R&D for future SiPM cameras for Fluorescence and Cherenkov Telescopes

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Abstract: Silicon Photo-multipliers are currently being considered for new generation Cherenkov and Fluorescence Imaging Telescopes. Some of the Silicon Photo-multipliers produced today achieve already better light detection efficiency and spatial resolution than standard photomultiplier tubes. Further increase of the Photon Detection Efficiency (PDE) of SiPMs is expected to be achieved by the manufacturers in the near future. Since SiPMs are CMOS based semiconductor devices, they are potentially less expensive than PMTs for equal photosensitive area and a drastic decrease in price over the next years is expected as more manufacturers will offer several improved and competing products. Additional advantages of SiPMs are that they are only biased with low voltages of the order of 30-70V thus simplifying the setup. SiPM are also resilient to high light levels, which make them ideal for field applications.

However, current commercially available SiPMs still present a high level of dark current, after-pulsing and crosstalk. Some progress in the optimization of some prototypes of SiPMs has been already achieved. Further optimizations of these parameters are expected in the near future as a result of joint R&D programs with the industry.

In this poster, a strong R&D program of several collaborating groups that cover the main aspects of the use of SiPM in a telescope will be presented: That are (i) a testbench for the characterization of SiPMs, the development of (ii) low cost and low noise readout electronics for a very large amount of channels, (iii) an simple and efficient way of cooling without condensation with high temperature stability at the focal surface, and (iv) an efficient optical light guides to maximize the light collection is needed.

Keywords: SiPM; Photon detectors; Fluorescence; Cherenkov

1 Introduction

Silicon Photo-multipliers (SiPM) are currently being considered for new generation of Cherenkov and Fluorescence Imaging Telescopes. These new generation of cameras must increase the overall light detection efficiency and also increase the spatial and angular resolution of the telescopes.

Multi-pixel Geiger-mode APD, also called Silicon Photomultipliers (SiPMs) are currently being considered as the baseline photosensor element since the already existing prototype devices achieve better light detection efficiency than standard photomultiplier tubes. Further increase of the Photon Detection Efficiency (PDE) of SiPMs is expected to be achieved by the manufacturers in the near future as a result of joint R&D programs between research institutes and industry. Such devices are available in small sizes $(\sim 1-10\ \mathrm{mm}^2)$ allowing to build a highly pixelized focal surface with about $10^5\ \mathrm{pixels/m}^2$. The price of each pixel is significantly lower than that of a PMT and is expected to decrease drastically as mass production of these devices start in standard CMOS foundries.

Additional advantages of SiPMs are that they are only biased with voltages of the order of $30-70$ V, thus simplifying the setup. SiPM are also resilient to high light levels, which make them ideal for field applications. However, SiPMs still present a high level of dark current, afterpulsing and crosstalk. Current R&D programs in detector development are currently addressing these issues.

The potential application of the developed focal surface in upgrades to the installed facilities at the Pierre Auger Observatory [1, 2] or in the Cherenkov Telescope Array (CTA) [3] requires that the developed FS has high reliability, easy field maintenance with the lowest down-time achievable, and minimization of the total electrical power budget.

2 Focal surface architecture

The architecture of the focal plane being developed is based, as a baseline, on the use of Silicon Photo-multiplers [4, 5] arrays with enhanced photon detection sensitivity in the $300-600$ nm band, a fast temporal response and a spatial segmentation of a few square millimeters. The whole focal surface is being developed trying to keep it compatible with a more traditional approach based on the use of MultiAnode Photomultipliers (MAPMT). For such backup solution the Hamamatsu model R7600-03-M64, with 64 anodes arranged in an 8 8 matrix, used in other experiments [6, 7] is considered.

The increase on the number of photosensors due to the reduction of the individual pixel area leads to a larger number of active channels, requiring a compact and modular design. Moreover, to minimize noise pickup and crosstalk the system is designed with minimum cabling and distance between the photosensors and the frontend electronics. The mechanical and electronics interconnects of the entire system follows a modular approach. The photonsensors and associated front-end electronics are arranged in a basic unit that can be combined to build-up a larger focal plane. The basic unit consists of an array of 8×8 SiPM pixels and front-end electronics. The compactness of the front-end electronics allows to arrange these units in a sector of 32×32 pixels with minimal dead space. Each basic unit will communicate its digital data to the sector control board, in the focal surface backplane, that is also responsible for the first trigger level (L1). The data from sector boards is transmitted to higher level boards, housed in an off-detector crate, by means of high speed optical links. Such boards will perform data reduction and concentration and will also be responsible for the generation of second (L2) and third (L3) level triggers. An overall scheme of the architure is shown in figure 1. Further details on the architecture of the system can be found in [8, 9]. The trigger system will be distributed over several levels and will rely on the occupancy, persistence and signal levels.

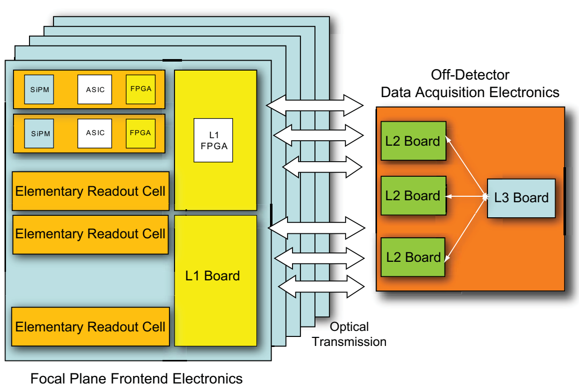

Figure 1: Architecture of the data acquisition system.

3 The front-end electronics

The front-end electronics have a key role in the system. Firstly, due to high density of pixels, the front-end electronics must be compact to allow that the basic units can be placed close toghether with minimal dead space. Secondly, to minimize the noise, the front-end electronics must be as close as possible to the sensors with minimum cabling. The solution adopted relies on early signal digitization using a dedicated mixed-signal ASIC which has also the signal conditioning electronics.

Photosensors will operate in Photon Counting mode [10] in the low-light regime reverting to a charge integration approach in the presence of very intense light bursts. In Photon Counting mode, the effects of electronics noise and the SiPM or MA-PMT gain differences are kept negligible allowing to lower the photoelectron trigger threshold [10]. High light levels require that the signals from the photosensors are recorded using the charge integration method. In this case the analogue signals from several pixels will be summed and then sampled by an ADC to minimize the number of ADC channels.

The focal surface is instrumented with 3×3 mm^2 SiPM pixels organized in basic units of 8×8, readout by a 64 input channel mixed-signal ASIC.

Feasibility tests to demonstrate the single photon counting of SiPM with current available ASICs were carried out. For this purpose, the MAROC3 ASIC developed by the OMEGA microelectronics group was evaluated [11, 12]. The MAROC3 is a 64 channel readout ASIC with a power consumption of 3.5 mW per channel. Each channel has a low impedance preamplifier with a variable gain setting. Three different shapers can be used for each channel: unipolar, bipolar and half-gain bipolar. The shaped pulse is compared against a threshold voltage defined by an in-core DAC. Using the OMEGA MAROC3 evaluation board, Hamamatsu S10362-33-100C MPPCs operating at gain $M = 2.4 \times 10^6$ (bias voltage of 70.67 V at room temperature $25°$C) were readout. Due to the large dark current of the 3×3 mm^2 SiPM (4 to 9 MHz) and the longer fall time of the 100 μm cells, a blocking capacitor of 220 pF was used to reduce the SiPM fall time down to 80 ns to avoid pulses pile-up. The MAROC3 fast bipolar shaper in the maximum gain configuration (2.3 V/pC) was used. The discriminator output (fig. 2) was connected to a CAEN N145 NIM counter. The threshold voltage of the discriminator was scanned and the number of counts recorded for each setting. At 0.5 pe the dark count measured with the MAROC3 is $4.5 - 4.6$ MHz in good agreement with the Hamamatsu value reported for this sample (4.8 MHz at 0.5 pe) - Fig. 3 . The value of the dark count at 1.5 pe over the dark count at 0.5 pe measured with the MAROC3 was 17.20%.

A prototype board called "Elementary Readout Cell", fig. 4, instrumented with the main electronics systems for the focal plane frontend and Level 1 trigger is also being developed, with the aim to demonstrate the detection of flu-

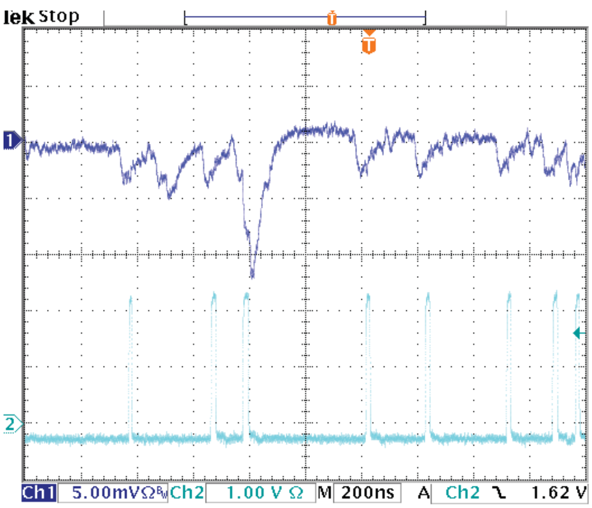

Figure 2: Typical oscilloscope traces obtained from a S10362-33-100C Hamamatsu SiPM (Dark) and from the MAROC3 output.

orescence and Cherenkov light with SiPMs both in single photon counting mode and charge integration, computation of first level trigger primitives, multiGbps optical transmission, slow-control and environmental monitoring. In this prototype, the SiPM array is readout by the MAROC3 ASIC. The 64 discriminator outputs as well as the serial datastream from the MAROC3 ADC is readout by an FPGA. The first level trigger algorithm will be implemented in this FPGA with valid data concentrated and transmitted at a maximum rate of 3.125 Gbps through optical links. For debugging and slowcontrol purposes, a RS232 and a USB2 data links were also included. The FPGA is also responsible for monitoring the temperature and humidity, using dedicated sensors readout over I^2C. Two 32-channel I^2C, $0 - 5$ V, DACs are used to tune the individual SiPM bias.

The PCB will be submitted for production in July 2011 and the first validation tests are scheduled for September 2011.

4 Testing facility at LIP

The use of SiPM to instrumentate a focal surface of an U-V telescope poses many challenges. The solutions adopted need to be evaluated in controlled conditions. Also the performance, and the dependence with several parameters, of the photosensors needs to be checked. For this purpose LIP has recently built a Dark Room and several test setups to address these points.

The experimental setup installed at LIP's dark room, shown in figure 5, consists of a cooling system, a gas-tight box with a transparent window and a cold plate inside. Currently the MAROC3 evaluation board is used to acquire data from the SiPM and to test the MAROC3 chip.

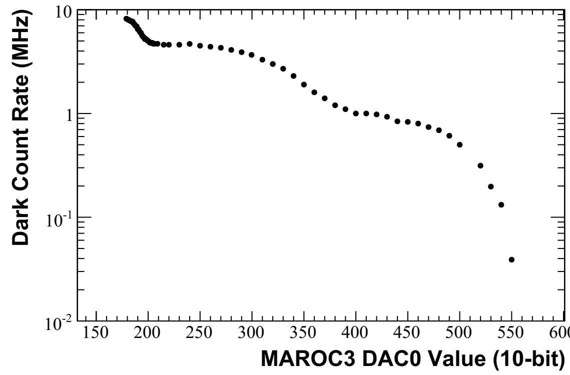

Figure 3: Photoelectron dark count spectra from a S10362-33-100C Hamamatsu SiPM operated at room temperature 25°C and a bias voltage of 70.67 V

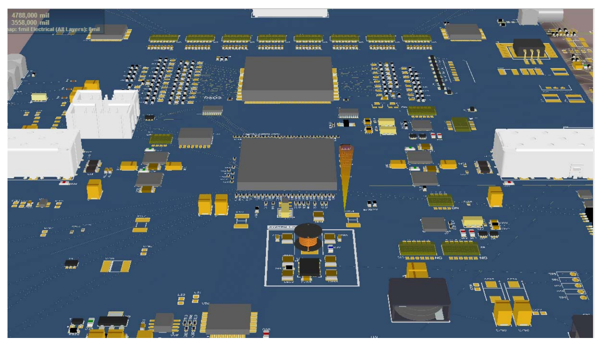

Figure 4: 3D view of the layout of the Elementary Readout Cell (ERC) prototype board

The cooling system is based on a phase-change cooler that can lower the temperature to $\sim -30°$C. An anti-freeze liquid is cooled and then pumped through a cooling plate, inside the box, where the sensor is placed. Currently the setup is capable of lowering the temperature of the SiPM to $\sim -15°$C. Updates on the capacity of the cooler, liquid flow and cooling plate performance are foreseen.

The cooling box, developed by LIP's Mechanical workshop at Coimbra, is a gas-tight box that encloses a copper cold plate. The box has a high transmittance ($> 95\%$) optical entrance window. The system can can be flushed with N_2 gas, allowing it to be cooled down without the risk of water condensation. The box is constructed in plastic to minimize heat losses and envolved by a thin copper foil to increase the shield from ambient electrical noise. Calibrated detectors can be can be mounted inside the box, in the space around the cooling plate, to serve as a reference for the characterisation of the SiPM performance.

A prototype to house an array of 4×4 SiPMs is being developed. The prototype, figure 6, will have a light concentrator system based on Winston cones that will be milled in plas-

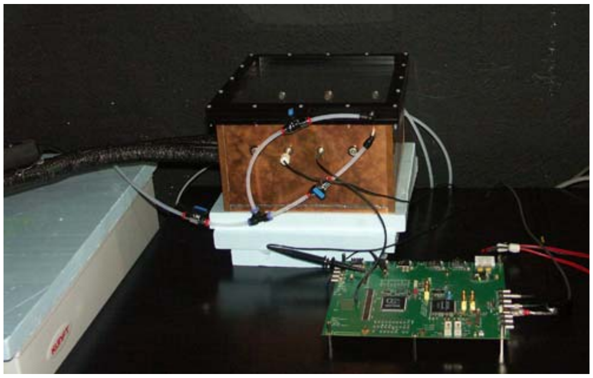

Figure 5: Experimental setup at LIP Dark room for the evaluation of SiPM, readout electronics and cooling.

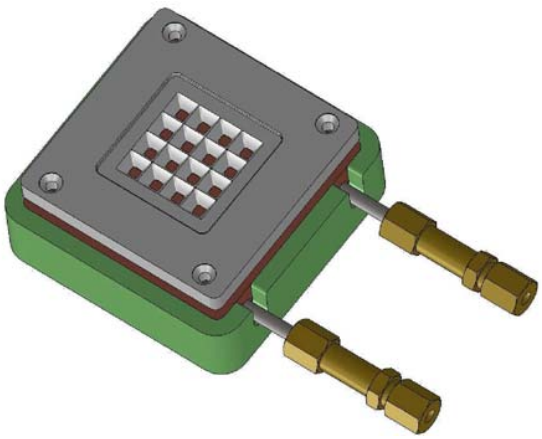

Figure 6: 3D view of the 4×4 SiPM array prototype mounted on top of the copper cooling plate.

tic. A high reflectivity UV ($\geq 97\%$ from 300 to 700 nm) foil will then be glued into the plastic form.

The setup is already operating with a single SiPM pixel mounted inside. Preliminary data show a reduction of the dark count for Hamamatsu S10362-33-100C from $\sim 4.5\,\mathrm{MHz}$ at $25°\mathrm{C}$ to $590\,\mathrm{kHz}$ at a temperature of $-14°\mathrm{C}$ for a threshold of $0.5\,\mathrm{pe}$. The dark count above $1.5\,\mathrm{pe}$ is estimated to be $60\mathrm{kHz}$. The bias voltage applied to the SiPM was regulated so that the gain remains constant and the output pulse amplitude is the same for the different temperatures used.

5 Summary and Future Work

In this paper, a concept for a new generation of focal surface based on the use of SiPM operated in Photon Counting mode was presented. The solutions being developed for data acquisition rely on highly integrated and low noise front-end electronics combined with fast optical links for digital data transmission.

A testing facility has already been installed at LIP and future upgrades are already planned. Experimental work concerning the characterization of SiPM, as well as the development of a liquid cooling system and prototype frontend and data concentrator boards for the focal plane electronics have been initiated.

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