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Modernization of the pulse shape discrimination method for neutron and gamma quanta in scintillation detector

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Abstract. In this paper, we investigated the efficiency of several known and new methods of digital pulse shape discrimination for neutrons and gamma quanta. Experimental data were obtained on a setup consists of a Pu-Be neutron source, organic p-terphenyl scintillation detector and 14 bits, 500 MHz sampling rate flash-ADC with capability to store and upload to the host computer long waveforms for further analysis. A comparison is made in between the results of using traditional and new methods for calculating the signal separation efficiency of Figure of Merit (FOM). The best known from the literature value of the efficiency of neutron and gamma quanta discrimination for the Pu-Be source is FOM = 1.5. We obtained the separation efficiency FOM = 1.77 in the scintillation detector with the p-terphenyl crystal, by a new method. Note also that for the known liquid scintillator BC-501A FOM≈1. A new method of scintillation detector pulse shape discrimination from neutrons and gamma quanta is used to detect the neutron yield from compact neutron generator that is created on the basis of carbon nanotubes.

1. Introduction

A registration of fast neutrons in the presence of intense gamma radiation background is required in many fundamental and applied research. Such tasks are control of spent nuclear fuel, measurement of the yield of fast neutrons from neutron generators, monitoring of neutron and gamma background in underground low-background experiments (neutrino and dark matter detectors), and environmental monitoring. Scintillation detectors with organic crystals are often used for the registration of fast neutrons. In such scintillators, the flash of scintillation light contains two components: fast and slow. The fast component stays the same for particles of different types. The intensity of the slow component in some organic scintillators is greater when registering fast neutrons than gamma rays. Analysis of the pulse shape of such a scintillation detector allows to discriminate the signals from neutrons and gamma rays. One of the scintillators, which allows efficient pulse shape discrimination for neutrons and gamma, is a single crystal p-terphenyl [1-6]. A modern technique of digital acquisition with the following digital processing of the output pulses from a scintillation detector allows to discriminate signals from gamma quanta and neutrons.

2. Experimental setup

In order to optimize methods for neutron-gamma pulse shape discrimination, we provided experimental studies with a Pu-Be neutron source. The setup consists of a Pu-Be neutron source, a p-terphenyl cylinder organic crystal scintillation detector (diameter = 25 mm, height = 25 mm), CAEN DT5730 digitizer, and a personal computer. Hamamatsu R6094 photomultiplier detects light photons from a p-terphenyl crystal. The signals from the PMT R6094 come to the CAEN DT5730 analog input (14 bit, 500 Ms/s, bandwidth 250 MHz). The impedance of the analog input is 50 Ohm. Digitizer can store and save to file a different number of samples per event. We stored 500 samples per event. Thus, one time bin equals to 2 ns, the waveform length is 1 µs. Waveform signals from the digitizer's output through a USB port are fed to a personal computer.

3. The digital methods of neutron-gamma discrimination by the pulse shape

All digital methods of neutron-gamma pulse shape discrimination use a comparison of the relative intensity of the slow component of the scintillation flash. To this end, the areas of signal sections in the predefined gate are calculated for each output pulse of the scintillation detector. Gate selection is one of the main differences of pulse shape discrimination algorithms. We used two types of gates: 1) S_{short} short gates include the main signal part and S_{long} long gates include the entire signal area (figure 1); 2) the S_{fast} gate includes the fast signal part and the S_{slow} gate includes the slow signal part (figure 2).

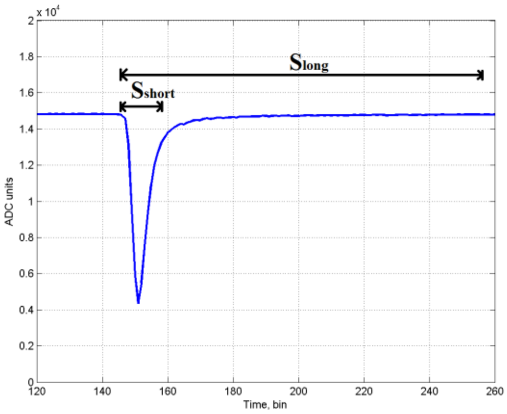

Figure 1. Waveform with indication of the short and long gates.

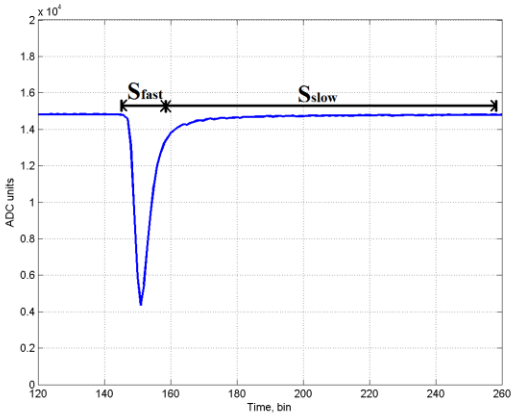

Figure 2. Waveform with indication of the fast and slow gates.

The PSD (Pulse Shape Discrimination) parameter serves as a parameter for discriminating signals by the shape of the pulse's waveform. The quantitative criterion for the efficiency of the separation of peaks from neutrons and gamma quanta is the FOM (Figure of merit) value FOM. The value of FOM = $(\text{max}_n - \text{max}_\gamma) / (\text{FWHM}_n + \text{FWHM}_\gamma)$.

Usually the gate is set relative to the position of the trigger. The best value of the efficiency of neutron-gamma discrimination for the Pu-Be source was obtained in [3] and FOM = 1.5 for the gate of the first type.

However, the position of the signal's maximum fluctuates relative to the moment of the trigger. So, we set the position of the gate relative to the maximum of the signal t_{max} for both types of gates. We investigated three methods for calculating the efficiency of pulse discrimination.

In the first method, to calculate the PSD parameter, we use the following ratio $\text{PSD}_1 = (S_{\text{long}} - S_{\text{short}}) / S_{\text{short}}$. The histogram of PSD_1 values is shown in figure 3. The beginning and end of the short and long gates are calculated by the formulas: $t_{\text{beg\_s}}=t_{\text{beg\_l}}=t_{\text{max}}+\Delta_1$; $t_{\text{end\_s}}=t_{\text{max}}+\Delta_2$; $t_{\text{end\_l}}=t_{\text{max}}+\Delta_3$. The parameters Δ_1, Δ_2, Δ_3 vary to find the optimal FOM value. The amount of PSD_1 histogram smoothing also varies. Figure 4 shows the dependence of the FOM on the position and duration of the gate. The best value of the separation efficiency of signals from neutrons and gamma quanta is FOM=1.37±0.05.

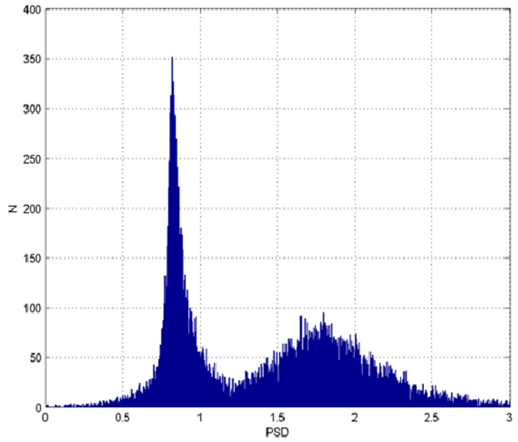

Figure 3. PSD_1 histogram.

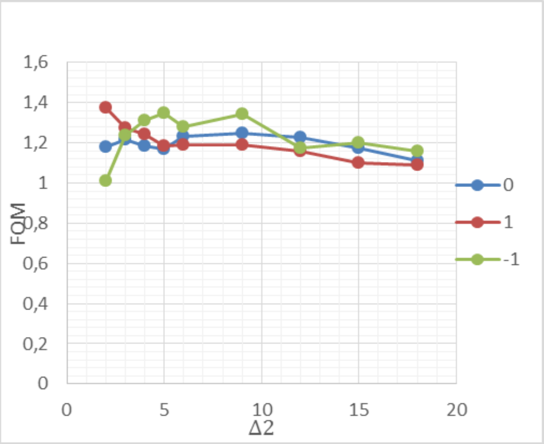

Figure 4. Method #1. FOM versus Δ_2 with Δ_1=0, -1, 1; Δ_3=300.

In the second method, we find the value of the PSD parameter using the formula $PSD_2 = S_{slow} / S_{fast}$. The histogram of PSD_2 values is shown in figure 5. The beginning and end of the gate are calculated by the formulas: $t_{beg\_fast}=t_{max}+\Delta_1$; $t_{beg\_slow}=t_{end\_fast}=t_{max}+\Delta_4$; $t_{end\_slow}=t_{max}+\Delta_3$. The parameters Δ_1, Δ_4, Δ_3 and the number of smoothings of the PSD_2 histogram vary. Figure 6 shows the FOM dependency for the second method. The best value of the separation efficiency of signals from neutrons and gamma quanta is FOM = 1.54 ± 0.06.

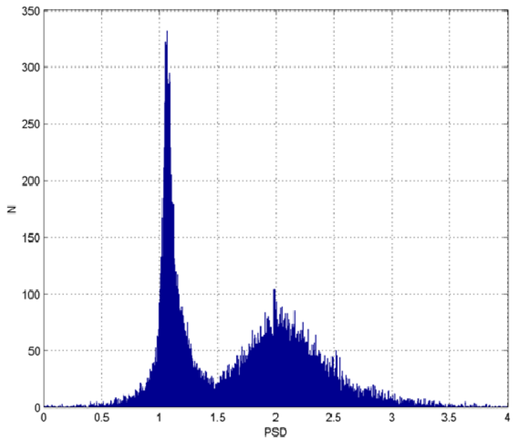

Figure 5. PSD_2 histogram.

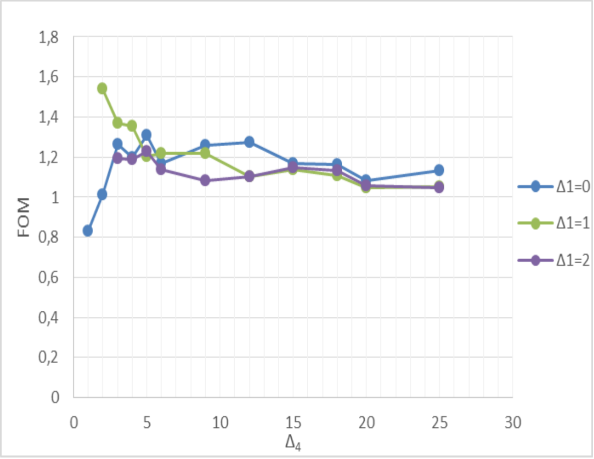

Figure 6. Method #2. FOM versus Δ_4 with Δ_1=0, 1, 2; Δ_3=300.

In the third method, we calculate the value of the PSD parameter using the formula $PSD_3 = (S_{long} - S_{short}) / S_{long}$. The histogram of PSD_3 values is shown in figure 7. The beginning and end of the gate are calculated using formulas similar to Method 1. The parameters Δ1, Δ2, Δ3 and the number of smoothings n of the histogram PSD_3 vary. Figure 8 shows the FOM dependency for the third method.

The best value of the separation efficiency of signals from neutrons and gamma quanta is FOM = 1.77 ± 0.07.

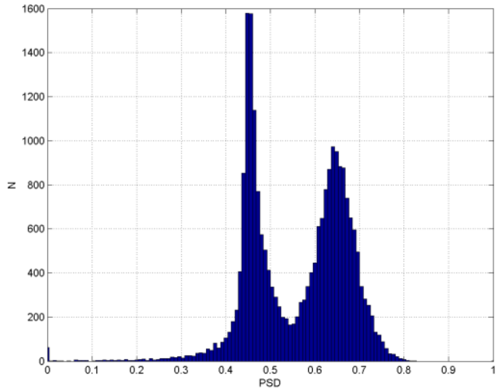

Figure 7. PSD$_3$ histogram.

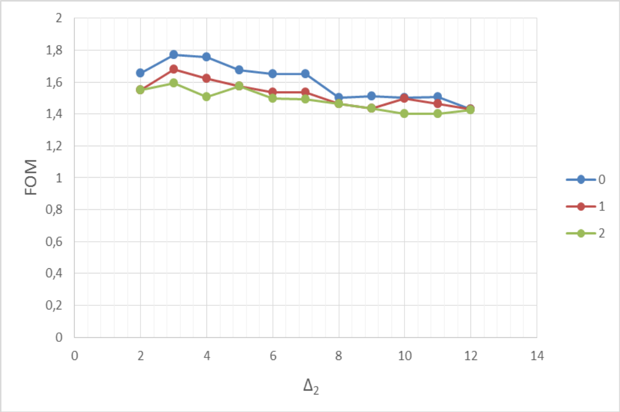

Figure 8. Method #3. FOM versus Δ2 with n=0, 1, 2; Δ_1=1; Δ_3=300.

4. Conclusion

A p-terphenyl scintillation detector allows efficient detection of fast neutrons against the background of gamma radiation. Digital methods analyzing the shape of the pulses waveform from the detector make it possible to separate signals from fast neutrons and gamma quanta. The selection of the gate position relative to the maximum of the signal increases the efficiency of separation of signals from neutrons and gamma quanta. Optimizing the position and duration of the gate is important. With the new method, we obtained the separation efficiency of the signals FOM = 1.77. For the known BC-501A liquid scintillator, the magnitude FOM ≈ 1. The scintillation detector with the p-terphenyl crystal was used to measure the neutron yield in the new developed neutron generator using carbon nanotubes [7, 8].

Acknowledgments

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