LANSCE-R WIRE-SCANNER ANALOG FRONTEND ELECTRONICS (AFE)*

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Abstract

A new AFE is being developed for the new LANSCE-R wire-scanner systems. The new AFE is implemented in a National Instruments cRIO module installed a BiRa 4U BiRIO cRIO chassis specifically designed to accommodate the cRIO crate and all the wire-scanner interface, control and motor-drive electronics. A single AFE module provides interface to both X and Y wire sensors using true DC coupled transimpedance amplifiers providing collection of the wire charge signals, real-time wire integrity verification using the normal data-acquisition system, and wire bias of 0V to +/-50V. The AFE system is designed to accommodate comparatively long macropulses (>1ms) with high PRF (>120Hz) without the need to provide timing signals. The basic AFE bandwidth is flat from true DC to 50kHz with a true first-order pole at 50kHz. Numeric integration in the cRIO system provides real-time pulse-to-pulse numeric integration of the AFE signal to compute the total charge collected in each macropulse. This method of charge collection eliminates the need to provide synchronization signals to the wire-scanner AFE while providing the capability to accurately record the charge from long macropulses at high PRF.

INTRODUCTION

One of the systems being replaced in the LANSCE upgrade are the wire-scanner systems. Both the mechanical actuators and the data-acquisition and control electronics are being replaced.

The National Instruments (NI) CompactRIO (cRIO) system [1] has been selected for the wire-scanner systems as well as a number of other LANSCE systems. The basic cRIO crate is shown in Figure 1.

Figure 1: NI cRIO Crate.

The majority of the wire-scanner system is comprised of commercial off-the-shelf (COTS) cRIO modules. The wire-scanner analog frontend electronics (AFE) cRIO module however is a custom LANL design developed to meet the specific needs of the LANSCE wire scanners.

WIRE-SCANNER CHASSIS ASSEMBLY

The LANSCE electronics is to be packaged in a standard 4U 19-inch rack chassis. The BiRa BiRIO cRIO chassis system [2] has been selected for LANSCE-R to house the wire-scanner electronics. This chassis system is shown in Figure 2.

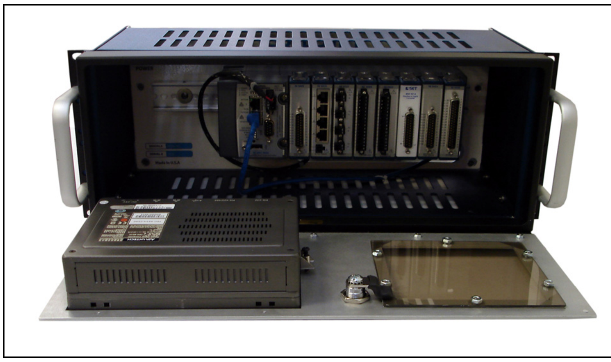

Figure 2: Wire Scanner System BiRIO Chassis.

The BiRIO chassis allows for convenient mounting of the cRIO crate in the foreword volume, and provides substantial wiring area in the rear volume providing both convenience and well-managed lead dress.

This same chassis system is also being used in several other LANSCE-R applications.

AFE DESIGN GOALS

The operational parameters of the LANSCE accelerator are bounded with comparatively narrow operational limits since LANSCE is a production accelerator rather than a purely experimental system. This simplifies the AFE requirements somewhat.

AFE Dynamic Range

The dynamic range of the wire signals for the LANSCE-R application is comparatively small. The total collected charge is a function of the location of the wire scanner in the accelerator. The maximum charge collected by the sense wire varies over nominally a factor of 100 along the accelerator for a given beam configuration. The dynamic range needed in any specific profile measurement is nominally 100:1. Therefore a

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total dynamic range of nominally 10,000:1 is required. This dynamic range may be provided in the AFE without the need for gain switching.

An NI cRIO-9222 digitizer module is used to digitize the analog output from the two AFE wire-signal channels. The 9222 provides full 16-bit precision plus an additional sign bit. Since the basic resolution of this digitizer is 65,000:1, no scale switching is required to meet the needed dynamic range. A third channel of the 9222 is used to digitize the wire bias potential as a verification of the wire-bias potential.

AFE Bandwidth

The sense wire remains at each scan position for only a single macropulse, and is moved to the next position between macropulses to minimize the time required to collect a profile. This operational profile requires the AFE to have sufficient bandwidth and recovery speed to collect the wire signal on a pulse-by-pulse basis.

The charge collected during each macropulse is to be integrated to provide the total collected charge in each macropulse at each wire position through the scan. Also, a design goal is to utilize an RC integrator that recovers to baseline between macropulses. This topology eliminates the need to provide integrator reset commands to the AFE.

Typically the integration function would be an analog function integral in the AFE. Classically this is provided by setting a low AFE bandwidth, e.g. a 1Hz to 5Hz response pole, with a well-defined first-order response to nominally 10kHz.

However, the maximum pulse-repetition frequency specified is 120Hz, 8.33ms period. And the longest macropulse that is to be accommodated is nominally 700µs. A simple RC integrator cannot provide accurate integration of a 700µs pulse and recover sufficiently in 8.33ms.

The collection of wire charge in the LANSCE-R AFE is implemented in a hybrid analog and digital data-acquisition structure. The AFE bandwidth is set at nominally 50kHz with a well-behaved first-order response to nominally 1MHz. The AFE is therefore an integrator, but with a 50kHz pole.

The AFE signal is digitized at 500k samples per second, and the full 50kHz data record recorded. This wide-bandwidth data is a temporal representation of the actual beam current during the macropulse captured with a 50kHz bandwidth. The 50kHz data record is then numerically integrated in the cRIO system with a response pole at nominally 5Hz and a zero at 50kHz. This provides an integral response from 5Hz to nominally the sample rate of the digitizer. This approach of wide-bandwidth analog data collection and numeric integration provides a very accurate integral of the charge in each macropulse without the need to provide integrator reset signals, and additionally provides temporal beam-current characteristics within each macropulse.

Wire Bias

The charge collection is optimized by applying a bias to the sense wires. The AFE provides the means to apply bias potentials up to ±50V to each sense wire.

Wire Integrity

A requirement of the AFE design is to provide in the data acquisition system the means to validate the integrity of each sense wire. Also, since a false indication of a failed wire that could be caused by failure of the integrity system itself could result in needless, and costly, machine down time, the wire integrity monitoring system must also provide a verification of its own integrity.

The AFE effects the wire integrity verification by applying a known potential to one end of the wire and recording the signal at the other end of the wire. A portion of the interrogation signal is also applied directly to the AFE input to provide an output signal even when the wire it totally open. A competent wire is witnessed by a specific signal level during the integrity test. A failed wire is witnessed by a reduced but well-defined output signal level. A failure of the wire-integrity system is witnessed by no signal during integrity verification.

Grounding

Careful attention must be given to the grounding and shielding topology due to the low signal levels that must be collected at a substantial distance from the sensors in an industrial environment having numerous equipments generating nuisance electromagnetic fields and coupling nuisance currents on the facility ground structure.

The grounding design developed for the LANSCE-R wire-scanner systems has been quite successful. The complete details of the grounding topology utilized are quite detailed due to the number of noise sources which must be considered. Reporting the complete details of the grounding and shielding design is well beyond the space allotted to this paper.

However, the most troublesome noise source encountered was the motor driver driving the actuator stepper motor. The full motor drive must remain active during the entire scan due to the scan speed required. Therefore the motor drive current cannot be disabled during the collection of the wire signal. A combination of shielding, guarding and grounding-configuration management successfully eliminated all motor-drive artefacts.

The basic simplified AFE circuit diagram is shown in Figure 3. The wire signal is collected from each end of the wire and applied to the input of two transimpedance amplifier stages through coaxial cables. Although this amplifier configuration appears to be a differential amplifier, it is simply two similar stages with summed outputs. These amplifier stages are referenced to the bias potential. The shields of the wire-signal cables are returned to the bias supply rather than ground to provide a true guard configuration for each signal.

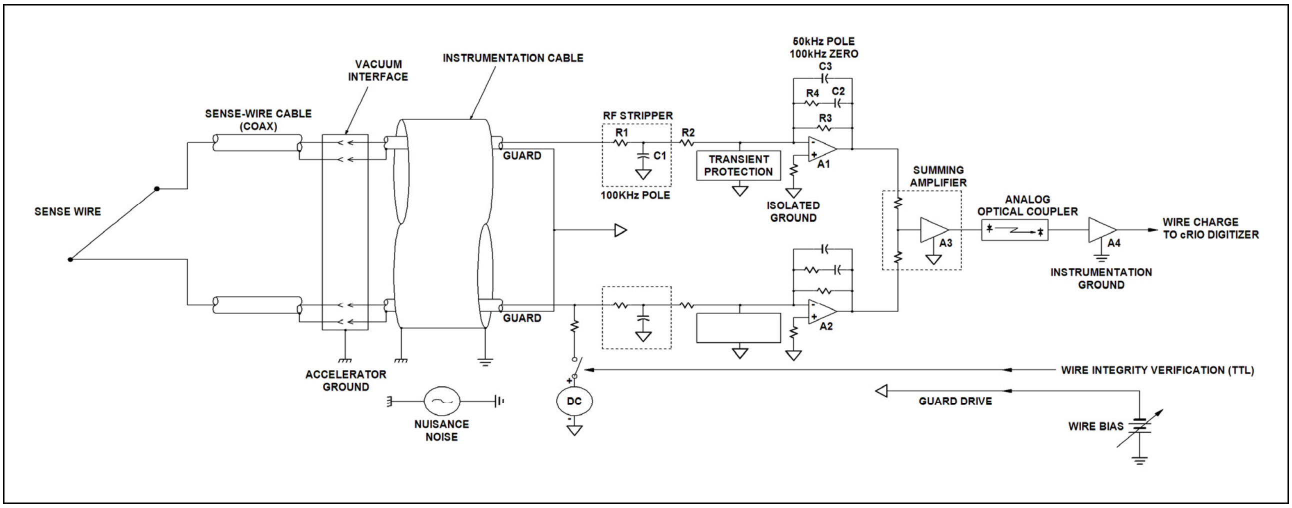

Figure 3: Wire Scanner AFE Analog Configuration.

An overall shield isolated from the individual signal coax cables is provided over the coaxial cables to provide an overall ground shield to the signal cable.

The overall shield is connected between the equipment grounds of the beam line and the wire-scanner electronics. It is reasonably expected that there will be a difference in potential between these two grounds with frequency components within the bandwidth of interest in the sense-wire data. If the shields of the wire-signal coax were simply connected between the two equipment grounds, any ground noise would be coupled into the signal path due to nuisance currents introduce into the shield and the less than ideal shielding effectiveness of the coax.

The overall shield carries all of the nuisance currents due to inter-ground potentials, and provides shielding from electromagnetic fields.

The input to a transimpedance amplifier is a low impedance, so the signal potential at the input terminal is effectively zero with respect to the amplifier signal reference over the operational bandwidth of the amplifier. The signal reference for this AFE design is the bias potential. Therefore, connecting the signal coax shields to the bias potential forces the shield potential to be identically the same as the potential at the transimpedance-amplifier input. Noise coupled to the signal coax shield is therefore communicated to the bias source and prevented from coupling into the wire-signal path.

Initial Experimental Results

The first-article wire-scanner AFE installed in the complete prototype cRIO wire-scanner electronics system was integrated with the first prototype of the new actuator system and installed on the LANSCE beam line in late December 2010. All elements of the new LANSCE-R wire-scanner system functioned as expected and excellent data were collected. A typical profile collected during this initial experimental period is shown in Figure 4. The data of Figure 4 were collected on a pulse by pulse basis with the number of data point equal to the total number of macropulses during the scan.

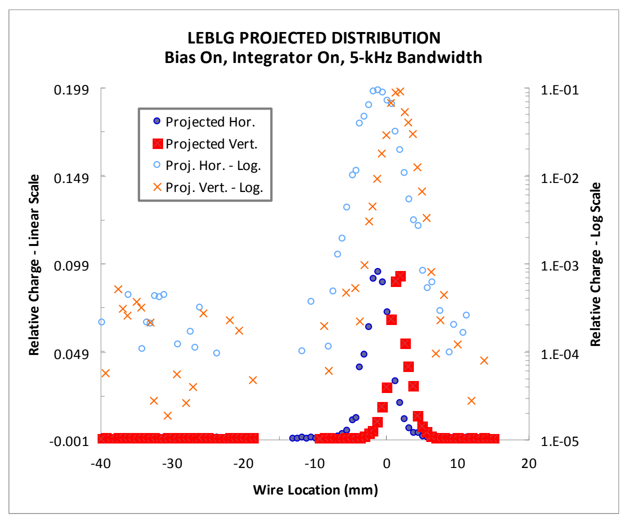

Figure 4: X and Y LBEG Beam Distributions.

These initial results confirm that the new LANSCE-R wire-scanner system and specifically the AFE meet all of the design goals. Specifically, the specified dynamic range is provided with the specified response characteristics.

CONCLUSIONS

The design of the new LANSCE-R wire-scanner AFE meets all the of design specifications. The specified sensitivity, dynamic range and bandwidth are achieved, and nuisance noise is successfully rejected.

REFERENCES

[1] National Instruments, Inc., Austin, TX 78759-3504, www.ni.com/compactrio.

[2] BiRa Systems, Inc., Albuquerque, New Mexico, USA, www.bira.com.