Bulgarian Academy of Sciences. Space Research Institute.
Aerospace Research in Bulgaria. 21, 2007, Sofia

A METHOD FOR INVESTIGATION AND EVALUATION OF THE RELIABILITY OF ELECTRONIC DEVICES DURING THE PROCESS OF DEVELOPMENT AND OPERATION

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Abstract

The requirement for evaluation of the reliability of electronic devices (ED) for every day and special use is connected with new methods for design and construction. This applies most of all to aerospace equioment and sistems. They must satisfy a complex of technological requirements. The most important of them must be restrictions by size, weight, power consumption, high stability of output parameters and high reliability in the process of usage. It should be taken into account that process in question takes place in the condition of a wide range of change in temperate, humidity, pressure, vibrations, in the presence of active disturbances, radiation and random variances of the nominal of the elements of ED, provoked by change in production technology. This paper examines an engineering method for research of the local sub domains for stable work of the circuits in ED. The method is continuation of the method of boundary tests, created in 1968 and suggested in[1].

1. Introduction

Satisfying the requirements for ED is a complex and multisides problem of the optimization and modelling theory. Three basic groups of methods for optimization of ED work areas with respect to decreasing probability for gradual failures are described in technical literature : the method of statistical tests (normal and speeded) [1; 2], the method of optimization with analysis of intermediate results [2] and the "Monte-Carlo" statistical modelling method [3]. Among the most effective methods from the second group are the Gauss – Zeidel method, the relaxation method, and the gradient method [3]. From the point of view of engineering design, the general disadvantage of the mentioned methods is their complexity, labour-consumption and poor clearness. The treatment of the problem consists in dividing the multidimensional domain of the circuit's stable work into local sub-domains and optimizing the last domains with sufficiently high probability for stable work ($P \geq 0,95$). Thus, the clearness of the analysis of the local sub-domains (two-dimensional or three-dimensional) give the possibility to apply the heuristic approach during the design process.

2. Solution of the problem

The solving of the formulated problem after the proposed method takes place in 4 steps described below.

2.1. Detrmination of the local sub domains of the ED cicuit's stable work

Thus can be done using the system of equations:

(1) $V_B(t) \leq W_B(t)$, $(B = 1, 2, \ldots\ldots, k)$,

where: $V_B(t)$ and $W_B(t)$ are generalized functions of the ED parameters $q_1, q_2, \ldots, q_n$, which include the parameters of the electronic elements, semiconductor depending on one devices and power supply sources common independent variable, the time t.

The functions $V_B(t)$and $W_B(t)$ also depend on the characteristics of the disturbing signals and the exploitation conditions. Conditions (1) are obtained from the analysis of ED's physical model. When the system of equations (1) is functionally incomplete with respect to the parameters $q_i\ (i = 1, 2, \ldots, n)$ it is completed based on physical considerations by introducing new conditions or adopting part of the parameters q_i, as determinative. The stable work domain of ED, determinate by system (1) is multidimensional with respect to the parameters q_i. The analysis of such a multidimensional domain is not very effective in obtaining engineering formulas to determine the optimal values of the parameters q_i. Therefore, it is advisable to divide the steady work domain of ED into local sub-domains.

The nature of the division is in solving the system of equations (1) in such a way as to obtain two relations of the type:

$$(2) \qquad q_m \le F_1(q_r),\ q_m \ge \Phi_1(q_r),\ (m, r \le n,\ m \ne r),$$

where: q_m, q_r are two of the parameters, that are searched for.

Conditions (2) determinate the local sub domain (q_m, q_r) of stable work of ED. Moreover, we must take into account that in relation (2) more than two parameters q_i can be included . In this case, the boundary of the local sub domain depends parametrically on the additional parameters q_i. Taking into consideration the values (q_m, q_r) in the initial system (1), we obtain a second local sub domain.

$$(3) \qquad \frac{q_p}{\overline{q}_m} \le F_2(q_s, \overline{q}_m, \overline{q}_r),\ \frac{q_p}{\overline{q}_m} \ge \Phi_2(q_s, \overline{q}_m, \overline{q}_r), \ldots (p, s \le n,\ p \ne s),$$

from the analysis of which we defines the mean values $\overline{q}_m, \overline{q}_r$ of another two parameters of the ED.

Using the values $\overline{q}_m, \overline{q}_r, \overline{q}_p, \overline{q}_s$ obtained from the initial system (1), we determine the next local sub-domain and etc. until we obtain the mean values of all parameters q_i. The values $\overline{q}_i$ must be chosen taking into account the possible dispersion of the quantities q_i and the coefficients, which define the functions $F_1, F_2, \ldots, \Phi_1, \Phi_2, \ldots$.

2.2. Stochastic analysis of the local sub domain of stable work of the ED

When taking into account the dispersion of the quantities q_i and the coefficients which determine the functions $F_1, F_2, \ldots, \Phi_1, \Phi_2, \ldots$ each of the relations of a type (2), (3) having the following general appearance:

(4) $\mu_j(t) \le \nu_j(t)$, $(j = 1,2,3,....,l)$, $(l \le n/2)$

must be replaced by an additionally specified relation of the following type:

(5) $\bar{\mu}_j(t) \le \bar{\nu}_j(t).\left[1 + Z_j(t)\right]$,

where the dimensionless random quantity $Z_j(t)$ determines the influence of the destabilizing factorswith time t, on the output characteristic $Z(t)$ of the ED, i.e. its relative error.

In the general case, the dimensionless random quantity $Z_j(t)$ is determinated by the equation:

(6) $Z_j(t) = \dfrac{\Delta Z}{\bar{Z}}$,

where: ΔZ is the displacement of the output characteristics $Z(t)$ of the ED from its nominal value $\bar{Z}(t)$ caused by the influence of the destabilizating factors with time t.

We assume, that the displacement of the basic perameters q_i of the ED are small (this condition is satisfied with correct by true design and normal exploitation of the ED), i.e.:

(7) $\Delta q_i << \bar{q}_i$,

and $\Delta \nu_j(t) << \bar{\nu}_j(t)$, $\Delta \mu_j << \bar{\mu}_j$ we represent the relative error $Z_j(t)$ of the functions $L_j = \nu_j / \mu_j$ in the form:

(8) $Z_j(t) = \dfrac{\Delta L_j}{\bar{L}_j} \approx \dfrac{\Delta \nu_j}{\bar{\nu}_j} - \dfrac{\Delta \mu_j}{\bar{\mu}_j}$.

Taking into account relation (6), we represent $Z_j(t)$ in the following form:

(9) $$Z_j(t)=\sum_{i=1}^{n} a_{ij}.(\Delta q_i/\overline{q}_i),$$

where: $a_{ij} \approx \frac{\partial L_j(q_1,q_2,...,q_n)}{\partial q_i}\cdot\frac{\overline{q}_i}{\overline{L}_j(\overline{q}_1,\overline{q}_2,...,\overline{q}_n)}$, and the derivatives $\partial L_j/\partial q_i$ are determinated for the points $(\overline{q}_1,\overline{q}_2,...,\overline{q}_n)$.

Equation (9) is the error equation of the error of the output characteristics of the ED which determines the relation of the relative displacements $Z_j(t)$ at the boundaries of the determined local sub-domains with the relative displacements $\Delta q_i/\overline{q}_i$ of the parameters of the ED.

Based on the theoretical investigations made in [4], equations (9) can be transformed in the following form:

(10) $$\frac{\Delta Z}{\overline{Z}}=\sum_{i=1}^{n}\left(\frac{\Delta Z}{\overline{Z}}\right)_{q_i} \cong \sum_{i=1}^{n} a_{i1}.\left(1+m_i\cdot\frac{\Delta q_i}{\overline{q}_i}\right)^{r_i}\cdot\frac{\Delta q_i}{\overline{q}_i}.$$

Relation (10) is an expanded interpretation of the equation of the "small" relative errors from (9), which is characterized by the existence of a "partial" (by „ i ") influence coefficient, defined by the multiplier, accounting for the non-linear terms of the second and higher order.

2.3. A priory determination of the parameters of the partial series from equation (10)

This determination is based on the use of the influence of the artificial by formed change of the i-th **basic parameter** (BP) Δq_i, on **the output characteristics** (OC) $(\Delta Z)_{q_i}$ at constant values of the other BPs.

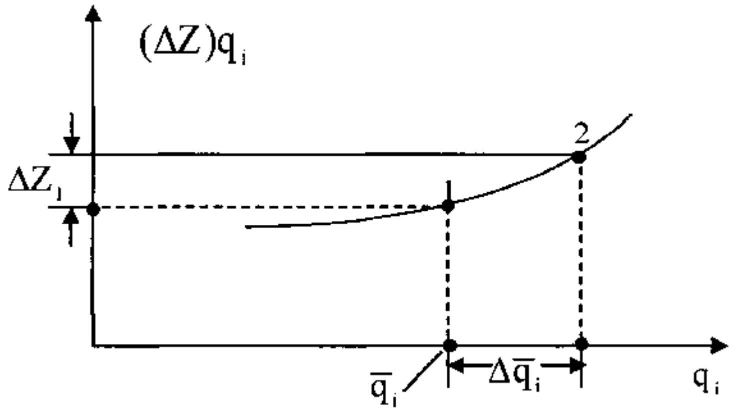

Fig. 1. A priory determination of the parameters of the partial series from (10)

That is accomplished by using the following initial data and procedures:

1. For BP q_i, two a priory points are used with coordinates - p.1 $\left[\overline{q}_i,(\Delta Z)_{q_i}\right]$, p.2 $\left[(\overline{q}_i+\Delta\overline{q}_i),\Delta\overline{Z}_1\right]$, which are shown in the Fig. 1, where $\overline{q}_i,\overline{Z}$ are the known nominal of the i-th BP and the OC; $\Delta\overline{q}_i,\Delta\overline{Z}_1$ are the given changes of the i - th BP and the measured change of ΔZ.

2. For p.1 we determine according by the derivative $(\partial Z/\partial q_i)$ and the value of the coefficient $\overline{a}_{i1}=\left\lfloor(\partial Z/\partial q_i)_{\overline{q}_i}\right\rfloor.(\overline{q}_i/\overline{Z})$.

3. Along the coordinates of p.1 (the end of the a priory range, beginning of the a posteriori range of prediction) $(\Delta Z_1,\Delta\overline{q}_i)$ we determine the parameter $\overline{m}_i$ according to:

$$\text{(11)}\qquad \overline{m}_i=\frac{\Delta\overline{Z}_1/\Delta\overline{q}_i}{(\partial Z/\partial q_i)_{\overline{q}_i}}.$$

4. From relation (9) presented in suitable a priory form:

$\frac{\Delta\bar{Z}_1}{\bar{Z}} = \bar{a}_{i1} \cdot \frac{\Delta\bar{q}_i}{\bar{q}_i} \cdot \left(1 + \bar{m}_i \cdot \frac{\Delta\bar{q}_i}{\bar{q}_i}\right)^{r_i}$, we obtain after appropriate transformations:

$$(12) \qquad \bar{r}_i = \frac{\lg \frac{(\Delta\bar{Z}_1/\bar{Z}).\bar{q}_i}{\bar{a}_{i1}.\Delta\bar{q}_i}}{\lg[1 + \bar{m}_i.(\Delta\bar{q}_i/\bar{q}_i)]}.$$

2.4. Prediction of the relative displacement (error) of the output characteristics of the ED in the case of its complex dependence on individual BPs

During stable work regimes of the ED, the following is valid for formulas (7) to (10):

$(\Delta q_i/\bar{q}_i) << 1$, $(\Delta Z/\bar{Z}) << (a_{i1}.\Delta q_i/\bar{q}_i)$, $|r_i| < 1$. From these conditions we can transform (10) in the following form:

$$(13) \qquad \frac{\Delta Z}{\bar{Z}} = \sum_{i=1}^{n} \left(\frac{\Delta Z}{\bar{Z}}\right)_{q_i} \cong \sum_{i=1}^{n} a_{i1}.\left(1 + m_i.\bar{r}_i \cdot \frac{\Delta q_i}{\bar{q}_i}\right) \cdot \frac{\Delta q_i}{\bar{q}_i}.$$

Equation (13) is "*expanded equation of the accidental relative error*", which gives the probability for predicting the relative error ξ_{OC} of the OC of the ED with complex change of the BP_i $(i = 1,\dots,n)$ which determine it out side the range $\Delta\bar{q}_i$ for $|\Delta q_i| > |\Delta\bar{q}_i|$ according to:

$$(14) \qquad \xi_{OC} = \frac{\Delta Z}{\bar{Z}} \cong \sum_{i=1}^{n} \bar{a}_{i1} \cdot \left(1 + \bar{m}_i.\bar{r}_i \cdot \frac{\Delta q_i}{\bar{q}_i}\right) \cdot \frac{\Delta q_i}{\bar{q}_i}.$$

As a matter of principle, equation (14) is a relation of relative accidental errors, which depends on a great number of non-dominating factors with normal distribution. It is important to note, that in the common case the distribution of the process of change in ξ_{OC}, as a result of its non-linear character is a multiplication of Veybul distributions [4].

With $[\overline{m}_i.\overline{r}_i.(\Delta q_i/\overline{q}_i) << 1]$ and in the general case condition $(x/x^2) \cong M(x)/M(x^2) \cong \sigma_X/\sigma_X^2$ where is satisfied for the mathematical expectation $M(\Delta q_i/\overline{q}_i)$ and the dispersion $D(\Delta q_i/\overline{q}_i)$ of the individual BP_i, the mathematical expectation and the dispersion of the OC of ED $(\Delta Z/\overline{Z})$ can be determined, according to:

$$M\left(\frac{\Delta Z}{\overline{Z}}\right) \cong \sum_{i=1}^{n} \overline{a}_{i1}.\left[1 + \overline{m}_i.\overline{r}_i.M\left(\frac{\Delta q_i}{\overline{q}_i}\right)\right].M\left(\frac{\Delta q_i}{\overline{q}_i}\right), \tag{15}$$

$$D\left(\frac{\Delta Z}{\overline{Z}}\right) \cong \sum_{i=1}^{n} \overline{a}_{i1}^2.\left[1 + \overline{m}_i^2.\overline{r}_i^2.D\left(\frac{\Delta q_i}{\overline{q}_i}\right)\right].D\left(\frac{\Delta q_i}{\overline{q}_i}\right). \tag{16}$$

3. Case study of an electronic circuit

As a subject of the case study, the circuit of a generator based on the integrated circuit NE 555 - electronic timer [5], is chosen. The circuit and its elements are shown in Fig. 2.

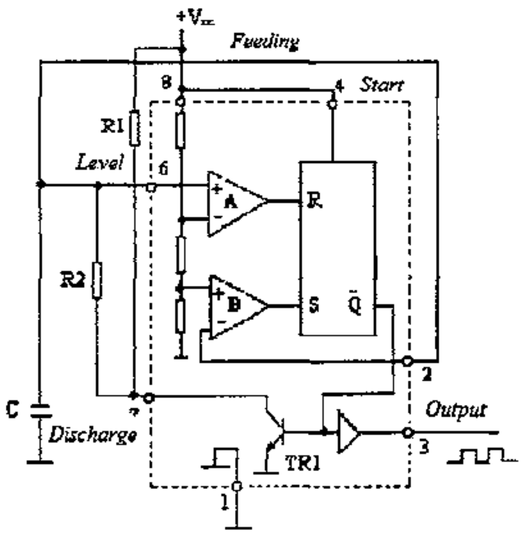

Fig. 2. Electronic circuit of a generator based on the timer NE 555

The investigation was carried out on the basis of equations (15) and (16), which were transformed in the following form:

$$(17)\quad M\left(\frac{\Delta f}{\overline{f}}\right)\cong\sum_{i=1}^{n}a_{i1}.\left[1+\overline{m}_i.\overline{r}_i.M\left(\frac{\Delta C}{\overline{C}}\right)\right].M\left(\frac{\Delta C}{\overline{C}}\right),$$

$$(18)\quad D\left(\frac{\Delta f}{\overline{f}}\right)\cong\sum_{i=1}^{n}a_{i1}.\left[1+\overline{m}_i.\overline{r}_i.D\left(\frac{\Delta C}{\overline{C}}\right)\right].D\left(\frac{\Delta C}{\overline{C}}\right),$$

where: $\overline{f}$ - the mean (nominal) frequency of the generated electrical oscillation at the output of the timer NE 555 $(\overline{f}=1\,kHz)$; Δf - the displacement of the timer frequency from $\overline{f}$; $\overline{C}$ - the mean (nominal) value of the capacitor C from Fig. 2 $(\overline{C}=1\,nF)$; ΔC - the displacement of the value of capacitor C from the its mean (nominal) value $\overline{C}$; $R_1=5\,k\Omega$; $R_2=470\,k\Omega$.

In Fig. 3 and Fig. 4 the graphic simulation investigations of equations (17) and (18) using the "*Mathematics*" program are shown, investigating the functional relations:

$$(19)\quad M\left(\Delta f/\overline{f}\right)=F\left[M\left(\Delta C/\overline{C}\right)\right],$$

$$(20)\quad D\left(\Delta f/\overline{f}\right)=F\left[D\left(\Delta C/\overline{C}\right)\right].$$

Functional relations (19) and (20) are investigated under the conditions of the experiments with the timer from Fig. 2, whereas with a change of the capacitor value C by $\Delta C=100\,pF$ we have $\Delta f=10\,Hz$. Under this condition, from equations (9), (10) and (11), the following relations for mathematical expectation M and dispersion D were obtained:

(21) $$M\left(\frac{\Delta f}{10^3}\right)=\left[1+10^{20}.\Delta C.\lg(\Delta f)\right].M\left(\frac{\Delta C}{10^{-9}}\right),$$

(22) $$D\left(\frac{\Delta f}{10^3}\right)=10^{12}.\left[1+10^{40}.\lg^2(\Delta f)\right].D\left(\frac{\Delta C}{10^{-9}}\right),$$

where M is mathematical expectation and D is dispersion.

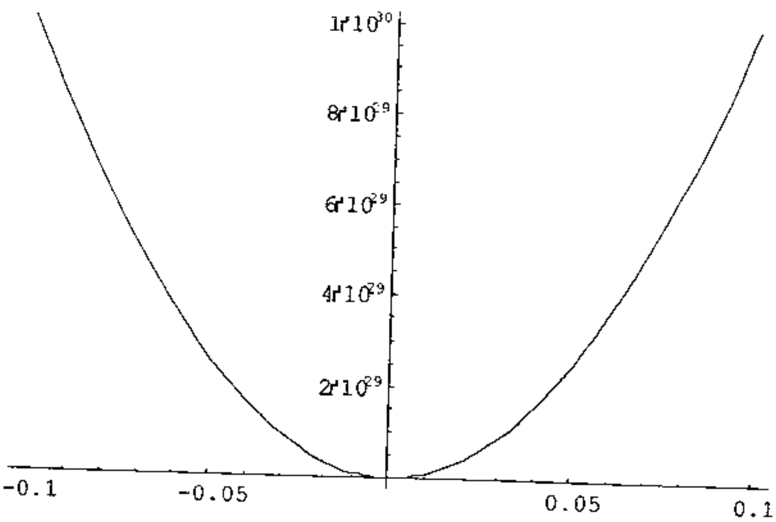

Fig.3. Graphical representation of the function

$$M\left(\frac{\Delta f}{10^3}\right)=F\left[M\left(\frac{\Delta C}{10^{-9}}\right)\right]$$

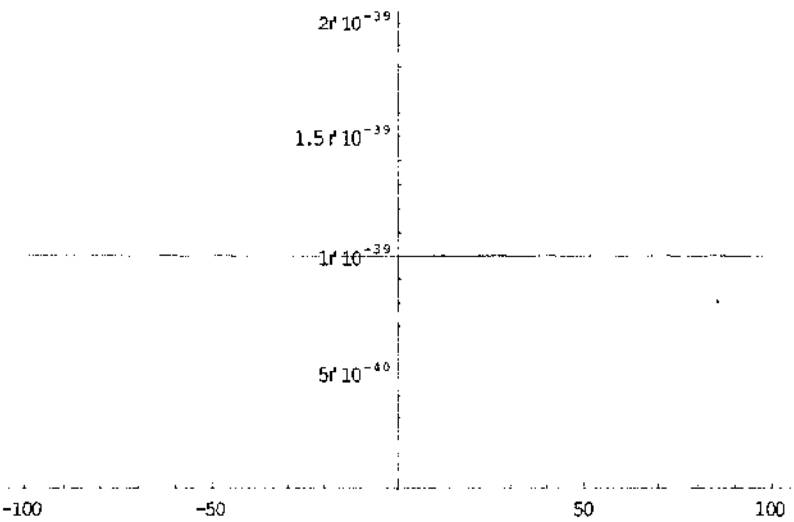

Fig.4. Graphical representation of the function

$$D\left(\frac{\Delta f}{10^3}\right)=F\left[D\left(\frac{\Delta C}{10^{-9}}\right)\right]$$

4. Conclusions

On the basis of the results from this investigation, we can formulate the following conclusions:

1. Equations for mathematical expectation and dispersion of the output characteristics of electronic devices for every day and special use have been derived. From the analysis of these equations the technological conclusion for the high reliability to external influence on the test circuit in the connection regime recommended by the producer has been made.

2. On this basis simulation case investigation of an electronic circuit (electronic timer) has been carried out. The simulation investigation evidences of the good symmetry of function $M\left(\Delta f/\bar{f}\right)$ and stability of function $D\left(\Delta f/\bar{f}\right)$.

3. Based on the type of the graph of function $M\left(\Delta f/\overline{f}\right)$, it can be ascertained that the probability for generation of the nominal specified by the producer frequency of the output pulses is maximum in the domain of the solution of this function. The uncertainty of the dispersion of the generated frequency is uniform and symmetrical at deviation from the nominal value. All investigation have been made only for a change of the capacity of capacitor C from the connection shown in diagram Fig.2, whereas the influence of resistors R_1 and R_2 has not been accounted for.

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МЕТОД ЗА ИЗСЛЕДВАНЕ И ОЦЕНКА НА НАДЕЖДНОСТТА НА ЕЛЕКТРОННИ АПАРАТУРИ В ПРОЦЕСА НА РАЗРАБОТКА И ЕКСПЛОАТАЦИЯ

Н. Петров, Б. Бойчев

Резюме

Изискването за оценка на надеждността на електронните апаратури (ЕА) с битово и специално предназначение изисква принципно нови методи за проектиране и конструиране. Това е особено актуално за аеро-космическите апарати и системи. Те трябва да удовлетворяват комплекс

от тактико-технически и технологични изисквания. Най-важните от тях следва да бъдат ограничения по отношение на габарити, тегло, консумирана и разсейвана мощност, висока стабилност на изходните параметри и висока надеждност в процеса на експлоатация. Трябва да се има предвид, че въпросният процес се извършва в условията на широк диапазон на изменение на температурата, влажността, налягането, вибрациите, наличието на активни смущения, радиация и неизбежни случайни вариации на номиналите на елементите на ЕА предизвикани от изменението на технологията на производство. В настоящата статия се разглежда инженерен метод за изследване на локални подобласти за устойчива работа на схемите в ЕА. Методът се явява продължение на метода на граничните изпитания създаден през 1968 г. и предложен в [1].