From Reference Board to Rugged Military SBC

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Intel processor reference designs are developed by Intel to assist engineers in the design of Intel processor-based products. The less a design deviates from the reference design, the easier the design is. When developing a commercial product, such as an ATX motherboard, the core design can be left intact — the processor, south bridge, memory, and power supplies — and functionality can be added or removed based on the application's requirements.

But, for rugged military applications, a design engineer's job is much more difficult. Size, Weight, and Power (SWaP) constraints and any combination of heat extremes, high levels of shock and vibration, high humidity, dust, salt, fog, and EMI all require major modifications to an Intel reference design to ruggedize it.

Figure 1. The size of a full size ATX motherboardis about 9.6

The VPX Standard

To turn an Intel reference board into a ruggedized single board computer (SBC), engineers rely on standards like VITA 46 (the VPX standard), defined specifically to address the demands of military applications. The VPX standard defines 3U and 6U modules that plug into a backplane that supports high-speed fabric interconnects for board-to-board communication with protocols such as PCI Express, RapidIO, and Ethernet.

The companion standards REDI (VITA 48) and OpenVPX (VITA 65) define cooling methods and system-level specifications, respectively. When combined, these three standards provide engineers with guidelines and resolutions to board and system design issues. Many challenges, however, still exist to complete the transition from reference board to SBC.

Hardware Changes

While the ATX form factor of reference boards measures approximately 10 inches x 12 inches (Figure 1), 3U VPX boards are a mere 4 inches x 6 inches (Figure 2). Careful component selection is essential given the reduced space and increased performance demands of rugged boards.

The connectors common on an ATX board consume the most space and are all removed to fit the VPX standard on the XPedite7470, a 3U VPX SBC incorporating the latest Intel Core i7 processor (Sandy Bridge). For instance, the reference board's PCI Express connector is replaced with PCI Express lanes that are routed to the SBC's backplane and XMC connectors. USB, Ethernet, DVI, serial, and SATA are also all routed to the front panel or backplane.

Ruggedized military systems also require industrial temperature parts wherever possible to meet the -40° to +85°C operating temperature range. For many of the components, such as logic gates, buffers, and passives, changing to industrial temperature parts is as easy as changing a letter in the part number; but some components are unavailable in the industrial temperature range, which requires alternative components to be selected. Additionally, other components must be substituted due to their size, features, power consumption, or an engineer's familiarity with the part.

Beyond individual component changes, some system-wide changes must also be made for a rugged SBC. The Intel Core i7 reference design uses a standard 240-pin SODIMM for memory, a poor choice for applications facing a significant amount of shock and vibration. Rugged DDR3 memory modules do exist, but fitting them on a 3U VPX would be extremely difficult, if not impossible. Much better space efficiency, signal integrity, and thermal performance can be achieved by eliminating the connector and soldering the DDR3 directly to the board.

This is a major deviation from the reference design, which requires redesigning the DDR3 layout. This can be engineering-intensive, due to the high-speed bus and strict routing rules. When changing the design to implement soldered memory in a very small space and in close proximity to other subsystems, signal routing (ensuring properly length-matched traces), impedance matching, and proper termination must be carefully engineered to ensure good signal integrity at high signaling rates over temperature.

Optional Modifications

A number of other changes can be made to a reference board design based either on the discretion of the engineer or the intended application of the board.

Intel reference boards use a simple microcontroller (commonly referred to as the embedded controller) for power sequencing and board management functions. To save space in small embedded designs, this is often replaced with discrete logic. In addition to the embedded controller, a "Super I/O" controller provides legacy I/O such as keyboard, printer, and serial ports. This part can be replaced with a much smaller part that only provides the serial ports.

Figure 2. The size of a 3U VPX module is about4

Rugged military applications also demand rugged storage solutions. On the XPedite7470 SBC, for example, one of the USB ports interfaces to a NAND flash controller, similar to a thumb drive. This flash memory is where the operating system typically resides and can be used by the application. In addition, SATA is routed to the mezzanine site, where a storage XMC, such as the XPort6103 512 GB SSD, can be added. SATA is also routed to the backplane allowing storage to be located elsewhere in the system.

The Ethernet controller on the Sandy Bridge reference platform only provides one Ethernet port and is not rated to industrial temperature, yet many applications require two or more ports. Additionally, some systems need a 1000BASE-BX Ethernet interface to the backplane, while others need 10/ 100/1000BASE-T Ethernet, so it is practical to support both. Therefore, the XPedite7470 uses an industrial temperature rated PCIe Gigabit Ethernet controller to provide a 10/100/1000BASE-T interface, and includes the option of incorporating an additional industrial temperature rated component to convert 10/100/ 1000BASE-T to 1000BASE-BX.

The embedded graphics core in the Intel Sandy Bridge processor offers engineers several choices for video implementation. As the digital successor to VGA, HDMI/DVI is standard. Display-Port is also supported and offers higher bandwidth than HDMI/DVI, for larger displays, multiple displays from a single port, or full HD 3D displays. It provides two-way communications, offering support for peripheral input, such as touchscreen interfaces.

Supporting both HDMI/DVI and DisplayPort makes sense to fulfill current requirements and anticipate future needs. This is why the XPedite7470 incorporates dual-mode DisplayPort as well as an HDMI/DVI driver. The driver can, however, be bypassed to offer dualmode DisplayPort, which can be converted to HDMI/DVI using cable adapters if needed.

BIOS Changes

Successfully developing a rugged SBC from a reference board requires more than hardware modifications. Nearly every hardware change to the reference design requires a similar BIOS change. For instance, soldered memory configurations require special handling of SPD configuration data in the BIOS, and removal of the Embedded Controller (EC) requires numerous BIOS changes; the reference BIOS routinely talks to the EC, and ACPI functions instruct the operating system to talk to the EC. The SuperI/O chip generally contains a legacy keyboard controller, which is required by many legacy operating systems. Consequently, the BIOS must emulate a keyboard controller in software to remain compatible with these operating systems.

Figure 3. The X-ES XPand3200 is a deployable AirTransport Rack (ATR) conduction-cooled chassis,which represents typical system packaging of 3UVPX boards. The sides of this chassis have beenremoved to expose the 3U VPX payload modules.The dimensions of the chassis are 8.75

A BIOS for rugged SBCs starts with a commercial BIOS like that of a laptop manufacturer. However, a BIOS for commercial systems is geared toward the reference platform with simple PCI/PCIe topologies, quick boot time, and popular commercial operating systems like Windows.

Embedded systems can feature advanced and custom PCI/PCIe device topology, advanced Built-In Tests (BIT), and may require support for a variety of operating systems, like VxWorks, Linux, or INTEGRITY. Furthermore, VPX boards that utilize PCIe for peer-to-peer communications between boards require PCIe non-transparent bridging. These advanced features require BIOS support for configuration and execution.

It is also common for PCI/PCIe peripheral devices in embedded systems to require additional startup time, beyond what is in the specifications. The BIOS, consequently, needs to have facilities to delay PCI enumeration by a fixed time, or until a signal has been asserted, to allow all of the boards in the system to boot.

VPX boards often need to support advanced Built-In Tests. While a standard BIOS would simply enumerate the devices it finds, for BIT, the BIOS has to test for the devices it knows are on the board. BIT also includes advanced memory testing, which can considerably increase boot time. Because BIT adds to the total boot time, the tests are typically configurable in the BIOS so that users can achieve a balance between boot time and Built-In Tests.

System Integration Differences

Just as the boards themselves differ extensively from one another, system development for rugged SBCs is fundamentally different from systems based on an ATX board. An ATX motherboard is built of components, such as chassis, power supplies, PCI/PCIe cards, and disk drives, readily available from numerous commercial sources.

Building a conduction-cooled 3U VPX system, however, may require the ATR chassis, power supply, I/O interfaces and cabling, or other components to be custom built for each application. The completed system is then subjected to rigorous environmental and EMI/EMC qualification testing prior to deployment.

Traditionally, rugged military system developers used air-cooled hardware for development and would transition to deployable, conduction-cooled hardware for integration and final testing, when it became available. Unfortunately, developing an air-cooled system and then transitioning to a conduction-cooled system can add risk and lengthen the development process.

Early access to deployable hardware shortens the time required for end-application software development. To speed development of these complex systems, X-ES developed the XPand1200, an air-cooled development platform that supports conduction- cooled 3U VPX modules along with COTS air-cooled Rear Transition Modules (RTMs), which allow standard I/O cables to be used. This enables software development on the same conduction- cooled hardware that will be deployed. In parallel with software development, a custom deployable chassis (Figure 3) and backplane can be developed. When the custom hardware development is completed, the deployed system integration and testing can begin by integrating the same conduction-cooled boards that were used for software development.

The Finished Product

Developing an air- or conduction-cooled 3U VPX board from an Intel reference design is a complex process, entailing hardware, firmware, and system modifications, in order to meet the ruggedization requirements of military applications.

Getting involved in the Intel Early Access program ensures access to the latest technology for development of ruggedized Intel-based SBCs. This in turn ensures military system designers early access to the newest technology for their applications.

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