Fast Bunch Integrator
A System for Measuring Bunch Intensities in the Fermilab Main Ring

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ABSTRACT

In order to support the proposed luminosity increases in the Fermilab Tevatron Collider, a new Fast Bunch Integrator (FBI) system has been developed. FBI is used to precisely measure the intensity of each bunch in the Main Ring before injection into the Tevatron. These intensity measurements are particularly useful for monitoring the coalescing process as it takes place. This newly designed FBI system will also be used in the Main Injector when complete. The FBI system is comprised of a VME Front End which communicates with Fermilab's ACNET via an Ethernet connection. The boards in the VME crate are a Motorola 162 CPU, a Fermilab designed Pulse Pattern Generator (PPG), 2 Fermilab designed Integrator boards (one for protons and one for antiprotons), and 2 "Comet Analog Digitizer" boards by Omnibyte corporation. The embedded software makes use of the VxWorks operating system by Wind River Systems.

Precise timing pulses are produced by the PPG to trigger the integrators and the digitizers just as the bunches are passing the detection equipment in the beam pipe. The embedded software is required to program the PPG so that the pulses occur at the correct times. The embedded software also has real-time requirements because the intensity readings must be retrieved from the hardware quickly to make the data available to ACNET for console displays and for continuous plots.

Software has been created to produce a local terminal display which mimics the remote console access. This local display is useful for system access in the field and for debugging purposes.

INTRODUCTION

The Fast Bunch Integrator (FBI) is a system which monitors the bunch intensity of the protons and antiprotons in the Main Ring (or the future Main Injector) and supplies this data to ACNET. The data will be particularly useful during the coalescing procedure. The data is supplied in a suitable form for continuous Fast Time Plotting (FTP) and Snap Shot Plotting (SNP). The data is also supplied in a suitable form for all normal slow ACNET accesses such as Parameter Pages, and Data Loggers.

THEORY

In order to increase the luminosity of colliding beam physics in the Tevatron, a process of coalescing must take place in the Main Ring before injection. This process packs the Main Ring batches into high intensity bunches. The end result of the coalescing process is 12 high-intensity proton bunches and 4 high-intensity antiproton bunches. In order to get 36 on 36 in the Tevatron, 3 injections of 12 proton bunches and 9 injections of 4 antiproton bunches will be required.

The goal of FBI is to get an intensity reading for each coalesced bunch in the Main Ring. We are not trying to create a "scope picture" of the bunches, we are simply trying to get an intensity value for each bunch. To achieve this goal, the intensity signal is used as an input to an integrator circuit. The output of the integrator depends upon the magnitude of its input and upon the amount of time it is allowed to integrate. The integrator takes two readings on each bunch; a wide gate reading and a narrow gate reading. The wide gate reading is used to determine the intensity of the batches before coalescing. The narrow gate reading is used to determine the intensity of the bunch after coalescing. The narrow gate reading should go higher and higher as the coalescing process takes place. The wide gate reading should not change much during the coalescing process but may decrease slightly due to losses incurred by the coalescing process.

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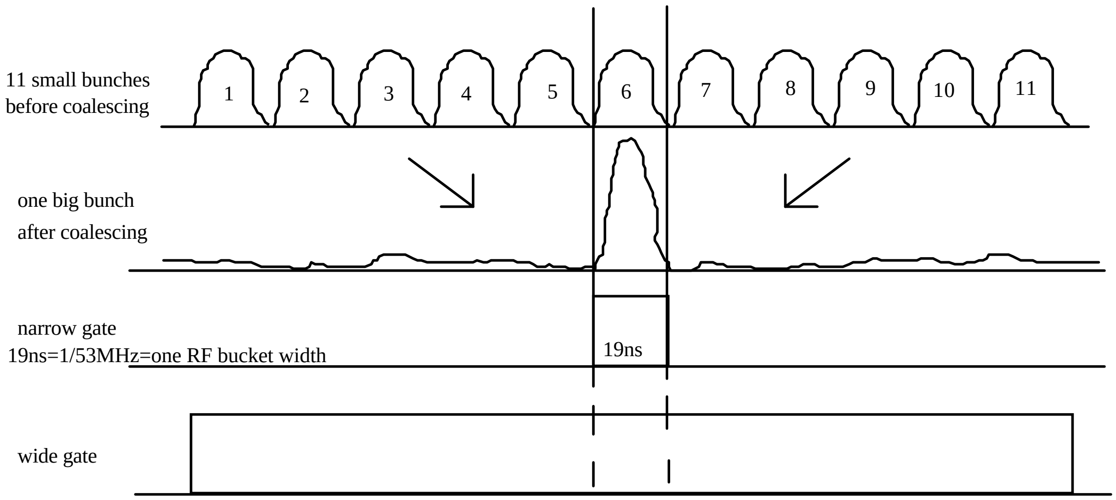
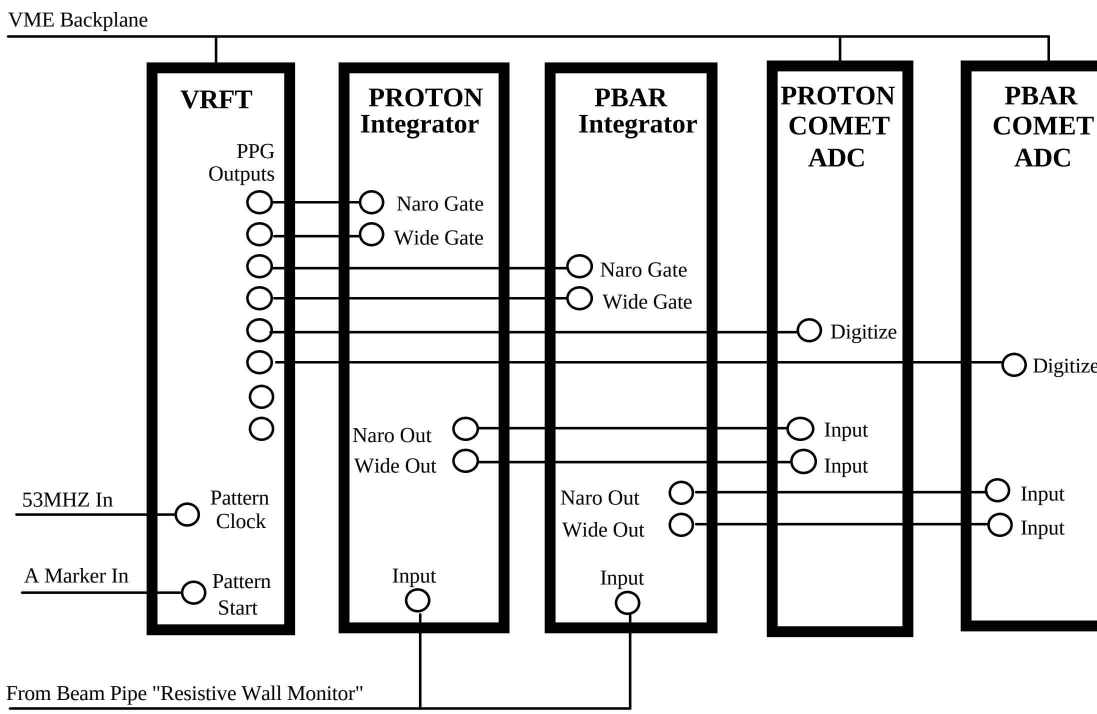


HARDWARE

The FBI project consists of a VME crate connected to ACNET via Ethernet. The boards in the crate are a Motorola 162 CPU, a Fermilab-designed VUCD Tevatron clock decoder board, a Fermilab-designed VRFT pulse pattern generator board, 2 Fermilab-designed integrator boards, and 2 Comet digitizer boards from Omnibyte Corporation.



THE VRFT PULSE PATTERN GENERATOR

The VRFT pulse pattern generator (PPG) is used for all of the critical timing. It has 8 outputs which are driven by the pattern generator. The pattern can be programmed so that pulses of various widths occurring at various delays from the "Pattern Start" can occur on any output. The pattern memory is 64K bytes long so a maximum pattern length of 64K buckets can be used. Each bit in a pattern byte corresponds to one of the 8 outputs. The pattern proceeds from one byte to the next as the 53MHz clock ticks occur.

The PPG outputs are used for the integrator gate pulses as well as the trigger pulses for the digitizer boards. The PPG is triggered to start a pattern on the Main Ring A Marker. This signal occurs once per turn. The PPG clock runs at 53MHz so the minimum output pulse width is 1/53MHz=19ns=1RF Bucket. This makes it very convenient for the experts to set the pulse delays in terms of "Buckets off the A Marker."

THE INTEGRATOR BOARDS

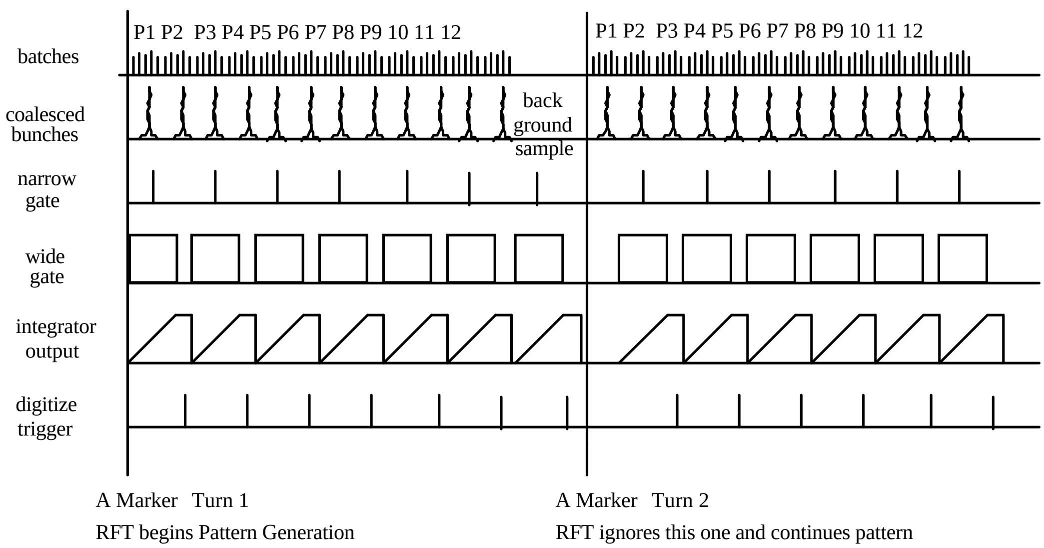
The Integrator boards were designed at Fermilab. These boards take their input from the "Resistive Wall Monitor" in the Main Ring beam pipe. The purpose of these boards is to integrate the input signal upon command from the gate pulses that are provided by the PPG. The narrow gate is programmed to occur just as the coalesced bunch comes by. The wide gate is centered upon the narrow gate and is used to integrate several pre-coalesced bunches. The output of the integrator boards provides intensity signals to the Comet digitizer boards.

In order to get accurate intensity readings, it is necessary to periodically take a reading when no bunches are passing by in the beam pipe. This is called a "background sample". The background sample must be subtracted from all of the bunch intensity readings. It was originally thought that the background subtraction would be done in the Integrator boards, but the design has proven to be too difficult and now the background subtraction is done in software.

THE COMET DIGITIZERS

The Comet digitizer boards contain a large amount of memory. Each time a digitize trigger occurs it puts the new data in the next consecutive memory location. When the PPG pattern takes place, the data items stack up in the Comet memory until the pattern ends and then the microprocessor can retrieve the data.

The time between bunches after coalescing is 378ns. We sample every other bunch at 756ns. In order to get readings on all bunches, we take readings over 2 turns. The first turn yields the odd numbered bunches and the 2nd turn yields the even numbered bunches. The PPG gets its "start pattern" signal from the Main Ring A Marker. The A Marker occurs once per turn and is always present when the Main Ring is running.



The PPG is programmed so that its pattern runs for 2 turns. The PPG will ignore the 2nd A Marker because it is designed to ignore triggers until the pattern is complete. After 2 turns have elapsed, one reading for all 12 Proton bunches and 4 Pbar bunches will be sitting in the respective Comet boards memories. The readings will be in interleaved order such as P1 P3 P5 P7 P9 P11 P2 P4 P6 P8 P10 P12 in the Proton Comet and A1 A3 A2 A4 in the Pbar Comet.

SOFTWARE

The embedded software makes use of the VxWorks operating system by Wind River. This is a multitasking operating system that has very good network capabilities. The software makes its data available to ACNET using an Ethernet connection. The embedded software has 3 main jobs to do. It must load the PPG to create the correct pulse pattern for system operation, it must retrieve the intensities from the Comets in a timely fashion and it must make the data available to ACNET for plots and parameter pages.

LOADING THE PULSE PATTERN

From ACNET the experts have SETTING capability for the various pulse delays and pulse widths. Here is an example of the settings.

P1 gate delay 0 buckets	A1 gate delay 30 buckets
P2 gate delay 20 buckets	A2 gate delay 50 buckets
P3 gate delay 40 buckets	A3 gate delay 70 buckets
P4 gate delay 60 buckets	A4 gate delay 90 buckets
P5 gate delay 80 buckets	Pbar background 300 buckets
P6 gate delay 100 buckets	
P7 gate delay 120 buckets	Proton Naro Gate Width 1 buckets
P8 gate delay 140 buckets	Proton Wide Gate Width 11 buckets
P9 gate delay 160 buckets	Pbar Naro Gate Width 1 buckets
P10 gate delay 180 bucket	Pbar Wide Gate Width 11 buckets
P11 gate delay 200 buckets	Background Sample Width 5 buckets
P12 gate delay 220 buckets	Digitize Pulse Delay Off Wide Gate 0 buckets
Proton background 300 buckets	Digitize Pulse Width 1 buckets

These settings are kept in battery backed RAM on the CPU board, so that reasonable settings will always be available after a reboot. Any time a setting is changed from ACNET, the embedded software saves the new setting in BBRAM and then loads the new pulse pattern into the PPG. That way the pattern is all set to go when ACNET asks for intensity data. The pattern settings are not expected to be changed very often.

RETRIEVING THE INTENSITY DATA

When ACNET asks for intensity data a routine is called which performs the following:
1. Enable the PPG external trigger so that the next A marker triggers the pattern.
2. Wait for the pattern to end by watching the Comet data counter.
3. Disable the PPG.
4. Retrieve the data.
5. Sort out the data.
6. Subtract off the background.
7. Return one pattern's worth of intensity readings to the caller.

This routine takes about 250 uS to execute which is fast enough even if it is called at 720Hz for Fast Time Plots. It returns intensity readings for all 12 proton bunches and all 4 antiproton bunches even if ACNET is only asking for one reading. It would be inefficient to attempt to change the PPG pattern to get just the particular bunch that ACNET is asking for. The software just takes the intensity reading that it needs and returns that single reading.

When this project was first conceived, we thought that we would let the PPG board continually play its pattern and let the data stack up in the Comet boards memory to be periodically retrieved by the microprocessor. In that way, data for every turn would be taken and would be available for ACNET. It turns out that it takes 1 uS per word to retrieve data from the Comet which is typical for off board VME access, so retrieving large blocks of data requires a lot of dead time when the PPG must be disabled and several turn's worth of data must be allowed to pass by. Experience has shown that it is better to wait until ACNET asks for data and then enable the PPG for one pattern each time data is asked for. For Snap Shot Plots, the PPG will be enabled for several patterns so that several consecutive turns' worth of data is taken.

USER INTERFACE

The FBI system can be accessed via a normal Fermilab ACNET console parameter page. Bunch intensities are displayed in text form and updated at a 1Hz rate. Bunch intensities can also be display graphically using the standard Fast Time Plot and Snap Shot Plot facilities. The Fast Time Plot updates at a 720Hz rate and the Snap Shot Plot gathers its plot data every other turn. The gate delays and gate widths can be set by a user at the parameter page.

A local terminal display has also been created for the FBI project. The local terminal is simply a standard VT220 terminal attached to the CPU board in the VME crate. Software has been created to display all of the pertinent readings and settings. The local terminal display has proven to be quite useful during the setup and debugging phase.

CONCLUSION

The FBI project is a blend of commercial hardware with custom hardware and a commercial operating system with custom software. The information from the FBI system is made available to the Fermilab ACNET system so that it can be displayed and analyzed using a typical ACNET Console. The end result is a successfully functioning system which meets the real-time needs for information about the bunch intensities in the Fermilab Main Ring.