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Study of sampling rate influence on neutron–gamma discrimination with stilbene coupled to a silicon photomultiplier

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HIGHLIGHTS

- Linear interpolation used in digital charge comparison.
- Good PSD performance achieved at Low sampling rate.
- PSD performance of a stilbene scinitillator coupled to a SiPM was investigated.

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ABSTRACT

Choosing a digitizer with an appropriate sampling rate is often a trade-off between performance and economy. The influence of sampling rates on the neutron-gamma Pulse Shape Discrimination (PSD) with a solid stilbene scintillator coupled to a Silicon Photomultiplier was investigated in this work. Sampling rates from 125 MSPS to 2 GSPS from a 10-bit digitizer were used to collect detector pulses produced by the interactions of a Cf-252 source. Due to the decreased signal-to-noise ratio (SNR), the PSD performance degraded with reduced sampling rates. The reason of PSD performance degradation was discussed. Then, an efficient combination of filtering and digital signal processing (DSP) was then applied to suppress the timing noise and electronic background noise. The results demonstrate an improved PSD performance especially at low sampling rates, down to 125 MSPS. Using filtering and DSP, the ascribed Figure of Merit (FOM) at 125 keV_{ee} (± 10 keV_{ee}) increased from 0.95 to 1.02 at 125 MSPS. At 300 keV_{ee} and above, all the FOMs are better than 2.00. Our study suggests that 250 MSPS is a good enough sampling rate for neutron-gamma discrimination in this system in order to be sensitive to neutrons at and above ~ 125 keV_{ee}.

1. Introduction

In the past few years, efforts to develop better neutron detectors for homeland security, nonproliferation and safeguards applications have grown considerably (Pozzi et al., 2013). Recently, Silicon Photomultipliers (SiPMs) have become increasingly attractive with numerous desirable features such as: low sensitivity to magnetic fields, low voltage requirement, capability of room temperature operation, scalable architecture, small size, and competitive cost (Ruch et al., 2015). When coupled to a scintillating material, these devices can be used in a variety of radiation instrumentation systems including those designed for dosimetry (Moutinho et al., 2014; Jackson et al., 2014), medical imaging (Raylman et al., 2014; Llosa et al., 2009; D'Ascenzo and Saveliev, 2012; Stolin et al., 2013), high-energy physics (Bloser et al., 2014; Andreotti et al., 2010), and homeland security (Sinclair et al., 2014).

Stilbene scintillators are widely used as neutron detectors in mixed neutron and γ-ray radiation fields because of their high light output, resulting in excellent pulse shape discrimination (PSD) capability and high detection efficiency for fast neutrons (Xing Zhang et al., 2012). In recent years, unique digital PSD time domain methods have been proposed due to the availability and variety of high-speed waveform digitizers (Liu et al., 2010). Choosing an appropriate sampling rate for them is always a tradeoff between performance and economy. Higher sampling rate will often improve PSD, up to a certain point. However, high sampling rates require increased power consumption (see Fig. 1), memory and cost, which could be a very important factor when building imaging arrays with multiple channels or for portable instrumentation.

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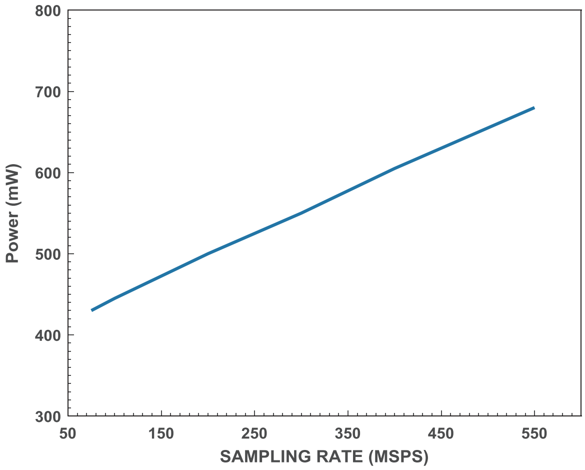

Fig. 1. Power consumption of a typical Analog-to-Digital converter device, AD9434, increases almost linearly with sampling rate (AD9434 Datasheet, 2016).

Past work has shown that good PSD performance (FOMs > 2.29) with solid stilbene coupled to a silicon photomultiplier was achieved at energies above 500 keV_{ee} by using a 500 MHz, 14-bit digitizer (.Preston et al., 2014). While the influence of sampling rate with liquid scintillators and PMTs were discussed before (Flaska et al., 2013; Hellesen et al., 2013),in this paper, the influence of sampling rate on the PSD performance from 115 keV_{ee} to 500 keV_{ee}, observed with stilbene coupled to SiPM, is investigated. A digital pulse processing filter combined with linear interpolation was effectively implemented to suppress the noise that degrades PSD performance at lower sampling rates.

2. Setup and pulse collection

A single 8 × 8 × 60 mm^3 stilbene crystal from Inrad optics (Inrad Optics Inc, 2015) was coupled to a SensL MicroFC-60035 SiPM (C-Series Low Noise, 2016). In order to increase the efficiency of light collection, several layers of Teflon were used to cover the surface of the stilbene crystal. Saint-Gobain BC-630 silicone grease was used to optically couple the stilbene crystal and the SiPM. A U1065A Acqiris 10-bit DC282 digitizer was used to digitize and collect the pulses of the SiPM. A 100 mV dynamic range was set, and sampling rates from 125 MSPS to 2 GSPS were chosen in the experiments.

First, the detector was calibrated using a Na-22 and a Cs-137 source. Then, the detector was used to acquire pulses from a Cf-252 spontaneous fission source, with activity of approximately 40 μCi.

Gamma and neutron pulses were first collected with sampling rates of 2 GSPS (see Fig. 2). This expected and well known shape difference is

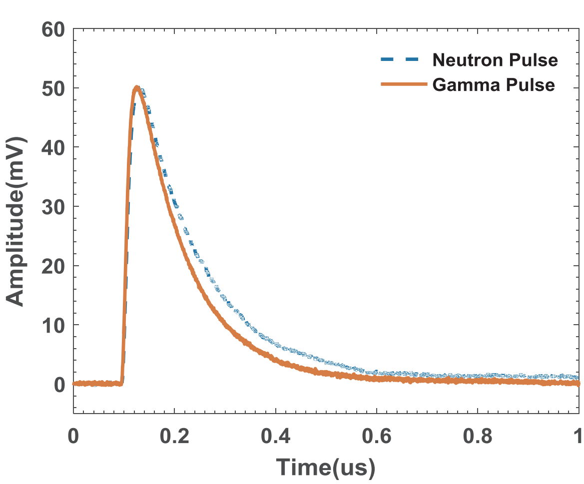

Fig. 2. Digitized gamma and neutron pulses.

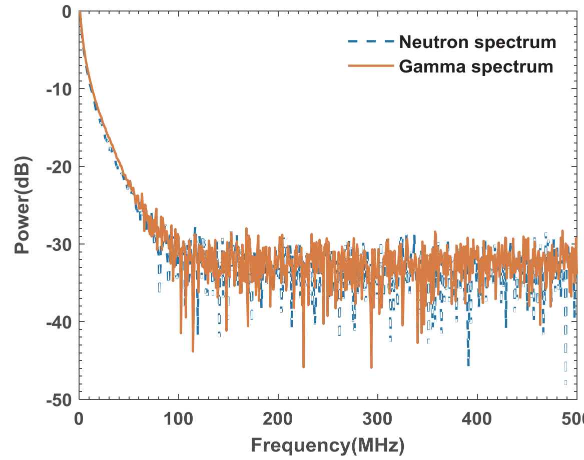

Fig. 3. Gamma and neutron frequency spectrum with Hann window used.

used for neutron-gamma discrimination.

A fast Fourier transform (FFT) of the neutron and gamma pulses was used to investigate their frequency spectra (see Fig. 3). It is clear that a majority of the pulse power is spread over frequencies below 100 MHz. According to the Nyquist-Shannon sampling theorem, sampling rates above 200 MSPS are able to obtain the entire frequency domain of neutron and gamma pulses (The Nyquist Sampling Theorem, 1949).

3. PSD performance with different sampling rates

PSD was performed using a standard digital charge comparison (DCC) technique in which the ratio of the integral of the pulse tail to the total integral of each pulse was calculated to identify the type of incident radiation (Flaska and Pozzi, 2007). To get the tail-to-total ratio, a constant-fraction timing method was used to align all the pulses. Four parameters were chosen: 1) the constant fraction f, 2) the time before the CFD timing at which the total integral begins (T_{1start}), 3) the time after the CFD timing at which the tail integral begins (T_{2start}), and 4) the time after the CFD timing at which both integrals end ($T_{1,2stop}$) (Cester et al., 2014). To optimize these values, many combinations of plausible values were used to calculate the standard PSD FOM using an automated script. The FOM used in this work is calculated in the standard way as:

$$\mathrm{FOM} = \frac{S}{FWHM_n + FWHM_\gamma} \tag{1}$$

Where S is the separation between the neutron and gamma-ray peaks and $FWHM_n$ and $FWHM_\gamma$ are the full width at half max values of the neutron and gamma peaks (Knoll, 2010). The optimized T_{2start} values differ by sampling rate and are shown in Table 1. The other optimized values did not depend upon sampling rate; they are $f = 0.2$, $T_{1start} = -180$ ns, and $T_{1,2stop} = 1000$ ns.

After these optimized PSD parameters were chosen, the tail-to-total ratio versus pulse was calculated as sampling rate was varied. Fig. 4 shows example data of tail-to-total ratio versus pulse height (200,000 pulses measured). A clear separation between gamma and neutron regions at larger pulse heights is evident as sampling rate varies.

Table 1
Optimized T_{2start} value.

Sampling rate	T_{2start} (ns)
2 GSPS	40
1 GSPS	40
500 MSPS	54
250 MPSP	64
125 MSPS	88