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PARTICLE IDENTIFICATION VIA PULSE-SHAPE DISCRIMINATION WITH A CHARGE-INTEGRATING ADC

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A charge-integrating ADC has been used to sample the intensity in two different time regions of a pulse and thus to sense the shape of the pulse. This idea has been applied to produce neutron/γ-ray discrimination from pulses in a liquid scintillation detector. Optimization of available parameters yields good pulse-shape discrimination for pulses greater than those produced by 100 keV electrons. The method uses only general purpose electronics.

1. Introduction

It has been known for some time that when a charged particle passes through some types of organic scintillators, the resultant scintillation pulse can be approximated as the sum of two exponential decays, a fast one and a slow one [1–3]. The relative intensities of the two parts are dependent upon the rate of energy loss of the charged particle. This rate is generally much higher for protons and α-particles than for electrons. Since these are the charged particles that result, respectively, from neutron and γ-ray interactions in the scintillator, this pulse-shape effect has been used to distinguish between neutrons and γ-rays.

The various methods used for this purpose generally fall under one of two categories. In one the photomultiplier signal is shaped so that a zero-crossing time bears the pulse-shape information [4–8]. In the other a comparison is made of the total charge in the anode pulse to the charge of some fraction of the pulse [9,10]. Some version of each category has been refined to the point that a commercial NIM module [5,10] is available. As neutron experiments have evolved from single-detector setups to multidetector arrays [11,12] the desirability of developing more reliable and less costly methods of neutron/γ-ray discrimination has greatly increased. In this paper we report on one such method, a scheme that uses two channels of a charge-integrating ADC (a QDC).

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2. Basic considerations

If one channel of QDC is used to integrate the entire anode pulse from a scintillation spectrometer and one to integrate either the early or (equivalently) the late part of it, then for a given total charge the second integral depends on the particle type. To exploit adequately and with simplicity the pulse-shape difference between neutron and γ-ray scintillations one must choose a suitable time t_d in the pulse to use as an effective dividing line between the fast and slow components when generating that second integral. Ideally, one wishes to maximize the difference between the integrals for neutrons and γ-rays while minimizing the statistical spreads in those integrals. Unfortunately, the value of t_d that maximizes the difference is not the value that minimizes the spreads. Initially the γ-ray pulse is bigger than the neutron pulse, but for a given total charge the pulses intersect and cross over at a later time. Clearly, an integral from 0 to t_d (or equivalently from t_d to ∞) maximizes the difference if t_d is chosen to be that intersection time. However, the spread is minimized, in fact approaches zero, if $t_d \to 0$ (or equivalently $\to \infty$). Therefore, a compromise value of t_d must be found empirically.

We have referred to an equivalence between use of the early part of the pulse and the late part of the pulse. To see this equivalence, consider pulses of a given amplitude or total charge, $Q_{total} = Q_{early} + Q_{tail} = \int_0^{t_d} q\,dt + \int_{t_d}^{\infty} q\,dt$. From $0 = \delta(Q_{early}) + \delta(Q_{tail})$ we see that the two parts of pulses of a given amplitude have equal statistical spreads. Also, for neutron and γ-ray pulses of the same amplitude and being split at the same time t_d, $Q^{\gamma}_{early} + Q^{\gamma}_{tail} = Q^{neut}_{early} + Q^{neut}_{tail}$. Hence, $Q^{\gamma}_{early} - Q^{neut}_{early} = Q^{neut}_{tail} - Q_{tail}$; i.e., the separation between neutron and γ-ray signals is the same whether we use the integrals up to t_d or beyond t_d.

With the statistical spreads the same for Q_{early} and Q_{tail}, and with the n–γ centroid separations also the same for the early part and for the remaining part of the pulses, the quality (or figure of merit [13]) of neutron/γ-ray discrimination is, likewise, the same. The choice of which to use is, therefore, based on secondary considerations. For use with a single QDC module, in which all channels receive the same gate pulse, a long delay (~ 300 ns) is required if we use the early integral while Q_{total} is being obtained in another channel. The total pulse and the tail of the pulse can be integrated simultaneously by delaying the total pulse before integration but the delay is much shorter (~ 50 ns). Simply to use shorter delays we chose the latter method.

3. Experimental systems

The experimental system consisted of a liquid scintillation detector, a Pu–Be source as an emitter of neutrons and gamma rays, simple CAMAC electronics to sample the pulse shape, and a data acquisition system to write the results to the computer. The detector was fairly large, containing 0.55 l of NE213 in a glass cell 11 cm in diameter by 5.7 cm thick. The cell was epoxied

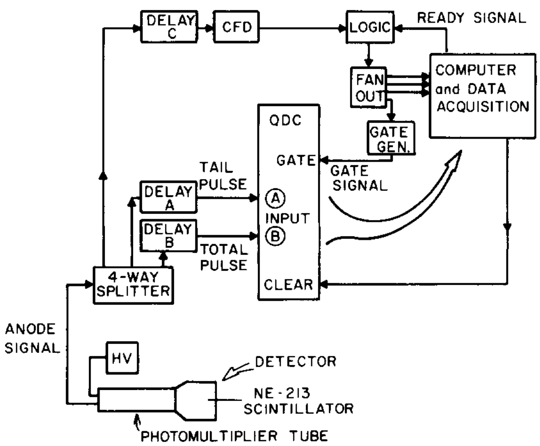

Fig. 1. Schematic of the experimental setup using a QDC for pulse-shape discrimination.

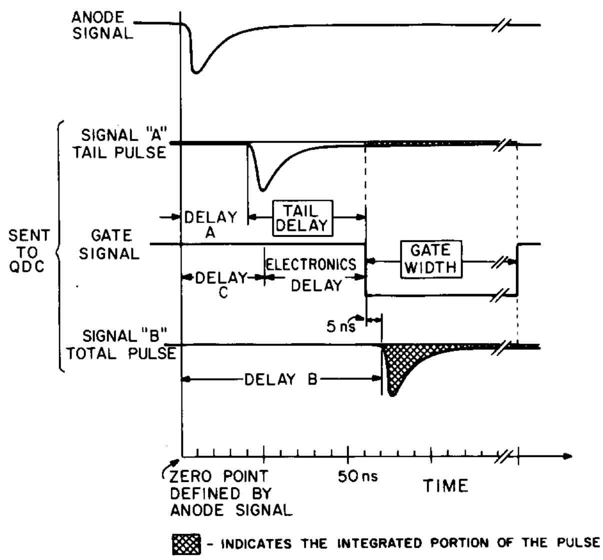

Fig. 2. Display of the relative arrival times of signals at the QDC.

via a conical, 5 cm long light guide to an RCA 8575 (4.5 cm diameter) photomultiplier tube. The data acquisition system is based on the 68010 microprocessor and is described elsewhere [14,15]. Typical acquisition rates were 3000 events per second.

The pulse-shape discrimination system is illustrated in figs. 1 and 2. We used only the anode signal of the photomultiplier (see fig. 1), thus obviating the need for a preamp and a long delay line, both of which were required in older systems (ref. [2], for example). The anode signal is divided into three identical signals, S_A, S_B, and S_C, by using a passive splitter. Two of these signals, S_A and S_B, are given different delays, A and B, and then sent to their respective QDC channel inputs. The third signal, S_C, is delayed and passed through a constant fraction discriminator (CFD) to produce a logical flag to indicate that an event has occurred and to trigger the gate signal to the QDC.

The relative timing of these signals is displayed in fig. 2. The delay of the third anode signal, delay C plus the electronics' delay, determines when the gate to the QDC opens, This delay, t_d above, is made long enough to include the long the tail of the anode signal, S_A. Anode signal S_B is delayed a greater amount so that the gate essentially includes the entire pulse.

4. Adjustable parameters and results

Plotting the charge in the tail of the pulse against the total charge leads to the two-dimensional spectra in figs. 3 and 4. Note that fig. 4 is an expansion of the first few

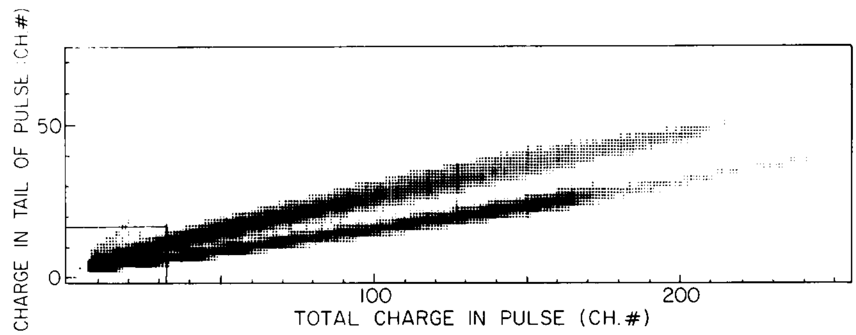

Fig. 3. Two-dimensional spectrum of total charge vs charge in the tail of the pulse. The 2048 channels in the x and y directions have been compressed into 256 and 128 channels, respectively. The gate width is 300 ns and the tail delay is 35 ns. The box at the lower left is expanded in fig. 4.

channels, those within the rectangular box in fig. 3. One can easily see the separation between neutron (upper) and γ-ray (lower) events in fig. 4 down to a pulse height (or total integrated charge) equivalent to that produced by a 100 keV electron. The energies in fig. 4 result from a calibration of channel number vs electron energy obtained by measuring the known Compton edges of several γ-ray sources.

The parameters *gate width* and *tail delay* shown in fig. 2 are important for optimizing the discrimination. In order to see the effects of adjusting these parameters, one-dimensional spectra were produced by projecting onto the ordinate the data in the slices shown in fig. 4, i.e., we constructed spectra for each of three values of equivalent electron energy. (This term means the energy of an electron that produces the same amount of light and, therefore, of total charge in the anode pulse as the neutron- and γ-ray-induced pulses we have here.) This was done for different values of gate width and tail delay. The results for gate width are presented in fig. 5 and for tail delay in fig. 6. Fig. 5 shows that good neutron/γ-ray discrimination can be realized over a wide range of gate widths at the higher energies. At the 100 keV level optimum results are achieved for gate widths around 300 ns. Likewise, fig. 6 indicates an optimal range of 25–45 ns for the tail delay with this detector, but a much wider range is tolerable. Fig. 6 is for pulses having an equivalent electron energy of only 100 keV. It is clear from fig. 4 that neutron/γ-ray separation becomes progressively simpler as the energy increases above 100 keV.

Fig. 7 shows our PSD spectra for fixed energy slices with with optimal values of gate width (300 ns) and tail delay (35 ns). The separation of neutron and γ-ray

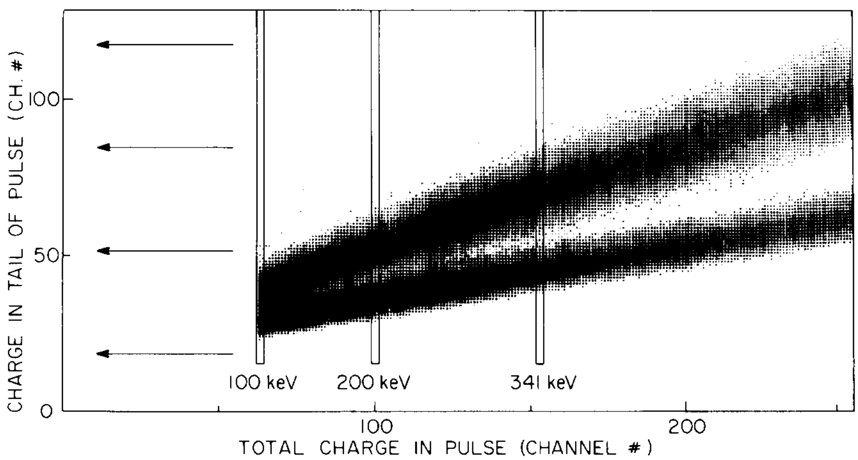

Fig. 4. Expansion of the box in the lower left of fig. 3 showing the first 128 channels of the tail pulse. The gate width is 300 ns and the tail delay is 35 ns. Also shown are the positions of three of the energy slices in which data are projected onto the y-axis to create the one-dimensional spectra in figs. 5–7. Each energy value – 100, 200, and 341 keV – is that of electrons that would produce anode pulses of the same size (or total charge) as observed here.

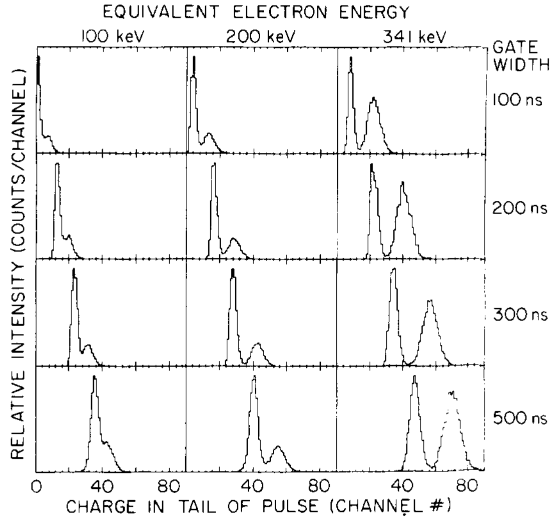

Fig. 5. One-dimensional spectra for gate widths of 100 to 500 ns for the three indicated equivalent electron energies. The tail delay has been held constant at 60 ns for these spectra. In each spectrum the first group is due to γ-rays, the second to neutrons.

pulses is excellent for energies above 100 keV. Comparison is made in fig. 7 with two spectra taken by Chalupka et al. using the difference in zero-crossing time for neutron/γ-ray discrimination [7]. Their detector was smaller (12.7 cm diameter × 2.54 cm thickness) than ours and was coupled directly to a 12.7 cm diameter XP 1041 photomultiplier tube, thus having lower neutron detection efficiency but better light collection. The energy ranges for their top and bottom spectra were 30–60 keV and 60–120 keV, respectively. Using lead shielding they selectively attenuated the gamma rays. Taking all of these factors into consideration, the degree of discrimination achieved by the two methods appears quite comparable.

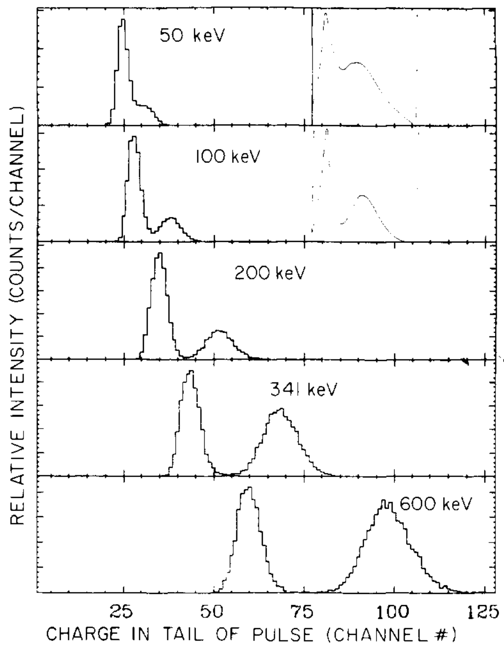

Fig. 7. One-dimensional spectra with optimal gate width (300 ns) and optimal tail delay (35 ns) at various energies. The indicated energies – 50 to 600 keV – are those of electrons that would produce anode pulses of the same size and produced by the neutrons and γ-rays observed here. The two spectra at the upper right were copied from Chalupka et al. [3] for comparison with the present results. (See text.) In each spectrum the first group is due to γ-rays, the second to neutrons.

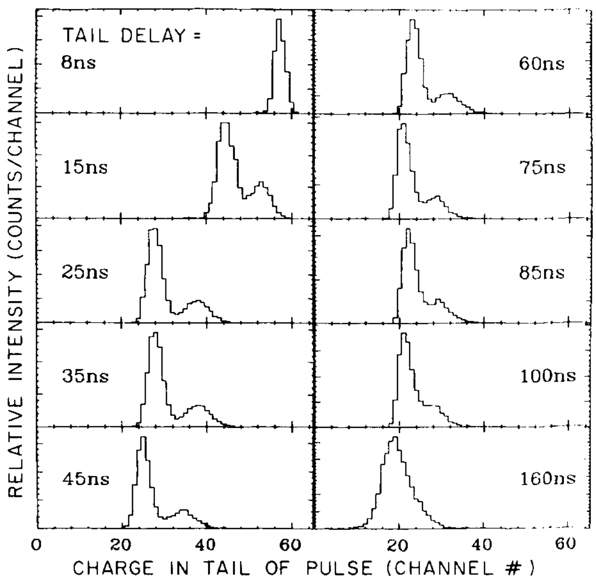

Fig. 6. One-dimensional spectra for anode pulses whose size (or total integrated charge) is the same as that produced by 100 keV electrons. The gate width is 300 ns for all the spectra, and the tail delay varies, as indicated, from 8 to 160 ns. In each spectrum the first group is due to γ-rays, the second to neutrons.

5. Conclusions

In addition to giving good neutron/γ-ray separation down to a rather low energy, our method has the advantage that it requires only general purpose electronics; there is no need for special modules of limited versatility. Also, since only the anode signal is utilized, such inconveniences as long delay lines and preamps and amplifiers are avoided. The method is also fairly compact; one LeCroy QDC module can service up to six neutron detectors. Of great importance is the observation that the system is highly stable, requiring no monitoring or adjustment once the initial timing is established. The use of QDCs for pulse-shape discrimination can be a simple, viable option for many experiments.

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