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# AD systems for processing of low frequency signals based on self calibrate ADC and DAC with weight redundancy

***Abstract.*** *Static and dynamic characteristics of modern AD systems of low signals processing are defined by the parameters of ADC and analog devices. Improvement of accuracy and speed of AD systems is possible due to the usage of self-correcting ADC of bitwise balancing ,based on computation n systems with weight redundancy. The ratio between the digit weights in these computation systems is 1 < α < 2. If α = 1.618 "golden ratio" code is formed. It is shown that increasing of the accuracy and speed of ADC several times is possible due to calibration of static and auto-compensation of dynamic balancing errors. Structural block diagrams of the converters for symmetric and asymmetric computation systems are given. The structure of multichannel AD system and method of self-correction of the parameters of input analog devices are developed. Method of calibration and compensation linear distortions of amplitude-frequency and phase-frequency characteristics of measuring channels is shown. The parameters of the developed multichannel AD system for seismic measurements are presented.*

***Streszczenie.*** *Cechy statyczne i dynamiczne nowoczesnych systemów AC do przetwarzania małych sygnałów są definiowane przez parametry przetworników AC i peryferiów analogowych. Poprawa dokładności i szybkości systemów AC jest możliwa dzięki wykorzystaniu samokorygującego przetwornika AC z bilansowaniem bitowym, na podstawie obliczeń n systemów z redundancją wagi. Współczynnik pomiędzy wagami cyfr w tych systemach obliczeniowych wynosi 1 < α < 2. Jeśli α = 1,618 sformułowany zostaje kod "złoty podział". Wykazano, że możliwe jest kilkukrotne zwiększenie dokładności i szybkości przetworników AC dzięki kalibracji statycznej i automatycznej kompensacji błędów dynamicznych. Zaprezentowano schematy blokowe konwerterów dla symetrycznych i asymetrycznych systemach obliczeniowych. Zostały opracowane struktury wielokanałowego systemu AC i sposobu samodzielnego korygowania parametrów analogowych urządzeń wejściowych. Pokazano metody kalibracji i kompensacji zniekształceń liniowych charakterystyk amplitudowo-częstotliwościowych fazowo-częstotliwościowej w kanałach pomiarowych. Zaprezentowano parametry opracowanego wielokanałowego systemu AC do pomiarów sejsmicznych (**Systemy analogowo-cyfrowe do przetwarzania sygnałów niskoczęstotliwościowych oparte na samokalibrującym się przetworniku analogowo-cyfrowym i cyfrowo analogowym z redundancją wagi**).*

**Keywords**: AD systems, "golden ratio", analog–code and code–analog conversion, dynamic characteristics, digital processing, analog signals.
**Słowa kluczowe**: systemy analogowo-cyfrowe, złoty współczynnik, konwersja analogowo-kodowa I kodowo-analogowa, charaktersystyki dynamiczne, cyfrowe przetwarzanie, sygnały analogowe

## Introduction

In recent decide the requirements, regarding static and dynamic characteristics of measuring – information systems for conversion and processing of low frequency signals, the spectrum of which is beyond the limits of audible range, substantially grew. Such analog-digital systems (AD-systems) are used in seismic measurements, tensometry, hydro acoustics, sound location, biomedicine, television and radio broadcasting and in other branches of modern science and engineering. At the same time, achieving the necessary characteristics of AD-system depends the properties of analog to digital (ADC) and digital-to-analog (DAC) converters and other analog devices – amplifiers, switches, filters, etc.

## Actuality

Structural–functional organization of AD system for processing of low frequency signals, selection of element base is determined by the ranges of levels and frequencies values of the investigated signals as well as the requirements regarding static and dynamic characteristics of conversion. In this case, statics characteristic, depending on the systems usage must provide the following complex of indices:

- wide dynamic range of signals, which are converted and processed (up to 100–140 dB);
- great separating power (from 16 to 24 binary bits);
- small nonlinearity of analog-code and code-analog conversion (0.001–0.01%).

System dynamic characteristics must take consideration the following basic indices:

- wide frequency range of signals (0.1 Hz–100 Hz);
- minor distortions of signals spectrum (-90–120 dB);
- low ratio of nonlinear distortion of signals form (0.001–0.01%);
- low irregularity of amplitude-frequency characteristic (AFC) (±0.03 dB) and nonlinearity of phase-frequency characteristic (DFC) (±0.1°) in the band of valid signal.

In multichannel AD signals, taking into account joint processing of the signals, additional high requirement, regarding the identity of static and dynamic characteristics of all the channels and requirements, regarding the minimization of interchannel influence emerge.

To provide the realization of the above-mentioned requirements the application of the method of creation of self-correcting ADC and DAC with weight redundancy [1, 2], as well as method analogs devices construction on the base of push-pull D.C. amplifiers with balance feedback, is promising.

It should be noted that in spite of availability of the results of research, dealing with this scientific direction [3–5], the application of the above-mentioned methods to AD system is not sufficient. That is why, the subject on the paper devoted to the directions of such systems development is urgent.

**Aim of the research** – improvement of static and dynamic characteristics of AD-system for processing of low frequency signals at the expense of application in measuring channels of ADC and DAC with weight redundancy.

**Problems of the research to be carried out:**

- analyze the possibility of application of ADC and DAC with weight redundancy for improvement of static and dynamic characteristics of conversion channels of multiplied AD-systems;
- consider methods aimed of improvement of accuracy and speed of AD-system as a result of spreading the principles of correcting static and compensating dynam-

ic errors of redundant ADC and DAC additionally on functional units off measuring channels;
- consider structural diagrams of AD-systems for measurement and analysis of low frequency signals on the base of ADC and DAC with weight redundancy as well as present the obtained values of their static and dynamic parameters.

**Problems solution**

In compilation systems with weight redundancy (CSWR) non binary base of compilation system 1<α<2 is used digit weights are presented in the form:

(1) $$Q_i = q \cdot \alpha^i$$

where: *q* – is digital resolution and real number can be presented in CSWR in the form of the sum of digit weights:

(2) $$X = \sum_{i=0}^{N} a_i \cdot q \cdot \alpha^i$$

where $a_i = \overline{0,1}$ – is binary bit of N-bit conversion result.

So – called "Golden proportion" code also refers to CSWR with the base $\alpha = \left(\sqrt{5}+1\right)/2 \approx 1{,}618$. "Golden proportion" is the boundary of two neighbor numbers of Fibonacci series relations [2].

Main advantage of CSWR, realized in case of analog-to-digital conversion is in the absence of "breaks" in inverter characteristic, caused by deviations of real digit weights from calculated values. For "binary" ADC these deviations must not exceed half of least significant digit. For ADC, based on "golden proportion" relative error of digit weights clue to technological, temperature, temporal factors may reach up to 23.6% that will not lead codes skip [1–3]. Thus, there exists a possibility, knowing the exact values of real digit weights, participating in conversion, to obtain the exact value of input analog signal. The problem is reduced to determination of real digit weights in special operation mode at ADC, called self-calibration.

Additional feature of ADC of digit wise balancing, based on CSWR is accelerated analog-to-digital conversion. This feature of self-correction is connected with the reduction of time of each comparison steps clue to the correction of the errors by means of switching on the least significant digits [1, 3, 6].

It was proved theoretically and experimentally [1–4], that the application of weight redundancy in AD-conversion engineering allows to improve significantly (by 1-2 orders) the linearly of conversion characteristic of the devices, constructed on inexact elements, for instance, on condition of DAC construction without technological adjusting of digits weight. Besides, there is a possibility to increase considerably (5-8 times) the rate of bitwise analog-to-digital conversion at the expense of automatic compensation up dynamic errors of balancing [1, 3]. These advantages of CSWR for construction of accurate both in symmetric basis of calculus (1, 1) and in more comprehensive – asymmetric (0, 1) basis.

Structural diagrams of ADC of bitwise balancing, using compensating DAC, on the base of CSWR is shown in Fig. 1a, b. In this case, ADC, based on CSWR contains two digital-to-analog conversions with weight redundancy: positive α DAC "+" and negative α – DAC "-", two registers of step-by-step approximation RSA 1 and RSA 2, analog signals adder (∑), digital computation device DCD, memory unit (MU), comparator circuit (CC) and control unit (CU).

It is expedient to use the considered information converters in the systems of digital processing of analog signals, basic structural diagram of the given system is shown in Fig. 2. It contains CC, a-DAC, RSA and CU, all these block form the core of system ADC – block of digitwise balancing (BDB). The possibility of sending external control signal Yex is provided in CU. The task of BDB is conversion of analog signal from the output of sample and hold unit (SHU) into operation code K(α), formed in RSA. For correction of instrument errors of analog units and conversion of operation of code K(2) into binary code separate digital computing device, DSD and MU is used. At the stage of system manufacturing and analog units configuration high precision measurement of ADC digitals weights and analog path zero shift is performed. The results obtainted in the form of binary codes are fed into ROM and are further used for the operation of CC. For communication of CC. with PC serial or parallel interface (IF) is used depending or the necessary rate of information transfer.

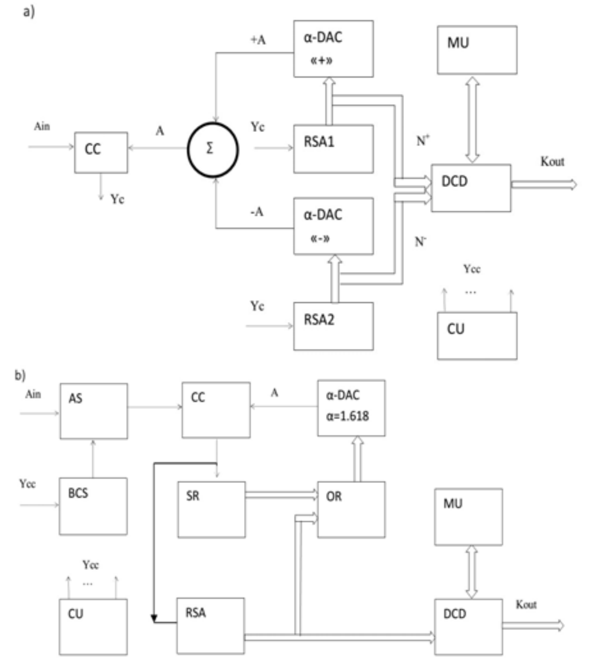


Fig.1. Structural diagrams of bitwise self-calibrated ADC of accelerated speed with weight redundancy on the base of: a) CSWR (1, 1); b) CSWR (0, 1)

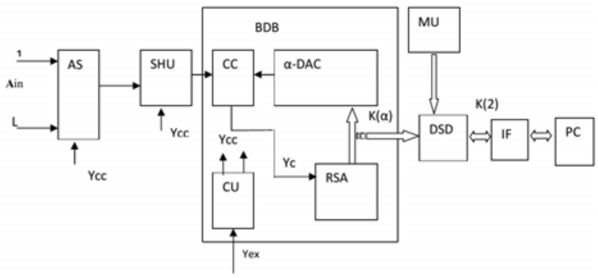


Fig.2. Structural diagram of system of digital processing of analog signals

Structural diagram of multichannel system with n channel of parallel amplification of acoustic sensors signals, their AD – conversation and common computer processing and analyze is shown in Fig. 3. Such AD – system can be used in seismic measurement (sensor – geophones) in technical diagnostics and biomedicine (sensors – electronic stethoscopes), etc. Analysis and common processing of signals from the system of such type, as a rule, contains reiteration summation of channel signals with various phase shifts and computation of their mutually – correlation function – for electronic scanning of acoustic signals sources and their identification.

Scheme in Fig. 3 contains: S-sensors of input analog signals (m in each channel), IS – input switches;

PA – programmable amplifiers; LPF – anti-alias low pass filter; OC – overload comparators; SADC – signaling, selfcorrecting AD-convertor; SRV – source reference voltage for multiplying DAC of reference signals.

Serial usage of several sensors of input signal S(1..m) is necessary for the economy of system channels amount in case of possible replacement of the groups or types of sensors or change of the direction of acoustic signal reception. The selection of optimal gain factor or realization of repeated measurements are possible as a result of usage of OC, that control possible overloads by input signals.

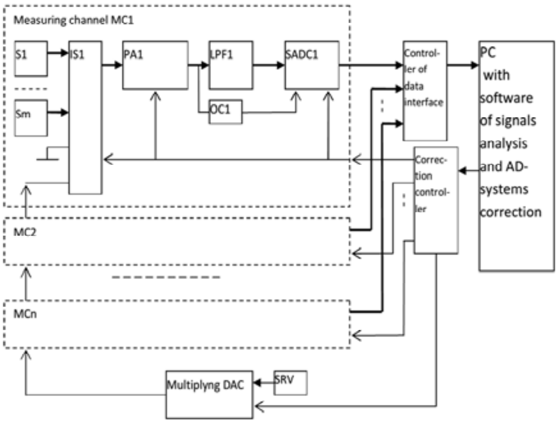


Fig.3. Structure of multichannel AD-system of acoustic sensors signals analysis with the correction of measuring channels characteristics

Interface controller, on the base of microprocessor or specialized signal processor performs data reception from SADC channels and their transmission to personal computer (PC) across the selected standard interface (USB, SLPDIF, Bluetooth, Ethernet, Wi-Fi). PC by means of specialized software (SW) carries out signals analysis and controls the of AD – system correction v, a correction controller. Specific device, added to self correcting AD – system is multiplying DAC with strictly fixed maximum amplitude of output signal , equal to value of SRV voltage. DAC, depending on the algorithm and calibration step, reproduce signal: pulses or fixed amplitude and period, harmonic and polyharmonic signals from the predefined set of frequency [4]. These reference signals are simultaneously by sent to the input of measuring channels across switches of is and they arrive at the inputs of the programmable amplifiers PA. The processor of correction of static and dynamic characteristics of is takes place successively for each gain of PA and comprises the parameters of switches, amplifiers, filters ADC. If ADC is constructed on the base of CSWK, then the above mentioned process is preceded by their selfcorrection in accordance with the known methods. In this case, circuit engineering of SADC analog devices has its characteristic features and could be built on current amplification principle.

In the mode of conversion and sensors signals processing mode the results of the correction are used for individual correction of each channel signals [4]. Parameters of the determined real static characteristics (in temporal area) are real AFC an FTC (in frequency areal) are taken into account. Adaptation of AD-system to the level and composition of the signal in each channel is possible both at the expense of hardware components (output signal of OC, ADC) and by the results of software analysis of frequency spectrum (in signal processor and in PK).

Structure, showed in Fig. 3 provides the usage of separate ADC in each channel: this, in particular, may be modern delta-sigma ADC, where as a result of redundant frequency of sampling and digital filtration – decimation, output data on the level of 20-24 binary digitals could be obtained for law frequency and audio bands of the signal. However, such delta-sigma ADC have very long transient processes, that is why, the channel be used in the systems with on-line switching of input sensors, with pulse signals, switching overloads of amplifiers of short duration, etc. For such application circuit with serial AD-signal conversion in channels as a result of usage of multichannel analog switch AS and ADC of digitwise balancing with weight redundancy shown in Fig 4 is more optimal and economic efficient solution [6]. Such type sell correcting ADC integrally supplement the structure of the considered multichannel AD-system for the analysis of low frequency signals.

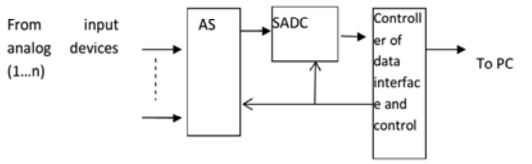


Fig.4. Variant of the circuit with serial AD-conversion of channel signals

Let us consider characteristic features of input structural elements of the given multichannel analog-to-digital self-calibrated system.

Input sensors of analog signals can be converted either in voltage or in current various physical signals and differ greatly by the principles of action. Passive sensors of analog signals are those sensors that directly create output voltage, proportional to the action of external physical impacts – acoustic and hydro acoustic dynamic microphones, photovoltaic elements, ferroelecric sensors, thermocouples, etc. Equal voltages, generated by these sensors, are rather small – from tens to hundreds millivolts. That is why, additional input amplifiers may be used in each channel.

The above-mentioned sensors do not require additional supply circuits – unlike sensors, output signal of which is the result of modulation by measured physical magnitude of one of variable parameters – resistance, capacitance, inductance. Such active sensors include potentiometric transducers, thermoresistors, tensometers, galvanomagnetic sensor, etc. As a rule, for better extraction of useful signal in such sensors bridge supply circuits, that form output differential voltages or currents of low level are used. For better extraction of useful signal on the background of external noise bridge supple circuits with polarity switching or variable voltage modulation can be used on connecting line.

Active sensors, information parameter of which is the amplitude, frequency or the phase of output variable voltage, form a separate group. In these sensors measured physical magnitude influences the capacitance, inductance or mutual inductance of circuit components. Capacitance sensors, inductive sensors, transformer sensors, magnetostrictive sensors, string sensors belong to such sensors. Their output signals can be sent directly to AD-circuit or preliminary converted in proportional constant voltage.

Inherent conversion characteristics of input sensors, that directly influence the resulting accuracy of AD-system measurement are of great importance. However, greater part of parameters of sensors conversion characteristics can be determined both at the stage of their manufacturing and in the process of operation – during separately organized procedure of calibration, with fixation of real values of parameters and further correction of converting characteristic. For instance, non-linearity of static transfer characteristic of measuring sensors in each channel can be determined and corrected [4, 7, 8]. Also, non-uniformity and conidentity of frequency characteristics of measuring channels is determined and corrected [9–11].

Input circus of analog switching of signal directly interact with the sensors of physical values, that is why, they must be calculated for corresponding types of input lines and switching connections. Protective elements from voltage and current overloading based on symmetric circuits, using input limiting resistors and protective diodes, are obligatory. In some cases transformers and optoelectronic circuits of galvanic insulation of inputs may be used. These additional security elements may also influence considerably the parameters of measurement accuracy. However, when security circuits are connected to input switches, their parameters of non linearity and interchannel nonidentity can be taken into account and corrected with the parameters of input sensors [4, 10].

Programmable amplifiers in AD-system perform two main functions – conversion of differential input signal, removing in-phase component and matching the dynamic range of input signal with the range of input voltages LPF and SADC. Programmable amplifiers are built according to classic differencing scheme on three operational amplifiers, however, they can be built on current amplifiers with symmetric input, intermediate and buffer stages [12, 13]. These current amplifiers have better frequency properties and can be used in fast-acting measuring channels of self-correcting AD-systems.

In the process of calibration for each of gain ratios of programmable amplifier its “zero” shift and gain ratio error must be determined and taken into account. Such procedure is possible due to the connection of input analog switch to “zero” buses and DAC of reference signals (Fig. 3). Procedure of various gain ratios calibration is built by the scheme “top-down” [4]. The amplifier is first calibration on the largest input range – multiplying DAC of reference signals generates voltage, amplitude of which is assigned by the source of reference voltages (SRV). Further DAC forms the signal of less reference voltage, value of which is accurately measured on the calibrated gain ratio. Then programmable amplifier is switched on smaller input range, where this reference voltage is measured again and corresponding gain ratio is calibrated [15].

As a result of application of the methods of correction of static and dynamic characteristics in multichannel AD-system for processing of seismic signals such basic technical parameters were obtained:

- number or measuring channels – 128;
- voltage level of input analog signals $\pm$1 V;
- frequency band of input signal from 2-2000 Hz;
- dynamic range, limited by signal-nose radio – not less than 126 dB;
- spectral separation power – not less than 140 dB;
- non-lineal distortions – not more that 0.003%;
- irregularity and nonidentity of AFC/FTC channels – not more that 0.03dB/0.1°.

Multichannel sell correcting AD-system is realized in the form of block, 4U height in the construction Rack 19’, it is manufactured in short production and 15 successfully used for seismic prospecting of gas and oil [12].

### Conclusions

1. The possibility of improvement static and dynamic is of AD-system for processing low-frequency signals by means of applying ADC ad DAC with weight redundancy is shown.
2. Methods accuracy and speed increase of AD-systems clue to spreading of the principles of correction static and compensation of dynamic errors of redundant ADC and DAC additionally to functional units of measuring channels are considered.
3. Structural diagrams of AD-systems for measurement and analysis low-frequency signals, on the base of ADC and DAC with weight redundancy are suggested. It is proved that their application improves the values of static and dynamic parameters of the systems.

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