Journal of Physics: Conference Series

PAPER • **OPEN ACCESS**

Low Background Readout Electronics for Large Area Silicon Photomultipliers

To cite this article: A. Fabbri *et al* 2022 *J. Phys.: Conf. Ser.* **2374** 012085

Journal of Physics: Conference Series **2374** (2022) 012085 doi:10.1088/1742-6596/2374/1/012085

Low Background Readout Electronics for Large Area Silicon Photomultipliers

A. Fabbri, S. M. Mari, P. Montini, F. Petrucci, D. Riondino, and S. Sanfilippo

Università degli Studi Roma Tre and INFN sezione di Roma Tre, Roma (Italy)

E-mail: andrea.fabbri@roma3.infn.it

Abstract. In this work we present a low noise high speed readout electronics for large area Silicon Photomultipiers (SiPMs) to be used in a cryogenic environment. The board is able to manage the signals coming from a 25 cm^2 SiPM tile, showing ¡10% SPE resolution and wide dynamic. The sub–nanosecond timing properties make them suitable to work with the typical mixtures of Liquid Scintillators currently being used in particle and astroparticle physics experiments. The boards have been tested with several types of SiPMs from room temperature down to -70 C showing excellent single photo–electron resolution in all the enviroments. The board's PCBs have been developed with ultra low background material in order to be used in rare event searches.

1. Introduction

Silicon Photomultipliers (SiPM) are currently being widely used in several kind of applications, e.g. in high energy physics experiments as well as in other research and industrial fields. The excellent photon detection efficiency (PDE), single photon resolution, timing performances, low operating voltage and robustness make them a good replacement candidates of conventional photomultipliers for light detection from single photon up to several hundreds of photons. On the other hand SiPM cells have typically a smaller size ($\sim$ 1 cm^2) compared to the one of a PMT. In order to build a SiPM based detector with a size comparable to the one of a PMT several SiPM cells have to be coupled together and their outputs has to be merged into a single analog output by means of a dedicated front–end electronics. The front–end electronics must be designed in order to deal with the relatively high SiPM capacitance without degrading the performances. In many applications SiPMs need to be cooled down to cryogenic temperatures in order to keep the dark count rate to an acceptable level. The front–end electronics has therefore to be designed to work smoothly at low temperatures and to have a low power consumption in order to avoid excessive heat dissipation in the cryogenic environment. In this work we present low noise front–end electronics for large area SiPMs. The electronics has been designed in order to guarantee a single photon resolution better than 10% a sub–nanosecond timing resolution and a wide dynamics (1-250 p.e.). The performances make them suitable to be used in large area new generation liquid scintillator particle and astroparticle physics experiment.

2. SiPM Front–end board

The front–end board (FEB) is directly coupled to the 25 cm^2 SiPM tile. The tile is split in 4 quadrants and each quadrants is read–out by an independent transimpedance amplifier (TIA) as schematized in figure 1.

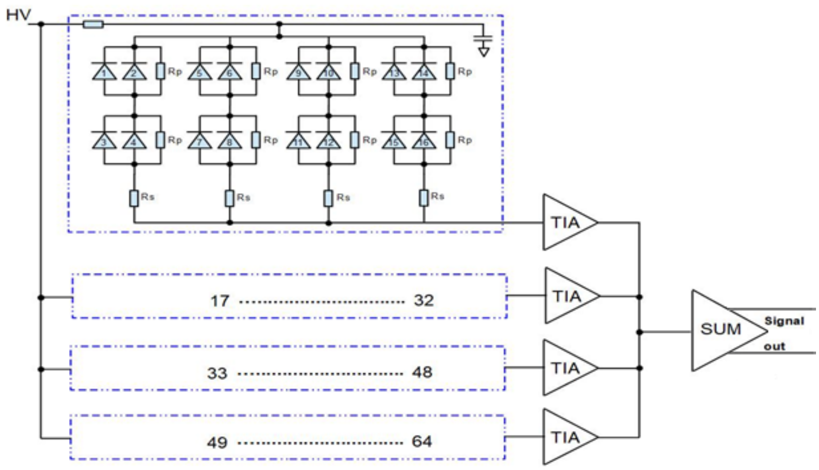

Figure 1. Passive gangling of 64 element SiPM tile. Four TIAs share the input capacitive load.

Signals coming from each TIA are subsequently summed by a second stage amplifier. An ADC driver is used to bring the signals out of the cryostat in analog differential form thus allowing the use of 10 m twisted cable without adding significant noise. The implemented TIA scheme is a standard one (figure 2) with a small feedback capacitance that can be added to compensate the effect of the input one.

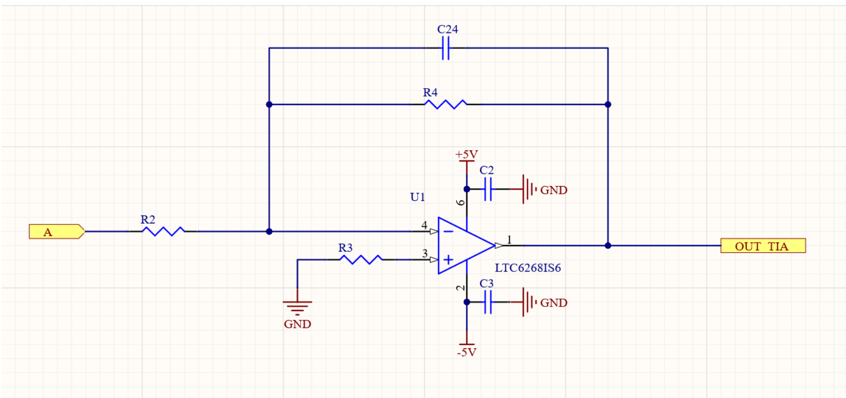

Figure 2. TIA schematic.

The amplifier gain V/I can be easily changed by changing R4 value, resistors up to 50kΩ was tested without output oscillation. For a given SiPM with $\tilde{1}0^6$ gain factor and $\tilde{1}$ nF load capacitance, a 1kω feedback resistor gives single PE signal of about 8 mV thus corresponding to a dynamic range of 1-250 PE in the 0-2 V range. Bandwidth depends from the selected gain, however it can be further adjusted by changing R2 value. If SiPM anode is directly connected to TIA input the maximum bandwidth is achieved and it depends from the SiPM size and its relative capacitance. For small size SiPM, like 1 mm^2 ones, the capacitance is usually lower than 100 pF and the related bandwidth is too high for the selected LTC6268 amplifier, so a resistor higher than 30 Ω is needed. On the other hand, starting from 6x6 mm^2 SiPM, that usually have a terminal capacitance bigger than 1 nF, direct connection can be deployed. Several test was made with different size SiPM from different vendor, with high gain and terminal capacitance differences: an optimal configuration in terms of gain and bandwidth can be easily obtained in all the tested configuration.

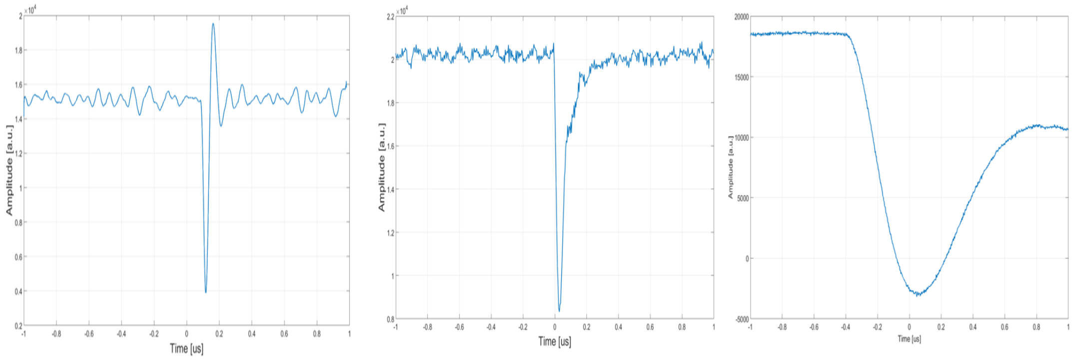

Figure 3. Signal output obtained from the same SiPM (1.3x1.3mm^2) with different input resistor.

Figure 3 shows how the pulse bandwidth can be adapted for a 1.3x1.3 mm^2 SiPM: from left to right the input resistor is increased starting from a direct connection (= 0Ω) up to 300Ω. The FEB has been extensively tested at temperatures down to -70 °C using a climatic chamber. Several samples have been stressed with several thermal cycles showing no failures. Moreover, Mean Time Between Failures (MTBF) was evaluated, thanks to the small component number and the selected materials and operative voltages for capacitance and resistors, an MTBF of 93·10^6 hours is achieved. The prototypes have been built using the standard FR4 PCB substrate; low background materials like Pyralux and Aramid have been tested showing the same performances.

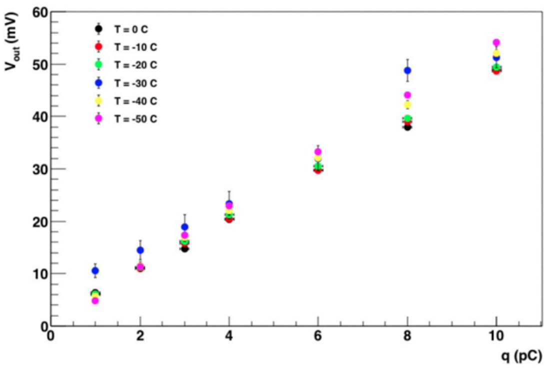

Figure 4. FEB linearity at different temperatures

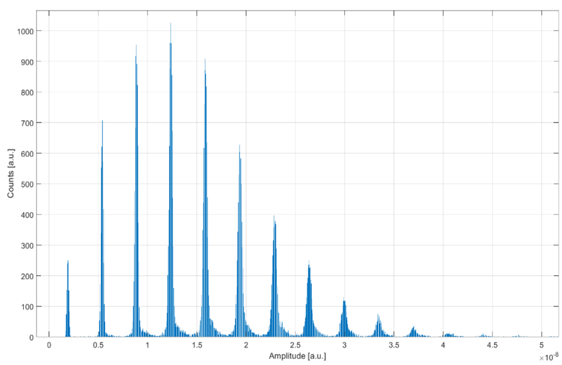

Figure 5. Amplitude spectrum obtained from raw waveforms for a 6x6 mm2 coupled to the proposed FEB.

The linearity at different temperatures has been tested by using a charge injector and is shown in figure 4.

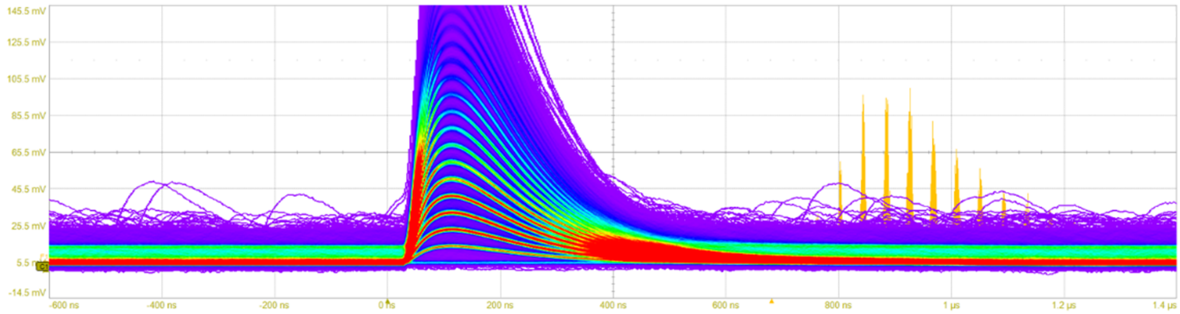

Figure 6. Signals coming from a FEB coupled to a Hamamatsu S13660 6x6 mm^2 SiPM cell.

In figure 6 an examples of the signals coming from the FEB coupled to a Hamamatsu S13660 6x6 mm^2 SiPM cell are shown while in figure 5 a typical amplitude spectrum from raw waveforms is shown: twenty thousand wave-forms obtained with an UV laser source was evaluated in terms of maximum value (peak) and the obtained results is distributed in the plot. The left-most peak is related to noise plateau, while the energy resolution for single photon energy is around 5%.

Figure 7 shows a picture of both side of the FEB. The external dimensions are 3.3 cm x 3.5 cm. Different connector can be soldered on the input pins, while low voltages for TIAs and high voltages for SiPM can be delivered to two different connectors, one on each side of the board. Output signal can be read single ended from the SMA connector or differential from the O+ / O- pads. A 0Ω resistor position enables one of the two outputs.

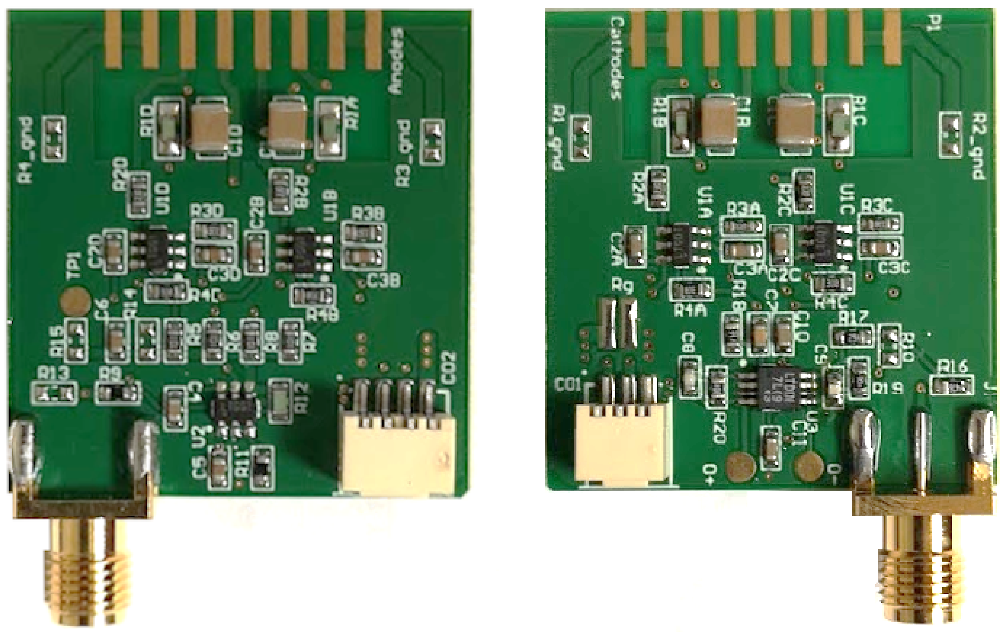

Figure 7. FEB with aramid substrate.

3. Conclusions

A very flexible solution for SiPM readout was presented. Single elements from 1 mm^2 up to 5x5cm^2 can be read with the same front end. The use of Commercial Off The Shelf (COTS) components reduces the overall cost of the FEB, moreover it allows easily changing front end gain and time performances as function of the SiPM dimensions, gain and terminal capacitance. FEB shows an high dynamic range (+/- 2V or 1-250 p.e.), high reliability ($93 \cdot 10^6$ hours) and high performances in terms of energy and time resolution with single photon counting capabilities in a temperature range starting from -70$\circ$ to room temperature and it is well suited for the next generation astroparticle experiments.

References

[1] A. Abusleme et al., TAO Conceptual Design Report: A Precision Measurement of the Reactor Antineutrino Spectrum with sub–percent Energy Resolution, arXiv:2005.08745 [physics.ins-det], (2020)
[2] A. Abusleme et al., JUNO Physics and Detector, arxiv:2104.02565 [hep-ex], (2021)