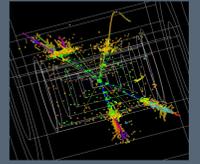


Ivo Polák on behalf of the CALICE Collaboration

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Introduction

- The gain of SiPMs depends both on bias voltage and on temperature
- Gain decreases with temperature
- Gain increases with bias voltage
- For stable operations, we need to keep gain constant.
- In an analogue hadron calorimeter with millions of channels, this is a difficult task due to temperature variations.
- Thus, it is desirable to adjust V_{bias} to compensate for T changes to keep the gain constant.
- Goal: build a V_{bias} regulator to keep gain constant (<1%).
- First, we need to measure SiPM gain vs temperature and vs V_{bias}
- determine dV/dT to obtain constant gain
- apply the compensation and demonstrate proof of principle
- This is work conducted in the framework of the EU project AIDA

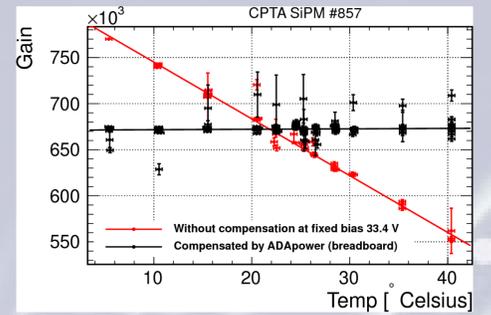
Summary for test 2013 at CERN

We measured dG/dT & dG/dV dependence for 4 different SiPM types. We found linear dependence dG/dV . We measured SiPM gain vs temperature and determine dV/dT to obtain constant gain and then found linear dependence dG/dV .

More see G.Eigen, LCWS13, Tokyo, Japan, 11 to 15 November 2013

We compensate variation of T by trimming of bias voltage at SiPM.

The gain stabilization with the breadboard and also with PCB prototype works rather well in the region, accuracy is at the level of 1%.



Example of Compensated SiPM by ADAPower regulator

Temperature range was 5 to 40 °C

Various dV/dT :

- 15-20 mV/K for CPTA & KETEK sensors
- 55 mV/K for Hamamatsu sensors

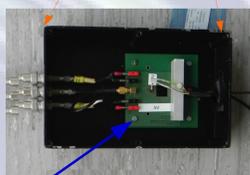
SiPM test setup

We work in a climate chamber at CERN that is stable within 0.2°C

Use digital oscilloscope read out by PC, low voltage & bias voltage power supplies

Use pulse generator for LED signal

Blue LED shines on SiPM



SiPM + preamp + T sensor + LED

SiPM tested

We measured the dG/dT & dG/dV dependence for 15 SiPMs from 3 manufacturers

We tested the V_{bias} adjustment on 4 SiPMs:

- CPTA 857
- CPTA 1677
- KETEK W 12
- MPPC 50um 11759

MPPC 20um "B"

Note that CPTA sensors were attached to 3x3 cm² scintillator tiles while the other sensors were directly illuminated by blue LED

Manufacturer and Type #	Sensitive area (mm ²)	Pixel pitch (µm)	#pixels	Typical V_{bias} [V]	Typical G ($\times 10^3$)	Serial #
Hamamatsu S10943-8584(X)	1 x 1	50	400	71.69	7.49	11759
S10943-8584(X)	1 x 1	50	400	71.57	7.49	11766
S10943-8584(X)	1 x 1	50	400	71.50	7.48	11770
S10943-8584(X)	1 x 1	50	400	71.33	7.48	11771
Sample A	1 x 1	20	2500	66.7	2.3	A1
Sample B	1 x 1	20	2500	73.3	2.3	B1
Sample A	1 x 1	15	4440	67.2	2.0	A2
Sample B	1 x 1	15	4440	74.0	2.0	B2
CPTA	1 x 1	40	796	33.4	7.1	857
	1 x 1	40	796	33.1	6.3	922
	1 x 1	40	796	33.3	6.3	975
	1 x 1	40	796	33.1	7.0	1065
	1 x 1	40	796	33.3	14.6	1677
KETEK MP15 V6?	2(1.2 x 1.2)	15?	?	-28	?	W8
MP20 V4?	3 x 3	20?	?	-28	?	W12

Summary of dV/dT Measurements

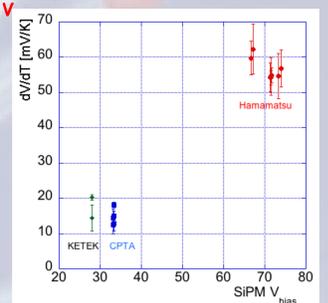
V_{bias} for Hamamatsu is ~70 V while V_{bias} for CPTA is ~33 V & V_{bias} for KETEK is ~28 V

For KETEK and CPTA, dV/dT is ~15-20 mV/K for Hamamatsu, dV/dT is ~55 mV/K

Thus, compensation will be simpler for CPTA and KETEK SiPMs

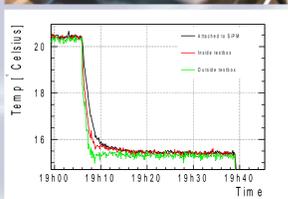
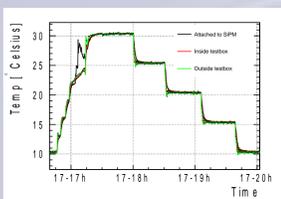
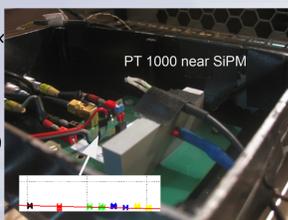
We tested the compensation on: 4 SiPMs in 2013

The same 4 and 1 additional SiPMs in 2014



Temperature measurement

- Use 3 pt 1000 sensors
- Near SiPM, inside and outside black box
- Use LM35 sensor for compensation feedback
- Vary T from 5°C to 40°C in 5°C steps except in 20°-30°C range (2°C steps)
- TSiPM ~ TSET + 0.4°C
- offset is same over entire range

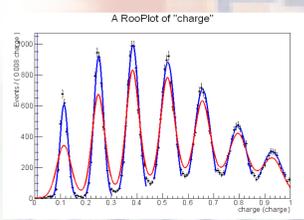


SiPM Gain determination

Determine gain by fitting Gaussian functions to peaks of single pe spectra

Define gain as

- Distance between 1 pe & 2 pe peaks (MPPCs)
- Distance between pedestal & 1 pe peak (CPTA, KETEK)



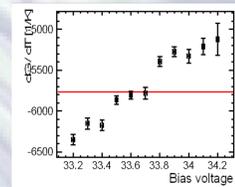
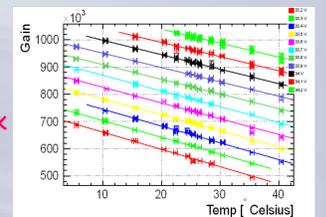
Define the error on the gain as the errors of the two fitted Gaussian mean values added in quadrature

Quality cut: Require gain extracted from Gaussian peaks and that from multikernel peaks not to differ by more than 20% (a sign of a bad fit)

RooFit multikernel function Individual Gaussian fits

Gain vs Temperature for CPTA 857

- At $V_{bias}=33.4$ V & $T=25$ °C: $G=6.4 \times 10^5$
- Extract $V_{breakdown}=31.9$ V
- 0th order polynomial fit yields: $dG/dV=(4.32 \pm 0.01_{stat}) \times 10^5/K$
- 1st order polynomial fit yields: $dG/dV=(4.41 \pm 0.11_{sys}) \times 10^5/K$



0th order polynomial fit yields: $dG/dT=(-5.76 \pm 0.02_{stat}) \times 10^3/K$

Determine: $dV/dT = -dG/dT / dG/dV = 13.33 \pm 0.35$ mV/K

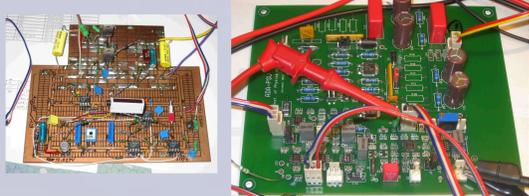
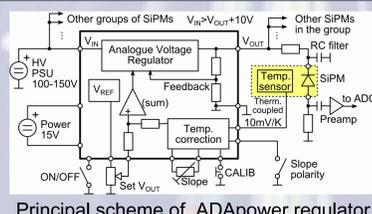
Gain stability: $\sigma(dV/dT) = (dG/dV) \cdot (\Delta T/G) = 0.31\%$

Adaptive Power Regulator two Prototypes (ADAPower)

Design Considerations

In the design of the bias voltage regulator test board we considered the following requirements.

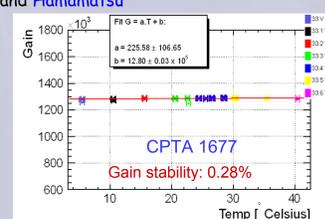
- Provide stable regulated output DC voltage from 15 V to 90 V.
- Achieve a stability better than 5 mV and keep the temperature influence to less than 1 mV/°C (100 ppm/°C) in the entire range of V_{out} .
- Use a trimming signal with a slope of 10 to 100 mV/°C.
- Provide a soft start.
- Have an ON/OFF ability.
- Provide analog settings with later possibility to implement digital settings with DAC.



PCB prototype finished in Jan 2014
 Extended V_{out} range:
 SiPM <130 V switchable to APD variant up to 450V
 Has a front panel with coarse and fine tuning
 Delivered to CERN in Feb 2014
 5 SiPMs measured, same setup, data analysis ongoing
 T range extended: 1 ~ 50°C

Gain after V_{bias} Adjustment for 3 types of SiPMs

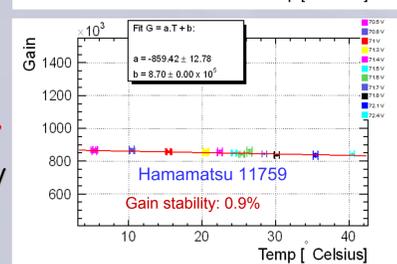
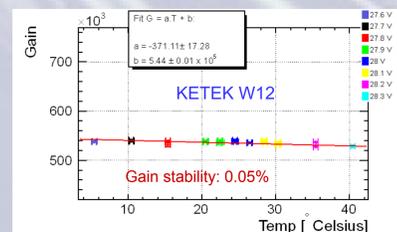
Perform similar study with 3 other SiPMs from CPTA, KETEK and Hamamatsu



CPTA 1677: non-uniformity $\pm 0.3\%$

KETEK W12: non-uniformity $\pm 1.2\%$

Hamamatsu 11759: non-uniformity $\pm 1.7\%$



Adjustment V_{out} range $\Delta V=0.7$ (1.9)V for CPTA & KETEK (Hamamatsu)

Gain stability is better than 0.9% !