

Evaluation performance of digital integrated circuits while exposed to radiation

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Abstract. The methods of functional-logical simulation of digital integrated circuits (ICs) exposed to radiation are observed. It is shown that in a number of cases functional and electrical deterioration of ICs performances have both deterministic and non-deterministic nature. Methods for simulating IC failure exposed to radiation based on the model of fuzzy digital machine and Brauer probabilistic reliability machine are proposed.

1. Introduction

Digital integrated circuits (ICs) are widely used in electronic systems [1], in some cases under high radiation level conditions. Analysis of the radiation test results shows there is a statistical dispersion of threshold levels of failure for functional and parametric failures for similar ICs [2].

In our radiation IC reliability studies, we use the digital machine model involving apparatus of probability theory. In Boolean reliability networks internal IC models are used in state-space terms in models where the axioms of a Boolean lattice [2,3] are applicable. In the situation in where the physical mechanisms of IC failure must be taken into account, the construction of a functional-logical model assumes transition from axioms of Boolean lattice to the axioms of a vector lattice with the corresponding change of algebraic operations to operations "minimum", "maximum" and "complement" $\chi \in X$ [3].

Thus, the real nature of the IC radiation behavior is determined by the specific ratio of the radiation-sensitive parameters of its internal elements, taking into account the impact of the spread. The ratio between the probability-density function of the spread and criterion function [4,5] should be determined by the usefulness of IC functional-logical radiation behavior models for a particular occasion. It should be noticed the parameters of the distribution functions characterizing statistical uncontrollable factors are themselves dependent on radiation. Moreover, the nature of their changes during irradiation depends on many factors, including the type of radiation, its intensity, and range, type a criteria parameter characterizing the radiation resistance of ICs and work mode. Therefore, in different ranges of levels or intensities of the impact of the IC model can be either of fuzzy or probabilistic nature. Carrying out such a comparison is an essential step in the overall analysis of the IC radiation resistance.

2. Model environment

With the radiation dose increasing the value of logic zero "0" and "1" in the IC changes. This leads to amplitude distribution spread of logic voltage levels "0" and "1", as shown in Fig. 1. In this case, to assess the nature of distributions it is necessary to expand the set of modalities (level of logic signals) to the continuum $\chi \in [0,1]$. In this case, it is preferable to describe a continuum set by fuzzy logic (fuzzy sets). Here we add it by apparatus of probability theory [5,6]. With increasing doses of ionizing



radiation, these distributions come together (indicated by arrows), making the difference logic signal levels decreases. Operating capacity of the logic element (LE) can be characterized by the magnitude of the probability distribution which can be calculated as follows.

Let the distribution of logical "0" zero indicates a function $F(x)$ being like:

$$F(x) = \begin{cases} f(x), & x \in \Delta_0 \\ 0, & x \notin \Delta_0 \end{cases}, \quad (1)$$

Moreover, the distribution of logic "1" unit denotes a function being like:

$$\Phi(x) = \begin{cases} \varphi(x), & x \in \Delta_1 \\ 0, & x \notin \Delta_1 \end{cases}, \quad (2)$$

where Δ_0 is the ultimate distribution area «0»; Δ_1 is the ultimate distribution area "1" while $0 \leq \Delta_0 < 1/2$, $1/2 \leq \Delta_1 < 1$ (see Fig. 1).

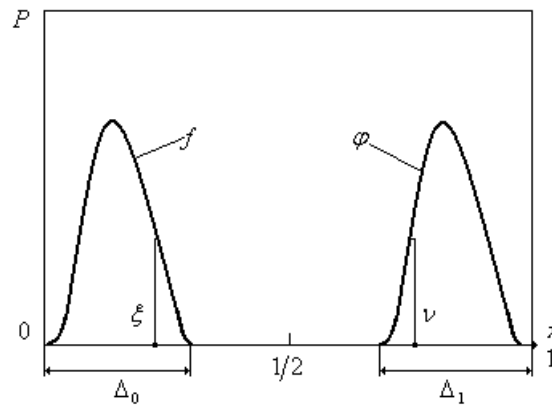


Figure 1. The probability distribution of the voltage amplitudes of logic levels "0" and "1" depending on the radiation dose.

In this case, it is obvious that:

$$\int_0^{\Delta_0} f(\xi) d\xi = 1 \quad (3)$$

$$\int_{1-\Delta_1}^1 \varphi(1-\nu) d\nu = 1 \quad (4)$$

If ξ and ν are random variables, the difference $\nu - \xi$ is also a random variable from the logical pulse switching elements, and the probability that the value of the product $f(\xi) \cdot \varphi(\nu)$ [7,8].

Then the fuzzy probability value of the switching pulse, respectively, equal to:

$$\tilde{P} = \iint_{\Omega} (\nu - \xi) \cdot f(\xi) \varphi(\nu) d\xi d\nu \quad (5)$$

where $\Omega = [0, \Delta_0] \times [1 - \Delta_1, 1]$.

As a result of the transformation, the integral (5) can be written as follows:

$$\tilde{P} = \int_{1-\Delta_1}^1 \nu \varphi(1-\nu) d\nu - \int_0^{\Delta_0} \xi f(\xi) d\xi \quad (6)$$

The second integral in equation (6) describes the fuzzy probability of "0" (logic zero), consequently:

$$1 - \int_0^{\Lambda_1} \lambda \varphi(\lambda) d\lambda = 1 - \tilde{P}_1 \quad (7)$$

where \tilde{P}_1 is the fuzzy probability of logic one "1".

Therefore, from the expressions (6) and (7) finally find the fuzzy probability value of the pulse switching logic element:

$$\tilde{P} = 1 - (\tilde{P}_1 + \tilde{P}_0) \quad (8)$$

In practice, the actual distribution asymmetrical, but even that case, the resulting formula (8) is valid for them.

Failures of systems under the influence of radiation factors depend not only on the values of the fuzzy probability but also on their probability of switching elements themselves in LSI [9,10]. The amount of each switching LSI logic element per unit time is the multiplicity of nodes connected to this element. Critical nodes in the LSI are fuzzy sets of LE with a large multiplicity of nodes. When LSI Logic degradation probability of switching can either decrease or increases in a certain range. Therefore, despite the fact that the fuzzy probability for logic elements is decreasing, the logic element, however, can recover after a failure in a certain range of radiation exposure. In this case, the physical processes are contributing largely in explaining the emergence of the systematic slot effect.

3. Conclusions

The actual nature of ICs performance under ionizing radiation is determined by the specific ratio between determined and non-determined radiation-sensitive parameters of the logic elements considering effects of their statistical spread. In this case, the relationship between the density-probability distribution function of the spread and criterion function determines in the end, the feasibility of using functional and logic ICs radiation behavior patterns in relation to each particular case. Carrying out such a comparison is an essential step in the overall analysis of ICs radiation resistance. It should be noted that in different ranges of levels and intensities of the impact the ICs model can be either of fuzzy or of probabilistic nature. That structure of the model is a probabilistic one with operators such as probability, and a criterion function is a superposition of statistical and deterministic criterion function. At the same time, the relationship between fuzzy logic and probability is defined, which makes it highly accurate method to assess the quality of the IC operation when exposed to radiation.

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