High Dynamic Range Diamond Detector Readout System for the CERN’s Beam Wire Scanners Upgrade

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Abstract: A secondary particle shower acquisition system is under design for the upgrade of CERN’s beam wire scanners. The system must be capable of performing bunch-by-bunch synchronous measurements with an integration time of 25 ns and to cope with signal variations of up to 6 orders of magnitude. The whole dynamic range must be covered by the acquisition system with a single configuration and should have no tuneable parameters. The secondary particles are sensed by a polycrystalline diamond detector with the signal digitization performed nearby with a custom front-end system, designed to resist a total ionising radiation dose up to 1 kGy in 10 years. The digital data transmission, front-end synchronisation and control are performed through a bi-directional optical link operating at 4.8 Gbps using CERN’s GBT protocol. For the digitization, two radiation tolerant integrator ASICs (ICECAL and QE10) are under study.

Motivation:
- Beam Wire Scanners Upgrade
- New detector used (pCVD)
- High dynamic range needed
- Low noise measurements
- One single system for LHC, SPS, PS & PSB
- Avoid the need of tuneable parameters

SYSTEM REQUIREMENTS
| Dynamic Range | 3 MeV – 1 GeV (CdC) |
| Integration Window | 25 ns (40 MHz) |
| Synchronization | LHC, SPS, PS & PSB, Bunch by Bunch |
| Link Distance | up to 250m |
| Irradiation Rating | 10 MeV/nA/year |

Proposed System Architecture Overview:
A front-end will be placed near the detector for digitalization to avoid transmission over long coaxial cables and maintain the pCVD signal dynamics and quality. Once digitalized, the data will be sent through an optical link at 4.8 Gbps following the GBT protocol. The optical link provides data transmission, front-end slow control and systems synchronisation. The Back-End solution envisaged is based on the new VFC board developed by the CERN’s BIL group.

The development of a custom radiation-hard and high dynamic range acquisition front-end is needed. To provide a reliable solution, the evaluation of diamond detectors as beam profile monitor and the test of different readout ASICs are required.

Analogue Front-End tests with an Alpha Source:
To evaluate diamond detectors as beam profile monitors, it is required a radiation tolerant transimpedance amplifier (TIA) with fast slew rate, matched to 50 ohm to properly transmit the signal through long coaxial cables. For this, THY3031 has been chosen as operational amplifier in transimpedance configuration, using Rf = 1 kΩ and 50 ohms input and output impedance. The same configuration used on the operational beam wire scanners photomultiplier tubes (PMT) pre-amplifiers.

This amplifier was evaluated with a diamond detector and a 10AM alpha source as shown on the pictures.

Logarithmic current sweep: Measurements Vs Normalized response

A prototype front-end was tested using a pure alpha source with a 10AM source, using a diamond detector and a pre-amplifier. It was used for comparison. The measurements were collected on the surface with a Lecroy scope at 2.6GSPS. Around 80M of CRO cables were used for signal transmission.

Full Acquisition System Prototype for QE10pS Evaluation:
A complete test set-up has been evaluated under laboratory conditions. The back-end system framework is based on an Igloo development kit.

The setup was used for the QE10 front-end evaluation. This charge integrator and digitization ASIC reach a dynamic range of 1 eC (1.25-140 eC) exceeds 8 bits by using a pseudo-logarithm digitalisation scheme. The charge encoding algorithm contains 16 sensitivity levels divided on 4 ranges.

The front-end was characterized in terms of linearity, difference with respect to the nominal response and sensitivities in each subrange. Linear sweeps with a Keithley current source were done. Each point on the following chart corresponds to the average value detected during 25ns with constant current.

Autonomous Front-Ends for QE10 & ICECAL evaluation:
The readout system needs to be evaluated with two different integrator ASICs, for this, a modular design is used. Each readout ASIC candidate is hosted in a custom Radiation-Tolerant mezzanine with a SAMTEC connector that fits on a motherboard, the Igloo UHBD board (designed by Foxlink) that drives the optical link.

IceCal V3 Mezzanine

Comprises an ICECAL integrator ASIC, with 4 input channels and 13 dynamic range stages. The ASIC output provides an analog voltage every 25ns, that is digitized by an ADC. The mezzanine is powered with radiation hard FESTM1 modules.