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Development of Single-Line Multi Voltage Threshold and Optimization Of Input Pulse Shape and Threshold Level

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Introduction In positron emission tomography (PET) system, the energy and timing information of gamma rays acquired in coincidence manner contributes to the image quality. Furthermore, it is required to detect both information simultaneously and time-over-threshold (TOT) method is widely applied to get those information. TOT method get energy information from pulse width and timing information from arrival time of the analog scintillation pulse. However, the conventional TOT method has limitations, such as nonlinearity, which led to the development of the multi-level threshold method. Multi-level threshold method still suffers from the number of channels and bulky circuit size. In this study, we propose the developed version of multi-level threshold method which reduced the number of channels by integrating three discrete digital pulses into one by XOR gate. Additionally, the methods of optimization of input pulse shaping and threshold setting for data acquisition are proposed for better general performance of detector.

Methods

A. Single Line Multi-Voltage Threshold Method Single-line multi-voltage threshold method (SLMVT) is achieved by incorporating digital outputs by a XOR gate from each threshold as shown in **Fig. 1.** Each digital pulse resulted in from scintillator pulses passing comparators of certain thresholds compose the single-line digital pulses composed of three rising edges and three falling edges. The circuit for SLMVT consists of non-inverting amplifier (AD8000; Analog Devices), RC low-pass filter, three fast comparators (ADCMP601; Analog Devices), and an 3-input XOR gate (NC7SZ386P6X; On Semi). The analog scintillation pulses were obtained using an LYSO-SiPM detector in which a single 4 x 4 mm SiPM was coupled with a 3 x 3 x 20 mm LYSO crystal by optical grease. A Na-22 source was attached to the reference detector for data acquisition, totally 10,000 events with 1,024 samples per pulse were acquired with sampling rate of 1 giga-sample/s.

B. Energy estimator In this method, 6 discrete timestamps are derived from three different threshold voltages as a single line. By using these timestamps, three different energy estimators were applied to calculate the energy of each pulse and compare with analog pulse. According to the shape that can be formed through connecting timestamps, the estimator is divided into rectangular shape, trapezoidal shape, and crossing-point triangular shape energy estimator methods. The low pass filtering and threshold setting are required for better performance. In case of low pass filtering, 6 values from 5.6 ns to 84 ns are picked the combinations of three thresholds from 30, 40, 50 mv to 70, 100, 130 mv are tested by sweeping the lowest threshold and threshold interval.

Results

A. Energy performance The accuracy of 3 input XOR gate on detecting 6 separate points depend on the degree of filtering. The fast rising edge results in overlapping between digital pulses, which produces erroneous digital pulses. This problem can be mitigated through RC filter and only 2% among 10,000 events showed error cases in the biggest RC filter. To measure the accuracy of estimating energy histogram with 6 timestamps, the energy resolution of Analog Digital Converter (ADC), conventional TOT and single-line MVT values at each RC values are compared. Through the optimization of RC filter and threshold setting, the resolution of three energy estimators converges to about 10.33%

which is close to 11.20%, the energy resolution measured by ADC. The energy linearity of events in 200 – 550 keV is tested, which produced 0.92 R^2 value at best in crossing-point triangular sum estimator.

Conclusion

In this work, the proper method for reducing the required channel numbers while applying the advantages of multi-level voltage threshold method was suggested. The energy performance of this method is optimized through pulse shaping and threshold setting, which resulted in almost 10% energy resolution and 0.92 R^2 energy linearity.

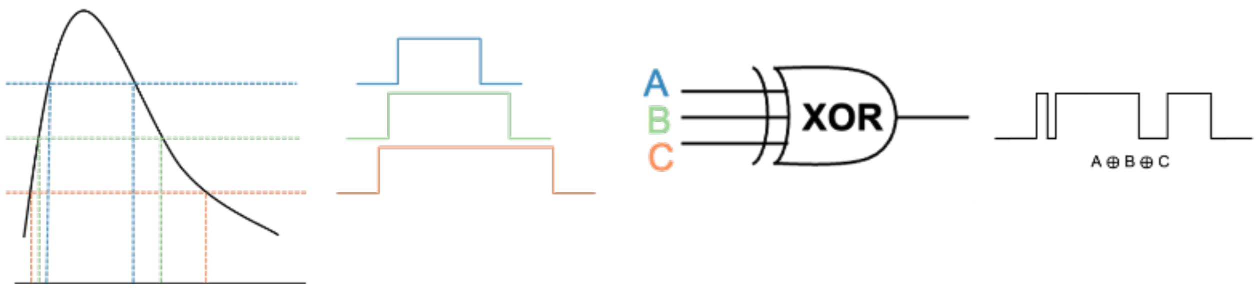

Figure 1. Schematic of the proposed single-line multi-voltage threshold method implemented with a 3-input XOR gate.