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THE PROJECT EVALUATION OF IC RELIABILITY AND RADIATION RESISTANCE

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The article discusses estimation of the probability of failure-free operation of spacecraft electronic systems under the influence of cosmic radiation. The article describes characteristics of ionizing radiation and the techniques for calculating the cumulative dose and probability of catastrophic failure. Main steps for the formation of the integrated circuit failure rate model under the low-intensity radiation exposure are illustrated.

Keywords: electronic systems, reliability, radiation influence

INTRODUCTION

Spacecraft electronic systems are exposed to various damaging factors during their operation in space. Major factors capable of damaging the electronic systems are: ionizing radiation, cosmic plasma, thermal radiation of the sun and planets, weightlessness, micrometeorites, cosmic vacuum, and closed volume of the surroundings.

Ionizing radiation consist of primary charged particles — heavy charged particles (protons, neutrons and ions), and secondary nuclear particles — products of nuclear reactions associated with the primary particles. The main ionizing radiation effects on the electronic systems are associated with ionization and nuclear energy losses of primary and secondary particles in the active and passive areas of semiconductors and integrated circuits (IC). There are two basic mechanisms of energy transfer from radiation to matter: ionization and substitution of atoms that cause degradation effects in the electronic systems. Depending on which type of mechanism dominates, subsequent parametric (or less frequently - functional) component failure may be reversible — relaxation phenomenon (dissipation of the charge brought on by radiation). Particles of higher energies lead to single event effects (SEE) — soft errors (recoverable) or herd errors (non recoverable). Hard errors concern Single Event Burnout (SEB) in power MOS, IGBT or power bipolar transistors, dielectric breakdown in gates (SEGR) or in capacitors, microdose-induced threshold voltage variation in MOS transistors. In bulk CMOS technology, PNPN parasitic structures may be triggered giving a Single Event Latch-up (SEL). SEL is associated with a strong increase of power supply current. SEL can be destructive by overheating of the structure and localized metal fusion, so it also can be considered as a hard error. A SEL needs a power cycle to be deactivated.

In addition the following may occur: change the transparency of optical media (radiation staining and/or cracking of optical glass), photonic noise in optoelectronic equipment due to radio-nuclear and cosmic radiation effects in optical components, breakdown and cracking of insulating materials due to electrification of dielectrics and radiation-induced chemical reactions, reduction of power supply sources due to the degradation of solar panels, etc.

1. RADIATION ENVIRONMENT MODEL

Electronic system is influenced by many different factors, each may cause a malfunction or failure of entire system.

The main sources of ionizing radiation in space are:

- Electrons and protons from natural radiation belts;
- Solar cosmic rays;
- Galactic cosmic rays.

Models describing the radiation environment, tend to be based on the following assumptions:

- Particle flows are omni-directional (isotropic);

- Orbital integration is presented for different heights and angles of incedent;

- Data on the spatial distribution of the charged particles are usually presented in the (L, B)-coordinates (L - orbit height normalized to the radius of the Earth; B - magnetic field);

- Given fluence φ (> E) [cm-2s-1], which is the rate of change of the fluence at all energies above the threshold energy E;

- Given the differential flux density φ (E) [cm-2s-1 MeV-1], which is a rate of change in the fluence dependent on the particle energy for a certain level of energy;

- Models correspond to certain periods of time and, therefore, refer to the conditions of the solar minimum or solar maximum.

Currently there are two accepted models - AE-8 (AE-8min, AE-8max) and AP-8 (AP-8min, AP-8max), which describe the distribution of electrons and protons for minimum and maximum solar activity. These models are the spatial distributions of electrons with energies of 0.1-10 MeV and protons with energies 0.1-400 MeV, respectively.

Such characteristics of solar cosmic rays as streams of charged particles and energy spectra vary greatly from flash to flash. Ions of heavier elements that make up the solar cosmic rays generally do not contribute substantially to the total amount of absorbed dose. However, they can cause malfunctions and failures due to the effects of individual nuclear particles. In assessing these effects it is necessary to use integral energy spectra of protons and spectra of linear energy transfer (LET) of ions.

Despite the fact that, traditionally, it is assumed that the accumulation of dose occurs uniformly (irradiation intensity is constant), there is a large range in the dose intensity, mainly due to the period of the solar cycle and other characteristics of space weather [1, 2].

2. METHOD OF PREDICTING THE RELIABILITY OF ELECTRONIC SYSTEMS WHEN EXPOSED TO IONIZING RADIATION

It is customary to consider the following two related issues separately: ensuring reliability of electronic and software systems and radiation resistance of electronic systems. Under conditions of a long-term space mission, radiation exposure of electronic systems has damaging effects on thermal and electric modes of electronic components and output characteristics of the electronic system. As a result, the problem of "radiation safety", as of yet, has not been fully resolved because of the lack of reliable methods and the appropriate methodological and normative support.

Existing standard documents provide a separate evaluation of the reliability and radiation resistance, as if they were two independent indicators of electronic systems quality. Reliability of electronic components for the current technical conditions is characterized by failure rate. Radiation resistance parameters of electronic components is given in the specification and corresponds to the maximum dose of radiation exposure after which the electronic component parameters remain within the limits of technical terms. Measure of resistance of electronic components to the effects of low-intensity cosmic radiation is the safety factor, defined as the ratio of the total ionizing dose (TID) and dose electronic component had gained during spacecraft active lifetime.

When ionizing CMOS IC charge point defects of silicon oxide and partly charging major technological defects occurs. Under conditions of low-intensity radiation diffusion processes of natural aging and radiation defect formation become influenced each other and enhance the degradation of the electrical parameters of IC in general.

According to the guidance document [3], resulting failures in an IC can be divided into two classes:

- Failures of the 1st kind - direct radiation failures arising from exposure to ionizing radiation;
- Failures of the 2nd kind - random IC failures when tested on reliability due to degradation processes, which can be affected (or not affected) ionizing forcing.

Applying electronic components of "Space" quality level almost completely eliminate the contribution of the 1st kind failures in the total number of failures. However, for well known reasons, in electronic systems ICs of "commercial" quality level are widely used, which have a relatively low resistance to ionizing radiation. This increases the likelihood of failures during their operation.

IC failure probability is calculated as:

$$Q(t_{LT}) = 1 - P(t_{LT}),$$

where: $Q(t_{LT})$ - the IC probability of failure; $P(t_{LT})$ – the probability of failure-free operation, estimated by the equation:

$$P(t_{LT}) = P_1(t_{LT}) \cdot P_2(t_{LT}) \cdot P_3,$$

where: $P_1(t_{LT})$ - the probability of failure-free operation under the low-intensity irradiation; $P_2(t_{LT})$ - the probability of failure-free operation in the absence of exposure to cosmic radiation; P_3 - the probability of failure-free operating under the impact of single nuclear particles; t_{LT} - active lifetime.

Failure probability under the low-intensity irradiation Q_2 is estimated by the equation:

$$Q_2(t_{LT}) = 1 - P_1(t_{LT}) = 1 - e^{-\lambda_{rel} \cdot t_{LT}},$$

where: λ_{rel} - the failure rate in the absence of exposure to radiation; t_{LT} - active lifetime.

The IC probability of failure due to the SEE is estimated by the equation [3]:

$$Q_3 = 1 - P_3 = \exp(-\nu \cdot t_w),$$

where: ν - frequency of IC probability failures due SEE; t_w - the time of IC operating mode.

The frequency of IC probability failures due SEE is estimated by the equation:

$$\nu = \int_{L0}^{Lmax} \sigma(L) \cdot \varphi_{\text{ТЗЧ}}(L) dL + \int_{E0}^{Emax} \sigma(E) \cdot \varphi_p(E) dE,$$

where: σ (L), σ (E) - the cross-sections of the single effects LET of the charged heavy particles and the protons energy, respectively.

Thus, to use the model to estimate the probability of IC failure we need to estimate the contribution of low-intensity radiation to the failures rate.

Since the failures of the 1st kind are not connected with the internal mechanisms of failure formation in IC, they do not depend on time, in other words they depend only on the probability that IC accumulate the limit dose - D_{TID}. Therefore, the possibility to accumulate limit dose may be presented as a function of a constant distribution of the sensitivity of IC to ionizing radiation. Radiation intensity is assumed constant.

Thereby draw a parallel between failures IC caused by exposure to ionizing radiation, and failures due to electrostatic discharge (ESD) may be denoted. This allows one to use a method of forming a model failure rate for CMOS IC [4], according to which the probability of failure-free operation is:

$$Q_1 = \int_0^{t_{LT}} f(D_{TID}) = \int_0^{t_{LT}} \frac{C}{\sigma(D_{TID})\cdot\sqrt{2\cdot\pi}} \cdot exp\left(\frac{\left(\frac{D_D - M(D_{TID})}{\sigma(D_{TID})}\right)^2}{2}\right),$$

where: $f(D_{TID})$ – the probability density of failures (fig. 1); $M(D_{TID})$ - the mathematical expectation level of radiation resistance; $\sigma(D_{TID})$ - standard deviation; D_D – actually accumulated dose; C – the normalizing factor.

$$C = \frac{1}{F(D_{TID.max}) - F(D_{TID.min})},$$

where: $F(D_{TID.max})$, $F(D_{TID.min})$ - the values of the normal distribution function.

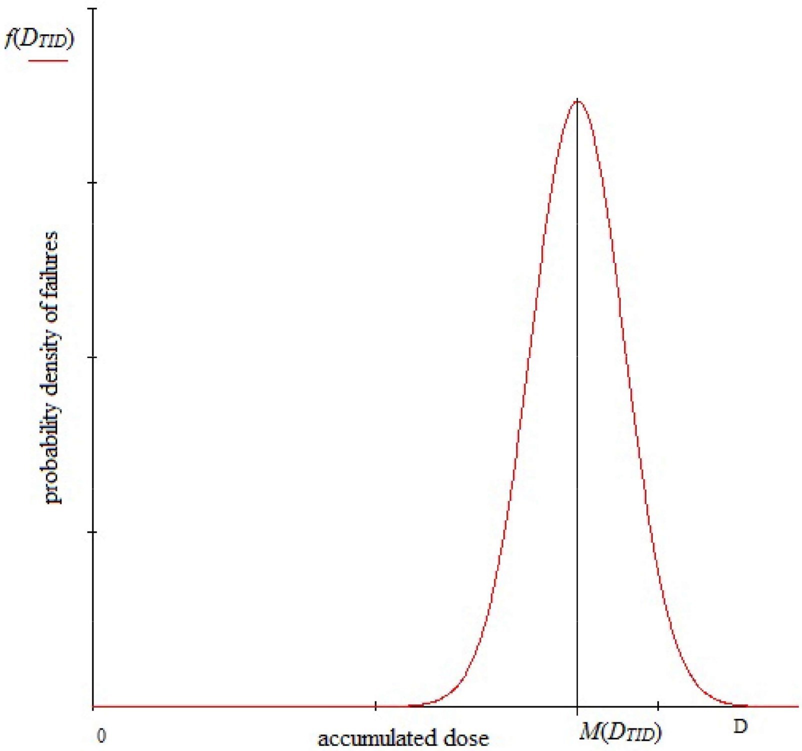

Fig. 1. Schematic graph of the probability density of failures

However, to estimate only the reliability is not enough to justify the possibility of using IC in terms of exposure to cosmic radiation.

Since IC correspond to the products of general purpose type I, it is characterized by continuous long-term use, unrecoverable, maintenance-free, which is a transition in the limit state leads to disastrous consequences, fraying, aging during storage.

For such products the following reliability indices are normalized:

- Failure rate;
- Average resource;
- Medium period of the conservation.

That is necessary to determine the IC minimum time to failure (MTTF) T_{MTTF}.

IC limit state criteria, according to [5], is formulated as "Increasing failure rate above the permissible level λ_{max}».

The value λ_{max} can be obtained by knowing the values of Q_1 and t_{LT} from equation:

$$1 - Q_1 = e^{-\lambda_{max} \cdot t_{LT}}.$$

Hence:

$$\lambda_{max} = -\frac{\ln(1-Q_1)}{t_{LT}}.$$

To evaluate T_{MTTF} the methodology described in [6] for the prediction of reliability and durability is used. Also suitable probabilistic and physical failure models recommended in [6] are used.

According to [4], the distribution function of time to failure IC is an α-distribution:

$$f(t) = \frac{C \cdot \beta}{t^2 \cdot \sqrt{2 \cdot \pi}} \cdot e^{-\frac{\left(\frac{\beta}{t} - \alpha\right)^2}{2}},$$

where: α, β – distribution parameters.

Parameter α – the relative rate of change of a characteristic parameter (uniformity coefficient determines the rate of change of the parameter)

$$\alpha = \frac{D_D}{\sigma(D_{TID})}.$$

Parameter β - relative reserve of durability:

$$\beta = \frac{M(D_{TID}) \cdot t_{LT}}{\sigma(D_{TID})}.$$

When using this model, the value T_{MTTF} equal to electronic equipment operating time t, in which the density distribution $f(t) \approx \lambda(t)$ first reaches a critical value $f_{critical}(t=T_{MMTF}) \approx \lambda_{max}$ (fig. 2.) [3]. Then the value T_{MTTF} can be found from the equation:

$$\lambda_{MAX} = \frac{C \cdot \beta}{T_{\text{М.Н.}}^2 \cdot \sqrt{2 \cdot \pi}} \cdot e^{-\frac{\left(\frac{\beta}{T_{\text{М.Н.}}} - \alpha\right)^2}{2}},$$

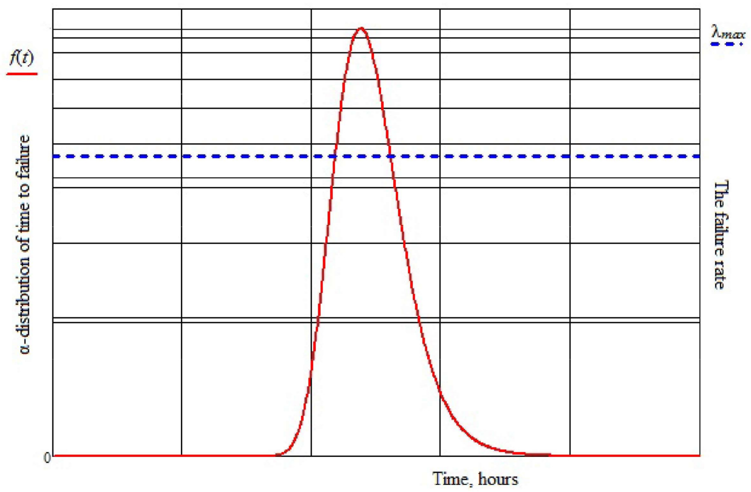

Fig. 2. Schematic graph of α-distribution of time to failure and failure rate

Estimation of the effect of radiation on the probability of failure-free operation of IC can be calculated by values P1(t) and P2(t), where:

$$P1(t) = e^{-\lambda_{rel} \cdot t},$$

$$P2(t) = e^{-(\lambda_{rel} + \lambda_{\max}) \cdot t},$$

CONCLUSION

Primarily research is aimed to analyze the reliability of electronic equipment of spacecraft considering the influence of ionizing radiation. At the given stage the model was built to estimate the probability of failure at the impact of low-level radiation on the IC.

Based on the results of previous tests for radiation resistance model parameters were calculated – mathematical expectations, standard deviation, and the normalizing factor for CMOS IC. That allow approximately estimate the minimum time before failure.

In conclusion, it should again be noted that the coefficients of the model depend not only on the strength of IC, but also the characteristics of the orbit of the spacecraft [7], so it is necessary to assess the probability calculations for specific values of the height and angle of inclination.

In addition, to improve the accuracy of estimation of resistance IC, they should be divided by technological groups (analog, digital, memory chips, FPGAs, microprocessors, etc.) and for each of them to get the model parameters.

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METHOD OF PARALLEL INFORMATION PROCESSING FOR THE OPTICAL SWITCHBOARD

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The problem of developing a method of high-speed information processing in the optical switching systems is solved. This method will allow to increase information transfer speed in switching structure also won't demand the high-capacity optical buffer device and will allow to apply optical switchboards in high-performance computing systems and communication systems. The algorithm of search of free channels of the data, realized in the microcontroller is simulated.

1. Introduction

We can't present modern computer facilities, communication systems, managements and processing of signals without application of optical technologies. It is dictated by modern requirements: increase in information capacity of channels, speed of processing of messages and increase of reliability of communication systems.

Transformation of an optical signal in electric and back reduces information processing speed, however, the majority of network problems while is solved on the basis of electronic