CEBAF DISTRIBUTED DATA ACQUISITION SYSTEM*

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Abstract

There are thousands of signals distributed throughout Jefferson Lab's Continuous Electron Beam Accelerator Facility (CEBAF) that are useful for troubleshooting and identifying instabilities. Many of these signals are only available locally or monitored by systems with small bandwidths that cannot identify fast transients. The Distributed Data Acquisition (Dist DAQ) system will sample and record these signals simultaneously at rates up to 40 Msps. Its primary function will be to provide waveform records from signals throughout CEBAF to the Experimental Physics and Industrial Control System (EPICS). The waveforms will be collected after the occurrence of an event trigger. These triggers will be derived from signals such as periodic timers or accelerator faults. The waveform data can then be processed to quickly identify beam transport issues, thus reducing down time and increasing CEBAF performance. The Dist DAQ system will be comprised of multiple standalone chassis distributed throughout CEBAF. They will be interconnected via a fiber optic network to facilitate the global triggering of events. All of the chassis will also be connected directly to the CEBAF Ethernet and run EPICS locally. This allows for more flexibility than the typical configuration of a single board computer and other custom printed circuit boards (PCB) installed in a card cage.

BACKGROUND INFORMATION

Jefferson Lab's CEBAF is seven-eights of a mile long, shaped similar to a racetrack, and buried underground for radiation shielding. It consists of an electron injector, 2 linear accelerators (Linacs), 2 re-circulation arcs, and 3 experimental end stations. Each Linac is divided into 27 zones. Cryogenic modules reside in 20 of the zones and house 8 RF cavities each. Every cavity is driven by a klystron and controlled by a RF Control Module (RFCM) located in a service building rack directly above the Linac. Each RFCM outputs 6 signals that represent gradient and phase control information for the cavity under its control, these signals are listed in table 1. In addition, there are 25 cavities with RFCM cards distributed among 4 zones in the injector. This is a total of 345 RFCM cards which yield 2,070 signals.

Table 1: RFCM Signals

Phase Signals: +/-5 V	**Gradient Signals: 0 – 10 V**
Phase Ask (PASK)	Gradient Ask (GASK)
Phase Measure (PMES)	Gradient Measure (GMES)
Phase Error (PERR)	Gradient Error (GERR)

RF Cavity Instabilities

The RF cavities, and the klystrons that drive them, are often run near their maximum RF power. Effects on the cavity from electron beam loading can make it difficult for the RFCM to maintain the cavity's gradient and phase. This could be due to microphonics, the cavity being out of tune, or a miscalculation of the maximum power. As a result, the RFCM requests more power from the klystron and pushes the klystron beyond its nominal range.

Occasionally, the RFCM control loop oscillates as the klystron is driven into saturation. This causes an energy change in the electron beam which results in beam motion. Once the gradient or phase becomes unstable enough, the beam can no longer traverse the accelerator and begins to strike the beam pipe. Beam loss detection systems then shut down the accelerator to protect against a burn through. This beam motion has also been correlated with oscillatory beam loss data from the BLA system that occurs at the same frequency. Figure 1 shows oscillatory horizontal beam motion in a high dispersion area caused by an unstable cavity. Approximately 4 msec after the instability starts, the beam is shut down by a beam loss detection system at time 0.0 on the graph.

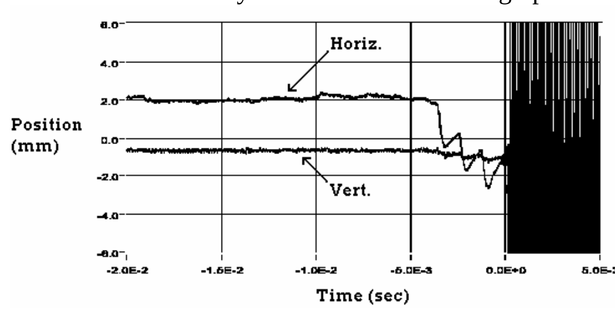

Figure 1: BPM motion.

Once the accelerator is shut down, the effects of beam loading diminishes and the struggling cavity and RFCM returns to a stable state. This entire process happens within 10 msec. Although these instabilities can be indirectly detected using the BPM and BLA systems, the responsible cavity cannot be easily identified. Diagnostics on the RFCM cards do not have the bandwidth necessary to identify the problematic cavity and report it back through EPICS. The only option is to check each of the 345 cavities by hand.

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Reliable cavity and RFCM operation is crucial for meeting the needs of physics experiments. The main purpose of the Dist DAQ system will be to monitor the RFCM control signals although other vital systems may be incorporated in the future. This could include magnet control, Beam Position Monitor (BPM), Beam Loss Monitor (BLM), and Beam Loss Accounting (BLA) signals.

THEORY OF OPERATION

The Dist DAQ system will monitor all the available RFCM signals in the accelerator. This will offer insight into the behavior of the RFCM control loop and help quickly identify misbehaving cavities. It will operate similarly to a triggered oscilloscope with a large number of inputs and have a sample rate high enough to identify fast transients that are currently undetectable. Each channel will be sampled simultaneously and stored in circular buffers. Event triggers will be used to freeze the buffers and provide a snapshot of all the signals. Once the buffers have been read, the system will reset and continue sampling until the next event trigger. These triggers may be based on fast shutdown (FSD) events, beam sync, software timers, or any other relevant signals. The data will be stored in files and provide the foundation for automated troubleshooting and testing tools for RFCM cards and other systems that are integrated in the future. These tools will include performing an autopsy after a FSD event trigger to quickly determine the root cause of the fault. Software initiated event triggers could also be used to collect data and preemptively evaluate the performance of accelerator systems. The Dist DAQ system is currently being designed and will be tested in the CEBAF Injector before being expanded to the entire accelerator.

SPECIFICATIONS

The Dist DAQ system will consist of 44 Data Acquisition Chassis (DAQ Chassis) and 4 Event Trigger Chassis (ET Chassis). These standalone chassis will run EPICS locally and communicate via the CEBAF Ethernet. A DAQ Chassis will be installed in each zone that has a RFCM rack. This includes 4 zones in the injector service building and 20 zones in each Linac service building. Each DAQ Chassis will receive global event triggers from a dedicated fiber optic network. They will monitor the 48 signals produced by the 8 RFCM cards in a rack and also have 12 spare channels for incorporating future systems. This zone setup is illustrated in figure 2.

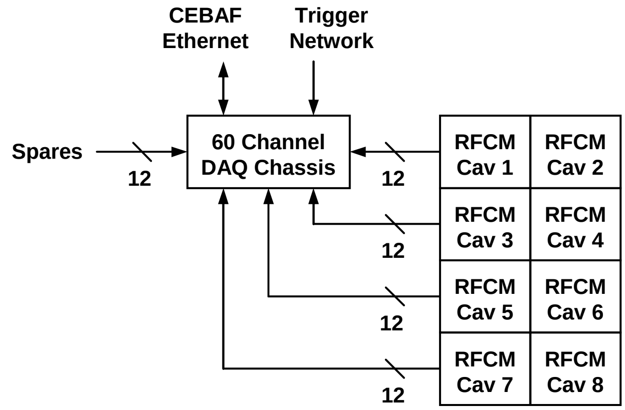

Figure 2: Dist DAQ zone setup.

The Central ET Chassis (CET Chassis) will reside in the Machine Control Center (MCC). A star topology, shown in figure 3, will be used to distribute the event triggers from the CET Chassis to 3 Repeater ET Chassis (RET Chassis) located in the 2 Linacs and the injector. The RET Chassis will relay the CET Chassis event triggers to all of the DAQ Chassis in their respective service buildings. If an event trigger originates from a RET Chassis, it is first sent to the CET Chassis and is then distributed back out through the star configuration. This results in equal propagation delays to all the DAQ Chassis to ensure synchronous triggering of all signals.

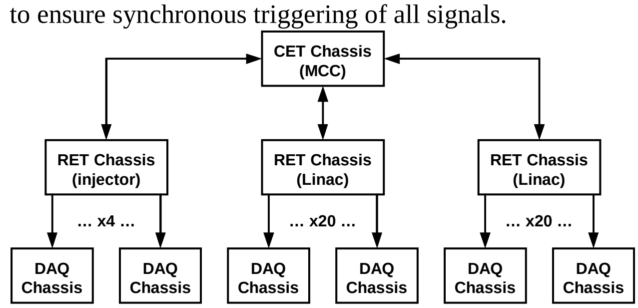

Figure 3: Event trigger network.

Data Acquisition Chassis

The DAQ Chassis will have 2 ADC PCB modules that monitor 30 inputs each. The ADC boards will accept +/-15 V inputs that are divided into 5 groups of 6. Each group will have 6 dedicated 1.25 MHz ADC channels with a resolution of 16 bits. An additional 40 MHz, 14-bit ADC channel will be multiplexed across the 6 inputs and used to detect higher frequency signals components. A 16-bit digital-to-analog converter (DAC) will be multiplexed to the 7 ADC channels and an output channel. The DAC will be used as a self check for the ADC channels and available as an output if need in the future. All of these components will be controlled by a Field Programmable Gate Array (FPGA) that also processes and stores the ADC data in static random access memory (SRAM). The data will be organized in circular buffers and collection will cease when an event trigger is received. The FPGA then transfers the data to another PCB that is running EPICS. After the transfer, the FPGA will resume data collection.

An Input/Output Computer (IOC) PCB will also reside in the DAQ Chassis. It is responsible for receiving fiber optic event triggers and freezing the corresponding ADC channels on the ADC boards. It also collects the appropriate ADC data and makes it available to EPICS. This is accomplished using a reconfigurable, 32-bit Altera Nios® II processor that is imbedded into a FPGA. The processor runs EPICS on top of the uClinux™ operating system and communicates to the control system via a 10/100 Ethernet interface. Flash memory is used to store the uClinux boot program and synchronous dynamic random access memory (SDRAM) holds ADC data and is used to run the EPICS program.

Event Trigger Chassis

Each ET Chassis will contain the same IOC board used in the DAQ Chassis. They will be responsible for creating the event triggers based on trigger inputs such as FSD and beam sync signals as well as distributing the event triggers to all of the DAQ Chassis. To accomplish this, the chassis will also include a Trigger PCB that accepts fiber optic, TTL, and analog trigger inputs. The board will also have fiber optic inputs and outputs used to distribute event triggers to other ET and DAQ Chassis.

SOFTWARE TOOLS

All data and controls will be available through EPICS. The user controls will include selecting sample rates and configuring global triggers. The sample rate will be configured on a channel by channel basis. Global event triggers will be created based on different trigger signals. Each trigger can include just one channel, all channels, or any combination of channels. This yields global trigger tables that will reside in the CET Chassis and used to generate the even triggers. Data collected from each event will be stamped with the date, time, event type, and event number then stored in file-based ring buffers. A ring buffer will exist for each type of event trigger. The length of the ring buffers will be selectable and users will be able to find any event in the buffers based on the stamped information. These files will be used as a platform to build automated software for detecting RF cavity abnormalities. High level software applications will display the information in these files as well as analyze them to find signals with large standard deviations and frequency information that indicate instabilities. A set of standard operating modes are defined below.

Oscilloscope Mode

This mode allows RF maintenance staff to observe the RFCM signals for individual cavities remotely. They will be able to trigger the signals with beam sync or take data in a free-running mode. Data will be presenting in an oscilloscope-like format for interpretation by the RF maintenance staff. The multiplexed 40 MHz channels will only be configurable using this mode. This and other modes will use the dedicated RFCM and spare 1.25 MHz channels in tandem.

RFCM Health Check Mode

The automated RFCM Health Check routine will regularly trigger the Dist DAQ to collect tens of milliseconds of data from all the GMES and PMES signals. The software will then calculate the standard deviation, peak-to-peak values, and Fast Fourier Transforms (FFT) for the acquired signals. Abnormal cavities will be flagged for intervention by operators and RF maintenance staff. The program could also automatically adjust cavity parameters to try to correct certain identifiable problems.

Autopsy Mode

A Dist DAQ trigger will be generated by FSD events and include all the PMES and GMES RFCM signals. Data will be recorded for tens of milliseconds before the FSD fault. The standard deviation, peak-to-peak value, and FFT will be calculated for each signal. Any cavity exhibiting abnormalities just prior to the fault will be flagged and presented to the operations staff for interpretation and intervention.

CONCLUSIONS

The Dist DAQ system will provide the foundation for many automated tools that will help maximize RF cavity performance. It will also allow users to remotely capture and view various signals from throughout CEBAF in an easy-to-use oscilloscope format. The high sample rate and circular buffers will allow previously undetectable issues to be uncovered and addressed. The system can be expandable to incorporate other accelerator signals by simply adding DAQ Chassis as needed or using spare channels. The standalone chassis design frees the system from the traditional card cage topology, thus reducing costs and increasing flexibility. All of these features will result in the Dist DAQ system being a valuable asset to the operation CEBAF.

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