Application of the flicker noise filtering algorithm by changing the modulation frequency in an acousto-optic spectrum analyzer

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Abstract. The article discusses the noise characteristics of the system for collecting data and processing spectral signals in an ozonometer. Low-frequency flicker noise introduces significant distortions into the useful signal path. In order to reduce low-frequency flicker noise, a method was developed based on the use of modulation of the useful signal at the output of the acousto-optic spectrum analyzer with a certain frequency. This method creates an artificial filter. The choice of the modulation frequency determines the frequency response of this filter. It is necessary to choose it such that the maximum signal attenuation is in the low frequency region, where the influence of flicker noise is strong. In this work, a noise signal was simulated using the Matlab environment and its filtering by changing the modulation frequency of the synthesized signal.

1. Introduction

In previous articles devoted to a data acquisition system (DAS) for multichannel acousto-optic spectrum analyzers AOS) [1] based on an INTEL FPGA chip, it was described its creation, modeling of its algorithms and methods for improving its parameters [1]. It was described that the use of FPGA allows for accurate generation of control signals due to its hardware logic, and also provides the convenience of reconfiguring parameters and changing algorithms. In the next work, a method was described for reading the charge of a charge coupled device (CCD), generating a signal \( F_m \) only in a steady state, excluding the time interval of the transient process [2]. The transient process when the antenna was opened with the shutter was eliminated by the delay in the generation of the \( F_m \) signal, and the transient process when the antenna was closed was eliminated by an earlier setting of the SHUT signal.

In this work, a noise signal was simulated and filtered by changing the modulation frequency \( F_m \). The article describes the method of filtering from low-frequency noise (flicker noise), implemented in software in this DAS. It was noticed that mostly the noise is concentrated in the low frequency region. I wanted to improve the measuring characteristics, to reduce noise in the low-frequency region. A new filtering method was applied based on the frequency response of the CCD photodetector.

2. Frequency digital filtering method with changing the frequency of modulation

The filtering algorithm by changing the modulation frequency \( F_m \) can be represented as a mathematical model of a frequency digital filter with a transfer function depending on the modulation frequency.
According to its characteristics, the filter is analogous to a digital filter with double correlated sampling (DCS), which has a transfer function that depends on the modulation frequency [4]. The frequency response of the filter of the CCD photodetector with double correlated sampling has the form $1 - \cos(\pi*f/f_m)$, where $f_m$ – modulation frequency (see figure 1).

By changing the frequency $F_m$, you can filter the CCD signal, attenuating its low-frequency part. It can be seen from this characteristic that we can choose a modulation frequency at which low-frequency noise components will fall into the attenuation region (frequency range from 0 to $f_m$) and have no noticeable effect on the useful signal.

The algorithm for modeling the noise signal and its filtering was created and tested in the Mathcad program. For the theoretical modeling of this method, the noise model from [7] was used as an input signal, with a uniform distribution law and equal amplitudes of frequency components. In terms of its noise characteristics, it is similar to flicker noise. The graph of this noise signal is shown in figure 2.

Flicker noise is noise that occurs in electronic components that are accidentally affected. It has a spectral power proportional to $f^{-1}$ (rose noise). It has a significant effect at low frequencies, causes instability of the zero offset, with increasing frequency, the intensity of the noise decreases uniformly, at high frequencies it is covered by white noise.

Further, a constant value $U = 5$ V was added to the noise signal, which means the useful component of the signal from the PCOS. After that, the $F_m$ modulation signal was generated in software is shown in figure 3. Where $T_{fm}$ is the period of the modulation frequency, $t$ is the sampling step along the time scale, equal to $2 * 10^{-5}$ s. The modulation signal was created as a series of trapezoidal pulses so that the rise and fall of the pulse was stretched in time and similar to the gradual opening of an antenna horn with a rotating shutter [2]. An analytical record of the $F_m$ modulation signal is shown below:

$$k_{sin} = T_{fm} \times 0.05$$
Modulation of the signal with frequency, $F_m$, was performed by multiplying the resulting signal by the modulation function. In figure 4 it consists of alternating sections, where the section with a high average amplitude of the noise signal means the antenna signal, and the section with low amplitude represents the equivalent signal.
Figure 4. Signal modulated with frequency $F_m$.

Next, the signal is accumulated, which is contained in the bufSign array the number of times determined by the value of the NumSum variable, NumElem is the number of elements in the signal sample, LenSample is the number of elements taken for processing. In this case, it is equal to 512, that is, the power of 9 of the number 2, in order to be able to apply the fast Fourier transform function of the library function fft of the Mathcad program to this series of numbers. The subscript of an array is the number of its element. The analytical record of the signal after the accumulation cycles is shown below:

$$NSum = 5 \quad LenSample = 1024$$

$$NElemInPeriod = 830 \quad in = 0,1...NumElem$$

$$res\_sum_{in} = \sum_{ik=0}^{NSum}bufSign_{ik*NElemInPeriod+in}$$

Figure 5. Signal graph after accumulation cycles.
3. Results

On the graph of the obtained frequency response in the frequency band of 0-100 Hz, corresponding to the low-frequency part of the range, the largest amplitudes were recorded. Based on their results, a graph of the signal amplitude versus frequency was plotted in figure 6. On it $A_{\text{Max}}$ is the amplitude of the noise signal.

![Graph of the dependence of the level of the simulated noise signal on the frequency $F_m$.](image)

**Figure 6.** Graph of the dependence of the level of the simulated noise signal on the frequency $F_m$, built theoretically.

The experimental part of the work was carried out on the basis of the data of measurements of the DAS, their recording into files using the "Monitor" program and processing and plotting in the "Mathcad" program. To experimentally check the correspondence of the CCD signal detection system to the mathematical model of the frequency digital filter DCS and the dependence of the signal-to-noise ratio (SNR) on the modulation frequency, the signal was measured for different values of the modulation frequency $F_m$ from 20 to 40 Hz. For each of these samples, the SNR were calculated (as the ratio of the mathematical expectation to the square root of the variance [6]) and a plot of the SNR versus frequency $F_m$ was plotted. This experimental check showed a correlation with theoretical data of about 15%.

![Experimental graph of SNR versus frequency $F_m$.](image)

**Figure 7.** Experimental graph of SNR versus frequency $F_m$. 
This graphs show that as the frequency $F_m$ increases, the level of low-frequency components decreases. Thus, in our device, we applied a digital filter DCS, implemented in software, which can be used to filter flicker noise.

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