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METHODS OF ESTIMATION OF THE CHANNEL STATE OF AIR DEFENSE SYSTEMS

The subject of study in the article is the methods for assessing the state of channels of air-conditioning complexes operating in a complex electronic environment. The methods discussed in this article include the method of least squares, the method of mean square deviation, channels estimation methods for iterative methods of signal processing at reception, suboptimal algorithms for iterative channel estimation and information symbols based on the maximum likelihood method, linear unbiased estimation methods with minimal dispersion and methods of linear estimation with a minimum of mean square deviation. **The purpose** of the study is to conduct an analysis of existing methods for assessing the state of the air defense airway channels in the conditions of radio-electronic suppression and multi-beam propagation of radio waves. The tasks solved in the study: a mathematical description of known methods for assessing the state of the channels and the development of recommendations for the synthesis of optimal methods for assessing the state of the channels. The methods used in the study: theory of communication, theory of noise immunity and electronic warfare. In the course of the study, recommendations were obtained for the synthesis of optimal methods for assessing the status of channels under the conditions of intentional interference. **Conclusions**: in the presence of sufficient a priori information about the transmission of information symbols, the best results on the criterion of the ratio of accuracy of estimation and complexity of implementation is demonstrated by the algorithm of linear estimation at the minimum of the mean-square deviation. In the absence of sufficient a priori information about the transmission of symbols, the best option is an unmatched estimate for the minimum of the smallest squares. In order to increase the accuracy of the evaluation of the transmission characteristics of the air defense airway channels in the conditions of a complex electronic environment it is advisable to use iterative principles.

Keywords: radioelectronic environment; intentional interference; anti-aircraft defense; methods of analysis.

Introduction

Formulation of problem. Noise immunity of reception signals in modern systems of air defence (AD), which operate in a complex electronic environment [1], largely depends on the estimation accuracy of the channel state, which is determined by the transfer function [1-3].

In the presence of objective and accurate information on the status of the channels is the ability to carry out activities aimed at improving the noise immunity, the functioning of AD.

Because of this, ***aim of the article*** is analysis of existing methods of evaluation of condition of channels of air defense systems in the conditions of jamming and multipath propagation.

Methods of solving scientific problems. For solution scientific problems used methods of analysis and synthesis of complex technical systems, theory of noise immunity of radio systems and mathematical modeling techniques.

Main material of research

Problem of estimating transfer characteristics of the control channels and data transmission can be represented as finding their values is the impulse response or the corresponding values of the frequency characteristic.

Classification of methods for assessing the quality of the channel showed on Fig. 1.

Necessity of ensuring high precision estimates of the channels limits effectiveness of practical application of modern complexes of AD. To avoid this problem by developing robust against the estimation errors of channels of reception algorithms.

However, this approach, as shown in [4], cannot always provide satisfactory results, and, as a rule, leads to significant complication of electronic equipment.

Determining the structure and parameters of the system observations is one of the main tasks of the modern theory and technology of automatic control. This problem arises in the study of the properties and characteristics of objects to further control them, and as a consequence the creation of adaptive systems that are based on the identification of the object produced by the optimal control actions.

Identification means definition of the system structure and its parameters by analyzing the input and output of the system [3-5].

The main objective of identification is to identify the best in some sense of evaluation of the characteristics of the object.

Distinguish between ***parametric*** and ***nonparametric*** identification.

When using the methods of parametric identification determined from the coefficients of the transfer function or the equation object.

Second group of methods is used to identify temporal or frequency characteristics of the objects and characteristics of the random generated process objects. According to the obtained characteristics determined by the transfer function or the equation object.

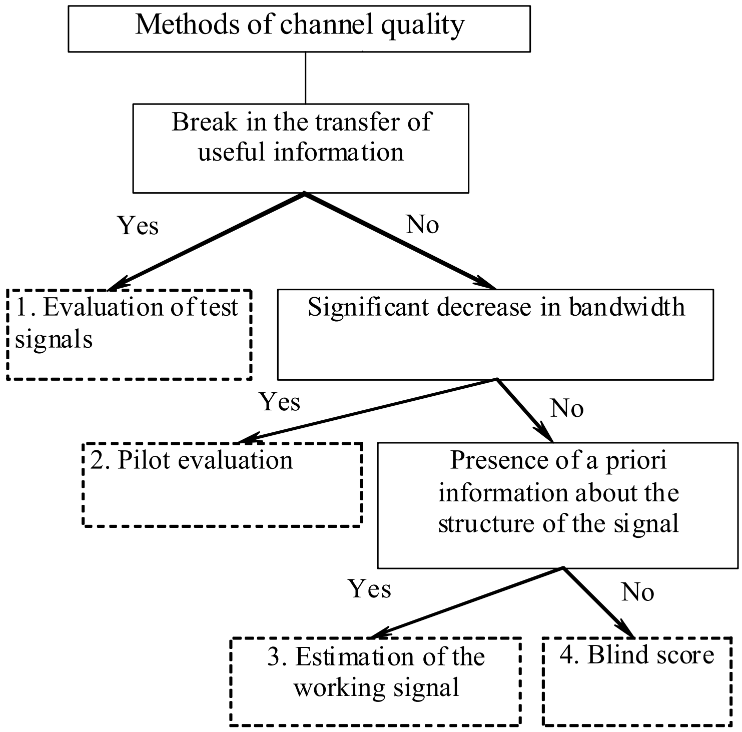

Fig. 1. Classification of channel quality assessment methods

First consider more on methods of ***nonparametric identification.***

Determination of transfer function of the temporal characteristics of the object. As is well known differential equation and transfer function are the most common forms of communication between the state variables at the input and output of a linear system. Large spread of methods of identification of deterministic objects by defining transient response curve of acceleration characteristic $h(t)$ for given step change of the control input:

$$h(t) \approx \frac{y(t) - y_0}{u - u_0}, \quad (1)$$

where $y(t)$ – variable in output values of the object fed to its input speed control u (curve acceleration);

y_0 and u_0 values of the entry and exit of the object before the start of the experiment.

If the control object does not allow to change output coordinates to input instead of the step action serves single pulse or series of pulses.

Determination of transfer function by frequency characteristics of the object. The essence of the method lies in the fact that the first experimental take off the frequency characteristic of the object, and then according to the experimental characteristics of the calculated transfer function.

When removing the frequency characteristics of the use such methods of influence on the object as a sine wave method and the method of „rectangular" waves [7-9].

Main disadvantage of these methods is long-time experiment that is spent mainly on the expectation of steady state oscillation and gain sufficient to approximate the frequency characteristics of the values.

Correlation method of identification. Output variables of the object $y(t)$ are determined not only deterministic control inputs $u(t)$ but also by uncontrollable factors (noise) $e(t)$ that may take place and cause a deviation of the output variables from given values. To obtain the equation of the relationship between the statistical characteristics of the input and output ergodic process for stationary processes using statistical characteristics and, in particular, correlation functions or spectral density functions.

To improve accuracy of the estimated correlation functions is necessary to choose monitoring interval of signals for which these correlation functions.

Identification of object parameters by the spectral method. Spectral identification methods based on using of the unit matrix operators. These methods are a further development of frequency methods based on the decomposition of signals of the object on orthonormality functions, not necessarily harmonious. The result of identification is the determination of the integral equation kernel object, which in the simplest case a linear one-dimensional systems coincide with the weighting function. Spectral methods can be used to identify time-varying systems whose parameters and, in particular, the kernel of the integral equation, change over time.

In AD systems much more widespread ***parametric identification*** methods [10].

Parametric identification allows to find values of coefficients of model object with measuring values of the managed y and control u signals of the object.

This assumes that the structure and the model of the object is known.

Important advantage of the methods of parametric identification is the ability to use recursive algorithms that allow for the current identity in real time at the nominal operation modes of the object. These methods include: method of least squares, maximum likelihood method and the method of stochastic approximation.

Least squares method (LSM). Using LSM when effect of time correlated noise, that is, when minimizing the loss function according to the criterion of least squares causes a shift of the parameter estimates is the increase in the variance of these estimates. The deterioration of these estimates leads to a decrease in the quality of governance. To obtain nesman estimates used generalized LSM (GLSM). When using GLSM estimated parameters of models of the object and noise at its output.

Model least squares (LS) is described using equation

$$y(z)=\frac{B(z)}{A(z)}z^{-d}u(z)+\frac{1}{A(z)}e(z), \qquad (2)$$

where $A(z)$, $B(z)$ – operators, form of which is unknown, but the known parameters (control coefficients),

$y(z)$ – output sequence,

$u(z)$ – input signal sequence,

$e(z)$ – unknown sequence of identically distributed random variables with zero mathematical expectation and unit variance (sequence interference);

z^{-d} – ratio of preventing delay of the signal in the object, equal to an integer number of sampling periods.

This method is using for large relations signal/noise, as in small ways, he gives a significant bias of the parameter estimates. The advantage of this method is that the reliable convergence of the estimates requires a relatively small amount of computations.

Method of auxiliary variables. Method of auxiliary variables (MAV) is using when there is correlation between noise $e(k)$ and elements of the data vector $\Psi(k+1)$ and model object and noise presented in the full model (3). The identification algorithm by the method of auxiliary variables similar to the LSM algorithm.

For the implementation of the algorithm introduce a vector of auxiliary variables. MAV allows to compute only the estimates of the parameters of object identification. In that case, if the desired estimation of the model parameters forming the noise filter, you can use LSM:

$$y(z)=\frac{B(z)}{A(z)}z^{-d}u(z)+\frac{D(z)}{C(z)}e(z), \qquad (3)$$

where $C(z)$, $D(z)$ – operators, form of which is unknown, but known parameters (coefficients).

Method provides reasonably accurate estimate of the parameters. It is used at high intensities of noise, and their correlation with variables of the object. To speed up convergence of estimates at the initial stage it is recommended to use a recursive LSM. The disadvantage is large amount of computation.

Maximum likelihood method. Maximum likelihood method (MLM) is that estimates of the parameters θ are their values at which the likelihood function reaches its maximum. Value $\theta_{\max}$ depends on the sample $(x_1, x_2, ..., x_l)$:

$$(\theta_{\max})=\Gamma(x_1, x_2, ..., x_l), \qquad (4)$$

where $(x_1, x_2, ..., x_l)$ – basis of the state space.

The corresponding function of sample $\Gamma(x_1, x_2, ...x_l)$ is called the most plausible estimate θ .

Model of maximum likelihood (ML) has form

$$y(z)=\frac{B(z)}{A(z)}z^{-d}u(z)+\frac{D(z)}{A(z)}e(z). \qquad (5)$$

If the fair model noise D/A, then this method ensures high accuracy of estimates. However, it requires more computations than the LSM.

Method of stochastic approximation. Method of stochastic approximation (MSA) is developed for determination of roots of an equation, if the value of the function at a given argument value observed in the presence of interference.

MSA organizes sequence of solutions for finding estimates of the parameter vector in each dimension $\hat{\theta}(k)$, such as

$$\lim_{k\to\infty}\hat{\theta}(k)=\theta. \qquad (6)$$

MSA can be easily extended to the problem of determining the parameters in stochastic systems in terms of consistent estimation (recursive identification).

Disadvantage of MSA – slow convergence of the estimates $\hat{\theta}(k)$ even if the variance $e(k)$ is significantly less variance $y(k)$.

Despite the slow convergence of the estimates, the algorithms of the

MSA due to its simplicity find application in practical problems of identification of linear and nonlinear models of objects with independent additive noise.

Acceptable estimation accuracy while using method is achieved in very large number of measurements. When small amounts of computing and noises of high intensity, all methods (except MSA) have the same quality of the estimates, therefore, give preference to the GLSM because it is simpler and other guarantees the convergence of the estimates. The advantage GLSM manifests itself in large volumes of measurements.

Robust method of estimation. Robust evaluation is the application of ideas of MLM in a situation when the form or the parameters of the distribution, which is based on the method determined fully. Uncertainty distributions can be described with the introduction of a parameter that belongs to the set Ξ.

Then instead of the density that appears in the MLM, there is a conditional density $p(y \mid \tau, \xi)$. Solution to the problem is to select "the worst" in plural Ξ value ξ_*, parameter ξ_* and then use MLM based on density $p(y \mid \tau, \xi_*)$.

This idea has received recognition and development and is known as *robust estimation* or *stable of MLM* [12].

Maximum entropy method (Berg). Maximum entropy method of Berg [5, 10] refers to the category of parametric methods of spectral analysis. In such methods, in accordance the studied process is given always the a priori model of the spectral density and the problem of estimating model parameters based on the analysis of the studied time series.

In the method of Berg use variational principle to evaluate the quality of the model is searched for the process with maximum entropy or the process, the spectrum of which corresponds to the most random time series, and correlation function of this series have the best match to the given sequence.

Estimation of the spectral density in the method of Berg is equivalent to using autoregressive model of the first order with the input white noise. The Burg's method, perhaps, has the highest spectral resolution among all spectral methods.

Disadvantages of the method include absence of accurate information about values of amplitudes and phases of harmonics and the necessity of preliminary selection the parameter of the autoregressive order, because for large parameters, numerical greater than half the length of the row, this method can be unstable and, in particular, can occur in the splitting of the spectral components.

Note also that the method is not designed to work with simple harmonic signals.

Following algorithms for the estimation of the channels, based on using considered methods of identification.

Algorithm for estimating the parameters of the channel using precisely known (pilot) and unknown information symbols. Least squares estimator and the weighted average least squares error of the IX channel on test symbols has the form

$$\hat{\mathrm{h}}_{\mathrm{MSDE}} = (\mathrm{X}_p^H \mathrm{W} \mathrm{X}_p)^{-1} \mathrm{X}_p^H \mathrm{W} y,$$

where $\mathbf{X}_p^H$ – matrix of samples with pilot signal and the impulse response;

$\mathbf{W}$ – matrix samples of the additive noise with mean zero and correlating matrix;

$\mathbf{R}_{\mathrm{W}} = E\{ww^H\}$,

$\mathbf{X}_p$ - the matrix of samples with pilot signals.

Complexity of the estimation algorithm using pilot symbols is low, because the matrix

$$(\mathbf{X}_p^H \mathbf{W} \mathbf{X}_p)^{-1} \mathbf{X}_p^H \mathbf{W}$$

is known and can be calculated in advance and not in real time with any required precision.

In the absence of a priori information about transmitted symbols and assessment IX will always be null, so almost these methods can also be used only if an iterative algorithm of reception on all iterations except the first, as alternative to proposed below ML algorithm.

Advantage of considered estimation algorithm is that it does not require knowledge of the statistics of noise in any form.

Algorithms, which are discussed later, not have this property.

Standard deviation estimates (SDE) is handy feature. We know that from this point of view, the best estimation will be the minimum standard deviation of estimates (MSDE), which is the posterior mean. In the case when **h** and **y** in conjunction gaussi, it can be obtained as follows:

$$\hat{\mathrm{h}}_{\mathrm{MSDE}} = (\mathrm{X}_p^H \mathrm{W} \mathrm{X}_p)^{-1} \mathrm{X}_p^H \mathrm{W} y \qquad (7)$$

where

$$\bar{\mathbf{h}} = E\{\mathbf{h}\},$$

$$\mathbf{R}_{\mathbf{h}y} = E\{(\mathbf{h} - \bar{\mathbf{h}})(y - E\{y\})^H\}.$$

Methods of evaluation channels when iterating methods of signal processing at reception. ML estimator of vector counts IX. ML algorithm is an iterative method of maximum likelihood estimation is convenient in the case when the unknown associated parameters, for example, the information symbols [6-11].

Key idea of the ML algorithm lies in choice of the complete data set **z,** to integration and the maximization could be easily carried out. The main property of this algorithm is that

$$p(y \mid \hat{\Theta}_{ML}^{(i+1)}) \geq p(y \mid \hat{\Theta}_{ML}^{(i)}),$$

that is likelihood function monotonically increases at each subsequent stage of the assessment.

In the General case, the ML algorithm converges to local maximum of the likelihood function $p(y \mid \Theta)$. Ability to reach the global maximum depends on the initial conditions.

Rate of convergence depends on the choice of the complete data set **z**.

Main difficulty of the calculation is to use the a posteriori density function the probability distribution that imposes statistical dependence between iterations, and ultimately leads to the dependence of the magnitude of the displacement from the initial conditions.

Suboptimal algorithm for iterative estimation channel and information symbols based on ML algorithm. ML algorithm is based on using posteriori information about the information symbols, and therefore, its using in iterative procedures requires reinitialize after each evaluation cycle, **h**, that is, the zeroing of "external" information of all modules is supplied via the feedback channels to the inputs of a priori information to all processing modules. This greatly increases the number of iterations and, as a consequence, the volume of the computational cost. If not to reinitialize algorithm of reception after each evaluation cycle, would be violated, turbo principles, and the estimation algorithm will not be ML algorithm.

However, this technique will lead to substantial reduction in computations, so this approach deserves attention.

Nesman linear estimation with minimum variance (NLE). This estimate is calculated as

$$\hat{\mathrm{h}}_{\mathrm{NLE}} = \mathrm{A}y,$$

where the matrix **A** is chosen such that the rating was nesman and SDE error of each element of the vector **h** would be minimal in evaluation only using known test characters

$$\mathbf{A} = (\mathbf{X}_p^H \mathbf{R}_w^{-1} \mathbf{X}_p)^{-1} \mathbf{X}_p^H \mathbf{R}_w^{-1}.$$

When estimating using the information contained in the unknown information symbols

$$\mathbf{A} = \\ = \left({}^{(e)}_{Ex}\{\mathbf{X}^H\}\mathbf{R}_\Sigma^{-1} E_x^{(e)}\{\mathbf{X}\} \right)^{-1} E_x^{(e)}\{\mathbf{X}^H\}\mathbf{R}_\Sigma^{-1}, \quad (8)$$

where

$$\mathbf{R}_\Sigma = \mathbf{R}_w + \\ + E_x^{(e)}\{\mathbf{X}\mathbf{h}\mathbf{h}^H\mathbf{X}^H\} - E_x^{(e)}\{\mathbf{X}\}\mathbf{h}\mathbf{h}^H E_x^{(e)}\{\mathbf{X}^H\}. \quad (9)$$

As can be seen from the formula (9), to assess need to know **h**. As **h** can be used to preliminary estimate **h**.

For example, obtained at the previous iteration, and in the first iteration, estimate obtained by using any of the methods that do not require priori information.

Unlike previous evaluation methods, this method requires priori information about the channel and knowledge of the statistics of noise (generally in the form of its correlation matrix $\mathbf{R}_w$).

Linear estimation in the minimum mean-square deviation (MMSD).

This assessment defined as

$$\hat{\mathrm{h}}_{\mathrm{MMSD}} = \mathrm{A}y + \mathrm{b}$$

where matrix A and vector **b** chosen so that the evaluation was nesman and should have the minimum error for each component of the vector **h**.

If

$$E_{\mathbf{h}}\{\mathbf{h}\} = \overline{\mathbf{h}}$$

and

$$E\{(\mathbf{h} - \overline{\mathbf{h}})(\mathbf{h} - \overline{\mathbf{h}})^H\} = \mathbf{R}_{\mathbf{h}},$$

that

$$\hat{\mathrm{h}}_{\mathrm{MMSD}} = \overline{\mathrm{h}} + \mathrm{R_h} E_x^{(e)}\{\mathrm{X}^H\}(E_{\mathrm{h}}\{\mathrm{R}_\Sigma\} + \\ E_x^{(e)}\{\mathrm{X}\}\mathrm{R_h} E_x^{(e)}\{\mathrm{X}^H\})^{-1}(y - E_x^{(e)}\{\mathrm{X}\}\overline{\mathrm{h}}), \quad (10)$$

accordingly

$$E_{\mathbf{h}}\{\mathbf{R}_\Sigma\} = \mathbf{R}_n + \\ + E_x^{(e)}\{\mathbf{X}\mathbf{R}_{\mathbf{h}}\mathbf{X}^H\} - E\{\mathbf{X}\}\mathbf{R}_{\mathbf{h}} E\{\mathbf{X}^H\} + \\ + E\{\mathbf{X}\overline{\mathbf{h}\mathbf{h}}^H\mathbf{X}^H\} - E_x^{(e)}\{\mathbf{X}\}\overline{\mathbf{h}\mathbf{h}}^H E_x^{(e)}\{\mathbf{X}^H\}. \quad (11)$$

Unlike NLE score (11) in the absence of information on the information symbols, that is, when $E\{\mathbf{X}\} = 0$.

In the same way as in the case of NLE, this estimation may use the available a priori information on the channel (keeping performance in case of its absence), and requires knowledge of the statistics of the noise (in the General case, the correlation matrix of the noise $\mathbf{R}_w$).

Conclusion

Thus it is possible to draw the following conclusions:

1. If sufficient a priori information about the transmitted information symbols the best results according to the criterion of the ratio of the estimation accuracy and the complexity of the algorithm demonstrates linear estimation in the minimum SDE.
2. In the absence of sufficient a priori information about the transmitted symbols is not the best offset option estimates the minimum least squares.
3. To improve the accuracy of estimation of transmission channel characteristics of air defense systems in a complex electronic environment, it is advisable to use iteration principles.

Directions for further research will be focused on the development of a combined evaluation method of the channel state of air defense systems in electronic environment complex.

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Аналіз методів оцінки каналів комплексів протиповітряної оборони

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Предметом вивчення в статті є методи оцінки стану каналів комплексів протиповітряної обстановки, що функціонують в складній радіоелектронній обстановці. До зазначених методів, що були розглянуті в статті відносяться: метод найменших квадратів, метод середньоквадратичного відхилення, методи оцінювання каналів при ітеративних способах обробки сигналу на прийомі, субоптимальні алгоритми ітераційного оцінювання каналу та інформаційних символів на основі методу максимальної правдоподібності, методи лінійної незміщеної оцінки з мінімальною дисперсією та методи лінійного оцінювання за мінімумом середньоквадратичного відхилення. **Метою** дослідження є проведення аналізу існуючих методів оцінювання стану каналів комплексів протиповітряної оборони в умовах радіоелектронного подавлення та багатопроменевого поширення радіохвиль. Завдання, що вирішувалися в дослідженні були: математичний опис відомих методів оцінювання стану каналів та розробка рекомендацій щодо синтезу оптимальних методів оцінювання стану каналів. Використовуваними методами в дослідженні є: теорія зв'язку, теорія завадозахищеності та радіоелектронної боротьби. В ході дослідження отримані рекомендацій щодо синтезу оптимальних методів оцінювання стану каналів в умовах впливу навмисних завад. **Висновки.** При наявності достатньої апріорної інформації про передаванні інформаційні символи кращі результати за критерієм співвідношення точності оцінки і складності реалізації демонструє алгоритм лінійного оцінювання за мінімумом середньоквадратичного відхилення. За відсутності достатньої апріорної інформації про передаванні символи кращим є незміщений варіант оцінки за мінімумом найменших квадратів. Для підвищення точності оцінювання передаточної характеристики каналів комплексів протиповітряної оборони в умовах складної радіоелектронної обстановки доцільно використовувати ітеративні принципи.

Ключові слова: радіоелектронна обстановка; навмисні завади; протиповітряна оборона; методи аналізу.

Анализ методов оценки каналов комплексов противовоздушной обороны

Р.Н. Животовский, С.Н. Петрук

Предметом изучения в статье есть методы оценки состояния каналов комплексов противовоздушной обстановки, функционирующих в сложной радиоэлектронной обстановке. К указанным методам, которые были рассмотрены в статье относятся: метод наименьших квадратов, метод среднеквадратичного отклонения, методы оценки каналов при итеративных способах обработки сигнала на приеме, субоптимальные алгоритмы итерационного оценивания канала и информационных символов на основе метода максимального правдоподобия, методы линейной несмещенной оценки с минимальной дисперсией и методы линейного оценивания по минимуму среднеквадратичного отклонения. **Целью** исследования является проведение анализа существующих методов оценки состояния каналов комплексов противовоздушной обороны в условиях радиоэлектронного подавления и многолучевого распространения радиоволн. Задачи, которые решались в исследовании были: математическое описание известных методов оценки состояния каналов и разработка рекомендаций по синтезу оптимальных методов оценки состояния каналов. Используемыми методами в исследовании являются: теория связи, теория помехозащищенности и радиоэлектронной борьбы. В ходе исследования получены рекомендации по синтезу оптимальных методов оценки состояния каналов в условиях воздействия преднамеренных помех. **Выводы**. При наличии достаточного априорной информации о передаче информационные символы лучшие результаты по критерию соотношения точности оценки и сложности реализации демонстрирует алгоритм линейного оценивания по минимуму среднеквадратичного отклонения. При отсутствии достаточной априорной информации о передаче символы предпочтительным является несмещенной вариант оценки по минимуму наименьших квадратов. Для повышения точности оценки передаточной характеристики каналов комплексов противовоздушной обороны в условиях сложной радиоэлектронной обстановки целесообразно использовать итеративные принципы.

Ключевые слова: радиоэлектронная обстановка; умышленные помехи; противовоздушная оборона; методы анализа.