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Pulse-shape discrimination of the new plastic scintillators in neutron–gamma mixed field using fast digitizer card

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HIGHLIGHTS

- A newly developed digital spectrometric system employing a fast digitizer card has been verified.
- The PSD properties of EJ-299-33, BC-501A and BC-501 scintillators are compared by measurements in the Van de Graaff laboratory.
- All scintillators achieve improved discrimination capability by utilizing the composite digital channel.

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ABSTRACT

Recently invented plastic scintillator EJ-299-33 enables pulse-shape discrimination (PSD) and thus measurement of neutron and photon spectra in mixed fields. In this work we compare the PSD properties of EJ-299-33 plastic and the well-known NE-213 liquid scintillator in monoenergetic neutron fields generated by the Van de Graaff accelerator using the $^{3}H(d, n)^{4}He$ reaction. Pulses from the scintillators are processed by a newly developed digital measuring system employing the fast digitizer card. This card contains two AD converters connected to the measuring computer via 10 Gbps optical ethernet. The converters operate with a resolution of 12 bits and have two differential inputs with a sampling frequency 1 GHz. The resulting digital channels with different gains are merged into one composite channel with a higher digital resolution in a wide dynamic range of energies. Neutron signals are fully discriminated from gamma signals. Results are presented.

1. Introduction

In suitable scintillation detectors, fast digitizing of scintillation pulses can enable determination of type of nuclear radiation, e.g., neutron and photon discrimination in a mixed field. Liquid scintillating detectors are widely used to achieve neutron–gamma discrimination due to their excellent pulse-shape discrimination (PSD) properties.

Recently, a new class of plastic scintillating materials with PSD properties has been developed (Zaitseva, 2012; van Loef, 2014; Zhmurin et al., 2014; Blanc et al., 2014). In this paper, we study the PSD properties of the new plastic scintillator, EJ-299-33 (Zaitseva, 2012; Lawrence et al., 2013; Pozzi et al., 2013; Nyibule et al., 2014; Cester et al., 2014; Pozzi et al., 2014), and two liquid scintillators, BC-501A (NE-213) (Luo et al., 2013) and BC-519 (Horváth et al., 2000) using a two-parametric digital spectrometric system which we newly developed. The assembled digital spectrometric system is shown in Fig. 1.

2. Two-parametric digital system for neutron–gamma spectrometry

The digital spectrometric system minimizes the drawbacks of analog devices and provides substantial simplification for the operation and setting of the system.

Fig. 2 schematically shows the signal and data flow inside the digital spectrometric system. The detector signal output is connected to an analog input amplifier and split into two branches (channels) with a different gain.

Each signal channel is digitized by a fast ADC type ADC12D1000 by Texas Instruments with 12 bits resolution.

The ADC works with a sampling frequency of 1 GHz. The output signals are processed in FPGA Xilinx Virtex-6 at a speed of 24 Gbps. The amplified digitized channel and the non-amplified

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Fig. 1. Two-parametric digital spectrometric system. From the left side: digital spectrometer, amplifier and detector with HV connector.

digitized channel are merged into one composite channel. The composite channel algorithm is illustrated in Fig. 3. The connection between the ADC card and the computer is realized via 10 Gbps optical ethernet. A transfer protocol has been designed for real-time transmission of measured data into the computer memory.

3. Neutron–gamma discrimination

3.1. Pulse-shape discrimination by charge integration

The digital spectrometer has incorporated the integration method (Brooks, 1959) for recognition of neutron and photon pulses within the signal processing unit. The method is based on pulse charge comparison. The PSD parameter is calculated to recognize neutron and photon events:

$$PSD = \frac{\int_{T_{\mathrm{tail}}}^{T_{\mathrm{end}}} \mathrm{pulse}(t)\,\mathrm{d}t}{\int_{0}^{T_{\mathrm{end}}} \mathrm{pulse}(t)\,\mathrm{d}t}, \qquad (1)$$

where T_{tail} is an optimized beginning of the tail part of the pulse and T_{end} is an optimized end point of the pulse.

3.2. Figure of merit

The quality of neutron–gamma discrimination for a given scintillator is characterized by the figure of merit (FOM):

$$FOM = \frac{\Delta_{\mathrm{gn}}}{FHWM_{\mathrm{gamma}} + FWHM_{\mathrm{neutron}}}, \qquad (2)$$

where Δ_{gn} is the separation between the gamma-ray and neutron peaks and *FWHM* is the full-width at half maximum of the relevant peak on the corresponding section of the 2D histogram: light output vs. PSD parameter (PSD histogram).

3.3. Quality function

The separation quality function (QF) for a given section of the PSD histogram (PSD section) is defined as follows (Matěj et al., 2014):

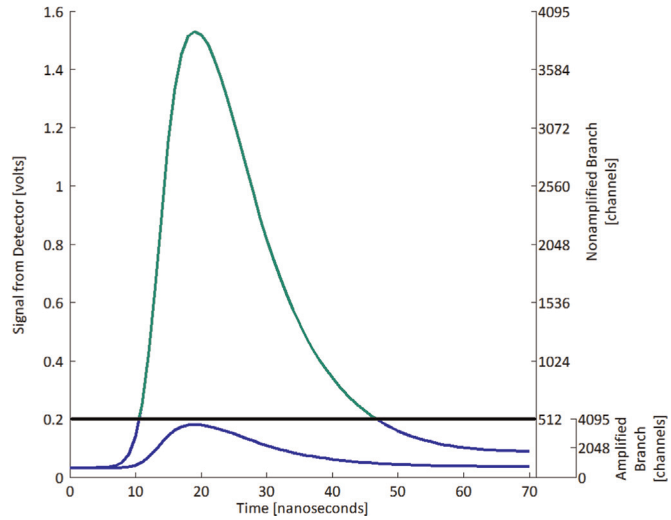

Fig. 3. Low-energy pulses are completely sampled by amplified branch. High-energy pulses are sampled by non-amplified branch for the sample value in the amplified branch range (blue color). Otherwise, the signal is sampled by non-amplified branch (green color). This method increases the dynamic range of the detected signal especially in the low voltage area and, as a consequence, the neutron–gamma separation is enabled towards lower neutron energy. (For interpretation of the references to color in this figure caption, the reader is referred to the web version of this paper.)

$$QF = FOM \cdot \frac{\Sigma_2}{\Sigma_1}, \qquad (3)$$

where *FOM* is the figure of merit defined in Eq. (2), Σ_1 is the whole area of the PSD section and Σ_2 is the area of the part of the PSD section bounded from below by the minimum level between the neutron and gamma-ray peaks. The quality function construction is illustrated in Fig. 4. All detected particle events are properly separated for a PSD section satisfying $QF > 1$. In comparison with the FOM function, the function quality introduces a more conservative criterion for evaluation of the quality of PSD separation at particle events.

4. Energy calibration

Integrated digitized pulses were linearly calibrated in keVee units, or keV electron equivalent. The linear transformation coefficients were derived from positions of the Compton edge (Dietze and Klein, 1982) in spectra of two gamma-ray sources ^{137}Cs and ^{60}Co. Sources of activity 350 kBq were placed on the center of the front face of each detectors. Measurement time was determined in accordance with count rates from the detectors. High voltages were adjusted for the following detectors: EJ-299-33 = 1.04 kV, BC-501A = 1.35 kV and BC-519 = 1.48 kV.

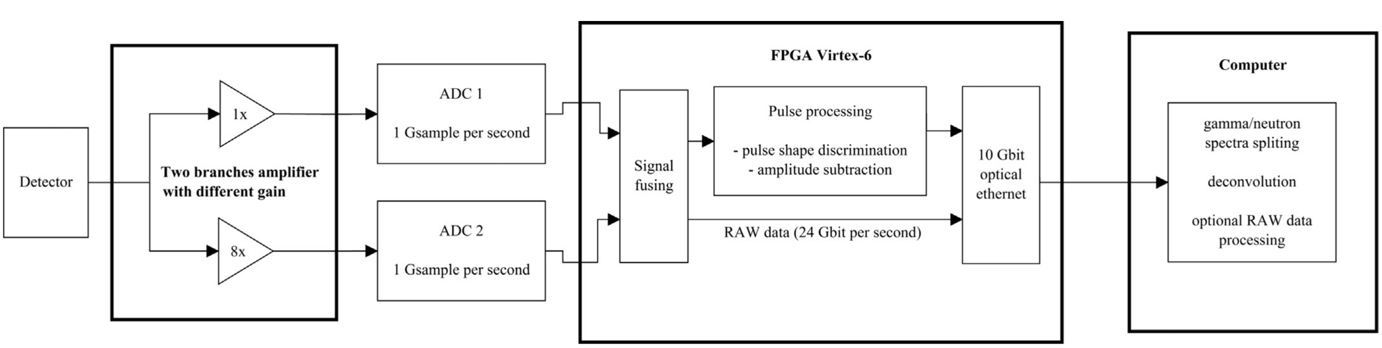

Fig. 2. Scheme of the two-parametric digital spectrometric system.

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