Real-Time Measurement System with Automatic Gain Detection and Autocalibration for Silicon Photomultipliers

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Introduction

Silicon photomultiplier (SiPM) is a semiconductor device which gain strongly depends on the temperature. In precise measurements the gain has to be kept stable, without fluctuations. One of the methods to achieve this is based on Peltier modules attached to each SiPM. The method is not always feasible, especially in measurements with a large number of detectors where additional cooling modules take more place, add excessive circuitry, and increase the cost of the measurement system. The paper introduces an enhanced method of SiPM's gain stabilization which can automatically adapt to any model of the detector.

Gain of a SiPM

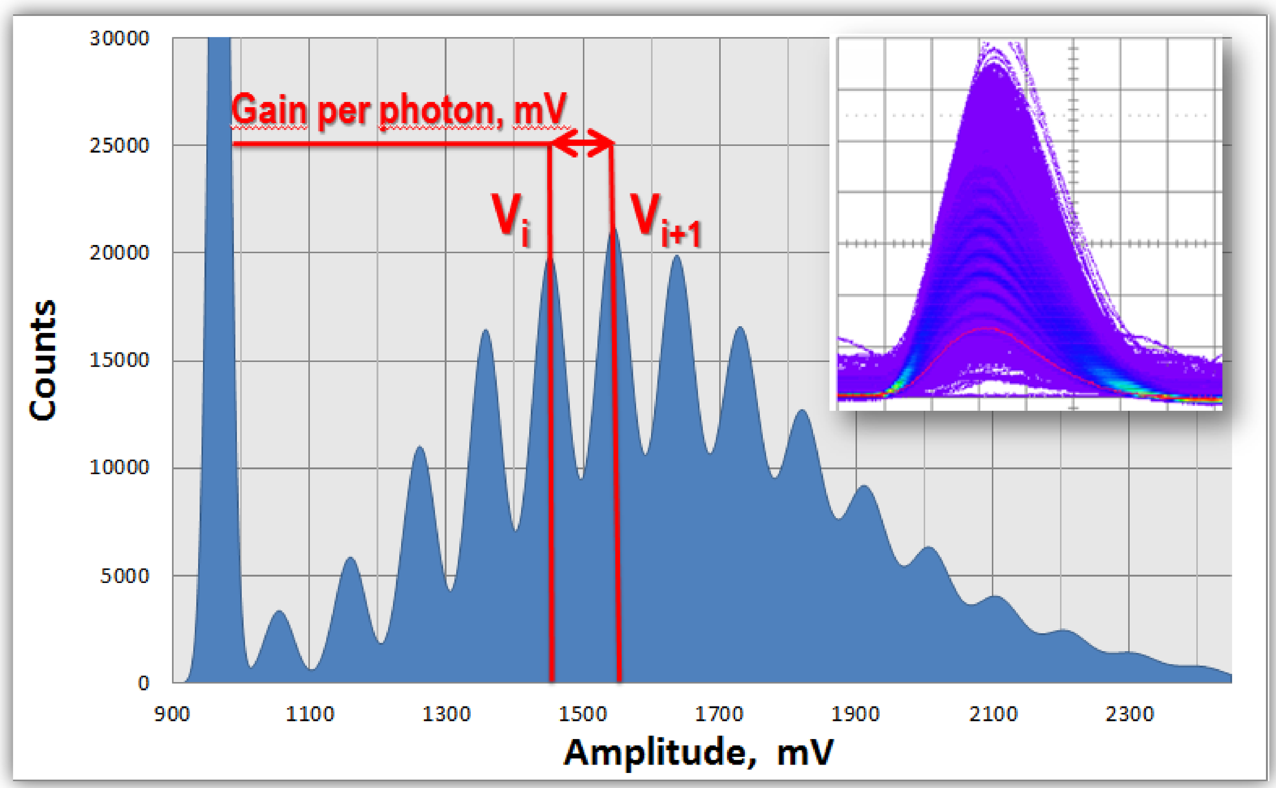


Figure 1. Histogram of signals acquired from a SiPM

Fig. 1 presents how the gain of a SiPM can be calculated. Since the distance between two following local maxima is constant, gain per photon is an averaged value of all distances (where G – is gain per photon, V_i is the local maximum of i-th peak on the histogram; N is the number of peaks):

:

$$G = \frac{1}{N}\sum_{i=1}^{N} V_{i+1} - V_i$$

Gain stabilization parameters

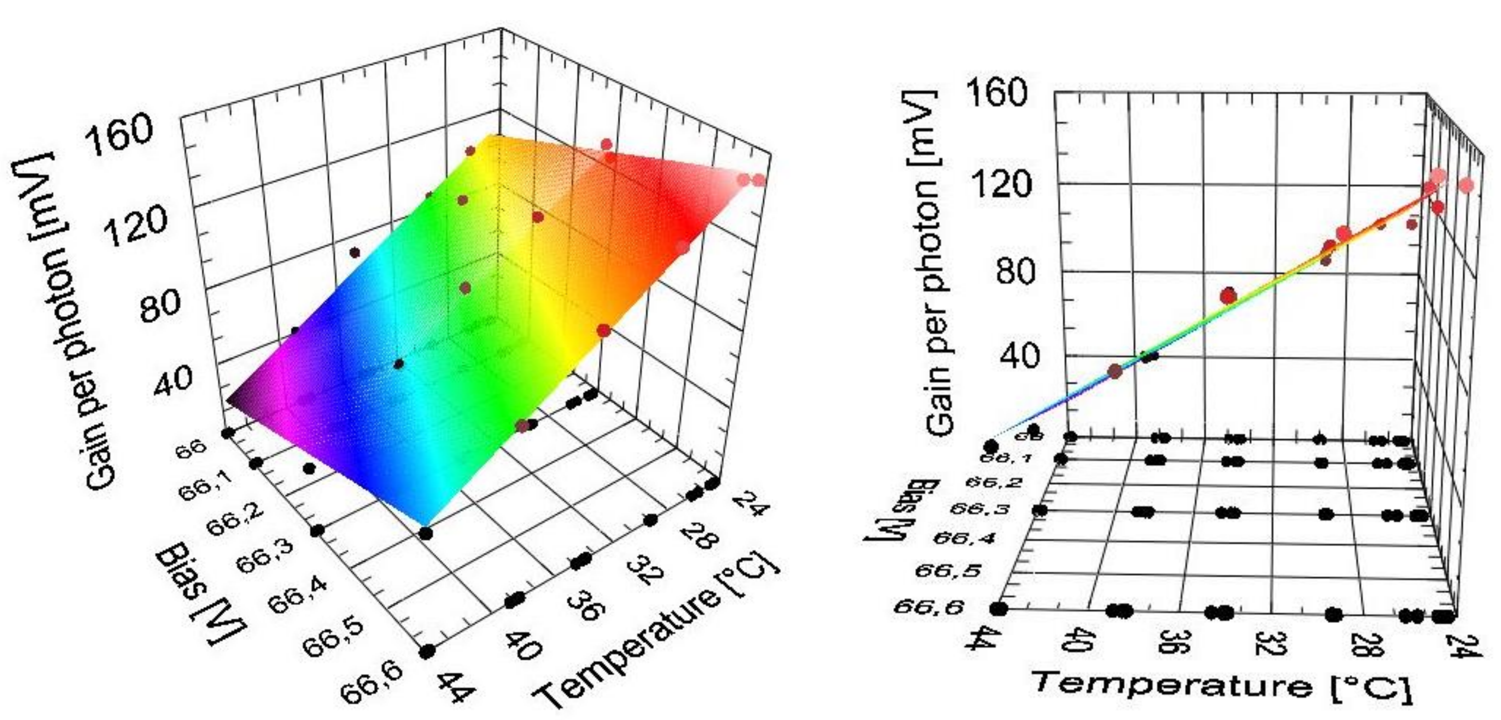
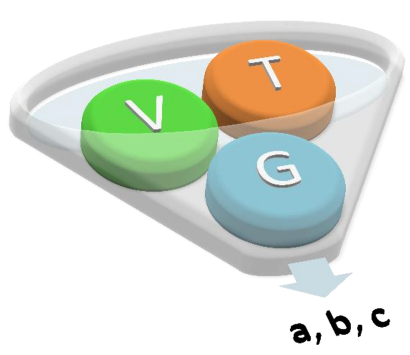


Figure 2. Measurements of the SiPM in various temperature and bias conditions. Each point (sphere) represents a histogram from Fig.1

Gain of a SiPM strongly depends both on a voltage bias and temperature. Fig.2 presents measurements performed in changing temperature and bias conditions. In order to add a single point to the plot it is required to acquire a complete histogram (Fig. 1). The points form a plane which can be described by the function:



$$G(V,T) = aV + bT + c$$

$$a = \frac{dG}{dV} \qquad b = \frac{dG}{dT}$$

G – gain; T – temperature; V – bias voltage; a, b, c – coefficients representing SiPM model.

When coefficients of the specific SiPM have been determined prior to the measurement, the system reads temperature of the detector and calculates appropriate bias. However, when the coefficients of the specific SiPM are unknown, the system should be capable of calculating them at the time of a measurement and apply the bias. Regardign these requirements, it is demanded to monitor temperature, bias and gain of the SiPM. While, the former two can be easily checked, the latter is far more difficult to estimate.

Automatic gain detection

Gain per photon can be estimated by means of a non-linear best fit function that searches for the gaussian curves in the histogram data (Fig. 1). This method has been implemented in a LabVIEW software application and is based on floating-point variables. From the viewpoint of hardware implementation this approach is ineffective since it requires large computional resources. A much simpler gain detection method has been developed and implemented in FPGA architecture. It is based on a one-dimensional gradient calculated from a histogram. It can be described in a simplified form by an algorithm (dout_grad is the calculated gradient):

```
for i = 2:length(ADC)-1
 begin
   dout1 <= ADC[i-1]
   dout2 <= ADC[i+1]
   if (dout2 < dout1)
      dout_grad[i]<= 0
   else
      dout_grad[i] <= dout2–dout1
```

In a noiseless data the gradient would be positive until it reaches the peak value of histogram's local maximum. Because the noise is present in all measurements, a threshold value has to be defined. The remaining part of the algorithm operates in the following order:

- If **dout_grad** exceeds the threshold it is accepted as a SiPM's signal
- **dout_grad** is assigned to a specific histogram's peak based on the index number. Range of index numbers cannot exceed a predefined distance. If an index exceeds this distance it is assigned to another peak.

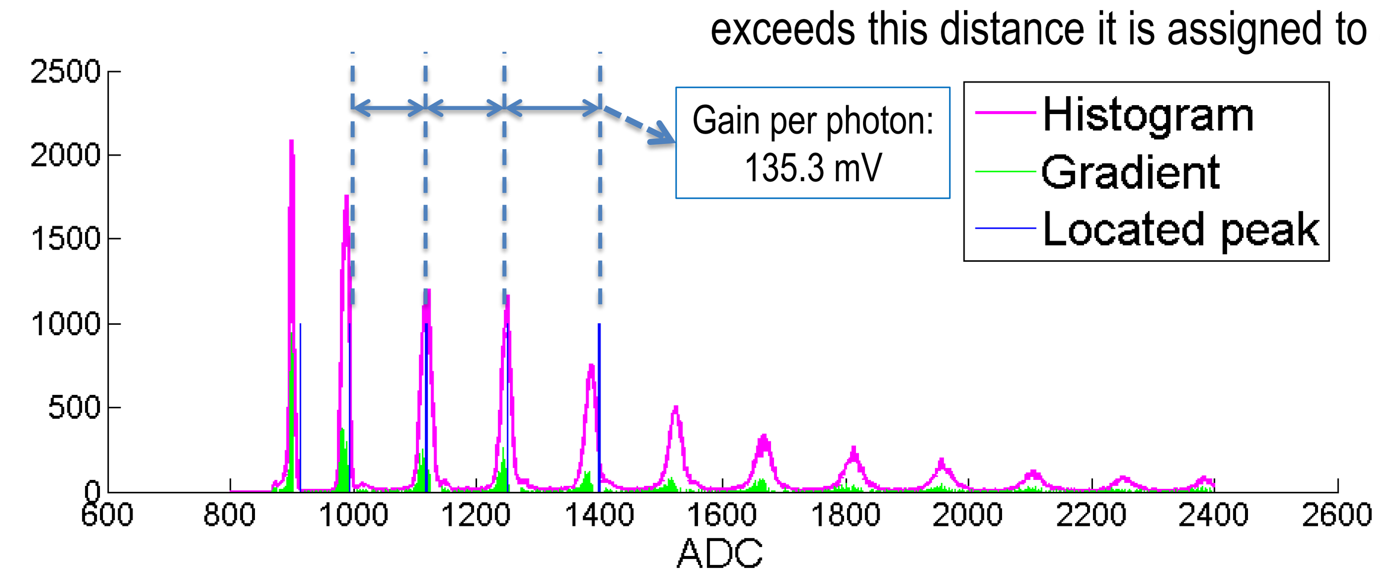


*Figure 3. Histogram acquired from a SiPM, Bias is set to **66.6 V** and temperature equals **29.3 ºC***

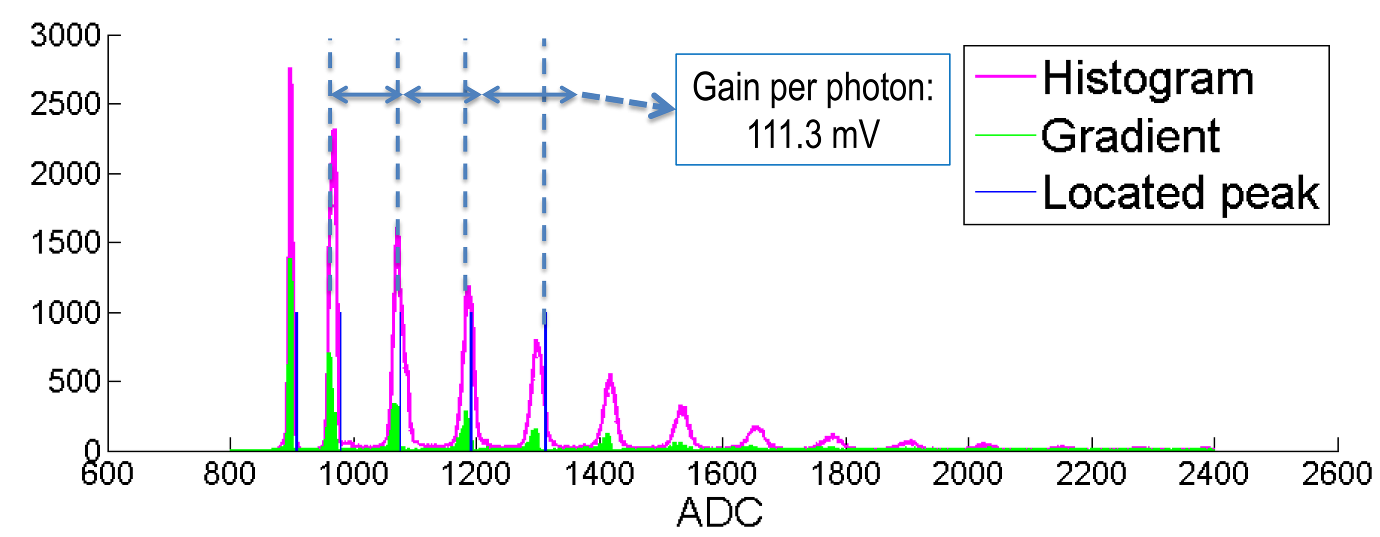


*Figure 4. Histogram acquired from a SiPM, Bias is set to **66.6 V** and temperature equals **33.9 ºC***

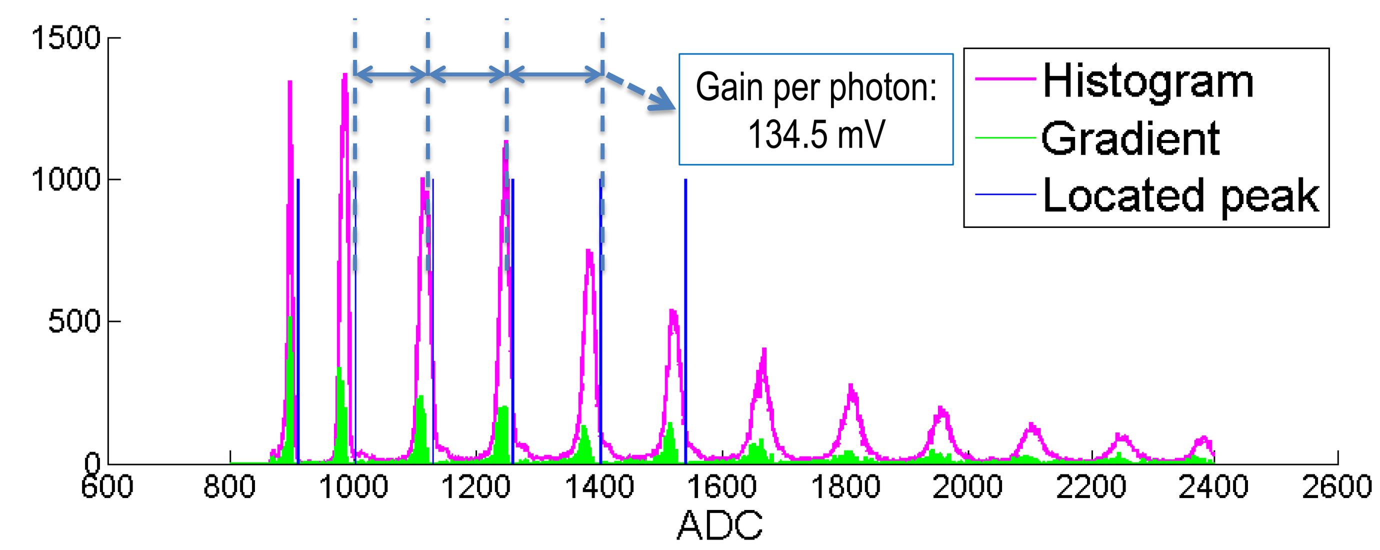


*Figure 5. Histogram acquired from a SiPM, Bias is set to **66.9 V** and temperature equals **33.9 ºC***

Fig. 3-5 present histograms acquired from the same SiPM, measuring the same light intensity. Under constant bias (66.6 V) the gain is changing with temperature. The system had calculated the gain of SiPM automatically and assigned required bias in order to keep the gain constant (Fig. 5). The bias was estimated based on a, b, c parameters of given SiPM.

Conclusions

- The system automatically estimates the gain of a SiPM
- It is stabilizing the gain with an error below 1%
- The SIPM used in measurements is Hamamatsu S12571-100C
- Parameters calculated by the system: a = 75.9, b = -4.75, c = -4785

Acknowledgment

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Reference

[1] P. Dorosz et al., "Silicon Photomultiplier's Gain Stabilization by Bias Correction for Compensation of the Temperature Fluctuations," Nuclear Instruments and Methods Section A, vol. 718, no. 1, pp. 202-204, 2013.