A gain control and stabilization technique for Silicon PhotoMultipliers in low-light applications around room temperature

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Abstract

An experiment setup in dark condition was established to investigate the temperature and bias voltage dependence of the Multi-Pixel Photon Counter(MPPC), one type of the Silicon PhotoMultiplier (SiPM) detectors developed by Hamamatsu. The dark current of an MPPC at a given gain can be approximated by an exponential function of temperature which similar to the behavior of a NTC thermistor. According to these facts, a gain control and stabilization circuit for MPPC is developed by using a programmable current sink with temperature compensation. Detailed design and performance analysis results of the circuit in the temperature range from 5.1ºC to 33.3ºC are reported.

Introduction

The Silicon PhotoMultiplier (SiPM) consists of an array of Avalanche PhotoDiodes working in the Geiger mode which biased above the breakdown voltage and connected in parallel. The SiPM is an novel candidate to replace the PhotoMultiplier Tubes (PMT) with

many advantages:

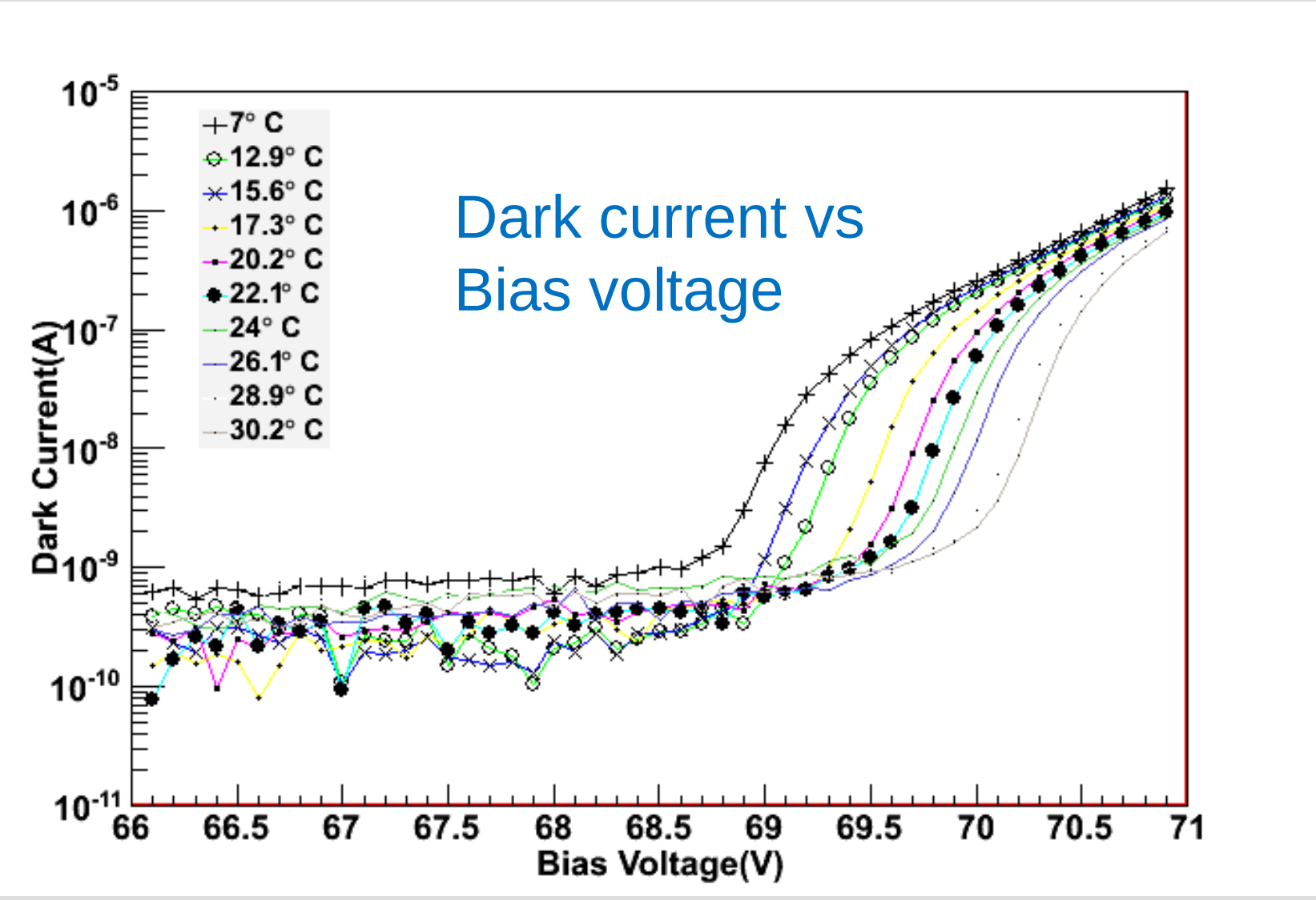
- High Photon Detection Efficiency(PDE)
- Insensitive to magnetic field
- High gain(up to 10^6) with low operating voltage(<100V)

and drawbacks:

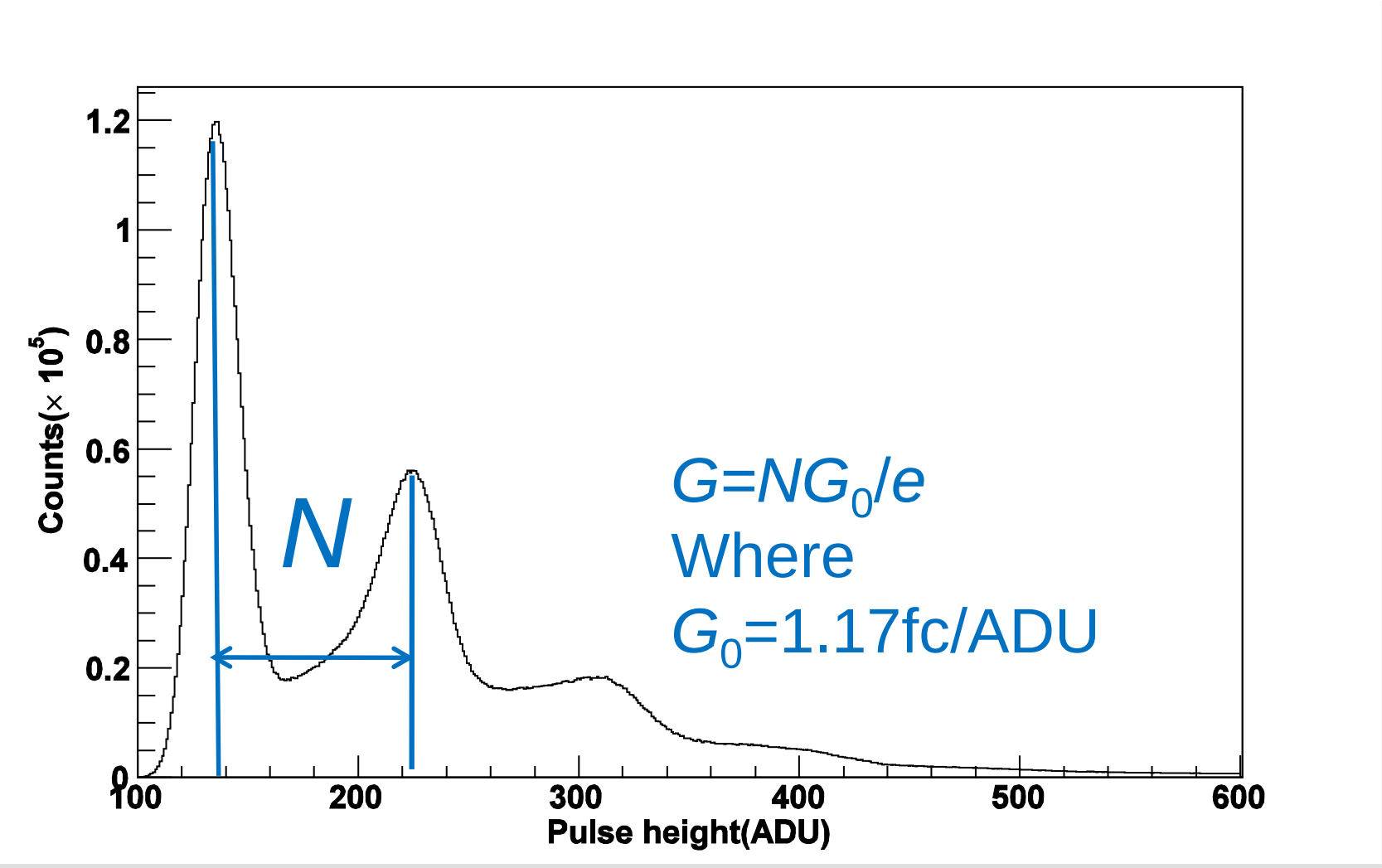
- High dark count rate (Mcps) depending on operating temperature
- Breakdown voltage increasing linearly with the operating temperature
- Gain decrease by a factor about 2 with operating temperature increasing 10ºC

Results and Discussion

Static Measurement



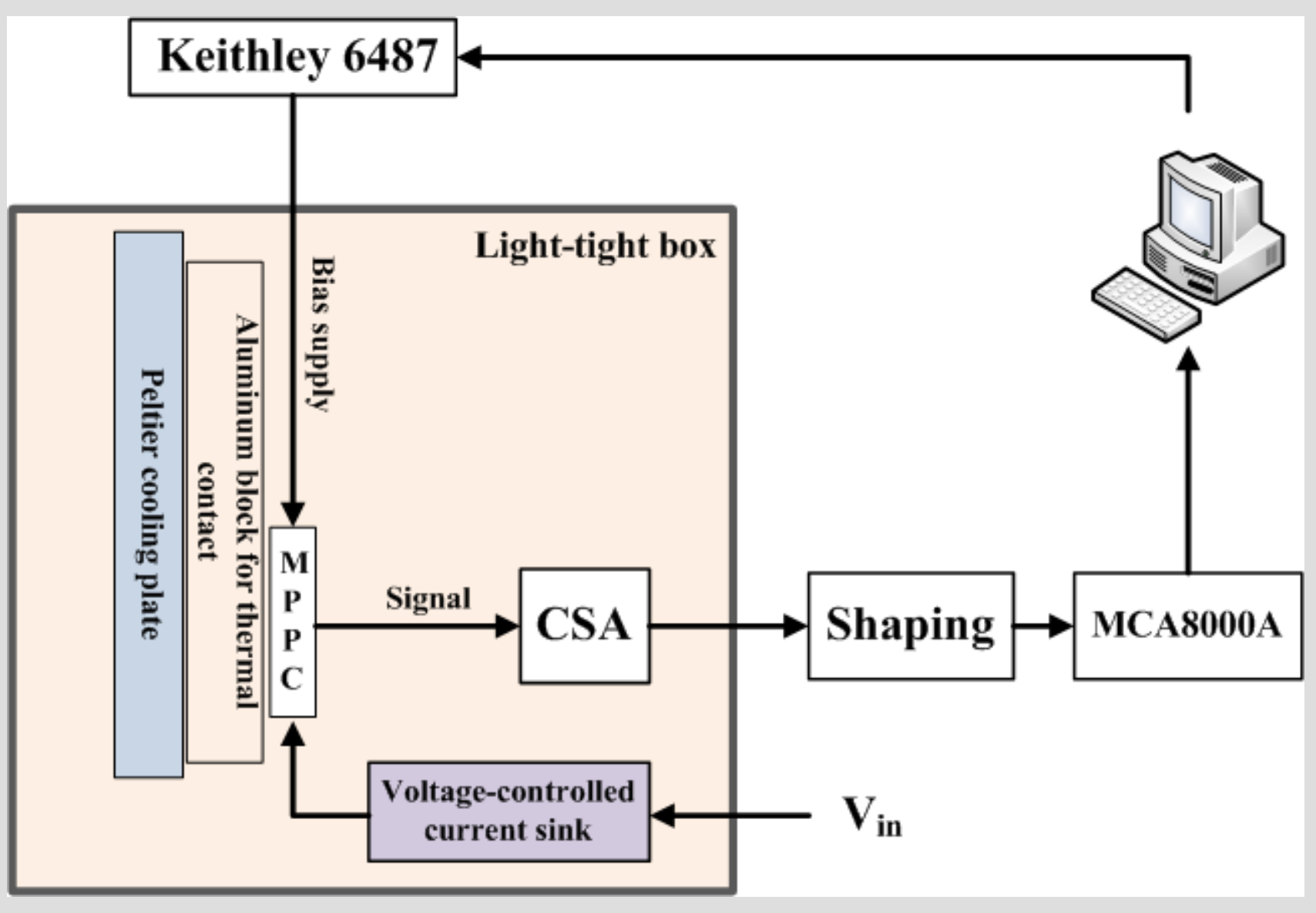
The dark current is a function of bias voltage and operating temperature.

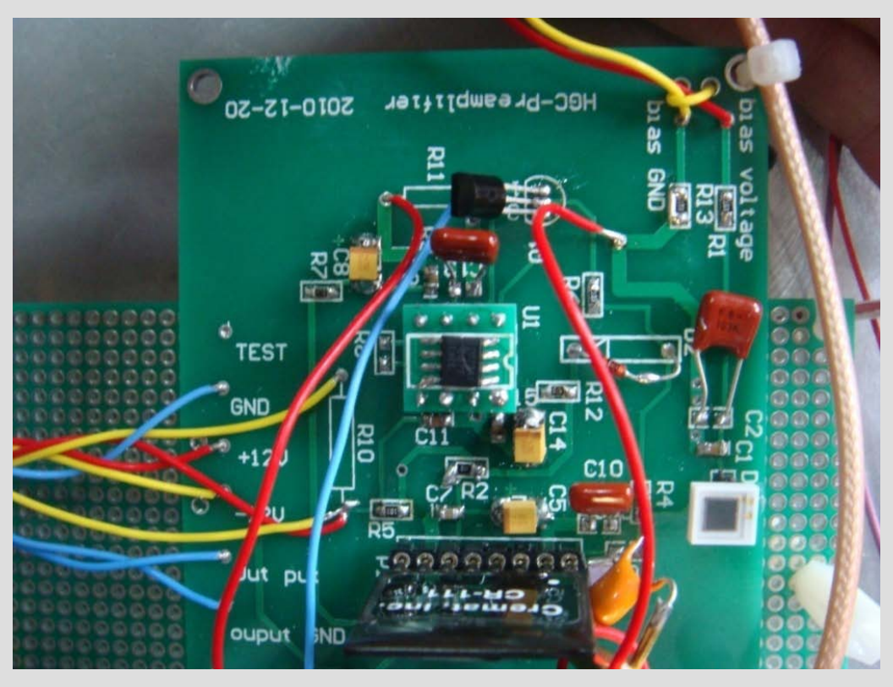


The pulse height distribution can be fitted by the sum of several Gaussian distributions. The distance ***N*** between the peaks is proportional to the gain (***G***) .

The acquisition system was calibrated by a signal generator. The system gain in unit of charge per MCA channels(ADU) is $\boldsymbol{G}_0$=1.17fc/ADU. The threshold was set about 0.5pe over pedestal signal, so there was no pedestal peak in the spectrum.

Experiment setup





MPPC:S10362-33-050C

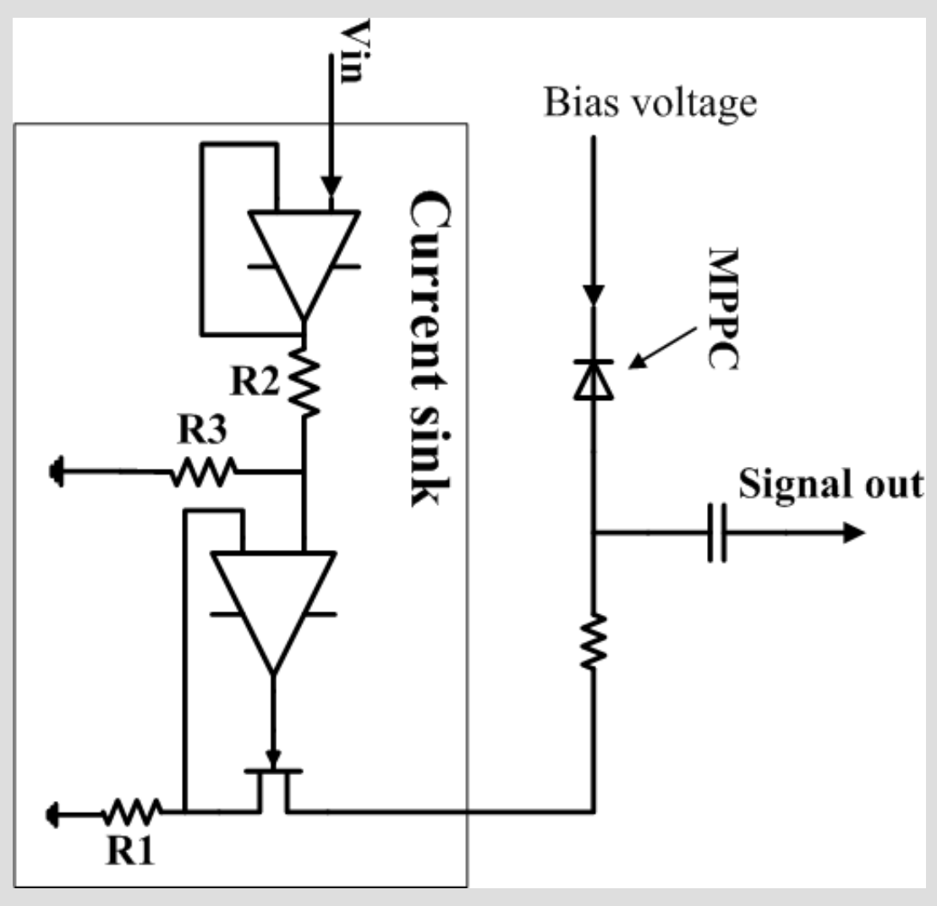
Data acquisition system:

- CSA: CR-111(150mV/pC)
- Shaping : CR-200-100ns
- MCA8000A

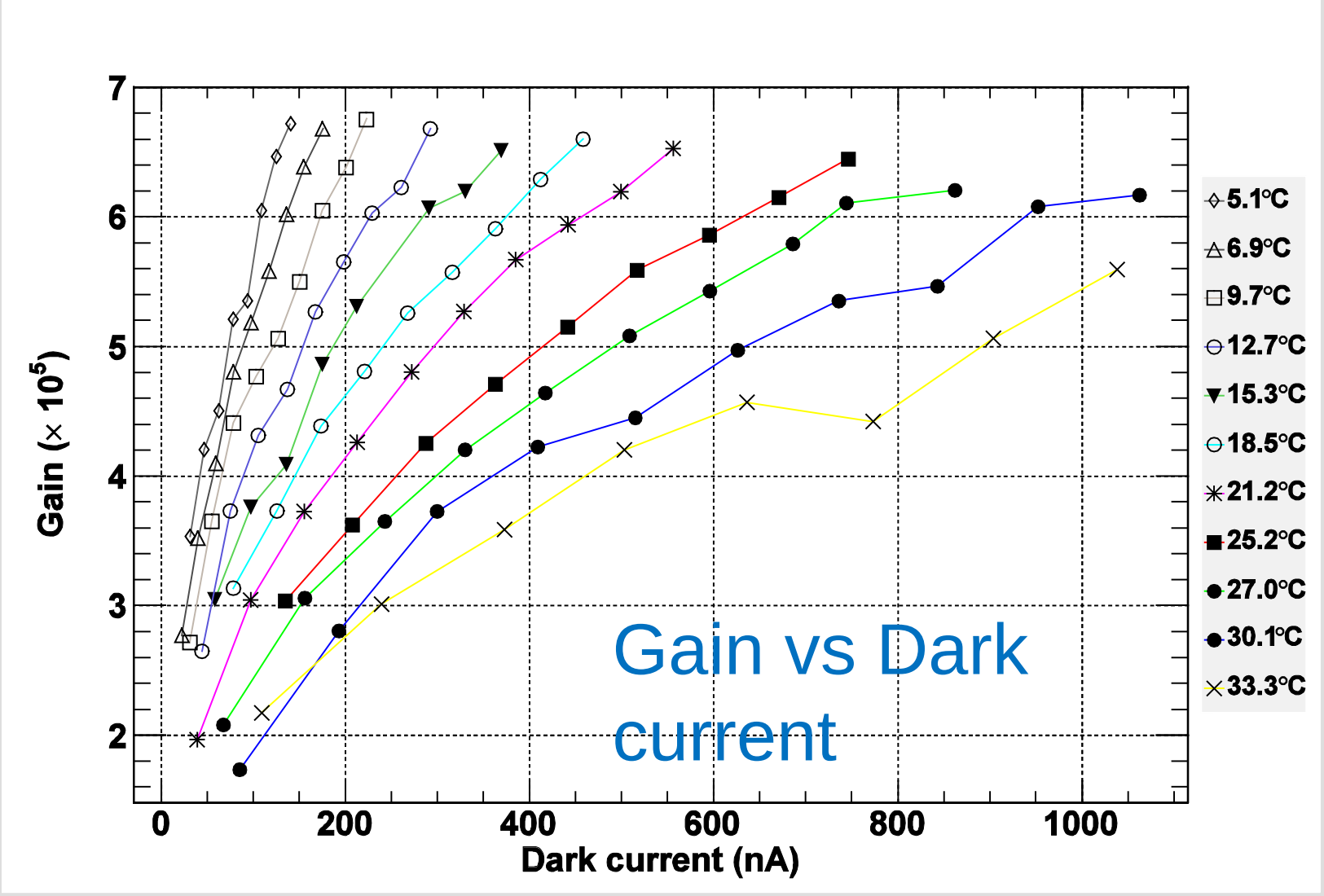
Instead of controlling the bias voltage to adjust the gain, a current sink was designed to control the current flowing through the MPPC by a control voltage (V_{in})

$$I=\frac{1}{R_1}\frac{R_3}{R_3+R_2}V_{in}$$

where R_1 and R_2 could be replaced by thermistors for temperature compensation. The dark current and gain were measured in dark condition with temperature ranging from 5.1ºC to 33.3ºC.



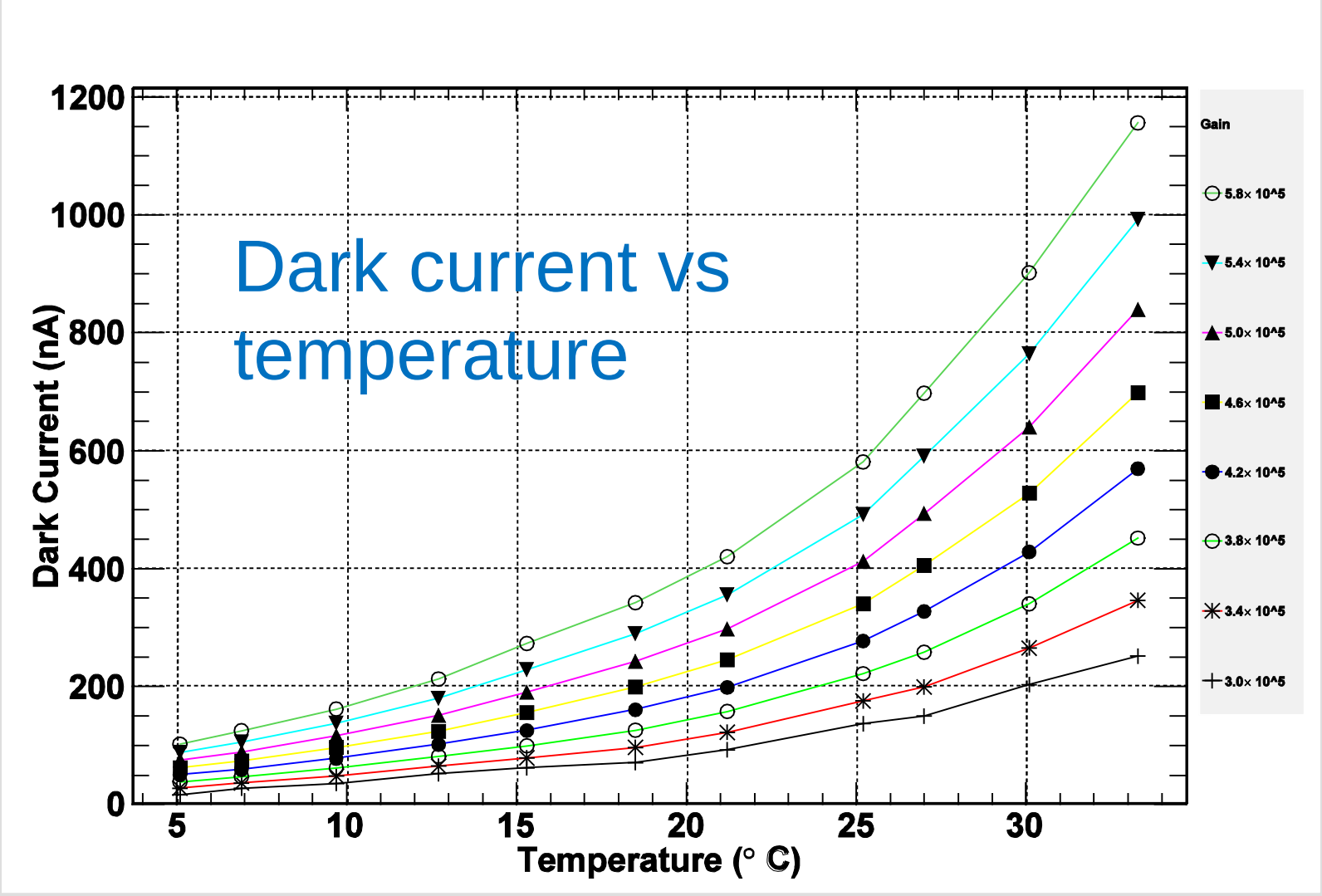
Gain measurement



- The dark current can be approximated by an exponential function of operating temperature around the room temperature for a given gain, similar to the behaviour of a NTC thermistor.

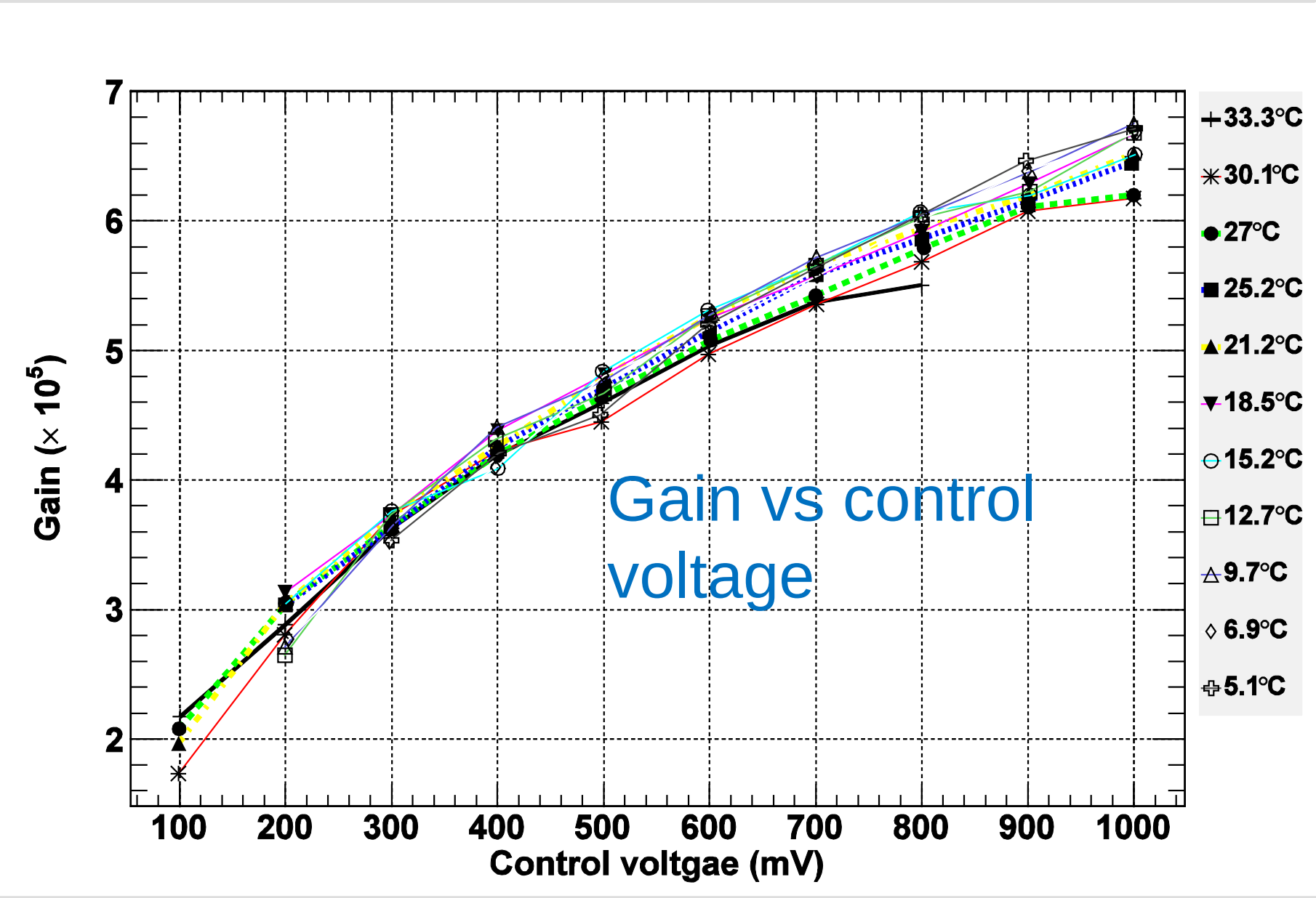
$$I=A\exp\{-B(1/T-1/T_0)\}$$

Gain	B(K^{-1})	A(nA)
3.0×10^5	7237±38	131.55±0.38
4.2×10^5	7555±19	282.20±0.39
5.0×10^5	7459±13	421.71±0.38



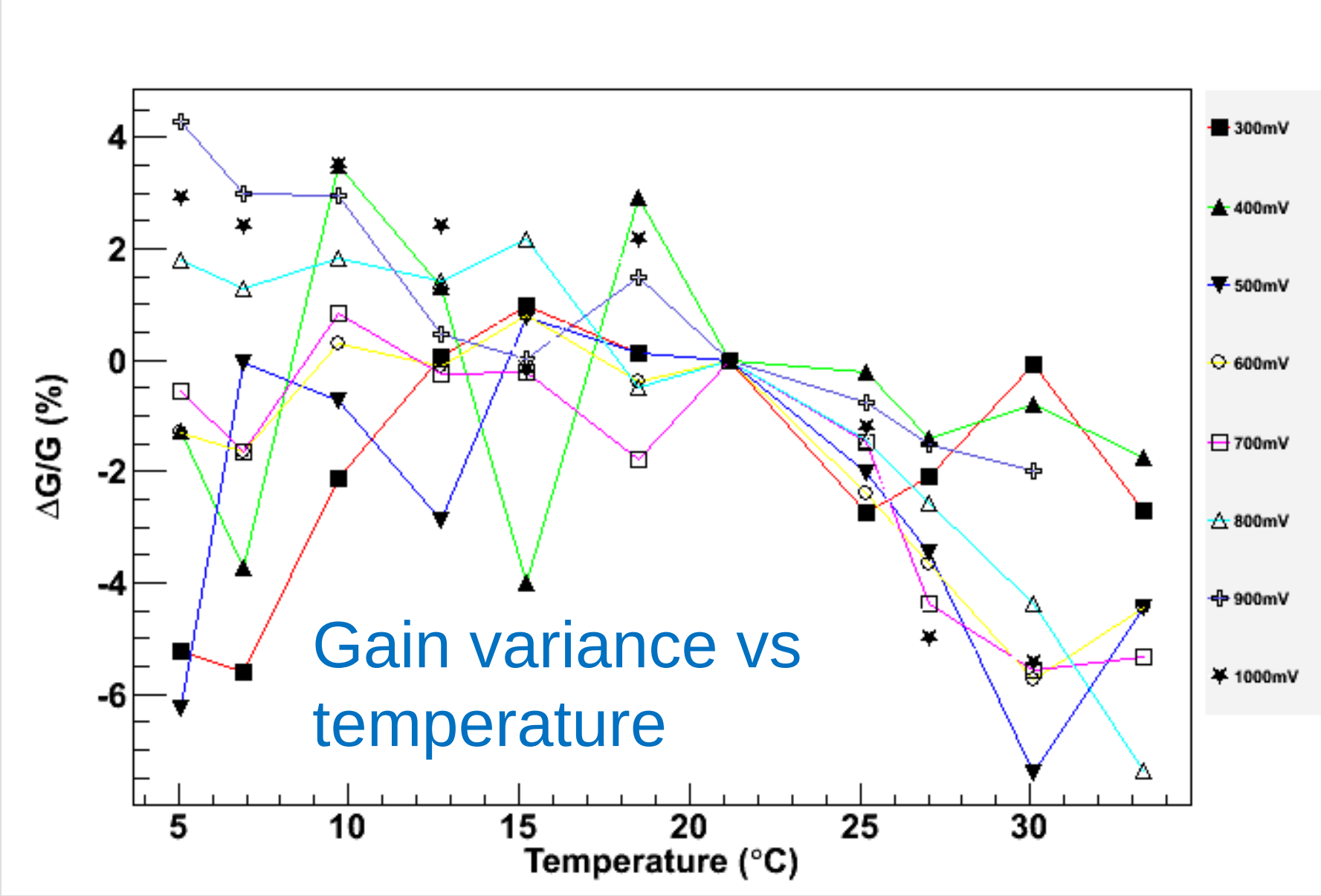
- Two thermistors were used to compensate the temperature variance in the current sink according to the fitting results.

Gain control



With thermistors, the relative gain variance is smaller than 6% in the temperature range from 5.1 to 33.3ºC for varies gain ranging from 2×10^5 to 7×10^5

The gain could be controlled through the input voltage of the current sink module.



Summary

- The gain was determined from the pulse height distribution.
- Except the bias voltage, the gain is also a function of dark current.
- On the other hand, the dark current follows an exponential function of the operating temperature for a given gain.
- According to these facts, a voltage-controlled current sink module with temperature compensation using thermistors was developed for gain stabilization.
- A relative variation less than ±3% was achieved for gain about 5.5×10^5 in the temperature range from 5.1 to 33.3ºC.