COTS Bladed Server Architecture for High Performance Defense Applications

Rob Persons
Senior System Architect
SMART Embedded Computing
www.smartembedded.com
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AdvancedTCA® (or ATCA®) technology has proven itself to be one of the most successful open, bladed architectures for high-performance, ultra-reliable network computing. The PCI Industrial Computer Manufacturer Group (PICMG®) ratified the original ATCA open standard specification 15 years ago, has enhanced it over the years, and continues be an active organization of vendors and users. ATCA has defined a system architecture that supports systems which are compact, light and power efficient—which has become an ideal choice for military, aerospace and security systems.

Since 2012, a number of large military programs have adopted ATCA technology. This paper addresses the forces driving the requirements of high performance embedded computing (HPEC) for military and aerospace applications, including the modular open system approach (MOSA), commercial off-the-shelf (COTS), and reduced size, weight, power and cost (SWaP-C) as it applies to ATCA.

Data transmission, packet processing and high performance computing are becoming more important functions in military, aerospace and security equipment.

This is driving defense and aerospace contractors to examine and adopt AdvancedTCA® (ATCA®), which has proved so successful in the telecom and network equipment markets, as the foundation compute technology which can be successfully deployed in the tough conditions experienced by soldiers, pilots and sailors.

The military and aerospace equipment industries have been undergoing a similar structural shift as that experienced by telecom equipment manufacturers just over ten years ago, and for similar reasons.

Prior to the establishment of the ATCA standard, the telecom equipment market was fragmented with proprietary technologies that did not interoperate, which increased cost and risk for telecom equipment manufacturers.

Military systems which require large amounts of centralized compute power have similarly evolved to become highly reliant on a robust data and network-centric model, previously built on proprietary bladed technologies. Fault tolerance and fast access to intelligence data at all levels is essential to maximize effectiveness of military operations.

Figure 1: A wide range of ATCA products are available from an ecosystem of many vendors

Traditional military computing infrastructure is not meeting the diversity of demands. The highly competitive and technically demanding telecom industry recognized these challenges and developed ATCA as a standards-based environment to drive compatible innovative solutions from suppliers.

Commercial off-the-shelf (COTS) components and platforms based on this open system standard, enable system manufacturers to reduce product costs and to develop products more quickly and cost effectively.

By choosing products that comply with an established open standard, defense and aerospace contractors gain the security of knowing they have access to multiple sources of supply for interoperable products.

n addition to meeting functional computing requirements, there is a mandate to adopt more flexible open standards based solutions.

Worldwide, defense organizations are under pressure to deliver leading edge high performance computing systems for all facets of military operations while simultaneously being restrained by budgetary controls.

Solutions must be found that satisfy these demands without making compromises.

The US Department of Defense has been spearheading a strategy that is mandating a modular open system approach (MOSA), COTS, and reduced size, weight, power and cost (SWaP-C) based solutions as part of the strategy for achieving this objective.

Why Defense Programs Have Adopted ATCA

Computers are an essential part of military, aerospace and security equipment. The conditions in which they are used cover a broad spectrum.

A soldier on the battlefield might use a handheld device as an impromptu hammer in an emergency so his digital device, like any other piece of his personal equipment, needs to be extremely rugged.

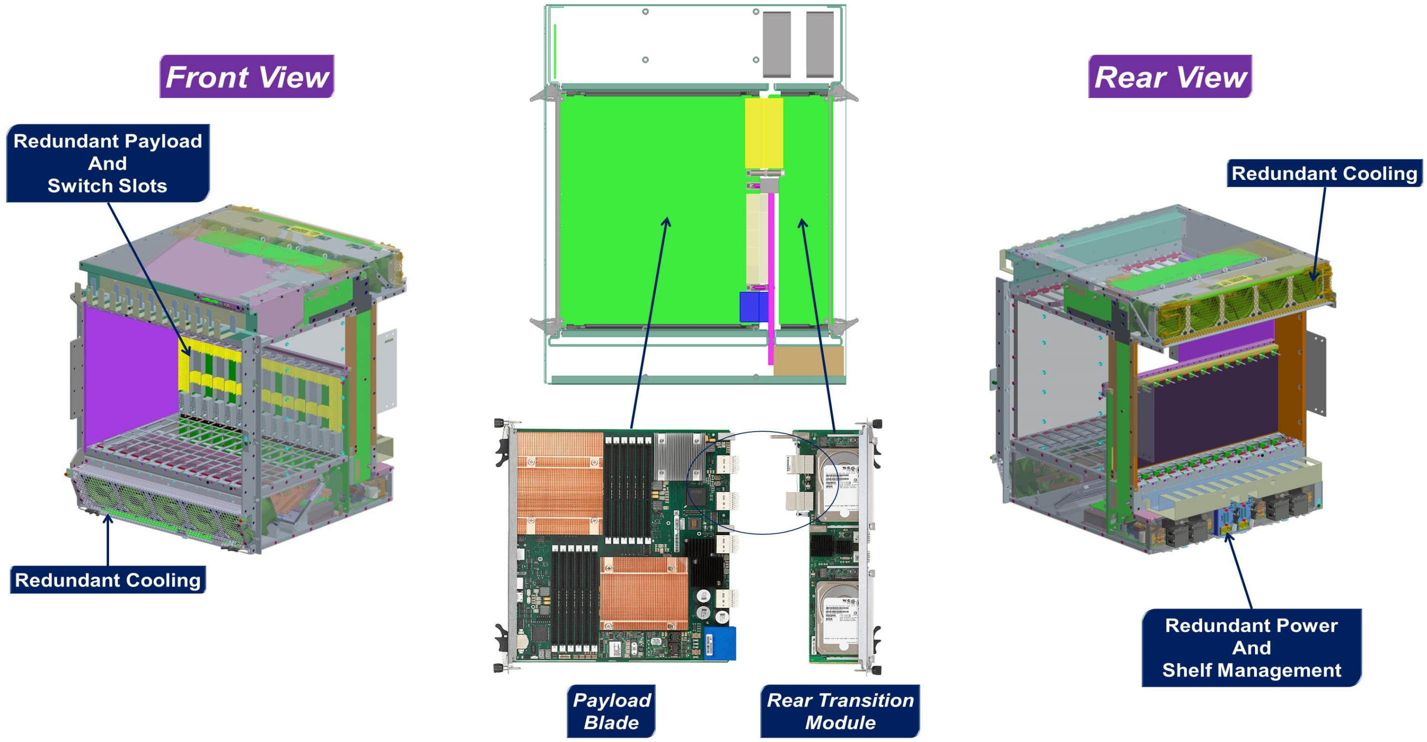

Figure 2: ATCA Basic System Components

On the other hand, a government security facility monitoring communications traffic in an air-conditioned data center can run servers no more rugged than the enterprise systems used by banks and other multinational companies. ATCA technology occupies the middle ground between these two extremes.

Whether it is mobile, compact data centers supporting battlefield operations, tactical defense systems on destroyers and aircraft carriers, or supercomputing data processing systems on board tactical aircraft, embedded computing technology must be capable of providing high performance while tolerating some shock, vibration and thermal stress.

Existing open standards such as VMEbus or OpenVPX, provide a rugged form factor, but strict electrical power and thermal limits mean that it cannot provide the high computing performance required in today's high performance tactical systems. High performance OpenVPX systems require expensive, esoteric cooling systems to cool modern and power hungry processors.

On the other hand, enterprise-grade servers offering the blazing speed required to support cloud-based computing and other network operations offer a short lifespan, excessive power consumption, and a tangle of network and power cables which is impractical for typical military applications.

This is exactly the sweet spot for ATCA: an open standard that supports leading-edge packet and data processors while providing a degree of ruggedness in a compact and power-efficient bladed architecture.

Survivable High Performance Open Computing Standard

ATCA architecture was designed from the beginning as an ideal basis for network-ready, carrier-grade common platforms. The standard provides open specifications covering the following elements:

- ATCA is inherently rugged because the enclosure standards must be able to meet Network Equipment Building Systems (NEBS) Level 3 Environmental requirements, which includes operation in extended temperature ranges and in earthquakes
- Hot-swappable blades capable of carrying at least 200W of processing power (and up to 400W where conditions permit)

- Support for latest ultra-high-speed data and packet processors, like the new Intel® Xeon® Gold processors which are supported for 15 years on Intel's Embedded Roadmap

- Ethernet fabric connectivity between blades of up to 40Gbps

- Rear transition modules (RTMs) supporting additional functionality and enhanced storage and networking interfaces

- A common system and element management structure designed to support interoperability between vendors

Compared to conventional enterprise-grade rack-mount systems – the architecture found in the data centers of large corporations and Internet service providers – a bladed system offers substantial benefits for military, aerospace or security equipment. These benefits are often branded with the SWaP-C moniker – for size, weight, power and cost.

Size and Weight

In a bladed architecture such as ATCA, servers are slotted next to each other into a chassis that interconnects all components through a pair of integrated switches through the backplane.

This is inherently a more compact structure than a rack-mount chassis because it eliminates unreliable power and cooling elements that accompany individual rack-mount chassis. The specification provides for a centralized rugged cooling chassis infrastructure that supplies sophisticated airflow routing and other thermal management techniques suitable for such compact mounting arrangements.

What's more, ATCA systems are designed to fit into the telecom standard 600mm rack depth whereas enterprise systems are often deployed in 1000mm deep racks. These 1000mm deep systems preclude the use of many well-established legacy shock isolated racks deployed in many military applications.

The ATCA chassis is both smaller and lighter than a comparable rack of servers and removing the need

AdvancedTCA products are actively engaged in the following key applications:

- Shipboard communications and data center consolidation
- Naval tactical combat systems refresh
- Airborne reconnaissance
- Theater command centers Mobile Tactical Operations Centers (TOCs)
- Ground and airborne battle management systems
- Land Based and Naval Universal UAV Ground Stations
- C4ISR

for cabling between each server in a bladed system also saves space and weight.

This is especially relevant in 40G applications, where small integrated and redundant 40G switches in ATCA systems eliminate large external 40G switches and reduce the amount of total space and weight of the complete system.

System Cabling Complexity

ATCA technology reduces overall system complexity and cost by integrating data plane fabrics into the chassis backplane. Compared to a typical rack of 1U servers with external switches, ATCA eliminates a veritable rat's nest of cables necessary to interconnect all the servers together.

To create a highly available network of 1U servers, a redundant switch with an additional complement of cables would also have to be part of the system infrastructure. ATCA eliminates all of these external cabling issues, which makes system maintenance much easier.

If a processor needs to be replaced for maintenance, a board is ejected from the front of the running ATCA system while – with 1U servers – an entire server would have to be replaced, which requires removing all the external connections to the system. Field maintenance of ATCA based equipment is now practical compared with a rack full of thin servers deployed in an application.

Many 10G network interfaces and all 40G interfaces require the addition of SFP+ and QSFP+ modules to support the physical interface between the servers and the switches. This adds additional items that must be managed and stocked just to maintain the interconnection within a rack of servers.

The only modules and cabling needed in an ATCA system are for the integration of this system into the remaining part of the network through a few external interfaces of the integrated redundant switches.

ATCA eliminates considerable complexity in long term life cycle management and maintenance by eliminating massive amounts of cabling. In a standard 19-inch rack, up to 12 dual-processor server blades with 14-core processors and 512GB of memory per payload board may only have a pair of 40G fiber cables leaving the centralized switches.

Compare this to the myriad of cables to connect 12 rack-mount servers and there is greatly reduced complexity of cable management in a typical tactical rack.

Power & Cost Advantages

Each ATCA chassis has a single power unit supplying power to all blades. By contrast, each server in a rack-mount system has its own discrete power supply. ATCA systems are both easier to service and more power efficient because it eliminates multiple AC to DC power conversions that occur with each rack-mount server.

The big payback on adopting ATCA in the field is evidenced in power consumption efficiencies and thus reduced operating costs.

Fuel to power generators in forward field deployments can cost anywhere from $13/gallon in peacetime up to $600/gallon in hostile areas.

A significant percentage of power loss in computing platforms is from conversion from AC to DC. With ATCA systems designed to operate on DC power, costly conversion steps are eliminated.

Improved compute efficiencies also result in reduced demand on cooling, which further contributes to the economy of the platform. Reduced power consumption delivers large payback dividends over the full operational lifecycle.

Furthermore, as a proven open standards-based technology, ATCA technology lowers the cost of development and creates a common platform, thus reducing the integration cost of hardware and software needed to build an application. Some industry experts estimate that ATCA blades can save up to 40 percent in overall product development costs for a system integrator.

Focus on Reliability

While some of the SWaP-C benefits apply generically to bladed architectures, the specification of ATCA products places particular emphasis on reliability: In telecom systems, the minimum requirement is for 99.999% uptime which translates to 5.26 minutes of downtime a year.

This is supported in many aspects of the ATCA specification designed to eliminate single points of failure and to reduce operator mishandling such as the RTM specification for connecting to the backplane, which also eliminates any requirement for manual insertion of cables, and in robust thermal management arrangements.

AdvancedTCA and MOSA share a common set of goals which include:

- Adapt to evolving requirements and threats
- Promote transition from science and technology into acquisition and deployment
- Facilitate systems integration
- Leverage commercial investment
- Reduce the development cycle time and total life cycle cost
- System interoperability with minimal or no modification of components
- Enhance commonality and reuse of components among systems
- Access to cutting edge technologies and products from multiple suppliers
- Mitigate the risks associated with technology obsolescence
- Limit exposure to single source of supply over the life of a system
- Enhance life-cycle supportability
- Increased competition from multiple vendors

In addition:

- ATCA technology supports hot-swappable blades, and thus facilitates improved serviceability and repair arrangements
- The ATCA specification requires tolerance of extreme operating conditions including earthquake tolerance as defined in the telecoms industry's NEBS Level 3 specification and temperatures up to 55°C
- The alignment between ATCA and the DoD's open architecture MOSA directive can be seen in the sidebar, but it's worth emphasizing that ATCA is a truly open standard, managed by an organization that is independent of any single vendor and with no single dominant market player

Military System Management

The use of system management for military applications is potentially a new subject for many programs.

High availability (HA) techniques have been implemented on mission critical and safety critical applications, but the approach has always been based on a proprietary set of functions developed by the system integrators and have typically been completely redundant systems.

An open system management standard has been developed on top of the ATCA specification by the Service Availability Forum (SA Forum).

The use of the SA Forum standard as a foundation for military applications now defines an open way to manage systems and to create more efficient redundancy schemes.

A very common approach to redundancy in communication systems is the concept of sparing a small number of processor blades that can be put into service when a failure has occurred instead of duplicating all computing resources in a chassis or duplicating the entire chassis.

This N+1 approach helps reduce cost and the total power required for a very effective redundancy model. If 2N redundancy is absolutely necessary for the most critical applications, the SA Forum standards are well suited for that.

In some cases the systems don't need to be highly available. The SA Forum standard can still be useful because software can be written to remotely inventory all hardware pieces in a chassis and the revision levels of all software and firmware in those systems.

Also, the system management infrastructure can control the initial power state of payload boards in the system where upon initial power up, only select boards can be powered when the system initializes.

Essentially a cold sparing scheme can be created in situations where total available power for the rack cannot support a full complement of blades powered up.

If a failure occurs, automated software can deactivate a failing board and power on a backup in the same system without any physical interaction with the payload board. This and many other flexible options are available with the open system management infrastructure of ATCA.

It can also be valuable if simple environmental monitoring of the system is desired without any software that reacts to bad events that might occur.

At a minimum, the ATCA system will manage the proper cooling of the system, will allow for hot swapping of components and will protect the system through electronic keying even if no management software is written for the application.

Another aspect of the SA Forum framework, which is useful even if no management software is written, is the ability to update firmware remotely.

Well defined system utilities exist that can control which redundant bank of firmware is used on the next reboot and can update a specific bank of flash with an updated BIOS image.

Barge Tested

The robustness built into the ATCA specification has been realized in practice by a US military contractor, which carried out a military standard test called afloat shock testing (better known in the defense industry as Class A barge testing) on shock isolated racks to be deployed with ATCA equipment (supplied by SMART Embedded Computing) integrated in the rack operating test software.

Figure 4: Tests by Northrop Grumman demonstrated that ATCA equipment is able to survive afloat shock testing (commonly called "barge testing"), showing its suitability for deployment as shipboard systems. MIL-S-901D Heavyweight Shock Test Photographs courtesy of National Technical Systems in Rustburg, VA.

The test involved detonating an underwater explosive charge beneath a floating platform carrying the ATCA equipment and enterprise server equipment. The success of the test clearly demonstrates the inherent ruggedness of ATCA equipment operating in battle ready operations.

SMART EC has developed an enhanced version of its 14-slot 40G fabric workhorse, the AXP1440, to be even more rugged for shipboard applications. The AXP1440-D uses an innovative chassis design which integrates a mechanism that tightly attaches the front payload boards to the backplane, eliminating the affects of excessive vibration which prematurely reduces the life expectancy of systems in shipboard military environments.

A special alignment block was created to adapt standard ATCA payload blades to be added to this rugged chassis without the need for a redesign of the blade and enhancing the interoperability qualities of ATCA.

The AXP1440-D and complimentary set of switches and processor blades completed a rigorous shock and vibration test suite by the U.S. Navy based on MIL-STD-167-1A for all principal axes including:

- Exploratory Vibration Testing
- Variable Vibration Testing
- Endurance Vibration Testing
- Shock Testing

The system endured 1.6G (S-S), 2.3G (F-B), 1.9G (VERT) for all resident frequencies for a total of 2 hours. Shock testing was to 18-20G in the Y– Axis and 10-20G in X and Z axis.

SMART EC ATCA server boards utilize processors that are part of the Intel® Embedded Roadmap which had traditionally supported processors for seven (7) years but recently increased the support level to 15 years with all components that use the 22nm manufacturing process.

SMART EC offers the latest generation of ATCA server blades based on the Intel® Xeon® Scalable processor family, formerly known as Skylake, called the ATCA-7540 and a ruggedized version called the ATCA-7540-D.

SMART EC can now support these processor boards an unprecedented 15 years due to this commitment by Intel to support the processor and peripheral host controllers for 15 years.

The ATCA-7540 will work in the AXP1440-D and can easily replace the processors in deployed systems when ships are back in port for scheduled retrofitting. Along with support for the latest Intel Xeon Scalable processors, the new board will support up to 384GB of DDR4 ECC RAM, dual on board M.2 solid state SATA storage devices, integrated dual 40G Ethernet interfaces, integrated PCH with integrated support for Quick Assist Technology (Encryption/Decryption), and backward compatibility with SMART EC's line of existing RTMs with a variety of additional I/O support.

Rugged Compute Platform

Most of the current deployments have been in naval environments but ATCA technology is also being deployed in mobile command-and-control applications that extends military capability in network-centric warfare infrastructure.

These command-and-control systems can be linked together and quickly deployed in the field giving military personnel the ability to use pre-integrated ATCA platforms that offer supercomputing capabilities, switching and storage all in one easily portable package.

A current U.S. Marine application using SMART EC's AXP640 system has created a mobile command platform that combines scalable technology insertion with highly reliable design in a field deployable, ruggedized package. This demonstrates a flexible and modular approach with choices for different switching, power levels, I/O, and blade content in a rugged military standard MIL810 transit case.

This platform demonstrates the ability of ruggedized ATCA systems to provide redundant system-level infrastructure, power inputs, and I/O management; the ability for latent and silent fault analysis which includes dual image firmware; for robust upgrade processes; and redundant internal power infrastructures.

The AXP640 rugged compute platform was designed for tented field and mounted deployments. Tented field deployments are integrated into rugged transit containers to meet stringent shock and vibration requirements.

This application was processing video data from a variety of fielded sensors, evaluation and tagging of the video with meta-data, and then distributing to deployed analysts. Other common applications

Figure 6: The 14-slot AXP1440-C06 rugged compute platform developed by SMART EC has been qualified for Aegis Weapon System, SSDS, and a number of other Naval tactical systems. The AXP1440-C06 features:

- *12 CPU blades each with 40 Gigabit Ethernet interfaces into a redundant central switch fabric*
- *1.5TB of SSD storage per blade*
- *40 Gigabit Ethernet network switch blades*

include command, control and mission logistics as well as communications and messaging.

AdvancedTCA technology is well suited for ship, air, and vehicle mounted implementations that may have physical /accessibility restrictions, data pre-load requirements and where low power provides strategic and cost advantages.

Ready for Service

With ATCA being tested in some of the most extreme conditions and with systems deployed in theaters of operations today, we can confidently say that the ATCA architecture is at a technology readiness level of 9.

Programs operating with ATCA based systems and payload boards:

- P8 Poseidon Multi Mission Aircraft (MMA) – heterogeneous blend of ATCA products from SMART EC and other manufacturers
- Aegis Weapon System TI-16 Refresh – SMART EC AXP1440 and ATCA-7480 server boards
- Aegis Ashore (BMD) – SMART EC AXP1440 and ATCA-7480 server boards

- Ship Self Defense System TI-16 Refresh – SMART EC AXP1440 and ATCA-7480 server boards
- Surface Electronic Warfare Improvement – SMART EC AXP1440 and ATCA-7480 server boards
- Common Ground Station for UAVs
- DARPA ASW Continuous Trail Unmanned Vessel (ACTUV)

Figure 6: The 6-slot AXP640 chassis used in Computer Systems Center Incorporated© (CSCI) DASCAN. The AXP640 features:

- *Four dual processor (8-core) ATCA-7370 CPU blades*
- *Third-party ATCA 10G switch*
- *Third-party ATCA SSD Raid*

Photo Courtesy of CSCI: CDR (retired) Jerry Buck operating CSCI DSCAN.

ATCA is a solid choice for network systems operating in a harsh environment but not requiring full military ruggedization.

Ideal applications include sheltered mobile battlefield command-and-control, scalable computing centers on board naval vessels, and control and other computing systems for high bandwidth net-centric tactical aircraft missions.

By virtue of its almost universal adoption in the telecoms equipment industry, the ATCA standard has proven itself to be the most successful open, bladed architecture for high-performance, ultra-reliable network computing.

Its compact, light and power-efficient design and moderate ruggedness makes it the ideal choice for military, aerospace and security equipment makers who want to take advantage of the latest processor technology in shock, vibration and heat-resistant design.

About SMART Embedded Computing

SMART Embedded Computing (SMART EC) is part of the SMART Global Holdings, Inc family of companies.

We are a global leader in the design and manufacture of highly reliable embedded computing solutions for a broad range of defense, industrial IoT (IIoT), edge computing, and communications customers.

Building on the acquired heritage of industry leaders such as Motorola Computer Group and Force Computers, SMART EC is a recognized leading provider of advanced computing solutions including application-ready platforms, single board computers, enclosures, blades, enabling software and professional services.

For more than 40 years, customers have trusted us to help them accelerate time-to-market, reduce risk and shift development efforts to the deployment of new, value-add features and services that build market share.

Our engineering and technical expertise is backed by world-class manufacturing, global sales offices and advanced worldwide logistics capabilities that can significantly reduce time-to-market and help customers gain a clear competitive edge.

Contact

+1 602-438-5720

info@smartembedded.com

www.smartembedded.com