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

Zheng-Wei Li, Yu-Peng Xu, Cong-Zhan Liu, Yan-Guo Li, Mao-Shun Li, Tian-Xiang Chen, Wei-Wei Cui, Yong Chen, Da-Wei Han, Wei Hu, Cheng-Kui Li, Wei Li, Xiao-Yan Liu, Bo Lu, Juan Wang, Yu-Sa Wang, Yan-Ji Yang, Yue Zhu, Gang Li, Jian-Ling Zhao, Jing Wang, Neng Pu, Xia-Fei Li and Min-Nan Kong

Institute of High Energy Physics, CAS (China)

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 5.1°C to 33.3°C 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 a novel candidate to replace the PhotoMultiplier Tubes (PMT) with many advantages:

- High Photon Detection Efficiency (PDE)
- Insensitive to magnetic field
- High gain (up to 10⁶) 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 10°C

Experiment setup

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)

\[ I = \frac{R_1}{R_1 + R_2} V_{in} \]

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 5.1°C to 33.3°C.

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 channel(ADU) is \( G_0=1.17\text{fC/ADU} \). The threshold was set about 0.5pe over pedestal signal, so there was no pedestal peak in the spectrum.

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.

\[ I = IA \exp(-B(1/T-1/T_0)) \]

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

Gain control

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

With thermistors, the relative gain variance is smaller than 6% in the temperature range from 5.1 to 33.3°C for varies gain ranging from \( 2\times10^5 \) to \( 7\times10^5 \)

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 \( \pm 3\% \) was achieved for gain about \( 5.5\times10^5 \) in the temperature range from 5.1 to 33.3°C.

Gain vs Dark current

Gain vs Dark current

MPPC:S10362-33-050C

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

Gain variance vs temperature

Gain variance vs temperature

<table>
<thead>
<tr>
<th>Gain (G)</th>
<th>B(K⁻¹)</th>
<th>A(nA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0×10⁵</td>
<td>7237±38</td>
<td>131.55±0.38</td>
</tr>
<tr>
<td>4.2×10⁵</td>
<td>7555±19</td>
<td>282.20±0.39</td>
</tr>
<tr>
<td>5.0×10⁵</td>
<td>7459±13</td>
<td>421.71±0.38</td>
</tr>
</tbody>
</table>

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With thermistors, the relative gain variance is smaller than 6% in the temperature range from 5.1 to 33.3°C for varies gain ranging from \( 2\times10^5 \) to \( 7\times10^5 \)