IRRMA6 #21

A Digital Spectrometer Approach to Obtaining Multiple Time-Resolved Gamma-Ray Spectra for Pulsed Spectroscopy

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Abstract- Neutron-induced gamma emission and its detection using a pulsed neutron generator system is a recognized analytical technique for quantitative multi-elemental analysis. Traditional gamma-ray spectrometers used for this type of analysis are normally operated in either coincidence mode by counting prompt gamma-rays from inelastic scattering when the neutron generator is ON, or anti-coincidence mode by counting prompt or delayed gamma-rays from thermal neutron capture or delayed activation when the neutron generator is OFF. We have developed a digital gamma-ray spectrometer for concurrently measuring both the inelastic and capture gamma-rays emitted from a sample when activated by 14 MeV neutrons from a pulsed neutron generator. The spectrometer separates the gamma-ray counts into two independent spectra together with two separate sets of counting statistics based on the external gate level. Occasionally there might be a need for multiple time gates to acquire gamma-ray spectra at different time intervals. For that purpose we are developing a multi-gating system that will allow gamma-ray spectra to be acquired concurrently in real time with up to 16 time slots. These 16 time slots will have adjustable width and time delay that can be arbitrarily allocated within the

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ON and OFF periods. The conceptual system design and considerations for performing gate signal testing and tracking together with pulse height analysis and bin allocation into spectra in real time will be presented.

PACS: 07.50.Qx; 07.85.Nc; 82.80.Jp; 84.30.Sk

Keywords: Pulsed neutrons; Non-intrusive and non-destructive analysis; Digital signal processing; Digital gamma spectroscopy.

1. Introduction

Neutron induced nuclear reactions using a pulsed neutron generator have been widely used in quantitative multi-elemental analysis [1,2]. The three major types of nuclear reactions include: prompt gamma-ray emission following inelastic neutron scattering from a target nucleus; prompt gamma-ray emission following thermal neutron capture by the target nucleus (these reactions occur when fast neutrons thermalize in the matrix and get absorbed); and the third type of reaction is the delayed activation whereby the target atom absorbs a neutron creating a radioisotope with long half-life. The thermalization process of the fast neutrons depends on the matrix composition and may take between a few to hundreds of microseconds.

Pulsed neutron generators exploit the fact that gamma-rays from these three types of reactions have different temporal characteristics. Fig. 1 shows the typical timing scheme of such a neutron generator. By separating neutron capture events from inelastic ones, the signal-to-noise ratio can be improved by removing the background due to mutually interfering signals, and the apparatus sensitivity will be increased by lowering the minimum detection limit (MDL) which is proportional to the square root of the background. To accomplish this, spectrometer systems are generally operated in either coincidence or anticoincidence mode, i.e. either counting prompt gamma-rays from inelastic scattering when the neutron generator is ON, or counting delayed gamma-rays from the other reactions when the neutron generator is OFF, respectively.

We have developed a digital gamma-ray spectrometer for concurrently measuring both the inelastic and capture gamma-rays emitted from a sample when activated by 14 MeV neutrons from a pulsed neutron generator. At present the TTL ON/OFF signal from the neutron generator is connected to the gate input of an XIA POLARIS digital gamma-ray spectrometer [3], which directs the spectrometer to separate the gamma-ray counts into two independent spectra based on the level of the neutron generator's TTL signal. By this means, both types of spectra are acquired for further analysis in a single counting period, together with two separate sets of input count rate, output count rate, live time and real times.

Further subdividing data acquisition within the ON and OFF periods should allow the statistics to be further improved. For that purpose we are developing a multi-gating system that will allow gamma-ray spectra to be acquired concurrently in real time with up to 16 time slots. These 16 time slots will have adjustable width and time delay that can be arbitrarily allocated between the ON and OFF periods. The conceptual system design and considerations for performing gate signal testing and tracking together with pulse height analysis and bin allocation of spectra in real time will be presented in this paper.

2. The Polaris digital spectrometer

The XIA Polaris is a high-precision, all digital spectrometer, comprising a single digital signal processing channel, a preamplifier power supply and a detector bias supply (up to +/- 5,000V) in a desktop module. The Polaris provides up to 64K channels spectrum length. Connection to the host computer is by USB or EPP (Extended Parallel Port - IEEE 1284). Fig. 2 shows a simplified block diagram of the Polaris. Two Field Programmable Gate Arrays

(FPGAs), shown as two dashed-line boxes in the figure, are used to implement major signal processing functionalities: fast trigger, energy filter and pileup inspection are implemented in the signal processing FPGA on the left, whereas memory management and interface communications are implemented in the communication FPGA on the right.

The Polaris is programmed to recognize the neutron ON and OFF periods through the Gate input and directs the interface logic to accumulate two independent histograms (inelastic and thermal, up to 32K channels each) of gamma-ray energy based on the level of the TTL neutron ON/OFF signal. By this means spectra from both inelastic neutron scattering (ON) and thermal neutron capture (OFF) can be concurrently measured. Fig. 3 shows typical inelastic and prompt gamma spectra acquired from a pine stand at Brookhaven National Laboratory (BNL).

3. Conceptual design of a multi-gating system

To create a system that is capable of acquiring multiple time-resolved gamma-ray spectra, only the firmware, DSP code and interface software of the Polaris need to be modified. The time sequence of the proposed system in response to periodic external triggers is shown in Fig. 4. Up to 16 time slots can be arbitrarily assigned between two adjacent external triggers. Each time slot will have its own set of counting statistics, CS_i (i=0-15), namely, live time, number of triggers, number of processed counts and dead time, and up to 4K histogram length. Prior to starting the data acquisition, two configuration modes can be set by the user. In the first mode, a user can assign arbitrary time-slots by specifying the duration of each time slot. Let's define the duration of each time slot as Δt_i (i=0, 1, ⋯, (*NumSlots*-1)), then the starting time of each slot, t_i, following the rising edge of each external trigger, is:

$$t_i = \sum_{j=0}^{i-1} \Delta t_j \tag{1}$$

In the second mode, a user assigns uniform time slots by specifying the total number of equal-length time slots (up to 16), *NumSlots*. In this case, the starting time of each slot is:

$$t_i = i * \frac{\Delta T}{NumSlots} \tag{2}$$

where ΔT is the time interval between two adjacent rising edges of the external periodic trigger signals. ΔT can be measured by the system itself in a calibration mode in which the time between multiple rising edges is measured and ΔT is derived by averaging the time over the number of edges.

4. Implementation of the multi-gating system

Every time a rising edge of the gate signal is detected, the first set of counters, CS_0, is enabled to accumulate triggers or live time. Every event detected in this period will be tagged so that the system knows which spectrum it should put the event into after the event energy is reconstructed in the DSP at a later time. The second set of counters, CS_1, follows the end of the first period and so on. As soon as the system detects the next rising edge of the gate signal, it switches the counting back to CS_0. This will ensure that all the events will be tallied into the correct spectrum and will accommodate any changes of gate signal frequency and duty cycle.

5. Conclusion

The application of neutron-induced nuclear reactions to multi-elemental analysis can benefit from the capability of advanced digital gamma-ray spectrometers to acquire multiple time-resolved spectra simultaneously. No additional hardware is necessary. We presented sample dual spectra (generator ON/OFF) from the Polaris digital spectrometer and also the conceptual design of a multi-gating system. Experimental data will be reported elsewhere following experiments at BNL’s test site.

5. Acknowledgements

This research was sponsored in part by U.S. DOE STTR grant DE-FG02-04ER86200.

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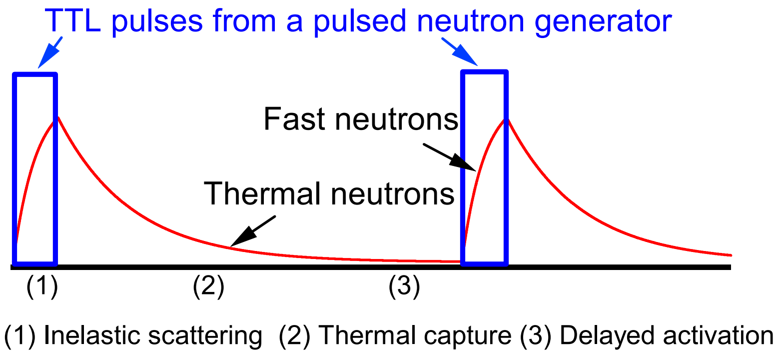

Fig. 1. Temporal characteristics of a pulsed neutron generator.

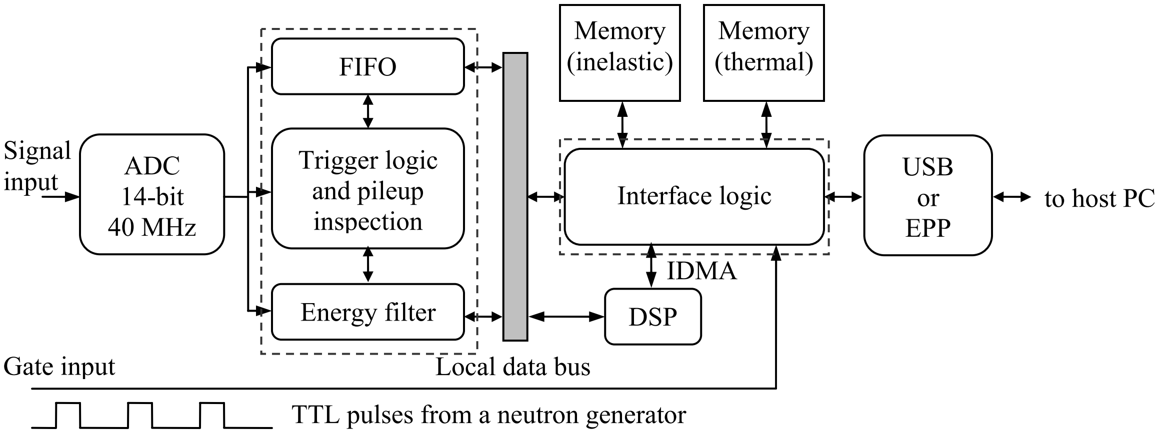

Fig. 2. Simplified block diagram of XIA's Polaris digital spectrometer.

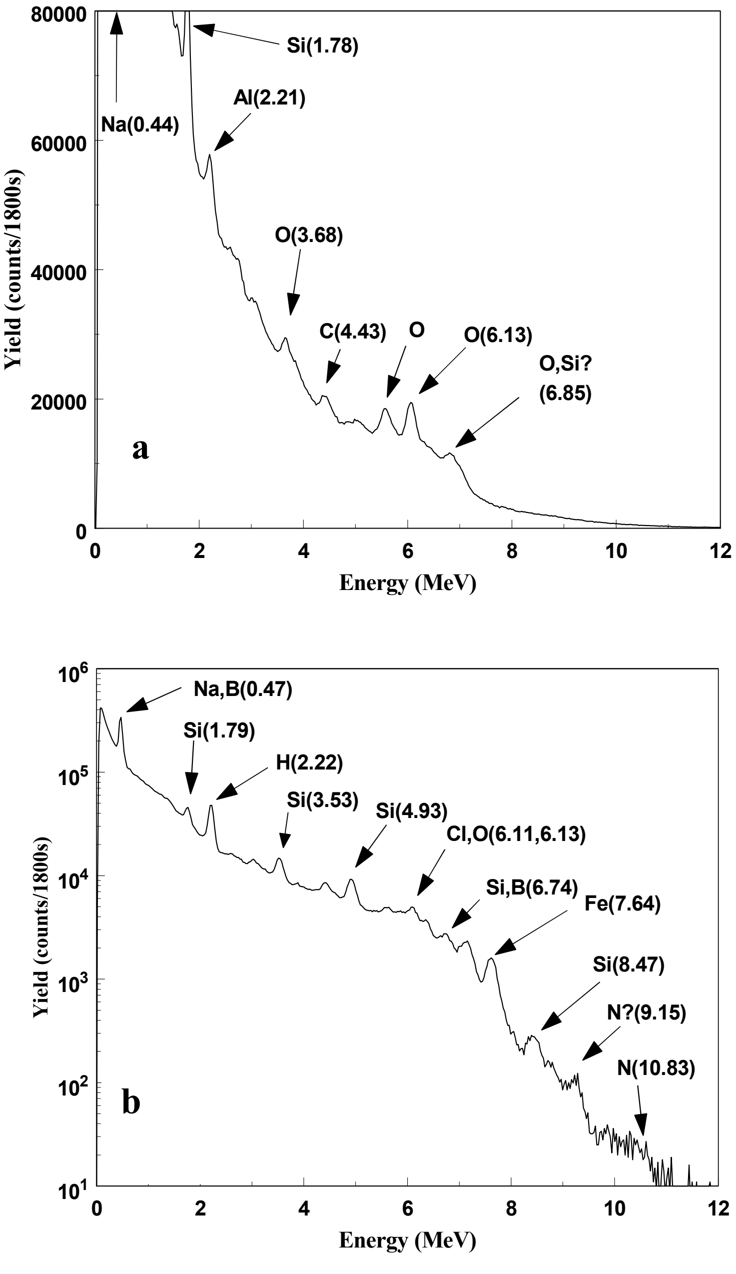

Fig. 3. Typical "Inelastic" (a) and "Prompt" (b) gamma spectra from a pine stand using NaI(Tl) detectors [4,5].

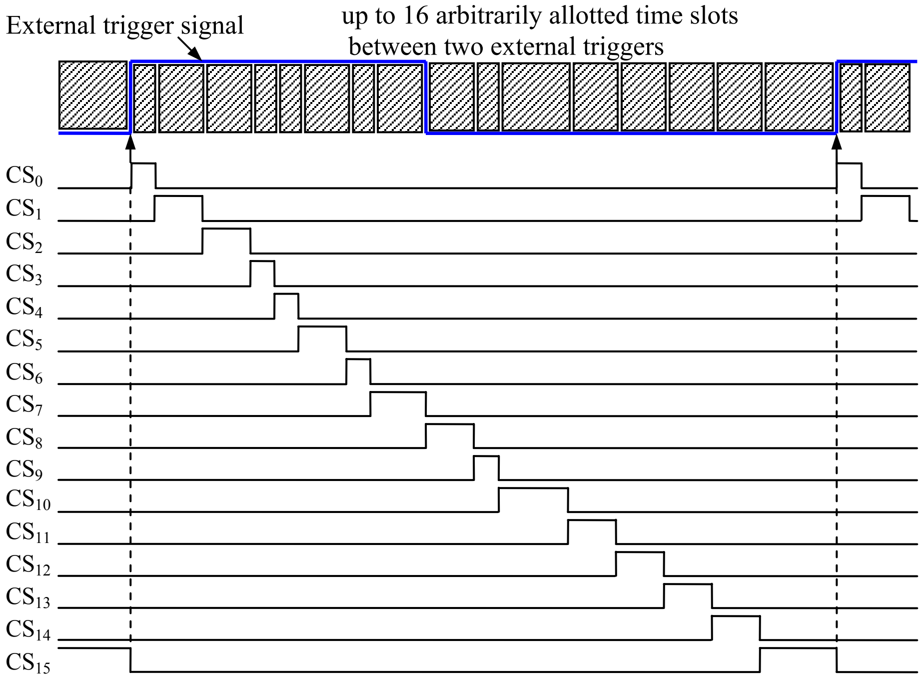

Fig. 4. Time sequence of multi-gating system in response to periodic external triggers.