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Digital neutron-gamma discrimination in a wide energy range using pulse reconstruction method

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HIGHLIGHTS

- The pulse reconstruction method was utilized to perform neutron-gamma discrimination (NGD) with NE213 scintillator.
- A digital storage oscilloscope with an 8-bit digital-to-analog convertor was responsible for receiving the scintillator anode pulses.
- The NGD results on an Am–Be combined neutron-gamma source represents the feasibility of the proposed method.

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ABSTRACT

In this research, based on pulse reconstruction method, digital storage oscilloscopes with an 8-bit digital-to-analog convertor was used to successfully perform the neutron-gamma discrimination with NE213 (or its equivalent BC501A) scintillator anode pulses at minimum discrimination bias value of 95 keVee (or keV electron equivalent). Also, a 100 mCi ^{241}Am–Be source and micro-Curie gamma ray sources (^{137}Cs and ^{22}Na) were used for the system calibration and discrimination studies. The results confirm the feasibility and simplicity of the proposed method.

1. Introduction

Gamma rays are always accompanying neutrons in isotopic neutron sources which reinforce the importance of neutron-gamma discrimination (NGD) techniques (Knoll, 2010). The NGD has important applications in neutron flux/spectrum determination in heavy ion therapeutic systems, fast neutron (above tens of MeVs) production in spallation reactions (Yoshioka, 2011) and photoneutrons of about 1 MeV energy produced as a result of high-energy (above 12 MeV) X-ray interactions in medical linear accelerators (Esposito et al., 2008). A variety of NGD techniques such as zero-cross, Owen, time-of-flight, and charge comparison methods have been frequently used by many researchers around the world (Divani-Vais et al., 2012; Binaei Bash et al., 2013). The digital discrimination systems introduced and significantly developed in recent years have found numerous applications and they show many advantages over analog systems. The reduction in the size of required electronics, multi-parameter analysis feature, high-compatibility with other hardware, enhanced efficiency, stability and manageability are the most important advantages (Siddavatam, 2014).

Both anode and dynode pulses can be used for discrimination process, however anode pulses result in more efficient and precise pulse-shape discrimination (PSD). The end region of decay time is a characteristic of radiation type in fast anode pulses (i.e., with 50 Ω load resistor) (Cvachovec, 2011). Fig. 1 shows two anode pulses of NE213 scintillator when exposed to neutrons and gamma rays representing different decay times.

The digital NGD with anode pulses, when performed in wide energy range and especially in low-energy, requires a fast analog-to-digital convertor (ADC) with 12-bit or higher precision. The design and fabrication of such electronic circuitry is complex and costly.

Some researchers prefer to use 8-bit ADCs which take advantage of simple driving circuit but these ADCs are basically

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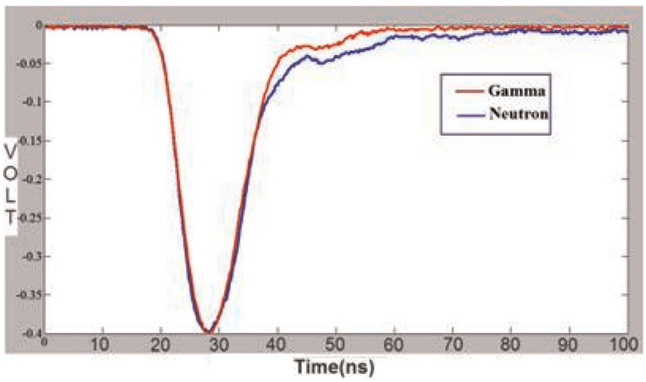

Fig. 1. The anode pulses of an NE213 scintillator when exposed to neutrons and gamma rays.

unable to cover wide range of energies because when the circuit operates in high-gain mode, large-amplitude pulses saturate giving no clear peak magnitude. On the other hand, when using these ADCs in low-gain mode, the discrimination factor weakens for low-amplitude pulses (Takaku and Baba, 2011). In the present study, it has been tried to perform the neutron-gamma discrimination in wide dynamic range of pulses using an 8-bit ADC and by incorporating pulse reconstruction method.

2. Materials and methods

The setup of Fig. 2 has been used for the NGD measurements. The detector includes a ⌀3 in. × 3 in. cylindrical aluminum cell of NE213 scintillator, optically coupled to a 3 in. R6091 HAMAMATSU photomultiplier tube (PMT) covered with a thin mu-metal cylinder and jointed to a resistor voltage divider. A 100 mCi ^{241}Am–Be neutron source in paraffin wax as moderator has been used for the NGD measurements whilst the energy calibration has been undertaken with 0.5 μCi and 2 μCi ^{137}Cs and ^{22}Na gamma-ray sources, respectively. The digital sampling of anode pulses has been performed with an 8-bit 500 MHz–5 Gs/s digital storage oscilloscope.

The anode pulse has been digitized and each pulse is stored in the form of a two-column time-amplitude matrix such that all characteristics including rise-time, fall time, amplitude etc. can be extracted. The number of rows is apparently dependent on the oscilloscope timing resolution. In this research, according to the required precision and the data acquisition/storage/processing speed, it has been decided to select 500 points for each pulse. A computer software, specifically written in C#, has been prepared for the data processing of the present study. The software takes average on every 10 points to reduce noise and consequently smooth the pulse.

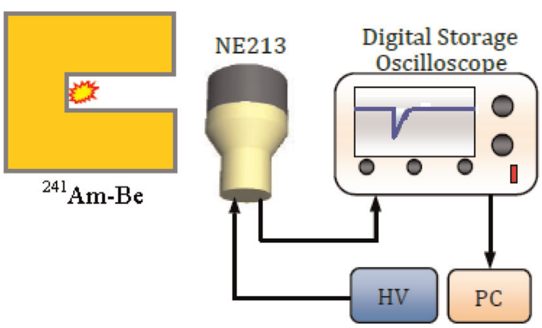

Fig. 2. A schematic of experimental setup for digital NGD.

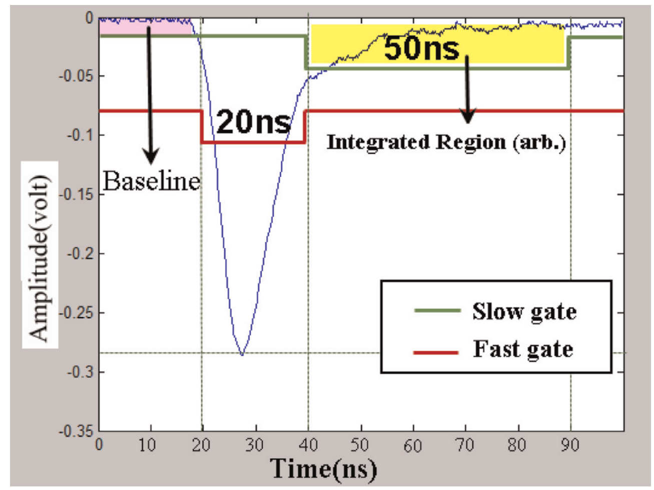

Fig. 3. A time gate used for sampling from anode pulses with pulse-heights reaching to 10% of maximum amplitudes.

In order to determine the best discrimination quality, different parameters of anode pulses have been experimentally studied. It has been finally decided to take the area under the decay region in the time interval shown in Fig. 3, up to 10% of pulse amplitude as recommended by Yoshioka (2011). The NGD curve can be produced by plotting the above integration in terms of peak amplitude. By decreasing the volt division of oscilloscope, the procedure can be performed for low-amplitude pulses, and hence the discrimination is achievable for very small thresholds. But as shown in Fig. 4, small volt divisions result in the saturation of pulses which prevents recording the pulse amplitudes. This problem can be resolved by fitting an appropriate curve to the points which are in unsaturated region of the pulse.

The anode pulse function can be calculated in two different ways: (1) using scintillation light yield curves for different charged particles (Cvachovec, 2011) and the PMT equivalent circuit or (2) using data fitting on several pulses and determination of pulse function.

The precise calculation of pulse function based on PMT equivalent circuit and scintillator behavior is relatively difficult due to numerous capacitors and inductors of such acquisition device. Then, the fitting process has been undertaken with complex function feature of MATLAB software and after some try and error it has been decided to implement the following third-order Gaussian function for data fitting on a sampled anode pulse:

$$F(x) = k\left(a_1 e^{-\left(\frac{x-b1}{c1}\right)^2} + a_2 e^{-\left(\frac{x-b2}{c2}\right)^2} + a_3 e^{-\left(\frac{x-b3}{c3}\right)^2}\right) \quad (1)$$

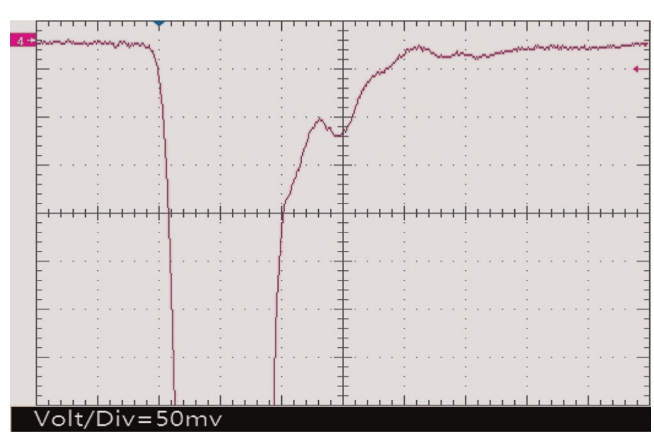

Fig. 4. The saturated anode pulse of an NE213 scintillator.