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Neutron/Gamma discrimination code based on trapezoidal filter

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ABSTRACT

Neutron/gamma discrimination techniques are widely applied in scintillator-based neutron diagnostics for present nuclear fusion tokamak experiments (e.g. JET – Neutron Camera and compact neutron spectrometer) and will also be necessary for neutron diagnostics of up-coming machines (e.g. ITER Radial Neutron Camera). Neutron/gamma discrimination in scintillators relies on the fact that the detectors output pulses have different shapes depending on the impinging particle; several discrimination techniques are described in literature such as the charge-integration, curve-fitting and pattern recognition [1].

This paper aims at describing a new technique for neutron/gamma discrimination in scintillators based on trapezoidal filtering, which targets Field Programmable Gate Array (FPGA) implementation due to its recursive nature. Furthermore its capability to restore the baseline of each detected pulse and the fact that the output signals are shorter than the correspondent incoming pulses, points this technique as a promising solution for applications in high count rate conditions. First results coming from the application of a real-time FPGA implementation of the trapezoidal filter to simulated neutron/gamma data including pile-up events and to real scintillator data will be presented.

1. Introduction

Neutron/gamma discrimination techniques are widely applied in scintillator-based neutron diagnostics for present nuclear fusion tokamak experiments (e.g. JET – Neutron Camera and compact neutron spectrometer) and will also be necessary for neutron diagnostics of up-coming machines (e.g. ITER Radial Neutron Camera). neutron/gamma discrimination in scintillators relies on the fact that the detectors output pulses have different shapes depending on the impinging particle.

Several discrimination techniques are described in literature such as the Charge-Integration (CI), Curve-Fitting and Pattern Recognition [1,2]. This paper will describe a new neutron/gamma discrimination technique based on the trapezoidal pulse shaper. The trapezoidal technique is already fully described and applied in nuclear fusion environment for Pulse Height Analysis (PHA) [3,4]. During the second enhancement phase of the Gamma-ray Camera diagnostic at JET, the real-time trapezoidal based technique was implemented in the FPGA. This technique allowed that both gamma and X-rays could be detected without the need the pre-amplifiers gain change. The Trapezoidal shaper was successfully used to: i) detect events in a harsh environment (the low amplitude events (X-rays) were embedded in noise; and ii) perform the pulse height spectra [5].

The recursive nature of the trapezoidal shaper targets the Field Programmable Gate Array (FPGA) implementation as an Infinite Impulse Response (IIR) filter which is running directly into the acquired data up to the end of the acquisition. That is, the output of the filter, in contrast to Finite Impulse Response (FIR) filters (same filter applied off-line), have internal feedback and continue to respond indefinitely up to the end of the acquisition.

Besides the recursive nature, this filter presents three features which are tackled for nuclear spectroscopy: i) allows elimination of the DC offset inherent to preamplifier signals. This feature discards the need of DC offset restoration processing block and up to a certain point, can resolve pile-up, that would be discriminated and discarded in the classic CI technique; ii) applies sufficient amplification of the short exponential pulses and iii) acts also as a moving average filter. These two last features allow to achieve the maximum usage of the resolution of the sampling ADC reducing the inherent signal noise.

Section 2 will describe the trapezoidal shaper as an ideal technique for neutron/gamma and Pile-Up (PU) discrimination. Section 3 will present results of the trapezoidal filter Pulse Shape Discrimination (PSD) method applied to synthetic data. Section 4 will crosscheck this technique with the CI technique to data acquired from scintillators in the presence of neutrons.

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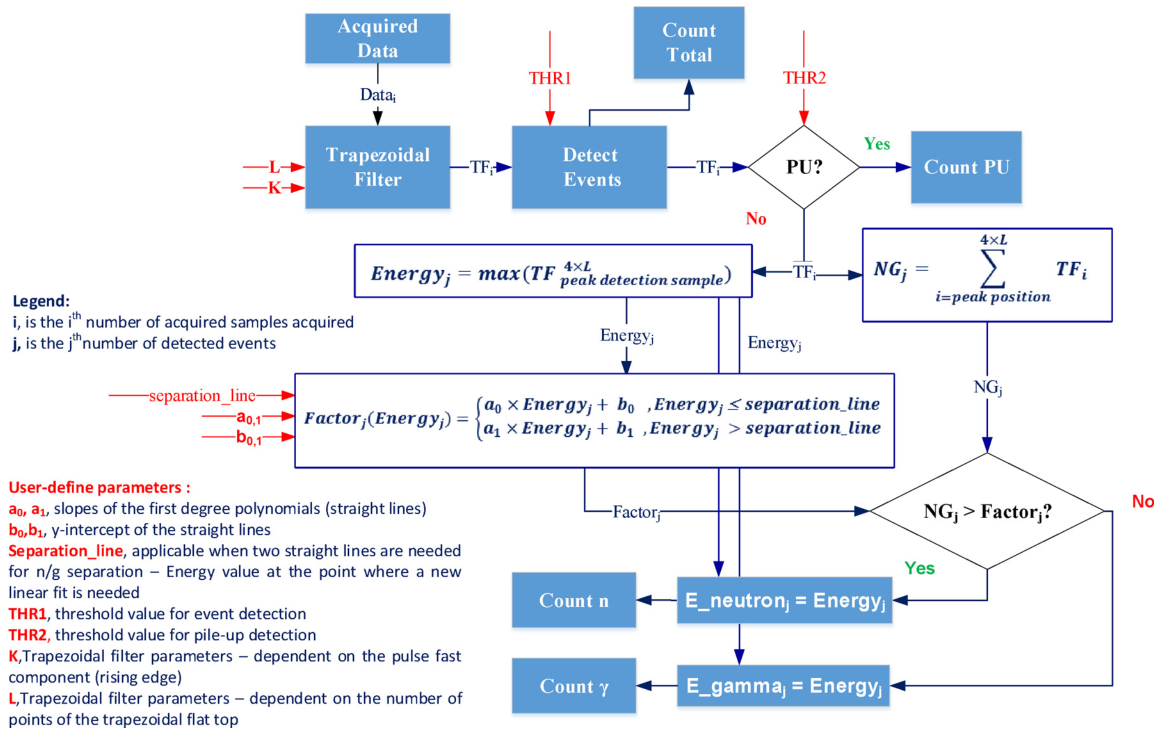

Fig. 1. Trapezoidal Shaper Technique or n/γ discrimination.

2. Trapezoidal filter applied to pulse shape discrimination

Fig. 1 describes a new technique to be implemented in FPGA based on the trapezoidal shaper for: i) Pulse detection; ii) PHA; iii) PU resolving and discrimination, and finally iv) Neutron/gamma Pulse Shape Discrimination (PSD).

The Trapezoidal Filter (TF) is directly applied to the acquired data followed by the event detection block based on two methods, widely used in nuclear fusion [6,7]: i) level detection where a threshold value (THR1) is set and the Trapezoidal Filter (TF_i) output word is compared with theTHR1value. If the TF is higher than THR1 an event is detected; ii) flank detection, where the result of TF_i minus TF_{i-1} is compared with the THR1 value. If the subtraction result (derivative) is higher than THR1 an event is detected. After the event detection a PU block is applied, where a THR2 value is applied to detect PU. The trapezoidal method smooths the original pulse and shortens the pulse width, this allows the THR2 value to be equal or even lower than the correspondent value applied to the original pulse.

If no PU occurs, then two concurrent actions are applied to TF:

1 The maximum of the TF event (peak value) calculation – Event Energy;
2 Integration of the TF event from the peak up to 4 times the L parameter value – Event area- NG.

Finally, to perform the discrimination between neutron and gamma three previous calibrations are needed every time a new detector + pre-amplifier is used:

1 Set the trapezoidal parameters, K and L. A raw acquisition without any filter is done to acquire the pulse directly from the detector to define the K and L parameters, K is dependent on the pulse fast component and L will define trapezoidal flat top [3];
2 Set the event and PU detection parameter, THR1, THR2. A raw acquisition of the TF is needed;
3 Calibrate the separation between neutron and gamma. An acquisition is done outputting the values of NG and Energy. Then, plotting the NG values in the y-axis and the Energy values in the x-axis, a first-degree polynomial fit is performed to find the factor values, Fig. 1. Depending on the detector signal one or two slopes are defined and the parameters of the slopes as well as the separation value of the two slopes are retrieved.

Only after these calibrations the algorithm is ready to discriminate neutron/gamma. If the NG value is higher than the Factor value for the correspondent Energy level, a neutron is detected otherwise a gamma is detected. The Energy value of the correspondent particle is then stored in the respective array, E_neutron/E_gamma and the type of particle is counted. At the end neutron and gamma spectra can be built from the respective arrays.

3. Results of the TF PSD method using simulated data

To test the described algorithms a testing apparatus was set with an evaluation board of Xilinx featuring a Kintex 7 FPGA [8], installed in a standard PC, with a custom acquisition FPGA Mezzanine Card (FMC) with two 12-bit channels @ 1600 MHz [9]. To perform the tests, acquisitions were made by oversampling the synthetized pulses @ 1600 MHz and averaging the output to 400 MHz with an increase of 1 bit of resolution. Data was acquired in raw mode. To simulate data a digital

signal emulator from CAEN, DT5800 was used [10]. A MATLAB code with the trapezoidal filter for n/ γ discrimination was applied to the continuous acquired data and not only to segments of data in case only the detected events were stored [11].

First, two types of signals were defined in the CAEN signal emulator. Fig. 2 depicts the two emulated particles, the full line presents the gamma pulse, Eq. (1), the offset value corresponds to 10 (CAEN rise time ≥ 5 ns - each sample corresponds to 5 ns), the gamma falling edge constant is defined as $\theta_g = 16$ ns. The dotted line represents the neutron pulse, $\theta_n = \theta_g \times 1.2$ ns.