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PROSPECTS FOR PROBABILISTIC-PHYSICAL ANALYSIS OF RELIABILITY IN THE DESIGN OF RADIO-ELECTRONIC SYSTEMS

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Abstract—*The comparative analysis of reliability prediction methods in the design of radio-electronic systems was carried out. In the systems design, it is offered to pass on to the method of probabilistic-physical analysis of reliability with the application of exponential and diffusive non-monotonic distributions of components failure. The usage of the method of probabilistic-physical analysis of reliability can provide considerable economic effect, by reducing the cost of systems samples in several times.*

Index Eerms—Probabilistic-physical analysis; exponential distribution, diffusive non-monotonic distribution, components no-failure operation time, reliability calculations, designing, radio-electronic systems.

I. INTRODUCTION

One of the main problems solved when developing radio-electronic systems (RES) is the problem of reliability assurance. High reliability of RES is provided with the actions which are carried out at all development stages, manufacturing and operation. The special place in this process belongs to the development stage as the basic principles of reliability assurance are chosen at this stage.

Reliability requirements of the system to be designed are set in the technical design specification on its development. At the early stages of RES development, it is constructed the program of reliability assurance which is detailed and specified at the subsequent development stages. Reliability calculation of the designed system is one of the elements of this program. The first reliability calculations are performed at early development stages of the system, and along with the clarification of system information, the reliability calculations are specified as well.

Reliability calculation is a procedure of system reliability in dices estimation with using the methods based on: reference data on system components reliability; the data on analog system reliability; the data on materials properties; the other information which is available by the time of calculation [1].

According to the structure of the calculated reliability indicators (RI) of systems, there are dist in guihed the calculation methods of: *reliability; maintainability, durability, storability, complex reliability indicators.*

Structural methods of reliability calculation of the system are based on system representation in the form of the logical (structural – functional) scheme describing the dependence of system states and transitions on the states and transitions of its elements, with the subsequent descriptions of the constructed structural model with the help of adequate mathematical model and calculation of the system's RI according to the known characteristics of its elements reliability.

Physical methods of reliability calculation of systems are based on application of the mathematical models which describe the physical, chemical and other processes leading to objects failure (objects reaching the limit state), and calculation of RI based on the known parameters of object load, characteristics of the substances and materials applied in an object taking into account features of its design and manufacturing techniques.

The source data for system reliability calculation can be presented by: priori data on reliability by experience of system application in similar or close conditions; the estimates of reliability indicators received in the experimental or computation way; calculated or experimental estimates of loading parameters of components and elements of a construction.

The adequacy of models and methods of systems reliability calculation is evaluated: by comparing the calculation results and the experimental evaluation of RI of analog systems to which similar models and methods of calculation were applied; research work of models sensitivity to violations of assumptions and propositions made at their construction, and also to imprecisions of the source data for calculation; examinations and approbations of the applied models and methods.

II. Problem Statement

One of the main objectives on reliability assurance solved in the process of RES designing is the correct choice of adequate mathematical models for definition of system reliability indices sat different design stages. In world practice of RES designing, since 50–60th years of the 20th century, the probabilistic approach has been applied for calculations of indicators of non-failure operation, maintainability and durability. For calculations of reliability of electronic elements and systems theoretical laws of random variables distribution are used: exponential, Weibull, Rayleigh, logarithmic – normal, etc. A single-parameter distribution exponential law is commonly used for RES reliability calculation.

In parallel with probabilistic approach at RI calculation from the 80th of the 20th century, the probabilistic – physical approach, applied to reliability calculation of electronic, electromechanical and mechanical devices, failures of which are characterized by processes of wear and aging, has begun to develop. At the same time mathematical models of reliability with using of two-parametrical laws of distribution are applied: diffusive (DM and DN), alpha, linear, etc. Diffusive non-monotonic (DN) distribution of random variables is the most frequently used when calculating reliability of unrecoverable devices.

In this work the short comparative analysis of advantages and disadvantages of probabilistic and probabilistic – physical approach when carrying out calculations of the designed RES reliability is carried out and the prospects of using exponential and DN distributions for prediction of RES reliability are defined.

II. Problem Solution

A. Probabilistic approach at reliability calculation

A1. Short characteristic of exponential distribution

Reliability function of electronic elements has an appearance:

$$P(t) = e^{-\lambda t},\ t \ge 0;\ \lambda > 0. \qquad (1)$$

From (1) it follows that the exponential law (1) is defined by one parameter λ, which represents constant failure rate. As the converse statement is also correct, the period of elements normal operation is characterized by exponential distribution of no-failure operation interval.

Mean operating time to first failure:

$$T_{\text{av}} = \frac{1}{\lambda}, \qquad (2)$$

equals to the inverse value of failure rate. Replacing in (1) value λ by $1/T_{\text{av}}$ according to (2) we receive equation for calculation reliability function:

$$P(t) = e^{-\lambda/T_{\text{av}}},\ t \ge 0;\ T_{\text{av}} > 0. \qquad (3)$$

On an interval, which exceeds average time T_{av} at the exponential distribution, $P(t)$ is equal:

$$P(T_{\text{av}}) = \frac{1}{e} \approx 0.368. \qquad (4)$$

Duration of the normal operation period before aging can appear to be significantly smaller, than T_{av}, that is the time interval on which it is admissible to use exponential model, often happens to be less than mean operating time to first failure, calculated for this model.

The mathematical expectation of operating time to first failure is equal:

$$M(T) = \frac{1}{\lambda} = T_{\text{av}}, \qquad (5)$$

variance of operating time to first failure is equal:

$$\sigma_T^2 = \frac{1}{\lambda^2} = T_{\text{av}}^2, \qquad (6)$$

The gamma-percentile life is equal:

$$T_\gamma = \frac{1}{\lambda}\ln(\gamma) = -T_{\text{av}}\ln(\gamma). \qquad (7)$$

The constancy of failure rate serves as the condition of using the exponential law of time distribution to the system failure that is specific to sudden failures on time interval when the period of system artificial aging has ended, and the period of wear and aging hasn't begun yet, i.e. for normal service conditions. Failure rate of difficult systems becomes constant if they are caused by failures of a large number of the fitting elements.

Sudden failures are caused by severe environment of many coincidences and therefore have constant intensity. Exponential distribution finds quite broad application in the theory of mass service, describes artificial aging distribution of difficult products failures, no-failure operation time of the elements of the radio-electronic equipment. The assumption of exponential distribution significantly simplifies reliability calculations, explains broad application of the exponential law in engineering practice. As exponential distribution is a single – parameter, it is convenient for carrying out non-failure operation calculations, collecting and processing of statistical data on failures of electronic elements while in operation.

A2. The exponential models of reliability used in the process of RES designing

Nowadays in world practice of RES designing when predicting reliability indices, the reliability coefficient models which are based on exponential distribution for predicting of operational failure rate of electronic elements, are widely used [1].

In Russia, Ukraine and Belarus [2] the following mathematical model for operational failure rate of electronic elements was used:

$$\lambda_p = f(K_p, K_1, ..., K_n), \quad (1)$$

where $K_p, K_1, ..., K_n$ is the mode coefficient and coefficients considering dependence of operational intensity on various factors; t is the environment temperature.

In the USA, France, Germany, Italy and other western countries the similar (8) mathematical model of electronic components reliability [21] was used

$$\lambda = \lambda_{\text{ref}} \cdot \pi_u \cdot \pi_I \cdot \pi_T \cdot \pi_E \cdot \pi_S \cdot \pi_{ES}, \quad (9)$$

where λ_{ref} is the operational failure rate of EC under nominal conditions; π_u is the coefficient of electric voltage burden; π_I is the coefficient of electric current burden; π_T is the coefficient which takes account of environ mental temperature; π_E is the coefficient which takes account of influence of external factors; π_S is the coefficient which takes account of the number of transitions of EC; π_{ES} is the coefficient which takes account of electric vibrations.

The coefficients $K_p, K_1, ..., K_n$ of model (8) and coefficients $\pi_u \cdot \pi_I \cdot \pi_T \cdot \pi_E \cdot \pi_S \cdot \pi_{ES}$ model (9) are described by mathematical models of dependences of EC operational failure rate on electric loading and parameters of the environment [21].

A3. Standards and manuals for reliability calculation of electronic elements

In Russia, Ukraine and Belarus, for RES reliability prediction there are used the reference books on EC reliability developed by Jet Research Institute "Elektrostandart", St. Petersburg, edition 2002, 2004, 2006 and 2010 [2], [19], [20].

For RES reliability predicting in the USA the following standards and manuals are used: MIL-HDBK-217F, RIAC MIL 217 Plus (PRISM), NPRD/EPRD, IEEE Gold book [16], [21], [23];

The following manuals FIDES Guide 2004, RDF:2003, IEC TR 62380, IEC 61709, RDF 2000, HRD5, Telcordia SR-332 (Bellcore), NPRD-95, Siemens SN 29500 [22] are used in countries of Western Europe and the reference book GJB/z 299B – is used in China.

For RES reliability prediction it is also used the operational information about reliability indices obtained by results of the accelerated tests provided in Data Sheet for electronic elements and also in directories of the world firms developing and manufacturing electronic elements and modules.

A4. Systems of automated reliability calculation

For decreasing of operations labor content at prediction of reliability of EC, in world practice there are developed and are widely applied sub systems of automated calculation reliability indicators of electronic elements and RES.

The considerable success at the same time is achieved in the USA and the European countries where operations on automated reliability analysis of RES are concentrated at several large engineering centers and are carried out with use of the Reliability Manager programs, which is a part of a CAD Mentor Graphics, and also the software packages RAM Commander 7.7 (MTBF Calculation), the Lambda predict (Λ – predict), 217 Plus, FIDES Guide 2004, RDF 2003, NPRD-95 [18].

In the CIS countries (Russia, Belarus, Ukraine and Kazakhstan) there are developed and operate the systems of automatic reliability calculation and optimization of electronic devices (SoARC) which represent the modular program complexes allowing to evaluate (predict) the faultlessness indices of electronic devices at the level of units and modules, relying on the data about elements reliability, the electrical modes and conditions of their operation [2].

The communication mode with PC is inter active. The SoARC systems include the database about the generalized indices of faultlessness of different classes and groups of elements of production of the CIS countries and elements of foreign production.

In Jet Research Institute "Elektronstandart" (St. Petersburg, Russia) there are developed automated reference manuals on EC reliability (edition 1996 - 2010) which are used by scientific research institute and the industrial enterprises.

The automated workplace of "ASONIKA" of development of Moscow institute of electronics and mathematics (Russia, Moscow) [11] and the SoARC system, developed by BSU of informatics and radio electronics (Belarus, Minsk) belongs to the SoARC systems [2].

A5. Disadvantages of using the exponential law of reliability

The reliability model selection is the complex scientific and technical task. It can be solved by methods of mathematical statistics if there is a big statistical material about failures of the researched system. Due to high reliability of the integrated circuits (ICs) and its components, as a rule, there is lack of statistical data about failures. In the latter case during the model selection they are guided by results of accelerated tests, physical reasons, and previous experience. In case of approximate evaluations the exponential model is often chosen as the most convenient from the point of view of analytical conversions. This model is recommended to use in case of execution of reliability calculations in the absence of other initial data, except failure rate. In case of existence of more complete initial data it is reasonable to use more accurate two – parameter models.

Physically it means that the exponential law of distribution doesn't consider background of the current process. Theoretically this law can be applied only to RES which aren't susceptible to wear while in operation and to aging in time that contradicts their nature. Therefore, we will only put this law of distribution into practice when processes of aging and wear in RES proceed enough slowly and also rather small period of their "life" is analyzed. As a rule, the exponential law is used at an assessment of reliability of difficult products which failures are caused by a large number of the components they are consist of, and also when determining time between failures of non-restorable products and random time between the next failures in the restorable products.

Since the exponential distribution doesn't consider aging and wear at all, it excludes a possibility of better materials selection at products manufacturing or carrying out scheduled maintenance while in operation. Therefore determination of indicators of durability of RES electronic elements and components (operating life and useful life) with use of exponential distribution leads to big errors.

In a number of works of foreign experts it is absolutely fairly noted that the widespread American standard MIL-HDBK-217 based on use of exponential distribution isn't intended to provide reliability indicator with the guaranteed accuracy [9]. More likely, he is intended to be used as the tool at an assessment of suitability and comparison of new projects versions. The model of exponential distribution was sharply criticized for a long time by scientists and experts of the manufacturing industry.

Generalizing domestic and world practice of use of single – parameter exponential distribution at design of RES, it is necessary to make a conclusion that it is expedient to use it only at early design stages for justification of option of structural creation of electronic systems and it is impossible to use it for receiving the final (specified) estimates of reliability and durability of highly reliable systems.

B. Probabilistic – physical method of reliability calculation

In recent years, probabilistic – physical models of reliability [5] – [8] which can successfully replace the existing apparatus of a researching and prediction of reliability, gain ground. Probabilistic – physical approach is based on use of distribution laws of failures (reliability models) following from the analysis of physical processes of degradation which lead to failure. At the same time physical processes of degradation are considered in the form of random processes. The last approach to a reliability research is called *probabilistic – physical* as it directly establishes connection of probability of reaching the critical level with the physical key parameter, i.e. connects value of failure *probability* and *physical* parameter, which leads to failure. As a consequence parameters of the received probabilistic distribution of failures have certain physical sense. In particular, in the considered two-parameter probabilistic – physical models of failures [5] the parameter of scale coincides with value of average speed of the key parameter change, and parameter of a form – with coefficient of this speed variation. It is accepted to name the Failure distribution (distribution of error – free running time), parameters of which have concrete physical interpretation, unlike strictly probabilistic distributions (models) of failures (exponential, Weibull, logarithmic - normal, etc.), as probabilistic – physical distribution (model) of failures [5].

All methods of calculation of reliability indices, based on use of strictly probabilistic models of failures distribution (exponential, Weibull, etc.), allow only two possible states of system elements– the operational and state of failure, the probabilistic combination of which defines also double positioning state of system, in general – state of operability or non-operability. The calculation method [5] based on use of probabilistic – physical model differs from strictly probabilistic methods in the fact that it considers a continuous set of elements states and system with continuous time and is called a probabilistic – physical method. By results of a research of the certain parameters characterizing technical state of an object it is possible to find the parameter informing on the system resource expenditure and, having evaluated the speed of its change and knowing its extreme value, it is possible to predict all necessary indices of system reliability [5].

B1. Short characteristic of diffusive non-monotonic distribution

The degradation processes leading to failures have the accidental nature, and change of their values carries both monotonous and non-monotonic character. Complicated products of the electronic equipment are at the same time vulnerable to the action of a set of processes. All these processes uncorrelated and slightly correlated among them, form the general process of product degradation. The key parameters of the investigated degradation processes, capable to cause failure of any component, have the different physical nature. Any element or the device can be conditionally presented in the form of set (from one to a great amount) of independent primitive component (PC) for which only one physical parameter will be the key one. The failure of any, the weakest component leads to failure of an element (device). By normalizing all key parameters on their extreme values which cause failure of PC, it is built the generalized process of degradation of a product (set of PC) with a uniform area of coordinate's values and the general time. In Fig. 1 the degradation process is qualitatively presented.

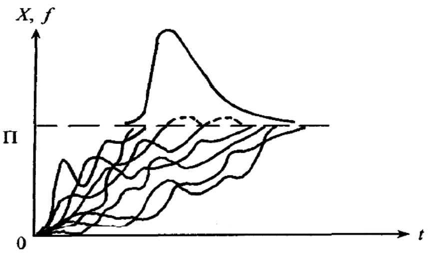

Fig. 1. Model of random process of degradation (Markov non-monotonic process) and the scheme of formation of operating time distribution (DN – distribution)

The shown process with a set of realization can correspond to one difficult "integrated circuit" product, which have number of PC. The process realization in this case is the changes of the PC key parameters. For the simple elements like "Resistor", which have single PC, the considered process is formed by a set of identical products. Generally, when process of degradation of the set of the single – type products (simple and difficult) is considered, each sample is presented by the only realization of the weakest PC [5]. Process of degradation of set of the single – type products can be approximated by continuous Markov process of diffusive type that is the investigated process is controlled by the stochastic differential equation of the first order (the equation of the type Kiyosi Ito):

$$dx(t) = A(t)dt + B(t)d\eta(t), \qquad (10)$$

where $x(t)$ is the constitutive parameter; $A(t)$, $B(t)$ are deterministic functions, which characterize change of average value and variance of the key parameter (drift diffusion coefficients); $\eta(t)$ a random component of Gaussian process [17].

The problem of determination of distribution of time to system's first failure in this case comes down to the solution of a problem of the first hitting the table top area by process (9) (at normalized process the upper bound is equal to one). This problem is completely solved if the conditional density of process transition probability from one state into another is known. For Markov process of diffusive type, conditional transitional density $\omega(t,x)$ corresponding to process (9) is described by Fokker–Plank–Kolmogorov's equation representing the differential equation in partial derivatives of the following form:

$$\frac{\partial\omega(t,x)}{\partial t} + A(t)\frac{\partial\omega(t,x)}{\partial x} - \frac{[B(t)]^2}{2}\frac{\partial^2\omega(t,x)}{\partial x^2} = 0. \qquad (11)$$

During the solution of the last equation it is necessary to set boundary conditions which depend on a type of process realization, in particular on their non-monotonic or monotonous character. Process of the electronic equipment products degradation along with monotonous realizations (mechanical destruction) owing to the electric phenomena has also non-monotonic realizations therefore generally it is accepted to consider degradation of these products as process with non-monotonic realizations (see Fig. 1).

In order to determine the expression for the distribution law of first failure time, the first hitting of limit by the considered process (9), it is necessary to concretize the $A(t)$ and $B(t)$ functions. We will consider the process of products degradation (9) for set of the single – type products as uniform, i.e. with a constant average speed and a constant average quadratic deviation of speed (or constant coefficient of a speed variation). In that case the kinetic equations of process (9) can be written down in the following form:

$$dx(t) = adt + bd\eta(t), \qquad (12)$$

where a is the drift coefficient (average speed of change of the key parameter); b is the diffusion coefficient (b^2 the average speed of change of variance of the constitutive parameter). The solution of the kinetic equation (12) and derivation of formulas for diffusive non-monotonic (DN) distribution is submitted in works of professor V. P. Strelnikov [5], [7], [8].

The formulas which are most applied when calculating reliability for DN-distribution when using parameter $\mu = 1/a$ have the following form [5]:

– for DN-distribution density:

$$f(t) = \frac{\sqrt{\mu}}{vt\sqrt{2\pi t}} \exp\left[-\frac{(t-\mu)^2}{2v^2\mu t}\right]; \qquad (13)$$

– for the integrated function of DN-distribution:

$$F(t) = \Phi\left(\frac{t-\mu}{v\sqrt{\mu t}}\right) + \exp\left(\frac{2}{v^2}\right)\Phi\left(-\frac{t+\mu}{v\sqrt{\mu t}}\right); \quad (14)$$

– for mathematical expectation:

$$M[T] = \mu; \qquad (15)$$

– for variance:

$$D[T] = \mu^2 v^2; \qquad (16)$$

– for *a* gamma-percentile life:

$$T_\gamma = \mu x\left(1 - \frac{\gamma\%}{100}; v\right). \qquad (17)$$

In department of reliability of IPMMS NAS of Ukraine within the last three decades it is formulated and developing the new methodology of the reliability research with use of probabilistic-physical methods. Nowadays there are rather developed methods of the solution of all main objectives of products reliability (reliability assessment of elements of mechanical and electronic products, technical systems) on the basis of the two-parameter diffusion monotonic (DM) and diffusion non-monotone distributions [5] – [8]. At the same time it is defined the most completes specifications of reliability (mean operating time, gamma percentile operating life, reliability function, residual operating life, etc). It is necessary to mark that probabilistic-physical methods of reliability indices assessment are very effective in the conditions of observation (while in operation) of high-reliable objects, in particular, the nuclear power plants equipment when there is a low statistics about failures. The application of DN-distributions showed their high performance in the process of accelerated tests for prediction of reliability indices of electronic elements: large integrated circuit (LICs) and very-large scale integrated circuits (VLICs), the active and passive electronic elements (transistors, diodes, capacitors, resistors, etc.) [18] –[20].

C. Characteristic of failure distribution of RES element basis

In reference manuals on reliability of electronic component (EC) [20] there are provided operational intensities of sudden and gradual failures, the minimum operating time and gamma percent life of EC determined by results of accelerated tests and operation.

Table I presents the distribution of sudden and gradual failures of the RES element base on the basis of "Reference books on reliability of the electronic components" used in Russia [20]. From table 1 it follows that the percent of gradual failures of electronic components (EC) can volatile between 0 and 100%.

TABLE I

DISTRIBUTION OF SUDDEN AND GRADUAL FAILURES OF EC

no	Device group	% sudden failures	% gradual failures
1	*Semi-conductor devices-* Diodes (except SHF)	20	80
2	*Optoelectronic device –* Optoelectronics	50	50
3	*Devices of quantum electronics–* Semi – conductor injection laser with pulse operation mode	0	100
4	*Indicators –* Semiconductor indicators	67	33
5	*Photoelectric device –* Phototransistor and photo receiving devices	10	90
6	Electromechanical band width filter	50	50
7	Fixed – value resistor	5	95
8	*Capacitors –* Ceramic capacitors with rated voltage of 1600 V.	41	59
9	Relay and circuit breakers, disconnect switches and automatic switching units	50	50

Considering that in the first and third part of life time (resource) of EC sudden failures predominate, and gradual failures increase in the second and third parts of EC life time, then it is recommended to present the EC distribution of reliability function in the following form [13]:

– at development of sudden failures – in the form of exponential distribution:

$$P_{\mathrm{ES}}(t) = P_{\mathrm{sud.\,ES}}(t) = \exp(-\lambda_{\mathrm{ES}}\, t); \quad (18)$$

– at development of gradual failures – in the form of DN-distribution:

$$P_{\mathrm{ES}}(t) = P_{\mathrm{grad.\,ES}}(t) = \Phi\left(\frac{t-\mu}{\nu\sqrt{\mu t}}\right) - \exp\left(\frac{2}{\nu^2}\right)\Phi\left(-\frac{\mu+t}{\nu\sqrt{\mu t}}\right); \quad (19)$$

– at combined development of sudden and gradual refusals – with the help of superposition of exponential and DN-distributions:

$$P_{\mathrm{ES}}(t) = P_{\mathrm{sud.\,ES}}(t)\, P_{\mathrm{grad.\,ES}}(t). \quad (20)$$

IV. PROSPECTS OF RELIABILITY INDICES PREDICTION AT DESIGNING OF RES

The widespread application of means of computer technologies and algorithmic languages of programming at designing of RES allows the usage of more difficult and adequate mathematical models for prediction of systems reliability indices.

Modern highly reliable RES are the restored served objects which are projected on the basis of non-restorable components: electronic, optoelectronic and electromechanical blocks, modules and elements.

On the basis of the materials presented in the section III of this paper it is possible to formulate the following prospects of using exponential and DN-distributions for reliability prediction at various design stages of RES:

A. At the stage of development of technical proposal and scheme design of RES

It is carried out the approximate calculation of reliability and the assessment of sets of single and grouped system spare tools and accessories. It is reasonable and sufficient the application of exponential distribution for prediction of indicators reliability and maintainability of system and its components.

B. At a development stage of the RES contract design

The approximate calculations of reliability, calculation of sets single and grouped system spare tools and accessories are carried out.

For carrying out calculation of indicators of electronic modules and elements reliability, it is sufficient to use the exponential distribution which allows defining the smallest (worst) estimates of system reliability indices.

Note. At development stages of outline and technical projects indicators of durability of systems are determined by the smallest value of gamma percent operating life (the minimum operating life) of electronic modules and elements.

C. At a development stage of RES specification documentation

More precise calculation of reliability, maintainability and durability of system is carried out. The specified calculation of optimum sets single and grouped system spare tools and accessories is carried out. The calculations of indicators of optimum maintenance are carried out: optimum terms of preventive replacements of modules and devices, optimum preventive maintenance of system. For carrying out calculation of reliability indicators of electronic modules and elements, it is reasonable and sufficient to use the exponential distribution (at development of sudden failures), DN-distributions (at development of gradual failures) and superposition of distributions (20) (at development of sudden and gradual failures).

When calculating indicators of RES durability (a full and residual operating life, useful life) it is expedient to use the DN-distribution and superposition of distributions.

V. CONCLUSIONS

The method of the probabilistic-physical analysis and prediction of indicators of RES reliability in the process of designing with the use of exponential and diffusive non-monotonic distributions, considered in this paper, allows considerably reduce economic costs of development, tests and production of serial samples of systems in several times [6]. Therefore it is perspective when developing means of military radio electronics-radar station with Active Phased Array Antenna (APAA) and other systems, and also the expensive electronic equipment for nuclear and thermal power plants.

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В. В. Костановський, О. Д. Козачук. Перспективи імовірнісно-фізичного аналізу надійності під час проектування радіоелектронних систем

Проведено порівняльний аналіз методів прогнозування надійності при проектуванні радіоелектронних систем. Пропонується при проектуванні систем перейти до методу імовірнісно-фізичного аналізу надійності із застосуванням експоненціального і дифузійного немонотонного розподілів відмов елементів. Використання

методу імовірнісно-фізичного аналізу надійності може дозволити отримати значний економічний ефект, зменшивши вартість зразків систем у декілька разів.

Ключові слова: імовірнісно-фізичний аналіз; експоненціальний і дифузійний немонотонний розподіл відмов елементів; прогнозування показників надійності; проектування; радіоелектронні системи.

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В. В. Костановский, О. Д. Козачук. Перспективы вероятностно-физического анализа надежности при проектировании радиоэлектронных

Проведен сравнительный анализ методов прогнозирования надежности при проектировании радиоэлектронных систем. Предлагается при проектировании систем перейти к методу вероятностно-физического анализа надежности с применением экспоненциального и диффузионного немонотонного распределений отказов элементов. Использование метода вероятностно-физического анализа надежности может позволить получить значительный экономический эффект, уменьшив стоимость образцов систем в несколько раз.

Ключевые слова: вероятностно-физический анализ; экспоненциальное и диффузионное немонотонное распределения отказов элементов; прогнозирования показателей надежности; проектирование; радиоэлектронные системы.

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