Study on Timing Performance of a Readout Circuit for SiPM

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ABSTRACT – In recent years, SiPM photoelectric devices have drawn much attention in the domain of time-of-flight-based positron emission tomography (TOF-PET). Using them to construct PET detectors with excellent coincidence time resolution (CTR) is always one of research focus. In this paper, a SiPM readout pre-amplifier based on common-base current amplifier structure followed by a Pole-Zero (PZ) compensation network is constructed, and the main factors that affect the timing performance of the PET detector are investigated. By experimental measurement, we found that the CTR is heavily related to the bandwidth of the amplifier, bias voltage of SiPM, comparator threshold, and PZ network parameter. The test setup has two detectors, one with LYSO crystal (3 mm × 3 mm × 10 mm) coupled with a Hamamatsu SiPM (S12642-0404), and the other with LaBr3 coupled to a PMT-R9800. After the optimization of the readout circuit with related factors, the CTR between the two detectors is measured as 266ps FWHM. The test result is a helpful guideline for the readout ASIC chip design in our next step.

Readout Circuit

The pre-amplifier consists of a common-base amplifier and a PZ compensation network, which is shown in Fig. 1. The biasing network of bipolar junction transistor (BJT, BFS17W) consists of resistors marked as Re1, Re2 and Rc. The quiescent point did not change throughout the experiment. Re2, C and rin, i.e. the input resistance of common-base amplifier, constitute the PZ compensation structure. The output signal is read from the collector resistance.

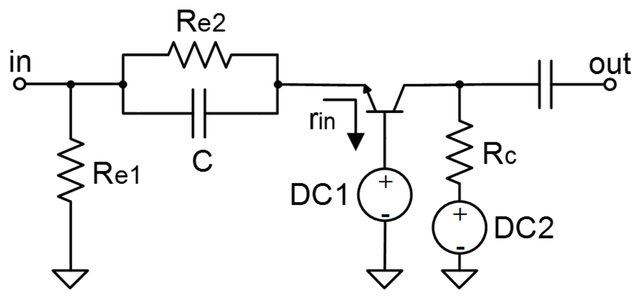


Fig. 1 Schematic diagram of pre-amplifier based on common-base amplifier and PZ compensation.

Measurement System

One a test detector module consisting of a LYSO crystal optically coupled to a channel of SiPM array, and the other a coincidence detector constructed by a block of LaBr3 crystal coupled to PMT. The programmable high-voltage power supply of SiPM provides temperature compensation function connecting with the temperature sensor attached near SiPM in lightproof box. The signals coming out from the SiPM were amplified by the pre-amplifier mentioned above. And the anode signals coming out from PMT were attenuated by a attenuator for amplitude adjustment. The amplified SiPM signals and attenuated PMT signals were then fed into our homemade discriminator board. This board provides dual-threshold differential discriminator and FPGA-based TDC for time measurement and energy measurement based on time-over-threshold method. The threshold of discriminator could be configured by adjusting threshold setup network.

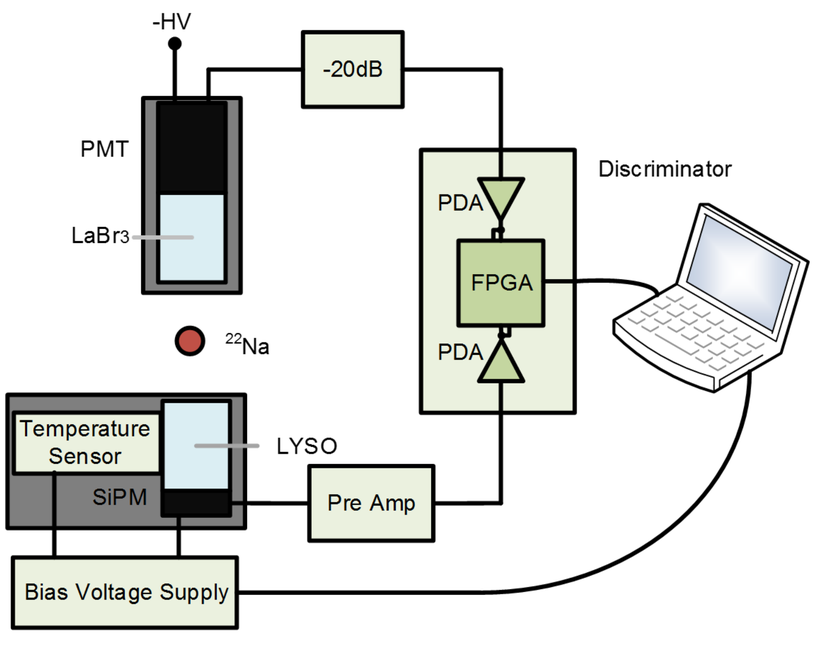
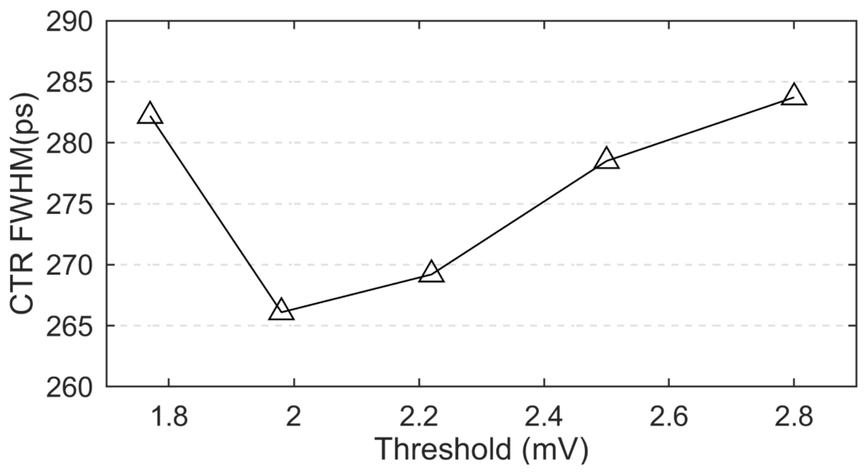
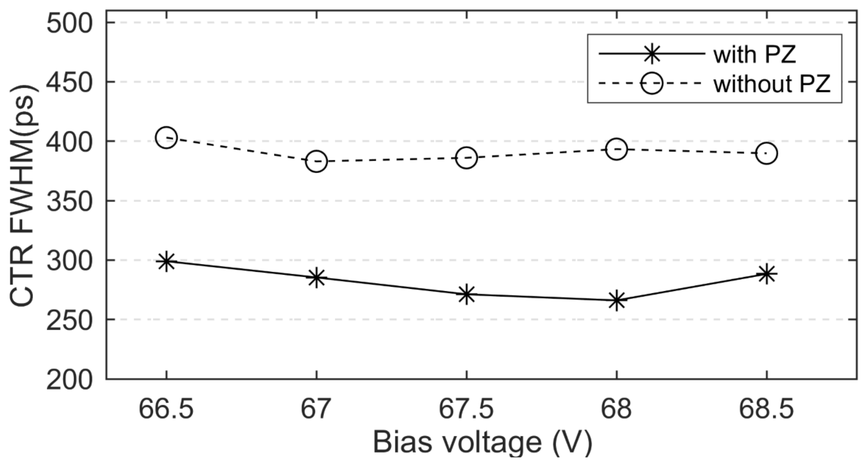


Fig. 2 Experimental setup

Test Results



(a) CTR v.s. threshold plots. Bias voltage set to 68 V and PZ compensation network deployed.



(b) CTR v.s. bias voltage plots. Thresholds are optimized.

Fig. 3 Test results

Fig. 3(a) shows the effect of threshold. This curve is measured under bias voltage of 68V. For LED, lower timing threshold yields better timing resolution. But because of the SiPM electronic response and noise, the CTR will be worse if the threshold is too low. The CTR versus bias voltage curves is shown in Fig. 3(b). As the bias voltage starts from 66.5V, CTR is becoming better due to the increased PDE and gain. After the best point, the negative effect of dark count is comparable with the positive effect, which makes CTR begin to decrease. Considering the PZ structure, two curves show that this structure can improve CTR significantly.

Conclusion

Readout circuit of SiPM is very challenging part in TOF-PET detectors. The electronics scheme with the optimized SiPM bias voltage, timing threshold and dark count shaping parameter can significantly improve the timing performance. A CTR of 266ps FWHM has been achieved in our experiment. Considering the other factors limiting CTR, including the size of crystal and operating temperature, our results show excellent performance to the SiPM used in our experiment.

References

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