Application Note AN3250
Pulse Shape Discrimination with different CAEN digitizers running DPP-PSD firmware

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Introduction

Pulse Shape Discrimination (PSD) is a technique widely used in both basic and applied research. One of the most common PSD applications is the discrimination between neutrons and gamma rays in fast neutron measurements. During the last years, Pulse Shape Discrimination has been significantly improved thanks to the use of fast digitizers and Digital Pulse Processing (DPP). The digital approach, therefore, replaced in many cases those analog systems that have been developed and successfully operated for several decades.

Digital Pulse Processing offers many advantages in respect to the traditional systems. The detector signals can be processed on real time by the FPGAs housed in the digitizers. This allows for higher trigger rates because no conversion time is needed to digitize the input pulses and perform the analysis. The setup is considerably easier and more compact since the detector can be directly connected to the digitizer and no other electronic module is needed for the data acquisition. Finally, when the on-line analysis is not sufficient, the raw digitized signals can be used for a refined off-line analysis.

The choice of the digitizer characteristics, in terms of sampling rate and resolution, depends on the detector signals and the requirements of the specific application.

In this application note[1], Pulse Shape Discrimination between neutrons and gamma rays in liquid scintillators is studied by using DPP-PSD firmware running on CAEN digitizers. The dependence of the Figure of Merit (FoM) on the digitizer sampling rate and resolution is experimentally determined.

Experimental setup

For the measurements reported in this application note, a 2” x 2” liquid scintillation cell of EJ-301 liquid scintillator coupled to a H1949-51 Hamamatsu linearly focused 12 dynode photo-multiplier (PMT) has been used. The PMT has been biased between 1650 and 1380 V depending on the dynamic range to be studied. The anode signal was directly processed by a set of CAEN digitizers: **V1720** (250 MS/s, 12 bit), **DT5751** (1 GS/s, 10 bit) and **DT5730** (500 MS/s, 14 bit). It is worth mentioning that the three devices show different input ranges: 2 Vpp for both DT5730 and V1720 and 1 Vpp for DT5751. Consequently the dynamic range of the input signals has to be adjusted to avoid saturation and a calibration is needed for each module. In case of liquid scintillators, the calibration is obtained from standard gamma ray sources taking into account that the gamma ray spectra are dominated by the Compton scattering. The determination of the correct calibration using Compton Edges has been the subject of several works in the past. We will refer in the following to the procedure described in ref. [1] with ^{22}Na gamma ray sources.

Figure of Merit

DPP-PSD firmware is based on the so-called charge integration method. It relies on the comparison, for each event, between the delayed and the total scintillation light. The pulses associated with gamma rays and neutrons exhibit, in fact, different shapes. The proton recoil generated in the (n,p) scattering shows a larger delayed light emission in respect to the electron event associated with the gamma rays detection.

Consequently, PSD can be computed on-line in the FPGA by means of two charge integrating gates with different programmable widths. A Short Gate is used to integrate the charge related to the prompt light emission while a Long gate evaluates the total light collection. The PSD parameter is therefore expressed as the ratio between the delayed and the total light output:

$$PSD = \frac{Q_L - Q_S}{Q_L}$$

Q_L = charge within long gate
Q_S = charge within short gate

For the measurements shown in this application note, Short and Long gates have been set to 68 ns and 128 ns respectively.

Once the PSD parameter is evaluated, a PSD versus total light output 2-D plot can be generated. In **Fig. 1** the 2-D plot of AmBe and ^{252}Cf sources measured with DT5730 running DPP-PSD firmware is shown.

[1] *Based on “Pulse shape discrimination with fast digitizers”, L. Stevanato et al, NIMA 748 (2014) 33–38, DOI: 10.1016/j.nima.2014.02.032*

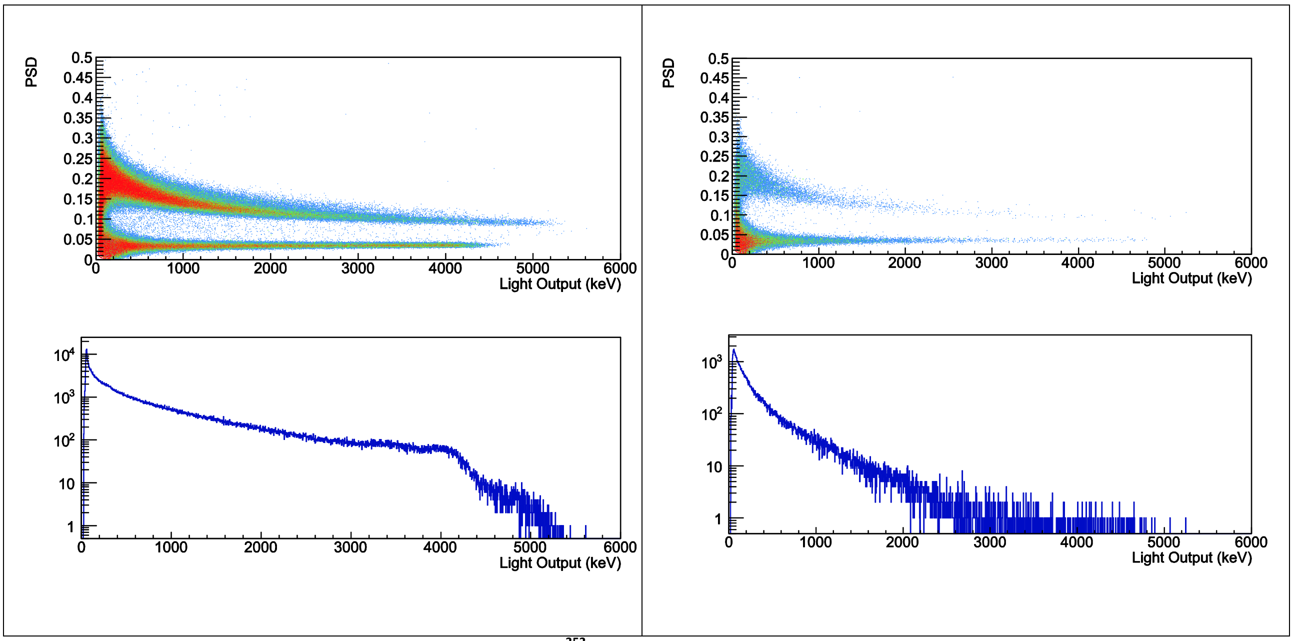

Fig. 1: PSD versus total light output for AmBe (upper left) and ^{252}Cf (upper right) sources, upper panels. The total light output spectra are in the lower panels.

In case of the AmBe source, the gamma ray spectrum extends from the 59 keV line of the ^{241}Am decay to the 4.4 MeV gamma ray of the ^{9}Be(α, n)^{12}C* reaction. Both structures are clearly recognizable in the lower panel of Fig.2 where the total light output distribution, i.e. the projection of the 2-D plot on the x-axis, is shown.

In this plot, 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 being 4.16 MeV its expected value. The difference between measured and expected values represents a quantitative check of the precision in the energy calibration of the spectrum obtained by using the ^{22}Na source and the procedure of ref.[1]

Looking to the 2-D plot in Fig.2, it appears that the gamma ray PSD value is constant in the whole range. Conversely, the neutron PSD value decreases as the total light increases. This feature is quantitatively shown in **Fig. 2** where the mean values of the PSD parameter is reported as a function of the total light for gamma ray and neutrons.

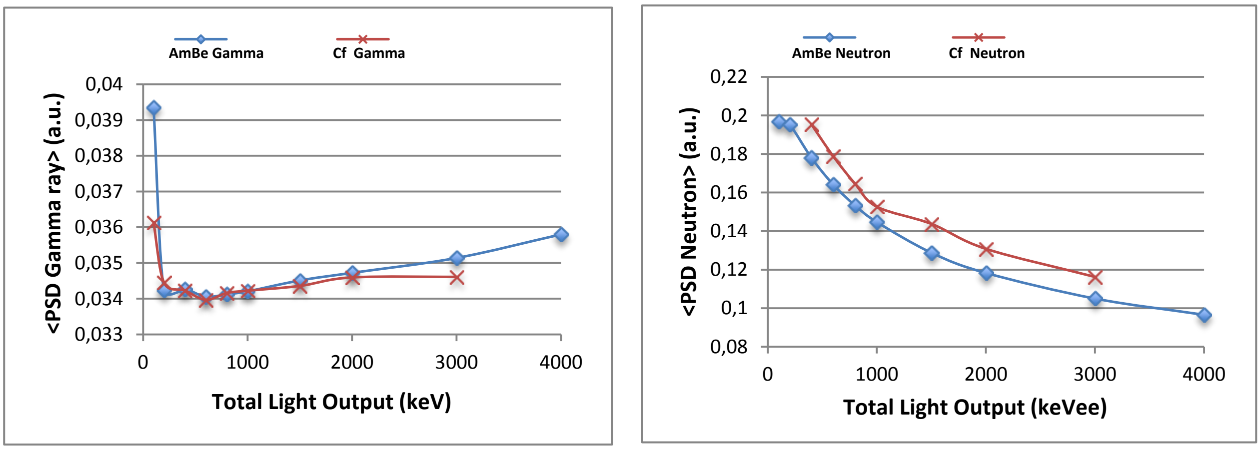

Fig. 2: Mean value of the PSD parameter for gamma ray (left panel) and neutrons (right panel) as a function of the total light output.

The decrease of the neutron PSD value is clearly confirmed in Fig. 3 where average shapes of the neutron events are shown for different cuts in total light output. The average shapes of the signals are normalized to compare the relative role of the delayed component that determine the value of the PSD parameter.

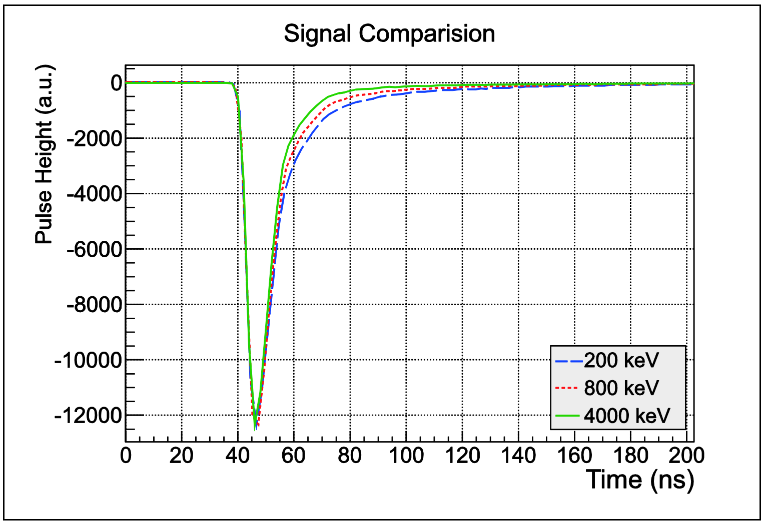

Fig. 3: Average signal shapes for neutron events with total light output of 200, 800 and 4000 keVee. The spectra are normalized to the pulse minima.

From Fig. 3, a clear reduction of the tail component with respect to the peak is observed, causing the decrease of the PSD parameter value. This fact was already evidenced in ref. [2]. The effect could be explained by considering that the emission of delta electron is more frequent as the energy of the recoil proton increases. In this case, the energy released in the detector by delta electrons does not contribute to the signal tail.

It is possible to define a so-called Figure of Merit for a quantitative evaluation of the resulting neutron-gamma ray discrimination. Such quantity has been proposed in ref. [3]. A PSD distribution can be obtained as a one-dimension histogram by projecting the events above a given total light cut value on the y-axis. The two resulting peaks can be analysed by Gaussian fits and then the FoM is defined as:

$$FoM = S / (\Gamma_e + \Gamma_p)$$

S = difference between the two centroids of the neutron and gamma peaks

$(\Gamma_e + \Gamma_p)$ = sum of the gamma and neutron full widths at half maximum (FWHM).

Experimental results

A first test has been performed by using the three digitizer models. The FoM values for different narrow windows (about 70 keVee) on the total light output are reported in Fig. 4.

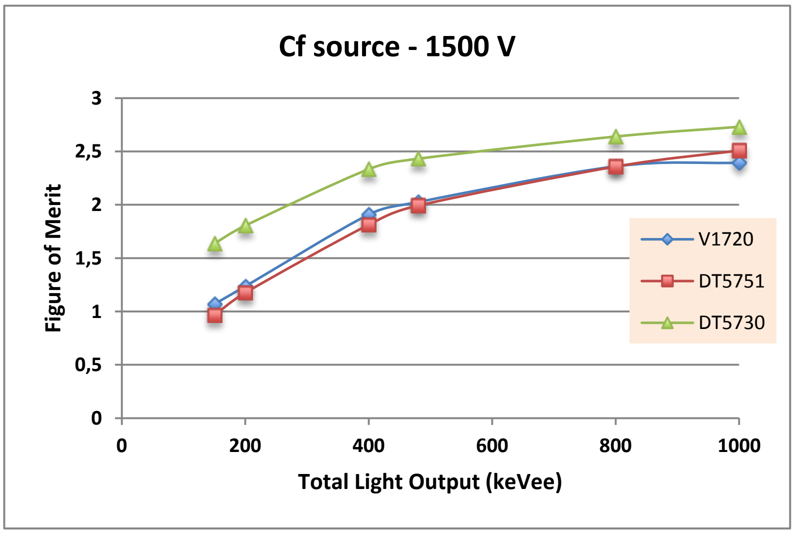

Fig. 4: FoM values measured on-line by the different digitizers for narrow windows on the total light output.

It is clear that the PSD improves as the total scintillation light increases thanks to the better signal/noise ratio. Moreover, the DT5730 digitizer is providing the best FoM value with respect to both V1720 and DT5751. The better performances obtained with DT5730 are particularly clear for low total light output values, i.e. for lower energy neutrons. The lower window reported in Fig.5 is associated with the cut 150 ± 50 keVee. To study more deeply the digitizer performances, the effects due to sampling rate and resolution need to be considered separately.

Concerning the sampling rate, the analysis reported in ref.[4] relative to a liquid scintillator BC501A, equivalent to EJ-301, demonstrated that the highest frequency component of the resulting pulses is about 100 MHz. Consequently, a sampling rate of 250 MHz seems to be fully adequate. However, a time jitter on the trigger threshold crossing affects the gate generation and the resulting PSD performances. Of course, this effect is inversely proportional to the sampling rate.

On the other hand, the accuracy in the charge integration and baseline subtraction strongly depends on the ADC resolution until the limit due to the intrinsic resolution of the scintillator is reached. In order to estimate the role of each parameter in the overall neutron-gamma ray discrimination performances, an off-line analysis on the raw data acquired with the DT5730 digitizer has been carried out.

It is possible therefore to study the FoM and the detector resolution as a function of different sampling rates between 500 and 250 MHz and/or resolution in the range 10-14 bit. The detector resolution is determined directly from the spectra collected with a ^{22}Na gamma ray source by using the procedure described in ref. [1]. In particular, the resolution σ/E was extracted from the Compton Edge of the 511 keV photons. Results from this analysis are reported in Fig. 5

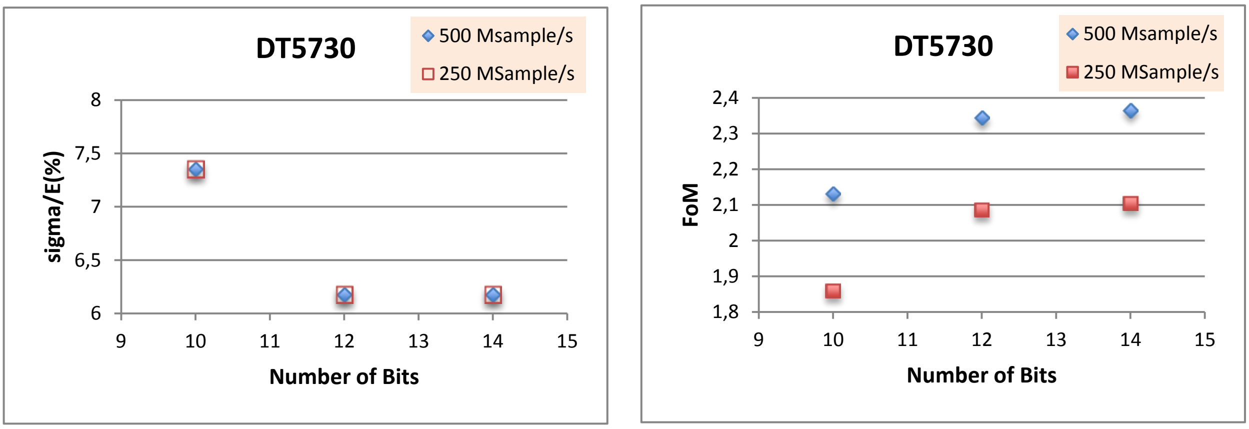

Fig. 5: Energy resolution, as determined from the 511 keV Compton Edge (left panel) and FoM (right panel) for different sampling rates and digitizer resolutions. For details see the text.

By looking in the upper panel of Fig. 5, it appears that the energy resolution does not really depend on the sampling rate and it is quite constant above 12 bit. This shows, in our opinion, the limit represented by the intrinsic resolution of the detector, essentially governed by the scintillation statistics.

On the other hand, the lower panel shows a sizeable improvement of the FoM (the energy window 480 ± 75 keVee has been considered for this plot) both increasing the sampling rate from 250 MHz to 500 MHz and the resolution from 10 to 12 bits. A small further gain (about 1%) is obtained by increasing the resolution to 14 bit.

Conclusions

The pulse shape discrimination (PSD) between neutrons and gamma rays in liquid scintillators is studied by using the charge integration method with fast digitizers with sampling rate between 250 and 1000 MS/s and resolution between 10 and 14 bits. The dependence of the FoM on the digitizer sampling rate and resolution is experimentally determined: the best results are obtained by using 500 MS/s sampling rate and a resolution equal or better than 12 bits. This results is also due to the time jitter in the position of the integration gates that is important when the number of samples is small with respect to the rising time of the signal as in the case of the 250 MS/s sampling rate.

Acknowledgements

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References

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[2] C. Guerrero et al., Nucl. Instr. Meth. A597 (2008) 212-218
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