OFF-THE-SHELF EPICS INSTRUMENTATION FOR REMOTE WAVEFORM MONITORING & ANALYSIS

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Abstract

Off-the-shelf instruments based on the LAN eXtensions for Instrumentation (LXI) standard that include embedded EPICS input/output controllers (IOCs) are an ideal solution for many particle accelerator applications. These applications require responsive remote control and real-time waveform monitoring for critical accelerator systems including machine protection and beam position monitoring. These instruments have the same feature sets and powerful analysis capabilities that today's high-end benchtop instruments have. With an embedded EPICS controller, the instruments easily integrate into the EPICS environment without the need for EPICS drivers or external controllers. They can be controlled and monitored by EPICS applications such as EDM and MEDM. These EPICS oscilloscopes and digitizers perform advanced real-time waveform math and analysis using on-board FPGAs and DSP. This paper will detail how ZTEC Instruments' EPICS oscilloscopes are being used at facilities around the world for real-time control and monitoring via EPICS.

ADVANTAGES OF COTS INSTRUMENATION

Commercial off-the-shelf (COTS) test and measurement instrumentation offers many advantages to the high energy physics and accelerator communities. Purchasing COTS instrumentation saves time, effort and cost when compared to developing instrumentation internally. This advantage tends to become bigger as the quantity of instruments needed increases. Providers of COTS instrumentation are better positioned to manufacture and deliver large quantities of products at reasonable prices than are most accelerator facilities. Engineers and scientists at accelerators are better suited to designing custom, specialized products, in small quantities, that aren't otherwise available in the marketplace. Since accelerators typically don't have the resources to develop and manufacturer large quantities of general purpose products like digitizers and oscilloscope they will purchase COTS general purpose instruments whenever possible.

Unfortunately however, COTS instrumentation often does not easily interface with specialized particle accelerator control system software, nor does it have the advanced signal analysis and high-performance data acquisition capabilities needed for many accelerator applications. Because of COTS instrumentation limitations, it is often necessary to develop custom instrument drivers and download large amounts of acquired data for external processing.

In order to better meet the specific needs of particle accelerator customers, ZTEC Instruments provides high performance digital oscilloscopes and digitizers with an embedded Experimental Physics and Industrial Control System (EPICS) input/output controller (IOC). EPICS is the most commonly used control system for particle accelerators in the world and ZTEC is the only manufacturer of high performance oscilloscopes and digitizers with an embedded EPICS IOC.

EMBEDDED EPICS INSTRUMENTS FOR ACCELERATOR APPLICATIONS

ZTEC Instruments introduced its first EPICS oscilloscope in 2007. Today, several series of ZTEC EPICS oscilloscopes and digitizers are available as standard products, designed to meet the challenging requirements of the accelerator community including high speed and high resolution applications. High speed EPICS oscilloscopes are available with up to 1 GHz analog bandwidth, 4 GS/s maximum real-time sampling rate and 8-bit resolution. High resolution EPICS oscilloscopes are available with up to 14 bits of resolution. An overview of ZTEC's EPICS products is shown in Table 1.

Table 1: ZTEC Instruments' EPICS oscilloscopes

Series	Resolution	Max real-time sampling rate	Analog bandwidth
ZT4610	8 bit	4 GS/s	1 GHz
ZT4210	8 bit	1 GS/s	300 MHz
ZT4420	12 bit	1 GS/s	300 MHz
ZT4430	13 bit	500 MS/s	300 MHz
ZT4440	14 bit	800 MS/s	300 MHz

ZTEC's EPICS oscilloscopes have process variables (PVs) supporting all instrument functions. With over 900 PVs, the EPICS oscilloscopes may be controlled and monitored completely via EPICS and Channel Access (CA). Users of the EPICS oscilloscopes can modify the PV database file of each oscilloscope to better fit their application requirements. For example, the PV prefix can be modified to meet local PV naming conventions. Also, it is necessary to modify the PV prefixes anytime more than one EPICS oscilloscope is on a single network so that each instrument has unique PV names. The PV database file can also be modified to include specialized forward links (FLNKs) and fanout PVs to perform special EPICS functions in a system.

With free EDM and MEDM panels, ZTEC's EPICS oscilloscopes are a complete off-the-shelf EPICS-based solution for advanced data acquisition, data analysis and waveform monitoring. Providing a high performance out-of-the-box solution saves users the development time and costs associated with securing their own software resources to write the necessary EPICS drivers for other COTS instruments. Figure 1 shows two ZTEC EDM panels. The top panel includes basic vertical and horizontal scale control as well as real-time display of the input channel 1 waveform. The bottom panel shows waveform parameters calculated automatically on-board the instrument.

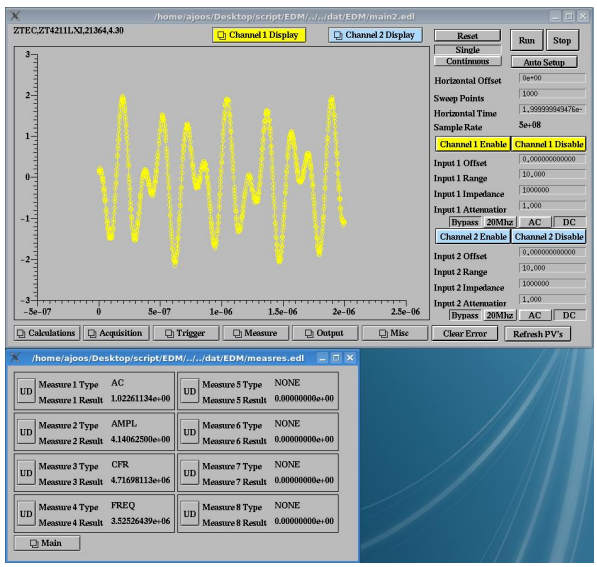

Figure 1: EDM panels for ZTEC EPICS oscilloscopes.

REMOTE WAVEFORM MONITORING & ANALYSIS

Because of the large physical distances spanned by particle accelerators, instrumentation situated around accelerators must be remotely monitored and controlled. The remote monitoring and control use model is dramatically different from the manual use model that most instruments are optimized for. Most benchtop oscilloscopes have large displays for viewing waveforms and have knobs to turn and buttons to push for controlling these instruments. While most modern instruments can also be controlled remotely via Ethernet, they do not update as quickly, nor are they nearly as responsive as are instruments that are designed specifically for remote monitoring.

Side-by-side comparisons of ZTEC LXI (LAN-controlled) instruments and a benchtop oscilloscope controlled and monitored via Ethernet show dramatically different performance in terms of waveform update rates and instrument responsiveness. For each instrument we recorded how long it takes to capture 100 waveforms of 1,000 points each. We then divide that time by 100 to approximate the time it takes for each acquisition. Using ZTEC's ZScope display and control software to monitor the ZTEC instruments (Fig. 2), we observe updates of 3-5 Hz and instrument control with no noticeable delay when making a change to the instrument. The benchtop oscilloscope display updates only once every three to four seconds, or 0.33 – 0.25 Hz. Additionally, there is noticeable delay between remotely making a change to the benchtop instrument's settings and when the change is reflected on the software display. Clearly, the benchtop instrument is not optimized for remote monitoring and control.

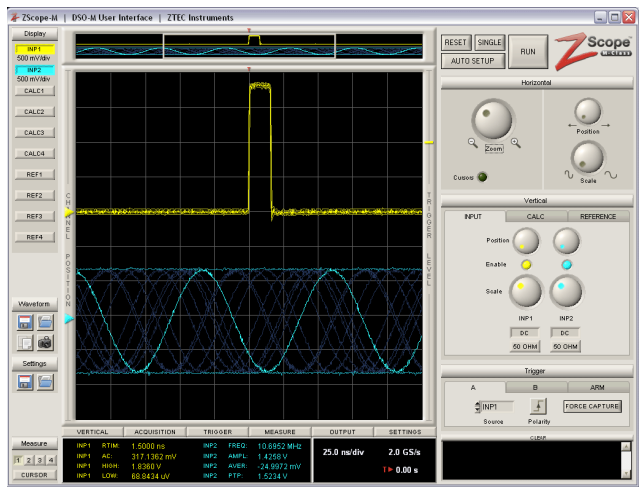

Figure 2: ZScope software for remote instrument monitoring and control

On-Board Signal Analysis

On-board signal processing and data reduction reduces data transfer time, speeds up data acquisition rates and analysis times and enables more responsive remote monitoring. Instead of acquiring waveform data and then downloading it from the instrument to software such as MATLAB® for additional analysis, advanced COTS instruments perform the math and analysis on-board the instrument, in real-time, without having to download the entire waveform.

Nearly all of today's benchtop oscilloscopes provide extensive on-board signal analysis. However, as discussed above, benchtop instruments are typically not as well suited for remote monitoring as are modular instruments specifically designed for remote interactions. On the other hand, modular instruments like PXI/cPCI, PCI and VXI, while reasonably well-suited for remote applications, traditionally have not had the on-board signal processing capabilities necessary to meet many accelerator requirements. Therefore, modular instruments would be used only to digitize a waveform and then download the entire waveform (or waveforms) to an external controller for further analysis.

On-board data analysis is especially important with today's long-memory instruments. With acquisition memory lengths of hundreds of millions of data points and longer, it can be very time consuming to download every waveform from every channel, even with fast data

buses like PCI and PCI Express (PCIe). For most applications, it is much faster to use on-board processing to extract the desired information from the signal and reduce the data before transferring it to a PC than it is to simply download every data point that is captured.

For example, assume that an event is used to trigger an oscilloscope. The trigger event indicates that a pulse will occur sometime within the next 1ms, but the exact time of the pulse's occurrence within the 1ms window is unknown. The user of the oscilloscope only wishes to know two bits of information: 1) when the event started relative to the trigger event and 2) the area under the pulse. If the instrument samples at 1 GS/s for 1ms, one million data points are captured. Instead of transferring all one million data points to a PC for analysis, an oscilloscope or digitizer with built-in processing can calculate the time of the rising edge of the pulse, perform an integration of the pulse and then transfer the results of these two calculations to a PC. The amount of data transferred in this case, using on-board processing, is much less and the time required for data transfer is also less than if the entire waveform had to be transferred to a PC. These time savings are particularly significant when there are multiple instruments sharing a single bus, e.g., the PCI bus on the backplane of a PXI chassis.

ZTEC Instruments' M-Class EPICS and non-EPICS oscilloscopes and digitizers use on-board FPGAs and DSP to perform waveform math and calculate over forty waveform parameters. On-board waveform math includes algebraic functions, integration, differentiation, Fast Fourier Transforms (FFTs), histograms, parameter trending, limit/mask testing, and others. Waveform parameters related to voltage, time and frequency are also automatically calculated.

EXAMPLES OF EPICS OSCILLOSCOPES USED FOR REMOTE APPLICATIONS

ZTEC's EPICS oscilloscopes are being used and evaluated at particle accelerators around the world because they easily integrate into existing EPICS-based control systems and because they can perform real-time waveform analysis. Two examples are outlined below.

Oak Ridge National Lab's Spallation Neutron Source (SNS) has evaluated the EPICS oscilloscopes for use in real-time monitoring of injection and extraction kicker waveforms for machine protection. The oscilloscopes capture the kicker waveforms and compare it in real-time to a pre-defined waveform mask consisting of upper and lower limits for the waveform. If the acquired waveform falls within the upper and lower mask limits, the oscilloscope outputs a pulse indicating to the SNS machine protection system that the waveform is within the allowed range. The oscilloscope then re-arms for the next kicker waveform occurring at a rate of 60Hz. The instruments are completely controlled and monitored remotely using EPICS. Figure 3 shows kicker waveforms that are captured and then compared to a pre-defined mask in order to determine whether or not the waveforms fall within an allowable range.

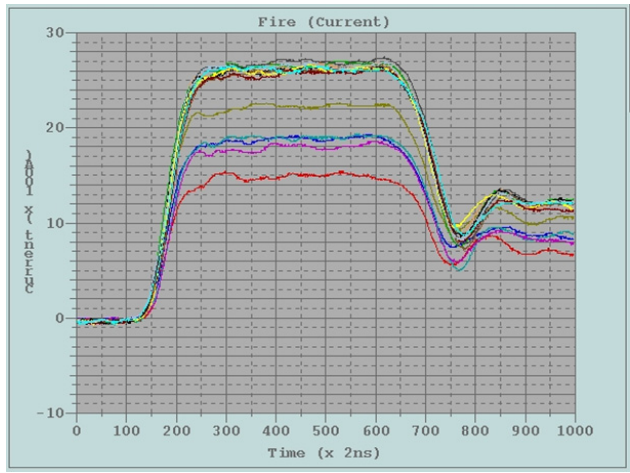

Figure 3: Real-time mask testing is performed on kicker waveforms at a rate of 60 Hz.

Lawrence Berkeley National Lab's Advanced Light Source (ALS) also uses ZTECs EPICS oscilloscopes for remote monitoring of various beam position monitors, kicker waveforms and klystron signals around the machine. ALS determined that the ZTEC EPICS oscilloscopes are time and cost-effective because they easily integrate into their EPICS control system and they don't have to create their own EPICS drivers. With PVs for all instrument functions and EDM panels for control and monitoring, the ZTEC EPICS oscilloscopes can be monitored in the ALS control room via EPICS.

CONCLUSION

COTS EPICS instrumentation with advanced on-board waveform processing provides advantages over developing in-house solutions and purchasing non-EPICS benchtop and modular instrumentation. Developing in-house solutions for large quantities of general purpose instrumentation is not practical for most accelerator facilities. It is desirable to purchase COTS instrumentation whenever possible, as long as the instruments can be easily integrated into the software environment (e.g., EPICS) and have sufficient performance. ZTEC's EPICS oscilloscopes and digitizers designed for remote interfacing with on-board processing and a complete EPICS interface are cost and time-effective for many accelerator applications requiring remote monitoring and control.

REFERENCES

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[3] ZTEC Instruments, M-Class Digital Storage Oscilloscope, User's Manual, November 30, 2009.