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Comparison of analog and digital pulse-shape-discrimination systems

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ABSTRACT

Pulse shape discrimination (PSD) performance of two optimized PSD systems (one digital and one analog) is compared in this work. One system uses digital charge integration, while the other system uses analog zero crossing. Measurements were conducted with each PSD system using the CAEN V1720 (250 MHz) data acquisition system. An organic-liquid scintillator, coupled to a photo-multiplier tube, was used to detect neutrons and gamma rays from a Cf-252 spontaneous-fission source. The PSD performance of both systems was optimized and quantified using a traditional figure-of-merit (FOM) approach. FOM's were found for three, 300 keVee light-output bins, spanning from 100 to 1000 keVee, and one larger bin from 100 to 1800 keVee. Digital PSD outperformed analog PSD in the lowest light-output bin by approximately 50%, and by 11% for the highest light-output bin.

1. Introduction

Scintillators are radiation detectors that create a measurable collection of light photons when a sufficient amount of energy is deposited from radiation [1]. By coupling light-readout electronics – for example, a photo-multiplier tube (PMT) – to the scintillator, the light can be collected and converted into a voltage pulse, allowing for data acquisition/processing. Some types of scintillators, such as organic-liquid scintillators, are sensitive to both gamma rays and neutrons. Additionally, in organic-liquid scintillators the amount of light produced as a function of time differs based on the type of radiation.

Gamma rays interact in the organic-liquid scintillator via Compton scattering, where outer-shell electrons are ejected from their orbitals and ionize hydrocarbon molecules along their tracks. This process creates a collection of light photons with a narrower time distribution in contrast to light-photon distributions created by neutrons [1]. Typically in organic scintillators, neutrons elastically scatter on either hydrogen or carbon nuclei. When colliding with hydrogen, the neutron will either partially or fully transfer its kinetic energy to the nucleus. On the other hand, if the neutron collides with carbon, only a fraction of its energy can be transferred to the nucleus. The recoiled nucleus then ionizes hydrocarbons in its vicinity. This process of light production is inherently slower than light production induced by gamma-ray interactions. This difference between gamma-ray and neutron scintillation-pulse shapes is exploited by pulse-shape-discrimination (PSD) techniques [1–3,5].

The two general categories of PSD hardware are analog and digital-based systems. Analog PSD typically consists of a module that is designed to perform specific tasks on the voltage pulse from light-readout electronics, using analog circuitry [2,3]. The zero-crossing PSD technique is one of the traditional approaches to analog PSD. In zero-crossing, the time at which the tail of a pulse crosses a prescribed amplitude threshold (referred to as “zero”), is reported as a voltage, and is used as a PSD parameter. Particle discrimination is achieved by separating particles based on this voltage. This discrimination technique is relatively easy to implement into analog circuitry and is therefore a typical choice for analog PSD [7].

Another common method of PSD, digital charge integration (DCI), consists of digitizing the voltage pulse from a light-readout electronic and applying integration techniques to the discretized pulse. Digitizing the pulses also allows the user to apply various data-processing techniques, such as removing clipped (larger than the dynamic range of the digitizer) and double (pileup) pulses, before applying the integration techniques. The analog, zero-crossing PSD technique and the charge-integration technique of the digital-PSD approach (referred to in this work as DCI) share the same goal: To differentiate between gamma-ray and neutron pulses based on the inherently different shapes of pulses measured in a PSD-capable organic scintillator. This work compares the PSD performance of the analog and digital PSD approaches, while maintaining almost identical measurement constraints between the two systems during comparison. The motivation behind this work is to assess the PSD performance of optimized digital and analog PSD systems in a direct and reasonably unbiased comparison.

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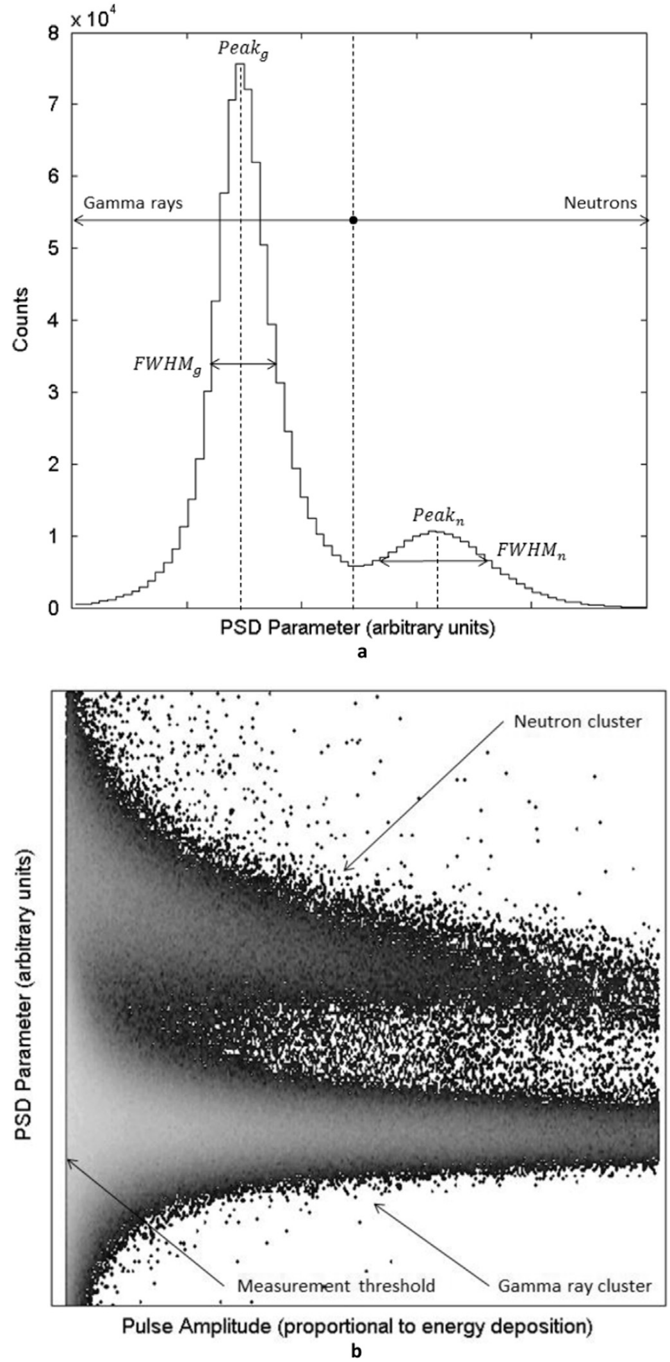

Fig. 1. (a) Sample PSD parameter histogram (PPH). (b) Sample PSD image.

The analog and digital PSD systems compared in this work output the same type of information; a PSD-parameter histogram (PPH). The measured PPH is used to assess the PSD performance. A sample PPH from Cf-252 data is shown in Fig. 1a. PSD performance constitutes how well the gamma-ray and neutron distributions are separated from each other in the PPH. The actual comparison method used to quantify the PSD performance of both systems is described in Section 2.1. Accurately identifying/separating gamma rays and neutrons in mixed-radiation fields can provide valuable information for a number of research disciplines that use PSD-capable scintillators, including reactor instrumentation, dosimetry, nuclear nonproliferation, and nuclear safeguards [1].

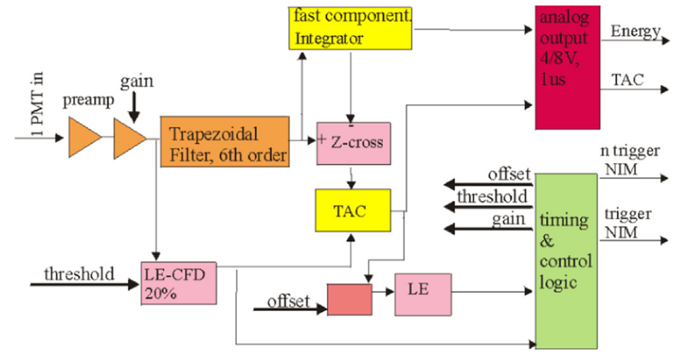

Fig. 2. MPD4 schematic [4].

1.1. Description of analog PSD system

The Mesytec MPD4 system has four channels, each capable of receiving pulses from a single detector [4]. Each pulse is sent through a 6th-order-trapezoidal filter that proportionally increases the full width at half maximum (FWHM) of the pulse [4], followed by a capacitor that integrates the fast component of the pulse from 0 to 20 ns. This integrated value is then reported as a voltage, which is proportional to the energy deposited by the particle that created the pulse. The MPD4 refers to this value as the amplitude of the pulse (AMPL), although it should be emphasized that AMPL is indeed an integral. The time at which the filtered pulse crosses zero is also reported as a voltage, and it is referred to by the MPD4 as the time at zero crossing (TAC). The TAC parameter is used to discriminate between particle type; typically, gamma rays have smaller TAC values than neutrons. A diagram of the MPD4 electronics is shown in Fig. 2 and sample AMPL and TAC pulses are shown in Fig. 3.

TAC and AMPL values are reported as the amplitudes of a shaped, approximately 1 μs-long pulse, created by the MPD4. For every single scintillator pulse accepted by the fixed-threshold setting of the MPD4 (0.07 V) two outputs are created (TAC and AMPL). A scatter plot of TAC and AMPL produces a PSD image showing a cluster of gamma-ray data and a cluster of neutron data.

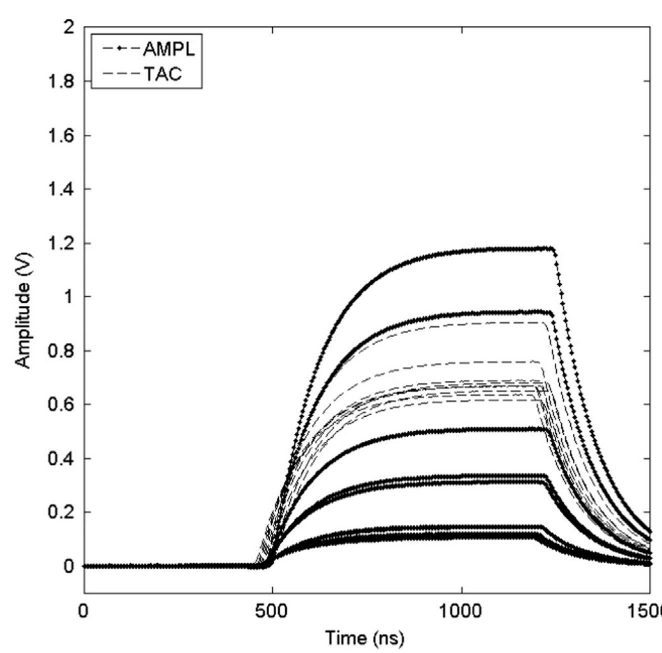

Fig. 3. Sample pulses from MPD4 when connected to an EJ309 organic-liquid scintillator as digitized by the CAEN V1720. The pulse amplitude represents either the AMPL or TAC of a recorded event.