Nuclear Instruments and Methods in Physics Research A 858 (2017) 57–61

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

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

Baseline restoration technique based on symmetrical zero-area trapezoidal pulse shaper

Guoqiang Zeng[a], Jian Yang[a,*], Tianyu Hu[a], Liangquan Ge[a], Xiaoping Ouyang[b], Qingxian Zhang[a], Yi Gu[a]

[a] Key Laboratory of Applied Nuclear Techniques in Geosciences Sichuan, Chengdu University of Technology, Chengdu 610059, China
[b] Northwest Institute of Nuclear Technology, Xi'an 710024,China

ARTICLE INFO

Keywords:
Baseline restoration
Symmetrical zero-area
Pulse shaping
Digital signal processing

ABSTRACT

Since the baseline of the unipolar pulse shaper have the direct-current (DC) offset and drift, an additional baseline estimator is need to obtain baseline values in real-time. The bipolar zero-area (BZA) pulse shapers can be used for baseline restoration, but they cannot restrain the baseline drift due to their asymmetrical shape. In this study, three trapezoids are synthesized as a symmetrical zero-area (SZA) shape, which can remove the DC offset and restrain the baseline drift. This baseline restoration technique can be easily implemented in digital pulse processing (DPP) systems base on the recursive algorithm. To strengthen our approach, the iron's characteristic x-ray was detected using a Si-PIN diode detector. Compared with traditional trapezoidal pulse shapers, the SZA trapezoidal pulse shaper improved the energy resolution from 237 eV to 216 eV for the 6.403 keV Kα peak.

1. Introduction

Many pulse shaping methods are used to improve the energy resolution and the stability of radiation measurement systems, such as the Gaussian shaper, trapezoid shaper, cusp-like shaper and 1/f shaper [1–3]. Since these methods are unipolar in shape and are not zero-area, The DC offset and drift exist in the baseline of the pulse shaping. Therefore, a baseline restorer should be designed to accurately extract the peak location of the pulse signals. The optimum baseline filter theory have been discussed in some literatures [4,5]. Some digital baseline restorers are also already implemented in the digital systems and even can be used in high count rates systems [6–9]. But these baseline restoration approach may be more complex than their pulse shaping.

The baseline filter and restoration method of the zero-area pulse shaping have been mentioned have been mentioned in the reference [10]. But it cannot be easily implemented in the digital systems. Ref. [11] studied the bipolar triangular shaper for pile-up correction. Since the triangular shape is not a zero-area, its baseline would have serious undershoot at the pulse pile-up. The BZA trapezoidal shaper for neutron-gamma discrimination was studied in Ref. [12], which used the flat-top to determine the neutron and gamma signals. Due to its zero-area shape, the BZA trapezoidal shaper can be used for baseline restoration, but cannot restrain the baseline drift. The BZA cusp-like shaper, which is also not a symmetrical shape, was studied in Ref. [13]. In this work, we use an simplest SZA trapezoidal shape based on the extensively applied trapezoidal shaper. Its zero-area shape can be used for baseline restoration, and its symmetrical shape can automatically eliminate the baseline drift. Most of all, It can be easily implemented in field programmable gate array (FPGA) and only need a little logic element by the recursive algorithm.

2. Method of the baseline restoration

The exponential signal is a typical output of a nuclear detector. The digital signal processing method of the exponential signal using a traditional trapezoidal pulse shaper is shown in Fig. 1 [14]. The analog pulse signal is digitized by the high-speed ADC, and then the digital pulse signal is deconvoluted to remove the exponential tails in order to obtain a unit impulse signal. Finally, the unit impulse signal is put into the synthesis system of the pulse shaping. Since the input of the synthesis system is the unit impulse signal, $\delta[n]$, the output of the trapezoidal shaper is merely the transfer function $h_X[n]$ of synthesis system.

The function fitting of the nuclear pulse signal frequently uses the uni-exponential and bi-exponential models [15]. In this work, the original pulse signals are characterized by the uni-exponential model and the discrete expression to perform the characterization is shown in

* Corresponding author.
E-mail addresses: 24829500@qq.com (G. Zeng), 22105653@qq.com (J. Yang).

http://dx.doi.org/10.1016/j.nima.2017.03.049
Received 18 September 2016; Received in revised form 7 March 2017; Accepted 26 March 2017
Available online 28 March 2017
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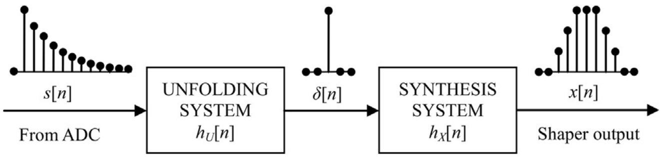

Fig. 1. Functional block diagram of a trapezoidal pulse shaping system using the unfolding-synthesis technique.

Eq. (1).

$$s[n] = Aa^{n-n_0}u[n-n_0] + (B+Cn)u[n] \tag{1}$$

Where $a=exp(-T_S/\tau_O)$, T_S is the ADC sampling period, n_O is the initial position of the pulse signal, and $u[n]$ is the discrete step signal. In order to facilitate the analysis of the baseline restoration technique, Eq. (1) contains an initial DC offset, B, and a baseline shift, Cn, at a particular rate. The baseline shift sections have led to an imbalance of the bilateral baseline, which can be used to analyze the baseline drift. First, an analysis must be performed on the influence of the deconvolution system on the baseline of the original pulse signal. Eq. (2) shows the recursive difference equation of the deconvolution system.

$$v[n] = s[n]-as[n-1] \tag{2}$$

Eq. (1) is substituted into Eq. (2) to derive the output, $v[n]$, of the deconvolution system.

$$v[n] = A\delta[n-n_0]+B\delta[n]+(1-a)(B+Cn)u[n-1] \tag{3}$$

Eq. (3) show that $v[n]$ still contains a baseline DC offset and a baseline drift. As a result, the deconvolution system cannot restore the baseline, and the baseline is only reduced. In addition, $v[n]$ also includes two unit impulse signals. The $A\delta[n-n_O]$ is from the deconvolution of the pulse signal, and the $B\delta[n]$ is from the deconvolution of the step signal (DC offset). The unit impulse signals are synthesized to the expected shape through the pulse synthesis system, but the baseline DC offset and the baseline drift are not clearly identified. Thus, the analysis of the convolution of $v[n]$ and the transfer function, $h_X[n]$, is shown in Eq.(4).

$$\begin{aligned} x[n] = v[n]*h_X[n] &= \sum_{k=0}^{N-1} v[k]h_X[n-k] = \sum_{k=0}^{N-1} v[n-k]h_X[k] \\ &= A\sum_{k=0}^{N-1}\delta[n-n_0-k]h_X[k]+B\sum_{k=0}^{N-1}\delta[n-k]h_X[k]+(1-a) \\ &\times\left\{B\sum_{k=0}^{N-1}u[n-k-1]h_X[k]+C\sum_{k=0}^{N-1}nu[n-k-1]h_X[k]\right\} \end{aligned} \tag{4}$$

Where N is the number of points used for the pulse shaping. The convolution is divided into four parts. The two parts on the left are the impulse responses $h_X[n-n_O]$ and $h_X[n]$. The third part is equivalent to a single integral of $h_X[n]$, and the fourth part is equivalent to double integral of $h_X[n]$. The last two parts directly determine the change of the baseline through the pulse shaping. Selecting a=0.988, B=0.2 and C=0.001 to analyze the integral of the pulse shaper's transfer functions, such as the trapezoidal shaper, the BZA trapezoidal shaper and the SZA trapezoidal shaper. The shaping time is 15μsec and the corresponding flat-top time is 1μsec.

Fig. 2 shows the integral of the trapezoidal shaper's transfer function, which generates a stable baseline DC offset through a single integral of its transfer function while the double integral of its transfer function generates a baseline drift. The baseline variations of the input pulse signal have the same influence on the baseline of the trapezoidal shaper. The baseline of the BZA trapezoidal shaper is stable and has no DC offset through the single integral, but the double integral of its transfer function generates a stable baseline DC offset. Thus, the BZA trapezoidal shaper cannot restrain the baseline drift. However, the baseline of the SZA trapezoidal shaper is stable through both single integral and double integral, so it effectively can both restore the baseline and restrain the baseline DC drift. In addition, Fig. 2 shows the normalized amplitude, and it can be observed that the baseline fluctuations of the SZA trapezoidal shaper are the smallest among these shapers.

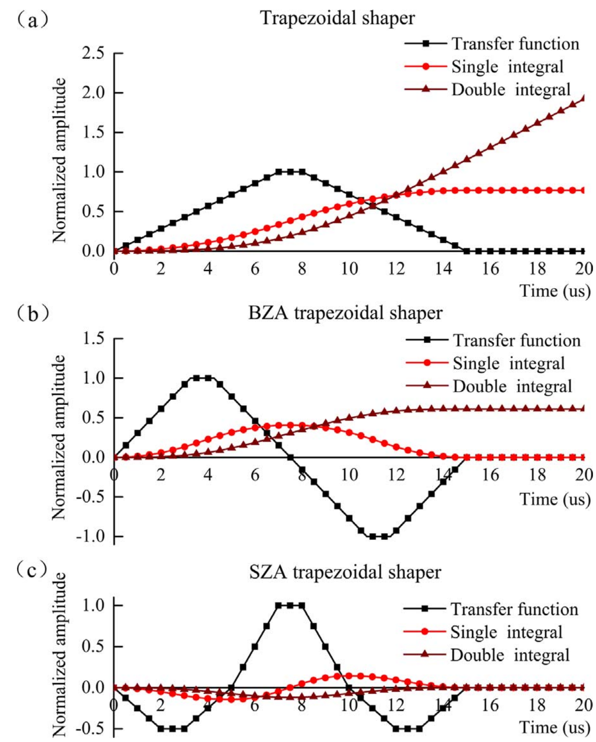

Fig. 2. The integral of the transfer functions (a)the results of the trapezoidal shaper, (b) the results of the BZA trapezoidal shaper, and (c)the results of the SZA trapezoidal shaper.

3. Recursive algorithm of the SZA trapezoidal shaper

The algorithm of the SZA trapezoidal shaper is based on the recursive difference equations in the time domain [16], as shown in Eqs. (5)–(11). Since the recursive algorithm is beneficial to reduce the multiplication operations, it can output the results in real-time.

$$v[n] = s[n]-a\bullet s[n-1] \tag{5}$$

$$p[n] = v[n]-v[n-l] \tag{6}$$

$$q[n] = p[n]-p[n-l-m] \tag{7}$$

$$r[n] = r[n-1]+q[n] \tag{8}$$

$$x[n] = x[n-1]+r[n] \tag{9}$$

$$y[n] = x[n]-x[n-2l-m] \tag{10}$$

$$z[n] = y[n-2l-m]-y[n] \tag{11}$$

Where l is the hypotenuse points of the isosceles trapezoid and m is the flat-top's points. When m=0, the shapebecomes an SZA triangle. Fig. 3 shows the recursive method of the SZA trapezoidal shaper, which can

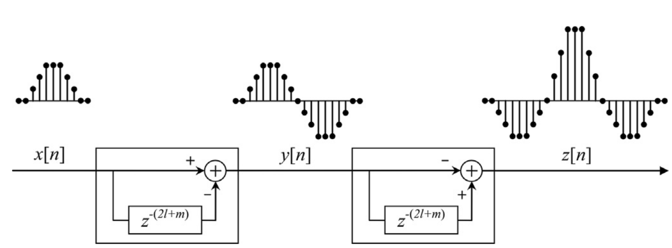

Fig. 3. The recursive method of the SZA trapezoidal shaper.