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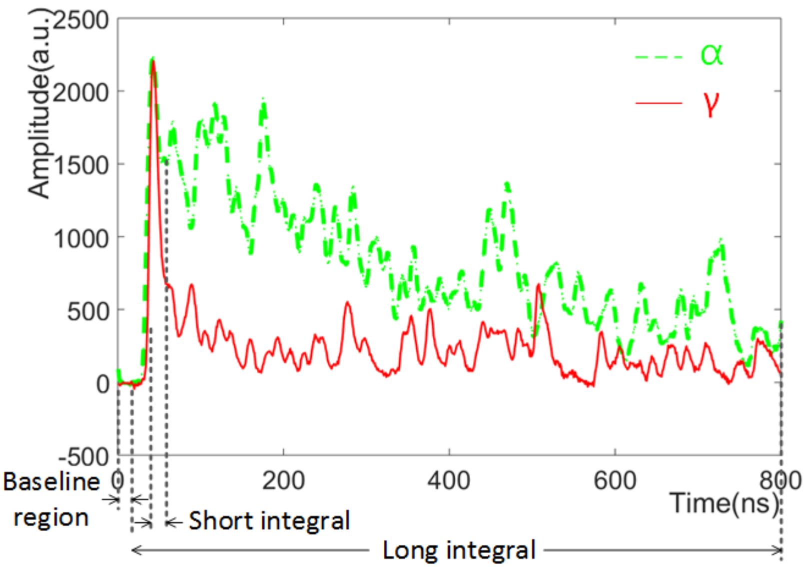

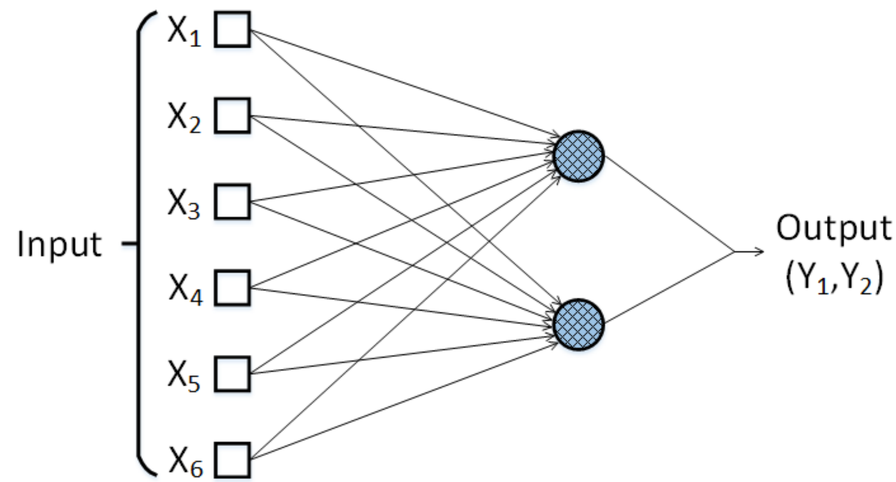

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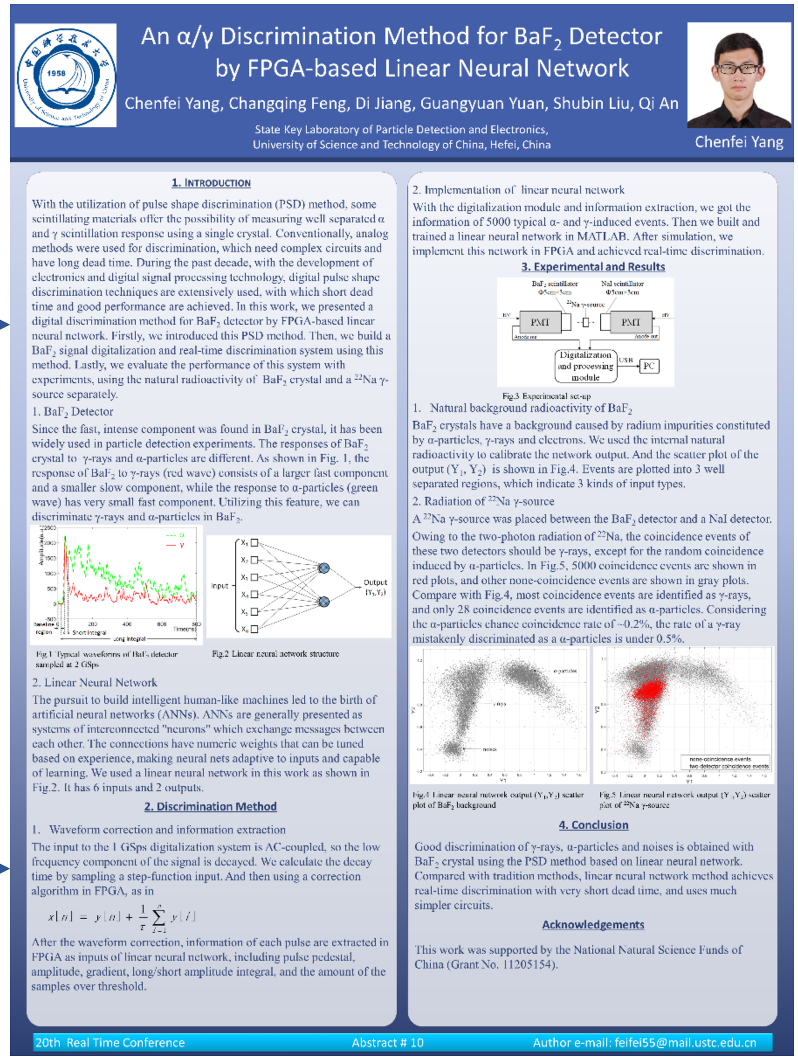

An α/γ Discrimination Method for BaF_2 Detector by FPGA-based Linear Neural Network

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1. Introduction

With the utilization of pulse shape discrimination (PSD) method, some scintillating materials offer the possibility of measuring well separated α and γ scintillation response using a single crystal. Conventionally, analog methods were used for discrimination, which need complex circuits and have long dead time. During the past decade, with the development of electronics and digital signal processing technology, digital pulse shape discrimination techniques are extensively used, with which short dead time and good performance are achieved. In this work, we presented a digital discrimination method for BaF_2 detector by FPGA-based linear neural network. Firstly, we introduced this PSD method. Then, we build a BaF_2 signal digitalization and real-time discrimination system using this method. Lastly, we evaluate the performance of this system with experiments, using the natural radioactivity of BaF_2 crystal and a ^{22}Na γ-source separately.

1. BaF_2 Detector

Since the fast, intense component was found in BaF_2 crystal, it has been widely used in particle detection experiments. The responses of BaF_2 crystal to γ-rays and α-particles are different. As shown in Fig. 1, the response of BaF_2 to γ-rays (red wave) consists of a larger fast component and a smaller slow component, while the response to α-particles (green wave) has very small fast component. Utilizing this feature, we can discriminate γ-rays and α-particles in BaF_2.

Fig.1 Typical waveforms of BaF_2 detector sampled at 2 GSps

Fig.2 Linear neural network structure

2. Linear Neural Network

The pursuit to build intelligent human-like machines led to the birth of artificial neural networks (ANNs). ANNs are generally presented as systems of interconnected "neurons" which exchange messages between each other. The connections have numeric weights that can be tuned based on experience, making neural nets adaptive to inputs and capable of learning. We used a linear neural network in this work as shown in Fig.2. It has 6 inputs and 2 outputs.

2. Discrimination Method

1. Waveform correction and information extraction

The input to the 1 GSps digitalization system is AC-coupled, so the low frequency component of the signal is decayed. We calculate the decay time by sampling a step-function input. And then using a correction algorithm in FPGA, as in

$$x[n] = y[n] + \frac{1}{\tau}\sum_{i=1}^{n} y[i]$$

After the waveform correction, information of each pulse are extracted in FPGA as inputs of linear neural network, including pulse pedestal, amplitude, gradient, long/short amplitude integral, and the amount of the samples over threshold.

2. Implementation of linear neural network

With the digitalization module and information extraction, we got the information of 5000 typical α- and γ-induced events. Then we built and trained a linear neural network in MATLAB. After simulation, we implement this network in FPGA and achieved real-time discrimination.

3. Experimental and Results

Fig.3 Experimental set-up

1. Natural background radioactivity of BaF_2

BaF_2 crystals have a background caused by radium impurities constituted by α-particles, γ-rays and electrons. We used the internal natural radioactivity to calibrate the network output. And the scatter plot of the output (Y_1, Y_2) is shown in Fig.4. Events are plotted into 3 well separated regions, which indicate 3 kinds of input types.

2. Radiation of ^{22}Na γ-source

A ^{22}Na γ-source was placed between the BaF_2 detector and a NaI detector. Owing to the two-photon radiation of ^{22}Na, the coincidence events of these two detectors should be γ-rays, except for the random coincidence induced by α-particles. In Fig.5, 5000 coincidence events are shown in red plots, and other none-coincidence events are shown in gray plots. Compare with Fig.4, most coincidence events are identified as γ-rays, and only 28 coincidence events are identified as α-particles. Considering the α-particles chance coincidence rate of ~0.2%, the rate of a γ-ray mistakenly discriminated as a α-particles is under 0.5%.

Fig.4 Linear neural network output (Y_1,Y_2) scatter plot of BaF_2 background

Fig.5 Linear neural network output (Y_1,Y_2) scatter plot of ^{22}Na γ-source

4. Conclusion

Good discrimination of γ-rays, α-particles and noises is obtained with BaF_2 crystal using the PSD method based on linear neural network. Compared with tradition methods, linear neural network method achieves real-time discrimination with very short dead time, and uses much simpler circuits.

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