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UVSiPM: a light detector instrument based on a SiPM sensor working in single photon counting

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Abstract

UVSiPM is a light detector designed to measure the intensity of electromagnetic radiation in the 320–900 nm wavelength range. It has been developed in the framework of the ASTRI project whose main goal is the design and construction of an end-to-end Small Size class Telescope prototype for the Cherenkov Telescope Array. The UVSiPM instrument is composed by a multipixel Silicon Photo-Multiplier detector unit coupled to an electronic chain working in single photon counting mode with 10 nanosecond double pulse resolution, and by a disk emulator interface card for computer connection. The detector unit of UVSiPM is of the same kind as the ones forming the camera at the focal plane of the ASTRI prototype. Eventually, the UVSiPM instrument can be equipped with a collimator to regulate its angular aperture. UVSiPM, with its peculiar characteristics, will permit to perform several measurements both in lab and on field, allowing the absolute calibration of the ASTRI prototype.

Keywords:
detector: SiPM

1. Introduction

UVSiPM is a stand-alone portable photon detector instrument designed to measure electromagnetic radiation in the 320–900 nm wavelength range. It has been developed in the framework of ASTRI (Astrofisica con Specchi a Tecnologia Replicante Italiana) Project [1] a Flagship Project financed by the Italian Ministry of Education, University and Research (MIUR) and led by the Italian National Institute of Astrophysics (INAF). The ASTRI project is focused, in its first phase, on the design and construction of an end-to-end Small Size scale Telescope prototype for the Cherenkov Telescope Array (CTA) [2], the international next generation ground-based observatory for very high energy gamma-rays (from a few tens of GeV up to several hundred of TeV). The ASTRI project will cover the highest part of the energy spectrum adopting innovative and challenging solutions never used in the framework of Cherenkov telescopes: the optics system will be based on a double mirror in Schwarzschild-Couder configuration instead of the standard single mirror; the camera will be composed by an array of monolithic multipixel Silicon Photo-Multipliers (SiPM) instead of the usual Photo Multiplier Tubes (PMT).

UVSiPM, developed at IASF-Palermo and based on the same SiPM used for the ASTRI prototype, has the aim of characterizing the device and evaluating its performance in lab; the final goal is to use UVSiPM as tool for the on field absolute calibration of the ASTRI prototype. The instrument is designed around a single multipixel (4×4 pixels) SiPM sensor coupled to an electronic chain working in Single Photon Counting (SPC) mode, capable of 10 ns double pulse resolution. Fig. 1 shows the UVSiPM detector and electronics. For on field measurements, a collimator will be mounted in front of the

Figure 1: UVSiPM detector.

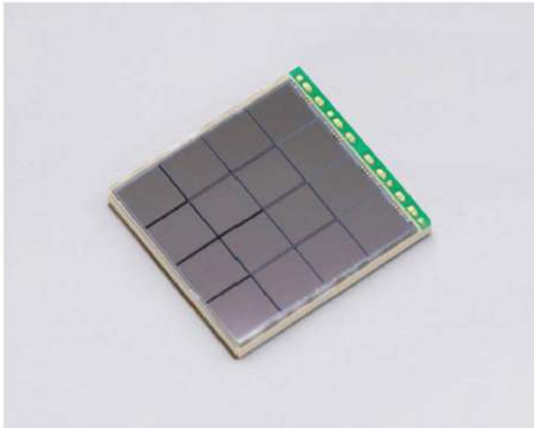

Figure 2: The monolithic SiPM array Hamamatsu S11828-3344 used in the ASTRI camera.

UVSiPM detector to regulate the angular aperture of the instrument.

2. SiPM general characteristics

Silicon Photo-Multipliers are a family of light sensors with very interesting characteristics. They are basically Avalanche Photo Diodes working in Geiger-mode, in which the reverse bias voltage is set beyond the Breakdown Voltage (overvoltage). In this way, a single photon absorbed in Silicon develops a saturated current avalanche with a gain of the order of 10^6. There are many advantages in using SiPMs compared to the traditional PMTs: excellent single photon resolution, high Quantum Efficiency (QE), no HV (bias voltages of the order of 30–90V), no damage when exposed to ambient light, insensitive to magnetic fields, small size. The drawbacks however are: high dark counts, afterpulses, optical crosstalk, gain strongly dependent on temperature.

SiPMs are the sensor that will be used to fill the camera at the focal plane of the ASTRI prototype. The device chosen is the Hamamatsu S11828-3344M[1], a monolithic SiPM array in a configuration of 4x4 square pixels (see Fig. 2) with a geometrical filling factor of about 74%. Each pixel, 3x3 mm in size, is made up of 3600 elementary diodes of 50 μm pitch.

[1]http://sales.hamamatsu.com/info/eul/MPPC/MPPC.html

3. The UVSiPM instrument

The UVSiPM instrument is basically composed by the SiPM sensor Hamamatsu S11828-3344M, coupled to an electronic chain working in SPC mode, with a double pulse resolution of 10 ns.

The total Photon Detection Efficiency (PDE) of SiPMs is defined as:

$$PDE = QE \times FF \times GAP$$

where QE is the quantum efficiency, FF the pixel filling factor and GAP the Geiger avalanche probability. A typical PDE of an Hamamatsu SiPM is plotted in Fig. 3. The sensor response ranges from UV to infrared wavelength due to the *p-on-n* technology used by Hamamatsu.

Normally the PDE is measured from the mean value of the output current, when the device is exposed to a known photons flux. In this way, pulses coming from crosstalk or afterpulses are included in the total PDE leading to an overestimate of the real efficiency. Evaluating the level of crosstalk and afterpulses is then one of the task of the SiPM sensors characterization.

When a photon is absorbed in Silicon a current avalanche produces an output pulse with a sharp rise-time (the discharge) followed by a very long tail (the recovery from the breakdown) as shown in Fig. 4. Typical rise-time is of the order of few hundreds of picoseconds, whereas the recovery time is in the range of tenths of nanoseconds. From Fig. 4, it is also evident the SiPM capability of distinguishing the number of detected photoelectron from the level of the pulse height. At high

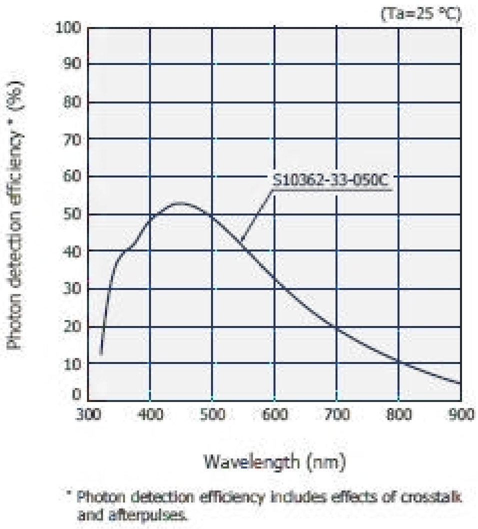

Figure 3: A typical example of SiPM Photon Detection Efficiency (Courtesy Hamamatsu)

pulse rate pile-up effects occur and afterpulses also contribute to rise the pile-up effects.

The most efficient way to count pulses with the peculiar shape produced by the SiPM, i.e. fast rise followed by a long tail, is to use the derivative of the signal. The electronics that performs this function is composed by an input amplifier buffer AC coupled to the SiPM, followed by a shaping circuit that gives the derivative of the signal cutting the negative part (pole-zero cancellation); an inverting amplifier drives a comparator whose threshold is set through a 12-bit DAC. Fig. 5 presents a snapshot from the oscilloscope that shows how a long tail pulse (SiPM-like) is changed into a short one. Fig. 6 shows the block diagram of the electronics and a snapshot from the oscilloscope in which two piled up pulses taken from a pulse generator are resolved in two separate pulses.

A FPGA is in charge to manage the pulse counting and the housekeepings collection. The communication with an external PC to control the instrument and the data exchange is managed by the DELPHIN[2], a proprietary interface board designed at IASF Palermo.

4. UVSiPM and ASTRI: main applications

UVSiPM has been designed as support instrumentation of the ASTRI prototype. Both of them use the same model of SiPM sensor and several kind of measurements, both in lab and on field, are foreseen for the characterization of the sensors and the calibration of the whole camera at the focal plane of the ASTRI prototype. The characterization of the SiPM will be carried out at the COLD Detector Laboratory in Catania (OACT/INAF). Among all the measurements, the most important are: PDE, dark counts, level of crosstalk and afterpulses evaluated as function of wavelength, overvoltage and temperature. Measurements of the detector response versus of the photon incidence angles are also planned.

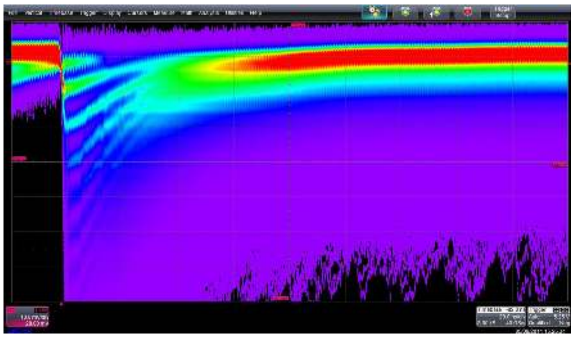

Figure 4: A typical example of SiPM pulse waveform.

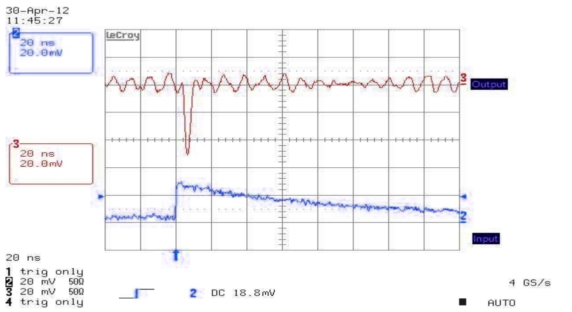

Figure 5: Snapshot from the oscilloscope that shows an amplified SiPM-like signal (green curve) and the relative fast shaper output (brown curve).

The design and implementation of UVSiPM derive from the well-tested UVscope instrument [3], developed at IASF-Palermo, whose sensor is a calibrated Multi-Anode PMT (MAPMT) working in SPC mode. The simultaneous usage of the two instruments on field, both provided with a calibrated John-B-25 Johnson/Bessel filter and equipped with collimators of proper length, will allow us to test the performance of UVSiPM under real observing conditions. The measurements will be based on the evaluation of the night sky background with the two instruments (UVSiPM and UVscope). The

[2]http://www.iasf-palermo.inaf.it/cgi-bin/INAF/pub.cgi?href=facilities/electronic/instruments/delphin/index.html

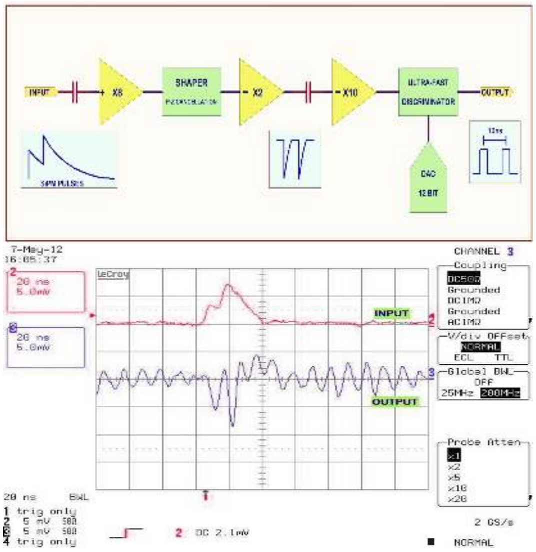

Figure 6: The block diagram of UVSiPM front-end electronics is presented in the top panel; a snapshot from the oscilloscope in which two piled up pulses (green curve) are resolved (brown curve) is shown in the bottom panel.

comparison will allow us to test the end-to-end performances of SiPM vs MAPMT and then to use UVSiPM for the absolute calibration of ASTRI telescope.

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