Nuclear Instruments and Methods in Physics Research A 748 (2014) 33–38

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

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

Pulse shape discrimination with fast digitizers

D. Cester [a], M. Lunardon [a], G. Nebbia [b], L. Stevanato [a,*], G. Viesti [a], S. Petrucci [c], C. Tintori [c]

[a] Dipartimento di Fisica ed Astronomia dell'Università di Padova, Via Marzolo 8, I-35131 Padova, Italy
[b] INFN Sezione di Padova, Via Marzolo 8, I-35131 Padova, Italy
[c] CAEN S.p.A., Via Vetraia 11, I-55049, Viareggio, LU, Italy

ARTICLE INFO

Article history:
Received 3 February 2014
Accepted 17 February 2014
Available online 22 February 2014

Keywords:
Liquid scintillator
Digital signal processing
Pulse shape discrimination

ABSTRACT

The pulse shape discrimination (PSD) between neutrons and gamma rays in liquid scintillators is studied by using the charge integration method with fast digitizers having different technical characteristics. The use of the Figure of Merit (FoM) to verify the PSD capability is discussed. The dependence of the FoM on the digitizer sampling rate and resolution is experimentally determined. The effects due to the type of source and the irradiation geometry are also evidenced and discussed.

1. Introduction

The pulse shape discrimination (PSD) in organic scintillators has been the subject of a large number of experimental works since its 1959 discovery in stilbene crystals [1]. A short review of PSD development is given in Refs. [2,3]. Today PSD is applied in several different areas in basic and applied research. In this work we refer essentially to the discrimination between neutrons and gamma-rays performed with liquid scintillators that is of primary interest in fast neutron measurements.

An important step in the development of PSD technology was represented by the introduction of fast digitizers replacing the analogic electronic systems that have been in use for several decades [4]. The Digital Pulse Processing (DPP) performed by using the new generation of fast digitizers offers several advantages with respect to the traditional analogic front-end: the detector signal is processed directly by the fast digitizer in which basic information related to time and amplitude is computed on-line by FPGA. When the on-line analysis is not sufficient, the digitized signals can be stored for off-line processing. The choice of the digitizer characteristics, in terms of sampling rate and resolution, is determined by the detector quality and by the specific application requirements [5].

In case of pulse-shape discrimination with liquid scintillators, the most used technique for PSD analysis is the so-called charge integration method [6] that determines, for each event, the delayed light output with respect to the total scintillation light. It is known, indeed, that pulses associated with gamma rays and neutrons exhibit different shapes: the proton recoil generated in the (n, p) scattering exhibits a large delayed light emission compared to the electron associated with the gamma ray detection [2]. Consequently, the PSD parameter can be computed on-line by the FPGA using different integration gates and can be expressed as the ratio between the delayed and the total light output.

Once the PSD parameter is evaluated and a PSD versus total light output 2-D plot is generated, it is useful to define a quantity that provides a quality assessment of the neutron–gamma discrimination. Such quantity is the so-called Figure of Merit (FoM) as proposed in Ref. [7]. Assuming that a PSD distribution is obtained as a one-dimensional histogram by a selection on the total scintillation light in the 2-D plot, the two resulting peaks, associated to gamma ray and neutron, can be analyzed by two Gaussian fits, thus defining the FoM as

$$\mathrm{FoM} = S/(\Gamma_e + \Gamma_p)$$

where S is the difference between the two centroids of the neutron and gamma peaks and $(\Gamma_e + \Gamma_p)$ is the sum of the gamma and neutron FWHM.

It is of general interest to verify the quality of the discrimination between neutrons and gamma rays using fast digitizers with different sampling rates and resolutions. Some information on this subject has been reported in recent studies [4,5,8]. In this work we present a complete assessment on the PSD obtained by using a set of digitizers spanning from 250 to 1000 MSample/s with resolution from 10 to 14 bits, providing a systematic approach to the problem. Moreover the dependence of the FoM on some experimental details is also discussed in order to verify the possibility of comparing results from different studies.

* Corresponding author. Tel.: +39 0498275936.
E-mail address: luca.stevanato@unipd.it (L. Stevanato).

http://dx.doi.org/10.1016/j.nima.2014.02.032
0168-9002

2. Experimental details

The pulse shape discrimination capability has been studied using a 5.1 cm × 5.1 cell filled with a standard EJ-301 liquid scintillator. The scintillator is coupled to a H1949-51 Hamamatsu linearly focused 12 dynode photo-multiplier (PMT). The PMT was operated at a bias between 1380 and 1650 V depending on the dynamic range to be studied. The PMT anode signal was directly processed by a set of CAEN fast digitizers: V1720 (250 MHz sampling rate, 12 bits resolution), DT5751 (1 GHz sampling rate, 10 bits resolution) and DT5730 (500 MHz sampling rate, 14 bits resolution). In addition, the off-line analysis of the latter digitizer was performed converting event by event the data in order to simulate a 250 MHz sampling rate and lower (10 and 12 bits) resolutions.

In using the DPP it is extremely important to optimize the relevant parameters used for the on-line processing. Once the signal triggers the low energy threshold of the device at $t=0$, the integration gates start from a negative pre-gate time $t=-T_{pre}$. The Long Integration Gate and the Short Integration Gate are used to determine the total light output and the prompt light emission respectively. In order to obtain the total charge associated with the two gates it is extremely important to determine accurately the baseline of the signal. This is normally obtained with a third gate (Baseline Gate) located before the pre-gate time T_{pre}. The signal processing quantities are illustrated in Fig. 1.

Finally, it is worth mentioning that the maximum voltage digitized in a single sample is 2 V for the DT5730 and V1720 models and 1 V for the DT5751 one. Consequently the dynamic range of the signals has to be controlled to avoid saturation. In this respect, a calibration of the pulse height is needed. In case of liquid scintillators the calibration is obtained from standard gamma ray sources taking into account that the gamma ray interaction is dominated by the Compton scattering and thus the relevant feature in the distribution is represented by the Compton Edge. The determination of the correct pulse height calibration using Compton Edges has been the subject of several papers in the past (see Refs. [1,2]). We will refer in the following to the procedure described in Ref. [9] with ^{22}Na gamma ray sources.

3. The Figure of Merit

The PSD parameter is computed event-by-event in the digitizer's FPGA as

PSD = (Long Gate Integration–Short Gate Integration)/Long Gate Integration

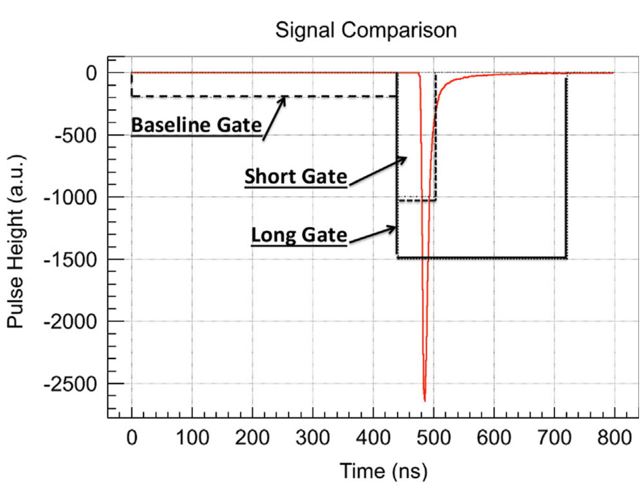

Fig. 1. DPP quantities: the Short and Long Integration Gates and the Baseline Gate.

The integration gates used in this work are 280 ns (Long Gate) and 68 ns (Short Gate) for the Long and Short Gates, with T_{pre} set to 40 ns. The Baseline Gate includes 16 samples. Low energy threshold of approximately 10 mV was used.

Typical 2-D plots of PSD versus the calibrated total light output are shown in Fig. 2, measured with Am/Be and ^{252}Cf sources using the DT5730. In case of the Am/Be source, the gamma ray spectrum extends from the 59 keV line of ^{241}Am to the 4.4 MeV gamma ray from the ^{9}Be(α, n)^{12}C* reaction. Both structures are clearly visible in the total light output distribution in the lower panel of Fig. 2(a). In this distribution the ^{241}Am peak resulted at an energy of 55.2 keV and the Compton Edge of the 4.4 MeV transition at 4.0 MeV with the expected value for the Compton Edge at 4.16 MeV. The difference between calibrated and expected values represents a check of the precision in the energy calibration of the spectrum obtained using a ^{22}Na source and the procedure of Ref. [9]. Looking at the 2-D plot in Fig. 2 it appears that the PSD

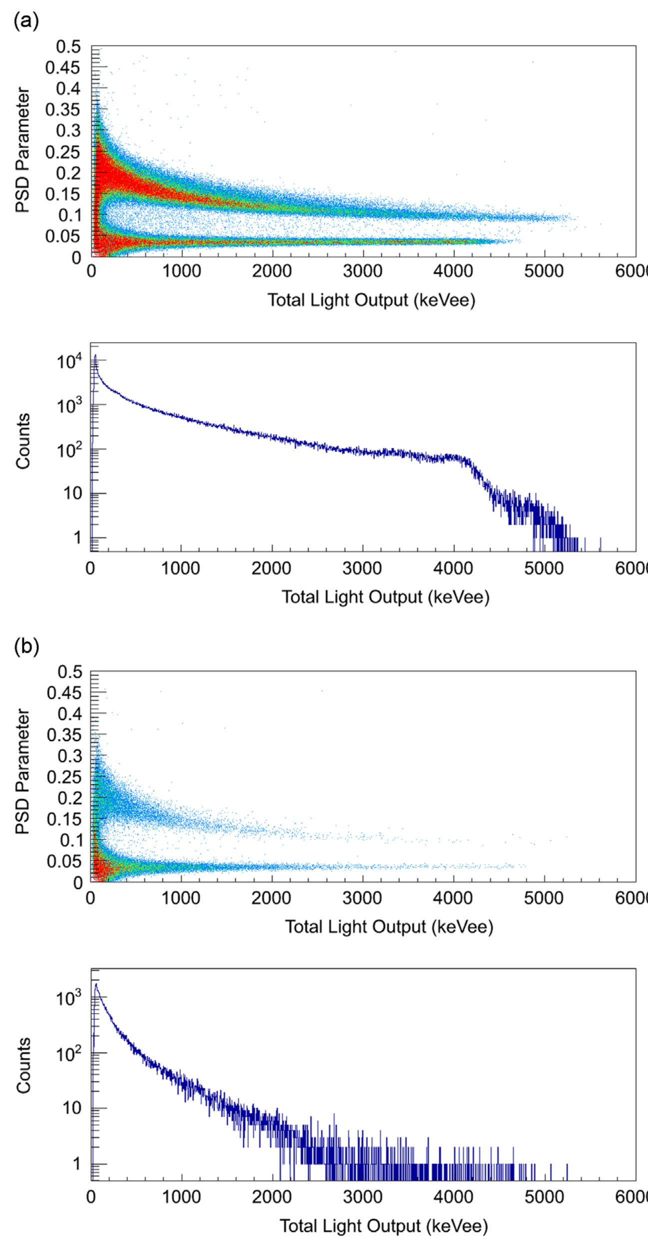

Fig. 2. PSD versus total light output for Am/Be (a) and ^{252}Cf (b) sources. The corresponding total light output spectra are shown in the lower panels.