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WaveDAQ: an highly integrated trigger and data acquisition system

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Abstract

The WaveDAQ is a full custom, compact and highly integrated trigger and data acquisition system. Despite the decisive urge from the MEG II experiment at PSI aiming at a sensitivity of 6×10^{-14} on the $\mu \to e\gamma$ decay, it is a general purpose device suited for small and medium-sized applications in the range from 16 to about 10000 channels. It exploits the performance of the DRS4 waveform digitiser with a sampling speed programmable from 1 to 5 GSPS; each input channel can supply HV to arrays of SiPMs and provides a front-end amplification with gains chain in the range from 0.5 up to 100 and GHz bandwidth. Input signals are, in parallel to the DRS4, digitised at 80 MSPS and used in an FPGA-based trigger; fast discriminators associated to each input channel are also used for online reconstruction. This paper presents the WaveDAQ design principles and the results obtained by a demonstrator in the MEG II pre-engineering run in fall 2017 with a homogeneous LXe detector and a plastic scintillation detector both readout by SiPMs and in the tests associated to the ΔE-TOF prototype of the FOOT detector.

Key words: Front End, Trigger, DAQ and Data Management, Digital circuits, integrated electronics;
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1. WaveDAQ system

The WaveDAQ (WDAQ) is a compact and highly integrated trigger and data acquisition system scalable from 16 to about 10000 channels. It consists of 4 specific boards hosted in a custom backplane. One crate, whose sketch is shown in Fig. 1, has 16 digitising boards, called WaveDREAM Boards (WDB) used to receive 16 inputs to be digitised by the Domino Ring Sampler chip (DRS4) with sampling speed in the range of 1-5 Giga Sample Per Second(GSPS) [1] and in parallel at 80 MSPS for trigger processing. Each WDB has a dedicated serial connection to the two higher level boards, 5.12 Gbit/s to the Trigger Concentrator Board (TCB) and up to 1.28 Gbit/s to the Data Concentrator Board (DCB). A DCB has a 1 Gbit/s ethernet link to the offline storage. The trigger, synchronisation and busy signals are distributed on the backplane together with a low jitter (≤10 ps) and low skew clock distributed by the so-called trigger bus. If more than 256 channels are needed, several WaveDAQ crates can be combined and connected to a dedicated trigger crate, which collects the data from lower level crates and perform a global trigger. To distribute the trigger bus signals to all the WDBs in a multi-crate system, we developed a dedicated fan-out board, named Ancillary. It also collects the busy signal from all the WDBs signal and sends it via the backplane in the trigger crate to the master TCB.

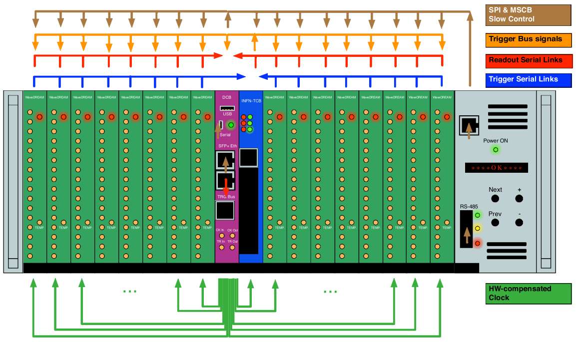

Figure 1: Sketch a one WaveDAQ crate. The green board are the digitising WaveDREAM boards, in magenta the Data Concentrator Board and in blue the Ttrigger Concentrator Board. The green arrows beyond the crate indicate the HW-compensated clock distribution, above there reported the trigger serial links from the WDBs to the TCBs in blue, the serial links of the WDBs and the TCB to DCB in red, the trigger bus in orange and the SPI slow control in brown.

2. WaveDREAM board

The WDAQ cornerstone is the WaveDREAM board which integrates the DAQ and trigger functionalities in a single board, shown in Fig. 2 (left). It contains 16 channels with variable gain amplification and flexible shaping through a programmable pole-zero cancellation. Switchable gain-10 amplifiers and programmable attenuators allow an overall input gain from 0.5 to 100. A low-noise onboard power supply can be used to power

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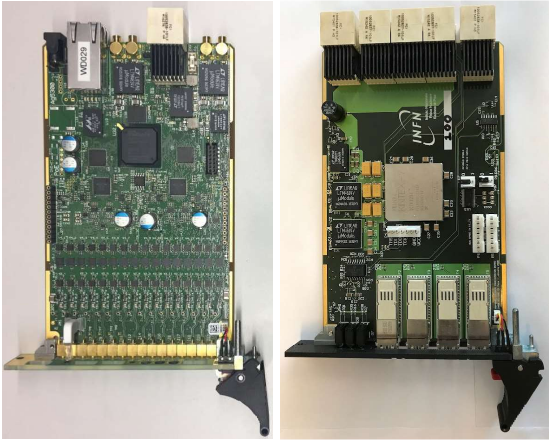

Figure 2: WaveDREAM board (left) and TCB board (right).

SiPMs arrays with 240 V.

The FPGA processes ADC data in real-time with complex algorithms such as the calibrated sum of all the input channels on which thresholds can be applied for triggering.

Stand alone board operation is possible by means of a 1 Gb/s ethernet connection and a Power Over Ethernet Supply.

3. Trigger Concentrator Board

A trigger concentrator board (TCB) collects data from the WDBs to be processed on an FPGA. It is shown in Fig 2 (right). The FPGA provides full flexibility by allowing us to adapt the reconstruction to meet any experimental needs.

The WaveDAQ trigger is an evolution of the MEG trigger design described in [2, 3, 4] It can handle up to 64 trigger algorithms in parallel with individual pre-scaling factors. A TCB can be configured to receive, elaborate and transmit serial data both from the backplane (top side in the Fig. 2) to the front-panel and vice versa. This is exploited in large applications where a trigger concentration crate is needed. In that case some TCBs will be used to collect the data from the front-panel and then pass it via the backplane serial links to the master TCB.

4. System demonstrator

A system demonstrator was built and successfully run at PSI during fall 2017. It consists of 4 digitising crates, 1024 channels, accompanied by a trigger and synchronisation crate. It was used to read out a scintillation time of flight detector, a part of an LXe calorimeter plus auxiliary channels (LED and laser synchronisation pulses). Despite the limited number of channels compared to the system available resources, most of the features required in large applications had to be operational such as: serial data connection and trigger processing, board synchronisation, trigger, event type and number distribution and busy collection. In particular we measured a board-to-board synchronicity better than 10 ps in a time scale of more than one month.

5. Applications

The MEG II experiment ah the Paul Scherrer Institut (PSI) aims at measuring the branching ratio of the $\mu \rightarrow e\gamma$ decay with a sensitivity of $6{\times}10^{-14}$ [5]. The experiment is equipped a with drift chamber to measure the positron track and a scintillation device for its time of flight; as well as a liquid Xenon detector for the photon detection. The WaveDAQ will read out the whole detector, ≈8000 channels from SiPMs, PMTs and the amplified pulses from the drift chamber anode wires. A complex trigger reconstruction mainly based on the photon energy discrimination, but also positron-photon relative timing and direction, will reduce event rate from the target by almost 7 order of magnitudes to about 10Hz. The positron time of flight detector is installed and commissioned at PSI with WDAQ, and a time resolution of about 35 ps had been measured.

The FOOT experiment (Fragmentation Of Target) aims at identifying the fragments produced by accelerated ion beams onto a hydrogen-enriched target[6]. The measurement of the fragments time of flight from the production target to the ΔE-TOF detector and their dE/ dx are mandatory for particle identification. WDAQ is adopted for trigger and readout of the FOOT scintillation devices (80 channels) and DAQ rates up to 1 kHz. The time resolution of a detector prototype irradiated with ions was measured in the range of 20-150 ps.

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