Analysis of Radiation Influence on the Reliability Indexes of Control Systems Components

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***Abstract*—The paper considers the use of alpha-distribution to analyze the influence of radiation on the reliability of command and measuring systems of the spacecraft.**

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I. INTRODUCTION

Operability is a state of the object at which it is able to perform specified functions, while maintaining the values on the limits established by the normative and technical documentation [1].

Failures associated with the departure of the values of the parameters of onboard equipment of command-measuring system (CMS) for the specified limits are called gradual. Failure is preceded by the accumulation of certain changes within the object.

Spacecraft (SC) CMS are non-reducing objects, applicable to the first failure. To evaluate the reliability of such objects are used stochastic characteristics of the random variable - time to failure T_0. If the operating time is expressed in units of time, it also uses the terms "Time Before Failures" or "Time to Occurrence of Failure" [1].

Complete characteristic of random variable is its distribution law. Operating time to failure distribution can be described using various indicators of reliability:

- The reliability of the function $p(t)$;
- Density of the time to failure $f(t)$;
- The failure rate $\lambda(t)$.

The reliability function expresses the probability that the random variable time to failure of the object is greater than a predetermined operating time.

Often, as an index of the reliability is used the probability of failure-free operation - the probability that within a given time to failure will not occur failure [2].

Spacecraft CMS is an automated control system for spacecraft complexes. The distinctive characteristics of the onboard command and measuring systems are high reliability, interference immunity from the effects of natural and artificial interference and authenticity the exchange of information with ground control complex.

At long active lifetime (10-15 years), the question of radiation impact on the reliable indexes is particularly acute. In particular, this applies to equipment operating in space and operating in continuous mode.

II. DETERMINING PARAMETER AND ALPHA-DISTRIBUTION

Among several characteristics of the object usually can be selected a basic characteristic which determines the operability-determining parameter. In the case of spacecraft's command-measuring systems and electronic components included in their composition, as the determining parameter can be selected the level of the limit value of the accumulated dose for an electronic component d_{AD} [3, 4].

At further exploitation of the object, this parameter under the influence of ionizing space radiation will change. Thus, determining parameter is a polar function of the random operating time, the implementation of which all pass through the pole.

Analysis of the test results of various electronic components on the radiation resistance has shown that it is possible to accept a truncated normal distribution for determining parameter d_{AD} [5]:

$$f(D) = \frac{C}{\sigma(d_{TID})\cdot\sqrt{2\pi}} exp\left[-\frac{1}{2}\frac{(D-m(d_{TID}))^2}{\sigma(d_{TID})}\right] \quad (1)$$

where: $f(D)$ - the probability density; $m(d_{TID})$ - the mathematical expectation; $\sigma(d_{TID})$ - the mean square deviation; C - the normalizing factor.

Failure density distribution under the influence of accumulated dose [5]:

$$f(t) = \frac{C\cdot\beta}{t^2\sqrt{2\pi}} exp\left[-\frac{\left(\frac{\beta}{t}-\alpha\right)^2}{2}\right] \quad (2)$$

where:

$$\beta = \frac{\Pi\cdot t_{LT}}{\sigma^*};\ \alpha = \frac{m^*}{\sigma^*}.$$

β – the relative durability reserve, has the dimension of operating time (time); α – average relative rate of change of parameter or coefficient of uniformity rate of change of the parameter, dimensionless; Π – the value of determining parameter; m^* - the mathematical expectation level of accumulated dose of ionizing radiation over the lifetime; σ^* - the mean square deviation level of accumulated dose of ionizing radiation; t_{LT} - active lifetime.

The density distribution of failures (2) is an alpha-distribution [6]. This type of distribution is typical used in the research that considered the time of arrival in a certain state. The difference of alpha-distribution is that its parameters α and β characterize the process of approximation to the considered state – state of a determining parameter achieving a specification limit.

The probability of failure-free operation of the electronic component when exposed to low-energy particles (particles with energies up to 1 MeV) – P(t) from eq. (2) is determined by the model:

$$P(t)=1-F(t) \quad (3)$$

where: $F(t)$ – the alpha-distribution function:

$$F(t)=\int_{-\infty}^{t} f(t)dt \quad (4)$$

Then the total probability of failure-free operation of an electronic component will be determined as:

$$P_{\Sigma}(t)=P_{\lambda}(t)\cdot P_{\nu}(t_{op})\cdot P(t) \quad (5)$$

where:

- $P_{\lambda}(t)$ – the probability of failure-free operation without exposure to ionizing radiation is measured according to [7];
- $P_{\nu}(t_{op})$ - probability of failure-free operation under the influence of high-energy particles, calculated in accordance with [8];
- $P(t)$ - the probability of failure-free operation when exposed to space particles of low-energy.

III. RELIABILITY RESEARCH

Using the model (4) do research for reliability of the Xilinx chip XQ4028EX-4CB228M from the on-board equipment of command-measuring system. Chip XQ4028EX-4CB228M – is a programmable logic integrated circuit such as FPGA logic capacity of 28,000 system gates, manufactured in CMOS technology. Figure 1 shows the chips XQ4028EX-4CB228M test results the dependence of the static current consumption from the value of the accumulated dose of X-rays.

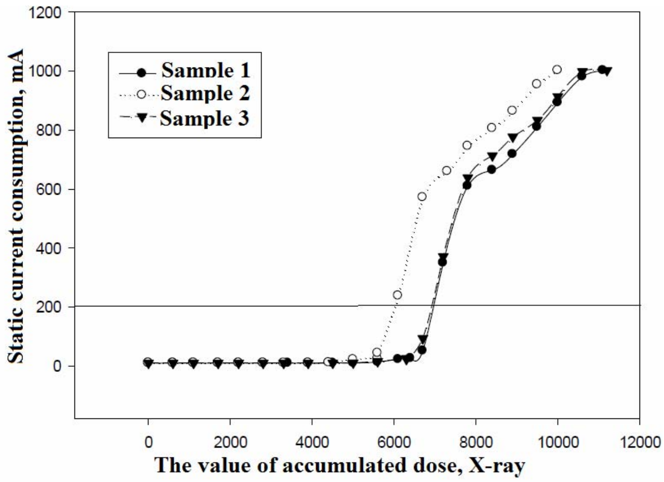

Fig. 1. Dependence of the static current consumption samples XQ4028EX-4CB228M chips from the value of accumulated dose

According to test results the following model parameters were obtained: $m(d_{TID})$=14120; $\sigma(d_{TID})$=2985; Π = 10400; the coefficient of variation ν = 0,211.

Based on the operating conditions, the parameters are obtained: m^*=7000 rad; σ*=1477; t_{LT} = 43800 hours.

Then, using equation (3), we can plot the alpha-distribution - curve distribution density of time to failure (see Fig. 2).

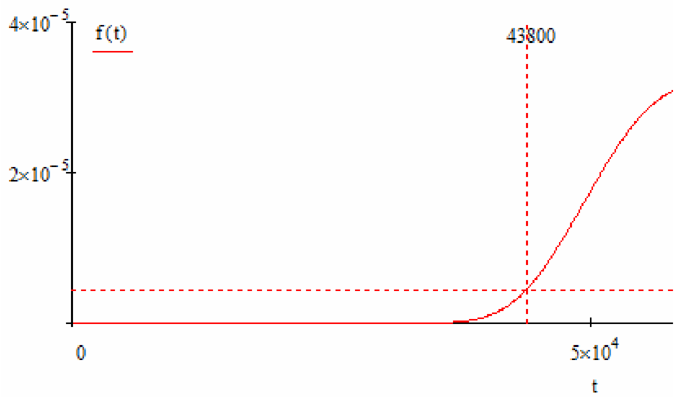

Fig. 2 - Graph distribution density from operating time to failure to chip XQ4028EX-4CB228M

For comparison, we will assess the probability of failure-free operation using alpha-distribution and the model described in the standard [9]:

$$P2(t)=2-\exp(K_R\cdot D)^2 \quad (6)$$

where K_R - coefficient of radiation damage to the chip; D - accumulated dose.

Radiation damage coefficient K_R is determined for each individual product in the tests. In this case, $K_R = 0{,}4\cdot 10^{-4}$ 1/rad, $D = m^*$=7000 rad.

Figure 3 shows graphs of the probability of failure-free operation built according to model (3) and (6).

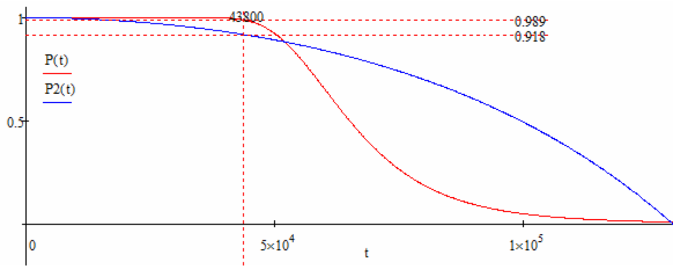

Fig. 3 - Graphics of probability of failure-free operation for models (3) and (6)

For the period of active life equal 5 years, the probability of failure-free operation under the influence of ionizing radiation of space, calculated by the model (3) is $P(t=43800)=0.989$, and by the model (6) - $P2(t=43800)=0.918$.

Now define the time to failure. The value of the minimum time to failure T_f is equal to the total operating time since the beginning of operation, in which the distribution density $f(T_f)\approx\lambda(T_f)$ first reaches a critical value $f_{cr}\approx\lambda_{cr}$. It is convenient to specify the critical value in δ parts from the value of the density distribution at the point of mode $\delta f(T_m)$. At the same T_f value for alpha-distribution can be found from the equation:

$$f(T_f) = \delta f(T_m),$$

where T_m – mode.

We set $g_f=T_f/\beta$. At that can be found the dependence of gf(α) as a graph or analytical expression. Operating time before the start of massive failures:

$$T_f = \beta g_f(\alpha)$$

Figure 4 shows the relationship between values λ_{cr} and T_f. According to the schedule is possible to determine the value of the minimum operating time through λ_{cr}.

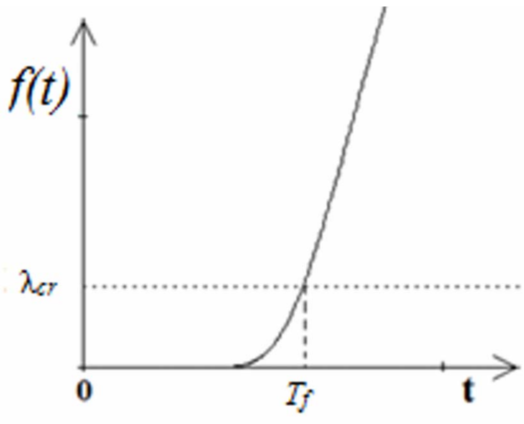

Fig. 4 - Connection between λ_{cr} and T_f

Knowing the value of T_f and using the ratio from [10], we can calculate the average resource $T_{av.res}= 2T_f$.

So for chip XQ4028EX-4CB228M value $\lambda_{cr}=3\cdot10^{-7}$, $T_f=70000$ hence, the average resource is equal $T_{av.res}=140000$. Knowing the value of average resource is possible to define if necessary durability and other parameters in accordance with predetermined requirements.

IV. Conclusion

To predict the indexes of radiation resistance, reliability and durability of the results of the tests carried out previously can be used in the radiation resistance of electronic components that are similar in functionality and design and technological implementation and belonging to the same process group.

The paper considers the approach to the research of reliability, including durability, taking into account the effect of ionizing radiation of outer space, on the example of modern FPGAs from Xilinx using alpha-distribution model.

However, the value of the level of resistance and reliability of integrated circuits depends not only on the characteristics of the distribution law of the maximum-tolerated dose, but also on the accumulated dose.

Therefore, if the predicted reliability evaluation indexes does not satisfy the requirements of one of the way to provide the required values of parameters of reliability is to reduce the value of accumulated dose

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