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Discrimination of neutron and photon signals using time and frequency domain data

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Abstract Two new methods for the digital discrimination of neutrons and gamma-rays in a mixed radiation field are presented. There are many methods available which take advantage of time-domain pulse shape discrimination of these two signals. However, there are no methods based on frequency-domain characteristics of them, in particular using discrete Fourier transform (DFT). Applying DFT, we can distinguish between these radiations much better. Combining time and frequency domain PSDs, we can further increase the discrimination quality while improving computation time to be applicable for field measurements.

Keywords Neutron detection, neutron spectroscopy, digital pulse shape discrimination technique, time domain PSD, frequency domain PSD, organic scintillator

1. INTRODUCTION

The range of applications of neutron detectors grows fast. Nowadays, neutron detectors are used for neutron imaging techniques, nuclear research, nuclear medicine applications, and safety issues, and their usage spans on various branches of science including nuclear physics, biology, geology, and medicine. The main problem in neutron detection is the discrimination of neutrons from the background gamma-rays. Fast neutrons produce recoil protons whose detection is the most common method to detect neutrons. Organic scintillators are widely used to detect these recoil protons. Fast neutrons in organic scintillators produce recoil protons through (n, p) elastic scattering and energy of a recoil proton at the highest level is equal to the energy of the neutron [1].

Among organic scintillators, stilbene and NE-213 come with some advantages for neutron spectroscopy purposes; they have rather low light output per unit energy, but this light output induced by charged protons can be easily distinguished from electrons/photons. Hence, stilbene and NE-213 scintillators produce very good results using pulse shape discrimination (PSD) methods.

Time-domain PSD methods do not have heavy computational loads and hence are most suitable for real-time applications. Classically, following analog PSD techniques were most often used for n/γ-ray discrimination [2]:

1) rise-time inspection;
2) zero-crossing method;
3) charge comparison.

Although analog techniques make good n/γ-ray discrimination, availability of precise and fast digitizers and various PSD algorithms have made it possible to do fine discrimination of these radiations digitally. Among digital PSD methods, pulse rise-time algorithm and charge comparison are probably the most favorable ones.

2. TIME-DOMAIN PSD

2.1 Pulse rise time and pulse rise-decay time algorithms

Stilbene and NE-213 organic scintillators produce pulse shapes with very fast rise times. In pulse mode operation of radiation detectors [3], for integrated pulses from a large anode resistor (about 20 to 30 kΩ), the rise time is roughly 15 ns for electrons (gamma ray interactions) and 18 ns for protons (neutron scatter interaction). However, the decay time for neutrons and photons is the same and very long (several microseconds). Using a small anode resistor (e.g., 50 Ω), the rise time is the same and about 20 ns for both pulses, but photon pulses have shorter decays than neutrons. In order to sample pulses from either a large or a small anode resistor for precise discrimination, fast enough pulse digitizers with at least 1 GS/s are needed.

Two computationally simple digital PSD algorithms are as follows [4]:

1) 5-95% pulse rise time, to be applied to pulses from a large anode resistor;
2) pulse rise-decay time over 10% level, to be applied to pulses from a small anode resistor.

Using an integrating preamplifier, signal/noise ratio of pulses will improve but the pulses will have long decay times. On the contrary, directly using current pulses saves decay times, and makes the detection system simple as well, but at the cost of more vulnerability to noise.

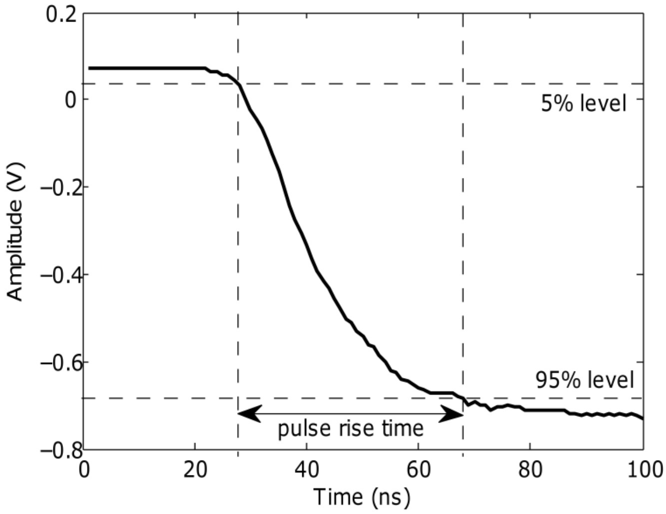

Fig. 1. Application of 5-95% pulse rise time algorithm on a sample neutron signal from a stilbene scintillator obtained from a large anode resistor.

Fig. 1 illustrates a sample neutron signal from a stilbene scintillator obtained from a large anode resistor. Depending on the noise level of the pulse baseline and the quality of the resulting signal discrimination, various upper and lower threshold amplitudes can be applied, e.g., 5-95% or 10-90%. Fig. 2 depicts a sample neutron signal from the stilbene scintillator which is obtained from a small anode resistor and then its amplitude is reversed for a better view. In this case, the time during which the pulse remains over a 10% level amplitude is calculated.

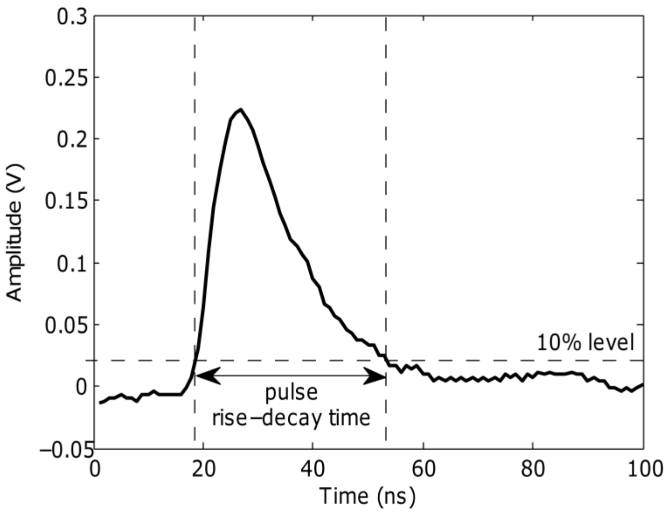

Fig. 2. Application of pulse rise-decay time algorithm over 10% level on an amplitude-reversed sample neutron signal from the stilbene scintillator obtained from a small anode resistor.

2.2 Results

Since the pulses from the stilbene scintillator have very fast rise times when using large anode resistor, and fast rise plus decay times when using small anode resistor, it is better to set the amplitude level percentages as minimal as the maximum noise amplitude of the pulse baseline signal. This gives more room for the pulses to rise or decay and increases the difference in measured times for neutron and photon signals. Hence, the pulses are better spread at the final plot which gives better discrimination.

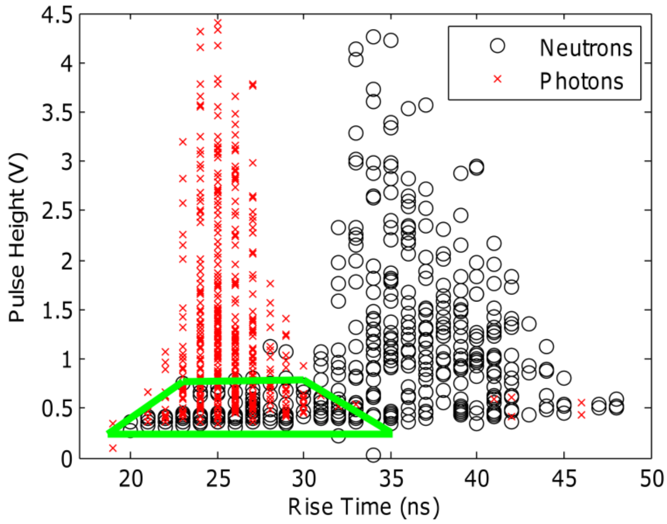

Fig. 3. Results of signal discrimination work for pulses from a large anode resistor using 5-95% pulse rise time algorithm; the overlapping area is shown by a trapezoid.

Illustrated in Fig. 3 are results from discrimination tests for pulses from a large anode resistor using a 5-95% algorithm. Almost 35.35% of neutrons and 36.30% of photons overlap in a trapezoidal area shown in this figure. Overall, this method does not make a decent discrimination.

Fig. 4 shows the results from discrimination tests for pulses from a small anode resistor using pulse rise-decay time algorithm (over 10% level). The area shared between these two signals is almost a triangle, surrounded by the distinct areas of the two signals. Using this method, almost 14.40% of neutrons and 25.45% of photons overlap. If we assign all the signals in the shared area as photons, the probability of one incoming photon signal to be correctly detected will be 100%, and the probability of one neutron to be correctly detected will be 85.60%. This method (applied on pulses from a small anode resistor) gives a better result than the pulse rise time method (applied on pulses from a large anode resistor), but still not accurate enough for practical purposes. To make the discrimination accurate, an algorithm is needed which is sensitive to the curve of the signals independent of the time over specific level. Fourier transform is probably the best solution.

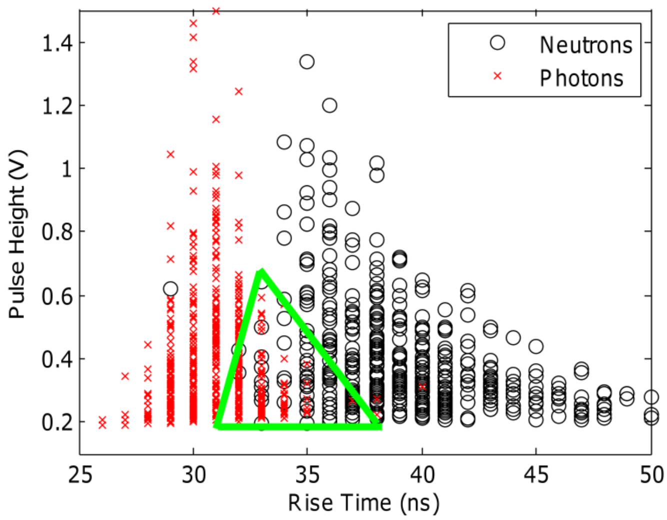

Fig. 4. Results of signal discrimination work for pulses from a small anode resistor using pulse rise-decay time algorithm over 10% level; the overlapping area is almost a triangle.

3. FREQUENCY-DOMAIN PSD

3.1 DFT algorithm

Although any frequency-domain technique would be highly computationally intensive, today's fast digital signal processors allow us to utilize them for real-time applications in filed instruments. A new discrimination technique using discrete Fourier transform (DFT) is proposed in this paper. This method has some advantages:

1) it discriminates well at pulse frequency vs. pulse height coordination system;
2) since the frequency bands of neutron and photon signals are limited and predetermined, applying digital signal processing techniques like Goertzel algorithm, it is possible to obtain the required isolated frequencies without computing the entire DFT-sequence, resulting in a fast frequency analysis.

Discrete samples representing neutron and gamma signals are some short segments whose frequencies cannot be caught by direct application of DFT methods like FFT or correlation. However, exploiting some digital signal processing skills, their frequencies are achievable. In the case of signals from a large anode resistor, the frequencies of the rise time curves of the two signal types are very close to each other and almost indistinguishable, hence producing no useful results. However, in the case of signals from a small anode resistor, plotting frequency-domain vs. pulse height provides highly accurate discrimination of the two radiations. Thus, in the rest of this paper, only the signals from a small anode resistor are considered. For these signals, subtraction of the frequency of rising curve from the frequency of the whole signal leaves the frequency of the decaying curve which contains the features of the signal type. By padding the time-domain signal with zeros, higher resolution can be obtained in the frequency-domain signal.

3.2 Results

Fig. 5 illustrates the discrimination done via DFT methods. The shared area between neutrons and photons is almost a rectangle. Applying this method, almost 1.55% of neutrons and 21.40% of photons overlap. If we assign all the signals in the shared area as photons, the probability of one incoming photon signal to be correctly detected will be 100% and the probability of one neutron to be correctly detected will be 98.45%.

4. TIME- AND FREQUENCY-DOMAIN PSDS COMBINED

4.1 Pulse rise-decay time algorithm combined with DFT algorithm

Although the application of DFT methods results in a very precise discrimination, it is still possible to improve this accuracy while at the same time decrease the average run time to the level almost equal to that of rise-decay time algorithm. This method, proposed in this paper, combines rise-decay time algorithm with DFT methods

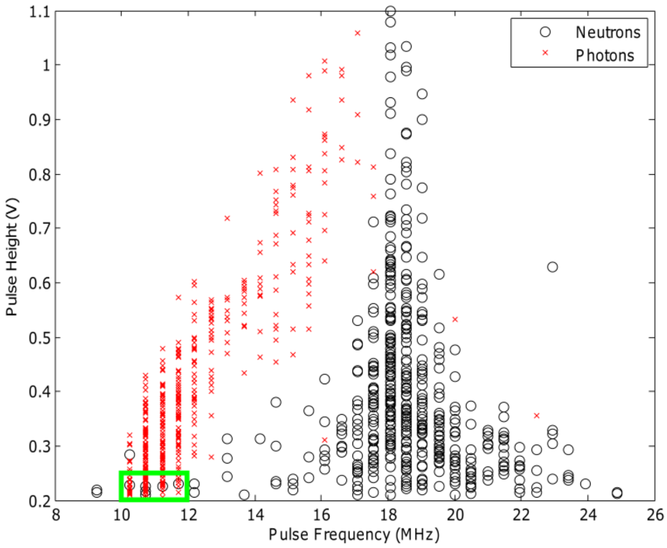

Fig. 5. Results of signal discrimination work for pulses from a small anode resistor using DFT methods; the overlapping area is almost a rectangle.

(sections 2 and 3); first, discrimination process goes through the rise-decay time algorithm, and if the incoming signal falls outside the common area between the two radiations (outside the triangle in Fig. 4), it can be precisely detected. This can happen for almost 85% of neutrons and 75% of photons. However, if the incoming signal falls inside the triangle, the signal is directed to the second phase of discrimination process which is frequency analysis.

4.2 Results

Applying rise-decay time algorithm as the first phase of this method, 14.40% of neutrons and 25.45% of photons fall in the common area (section 2.2). These undetected signals are then passed to the DFT algorithm for further processing, of which in turn 2.43% neutrons and 30.26% photons fall in the shared rectangle. The overlapped signals of both types from first phase have more tendency to fall in the overlapping area in the second phase (2.43% > 1.55%, and 30.26% > 21.40%). Overall, almost 99.65% of neutrons and 92.30% of photons are exactly detected. Taking all the undetected signals as photons, the probability of one incoming photon signal to be correctly detected will be 100%, and the probability of one neutron signal to be correctly detected will be 99.65%.

5. CONCLUSION

The results of application of the three methods discussed in this paper for the discrimination of the signals from small anode resistor are summarized in table 1. For the last two columns of the table, the incoming unknown signals falling on overlapping areas in all three methods are treated as photons which results in 100% correct photon detection, but leaves neutron detection error prone. Using this policy, the column "correct detection of one neutron" in the table can be used as a good parameter for comparison of the three methods.

Table 1. Comparison of the three methods discussed in this paper for signals from small anode resistor.

Method	No. of neutrons	No. of photons	No. of neutrons overlapped	No. of photons overlapped	Correct detection of one neutron	Correct detection of one photon
Rise-decay time	2000	2000	288 (14.40%)	509 (25.45%)	85.60%	100%
DFT	2000	2000	31 (1.55%)	428 (21.40%)	98.45%	100%
Rise-decay time + DFT	2000	2000	7 (0.35%)	154 (7.70%)	99.65%	100%

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