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# Baseline restoration method based on mathematical morphology for high-pressure xenon detectors

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## ABSTRACT

The shift of baseline has always existed in high-pressure xenon (HPXe) detectors because of the influence of external acoustic noise. This problem seriously influences the spectrometric characteristics of these detectors. A special baseline restoration method is required to remove the shift of baseline in real time. This study demonstrated that the top hat transform based on mathematical morphology can restrain the shift of baseline in digital multichannel analyzer. An improved baseline restoration (IBLR) method based on mathematical morphology was proposed and implemented in field programmable gate array (FPGA) to obtain superior baseline restoration. The structuring element of the IBLR method can be adjusted automatically in real time according to the characteristics of the baseline. Experimental results show that the IBLR method can maintain an excellent energy resolution over a wide shift range of baseline. To strengthen our conclusion, we carried out an external acoustic noise experiment on a HPXe detector. The HPXe detector with IBLR was virtually unaffected by external acoustic noise.

## 1. Introduction

With the widespread application of nuclear technology, radiation monitoring with high energy resolution detectors is required for extreme environments such as wide temperature variations or high radiation exposures [1–3]. High-pressure xenon (HPXe) detectors with excellent energy resolution [4,5] have good physical characteristics such as wide operating temperature range (from −20 °C to 100 °C) [6], high radiation resistance [7], and long term performance [8]; these characteristics are suitable for radiation detection in extreme environments [9,10]. However, these devices still have a serious shortcoming, that is high sensitivity to external acoustic noise (vibroacoustic effects) [11–13]. When a HPXe detector is affected by external acoustic noise, the detector's spectrometric characteristic deteriorates significantly. This problem makes HPXe detectors more operate in laboratory and limits its applications in some strong acoustic noise environments, such as airborne radiation monitoring, radiation customs control, and orbital station radiation monitoring.

HPXe detectors without vibroacoustic effects will have a widespread application prospect because of the high energy resolution and good physical characteristics. Thus, many methods have been used to remove the vibroacoustic effects of HPXe detectors. Different shock and sound absorbers are used to protect HPXe detectors from vibroacoustic effects, but they are not always efficient and lead to a notable increase of equipment mass and size [14]. The cylindrical ionization chamber with a Frisch grid made from electrochemically etched foil has higher stability to vibroacoustic effects over a wide range of noise levels [15]. The implementation of a digital third order Butterworth filter effectively mitigates the vibroacoustic effects [16]. Novikov et al. [17] proposed that the presence of high external acoustic perturbations alters the capacitance between the Frisch grid and the anode, resulting in a corresponding shift of baseline. In addition, the resistance to acoustic noise is achieved by removing the shift of baseline through digital signal processing. Although these methods have positive resistance effect to the vibroacoustic effects, the energy resolution still evidently deteriorates as external acoustic noise increases. Compared with other methods, the digital signal processing method has better performance in terms of resistance effect and flexibility. Thus, removing the shift of baseline by digital signal processing is an ideal way to eliminate the vibroacoustic effects of HPXe detectors.

In the current work, the feasibility of baseline restoration based on mathematical morphology was demonstrated. For superior performance under serious shift of baseline, the improved baseline restoration (IBLR) method based on mathematical morphology was proposed and implemented; this method can automatically adjust the structuring element

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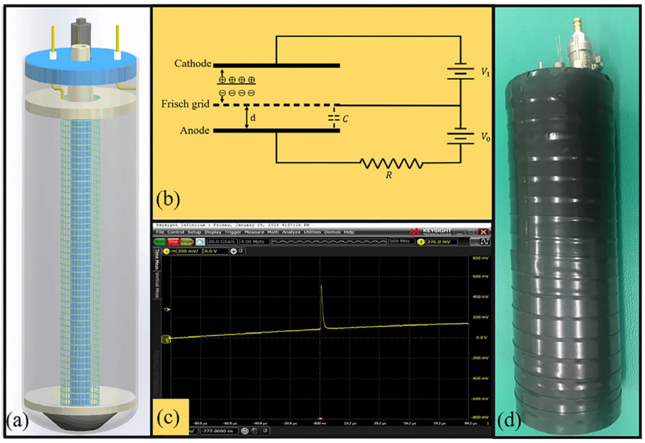

**Fig. 1.** HPXe detector: (a) structure of HPXe detector, (b) schematic of HPXe detector, (c) the shift of baseline in HPXe detector under external acoustic noise, (d) prototype of “Nucl-x-HPXe”.

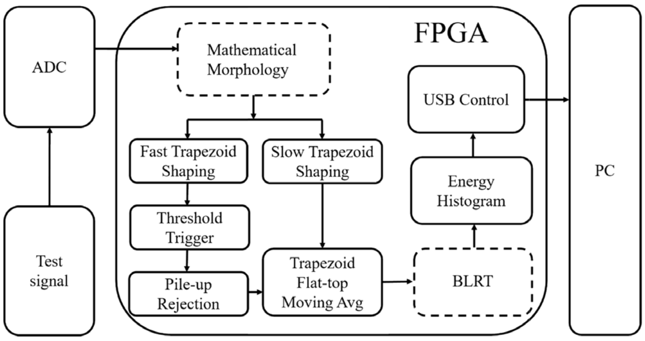

**Fig. 2.** Block diagram of DMCA in FPGA, mathematical morphology method: upper left dotted box; BLRT method: bottom right dotted box; NBLR: without dotted boxes.

according to the characteristic of the baseline. Moreover, HPXe detectors with IBLR can operate under high external acoustic noise.

## 2. Method and principle

### 2.1. *Experimental device*

The HPXe detector is the pulse ionization chamber with a Frisch grid, and the dependence of the pulse amplitude on position of interaction in electron-sensitive ion chambers can be removed through the use of the structure with a Frisch grid [18] shown in Fig. 1(a). However, when the HPXe detector is exposed to external acoustic noise, the Frisch grid resonates with the acoustic noise. The detector capacitance between the Frisch grid and the anode is altered due to the vibration of the Frisch grid. Therefore, the corresponding shift of the baseline occurs in strong acoustic noise environment (Fig. 1(c)), the nuclear pulses are superimposed on the corresponding shift of the baseline. In the noise characteristics, it is the low-frequency noise which frequency is depended on the frequency of acoustic noise environment. The HPXe detector used in this work is the “Nucl-x-HPXe” designed by our laboratory (Fig. 1(d)), and it was designed by reference to Moscow Engineering Physics Institute (MEPhI) [19].

The “Nucl-x-HPXe” detector is a cylindrical pulse ionization chamber filled with Xe + 0.3% $H_2$ mixture. The xenon is pressurized to achieve a nominal density of 0.3 g/cm$^3$ at 50 atm. The gas purity can reach the value that corresponds to the electrons’ lifetime of 1 ms. The detector has an outside diameter of about 106 mm and an active diameter of about 100 mm. The detector’s sensitive volume is 2 liters. The anode diameter and shielding grid diameter are 20 mm and 36 mm respectively. The voltage of cathode and shielding grid are −20 kV and −12.5 kV. Therefore, The signal is measured from the anode through the charge sensitive preamplifier.

The focus of this study is the removal of the shift of baseline caused by external acoustic noise; thus, a special baseline restoration should be designed in digital multichannel analyzer (DMCA). When the detector is exposed to external acoustic noise, the baseline of detector signal will shift. We defines the difference between the highest and lowest baseline values as the shift levels of baseline. The shift level of baseline is not easy to control accurately by external acoustic noise. To evaluate the performance of baseline restorations, we added an adjustable shift of baseline to the HPXe detector’s signal as test signals in a quiet environment. The adjustable shift of baseline was a 1000 Hz sinusoidal signal generated by a signal generator (RIGOL DG4062), because previous research showed that HPXe detectors reached the highest sensitivity to 1000 Hz sinusoidal noise [16]. Different sinusoidal signal amplitudes (0–900 mV) provided different slopes and highs of the baseline, and the 900 mV sinusoidal signal is similar to the shift level of baseline caused by 90 dB in this study. In addition, there is approximately an exponential relationship between shift level of baseline and external acoustic noise.

Baseline restorations can be implemented in DMCA, which was designed by our laboratory in field programmable gate array (FPGA). The block diagram of the DMCA in FPGA is shown in Fig. 2. Test signals were digitized by a high-speed ADC (AD9226) for digital signal processing in the FPGA (Altera EP4CE). Different baseline restoration methods such as the mathematical morphology method, baseline restoration of trapezoidal pulse shaping (BLRT) [20] and no baseline restoration (NBLR) were studied. In addition, the test signals were connected to an Ortec model 926 multichannel buffer for comparison.

### 2.2. *Mathematical morphology*

Mathematical morphology is a technique for analyzing and processing geometrical structures. Mathematical morphology filter is different from common filtering methods that transform between the time and frequency domains; it is based on integral geometry and stochastic theory and does not involve difficult mathematical transformations and formulas. The goal of mathematical morphology transformations is to maintain the morphological characteristics and eliminate noise effectively. In recent years, mathematical morphology has been used in one-dimensional signal processing, such as electrocardiogram and Raman spectrum background subtraction [21,22], because it requires minimal calculation without an iteration procedure and it shows an excellent processing effect. The goal of baseline restoration is to maintain pulse amplitude and eliminate the shift of baseline effectively; thus, it is a suitable method to solve the shift of baseline in HPXe detectors.

Most morphological operations are based on erosion and dilation, and the effect of morphological operations depend on the structuring element [23]. Fig. 3(a) shows the erosion and dilation of a ideal negative exponent signal which is generated from the MATLAB. The dilation expands the signal upward, and the pulse amplitude information is retained. The erosion shrinks the signal downward, and the bottom profile of signal is recorded. The degree of expansion and shrinkage depends on the height of the structuring element, and the length of the structuring element should be longer than the negative exponent pulse [24]. The result obtained by erosion operation continues to be operated by the dilation operation, and the result of opening operation (Erosion-Dilation) is shown in Fig. 3(b). An estimated baseline, which overlaps with the bottom of the signals can be obtained by the opening operation. Thus, the shift of baseline can be solved by subtracting the estimated baseline from the original signal; this method is called top hat transform (THT) in mathematical morphology.