Neutron/γ-ray Pulse-Shape Discriminator[†]

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Abstract

We present a neutron/γ-ray pulse-shape discriminator that is inexpensive and highly stable. Both of these favorable attributes come from the fact that the basic element of the device is a length of co-axial cable. The quality of discrimination is similar to that obtained with other modern devices.

1. Introduction

A common problem with radiation detectors is that they are normally sensitive to more than one type of radiation. In some cases slight differences in the signals produced by different radiation types can be used to identify the desired type. An example is the use of the liquid scintillator NE-213, a substance consisting of H and C atoms, to identify neutrons when γ rays and/or cosmic rays are also present. In NE-213, most of the light is emitted with a time constant of a few ns, the remainder more slowly. The division between fast light and slow light depends upon the ionization density of the exciting particle. Lightly-ionizing particles, either electrons from Compton-scattered γ rays or relativistic cosmic-ray muons, produce more of the fast fluorescence than do the more highly-ionizing protons scattered by neutrons or the α particles and protons resulting from breakup of carbon nuclei in NE-213. Hence, the shape of the pulse is different for the two categories of radiation [1-3], and pulse-shape discrimination (PSD) of the related photomultiplier signal is used to identify the neutrons.

Early PSD methods used the zero-crossing time of a double-differentiated pulse to distinguish neutrons from γ rays [4-7]. More recently, two charge-integrating ADC's (QDC's) were used to find the fraction of the total charge that was in the head, or, with equal quality, the tail of the pulse [8]. The crucial element in this method, setting the time that separates out the head or the tail from the pulse, was done with an electronic time gate on either head or tail. Tail charge was produced by Toke *et al.* [9] by differentiating the inverted signal and cutting the positive part. Their circuit is based on two transistors that permit individual setting of the

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cut level. The method presented here requires no level to be set. As in [8], it also uses two QDC's, one to integrate the current in the head of the pulse and another to integrate the total current in the pulse, but the electronic gate for setting the time between head and tail is replaced by a simple shorted coaxial cable that never needs adjustment. This replacement results in low cost and in high stability against changes in counting rate and ambient temperature since its basic element is just a piece of cable.

Initial design work at Ohio University led to a circuit developed at the KFKI RMKI Detector Laboratory and implemented at the National Superconducting Cyclotron Laboratory (NSCL) while its *Neutron Wall Array* [10] was being built. The *Array* consists of two 2m × 2m position-sensitive *walls*, each *wall* consisting of 25 2-m long glass cells, each cell filled with 10 ℓ of NE-213 and viewed at both ends by photomultiplier tubes. To cover the required dynamic range of pulse heights, each of the 100 photomultiplier tubes required two circuits, one whose input was the anode signal, the other for which the anode signal input was attenuated. Hence, we required a total of 200 PSD circuits.

2. Method

Figure 1A shows a schematic of the method of Heltsley et al. [8]. The anode signal from the detector is split into two signals, each integrated by a QDC. One of the two signals is delayed before entering the QDC. If the QDC is gated so that the integration starts at the beginning of the delayed signal, all of it will be integrated, giving Q-TOTAL. Only the tail of the other signal will be integrated, giving Q-TAIL. PSD is accomplished by comparing Q-TAIL to Q-TOTAL. The ratio will be larger for a neutron-induced pulse than for a pulse induced by a γ ray or cosmic ray since the NE-213 scintillator favors the slow light when excited by highly-ionizing radiation.

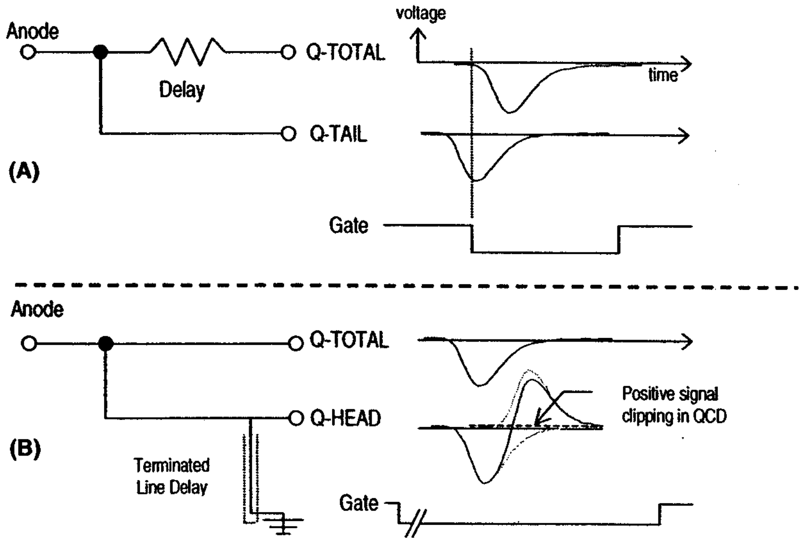
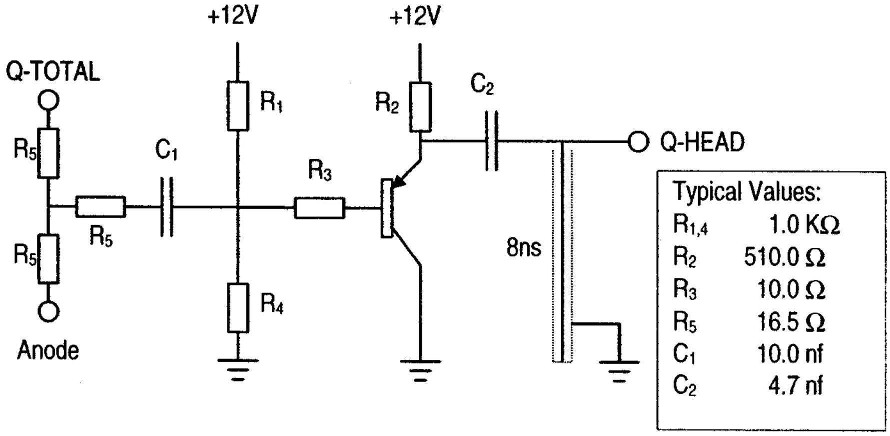


Fig. 1. Two methods for charge integration in pulse-shape discrimination. 1A is the more traditional approach using a fixed signal delay and a coordinated gate signal. 1B is the new approach presented here that uses a terminated delay-line and a long gate signal with an arbitrary start time.

The method shown in Fig. 1A produces acceptable results, but it is nevertheless difficult to implement for a large number of detectors looking for two signals in near coincidence. Dissociation of neutron-rich nuclei—^{11}Li → ^{9}Li +n + n [11], ^{8}He → ^{6}He + n + n [12], and ^{6}He → ^{4}He + n + n [13]—is an example of nuclear physics experiments in which two neutrons must be detected. The complication arises from the critical timing of the gate signal. If one is expecting two or more signals, then each pair of anode signals (Q-TOTAL and Q-TAIL) must have its own gate signal coordinated to coincide with the start of the Q-TOTAL signal. Unfortunately, most common QDC modules have many input channels controlled by a single gate signal. The first neutron opens the gate, and Q-TAIL and Q-TOTAL are properly integrated. By the time the second neutron arrives both of its signals may be fully integrated, resulting two Q-TOTALs and no Q-TAIL. One solution to this problem is to use external linear gates before the QDC input, in effect giving each QDC channel its own gate. This method was used [11] and found to be cumbersome to set up, and the linear gates drifted by nanoseconds when counting rate and temperature changed.

To overcome these problems, we developed a PSD method that still uses two QDC channels to compare the charge in a time fraction of the signal to the total charge of the anode signal, but the time fraction is independent of when a gate starts. How we accomplish this is shown in Fig. 1B. We split the anode signal into two signals as before and then place a shorted delay-line close to the input of one of the two QDC inputs. A positive reflection of the signal is created by the shorted delay-line and added to the original signal. After some fixed time, equal to twice the length of the shorted delay line, the reflected pulse will mix with the later part of the original pulse, resulting in a positive region of the pulse. The QDC we used (a Lecroy 2249W module) has a circuit that prevents positive charge from being integrated. As a result, we integrate only the negative portion of the signal, the head of the pulse, which is always a fixed time fraction of the original signal. The length of delay determines what fraction of the pulse is eliminated from the charge integration by being made positive. The long gate indicated in Fig. 1B defines the time interval during which the pulse is integrated and allows time for signals from other neutrons to arrive.



Typical Values:

R1,4	1.0 KΩ
R2	510.0 Ω
R3	10.0 Ω
R5	16.5 Ω
C1	10.0 nf
C2	4.7 nf

Fig. 2. Schematic of the pulse shape discrimination circuit.

After demonstrating that this concept works in practice, we enhanced it by using an emitter-follower circuit that allowed us to match the impedance of the input to the

QDC. By actively separating the cable from the source the emitter-follower prevents the reflected pulse from making its way back to the other QDC channel. The circuit is shown in Fig. 2.

Figures 3 and 4 show the circuit produced by the NSCL electronics shop for use with the NSCL *Neutron Wall Array* [10]. As can also be seen from Fig. 2, it can be produced for much less than can a linear gate module. Our parts cost was ~ $25 per circuit for the 200 circuits we built.

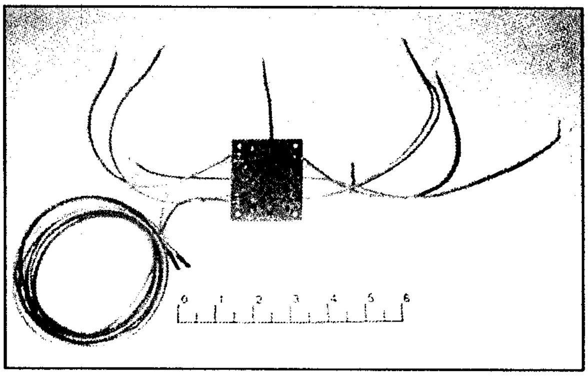


Fig. 3. A circuit board showing two of the pulse-shape discrimination circuits, one for analyzing the smaller pulses (anode signal input), the other for analyzing the larger pulses (attenuated anode signal input). The coils of wire at the lower left of the circuit board are the two shorted delay lines. The scale shown is in inches.

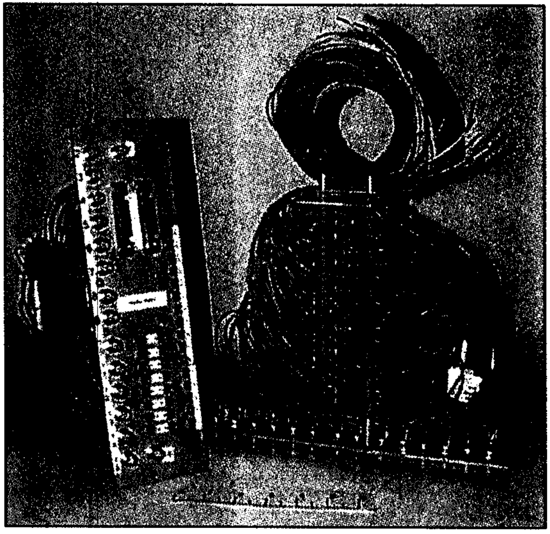


Fig. 4. A photograph of two modules, each module containing 16 circuit boards. Scale in inches. Through a BNC connector the anode signal enters a board where it feeds one circuit directly and another through an attenuator. The two Q-HEAD signals leave through Lemo connectors and the two Q-TOTAL signals through ribbon cable. The cost of the parts shown is ~ $25 per circuit.

3. Performance

Figure 5 shows a 2-dimensional PSD spectrum taken with one of the 10-ℓ glass cells of the NSCL *Array* [10]. An uncollimated Pu-Be source irradiated the entire 2-m length of the cell. (Note: The pulse-height data for this spectrum are the geometric mean of the signals from

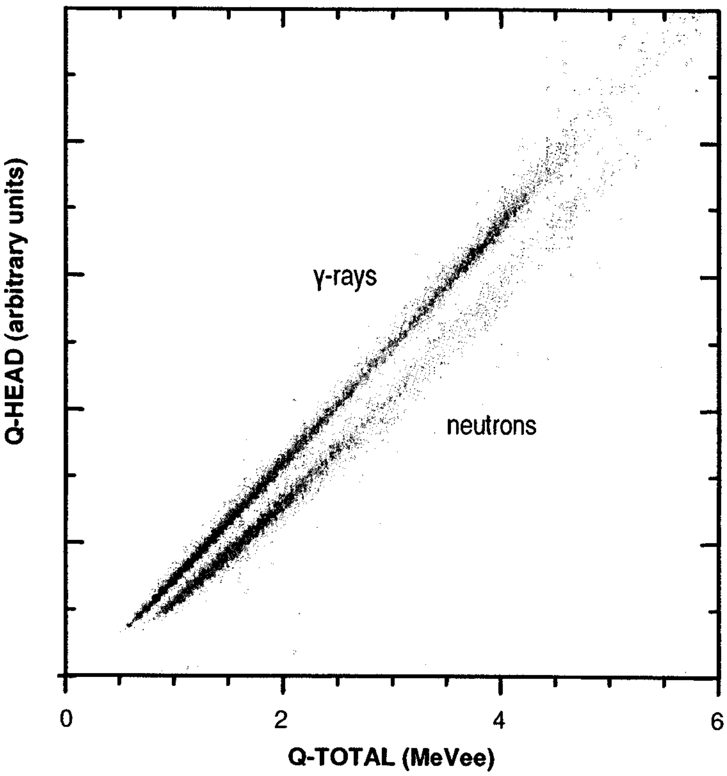


Fig. 5. A PSD spectrum from one 10-ℓ cell in the NSCL *Neutron Wall Array*. The neutrons and γ rays are from a PuBe source placed ~ 1 m from the center of the cell.

both photomuliplier tubes at the ends of the cell.) The Q-TOTAL values in the figure are expressed in scintillator light units *electron equivalent energy* (MeVee). One MeV of energy deposited in the scintillator by a γ ray produces 1 MeVee of light. But it takes a proton of ~ 3-MeV to produce 1 MeVee of light. Hence, a neutron must have at least ~ 3 MeV to produce 1 MeVee of light. Since a γ ray produces a bigger fraction of its light in prompt fluorescence than does a neutron, the upper branch represents γ rays. The Pu-Be source produces neutrons with a spread of energies up to ~ 12 MeV (at most ~ 6 MeVee of light) and 4.44-MeV γ rays from decay of ^{12}C in its first excited state. The Compton edge at 4.25 MeV (4.25 MeVee of light) is quite discernable in this branch. Muons are both above and below 4.25 MeVee.

From some of the data in Fig. 5 we constructed 1-dimensional pulse-height spectra of Q-HEAD at discrete values of Q-TOTAL and found that the *figure of merit* [14], M, defined as the separation between the centroids of the two peaks divided by the sum of the widths (FWHM) of the two peaks, increased from ~ 1.3 at the lower light values to ~ 1.6 at the higher values. With the method of Heltsley et al. [8] we obtained the same behavior. In spite of the facts that our light collection efficiency with the 2-m long cells was only ~ 20% per phototube and there was some time spread introduced by the long geometry, the neutron/ γ-ray separation is adequate down to 1 MeVee. With smaller scintillator volumes, it is possible to obtain good PSD at light levels well below 1MeVee.

Since the basic element of the device is a passive element—a length of shorted co-axial cable—it should be very stable, and our experience with the 200 units we built has not revealed any drifts or any kind of deterioration. The device may be applicable to particle identification with other radiation detectors, but we have not done any work on those possibilities.

Acknowledgements

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