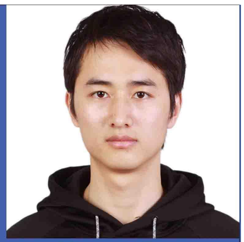
Nuclear Pulse Charge Measurement with a Method of Time Over Linear Threshold

Zhengqi Song, Yonggang Wang, Yong Xiao, Qiang Cao
Department of Modern Physics, University of Science and Technology of China, Hefei Anhui, China



Zhengqi Song

***Abstract*—Time over dynamic threshold (TODT) method, proposed in our previous work, has been successfully used for nuclear pulse charge measurement in PET detectors. It has advantages of strict linearity, large dynamic range, and better energy resolution, but requires a relatively complex circuit to generate specific dynamic threshold. In this paper, we propose to replace the dynamic threshold by a simpler linearly increasing threshold (called as TOLT method) with the aim to simplify the threshold generation circuit meanwhile maintaining its high energy resolution. Mathematical analysis on this replacement and the related realization circuit are presented. By energy spectrum measurement of PET detectors, the method is evaluated. The energy resolutions of PET detectors, composed of a PMT coupled with LYSO and LaBr3 crystal, are measured as 12.54% and 5.18% respectively, which is equivalent to the result obtained by TODT method. The test results show that the TOLT method is more practicable for charge measurement of nuclear detectors.**

Test Circuit

In Fig .1, assume a pulse signalis coming from PMT, after passing through a shaping circuit built by A1 and RC, the shaping signal will be fed into two comparators. One of them (C1) is for leading-edge timing. The output of C1 is lead-edge timing signal that triggers LT.

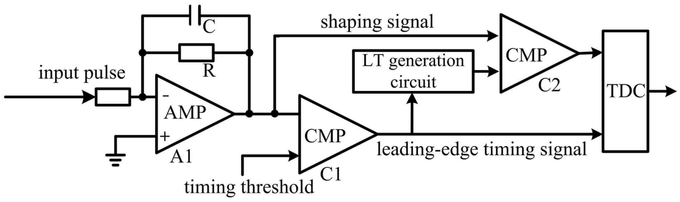


Fig. 1 The Test circuit for TOLT method.

C2 flips when the voltage of LT is over the voltage of shaping signal, we call this moment as TOLT (time over linear threshold). Time stamp of TOLT will be recorded by a high-precision (RMS 40ps) TDC. Fig .3 shows the conception of TOLT measurement.

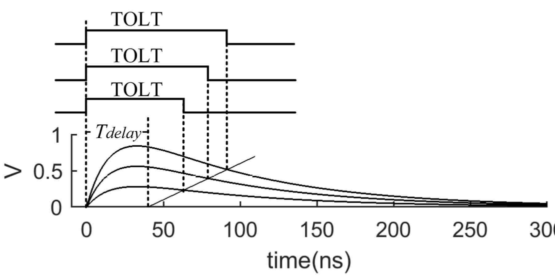


Fig. 2 The Conception of TOLT measurement.

Mathematical Interpretation

Shaping signal can be expressed as (1) if we set leading-edge time as zero point. Value of E represents pulse charge.

$$U_{shaping} = E(e^{-t/\tau_2} - e^{-t/\tau_1}) \qquad (1)$$

When threshold starts to ramp from the 0, the slope is K:

$$U_{LT} = K(t - T_{delay})$$

At the moment of TOLT, the LT equals to shaping signal:

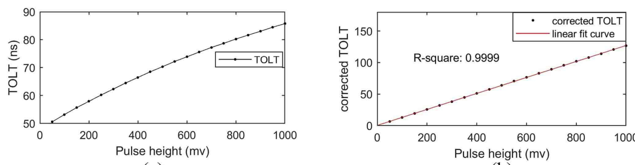
$$E(e^{-TOLT/\tau_2} - e^{-TOLT/\tau_1}) = K(TOLT - T_{delay})$$

Or it can be written as:

$$\text{pulse charge} \propto \frac{TOLT - T_{delay}}{(e^{-TOLT/\tau_2} - e^{-TOLT/\tau_1})} \qquad (2)$$

Tdelay, τ_2, τ_1 are all constants during the test, they can be measured advanced. With (2), the relationship between TOLT and pulse charge can be corrected to strict linearity. So the measured energy resolution can reach a high level.

Test Results



(a) (b)

Fig. 3 (a) relationship between TOLT and pulse height; (b)relationship between pulse height and corrected TOLT.

Fig .3 shows the linearity measured from the test circuit. Pulses with different height are generated by an Arbitrary Function Generator (AFG3252) from Tektronix. TDC built in cyclone III FPGA is used to measure TOLT. Measured relation between TOLT and pulse height has been draw out in Fig .3(a). After correction had been performed, relation between corrected TOLT and pulse height yields strict linearity as shown in Fig. 3(b)

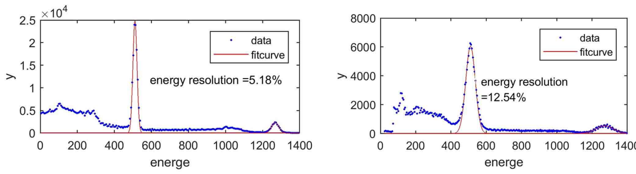


Fig .4. measured energy spectrum of left:LaBr3, right:LYSO

Then the energy spectrum of LaBr3 and LYSO had been measured. Na-22 had been used as radioactive source. gamma rays will be detected by PMT R9800 from Hamamatsu, which outputs pulses to our test circuit. After correction, energy spectrums are shown in Fig .4. Gaussian Fitting had been used for peak at 511Kev. Energy resolutions, represented by FWHM/511Kev, equals to 5.18% and 12.54% for LaBr3 and LYSO respectively. The measured energy resolutions are reasonably fine compared to TODT method.

Conclusion

Combining FPGA with the front-end circuit brought some new prospects to the TOLT method. The LT generation circuit in this paper, though simple, can be simplified further by using I/O port on FPGA as constant current source. Other components, like TDC and correction table, can all be easily constructed in FPGA without adding complexity to the system. To fully exploit advantages of FPGA, schemes with high integration and low cost would be easier to realize. This points out the direction to our future work: in front-end circuit, the pursuit of higher integration level will never stop.

References

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[2] Yonggang, Wang. "A novel nuclear pulse digitizing scheme using time over dynamic threshold." *Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC), 2011 IEEE*. IEEE, 2011.