
CERN

Micro-controller : Reading temperature of SiPM detector and compensating operating voltage for the same gain

XV ICFA SCHOOL ON INSTRUMENTATION IN ELEMENTARY PARTICLE PHYSICS

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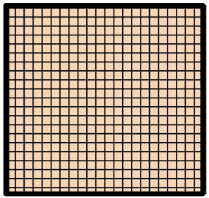
Section 1

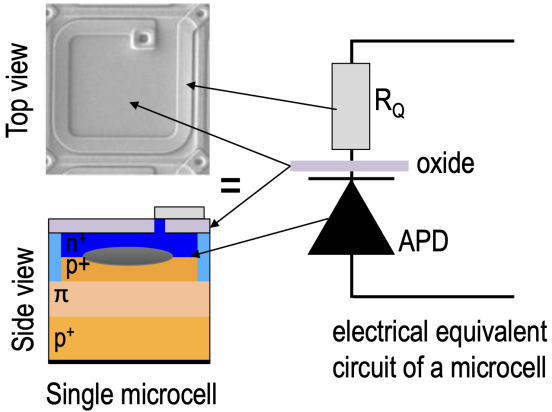
Introduction

- (SiPMs) solid-state photodetectors with high amplification factors
- Enable single-photon detection in various scientific experiments.
- Maintaining stable gain is crucial for SiPM performance, but temperature fluctuations can affect it.
- Two approaches for temperature control in SiPMs include:
  - Utilizing temperature sensors located near the SiPM sensors to adjust power supply voltage.
  - Using averaged SiPM current as a temperature-sensing signal to adjust bias supply voltage.

Figure of SiPM (image not to scale)



SiPM is an array of microcells



SiPM structure

Overvoltage is defined in terms of:

$$\mathrm{V_{OV}} = \mathrm{V_{bias}} - \mathrm{V_{bd}(T)} \tag{1}$$

The Gain of SiPM

$$\mathrm{G(V,T)} = \frac{Avalanche_{charge}}{q} = \frac{C_d(V_{bias} - V_{bd})}{q} \tag{2}$$

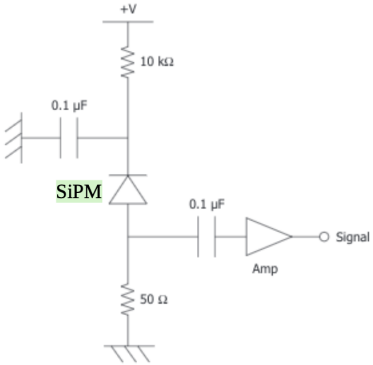
Breakdown Voltage

$$\mathrm{V_{bd}(T)} = \mathrm{V_{bd}(T_0)} - \beta * (T - T_0) \tag{3}$$

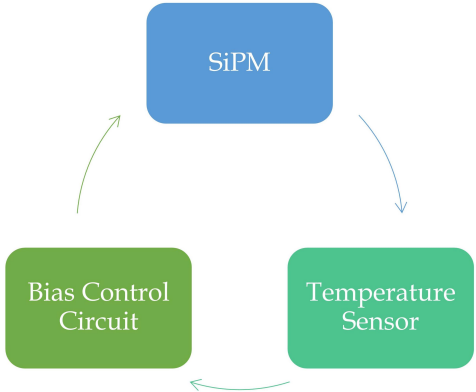
The Gain of SiPM

$$\mathrm{G(V,T)} = \frac{C_d(V_{OV} + V_{bd}(T))}{q} = \frac{C_d((V_{OV} + \beta(T - 25))}{q} \tag{4}$$

Biasing is the process of applying a voltage to the SIPM to control its performance.

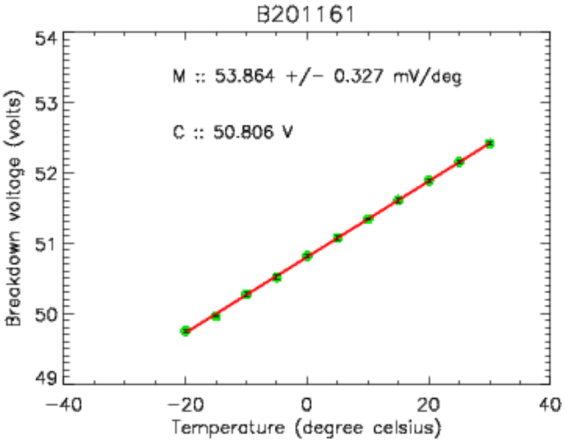


Biasing of SiPM



Basic diagram of thermo-compensated SiPM

- The temperature coefficient of a SiPM refers to how its performance changes as the temperature changes.
- SiPMs typically have a negative temperature coefficient, which means that their gain (amplification of the signal) decreases as the temperature increases.



Temperature coefficient of SiPM

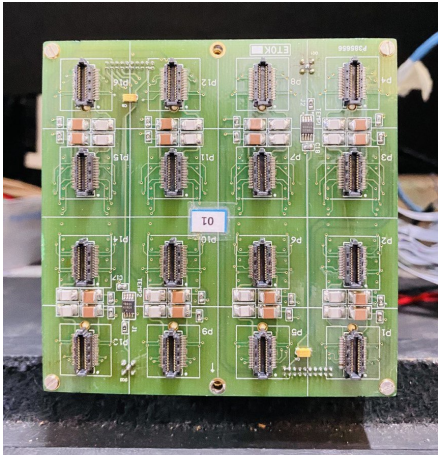
Section 2

Experimental Setup

- Solid-state photodetector capable of single-photon detection due to its high amplification factor
- Lower operating voltage
- Immunity to magnetic fields and ruggedness
- Low light levels detection.
- Variation of gain as a function of temperature.

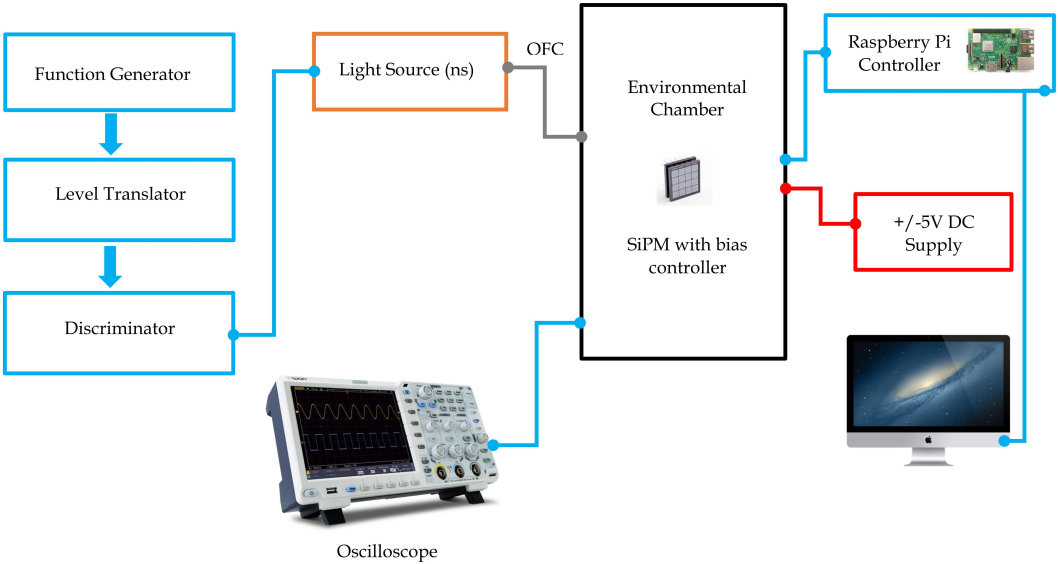
16 channels 4×4,

50×50 um pixel size



SiPM board with temperature sensor

(S13361-3050AS-04 series SiPM)



Block diagram of experimental setup

Setup to study gain vs temperature of SiPM

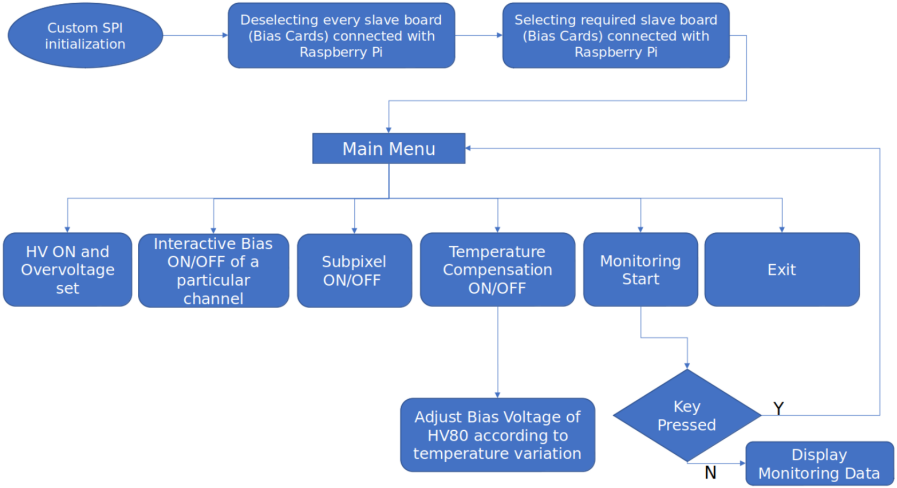
SiPM Board

Temperature compensated bias unit

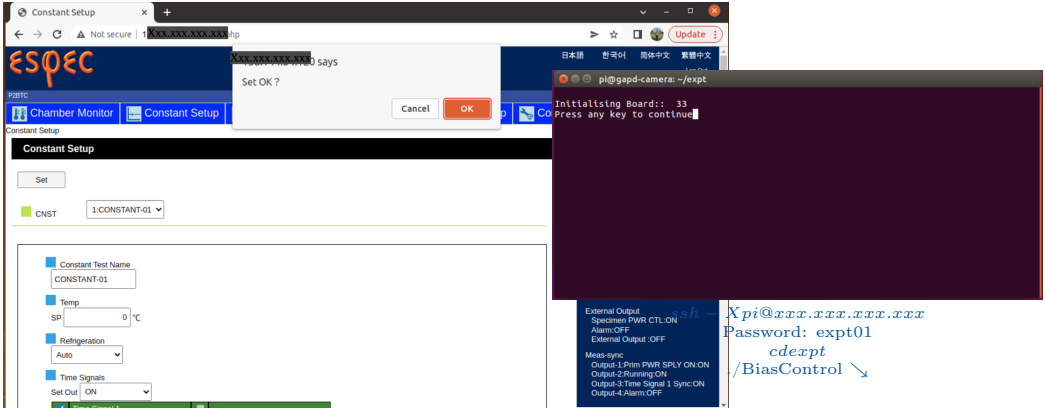
Preamplifier

Raspberry Pi4 AND Microcontroller (ATxmega256A3U)

Description of instruments used in the measurement setup



Application Control Software



Web Application to control the Environmental chamber

Section 3

Experimental Observations

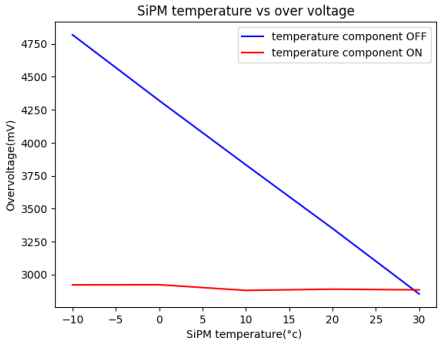
Left Data is taken with OFF Temperature Compensation right data is taken with ON in the table below.

ENVIR. CHAMBER TEMPERATURE (DEGREE CELCIUS)	SiMP/GAPD Sensor Temperature	Pulse Amplitude (mV) ± stdev	Bias Voltage (mV)	Over Voltage (mV)	SiMP/GAPD Sensor Temperature	Pulse Amplitude (mV) ± stdev	Bias Voltage (mV)	Over Voltage (mV)
30	29.6875	251.68±6.97	55469	2852	29.2500	244.91± 6.53	55489	2883
20	20.6250	275.84±7.40	55474	3349	19.6250	247.03±6.89	54976	2888
10	10.6875	306.84 ± 8.86	55464	3832	10.000	251.37±7.16	54458	2879
0	0.7500	340.11±9,65	55454	4320	0.5624	254.04±7.15	53975	2922
-10	-8.8750	366.64 ± 10.64	55464	4819	-9.1250	257.17±7.38	53472	2921

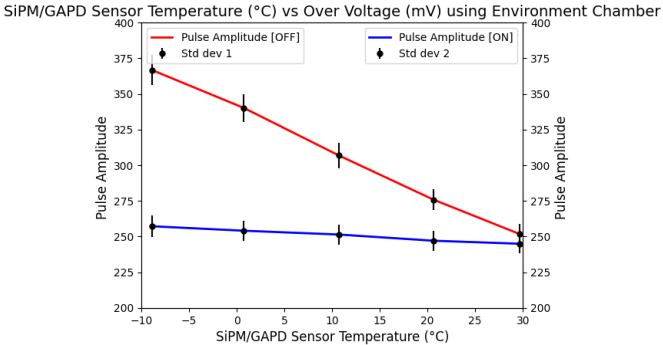
Section 4

Results

- An important consideration for optimizing SiPM performance



- We see that pulse amplitude or gain of SiPM decreases as we increase its temperature and it is almost constant when temperature compensation is on.



Section 5

Conclusion

- For a fixed bias voltage, the gain of a SiPM changes linearly with temperature
- Breakdown voltage varies linearly with temperature
- Adjusting the bias voltage with the help of bias control and Temperature compensation circuit
- Overvoltage remains constant which eliminates gain-temperature dependence.

References

Kaplan A., et al. Nucl. Instrum. Methods Phys. Res. A, 610 (1) (2009), pp. 114-117.

Licciulli F., Marzocca C. IEEE Trans. Nucl. Sci., 62 (1) (2015), pp. 228-235.

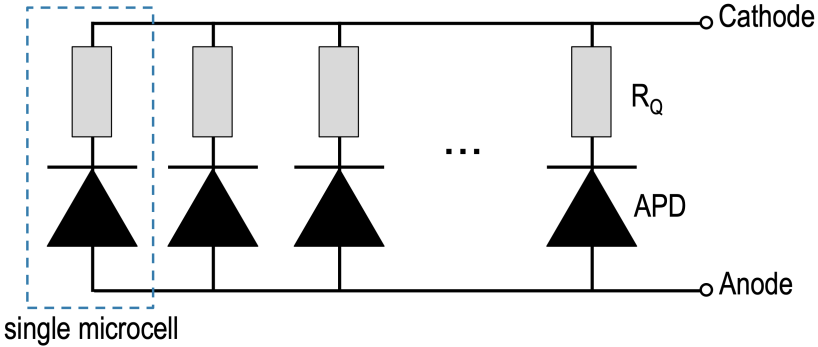
Silicon Photomultiplier Operation, Performance Possible Applications
https://www.hamamatsu.com/content/dam/hamamatsu-photonics/sites/static/hc/resources/W0003/sipm_webinar_1.10.pdf

Thank you for listening!!

Section 8

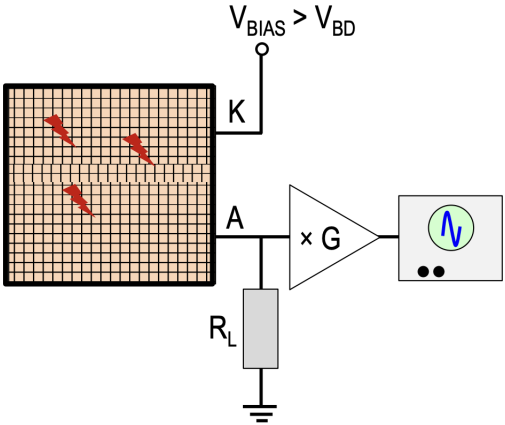
Backup

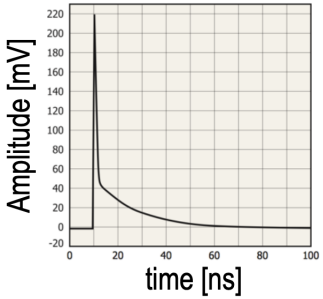
SiPM structure



All of the microcells are connected in parallel.

SiPM operation

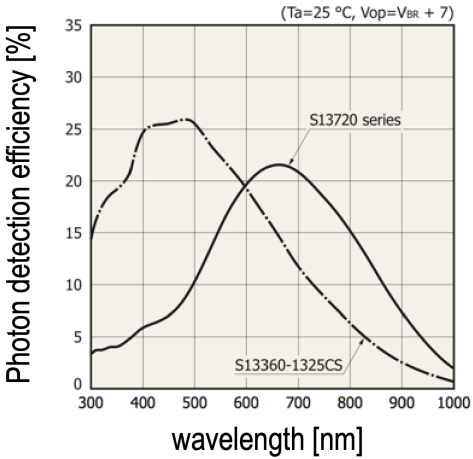




Example of single-photoelectron waveform (1 p.e.)

Gain = area under the curve in electrons

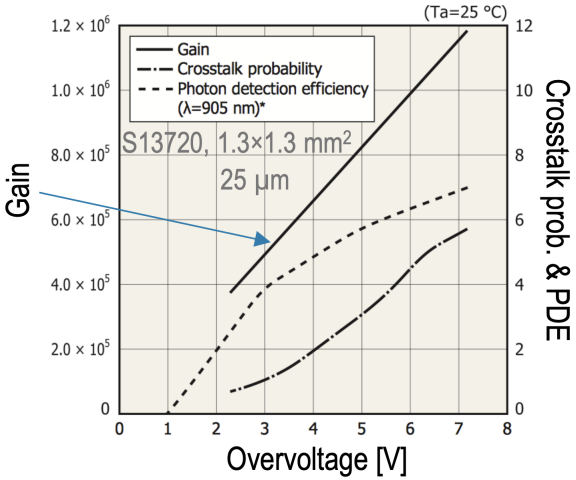
Photon detection efficiency



- Photon detection efficiency (PDE) is a probability that an incident photon is detected. It depends on:
  - wavelength
  - overvoltage
  - microcell size

Peak PDE 20% – 50%

Gain



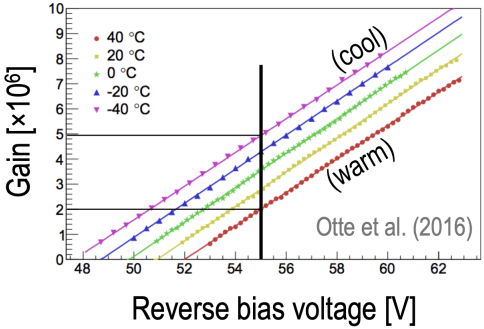
- Gain of SiPM is comparable to that of a PMT.

  Excess noise very low:
  F ~ 1.1, mostly due to crosstalk

- Gain depends linearly on overvoltage

Does gain of an SiPM depend on temperature?

Yes – if the bias voltage is fixed



Does gain of an SiPM depend on temperature?

No – if the overvoltage is fixed