

# Multisensor transducer based on a parallel fiber optic digital-to-analog converter

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**Abstract.** Considered possibility of creating a multisensory information converter (MSPI) based on new fiber-optic functional element-digital-to-analog (DAC) fiber optic converter. The use of DAC fiber-optic provides jamming immunity combined with low weight and cost of indicators. Because of that MSPI scheme was developed based on parallel DAC fiber-optic (Russian Federation Patent 157416). We came up with an equation for parallel DAC fiber-optic. An elaborate general mathematical model of the proposed converter. Developed a method for reducing conversion errors by placing the DAC transfer function between  $i$  and  $i + 1$  ADC quantization levels. By using this model it allows you to obtain reliable information about the technical capabilities of a converter without the need for costly experiments.

## 1 Introduction

Fiber-optic digital multisensor transducers (MSTs) are a class of multi-input binary signal transducers designed for collection of data on threshold parameters of the controlled object, their transmission over a shared channel and restoration at the output in a form suitable for control and monitoring systems application.

The main competitive advantage of transducers of this class compared with their electronic counterparts is evident in design of multivariable control systems of spatially distributed objects operating under strong electromagnetic fields, as well as in explosive and environmentally hazardous environments. Such operation conditions are typical for control systems used for space purposes, conventional and nuclear power engineering, chemical industry and other fields.

The main requirements of MSTs in these conditions are: immunity to electromagnetic interference, zero risk of abnormal spark formation, high number of monitored parameters and accuracy of reproduction of the input signal values, high performance — typical for electrically passive control systems with pneumatic and hydraulic actuating units.

The problems of development of MSTs and their components are expounded in patent literature and research work of Russian and foreign authors among them V.M. Grechishnikov, V.A. Zelensky, O.A. Kulish, G.I. Leonovich, J. H. Hong, C. M. Verber, I. A. Galton, Y-K. Chen, A. Leven whose work is highlighted [1, 2].

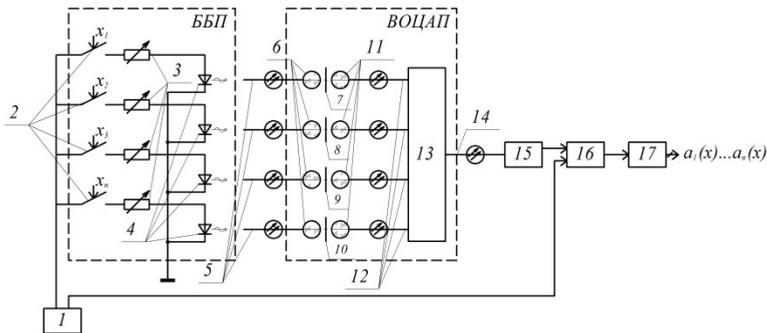
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## 2 Parallel FODAC-based MST

Examples of MST based on parallel digital to analog fiber optic converter are discussed in section [3, 4]. In the existing devices there are significant errors in generalization of quantized signal at the output of the DAC due to unevenness of optical radiation entering into the channels limiting metrological characteristics of the device as a whole. In order to address this problem, the modified MST design was proposed [1]. The problem of non-uniformity of optical input in MST described above is solved by replacing fixed-value resistors in the LED supply circuit with trimming resistors, and supplying offset 0.5V of quantization increment of FODAC output parameter to the input of the amplifier. A diagram of MST is shown in Figure 1.

MST circuit includes a reference voltage source 1, a four-channel binary converter unit (BCU), a FODAC, a common fiber optic light guide 14, a photo detector 15, an amplifier 16, an ADC 17. Each channel of BCU includes an electronic key 2, a trimming resistor 3 and LED 4. FODAC includes transmitting optical fibers 5, transmitting spherical lenses 6, weighting elements 7-10, receiving spherical lenses 11, receiving optical fibers 12, a Y-coupler 13.



**Fig. 1.** Diagram of parallel FODAC-based MST.

MST operates as follows. When keys 2 are closed, REF 1 sets the level of direct optical radiation at the output of LED 4. Optical radiation flows through the transmitting optical fiber 5 and the transmitting spherical lens 6 to weighting elements 7-10. They provide weighting of each light flux in accordance with the law  $2^{-i}$ . Then each of the light flows is transmitted to the Y-coupler through the receiving spherical lens 11 and the receiving optical fiber 12. Optical signals are generated and transmitted to the final position of the actuating mechanism. Optical signal from the output of the Y-coupler is transmitted through the common optical fiber 14 to the photodetector 15. Then the signal is amplified at the amplifier 16 and receives offset voltage  $U_{ref}$  from the second output of REF. Upon amplification and offsetting, the voltage is supplied to the input of ADC where it is converted into code  $\{a_i\}$  that explicitly corresponds to terminal positions of actuators  $\{x_i\}$ .

## 3 Generalized mathematical model of a parallel FODAC-based MST

A mathematical model of a parallel FODAC was derived in [4, 5]. For ADC output signal to match DAC input signal, it is necessary for DAC quantization increment ( $\Delta_q^{DAC}$ ) to match the value of the ADC quantization increment ( $\Delta_q^{ADC}$ ):  $\Delta_q^{ADC} = \Delta_q^{DAC}$ . Given that

$$\Delta_q^{ADC} = \frac{U_{ref}}{2^n}, \text{ and } \Delta_q^{DAC} = p_0 x_0 2^{-(n-1)}, \tag{1}$$

where  $U_{ref}$  is ADC reference voltage,  $n$  is ADC discharge,  $p_0$  is step of quantization of the analog output. We obtain:

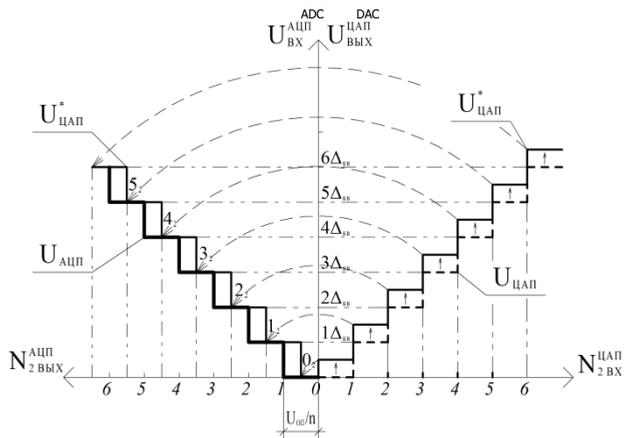
$$p_0 x_0 2^{-(n-1)} = \frac{U_{ref}}{2^n}, \quad p_0 R_{feed} S_{PD} 2^{-(n-1)} = \frac{U_{ref}}{2^n}. \tag{2}$$

A group of expressions below follows from (2):

$$R_{feed} = \frac{U_{ref}}{2 p_0 S_{PD}}; \quad p_0 = \frac{U_{ref}}{2 R_{feed} S_{PD}}; \quad S_{PD} = \frac{U_{ref}}{2 p_0 R_{feed}}. \tag{3}$$

The equality  $\Delta_q^{ADC} = \Delta_q^{DAC}$  can be obtained by variation of feedback resistance, optical power level at the output of the BCU or changing of photodevice sensitivity.

As shown in Figure 2, it is evident that the scale of DAC transfer characteristic coincides with the levels of ADC quantization, and the slightest signal instability can lead to significant errors in ADC operation. To avoid these, it is necessary to shift  $U_{off}$  up by an amount equal to:  $\Delta U_{off} = 0,5 \Delta_q^{DAC}$  (parameter  $U_{DAC}^*$ ). The transformed offset parameter has DAC output quantization levels between  $i$  and  $i+1$  of ADC quantization levels (see Fig. 4). This provides one-to-one correspondence between the output code of ADC ( $a_0, a_1, \dots, a_{n-1}$ ) and the input code of the data collection device ( $x_0, x_1, \dots, x_{n-1}$ ) set by the position of the 2.



**Fig. 2.** Parameters of conversion provided by FODAC and ADC.

Through these operations, the following one-to-one correspondence is achieved:  
 $\{x_i\} = \{a_i\}$

The signal at the output of the amplifier:

$$U_{\Sigma}(x) = S_{PD} R_{feed} \mathcal{G}_i p_0 N[\{x_i\}] + \Delta U_{off} \tag{4}$$

where  $p_0$  is quantization interval of the analog output signal;  $\mathcal{G}_i$  is the coefficient of energy losses in fiber-optic communication lines;  $S_{PD}$  is the sensitivity of the detector;  $R_{feed}$  is feedback resistance of a transducer transforming photoelectric current into voltage;  $\Delta U_{off}$  is zero offset voltage;  $N[\{x_i\}] = P^*$ .

Let us assume ADC to be voltage-to-code converter (VCC) with parallel conversion [6]. The output signal of  $i$  comparator of VCC unit can be set by a single function with the following form:

$$e_m = \begin{cases} 1 & \text{at } U_{\Sigma}(x) + \Delta U_{off} \geq \frac{m}{n} U_{ref}; \\ 0 & \text{при } U_{\Sigma}(x) + \Delta U_{off} < \frac{m}{n} U_{ref}, \end{cases} \quad (5)$$

where  $U_{ref}$  is ADC reference voltage,  $m = 2^{n-1}$ .

Using Boolean algebra rules, we can obtain expressions for the values of bit digits of the output code as follows:

$$\begin{aligned} a_0(x) &= \overline{\overline{b_1(x)b_3(x)b_5(x)b_7(x)}}; \\ a_1(x) &= \overline{\overline{b_2(x)b_3(x)b_6(x)b_7(x)}}; \\ a_2(x) &= \overline{\overline{b_4(x)b_5(x)b_5(x)b_7(x)}}; \end{aligned} \quad (6)$$

where  $\begin{cases} b_i(x) = e_i(x)\overline{e_{i+1}(x)}; \\ b_m(x) = e_m(x)e_0(x), \end{cases}$  where  $i = 1, \dots, (m-1)$ .

Thus, the resulting mathematical model makes it possible for us to investigate a set of metrological characteristics of optical DACs, taking into account deviations of design parameters of the transducer ( $S_{\Phi II}$ ,  $R_{OC}$ ,  $\mathcal{G}_i$ ,  $p_0$ ,  $N[\{x_i\}]$ ,  $\Delta U_{CM}$ ) from the nominal value, in accordance with the procedures set forth in [6].

## 4 Conclusion

We propose the original design of parallel FODAC-based MST for control systems with electrically passive pneumatic and/or hydraulic actuators. An equation for FODAC conversion was obtained, taking into account the passive nature of its optical circuit. We considered a method to reduce the error of conversion by placing DAC transfer factor between  $i$  and  $i+1$  ADC quantization levels. A generalized mathematical model of the proposed data collection device was developed to display data transduction processes in its analog, analog-to-digital and digital functional elements. Application of this model makes it possible to obtain reliable information on the technical capabilities of the described transducer with no need for costly physical experiments.

## References

1. S. Chin-Chong Tseng, US Patent 3985423 (1974)
2. V.M. Grechishnikov, O.V. Terjaeva, RF Patent 157416 (2015) (in Russian)

3. V.M. Grechishnikov, V.G. Domrachev, O.V. Teryaeva, A.A. Yudin, *Measurement Techniques* **57**, 1309 (2015)
4. V.M. Grechishnikov, O.V. Teryaeva, *Russian Aeronautics* **59**, 426 (2016)
5. V.M. Grechishnikov, V.G. Domrachev, I.V. Retinskaya, O.V. Teryaeva, *Measurement Techniques* **58**, 1127 (2016)
6. V.M. Grechishnikov, *Metrologiya i radioizmereniya* (Publishing House of Samara National Research University, 2007) (in Russian)