

# Research on Pulse Shaper Based on Trapezoidal Function

Zhenwei Han<sup>1,2,\*</sup>, Kefei Song<sup>1</sup>, Yang Liu<sup>1</sup>

<sup>1</sup> Changchun Institute of Optics, Fine Mechanics and Physics, Chinese Academy of Sciences, Changchun 130033, China

<sup>2</sup> University of Chinese Academy of Sciences, Beijing 100049, China

\* Corresponding author: Zhenwei Han (Email: hanzhenwei1234@163.com)

**Abstract:** In order to improve the time resolution and spatial resolution of photon-counting imaging system, the pulse shaper based on trapezoidal function is studied. The signal with an exponential decay shape from charge sensitive amplifier is converted to digital discrete signal by ADC and then the discrete number sequence is filtered and shaped by digital signal processing technology. The amplitude linearity and time width of the trapezoidal shaper are simulated and verified using software-generated single exponential signals and double exponential signals. While the continuous pulses are applied to the trapezoidal shaper, the separation characteristics of the trapezoidal algorithm for pulses pile-up is verified, and the setting method of the rise edge and fall edge parameters of the trapezoidal shaper is proposed, which can realize the high counting capability of the system.

**Keywords:** Trapezoidal function; Pulse shaper; Pulses pile-up; Photon counting.

## 1. Introduction

Photon counting imaging detection plays an important role in solar activity monitoring, atmospheric and marine environment monitoring. The far ultraviolet radiation imaging measurement technology can realize the effective and accurate monitoring of the global ionosphere distribution, which is of great significance to the global navigation satellite system. Based on the X-ray, extreme ultraviolet and ultraviolet band photon count imaging detection technology, researcher can establish the solar, space environment and atmospheric environment monitoring system, monitoring the distribution and diffusion of atmospheric pollution, monitoring the thickness, distribution and composition of seawater oil pollution.

Since the photon to be detected and the charge pulse output by the position-sensitive anode of the detector are independent events, the pulse amplitude and pulse interval follow Poisson distribution. Photoelectric pulse signal can be regarded as high-speed random signal, which generally presents the form of peak pulse and contains noise signal. Therefore, amplitude extraction is not easy, and the signal attenuation width of charge sensitive amplifier is wide, which is easy to generate signal accumulation, which adds difficulty to amplitude extraction. The amplitude information of the photoelectric pulse is closely related to the position of the incident photon, so the accurate extraction of the amplitude of the photoelectric pulse is very important.

When processing the photoelectric pulse signal, special filtering processing is needed to make the amplitude extraction easier. Filtering process is to extract the signal to be analyzed from the input signal and ignore the interference signal. Here, the filtering processing of photoelectric pulse signal means that the pulse amplitude information of photoelectric pulse signal can be accurately presented, the accumulation of nuclear signal can be reduced, and noise interference can be eliminated as much as possible. The method of pulse shaper can greatly improve the extraction of pulse amplitude. Good pulse shaper can effectively separate stacking signals, deduct the amplitude of tail stacking, and

provide a relatively flat amplitude information platform for subsequent processing to extract more accurate amplitude information. In order to improve the practicability of the photoelectric pulse shaper algorithm, the trapezoidal shaper algorithm is studied and improved in this paper.

## 2. The algorithm of Trapezoidal shaper

In photon counting imaging system, the detector usually uses low noise charge sensitive preamplifier to realize the initial conversion of charge pulse signal. The feedback resistor of the charge sensitive preamplifier is typically large to improve charge collection efficiency. The feedback resistor with shunt capacitance results in a long fall time at the charge sensitive preamplifier output. The output signal from the charge sensitive amplifier can be approximated by double exponential model:

$$V_i(t) = A(e^{-t/\tau_1} - ke^{-t/\tau_2}) \quad (1)$$

where  $\tau_1$  is the fast time constant of double exponential signal and  $\tau_2$  be the slow time constant of double exponential signal. The rise time and decay time of pulse signal are determined by  $\tau_1$  and  $\tau_2$ . The  $A$  is the input pulse amplitude, and  $k$  is the proportionality constant.

Let the sampling period be  $T_s$ . After digital discretization of Formula 1, Z transformation of  $V_i(t)$  can be obtained by (2).

$$V_i(z) = A \left( \frac{z}{z - e^{-T_s/\tau_1}} - \frac{z}{z - e^{-T_s/\tau_2}} \right) \quad (2)$$

Trapezoidal shaper is to convert the input exponential attenuation signal into trapezoidal signal of equal proportion, and the time domain signal waveform of trapezoidal pulse is shown in Fig.1.

The time-domain expression of trapezoidal pulse can be expressed as a piecewise function:

$$V_0(t) = \sum_{i=0}^4 y_i(t) \quad (3)$$

$$y_1(t) = \frac{Atu(t)}{t_a} \quad (4)$$

$$y_2(t) = -\frac{A(t-t_a)u(t-t_a)}{t_a} \quad (5)$$

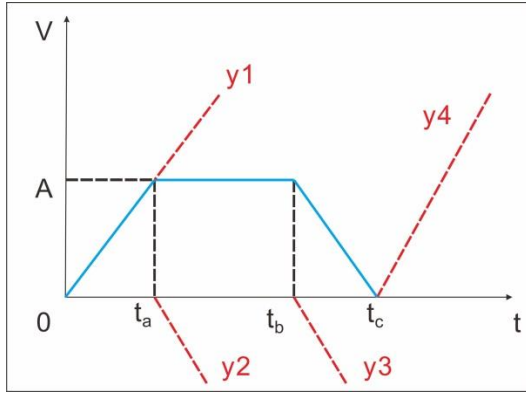


Figure 1. Trapezoid shape in time domain

$$y_3(t) = -\frac{A(t-t_b)u(t-t_b)}{t_a} \quad (6)$$

$$y_4(t) = \frac{A(t-t_c)u(t-t_c)}{t_a} \quad (7)$$

where  $t_a$  represents the rise time of the trapezoid pulse,  $t_b - t_a$  is the flat top width of the trapezoid pulse, and  $t_c$  is the bottom width of the trapezoid pulse. And  $A$  is the trapezoid pulse amplitude.

Let the sampling period be  $T_s$ . After digital discretization of Equation (3), Z transformation of  $V_o(t)$  can be obtained by (8).

$$V_0(z) = \frac{Az^{-1}(1-z^{-n_a} - z^{-n_b} + z^{-n_c})}{n_a(1-z^{-1})^2} \quad (8)$$

where  $n_a = t_a/T_s$ ,  $n_b = t_b/T_s$  and  $n_c = t_c/T_s$ .

The transfer function of trapezoidal shaper can be given by (9).

$$H(z) = \frac{V_0(z)}{V_i(z)} = \frac{z^{-1}(1-z^{-n_a} - z^{-n_b} + z^{-n_c})}{n_a(1-z^{-1})^2 \left( \frac{z}{z-e^{-T_s/\tau_1}} - \frac{z}{z-e^{-T_s/\tau_2}} \right)} \quad (9)$$

### 3. Simulation and results of trapezoidal pulse shaper

As illustrated in Fig. 2, the ideal exponential decay pulse is first used as the input pulse and corresponds to two trapezoid pulses. The rise edge time of the exponential pulse is 0, and the tail attenuation duration is 100us. The ordinate is the pulse amplitude, the abscissa is the sampling point, and the interval of each point is 20ns. The shape of trapezoid is symmetrical in rise time and fall time, so it was an isosceles trapezoid for optimum signal to noise ratio. The trapezoidal flat top is beneficial to extract the input pulse amplitude.

However, the actual input charge pulse rise edge is not ideal. Due to the charge sensitive preamplifier response time, the rise time of input pulse is about tens of ns. In view of this input pulse characteristic, we optimized the trapezoidal shaping method to make the flat top time of the trapezoid as short as possible to ensure the stability of the algorithm. The rapidity of the algorithm and the ease of fpa implementation are also important concerns.

In the high-counting rate application pulse pile-up would certainly appear on the falling edge of the charge sensitive

preamplifier output when the interval time between the two adjacent events is shorter than the fall time. In order to mitigate pulse pile-up, the charge sensitive preamplifier is usually followed by a trapezoidal pulse shaper, which can regulate the shape of the output pulse to reduce the fall time of the charge sensitive preamplifier output. Meanwhile, the smooth pulse generated by the trapezoidal pulse shaper improves the signal-to-noise ratio (SNR) of the analog front-end chains, which facilitates the measurement of the pulse amplitude due to a flap maximum instead of a steep shape.

When the photon count rate is higher, the two input pulses are closer together, as shown in Fig.4 and Fig.5. If the trapezoidal shaper width is larger than the interval of two input pulses, the overlapped input pulses cannot be separated effectively. Measures to optimize trapezoidal shaping parameters were taken by reducing the flat top width of the trapezoid pulse  $t_b - t_a$  and increasing the rise time of the trapezoid pulse  $t_a$ . However, the optimized  $t_b'$  must be greater than  $t_b$  otherwise the SNR will decrease rapidly. The falling edge of the trapezoid pulse  $t_c - t_b$  is reduced to less than the rise time of the trapezoid pulse  $t_a$ , which is beneficial to reduce the pulse accumulation.

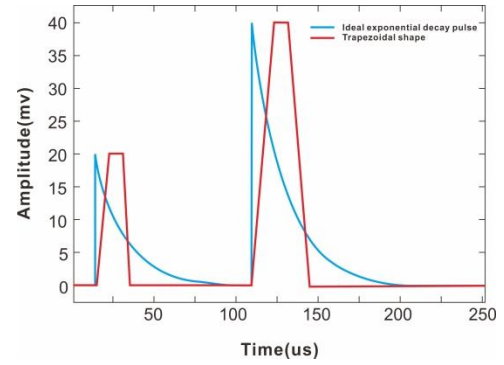


Figure 2. Simulation of trapezoidal shape for ideal exponential decay pulse

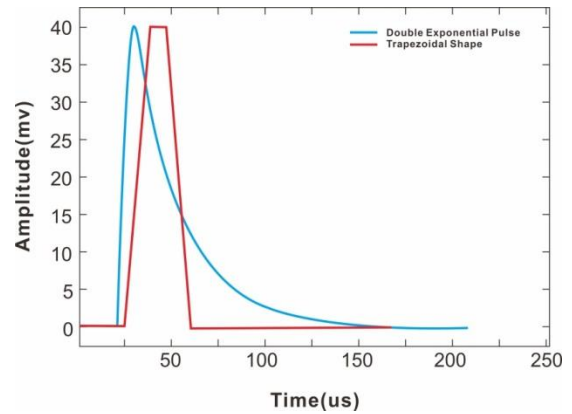


Figure 3. Simulation of trapezoidal shape for double exponential pulse

In order to verify the processing capability of the above method on the noisy pulse, the pulse output of CSA is used as the input. The tail decay time of the output signal from the charge sensitive amplifier is 200us. Discrete digital waveforms by the sampling period 50ns are reconstructed in Fig.6. The curve after trapezoid shaper reduces the tail width of the input pulse significantly and extracts the amplitude of the input pulse linearly.

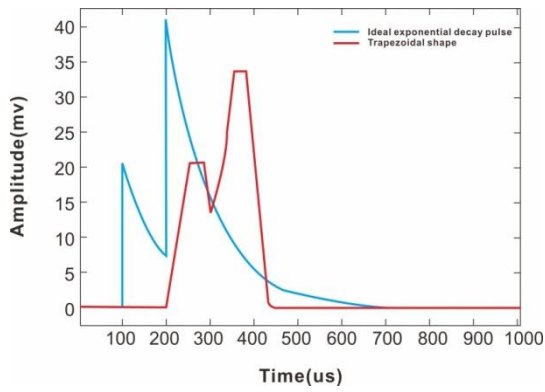


Figure 4. Simulation of trapezoidal shape for pulse pile-up

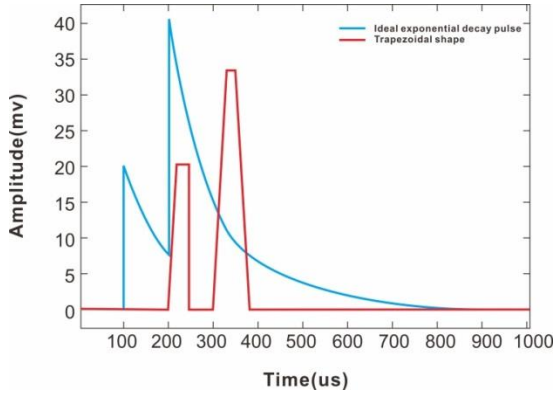


Figure 5. Simulation of optimized trapezoidal shape

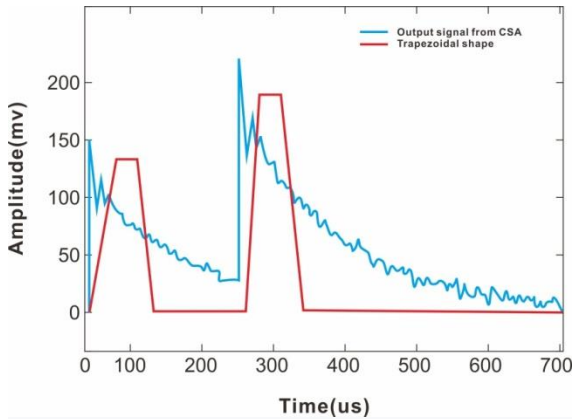


Figure 6. Test result of trapezoidal shape for the output signal from charge sensitive amplifier

## 4. Conclusions

It can be concluded from the above discussion that the trapezoidal shaper parameters should be selected according to the actual demand. In high resolution applications, the rise edge of the trapezoidal shaper can be as large as possible and the duration of the flat top can be extended. In the application of high counting rate, the rising edge of trapezoidal shaper can be shortened appropriately, the duration of flat top can be greatly reduced, and the falling edge of tail can be greatly reduced, but the undershoot compensation should be careful.

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