A High Speed Time-Stamping and Histogramming Data Acquisition System for Position Encoded Data

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Outline

- New Neutron Research Reactor in Australia
- Neutron Detector and Position Encoding Electronics
- Timestamping and Histogramming DAQ
- Pictures from Detector Installation
Neutron Scattering at OPAL - Australia

New research reactor: commissioning stage now operation starting in 2007
20 megawatt reactor
4 beamlines
  2 thermal, 2 cold
8 beam instruments on startup
Electronics System Block Diagram

- 8 - Preamp / Driver Motherboards
- 8 - Processing Modules
  - 32 Cathode Channels
  - GBLR
  - ADC
  - Anode Processing
  - Digital Centroid Finding Module
- 8 - Readout Modules
  - USB 2.0
  - Ethernet
  - Fiber
- 1 - Instrument Control PC
- 4 - RackMount PC's
  - Gigabit Ethernet
  - 20 Meters MT-RJ Duplex Fiber cables
  - Outputs X,Y position information only
  - Custom PCI cards add Timestamping, Framing and Histogramming Features
- Histogramming PC
120° Two-Dimensional Thermal Neutron Detector

- $^3$He filled multiwire proportional chambers with interpolating cathode readout
- $1.5\text{m} \times 20\text{cm} = 0.3 \text{ m}^2$ area, $>10^5$ resolution elements, 1.3 mm FWHM
- high count rate, $> 10^6$ s$^-1$
- Single gas volume, 8 independent wire segments – designed to have no dead region between segments
- 2nd Detector of this type built – 1st one installed at the LANSCE Protein Crystallography Station in 2001

Shielded enclosure for front-end electronics ($\times 8$)
120° Detector & Position Encoding Electronics
Detector Charge Collection

15 readout taps per segment

17 readout taps per segment
Cathode Channel ADC Outputs

![Graph showing ADC outputs for Y channel number and X channel number with indications of events at preamp location and between preamps.]

Charge
Amplitude

Y channel number

X channel number

Event at preamp location

Event between preamps
Steps to Calculate the X,Y Position for an Event

- Read 17 x-axis ADC’s, 15 y-axis ADC’s, 3 neighbor x-axis ADC’s
- For each channel
  - Offset Correction (subtraction)
  - Gain Correction (multiplication)
- Search for channel with the maximum charge
- Calculate center of charge
- Send X,Y position to DAQ
- Completed in under 3μS in FPGA
Center of Charge Equation

\[
\left( \frac{c - a}{a + b + c} + \frac{\text{node#}_{\text{max}}}{\text{bins/node}} \right) \times \text{bins/node}
\]
Position Encoding Across Boundaries

Left Segment | Right Segment

A_{left} \quad \quad A_{boundary} \quad \quad A_{right}

Y_{in} \quad X_{in} \quad \quad \quad X_{in} \quad Y_{in}

Centroid Finding Circuit (CFC_L) \quad \quad \quad Centroid Finding Circuit (CFC_R)

\downarrow X-Y_{out} \quad \quad \quad \quad \quad \downarrow X-Y_{out}

Spread of the cathode induced charge
Position Encoding Across Boundaries Implementation
Preamp Driver Motherboard
VME Motherboard

Digital Logic Daughterboard

Anode Trigger Logic Daughterboard

36 5 MS/s ADC’s

GBLR shapers
Readout Module

Connection to the VME board

FPGA

Fiber Interface to DAQ

USB Interface
For front end control, calibration, etc.

RS-485 Parallel X,Y Position output
LabVIEW Interface

Histogram
LabVIEW Interface
Anode Pulse Height Distribution
LabVIEW Interface
ADC Outputs
LabVIEW Interface
Status & Control
LabVIEW Interface
Calibration
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- 4 - RackMount PC's
  - Histogramming PC
  - 20 Meters MT-RJ Duplex Fiber cables
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  - Gigabit Ethernet
- Outputs X,Y position information only
- Custom PCI cards add Timestamping, Framing and Histogramming Features – Focus of this talk

8 - Preamp / Driver
DAQ - System Requirements

Provide the ability to capture, timestamp, and histogram, position encoded neutron data.

- **Max throughput**: $2 \times 10^6$ events/sec
- **Start and Stop Run** $\Rightarrow$ Data Set Signal (2 external source, 2 internal source)
  - Determines end of data collection
  - External sources (direct or scaler)
    - Example: beam monitor (ends data run on predetermined flux)
  - Internal sources
    - Time based (hardware counter)
    - Frame signal counter
- **Data Frame Signal** (2 external sources, 1 internal source)
  - Determines change in histogramming location
  - External Sources
    - Examples: auxiliary equipment on sample, such as magnets, furnaces, refrigerators, pressure devices
  - Internal source
    - Time based (hardware counter)
    - Available for driving other auxiliary equipment
    - Wide Frame signal range: 1mHz to 1Mhz.
- **Timestamp resolution**: 40ns.
  - Programmable 32 bit counter provides timestamp
  - Counter reset on Frame signal
- **4 external veto signals inputs**
  - To reject frames of data. Data can be rejected if any veto signal was asserted during the frame. (software determined)
- **High Speed Fiber Transceiver Interface**, allows system to be remotely located away from radiation source
- **Daughterboard Connector** provides a configurable interface capable of matching to various detectors.
- **Scalable to synchronize across multiple detector segments**. Must synchronize the starting / stopping of acquisitions and framing signals between the multiple segments - BNL detector has really 8 detectors
System Implementation Hardware

- **Minimize Custom Hardware** (PCI card)
  - Receiving X,Y position information via fiber optic
  - Timestamp added
  - Frame Number added
  - veto signals latched

- **All this information buffered locally and sent over PCI**
  - Packet is 4 32 bit words

```
HEADER
VETO  YPOS  XPOS
TIMESTAMP
FRAME NUMBER
```

- All histogramming functionality performed general purpose computer
  - Cheap – compared to custom hardware
  - Lots of expandable DRAM for histogram storage
  - Huge amounts of disk space if foregoing histogramming altogether (if storing event mode data)
Block Diagram of DAQ

- PCI card
- General Purpose Computer

- TLK1501 Interface
- Event FIFO (8k * 16)
- SSRAM Control Logic
- SSRAM
- Data Set, Frame & TimeStamp Logic
- Data Set, Frame & TimeStamp Logic
- Fiber I/O
- X,Y position words from detector
- SCSI Connector
- data set direct
- data set scaler
- data frame direct
- data frame scaler
- veto (4)
- data set out
- frame out
- veto out
- PCI Interface Logic
- PCI Bus
- Histogram Filler Program
- CPU
- BAT
- OAT
- FAT
- Etherne
PCI Board

- EPC16 Altera Configuration FLASH
- Programming Header
- 256k * 64 local buffer memory
- DaughterBoard Interface
- BNL Detector Interface – X,Y position information
- Control I/O connects to distribution box
- Altera Stratix FPGA
- 3.3v – 5v translators
Distribution Box

Provides I/O for starting/stopping acquisition

Provides I/O for framing signals

Synchronizes these events across multiple segments
Data Set Logic

Implement the starting and stopping of an experiment
Must Synchronously Start and Stop across multiple detectors

This Signal is the Data Set Direct Input for all Target Modules
Data Frame Logic

This Signal is the Data Frame Direct Input for all Target Modules

Data Frame Direct (Master) (Ext Input)
Data Frame Scaler (Ext Input)
System clock
Data Frame Direct (Target) (Ext Input)
Data Frame Scaler
Data Frame Timer
Data Frame Control Register
Master/Target Select
Data Frame Signal

- Data Frame Logic Diagram
- System clock
- Data Frame Direct (Master) (Ext Input)
- Data Frame Scaler (Ext Input)
- System clock
- Data Frame Direct (Target) (Ext Input)
- Data Frame Scaler
- Data Frame Timer
- Data Frame Control Register
- Master/Target Select
- Data Frame Signal

This Signal is the Data Frame Direct Input for all Target Modules
Some Typical Experiment Setups and Histogramming Requirements

• **Steady state Measurements**
  – Easiest case, single histogram

• **Kinetic Measurements**
  – Look at real time changes in structure while increasing some parameter of the sample such as temperature, pressure, magnetic or electric fields
  – Frame signal might come from auxiliary device or internal frame signal (time based) could drive the auxiliary device

• **Time of Flight Measurements**
  – All wavelengths lambda are allowed to scatter from the sample and are determined by recording the times at which neutrons arrive at a detector
  – Frame signal most likely from choppers (reactor), T\textsubscript{o} pulse (Spallation Source)

• **Stroboscopic Measurements**
  – Since neutron sources do not deliver sufficient flux to examine singular short-time events in the millisecond range, measurement is repeated over many cycles of the process
  – Frame signal might come from auxiliary device or internal frame signal (time based) could drive the auxiliary device

• **Time Evolving Stroboscopic Measurements**
  – Measuring for example the fatigue in ferroelectric ceramic. Apply electric field at say 1Khz (frame rate) but every 100k cycles switching to a new period of histograms to record time evolving variation
Histogramming Software

- Difference from regular time of flight data acquisition electronics is in software. Two address tables are used instead of one
  - OAT: Offset Address Table
  - BAT: Base Address Table

- Histogram memory is divided up into a series of “periods”. Each “period” has its structure defined in the OAT
  - OAT contains addresses relative to one frame of time.

- The frame number is used to read a base address from the BAT. This base address points to the first element of the period in memory into which that frame should be written

![Diagram of Histogramming Software](image)
Histogramming Software Implementation

- Using these two lookup tables provides for a simple and fast code implementation, Histogramming function called once all events in a given frame are received and veto signals checked. A few memory references and some pointer arithmetic

```c
Histogram()

...

batoffset = bat[framenum] * PERIODSIZE
while (numevents_in_frame)
    xyoffset = y + (512 * x);
    oatoffset = OAT[timestamp] * HISTSIZE;
    histoffset = batoffset + oatoffset + xyoffset;
    *histptr++
```
Complete Acquisition System

- Distribution Box
- 4 IBM eServer x226 computers – each holds 2 PCI cards – running SUSE Linux
- Servers communicate with Instrument Control computer via Gbit Ethernet
- Fiber Connections to Detector
Labview Interface – UIR data from 8 segments
First Data!
22mm MgO sample