board. Schematically, the overall circuitry between the front end and the system bus may be nearly identical, but the physical partitioning occurs at two different points.

To illustrate this, **Figure 2** shows two different implementations of a 4-Channel A/D converter software radio module for 3U OpenVPX™, highly suitable for MIL/

AERO applications. Notice that both block diagrams feature the same A/D converters and FPGAs and provide the same x8 PCIe interface to the OpenVPX backplane. The XMC implementation on top uses the XMC connector between the FPGA and the backplane, while the FMC implementation below uses the FMC connector between the A/Ds and the FPGA.

Because most of the power is consumed by the FPGA, comparing power dissipation between FMC and XMC modules will strongly favor the FMC. However, since the same resources are used in both block diagrams, the overall 3U module power dissipation is nearly identical. ➢

Figure 2. Simplified Block Diagrams Comparing XMC and FMC 4-Channel A/D Software Radio Modules for 3U OpenVPX
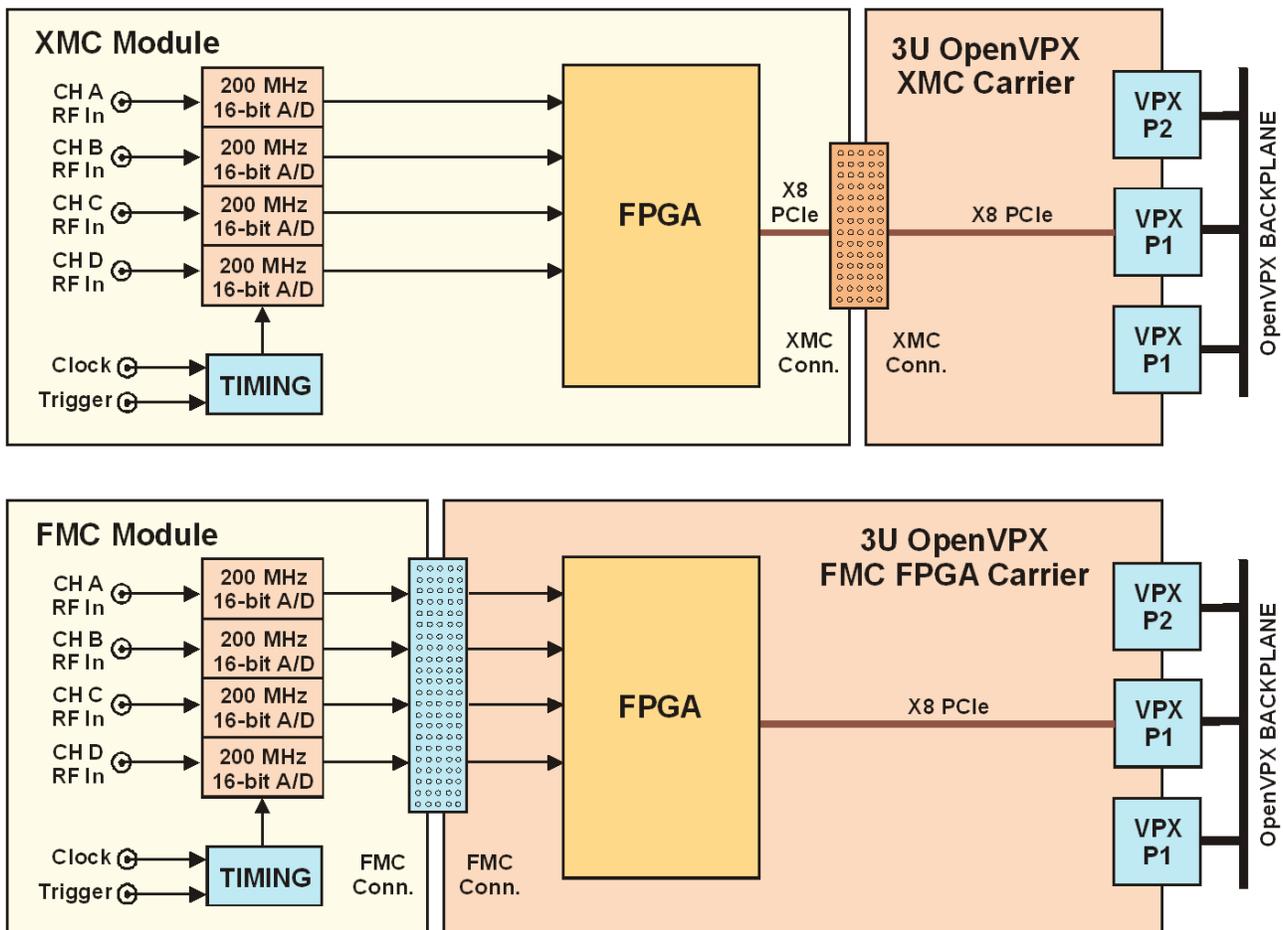
In a comparison among PMC, XMC, and FMC modules, there is one additional factor. Gigabit serial interfaces implemented in FPGAs typically consume more power than parallel bus interfaces. So when considering PMC products versus XMC/FMC products, the PCI bus of the PMC module will typically draw less power than a PCIe link. Of course, the extra power required for PCIe delivers tremendous benefits in both speed and connectivity.

Software and FPGA Development Issues

Each FMC presents a unique electrical interface that must be connected to an FPGA configured precisely to handle that specific device. This may be a reasonable solution if the FMC module and the FMC carrier are both supplied by the same vendor, and the FPGA on the carrier is preconfigured by the vendor for the specific FMC module installed.

For 6U carriers with two or three FMC sites, the FPGAs must be configured to match the specific combination of each of the FMC modules installed at each site. This FMC-to-FPGA dependency creates a potentially large number of combinations resulting in configuration management and customer support issues. It may mean longer delivery times for first-time combinations, and higher costs. Also, the vendor may not offer an FMC carrier for the desired form factor or system architecture required.

When a customer purchases an FMC module from one vendor and an FMC carrier from a different vendor, additional challenges arise. Someone must develop custom FPGA configuration code for the carrier to support the FMC module. Perhaps the FMC vendor will agree to develop code for a third-party carrier. Perhaps the carrier vendor will develop code for a third party FMC module.

Failing either of these strategies, the customer must configure the FPGA himself, or hire a consultant to do the job. In this case, both the FMC module and the FMC carrier are third-party products with two different technical support resources. If something doesn't work, it can be diffi-

cult to resolve problems in an efficient and effective way. And, if either the FMC module vendor or the FMC carrier vendor should revise his product, it may affect the interoperability of the two boards.

Perhaps the most challenging aspect of FMCs is the development of software drivers and board support libraries covering the myriad combinations of modules and carriers. Unless this is supplied from a single vendor who also supplies the FMC module and carrier, the same support and development issues discussed above for FPGA development may arise.

In contrast, PMCs and XMCs use industry standard system interfaces, typically PCI and PCIe, with a strong trending towards XMCs with PCIe. Nearly all recent embedded systems take advantage of the widely-adopted PCIe standard for interconnecting system elements. This includes VXS, VPX, AMC, and CompactPCI, as well as high-performance PC platforms using PCIe cards installed in motherboard expansion slots.

Since PCIe is the system interface on most XMCs, they can be installed directly or with simple mechanical adaptors into all of these system architectures. Most importantly, these adapters can be obtained from a variety of vendors since they are simply redirecting the PCIe bus, thus eliminating the need for anyone to develop custom FPGA code for new combinations.

Device drivers and application software developed for popular embedded operating systems simply work, regardless of the architecture. This is due to the inherent connectivity of PCIe through bridges, switches, extender cables and

expansion chassis regardless of the form factor of the boards, modules and backplanes.

All of these factors greatly reduce dependency on the XMC vendor and problems resolving multi-vendor responsibility. XMCs take advantage of an industry standard system interface, eliminate the need for custom FPGA development, easily support a wide range of system architectures, and come with complete software drivers and board support libraries. This can result in dramatic savings in systems integration and software development costs so important to MIL/AERO program budgets and schedules.

3U VPX XMC-Based Example

Figure 3 shows two Pentek Onyx® Model 52761 3U VPX modules that consist of an XMC module mounted on a simple VPX carrier, like the top diagram in **Figure 2** on page 4. The 71761 XMC module exploits the latest Virtex®-7 FPGA ➢
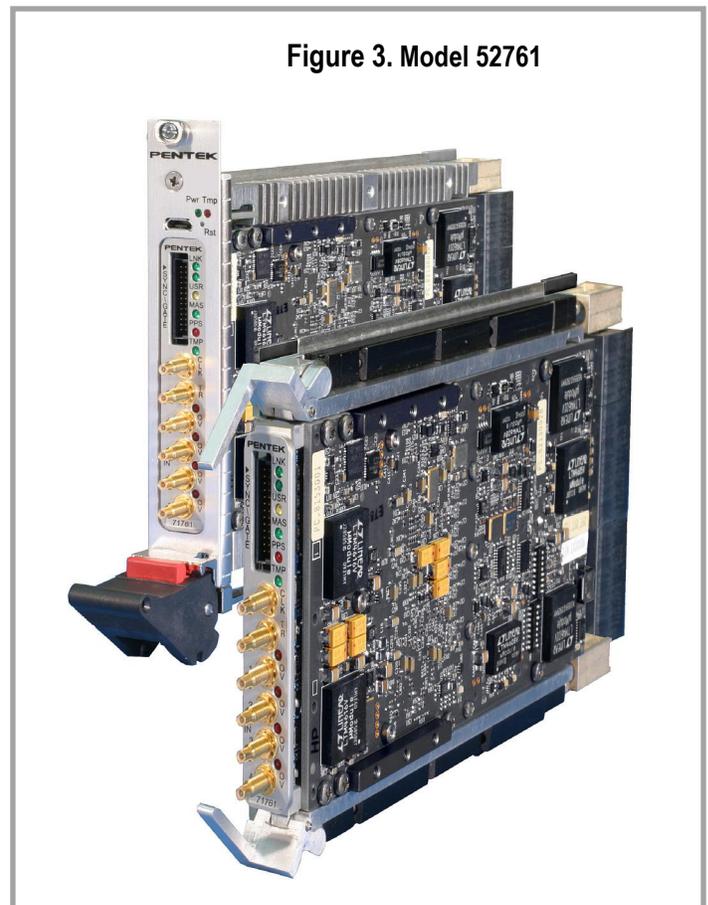
Figure 3. Model 52761

Figure 4. Model 5973-316

technology and features four 200 MHz 16-bit A/Ds and four multiband digital downconverters. It is equipped with dual XMC connectors, each capable of supporting 8 lanes of gigabit serial links. The standard product uses one of these connectors for a PCIe Gen 3.0 x8 interface, delivering a peak data transfer rate of 8 GB/sec through the 3U VPX carrier to the VPX backplane.

Two versions of this product are shown: the top one is for air-cooled systems and the bottom one is for conduction-cooled systems.

As a testament to their versatility, Pentek XMC modules are also available in PCIe, CompactPCI, 6U VPX, and AMC form factors by using other adapters, and are supported with Ready-Flow® Board Support Libraries for Windows, Linux, and VxWorks. Customers wishing to add custom IP for signal processing or special algorithms can choose the GateFlow® FPGA Design Kit containing full VHDL source code and the complete FPGA project. However, many customers take advantage of the rich collection of factory-installed FPGA functions addressing communications and radar applications, saving the need for custom FPGA development.

3U VPX FMC-based Module

Figure 4 shows an air-cooled **Model 5973-316 3U VPX FlexorSet**® module consisting of a Model 3316 FMC mounted in a 3U VPX FMC carrier, like the bottom diagram in **Figure 2**. The Model 3316 FMC has eight 250 MHz 16-bit A/Ds with full synchronization between channels and across other modules. This high ➤

Table 2: Feature Comparisons of PMC, XMC, FMC, and FMC+ Mezzanine Modules

Feature	PMC	XMC	FMC	FMC+	FMC+ e
maximum data parallel I/O rate	1 GB/s	-	10 GB/sec	20 GB/sec	20 GB/sec
maximum data serial I/O Rage	-	32 GB/sec	20 GB/sec	76 GB/sec	90 GB/sec
full duplex serial I/O	No	16 lanes	10 lanes	24 lanes	32 lanes
PC board size	110 cm^2	110 cm^2	53 cm^2	53 cm^2	61 cm^2
interface	shared bus	dedicated point-to-point	custom		
system interface standards	PCI PCI-X	PCIe SRIO	none		
relative power dissipation	medium	high	low		
software drivers	yes	yes	maybe		
multi-vendor carrier/module interoperability	excellent	excellent	poor		
vendor dependency	low	low	high		
requires custom FPGA design	no	no	yes		
system integration time	normal	normal	high		

channel-density solution is ideal for phased array radar and software radio applications.

The 3U VPX FMC carrier contains a Virtex-7 FPGA which accepts data from the FMC A/Ds, performs optional digital down conversion, and a PCIe Gen 3 x8 system interface to the VPX backplane. In fact, the circuitry for the **Model 52761** in **Figure 3** and the **Model 5973-316** in **Figure 4** are quite similar, illustrating the equivalency of the XMC and FMC architectures when applied to VPX products.

Pentek's combination of FMC modules and FMC carriers are offered as Flexor-Sets. These complete sub-systems include factory-installed FPGA code to optimize the features. Like XMC modules, Pentek offers ReadyFlow Board Support Libraries for C-language development, and the GateFlow FPGA Design Kit for user-defined IP development.

The FlexorSet approach nicely solves traditional problems inherent in FMC technology: compatibility issues between FMC modules and carriers, developing custom FPGA configuration code, and the lack of tools for software development.

Summary

Table 2 summarizes the points discussed in this article, comparing PMC, XMC, FMC, and FMC+ modules. Military and aerospace system integrators must weigh the pros and cons of each, remembering that all three are available in rugged versions suitable for deployment in severe environments. With hundreds of vendors and thousands of products, designers have many available choices.

FMC modules can be quite effective as long as the same vendor supplies both the mezzanine module and the carrier with tested and installed FPGA configuration code, like FlexorSet offerings. Otherwise, XMC modules offer excellent solutions for embedded systems due to the proliferation of links, carriers, backplanes, and adaptors all based on PCIe. This eliminates the need for a custom FPGA development effort for each new application, minimizes product support issues, and speeds development cycles. ❑

Pentek Introduces New Software Radio Modules with Texas Instruments ADC32RF45 A/D Converter

Flexor Model 3320

Pentek recently introduced two new FlexorSets featuring the ground-breaking Texas Instruments (TI) ADC32RF45 dual 14-bit 3 GSPS A/D converter. The FlexorSet Model 5973-320 for 3U VPX and Model 7070-320 for PCIe consist of the new **Flexor®** **Model 3320** configurable 2-channel A/D and 2-channel D/A FMC installed on either of two carriers. The carriers contain optimized Pentek FPGA intellectual property (IP) for A/D acquisition and D/A waveform generation, optimally matching the features of the FMC. A rich set of software development tools enables rapid application development and speeds time to market.

The Model 3320 FMC front end accepts two analog RF or IF inputs on front panel connectors into a Texas Instruments ADC32RF45 dual A/D converter with built-in multiband DDCs, setting a new benchmark for Pentek channel density and conversion speeds in a transceiver product.

"High-performance transceiver products like the Pentek FlexorSet models require the high sample rate and dynamic range that TI's ADC32RF45 and DAC39J84 offer," said Philip Pratt, High-Speed Products Business Development Manager, Texas Instruments. *"The combination of TI's 14-bit, 3 GSPS ADC and quad-channel, 16-bit, 2.8 GSPS DAC, with the Virtex-7 and optical interconnects, helps system designers create complete and powerful radar, communications and software radio sub-systems."* ➤

Pentek's FlexorSets: the Model 3320 FMC on Model 5973 (VPX) and 7070 (PCIe) carriers

For more information about Texas Instruments delivering the industry's first RF sampling 14-bit, 3-GSPS analog-to-digital converter, see here.

On the output side, the Texas Instruments DAC39J84 D/A converter accepts baseband real or complex data streams from the FPGA. Each stream then passes through digital interpolation and upconversion stages before delivery to the D/A at sampling rates up to 2.8 GSPS, a new high for Pentek products.

Users can select from three selectable conversion profiles to match the requirements of a wide range of applications. Profiles include A/D and D/A sample rates, bits of resolution, as well as digital downconverter and digital upconverter modes. Both models offer native x8 PCIe Gen 3 system interfaces, delivering peak rates of up to 8 GB/sec.

FlexorSet carriers offer a choice of Virtex-7 FPGAs to match the specific requirements of the processing task. Optional LVDS connections to the FPGA provide custom I/O for flexible platform configuration. Optional optical interfaces for FPGA gigabit serial links offer fast connections between boards and systems. The 3U VPX Model 5973-320 supports these optical links through VITA 66.4 backplane connectors.

"The FlexorSet integrated solution reinforces the value of combining FMC and carrier as a matched set to simplify development tasks for our customers," said Robert Sgandurra, Director of Product Management, Pentek.

Bundling for Seamless Integration

Both FlexorSets come pre-configured with a suite of built-in functions for data acquisition, time tagging, and waveform generation, all tailored and optimized for the FMC and carrier. This IP enables high-performance capture and delivery of data to provide an ideal turn-key signal interface for radar, communications, and general data acquisition applications, eliminating the FMC/carrier integration effort typically left to the user.

Development Tools and Software Support

FlexorSet presents system integrators with an ideal development and deployment platform for custom IP. The Pentek GateFlow® FPGA design kit gives users access to the complete factory-installed IP at the source level, allowing them to extend or even replace the built-in functions. GateFlow is engineered for the new Vivado® Design Suite from Xilinx.

Pentek's GateXpress® PCIe configuration manager supports dynamic FPGA reconfiguration though software commands as part of the runtime application. This provides an efficient way to quickly reload the FPGA, which slashes development time during testing. For deployed environments, GateXpress enables reloading the FPGA without the need to reset the host system, ideal for applications that require dynamic access to multiple processing IP algorithms.

Pentek's ReadyFlow® Board Support Package is available with drivers for Windows and Linux operating systems. The ReadyFlow C-callable library contains a complete suite of initialization, control and status functions, as well as a rich set of precompiled, ready-to-run-examples, accelerate application development.

By plugging the FlexorSets into a Pentek Model 8266 SPARK PC development system or a Model 8267 SPARK VPX development system, application work can begin immediately. The SPARK system saves engineers the time and expense associated with building and testing a development system and ensures optimum performance of Pentek boards. All SPARK development systems come with software and hardware installed and ready for immediate operation.

Form Factors

FlexorSets are designed for air-cooled, conduction-cooled, and rugged operating environments.

For more information about Model 5973-320, go to http://www.pentek.com/go/pipe5973-320. For more information about Model 7070-320, go to http://www.pentek.com/go/pipe7070-320. ❑
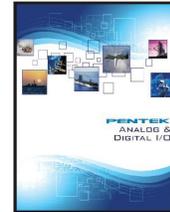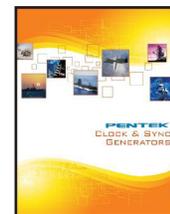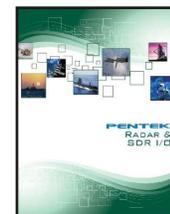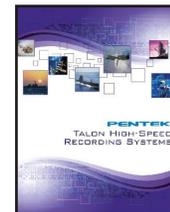
Pentek Introduces a New Series of Intelligent Signal Scanning Recorders

SENTINEL

- **Automatically tune, detect and record signals of interest**

- **Scan and search from 2 MHz to 6 GHz at 30 GHz/sec scan rate**

- **Capture instantaneous RF signal bandwidths up to 40 MHz**

- **3U to 6U 19-inch rackmount chassis with hot-swappable HDDs**

- **Storage capacities to 192 TB**

Pentek has recently added a new line to its popular family of Talon® signal recording and playback systems: the Sentinel™ Intelligent Signal Scanning rackmount recorder. The first product in this series, Talon Model RTS 2620, is suitable for military, security, and government intelligence (SIGINT, COMINT and ELINT) applications. The Talon RTS 2620 is the first recorder to combine and exploit the power of a Pentek Talon recording system with a fully integrated signal scanner, RF tuner, and RF upconverter.

A Pentek Model 78621 Cobalt® transceiver module serves as the data acquisition engine of the RTS 2620. Its 200 MHz 16-bit A/D converter provides 86 dB of spurious-free dynamic range and 74 dB of SNR. A digital downconverter (DDC) provides frequency zooming for signal bandwidths as low as a few kHz. The Model 78621 is coupled to a 6 GHz RF tuner front end with excellent dynamic range across its entire spectrum.

Sentinel Intelligent Signal Scanning

The Sentinel recorder provides automated signal monitoring and detection. The user specifies a start and stop frequency for the scan, covering any range between 2 MHz and 6 GHz. The RF tuner and DDC step across the scan range in consecutive bands, each programmable up to 40 MHz in width. RF energy in each band is detected to create a waterfall spectrum display of the entire scan.

Any band can be selected for continuous real-time monitoring and/or recording. In addition to manual band selection, a recording can be automatically started during a scan by configuring signal strength threshold levels to trigger a recording of the detected band. Each recording captures an instantaneous bandwidth up to 40 MHz.

"The RTS 2620 takes our world-class Talon recorder product line to the next level of integration. The new Sentinel scanner makes it extremely easy to automatically detect very small signals across a very large spectrum, a prime imperative for our signal intelligence customers," said Rodger Hosking, Vice-President of Pentek. *"Not only can this new recorder help engineers in a lab record and analyze signals of interest, it can also be deployed in a war-fighting environment where enemy signals need to be detected or captured for tactical purposes,"* he added. ➤
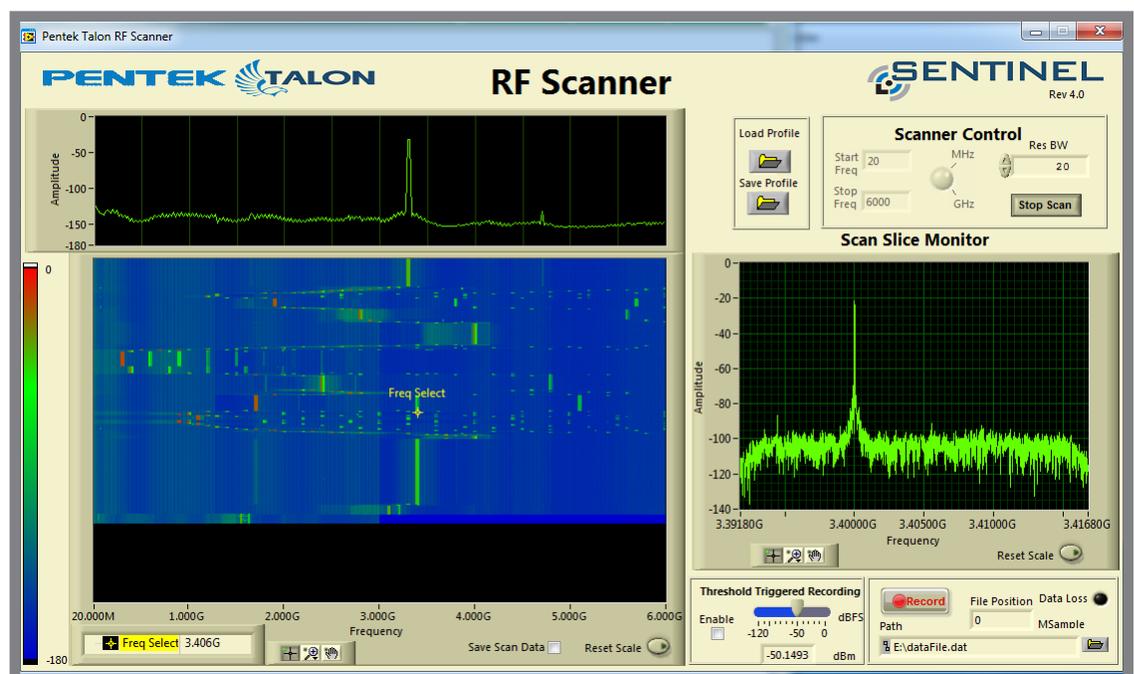
"Midwest Microwave Solutions is excited to be part of Pentek's announcement of the new Talon SIGINT recorders," said Phillip J. Rezin, President. He added, *"Integrating our RF tuner as the front end of the new Sentinel recorder with new control and scanning capabilities creates a more integrated, more complete recorder and a more sophisticated solution to communications applications."*

Ease of Operation

Sentinel recorders are built on a Windows® 7 Professional workstation with an Intel® Core™ i7 processor and provide both a GUI (graphical user interface) and API (Application Programming Interface) to control the system. Systems are fully supported with Pentek's SystemFlow® software for system control and turn-key operation. The SystemFlow software has been enhanced to include intelligent scanning and integrated control of the RF tuner and optional RF upconverter. The software provides a GUI with point-and-click configuration management and can store custom configurations for single-click setup. It also includes a virtual oscilloscope, spectrum analyzer, and spectrogram to monitor signals before, during, and after data collection.

Post processing and analysis software tools like MATLAB® can be installed directly on the Talon RTS 2620. Data files are recorded to the Windows native NTFS file system, which allows operators immediate access to recordings without the need for any file format conversion.

Configuration Options

Depending on storage requirements, the RTS 2620 is configured in a 3U to 6U 19-inch rack-mountable chassis, with hot-swappable data drives, front panel USB ports, and I/O connectors on the rear panel. The hot-swappable Hard Disk Drive (HDD) array is available in 2 to 192 TB configurations and supports RAID levels 0, 5, or 6.

Additional options include a 6 GHz RF upconverter to allow users to retransmit recorded signals at the same RF frequency at which they were recorded, GPS time and position stamping, and 10GbE or 40GbE offload facilities.

For more information, go to http://www.pentek.com/go/pipe2620. ❑
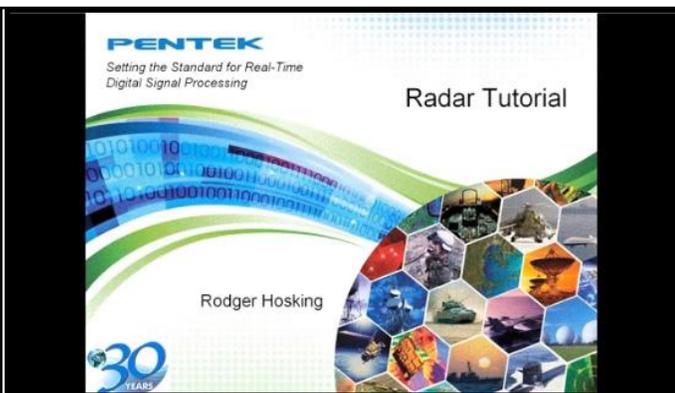
Learn About Radar

This informative tutorial covers these topics and more:

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- Advanced radar processing
- Types of radar
- Radar bands and applications
- Generating and acquiring radar pulses
- Resolving range ambiguity
- Radar technology is always evolving

To view this tutorial, click here or click the image above.

Putting VPX and OpenVPX to Work Handbook

by Rodger H. Hosking

This **NEW** technical reference for engineers is yours, **FREE**, when you click here to download.

Topics covered include:

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- VPX REDI
- OpenVPX
- Optical Resources
- FPGA Resources
- Products
- Complementary Products
- Applications