Journal of Physics: Conference Series

Stand-alone Low Power Consumption FEE and DAQ for the Readout of Silicon Photomultipliers.

To cite this article: Luigi Cimmino *et al* 2022 *J. Phys.: Conf. Ser.* **2374** 012183

Stand-alone Low Power Consumption FEE and DAQ for the Readout of Silicon Photomultipliers.

Luigi Cimmino*[1,2], Fabio Ambrosino[1,2], Lorenzo Bonechi[4], Roberto Ciaranfi[4], Raffaello D'Alessandro[3,4], Mariaelena D'Errico[1,2], Vincenzo Masone[2], Giulio Saracino[1,2] & Paolo Strolin[1,2]

[1]University of Naples Federico II.
[2]INFN sezione di Napoli.
[3]University of Florence.
[4]INFN sezione di Firenze.

E-mail: `cimmino@na.infn.it`

Abstract. We developed a front end electronics (FEE) and data acquisition (DAQ) system with a low power consumption, especially intended for stand-alone applications in unattended environments without standard electricity supply. The system works autonomously thanks to dedicated algorithms that are embedded. The FEE is based on the EASIROC chip, designed for the readout of Silicon photomultipliers (SiPMs). It digitizes the amplitude of the signals and provides time information with time of flight capability. The trigger logic is programmable and physical and accidental coincidences rates can be measured. The SiPMs temperature is controlled by thermoelectric cells. Thanks to a network of temperature and humidity sensors, a real-time software sets the optimal operating point of the SiPMs depending on external conditions and if necessary halts the system to avoid damage to the electronics. The system has been used in several muon radiography experiments.

1. Introduction

Particle detection in remote environments without standard electricity supply requires both a low power consumption and the capability of stand alone unattended operation. Being solid state devices as the transistor, Silicon photomultipliers (SiPMs) do not need H.V. supply and satisfy the first of these requirements. However, by the same token of solid state devices, their operation in sensitive to environmental conditions and in particular temperature, so that their utilization in stand-alone unattended experimental apparatus raises new problems. These are the general motivations for the design of dedicated front-end electronics (FEE) and data acquisition (DAQ) system, which was specifically carried out in view of its use in muographic imaging. The features of the system offer, however, advantages also for other applications.

The data acquisition system is designed to be modular and scalable, with a MASTER board managing the FEE boards, each of them dedicated to 32 SiPMs. The configuration is fully adaptable to the features of the experimental apparatus. In particular, the system has been used in the MURAY muon telescope [1] and in the MURAVES detector [2], consisting of an array of muon telescopes, as well as in the MIMA detector [3]. In all these applications, the basic detector elements are rods of plastic scintillators read by SiPMs and arranged in sets of planar arrays at a distance one from the other. Temporal coincidences of hits in different planes (accounting for the velocity of light that characterizes ultra-relativistic particles) determine the trajectories and the directions of muons having traveled through the body under investigation and crossing the planes of the detector, also called muon telescope.

2. Silicon Photomultipliers

SiPMs are solid state photodiodes characterized both by the high gain typical of the Geiger mode (with in addition the single photon resolution capability) and by a proportional response, given by sum of the signals in the microcells that are fired among those of the matrix into which the sensor is finely subdivided. The operation of the SiPMs is determined by the ”overvoltage” of the (reverse) ”bias voltage” applied to the device with respect to the ”breakdown voltage”, the minimum for Geiger discharge to take place in the microcells due to electrons generated in the active volume.

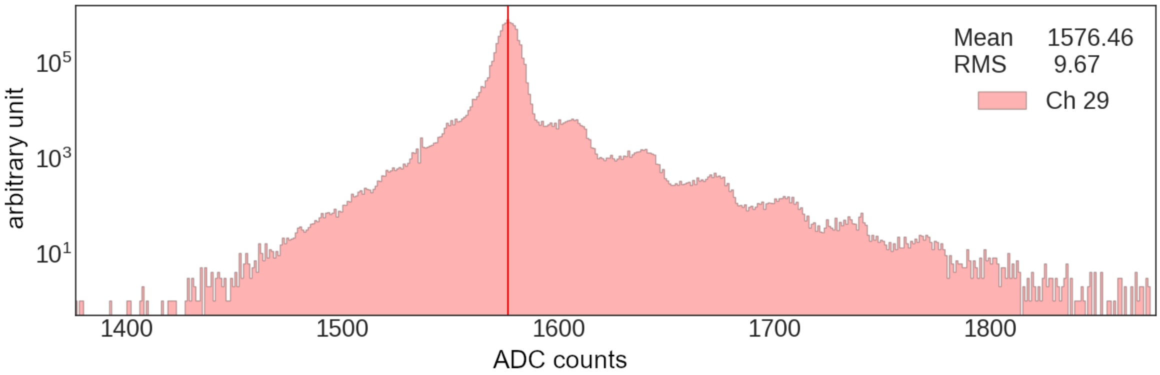

Figure 1. The dark counts spectrum of a SiPM. The difference in ADC counts between the main peak and the first to its right corresponds to one photoelectron.

The main source of noise is given by the dark counts rate induced by thermally generated electrons [4]. Figure 1 shows the typical dark counts spectrum of a Hamamatsu S13360-3050PE SiPM as measured by an analog-to-digital converter (ADC) for a 4.0 V overvoltage. The pedestal is followed by a sequence of peaks in correspondence to the number of detected photoelectrons. Thanks to the single photoelectron resolution, a precise settings of the threshold is possible. The SiPMs have been operated with a gain 1.7×10^6 and a dark counts rate of order 10^2 Hz at a temperature of 18° C.

The dark count rate increases with temperature. An increase in temperature has the double effect of increasing the dark counts rate and the breakdown voltages. Thus the DAQ system is connected tp temperature sensors in order to adjust the working conditions of the SiPMs, by acting on the bias voltages, the threshold levels, and if necessary the temperature settings.

As a result of an increase in the environmental temperature, the dark counts rate rises. Then the acquisition system lowers the temperature with a peltier system, but this produces an increase in the breakdown voltage V_{bd} of the SiPMs so we also increase the V_{bias} to maintain, as much as possible, a constant overvoltage level V_{ov} between different working points ($V_{bias} = V_{bd} + V_{ov}$). The acquisition system decides the working point (WP) to be set on the basis of the measured environmental conditions. The change in the WP takes also into account to the dew point, which depends on the temperature and the humidity. If the Peltier system wants to set a lower temperature, but there is a risk of condensation, the system works at a higher temperature, therefore with worse performance in terms of dark counts.

3. Front-end Electronics

Each FEE board is equipped with an EASIROC ASIC [5], which contains 32 SiPM channels. The power consumption is less than 2.5 W. The chip provides SiPM gain adjustment, tunable preamplification gain, signal shaping, charge measurement, high and low gain multiplexed outputs. The power distribution system housed in the FEE board provides supply for its operation and programmable bias voltages for the SiPMs. The FEE board also contains a TDC for the measurement of the time-of-flight (ToF) with 0.1 ns resolution [6].

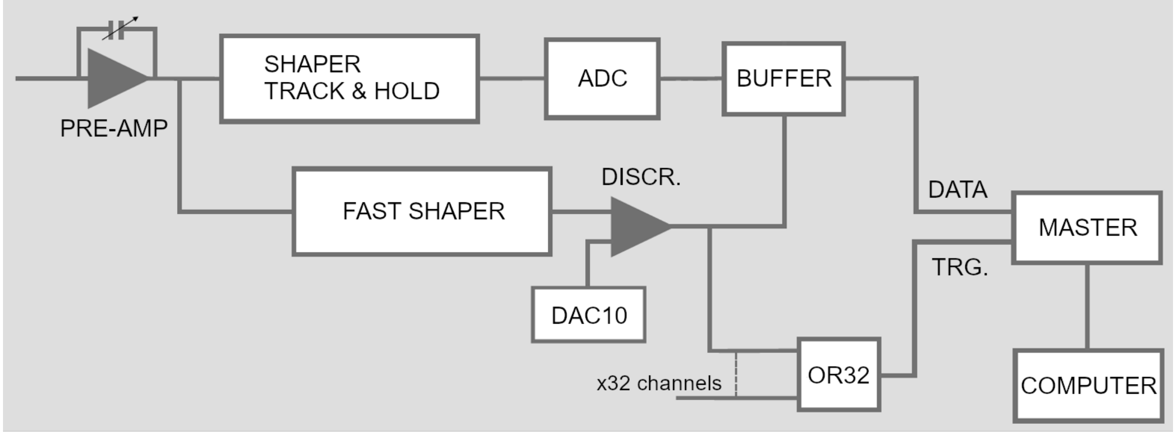

Figure 2. Simplified scheme of the FEE and DAQ system.

The signals detected by the SiPMs are processed through two different electronics paths, as shown in figure 2, one slow and one fast. In the slow path, the signals are amplified by a factor depending on the setting of a feedback capacitance. Two separated amplification paths (high and low gain) are available. In each path, a tunable shaper followed by a track and hold circuit and by a 12-bit ADC measures the charge deposited in the SiPM. In the fast path, a fast shaper followed by a discriminator gives a logic signal, according to the threshold level set by an integrated 10-bit DAC. The logical OR of all 32 fast path logical signal produces the local trigger (OR32) to be sent to the MASTER board to participate in the trigger logic.

4. Data Acquisition System

The MASTER board embeds an ARM single-board computer connected to the MASTER through its general purpose input/output (GPIO) interface. The FEE and the DAQ are managed by a software running on the ARM computer, written in C and Python3 programming languages. The software sets the parameters of the FEE, defines the operation of the MASTER board, collects and stores data in a network-attached storage (NAS), manages the SiPMs working point. The WP is the joint setting of the temperature and the bias voltage V_{bias} of the SiPMs.

An asynchronous communication protocol, developed at low level, ensures the exchange of information between the FEE boards and the computer through the MASTER board. Several GPIO lines are used to perform polling or interrupt operations, to generate clocks and to transmit data packets. An integrity check process and a vertical redundancy check ensure the quality of the data before storing. The system can be configured to acquire the trigger rate, the accidental rate, the single channel counts, the logic OR of the 32 channels, the SiPMs' analog signals in an acquisition either in random or satisfying a preset trigger logic.

For each event, data is temporarily downloaded into the computer RAM; a preset number of events are organized and stored before being permanently saved as a RAW file. The disk access is managed in such a way as to reduce disk access time to about 0.1% of the acquisition time.

When a single FEE board is present, the acquisition rate is $1.2KHz$. This rate scales down with an increasing number of FEE boards.

5. Conclusions

The FEE and DAQ system developed for SiPMs' readout is characterized by a low power consumption (few tens of watts) and is suitable for stand alone operation. Modularity and programmable features make it adaptable in real-time and versatile for a variety of requirements. The system has been successfully applied in a number of experiments.

References

[1] G. Saracino *et al.*, *Imaging of underground cavities with cosmic-ray muons from observations at Mt. Echia (Naples)*, Scientific Report, 7, 2017.

[2] G. Saracino *et al.*, *The MURAVES muon telescope: technology and expected performances*, Annals of Geophysics, 60(1), 2017.

[3] G. Baccani *et al.*, *The MIMA project. Design, construction and performances of a compact hodoscope for muon radiography applications in the context of archaeology and geophysical prospections*, Journal of Instrumentation, 13(119), 2018.

[4] D. Renker, *Geiger-mode avalanche photodiodes, history, properties and problems*, Nuclear Instruments and Methods A, 567, 2006.

[5] S. Callier, C. Dela Taille, G. Martin-Chassard, L. Raux, *EASIROC, an Easy and Versatile ReadOut Device for SiPM* Physics Procedia, 37, 2012.

[6] L. Cimmino *et al.*, *The MURAVES telescope front-end electronics and data acquisition*, Annals of Geophysics, 60(1), 2017.