시간 분해능 개선을 위한 양전자단층촬영 검출기의 정전용량 보정 기술 비교

Comparison of the Coincidence Timing Resolution of Capacitance Compensation Techniques on SiPM based PET detector

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Abstract

In this study, we compared the slew rate of the rise edge, amplitude according to gain, and coincidence timing resolution of two capacitance compensation technique to improve the timing resolution of PET detector, the active capacitance compensation technique using an op-amp and the passive compensation technique using a balun transformer. By using the conventional op-amp AD8000 rather than the RF amplifier, we optimized the gain of the capacitance compensated signal to have the optimal timing resolution. The active capacitance compensation technique showed 454.6 ps FWHM and the passive capacitance compensation technique showed 192.1 ps FWHM. we built the first experimental basis that the passive capacitance compensation technique on SiPM based PET detector can improve the timing resolution better than the active capacitance compensation technique.

1. Introduction

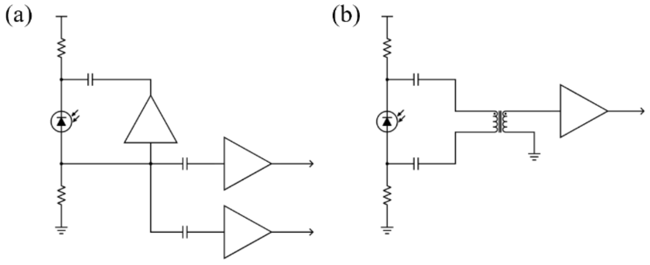
The coincidence timing resolution in PET system enables the time-of-flight technique which allows to reconstruct the image with less time and less dose. It is well known that with 10 pico-second coincidence timing resolution, the reconstruction step is unnecessary as the location of the annihilation is specified with 1.5 mm resolution event by event. Various methods were proposed to improve the coincidence timing resolution, including using fast scintillation crystal, measuring Cherenkov luminescence, and time-walk correction.

SiPM is highly used photosensor in PET systems, however, its detector capacitance needs to be compensated for improved timing resolution. Two capacitance compensation technique has been proposed, active compensation technique using an op-amp [1, 2], and passive compensation technique using a balun transformer [3, 4]. Both capacitance compensation techniques are based on isolating the shunt resistor, which converts the current signal generated from the SiPM to the voltage signal, from the detector capacitance. The shunt resistor combined with the detector capacitance act as a low pass filter which stretches the signal. On the active compensation technique, unity gain amplifier acts as a current source, producing the same amount of current that does not feel the detector capacitance. On the passive compensation technique, the circuit after the balun transformer is physically separated from the circuit before it. The capacitance compensated signal has an effect of not going through a low pass filter, so the rise edge is steeper than the conventional signal and the amplitude is greater. The circuit using high pass filter has been also proposed to improve the coincidence timing resolution, however, the high pass filter lessens the signal degrading the SNR.

In this study, we compared the slew rate of the rise edge, amplitude according to gain, and coincidence timing resolution of two capacitance compensation circuits. We experimentally evaluated and presented an optimal capacitance compensation circuit to improve coincidence timing resolution. Also, we first tested the conventional op-amp rather than RF amplifier on the passive capacitance compensation technique to control the gain of the compensated signal.

2. Materials and Methods

For the experimental set-up of the active compensation technique, we used 4 mm × 4 mm NUV-type single-channel SiPM (ASD-NUV4S-P; AdvanSiD, Italy) coupled with 3 mm × 3 mm × 20 mm LGSO crsytal. The detector capacitance of the SiPM used in this set-up was 840.6 pF. We used AD8000 (Analog Device, USA) for the bootstrapping amplifier. For the experimental set-up of the passive compensation technique, we used 3 mm × 3 mm pitch single-channel SiPM (MicroFJ-SMPTA-30035-GEVB; OnSemi, USA) coupled with 3 mm × 3 mm × 20 mm LGSO crsytal. The balun transformer was attached on the backside of the single channel SiPM socket. The detector capacitance of the SiPM used in this set-up was 1040 pF. We used 5.42μCi ^{22}Na point source for the radiation. Figure 1 shows the circuit diagram of



two experimental set-up.

Figure 1 (a) circuit diagram for active compensation technique (b) circuit diagram for passive compensation technique

The amplitude of the signal were optimized on each set-up, by sweeping the gain from 1 to 100. The gain was controllable by using the op-amp AD8000, rather than the RF amplifier. The over-voltage of the SiPM on both set-up were set to 2.5 V. For the coincidence timing resolution, we used R9800 PMT (Hamamatsu Photonics. K.K., Japan) coupled with 4 mm × 4 mm × 10 mm LYSO crystal as a reference detector. The single timing resolution of the reference detector was 233 ps. The threshold of the leading edge discriminator to set the timestamp of the coincidence events were optimized digitally. All measurements were progressed inside the thermostatic chamber set at 20 °C.

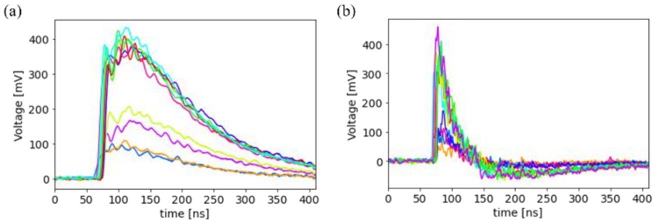


Figure 2 (a) signal pulses with active capacitance capacitance compensation technique, (b) signal pulses with passive capacitance compensation technique

3. Results and Discussion

Figure 2 shows the shape of the signal from each capacitance compensation technique. Since two techniques use different element to compensate the capacitance, the shape of the compensated signal is different. The gain of the signal on the set up using the active compensation technique was set to 40 and the gain of the signal on the set up using the passive compensation technique was set to 70. The amplitude used for the comparison were matched similarly.

Timing Resolution	(ps)
Active (Single)	321.4
Passive (Single)	135.8
Reference (Single)	233.3
Reference – Active (Coincidence)	397.1
Active – Active (Coincidence)	454.6
Reference – Passive (Coincidence)	272.4
Passive – Passive (Coincidence)	192.1

Table 1 Single timing resolution of the detector and coincidence timing resolution of the set-up

Table 1 shows the single timing resolution of the detectors and the coincidence timing resolution of the set up. The active capacitance compensation technique had poorer timing resolution than the passive capacitance compensation technique.

Figure 3 shows the histogram of the time difference at each set-up. The histogram from the passive compensation technique was well fitted to the Gaussian distribution, while the histogram from the active compensation technique didn’t.

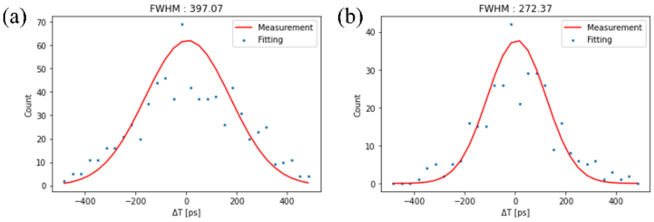


Figure 3 (a) histogram of the time difference at the active capacitance compensation technique (b) histogram of the time difference at the passive capacitance compensation technique

Because the passive component on the circuit is more stable than the active components, the passive compensation technique is more preferred. The above results prove that this method is better in terms of performance as well. The set-up we used were not optimized, since pole-zero cancellation, and over-voltage optimization were not applied. So, there are rooms to improve the coincidence timing resolution, although the comparisons were made under the same conditions as possible.

In conclusion, by this study, we built the first experimental basis that the passive capacitance compensation technique on SiPM based PET detector can improve the timing resolution better than the active capacitance compensation technique. Through the results of this experiment, we expect to improve the timing resolution on SiPM based PET detectors. For the further study, we are planning to apply this technique on the multiplexing circuit, using less balun transformers than the number of SiPM channels.

4. Reference

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