A simple temperature-dependent gain compensation technique for SiPM-based PET detectors

Hyeong Seok Shim[1,2], Hae Wook Park[3] and Jae Sung Lee[1,2,3,4]

[1]Interdisciplinary Program of Bioengineering, Seoul National University, Seoul, Korea
[2]Integrated Major in Innovative Medical Science, Seoul National University Graduate School, Korea
[3]Dept. of Nuclear Medicine, Seoul National University, Seoul, Korea
[4]Brightonix Imaging Inc., Seoul, Korea

Objectives:

Silicon photo-multiplier(SiPM) is commonly used radiation detector by its attracting properties, such as, immunity to magnetic fields, high gain, and small detector size. However, as the SiPM is based on the photodiode, the gain of the SiPM is dependent on the temperature.[1] The gain of the detector is the key factor to discriminate whether the signal is from the annihilation photon or not, so if the signal occurred from the event with same energy, the gain of the signal has to be constant even though the temperature is different. So, the compensation system for the temperature dependence of SiPM gain is necessary. Because the relationship between the breakdown voltage and the temperature, and the relationship between the breakdown voltage and the gain of the SiPM are known to be linear, temperature sensor can be an alternative for compensation system for the temperature dependence of SiPM gain. In this research, we suggest novel approach, in which the output of a temperature sensor automatically controls the bias voltage of SiPM in order to keep its gain constant.

Methods:

For concept verification, two detectors were used, a single-channel SiPM(ASD-NUV3S-P; Advansid, Italy) with a 3×3× $20mm^3$ LGSO crystal and 4×4 array MPPC(S14161-3050HS-04; Hamamatsu, Japan) with $3.12 \times 3.12 \times 15mm^3$ 4×4 LSO array.

1. single-channel SiPM

The breakdown voltage of the SiPM was 26.5V at room temperature (20℃). For the bias voltage of the SiPM, the SiPM cathode was directly coupled with the output terminal of the temperature sensor while the SiPM anode was coupled with the fixed voltage of -28.5V via SiPM anode. The output from the cathode of the SiPM was connected to the Nuclear Instrument Modules(NIMs) fan-in/fan-out module(N625, CAEN S.p.A, Viareggio, Italy) and was branched off to two ways, one to the domino ring digitizer(DRS4), and one to the leading edge discriminator(LED) module(N840, CAEN S.p.A, Viareggio, Italy) to make the trigger signal. The trigger signal was connected to the waveform digitizer(DT 5742B; CAEN S.p.A, Viareggio, Italy) which is based on domino-ring-sampler 4(DRS4).

2. 4×4 array MPPC

The breakdown voltage of the SiPM was 38.21V at room temperature(20℃). For the bias voltage of the SiPM, 16 channels SiPM cathode was terminated with 1MΩ and was coupled with the output terminal of the temperature sensor while the SiPM anode was all connected and coupled with the fixed voltage of -40V via SiPM anode. The output of the anode of SiPM was connected to a comparator to make the trigger signal. The trigger signal and each outputs of the cathode of the SiPM were connected directly to the domino-ring-sampler 4(DT 5742B).

3. temperature sensor

The temperature sensor(AD22103; Analog Devices, US)) was selected as the temperature sensor of the proposed system. The temperature coefficient of the AD22103 sensor can be controlled by the input voltage, so the sensor can compensate the temperature dependence of the various detectors. By applying 3.05V as the input voltage, the temperature coefficient of the sensor and the temperature dependence of the breakdown voltage of the single-channel SiPM optimally matched with the least difference. By applying 6.4V as the input voltage, the temperature coefficient of the sensor and the temperature dependence of the breakdown voltage of the 4×4 array MPPC optimally matched with the least difference.

Results:

On the single-channel SiPM, with the compensation technique, the position of the 511-keV photo peak on energy histogram changed 1.52% per 10℃, while without any compensation, it changed 13.27% per 10℃. On temperature varying situation from 10℃ to 30℃, with compensation, the energy resolution was 12.33%, and without compensation the energy resolution was 18.51%. On the MPPC SiPM, with the compensation technique, the position of the 511-keV photo peak on energy histogram changed 2.27% per 10℃, while without any compensation, it changed 17.06%. On temperature varying situation from 10℃ to 30℃, with compensation, the energy resolution was 14.04%, and without compensation the energy resolution was 19.48%. When the energy window was fixed with the energy histogram of 25℃ condition, the sensitivity of the 511-keV event was 0.96 in 10℃ to 20℃ and 0.95 in 30℃.

Conclusion:

In this study, automatically controlling the bias voltage of the SiPM with the temperature sensor output is proposed. As the relationship of the breakdown voltage and the temperature is exponential in the wide range, error can be larger when the system is above the range of 10℃ to 30℃. With the cooling system, the proposed technique would be a useful technique to compensate the temperature dependence of SiPM gain.

Reference:

[1] M. Ramilli, "Characterization of SiPM: Temperature dependencies", *Proc. IEEE Nucl. Sci. Symp. Med. Imag. Conf. Rec.*, pp. 2467-2470, 2008.