

PAPER • OPEN ACCESS

Evaluation of time to failure for radio transmitters under the radiation influence

To cite this article: M A Artjuhova *et al* 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **537** 022016

View the [article online](#) for updates and enhancements.



IOP | ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the **collection** - download the first chapter of every title for free.

Evaluation of time to failure for radio transmitters under the radiation influence

M A Artjuhova¹, V M Balashov¹, S A Nazarevich² and M S Smirnova²

¹Joint-stock company «Scientific and Production Enterprise “Radar MMS”» 37
Novoselkovskaya Str., Saint-Petersburg, Russia

²Federal state autonomous educational institution of higher education “Saint-Petersburg State University of Aerospace Instrumentation”, 67 A, Bolshaya Morskaya str., 190000, Saint-Petersburg, Russia

E-mail: artjuhova_ma@radar-mms.com

Abstract. Aerospace systems occupy an important place in the information, telecommunication, defense infrastructure of the country. These systems have strict requirements for safety and reliability. The study of dependability allows you to find the distribution of device operating time to failure. This is especially important for the non-recoverable onboard equipment of aerospace systems. Practice shows that even 5 years of active life is difficult to achieve, and for profitability it is required to ensure 2-3 times more. For such a period of operation, the radio transmission devices of spacecraft are exposed to prolonged exposure to ionizing radiation of natural origin. This leads to accelerated aging of materials, degradation of parameters of the electronic component base and single effects of failures and failures in semiconductor devices and integrated circuits, which must be taken into account when analyzing the reliability of newly developed and modernized devices.

1. Introduction

Usually, among the characteristics of the product, you can choose the main one, which determines its performance. This characteristic is called the defining parameter. Changing randomly during work or storage, the defining parameter reaches a critical value, after which the product fails. In a system consisting of many elements, the critical value of the determining parameter of each element depends on the position of the element in the system. The critical value of the determining parameter is called the boundary of the working area.

Failures associated with the variation of parameters beyond the boundaries of the working area are called gradual, they are preceded by the accumulation of some changes inside the product. These changes occur during the natural processes of aging and depreciation, and are also accelerated when exposed to various external factors.

Onboard electronic equipment of aerospace systems during operation may be exposed to vibrations, overloads, high temperatures, low pressure, electromagnetic fields and pulses, radiation of natural and artificial origin. All of these factors adversely affect reliability performance. The relationship of reliability and some of the external influencing factors is very well studied - for example, the effect of high temperatures on the failure rate. The consideration of other factors in the design, such as radiation, is not fully carried out [1].



2. Chip AT28C256F-25FM/883 analysis

For example, consider the effect of radiation on the operating time to failure of the AT28C256F-25FM / 883 chip (figure 1). Memory chip (EEPROM) AT28C256F-25FM / 883 is manufactured by Atmel on CMOS technology. The capacity of the chips is 256 kbps. In 2010, 5 samples were tested for resistance to a cumulative dose as part of the certification of elements for a complete set of onboard equipment of the "Resource P" spacecraft [2].

Figure 2 shows the dependences of the current consumption in storage mode with TTL and CMOS compatibility. The failure rate for TTL compatibility is 4.8 kR, for CMOS compatibility - 2.4 kR.

The functional failure of the AT28C256F-25FM / 883 chip in recording mode occurs at a level of 1.2 kR. Functional failure of the read mode is 7.2 kR.

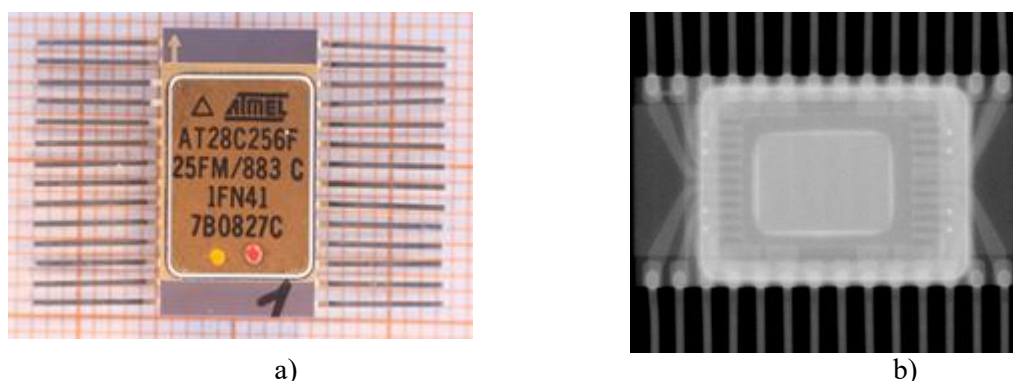


Figure 1. Sample AT28C256F-25FM / 883: a) photograph, top view of the case, b) x-ray photograph, top view of the case.

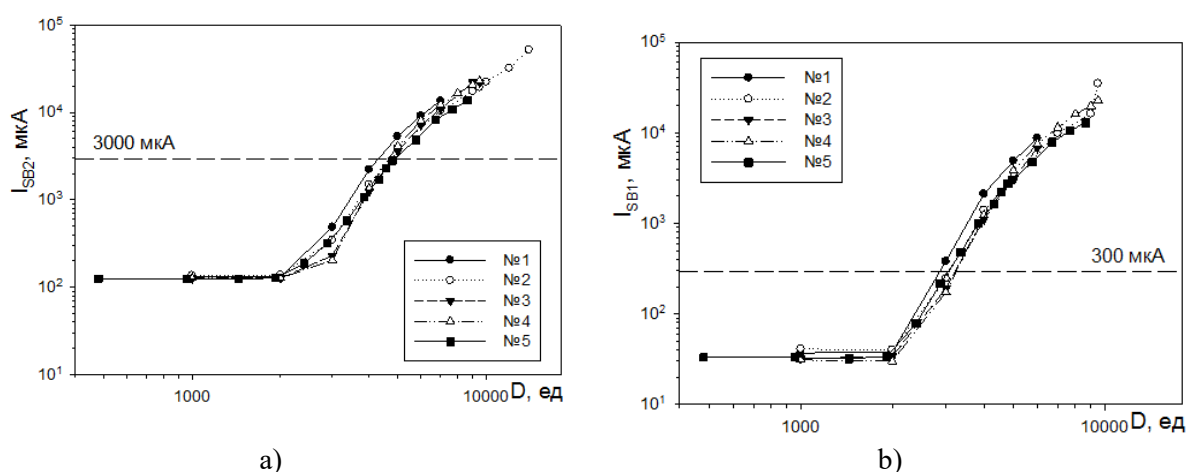


Figure 2. Dependence of current consumption in storage mode: a) with TTL compatibility (I_{SB2}) on the value of the exposure dose, b) with CMOS compatibility (I_{SB1}) on the value of the exposure dose.

Thus, the value of the operating time to failure AT28C256F-25FM / 883 chip depends on the radiation intensity and the selected operating mode. Under irradiation conditions, this must be taken into account when assessing the reliability indicators. [1, 3-6].

3. Operation analysis

Testing of a product or its component parts is always more preferable than analysis by computational methods or modeling. However, it is often impossible to imitate the whole complex of external influences. Therefore, they use data on the operation of analogues. There are a number of techniques

to assess the reliability of the equipment even in the absence of failures. However, the reliability of the estimates thus obtained strongly depends on the volume of statistical data.

The transmitter is part of the onboard equipment of a high-speed radio link installed on "Resource P" products (table 1).

Table 1. The lifetime of products "Resource P".

Product	Start of operation	End of operation	Lifetime
"Resource P" №1	25.06.2013	Until now	5 years 6 months
"Resource P" №2	26.12.2014	26.11.2018	
"Resource P" №3	13.03.2016	19.05.2017	5 months

To assess the reliability of the transmitter, we use data on the operation of products No. 1 and No. 3, the timing diagram of censoring is shown in Fig. 3. These products were chosen for the reason that the transmitter works well in the product No. 1, and it is reliably known that it was he who failed in product No. 3.

Such controlled operation is similar to the tests without fixing the time to failure when evaluating the probability of failure-free operation for the operating time T . In this case, the binomial distribution is used to estimate the probability of failure-free operation [8]. For evaluation, we take the value of the confidence probability $q=0,9$.

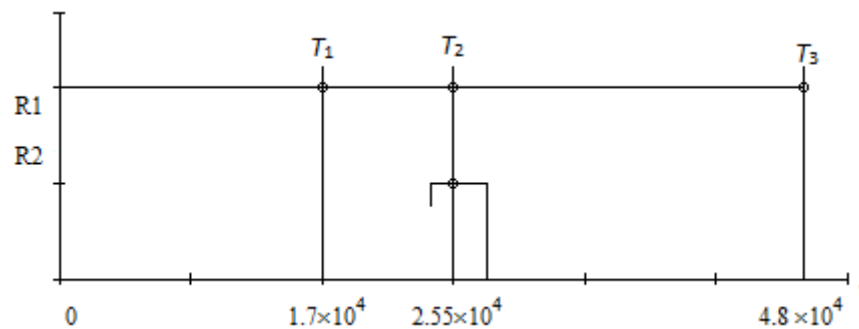


Figure 3. Timing diagram of censoring.

Let us estimate the lower limit of the probability of failure-free operation for three moments of censoring. At the moment of time $T_1=17000$ h one product is in operation, that is, the number of samples $N=2$, number of failures is $d=0$. Then $\underline{P}(T_1) = 0,900324$.

At the moment of time $T_2=25500$ h, $N=4$, $d=0$, $\underline{P}(T_2) = 0,948854$.

To the moment $T_3=48000$ h there was a failure of transmitters of the product "Resource P" № 3, therefor, $N=4$, $d=2$, $\underline{P}(T_3) = 0,798452$.

Knowing the lower limit of the probability of failure-free operation and the time interval, we can calculate the upper value of the failure rate and build the dependence on time (figure 4).

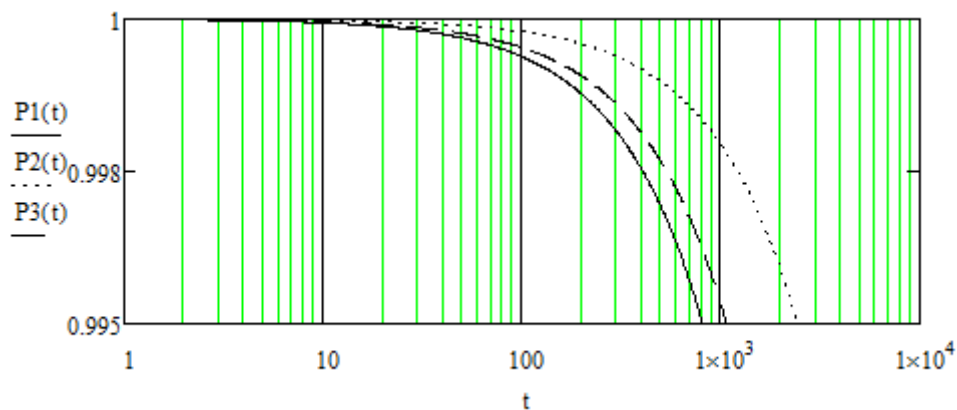


Figure 4. Dependence of the probability of failure-free operation of a radio transmitting device on time from the results of the operation analysis.

4. The use of α -distribution to account for the effect of the accumulated dose on time

In order to take into account the influence of radiation when estimating the time to failure it is necessary to build a mathematical model. As an approximate project estimate, the probability of a component failing under the cumulative dose exposure conditions can be represented as the product of two probabilities, assuming the independence of events:

$$P(t) = e^{-\lambda t} \cdot P_d(t), \quad (1)$$

where $P_d(t)$ - probability of failure-free operation of the element when exposed to the accumulated dose;

λ – the failure rate of the element, not dependent on radiation, but taking into account the electrical mode of operation, temperature and mechanical loads, etc.

When the resistance of an element is commensurate with the level of exposure to determine the probability $P_d(t)$, [6] it is suggested to use a model based on α -distribution. This model does not directly depend on the intensity of exposure, the initial parameters for it are the characteristics of the resistance of the element and the level of exposure. The α -distribution parameters characterize the process of approaching the state under consideration - the attainment of the margin of the tolerance field by a determining parameter. The probability $P_d(t)$ is determined as:

$$P_d(t) = 1 - \int_0^t \frac{\beta}{t^2 \sqrt{2\pi}} e^{-\frac{1}{2} \left(\frac{\beta}{t} - \alpha \right)^2} dt, \quad (2)$$

where α is the relative rate of change of the process, β is the relative margin of durability.

In the simplest case, for a device consisting of N series-connected elements, model (1) taking into account model (2) takes the form:

$$P_{dev}(t) = \prod_{i=1}^N e^{-\lambda_i t} \times \prod_{k=1}^K \left(1 - \int_0^t \frac{\beta_k}{t^2 \sqrt{2\pi}} \cdot e^{-\frac{1}{2} \left(\frac{\beta_k}{t} - \alpha_k \right)^2} dt \right), \quad (3)$$

where α_k , β_k are the parameters depending on resistance to the accumulated dose of the k -th element [6]; K - the number of elements having a safety factor in resistance to the accumulated dose lower than the required one, $K \leq N$.

Let us consider a radio transmission device consisting of two channels: a device for channel A, a device for channel B, and a common controller. Operation group is 5.3 according to [7], the active life - 5 years.

A generalized block diagram of the transmitter reliability is shown in figure 5. The device of channel B is in an unloaded reserve relative to the device of channel A. It is obvious that the weak point of the device is the controller responsible for switching between channels.

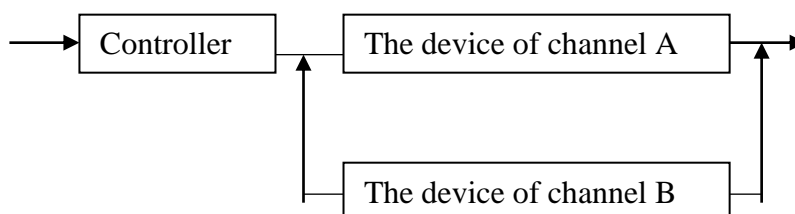


Figure 5. Structural diagram of the reliability of the radio transmitting device.

Evaluation of the protective capabilities of the device design from the effects of penetrating radiation on the elements located inside the device is carried out using the radiation geometry model of the device. Structurally, the model of the device is represented as a parallelepiped. The magnitude of mass protection for the “worst case” is 1.24 g/cm². In accordance with the operating model, the accumulated dose level for the minimum protection is 1.56 10³ rad.

Table 2. List of items that do not meet the requirements of resistance to the effects of the accumulated dose.

№	Name	The level of resistance, units
1	AT28C256F-25FM/883	4,8·10 ³
2	MQ80C186-10/BYA	3,0·10 ³
3	LM2991SX	5,5·10 ³
4	TPS75825KC	2,7·10 ³

From table 2 it can be seen that the safety factor [9] is 1.73. The probability of failure-free operation is estimated using model (3) (table 3). The required value of the probability of failure-free operation for the period of active existence of 5 years $P = 0.9995$. The total probability of failure-free operation meets the requirements of the technical specifications, which, however, is not consistent with the data of operation.

Table 3. The results of the calculation of the probability of failure of the transmitter.

Probability of uptime	Value
Probability $P_d(t)$	0,99996
Probability $e^{-\lambda t}$	0,99987
Final	0,99983

As can be seen, model (3) takes into account only gradual failures, since they are relatively easy to predict. However, besides the gradual degradation of the product, the effects of radiation can also lead to sudden failures - single effects: failures and catastrophic failures. In general, single effects depend on the sensitivity parameters of the elements and the characteristics of external effects [10] and the probability of their occurrence follows an exponential law. When the development of the equipment of the "Resource P" product began, there were no requirements for resistance to the effects of charged particles on single effects.

5. Conclusion

According to the regulatory documentation, the adequacy of the applied analysis methods is characterized by “full use in the calculation of all available information about the object, conditions of its operation, maintenance and repair, characteristics of the reliability of the component parts, properties of substances and materials used in the object” [11]. Analysis of the reliability of the designed equipment is one of the main problems in the development of individual highly reliable products. Basically, this is due to the inability to conduct some research in the laboratory and the lack of statistical data on the operation. The situation with the consortium of "Resource P" spacecraft clearly shows that in order to ensure the reliability of non-recoverable aerospace systems, a comprehensive detailed analysis of the types, consequences and criticality of failures is of primary importance [12].

The presented model based on α -distribution allows to increase the accuracy of reliability assessment, taking into account operating conditions in more detail, which meets the provisions of the standard [11]. In order to obtain greater reliability in analyzing the impact on the product reliability of the design and production stages of the product, it will be reasonable to adapt the method [13] of using the multifactor quality factor of the equipment production.

References

- [1] Wang Q, Chen D and Bai H 2016 A method of space radiation environment reliability prediction *IEEE Annual Reliability and Maintainability Symposium (RAMS)* (Tucson; United States) 7448073
- [2] LSI Test Report AT28C256F-25FM/883 for Resistance to Special Factors JKNU.IC0941.01.0006-PRD 2010 (Moscow: OJSC ENPO SPELS)
- [3] Gobchansky O and Popov V 2001 Increasing the radiation resistance of industrial automation equipment as part of the onboard equipment *Modern Automation Technology* (Moscow: STA-Press) **4** pp 36-40
- [4] Myrova L and Chepizhenko A 1988 *Ensuring the durability of communication equipment to ionizing and electromagnetic radiation* (Moscow: Radio and communication)
- [5] Guiding document RD 11 1003-2000. Semiconductor electronics products. Method for predicting the probability of failure-free operation under conditions of low-intensity ionizing radiation 2000 (St. Petersburg: Electronstandard)
- [6] Artyukhova M and Zhadnov V 2015 Prediction of reliability indicators of the onboard equipment of spacecraft when exposed to low-intensity ionizing radiation *Dependability* (Moscow: Dependability) **1** pp 13-8
- [7] GOST RV 20.39.304. 1998 A comprehensive system of general technical requirements. Instruments, devices, devices and equipment for military purposes. Requirements of resistance to external influencing factors (Moscow: Rosstandart)
- [8] 8RD 50-690-89. 1990 Methodical instructions. Reliability in technology. Methods for assessing reliability indicators from experimental data (Moscow: Standards Publishing House)
- [9] OST 134-1034-2012. 2012 Instrumentation, devices, instruments and equipment of spacecraft. Test methods and assessment of the resistance of the onboard radio-electronic equipment of spacecraft to the effects of electron and proton radiation of outer space according to dose effects
- [10] RD 134-0139-2005. 2005 Equipment, instruments, devices and equipment for spacecraft. Methods for assessing resistance to the effects of charged particles of outer space for single failures and failures
- [11] GOST 27.003 2016 Industrial product dependability. Contents and general rules for specifying dependability requirements (Moscow: Standartinform)
- [12] GOST 27.310-95. 2002 Dependability in technics. Failure mode, effects and criticality analysis. Basic principles (Moscow: Standards Publishing House)
- [13] RIAC-HDBK-217Plus 2006 *Handbook of 217 Plus reliability prediction models* (USA: RIAC)