Sampling requirements of frequency gradient analysis method for n/γ discrimination by liquid scintillators

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Introduction

The digitization of continous time signal is an essential operation for digital pulse processing to achieve pulse shape discrimination (PSD) of neutrons and γ-rays by liquid scintillators [1]. The quality of discrimination of a PSD method strongly depends on the sampling properties of the fast waveform digitizer [2]. It is very important to know the effects of sampling rate and ADC resolution on the PSD performance of various algorithms. It is obvious that, the high sampling rates and ADC resolution always improves the quality of discrimination but require a greater number of resources to save and process the data. Also, an over sampling of digital signal do not improve the quality of PSD beyond a certain limit [2]. Hence, a tradeoff between sampling rate, ADC resolution and discrimination quality is needed depending upon the desired application. In the present work, the frequency gradient analysis (FGA) method based on Fourier transform of pulses has been investigated in terms of sampling-rate requirements as compared to the well-known charge comparison (CC) method. The minimum sampling rate required for an efficient PSD with FGA method in a high-count rate environment has been identified.

Experimental Setup

The mixed n-γ pulses are recorded by exposing 5” ×5”, BC501 liquid scintillator coupled to R4144 PMT from Hamamatsu to a Am-Be source. The sampling of anode output of PMT is achieved by using different digital oscilloscopes and digitizers viz. Teledyne Lecroy HDO6054 (DSO-1) with 4 analog input channels, 12-bit resolution and 500 MHz bandwidth (BW), Teledyne Lecroy wave-surfer-3000 (DSO-2) with 4 analog input channels, 8-bit resolution, 200 MHz BW (DSO-2) and CAEN V1720, with 8 analog input channels, 12-bit resolution, 125 MHz BW. Several data-sets has been recorded at different sampling rates and voltage resolutions which are commonly available in commercial digitizers as depicted in table 1. The energy calibration of the data-sets has been performed by using 75% of Compton edge of γ-ray spectra of various γ-sources. Fig. 1 shows energy calibrated pulse height spectrum of Am-Be source at 2.5 GS/s. The energy distribution of each data-set was from approximately 250 keVee to 4.5 MeVee, which corresponds approximately to a proton recoil energy of 13 MeV.

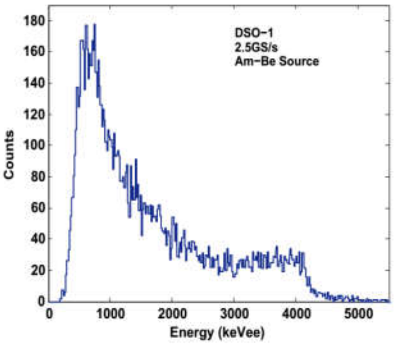

Fig. 1: The pulse height spectrum of Am-Be source.

The Frequency Gradient Analysis

The frequency gradient analysis works on pulses transformed into frequency-domain. This method exploits the difference between zero-frequency component and the first-frequency component of the pulse under consideration which are given as,

$$|X(0)| = \left|\sum_{n=0}^{N-1} x(n)\right| \qquad and$$

$$|X(1)| = \sqrt{\left(\sum_{n=0}^{N-1} x(n)\cos\frac{2\pi n}{N}\right)^2 + \left(\sum_{n=0}^{N-1} x(n)\sin\frac{2\pi n}{N}\right)^2} \tag{1}$$

where n is discrete time index, N is total number of samples. The type of interacting particle can be identified by using various kinds of discrimination parameters namely: d_{11}, d_{21}, d_{31} and d_{32} [3]. Out of these parameters d_{32} has been shown to give best performance with largest FoM. It is given as,

$$d_{32} = 1 - \frac{|X(1)|^2}{|X(0)|^2} \qquad (2)$$

The terms, $|X(0)|$ and $|X(1)|$ are highly affected by the length of processing-gate *(N)* which must be optimized to give maximum FoM. A data-set with energy threshold of 250 keVee is used to identify the optimized length of processing-gate which comes out to be 70 ns with pre-gate of 10 ns and post-gate of 60 ns.

Table 1: FoM values obtained by CC method and FGA method for 350 keVee energy threshold at different sampling rates

Sampling Rate	**FoM by CC** (Short-start = 12 ns, Both-end = 80 ns)	**FoM by FGA** (Pre-gate = 10 ns, Post-gate = 60 ns)
DSO-1, 250 MHz	0.9478±0.003	1.0264±0.003
DSO-1, 500 MHz	1.0272±0.002	1.0859±0.001
DSO-1, 1.25 GHz	1.0743±0.003	1.0875±0.002
DSO-1, 2.5GHz	1.0771±0.001	1.0962±0.003
DSO-2, 4GHz	0.8361±0.003	0.8568±0.002
CAEN V1720, 250 MHz	0.7683±0.002	0.8432±0.002

Results and discussion

For comparison of results with a standard method the charge comparison (CC) method has been used which exploits the ratio of the short integral to the long integral as a discrimination parameter over an optimized processing gate [4]. The short integral starts from 12 ns after the peak amplitude and long integral starts from peak amplitude. The end of both the integrals is same and is kept at 80 ns after the peak amplitude. The quality of discrimination of both the methods has been evaluated in terms of figure of merit (FoM) which can be calculated from the probability distribution graph of discrimination-parameter and is given as [4],

$$FoM = \frac{|\mu_n - \mu_\gamma|}{2.35(\sigma_\gamma + \sigma_n)} \qquad (1)$$

Here μ_n and μ_γ are the arithmetic means and σ_γ and σ_n are standard deviations of neutron and γ-ray Gaussian distributions respectively. The FoM increases with increase in the sampling rate, however the rise in FoM is very less as the sampling rate is changed from 500 MHz to 2.5 GHz in case of FGA. Hence, 500MHz, 12-bit resolution (DSO-1) is appropriate choice for FGA method to get maximum performance. The FoM obtained by DSO-2 is very less even at 4GHz for both the methods. This is due to low ADC resolution of DSO-2. Thus, both the sampling rate and voltage resolution must be chosen very carefully to maximize the performance of a PSD method.

The FoM obtained by FGA method is 8.29% higher as compared to the CC method at 250MHz. Hence, FGA is better choice at low sampling rate. Further, the width of processing-gate used in FGA is smaller than that is used in CC method. This feature of FGA method is very useful in high-count rate environment where the frequency of pile-up events is high.

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