Study of silicon photosensor applicability for scintillator detectors

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Abstract. The aim of the present work is the creation a prototype of anticoincidence system AC for gamma-telescope GAMMA-400. The detectors of AC are developed on the basis of plastic scintillator and silicon photomultipliers. This work is focuses on research of applicability of silicon photomultipliers SiPM by company SensL, type 60000 with BC-408 plastics for the prototype of anticoincidence system detector ACtop. In frame of project the assembly for measuring of the SiPM characteristics such as the linearity, boundary of saturation, the time resolution was developed. The final stage of work was the integration of the prototype of anticoincidence detector.

1. Introduction

Gamma-ray astronomy is science domain to study the properties of space objects such as pulsars, supernova remnants, active galactic nuclei, black holes, quasars and other astrophysical subjects by their gamma-emission – see, for example, [1]. Registration of γ-quanta involves the determination of its energy, the time and direction of their arrival. The special instruments are developed for this purpose named gamma-ray telescopes. Gamma-ray telescope is the instrument determining the aspect and time of photon arrival and measures it`s energy. Registration of photons with energy more than 100 MeV based on the generation of electron-positron pairs. This process proceeds by interaction of gamma-quants with the material of the gamma-ray telescope converter – see, for instance, [2]. Up to now the experiments in gamma-ray astronomy were carried out onboard satellites, such as: SAS 2 [3], GAMMA-1 [4], Egret [5], Fermi-LAT [2,6].

2. The GAMMA – 400 experiment

The international project GAMMA-400 intended for registration of γ-emission in the energy range $(0.1–3.0)\times10^3$ GeV [7]. The gamma-telescope GAMMA-400 has a traditional physical layout, it consists of converter, surrounded by anti-coincidence detectors, time of flight system, two calorimeters, and other detectors [8]. The principle of instrument operation is as follows: gamma-quantum is not registered in anticoincidence system, then it is converted into electron-positron pair in the converter-tracker, and then observed by the detectors of telescope. Anticoincidence detectors are used for rejection of the cosmic ray charged particles [9, 10]. The efficiency for charged particles has to be at least 0.99999, because the flux of high energy protons (10^4 $1/m^2s$), several orders of magnitude more than the gamma ray flux (10^{-1} $1/m^2s$) [11]. Proton flux is the main background of charged particles incident on the surface of gamma-ray telescope. Also low energy protons with flux $\sim10^7$ $1/m^2s$ [12, 13] should taken into account because of GAMMA-400 orbit mostly will in the outer Earth magnetosphere – see [14] and references therein in particular.

This work is devoted to the study of applicability of silicon photomultipliers SiPM by company SensL, type 60000 with BC-408 plastics for the prototype of anticoincidence system detector ACtop. The anticoincidence system consists of upper detector ACtop and 4 lateral ones AClat. Each detector is a set of scintillator bands arranged in two layers so as to maximize the rejection of charged particles. Each band is seen by photosensors from the ends of the scintillator. ACtop prototype consists of one scintillators band and two boards with 6 silicon photomultipliers (SiPM) on each. Besides the high protons flux registration efficiency and sensitive area ~10^4см^2 detector should have a high time resolution better than 10^{-8}s. This is necessary for the registration of backsplash particles from the calorimeters. This increases the efficiency of instrument. Time resolution of SiPM has to be less than 500 picoseconds for this experiment. The type 60000 SiPM by SensL company were used instead of usual vacuum photomultipliers due to their low supply voltage, insensitivity to magnetic fields, high time resolution and low sensitivity to temperature and supply voltage variations [15]. SiPM is the photodetector based on matrix of the microphotodiodes, formed on a common substrate, operated in Geiger mode – see, for example, [16].

3. The experimental technique and data analysis

The measurements were carried out by assembly, the scheme is shown in figure 1.

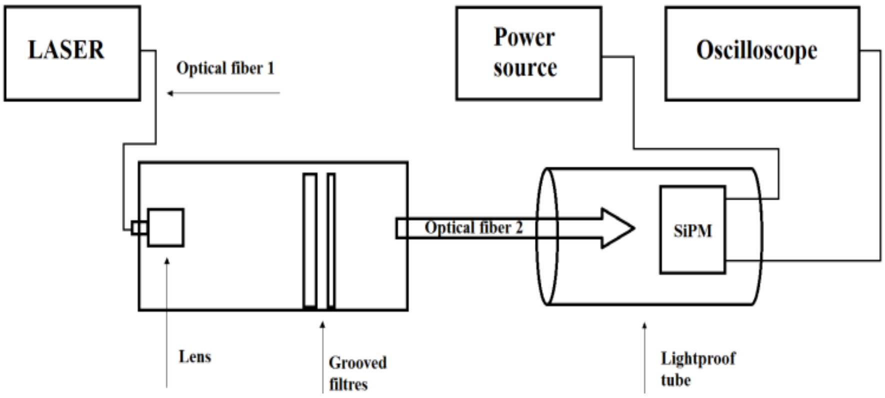

Figure 1. Scheme for measuring amplitude properties.

A beam of light coming from the laser to the input of the lens camera via optical fiber 1. The lens and grooved filters are in camera. Since in the optical fiber light has dispersion, an output beam is defocused. So at the input of the measuring path the lens was installed for light collecting. The focal distance of the lens is 15 cm. This value was chosen thus the light beam is strongly focused on the input of waveguide cable 2. After the lens it is necessary to install the set of grooved filters with different absorption for the light attenuation. Details of the camera are blacked to prevent light reflection. Then, already attenuated beam of light crosses on the fiber cable 2 input, and from the output of the optical fiber 2 reaches on the sensitive surface of SiPM. Laser Picosecond optical pulse generator PLS-405-660 (monochromatic, λ = 405 nm) was selected to generate light flashes to study of the SiPM properties. It emits a narrow beam of light precisely along the optical fiber. SiPM was biased by a low-voltage power supply and the SiPM signal is taken to an oscilloscope type TDS5000B. The intensity of the laser was attenuated using calibrated optical glasses.

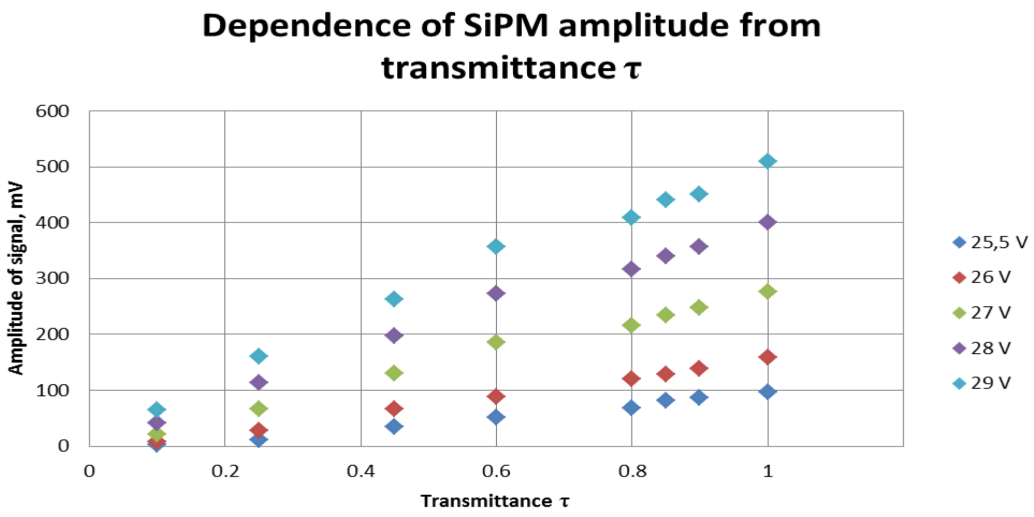

Figure 2. Dependence of SiPM amplitude from transmittance.

The measured signal amplitude dependence on the transmission coefficient of grooved filters is shown in figure 2 for different supply voltages. Same dependences were obtained for the whole SiPM set. This figure demonstrated the linearity in the wide range of incident light intensity. The pulse with minimal amplitude corresponds to the amplitude caused by scintillation of relativistic singly charged particle in scintillator of 1 cm thickness. The amplitude was measured for higher light intensity to determine the saturation area of the sensor. Dependence of amplitude from laser intensity is shown in figure 3. The graph shows the saturation region. For example, the saturation corresponds to the signal with amplitude of 640 mV at a supply voltage 29 V.

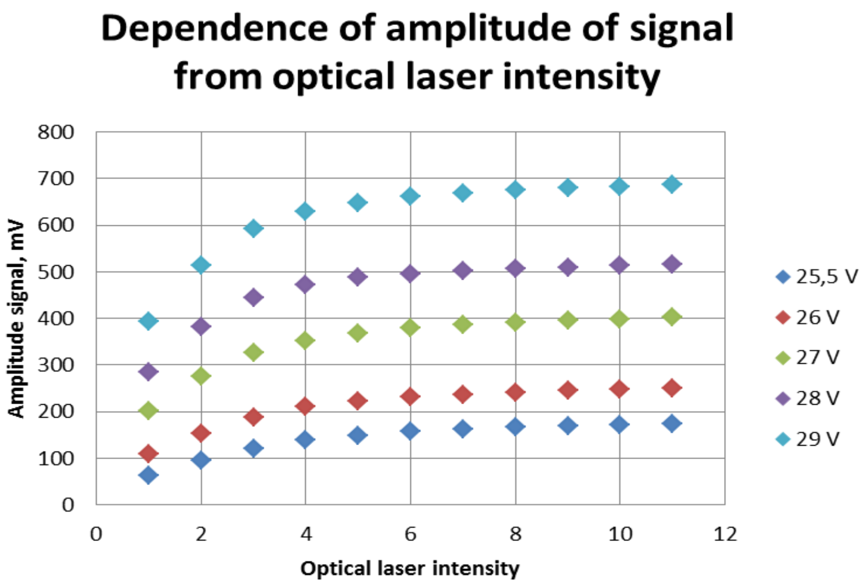

Figure 3. Dependence of SiPM amplitude on laser intensity.

The analysis of time resolution was carried out by means of the assembly shown in figure 4. The light signal is sent simultaneously onto two photosensors. The delay between the signals of pair of SiPM was measured. 2000 events were recorded for each pair of photomultipliers. Figure 5 shows a typical distribution of delays between SiPM couple pulses.

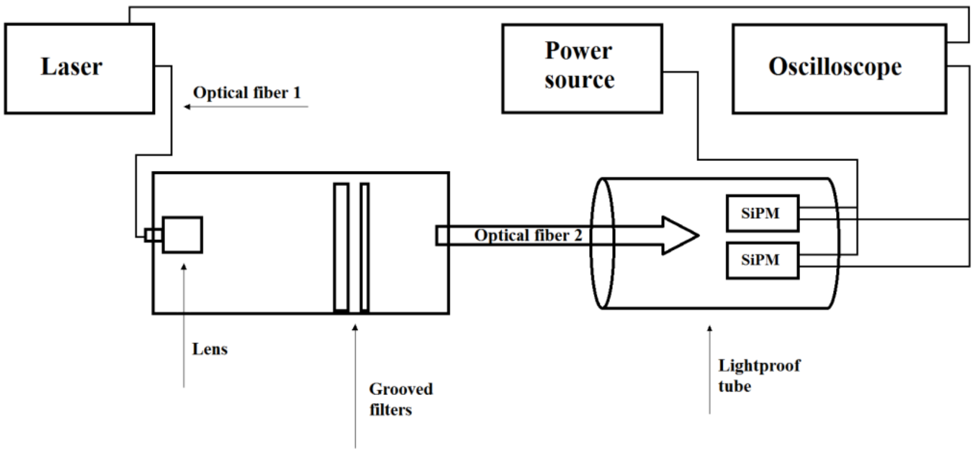

Figure 4. Assembly for measuring time resolution.

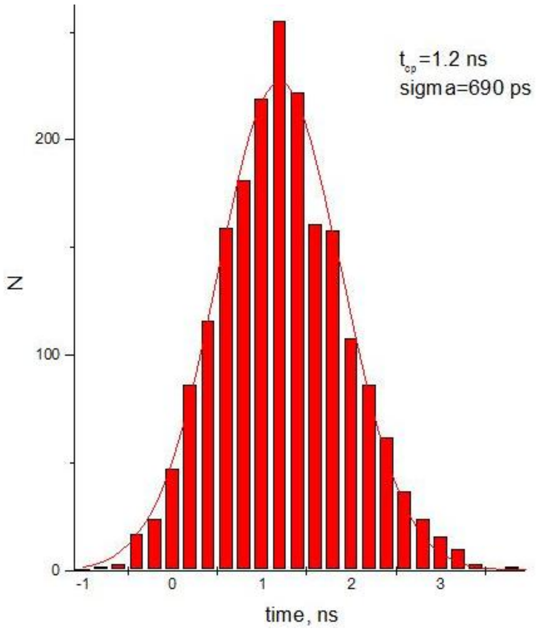

Figure 5. Distribution of delays between the signals from two SiPM

The obtained value of the standard deviation of the distribution was found to be σ = 690 ps. It corresponds to the 490±12 ps time resolution of SiPM.

4. Conclusion
Thus, following conclusions were reported. Firstly, each SiPM of the set is interchangeable, since their amplitude characteristics are similar. Second, the average time resolution of silicon photomultipliers is equal to 490±12 ps. The resulting value satisfies the requirement of at least 3ns needs to backsplash particles rejection in gamma-ray telescope GAMMA-400 [17]. Considering the measurements results, it was concluded that type 60000 SiPM by SensL company can serve for a replacement of the vacuum photomultipliers in anticoincidence detector of gamma-ray telescope.

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