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SYNTHESIS METHODS AND ALGORITHMS FOR EXPANDING THE DYNAMIC RANGE OF THE ADC

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Abstract: *The modern development of new technologies, in particular, the intensive use of programmable logic integrated circuits in digital information processing tasks, allows for algorithmically and programmatically solving problems, opens up real opportunities to increase accuracy and ensure the required signal conversion speed, and also, it will be possible to take into account the effects of noise and their elimination over the entire time interval band. The article discusses the main methods of digital information processing, analyzes the ways and possibilities of expanding the dynamic range of analog-to-digital converters, as well as the synthesis of appropriate conversion devices, primarily digital filters.*
Keywords. *Digital signal processing, continuous signal, digital signal, sampling, digital filter, analog-to-digital conversion, algorithm, single rectangular pulse, quantization.*

Аннотаци: *Янги технологияларнинг замонавий ривожланиши, хусусан, рақамли ахборотни қайта ишлаш масалаларида дастурланадиган мантиқий интеграл микросхемалардан жадал фойдаланиш муаммоларни алгоритмик ва дастурий равишда ҳал қилишга имкон беради, ахборот аниқлигини ошириш ва керакли сигнални ўзгартириш тезлигини таъминлаш учун реал имкониятларни очади, шунингдек, шовқин ва уларни бутун қайта ишлаш вақти оралиғида бартараф этиш самарадорлигини таъминлайди. Мақолада рақамли ахборотни қайта ишлашнинг асосий усуллари, аналог-рақамли ўзгарткичларнинг динамик диапазонини кенгайтириш усуллари ва имкониятлари муҳокама қилинган, шунингдек, тегишли ахборот ўзгарткич қурилмалар, рақамли фильтрларни синтезлаш таҳлил қилинган.*
Таянч сўзлар: *сигналларга рақамли ишлов бериш, узлуксиз сигнал, рақамли сигнал, дискретлаш, рақамли фильтр, аналог-рақамли ўзгартириш, алгоритм, бирлик тўртбурчакли импульс, квантлаш.*

Аннотация: *Современные развитие новых технологий (в частности, интенсивное использование в задачах цифровой обработки информации программируемых логических интегральных схем позволяет за счет алгоритмически-программных методом решения задач открывать реальные возможности повышения точности и обеспечения требуемого быстродействия преобразования сигналов. При этом, появляется возможность учитывать эффекты шумов и их устранять по всей полосе временных интервалов. В работе рассматриваются основные методы цифровой обработки информации, анализируются способы и возможности расширения динамического диапазона аналогово цифровых преобразователей, а также синтез соответствующих устройств преобразования, прежде всего цифровых фильтров.*
Ключивые слова. *Цифровая обработка сигналов, непрерывный сигнал, цифровой сигнал, дискретизация, цифровой фильтр, аналогово–цифровое преобразование, алгоритм, единичный прямоугольный импульс, квантование.*

Introduction

The efficiency of modern production is achieved by the creation of automated process control systems (automated process control systems) using timely intelligent measuring instruments with the function of self-monitoring and evaluation of the states of system elements of receiving and information in the process of their operation. Self-monitoring and diagnostics of the current dynamic states of control devices allows to increase the reliability of measurement information and the accuracy of controlled parameters, to improve the metrological characteristics of the most technical control systems and their reliability, as well as to ensure the quality of the functioning of the automated control system as a whole.

However, it should be noted that in modern measuring instruments with integrated microprocessors, there are sufficiently untapped reserves of technical improvement. Therefore, today the task of developing and implementing new variants of intelligent measurement tools for using these reserves of computing system performance becomes urgent [1-4].

Research Methods and the Received Results

An important issue of improving the quality of the functioning of measuring systems is the improvement of conversion methods and algorithmization of the processes of eliminating various noises and interference arising in the tasks of analog-to-digital information conversion. The article analyzes algorithms for evaluating the accuracy of digital signal processing (DSP) in a complex of issues caused by the development of digital and digital-analog element base, as well as the development of methods and algorithms for signal processing and generation. Currently, due to the development of new technologies, in particular with the intensive use of programmable logic integrated circuits (FPGAs) in DSP tasks, high performance due to algorithmic and software solutions to problems opens up new opportunities to improve accuracy and ensure the required signal conversion speed. The latter determines the relevance of training specialists in this direction. The parameters of real processes change continuously, hence the signals describing the events that occur are also continuous and are defined as continuous.

Let into a continuous signal S(t), defined in the interval [0, T]. Then the signal obtained from the harmonic signal S(t) by converting to a discrete form, intervals equal to time nT_d respectively, will be located in the interval $[0,(N-1)T_d]$.

To convert a continuous signal into digital form, the operations of sampling by time and quantization by level are performed. The total representation of these two operations from a mathematical point of view is determined by the algebraic identical sum of functions. Let's consider the functional diagram of the analog-to-digital converter, shown in Figure 2.1, and analyze it.

$Y_d(t)$ – this is a control signal for the supply of a rectangular pulse with a Δt duration and T_d - the period of repetition, under the influence of which $S(t)$ - the analog signal is periodically converted by closing the key into a discrete signal of the dimensional time axis nT_d. To describe the sampling signal, we use discontinuous functions $\delta(t)$ or $U(t)$ and we get the expression:

$$Y_d(t) = \sum_{k=-\infty}^{\infty} \delta(t - nT_d) \ or Y_d(t) = \sum_{k=-\infty}^{\infty} U(t - nT_d) \quad (1)$$

A filtered signal is received from the key output to the sampling devices by level:

$$S_d(nT_d) = \sum_{k=-\infty}^{\infty} S(t) U(t - nT_d) \quad (2)$$

At the output of the analog-to-digital converter (ADC) we receive a digital signal $S_d(nT_d)$, in l-bit binary code.

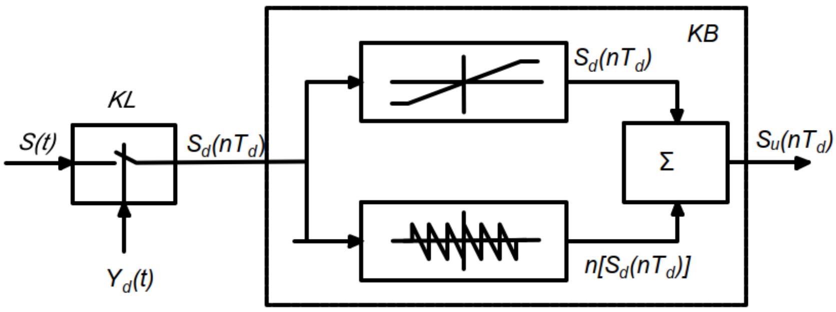


Fig.1. ***Structural and algorithmic representation of analog-to-digital transformation of a continuous signal.***

The reverse conversion of digital signals into analog form is performed through a chain of sequentially connected devices register, DAC and filter circuits. [5-9].

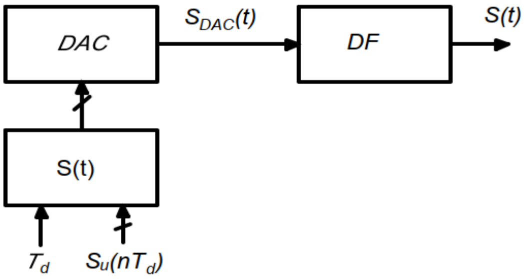


Fig. 2. ***- Conversion of a digital signal into a continuous.***

If we do not consider the dynamic errors of the DAC, we can imagine, with the arrival of a digital signal at its input, a sequence of time intervals T_d at the output, a step function is formed, in the form of a sequence of adjacent rectangular pulses, the duration of which is equal to a given time interval T_d and amplitude $S(nT_d)$.

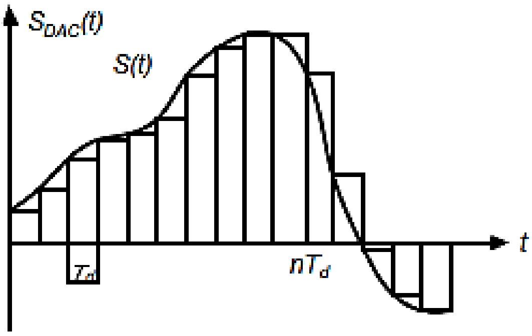
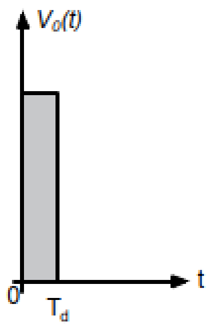


Fig. 3. ***The output signal of the digital-to-analog converter.***

All components are single rectangular pulses defined as with a single amplitude $V_0(t)$ and duration T_dc function $S_ц(nT_d)\delta(\tau - nT_d)$:

$$S_V(t) = S_ц(nT_d)\int V_0 t(-nT_d)d = S_ц(nT_d)V_0(t - nT_d) \quad (3)$$

Each single component is the amplitude of single pulses $V_0(t - nT_d)$ it is determined by the duration of the passage time of the same digital signal pulse $S_d(nT_d)$:



As a result, we get an expression equal to the sequence of pulses at the output of the DAC:

$$S_{DAC}(t) = \sum_{n=0}^{\infty} S_ц(nT_d)\int_{-\infty}^{+\infty} V_0(t-\tau)\,\delta(\tau - nT_d) = \int_{-\infty}^{+\infty} V_0(t-\tau)\left[\sum_{n=0}^{\infty} S_ц(nT_d)\delta(\tau - nT_d)\right]d\tau \quad (4)$$

Summary convolution of two consecutive functions $V_0(t)$

$$\sum_{n=0}^{\infty} S_d(nT_d)\delta(\tau - nT_d) \quad (5)$$

The determined spectral density corresponding to the first:

$$\overline{V_0}(\omega) = T_d \frac{sin(\omega T_d/2)}{(\omega T_d/2)} e^{-j\omega T_d/2} \quad (6\ )$$

a belonging to the function:

$$\sum_{n=0}^{\infty} S_{ц}\,(nT_d)\delta(\tau - nT_d) \quad (7)$$

Spectral density (4) Thus generalized to the expression of the time convolution of successive pulses (5) in the form as the product of spectral densities (6) and (7):

$$S_{DAC}(\omega) = \left\{\frac{sin\,\omega T_d/2}{\omega T_d/2} e^{-j\omega T_d/2}\right\}\left\{\sum_{k=-\infty}^{\infty} \overline{S}(\omega - \frac{2\pi}{T_d})\right\} \quad (8)$$

The first expression (8), the change of which does not depend on the changed signal, can be considered as the transmission coefficient of a digital-to-analog converter [10-15]:

$$\overline{K}_{DAC}(\omega) = \frac{sin\,\omega T_d/2}{\omega T_d/2} e^{-j\omega T_d/2} \quad (9)$$

To evaluate and analyze possible ways to expand the dynamic range of the ADC, we conduct research while considering a mathematical model as a basis and we will conduct an assessment of the dynamic range of the ADC in question in the spectral region.

Bearing in mind $S_d(nT_d) = S_d(nT_d) + \eta_d[S_d(nT_d)]$,

Let's write the equations of convergence for the complex spectrum of the signal at the output of the ADC:

$$\overline{S}(k) = \frac{1}{N}\sum_{n=0}^{N-1} S_d(n)e^{j\frac{2\pi}{N}nk} + \frac{1}{N}\sum_{n=0}^{N-1} \eta_d[S_d(n)]e^{j\frac{2\pi}{N}nk} \quad (10)$$

Note that the ADC input receives a signal $S(t) = \cos(\Omega t + \varphi_0)$ with distributed on the interval $[-\pi, \pi]$ initial phaseφ_0 . Frequency Ω and the analysis interval T_a, on which it is taken N samples from the signal S(t), are in a multiple ratio: $T_a = bT$, где $b = 1,2,3$ ...

Transformed into a discrete form of this signal , we will write:

$$S_d(n) = cos\left[\frac{2\pi}{N}nm + \varphi_0\right] \quad (11)$$

For values m = k in the graph for expression (11), a spectral line is illustrated due to the presence of quantization noise. The complex transmission coefficient of the digital filter corresponding to the frequency point k is determined by the expression:

$$K(e^{j\omega}) = e^{-j\omega\frac{N-1}{2}} e^{j\frac{\pi k}{N}} \frac{sin(N\omega/2)}{sin(\frac{\omega}{2}+\frac{\pi k}{N})} = e^{-j\omega\frac{N-1}{2}} e^{j\frac{\pi k}{N}} f_N(\omega, k) \quad (12)$$

Here $f_N(\omega, k)$- the amplitude frequency response of the filter. The graph corresponding to expression (12) is shown in Fig.4.

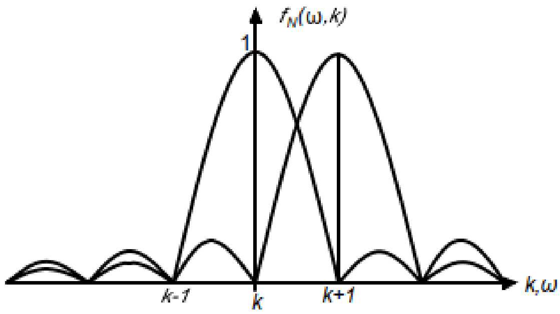


*Fig.4. **Frequency response of the k-th and k+1 filter.***

The value of the transmission coefficient of the k-th filter is different from 0 only for point k. Accordingly, the quantization noise at the output of the k-th filter will be determined by the expression:

$$S_{\eta,k}(m) = A_k(m)e^{j\varphi_k(m)} \quad (13)$$

here $A_k(m)$ – amplitude, a $\varphi_k(m)$ – the phase of the spectral component of the quantization noise in the i-th cell of the frequency resolution on the m-th realization of the input signal. With $A_k(m)$ distributed according to the normal law equally probable on the interval $[-\pi, \pi]$:

$$p(A) = \frac{1}{\sigma\sqrt{2\pi}} exp(-\frac{(A-m_\eta)^2}{2\sigma^2}) \quad (14)$$

Figure 5 shows the results of spectral analysis of an analog signal. The graph shows that in the range of values from -100 dB to -20 dB, spectral components of quantization noise are clearly observed [16-22].

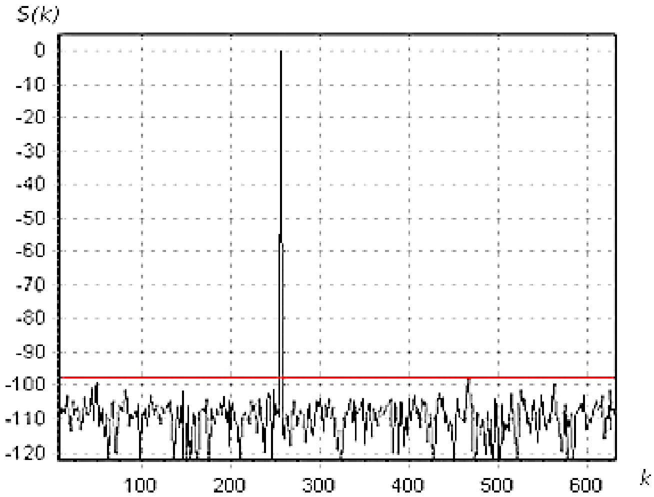


Fig. 5. ***The amplitude spectrum of the harmonic signal.***

Conclusion

The proposed algorithm is used to process m series of samples, sums up the differences between them. As a result of filtering, the spectral components of the measurement error located above the boundary frequency of the filter are weakened. The suppression of normal noise is carried out by the method of sampling the moving average. Research and analysis of circuit designs of filter has shown that it is advisable to use filters of higher orders for more efficient noise of discrete signals.

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