Applied problems of information systems operation

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METHOD OF SIGNAL PROCESSING IN MIMO SYSTEMS OF UNMANNED AVIATION COMPLEXES

Noise immunity of receiving signals in the MIMO (Multiple Input Multiple-Output) system essentially depends on the choice of the signal processing method on the receiving side. Existing methods of signal processing, in the MIMO system, that provide a given quality of information transmission, have high computational complexity, so there is a necessity to improve these methods. The purpose of this article is to increase the impedance of channels of control and data transmission of unmanned aerial systems, which was achieved by developing new method of signal processing in multi-antenna systems of unmanned aerial systems. The article developed an improved method of signal processing in MIMO systems of unmanned aerial systems, the essence of which is the ability to work with a known and unknown correlation matrix, the division of received signals into groups and the evaluation of each group, taking into account the evaluation error. During the research, the theory of communication, signal theory, the theory of antennas and the theory of noise-proof coding were used. The difference between an improved method is, that the method allows you to work with an unknown correlation matrix. While processing a signal in a demodulator, each iteration takes into account not only the estimate obtained in the previous step, but also the degree of accuracy of the character estimation. The proposed improved method has characteristics, that are close to the characteristics of demodulator, optimal for the criterion of maximum likelihood, but much less computational complexity. The method allows you to reduce computing costs by 20 times, compared with the maximum likelihood algorithm. The practical implementation of this method will allow the creation of software for communication equipment of unmanned aeronautical complexes, which operate in difficult conditions of the radio electronic environment.

Keywords: signal-interfering environment; information transfer speed; bit error probability; spatial-temporal processing4 MIMO system; parallel channels.

Introduction

One of the technologies, that significantly improves bandwidth and noise immunity of unmanned aerial vehicle (UAV) channels is MIMO (Multiple-Input Multiple-Output) technology, which allows to more efficient use of transmitter power and the strugglet against fading signals [1-9]. Improved efficiency was achieved through the using of space time coding (STC) techniques, that provide the transmission and reception of parallel streams of information. An analysis of the using and prospects of the UAV development carried out in [10-18] shows, that promising UAV should provide information transmission in a complex radioelectronic environment.

So, **purpose of the article** is the development of an advanced signal processing method in MIMO systems of unmanned aerial systems.

Presentation of main material research

An analysis of known STC systems [19-25] shows, that increasing the spectral efficiency of the MIMO system is usually due to the complication of the STC demodulator and the reduction of system impedance. Therefore, an important task is to choose a method of processing signals on the receiving side, which provides given quality of information transmission and was characterized by moderate computational complexity.

Let's conduct a comparative analysis of signal processing methods in the MIMO system with STC in terms of their efficiency and computational complexity.

Transmitted signals after the influence of the relay fading and white gaussian noise (WGN) in the radio channel, arrive at the V receiving tracks. Samples of complex inlets at the output of the receivers in one interval can be described by the vector-matrix equation [19-25]:

$$\mathbf{Z} = \mathbf{HA} + \mathbf{B}, \tag{1}$$

where $\mathbf{Z}$ is the vector, each component of which z_i, $i = \overline{1,V}$, is a countdown of a comprehensive bypass on i-th demodulator input of STC; $\mathbf{A}$ is the vector, each component of which a_j, $j = \overline{1,S}$ is a transmitted complex informational symbol, belonging to a plurality $\{a^{(1)}, \ldots, a^{(K)}\}$, K is the multiplicity of quadrature amplitude modulation (Quadrature Amplitude Modulation, QAM); $\mathbf{H}$ is the matrix, each element of which h_{ij} is a complex transmission coefficient of the propagation path of the signal, that is emitted j-th antenna and accepted by i-th antenna; $\mathbf{B}$ is the vector, each component of which b_i is a countdown of complex gaussian noise on i-th demodulator input STC, which has zero avaeage and variance $2\sigma^2$.

On the transmission side, information symbols a_i split into blocks with W characters were appropriately processed and radiated through S transmitting antennas for a given number of time intervals K_{given}. The spatial-temporal code can be presented, as a generating matrix, in which the rows correspond to the transmit antennas, and the columns are time intervals for character transfer:

$$\begin{vmatrix} s_{11} & s_{12} & \cdots & s_{1K_{\text{given}}} \\ s_{21} & s_{22} & \cdots & s_{2K_{\text{given}}} \\ \cdots & \cdots & \cdots & \cdots \\ s_{M_t 1} & s_{M_t 2} & \cdots & s_{M_t K_{\text{given}}} \end{vmatrix}, \tag{2}$$

where s_{jk}, $j=\overline{1,S}$, $k=\overline{1,K_{\text{given}}}$ is a function from complex information symbols a_i, i = 1, 2, ..., which was radiated by j-th antenna on k-th time interval. Symbolic speed of the MIMO system is defined as the ratio of the length of the information symbol block W to the amount of time, that necessary to transmit this block of time intervals K_{given}: $R_{\text{STC}} = W/K_{\text{given}}$. The higher the symbolic speed of R_{STC} spatial-temporal code, the higher efficiency of the using of frequency resources of the channel. Spatial-time codes are divided into two classes: orthogonal and non-orthogonal. Among the orthogonal codes, it is necessary to allocate the code of alamouti, whose generating matrix has the form [19-25]:

$$G=\begin{vmatrix} a_1 & -a_2' \\ a_2 & a_1' \end{vmatrix}. \tag{3}$$

Symbolic alamouti speed code is $R_{\text{STC}} = 1$. In the matrix (3), the rows are orthogonal to each other, the same is true for its columns. Due to this property on the receiving side it becomes possible to calculate the estimates by the method of maximum probability (MP) of the transferred symbols using the algorithm of weighting the received signals. The energy gain from using the alamoit scheme with two transmitting and one receiving antennas, compared to the usual SISO system is equal to 7 dB for the probability of mistaken acceptance $P_{\text{error}} = 10^{-2}$ by using four-position phase manipulation (QPSK, Quadrature Phase Shift Keying).

Unfortunately, for systems with more, than two transmitting antennas, while using QAM There are no orthogonal codes at speed $R_{\text{STC}} = 1$. While switching to more transmitting antennas, for example, 3 and 4, the symbolic speed of the corresponding orthogonal codes does not exceed 3/4. Symbol speed of the codes for five or more transmitting antennas does not exceed 1/2.

Increasing the bandwidth of data channels is possible using non-orthogonal spatial-temporal codes. The symbolic speed for non-orthogonal coding may reach a value, that corresponde to the number of transmit antennas S, if K_{given} time intervals can be transferred to a block with $W = K_{\text{given}}S$ informational symbols. This condition satisfies the code V-BLAST (Vertical Bell Labs Layered Space Time) [19-25]. Another example of a non-orthogonal code is the double code of alamouti.

Fig. 1 shows the characteristics of the MIMO system in the processing of signals by the maximum likelihood method for systems with 8 transmitting and 8 receiving antennas, using the code V-BLAST and the alamoit dual code for QPSK modulation. To demodulate the code V-BLAST at a symbolic rate of 4 is required signal/noise ratio h^2 on 5 dB higher (when $P_{\text{error}} = 10^{-3}$), than to demodulate the double code of alamouti with a symbolic rate 2. Increasing the spectral efficiency in the MIMO system, by using spatial-temporal code with a higher symbolic speed for a given number of transmitting and receiving antennas leads to a decrease in the energy efficiency of the system.

The filtration process STC is reduced to the solution of the equation (1), to the unknown a, because there is a random component in gaussian noise in the equation **B**, traditional methods for solving linear equations do not provide the necessary accuracy. Different methods can be used to calculate estimates of transmitted symbols: the method of zeroing (ZF is Zero Forcing), method of minimizing the mean square deviation (MMSD), the method of the sequential exclusion of the demodulated component (SIC is Successive Interference Cancellation), maximum likelihood method (ML) and the spherical decoding method (SD) etc [19-25].

Estimates of transmitted symbols by the ZF method are calculated as:

$$\hat{\boldsymbol{\theta}} = (\mathbf{H}'\mathbf{H})^{-1}\mathbf{H}'\mathbf{Y}. \tag{4}$$

The expression for computing the estimation of MMSD has the form:

$$\hat{\boldsymbol{\theta}} = (\mathbf{H}'\mathbf{H} + 2\sigma^2\mathbf{I})^{-1}\mathbf{H}'\mathbf{Y}. \tag{5}$$

The MMSD method allows to reduce noise and higher noise immunity compared to ZF. Computational complexity of both methods is proportional to S^3.

Comparative analysis of the signal processing methods in the MIMO system is shown in fig. 2, where the simulation results are presented using the program *MatCad 14*. The simulation were fulfilled the following conditions:

1) impulse characteristic of the channel is known on the receiving side;

2) the duration of all impulse characteristics are the same and equal to 4;

3) processing of 10^6 symbols was carried out by blocks of 50 characters.

In fig. 2 is a graph of estimation of noise immunity of accepted sequence of symbols for MMSD, SIC, MP and ZF algorithms. According to the results of the simulation, we can conclude, that the algorithm MP is the most harmful.

Significantly better characteristics, than the ZF and MMSD methods, have an SIC algorithm, which reduces to the sequential exclusion of demodulated components from the received signal.

On each iteration of this algorithm by the MMSD method, a rigorous evaluation of one of the components transmitted by i-th antenna, the replica of which is subtracted from the received signal.

The SIC method has a significant drawback - the effect of "multiplying errors". The number of arithmetic operations in this method is proportional to the S^4.

The best practice among known demodulation methods is the MP method. Evaluation of information symbols by the MP method is carried out by checking all combinations of the vector $\boldsymbol{\theta}$ from the set of possible values of the QAM symbol vector $\Theta = \left\{\theta^{(1)},...,\theta^{\left(K_{given}^{S}\right)}\right\}$:

$$\hat{\theta} = \underset{\theta}{arg\,min}\left\|\mathbf{Y} - \mathbf{H}\theta\right\|^2. \tag{6}$$

The computational complexity of this algorithm exponentially increases as the number of transmitting antennas increases S and proportional to the value K_{given}^{S}.

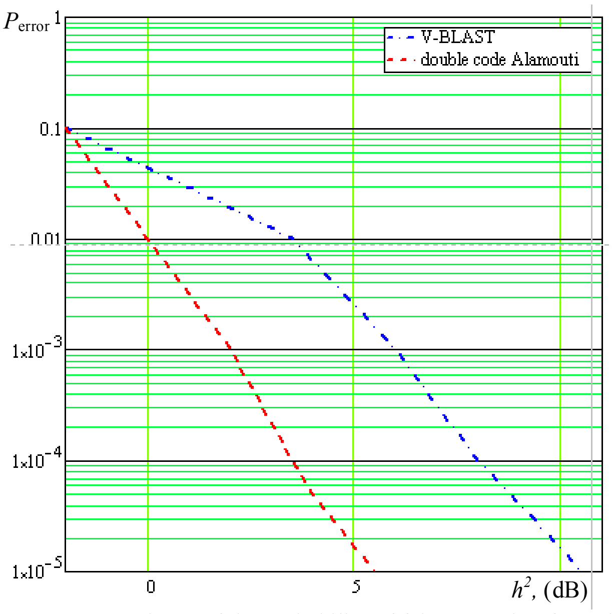

Fig. 1. Dependence of the probability of false reception from the signal/noise ratio for the double code of Alamouti and V-BLAST

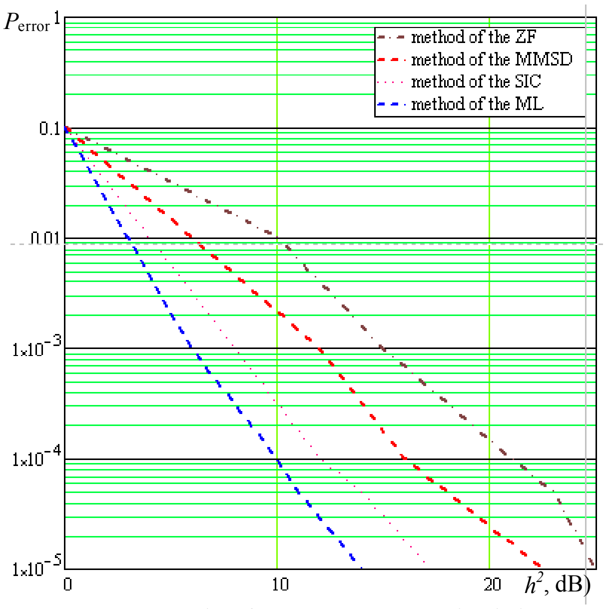

Fig. 2 Results of MIMO 8x8 system simulation, for ZF, MMSD, SIC and MP algorithms

Implement this real-time algorithm for the V-BLAST system, for example, with S = 8 and using of the modulation QAM-16, quite problematic. In this case, an interval must be performed on the interval of the duration of one information symbol 16^4 = 65536 symbol combinations.

In a spherical decoder, unlike the MP algorithm, the reduced combination of combinations is limited by a certain subset of combinations $\Theta^d \in \Theta$ [23]. Within a subset Θ^d hamming's distance from each of the combinations to some initial evaluation of the vector $\boldsymbol{\theta}$ does not exceed the value d is the radius of the " search sphere ". Demodulation quality $\boldsymbol{\theta}$ depends on the radius d. The greater the radius, the higher the reliability of the estimate, calculated by this method. However, with an increase d, increases the size of the subset of the vectors Θ^d, which is checked, and the computational complexity of the SD algorithm. The disadvantage of this algorithm is the random computational complexity, which depends on the signal/noise ratio. With a low average computational complexity of the SD algorithm, its maximum value may coincide with the computational complexity of the MP algorithm. This fact complicates the hardware implementation of SD, since the restriction of computational complexity in hardware causes degradation of the characteristics of the algorithm. Fig. 2 and in tabl. 1 shows the characteristics of the above-described processing methods for the V-BLAST system with 8 transmitting and 8 receiving antennas, during modulation of the QAM-16.

Table 1. **Noise immunity and computational complexity of different signal processing methods**

Method of processing	Signal/noise ratio h^2 (dB), when $P_{error} = 10^{-5}$	Computational complexity
ZF	25	S^3
MMSD	22,5	S^3
SIC	17,2	S^4
MP	14	K^S_{given}
SD	14	depends on the signal/noise ratio

Impedance of the MIMO system using the SD method coincides with the characteristics of the MP method with an unlimited number of steps. Obtained dependence of the error probability on the signal/noise ratio h^2 shows, that known algorithms with acceptable computational complexity are considerably inferior to the characteristics of the impedance of the MP algorithm.

Thus, the best noise immunity among the known methods of signal processing in the MIMO system is the method of maximum likelihood. The best-known characteristics of the known methods of signal processing has the maximum likelihood method [21-23]. But the computational complexity of this method exponentially increases as the number of transmitting antennas increases and is proportional to the value K^S_{given} . In [23], it describes the iterative quasi-optimal method of signal processing in the MIMO system. In this algorithm, user signals were divided into groups, then the initial values of information symbol estimates were established and replicas were generated for each group of signals. After deduction of the replica of the input signal, statistics are generated for demodulation. The processing of each group of signals is carried out using an optimal algorithm. Estimates of information symbols are determined by several iterations. In [20], the characteristics of signal processing for seven iterations for various variants of BLAST systems were analyzed. The complexity of this method is much smaller compared to the maximum likelihood method, when the characteristics of this algorithm significantly exceed the characteristics of V-BLAST, but there is a significant difference from the characteristics of the maximum likelihood algorithm. The noise immunity of this method can be greatly improved by taking into account the degree of accuracy of estimates on intermediate iterations with a known or unknown correlation matrix.

The scheme of realization of the proposed method is shown in fig. 3.

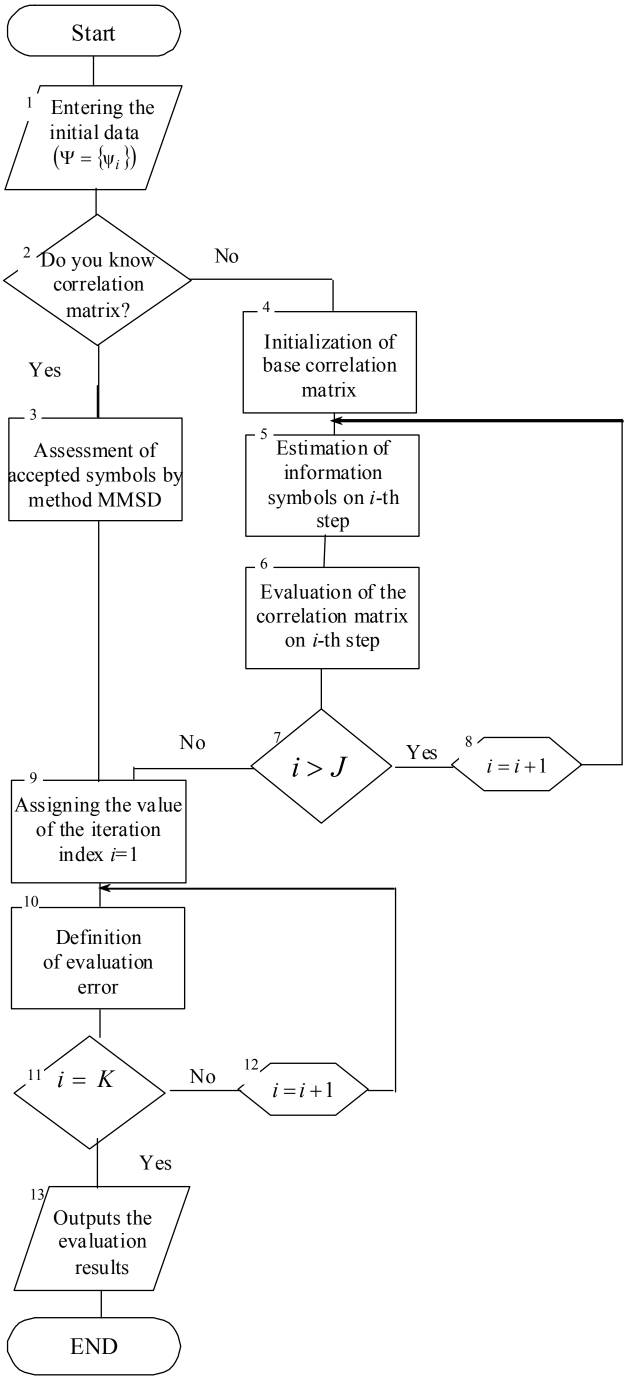

Fig. 3. Scheme of implementation of the signal processing method in the MIMO system

Output data (fig. 3, block 1) are parameters of system MIMO and channel $\Psi = \{\psi_i\}$, $i = \overline{1,6}$, where $\psi_1 \ldots \psi_6$ is the number of transmitting and receiving antennas, the number of iterations, the dimension of the ensemble of signals, the duration of the frame at the output of the demodulator, **H** is a channel matrix. Signals on the receiving side can be divided into two groups and equation (4) can be written in block form:

$$\begin{vmatrix}\mathbf{Z}_1\\ \mathbf{Z}_2\end{vmatrix} = \begin{vmatrix}\mathbf{H}_{11} & \mathbf{H}_{12}\\ \mathbf{H}_{21} & \mathbf{H}_{22}\end{vmatrix}\begin{vmatrix}\mathbf{A}_1\\ \mathbf{A}_2\end{vmatrix} + \begin{vmatrix}\mathbf{B}_1\\ \mathbf{B}_2\end{vmatrix}, \qquad (7)$$

which is equivalent to

$$\begin{cases}\mathbf{Z}_1 = \mathbf{H}_{11}\mathbf{A}_1 + \mathbf{H}_{12}\mathbf{A}_2 + \mathbf{B}_1;\\ \mathbf{Z}_2 = \mathbf{H}_{21}\mathbf{A}_1 + \mathbf{H}_{22}\mathbf{A}_2 + \mathbf{B}_2.\end{cases} \qquad (8)$$

Consider the case, when the correlation matrix is known. Then, at the initial stage, the estimation of the transmitted symbols is calculated by the method of the minimum of the avarage square error (block 3) [21]:

$$\hat{\mathbf{R}}^{(0)} = (\mathbf{H}'\mathbf{H} + 2\sigma^2\mathbf{1})^{-1}\mathbf{H}'\mathbf{Z}, \qquad (9)$$

where sign ' means the operation of the ermitian connection.

The precision of the initial estimation of vector **A** is determined by the correlation matrix of evaluation errors (block 10)

$$\mathbf{R}^{(0)} = 2\sigma^2(\mathbf{H}'\mathbf{H} + 2\sigma^2)^{-2}. \qquad (10)$$

Let it be, on the i-th iteration is a vector estimation $\mathbf{A}_2$:

$$\hat{\mathbf{A}}_2^{(i-1)} = \mathbf{A}_2 + \Delta_2^{(i-1)}, \qquad (11)$$

where $\Delta_2^{(i-1)}$ is the error of estimating vector $\mathbf{A}_2$ on i–1-th iteration, which is gaussian random variable with a zero avarage and correlation matrix $\mathbf{R}_2^{(i-1)}$.

Given the expression (11), equation (8) can be transformed into a form:

$$\begin{cases}\mathbf{Z}_{11}^{(i)} = \mathbf{Z}_1 - \mathbf{H}_{12}\mathbf{A}_2^{(i-1)} = \mathbf{H}_{11}\mathbf{A}_1 + \mathbf{H}_{12}\Delta_2^{(i-1)} + \mathbf{B}_1;\\ \mathbf{Z}_{12}^{(i)} = \mathbf{Z}_2 - \mathbf{H}_{22}\mathbf{A}_2^{(i-1)} = \mathbf{H}_{21}\mathbf{A}_1 + \mathbf{H}_{22}\Delta_2^{(i-1)} + \mathbf{B}_2,\end{cases} \qquad (12)$$

or

$$\begin{cases}\mathbf{Z}_{11}^{(i)} = \mathbf{H}_{11}\mathbf{A}_1 + \chi_{11}^{(i-1)};\\ \mathbf{Z}_{12}^{(i)} = \mathbf{H}_{21}\mathbf{A}_1 + \chi_{12}^{(i-1)},\end{cases} \qquad (13)$$

where $\chi_{11}^{(i-1)}$ та $\chi_{12}^{(i-1)}$ is the gaussian random variables with zero avarage and correlation matrices:

$$\begin{cases}\mathbf{K}_{11}^{(i-1)} = \mathbf{H}_{12}\mathbf{R}_2^{(i-1)}\mathbf{H}'_{12} + 2\sigma^2\mathbf{1};\\ \mathbf{K}_{12}^{(i-1)} = \mathbf{H}_{21}\mathbf{R}_2^{(i-1)}\mathbf{H}'_{22} + 2\sigma^2\mathbf{1}.\end{cases} \qquad (14)$$

In turn, the system of equations (14) can be written in the form

$$\mathbf{Z}_1^{(i)} = \mathbf{H}_1\mathbf{A}_1 + \chi_1^{(i-1)}, \qquad (15)$$

where $\mathbf{Z}_1^{(i)} = \begin{vmatrix}\mathbf{Z}_{11}^{(i)}\\ \mathbf{Z}_{12}^{(i)}\end{vmatrix}$, $\mathbf{H}_1 = \begin{vmatrix}\mathbf{H}_{11}\\ \mathbf{H}_{21}\end{vmatrix}$, $\chi_1^{(i-1)} = \begin{vmatrix}\chi_{11}^{(i-1)}\\ \chi_{12}^{(i-2)}\end{vmatrix}$.

Soft score of the first group of symbols $\mathbf{A}_1$, on i-th iteration is calculated as:

$$\hat{\mathbf{A}}_1^{(i)} = \frac{\sum_{\mathbf{A}^{S/2}} \mathbf{A}_1 e^{-0,5\frac{\left(\mathbf{Z}_1^{(i)}-\mathbf{H}_1\mathbf{A}_1\right)'\left(\mathbf{Z}_1^{(i)}-\mathbf{H}_1\mathbf{A}_1\right)}{\mathbf{R}_1^{(i-1)}}}}{\sum_{\mathbf{A}^{S/2}} e^{-0,5\frac{\left(\mathbf{Z}_1^{(i)}-\mathbf{H}_1\mathbf{A}_1\right)'\left(\mathbf{Z}_1^{(i)}-\mathbf{H}_1\mathbf{A}_1\right)}{\mathbf{R}_1^{(i-1)}}}}, \quad (16)$$

where $\mathbf{A}^{S/2}$ is the a set of values, that can receive a vector of information symbols of the first group.

To calculate the evaluation of the symbols of the second group $\mathbf{A}_2$ at this iteration repeat operations similar to the expressions (11) – (17), taking into account the found evaluation $\hat{\mathbf{A}}_1^{(i)}$. The correlation matrix of estimation errors in this step is calculated:

$$\mathbf{R}_1^{(i)} = E\left\{\hat{\mathbf{A}}_1^{(i)}\hat{\mathbf{A}}_1^{(i)\prime}\right\} = -\hat{\mathbf{A}}_1^{(i)}\hat{\mathbf{A}}_1^{(i)\prime} +$$

$$+\frac{\sum_{\mathbf{A}^{S/2}} \mathbf{A}_1\mathbf{A}_1' e^{-0,5\frac{\left(\mathbf{Z}_1^{(i)}-\mathbf{H}_1\mathbf{A}_1\right)'\left(\mathbf{Z}_1^{(i)}-\mathbf{H}_1\mathbf{A}_1\right)}{\mathbf{R}_1^{(i-1)}}}}{\sum_{\mathbf{A}^{S/2}} e^{-0,5\frac{\left(\mathbf{Z}_1^{(i)}-\mathbf{H}_1\mathbf{A}_1\right)'\left(\mathbf{Z}_1^{(i)}-\mathbf{H}_1\mathbf{A}_1\right)}{\mathbf{R}_1^{(i-1)}}}}, \quad (17)$$

Found on *i*-th iteration of evaluation $\hat{\mathbf{A}}_1^{(i)}$ і $\hat{\mathbf{A}}_2^{(i)}$ (blocks 4–7) form a general estimate of the vector of the transmitted symbols:

$$\hat{\mathbf{A}}^{(i)} = \begin{vmatrix} \hat{\mathbf{A}}_1^{(i)} \\ \hat{\mathbf{A}}_2^{(i)} \end{vmatrix}. \quad (18)$$

Under an unknown correlation matrix, the following sequence of actions occurs. Initialization of the basic correlation matrix occurs $\mathbf{R}_2(0) = I_N$ and setting the counter of iterations to a zero position $i = 0$ (block 4). After which happens the evaluation of information symbols A on *i*-th step by expression:

$$A_i = arg \min_{A\in\{U_{ti}\}^S} \wp\left(\mathbf{R}_2^{-1}\left\{(i-1)[\mathrm{H}-Z][\mathrm{H}-Z]^{\mathrm{H}}\right\}\right), \quad (19)$$

where $\{U_{ti}\}^S$ is the vector, that describes the alphabet of transmitting antennas, $\wp$ is the matrix trace.

After evaluation of information symbols, A the estimation of the correlation matrix happens at the second step in terms of expression:

$$\mathbf{R}_2(i) = L^{-1}\left[X - H\hat{\mathbf{A}}^{(i)}\right]\left[X - H\hat{\mathbf{A}}^{(i)}\right]^H, \quad (20)$$

where L is the the number of vector-columns of the matrix of space-time symbols.

After $i < J$, where J is the maximum number of iterations, $i = i+1$ happens a transition to the block 4.

Unlike the well-known, in the developed method, signal processing is possible with an unknown correlation matrix, and each iteration takes into account not only the score obtained in the previous step, but also the degree of accuracy of the character estimation.

To evaluate the effectiveness of the developed method, an imitation model was developed in the programming environment *MatCad 14*. Modelling was conducted for a system with 8 receiving and 8 transmitting antennas using quadrature amplitude modulation.

Fig. 4 shows the probability of error P_{error} from signal/noise ratio (SNR).

Relative signal/noise refers to the ratio $h_i^2/2\sigma^2$, where $2\sigma^2$ is a noise dispersion of observation, h_i^2 is the average signal strength in the interval of the duration of one information symbol in one receiving channel, that is $h_i^2 = E\left\{\sum_{j=1}^{M_t}\left|h_{ij}\right|^2\right\}$, *i* is number of input tract, $i = \overline{1, M_r}$.

It is believed, that for all receiving channels SNR is the same, since the matrix **H** consists of uncorrelated complex gaussian random variables with zero avarage and uniform dispersions. From fig. 4 we can see, that the least efficient algorithm has a minimum of mean-square deviation. The proposed quasi-optimal processing method has energy losses in comparison with the optimal demodulator of the order 1 dB (when $P_{error} = 10^{-5}$). At the same time, the V-BLAST algorithm has power losses close 3 dB.

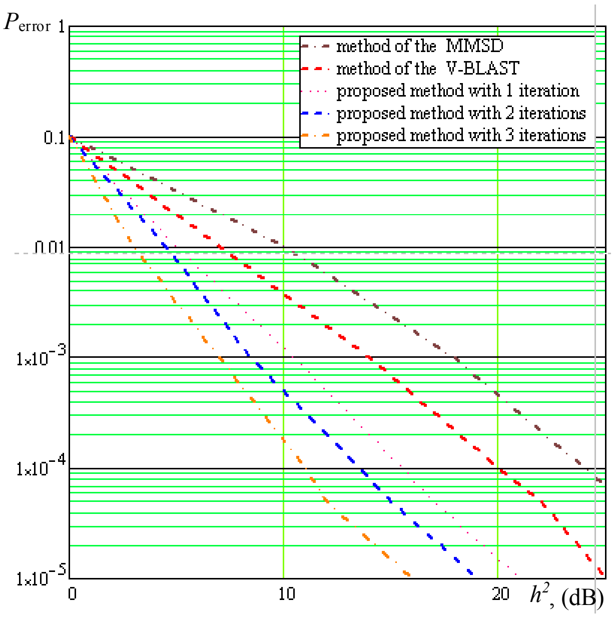

Fig. 4. Impedance of different methods of signal processing in the MIMO system

When dividing S flows into two subgroups, the complexity of the algorithm for *K*-position modulation is proportional to $K^{S/2}$, that is, with the number of antennas 8 and modulation QAM-16, it is necessary to perform computational operations for 256 combinations in the interval of the one information symbol duration.

Number of mathematical operations (addition and multiplication) with the number of iterations and in this method is proportional to the magnitude

$$28i K^{S/2} S^2 + 20i K^{S/2} S .$$

In MIMO system with 8 transmitting and 8 receiving antennas for demodulating one information symbol (with frequency of passage 100 мks) With modulation of QAM-16, the method allows to reduce the number of operations performed in real time, from 10 million in the case of an optimal demodulator to 500 thousand. Thus, the computational cost for implementing the proposed method is 20 times less, than the maximum likelihood algorithm.

According to the results of the simulation, we can conclude, that the proposed method has characteristics close to the characteristics of the demodulator, optimal for the criterion of maximum likelihood, but much less computational complexity. This method can be used to process signals in systems with more antennas and with high modulation multiplicity.

Conclusions

1. The noise immunity of receiving signals in the MIMO system, essentially depends on the choice of the signal processing method on the receiving side. Existing methods for processing signals, that provide a given quality of information transmission have a high computational complexity, so there is a necessity to improve these methods.

2. This article developed an improved method of signal processing in MIMO systems of unmanned aeronautical complexes, the essence is the ability to work with a known and unknown correlation matrix, the division of received signals into groups and the evaluation of each group, taking into account the evaluation error.

The difference between the advanced method and the known method, which determines its novelty and the essence of the improvement, is that the method allows to work with an unknown correlation matrix, and when processing the signal in the demodulator, each iteration takes into account not only the evaluation obtained in the previous step, but also the degree of accuracy character evaluation.

3. The proposed improved method has characteristics, that are close to the characteristics of a demodulator, optimal for the criterion of maximum likelihood, but much less computational complexity. So, in the MIMO system with 8 transmitting and 8 receiving antennas, demodulating one information symbol with modulation of QAM-16, the method allows to reduce computing costs by 20 times compared with the maximum likelihood algorithm.

The direction of further research is the development of a method for evaluating the parameters of the MIMO system channels of unmanned aeronautical complexes.

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Метод обробки сигналів у системах MIMO безпілотних авіаційних комплексів

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Завадостійкість приймання сигналів в системі MIMO (Multiple-Input Multiple-Output) суттєво залежить від вибору методу обробки сигналів на приймальному боці. Існуючі методи обробки сигналів, в системі MIMO які забезпечують задану якість передачі інформації, мають високу обчислювальну складність, тому виникає необхідність удосконалення цих методів. Метою зазначеної статті є підвищення завадозахищеності каналів управління та передачі даних безпілотних авіаційних комплексів, що досягається шляхом розробки нового методу обробки сигналів у багатоантенних системах безпілотних авіаційних комплексів. В статті розроблено удосконалений метод обробки сигналів в системах MIMO безпілотних авіаційних комплексів, сутність якого полягає в можливості роботи з відомою та невідомою кореляційною матрицею, розбитті прийнятих сигналів на групи і оцінці кожної групи з врахуванням помилки оцінювання. Під час дослідження були використані положення теорії зв’язку, теорії сигналів, теорії антен та теорії завадостійкого кодування. Відмінність удосконаленого методу, полягає в тому, що метод дозволяє працювати при невідомій кореляційній матриці, а при обробці сигналу в демодуляторі на кожній ітерації враховується не тільки оцінка, отримана на попередньому кроці, але й ступінь точності оцінювання символів. Запропонований вдосконалений метод має характеристики, близькі до характеристик демодулятора, оптимального за критерієм максимальної правдоподібності, але значно меншу обчислювальну складність. Метод дозволяє знизити обчислювальні затрати в 20 разів в порівнянні з алгоритмом максимального правдоподібності. Практична реалізація зазначеного методу дозволить створити програмне забезпечення для комунікаційного обладнання безпілотних авіаційних комплексів, що функціонують в складних умовах радіоелектронної обстановки.

Ключові слова: сигнально-завадова обстановка; швидкість передачі інформації; ймовірність бітової помилки, просторово-часова обробка, система MIMO, паралельні канали.

Метод обработки сигналов в системах MIMO беспилотных авиационных комплексов

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Помехоустойчивость приема сигналов в системе MIMO (Multiple-Input Multiple-Output) существенно зависит от выбора метода обработки сигналов на приемной стороне. Существующие методы обработки сигналов в системе MIMO, которые обеспечивают заданное качество передачи информации, имеют высокую вычислительную сложность, поэтому возникает необходимость совершенствования этих методов. Целью данной статьи является повышение помехозащищенности каналов управления и передачи данных беспилотных авиационных комплексов, достигается путем разработки нового метода обработки сигналов в многоантенных системах беспилотных авиационных комплексов. В статье разработан усовершенствованный метод обработки сигналов в системах MIMO беспилотных авиационных комплексов, сущность которого заключается в возможности работы с известной и неизвестной корреляционной матрицей, разбивке принятых сигналов на группы и оценке каждой группы с учетом ошибки оценивания. В ходе исследования были использованы положения теории связи, теории сигналов, теории антенн и теории помехоустойчивого кодирования. Отличие усовершенствованного метода, заключается в том, что метод позволяет работать при неизвестной корреляционной матрицы, а при обработке сигнала в демодуляторе на каждой итерации учитывается не только оценка, полученная на предыдущем шаге, но и степень точности оценки символов. Предложенный усовершенствованный метод имеет характеристики, близкие к характеристикам демодулятора, оптимального по критерию максимального правдоподобия, но имеющего значительно меньшую вычислительную сложность. Метод позволяет снизить вычислительные затраты в 20 раз по сравнению с алгоритмом максимального правдоподобия. Практическая реализация данного метода позволит создать программное обеспечение для коммуникационного оборудования беспилотных авиационных комплексов, функционирующих в сложных условиях радиоэлектронной обстановки.

Ключевые слова: сигнально-помеховая обстановка; скорость передачи информации; вероятность битовой ошибки, пространственно-временная обработка, система MIMO, параллельные каналы.