

Metrological reliability of primary transducers taking into account element stability and accuracy

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Abstract. Probabilistic characteristics of reliability of transient states of semiconductor converter when working together with integrated circuits are considered. The probability of effective transition of the integrated circuit, functioning with semiconductor converter, from the state of logical zero to the state of logical one is established and the corresponding probabilistic equations at sufficient signal and pause duration are obtained. During the period of operation of information and measurement devices and systems, failures occur, which can be sudden and gradual. Sudden failures are categorised as random events. The physical nature of sudden failures is due to the concentration of loads causing corresponding internal damage in the form of winding breakage or short circuit, parts breakage and others. Failure of any element and information device, in particular, measuring transducer of physical quantities, can be determined by the action of the following factors: structural imperfections of the initial materials of the product due to the presence of impurities, dislocations and concentration gradients; external influences - thermal mechanical and electrical loads.

1 Introduction

Failure of any element and information device, in particular, measuring transducer of physical quantities, can be determined by the action of the following factors: structural imperfections of the initial materials of the product due to the presence of impurities, dislocations and concentration gradients; external influences - thermal mechanical and electrical loads.

Failures of information devices and systems are random events. However, the causes that lead to the occurrence of failure are associated with certain physical and physicochemical processes occurring in materials and structures during operation. The choice of the approach to reliability determination by failure physics methods is conditioned by the assumption that chemical reactions and physical processes occurring on the surface and inside the measuring device cause deterioration of its electrophysical characteristics and, as a consequence, catastrophic and parametric failures [1-5].

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2 Research results and discussion

Let's consider probabilistic characteristics of reliability of transient states of semiconductor transducer of humidity of dispersed media at joint functioning by integrated circuits.

Reliability of integrated measurement circuits of semiconductor transducers of physical quantities with respect to the absence of parametric failures is determined from the value of functional (static and dynamic) stability margin. Static stability is understood as the transmission of signals by logic circuits, in which there is no transition of single signals to zero signals and zero signals to single signals not provided for by logic functions.

Dynamic stability of signal transmission by logic elements should be understood as preservation of sufficient signal duration and sufficient pause duration to ensure the transition from the state of logical zero to the state of logical one and back [6-10]. Functionally stable logic elements are characterized by two stable sections (Figure 1).

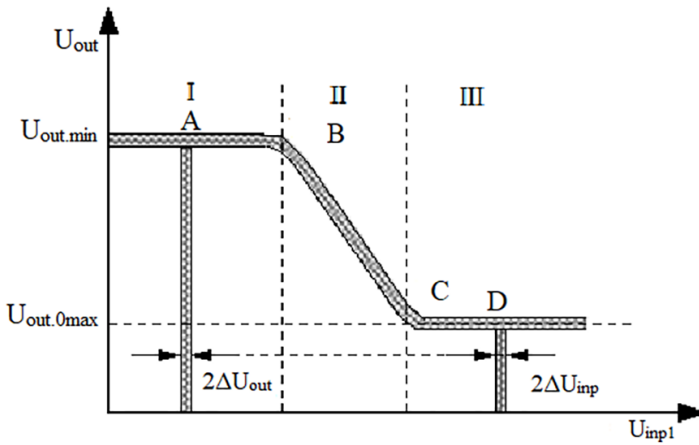


Fig. 1. Stable transition zones of the logic element semiconductor converter.

If through the points A, B, C and D to draw straight lines parallel to the ordinate axis, we obtain the boundary lines characterising the zones of stable operation of the logic element, which is associated with the effective transition of electrons from the valence band to the conduction band in the semiconductor functioning as a converter. The input signal in zone I is characterised by a stable initial value, and for zone III by a stable operating state [11-15].

For zone I

$$\pm U = U_n + U_0, \tag{1}$$

where - possible fluctuations of input signal value; - input signal mixing due to noise; - input signal mixing of semiconductor converter due to temperature influence.

For zone II [16-23]

$$\pm U' = U'_0 + K_2 \sigma_a, \tag{2}$$

where - mixing of the characteristic caused by temperature change; - mean square deviation of values corresponding to the given characteristic section. It can be determined from the relationship $\sigma_a = m \cdot \bar{U}$.

The result of the measurement is equal to: $m = 0,08 \div 0,15$, $K_2 \geq 3,0$.

For the zone III

$$\pm U'' = \Delta U. \tag{3}$$

As the most important static parameters we give four values of voltages. The four voltage values set the limits of the variable mapping (0 and 1) at the output and input of the element. Normal operation of the element requires that the voltage representing a logic one be high

enough and the voltage representing a 0 be low enough. These requirements are given by the parameters. The input voltages of a logic element are the output voltages of the previous (signal source). The levels guaranteed at the output of the logic element under acceptable load conditions are given by the parameters. Output levels are somewhat better than input levels, which provides a certain noise immunity of the element. For the level, negative interference reducing it is dangerous, and the permissible static interference [24-25]

$$U^{-nom} = U_{inp} \cdot 1min_{out.1min}.$$

For the level U_0 positive interference is dangerous, and the permissible static interference is

$$U^{+nom} = U_{inp} \cdot 0max_{out.0max}.$$

To perform stable signal transmission through the logic element of the measuring transducer it is necessary to fulfil the condition of non-overlapping of zone I and III with a spread $\pm U$ and $\pm U'$ on the band II, i.e. the stability of the logic circuit operation is characterized by the value of stability margin for the input level voltage "0":

$$S_0 = |U_{inp.0out.0max}|, \tag{4}$$

and for the input level voltage "1":

$$S_1 = |U_{inp.1} - U_{inp.1min}|,$$

where U_{inp0}, U_{inp1} - input level voltages "0" and "1" respectively;

$U_{inp.0max}$ the maximum allowed input travelling signal level at which the circuit is still in the state of logical one.

Thus, the values of the stability margin of integrated circuits, taking into account the variation of parameters, are determined for the level of "0" [10-11]:

$$S_0 = \left\{ |U_{inp.0max_{inp.0max}} - |\Delta U_{inp.0} + U_{inp.0}| \right\} \tag{5}$$

and for the input level voltage "1"

$$S_1 = \{ |U_{inp1} - \Delta U_{inp1}| - |U_{inp1min_{inp1min}}| \geq 0 \}. \tag{6}$$

Values $U_{inp0}, U_{inp1}, U_{inp1min_{inp1min}}$ are independent random events and their distribution density functions can be represented on the common abscissa axis as four normalized curves or, using the rules of composition, two normalized curves can be obtained (Figure 2).

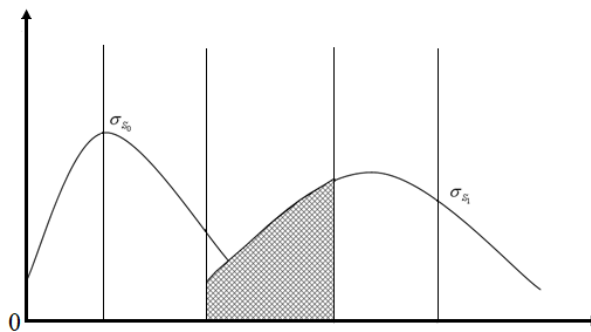


Fig. 2. Stable zones of transition from the state of logic zero to the state of logic one of functional logic elements logical one of functional logic elements.

Probability of effective transition of the integrated circuit of the semiconductor converter from the state of logic zero to the state of logic one at the input of the signal $U_{inp.0}$ and fulfilment of the condition $S_0 \geq 0$ is defined by the expression:

$$P_{\beta_1}(0 < S < \infty) = 1 - \frac{1}{\sqrt{2\pi}\sigma_{S_0}} \cdot \int_{-\infty}^0 \exp \left[-\frac{(U_{ex}-S_0)^2}{2\sigma_{S_0}^2} \right] dU_{inp}, \tag{7}$$

where $\sigma_{s_0} = \sqrt{\sigma_0^2 + \sigma_z^2}$ – root mean square deviation; σ_z – root mean square deviation of the value $\bar{U}_{inp.0max}$; $\bar{U}_{inp.0}$ – mathematical expectation of the quantity $U_{inp.0}$.

Expressing the integral through the Laplace function and passing to other limits of integration, we obtain

$$P_{\beta_1} 0,5 + F \left[\frac{S_0}{\sigma_{s_0}} \right] = 0,5 + F \left[\frac{\bar{U}_{inp.max} - \bar{U}_{inp.0}}{\sigma_{s_0}} \right] \quad (8)$$

Similarly, the probability of correct operation of the circuit when a voltage is applied to the input $U_{bx.1}$, characterising the transition of the element from the state of logical one to the state of logical zero and fulfilment of the condition $S_1 > 0$, is defined by the expression

$$P_{\beta_2} (0 < S_1 < \infty) = 1 - \frac{1}{\sqrt{2\pi}\sigma_{s_1}} \cdot \int_{-\infty}^0 \exp \left[-\frac{(U_{inp} - \bar{S}_1)^2}{2\sigma_{s_1}^2} \right] \cdot dU_{inp1} \quad (9)$$

or,

$$P_{\beta_2} 0,5 + F \left[\frac{S_1}{\sigma_{s_1}} \right] + F \left[\frac{\bar{U}_{inp.1min} - \bar{U}_{inp.1}}{\sigma_{s_0}} \right], \quad (10)$$

where $\sigma_{s_1} = \sqrt{\sigma_1^2 + \sigma_S^2}$ – mean square deviation, and σ_1 – root mean square deviation of the value $\bar{U}_{inp1min}$; \bar{U}_{inp1} – mathematical expectation of the quantity U_{inp1} .

Let us evaluate the parametric reliability at dynamic stability of the logic integrated circuit of the measuring transducer. The duration of the operating signal is selected on the basis of its minimum duration required for reliable operation of the circuit [20-32]:

$$\tau_H = k\tau_{Nmin}, \quad (11)$$

where k – response factor ($k = 1,5 \div 4,0$).

Signal duration reduction value ($\Delta\tau_n$) as it passes through $n - 1$ circuit is defined as

$$\Delta\tau_n = \tau_u(n - 1)^{-\tau_{un}},$$

where τ_{un} and $\tau_{u(n-1)}$ – pulse width on n and $(n - 1)$ elements respectively.

The magnitude of the decrease in the pause duration when the signal passes through the element is defined as

$$\Delta\tau_{nN} = \tau_n(n - 1),$$

where $\tau_{u(n-1)}$ and τ_{un} – pause time $(n - 1)$ and n circuits respectively.

The scheme will be dynamically stable if the following condition is fulfilled $S_{\partial u} = |\bar{\tau}_u - \tau_{umin}|$

$$S_{\partial u} = |\bar{\tau}_{np} - \tau_{nmin}|$$

where τ_{np} – mathematical expectation of the pause duration; τ_n – mathematical expectation of the quantity τ_{np} .

Taking into account (12) the probability of correct actuation n – of the circuit at sufficient signal and pause duration are defined respectively by the expressions:

$$P_{\beta_3} (0 < S_{\partial u} < \infty) = 1 - \frac{1}{\sqrt{2\pi}\sigma_S} \int_{-\infty}^0 \exp - \left\{ \frac{[\tau_u - (\bar{\tau}_u - \tau_{umin} 0^2)] \Pi}{2\sigma_S^2} \right\} \quad (13)$$

Or

$$P_{\beta_3} = 0,5 + F \left[\frac{\bar{S}_{\partial u}}{\sigma_S} \right] = 0,5 + F \left[\frac{\bar{\tau} - \tau_{umin}}{\sigma_S} \right] \quad (14)$$

$$P_{\beta_4} (0 < S_{\partial u} < \infty) = 1 - \frac{1}{\sqrt{2\pi}\sigma_S} \int_{-\infty}^0 \exp \left\{ -\frac{[\tau_n - (\bar{\tau}_n - \tau_{nmin} 0)] \Pi}{2\sigma_z^2} \right\} \Pi_n \quad (15)$$

Or

$$P_{\beta_4} = 0,5 + F \left[\frac{\bar{S}_{\partial u}}{\sigma_z} \right] = 0,5 + F \left[\frac{\bar{\tau}_{np} - \tau_{nmin}}{\sigma_z} \right]. \quad (16)$$

3 Conclusion

Thus, from equation (14) and (16) it can be seen that the probability of triggering the integrated circuit, which operates in conjunction with the semiconductor converter depends on the value of the function $F(x)$, as with the increase in its value increases the probability of triggering the integrated circuit, because this process is accompanied by a sufficient duration of the signal and pause with the same RMS transition error. Consequently, as the RMS transition error increases, the probability of triggering of the integrated circuit that operates with the semiconductor converter, which is characterised by the transition of electrons with minimum probability from the valence band to the conduction band, decreases significantly.

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