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Design and qualification of the Mu2e electromagnetic calorimeter electronic system

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Abstract

The Mu2e experiment [1] at Fermilab will search for the neutrino-less coherent conversion of a muon into an electron in the field of a nucleus. Mu2e detectors comprise a strawtracker, an electromagnetic calorimeter and a veto for cosmic rays. The calorimeter employs 1348 Cesium Iodide crystals readout by silicon photomultipliers and fast front-end and digitization electronics. The front-end electronics consists of two discrete chips for each crystal. These provide the amplification and shaping stage,linear regulation of the SiPM bias voltage and monitoring. The SiPM and front-end control electronics is implemented in a battery of mezzanine boards each equipped with an ARM processor that controls a group of 20 Amp-HV chips, distributes the low voltage and the high-voltage reference values, sets and reads back the locally regulated voltages. The electronic is hosted in crates located on the external surface of calorimeter disks. The crates also host the waveform digitizer board (DIRAC) that performs digitization of the front end signals and transmit the digitized data to the Mu2e DAQ. Calorimeter electronic is hosted inside the cryostat and it must substain very high radiation and magnetic field so it was necessary to fully qualify it. The constraints on the calorimeter front-end and readout electronics, the design technological choices and the qualification tests will be reviewed.

1. Introduction

The Mu2e calorimeter [2] plays an important role in providing particle identification, which consists of e/mu separation rejecting background, improve the track pattern recognition and a standalone trigger. The calorimeter is a high granularity crystal calorimeter consisting of 1348 un-doped CsI crystals, arranged in two disks. Each crystal is coupled to two large-area UV-extended SiPMs arrays. Each array consists of two series of three SiPMs. The two series are connected in parallel by the Front End electronics to have a double redundancy. Amplified signal is sent to a digitizer board. Digital data are then sparsified, packed, timestamped and sent to the main Mu2e DAQ system. The calorimeter is located in a very harsh environment with a 10^{-4} Torr vacuum, a uniform magnetic field of 1 T and exposed to a very intense particle flux (TID 30 krad/5 year for front-end and 12 krad/5 year for digitizer, NIEL of $\sim 10^{11}$ 1 MeV n_{eq}/cm^2), consequently both the detector and the readout electronic must be qualified to survive for the full duration of the experiment.

2. Readout electronics

Calorimeter electronics [3] is schematized in Fig. 2

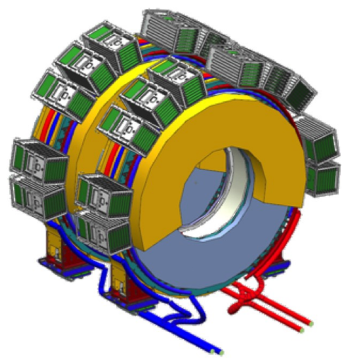

Figure 1: Mu2e electromagnetic calorimeter.

2.1. Front end electronics

The front-end electronics (FEE) consists of two discrete and independent chips (Amp-HV), for each crystal, directly connected to the back of the SiPM pins. These provide the amplification and shaping stage, a local linear regulation of the bias voltage and monitoring of current and temperature on the sensors. Groups of 20 Amp-HV chips are controlled by a dedicated mezzanine board (MB) equipped with an ARM (Advanced RISC Machine) to distribute the LV and the HV reference values and set and read back the locally regulated voltages. Groups of 20 signals are sent differentially to a digitizer

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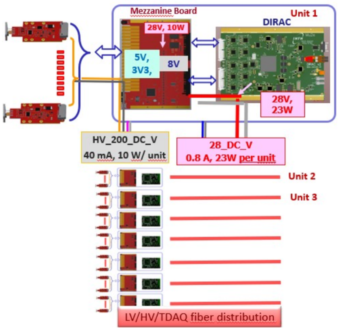

Figure 2: Mu2e ECAL electronic module.

2.2. *Digitizer board*

The digitizer module(DIRAC, DIgitizer and RedAdoutController) [4] provides a further level of amplification and digitizes up to 20 SiPM signals at the sampling frequency of 200 MHz with 12-bits ADC resolution; digitized data are zero suppressed, merged, packed by an onboard FPGA and sent optically to the event builder using a custom protocol. The core of the board is a large FPGA (MicroSemi Polafire MPF300T), that handles the ADCs (Texas Instruments ADS4229) protocol and timing, sparsifies and compresses the digitized data and forms a packet that is sent to the DAQ servers through an optical transceiver (CERN VTRX). A ultra-low noise clock jitter cleaner (Texas Instruments LMK04828) provides a high performance clocking tree in the board. The power on the board is handled by 3 DC-DC converters (Texas instruments LMZM33606) and combined with 6 LDO (Micrel MIC69502). The DIRAC board is 233 mm x 165 mm, has 16 layers realized in FR408-HR with a thickness of 2.127 mm, 100 differential lines and 50 single ended lines. The full calorimeter is readout through 140 DIRAC boards.

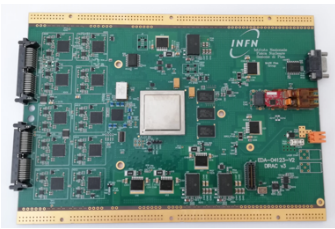

Figure 3: DIRAC board.

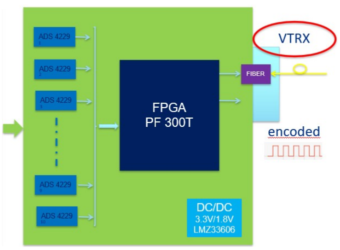

Figure 4: DIRAC block diagram.

3. Qualification tests

The harsh operating environment requires testing and qualifying all the components, both individually and at the board level. Prototypes of both front-end and digitizer were qualified against:

- TID (Total Ionizing dose)
- SEU (Single event upset)
- NIEL (Non-Ionizing Energy-Loss)
- B field (effects on DCDC converters)

Montecarlo simulations (Geant and Fluka) [5] were used to estimate the expected radiation levels on the individual components by integrating the expected fluxes for the entire Mu2e data taking period and applying appropriate safety factors. Front-end was qualified for TID up to 30 Krad while DIRAC board up to 12 Krad. NIEL against a total fluence of $\sim 10^{11}$ 1 MeV n_{eq}/cm^2. Magnetic field level was fixed to 1 Tesla. Several test campaigns have been performed, mainly at gELBE facility at HZDR laboratory in Dresden and ENEA facilities both in Frascati and Bracciano. Magnetic field tests were performed at INFN LASA laboratory in Milano. Several components didn't pass the qualification tests, mainly the monitoring ADC in the front-end electronic and the DCDC converters and the optical transceivers in the digitizer , and were replaced in the following board prototypes. Front-end prototype V4 and DIRAC V3 passed all qualification tests and are ready for production.

Acknoledgements

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References

[1] R. Bernstein, et al., Mu2e technical design report.
[2] R. Bernstein, et al., Mu2e calorimeter final technical design report.
[3] N. Atanov, et al., Mu2e calorimeter readout system, Nucl.Instrum.Meth.A 936 (2019) 333–334.
[4] E. Pedreschi, et al., The digitizer readout controller (dirac) of the mu2e electromagnetic calorimeter at fermilab, PoS (2020) 119.
[5] S. Di Falco, et al., Components qualification for a possible use in the mu2e calorimeter waveform digitizer, Journal of Instrumentation 12.