


Kofanov Yu.N., Strelnikov V.P.

METHODOLOGICAL IMPRECISION OF PREDICTION OF ELECTRONICS' MEAN LIFE TIME

The paper presents the methods for evaluating the mean time to failure (MTTF) of electronics products based on the application of DN distribution for various experimental and reference data on reliability – failure rate, failure probabilities, minimal time to failure, FIT. It is noted that MTTF predictive estimates based on exponential distribution are overstated by 70-500 times as compared to those based on DN distribution.

Keywords: *reliability, quantile, time to failure distribution (resource), mean time to failure (MTTF).*

Introduction

To solve practically all problems of reliability, we use specific theoretical models of reliability (time to failure distribution functions). Researchers of equipment reliability have recently used solutions of various reliability problems based on application of various theoretical models of reliability (exponential, Weibull, logarithmical normal, diffusive [1] and other distributions [2, 3]), which lead to substantial discrepancies of final results. Below you can find the results of assessing (predicting) the mean time to failure of electronic devices (ED) obtained with the use of various theoretical models of failures.

Assessment and prediction of ED mean time to failure

Modern hardware components are electronics products that feature rather high reliability. Owing to this, ED mean time to failure (MTTF) as a feature needed by ED producers as well as by developers of technical systems can only be assessed by a parametrical method, i.e. by means of application of respective theoretical models of time to failure. The application of one or another theoretical model of failures stipulates corresponding methodological imprecision of MTTF assessment. And the reliability of electronic devices is such that testing manages to provide products life corresponding to the experimental failure probability $F(t)$ =0,0001...0,0005, and based on these results, it makes it possible to predict mean time to failure of these products. It is known [4,5] that prediction of a mean value for quantiles of the specified probability level while using a one-parametric exponential law leads to overstatement of assessment by several orders of magnitude as compared to the known two-parametric laws. Naturally, the prediction of ED mean time to failure based on two-parametric distributions is more precise.

Below you can find the results of research and the causes of variation of predicted MTTF estimates using various theoretical functions of time to failure distributions exemplified by integrated circuits (IC).

To reduce the volume of testing for IC reliability assessment, major producers of electronic components make accelerated testing capable of getting assessments of reliability parameters for the time considerably shorter than the real longevity of IC. The main way to reduce testing duration is to force IC operation modes by temperature accelerating the basic physical and chemical processes of degradation of electronic components.

Acceleration coefficient A_t in relation to temperature is defined by researches according to the Arrhenius law:

$$A_t = \exp\left[-\frac{E_a}{k}\left(\frac{1}{T_f}-\frac{1}{T_n}\right)\right],$$

where E_a is the energy of activation (for IC $E_a = 0{,}7eB$); k is the Boltzmann constant (k = 8,617·10^{-5}); T_f is the temperature at which forced testing was made (in K); T_n is the operation temperature of components (in K). IC testing for reliability under increased temperature is generally made according to MIL-STD-883, method 1005 [6].

Table 1 presents acceleration coefficients in relation to temperatures of forced testing used by researchers [6,7] based on the above theoretical assumptions. However there is no experimental proof of these data and it is practically impossible to get it, as it is almost not real to get statistical data in normal operation conditions.

Table 1. Acceleration coefficient values in relation to forced testing temperatures

IC testing temperature, °C	IC operation temperature, °C	Coefficient A_t
150	55	258
140	55	162
135	55	128
125	55	77
100	55	20

The level of modern IC reliability is so high that even forced testing for reliability under increased temperature doesn't make it possible to identify the reliability parameters of some integrated circuits. Therefore, assessment of reliability parameters is done in generalized form and the parameters are grouped as to types of technology or rather numerous classes of integrated circuits. Thus, input data of reliability assessment (generally failure rate) includes methodological imprecision of temperature conversions as well as influences of various technological processes related to manufacture of individual integrated circuits.

Prediction of IC MTTF based on the results of experimental assessment of failure rate

As source data, quite huge results of testing of BiCMOS integrated circuits produced by Analog Devices [7] are used. [6] shows that IC like BiCMOS has reliability of FIT=5. FIT value was defined based on testing of N=26980 samples, and in this case the product (IC)×(hour))=EDH (total time of testing), i.e. EDH = 2763317240 hour, the number of failures for observation time r = 12. We shall calculate the mean time to failure T_0 (MTTF) of this IC.

Let us define the averaged time of testing for each sample: $\tilde{t}_н = \frac{\text{EDH}}{\text{N}} = 102420$ h. Now we calculate the experimental failure rate: $\tilde{\lambda}(\tilde{t}_н) = \frac{FIT}{10^9} = 5\cdot10^{-9}\,1/h$. Then we calculate the failure probability for moment $\tilde{t}_н$: $F(\tilde{t}_н) = \frac{r}{N} = 0{,}00044.$

Since there is no statistical data for assessment of parameters of two-parametric distributions, we assume that the variation coefficient of time to failure distribution is equal to entity (v = 1), as for exponential distribution. Note that researchers using a one-parametric exponential distribution to solve tasks automatically assume that the variation coefficient of time to failure distribution is equal to entity. Then using the source data ($\tilde{t}_н$, $\tilde{\lambda}(\tilde{t}_н)$, $F(\tilde{t}_н)$) and various theoretical functions time to failure distribution (exponential (E), Weibull (W), logarithmical normal (LN), DN and DM distributions) we get predicted MTTF estimates:

Exponential distribution: $T_0^E = \frac{1}{\tilde{\lambda}(\tilde{t}_н)} = \frac{1}{5\cdot10^{-9}} = 2\cdot10^8\,h = \frac{200000000}{8760} \cong 22830$ *years*.

Weibull distribution: with the variation coefficient equal to entity,

$$T_0^W = T_0^E = 22830 \text{ years}.$$

Logarithmical normal distribution:

The parameter of σ form of logarithmical normal distribution can be calculated from the following relation:

$$\sigma = \sqrt{\ln(\nu^2+1)} = \sqrt{\ln 2} = 0{,}833.$$

The parameter of a size of logarithmical normal distribution is calculated from the relation for failure probability:

$$\tilde{F}(\tilde{t}_н) = \Phi\left(U_{\tilde{t}_н}\right) = \Phi\left(\frac{\ln\tilde{t}_н - a}{\sigma}\right) = 0{,}00044;$$

hereinafter Φ(·) is the function of standardized normal distribution;

$$a = \ln\tilde{t}_н - \sigma U_{\tilde{t}_н} = \ln 102420 - 0{,}833\cdot(-3{,}33) = 14{,}31.$$

The mathematical expectation of time to failure:

$$T_0^{LN} = \exp\left(a+\frac{\sigma^2}{2}\right) = \exp(14{,}657) =$$

$$2316168\ h = \frac{2316168}{8760} = 264 \text{ years}.$$

Diffusive monotonous distribution (DM distribution):

The parameter of DM distribution v = 1.

The parameter of μ size of DM distribution is calculated from the relation for failure probability:

$$\tilde{F}(\tilde{t}_и) = DM(t;\mu,\nu) = \Phi\left(\frac{\tilde{t}_и - \mu}{\nu\sqrt{\mu\tilde{t}_и}}\right) = 0{,}00044;$$

$$\mu = \tilde{t}_и\left(1 + \frac{\nu^2 U^2_{\tilde{t}_и}}{2} - \nu U_{\tilde{t}_и}\sqrt{1 + \frac{\nu^2 U^2_{\tilde{t}_и}}{4}}\right) =$$

$$=102420\left(1 + \frac{(-3{,}33)^2}{2} + 3{,}33\sqrt{1 + \frac{(-3{,}33)^2}{4}}\right) = 1332694 \text{ h.}$$

The mathematical expectation of time to failure:

$$T_0^{DM} = \mu\left(1 + \frac{\nu^2}{2}\right) = 1332694 \cdot 1{,}5 =$$

$$= 1999041 ч = \frac{1999041}{8760} = 228 \textit{ years.}$$

Diffusive non-monotonous distribution (DN distribution):

The parameter of DN distribution $v = 1$.

The parameter of μ size of DN distribution is calculated from the relation for failure probability:

$$\tilde{F}(\tilde{t}_и) = DN(t;\mu,\nu) = \Phi\left(\frac{\tilde{t}_и - \mu}{\nu\sqrt{\mu\tilde{t}_и}}\right) +$$

$$+\exp\left(\frac{2}{\nu_2}\right)\cdot\Phi\left(-\frac{\tilde{t}_и + \mu}{\nu\sqrt{\mu\tilde{t}_и}}\right) = 0{,}00044;$$

$$\mu = \frac{\tilde{t}_и}{x(\tilde{F}(\tilde{t}_и);\nu)} = \frac{102420}{x(0{,}00044;1)} = \frac{102420}{0{,}0699} =$$

$$= 1465236 \textit{ h.}$$

Value $x(F; v)$ of relative time to failure $x = \tilde{t}_и / \mu$ is defined from the respective tables of DN distribution as per values F and v, or from solving the equation

$$\Phi\left(\frac{x-1}{\nu\sqrt{x}}\right) + \exp\left(\frac{2}{\nu^2}\right)\cdot\Phi\left(-\frac{x+1}{\nu\sqrt{x}}\right) = F.$$

The mathematical expectation of time to failure as per DN distribution:

$$T_0^{DN} = \mu = 1465236 ч = \frac{1465236}{8760} = 167 \textit{ years.}$$

The above predictive MTTF calculation of considered IC was done upon the assumption that the value of variation coefficient of IC time to failure distribution is equal to entity (v = 1). The experience of electronic systems operation suggests that a more correct value of variation coefficient of time to failure of electronic devices in operation modes, including IC, will be v = 0,8. Table 2 below presents MTTF predictive estimates of considered IC based on the hypothesis v = 0,8 that are calculated by analogy to the previous case.

Table 2. MTTF predictive estimates of BiCMOS IC by Analog Devices (in years) upon results of forced testing

v	E	W	LN	DM	DN
1,0	22830	22830	264	228	167
0,8	22830	5275	155	128	115

As follows from the above data, the discrepancy between IC MTTF predictive estimates, declared reliability (FIT=5), for example, between estimates based on exponential and diffusive non-monotonous distributions is about 100-200 times. If we do analogous predictions for IC with the reliability FIT=1, then the variation of MTTF predictive estimates will be about 500 times.

The mechanism of predictive estimates discrepancy

The discrepancy of IC MTTF predictive estimates obtained on the basis of the same experimental estimates of failure rate is defined by the type of a theoretical law of time to failure distribution. Fig 1 shows theoretical curves of time to failure distribution density *f*(*t*) (dashed lines) and failure rate λ(*t*) (solid lines), as well as predictive values of mean time to failure MTTF corresponding to experimental data for various distribution laws (E, LN, DN).

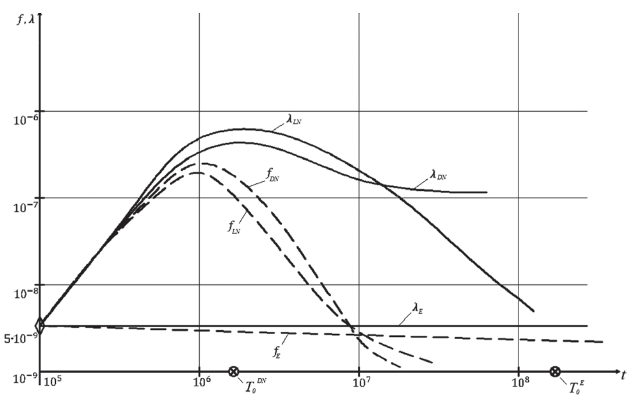

Fig. 1. Curves of predicted characteristics λ(*t*) and *f*(*t*)

Fig. 1 has the following symbols: $f_E, f_{LN}, f_{DN}, \lambda_E, \lambda_{LN}, \lambda_{DN}$ are respectively failure densities and rates for exponential, logarithmical normal and non-monotonous diffusive. As seen, the failure rate λ(*t*) and the distribution density *f*(*t*) of two-parametric distribution at the main time interval are quite substantially (by several orders) different from these characteristics as per exponential distribution, though the initial values for $\tilde{t}_н$ moment coincide. This phenomenon stipulates the same considerable discrepancy of MTTF predictive values for various distribution laws.

Therefore [5, 8], currently the application of exponential law overstates the mathematical expectation of time to failure (MTTF) of electronic devices by 50…500 and more times as compared to the value of the same characteristics issued from two-parametric models, which describe failure statistics in a more adequate way.

Conclusions

The exponential law of failure-free operation time distribution recently received wide application doesn't reflect real conditions for emergence of electronic devices failures. Its application brings a huge economic damage, first of all, to users of electronic devices who apply them as part of avionics and in other vital cases.

As theoretical and experimental researches show, the two-parametric diffusive distribution laws developed by the Institute of Problems of Mathematical Machines and Systems of the Ukrainian National Academy of Sciences provide the most adequate parameters of reliability for electronics products [5, 8].

References

1. **Strelnikov V.** The Status and Prospects of Reliability Technology – Part 1 // RAC Journal. – 2001, N 1. – P. 1 – 4; Part 2 // RAC Journal. – 2001, No. 2. – P. 8 – 10.

2. **Kofanov Yu.N.** Modelling and ensuring reliability of technical systems: Scientific edition. – Moscow: Energoatomizdat, 2011, – 324 p.

3. **Kofanov Yu.N.** Theoretical bases of designing, technology and reliability of radioelectonics: Higher school textbook. – Moscow: Radio and communications, 1991. – 360 p.

4. **Shor Ya.B.** Statistical methods of analysis and quality and reliability control. – M: Sov. radio, 1962. – 252 p.

5**. Strelnikov V.P., Feduhkin A.V.** Assessment and prediction of electronic components and systems reliability. – K: Logos, 2002. – 486 p.

6. **Romanov V.A.** Quantitative assessment of integrated circuits reliability upon results of forced testing // EKiS. – Kiev: VD MAIS, 2003, No.10. – P. 3-6.

7. Reliability and Quality Report. Fourth Quarter 1996. – Motorola, Inc., 1996.

8. **Gribov V.M., Kofanov Yu.N., Strelnikov V.P.** Assessment and prediction of avionics reliability: Ed. Kofanov Yu.N. – M: NIU VSHE, 2013. – 496 p.