COM Express Makes its Way into Rugged and Reliable Applications

Although not originally conceived for use in rugged systems, the COM Express specification is flexible enough to be adapted for use in extreme environments, bringing high-performance single-processor systems to a range of needed applications.

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The COM Express form factor has been very successful as a low-cost processor mezzanine in a variety of commercial, industrial and communication applications. But without ruggedization features commonly employed by other form factors such as PMC, PrPMC, XMC, VME, CompactPCI and VPX, can COM Express stand up to the rigors of the most demanding rugged applications that require maximum reliability?

First consider, what is a *rugged application*? A number of environmental factors determine ruggedness, such as temperature extremes, humidity, shock, vibration, pressure extremes and the cooling method. The amount and type of ruggedization depends on the severity of these environmental factors.

Since there isn't a single level of ruggedization that works for all applications, industries have defined various environmental requirements, such as those found in MIL-STD-810, IEC 60068, ISO-7637-2 and EN 50155. The most rugged applications need to withstand high levels of shock, vibration and humidity. The most thermally challenged applications demand system cooling with no airflow and have high temperature requirements that can create significant challenges to keeping the junction temperature of high-performance processors below +105°C. They also have low operating temperature requirements down to -40°C and below.

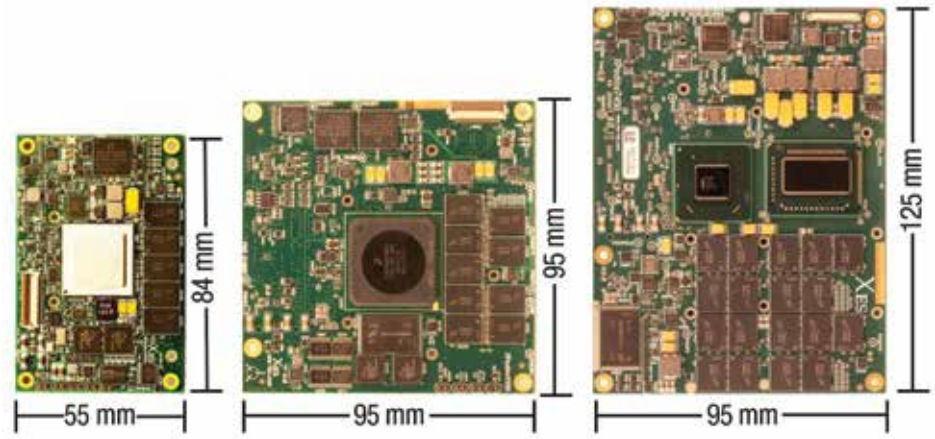

FIGURE 1

Rugged mini, compact and basic form factor COM Express modules. The additional mounting holes and soldered memory (no SoDIMM sockets) can easily be seen in these rugged modules.

What Is COM Express?

COM is an acronym for Computer On Module and *Express* represents the PCI Express interface between a module and a carrier. COM Express is a PICMG mezzanine module standard that defines processor subsystems and their native I/O. A COM Express module requires a processor, volatile physical memory (SDRAM) and chipset power supplies (sourced by 12V). Other functionality includes non-volatile memory (NAND Flash), serial interfaces (RS-232), Ethernet (10/100/1000BASE-T) and video. The carrier card provides I/O buffering and isolation, power to the COM Express module, and application-specific features such as additional I/O.

This standard makes it is easy for system designers to separate the processor subsystem and the I/O subsystem, both

FIGURE 2

A ruggedized mini form factor (55 x 84 mm) COM Express module, the X-ES XPedite5650 supports a Freescale QorIQ P2041 quad-core processor. The four additional mounting holes and soldered memory, as opposed to socketed SoDIMM memory, can be seen in the photo.

logically and physically. There are several reasons to do this. First, the life cycles of processors and I/O can vary widely. New generations of processors are introduced almost every year, while most I/O technologies tend to evolve much more slowly and tend to be application specific. Second, because COM Express is an industry standard with a large marketplace, companies can outsource the specialized design of high-performance processor subsystems to COTS vendors to focus on their added value with specialized I/O, application-specific functionality and application software.

The COM Express specification defines four module sizes—mini (84 x 55 mm), compact (95 x 95 mm), basic (125 x 95 mm) and extended (110 x 155 mm). The three most commonly used sizes are shown in Figure 1. COM Express modules support one or two high-density, low-profile connectors on the bottom side of the module. There are seven COM Express I/O types, but most new COM Express modules use one of the I/O types listed in Table 1.

Shortcomings for Rugged Applications

The developers of the COM Express standard envisioned COM Express being used in benign, forced air-cooled applications (in fact, most COM Express modules utilize a fan mounted on the heat sink); there are no provisions in the standard for dealing with severe shock and vibration or conduction and passive cooling in applications where forced air over the module isn't an option. While some commercial COM Express modules have been made to work in applications requiring lower levels of ruggedization, for the most severe environments, commercial COM Express modules are not an ideal choice.

The specification does not include provisions for cooling high-power, high-performance processors in rugged environments. For example, the COM Express standard defines as few as four mounting holes near the corners of modules, which can cause major problems for conduction-cooled applications. As the pressure between a heat sink and a module is increased when they are mated, PCB deflection of the module increases. In addition to adversely affecting the life and reliability of the module, this creates separation between the processor and heat sink resulting in a much less efficient thermal interface between them.

Commercial COM Express modules utilize SoDIMM memory modules, which can become unseated or temporarily disconnected under severe shock/vibration. Most commercial COM Express modules use commercial-grade ICs that support a 0° to +70°C temperature range.

It is important to note that many COM Express vendors will simply replace commercial grade ICs with industrial grade ICs and declare the module to be rugged. There is much more to making a board that will operate in the most severe environments than changing the bill of materials (BOM). Features such as soldered down SDRAM, class III fabrication and additional mounting holes cannot be added with a BOM change.

COM Express for Rugged Applications

Before getting into how COM Express can be used in rugged applications, it is worth mentioning VITA 59, or ESMexpress. This was an effort to create a rugged module based off the COM Express standard with a new connector because the backers believed that the existing COM Express connector was not rugged enough. For this and other reasons, VITA 59 has never had any traction in the market. Furthermore, Extreme Engineering Solutions has proven that with additional mounting holes to reduce board flex, the COM Express connector is reliable at the highest levels of shock and vibration in the VITA 47 and MIL-STD-810 specifications.

If the COM Express specification doesn't address features required by the most severe environments for embedded applications, how can it be used in these applications? The good news is that the COM Express standard does not prevent module manufacturers from designing in features that make the module rugged and reliable while still maintaining compliance to the standard.

There are some obvious changes that can make modules more rugged. COM Express modules can be designed to use soldered memory chips, as opposed to SoDIMMs, and they can be designed to use ECC memory for increased reliability. The removal of configurable SoDIMMs is more than made up for by the reliability of soldered ECC memory. Another obvious modification is to use industrial-grade ICs to expand the temperature range to operate at -40° to +85°C.

To ruggedize a COM Express module, additional mounting holes must be added

throughout the module with specific attention paid to the connectors and processor. Not only does this enable the design to be stiffer to resist damage and failure from shock and vibration, it is important in high temperature applications to minimize PCB deflection thus maximizing the thermal conductivity between the processor and the rigid cooling interface.

Class III PCB fabrication and assembly processes significantly improve the reliability of modules. A leaded solder process can mitigate the risk of tin whisker formation, which is important to many customers requiring long life cycles and maximum reliability. Conformal coating can also be applied to a module to allow for operation in high humidity environments. Some of these ruggedization enhancements can be seen in the rugged XPedite5650 COM Express module shown in Figure 2.

Two other, less-obvious engineering efforts contribute to making COM Express modules suitable for rugged applications. One involves engineering processes and practices routinely put in place by engineering organizations that develop highly reliable, rugged, conduction-cooled boards. These include stringent project and configuration management, thermal, structural and signal integrity simulation and analysis, component derating, high-temperature and cold-temperature performance analysis. In addition, there is IPC 9701 thermal fatigue analysis, reliability and maintainability (MTBF and MTTR), design verification, environmental qualification, BIT, Failure Mode, Effects and Criticality Analysis (FMECA) and Fault Detection and Isolation (FDFI).

COM Express Enclosures

Another less-obvious engineering effort involves the design of enclosures. COM Express modules are mounted on carrier boards of any shape and size. Therefore, custom enclosures are commonly designed around each specific application.

In conduction and passively cooled applications, the enclosure design is integral to providing cooling. In traditional, slot-based COTS board standards, such as VME, CompactPCI and VPX, modules were designed to be easily inserted and extracted from large, multi-board systems. The heat from these modules must be transferred through the relatively narrow side rails of the module to the chassis. While this is required in large, multi-board systems, it creates unnecessary thermal inefficiencies for small form factor systems based on a single processor.

COM Express Connector Type	I/O Provided by COM Express Connector	Primary Suitability
Type 5, double connector, 440 pins	32 PCI Express lanes, PEG, no PCI, no IDE, 4 SATA, 3 LAN (Gigabit Ethernet)	Freescale QorIQ processors and network heavy applications
Type 6, double connector, 440 pins	24 PCI Express lanes, PEG, no PCI, no IDE, DDI (for DisplayPort, HDMI, DVI or SDVO), 4 SATA, 1 LAN (Gigabit Ethernet), 2 Serial COM, USB 3.0	Intel Core i7 processors
Type 10, single connector, 220 pins	4 PCI Express lanes, no PEG, no PCI, no IDE, 2 SATA, 1 LAN (Gigabit Ethernet), single-channel LVDS only, DDI, no VGA, 2 Serial COM	Smaller and lower power processors such as Intel Atom and smaller Freescale QorIQ options

TABLE 1

Commonly used COM Express I/O types.

In contrast, a system based on COM Express can provide a direct and thermally very efficient interface between the hot components and a chassis' cooling interface. With the primary side of a COM Express module on the opposite side of the board from the COM Express connectors, the processor resides on the outside of the sandwich that is created when a COM Express module is mated with its carrier card. This is significant from a thermal management and system design perspective because the processor and other hot components can interface directly with the cooling interface of the enclosure. To further improve the thermal interface, the inside of the chassis wall that interfaces with the primary side of the COM Express module can be "skylined," that is, it can be machined to be a mirror image of the COM Express module so that all of the major heat producing components have a direct and unobstructed path with the chassis's cooling interface.

Because of the tremendous thermal efficiency of interfacing processors directly with the cooling interface of the enclosure, very high-performance processors, such as the Freescale QorIQ and Intel Core i7 processors, can be supported in high temperature environments. With other, less thermally efficient Small Form Factor standards, such as PC/104, VITA 73 and VITA 74, only less powerful processors, such as the Intel Atom, can be adequately cooled. Another advantage of having the primary side of the COM Express module in direct contact with the cooling interface of the enclosure is that securely attaching the entire module to the enclosure provides a high degree of mechanical stability against shock and vibration damage to the circuit board and internal components.

Building COM Express Systems

By nature, COM Express lends itself to small systems requiring only a single processor. COM Express wasn't designed, nor is it suited, for building larger, multi-processor systems. There are other industry standards, such as VME, CompactPCI, VPX, MicroTCA and ATCA, that are much better suited to building large, multi-board systems. However, these standards unnecessarily increase size, weight and power (SWaP) and limit the thermal performance of small single processor systems.

A COM Express system typically includes a COM Express module and a carrier card containing the application-specific I/O and functionality. This type of design has very little overhead—two

PCBs with a set of COM Express connectors. Because COM Express modules are small (a Mini COM Express module is about the size of a business card), and in many applications the only other board in the system is the carrier card, enclosures can be physically small. However, since each application dictates the size and composition of the COM Express carrier card it needs, there is no way to create a COM Express system standard based on a COM Express module and carrier card approach—every system is custom.

Mating a COM Express module to a custom carrier card isn't the only way to implement a COM Express design. Instead of developing a carrier card that contains all of the application's I/O, a carrier card can be designed with a COM Express site and an I/O mezzanine card site to support COTS mezzanine form factors such as IP, PMC, XMC, or miniPCIe modules.

Using this approach, a single carrier card can support a variety of COM Express modules and COTS I/O modules. Regardless of the I/O, the shape and size of the boards are the same, allowing a standard enclosure to be designed around them. Extreme Engineering Solutions used this approach to create the XPand6000 Series Small Form Factor (SFF) enclosures, shown in Figure 3. These enclosures include a customizable carrier card that supports a single COM Express module, a single PMC or XMC module and a 1.8" SSD. The PMC/XMC form factor was chosen because of the number of I/O solutions available on the market.

FIGURE 3

The X-ES XPand6000 Series rugged enclosure, which houses a carrier card that supports a COM Express module, a PMC or XMC for I/O, and a 1.8" SSD, illustrates that it is feasible to create a standard COM Express-based system and that not all COM Express-based systems have to be custom designs.

Not only can COM Express modules be ruggedized and include the features necessary for embedded computing applications, they can support very high-performance processors, unlike some other small form factor standards. COM Express is very well suited to meeting the needs of small embedded computing applications, and it fills a void that slot-card standards cannot fill. Even though the COM Express standard does not specify the size of carrier cards, with a little foresight, it is possible to develop COTS COM Express-based systems that can meet a growing need for small, rugged systems to be deployed in vehicles, small UAVs, industrial facilities and remote locations.

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