ELECTRONIC JOURNAL
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ISSN 1932-2321

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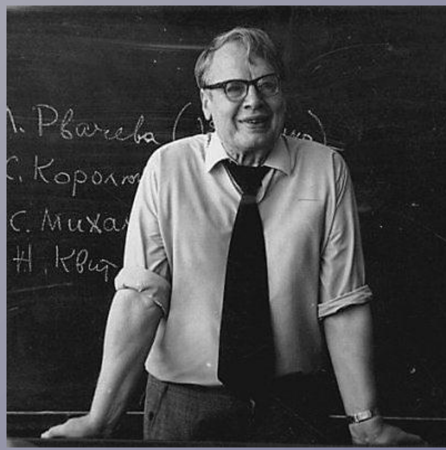
VOL.11 NO.4 (43)
DECEMBER, 2016

Gnedenko Forum Publications





RELIABILITY:
THEORY&APPLICATIONS

RELIABILITY
RISK ANALYSIS
MAINTENANCE
SAFETY

Vol.11
No.4 (43)
•
December
2016

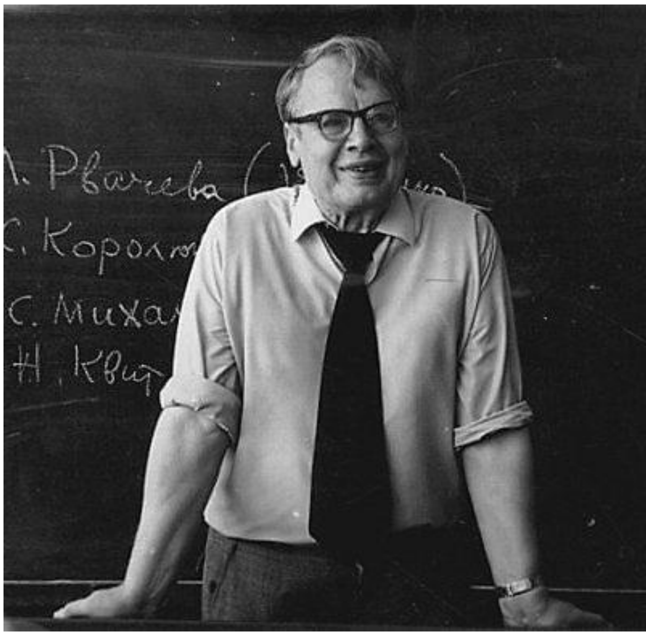
San Diego

ISSN 1932-2321

http://www.gnedenko-forum.org/Journal/index.htm

Journal of International Group on Reliability





RELIABILITY:

THEORY & APPLICATIONS

Vol.11 No.4 (43),
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In today's competitive marketplace, the design phase presents a perfect opportunity to test a product to find its maximum limitations and weak links. On the same context HALT (Highly Accelerated Life Test) has been adopted by many industries. HALT is a destructive stress testing methodology for accelerating product reliability during the engineering development process. It is a great process used for precipitating failure mechanisms in an electronics hardware design and product which may occur into the field.
The traditional HALT process which is followed by most of the industries, deals with destructive stress testing and subjective approach to fix the design weaknesses based on experience, followed by iterative HALT to check the robustness against the design fixes done which may not be relevant fixes.
This paper summarizes the effective way of conducting HALT by emphasizes on the "Analysis First" approach, the FMEA (Failure Mode Effect Analysis) and FEA (Finite Element Analysis) which will help identifying the critical functions along with associated components to be monitored during HALT and reduces the iteration of HALT by analyzing the board robustness against the stresses i.e. temperature and vibration prior to HALT respectively. And also presents the specification limits derived based on the product specification and chamber standard deviation, up to which the root cause and design fixes needs to be done, eliminating the subjectivity around it.

The paper considers the *technique of modeling of electronic reliability based on modeling electrical components* environment *temperature. As experience of the simulation and exploitation of electronic shows, one of the main factors that significantly affect the reliability characteristics is the thermal effect. This is confirmed by the statistics of a number of companies. In the paper for the simulation were used systems ASONIKA-K and ASONIKA-TM. On the example of a real electronic mean proved the need for a point temperature estimate for each electrical component and the account of these temperatures, instead of the average values in predicting the reliability indices. Such approach will significantly improve (20% - 40%) the accuracy of estimates of the mean time to failure. Developed engineering method to predict reliability, built on the "downward" hierarchical circuit simulation.*

In this paper, we have studied the estimation of parameters under failure censored data using step stress partially accelerated life testing. The lifetimes of test items are assumed to follow Mukherjee-Islam distribution. The estimation of different parameters and acceleration factor are obtained by Maximum Likelihood Method. Relative absolute bias (RAB), mean squared error (MSE), relative error (RE), standard deviation and confidence intervals are also obtained. Asymptotic variance-covariance matrix and also test method are given. Simulation studies have been introduced to illustrate the performance of all the statistical assumptions.

Simulation Of Reliability For Electronic Means With Regard To Temperature Fields

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Abstract

The paper considers the technique of modeling of electronic reliability based on modeling electrical components environment temperature. As experience of the simulation and exploitation of electronic shows, one of the main factors that significantly affect the reliability characteristics is the thermal effect. This is confirmed by the statistics of a number of companies. In the paper for the simulation were used systems ASONIKA-K and ASONIKA-TM. On the example of a real electronic mean proved the need for a point temperature estimate for each electrical component and the account of these temperatures, instead of the average values in predicting the reliability indices. Such approach will significantly improve (20% - 40%) the accuracy of estimates of the mean time to failure. Developed engineering method to predict reliability, built on the "downward" hierarchical circuit simulation.

The reported study was supported by RFBR, research project No. 14-07-00422 a.

Keywords: reliability, printed circuit boards, thermal analysis

I. Introduction

Reliability is a complex electronic device property, which, depending on the purpose and conditions of its application consists of a combination of properties: dependability, durability, maintainability and conservation.

Today the actual direction of the reliability theory is the prediction of indicators of reliability in the early stages of design. The direction uses different approaches, one of the key is a methodology for the synthesis of highly reliable electronic means on the criteria of reliability.

Practice of design and operation shows that the greatest impact on the reliability by climatic, mechanical and electrical effects [1]. General failure rate model of the printing assembly of the electronic means in the mode of operation is as follows [2]:

$$\Lambda_{PA\,EM} = K_a \cdot \sum_{j=1}^{m} \sum_{i=1}^{n} \lambda_{eij} \tag{1}$$

where: K_a – quality factor of production equipment, relative units; λ_{eij} – operational failure rate of the *i*-th type of product *j*-th group (see model below), 1/h; *n* – the number of products *j*-th group, items; *m* – number of product groups, items.

The model λ_{eij} in general for standard electronic components (chip resistors, chip capacitors, etc.) is as follows [2]:

$$\lambda_{eij} = \lambda_b(\lambda_{b.g.}) \cdot K_r(K_t) \cdot K_e \cdot \prod_{i=1}^{n} K_i \tag{2}$$

where: $\lambda_b(\lambda_{b.g.})$ – basic failure rate of type (group) of electrical components, calculated according to the results of tests on the electrical component reliability, durability, life, 1/hr; $K_r(K_t)$ – mode coefficient (temperature) takes into account the magnitude of the electrical load and (or) the ambient temperature (the product's enclosure), relative units; K_e – operating factor takes into account the severity of operating conditions, relative units; K_i – coefficient taking into account changes in operational failure rate depending on various other factors, relative units; n - number of factors taken into account, items.

Affecting electronic factors can be divided into four types of effects, as shown in Table 1.

Table 1: *List of external influencing factors*

№	Effects	Factor name
1	Climatic	• high pressure air or gas • reduced atmospheric pressure • changes in atmospheric pressure • Low ambient temperature • Increased ambient temperature • high humidity • atmospheric condensed precipitation • low air humidity • salt mist • solar radiation
2	Mechanical	• Broadband random vibration • acoustic noise • linear acceleration • seismic shock • Mechanical shock of single action • Mechanical shock of repeated action
3	Biological	• mold fungi • insects • rodents
4	Other	• static dust • Dynamic dust • aggressive environment (ozone, ammonia, nitrogen dioxide, sulfur dioxide, hydrogen sulfide)

Objective factors are determined by the time and conditions of use and include the operation time; climatic factors; mechanical factors; biological factors; operating modes. The typical distribution of electrical component failure due to objective reasons shown in Figure 1.

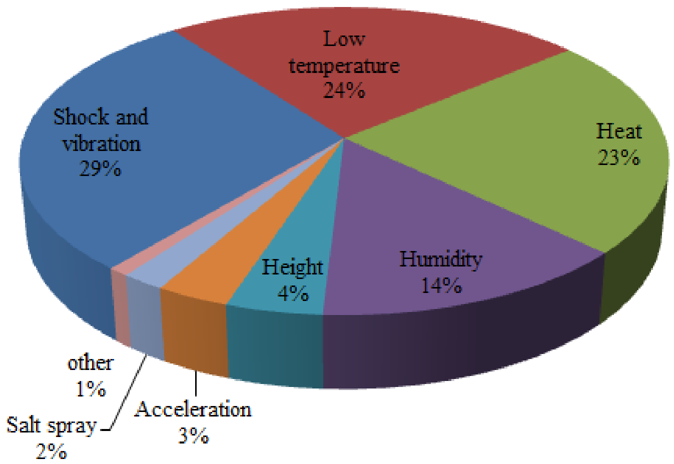

Figure 1: *The electrical component failure rate of various objective factors*

As seen from the model (2) and the real statistical failure (see. Figure 2) for each electrical component makes the largest contribution $K_r(K_t)$, and it, in turn, is determined by the point modeling of ambient temperature (or shell) of the element or of experimental investigations [3]. As shown in Figure 2 for a typical printing assembly change in the ambient temperature of +25 ° C to +80 ° C leads to a change in failure rate of more than 1.66 times.

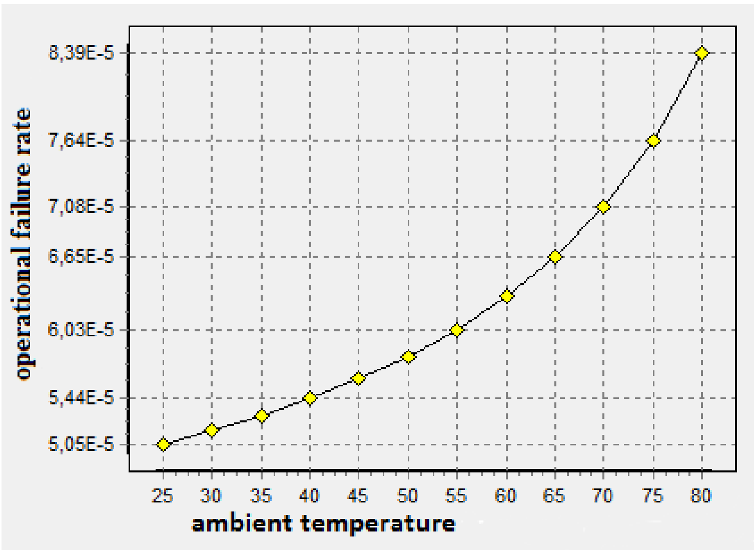

Figure 3: *Graph of operational failure rate of a typical printing assembly from ambient temperature*

II. Thermal analysis of electronic equipment

As shown in [3] thermal modeling reveals the weakness of the development, to correct them and protect from heat. This approach also allows one to get a more accurate value of time to failure under the conditions of use of the object prior to disposal. Thermal analysis will allow at a stage of simulations increase the value of system reliability indicators in the possible reduction of cost and the geometric dimensions. The fact that the higher the temperature, the lower the reliability. In the presence of operational data can be predicted the mean time to failure for a newly developed product.

Thermal modeling relevant because:

1. Analysis of temperature fields of electronic means - is rapidly expanding area of research;
2. Thermal analysis is applicable to many areas of design;

3. Thermal analysis is very important for engineering research.

Model of the failure rate of the temperature λ_d. The failure rate for any reference temperature T_r can be calculated using the following equation, and with known T_b and λ_b:

$$\lambda_d = \lambda_b / exp \frac{-AE\left(\frac{1}{T_b} - \frac{1}{T_d}\right)}{8.61735 \cdot 10^{-5}} \tag{3}$$

The failure rate is doubled by raising to 10 °C ambient temperature (K=293 °C) for AE=0.53. Most electronic solid state components have AE=0.4, and failure rate is doubled when the temperature rises to 13,5 °C.

Cooling systems [3] should be designed to control the temperature of the components. By varying the cooling systems in board electronic means in some cases could increase by 500% the average time to failure.

Implementation of the requirements of the thermal analysis leads to an additional increase in the cost of the design. However, the average cost of a heat-resistant electronic means compensated by saving operating costs.

A thermal analysis of the electronic means should be performed at the system level. Without it, it can happen that parts and components will continue to refuse. Components can be designed to work in normal conditions, but due to the low heat transmission from different heat generators, they can not work at increased temperatures.

There are two main areas in the thermal analysis of electronic means: 1. Knowing electrical component temperature and therefore to quantify the degradation of electrical parameters; 2. Reduce the temperature of the electronic components that improve system reliability. The first may predict "hot" spots in the development through detailed analytical prediction or through direct measurement of heat. The second allows local cooling of these areas that will significantly increase the component life time.

To select the mathematical models for calculating the reliability of foreign and national reference books were analyzed. For the basics reference [6] was taken as the most used and reliable.

Thermal modeling was carried out on the example of a typical printed board assembly of electronic means.

The task is this: to calculate the printing assembly for given thermal actions. Based on the analysis of the thermal characteristics of printed assembly conclude that the technical requirements for electrical components for thermal characteristics performed.

Data for calculation.

The initial data for the calculation of blueprints printed board assembly and output PCAD system files have been received, as well as maps electrical component operating modes. Design printed board assembly subsystem ASONIKA-TM, is shown in Fig. 3 (first side) and Fig. 4 (second side).

The capacity of heat generation electrical component in the PCA: B2 – 0,6 mW; R7 – 30 mW; R8 – 40 mW; R14 – 200 mW; R15 – 200 mW; R17 – 30 mW; R20 – 110 mW; R21 – 10 mW; R23 – 20 mW; R24 – 110 mW; R25 – 10 mW; R26 – 20 mW; R27 – 110 mW; R28 – 80 mW; R29 – 30 mW; D5 – 1500 mW; D6 – 1500 mW; D7 – 1500 mW; D20 – 157 mW; VT1 … VT3 - 40 mW; **Total 5777,6 mW.**

According to the results of thermal calculation unit in the subsystem ASONIKA-T obtained the following air temperature inside the unit:

- for natural convection 100,2 °C;
- with forced convection blowing speed of 1 m/s 53 °C.

Use the data the temperature values as the boundary conditions for the thermal design of printed assembly.

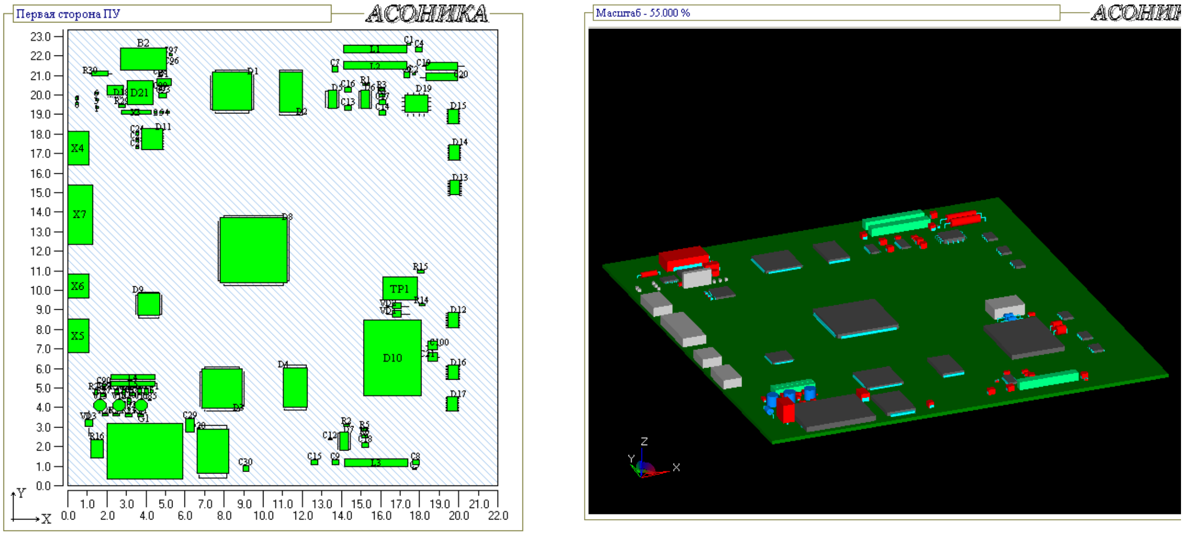

Figure 3: *Design of printed assembly in the subsystem ASONIKA-TM (side 1)*

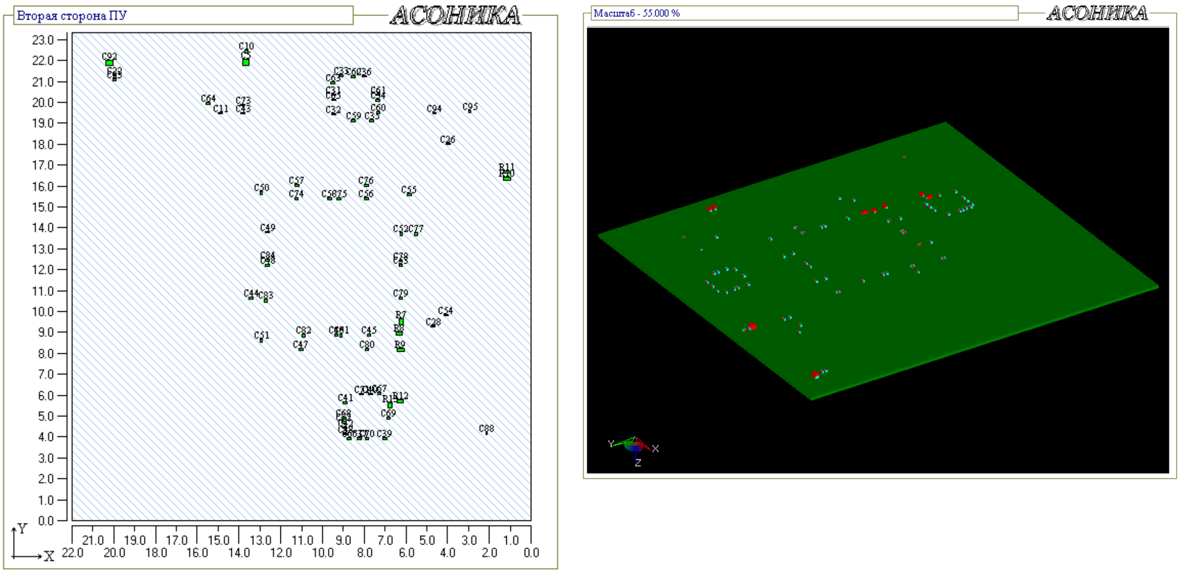

Figure 4: *Design of printed assembly in the subsystem ASONIKA-TM (Side 2)*

Results of thermal analysis.

Calculation of thermal characteristics of printed board assembly was held in an automated subsystem ASONIKA-TM. Fig. 5 and Fig. 6 shows obtained thermal characteristics for printed board assembly mode 1 in operation (the air inside the unit for natural convection 100.2 °C) and mode 2 (air inside the unit in a forced convection blowing speed of 1 m/s 53 °C). Maps of thermal modes of electrical component are presented in tables 2 and 3.

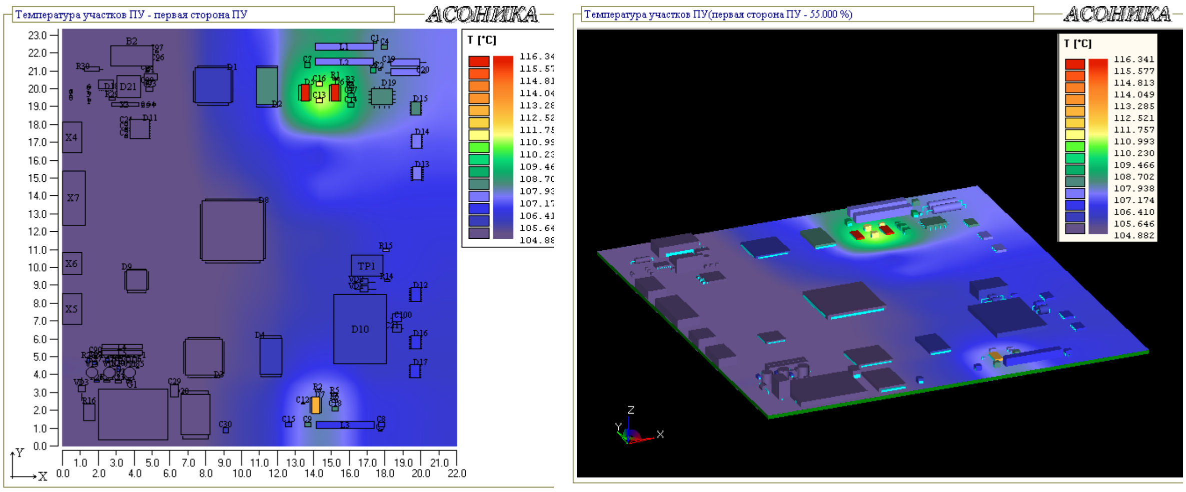

Figure 5: *Temperature Field for printed board assembly in mode 1*

Table 2: *Section of the map of thermal modes of electrical component (when stationary thermal action) for of printed assembly in mode 1*

№	Symbol of electrical components	side	The temperature of electrical components		Coefficient of thermal load, [relative units]	Overheat, [°C]
			Estimated, [°C]	Maximum permissible, [°C]		
1	R1	1	111.222	100.000	1.112	11.222
2	R17	1	105.574	100.000	1.056	5.574
3	R18	1	105.445	100.000	1.054	5.445
4	R19	1	105.418	100.000	1.054	5.418
5	R2	1	107.819	100.000	1.078	7.819
6	R20	1	106.025	100.000	1.060	6.025
7	R21	1	105.487	100.000	1.055	5.487
8	R22	1	105.418	100.000	1.054	5.418
9	R23	1	105.479	100.000	1.055	5.479
10	R24	1	106.004	100.000	1.060	6.004
…………………………………………..						
20	C1	1	108.730	85.000	1.279	23.730
…………………………………………..						
179	C95	2	105.153	100.000	1.052	5.153

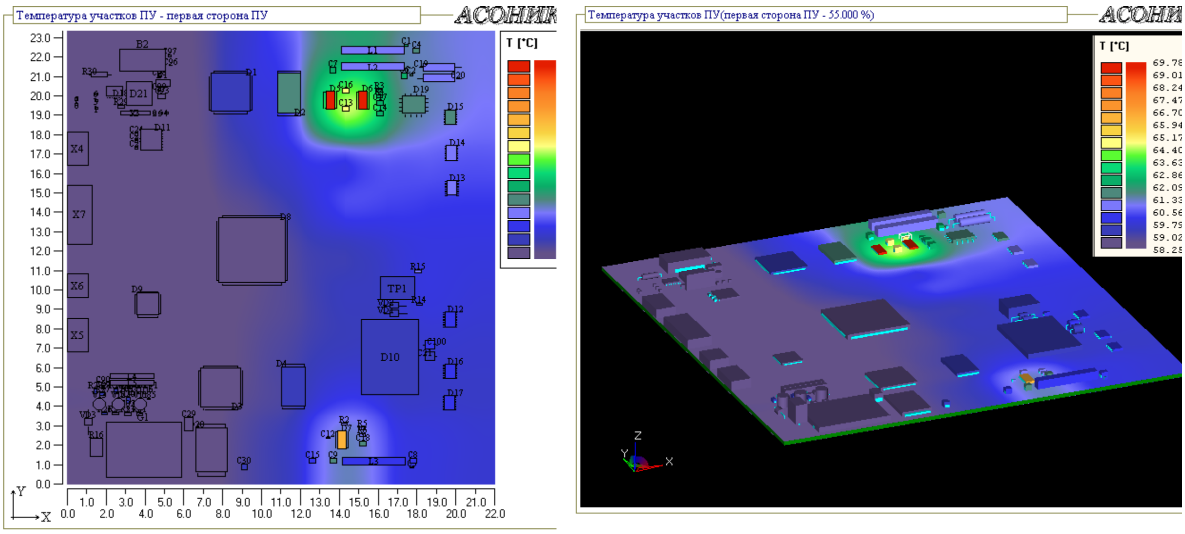

Figure 6: *The temperature field for a printed assembly in mode 2*

Table 3: *Section of the map of thermal modes of electrical component (when stationary thermal action) for the printing unit in mode 2*

№	Symbol of electrical components	side	The temperature of electrical components		Coefficient of thermal load, [relative units]	Overheat, [°C]
			Estimated, [°C]	Maximum permissible, [°C]		
1	R1	1	64.652	100.000	0.647	
2	R17	1	58.946	100.000	0.589	
3	R18	1	58.820	100.000	0.588	
4	R19	1	58.790	100.000	0.588	
5	R2	1	61.206	100.000	0.612	
6	R20	1	59.401	100.000	0.594	
7	R21	1	58.863	100.000	0.589	
8	R22	1	58.790	100.000	0.588	
9	R23	1	58.855	100.000	0.589	
10	R24	1	59.376	100.000	0.594	
………………………………………						
20	C1	1	62.169	85.000	0.731	
………………………………………						
179	C95	2	58.530	100.000	0.585	

III. Calculation of reliability printed board assembly

The first and one of the main steps of calculating the reliability of the printed board assembly is to identify the electrical component parameters.

Under the parameter identification should be understand the process of determining the parameters of a mathematical model of reliability calculation, for each specific type of electronic components. The process of identification of electronic components can be represented schematically in the form of an algorithm, illustrated in Figure 7. When performing the identification of electronic components, according to the algorithm, some points should be noted. Secondly, found in prior specifications, not always this information is sufficient for the calculation of reliability, in such cases, according to the block 9, was searched averaged parameters of technological groups and subgroups in the directory of the reliability of foreign-made product when checking the adequacy of the information. As a result of the identification of all part types from the list, we were assigned to a particular class of electrical component, and in line with the previously selected mathematical models, all the necessary parameters have been found.

Calculation of reliability of the printed board assembly.

An indicator of reliability of printed board assembly is its mean time to failure with no recovery in the process. Reliability of printed assembly is characterized by a set of failure rates of its components (electrical component). The scheme of calculating the reliability of printed board assembly corresponding to a predetermined criterion of failure, is a serial connection of a technologically and functionally combined electrical component groups.

Figure 8 shows the sequence diagram for calculating the reliability of the device included in printed assembly on the level of technology combined electrical component groups.

Operational electrical component failure rate was calculated according to the corresponding reference books [7-9] and a set of maps the correct application of electrical component.

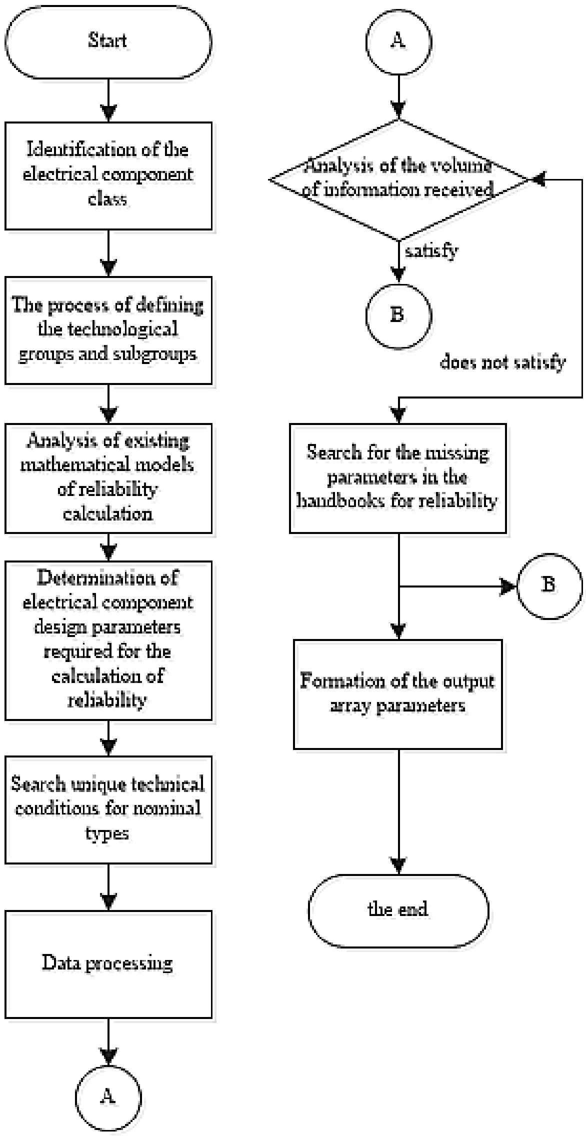

Figure 7: *Algorithm for electrical component identification process*

Figure 9 shows the window ASONIKA-K system with the results of printed assembly calculation (estimation).

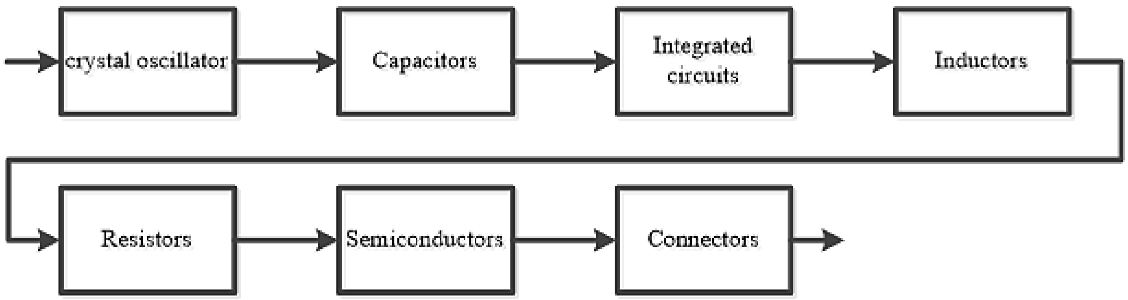

Figure 8: *The scheme of calculating the reliability of printed assembly*

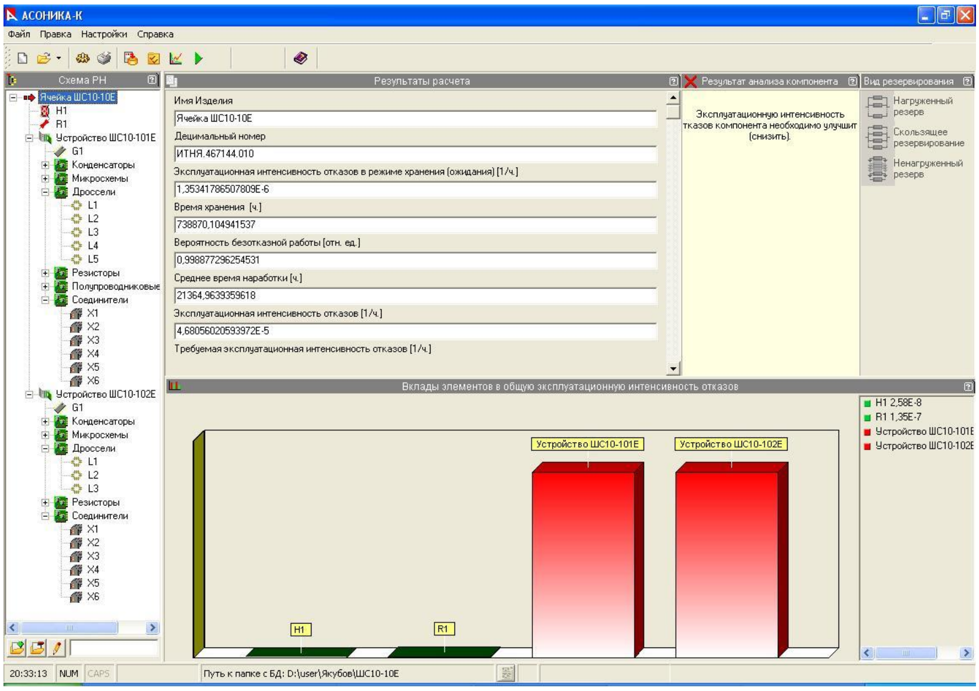

Figure 9: *ASONIKA-K system: the results of printed assembly calculation (estimation)*

As can be seen from Fig. 9, obtained by calculating the value of the average operating time of printed assembly is ≈21,364 thousand [hours] (Electric Load coefficients varying depending on the type of electric components from 0.1 to 0.7 at a temperature of 65 [°C]) that does not satisfy the technical requirements (T_0=150 thousand [hours]).

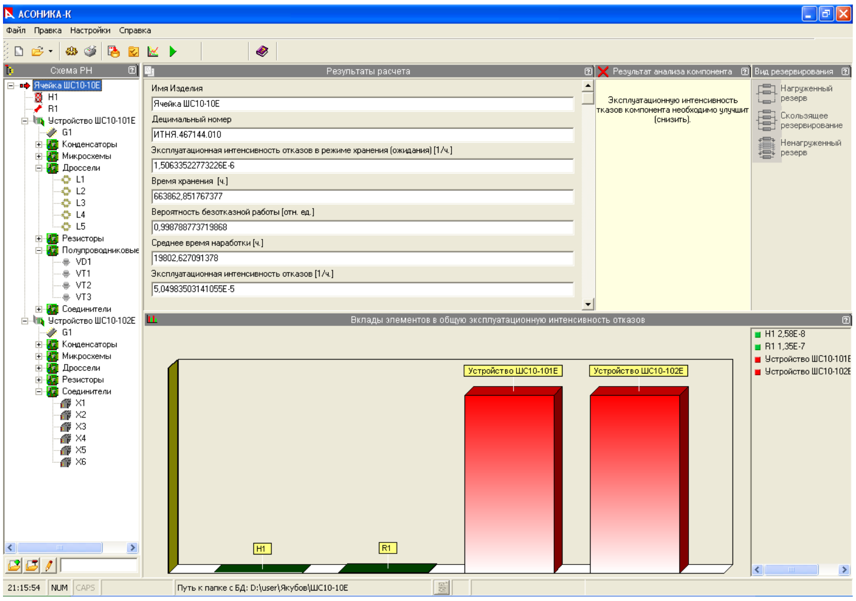

Figure 10: *System ASONIKA-K: The results of printed assembly calculation (adjusted calculation)*

Adjusted calculation printed board assembly reliability.

Adjusted calculation operating electrical component failure rate was based on electrical component temperature, the resulting heat-transfer simulation using subsystem ASONIKA-TM, and other data about the electrical component of printed assembly were taken from the set of maps of the correct application of electrical component.

Fig. 10 shows the window ASONIKA-K system with the results of printed assembly calculation (adjusted calculation).

As can be seen from Fig. 10 obtained by calculating the average value of use of printed assembly is ≈ 19,802 thousand [hours] (Load for electric coefficients varying depending on the type of electrical component from 0.1 to 0.7 at temperatures electro obtained by subsystem ASONIKA-TM), which does not meet the technical requirements (T0=150 thousand. [hours]).

Analysis of the results of calculations.

To assess the influence of ambient temperature environment was constructed operational temperature dependence of printed board assembly failure rate in the temperature range +25 ... + 85 [°C] for given values of electrical load coefficient depending on the type of electrical component from 0.1 to 0.7 (see Fig. 11).

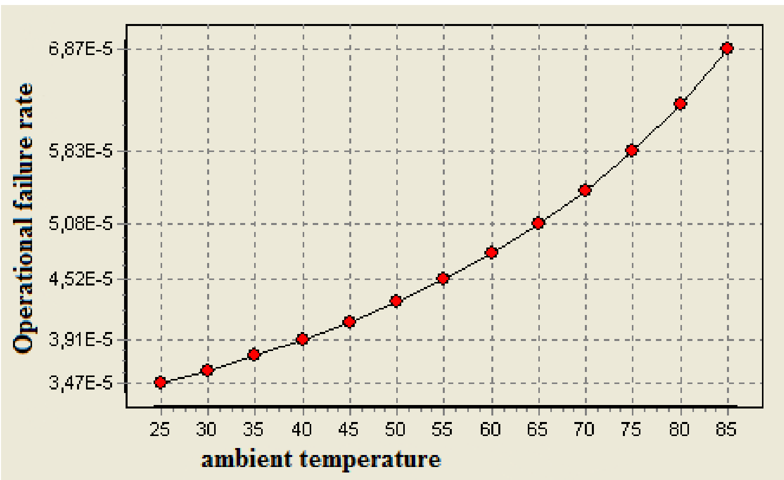

Figure 11: *Dependence of operational failure rate of printed assembly of temperature*

As can be seen from Fig. 11, a simultaneous change of electrical component temperature in the range +25 ... + 85 [°C] causes a change in the intensity of printed board assembly failures in 2 times.

Assessing the impact of the specific characteristics of reliability of electrical component on operational intensity printed board assembly failures carried out directly during the calculation.

Figure 12 shows the contribution classes printed board assembly electrical component to the total failure rate.

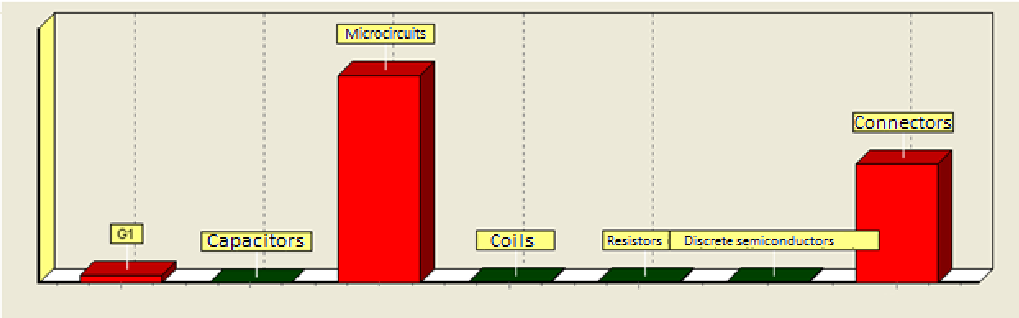

Figure 12: *Contributions of electrical component classes to the total intensity of the printed board assembly failure*

As shown in Figure 12 of the most unreliable class electrical component is a class "Integrated circuits" and "connectors".

Figure 13 shows the contribution of electrical component class "Integrated circuits" to the total failure rate.

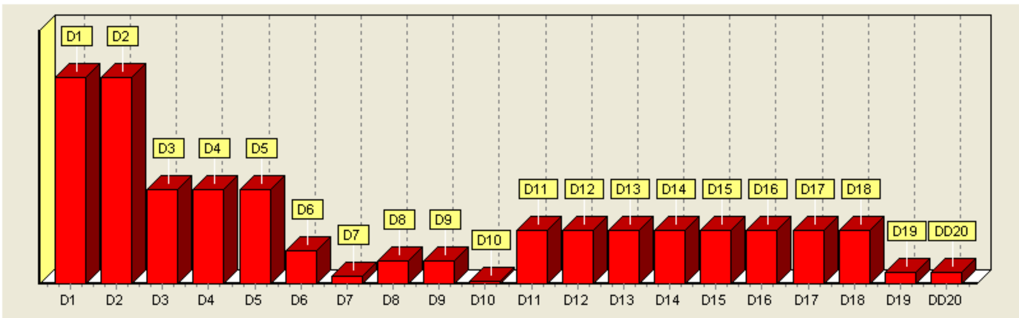

Figure 13: *Contributions of class "Integrated circuits" electrical components to the total failure rate*

As it follows from Fig. 13 unreliable chips are chips D1, D2 type TMS320VC5416PGE160 and D3-D5 type TPS73HD301PWPR, TPS73HD325PWPR.

Figure 14 shows the contribution of electrical component class "connectors" to the total failure rate. As it follows from Fig. 14, the connectors are unreliable connectors X1, X2 type C 6921 03164.

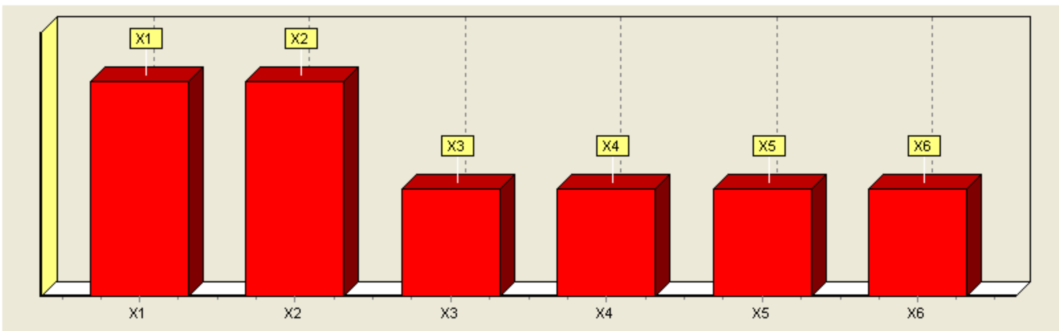

Figure 14: *The electrical component class contributions of "connectors" to the total failure rate*

IV. Conclusion

The calculation of printed assembly reliability has shown that:

- At a temperature of 65 [° C] average time to failure is not less than 21.364 thousand [hours.]. Electric load factor depending on the type of electrical component that varies in the range from 0.1 to 0.7;

- At temperatures of electrical component derived from simulations using subsystem ASONIKA-TM, the average time to failure is not less than 19.802 thousand [hours.], For the electric load factor depending on the type of electrical component, varying in the range of 0.1 to 0.7.

Options considered analysis printed board assembly reliability showed that the reliability of the product does not meet the requirements (mean time to failure is to be not less than 150000 hours). The most unreliable electrical component classes are the class of "Integrated circuits" and "connectors". To improve reliability, we can recommend the following measures:

- change the type of electrical component (use electrical components with less λ_b);

- to facilitate the operation of the electronic components (lower operating thermal and electrical load);

- reduce the number of electrical component (use the chip higher degree of integration);

- use electrical components with a high level of quality;

- reduce the ambient temperature (to increase the efficiency of the cooling system).

Using the concept of mathematical modeling of complex heterogeneous physical processes in the development of printed board assemblies within systems ASONIKA-K and ASONIKA-TM allows one to improve the accuracy of reliability parameters modeling;

In this paper: 1) proved by the example of printed board assembly need for differential evaluation of the temperature of each electronic components and their integration in predicting reliability, rather than the averaged temperature values; 2) developed a technique of mathematical modeling of reliability for thermal printed board assemblies that the example has proved its effectiveness.

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ISSN 1932-2321