Lights sensors: Photomultiplier tube (PMT) and Silicon Photomultiplier (SiPM)

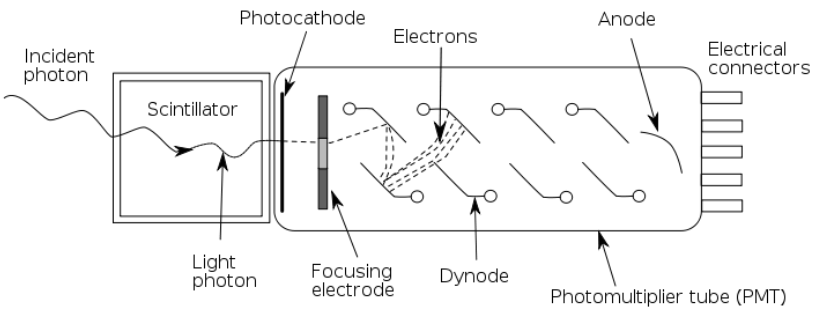
The aim of this practical is to practice with light detectors. The photomultiplier tube is the standard and well known vacuum photo-detector and are sensitive detectors of light in the ultraviolet, visible, and near-infrared ranges of the electromagnetic spectrum. These detectors multiply the current produced by incident light by as much as 100 million times.

Semiconductor devices, particularly avalanche photodiodes such as the silicon photomultipliers, are alternatives to photomultipliers.

Main Components:

Photomultiplier (PMT):

The invention of the photomultiplier is predicated upon two prior achievements, the discoveries of the photoelectric effect and the secondary emission (i.e., the ability of electrons in a vacuum tube to cause the emission of additional electrons by striking an electrode).

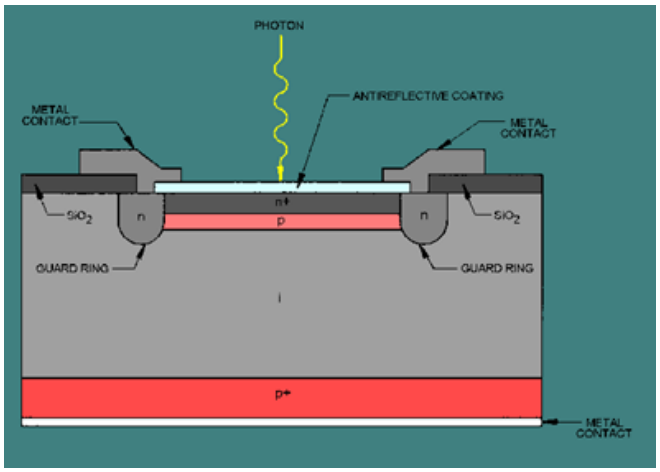


Photomultipliers are constructed from a glass envelope with a high vacuum inside, which houses a photocathode, several dynodes, and an anode. Incident photons strike the photocathode material, which is present as a thin deposit on the entry window of the device, with electrons being produced as a consequence of the photoelectric effect. These electrons are directed by the focusing electrode toward the electron multiplier, where electrons are multiplied by the process of secondary emission. The electron multiplier consists of a number of electrodes called dynodes. Each dynode is held at a more positive voltage than the previous one. The electrons leave the photocathode, having the energy of the incoming photon. As the electrons move toward the first dynode, they are accelerated by the electric field and arrive with much greater energy. Upon striking the first dynode, more low energy electrons are emitted, and these electrons in turn are accelerated toward the second dynode. The geometry of the dynode chain is such that a cascade occurs with an ever-increasing number of electrons being produced at each stage. Finally, the electrons reach the anode, where the accumulation of charge results in a sharp current pulse indicating the arrival of a photon at the photocathode.

Silicon photomultiplier (SiPM)

The Silicon Photomultiplier (SiPM) is a multipixel semiconductor photodiode, where the pixels are joint together on common silicon substrate. Each SiPM pixel operates in limited Geiger mode under bias voltage of 10-20% more than breakdown voltage, so each carrier generated by photons or

thermally gives rise to a Geiger-type discharge. This Geiger discharge is stopped when the voltage goes down below breakdown value due to external resistor *R* on each pixel (typical *R* value is about 100-200 kΩ). Each SiPM pixel operates as independent photon Geiger micro counter. Because all SiPM pixels work together on common load, the output signal is a sum of the signals from all pixels fired. So such a number of pixels, where each element operates digitally as a binary device, works an analogue detector, which can measure the light intensity.

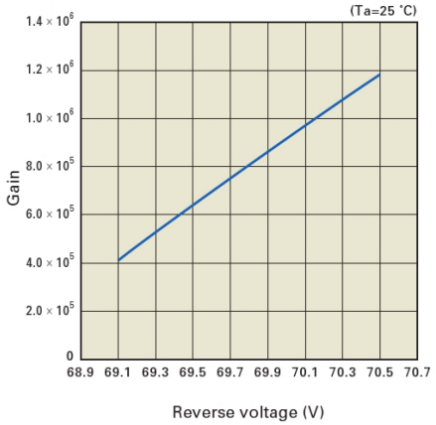


YAP crystal: Yttrium-Aluminum-Perovskite (**YAP**) is a fast, mechanically and chemically resistant scintillator material, with mechanical properties enabling precise machining to many different shapes. This inorganic scintillator is non hygroscopic, glasslike, with a high density (5.55 g/cm^3) and an effective atomic number Z=36. Main characteristics of this scintillation material are a good light yield (about 18000 photons/MeV) and a short decay time τ=27 ns at a **wavelength of maximum emission**, which is **350 nm**. **YAP** scintillators are normally employed for photon spectroscopy in different fields including Mössbauer spectroscopy, x-ray imaging and medical applications.

Plastic scintillator: A scintillator is a material, which exhibits scintillation—the property of luminescence when excited by ionizing radiation. A plastic scintillator consists of a solid solution of organic scintillating molecules in a polymerized solvent. Because of the ease with which they can be shaped and fabricated, plastic scintillators have become an extremely useful form of organic scintillator. The scintillation emission of a typical plastic scintillator has a maximum around 400 nm. Plastic scintillators are characterized by a relatively large light output [typically 25-30% of NaI(Tl)] and a short decay time, on the order of a nanosecond. This makes the material well suited for fast timing measurements.

<u>Set-ups:</u>

A) PMT is coupled with a YAP scintillator that is situated close to the Americium source. PMT has its input cable coming from the high voltage power supply and the output signal cable that will be connected to the oscilloscope to analyze signal shape.
B) SiPM sensor is coupled with a plastic scintillator in the detector set-up. High voltage power supply of around 70 V is given through the Ultravolt- module. It generates, with an input of ± 5V, the required power supply being tunable via computer software (on the desktop there is a shortcut icon for the program named temp_V_cycle). SiPM gain varies with temperature and the bias voltage as in the following figures.



Signal output is pre-amplified by its front-end electronics and at the end, LEMO cable carries the signal output coming from the detector. The pre-amplified signal needs to be discriminated by a low threshold discriminator (threshold for one photoelectron is about 20 mV) and connected to the counter. A fan-in fan-out module function is to makes multiple outputs from one or more analog or logic input and in our case will be used to send signal also to the oscilloscope.

Exercices:

A) Step 1: Using set up A - switch on the oscilloscope and watch the signal on the screen.

Amplitude	Rise time	Description of the signal (graphic representation)

Step 2: modify HV and watch the signal on the screen. What changes in the signal shape?
Question 1: Does the amplitude of the signals vary as you expected?
Question 2: Did you notice a change in the shape of the signals?
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B) Step 1: Using set up B switch on the oscilloscope and watch the signal on the screen.

Amplitude	Rise time	Description of the signal (graphic representation)

Step 2: Modify power supply (using the ‘temp_V_cycle’ programme on the desktop) around characteristic voltage value.

Power supply	Amplitude	Rise time

Remember that the gain is a function of voltage applied.

Question 3: What changes varying the HV applied?

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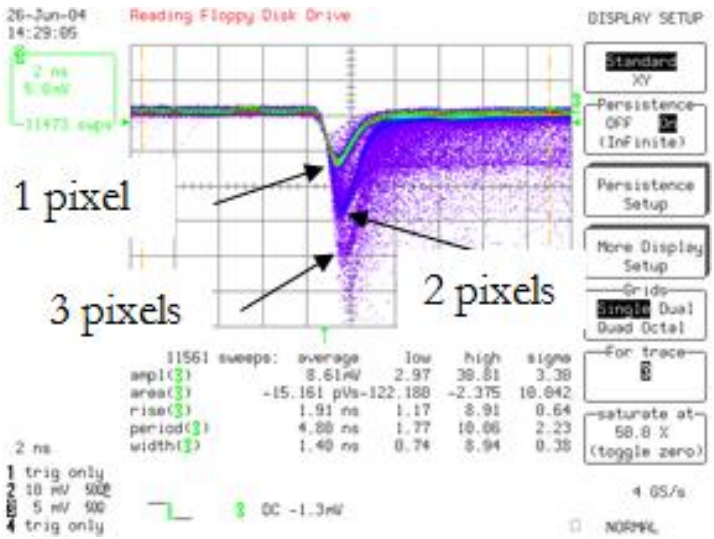
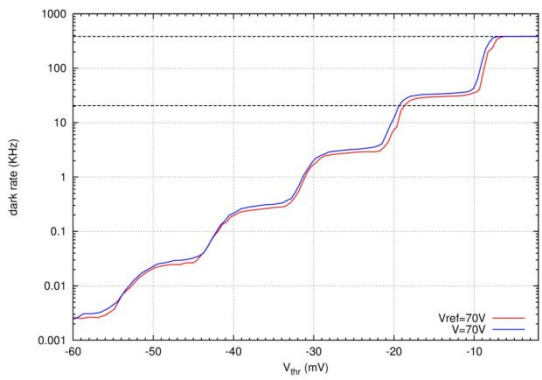
Step 3: Signal observation as function of the oscilloscope threshold. Connect the signal output to the oscilloscope. Vary the trigger value and identify the value of the threshold for one, two and three photoelectrons like in the figure. Pixels are as on-off device. If it is hit by one photon it is on. One pixel corresponds to one photoelectron.



Photoelectrons	Threshold value (trigger)
1	
2	
3	

Step 4: Dark Count Rate measurements as function of the discriminator threshold.

Threshold value	Counts



Step 5: Count rate measurement with the source at a fixed threshold.

Threshold value	Dark rate counts	Source count rate