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# The design and fabricate a pulse shape discriminator apply signal processing method using EJ-301 detector

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**Abstract:** The high quality measurements of neutron energy spectra are required in various fields of research and applications. However, in many cases the contribution of gamma background causes the inaccuracy of neutron spectrum. Therefore, the discrimination of gamma-ray events in neutron spectrum is necessary. In this article, an algorithm for digital implementation of the charge-comparison method for n/γ discrimination based on Digital Signal Processing technique is described. Furthermore, the APX-500 board was used as a hardware for the development of a Pulse Shape Disciminator, and is equipped with ADC ADM-414 14 bit-100 MSPS. The fully system has been tested with EJ-301 detector, using $^{252}$Cf neutron source.

**Keywords:** *Pulse Shaping Discriminator (PSD), Digital Signal Processing (DSP), EJ-301 scintillator.*

## I. INTRODUCTION

There are usually three sources of back-ground noise in neutron detection: alpha particles, beta particles, and high-energy photons (γ-rays). Alpha and beta particles can be easily shielded by various materials. However, γ-rays pass through physical barriers and when mixed with neutrons in the detection environment, they behave almost the same as neutrons and make it uncertain whether neutrons are detected or γ–rays [1]. Therefore, various methods of separating the neutrons from the gammas have been developed, including both analog and digital approaches such as zero crossing, constant fraction discriminator [2,3], charge comparison [3,4], frequency gradient analysis [5], rise time discrimination, pattern recognition [6], etc.

In this work, charge comparison is carried out and established to develop an optimum algorithm for Pulse Shape Discriminator (PSD) based on the different interactions between gamma and neutron rays with the material of detectors. A PSD module is designed and fabricated based on Digital Signal Processing (DSP) technique and Field Programmable Gate Arrays (FPGA) devices.

In the recent period at NRI, most of the radiation measurements have been digitalized, such as Digital Multichannel Analyzer (DMCA), coincidence measurement system. However, the application of digital signal processing techniques to discriminate pulses have not been studied so far. Novel DSP methods are introduced and studied in this work.

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## II. CONTENTS

### A. Subjects and Methods

This method shows that gamma-ray pulses have shorter tails than neutron pulses when interacting with the material of detectors and the ratio of these pulses will be approximately constant for pulses of common shape, independent of pulse amplitude [1]. An approach to the design is based on independent measurements of the integrated charge over two different time regions of the pulse.

The ratio of tail-to-total integrals is calculated as follow:

$$R = \frac{\text{Tail integral}}{\text{Total integral}} = \frac{A2}{A1} \qquad (1)$$

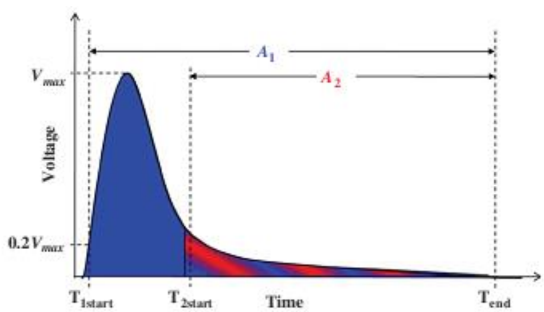


**Fig.1.** Illustration of the pulse shape from detector.

The time intervals over which the total and tail integrals are calculated, these parameters can be modified to increase the performance of the PSD method.

From the figure 1, the total integral (A1) and tail integral (A2) are computed for each pulse and used for classification as a neutron or gamma-ray. Pulse timing was achieved by measuring the time at which the pulse reaches 20% of the pulse amplitude.

$T_{1start}$ is the starting point of the total integral (A1) and $T_{2start}$ is the starting point of the tail integral (A2) and $T_{end}$ is the ending point of both. The timing for $T_{2start}$ and $T_{end}$ are decided empirically based on a specific detector used to achieve optimal results. Since pulses for heavy particles have a larger fraction of light in the tail, a larger ratio of tail-to-total will be obtained for neutrons compared to gamma rays.

The $Q_{Ratio}$ (R) for neutron pulses should be larger than the $Q_{Ratio}$(R) for gamma ray pulses for the same total charge deposited. The figures of merits (FOM) is calculated from the histogram of the Qratio versus peak height data. The FOM is defined as in figure 2 (note that this definition assumes that the pulse distributions are Gaussian):

$$FOM = \frac{Ch_n - ch_\gamma}{FWHM_n + FWHM_\gamma} \qquad (2)$$

Where as:

$Ch_n, Ch_\gamma$ are the values of neutron and gamma peaks respectively; $FWHM_n, FWHM_\gamma$ are the full-width-half-maximum of neutron and gamma peaks, respectively.

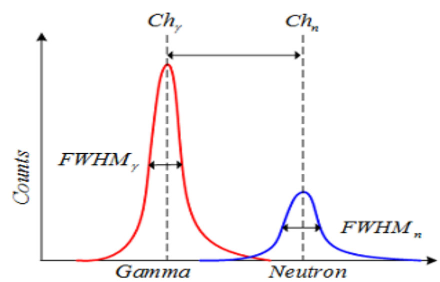


**Fig. 2.** Derivation of the figure of merit (FOM)

### B. Results

The design and implementation of the digital pulse shape discriminator is shown in figure 3.

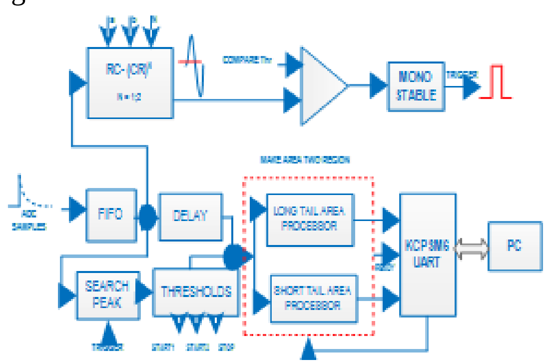


**Fig. 3.** The block diagram of Digital Pulse Shape Discriminator.

From this method is mentioned above, the Digital Pulse Shape Discriminator was fabricated. This system consists of the various component modules. All components have been designed, implemented using digital signal processing technique.

High technology development has created a variety of techniques such as flash analog digital convertor (ADC), FPGA, and dedicated DSP circuits. That makes the PSD based on digital signal processing technique widely applied. In modern DSP-based PSD systems, pulses from the detector are digitized by the fast sample ADC named ADM-414, the sample rate is 400 MSPS. The output from the ADC are then stored in the FIFO and analyzed by the PSD system to give the A1 and A2. The application software tools for the control of the instrument, data acquisition and processing was written under C++ builder program.

The total integral of the input pulse A1 is given by long tail area processor module while the short integral of the input pulse A2 is given by short tail area processor module.

The installation of the measurement configuration in order to test the algorithm for PSD is shown in figure 4.

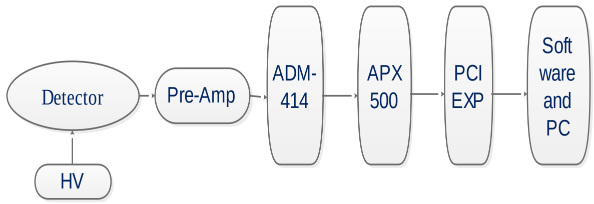


**Fig.4.** The set up of PSD system

Specifications:

+ ADC: ADM414-14bits, the sample rate is 400 MSps;

+ HV: +1200V

+ Sampling mode: stream mode;

+ Captured data: Channel 1.

In this experiment, the value of 3 thresholds are decided as follows:

+ T1start: 20% of peak value

+ T2start: 50% of peak value

+ Tstop: 5% of peak value

Typical pulse from pre-amplifier of EJ-301 detector are shown in figure 5.

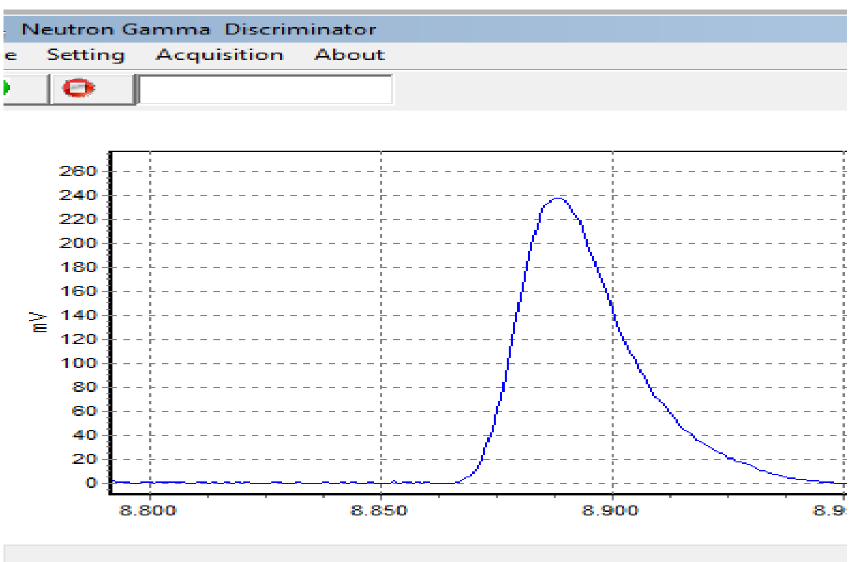


**Fig. 5.** The pulses are collected from ADM-414 board in “Stream mode”.

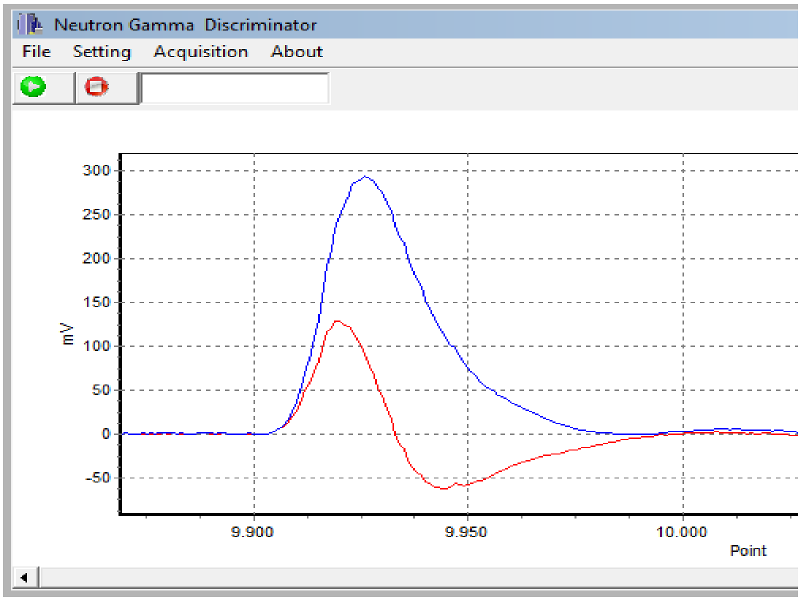


**Fig. 6.** The output pulse from CR-(RC)$^N$ network

The quantities of n-γ discrimination is shown with FOM and neutron peak -to- valley ratio.

The output pulses of RC-(CR)$^N$ filter is compared with adjustable threshold in order to reduce noise and create a trigger. After that, this trigger signal is used to initialize all components in system in figure 6. The blue pulse is input pulse from ADC. The red pulse is transferred CR-(RC)$^N$ filter. The value of N is 2.

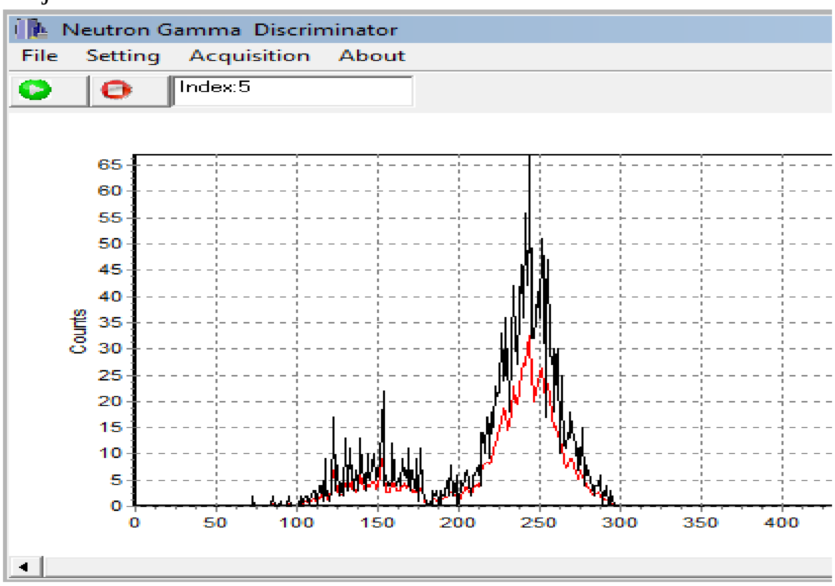


**Fig 7.** The FOM of PSD system

System is tested with $^{252}$Cf, the final result of PSD are presented in Fig 7. The data are smoothed by moving average filter (MA). FOM is calculated around 1.

**C. Discussion**

The sampling rate of the PSD is 400 MHz and that give a time resolution of 2.5 ns.

Therefore, the data points can catch the entire structure of the pulse. However, to improve the resolution and give better FOM, the GHz sampling rate ADC should be used.

Recommendation for further research, the possibility of pulse shape analysis to separate gamma rays and neutrons for organic scintillation detectors will be conducted carefully, other neutron sources should be studied such as Am-Be, thermal neutrons from nuclear reactors. The pie-up rejection will be carried out and designed in the near future.

## III. CONCLUSIONS

In this research, digital-pulse processing algorithm for discrimination of neutrons and γ rays in EJ-301 detector has been developed. In conclusion, the system has been designed and fabricated successfully with the peak-to-valley-ratio is 10 and FOM is larger than 1, enough to separate gamma rays and neutrons from the Cf-252 neutron sources.

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