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Simulation model to calculate the indices of reliability of redundant radio electronic systems

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Abstract. Purpose. *To define quantitative estimates of reliability indices of redundant radio electronic systems, the methods of reliability theory, analytical methods or simulation modeling are applied. This paper describes the application of these methods for systems of diverse complexity, as well as the complex of programs "Dialogue" developed for the calculation of reliability indices.* **Methods.** *The main obstacle for wide application of the simulation modeling method to obtain the reliability indices is high labor intensity of the creation of these models. The current software tools are not very useful. This problem can be solved using the developed complex of programs "Dialogue". This is achieved by creating the simulation models programs automatically on the basis of input initial data. The time of creation of a model is determined by the time of the input. Generating of the simulation models is based on the principle that if the system's behavior in case of failures is determined only by its scope structure, connections between components, failure criteria and redundancy switches, i.e. when the system's response to a failure of its component is uniquely defined in advance, then it will be possible to create models with equal structures for the systems with any configurations. It helps to create the basis for the initial text of the model, common for all simulation models of this type. Such basis forms a permanent part of the model, and the data which define the specifics of failure behavior of the concrete system, are set in form of insertions to the main text.* **Results.** *The complex of programs that is being described is intended to calculate the reliability indices of different technical systems using simulation models, and its consists of the program for the description of system to be simulated "Dialogue-OS", the program for the model synthesis "Dialogue-Synthesis" and special sub-programs combined to a separate library. The complex helps to create specialized simulation models of redundant systems which undergo statistical tests, and based on the obtained results the reliability indices are defined. Using the complex "Dialogue" we can obtain the following reliability indices: 1) probability of reliable operation for a predetermined period of time, 2) failure rate at the end of a predetermined period of time, 3) mean time to failure, 4) data to build a graph of dependence of the probability of reliable operation on time, 5) data to build a graph of dependence of the failure rate on time.* **Conclusion.** *This article provides the results of calculations carried out by theoretical methods, and by the method of simulation modeling that show a good coincidence (relative error is not more than 1%). The complex "Dialogue" makes it possible to calculate the reliability indices of redundant radio-electronic systems of any complexity with accuracy sufficient for practice. It should be noted that the complex "Dialogue" allows for creating the simulation model of reliability for redundant radio-electronic systems, whose reliability characteristics can not be calculated by theoretical methods due to their complexity.*

Keywords*: redundant systems, indices of reliability, reliability theory, simulation modeling, flowchart of the program.*

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Theoretical methods of calculation

To improve reliability of radio electronic systems (RES) under the insufficient reliability of the constituent elements, the redundancy is used, i.e. the availability in the system of large number of the elements in comparison to the number necessary to perform the required function (equipment redundancy).

Among the reliability indices which determine RES reliable operation, the following indices are used more often in practice:

- probability of reliable operation (PRO) per the predetermined period of time t – R(t);
- mean time to failure – T_0;
- failure rate per the predetermined period of time t – λ(t).

Analytical analysis of the system reliability under redundancy is usually executed with the following restrictive assumptions:

1. Failures of the redundant system elements are the simplest flow of random events.
2. All main and standby elements within one redundant system have equal reliability.

3. Switch devices are not taken into account (implemented in software or accepted as ideally reliable).

4. Redundant system is not performed during its functioning.

5. All elements of the system can exist only in one of two states: operable or non-operable (failure).

Reliability structure diagram (RSD) is a graphic image of operable state of the system. RSD shows a logic connection of operating elements (or units which combine them), necessary for the successful operation of the system. To define quantitative estimates of reliability indices of redundant radio-electronic systems, different methods are applicable. Depending on the RSD type one can use simple Boolean methods, theory of Markov processes and/or the fault tree analysis. Calculations could be performed using theoretical methods or the Monte-Carlo modeling [1] (method of simulation modeling).

The simplest variant is a sequential RSD, in which successful operation (no failure) of each of *m* elements of the diagram (Fig. 1) is required to assure successful functioning of the system. All elements of the diagram are in "on" position, the failure rate of the *i*-th element of the diagram shall be indicated as λ_i (i=1, …, m). RSD input is indicated by symbol I, output is indicated by symbol O.

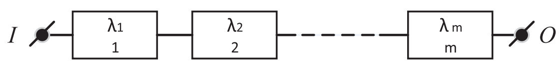

Fig. 1. Sequential RSD with m elements

With the assumptions accepted above the main quantitative characteristics of reliability of a sequential RSD shall be expressed by the following formulas [2]:

$$R_c(t) = e^{-t\sum_{i=1}^{m}\lambda_i}; \quad (1)$$

$$\lambda_c = \sum_{i=1}^{m}\lambda_i; \quad (2)$$

$$T_{0(c)} = \frac{1}{\sum_{i=1}^{m}\lambda_i}. \quad (3)$$

Generally, a parallel RSD may contain *m* of main elements, *l* of hot standby elements and *r* of cold standby elements. In a particular case when all main elements have equal failure rate λ_0, all *l* of hot standby elements have the same value of the failure rate λ_0, all r of cold standby elements are off and have the failure rate λ_p ($0 \le \lambda_p < \lambda_0$) up to the "on" moment, the diagram of this parallel redundancy is given in Fig. 2. Let us indicate the structure of this parallel system (m, *l*, r).

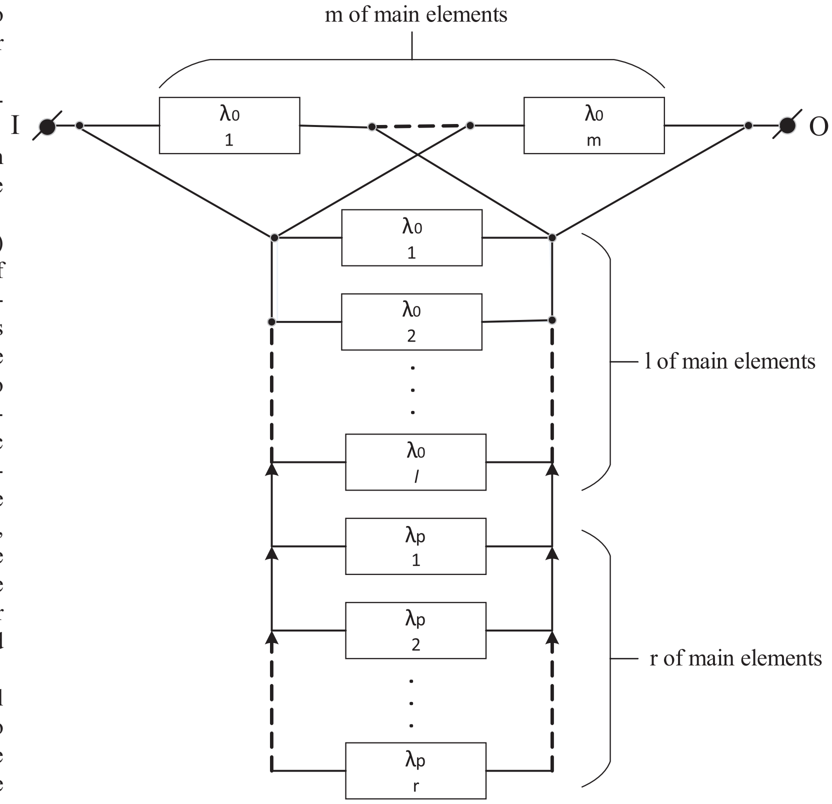

Fig. 2. Parallel RSD with the structure (m, *l*, r)

In a specific case for the structures with equal type of standby (m, *l*, 0) and (m, 0, r) we can obtain a common formula for PRO if the redundant system using the methods of homogeneous Markov processes:

$$R_c(t) = e^{-\lambda_0 t} \cdot \left[\frac{\prod_{j=0}^{n}(m + j\alpha)}{\alpha^n \cdot n!} \sum_{i=0}^{n} (-1)^i \cdot \frac{C_n^i}{m + i\alpha} \cdot e^{-(m-1+i\alpha)\lambda_0 t} \right], \quad (4)$$

where n is the number of standby elements (n = *l* or n= r);
m is the number of main elements (m ≥ 1);

$$\alpha = \frac{\lambda_p}{\lambda_0};$$

$n! = \prod_{k=1}^{n} k$ is a factorial of n;

$C_n^i = \dfrac{n!}{i!(n-i)!}$ is the number of combinations of n by i.

Mean time to failure is:

$$T_{0(c)} = \int_0^\infty R_c(t)dt = \frac{1}{\lambda_0}\sum_{i=0}^{n}\frac{1}{m+i\alpha}. \quad (5)$$

Rate of failure of the redundant system can be calculated by formula:

$$\lambda_c(t) = -\frac{R'_c(t)}{R_c(t)} = \lambda_0 \frac{\sum_{i=0}^{n}(-1)^i C_n^i e^{-(m+i\alpha)\lambda_0 t}}{\sum_{i=0}^{n}(-1)^i \frac{C_n^i}{m+i\alpha} e^{-(m+i\alpha)\lambda_0 t}}. \quad (6)$$

In a general case for systems with structure (m, *l*, r), which includes hot and cold standby elements, the expression for PRO of the redundant system $R_s(t)$ will depend on the mode of switching cold standby elements to "on" state. In particular, for systems, when cold standby elements turn to "on" state only after the failure of *l* modules from the main scope or from the hot standby, i.e. when the system acquires the structure (m, 0, r), the expression for $R_s(t)$ has rather complex structure [3]. In the simplest case for the redundant system with the structure (1, *l*, 1) the expression for $R_s(t)$ has the following form

$$R_c(t) = \left[1-(1-e^{-\lambda_0 t})^{l+1}\right] + (l+1)\cdot\lambda_0\cdot e^{-\lambda_0 t}\cdot\sum_{i=0}^{l} C_l^i(-1)^i \times \times\frac{\left[1-e^{-(i+\alpha)\lambda_0 t}\right]}{\lambda_0(i+\alpha)}. \quad (7)$$

Majority redundancy "m of n" often used in practice, is a particular case of the system shown in Fig. 2, if the structure will have the form (m, *l*, 0) (in this case n = m + *l*) or (m, 0, r) (in this case n = m + r).

In practice sequential and parallel diagrams of redundancy are often used. Fig. 3 shows the diagram which consists of a non-redundant element 1, the first parallel redundant group with the structure (1, 2, 0), which consists of elements 2, 3, 4 and the second parallel redundant group with the structure (1, 1, 0) which consists of elements 5 and 6.

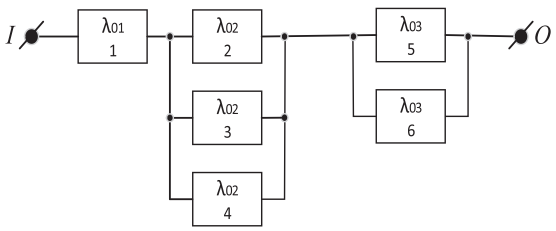

Fig. 3. RSD with sequential and parallel connection of the elements

The example of a more complex diagram with sequential and parallel redundancy is shown in Fig. 4 [1].

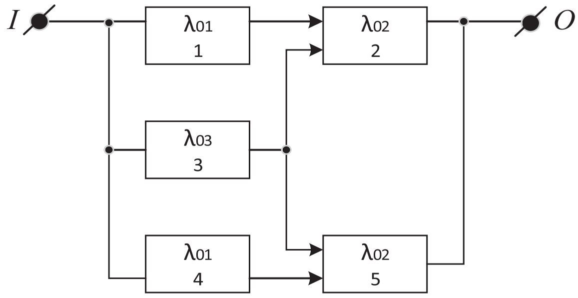

Fig. 4. RSD with sequential and parallel connection of the elements

The figure shows the system of fuel supply to the engines of a light aircraft. Element 1 is a fuel supplier for the engine of the port (element 2), element 4 is a fuel suppler for the engine of the starboard (element 5), and element 3 is a standby supplier for both engines. Failure of this system occurs in case both engines are failed

On the diagram of Fig. 4 elements 1, 3, 4 are control elements, and elements 2, 5 are controlled elements. The connections of control elements with controlled elements are indicated by an arrow.

A more complex diagram with control and controlled elements is shown in Fig. 5 [4].

The diagram consists of control elements C_1, C_2, C_3 and operating elements combined in three lines with sequential and parallel redundancy. Each control element controls its line of operating elements, and a failure of the control element will put the whole line out of operation. Such system of redundancy is used in the unit of optical sensors within the unit of thunderstorm activity registration used within the scope of a spacecraft.

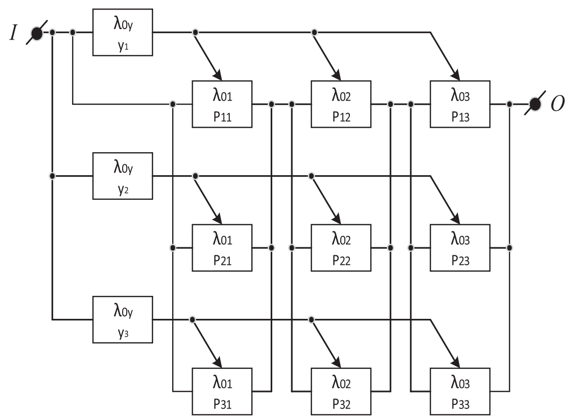

Fig. 5. RSD with control and operating (controlled) redundancy elements

In practice the diagrams with multilevel redundancy can be used (Fig. 6).

On the diagram shown in Fig. 6, at the first level of redundancy a majority diagram "2 of 3" with the structure

(2, 1, 0) is used, at the second level a parallel diagram with cold standby is used.

The analysis shows that for the simplest redundancy diagrams (Fig. 2) there are the formulas to calculate the indices R(t), T_0, λ(t) [1,2]. For the more complex diagrams (Fig. 4, 5) using a fault tree analysis, we can obtain the formulas to calculate the indices R(t) [1, 4], but it is difficult to calculate the indices T_0, λ(t), because such diagrams lose the property of the simplest flow of failures.

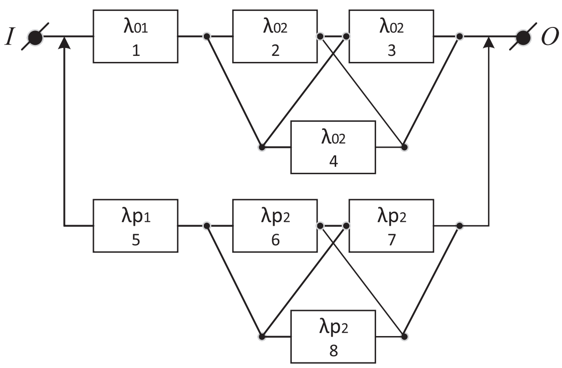

Fig. 6. RSD with two-level redundancy

For the diagram shown in Fig. 6, it is difficult to calculate even the index R(t), as for the diagram of the second level with cold standby it is necessary to know the value of index λ(t) for each line to calculate the index R(t) using the known formulas. Due to the fact that each line contains the redundant diagram of the first level, the flow of failures in the lines is not the simplest any more, and rate of failures of each line can not be calculated using the known formulas.

An alternative to theoretical methods of calculation of reliability indices if the method of simulation modeling which makes it possible to simulate real functioning of the redundant system of any complexity. Below is the description of the complex of programs for simulation modeling used to calculate the reliability indices of redundant systems.

The complex of programs "Dialogue"

The main obstruction of wide application of the simulation modeling method to obtain the reliability indices is a high labor intensity of the creation of these models. The current software tools are not very useful. This problem can be solved using the developed complex of programs "Dialogue". This is achieved by creating the simulation models programs automatically on the basis of input initial data. The time of creation of a model is determined by the time of the input.

Generating of the simulation models is based on the principle that if the system's behavior in case of failures is determined only by its scope structure, connections between components, failure criteria and standby switches, i.e. when the system's response to a failure of its component is uniquely defined in advance, then it will be possible to create models with equal structures for the systems with any configurations..

It helps to create the basis for the initial text of the model, common for all simulation models of this type. Such basis forms a permanent part of the model, and the data which define the specifics of failure behavior of the concrete system, are set in form of insertions to the main text.

Initial data for the synthesis of models are the following information:

- scope of the system and connections between its components;
- failure criteria;
- terms of standby switches;
- rates of failures of the system elements in different modes.

This data is sufficient to reflect the system's failure behavior in the model.

Hereinafter in the text the following terms will be used:

- system is the object of modeling, consisting of elements and units, in relation to which the reliability indices are being determined;
- element is the smallest indivisible part of the system, in which a failure occurs;
- unit is a conditional combination of elements and units;
- system components are elements and units composing the system's scope;
- main scope of the system are the elements and units excluding the switched standby and control components;
- switched standby are the components switched from the standby under the occurrence of special conditions;
- failure criterion – is the state of the component when the failure occurs;
- term of standby switch is the term when the failed component is substituted with a component from standby.

Before starting the program "Dialogue" it is necessary to prepare the part of initial data describing the system scope and connection between its components.

This preparation is based on the assignment of conditional units in the system and giving names to all units and elements.

The following types of units are used for this purpose:

- sequential (SEQ) (Fig.1);
- parallel (PAR) (Fig. 2);
- majority (MAJ), which is a particular case of a parallel unit;
- controlled (CON) (Fig. 5), consisting of control elements (C1, C2, C3) and objects of control (OC) including all operating components (Op_{11},…,Op_{33});
- standby unit (STB) (Fig.2), which is used to assign the cold standby components with any value of m, and to assign the hot standby components with m > 1.

Below is the description of the program "Dialogue", as well as the principles of operation of the simulation model obtained with the help of this program. The program is written in the REXX language using the interpreter Regina 3.6. The complex also includes system files and special sub-programs combined into a library, which are used under translation.

At the first level of the program operation an operator enters initial data describing the system and mode of tests. At the second level, as the result of the processing of the data entered, the synthesis is performed in relation to the model which is the initial text of the computer program Fortran 77, using certain SMPL sub-programs [5].

A flow-chart of the program "Dialogue" is shown in Fig. 7, with the main stages of the program operation.

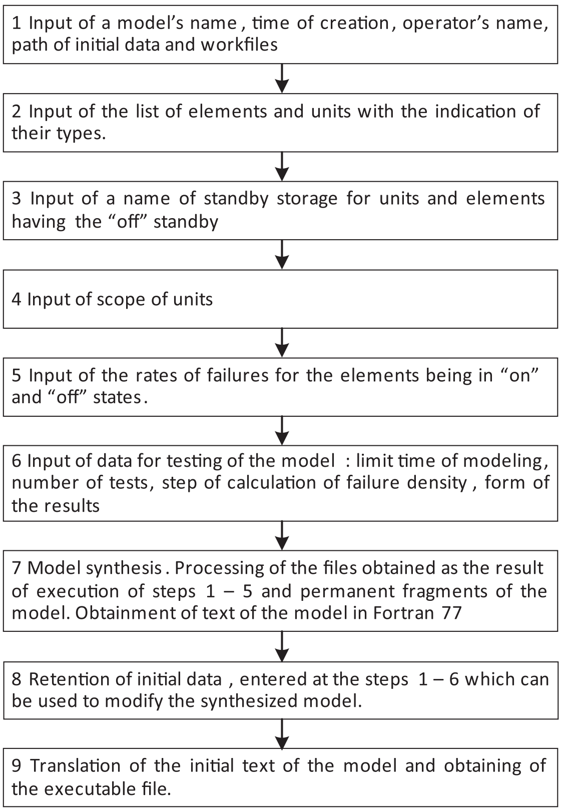

Fig. 7. Flow-chart of the program "Dialogue"

1. Input of the name of the model, time of creation, operator's name and a path of workfiles. The model's name shall be the name of the file with a model entry.

2. Input of the system scope: list of elements and conditional units with the indication of their types.

3. If a unit or an element has an "off" standby, the name of unit where they are stored, is entered.

4. Input of the scope of conditional units is made, including the unit of standby storage.

5. Input of the rates of failures of the elements for "on" and "off" states.

6. Input of data for testing of the model: number of tests, duration of modeling, calculation of failure density. Thus data can be modified on the start of the model's program.

7. Model synthesis. The input data are processed, forming the fragments of text of the model. Permanent parts which form the basis of the model are combined with the formed fragments. The result of combination of the program text in Fortran 77 and operating files.

8. Retention of initial data. To reduce the time of entry of initial data, if it is necessary to test several types of systems, the data entered could be retained, with the possibility to modify them partially and generate a new model.

9. Translation of the formed text of the program and obtaining of the executable file. To start the translation, the installed translator providing for Fortran 77 is required. The choice of this language is based on the fact that after the translation an executable code if formed. This code has a low redundancy in comparison to other languages. Translation and testing of the model can be carried out on another computer.

All obtained models have equal algorithm of operation, they differ only in terms of the parts which describe the system structure. That is why we shall use a generic term "model" for them below in the text.

The obtained models have the following characteristics**:**

– number of components in the system – not more than 100;

– law of distribution of the event to generate – exponential;

– one standby store may serve several components;

– a component can be served only by one standby;

– a standby of the component can be a component of another type, i.e. a standby of the element can be a unit, and vice versa;

– there is no standby for the components which are on standby;

– criterion of standby switch is a failure of the component.

The program "Dialogue" can set the following reliability indices as the results to be obtained:

– value of the probability of reliable operation per the predetermined period of time t – R(t);

– graph of dependence R(t) for the predetermined time interval from $t_{1(R)}$ to $t_{2(R)}$;

– value of mean time to failure – T_0;

– value of the system failure rate per the predetermined period of time t – λ(t);

– graph of dependence λ(t) for the predetermined time interval from $t_{1(\lambda)}$ to $t_{2(\lambda)}$ (failure density).

Principle of operation of synthesizable models is as follows:

1. On start of the program the time of failure is stochastically generated for each element. If this time is shorter than

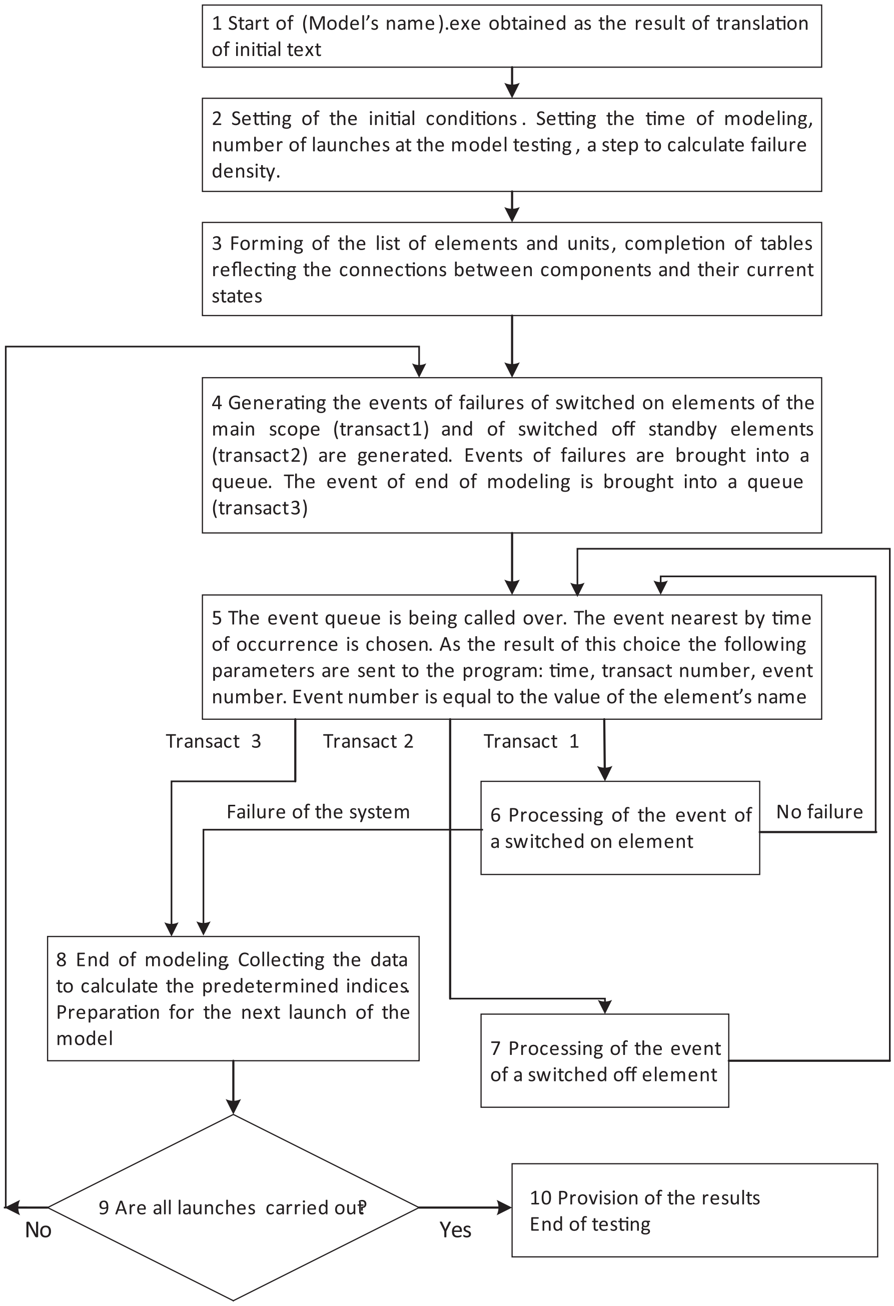

Fig. 8. Flowchart of the program of a simulation model

the predetermined time for the system to end its operation, an event is planned – a failure of the element. As the parameter of the event, the time of occurrence, as well as the name of the respective element are set. Besides there is generation of the event when the model ends its operation with the system ending its operation.

2. Events are brought into a queue and sorted by time.

3. A queue is being called over, and then the event with the shortest time is selected.

4. The selected event (failure of the element) is processed: the system components are being called over, it is necessary to determine whether this failure head to the failure of other components, or to the failure of the system, whether it is possible to switch standby.

5. If a limit time is achieved, or there is a system failure, the model's operation is stopped.

6. If a standby is switched instead of the failed component, the standby is turned on, the events which were generated

```
MODEL RIS2-1
RESULTS OF MODELING
Time of modeling=  1000
Number of tests=  200000
Number of failures=  50529
Number of success=  149471
Probability of reliable
operation=.7473550
Mean time to failure= WAS NOT
CALCULATED
step=   50
failure rate lambda(t)=.00058785
```

Fig. 9. Results of model testing

```
MODEL RIS2-1
MEAN TIME TO FAIULRE WAS CALCULATED
Time of modeling =  300000
Number of tests =  200000
Number of success =       0
Mean time to failure =  1834,26
```

Fig.10. Results of testing of the model to obtain mean time to failure

DATA OF THE FAILURE RATE GRAPH lambda(t)

step	time	lambda(t)
1	25	0.279248E-05
2	75	0.177235E-04
3	125	0.357058E-04
4	175	0.651742E-04
5	225	0.105678E-03
6	275	0.140588E-03
7	325	0.174245E-03
8	375	0.204881E-03
9	425	0.241084E-03
10	475	0.279565E-03
11	525	0.318051E-03
12	575	0.355583E-03
13	625	0.384560E-03
14	675	0.411543E-03
15	725	0.441098E-03
16	775	0.482188E-03
17	825	0.510980E-03
18	875	0.536080E-03
19	925	0.549788E-03
20	975	0.572966E-03

Fig.11. Data of the failure rate graph lambda(t)

for it earlier are rejected, and new failures are generated for the “on” state.

7. Model is launched for the predetermined number of times, after that the calculation of reliability indices is carried out.

It should be considered that the following split of the events into groups (transacts) is used in the model, in accordance with the type and processing algorithm:

– failures of switched on elements (transact1);

– failures of switched off standby elements (transact2);

DATA OF THE GRAPH OF PROBABILITY
OF RELIABLE OPERATION R(t)

step	time	R(t)
1	50	0,999710E+00
2	100	0,999125E+00
3	150	0,997345E+00
4	200	0,994370E+00
5	250	0,989405E+00
6	300	0,981660E+00
7	350	0,973620E+00
8	400	0,963880E+00
9	450	0,951950E+00
10	500	0,939040E+00
11	550	0,924295E+00
12	600	0,907600E+00
13	650	0,890265E+00
14	700	0,872485E+00
15	750	0,853265E+00
16	800	0,833265E+00
17	850	0,811605E+00
18	900	0,790305E+00
19	950	0,768880E+00
20	1000	0,747355E+00

Fig. 12. Data of the graph of probability of reliable operation R(t)

– completion of operation upon achievement of the time of end of modeling (transact3).

The result of the program “Dialogue” is the file (model Name).for with the model written in Fortran. After the translation of this file, an executable file if formed – (model Name).exe. Then it is started, statistical testing is performed.

A flowchart of operation of such models is shown in Fig. 8.

The operation is performed as follows:

1. Start of the executable file obtained after translation.

2. Setting of the initial conditions. It is necessary to set the time of modeling, number of launches at the testing of the model, a step to calculate failure density. This data can be modified under the program execution, and the calculation of failure density could be excluded.

3. The list of elements and conditional units is formed.

The events of failures of switched on elements (transact1) and of switched off standby elements (transact2) are generated. Events of failures are brought into a queue and sorted by the predetermined time of occurrence. The event of end of modeling is brought into a queue (transact3).

The event queue is being called over. The event nearest by time of occurrence is chosen. Depending on the transact number there may be the processing of failures of switched on main elements, the processing of failures of switched off standby elements or the end of modeling.

Processing of the failure of the main components. It is necessary to check whether the failure of this element lead to the system failure. As the element may be present in several conditional units simultaneously, it is neces-

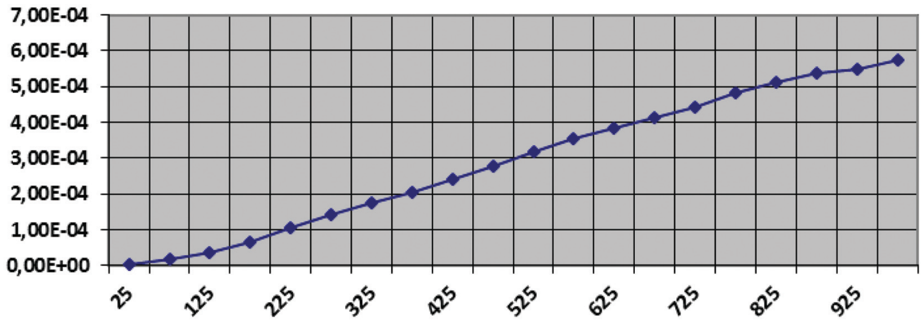

Fig. 13 Graph λ(t)

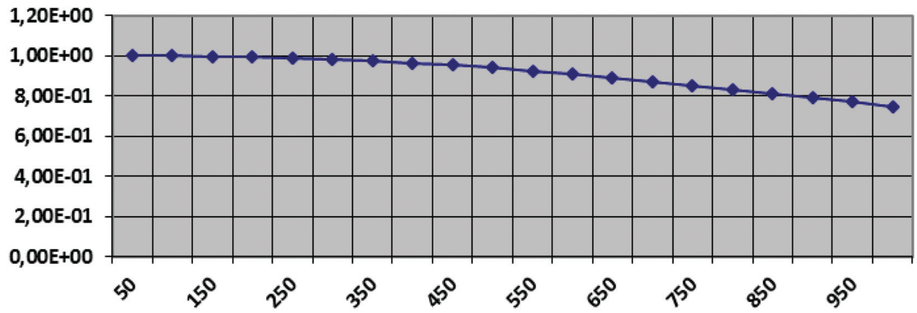

Fig.14 Graph R(t)

Table 1 – Comparative evaluation of the calculation of reliability indices of redundant systems

Examples for calculation			Comparative evaluation of the calculation performed					
			Indices	Calculation method				Relative error, %
				Theoretical		Modeling		
No.	**Description of the system**	**System characteristics**		**Results**	**Formulas**	**Results**	**The number of tests, step**	
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1	Fig. 1	m = 3 $\lambda_1 = 40 \cdot 10^{-6}$ $\lambda_2 = 4 \cdot 10^{-6}$ $\lambda_3 = 0{,}4 \cdot 10^{-6}$ t = 8760 h	$R_c(t)$ $T_{0(c)}$ λ_c	0,6777 22522 $44{,}4 \cdot 10^{-6}$	(1) (2) (3)	0,6782 22532 $44{,}22 \cdot 10^{-6}$	200000 100	0,073 0,044 0,405
2	Fig. 2 Structure (1, 2, 0)	$\lambda_0 = 1000 \cdot 10^{-6}$ t = 1000 h	$R_c(t)$ $T_{0(c)}$ $\lambda_c(t)$	0,7474 1833 $590 \cdot 10^{-6}$	(4) (5) (6)	0,7473 1834 $587{,}85 \cdot 10^{-6}$	200000 50	0,013 0,054 0,364
3	Fig. 2 Structure (1, 0, 2)	$\lambda_0 = 1000 \cdot 10^{-6}$ $\lambda_p = 100 \cdot 10^{-6}$ t = 1000 h	$R_c(t)$ $T_{0(c)}$ $\lambda_c(t)$	0,9012 2742 $244 \cdot 10^{-6}$	(4) (5) (6)	0,9021 2745 $243{,}65 \cdot 10^{-6}$	200000 100	0,100 0,109 0,143
4	Fig. 3	$\lambda_{01} = 10 \cdot 10^{-6}$ $\lambda_{02} = 40 \cdot 10^{-6}$ $\lambda_{03} = 100 \cdot 10^{-6}$ t = 8760 h	$R_c(t)$ $T_{0(c)}$ $\lambda_c(t)$	0,5885	(4)	0,5879 12418 $88{,}96 \cdot 10^{-6}$	200000 100	0,102
5	Fig. 4	$\lambda_{01} = 10 \cdot 10^{-6}$ $\lambda_{02} = 100 \cdot 10^{-6}$ $\lambda_{03} = 20 \cdot 10^{-6}$ t = 1000 h	$R_c(t)$ $T_{0(c)}$ $\lambda_c(t)$	0,9909	(8) [1]	0,9892 14535 $21{,}59 \cdot 10^{-6}$	200000 100	0,171

Table 1. Continuation

Examples for calculation			Comparative evaluation of the calculation performed					
			Indices	Calculation method				Relative error, %
				Theoretical		Modeling		
No.	Description of the system	System characteristics		Results	Formulas	Results	The number of tests, step	
1	2	3	4	5	6	7	8	9
6	Fig. 5	$\lambda_{0y} = 10 \cdot 10^{-6}$ $\lambda_{01} = 4 \cdot 10^{-6}$ $\lambda_{02} = 1 \cdot 10^{-6}$ $\lambda_{03} = 0{,}1 \cdot 10^{-6}$ t = 87600 h	$R_c(t)$ $T_{0(c)}$ $\lambda_c(t)$	0,6176	(3) [4]	0,6184 123332 $10{,}30 \cdot 10^{-6}$	200000 100	0,130
7	Fig. 6	$\lambda_{01} = 10 \cdot 10^{-6}$ $\lambda_{02} = 40 \cdot 10^{-6}$ $\lambda_{p5} = 1 \cdot 10^{-6}$ $\lambda_{p6} = 4 \cdot 10^{-6}$ t = 8760 h	$R_c(t)$ $T_{0(c)}$ $\lambda_c(t)$			0,9699 34217 $9{,}26 \cdot 10^{-6}$	200000 200	

sary to check what has the failure lead to in these units. The failure of each unit may lead to the failure of other units, etc. till the last unit is achieved. If the failed unit or element has a standby, it is substituted by a standby component. If there is a failure of the system, a failure counter is increased by one and the modeling is stopped. After the failure is processed, the next event is selected from the queue.

Failure of the switched off standby element is processed in the same way as it is described in clause 6, except for the possibility of standby switch and absence of failure.

The modeling ends for two reasons: achievement of limit time under no failure, or the failure of the system.

If the predetermined number of model launches is not achieved, there is a restart in unit 4. Upon each completion of operation the data used to obtain the results of modeling is collected.

If the predetermined number of model launches is achieved, the results are provided.

As the example of operation of the program "Dialogue", below are the results of RSD modeling shown in Fig.2 with the structure (1,2,0).

Example of the results of the model testing is shown in Fig. 9.

To obtain a reliable value of mean time to failure the model testing is carried out with time of modeling that assures the probability of reliable operation close to 0. Normally it is sufficient to set the time equal to $(1/\lambda)\times 20$, where λ is the least value of λ indices for the elements within RSD.

Example of the results of such calculation is shown in Fig.10

Results of testing in form of tables are shown in Figures 11-12.

Graphs of change of the failure rate $\lambda(t)$ and of the probability of reliable operation R(t) are shown in Figures 13-14. The graphы were constructed using the program not belonging to the complex "Dialogue".

Estimation of the obtained results

To certify the results of operation of the complex "Dialogue" a comparative evaluation of the calculation of reliability indices of redundant systems was performed. The calculations were performed based on the theoretical methods using the known formulas, and based on the operation of a simulation model. The calculation results are listed in Table 1.

According to the analysis of the calculation results listed in Table 1, relative error of the results is not more than 1%.

Moreover, the program "Dialogue" makes it possible to calculate the reliability indices of redundant systems in case there are no analytic formulas.

Thus the program "Dialogue" can be used to calculate the reliability indices of redundant radio-electronic systems.

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