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Imaging

Using ATCA Standards to Achieve Smoother System Processes

Gus Lowell

As more medical systems incorporate real-time data analysis, ATCA standards can help manufacturers ensure reliability while saving time and costs.

The Advanced Telecommunication Computing Architecture (ATCA) provides a standard platform and operating environment for the creation of large data- and computation-intensive systems. It was developed by the PCI Industrial Computer Manufacturers Group (PICMG) to facilitate development of high-availability and high-bandwidth telecommunication applications. Recently, developers of medical, high-energy physics and other applications have begun considering use of the ATCA platform in their nontelecom environments by taking advantage of standard components to accelerate development of systems requiring tera-operations-per-second (TOps/sec) data acquisition and analysis capabilities.

Medical devices are beginning to integrate multiple imaging modalities and incorporate real-time analyses or data-reduction processes to provide surgeons with improved decision-making tools. Adoption of ATCA standards for high-throughput data acquisition and analysis systems can dramatically reduce the development time and costs required for such complex systems, while ensuring high reliability, easy maintenance, and status monitoring. This article discusses ATCA standards, their application to a complex medical imaging system, and how the ATCA suite of technologies is applicable to medical systems in general.

Overview of ATCA

The ATCA standards were developed to facilitate interoperability of high-speed and high-reliability components for the telecommunications industry. Adoption of these standards facilitates system design, integration, and manufacturing. Since its initial development, ATCA has come to encompass a family of related standards under the general heading of xTCA.

The original ATCA specification defines a standard 8-U high 19-in. rack-mountable chassis, or shelf, which incorporates a backplane and can accommodate up to 16 pluggable cards or blades (see Figure 1). Each blade plugs into a slot, or node, in the shelf, and shelves with less than the maximum 16 available slots are acceptable under the standard. The shelf and the backplane connection to the blades provides redundant power sources, standard timing sources, a redundant control plane, and a data plane through which command and control traffic and application data may be routed. They also provide various telecom support functions such as a ringer signal. In addition, each shelf provides redundant dedicated processing blocks called *shelf managers*, which keep track of cards installed within the shelf and various redundant shelf support components such as cooling and power systems.

The ATCA specification also defines a space at the top rear corner of the blade that is left unobstructed within the shelf and is reserved for the installation of user-defined connectors. The shelf provides a small space behind the backplane into which application-specific rear transition modules (RTMs) can be installed and mated to those connectors. This provides an adaptable mechanism for routing input/output (I/O) signals out through the rear of the shelf rather than through the front panel.

Because the 8U cards defined as standard blades for ATCA represent a larger field replaceable unit than is required for some applications, a second standard, the advanced mezzanine card (AMC) specification, was developed to define smaller modules that could be plugged into a specially designed carrier blade in the ATCA shelf.

A third standard defines a microTCA (μTCA) shelf into which AMC modules may be plugged directly rather

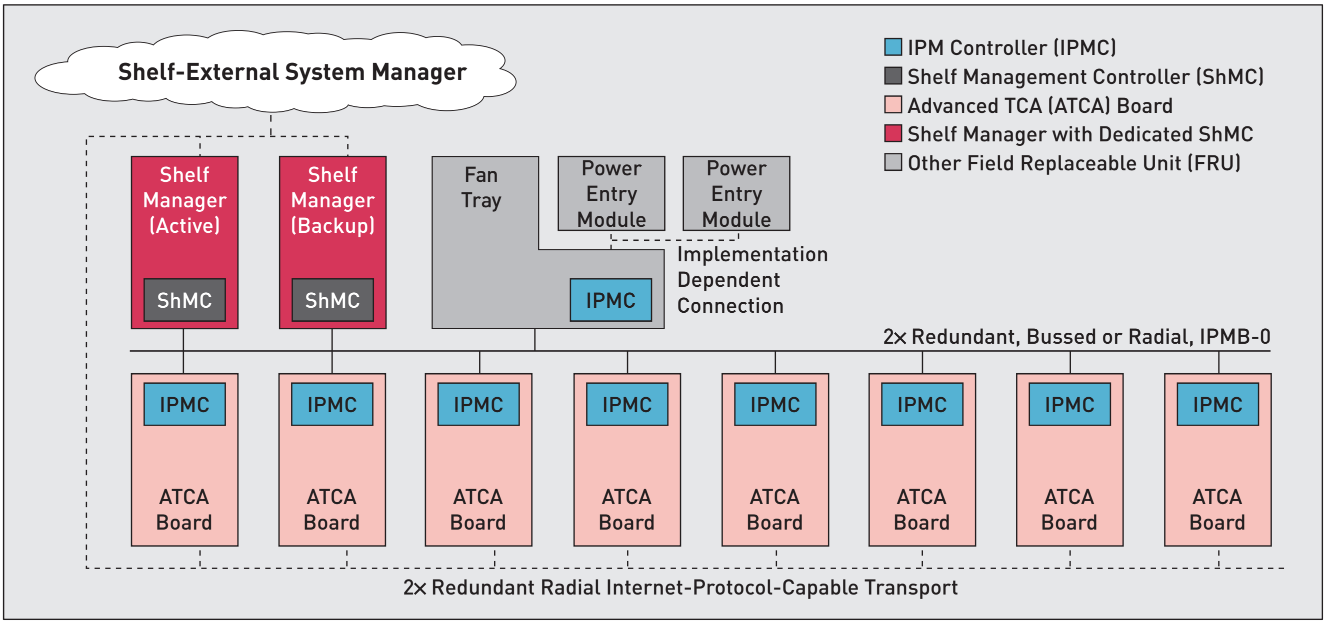

Figure 1. ATCA standard schematic from the PICMG 3.0 shortform specification.

than through use of an ATCA carrier. The µTCA shelf provides much of the same support for shelf management and other features as the ATCA shelf, but it places more restrictions on the use of the data plane fabric.

The control plane for the ATCA shelf is specified to use 1000-base-T as its transport protocol. Distribution of the control plane is configured as a dual star, with two nodes in the shelf designated to serve as the hubs for control plane distribution and with all other nodes having a single dedicated 1000-base-T link to each hub. It is assumed that the blades installed in the hub slots will provide the switching required for connecting the individual node links into a suitable control-plane network.

The data plane for the ATCA shelf is defined to be protocol agnostic, i.e., the backplane provides only wires through which application-specific transport protocols may be routed. Distribution of the data plane may be provided in different configurations; a given backplane will implement one configuration that must be specified as part of the shelf configuration. Three distribution schemes are defined specifically in the ATCA specification:

- *Dual star:* Identical to the control-plane distribution, logical slots one and two are reserved as hub slots, and each other node has exactly one fabric channel to each hub, for a total of two channels between each node and the hubs.
- *Dual dual star:* An augmented version of dual star with an additional two hubs in logical slots three and four. In addition to the dual-star channels, each other node has exactly one fabric channel to each additional hub, for a total of four channels between each node and the hubs.
- *Full mesh:* Each node has exactly one fabric channel to each other node. The dual star and dual dual star configurations are subsets of the full mesh configuration.

A port in the ATCA fabric comprises one full-duplex communication channel (two wire pairs). A channel in the ATCA fabric comprises four ports. The dual star configuration is the most common, followed by the full mesh. Even in the full mesh configuration, use of the control-plane requires some switching capability in the dedicated hub slots. Therefore, those slots will typically be reserved for specialized hub blades even when using a full-mesh data plane. Because the data plane is protocol agnostic, PICMG has defined several subsidiary standards that describe how to use specific transport protocols on the ATCA fabric. Protocols for which specifications exist include 1 and 10 Gb Ethernet, Serial RapidIO, Infiniband, and PCIe.

The Telecommunications Effect

For telecom applications, the most common protocol in use has traditionally been 1 Gb Ethernet, with 10 Gb Ethernet currently available as a replacement to provide better bandwidth. Therefore, because the telecom industry is by far the largest user of ATCA platforms, 1 and 10 Gb Ethernet are the de facto transport standards for use in ATCA shelves. It is difficult or impossible to find switching hubs or blades using other transport protocols for sale in the marketplace. The µTCA platform has found much broader application and within the nontelecom market, vendors of data acquisition and control processors have begun adopting PCIe as the de facto standard for both AMC modules and µTCA shelves. The reason for this adoption is twofold.

First, a single ATCA channel can carry four 1-Gb or two 10-Gb Ethernet links or a four-lane PCIe link. As Gen2 PCIe is rated for 4 Gb/sec per lane, the x4 PCIe link has four times the bandwidth of the 1-Gb link and about 80% of the bandwidth of the dual 10-Gb link. However, 10 Gb is still an emerging standard with limited (but growing) support, and the use of two 10-Gb links within the ATCA channel is not a standard configuration at the current level of technology. Thus, PCIe offers approximately a 1.6-× bandwidth advantage over a single 10-Gb link in current applications and uses a mature technology that is well supported on commercial computing platforms.

Second, the PCIe protocol stack, routing, and lane splitting and aggregation are implemented entirely in hardware, providing a simple memory-mapped API for the software interface. As a result, implementation of PCIe interfaces in software, and particularly in field-programmable gate array firmware, is much simpler than providing a TCP/IP stack for use on the Ethernet links. This also results in much lower latency (typically less than 200 ns/hop in the current generation of switches) than an Ethernet-based link can provide.

However, the divergence between ATCA and μTCA with respect to transport protocols means that it can be difficult to use the same PCIe-based AMC modules in both μTCA and ATCA shelves. In recent discussions, ATCA component vendors have indicated that they have very little interest in supporting PCIe as a backplane protocol because their largest customer—the telecom industry—does not want to use it. The primary impediment to the wider adoption of ATCA outside of the telecom industry is the lack of any standard components for use in the ATCA shelf that support PCIe as the transport protocol.

ATCA-Compliant Modules

If available, some ATCA-compliant PCIe protocol modules can be used independently or as an integrated development system by ATCA users who wish to use PCIe as a data distribution protocol—both for its own virtues and to facilitate integration of PCIe-based AMC modules currently available for μTCA platforms. Examples of ATCA-compliant PCIe protocol modules currently in development include the following:

- An ATCA hub blade that implements 1000-base-T switching for the control-plane and PCIe switching for the data plane.
- An AMC carrier blade that provides an interface between the PCIe connections on standard AMC modules and the PCIe network on the ATCA fabric.
- A high-performance data-processing AMC module that uses one MPPA pro-

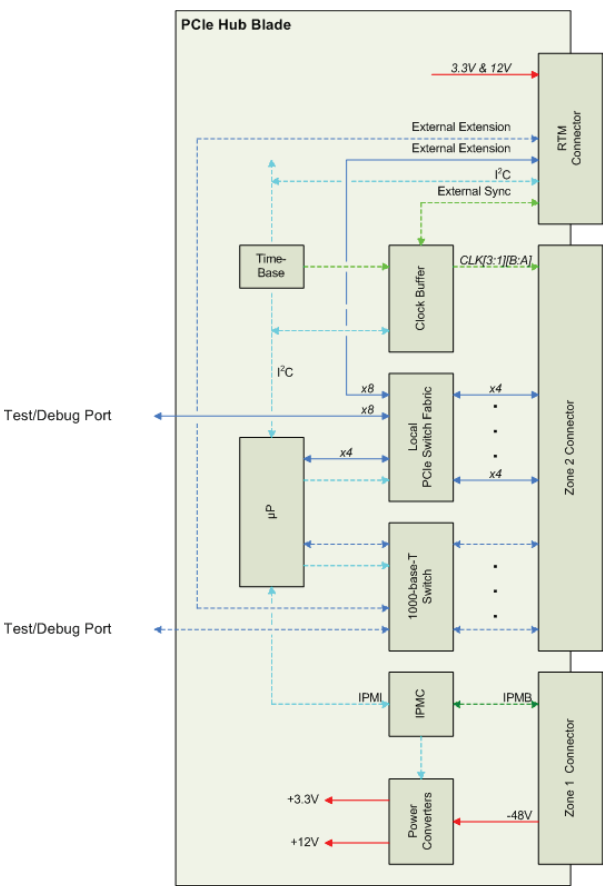

Figure 2. Block diagram of an ATCA Base-Fabric and PCIe Data-Fabric Hub.

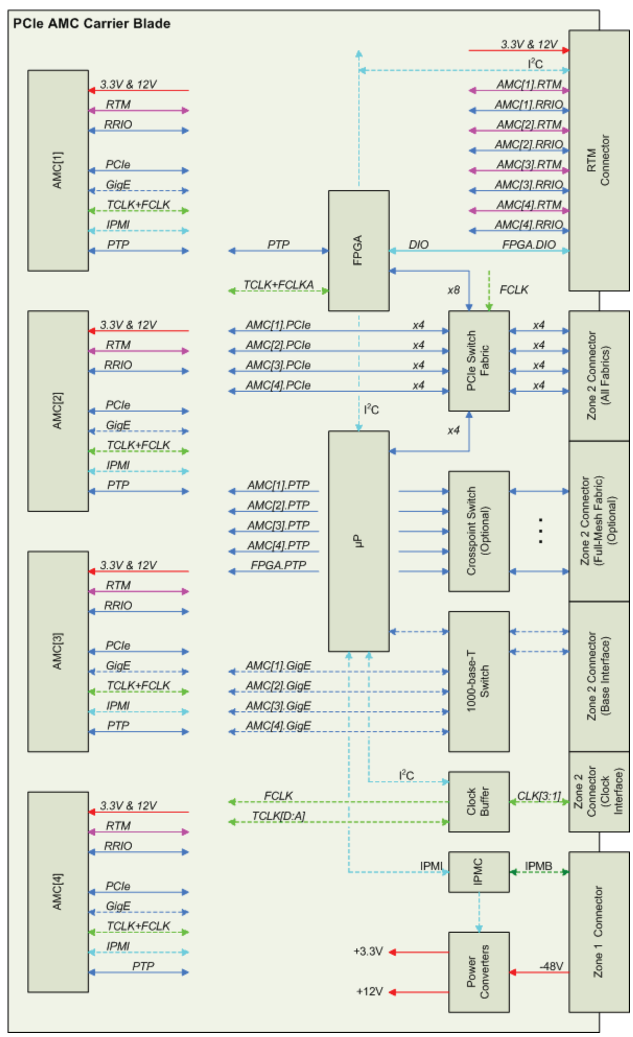

Figure 3. Block Diagram of an ATCA AMC Carrier with PCIe Data-Fabric Interface.

cessor to achieve processing capacity up to 1 TOps/sec. Up to four modules may be installed within the AMC carrier blade to provide a processing capacity on a blade of up to 5 TOps/sec.

These modules, along with a standard ATCA or μTCA shelf, would provide all of the components necessary to create a general-purpose data acquisition and processing system capable of operating at TOps/sec speeds. Standard off-the-shelf AMC modules mounted within a carrier blade or within a μTCA chassis can provide a wide range of signal I/O functions. The processing module provides high-performance processing of those data, and the PCIe fabric supported by the hub switch provides the connectivity required to move the data between the signal I/O and processing modules within an ATCA shelf.

Applications

The following section provides an example of ATCA adoption for a low-dose x-ray fluoroscopy medical imaging system. It highlights the effect that the use of the ATCA standards can have on the development time for such a complex system. The example also provides general guidelines on using ATCA components for current and emerging medical applications.

ATCA standards were employed in the development of a real-time x-ray tomosynthesis imaging system.[1,2] This system is intended for use in cardiac angiography and has the benefits of reducing x-ray dose to the patient by tenfold and the surgical staff by fivefold, along with providing improved image resolution and calibrated absolute feature sizes within the video images. It comprises a large-area scanning-beam x-ray source array that is situated just beneath the patient and a small area single-photon counting detector placed at a relatively long distance above the patient (see Figure 2). This configuration is inverted relative to current angiography systems. The combination of three novel elements—the source-detector relative geometry, a highly sensitive detector, and the large-area, x-ray source—lead to a tomographic imaging system with substantially improved signal-to-noise compared with what is currently available.

The resulting data collection, data transmission, tomographic image reconstruction, and video-rate display requirements represented significant electrical and software engineering challenges. The system produces 160 Gb/sec of raw data from the x-ray detector. The image tomosynthesis must accommodate 40 Gb/sec input and remain synchronized to the scanning beam x-ray generator. The real-time tomosynthesis produces 32 focal planes of 1000 × 1000-pixel images at 30 frames per second, requiring approximately 1.4 trillion mathematical operations per second.

In addition, the system must be designed to accommodate frequent field upgrades, configuration management, and maintenance. The combination of these requirements led to a system architecture and choice of components derived from the telecommunications industry, and thus adoption of the

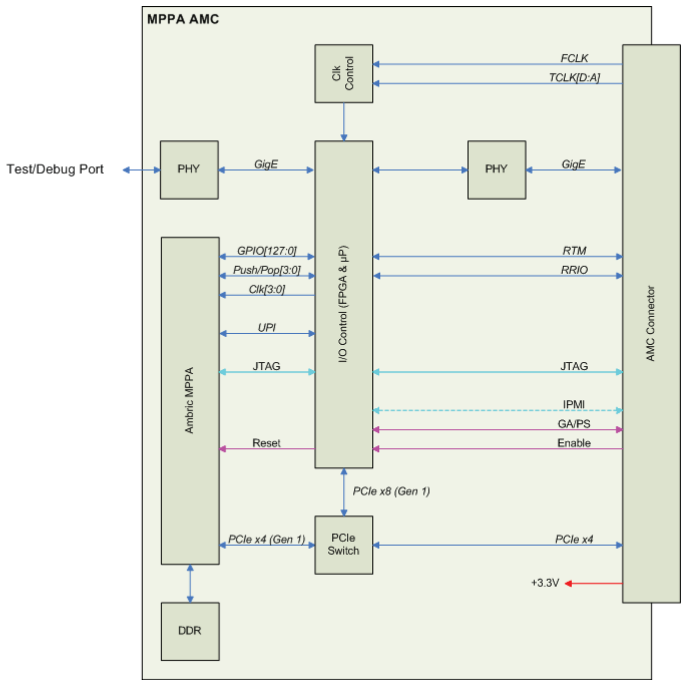

Figure 4. Block Diagram of an AMC Massively Parallel Processor Array (MPPA) with PCIe Data-Fabric Interface.

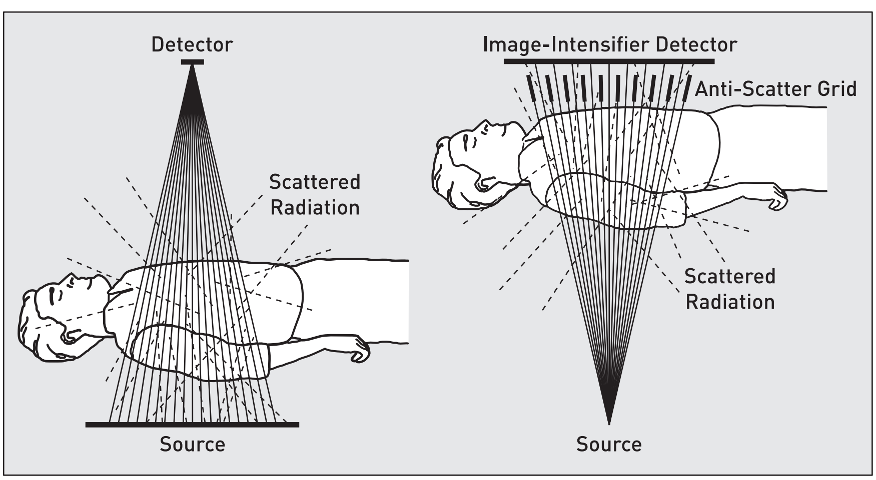

Figure 5. Comparison of geometry for a traditional angiography system (right) and an inverted real-time imaging system (left).

ATCA standards and components characterized by high reliability, high data-throughput capability, and distributed equipment.

The ATCA standards also offered the following:

- Automated configuration management and tracking enabled by Intelligent Platform Management capability, at both the rack level and component level, through standard shelf controllers.
- Standardized control- and data-plane fabrics.
- Full redundancy in control, data, and power.

It is estimated that the use of the ATCA standards and associated commercial infrastructure for components and development platforms saved the development team five years of effort.

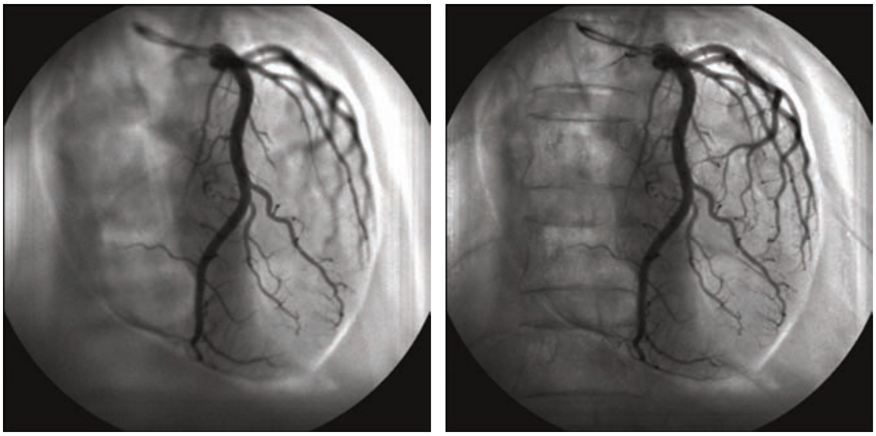

Figure 6. Reconstructions of an anthropomorphic chest phantom; (left side) Single-Plane and (right side) "Best Focus". In the single-plane image out-of-plane blurring is most evident in the upper right vessels and in the spine region

Other Medical Device Uses

Generally, ATCA components are useful for any system that requires real-time processing or transport of massive amounts of data. The compelling advantages of ATCA include:

- High computation density translates into small footprints for supercomputing capability.
- Ultrahigh reliability is built into the standards, with accommodation for redundant control, data, power supply, cooling, and other systems.
- Standard system health and status monitoring and update management.
- Rapid and modular configurability of off-the-shelf components speeds development time and reduces costs.
- Scalability allows systems to grow in size while keeping the architecture intact.
- Open-source standards ease applications development, vendor compatibility, and multisourcing of the components.
- Hot-swappable components ease maintenance and reduce system downtime.

Conclusion

The advantages presented by ATCA are important for many medical applications, including imaging systems that require real-time processing of raw data into video stream for diagnostic, therapeutic, or image-guided surgical purposes as well as storage and retrieval of large image data sets.

Systems based on ATCA are designed for ultrahigh reliability and ease of maintenance. From an end-user perspective, disruption in availability of a major piece of medical equipment or data retrieval from archives can cost hospitals revenue and have a significant effect on patient outcomes.

References

1. EG Solomon et al., "Scanning Beam Digital X-Ray (SBDX) System for Cardiac Angiography," *Proceedings of SPIE, the International Society for Optical Engineering* 3659 (1999): 246–257.
2. AP Lowell and W Sun, "Real-Time X-Ray Tomosynthesis Imaging Using an ATCA General-Purpose Data Acquisition and Analysis Platform," *IEEE Nuclear Science Symposium Conference Record* (2008): 27–31.

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