LANSCE 1L HARP DATA ACQUISITION SYSTEM UPGRADE*

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Abstract

The 1L Harp is the last beam diagnostic preceding LANSCE's 1L Target, the neutron source of LANSCE's Lujan Center, and consists of two orthogonal planes of stationary sense wires for monitoring the beam distribution prior to its arrival at the target. A new data acquisition system has been developed for the 1L Harp that features a National Instruments compactRIO contained within a BiRIO chassis hosting electronic circuits for signal conditioning and a new feature for sense wire integrity monitoring. Hardware design, software architecture, and preliminary data acquisition results will be described.

INTRODUCTION

The 1L harp is a fixed-position, beam diagnostic sensor for measurement of the beam's transverse profiles immediately prior to impingement on the 1L target. The sensor is composed of three planes of silicon-carbide (SiC) fibers; two sense planes for measuring horizontal and vertical beam profiles, and a bias plane for attraction of secondary electrons. Each sense plane is composed of seventeen, 0.079-mm diameter sense fibers spaced at 6-mm intervals. All fibers connect to individual 10 pF capacitors at one end and a cable plant at the other end for signal transmission to the data acquisition system [1] as shown in Fig. 1.

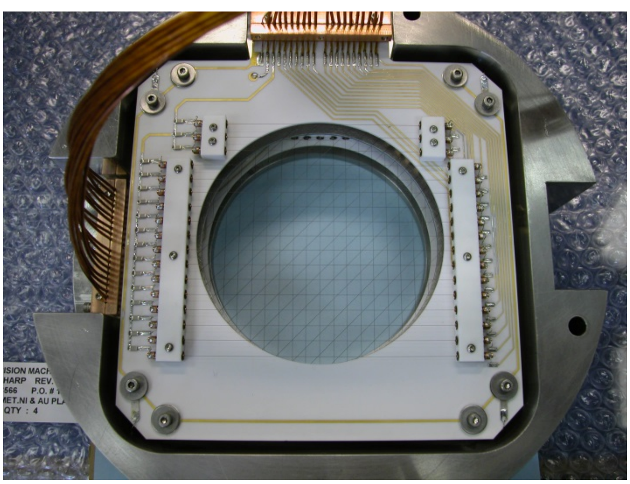

Figure 1: 1L Harp Sensor [1].

PRINCIPLE OF OPERATION

The 1L harp operates on the principle of secondary electron emission resulting from the interaction of the particle beam with the harp's sense wires. As the high-energy (800 MeV) H+ particle beam passes through the fiber's SiC material, electrons are forcefully removed from the fiber's surface into free space, leaving a positive charge gain within the fiber. The positive voltage resulting from the fiber's loss of electrons attracts a flow of electron current from the signal conditioning circuit to the sense wire, neutralizing the charge difference. This current and its associated net charge are transformed by the signal conditioning circuitry into a voltage signal proportionally related to the charge. Since the particle beam's transverse particle density is generally Gaussian, each fiber in the plane receives a different concentration of beam flux. This beam flux translates into secondary electron emission differences resulting in charge differences at the signal conditioning circuitry and finally a voltage difference at the ADC dedicated to each sense wire. Plotting the resulting voltages as a function of the fiber's relative position creates a Gaussian profile corresponding to the beam's transverse particle density.

Beam parameters at the 1L Harp are listed in Table 1. From the properties of the beam and the SiC fiber; application of the Bethe-Bloch formula described by Loveland in [2], with a ionization potential of 180 eV for SiC [3], and applying the Sternglass theory across the surface of a SiC fiber at beam center yields an expected negative charge loss of 484 picocoulombs.

Table 1: 1L Harp Beam Properties

Beam Property	Value
Beam species	H+
Beam energy	800 MeV
Longitudinal current profile	Triangular
Pulse duration	300 ns
Peak current	33.3 A
Transverse RMS	12.5 mm
Bunch charge	5 µCoulombs

SYSTEM HARDWARE

Data Acquisition System/ EPICS IOC

The data acquisition hardware consists of a National Instruments compactRIO with interfaces to three AFE (Analog Front End) boards and one integrity board housed within a BiRIO chassis as shown in Fig. 2. Logic signals for beam synchronization and AFE control connect to the compactRIO through a single NI-9401

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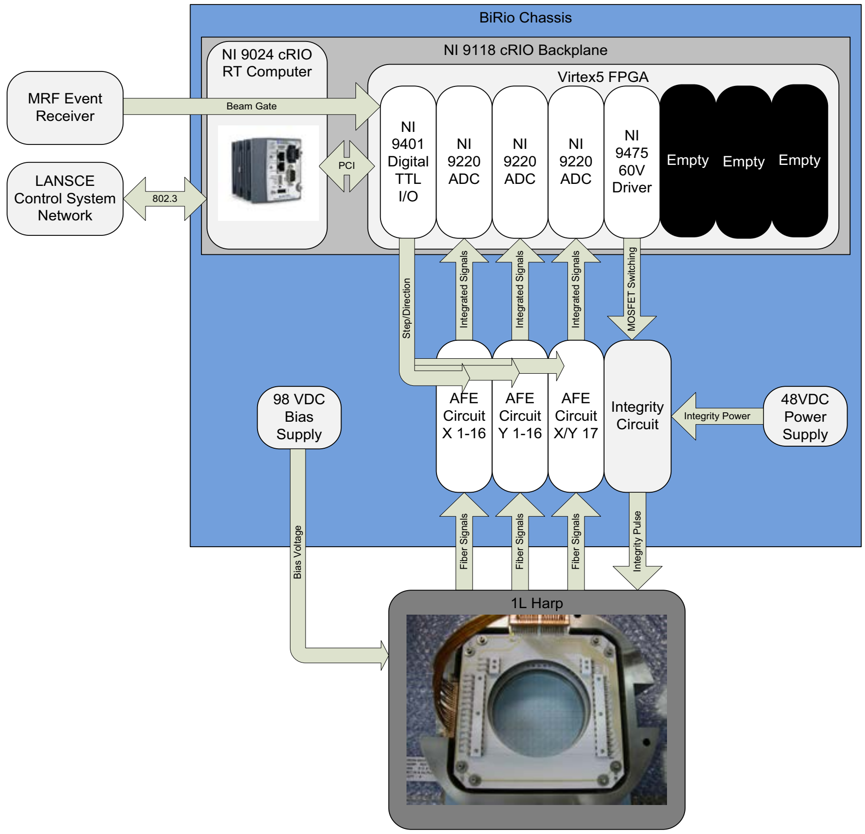

Figure 2: 1L Harp Data Acquisition System Hardware Diagram.

TTL logic module. Signals generated by the AFEs are digitized by three NI-9220 analog-to-digital conversion (ADC) modules. Finally, one NI-9475, 60V-source module is incorporated for integrity pulse generation. Additional circuitry includes a 98-volt power supply for the harp bias plane.

Beam Signal Conditioning Subsystem/Analog Front End (AFE)

1L Harp signals are integrated by AFE circuits depicted in Fig. 3. At the core of each circuit is a subcircuit of a Texas Instruments, ACF2101 dual switched integrator [4]. The ACF2101 provides on-die capacitors and multiplexing circuitry for integration, select, reset, and hold operations. Set at 100pF, the on-die capacitor is capable of measuring up to 1 nanocoulomb of positive charge before the integrator saturates. Low-pass filters with 40-kHz corners are applied before the ACF2101's as an anti-aliasing precaution. For this application, a beam pulse measured on the center fiber is expected to result in a negative 4.84-volt signal output from the integrator. Beam integration time is variable and can be set by the control logic signals applied to the ACF2101s. Additionally, the state of integration is reset after the measurement has been made to prevent interference to subsequent pulse measurements. The final value of each signal's integration is applied to the beam profile for observation. Figure 4 shows one of the system's three AFE circuits. This board contains eight ACF2101 integrators for processing sixteen, 1L Harp channels. Connections to the AFE board include the Harp sensor interface shown on the left of the board, a power connector shown on the top-center, a control connection to the right of the power connector, and the output connector to the ADC on the right.

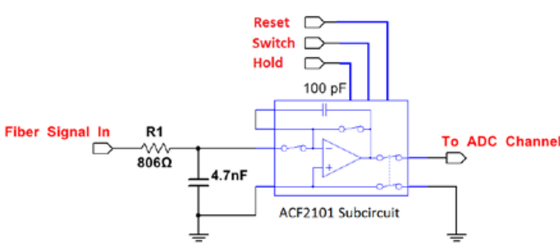

Figure 3: Circuit for one AFE channel.

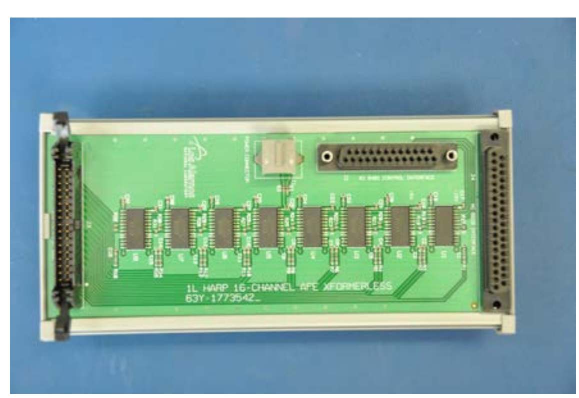

Figure 4: 16-Channel AFE.

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Integrity Subsystem

As beam-induced sense wire damage is a prevalent problem with harp diagnostics, a wire integrity subsystem has been incorporated for monitoring the continuity of the sense wires. The 1L Harp hardware accomplishes this by generating a 48-volt, square pulse to the 10 pF capacitor-end of the fibers. The 10 pF capacitors are applied in series to each wire at the harp and function to AC-couple the 48 volt pulse to the fiber. As the pulse translates through the capacitor-fiber circuit, it is attenuated to a signal on the order of 20 mV with an expected charge displacement of 480 picocoulombs. Measurement of this signal occurs in the same manner as the beam signal; via charge integration by the AFEs. Through this method, an acceptable integrity signal can be read as -4.8 volts by the ADCs. Adjusting the integrity pulse width and ACF2101 integration time allows for adjustment of the integrity signal received.

SYSTEM SOFTWARE

FPGA Software Architecture

1L Harp sense wire data acquisition starts with the compactRIO's FPGA and its associated I/O modules. The FPGA program consists of two parallel operations shown in Fig. 5. Process 1 simultaneously monitors the beam

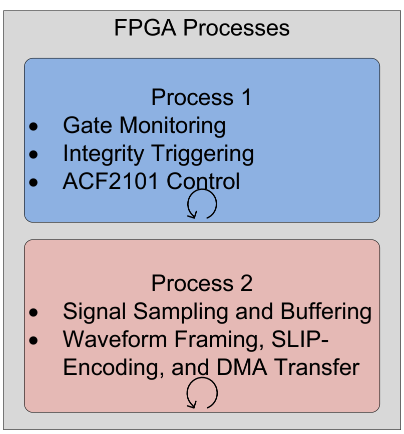

Figure 5: The compactRIO FPGA program architecture.

synchronization signal and applies the drive signals for all ACF2101 integrators via the NI-9401 module. Since the beam gate has a narrow, 300ns pulse width, the NI-9401 must sample at its fastest operating rate of 10 MHz to achieve 2-3 samples per pulse. When the gate has been detected by this process, a flag is set, notifying process 2. The primary purpose of the process 2 is to continuously sample the wire signals at the maximum ADC sampling rate of the NI 9220 modules. Once notified of a gate, this process will save the set number (typically 2) of pre-gate-edge samples and acquire a set amount (typically 8) of post-gate-edge samples across all 34 channels. Each set of samples spanning all 34 channels is framed, SLIP-encoded [5], and streamed over the DMA channel to the compactRIO RT computer. Once all prescribed samples have been streamed; a final, SLIP-encoded trailer frame is transferred over the DMA buffer. In addition to demarcating the end of a waveform set, the trailer frame distinguishes whether the data is a set of beam waveforms or a set of integrity waveforms.

Waveforms obtained by the compactRIO RT system generally have a monotonically-decreasing nature resulting from the charge integration process of the ACF2101. As a result of this, the final value of each integrated waveform represents the total accumulated charge for that channel and provides the best relative comparison between channels since the output signal-to-noise ratio improves with the time over which the integration occurs. It is for this reason that the final value of each channel's integrated waveform is represented in the transverse profile.

Integrity Process

The integrity process operates in a similar manner as that of the beam data acquisition process. Subtle differences include the manner in which the integrity process is triggered and how the integrity data is differentiated from beam data as it is transferred through the DMA channel. Since beam signals are characterized by a 20Hz pulse rate with 150 µs-long width, an opportunity for triggering an integrity acquisition presents itself within the remaining 49 ms of dead signal time. FPGA process 1 derives a virtual gate signal for process 2 by calculating the period of the last beam gate cycle and then adding half of that period to the time the next beam gate is expected to occur. This permits the integrity process to non-invasively interleave the integrity process between beam cycles.

RT Software Architecture

The software developed for the compactRIO's RT system consists of the two threads depicted in Fig. 6. The compactRIO RT computer utilizes a real-time (RT) process for deterministically extracting AFE/ADC

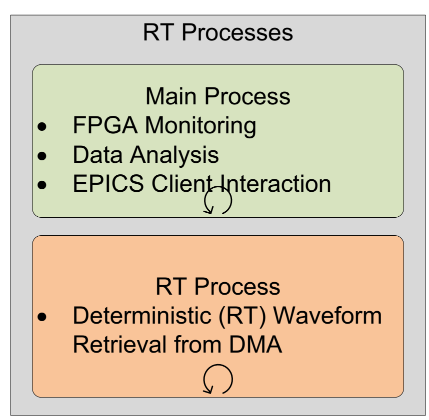

Figure 6: The compactRIO RT program architecture.

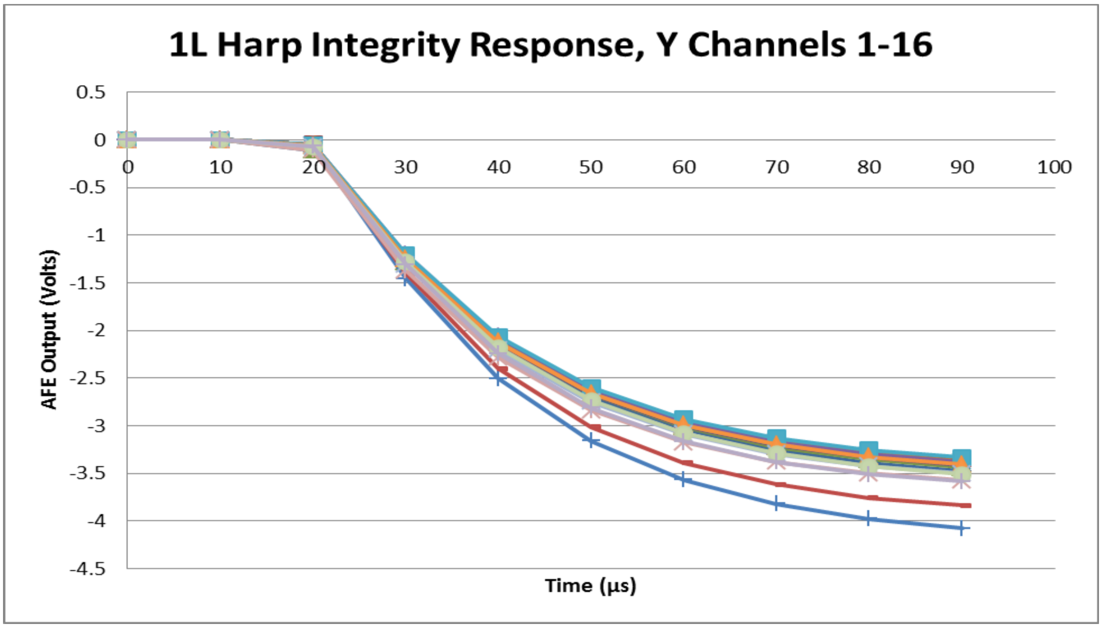

Figure 7: System Integrity Response.

waveforms from the DMA (Direct Memory Access) channel to ensure the DMA channel does not overflow. The data stream extracted from the DMA channel is reframed, SLIP-decoded, and transferred to an appropriate analysis routine within the "Main Process." The main process loads the analyzed data (transverse profiles for beam data and pass/fail results for integrity data) into EPICS process variables for observation by LANSCE operations staff.

PERFORMANCE

Initial testing of this system has yielded the data presented in Fig. 7. This data was captured by the system's compactRIO and represents sixteen channels of one AFE's response to an integrity pulse through the 1L Harp sensor. The results follow the expected negative integration pattern approaching -4.8 volts. In the final analysis, this data will be translated from volts to coulombs through the ACF2101's 100-pF integrating capacitance relationship.

Beam data has not yet been obtained since the LANSCE accelerator has been offline during the development of this system. However, beam data is expected to follow the similar response shape as the integrity signal with the final amplitude approaching -4.8 volts at the beam's transverse peak. When compared to the maximum measureable limit of -10-volts/1000-picocoulombs, the nearly -5 volts of peak expected output provides this system with a favorable 5-volt/500-picocoulomb operating margin.

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