Виконано синтез оптимального приймача сигналів, що спостерігаються на тлі двокомпонентної гаусівської марківської завади. Отримані математичні вирази для перетворень над відліками напруги спостережуваної суміші сигналу та завади. Потрібні операції обчислення зваженої кореляційної суми та зваженої енергетичної суми базовані на використанні нелінійних інерційних перетворювачів. Якість розрізнення сигналів оцінено шляхом комп'ютерного моделювання

Ключові слова: гаусівська марківська завада, кореляційна сума, щільність розподілу вірогідності, похибка розрізнення

Выполнен синтез оптимального приёмника сигналов, наблюдаемых на фоне аддитивной двухкомпонентной гауссовой марковской помехи. Получены математические выражения для преобразований над отсчётами напряжения наблюдаемой смеси сигнала и помехи. Требуемые операции вычисления взвешенной корреляционной суммы и взвешенной энергетической суммы основаны на применении нелинейных инерционных преобразователей. Качество различения сигналов было оценено путем компьютерного моделирования

Ключевые слова: гауссовская марковская помеха, корреляционная сумма, плотность распределения вероятности, ошибка различения

UDC 621.391:681.518

DOI: 10.15587/1729-4061.2017.118869

DESIGN OF A DEVICE FOR OPTIMAL RECEPTION OF SIGNALS AGAINST THE BACKGROUND OF A TWO-COMPONENT MARKOV INTERFERENCE

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1. Introduction

Enabling highly reliable reception of informational and service signals in automation and telecommunication underlies effective operation of technological and personal communication systems, signaling and control. Numerous external radio-electronic devices, as well as a number of natural processes, serve as sources of interfering electromagnetic oscillations that penetrate communication channels and distort useful signals propagating along them. This creates preconditions for the false interpretation of the specified signals, which leads to a significant decrease in the reliability of the received informational messages in general. Since the saturation of technological and consumer medium with the sources of radiation is steadily growing, it means that the quantity increases, as well as the nature differs, of the character of electromagnetic interferences to each particular system related to automation, communication, alarm, or control. Given this, there remains an important problem on solving the tasks of interference-free reception of informational messages.

2. Literature review and problem statement

Most radio electronic systems operate under conditions of complex electromagnetic environment. An essential (and sometimes the only one) disturbing factor in practice is a multicomponent additive interference. Methods and means for suppressing multi-component interferences attract at present much attention from specialists. Paper [1] describes a method for the suppression of such interferences based on a polynomial approximation of the phase and subsequent use of the phase information. Applying only one parameter narrows the range of interference situations for which a given method can be employed. Articles [2, 3] explore the possibility of nonlinear processing of an additive mixture of signal and a two-component interference in order to build the receiver, optimal for the criterion of maximum likelihood. The results of the studies outline a general approach to solving the problem, without providing for a direct numerical validation. The case when a source of a multicomponent interference is dispersed in space was considered in paper

[4], in which a spatial localization of sources of interference yields additional information to reduce their level. In fact, it was proposed an additional stage in the processing of a signal-interference mix, which is not formally associated with the subsequent processing and which does not form with it a unified integrated procedure, which can actually ensure maximum noise immunity. In article [5], authors synthesized nodes of the optimal receiver of signals in the automated locomotive signaling system (ALS) against the background of a two-component interference; the functionality of these nodes, however, requires further clarification. Such nodes generally implement a correlation method of reception, which is still very much relevant for many sectors of automation, communication. and location. Thus, in paper [6], correlation signal processing is used to determine the location of a vehicle. A concomitant increase in the signal-to-noise ratio at the output of a receiving device is examined in [7], though the emphasis is on improving the structure of only one, albeit important, node, – a correlator. A method, proposed in paper [8], to process a primary signal-jamming mix is focused on solving only a limited task to screen the data inapplicable for further operations. Application of correlation processing for estimating time delay of signals received from two spatially separated sensors was described in article [9]; the results obtained, however, are also narrowly focused. In paper [10], a cross-correlational process of handling received oscillations underlies a method for solving a particular task of interference suppression in the form of local reflections.

Thus, we can argue about some success in the development of procedure for eliminating multicomponent interferences in order to solve particular tasks in radio electronics. However, a certain fragmentation of the obtained results predetermines the rationality of efforts applied to searching for a unified approach to the development of such a procedure.

3. The aim and objectives of the study

The aim of the conducted research was the synthesis of basic nodes of the optimal receiver of signals observed against the background of the additive two-component Gaussian Markov interference.

To accomplish the set aim, the following tasks had to be solved:

– to construct a mathematical model of the probability density of signal from an automated locomotive signaling system, observed against the background of a correlated Gaussian interference;

– to synthesize a receiver of informational signals from an automated locomotive signaling system, which would implement optimum processing of a signal jamming mix;

– to estimate numerically noise immunity of the synthesized device.

4. Synthesis of mathematical structure for an optimum reception device

The feasibility of technical implementation of means for the effective elimination of a multi-component interference depends largely on the expression, accepted prior to the stage of design, which would describe a statistical relationship between a given interference and the signal. We shall state the following problem: it is required to convert the expression, found earlier in paper [5] for a function of the likelihood, so that the result of transformation allows engineering interpretation. This means that the appropriate signal processing device must consist of nodes that perform easily-implemented mathematical operations (using hardware or software tools).

The structures of nodes, obtained earlier in [5], can be specified for a practically important case of Gaussian noise. Using a record, given in [11], for the distribution density of a signal probability, observed against the background of a correlated Gaussian Markov interference in accordance with the notation introduced in paper [3], we shall find the required transformation y_{sk} over the observed voltage counts:

$$y_{sk} = -\frac{r}{\sigma^2\left(1-r^2\right)}\cdot\left(u_{k+1}-ru_k\right). \tag{1}$$

Similarly, we find the required transformation y_{sk+1} over the observed voltage counts:

$$y_{sk+1} = \frac{1}{\sigma^2\left(1-r^2\right)}\cdot\left(u_{k+1}-ru_k\right). \tag{2}$$

Denote the multiplier, which is not dependent on input voltage, before parenthesis as

$$G(r,\sigma) = 1\Big/\left[\sigma^2\left(1-r^2\right)\right]. \tag{3}$$

Considering a given multiplier, one can write

$$y_{sk} = -rG(r,\sigma)\cdot\left(u_{k+1}-ru_k\right), \tag{4}$$

$$y_{sk+1} = G(r,\sigma)\cdot\left(u_{k+1}-ru_k\right). \tag{5}$$

Calculate coefficients γ and $\varkappa$, which are included in the balanced energy sum, introduced in paper [5]. Expression for a two-dimensional probability density of the correlated Gaussian counts at s_k=0 and s_{k+1}=0 will be represented in the form:

$$\gamma_{sk}^2 = \frac{r^2}{\sigma^2\left(1-r^2\right)}. \tag{6}$$

Because it follows from comparison (4) and (5) that $y_{sk+1}=y_{sk}/(-r)$, the expression for γ_{sk+1}^2 will be obtained by simply dividing γ_{sk}^2 by r^2.

Finally, we find coefficient $\varkappa^2$ for the case of a Gaussian interference:

$$\varkappa^2 = -\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} y_{sk}y_{sk+1}\cdot p_2\left(u_k,u_{k+1}\right)\mathrm{d}u_k\mathrm{d}u_{k+1} = \frac{r}{\sigma^2\left(1-r^2\right)}. \tag{7}$$

Dependence of coefficients γ_{sk}, γ_{sk+1} and $\varkappa$ on the magnitude Δt is realized through their dependence on the magnitude r of the related Δt correlation coefficient.

Find expressions for $q\left(\vec{\lambda},\Delta t\right)$ and $\mu\left(\vec{\lambda},\Delta t\right)$. Weighted correlation sum takes the form:

$$q\left(\vec{\lambda},\Delta t\right) = q\left(\vec{\lambda},r\right) = \\ = \frac{1}{\sigma^2\left(1-r^2\right)}\sum_{k=1}^{K-1}\left(u_{k+1}-ru_k\right)\cdot\left[s_{k+1}\left(\vec{\lambda}\right)-rs_k\left(\vec{\lambda}\right)\right]. \tag{8}$$

The expression for the weighted energy sum takes the form:

$$\mu\left(\vec{\lambda},\Delta t\right)=\mu\left(\vec{\lambda},r\right)= =\frac{1}{2\sigma^2\left(1-r^2\right)}\cdot\sum_{k=1}^{K-1}\left[s_{k+1}\left(\vec{\lambda}\right)-rs_k\left(\vec{\lambda}\right)\right]^2. \quad (9)$$

One can see from (8) and (9) that in the case of r=0 (independent counts) weighted sums are converted into a normal correlation and energy sums. At completely correlated counts ($r\to1$), the weighted correlation sum of counts turns into a correlation sum of increments, while the weighted energy sum becomes an energy sum of increments. Note also that in the examined case for a Gaussian Markov interference, the processing of counts is linear.

We shall introduce coefficients $\mathcal{P}_1$ and $\mathcal{P}_C$, which characterize relative duration of the impulse noise in the interval of existence of a useful signal; in this case, $\mathcal{P}_1=1-\mathcal{P}_C$. Their physical sense is, accordingly, the probability that the input voltage contains only a fluctuational interference, and the probability that the input voltage contains a sum of fluctuational and impulse interferences. Then the density of probability distribution of a two-component interference at an arbitrary point of observation interval is:

– two-dimensional:

$$p_{n2}\left(n_k,n_{k+1}\right)=\mathcal{P}_1\cdot p_2\left(n_{1k},n_{1k+1}\right)+\mathcal{P}_C\cdot p_2\left(n_k,n_{k+1}\right); \quad (10)$$

– conditional:

$$p\left(n_{k+1}\,|\,n_k\right)=\mathcal{P}_1\cdot p\left(n_{1k+1}\,|\,n_{1k}\right)+\mathcal{P}_C\cdot p\left(n_{k+1}\,|\,n_k\right). \quad (11)$$

Both of these densities are non-Gaussian. Given this, we find transformation y_{sk} over the input signal counts:

$$y_{sk}= =-\frac{\mathcal{P}_1\cdot\frac{r_1}{\sigma_1^3\left(1-r_1^2\right)^{3/2}}\cdot\left(u_{k+1}-r_1u_k\right)\cdot\exp\left\{-\frac{\left(u_{k+1}-r_1u_k\right)^2}{2\sigma_1^2\left(1-r_1^2\right)}\right\}}{\mathcal{P}_1\frac{1}{\sigma_1\left(1-r_1^2\right)^{1/2}}\exp\left\{-\frac{\left(u_{k+1}-r_1u_k\right)^2}{2\sigma_1^2\left(1-r_1^2\right)}\right\}+\mathcal{P}_C\frac{1}{\sigma\left(1-r_2^2\right)^{1/2}}\exp\left\{-\frac{\left(u_{k+1}-r_2u_k\right)^2}{2\sigma^2\left(1-r_2^2\right)}\right\}}+ +\frac{\mathcal{P}_C\cdot\frac{r_2}{\sigma^3\left(1-r_2^2\right)^{3/2}}\cdot\left(u_{k+1}-r_2u_k\right)\cdot\exp\left\{-\frac{\left(u_{k+1}-r_2u_k\right)^2}{2\sigma^2\left(1-r_2^2\right)}\right\}}{\mathcal{P}_1\frac{1}{\sigma_1\left(1-r_1^2\right)^{1/2}}\exp\left\{-\frac{\left(u_{k+1}-r_1u_k\right)^2}{2\sigma_1^2\left(1-r_1^2\right)}\right\}+\mathcal{P}_C\frac{1}{\sigma\left(1-r_2^2\right)^{1/2}}\exp\left\{-\frac{\left(u_{k+1}-r_2u_k\right)^2}{2\sigma^2\left(1-r_2^2\right)}\right\}}. \quad (12)$$

Here we take into consideration that at a powerful impulse interference one can employ approximate equality $\sigma^2\approx\sigma_2^2$. In this case, magnitudes r_1 and r_2 represent, respectively, correlation coefficient of a fluctuational interference and correlation coefficient of the Gaussian Markov process. A "cutout" from this process creates the impulse interference.

Similarly, we find y_{sk+1}. Because for each of the Gaussian interference component this expression differs only by the absence of a multiplier (–r), we can write

$$y_{sk+1}= =\frac{\mathcal{P}_1\cdot\frac{1}{\sigma_1^3\left(1-r_1^2\right)^{3/2}}\cdot\left(u_{k+1}-r_1u_k\right)\cdot\exp\left\{-\frac{\left(u_{k+1}-r_1u_k\right)^2}{2\sigma_1^2\left(1-r_1^2\right)}\right\}}{\mathcal{P}_1\frac{1}{\sigma_1\left(1-r_1^2\right)^{1/2}}\exp\left\{-\frac{\left(u_{k+1}-r_1u_k\right)^2}{2\sigma_1^2\left(1-r_1^2\right)}\right\}+\mathcal{P}_C\frac{1}{\sigma\left(1-r_2^2\right)^{1/2}}\exp\left\{-\frac{\left(u_{k+1}-r_2u_k\right)^2}{2\sigma^2\left(1-r_2^2\right)}\right\}}+ +\frac{\mathcal{P}_C\cdot\frac{1}{\sigma^3\left(1-r_2^2\right)^{3/2}}\cdot\left(u_{k+1}-r_2u_k\right)\cdot\exp\left\{-\frac{\left(u_{k+1}-r_2u_k\right)^2}{2\sigma^2\left(1-r_2^2\right)}\right\}}{\mathcal{P}_1\frac{1}{\sigma_1\left(1-r_1^2\right)^{1/2}}\exp\left\{-\frac{\left(u_{k+1}-r_1u_k\right)^2}{2\sigma_1^2\left(1-r_1^2\right)}\right\}+\mathcal{P}_C\frac{1}{\sigma\left(1-r_2^2\right)^{1/2}}\exp\left\{-\frac{\left(u_{k+1}-r_2u_k\right)^2}{2\sigma^2\left(1-r_2^2\right)}\right\}}. \quad (13)$$

Results of modeling of the process of work of nonlinear inertial converters y_{sk} and y_{sk+1} are shown in Figs 1, 2 in the form of charts. They depict dependences of output magnitude $y(u_k, u_{k+1})$ for each of the converters on the input magnitudes u_k and u_{k+1} (dynamic characteristics of converters). The figures illustrate various combinations of root-mean-square deviations σ_1 and σ_2 of a fluctuational and an impulse component of the interference. Parameters $\mathcal{P}_1=0{,}9$; $\mathcal{P}_C=0{,}1$; r_1=0.15; r_2=0.9 are considered to be fixed.

It follows from Fig. 1 that at σ_1=0.3 V and σ_2=1.75 V dynamic characteristics of coefficient y_{sk} in the larger part of the examined range of input voltages are of monotonous, linearly growing, character.

It follows from Fig. 2 that at σ_1=0.3 V and σ_2=1.75 V dynamic characteristics of coefficient y_{sk+1} in the larger part of the examined range of input voltages are of monotonous, linearly growing, character.

Thus, in the region of modeling, nonlinear dependences $y_{sk}(u_k, u_{k+1})$ and $y_{sk+1}(u_k, u_{k+1})$ are close to the piecewise-linear ones. In practice, this corresponds to discrete switching of a permanent material transfer coefficient of some input amplifier (or attenuator). Solution on the magnitude of the transfer coefficient is made on the basis of analysis of the two input voltages: u_{k+1} (current point in time) and u_k (preceding point in time). Such a pattern may contribute to a significant simplification of the circuit implementation of non-linear transformers.

Assuming that correlation coefficients r_1 an r_2 are the magnitudes of one order, we shall take into consideration that at short enough pulse of the interference, we obtain $\mathcal{P}_C \ll \mathcal{P}_1$ and that at powerful interference, $\sigma^2 \gg \sigma_1^2$. In this case, coefficients γ_{sk}^2, γ_{sk+1}^2 and $\varkappa^2$, which are included in the balanced energy sum [5], are derived from the following ratios:

$$\gamma_{sk}^2\approx\frac{\mathcal{P}_1 r_1^2}{\sigma_1^2\left(1-r_1^2\right)}, \quad (14)$$

$$\gamma_{sk+1}^2\approx\frac{\mathcal{P}_1}{\sigma_1^2\left(1-r_1^2\right)}, \quad (15)$$

$$\varkappa^2\approx\frac{\mathcal{P}_1 r_1}{\sigma_1^2\left(1-r_1^2\right)}. \quad (16)$$

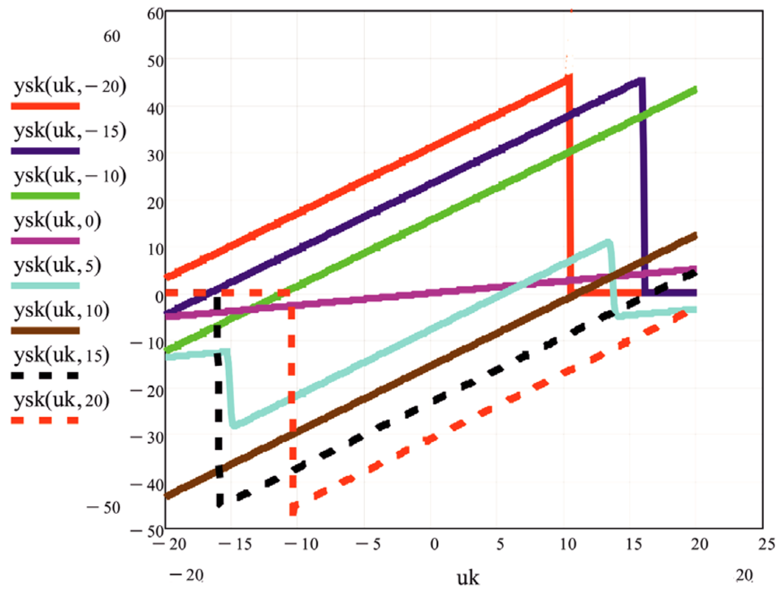

Fig. 1. Dependence of transformation coefficient y_{sk} of voltage count uk of the input signal on its magnitude at fixed magnitudes u_{k+1}

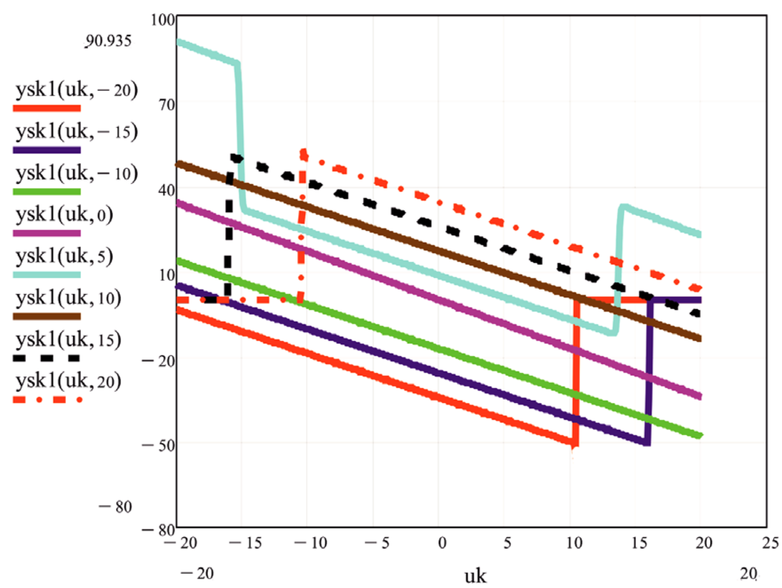

Fig. 2. Dependence of transformation coefficient y_{sk+1} of voltage count uk of the input signal on the magnitude of a given voltage at fixed magnitudes u_{k+1}

With respect to these ratios, the correlation sum equals:

$$q\left(\vec{\lambda},\Delta t\right)=\mathcal{P}_1\sum_{k=1}^{K-1}\frac{W_1(k,k+1)}{Z(k,k+1)}\left(u_{k+1}-r_1u_k\right)\left(s_{k+1}-s_k\right)+$$
$$+\mathcal{P}_C\sum_{k=1}^{K-1}\frac{W_2(k,k+1)}{Z(k,k+1)}\left(u_{k+1}-r_2u_k\right)\left(s_{k+1}-s_k\right),\qquad(17)$$

where

$$W_1(k,k+1)=\frac{1}{\sigma_1^3\left(1-r_1^2\right)^{3/2}}\exp\left\{-\frac{\left(u_{k+1}-r_1u_k\right)^2}{2\sigma_1^2\left(1-r_1^2\right)}\right\};$$

$$W_2(k,k+1)=\frac{1}{\sigma^3\left(1-r_1^2\right)^{3/2}}\exp\left\{-\frac{\left(u_{k+1}-r_2u_k\right)^2}{2\sigma_1^2\left(1-r_2^2\right)}\right\};$$

$$Z(k,k+1)=\mathcal{P}_1\sigma_1^2\left(1-r_1^2\right)\cdot W_1(k,k+1)+\mathcal{P}_C\sigma^2\left(1-r_2^2\right)\cdot W_2(k,k+1)$$

$Z(k,k+1)$ is the denominator of expression (17).

Thus, $q\left(\vec{\lambda},\Delta t\right)$ is the result of adding two weighted correlation sums of count increments, the first of which is taken at correlation coefficient r_1; the second, at correlation coefficient r_2.

The weighted energy sum with respect to the ratios obtained is:

$$\mu\left(\vec{\lambda},\Delta t\right)=$$
$$=\frac{\mathcal{P}_1}{2\sigma_1^2\left(1-r_1^2\right)}\sum_{k=1}^{K-1}\left[s_{k+1}\left(\vec{\lambda}\right)-r_1s_k\left(\vec{\lambda}\right)\right]^2.\qquad(18)$$

As far as the automated locomotive signal system is concerned, the number of differentiated signals equals four: “Green” (G, or 1), “Yellow” (Y, or 2), “Red-yellow” (R, or 3) and “No signal” (or 4) (4). In accordance with the criterion of maximum likelihood, a decision about the type of signal should be made by comparing the differences between the weighted correlation and weighted energy sums, computed for the signals of each type:

$$\rho_l=\rho\left(\vec{u}\,|\,\vec{\lambda}^{(l)}\right)=q\left(\vec{\lambda}^{(l)}\right)-\mu\left(\vec{\lambda}^{(l)}\right);$$
$$\rho\left(\vec{u}\,|\,\vec{\lambda}^{(4)}\right)=0;\quad l=1,2,3.\qquad(19)$$

Decision on the detection of a signal is made for such l^* for those

$$\rho_{l^*}=\rho\left(\vec{u}\,|\,\vec{\lambda}^{(l^*)}\right)>\rho\left(\vec{u}\,|\,\vec{\lambda}^{(4)}\right),$$

that is, at

$$\rho_{l^*}>0.\qquad(20)$$

But, if we have $\rho\left(\vec{u}\,|\,\vec{\lambda}^{(l)}\right)\leq 0$, for all l=1, 2, 3, we should make a decision about the absence of signal at all in the examined monitoring interval. If we do detect a signal, we shall make the following decision

$$\widehat{\vec{\lambda}}=\vec{\lambda}^{(D)}\ \text{at}\ \rho_D=\rho\left(\vec{u}\,|\,\vec{\lambda}^{(D)}\right)=\max_{l^*}\left\{\rho_{l^*}\right\}.\qquad(21)$$

Thus, a separate channel for the formation of statistics for $\vec{\lambda}^{(4)}$ turns out to be unnecessary, it will suffice to add a circuit of comparison to zero. Block diagram of the respective optimal reception device for signal detection and recognition is shown in Fig. 3.

Rectangles with denotations of weighted correlation and energy sums symbolize units for computing these sums for different values of the informational parameter. Blocks with symbol Σ are the adders with inverting (“–”) and non-inverting (“+”) inputs. Blocks with Z are the devices for comparing to zero.

In order to assess the quality of signal recognition, enabled by the designed optimal receiver, we performed computer simulation. The result is the obtained estimates of a theoretical limit for the indicator of a receiver limit – magnitude P_{mist} of the recognition error when sending a coded signal from the automated locomotive signal system (signal parameters were considered fully known). We chose a "Red-yellow" signal for recognition. Original data for the simulation follow:

1) magnitudes $\mathcal{P}_1$ and $\mathcal{P}_C$, for coefficients that characterize relative duration of the impulse interference in the interval of existence of the useful signal;

2) magnitude Δt for the interval of discretization of input voltage over time;

3) magnitudes r_1 and r_2 for correlation coefficients of random processes (these processes create fluctuational and impulse interference, respectively);

4) magnitudes σ_1 and σ_2 for the root-mean-square voltages of these interferences.

Numerical magnitudes of simulation parameters are as follows: $\mathcal{P}_1=0{,}9$; $\mathcal{P}_C=0{,}1$; $\Delta t=5\cdot10^{-3}$ s; $r_1=0.15$; $r_2=0.9$; $\sigma_2=2.05$ V; $\sigma_1=0.05$ V, 0.3 V and 0.6 V [12]. The pulse interference was in the first intra-pulse interval of signal "Green". Simulation results are shown in Table 1.

Based on the results obtained, we constructed curves for the probability of error P_{mist} on amplitude U_m of the carrying oscillation from automated locomotive signal system (Fig. 4).

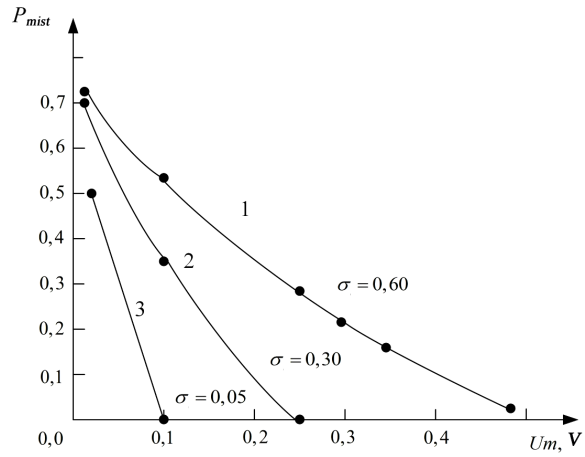

Fig. 4. Dependence of magnitude P_{mist} of the error in signal recognition on amplitude U_m of the carrying oscillation:
1 – root-mean-square value of interference voltage σ_1=0.6 V;
2 – root-mean-square value of interference voltage σ_1=0.3 V;
3 – root-mean-square value of interference voltage σ_1=0.05 V

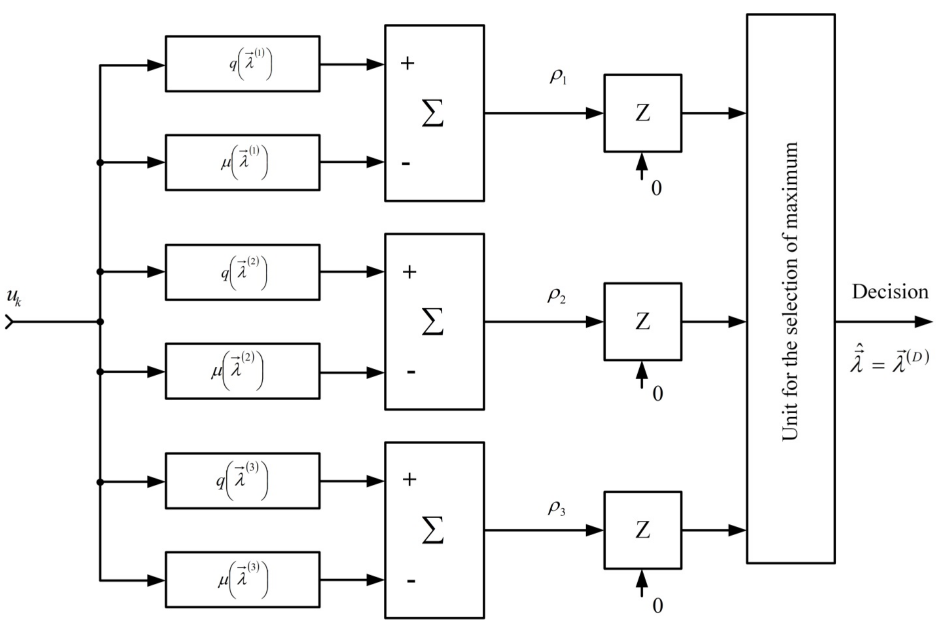

Fig. 3. Block diagram of the optimal reception device for signal detection from an automated locomotive signal system

The results of computer simulation allow us to argue about a very high reliability of signal detection-recognition (the magnitude of error is of order 10^{-2} per one received coded parcel). Such a value is reached under conditions of simultaneous action of fluctuational and impulse interferences at the receiver input. In this case, voltage of the fluctuational interference was of the same order of magnitude as the amplitude of the useful signal. Voltage of the impulse interference was of amplitude an order of magnitude larger than the amplitude of the useful signal.

Table 1

Error P_{mist} in the recognition of the sent coded informational signal from the automated locomotive signal system

Voltage U_m, V	0.02	0.05	0.10	0.15	0.20	0.25	0.30	0.35	0.40	0.45
Magnitude P_{mist} at σ_1=0.05 V	0.49	0.27	0.01	–	–	–	–	–	–	–
Magnitude P_{mist} at σ_1=0.3 V	0.71	0.55	0.35	0.22	0.1	0.01	–	–	–	–
Magnitude P_{mist} at σ_1=0.6 V	0.73	0.64	0.52	0.41	0.31	0.22	0.15	0.14	0.06	0.02

5. Discussion of results of the optimal signal detection receiver from an automated locomotive signal system

The synthesized basic nodes of the optimal signal receiver include in its base structure previously-known accumulators of correlation and energy sums. However, they accumulate, instead of products of counts of a signal-jamming mix and the reference signal, increments of the mentioned counts. Statistically reasonable weighing of increments provides for an instantaneous detection and suppression of impulse interference (a given factor was not considered in earlier studies). A gain at transition from accumulating the counts to the accumulation of increments is in the following. At a correlation coefficient of the interference approaching unity, the magnitude of the interference is the same for adjacent counts (while the signal magnitude is not). That is why, when subtracting ($u_{k+1}-u_k$), an interference is automatically removed. The difference obtained is equal to the magnitude of increment of the useful signal only. As a result, in contrast to a traditional correlation processing, the influence of interference on the receiver output signal is attenuated to a larger extent. Thus, the study we conducted takes into consideration statistical correlation of adjacent counts of the processed time series. An analysis was performed on the level of second momenta of the probability distribution functions. It was assumed that these momenta are constant over the interval of observation. This restricts the scope of application of the devised method under conditions of nonstationary interferences. Accounting for deeper statistical relationships remains, much to our regret, beyond capacities of the synthesized nodes. Ensuring it is one of the directions of further research. The second direction might include the specialization of the designed structures relative to more practical situations according to the needs of particular customers. The main challenge in this respect is the lack of information about statistical properties and dynamics of interferences.

6. Conclusions

1. We constructed a mathematical model of the signal probability distribution density, observed against the background of an additive correlated Gaussian interference. It is shown that its argument should consist of the differences between time-adjacent counts of signal-jamming mix voltages.

2. We synthesized a receiver of informational signals from an automated locomotive signal system, which performs optimal signal processing observed against the background of a Gaussian Markov interference, created by two components. Underlying it is the device built on the basis of totality of linear solvers, the so-called weighted correlation and weighted energy sums. These nodes employ increments of the observed series of counts of a signal-jamming mix, as well as the reference signal.

3. Computer simulation showed that an increase in the amplitude of useful signal leads to the fact that the error detection probability of the assigned signal quickly and monotonously decreases to a magnitude less than 10^{-2} per one received code parcel. This result was achieved in a 12-fold range of change in the root-mean-square voltage of a fluctuational interference. In this case, a pulse interference was also present at the receiver input. Its amplitude exceeded both fluctuational interference and the useful signal by more than three times. Thus, the designed optimal receiver can ensure high noise immunity when recognizing coded signals from an automated locomotive signal system.

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