AXIe and Big Physics

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The physics community has been an early adopter of modular systems, going back to the 1970s with CAMAC systems. High energy particle accelerators, complemented by complex instrumentation and control systems, represent the largest scale scientific experiments mankind has ever attempted, and are giving us unique insight into the origins of the universe and the world we live in today.

Figure 1: Superconducting supercolliders are high energy particle accelerators giving mankind unprecedented insight into the fabric of the universe.

As the scale, energy and complexity increases, new challenges are presented to the instrumentation systems required. AXIe [i] is poised to solve many "big physics" applications where high speed, high density and large channel counts are essential.

To understand AXIe's contribution, it is first necessary to understand the challenges facing the physics community. Next generation physics applications are characterized by the following critical needs:

- Large channel counts, with associated channel density and scalability issues
- High-speed instrumentation, which typically requires high power and cooling
- Multi-channel and multi-module synchronization
- Powerful and flexible processing power
- High throughput data transfers
- Range of instruments and modules needed
- Incorporation of custom modules

AXIe enables each of the critical needs. Products recently available from Agilent and Guzik are giving compelling proof points to the contribution AXIe can make. See Figure 2 below:

-Agilent 2 and 5 Slot Chassis
-Agilent M8190A Arbitrary Waveform Generator
-Guzik ADC 6000 Series Digitizer family
-Agilent M9703A Digitizer
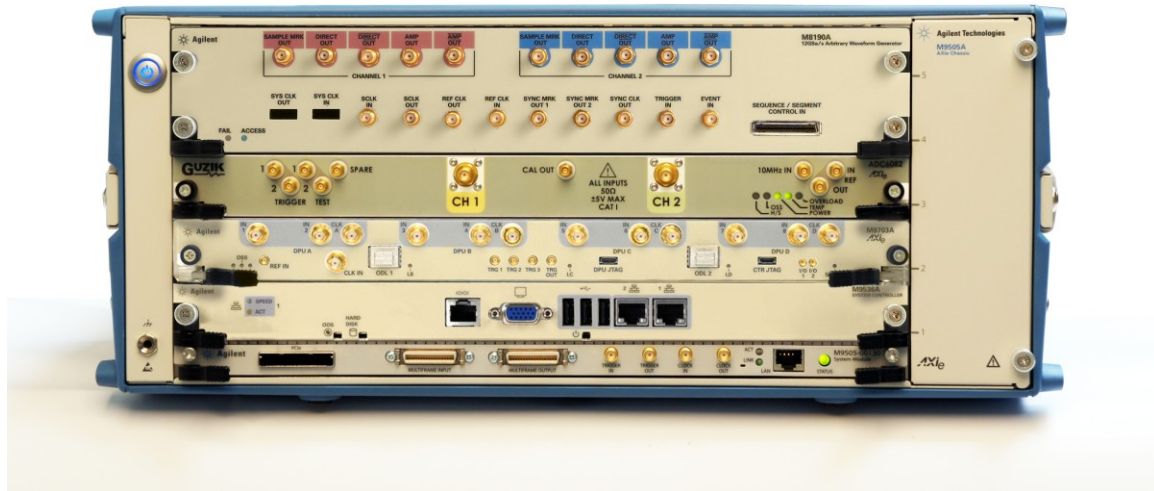-Agilent M9536A Embedded Controller

Figure 2: Agilent AXIe 5 slot chassis with Agilent AWG, Guzik ADC 6082, Agilent Digitizer and Embedded Controller

Delivering Unmatched Performance and Density
Large channel count requirements lead to an associated requirement of very high density. This is driven by a couple of advantages. One is to minimize rack space, or the number of rack cabinets. This has a clear cost and flexibility advantage. Secondly, by reducing rack space often the associated cabling can be shortened as well, since the instrumentation can be positioned closer to the sensors. This leads to higher signal integrity at high frequencies.

The 5-slot chassis is the current workhorse of physic applications. It can house five instrument modules when using an external controller, or four modules plus an embedded controller. Multiple chassis allow nearly unlimited scalability.

It is interesting to note that a 5-slot AXIe chassis requires just 4U of rack space, with no extra rack space required for cooling. This allows a good comparison to a PXI chassis, which also requires 4U of space, but often with an additional 1U for cooling. AXIe's horizontal configuration allows efficient cooling without redirecting airflow direction. The large board size allows efficient layout of high speed and high power digital electronics. Together, they deliver unmatched rack and power density. As a comparison point, 20 channels of 10Gs/s digitizers can be comfortably supported in a 4U AXIe

chassis. And that's with 16GB of memory behind each channel. A comparable PXI chassis can house about half that channel density, and nowhere near the memory depth. This is not to denigrate PXI- it's a proven architecture with granularity advantages due to the small board size, but this comparison of rack density shows a particular strength of AXIe and why it is called the "Big Brother of PXI"

High Speed Instrumentation
Density and speed are important for high energy physics. The Guzik AXIe digitizers use custom ADCs (Analog to Digital Converters) from Agilent which are also used in Agilent Digital Oscilloscopes. The digitizers can be configured at various channel and speed combinations: 4 channels of 10Gs/s, 2 channels of 20Gs/s, or a single channel at 40Gs/s. They may be combined together in the same chassis and deliver 8-bits of resolution. When more resolution is needed, the Agilent M9703A Digitizer can deliver 4 channels of 12-bits of resolution at 3.2Gs/s, or 8 channels at 1.6Gs/s. That's 40 channels in a single chassis.

Industry's deepest available memory and processing power
As noted above, the Guzik ADC 6000 Series supports 64GB of memory on each module. This allows very long data capture. Often, real-time processing is needed as well. For this, each module supports onboard 7Gs/s FPGA-based processing, which can be customized by the user. This is remarkable processing power, which is cooled efficiently in the 5-slot AXIe chassis.

Multi-channel and Multi-module synchronization
The AXIe platform is designed to provide multi-channel and multi-module systems.
Within a single AXIe module, this is straight forward: low-jitter digital design is eased by having a single large printed circuit board with critical traces kept on a single PCB. For multi-module synchronization, however, high frequency signal routing is required to distribute clock signals between modules. This is provided by the AXIe trigger bus[ii]. AXIe delivers 12 parallel trigger lines in each chassis, and a precision "star" trigger that originates from the system slot and goes to each instrument slot. Star trigger slot to slot time matching is specified to be less than 100ps. For multi-module synchronization, the user programmed FPGA onboard each Guzik digitizer module can be configured to allow these to enable or qualify trigger events. For example multiple digitizers can be configured within a single chassis to synchronously acquire 20 waveforms 10Gs/s, each with 4GHz of bandwidth. (See Figure 3)
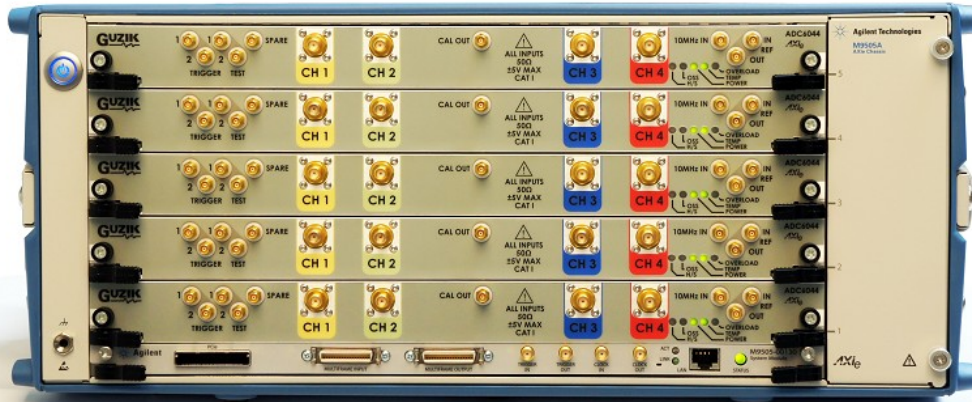
Figure 3: A single 5-slot AXIe chassis can support 20 digitizer channels of 10Gs/s each, with up to 16 GB or memory behind each channel.

High Throughput Data Transfer
AXIe enables high speed data transfer to the controller and between modules.
The data fabric is a PCIe Gen 2 bus that transfers up to 2GB/s to the system slot, and onward to an embedded or external PC. In addition, AXIe has defined a very high speed "local bus".

The local bus has a unique topology that delivers numerous advantages. It is simply a 62 lane segmented bus that links adjacent slots. That is, there are 62 differential pairs linking any given slot to the slot on it's left, and another 62 pairs linking it to the slot on its right. Being a segmented bus, each set of links is electrically independent. Any type of communication may exist on any or all of the links simultaneously. This allows vendors to define private communication protocols within "instrument sets", and have these operating in the same chassis with other instrument sets from other vendors.

The other advantage is that the short distance enables very high speeds. In the case of the Guzik digitizers, this enables real time streaming at 40GB/s. This data stream can be routed to other modules, such as memory modules, wide PCIe links to external computers, controllers, or to RAID devices. This is critical for capturing a short duration event in a very long time window. Note that this streaming speed can occur on any of the local buses between slots. Since the Guzik modules allow sharing of all the memory on any of the modules, up to 896GB of memory is available for any channel in 14 slot AXIe chassis. See Figure 4 for a graphical view of local bus data flow.
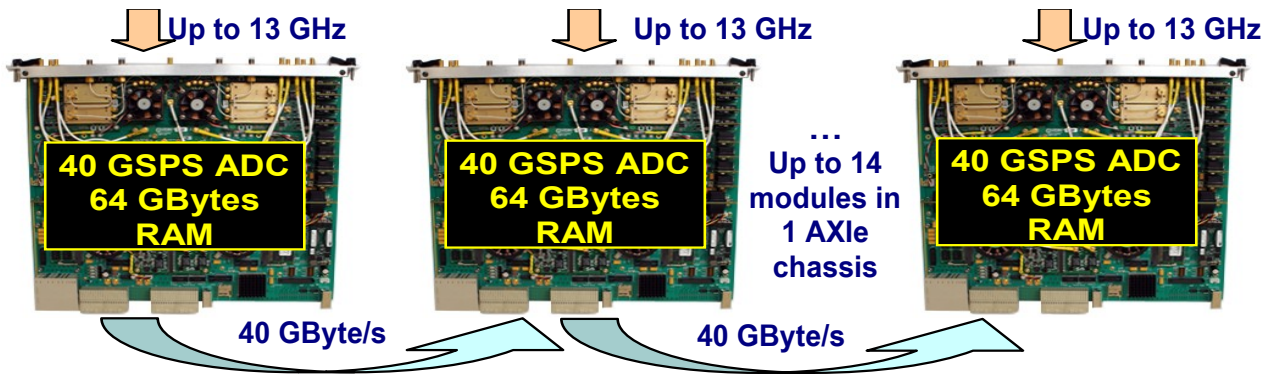
Figure 4: The AXIe local bus enables real-time streaming of 40GB/s between adjacent modules using today's technology. This allows modules to share memory, stream to DSP, or stream to RAID systems. The aggregate bandwidth is unmatched in any format or standard by orders of magnitude.

Processing Power

The user has a wide set of alternatives for processing: where it exists and how it is used. Agilent and Guzik digitizers both allow the user to download custom FPGA algorithms onto the module itself. This can be used for real time signal processing or event detection. The data can be streamed over the local bus for additional DSP.

With Guzik digitizers every module added to the chassis can increase aggregate processing power, which is shared using the local bus. Guzik is currently working on developing a dedicated DSP module. This module would increase the memory and processing capabilities, and also add external PCIe data streaming to a dedicated device, such as a RAID array. This is a powerful example of how the AXIe local bus can add capability that simply does not exist in other formats.

For less challenging applications, data can also be streamed over the PCIe Gen2 of the AXIe chassis to a PC. The computer may be externally connected via PCIe Gen2 cable, or it may be internal such as the Agilent M9536A Embedded Computer. The external computer may host multiple Graphics Processing Units (GPU-s) to further increase the processing capabilities of the entire system. The large combinations of processing choices allow nearly any application to be met.

Customization

AXIe is based on the Advanced Telecommunication Computing Architecture (ATCA or AdvancedTCA). Because of this, there is an ecosystem that allows users to develop customer modules, chassis and systems. This is important, since many physics applications require very specific signal conditioning and control modules. The large board size gives the user the real estate, power and cooling needed for many custom designs. Additionally, many of the commercial modules are highly customizable through FPGA design, and may be tailored for a unique application.

Range of Commercial Modules

COTS (Commercial Off the Shelf) instrumentation allows instrumentation to be deployed at the lowest cost, leveraging the installed base of commercial industry. The digitizer families currently available are just the start and many more are expected. Some experiments, requiring complex signal generation, can also take advantage of the Agilent M8190 Arbitrary Waveform Generator. With the compatibility AXIe offers with AdvancedTCA and PXI, many more processors and instruments may be added.

Summary

AXIe is the logical next step in the evolution of modular instrumentation for physics. It offers a step function improvement in performance, density, processing and throughput compared to its predecessors. As scientists gain unprecedented insight into the nature of the universe, AXIe will be a key measurement platform helping them do it.

AXIe is the next logical step in modular instrumentation for physics

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AXIe
2010->

AdvancedTCA
2002->

cPCI
1995->

VXI
1990->

VME
VXS
VPX
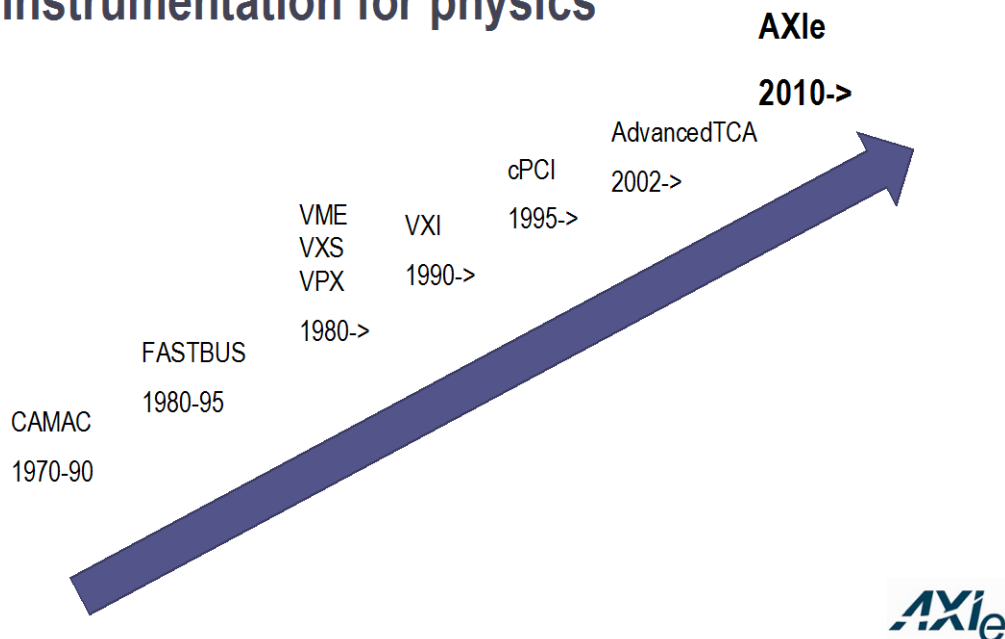1980->

FASTBUS
1980-95

CAMAC
1970-90

AXIe

Figure 5. Physics has been a major adopter of modular instrumentation going back to the 1970s and CAMAC. AXIe is poised to solve many of the challenges of the next generation of physics experiments.

[i] AXIe 1.0: Base Architecture Specification:
http://www.axiestandard.org/images/AXIe_1_0_Revision_1_0_20100630a.pdf
AXIe 1.0 Specification Errata:
http://www.axiestandard.org/images/AXIe_1_0_Revision_1_0_Errata_20110427.pdf

[ii] AXIe Timing and Triggering
http://www.atcanewsletter.com/English/Newsletters/2011/Articles/201102_Article_GregHill.html

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