ATCA* for Machines
*Advanced Telecommunications Computing Architecture

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The Advanced Telecommunications Computing Architecture is a new industry open standard for electronics instrument modules and shelves being evaluated for the International Linear Collider (ILC). It is the first industrial standard designed for High Availability (HA). ILC availability simulations have shown clearly that the capabilities of ATCA are needed in order to achieve acceptable integrated luminosity. The ATCA architecture looks attractive for beam instruments and detector applications as well. This paper provides a brief overview of ongoing R&D including application of HA principles to power electronics systems.

1 The Case for High Availability in Accelerator Systems

Large accelerators and detectors are production machines that require huge investments in capital cost, operations and maintenance for a successful result. In economic terms, a non-functioning machine is wasting capital at an enormous rate. Accelerators are typically designed to operate for extended periods on a 24/7 basis, followed by a period of inactivity to allow maintenance and re-staging of experimental apparatus. Ideally, the machines should be designed to run for the mission period without interruption.

Such an ideal is rarely met although some modern synchrotron light sources come close. Large particle detectors have inherently high redundancy to tolerate loss of isolated channels without interruption. However, the ILC machine itself consists of two 10 km linacs pointed at each other in which every critical component on every pulse must operate flawlessly. Stored beam machines enjoy some immunity to problems that happen between beam fills, but the ILC is a single-shot machine in which the loss of any non-redundant component (single point of failure) will interrupt operation. The simulations have shown that if the ILC is built with current technologies, it will be operable only about 15% of the time. High Availability design for the ILC is therefore a necessity, not an option.

High Availability of a complete machine involves many strategies. A common example for linacs is to include active standby RF stations to maintain design beam energy in case one or more units fail in service. At the same time, it is necessary to have physical access to repair the broken stations while the machine keeps running on the standbys. This has led to a key element of the current baseline design of the ILC, namely a second parallel tunnel to contain all the support equipment which is totally accessible while the beam is on. Similar problems with power supply failures has led to an investigation of partial redundancy modular designs in which a single module out of N modules in a supply can fail and be replaced without interruption of operation.

In the case of instrumentation and controls, although these low power components tend to be more reliable, the sheer numbers demand an aggressive approach using partial redundancy

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techniques and hot-swap repair strategies. Such designs require more intelligence to be built into the systems to detect and manage problems before they lead to machine interruption. The same intelligent diagnostics and platform management techniques need to be applied to all systems in the ILC.

Fortunately the ATCA system offers a huge advantage in a readily available industrially supported platform, as well as an example of features that can be copied to non-ATCA systems. The ILC R&D program intends to evaluate the platform for typical controls and instrumentation applications, many of which can be addressed with commercial off the shelf (COTS) components; while at the same time extending its capabilities to accommodate the high-performance circuitry peculiar to accelerators: Instruments such as sub-micron beam position monitors, highly integrated detector front ends, very high performance low level RF circuits for beam phase and timing control, and intelligent RF and DC power systems.

2 ATCA Features Summary

ATCA was invented by a large consortium of telecom providers under the PCI Industrial Computer Manufacturers Group (PICMG) which includes ~250 telecom, integrated circuit, modular instrument, shelf[1] and rack manufacturers. The telecom business segment alone is estimated at $10B annually. Several telecom companies have announced that all future products will us this platform. Some labs have joined PICMG as Associate members in order to access all the standards as well as to potentially help develop features of interest to the physics community within the PICMG framework.

The loaded shelf is designed for availability of 0.99999, which it achieves by the partial redundancy of various components and a hot-swap feature. This corresponds to a downtime of 5 minutes per year. The key elements of a shelf are: 5-16 module slots; dual Shelf Manager cards to sense all operating conditions of all modules; backplane of 2.5 Gb/s serial connections between controller slots and all modules (typically star or dual star) or all modules to all modules (mesh); dual controllers; redundant 48V power supplies and redundant fans. The 48 volt bulk supply feeds all modules via individual lines so no power fault will take down the shelf. All secondary voltages are developed on each module which ensures future compatibility as chip voltages change in future. The shelf managers, controllers, application modules, power supplies and fans are all hot-swappable. Controllers and Shelf Managers are typically dual-redundant while power supplies and fans can be 1 of N redundant – in other words, able to operate with 1 of N sections failed, and hot-swappable so the shelf never has to be turned off to make the exchange.

The function of the Shelf Manager (SM) is to detect the health of any module in the shelf, monitor its current, voltages or temperature, disable its power if it malfunctions and signal the high level control systems to dispatch a repair person. Once there the person observes by a blue LED that the module needs replacement, makes the exchange which the SM detects and returns it to service.

A chief feature for Telecom is data throughput, since telephony consists of transmitting, receiving, routing and processing data, so the shelf is designed in full mesh mode to have a

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[1] *Shelf* is a term used by the Telco industry for the crate or sub-rack that has been more commonly used in research. *Shelf* will be used in this document to be consistent with other AdvancedTCA documents.

throughput of 2.5 Tb/s. This throughput will increase as the base speed of serial data transmission keeps increasing. Parallel processing speed is of great interest to the large particle detector community. At the same time, backplanes can be easily tailored to the more modest speeds of machine controls systems so bandwidth is not wasted. Figure 1 shows several versions of shelves.

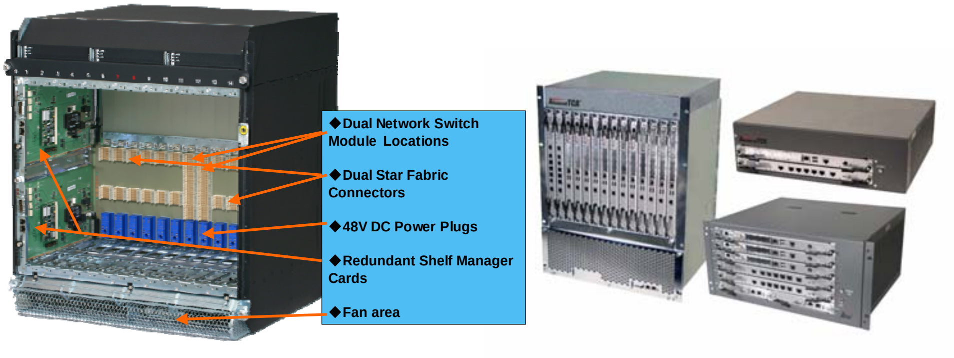

Figure 1: ATCA Shelf Options

3 Mezzanine Modules and Micro-ATCA Shelves

Since the investment in an ATCA module is substantial and processing and logic chips evolve rapidly, PICMG has developed options so that a base ATCA module can serve as a carrier board for several smaller modules. These mezzanines, Advanced TCA Cards (AMC), are also hot-swappable and different functions can be separated for future upgrades without affecting the base unit. Older types of mezzanine cards required the carrier to be removed before the mezzanine could be replaced. AMC's also allow design engineers to work on separate functions in parallel for faster overall development time of a system. In principle up to eight single wide single height AMC's can be plugged into a carrier. In addition, sizing options allow double wide and double high AMC's.

Where size permits, other standard mezzanines such as Industry Pack (IP) can be mounted on AMC's to gain entry to the ATCA platform. In this case the Mezzanine card becomes and adapter module for any IP function, thus allowing many more COTS industry choices when configuring a system.

A further option has been developed for packaging individual mezzanine cards in a separate much smaller shelf, called Micro-TCA (µTCA). This packaging does not include full ATCA features but is of interest for small configurations where low cost is paramount and some loss of redundancy and control is tolerable. Figure 2 shows AMC and µTCA shelf options.

4 Card Level Power Systems

Besides the maturing of multi-Gb/s serial data transmission and reception at the chip level to enable the ATCA technology, industry has introduced a suite of highly configurable hybrid power supply products designed for card-level applications. These are sophisticated 1 of N configurable miniature systems to simplify driving power-hungry dense components such as FPGAs and processors. The extremely high instantaneous switching currents needed to support high speed chips are provided by Point-of-Load regulators. The POL regulators can be monitored and controlled by the Shelf Manager. For example, the SM can adjust the conversion clock frequency and phase for noise minimization. Figure 3 is a block diagram of a typical suite of power components.

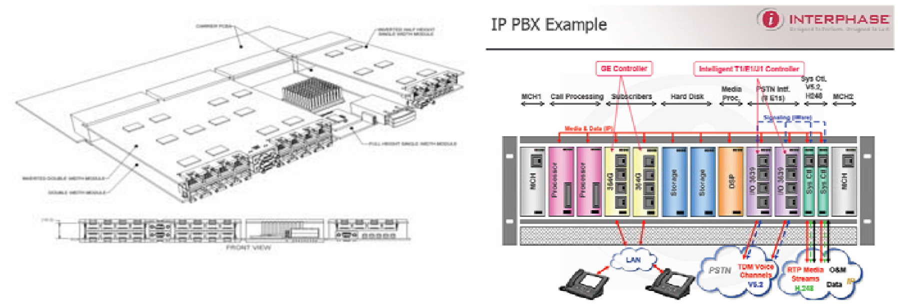

Figure 2: Mezzanine Boards on ATCA Carrier and μTCA Shelf

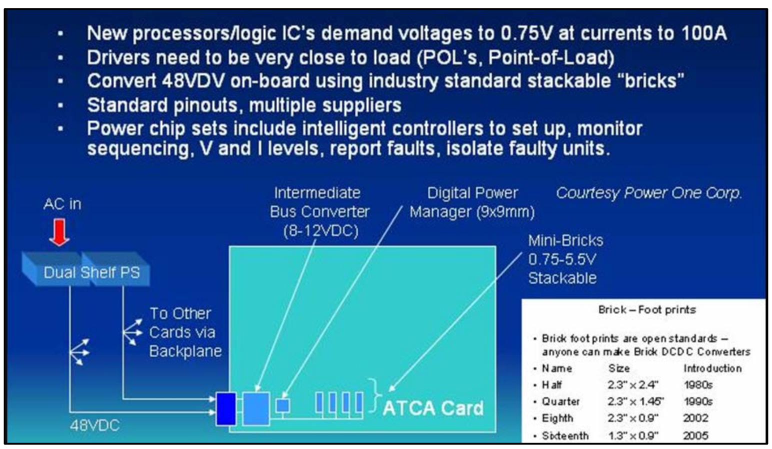

Figure 3: Board Level Intelligent Power System

5 Lab R&D Activities

SLAC, ANL, FNAL and DESY are engaged in exploratory evaluations of ATCA. SLAC in collaboration with University of Illinois Urbana Champaign and SAIC Corporation is developing an ATCA carrier for a slave VME board in order to gain quick access to the ATCA platform for VME COTS products. SLAC is also developing a controls and interlock systems for an ILC 10 MW RF station in VME which will be ported to ATCA in a second iteration. ANL is developing high level software platforms for the ILC control system based on an ATCA technical and cost model. FNAL is evaluating the core control system as well as developing a beam position monitor controller on ATCA. DESY has several initiatives including porting a low level RF control system and investigating µTCA for front end controls and interlock functions. At the 2007 IEEE Real Time Conference at FNAL in May 2007, an ATCA workshop was attended by 85 registrants. A number of vendors showed products, while the conference featured a number of papers on applications for a wide range of physics data acquisition and control experiments.

6 Conclusion

The ATCA system is a prime candidate for the core HA system for ILC controls. It also is a prime candidate for instrumentation modules providing analog interconnects and noise performance can be verified. The added cost of partially redundant systems seems reasonable. Similar principles are being applied in power electronics, specifically in DC and pulsed power supplies and high power pulse modulators. ATCA evaluations are aimed at understanding and demonstrating hardware and software in prototype settings, to verify architectures, performance and costs before ILC is ready for launch as a funded project by 2010.

7 Acknowledgments

The evaluations are being conducted by collaborators at the labs cited, joined by others who are not directly conducting R&D in their home labs. Key participants in the controls effort are John Carwardine (Lead) and Claude Saunders of ANL, Brian Chase, Manfred Wendt and Margaret Votava et al of FNAL, Stefan Simrock and Kay Rehlich of DESY, Michael Haney and Michael Kasten of UIUC, Shinichiro Michizono of KEK, and Robert Downing of SLAC and R.W. Downing Inc. Thanks also to the many others who are supporting these efforts as well as those in non-ILC labs undertaking independent efforts to employ the ATCA platform in experimental settings. Special thanks to Robert Downing for critiquing the manuscript.

8 References

[1] Slides: **http://ilcagenda.linearcollider.org/getFile.py/access?contribId=372&sessionId=83&resId=0&materialId=slides&confId=1296**

[2] Availability and Reliability Issues for ILC, **T. Himel**, **J. Nelson**, **N. Phinney** (**SLAC**) , **M. Ross** (**Fermilab**), SLAC-PUB-12606, Jun 27, 2007. 4pp, Contributed to Particle Accelerator Conference (PAC 07), Albuquerque, New Mexico, 25-29 Jun 2007

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