ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 4, Issue 6, December 2014

Evaluation of Technical Condition of a Radar with Redundancy

Anton Georgiev, Toncho Papanchev, Dimitar Kovachev
Dept. of Electronic Engineering and Microelectronics,
Technical University of Varna, Bulgaria

***Abstract*— This paper is devoted to problems arising on description and evaluation of technical condition of radar with reserved units. The implemented redundancy of the units in the Doppler radar is analyzed with the help of Markov chain modeling approach. We made a comparison of the reliability of a Doppler radar, developed by elements with very high reliability, and the reliability of a Doppler radar with redundancy.**

***Index Terms*—Doppler radar, Hardware redundancy, Markov chain, Reliability.**

I. INTRODUCTION

The Doppler Effect is used in order to detect moving targets on the ground surface [1]. The block diagram of such radar with continuous radiation and phase manipulation of the emitted signal [2] is shown in Fig.1. The moving target is detected by the Doppler Effect and the distance between it and the radar's antenna can be determined by correlation processing (at video frequency) of the received signal. The phase-manipulated signal is emitted, and after reflection by the target is received back with a time lag for signal distribution to the target and backwards. The modern implementation of a radar system usually contains a control system for simultaneous collection and analysis of information on the reliability. The purpose of the control system is to "track" continuously the radar operating condition and to provide an immediate indication for failure occurrence or other malfunctions; to "analyze" the measured parameters and after evaluation of their changes to "take intelligent management decisions" on the operability of the system (to reduce the power in the absence of power redundancy, to manage the redundancy structure by switching the respective redundant units, etc.). Fig.2 represents a simplified block diagram of such system. In this article we observed reliability analysis and examination of the impact of the redundancy on Doppler radar reliability. A Markov chain modeling approach is applied for this purpose. In [2] the authors have considered the radar system based on programmable FPGA. However, studies are focused only on design of the radar with series connected units in terms of reliability. Fig.3 presents the block diagram of a radar structure if FPGAs are used to design the basic parts of Doppler radar. The components, which have been additionally added and are required for the proper work of the FPGAs, are also pointed out. Redundancy implementation on blocks 1, 2, and 3 is subject of investigation in terms of achieved reliability and redundancy optimization. Block 4 remains not reserved, because of the considerable increased costs and constructive difficulties which would occur if adding reserve blocks. Increasing the reliability of block 4 is a task for future work.

In order to obtain sufficiently informative results, the implementation of commercial or mil-spec components in the radar design is examined.

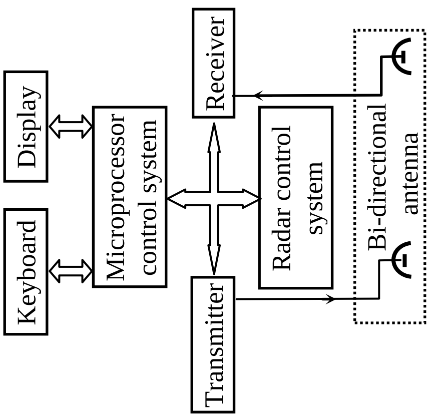

Fig.1. Block diagram of Doppler radar

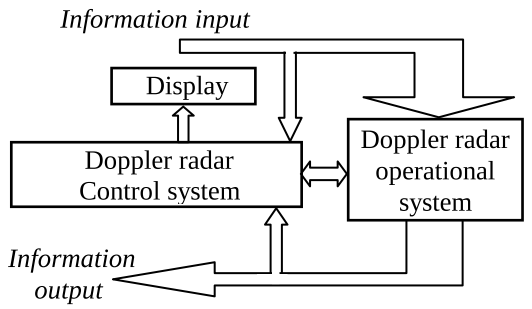

Fig.2. A simplified block diagram of a Doppler radar with control system

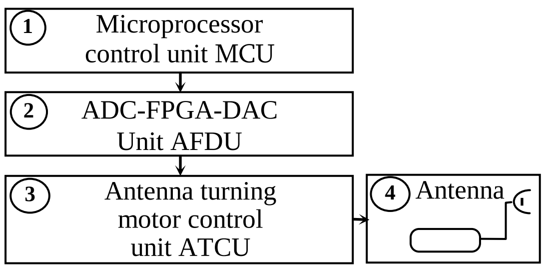

Fig.3. Summarized structure of Doppler radar with FPGA module for signal processing

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 4, Issue 6, December 2014

II. MARKOV CHAIN MODELING THEORY

In order to evaluate the radar, we used Markov chain modeling techniques. Markov chain modeling provides the probabilistic model of the system's state transition [3]. The state transitions of system failures are represented in a discrete time model. The system reliability, maintainability, and availability are evaluated. The state transition model assumes that two failures cannot happen at the same time [3]. If a continuous random process occurs with discrete states, the system transitions from one state to another may be examined as a result of random events [4], [8]. The random process with discrete states is described as a Markov process, if all probability characteristics of this process at the successive moments depend only on the current state, in which the process may be found at the present moment, and do not depend on that, how the process was running in the past [9]. The future state depends on the past states only if the past states affected the present state. If the process is a Markov one, then the events, causing a transition from one to another, have Poisson distribution. As mentioned in [5], the process of subsequent transition through the states operation – failure – repair – operation, is a homogenous Markov process with finite number k states (k=1÷N), in which a transition may occur only between two neighbor states: $\omega_{i,i+1}=\omega_i$, $\omega_{i,i-1}=\mu_i$, $\omega_{i,j}=0$, if $|j-i|>1$. Here $\omega_{i,i+1}$ is the rate of transitions from i-th to next state "i+1", and its meaning is a failure rate ω_i of such failure that transforms the technical condition of the system from current i-th state to the state "i+1". In opposite, the rate of transitions from i-th to state "i-1" $\omega_{i,i-1}$ describes the repair rate μ_i, when the system is restored to state "i-1" from i-th state. As the system has finite number of states N, so μ_0=0 and ω_N=0. The Kolmogorov's equations for the process [5] are written in (1)

$$\begin{cases} \dfrac{dP_0(t)}{dt}=-\omega_0 P_0(t)+\mu_1 P_1(t) \\ \cdots\cdots\cdots\cdots\cdots\cdots \\ \dfrac{dP_k(t)}{dt}=-(\omega_k+\mu_k)P_k(t)+\omega_{k-1}P_{k-1}(t)+\mu_{k+1}P_{k+1}(t) \\ \cdots\cdots\cdots\cdots\cdots\cdots \\ \dfrac{dP_N(t)}{dt}=\omega_{N-1}P_{N-1}(t)-\mu_N P_N(t) \end{cases}, \quad (1)$$

where $P_i(\mathrm{t})$ is the probability that the system stays at i-th state, i=0÷N. It should be noticed that if the number of the process states is infinite or sufficiently large, the last equation in (4) has not real meaning [6]. For the process to be stationary and independent from the choice of the initial moment, the following conditions have to be performed:

$$\sum_{k=1}^{\infty}\frac{\omega_0\omega_1\ldots\omega_{k-1}}{\mu_1\mu_2\ldots\mu_k}<\infty\ , \quad (2)$$

$$\sum_{k=1}^{\infty}\frac{\mu_1\mu_2\ldots\mu_k}{\omega_0\omega_1\ldots\omega_k}\approx\infty\ . \quad (3)$$

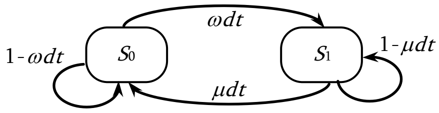

Fig.4. Markov chain model of a single model of the studied Doppler radar

In addition it may be said that if the number of states is finite, the stationary values of probabilities exist and they meet the conditions

$$\begin{cases} 0=-\omega_0 P_0+\mu_1 P_1 \\ \cdots\cdots\cdots\cdots\cdots\cdots \\ 0=-(\omega_k+\mu_k)P_k+\omega_{k-1}P_{k-1}+\mu_{k+1}P_{k+1} \\ \cdots\cdots\cdots\cdots\cdots\cdots \\ 0=\omega_{N-1}P_{N-1}-\mu_N P_N \end{cases}. \quad (4)$$

To solve (4), we introduced new unknown variables υ_k

$$\upsilon_k=\mu_{k+1}P_{k+1}-\omega_k P_k\ . \quad (5)$$

Using these variables, (4) could be simplified

$$\begin{cases} \upsilon_0=0 \\ \cdots\cdots\cdots \\ \upsilon_k-\upsilon_{k-1}=0 \\ \cdots\cdots\cdots \\ \upsilon_{N-1}=0 \end{cases}, \quad (6)$$

which means, that υ_k=0 for each k. Therefore we could write the followed equation

$$P_k=\frac{\omega_0\omega_1\ldots\omega_{k-1}}{\mu_1\mu_2\ldots\mu_k}P_0=\gamma_k P_0\ . \quad (7)$$

As all possible N states of the radar are registered in the composed model, and the probability of simultaneous occurrence of two or more failures tends to zero, it could be argued that the total set of all states of the radar forms a complete set of mutually exclusive random events. .Similar conclusions are formulated in [7] during studying of an electronic system for conversion of wind energy into electricity. Normalization condition for such a complete set of mutually exclusive random events is shown in (8)

$$\sum_k P_k=1\ . \quad (8)$$

In these circumstances, we can write the following equations:

$$P_k=\gamma_k\Big/\sum_{i=1}^{\infty}\gamma_i\ , \quad (9)$$

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 4, Issue 6, December 2014

$$\gamma_0 = 1, \tag{10}$$

$$\gamma_k = \frac{\omega_0\omega_1 \ldots \omega_{k-1}}{\mu_1\mu_2 \ldots \mu_k}\,. \tag{11}$$

III. MARKOV CHAIN MODEL OF THE STUDIED FPGA RADAR

A. Markov Model of Radar System without Redundancy

Fig.3 represents the basic system with serially connected units, hereinafter referred to as serial system. Fig.4 shows the Markov chain model of a serial system. Such model has two states S_0 and S_1. The state S_0 is the operational state and the state S_1 represents the set of all states of failure. The failure flow parameter is given by ω. The system repair rate μ is the reliability parameter, assessed both the maintainability of the radar and the efficiency of the applied maintenance approach. μ is used in the maintainability evaluation. *Let* $P_0(t)$ and $P_1(t)$ are probabilities of the system to stay at the respective system states at the current moment t ("t" states), and $P_0(t+1)$ and $P_1(t+1)$ are the same probabilities, but for the next moment $t+1$ ("$t+1$" states). So, the "$t+1$"-th state could be presented as a function of the previous "t"-th state. The probability $P_0(t+1)$ could have two previous t states - $(1-\omega\Delta t)P_0(t)$ and $\mu\Delta t P_1(t)$, and that of $P_1(t+1)$ are $\omega\Delta P_0(t)$ and $(1-\mu\Delta t)P_1(t)$. If these equations are expressed in a discrete model, (12) can be written as

$$\begin{bmatrix} P_0(t+1) \\ P_1(t+1) \end{bmatrix} = \begin{bmatrix} -\omega & \mu \\ \omega & \mu \end{bmatrix} \begin{bmatrix} P_0(t) \\ P_1(t) \end{bmatrix}. \tag{12}$$

Equation (12) describes the Markov chain model with discrete states of radar without redundancy.

B. Redundancy Optimization in Radar Systems

Due to the traditionally high reliability requirements regarding the radar systems, they belong to the group of electronic devices with a circuit design that contains some kind of redundancy. Typically these are systems with partial structural redundancy. The requirement for high reliability is in conflict with the demand for low cost production, especially in the context of the highly competitive market of electronic products. The optimization of the depth of implemented structural redundancy in product design aims to be chosen this minimum required redundancy, which allows achieving the reliability requirements. In practice the parallel connection in terms of reliability of radar blocks is used only for certain units, while other blocks are realized without structural redundancy (by series connection of units). In this sense, the radar is a typical electronic system with mixed connection in terms of reliability. If it is denoted with n the number of reserved elements in the radar structure, then if n increases, so that $n \to \infty$, it can be written

$$\lim_{n\to\infty} R_R(t) \approx \lim_{n\to\infty} \exp\left((1-R_0)^2 / n\right) = 1\,, \tag{13}$$

where $R_R(t)$ is the probability of flawless operation of the system with redundancy; R_0 - the probability of flawless operation of the single unit. The most common term for probability of flawless operation is reliability, so we will use both terms in our article. Equation (13) is referred to the loaded reserve and shows that it is theoretically possible to obtain reliability values approximately equal to one. In cases when half-loaded and unloaded reserve is used, this seems even more attainable. However, if the actual reliability of the switching system is reported (designed for establishing failure of a block and instantly switching to its reserved block), it seems unreal to achieve probability values approximately equal to one. The optimal level of reservations in particular electronic equipment can be described by the expression

$$\max_n R_R(t) = R_P^{(N_0)}(t)\,, \tag{14}$$

where N_0 is the optimal level of redundancy. Usually N_0 is a small number, as its increasing complicates unnecessarily the switching device structure and increases the system cost. There are number of methods for optimization the redundancy of electronic systems. In this section we analyzed the application of a method based on the sequential examination of the possible redundancy options. This method is convenient for practical applications because of its apparent simplicity, lucidity and high efficiency. To illustrate the method we examined an electronic system, composed of three blocks, connected in series in terms of reliability – Fig.5. We assumed that the specific values of reliability for a year of these three blocks are respectively: $R_1(t)$=0,88, $R_2(t)$=0,90 and $R_3(t)$=0,83, t=8760 h. Then the probability of flawless operation $R(t)$ of the system with serial reliability structure for a year would be

$$R(t) = R_1(t).R_2(t).R_3(t) = 0{,}88.0{,}90.0{,}83 = 0{,}65736\;. \tag{15}$$

Let it is necessary to achieve values of $R(t)$ at least 0,992. Obviously, the series reliability block diagram cannot ensure it. One way to achieve this reliability is the implementation of structural excess. For this purpose, the number of reserve blocks of the three main blocks must be optimized, so that the system probability of flawless operation acquires values equal or higher than the desired value 0,992. If the serial-parallel reliability block structure is implemented, consisting of three blocks, each of which is reserved with α_i (i=1÷3) number of blocks identical to the main one, then the requirement for

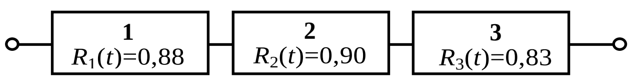

Fig.5. Serial reliability block diagram of an electronic system composed of three blocks

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 4, Issue 6, December 2014

achieving a value of 0,992 for the system reliability may be written as

$$R(t)=\prod_{i=1}^{3}\left[1-(Q_i(t))^{\alpha_i+1}\right]\leq 0{,}992\,, \qquad (16)$$

where $Q_i(t)=1-R_i(t)$ is the probability of failure of i-th single block, $i=1\div3$. The terms in brackets represent the probability of flawless work of i-th block, if it is combined with α_i identical units connected in parallel in terms of reliability.

As we know the reliability of each single block $R_i(t)$, $i=1\div3$, we could calculate the expressions $[1-(Q_i(t))^{\alpha i+1}]$. Table I represents these values for $\alpha_i=0\div6$. Using the values shown in Table I, the value of α_1 could be determined by the position, in which $[1-(Q_1(t))^{\alpha_1+1}]$ of the first block reaches for the first time 0,992. It is seen that $\alpha_1=2$, and the correspondent value is 0,998272>0,992.

The next step requires to be determined the value of the product of the probabilities for the flawless operation of the second and third block with redundancy, for satisfying the requirement $R(t)\geq 0{,}992$

$$\left[1-Q_2(t)^{\alpha_2+1}\right].\left[1-Q_3(t)^{\alpha_3+1}\right]= =\frac{0{,}992}{0{,}99827}=0{,}9937\,. \qquad (17)$$

It could be seen in Table I that $[1-(Q_2(t))^{\alpha 2+1}]$ reaches the value 0.993717 when $\alpha_2=2$, $[1-(Q_2(t))^{\alpha 2+1}]=0{,}999>0{,}993717$. Then the needed value of $[1-(Q_3(t))^{\alpha 3+1}]$ for the group of the third block and its reserved units, could be calculated for preserving the system reliability $R(t)\geq 0{,}992$, i.e.

$$1-Q_3(t)^{\alpha_3+1}=\frac{0{,}993717}{0{,}999}=0{,}994712\,. \qquad (18)$$

Using Table I it is easy to find out the value of α_3, for which the value of $[1-(Q_3(t))^{\alpha 3+1}]$ reaches for the first time 0,994712. This is the value $0{,}995087\geq 0{,}994712$, for $\alpha_3=2$. As a result of the analysis one of the options for reliability structural diagram of the electronic system is established. Under this option the first, the second, and the third blocks are reserved by two identical to them units. The resulting structure is shown in Fig.6 and represents a variation of series –parallel structure. If the numbers of reserved blocks α_1,α_2 and α_3 are more than 2, the system becomes unnecessarily expensive, therefore such options are not considered [10].

Table I. Blocks reliability data when the main blocks are reserved with up to six identical units

	Block 1	Block 2	Block 3
α_i	$1-Q_1^{\alpha_1+1}$	$1-Q_2^{\alpha_2+1}$	$1-Q_3^{\alpha_3+1}$
0	0,88	0,9	0,83
1	0,9856	0,99	0,9711
2	0,998272	0,999	0,995087
3	0,99979264	0,9999	0,99916479
4	0,9999751216	0,99999	0,9998580143
5	0,9999970146	0,999999	0,99997586244
6	0,99999964176	0,9999999	0,99999589662

Upon the optimization, it is not necessary to comply with certain sequence of blocks. The procedure could be started from the third block, optimizing the number of its redundant blocks, i.e. determining α_3, then could be determined α_1 and finally α_2. The algorithm is similar to the one described above. After performing the calculation procedures the first version of redundancy is achieved, with $\alpha_1=2$,$\alpha_2=2$, and $\alpha_3=2$. It is also possible to start the optimization procedure with determination of α_2, and then be determined α_1 and finally α_3, as the optimal solution again reaches two reserve units for each major block. Following the presented algorithm and choosing different sequences of searching, the redundancy optimization of electronic system could be performed, containing four, five or more main blocks, connected in series. It is possible to establish a set of combinations of values for α_1, α_2, α_3, α_4, α_5 etc., by which the desired level of reliability could be achieved. For example, the desired reliability could be obtained at such values: $\alpha_1=2$, $\alpha_2=1$, $\alpha_3=2$, $\alpha_4=2$, $\alpha_5=1$; or $\alpha_1=1$, $\alpha_2=2$, $\alpha_3=2$, $\alpha_4=2$, $\alpha_5=2$; or $\alpha_1=2$, $\alpha_2=2$, $\alpha_3=1$, $\alpha_4=1$, $\alpha_5=2$; etc. In such case it is expedient the optimization to be tailored to specified economic criteria for the electronic system.

The presented here algorithm for redundancy optimization of electronic systems, based on sequential examination of the possible options, is a very convenient for practical applications. Its advantages are demonstrated by implementation in specific situations. The algorithm solves one of the key issues - which of the main blocks of the system by how much additional blocks to be reserved. It enables selection of the optimal solution for hardware redundancy of electronic systems. The algorithm is flexible and through it could be implemented various combinations tailored to specific economic criteria.

C. *Markov Model of Radar System with Redundancy*

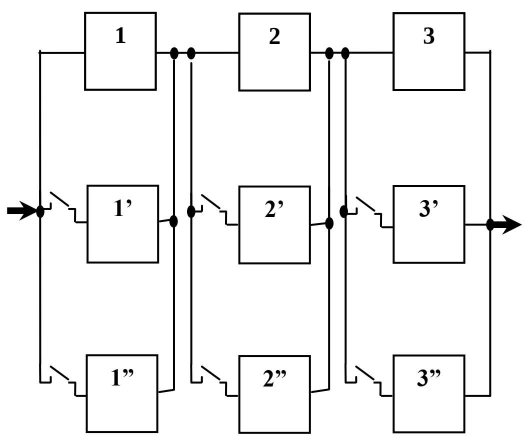

Fig.6. Reliability block diagram of the system, providing probability of flawless operation not less than 0,992

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 4, Issue 6, December 2014

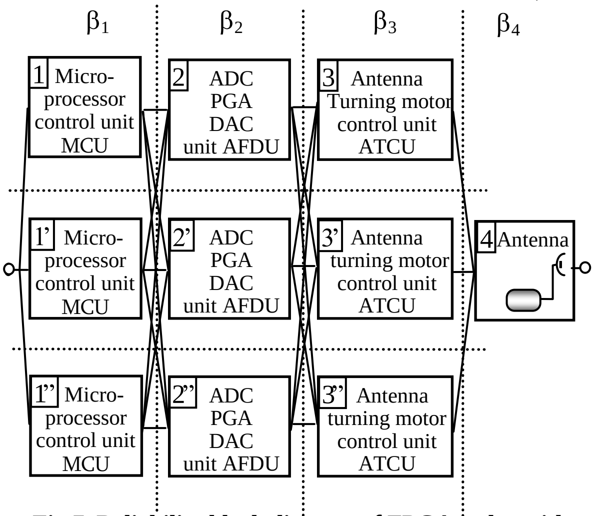

Fig.7. Reliability block diagram of FPGA radar with redundancy

For the present analysis an optimized version of the redundancy diagram is taken, which is evaluated in the previous section, and the three main blocks 1, 2, and 3, except block 4, are reserved by two blocks, identical by the main ones, or α_1 =2, α_2 =2, and α_3 =2. Fig.7 shows the proposed structure of radar with redundancy, briefly named redundant system. Obviously each microprocessor control unit (MCU) receives FPGA data. In case of a failure in one of microprocessor control units, it has no effect on the system operation. And because FPGA unit (AFDU) is triplicated, a failure of one AFDU has no influence on MCU. Block 4 is not reserved due to the reasons described in section I. MIL-HDBK-217F [11] and Telcordia SR332 [12] are used for reliability data of electronic components. The flows of random events "time to failure" and "time for repairing" possess some features of the Markov random process - continuity and finite number of states. Also the flow of system failures is ordinary, simple and without an after-effect, and the failure rate and the repair rate have constant values in time (ω = const, μ = const). The distribution laws of time between failures, the time to failure, the time to repair could be defined. The above described circumstances allow defining the process of system reliability changing by means of deferential equations where the unknown variables are the system probabilities to stay at the correspondent states. In Fig.8 it is proposed the Markov model of the radar with redundancy, according to the block diagram shown in Fig.7. The model is composed of nine states $S_1 \div S_9$, and the respective probabilities to stay at them are P_1(t) $\div P_9$(t). β_1, β_2 and β_3 are the states respectively of triplicated MCU, ADFU and ATCU (antenna-turning motor control unit). β_4 is the antenna state. For example, $3\beta_1$ means that all the three MCUs are working properly, and $2\beta_1$ means that one MCU has failed and the other two units work properly. The state S_9 is the failure state and S_1 to S_8 are the states for properly operation. The failure rates are as follow: $\omega_{\beta 2}$ is of AFDUs, $\omega_{\beta 1}$ is of MCUs, $\omega_{\beta 3}$ is of ATCUs and $\omega_{\beta 4}$ is that of the antenna. The repair rate μ designates the system repair rate of the radar with redundancy.

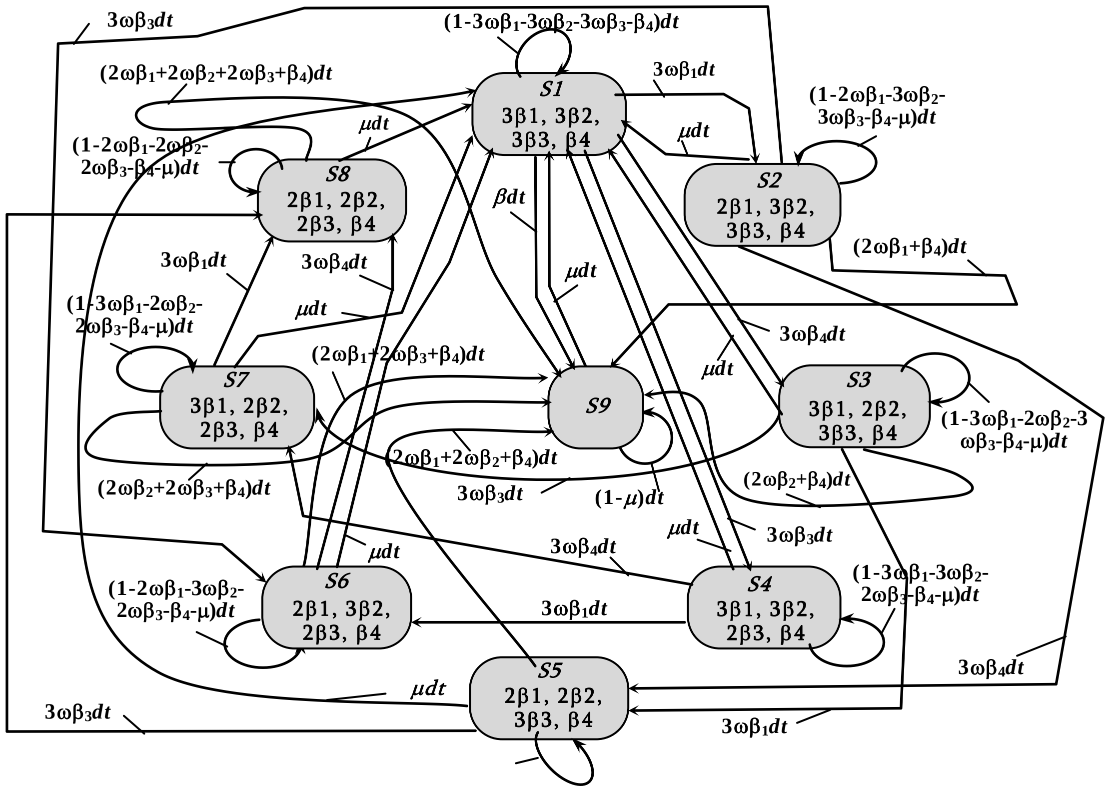

Fig.8. Markov chain model of the radar with redundancy

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 4, Issue 6, December 2014

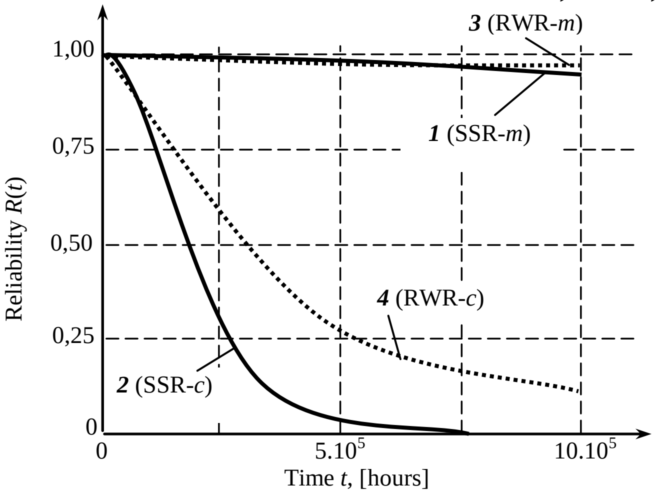

Fig.9. Reliability characteristics for different component types and redundancy implementation

The repair rate could be evaluated by experimental results, but in this paper we assume that the repair rate is 0,01[h^{-1}] for all states of the radar. The full discrete states equations are very complicated, so we present them in a simple form as (19)

$$\begin{bmatrix} P_1(t+1) \\ P_2(t+1) \\ . \\ . \\ P_8(t+1) \\ P_9(t+1) \end{bmatrix} = \begin{bmatrix} s_{11} & \mu & . & . & \mu & \mu \\ s_{21} & s_{22} & . & . & 0 & 0 \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ 0 & 0 & . & . & s_{88} & s_{89} \\ s_{91} & s_{92} & . & . & s_{98} & s_{99} \end{bmatrix} \begin{bmatrix} P_1(t) \\ P_2(t) \\ . \\ . \\ P_8(t) \\ P_9(t) \end{bmatrix} \qquad (19)$$

IV. RELIABILITY SIMULATIONS

Reliability R(t) of commercial and mil-spec components for serial system SSR and redundant system RWR of radar is examined using simulations. '*m*' is the index for the system composed of mil-spec components and '*c*' is that of commercial components. Equations (12) and (19) are used for evaluation of $R(t)$, respectively, for series reliability block diagram and series-parallel reliability block diagram. Both diagrams are shown in Fig.3 and Fig.7, respectively. The initial reliability is assumed as $R_1(0)=1$, because all the systems are assumed to work properly at the beginning. The states of proper operation are S_2, S_3, S_4, S_5, S_6, S_7 and S_8, P_2, P_3, P_4, P_5, P_6, P_7 and P_8, so the reliability is a step response, as it is seen in (19). Due to the lack of correlation between the probability of flawless work and the repair rate, in case of assessing the probability of flawless operation, the repair rate 'μ' could be assumed as 0. Results of reliability assessing are presented in Fig.9. For achieving a more complete view on the impact of redundancy implementation on the reliability, simulation results are shown for radar built by highly reliable "MIL-SPEC" elements (marked on the chart as "*m*"), on the one hand, and by elements which do not meet the requirements for a high reliability, or are not subjected to any reliability enhancing procedures or reliability classification procedures (elements for commercial use, shown on the chart as "commercial components" - „*c*"). The failure rates in MIL-SPEC elements are usually two to three orders of magnitude lower than that of the elements for commercial use. This is the reason why the probability of flawless operation of each of the blocks and the radar as a whole is much higher in the case when it is built by MIL-SPEC elements - curves 1 and curve 3 in Fig.9, compared with curves 4 and 2. In addition, curves 1 and 3 illustrate the very low dependence in time of the probability of flawless operation of the radar with MIL-SPEC elements. Another conclusion imposed by Fig.9 is a tremendous difference between the probability of flawless operation characterizing the "commercial use elements" radar with and without redundancy - curve 4 is located significantly above the curve 2. Regarding the "*m*"-elements radar, the difference between reliability for the observed reliability structures is not is not such clearly manifested - curves 1 and 3. The difference between the reliability of the four variants of the radar can be illustrated by the mean time to failure - Table II. *Maintainability M*(t) is the probability that a failed system will be restored to an operational state within a specified period of time t. The maintainability equation is shown in (20)

$$M(t) = 1 - e^{-\mu . t} . \qquad (20)$$

Obviously, maintainability is effective if the time to repair is small enough. The relation between repair rate and maintainability is shown in Fig.10. It is seen, that the maintainability is higher if the repair rate is high; if the system repair time is low, the system availability is good.

Availability $K_A(t)$, the meaning of which is the evaluation of the probability to perform correctly a task in an instance of time t, could be defined with its stationary value K_A^* as the ratio of Mean Time To Failure T_{MTTF}^* of the system to the sum of T_{MTTF}^* and Mean Time To Repair T_{MTTR}^*

$$K_A^* = \frac{T_{MTTF}^*}{T_{MTTF}^* + T_{MTTR}^*} . \qquad (21)$$

In this section the availability is evaluated using (12) and (19), and the repair rate is assumed to be equal to 0.01[h^{-1}] (value corresponding to T_{MTTR}^* = 100 hours). The adopted value is close enough to the real one, in cases when failure (failures) in one or several blocks due to implemented redundancy did not cause failure of the radar as a whole, i.e. the set of the conditions $S_2 \div S_8$ (Fig.8). Under these conditions, the amendment of K_A* would look as shown in Fig.11. Low failure rate has high availability and, basically, the availability of the radar with redundancy is higher than that of the radar with serial reliability structure. The availability of radar without redundancy and "*c*"-elements (*curve 4* - SSR-*c*) is 0,9948, the same radar structure with "*m*"-elements (*curve 3*) is 0,9994, that of radar with redundancy and "*c*"-elements (*curve 2* - RWR-*c*) is 0,9989 and the same redundancy structure, but with "*m*"-elements (*curve 1*) is 0,99989. If high availability is required, the system repair rates have to be high enough. If the RWR

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 4, Issue 6, December 2014

system reliability intends to achieve "*five nines*", the repair rate μ should be 0,1h^{-1}.

SYSTEM	MEAN TIME TO FAILURE
R-c	11713 hours
RWR-c	18423 hours
SSR-m	244677 hours
RWR-m	7124560 hours

Table II. Mean Time To Failure of each radar variants

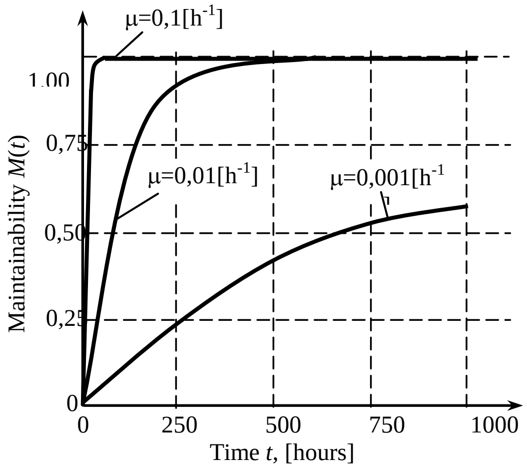

Fig.10. Maintainability characteristics for different components and identical schematics

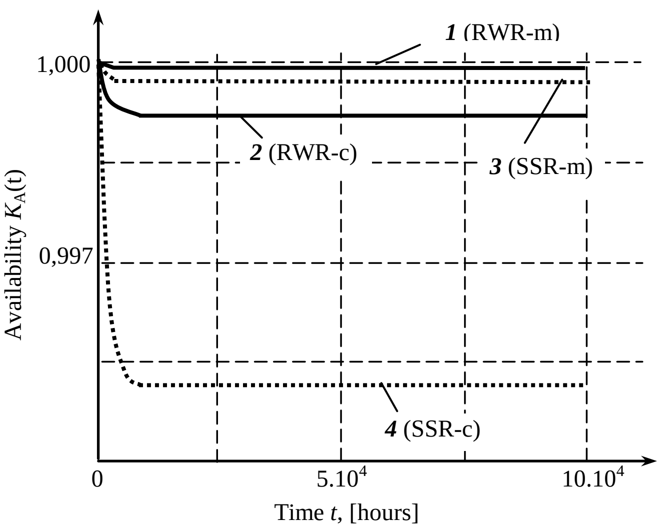

Fig.11. Availability of the radar with different design versions

V. CONCLUSIONS

In this article we explored the possibilities of increasing the reliability of electronic systems with high reliability requirements. For the purpose of this reliability study we described and proposed a method of redundancy scale optimization which method is based on the sequential examination of the possible redundancy options. At the core of the study is enshrined the Markov modeling method. Thanks to the research a response was given to the existing dilemma placed in front designers of electronic equipment – which of the two alternatives should be selected – structural redundancy or use of elements with high reliability characteristics. The study gives an unequivocal answer - a high level of reliability could be achieved more easily if highly reliable components are used. As an object of our study a Doppler radar with FPGA was chosen. Some of the most important reliability characteristics of the radar are analyzed – reliability, maintainability, and availability. The degree of reliability growth is evaluated by Markov chain model techniques. To obtain more comprechensive information, we studied several design options of products – non-reserved electronic system, built with highly reliable components (SSR-*m*), non-reserved system, built with elements having conventional reliability (SSR-*c*), electronic system with optimal redundancy implementation and two variants of design – with highly reliable components (RWR-*m*) and with conventional reliability components (RWR-*c*). The obtained results demonstrate that the implementation of redundancy in electronic system must be carried out under clear criteria for optimization of redundancy form the viewpoint of the system as a whole, and separately for each block, in order to avoid unnecessary increasing of costs and volume of the devices. One of the important conclusions is that in systems built with higly reliable components, the system reliability could be achieved sufficiently high without the use of structural redundancy. It means that the process of selection of the optimal design must include an assessment of such crityeria as cost, volume and weight of the device, and the optimal relationship between these crityeria have to be found.

REFERENCES

[1] R. W. Ditchburn, "Light", Blackie and Son Ltd., London, UK,1961.

[2] A. Georgiev, N. Georgieva and D. Kovachev, "Reliability of the Radar Made with Programmable FPGA", Ovidius University Annals of Mechanical Engineering, Volume IV, Issue I, Ovidius University Press, pp. 239-244, ISSN-1223-7221, 2002.

[3] R. Barlow and F. Proshan, "Statistical Theory of Reliability and Life Testing", Holt, Rinehatr and Winston, New York, 1975.

[4] R. Manian, D. W. Coppit, K. J. Sullivan and J. B. Dugan, "Bridging the Gap Between Systems and Dynamic Fault Tree Models", Reliability and Maintainability Symposium, Volume 22, Issue 2, January 1999.

[5] A. Георгиев, "Конструкция и технология на електронна апаратура", ТУ-Варна, ISBN 954-20-0232-7, 2002.

[6] D. Banjevic and A. Jardine, "Calculation of reliability function and remaining useful life for a Markov failure time process", IMA Journal of Mathematics, Oxford, UK, ISSN 1471-6798, 2006.

[7] A. Georgiev and N. Georgieva, "Markovsky model of the reliability of the autonomous system for transformation of the wind's energy", Annual School Lectures, Vol.22, pp. 7-12, ISSN 0861-0797, 2000.

[8] G. Szabo and P. Gaspar, "Practical Treatment Methods for Adaptive Components in the Fault-Tree Analysis", Reliability

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 4, Issue 6, December 2014

and Maintainability Symposium, Volume 22, Issue 2. January 1999.

[9] R. Brown, “Electric Power Distribution Reliability, Second Edition”, CRC Press Taylor & Francis Group, Boca Raton, Fl, USA, ISBN 978-0-8493-7567-5, 2009.

[10] A. Georgiev, “Facts that influence on the optimal number of the reserve modules in the electronic equipment”, International Scientific Journal ”Acta Universitatis Pontica Euxinus”, Technical University of Varna - Bulgaria, and Ovidius University of Constanta - Romania, Volume 1, Issue 1, pp. 103-107, ISSN 1312-1669, 2002.

[11] Military Handbook Reliability Prediction of Electronic Equipment MIL-HDBK-217F, Notice 2, US Department of Defense, USA 1995.

[12] Telcordia Technologies SR-332, Issue 1, Reliability Prediction Procedure for Electronic Equipment, 2001

AUTHOR’S PROFILE

Anton Slavchev Georgiev, PhD. Since 2004 - Assoc. Professor in Department of Electronics, Technical University of Varna, Bulgaria. 26 years teaching experience in higher education. Over 120 publications in the field of design and reliability of electronic devices, 20 of them are books. Chairman of Federation of the Scientific – Engineering Union Varna (member of the World Federation of Engineering Organizations WFEO). Scientific search in design and technology in electronics, semiconductor devices, reliability of electronic systems and communications. Team leader or member of scientific projects in the field of reliability and maintaining in electronics. Achievements in development and improvement of methods of technical maintenance and reliability estimation of electronic devices and systems.

Toncho Hristov Papanchev, eng. Since 2010 Assist. Professor in Department of Electronics, Technical University of Varna, Bulgaria. PhD student. 10 publications in the field of reliability assessment and improvement of electronic devices. Member of IEEE and Federation of the Scientific – Engineering Union Varna (member of the World Federation of Engineering Organizations WFEO). Scientific research in design and technology in electronics, semiconductor devices, reliability of electronic systems and communications. Member of scientific projects in the field of reliability of electronic devices. Achievements in improvement of methods of reliability prediction and parameters estimation based on failure data.

Dimitar Mihaylov Kovachev, PhD. Associate Professor in Department of Electronics and Microelectronics since 2010, and Head of Department of Electronics and Microelectronics since 2012, Technical University of Varna, Bulgaria. Over 70 publications in the field of digital systems design, FPGA/VHDL-based design, including some Doppler radar improvements, as well as OrCAD-based design of printed circuit boards, etc. Member of Federation of the Scientific – Engineering Union Varna (member of the World Federation of Engineering Organizations WFEO). Member of scientific projects in the field of digital devices design and FPGA-based neural networks implementation.