Radiation Physics and Chemistry 106 (2015) 50–55

Contents lists available at ScienceDirect

Radiation Physics and Chemistry

journal homepage: www.elsevier.com/locate/radphyschem

Simple algorithms for digital pulse-shape discrimination with liquid scintillation detectors

T. Alharbi

Department of Physics, Faculty of Science in Zulfi, Almajmaah University, P.O. Box 1712, 11932, Saudi Arabia

HIGHLIGHTS

- Two new algorithms for pulse-shape discrimination were developed.
- The performances of the algorithms were experimentally examined.
- The suitability of the algorithms for use in field instruments is discussed.

ARTICLE INFO

Article history:
Received 6 December 2013
Accepted 30 June 2014
Available online 9 July 2014

Keywords:
Neutron detection
Liquid scintillation detectors
Neutron-gamma discrimination
Digital
Pulse processing

ABSTRACT

The development of compact, battery-powered digital liquid scintillation neutron detection systems for field applications requires digital pulse processing (DPP) algorithms with minimum computational overhead. To meet this demand, two DPP algorithms for the discrimination of neutron and γ-rays with liquid scintillation detectors were developed and examined by using a NE213 liquid scintillation detector in a mixed radiation field. The first algorithm is based on the relation between the amplitude of a current pulse at the output of a photomultiplier tube and the amount of charge contained in the pulse. A figure-of-merit (FOM) value of 0.98 with 450 keVee (electron equivalent energy) energy threshold was achieved with this method when pulses were sampled at 250 MSample/s and with 8-bit resolution. Compared to the similar method of charge-comparison this method requires only a single integration window, thereby reducing the amount of computations by approximately 40%. The second approach is a digital version of the trailing-edge constant-fraction discrimination method. A FOM value of 0.84 with an energy threshold of 450 keVee was achieved with this method. In comparison with the similar method of rise-time discrimination this method requires a single time pick-off, thereby reducing the amount of computations by approximately 50%. The algorithms described in this work are useful for developing portable detection systems for applications such as homeland security, radiation dosimetry and environmental monitoring.

1. Introduction

Pulse-shape discrimination (PSD) techniques working with liquid scintillation detectors are widely used in fast neutron detection and spectroscopy applications. In such applications, the PSD techniques are used to separate neutron interaction events from interfering γ-ray interactions by exploiting a difference in the intensity of the slow component of the light pulses in organic scintillators that are initiated by the recoil protons and electrons (Knoll, 2000). PSD techniques also make the liquid scintillation detectors well suited for γ-ray spectrometry in mixed radiation fields for a wide energy range, as neutron and γ-ray events can be separated and both pulse height-spectra can be recorded simultaneously (Klein and Neumann, 2002). In addition to liquid scintillators, plastic scintillators with efficient neutron and γ-ray (n/γ) pulse-shape discrimination have been recently developed, which further extends the applications of PSD techniques (Zaitseva et al., 2012). The PSD methods are also required for use with phoswich scintillation detectors, e.g. in environmental radiation measurements, where information on the background events is reflected in the decay-time of the pulses (Hennig et al., 2007; Celis et al., 2007). With regard to these applications, analog PSD methods have been extensively studied over the last 50 years and a variety of PSD circuits have been developed (Brooks, 1959; Alexander and Goulding, 1961; Dewendra and Galloway, 1975; Bayat et al., 2012). In recent years there has been a strong interest in using digital techniques for PSD applications, and various digital pulse processing (DPP) algorithms were proposed for this purpose (Kaschuck and Esposito, 2005; Nakhostin and Walker, 2010; Shippen et al., 2010; D'Mellow et al., 2007; Yousefi et al., 2009). However, despite the existence of a large number of publications on different PSD algorithms, there is still a demand for algorithms with a reduced

http://dx.doi.org/10.1016/j.radphyschem.2014.06.031

computational overhead. A DPP algorithm with minimum computational overhead not only facilitates the implementation of the circuit on digital hardware such as field-programmable gates arrays (FPGAs) but also reduces the power required for pulse processing that is of importance for developing portable devices. In fact the power consumption of FPGAs can be considerable when compared to those of other sources of power consumption in a digital scintillation-based detection system such as light sensors and pulse digitizers (Paulo et al., 2010; Brunner et al., 1998; Anderson and Najm, 2004; Jamieson et al., 2009) and, therefore, its minimization is useful for a prolonged operation of portable devices. One important application of such devices is in search for elevated sources of neutron activity or the detection of illicit radioactive material (Flaska and Pozzi, 2007). Portable devices are also required for applications such as radiation dosimetry, low level environmental radiation monitoring (Hennig et al., 2007), landmine detection systems (Brooks et al., 2004), etc. In this paper we report on two DPP algorithms which aim to reduce the amount of computations, suitable for the implementation of fast real-time pulse processing in field instruments. The algorithms are experimentally examined for n/γ discrimination with liquid scintillation detectors by using a NE213 scintillator in a mixed radiation field and their performances are analysed.

2. PSD methods

2.1. Charge-to-current ratio method

In the pulse processing of liquid scintillation detectors, where the total energy deposition in the detector is of interest, the output pulses of the photomultiplier tubes (PMTs) must be integrated, in order to determine the total charge which is proportional to the deposited energy by the incident particle. In analog pulse processing systems normally an integrating preamplifier is used to integrate a PMT current pulse, and then a pulse amplifier/shaper is used to prepare the pulses for the final pulse-height measurement. In digital regime, this procedure can be simply performed by a numerical integration of sampled PMT pulses. Alternatively, a digital pulse shaper can be applied to the PMT current pulses. A pulse shaper can integrate the total charge in the PMT current pulses provided that the shaping time constant of the filter is long enough compared to the duration of PMT pulses. The typical scintillation time constants are on the order of 3–4 ns for the fast component and up to 270 ns for the slow components (Knoll, 2000). There are several digital pulse shapers available for this purpose with recursive algorithms such as trapezoidal and semi-Gaussian filters (Jordanov and Knoll, 1994; Nakhostin, 2011). Nevertheless, in our approach, a simple integration of pulses is used because the effect of pulse shapers on the PSD performance can be important only in low energy range, where the effect of electronic noise can be considerable (Kaschuck and Esposito, 2005; Nakhostin and Walker, 2010). In the charge-to-current ratio method, information on the type of radiation is extracted by simply comparing the amplitude of the PMT current pulse with the integral of the pulse and no further modification of the pulse is needed. The principle of this approach for n/γ discrimination is shown in Fig. 1. The method is based on the fact that, for neutron and γ-ray PMT pulses of the same amplitude, larger charge pulses are obtained for neutron events due to the larger contribution of the slow light component in a neutron pulse. The different steps of the DPP algorithm are as follows. (1) The peak value of a current pulse is determined. To simplify the peak finding procedure we use the fact that the peaking-time of PMT pulses in liquid scintillation detectors with a very good accuracy can be considered constant and, therefore, the sample value corresponding to a certain time after the pulse trigger time, i.e. the time at which the amplitude of the pulse exceeds

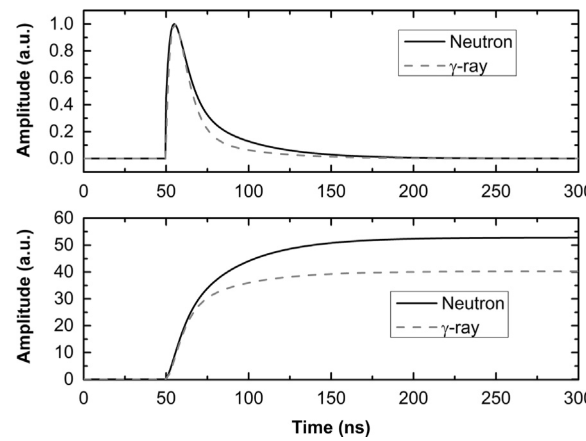

Fig. 1. The relation between the amplitudes of current and charge pulses from liquid scintillation detectors. (Top) Typical neutron and γ-ray pulses, generated using a mathematical model for NE213 scintillator (Marrone et al., 2002). The current pulses are normalized. (Bottom) The corresponding charge pulses after a simple numerical integration. A larger charge pulse is obtained for the neutron event.

the noise level, is taken as the amplitude of the current pulse. (2) The amplitude of the charge pulse (integral of the PMT pulse) is simply determined by taking the sum of the samples of the PMT pulse (Nakhostin, 2012). (3) A decision on the particle type is made by comparing the charge and current values. The details of this procedure are described in Section 3. It is notable that this approach was recently used to study discrimination properties of new scintillation detectors under development for solar neutrino experiments (O'Keeffe et al., 2011). The method is very similar to the charge-comparison method which has been widely used in both analog and digital pulse-shape discrimination systems. The charge-comparison method is based on a comparison of the integrals under a pulse, over two different intervals often referred to as the long integral and the short integral. The former corresponds to the area of the entire pulse, whilst the latter includes only the tail of the pulse which generally includes more than two-third of the pulse duration (Flaska and Pozzi, 2007; Gamage et al., 2001). In comparison with the charge-comparison method our approach avoids taking the short integral and, therefore, one can conclude that the new approach reduces the amount of computations by approximately 40%.

2.2. Trailing-edge pulse timing method

In analog domain, a trailing-edge constant-fraction discriminator (TCFD) technique is used with either unipolar or bipolar pulses to derive a time pick-off pulse after the peak time of a pulse from a shaping amplifier. The TCFD technique is widely used for n/γ discrimination in analog domain, when incorporated in timing single channel analyzers (Lee and Lee, 1998; Ortec, AN42, 1999). The principle of a TCFD timing module is illustrated in Fig. 2. The linear input pulse is stretched and attenuated and then used as the reference level for a timing comparator. The time pick-off pulse is generated when the trailing-edge of the linear input pulse crosses back through the fraction reference level. The fraction, *f*, is the fraction of amplitude decay toward the baseline as measured from the peak of the input pulse. Since the time of occurrence of the pick-off pulse is dependent on the decay-time constant of an input pulse, it provides an index for particle identification with detectors in which information on the particle type is reflected in the trailing-edge of pulses.

In digital regime the implementation of TCFD is easily done without modifying the original pulse, making it a simple and easy method for PSD applications. The principle of the digital n/γ discrimination method using this technique is shown in Fig. 3.