Development of sensitive measuring circuits for measurement of physicochemical parameters and their metrological characteristics

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Abstract. A sensitive measuring scheme has been developed for capacitive-semiconductor converters of humidity of dispersed media, and basic static characteristics have been obtained depending on the duration of bipolar pulses, providing an increase in accuracy and linearity of the static characteristics. A scientifically based increase in the reliability of the results of chemical analysis and physicochemical measurements, the identification and minimization of their errors are impossible without the use of the foundations of metrology - the science of measurements. At the same time, theoretical metrology is rather closely intertwined with the legislative - a set of state acts and regulatory documents that regulate the rules, requirements and norms that must be guided by when making measurements. Obviously, the more responsible the decision is made on the basis of the measurement results, the more stringent the requirements are imposed on them, the less the measurement results should depend on the subjective opinion of the experimenter. Main provisions of measurement error assessment and principles of uniformity of measurements required for rational performance of physical and chemical measurements and chemical analysis are presented. Regularities of normal and other most common types of random v.e. distribution are considered.

1 Introduction

In information-measuring equipment capacitance - semiconductor converters of humidity, flow, concentration and temperature of various objects and media are widely used to convert physical quantities with complex parameters, which is explained by a number of their positive properties, such as the accuracy of measurement of the parameters of objects, reliability, manufacturability and efficiency of measurement schemes [1-3].

The basis of the principle of action of capacitive-semiconductor converter of dispersed media humidity is the dependence between the humidity of the measured medium W and its electro-physical properties, the change in the active and reactive resistance of the transducers depending on the dielectric constant of the wet medium [4-6]. The essence of the method is to determine the permittivity of the medium by measuring the active and

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reactive resistance and energy losses of the electric capacitor, in which the role of the dielectric is played by the media [7-10].

The capacitive humidity converter was created taking into account the fact that at the same time the temperature, the total content of soluble salts and the humidity of the dispersed medium will be determined at the same point [11]. Consider capacitive semiconductor transducer is a transducer in the form of a probe, allowing measurement in dispersive media without extracting the samples [12-15].

The design of the capacitance-semiconductor converter is performed so that their longitudinal length is almost an order of magnitude greater than the transverse dimensions and therefore the flow distribution calculations should only take into account changes in the field in the longitudinal direction [16]. The static and dynamic characteristics of the probe capacitance-semiconductor converter can be analyzed in detail on the basis of a sensible mathematical apparatus describing the law of change in the flow distribution along the path of the flow lines, flow distribution changes $I_i(x)$, voltages $U_i(x)$ and the laws of change in the inverse reduction functions [17].

Graph models of the distributed circuit of the capacitive-semiconductor converter are reduced to the transition from complex differential and integral equations to the discretization of algebraic relations, describing and displaying unknown values of the quantities that are the nodal element in the distributed circuit of the converter [7-9]. When studying and displaying the transformation circuit of the probe capacitance-semiconductor converter based on the graph model, this circuit is conditionally divided into elementary sections Δx, consisting of input and output quantities and parameters, which, in turn, are exposed to external influences of quantities of different physical nature. In this case, the laws of change and distribution of external influencing quantities may be different, because the change in the laws of distribution depends on the physical nature of the chain, where the corresponding parameters are produced [2-5].

2 Materials and Methods

Statistical characteristics of a capacitance-semiconductor Converter with distributed parameters can be determined directly from the structural schemes and on the basis of a graph model using descriptions of inter-chain and intra-chain effects, as well as rules for finding the output values of serial, parallel and mixed connections of several transducers. In cases where the use of physical effects or intra-chain conversion for the implementation of the respective devices is required to provide the distribution in space of the parameter [3-8].

In capacitance-semiconductor converters, the input value is associated with the modulation of the electric flow F_{el}, which is a new principle of construction of capacitive-semiconductor humidity converters and is used to modulate humidity in the ranges $w_{\min} \leq w \leq w_{\max}$. To implement the described principle, a bipolar voltage is used as a reference source. It should be noted that when the input parameters are modulated with a change in the circuit function $\eta_i(w_{inp.})$, the transformation parameter changes λ_i. However, you can find a range where the conversion parameter change λ_i is negligible, a schematic function that can be represented as [4-6]

$$\eta_э(w_{inp.}) = \eta_{э0}\left[e^{w(w_{inp.})+\varphi_0} + 1\right] \tag{1}$$

The static characteristic of the capacitance-semiconductor Converter based on the developed generalized graph model for converting the humidity of dispersed media has the form [5]:

$$U_2 = U_1 \eta_1 \lambda_1 K_1 (I_1, I_p) K_2 \left[w_{inp.} \eta_p (w_{inp.}) \lambda_p (w_{inp.}) \right] K_3 (U_p, U_2) w_{inp.}, \tag{2}$$

where, U_1 – the input voltage; U_2 – output voltage; λ_i - parameter conversion of the input value; K_1, K_2, K_3 – inter-chain coefficients; $\eta_i(w_{inp.})$-circuit function.

Depending on the type of capacitance-semiconductor Converter and its geometric parameters, there may be different laws of distribution of specific reactive and active conductivity, which is described by the circuit function and further on the basis of simulation using a graph model, a feature of the distribution of specific reactive conductivity, which depends on the humidity of the dispersed medium, is revealed [1-6].

3 Results and Discussion

It is established that at small and medium values ($2 \div 6\%$) of the dispersed media humidity, the bridge measuring circuit does not provide the necessary gradation and sensitivity of the output signal. To increase the sensitivity of the output signal and linearization of the output characteristics of the capacitance-semiconductor converter at low and medium humidity values, a measuring circuit is developed (Fig.1., a), allowing with high enough accuracy to convert small changes in the active and reactive resistance of the converters into a DC signal. In this case, the semiconductor converter R_t is a current sensor, which is formed after the conversion of the active and reactive resistance of the converters.

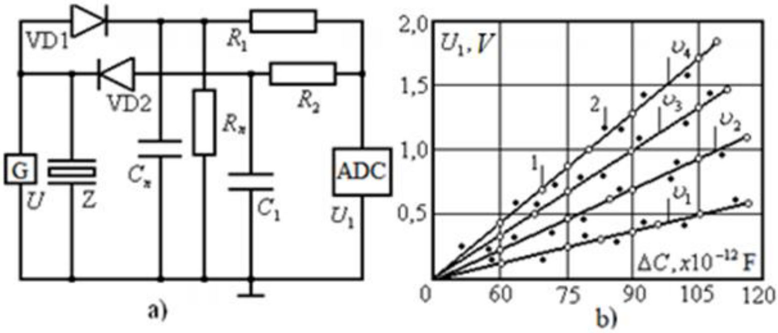

Fig. 1. Measuring circuit (a) and families of static characteristics, and capacitance-semiconductor converter humidity of dispersed media (b).

The scheme is a nonlinear double quadrupole. In it, the power supply U, capacitance-semiconductor converters C_n and R_t, capacitor C_1 and analog-to-digital converter (ADC)have a common ground point, which is its important advantage over bridge measuring circuits. The measuring scheme is investigated when feeding rectangular bipolar voltage pulses (Fig. 2., a), where υ – is the relative pulse duration $(0 \le \upsilon \le 1)$. For Figure 2, *b* is the transformation of the rectangular bipolar voltage pulse when measuring the humidity of dispersed media [6].

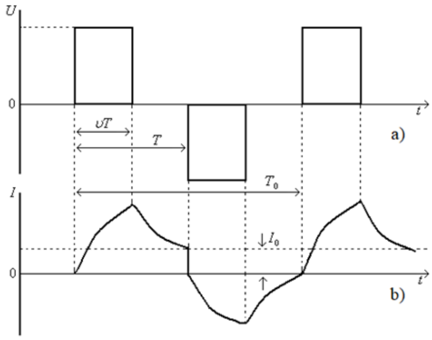

Fig. 2. Transformation of rectangular bipolar pulses at changes in reactive and active resistance capacitance-semiconductor converter.

Capacitance measurement is based on the principle of charge transfer and changes in the active and reactive resistances of capacitance-semiconductor converters at periodic charge and discharge of the capacitor. During the υT pulse time of positive polarity with amplitude U, the capacitor C_n is charged through a D_1 diode. After the end of the pulse, it is discharged through the resistor R_1 and analog-to-digital converter, as well as through the resistor R_2 and diode D_2 until the moment of time T, then recharged by the negative polarity pulse through the resistors R_1, R_2 and diode D_2. Similarly, the charge and discharge of the capacitor C_1 occurs.

Using the modified $Z-$transform of Laplace [7, 8], the expressions of the instantaneous value of the output current I_n are obtained, according to which the graph is plotted (Fig.1, b). The constant component of this current is $R_1 = R_2 = R$, when expressed by the formula:

$$I_1 = \frac{URR_t(R+2R_n)f}{(R+R_n)^2}\left[\left(e^{\frac{(R+R_n)\upsilon}{2R(R+2R_n)fC_n}}-1\right)e^{\frac{-(R+R_n)}{2R(R+2R_n)fC_n}}C_n-\left(e^{\frac{(R+R_n)\upsilon}{2R(R+R_n)fC_1}}-1\right)e^{\frac{-(R+R_n)}{2R(R+R_n)fC_1}}C_1\right] \quad (3)$$

and the static characteristic of the capacitive-semiconductor humidity Converter of dispersed media is as follows

$$U_1 = I_1 R_n, \quad (4)$$

where $f = 1/T_0 -$ is the frequency of the power supply.

In continuous feeding ($\upsilon = 1$) (3) is defined by the expression

$$I_1 = \frac{URR_t(R+2R_n)f}{(R+R_n)^2}\left[\left(1-e^{\frac{-(R+R_n)}{2R(R+2R_n)fC_n}}\right)C_n-\left(1-e^{\frac{-(R+R_n)}{2R(R+2R_n)fC_1}}\right)C_1\right] \quad (5)$$

and, therefore, the static characteristic of the capacitive-semiconductor humidity Converter is determined by the expression

$$U_1 = \frac{URR_nR_t(R+2R_n)f}{(R+R_n)^2}\left[\left(1-e^{\frac{-(R+R_n)}{2R(R+2R_n)fC_n}}\right)C_n-\left(1-e^{\frac{-(R+R_n)}{2R(R+2R_n)fC_1}}\right)C_1\right]. \quad (6)$$

Expressions (3) and (4) show that, in General, the characteristic of the circuit transformation is nonlinear both in continuous and in pulsed power. For figure 1, *b* presents a family of static characteristics of the circuit transformation

$$U_1 = I_1 R_n = F(\Delta C) \text{ and } U_1 = I_1 R_t = F(\Delta R),$$

constructed by the formula (4) for different values of the signal duration for the case of a differential converter, when

$$C_n = C_0 + \Delta C,\ C_1 = C_0 - \Delta C \text{ and } R_t = R_0 + \Delta R,\ R_1 = R_0 - \Delta R.$$

A characteristic feature of the graphs is that at small values υ with growth ΔC and ΔR they deviate from the line in the direction of decreasing sensitivity, and for large υ – in the direction of increasing sensitivity. As a result, for each family of static characteristics of the capacitive-semiconductor converter, there is a certain value of the pulse duration υ, at which the characteristic of the circuit conversion is almost linear.

The table shows the main characteristics of the conversion circuit at the values of its parameters $R = 47.10^3\, Om$, $\Delta C = 5.10^{-12}\, F$, $f = 25.10^4\, Hz$, $U = 30\, V$, $R_n = 10^6\, Om$.

The nonlinearity of the characteristics of the conversion of the input value of the capacitive-semiconductor humidity Converter of dispersed media is calculated as

$$\beta = \frac{\Delta C_0}{S\Delta C_n} = \frac{U_{on} - S\Delta C_n}{S\Delta C_n}, \qquad (7)$$

where ΔC_n and U_{0n}-limit values ΔC and U_{0n} for the range of moisture measurement of dispersed media; S – sensitivity corresponding to the approximating line.

The sensitivity of the capacitive-semiconductor moisture Converter of dispersed media is calculated by the method of least squares according to the formula:

$$S = \frac{\sum_i U_{0i}\,\Delta C_i}{\sum \Delta C_i}. \qquad (8)$$

Table 1. Key performance indicators of the transformation.

υ	U_{0n}	$S, V/pF$	ΔU_n, mV	β, %
0.25	1.00	0.21	-29.4	2.88
0.35	1.84	0.35	-29.8	2.71
0.4	2.16	0.32	-30.4	2.75
0.45	2.19	0.38	-32.6	2.82
0.5	2.25	0.46	-34.4	1.72
0.55	2.48	0.55	-32.6	1.61
0.6	3.15	0.64	-30.5	1.25
0.75	3.59	0.72	-5.41	0.15
0.8	3.83	0.76	6.7	0.17
0.85	4.04	0.81	19.0	0.48
0.9	4.22	0.84	31.1	0.74
0.95	4.33	0.86	40.4	0.94
1.0	4.38	0.88	44.1	1.02

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4 Conclusion

Thus, tabular data indicate that for small pulse durations $\upsilon \leq 0{,}75$, the absolute error of nonlinearity ΔU_n is negative and if $\upsilon \geq 0{,}75$-positive.At this boundary value υ, the nonlinearity β has a minimum value of only 0,15%. Comparison of data for continuous ($\upsilon = 1$) and pulsed power ($\upsilon = 0{,}75$) showed that the transition from continuous to pulsed power nonlinear characteristics of the conversion is reduced by more than six times. This fact gives practical value to the impulse power supply of the circuit, providing additional opportunities for linearization of its transformation characteristics.

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