Silicon Photomultiplier Research and Development Studies for the Large Size Telescope of the Cherenkov Telescope Array

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ABSTRACT

The Cherenkov Telescope Array (CTA) is the the next generation facility of imaging atmospheric Cherenkov telescopes; two sites will cover both hemispheres. CTA will reach unprecedented sensitivity, energy and angular resolution in very-high-energy gamma-ray astronomy. Each CTA array will include four Large Size Telescopes (LSTs), designed to cover the low-energy range of the CTA sensitivity (~20 GeV to 200 GeV). In the baseline LST design, the focal-plane camera will be instrumented with 265 photodetector clusters; each will include seven photomultiplier tubes (PMTs), with an entrance window of 1.5 inches in diameter. The PMT design is based on mature and reliable technology. Recently, silicon photomultipliers (SiPMs) are emerging as a competitor. Currently, SiPMs have advantages (e.g. lower operating voltage and tolerance to high illumination levels) and disadvantages (e.g. higher capacitance and cross talk rates), but this technology is still young and rapidly evolving. SiPM technology has a strong potential to become superior to the PMT one in terms of photon detection efficiency and price per square mm of detector area. While the advantage of SiPMs has been proven for high-density, small size cameras, it is yet to be demonstrated for large area cameras such as the one of the LST. We are working to develop a SiPM-based module for the LST camera, in view of a possible camera upgrade. We will describe the solutions we are exploring in order to balance a competitive performance with a minimal impact on the overall LST camera design.

Introduction

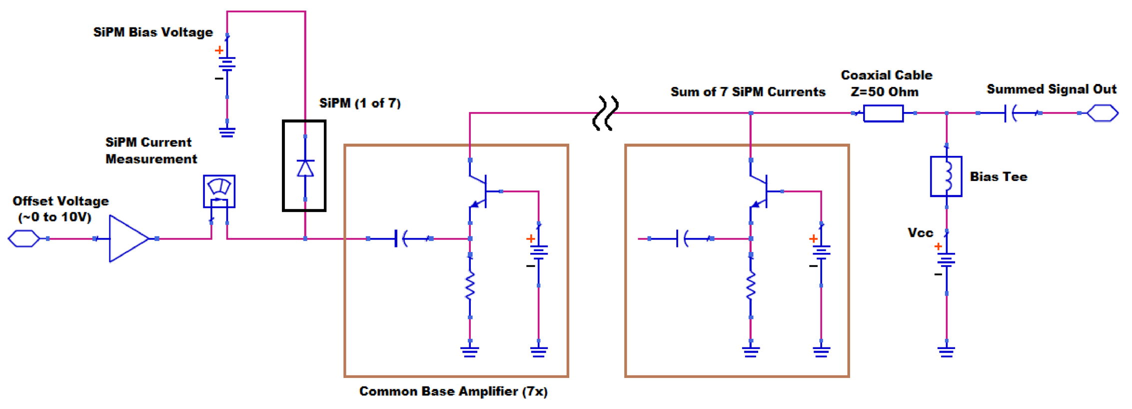
Four Large Size Telescopes (LST), 23 m in diameter and with a focal length of 28 m, are arranged at the center of both CTA arrays, to lower the energy threshold and to improve the sensitivity of CTA between 20 and 200 GeV [1,2]. A reflective surface of 368 m^2 collects and focuses the Cherenkov radiation into the camera, where 1855 PMT sensors are located.

SiPMs are very promising sensors for Cherenkov applications, thanks to the high quantum efficiency, high gain, fast response, and low-amplitude afterpulses [3-6]. In fact, the feasibility of SiPM for Cherenkov applications has been demonstrated for small scale telescopes; in addition, the First G-APD Cherenkov Telescope (FACT) has shown that SiPMs have a stable and reliable performance on the long term [7,8].

To cover the large pixel area of LST (1.5 inches in diameter) a single, large sensor is not feasible: the huge detector capacitance proportional to the sensor's area, ~50 pF/mm^2, would translate into an unacceptable level of electronic noise. Therefore, some method of summing the signal from several smaller sensors, while keeping a low input noise, must be investigated.

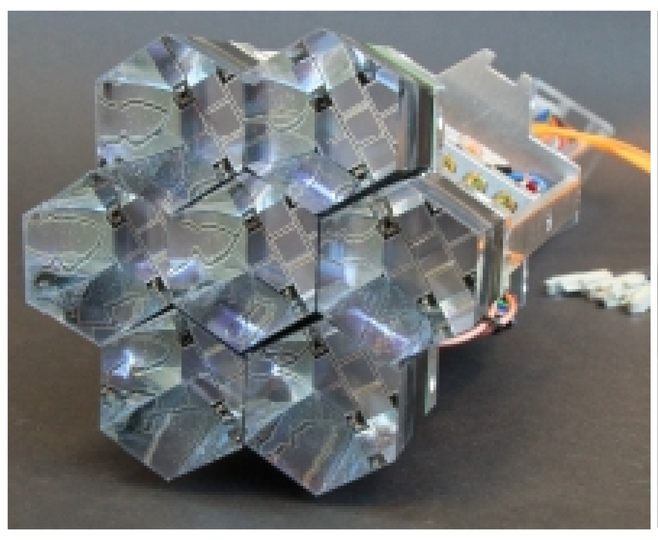
Solution 1

A first sum scheme, developed at the Max Planck Institute for Physics, Munich, is shown in figure.



The signal from each individual sensor is amplified by means of a common-base transistor amplifier, to produce a current pulse of adequate magnitude. Small differences in the gain of each sensor can be compensated by a small offset voltage (0-10 V) applied on top of the baseline HV power supply.

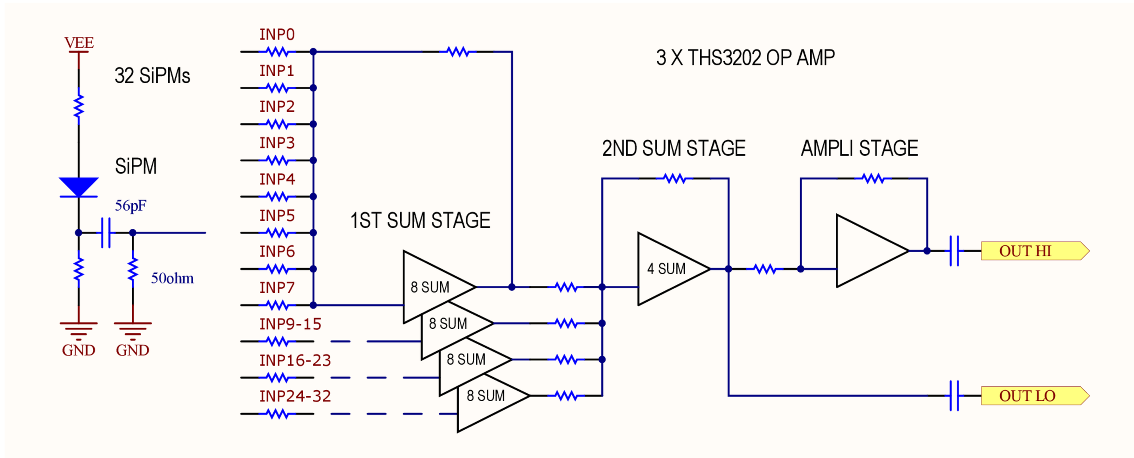
As an intermediate milestone, a smaller cluster was designed and assembled at the Max Planck Institute for Physics in Munich, within the Otto Hahn research group. Designed to fit into the MAGIC camera structure, each pixel mounts 7 6×6-mm^2 sensors and an optimized version of the MAGIC light guides.



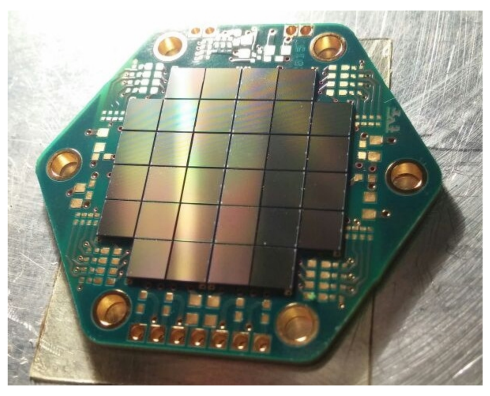
The first cluster prototype passed intensive tests in Munich for stability and reliability of operation and in May 2015 was installed in La Palma in the MAGIC camera, next to the PMT clusters. Performance and long term tests are ongoing, for a fair and detailed comparison between PMT and SiPM clusters.

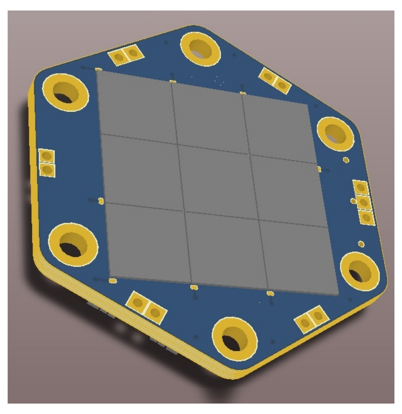
Solution 2

A second prototype circuit for the analog sum, developed at the INFN laboratories in Padova, is shown in figure.

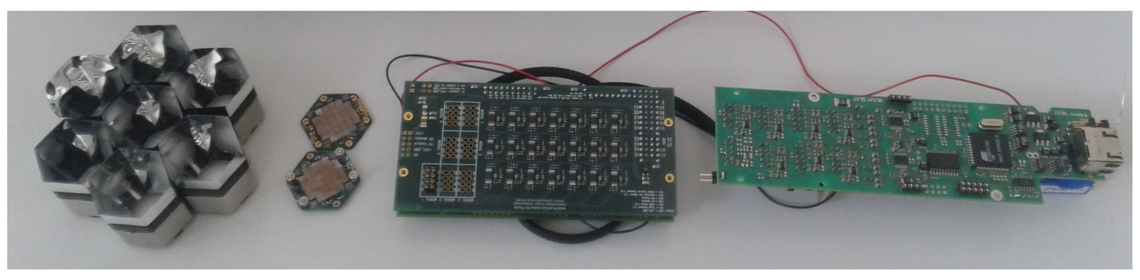


A first sum stage based on a fast, low-noise operational amplifier collects and sums the signals from the SiPM sensors, with some gain. A second stage collects and sums signals from the first sum stage, to give a single output; some additional gain can be applied here. A 16 3×3-mm^2 SiPM prototype was built, a 32 SiPM version is being tested, and a version mounting 9 6×6-mm^2 sensors is in production.



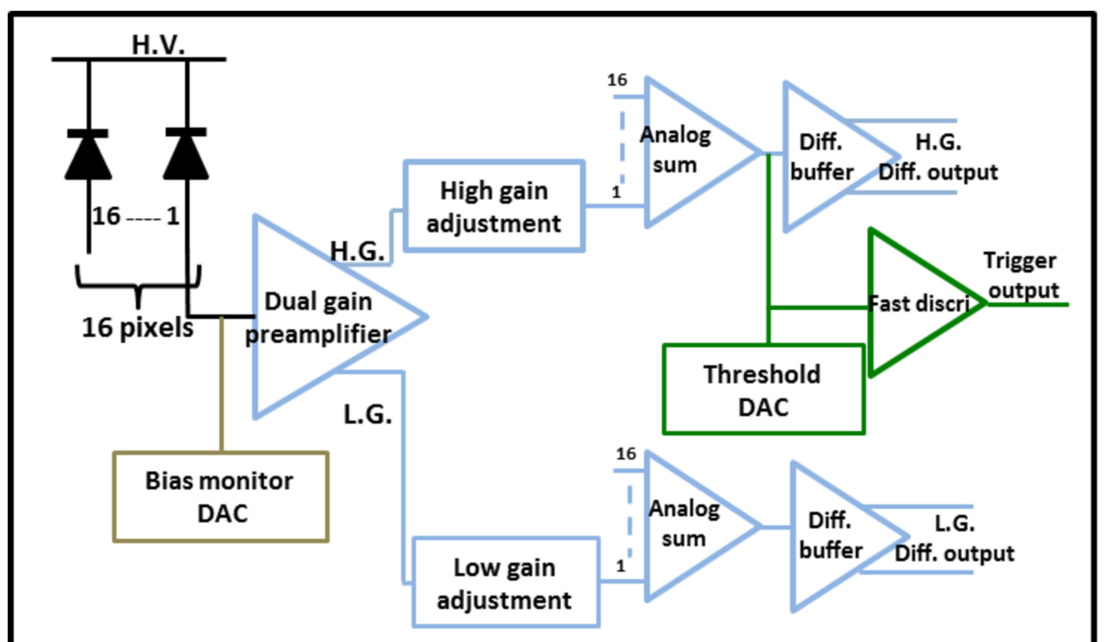


To tests this alternative SiPM sum design, a second MAGIC cluster is being assembled, each pixel mounting 9 6×6-mm^2 sensors and a curved lens to match the silicon active area to the standard MAGIC light guide. At this time, assembly and installation are expected to be completed within the end of 2015.



Solution 3

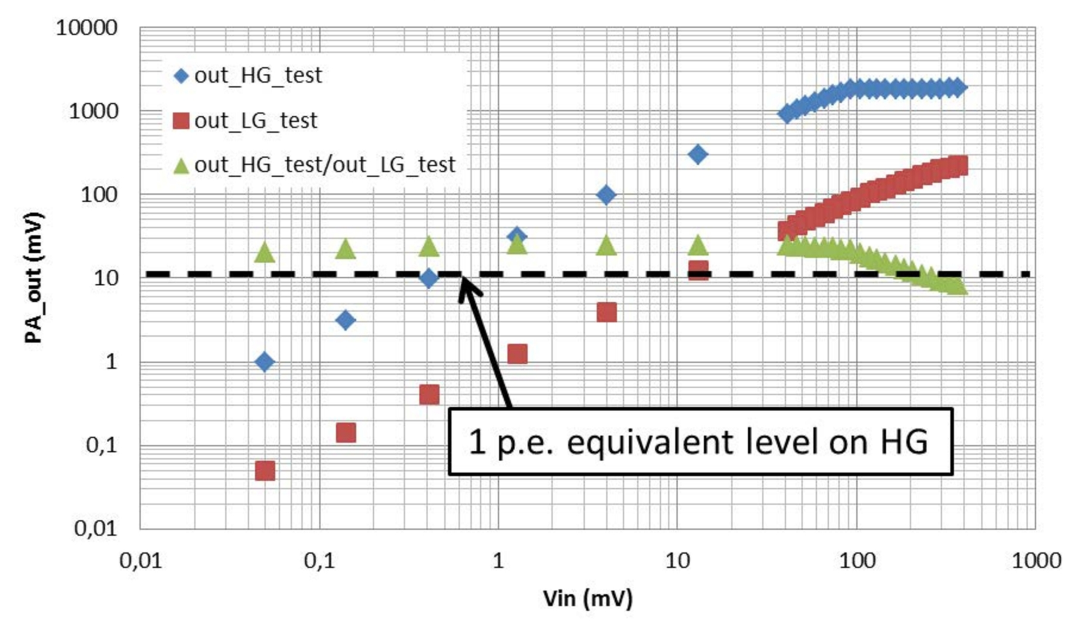
A fully integrated approach is also pursued: an ASIC, labeled "ALPS", was developed at the IN2P3 laboratories at LAPP, Annecy.



ALPS ASIC block diagram (analog part only)

Each of the 16 input channels is preamplified in a dual-gain preamplifier; the gain of each channel can be adjusted to compensate for a difference in gain among the SiPM sensors by means of digitally controlled resistors. The amplified signals are summed into the two outputs. Additional capabilities include a fast trigger output with adjustable threshold.

Pre-amplifier test : linearity



The first ASICs were received and electrically tested, confirming the simulated performance. Tests with a 16-sensor SiPM array are planned in the next future.

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