Influence of digital processing on the noise levels of spectrometric system for xenon gamma-spectrometer

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Abstract. Shaping and digital processing of xenon gamma-spectrometer signals were considered. Digital processing influence on the energy resolution of the spectrometric system of xenon gamma-spectrometer was shown. The analysis of contributions to the energy resolution showed that the limit of improvement of the resolution by using of digital processing is reached almost.

1. Introduction
The Xenon gamma ray spectrometer (HPXe spectrometer) is an instrument with a wide range of applications. This device can be applied as well as laboratory equipment and device for industry [1,2]. All these applications need the maximum possible energy resolution. To date, the HPXe spectrometer can achieve energy resolution at the level of 1.7% for the 662 keV gamma source $^{137}$Cs. The theoretically possible energy resolution of HPXe detector is 4 keV to 662 keV (i.e. 0.6%) [3]. Accordingly, an important task is to improve the energy resolution of the HPXe spectrometer. One of the ways to improve the energy resolution is the use of digital processing.

2. The influence of digital processing on the energy resolution
The energy resolution of HPXe spectrometer is determined by the self-noise, noise of charge sensitive amplifier, digital processing and different interferences. The self-noise mean that energy resolution of detector is limited by internal processes and properties (fano factor, energy for pair production, inefficiency of shielding grid, recombination and gas purity). Comparative analysis of the energy resolution same detector with the use of digital processing and without it (see figure 1 and figure 2) shows that the digital processing significantly improves the energy resolution.

Accordingly, there are two ways to improve the energy resolution of HPXe spectrometer:

- Reduction of the intrinsic noise of charge sensitive amplifier;
- Improved processing electrical signals from the HPXe spectrometer.

For the case of ideal digital processing of the electrical signals from HPXe spectrometer it is possible to obtain the energy resolution which defined by the self-noise of detector and noise of charge sensitive amplifier only (excluding electrical interferences). Analysis of contributions to energy resolution (see figure 1 and figure 2) shows that the energy resolution in case of ideal digital
processing (without contribution from \( \text{it} \)) is 1.63\% for 662 keV (i.e. 11 keV). Therefore it can be argued that the digital processing practically provides the best possible value of the energy resolution for HPXe spectrometer.

Figure 1. Contribution to energy resolution in case using “Colibri” analog signal processing unit [4]. It shows data for the energy 662 keV.

Figure 2. Contribution to energy resolution in case using digital signal processing. It shows data for the energy 662 keV.

3. The shaping and digital processing
The signal shaping must be high-quality for the effective digital processing. In this case, the signal, which input to the digital processing unit, has the shape of exponential discharge. This waveform provides sufficient accuracy of digitizing. The stages of signal conversion are shown in table 1.
The actual digital processing is reduced to the background subtraction of the waveform and its subsequent integration. Figure 3 shows the ideal case where the signal without noise and overlaps enters to the input of the digital processing unit.

### Table 1. The stages of signal conversion.

| Name               | Shape of signal          | Kind of signal in the zero approximation |
|--------------------|--------------------------|-----------------------------------------|
| Detector           | $i(t) = \frac{\partial q}{\partial t}$ | δ-function                              |
| Charge sensitive amplifier | $U(t) = \frac{1}{C} \int i(t)dt$          | Heaviside step function                  |
| Shaper             | $U(t) = \theta(t)e^{-\frac{t}{\beta C}}$ | Exponential discharge                    |
| Digital processing | $S = \int_{t_{dp}} U(t)dt$                | Final value                              |

**Figure 3.** The ideal case where the signal without noise and overlaps enters to the input of the digital processing unit. The intervals $\Delta t_{bg}$ ($t \in (t_{bg1}; t_{bg2})$ and $t \in (t_{bg3}; t_{bg4})$) are times when background is calculated. The interval $\Delta t_{dp}$ ($t \in (t_{dp1}; t_{dp2})$) is time when signal is processed.

The noise signal can be considered as a composition of harmonic oscillations of different frequencies. For our system reaction to the impact of oscillations of a single frequency is determined by the following formula:

$$f(\omega, \varphi) = -\frac{1}{\omega} (\cos(\omega t_{dp2} + \varphi) - \cos(\omega t_{dp1} + \varphi))$$

$$-\frac{t_{dp}^2}{2} \left( -\frac{1}{\omega \Delta t_{bg}} (\cos(\omega t_{bg2} + \varphi) - \cos(\omega t_{bg1} + \varphi)) \right)$$

$$-\frac{1}{\omega \Delta t_{bg}} (\cos(\omega t_{bg4} + \varphi) - \cos(\omega t_{bg3} + \varphi))$$  \hspace{1cm} (1)
The noise contribution to the energy resolution of each element of the spectrometric channel can be estimated using the Wiener-Khinchin theorem. This necessarily includes knowledge of the system response to a harmonic oscillation and spectral density of the self-noise at each unit of spectrometric channel. Application of this method will simplify the design of new units for spectrometric channel.

4. Conclusion
Modern methods of digital processing are an effective way to improve the energy resolution. The analysis of the energy resolution suggests that the limit of its improvement by using of digital processing is reached almost. The most perspective seems to decrease the self-noise of the electronic units of the spectrometric channel.

References
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