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Article

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Reference: Minochkin, Anatolii/Shyshatskyi, Andrii et. al. (2021). The improvement of method for the multi-criteria evaluation of the effectiveness of the control of the structure and parameters of interference protection of special-purpose radio communication systems. In: Technology audit and production reserves 4 (2/60), S. 22 - 27.
http://journals.uran.ua/tarp/article/download/235465/236847/546250.
doi:10.15587/2706-5448.2021.235465.

 ISSN 2664-9969

UDC 621.391
DOI: 10.15587/2706-5448.2021.235465
Article type «Reports on Research Projects»

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THE IMPROVEMENT OF METHOD FOR THE MULTI-CRITERIA EVALUATION OF THE EFFECTIVENESS OF THE CONTROL OF THE STRUCTURE AND PARAMETERS OF INTERFERENCE PROTECTION OF SPECIAL-PURPOSE RADIO COMMUNICATION SYSTEMS

Military radio communication systems are the basis of special purpose control systems and the object of the enemy's primary influence. Therefore, the issue of increasing the noise immunity of military radio communication systems is important and needs further research. Thus, the object of the research was chosen to be a military radio communication system. Maintaining a given level of noise immunity for military radio systems is one of the key issues in radio resource management, the effective management of which allows the use of the entire suitable frequency range for the transmission (reception) of electromagnetic energy by radio electronic devices. A number of works have been devoted to the ways search for increasing the noise immunity of military radio communication systems. One such way is to develop new (improve existing) approaches for assessing the effectiveness of military radio interference management. This work solves the problem of improving the method of multicriteria management effectiveness evaluation of the structure and parameters of the military radio systems noise protection.

The scientific problem is solved by the devices of multicriteria estimation of the of noise protection level of the military radio communication system, graphic display of the executed and not executed tasks, the aggregation scheme of formation of the integrated estimation of noise protection. The research used scientific methods of analysis and synthesis, also the theory provisions of signal-code structures and the provisions of the complex technical systems theory.

The peculiarity of the proposed improvement of the methodology is the multi-criteria assessment of the noise immunity level of the military radio communication system in the conditions of radio electronic conflict. The proposed technique allows:

- *to evaluate the effectiveness of noise protection management;*
- *to substantiate the optimal configuration of the military radio communication system in solving the problems of noise protection management in the conditions of radio electronic conflict;*
- *to identify the ways to increase noise immunity at the stage of operational management of the military radio communication system in the conditions of electronic conflict.*

The results of the research should be used in assessing the effectiveness of management of noise protection of military radio communication systems and determining the optimal structure and parameters of military radio systems.

Keywords: *military radio communication, multicriteria evaluation, radio electronic conflict, destructive influence, noise protection, radio resource, signal-code constructions.*

*Received date: 16.04.2021
Accepted date: 24.05.2021
Published date: 31.07.2021*

How to cite
Minochkin, A., Shyshatskyi, A., Hasan, V., Hasan, A., Opalak, A., Hlushko, A., Demchenko, O., Lyashenko, A., Havryliuk, O., Ostapenko, S. (2021). The improvement of method for the multi-criteria evaluation of the effectiveness of the control of the structure and parameters of interference protection of special-purpose radio communication systems. Technology Audit and Production Reserves, 4 (2 (60)), 22–27. doi: http://doi.org/10.15587/2706-5448.2021.235465

1. Introduction

Military radio communication systems (MRCS) are the basis of special purpose control systems and the primary priority of the enemy [1, 2]. Particular attention should be paid to the fact that the combat MRCS use takes place in conditions of shortage of various resources allocated for the organization of radio communication systems, as well as in the conditions of the use of radio electronic warfare by the enemy. Given all the above, the topical issue is the search for new ways to increase the noise immunity of radio communication systems, operating under the influence of radio electronic warfare and shortage of radio resources.

The analysis of scientific works [3–5] showed that the known scientific researches are directed on adaptive management of noise protection devices during destructive influence on them by the radio electronic warfare devices.

At the same time, some scientists have conducted research [6–8], which is devoted for the MRCS topology optimization and choosing the optimal route for information transmission in order to maximize the MRCS throughput.

However, the issues of structural-parametric synthesis of the MRCS noise protection subsystem under the influence of destabilizing factors remain little studied and require further research.

Thus, *the object of research* was chosen to be a military radio communication system. *The aim of research* is to increase the efficiency of the military radio communication system by assessing the effectiveness of the interference subsystem of military radio communication systems.

2. Methods of research

The following scientific methods were used in the research:
– analysis method – in the decomposition of destructive effects on the noise immunity of military radio communication systems;
– synthesis method – in the development of control solutions to increase noise immunity under the influence of destructive influences;
– provisions of the signal-code constructions theory – while assessing the noise immunity of the radio communication system;
– provisions of the complex technical systems theory – in the synthesis of the optimal topology of the radio communication system.

3. Research results and discussion

The implementation of the process of managing the structure and parameters of noise protection (Fig. 1), with individual characteristics in accordance with the changing time of the noise situation, requires the feedback organization. Such feedback requires the implementation of a process to evaluate the effectiveness of the synthesis in accordance with the current situation. The practical implementation of this process requires the improvement of the method of multi-criteria evaluation of the management effectiveness of the noise protection structure and parameters of special purpose radio communication systems.

Thus, the information-control system of response to changes in the noise immunity indicator, in relation to which the process of structural-parametric synthesis is implemented, is subject to evaluation of efficiency. In this case, the evaluation procedure has features that should be a requirement for the evaluation methodology being developed [9–11]:

1. The evaluation should be carried out according to the vector of criteria requirements.

2. The evaluation procedure will be applied to a single object – without comparative evaluation with analogues.

3. Evaluation of efficiency should reflect the degree of approximation of the noise protection system in terms of structure and parameters to the image of the radio communication system, so it has the property of interval evaluation.

Taking into account these features and in accordance with the classical scheme of solving the problem of multi-criteria evaluation, there are the necessary steps for implementation:
– establishing a system of criterion requirements for efficiency;
– determination of the calculation order of the values characterizing change of the established criterion requirements;
– formation of the aggregation scheme of the mathematical model definition of efficiency estimation by formation of the integrated estimation;
– interpretation of the obtained value of the integrated assessment.

The main idea of improving the method of multi-criteria evaluation of the management effectiveness of the noise protection structure and parameters of special purpose radio communication systems is to implement the formulated requirements in accordance with these stages.

3.1. Establishing a system of criterion requirements for efficiency. For the basic indicators to assess the effectiveness of structural-parametric synthesis of the noise protection system on the excessive structure of the noise protection system will continue to use a criteria system [12]:

$$\begin{cases} t_{ks} \to \min \quad \text{when } t_{ks} \le t_{ks\ por}, \\ D_{ks} \to \max \quad \text{when } D_{ks} \ge D_{ks\ por,} \\ IN_{ks} \to \max \quad \text{when } IN_{ks\min} \le IN_{ks} \le IN_{ks\max}, \end{cases} \quad (1)$$

where t_{ks} is the time spent on eliminating the deviation of the value of the noise immunity indicator from the nominal; D_{ks} is the reliability of decisions formed to eliminate deviations of the value of the noise immunity indicator from the nominal one; IN_{ks} is the information redundancy for decision-making to eliminate deviations of the value of the noise immunity indicator from the nominal one.

The performance indicators referred to in (1) are directly or indirectly related to the parameters of radio communication devices, namely:
– with a list of the system partial tasks as a whole, aimed at eliminating the deviation of the value of the noise immunity indicator from the nominal – T_{ks}^{S};
– with a list of information needs to eliminate deviations of the value of the noise immunity indicator from the nominal – I_{ks}^{S}.

Their relationship in the form of mathematical dependencies can be obtained by specifying the type of information and control system, tactical and technical characteristics and functional purpose of its elements and scope. The unifying value of these indicators may be the number of used radio communication devices (RCD), and, accordingly, the technical monitoring devices (TMD) required for their operation, and certain executive elements.

Then, carrying out in some way numerical scaling for a sign of noise protection – P_{ks}, it is expedient to enter *a vector of decisions on elimination of the values deviations of noise protection from nominal* – W_r. Graphical representation of the vector W_r is shown in Fig. 1, and the order of calculation of its numerical measure (length) is shown using the expression:

$$W_r = \sqrt{P_{ks\,W_r}^2 + T_{ks\,W_r}^2 + I_{ks\,W_r}^2}. \quad (2)$$

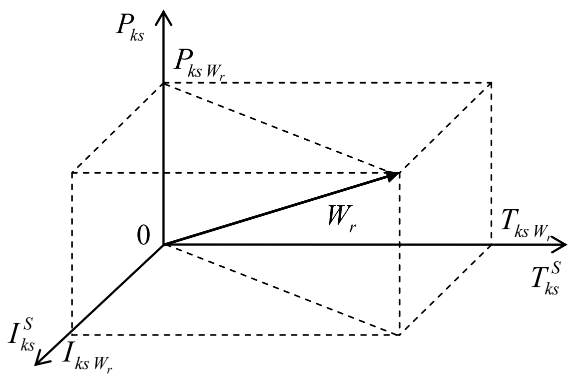

Fig. 1. Graphical representation of decision vector on elimination of level deviations of the noise protection from nominal

According to the essence of the task of configuring the system to respond to deviations in noise protection, two concepts should be introduced:

1) the required vector of solutions – W_{rW}, which is determined by the noise protection form and characterizes the requirements for the configurable system to reflect in its structure the current situation;

2) provided solution vector – W_{rS}, which characterizes the degree of reflection in the structure of the already synthesized system of the situation. In the general case, the vectors W_{rW}, W_{rS} will not coincide, which is explained by the factors of the two groups. The first should include factors due to the fulfillment of criterion requirements (1). For example, ensuring the best information redundancy of the system for responding to deviations in the level of noise protection generates the motion vector of decisions in the plane $P_{ks}0I_{ks}^{S}$, and ensuring the highest reliability of decisions – in the plane $I_{ks}^{S}0T_{ks}^{S}$. The movement of the solution vector in the plane may be a consequence of the operation of the system on a new (similar to the known) structure of the noise protection system. In this case, the mismatch of the *required* and *provided* vectors should characterize *the area of the task*, which reflects *the deviation of the system*. The second group of factors of mismatch of vectors W_{rW}, W_{rS} should include the causes of three categories: errors, failures, external actions.

The first of them includes errors: initial data (measurements); system configuration; arising in the work of software; generated by staff (operators, executive elements). The second category should include failures that occur in the work: system equipment (internal and external); data transmission channels (from information sources to executive elements); power supply systems, etc.

The category «external actions» includes [13]:

– the influence of a complex electronic environment on the operation of the system (intentional or unintentional);

– the actions on the ergatic system component, etc.

Discrepancies of this nature will characterize *the area of non-performance* of the task, which reflects *the system errors*.

The sizes of performance and non-performance areas of a task are defined at a stage of designing a system by methods of simulation modeling with the subsequent specification at a stage of real system operation.

Graphical representation of the areas of performance and non-performance of the task is presented in Fig. 2.

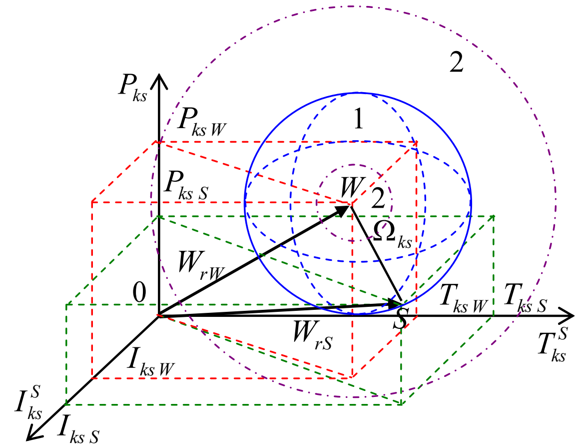

Fig. 2. Graphical display of performance and non-performance of the task areas

Fig. 2 has such markings:

– $P_{ks\ W}$, $P_{ks\ S}$ is the feature of the noise protection system, established by the system requirements and provided by the synthesized system, respectively;

– $I_{ks\ W}$, $I_{ks\ S}$ is the necessary and provided information needs of the system;

– $T_{ks\ W}$, $T_{ks\ S}$ is the necessary and performed by the configured system tasks to eliminate the causes of deviations from the required level of noise protection;

– Ω_{ks} is the *system deviation*. The established coordinates form a parallelepiped, hereinafter referred to as *the parallelepiped of solutions*. Restriction «from above» of the area of non-performance of the task is conditional. In fact, it is the parameter Ω_{ks} that can serve as a measure of the performance of the configured system (ICC) tasks in accordance with its intended purpose.

The magnitude of the deviation of the system is defined as the distance between two spatial points with known coordinates $W(T_{ks\,W}; P_{ks\,W}; I_{ks\,W})$, $S(T_{ks\,S}; P_{ks\,S}; I_{ks\,S})$, Fig. 2, according to the expression:

$$\Omega_{ks} = \sqrt{(T_{ks\,W} - T_{ks\,S})^2 + (P_{ks\,W} - P_{ks\,S})^2 + (I_{ks\,W} - I_{ks\,S})^2}. \quad (3)$$

For a specific system of response to the deviation of the required level of noise protection in accordance with (3) it is possible to determine the limit values $\Omega_{ks\,POR}^{\min}$ and $\Omega_{ks\,POR}^{\max}$ which is the radius of the inner and outer spheres centered at the point W. Their surfaces distinguish the areas of performance and non-performance of the target task system. Then, the condition for the configured system to perform deviation elimination tasks will look like:

$$\Omega_{ks\,POR}^{\min} \le \Omega_{ks} < \Omega_{ks\,POR}^{\max}. \quad (4)$$

The threshold $\Omega_{ks\,POR}^{\min}$ characterizes the situation when the minimum noise protection requirements for one reason or another are not met by the configured system, and the threshold $\Omega_{ks\,POR}^{\max}$ is determined by the potential capabilities of the noise protection system for the cluster level.

From Fig. 2, it follows that the area of non-performance of the task system absorbs the area of its implementation. In this regard, it can be argued that it is difficult to clearly distinguish between the concepts of deviations and errors of the system. Therefore, while evaluating the effectiveness of the system configuration results and the possibilities of its intended use, the mismatch of vectors W_{rW}, W_{rS} and the boundaries of the tasks scope will be analyzed, abstracting from the reasons that give rise to them.

3.2. Determination of the values calculation order that characterize the change of the established criteria. The implementation of the process of evaluating the effectiveness is carried out using the previously introduced concepts (Fig. 2): the coordinates of the parallelepiped solutions, threshold values $\Omega_{ks\,POR}^{\min}$, $\Omega_{ks\,POR}^{\max}$ and the deviation of the system Ω_{ks} with control of condition (3). The sequence of calculation of the specified parameters is carried out with the minimum requirements to the configurable system:

$$KS_{\min} = \left\{P_{ks\,\min}, T_{ks\,\min}^{KS}, I_{ks\,\min}^{KS}\right\},$$

in which the implementation of the target task is implemented with minimal efficiency.

Formation of the aggregation scheme of the integrated estimation formation is realized with simultaneous calculation of the partial indicator values. The calculation of the coordinates of the parallelepiped of solutions and the threshold values of the deviations of the system configured for the information management components (IMC) level is realized in several stages:

1. Finding the sums of significant items of the form parameters of the radio communication and weighting factors for them:

$$T_{A\,j} = \sum_{l=1}^{L_i} T_{ks\,j}^{ES}\left(T_{ks\,il}\right), \quad I_{A\,j} = \sum_{k=1}^{K_i} I_{ks\,j}^{ES}\left(I_{ks\,f}^{ID}\right)\left(I_{ks\,ik}\right),$$

$$GT_{A\,j} = \sum_{l=1}^{L_i}\left[T_{ks\,j}^{ES}\left(T_{ks\,il}\right)\cdot N_{kod\,l}\right],$$

$$GI_{A\,j} = \sum_{k=1}^{K_i}\left[I_{ks\,j}^{ES}\left(I_{ks\,f}^{ID}\right)\left(I_{ks\,ik}\right)\cdot N_{kod\,k}\right]. \quad (5)$$

2. Finding the sums of significant positions for the noise protection parameters of their weights:

$$T_{ks\,j} = \sum_{l=1}^{L_i} T_{ks\,j}^{KS}\left(T_{ks\,il}\right), \quad I_{ks\,j} = \sum_{k=1}^{K_i} I_{ks\,j}^{KS}\left(I_{ks\,ik}\right),$$

$$GT_{ks\,j} = \sum_{l=1}^{L_i}\left[T_{ks\,j}^{KS}\left(T_{ks\,il}\right)\cdot N_{kod\,l}\right],$$

$$GI_{ks\,j} = \sum_{k=1}^{K_i}\left[I_{ks\,f}^{KS}\left(I_{ks\,ik}\right)\cdot N_{kod\,k}\right]. \quad (6)$$

3. Finding the sums of significant items of parameters $KS_{\min}$ and weights for them. This operation is performed similarly to (6) and gives the result – $T_{ks\,\min}$, $I_{ks\,\min}$, $GT_{ks\,\min}$, $GI_{ks\,\min}$.

4. From the received parameters partial criterion requirements and efficiency indicators of the configured system are formed:

– A_j is a list of performance criteria for all available radio communication devices in quantity N_{RCD};

– S_j is the list of performance criteria included in the configured radio communication system in quantity N_{RCD}^{opt};

– K_{Si} is the generalized values of indicators that characterize the requirements for the system and the level of noise protection;

– $K_{S\,\min}$ is the generalized values of indicators that characterize the minimum requirements for the system, which are determined:

$$A_j = \begin{cases} T_{A\,j} \to \max, \\ I_{A\,j} \to \max, \end{cases} \quad S_j = \begin{cases} T_{S\,j} \to \max, \\ I_{S\,j} \to \max, \end{cases}$$

$$K_{S\,i} = \begin{cases} T_{ks\,i}, \\ I_{ks\,i}, \end{cases} \quad K_{S\,\min} = \begin{cases} T_{ks\,\min}, \\ I_{ks\,\min}. \end{cases} \quad (7)$$

5. The calculation of the parallelepiped coordinates of the solutions according to the initial data (5) is performed using a discrete convolution. It happens because of the essence of the established criteria and performance indicators that reflect the essence of the multi-criteria task of structural-parametric synthesis of the system of noise protection of military radio communication devices. Data rationing is implemented to the sum of all values in the index j+2 (including data $K_{S\,i}$ and $K_{S\,\min}$). Thus, there are the parallelepiped coordinates of the solutions:

– for the synthesized system:

$$T_{ks\,S} = \sum_{j=1}^{N_{ARM}^{opt}} GT_{A\,j0}\left(1 - T_{A\,j0}\right)^{-1},$$

$$I_{ks\,S} = \sum_{j=1}^{N_{ARM}^{opt}} GI_{A\,j0}\left(1 - I_{A\,j0}\right)^{-1}; \quad (8)$$

– for the maximum capabilities of the system, characterizing the use of all available RCD:

$$T_{S\,\max} = \sum_{j=1}^{N_{ARM}} GT_{A\,j0}\left(1 - T_{A\,j0}\right)^{-1},$$

$$I_{S\,\max} = \sum_{j=1}^{N_{ARM}} GI_{A\,j0}\left(1 - I_{A\,j0}\right)^{-1}; \quad (9)$$

– for the minimal capabilities of the system $K_{S\,\min}$:

$$T_{S\,\min} = GT_{ks\,\min 0}\left(1 - T_{ks\,\min 0}\right)^{-1},$$

$$I_{S\,\min} = GI_{ks\,\min 0}\left(1 - I_{ks\,\min 0}\right)^{-1}; \quad (10)$$

– for the center of the decision area, defined by the requirements of the noise protection system:

$$T_{ks\,W} = GT_{ks\,i0}\left(1 - T_{ks\,i0}\right)^{-1},$$

$$I_{ks\,W} = GI_{ks\,i0}\left(1 - I_{ks\,i0}\right)^{-1}. \quad (11)$$

Expressions (1)–(11) are in fact *a mathematical model for evaluating the effectiveness of interference protection of military radio communication devices.*

6. The received coordinates of decision parallelepipeds allow to carry out calculations of deviation of system Ω_{ks} and threshold values $\Omega_{ks\,POR}^{\min}$, $\Omega_{ks\,POR}^{\max}$. It is assumed that the presence of a typical situation of deviation in the relevant database and its correct identification gives equality of signs: $P_{ks\,W}=P_{ks\,S}=P_{S\,\min}=P_{S\,\max}$. Therefore, the procedure for calculating these parameters is not given. In the general case:

$$\Omega_{ks\,por}^{\min} = \sqrt{\left(T_{ks\,W} - T_{S\,\min}\right)^2 + \left(P_{ks\,W} - P_{S\,\min}\right)^2 + \left(I_{ks\,W} - I_{S\,\min}\right)^2},$$

$$\Omega_{ks\,por}^{\max} = \sqrt{\left(T_{ks\,W} - T_{S\,\max}\right)^2 + \left(P_{ks\,W} - P_{S\,\max}\right)^2 + \left(I_{ks\,W} - I_{S\,\max}\right)^2}. \quad (12)$$

3.3. Interpretation of the obtained value of the integrated assessment. The results of the calculations allow to conclude that it is possible to use a configured system to eliminate deviations of the noise immunity level from the nominal in the form of a binary characteristic [13–15]:

– «effective» is the condition (4) is fulfilled;
– «ineffective» is the condition (4) is not fulfilled.

The introduction of a detailed scale of efficiency gradation for the case of IMC synthesis is impractical.

Based on the above, it can be noted that the essence of the improved method of multicriteria evaluation of the effectiveness control of the structure and parameters of noise protection of special purpose radio communication systems is reflected in a set of six steps.

The main advantages of the proposed evaluation methodology are:

– it has a flexible hierarchical structure of indicators, which allows to reduce the task of multicriteria evaluation to one criterion or to use a vector of indicators for selection;
– unambiguity of the received estimation of the noise protection condition;
– wide scope of use (support and decision-making systems);
– simplicity of mathematical calculations;
– ability to adapt the system of indicators in the course of work.

Restrictions on the use of this technique include:

– need to form and constantly update the knowledge base;
– assessment of the noise protection state occurs with delays caused by the need for calculations and delays that occur due to the remoteness of the posts of collection and analysis of noise protection from each other;
– for the correct start of work it is necessary to have a typical knowledge base of the work region;
– method should not be used in one-parameter assessment of noise immunity.

The disadvantages of the proposed method include:

– lower accuracy of assessment for a single parameter of noise immunity assessment;
– lower accuracy of estimation in comparison with other estimation methods.

Areas of further research will be aimed at developing a methodology for intelligent control of interference protection devices of military radio communication systems in the context of electronic conflict.

4. Conclusions

In the course of the research, the method of multicriteria evaluation of the effectiveness of control over the structure and parameters of noise protection of special purpose radio communication systems was improved.

The essence of this technique is a multi-criteria assessment of the management effectiveness of the structure and parameters of noise protection of the military radio communication system in the context of electronic conflict.

The proposed technique allows:

– to evaluate the effectiveness of noise protection management;
– to substantiate the optimal configuration of the military radio communication system in solving the problems of noise protection management in the conditions of electronic conflict;
– to identify ways to increase noise immunity at the stage of operational management of the military radio communication system in the conditions of radio electronic conflict.

The research results should be used in assessing the effectiveness of noise protection management of military radio communication systems and determining the optimal structure and parameters of military radio communication systems.

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