SiPM timing characteristics under conditions of a large background for lidars

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Abstract. Silicon photomultipliers (SiPM) have found their use in various fields of industry and scientific experiments. This paper considers study of the SiPM possibility to detect low-intensity light pulses (down to single photons) under high-intensity background illumination. This may be useful for the development of laser rangefinders operating under natural light using SiPM as crucial photosensor. Moreover, the presented data describes some physical properties of LIDAR with SiPM under radiation exposure, which always affects its intrinsic noise.

1. Introduction
The determination of the distance to both fixed sites and moving target by means of variable methods is one of the most critical issues of our time. For this purpose, light detection and ranging (LIDAR) are often utilised. In this paper, we consider the possibility of employing silicon photomultipliers (SiPM) in LIDAR. It could be useful for the development of laser rangefinders operating under natural light using SiPM as main photosensor.

SiPMs are very compact devices; it’s compatible with complementary metal-oxide semiconductor (CMOS) technology. SiPM production could be low-cost relatively to the convention vacuum photomultipliers. The first prototypes were developed in 1980s-1990s in Russia. The silicon photomultiplier consists of an array of independent cells operating in Geiger mode. The photodetector has the excellent photon-counting capability, high photon detection efficiency, high time, and amplitude resolution; the detector also insensitive to magnetic fields, up to about 7 T. Therefore this type of photodetectors is an advanced instrument used in many applications (e.g. modern physics experiments, accelerators, modern medicine, and outer space), and hence LIDAR with SiPM could benefit a lot for the accuracy of range measurement.

This article outlines the physical properties of the SiPM operations under high-intensity background illumination; herewith it registers one-photon impulses. The problem is relevant for LIDAR, for example that might be related to radiation exposure.

At the beginning of the article a laboratory-scale experimental facility is presented, thereafter, that would be involved. The substance of article contains experiments results and a discussion on the results is presented. The conclusion places capabilities of LIDAR, for which the major component is SiPM, and about the potential applications of this technique.
2. The experimental results

2.1. A description of the laboratory-scale experimental facility

The laboratory-scale experimental facility consists of 4 parts: a detecting module (1) with both SiPM and a notch filter; a wideband 1 GHz preamplifier with a gain 100; lens (2); a laser (3) and a reflecting surface (4).

In this case SiPM 1x1mm² was used; its peak sensitivity wavelength is 490 nm, the photon detection efficiency (PDE) is 10-12%, the dark count rate (DCR) is from 1 to 3 MHz.

The detecting module registers the laser radiation reflected from a surface. The signal of SiPM with fluctuations can be seen in Figure 2. Background noise flow has roughly equal amplitude. The background noise level had been increased intentionally for research purposes, at least in order to show that SiPM is capable of detecting the reflected laser radiation, even when external noise level is high.

![Scheme of the experimental setup](image1.png)

**Figure 1.** Scheme of the experimental setup.

![SiPM signal waveform](image2.png)

**Figure 2.** SiPM signal waveform of SiPM with an average background noise pulse rate 100 MHz.

The detector was operated in the linear mode, it can be seen in Figure 3, that shows the verification plot of the single-photon pulse frequency as a function of SiPM current, a linear relationship was observed. Plot is a calibration dependence of the single-photon pulse frequency and here it’s needed to guarantee the results of measuring.

![Verification plot of the single-photon pulse frequency](image3.png)

**Figure 3.** The calibration plot of SiPM current as a function of the noise pulse rate.

![SiPM amplitude vs. current](image4.png)

**Figure 4.** SiPM amplitude vs. current of SiPM.
2.2. An external impact analysis

Further research is needed to analyse the influence of external factors like an external light action, as in this case. The Figure 4 shows the increase number of photon-discharged microcells, when the constant background intensity changes. This may be explicable by the fact that photons are incident on the surface of microcells, when they are activated. If search of the optimum, it needs to take into account, that the amplitude of SiPM signal decreases, when the total number of microcell grows.

Changes of external indirect lighting could affect LIDAR parameters, such as time resolution et al. The Figure 5 provides time resolution as function of average SiPM current, an average number of photon-discharged microcells changes between 6 and 25. As can be seen here, the increasing background illumination leads to decreasing values of time resolution.

**Figure 5.** Plot of time resolution vs. current of SiPM for different average number of microcells.

**Figure 6.** Amplitude spectrum of SiPM.

Oscilloscope measures an amplitude spectrum, as represented in the Figure 6, an average background noise rate is 5 MHz, and the notch filter attenuates the background noise. This is a common spectrum demonstrating the photon-counting capability of SiPM.

**Figure 7.** Plot of time resolution vs. a background noise frequency, constant fraction discriminator is used.

**Figure 8.** Measuring of distance to rapidly moving objects.
2.3. Time resolution for distance measurements
The accuracy of range measurement to a target can be defined by time resolution. Time resolution starts to deteriorate when the constant fraction discriminator’s threshold value is reduced, and it can be seen in Figure 7. Time resolution grows with the increasing of background noise; because, since, statistically, the SiPM signal and the background noise signal could be added to each other.

The Figure 8 indicates the time spectrum, here LIDAR measures the subject distance, changed between 120 cm and 129 cm. Laser pulse duration is 30 ps. In addition, here account should be taken, that 1-5 photons are registered by SiPM in the detecting module. LIDAR has the ability to calculate distances by measuring the time for a signal to return. Therefore, if measurements are made using this method, then the accuracy of LIDAR varies between 5 and 10 cm.

3. Conclusion
The use of SiMP as the substantial photosensor in LIDAR presents clear advantages, such as fast performance and the photon-counting capability along with good time resolution. This device can be used in systems of soft landing on the Moon and in the automobile industry. Furthermore, on this basis 3D – LIDAR could also be created.

Acknowledgements
The authors are grateful to E.F. Maklyaev and Y.A. Melikyan for useful discussions. This work was supported by Competitiveness Program of National Research Nuclear University MEPhI.

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