A VME AND FPGA BASED DATA ACQUISITION SYSTEM FOR INTENSITY MONITORS*

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Abstract

A universal data acquisition system supporting toroids, DCCTs, Faraday cups, srapers and other types of instrumentation has been developed for reporting beam intensity measurements to the Fermilab Accelerator Controls System (ACNet). Instances of this front end, supporting dozens of intensity monitor devices have been deployed throughout the Fermilab accelerator complex in the Main Injector, Recycler, Fermilab Accelerator Science and Technology (FAST) facility and the PIP-II Injector Experiment (PXIE). Each front end consists of a VME chassis containing a single board computer (SBC), timing and clock module and one or more 8 to 12-channel digitizer modules. The digitizer modules are based on a Cyclone III FPGA with firmware developed in-house allowing a wide range of flexibility and digital signal processing capability. The front end data acquisition software adds a list of new features to the previous generation allowing users to: take beam intensity measurements at custom points in the acceleration cycle, access waveform data, control machine protection system (MPS) parameters and calculate beam energy loss.

INTRODUCTION

Beam intensity instrumentation is a critical part of every particle accelerator. The Fermilab Accelerator Division Instrumentation department is tasked with developing world-class beam instrumentation that can support the laboratory's growing complex of diverse particle accelerators. To meet these demands, a VME digitizer module has been designed in-house for acquiring signals from toroids, DCCTs, and other types of beam instrumentation. The module's firmware also provides enhanced digital signal processing capability that can be customized to unique situations.

Data acquisition software developed at Fermilab and proven in one situation is often put to use in another with some degree of modification. In the past, each deployment of a beam intensity data acquisition system was managed as a separate software project even though each descended from a common code base (a practice known to software developers as forking). The problem with this approach is that each instance (a fork) of the common software does not benefit when a bug fix or new feature is applied to another. Diligent management and time-consuming development were necessary to ensure that software and firmware changes were made to each fork of the code base and tested properly.

* This work was supported by the DOE contract No. DEAC02-07CH11359 to the Fermi Research Alliance LLC.
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Faced with a rapidly increasing demand across the laboratory for beam intensity monitors based on the in-house designed digitizer module, the decision was made to coalesce the data acquisition software development into a single unit that is flexible enough to be used in all situations. Instead of each deployment of an intensity monitor data acquisition system running custom software, all deployments will run the same software configured individually for the application.

DIGITIZER MODULE

The beam intensity data acquisition system was developed to utilize two variations of an in-house designed 6U VME digitizer module. One variation of the digitizer module samples at 125 MS/s and supports 8 channels and another samples at 250 MS/s and supports 12 channels. Both variations are equipped with 192 MB of DDR2 SDRAM for data buffering and a Cycle III FPGA for signal processing (see Fig. 1).

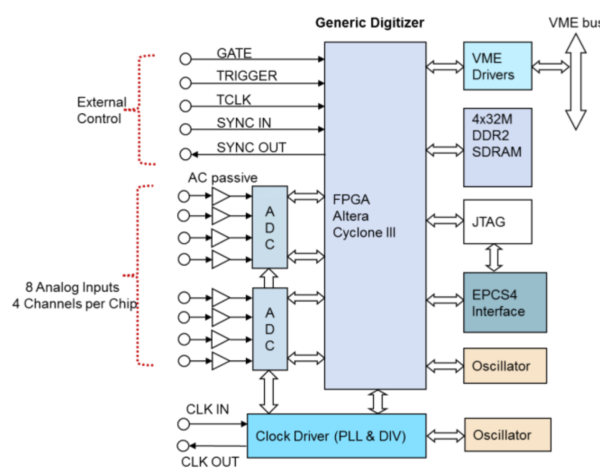

Figure 1: 125MS/s 8-channel VME Digitizer Module.

The FPGA firmware can be divided into two sections. One section supports the basic infrastructure required for any general application: an ADC data receiver, a VME bus driver, a memory driver, a serial port interface and a sync signal decoder for smart triggering. The section other supports application specific algorithms including the intensity calculation.

Beam intensity is calculated by the digitizer module's firmware and presented to the data acquisition software in raw ADC counts over the VME bus. When beam current is measured the digitizer module also provides a calculation of the beam pulse length. Scaling to beam intensity or beam current is the responsibility of the data acquisition software.

The digitizer modules have optional support for interfacing with a Machine Protection System (MPS) via thresholds set on integrated beam intensity and pulse width. The threshold comparisons are done by the digitizer module's firmware immediately after the beam pulse is integrated. If the thresholds are exceeded an alarm signal is pulled, tripping the MPS. The data acquisition software provides an interface for programming the thresholds but does not play any part in the threshold comparisons.

FRONT END NODE

Front Ends are components of the Fermilab Accelerator Controls System (ACNet) responsible for data acquisition. A single front end may be responsible for one or more devices (e.g. a toroid) logically represented in the controls system. A basic intensity monitor front end consists of a VME crate, one or more digitizer modules, a timing module and a MVME 5500 SBC (see Fig. 2).

Figure 2: An intensity monitor Front End deployed at PXIE.

The digitizers modules are gated by an external timing signal synchronized with the beam pulse. When the gate signal is present the digitizers integrate the beam pulse and an interrupt signal is generated on the VME bus when the gate goes away. When the interrupt occurs, the software running on the SBC collects the data from each digitizer module, processes it and holds it in memory to service data requests from the control system. The timing module is present to process requests that are synchronous with events other than the external gate signal.

DATA ACQUISITION SOFTWARE

The data acquisition software is responsible for configuring the digitizer modules to make a beam intensity measurement, acquiring the data after the measurement has been made, processing the data and scaling the data to beam intensity or current and delivering the data to ACNet.

A key component to the data acquisition software is the configuration script. Each beam intensity monitor front end has a unique configuration script that initializes the digitizer modules, maps intensity device objects to digitizer inputs, sets the scaling methods and coefficients and sets up the various beam intensity measurements to be made.

Measurements may be made pulse-to-pulse or continuously, depending on the type of instrument (i.e. Toroid measurements are typically pulse-to-pulse while a DCCT is measured continuously).

CYCLE & SUM MEASUREMENTS

The Fermilab Main Injector and Recycler have a beam cycle of 1.33 seconds when delivering beam to the NuMI beamline. For this cycle and others it is desirable to measure the beam intensity via a DCCT on certain events such as beam injection (up to 12 events), start of ramp, flat top and just before extraction. Cycle Measurements are a feature of the data acquisition software that allow these measurements to be made, stored in memory and delivered to other components of the controls system at the end of the cycle.

For these machine cycles it is also necessary to sum the beam injected into the machine via the injection beam line toroid. Sum Measurements reset to zero at the beginning of a machine cycle, add the beam intensity measured by the toroid after each injection event and hold the sum until the beginning of the next machine cycle. This sum is then compared with the beam measured before extraction and the beam measured in the extraction beam line and reported to management.

BEAM ENERGY LOSS MEASUREMENTS

Beam Energy Loss measurements sample the Main Injector and Recycler DCCT right after beam is injected. The difference between the injected beam sample and the current reading of the DCCT (adjusted for the beam energy) is used to calculate the amount of beam energy loss experienced during the cycle as well as over the previous hour and 24-hour period.

USER INTERFACE

The data acquisition software was designed to deliver beam intensity measurements to three different types of users: operators, instrumentation experts and other components of the controls system. Measurement data can be delivered via ACNet, the Machine Data Distribution (MDAT) system [1], a command line interface or over network attached storage.

Beam intensity is available to operators through ACNet devices. ACNet devices are updated either pulse-to-pulse or continuously at 720Hz, depending on the nature of the intensity monitor. Operators can view the data from dedicated consoles and can plot them in real time (see Fig. 3).

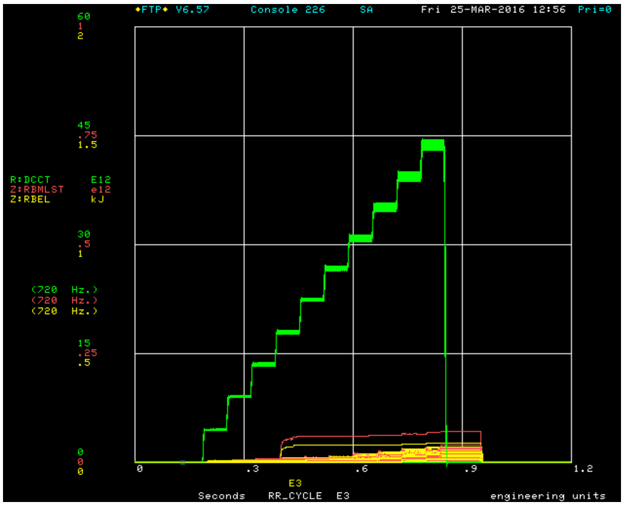

Figure 3: A real time plot of beam intensity and beam energy lost in the Recycler measured with a DCCT.

In addition, instrumentation experts have access to the raw waveform data recorded by the digitizer modules during the beam pulse. Due to bandwidth limitations, waveform data is only collected from the digitizer modules when requested by an expert. Waveform data collection may be requested through ACNet and remains on while the data is being plotted. Five minutes after the last plotting request the data collection is automatically turned off. Experts may also request that raw waveform data be saved to a comma-separated value (CSV) file for a user-defined number of pulses.

Other components of the controls system consume beam intensity information for machine learning, reporting and other tasks. The Front End may be equipped with a MDAT transmitter for reporting beam intensity in real time or the beam intensity data can be consumed through ACNet.

CONCLUSION

As of publication eight intensity monitor data acquisition systems have been deployed in diverse configurations across the Fermilab accelerator complex supporting over two dozen intensity monitors. A quarterly release schedule has been established for the data acquisition software to ensure each deployment of the intensity monitor front end has the latest features and bug fixes. Near future plans are to deploy three more front ends over the next year and to retire the single remaining previous-generation intensity monitor front end in the beginning of 2017.

REFERENCES

[1] D. Beechy *et al.*, "Time and Data Distribution Systems at the Fermilab Accelerator", *Nuclear Instruments and Methods in Physics Research*, A247, 1986.