The main purpose of the project revolves around detection of extremely small light intensities. Finding a method of measuring the smallest entity of light i.e. single photon. Research focused on finding a methods of single photon detection gain a lot of interest thanks to the work of Albert Einstein who described so called “Photoelectric effect”. This effect is the observation that many metals emit electrons when light shines upon them. Electrons emitted in this way are called photoelectrons. The phenomenon has been studied since in electronic physics, quantum chemistry or electrochemistry. Single photon detection is problematic due to the fact that when photon falls on the metal surface it produces only one electron-hole pair. It is not possible to detect single electrons. But after some years there have been developed a method of detecting single photons with the use of Photomultiplier Tube (PMT). The detector operated in very high electric field (>1kV). Single electron-hole pair appearing due to photoelectric effect was accelerated in high electric field and directed to the set of metal plates called dynodes. Collision with each dynode caused the spiking of another electron-hole pairs from the dynode structure. Each collision brought more pair and finally after stream of electrons passed through entire PMT it was multiplied about 10 million times. So from single electron the gain was 100 million electrons. The issue of the PMT was large dimensions, high bias voltage (>1kV), sensitivity to magnetic field and low mechanical strength. Until recently PMT was the only solution for single photon detection. In the late 90s creation of Silicon Photomultiplier (SiPM) change this situation. SiPM is a semiconductor device, an array of photodiodes connected together in parallel. Each element of this array consists of diode and a quenching resistor to limit current flowing through the junction. When SiPM is biased beyond electrical breakdown (Geiger mode) typical gain is between 10^5 and 10^6 (comparable to these of PMTs). One a photon entering the photodiode due to photoelectric effect give birth to one electron-hole pair. This pair is accelerated in electric field and due to the proper doping of layers of the detector structure it reaches high velocities. It collides with the structure and create another electron-hole pair, hence multiplying the charge. Because of the proper polarization of the structure (Geiger mode) the multiplication is always identical and the resulting pack of electrons is called an avalanche. Each photon can be a source of an avalanche in a single cell and because of an isolating ring this avalanche does not spread out of the cell. Each avalanche represents exactly the same value. The total output is a sum of current from all microcells hence it is proportional to the number of avalanches, which in turn is proportional to the light intensity. The output is a discrete signal. The main advantages of SiPM with respect to the standard photomultiplier are: the compact size, high sensitivity (single photon discrimination), low power consumption and low operating voltage - lower than 100 V. Moreover, it is immune to magnetic field and has very high mechanical strength. The aim of this project is to utilize SiPMs in the measurement of single photons. These detectors are becoming more and more popular in the field of light detection but there are still being upgraded in terms of detector’s construction and methods of measurement. The project focuses on one of SiPM’s main issues, i.e. its susceptibility to the fluctuation of temperature. When temperature changes the gain of the detector is also changing. This adversely affect the sensitivity of measurements, especially in single photon detection, where parameters of the measurement setup need to remain constant during measurement. This unwanted influence can be reduced by introducing Peltier modules that could regulate the temperature. But it is also associated with extra costs of the measurement system, additional external control and cables of the modules itself. This is acceptable compromise in case of measurement system with single or very few detectors. However, in multichannel, multidetector systems there is a need of other solution. Bias voltage of the detector also has strong impact on the gain of the detector. These dependence can be utilize to compensate the influence of the temperature by regulating the bias. As a result the SiPM’s gain is stabilized. Another aim of the project is to create a measurement system for the detection of signals from SiPMs. The detector cannot operate on its own that is why there is a need of designing a dedicated front-end ASIC to amplify and convert SiPM’s signals. The development of high-speed electronic circuits for measurement of physical quantities related to the registration of photons, such as amplitude or time brings many scientific challenges that need to be resolved in the project. The final aspect of the project is to verify the correctness of all proposed methods of single photon detection, SiPM’s gain stabilization and front-end ASIC design. This is going to be verified during the measurements of fluorescence of biomarkers. Fluorescence is the phenomenon where substance that has absorbed light of specified wavelength is shortly after emitting light of different wavelength. By detecting the intensity of emitted light it can be determined what was the quantity of the substance. The substance is called fluorescent dye and it can be attached to e.g. antibody of specific substance i.e. an enzyme. In this way it is possible to measure the quantity of this enzyme. Examples of potential application are: determination of very small samples of DNA from spots of blood, tissue sections, the study of naturally occurring bioluminescence substances in plants, determination of enzymes acting as activators in chemical reaction, the interaction of substances in cells, monitoring active proteins in living cells, the in-vivo gene expression testing, using a variety of bioluminescent markers (i.e. infectious diseases), determination of antigens, antibodies or molecules by enzymes in the immune system, monitoring the biotechnology processes, nucleic acid testing, testing food samples, protection of the environment (i.e. testing water), testing HIV, hepatitis, certain hormones, enzymes, bacteria.

Designed front-end ASICs can be utilized in the research concerning the detection of extremely low intensities of light (single photon detection). It will be possible to build applications that are characterized by very high detection sensitivity. Implemented gain stabilization algorithm is desired mainly in the research with large number of detectors, where keeping the temperature of all SiPMs on constant level is difficult. These studies may include e.g. physical experiments with scintillators, applications for the measurement of Cherenkov radiation, Positron Emission Tomography systems and many others. Project results will also strongly influence luminescence research. Especially, studies on the fluorescence of biomarkers in microfluidic systems, which will be developed within the project scope of work. The versatility of the method may allow to adjust it to the measurement of many substances. Development of methods for the measurements made with a very precise, but inexpensive Silicon Photomultipliers could help to increase the availability of this type of study to other research centers, which is likely to lead to new discoveries in the field of medicine and biochemistry.