МЕТОДИ ТА ЗАСОБИ ЗАХИСТУ В КОМУНІКАЦІЙНИХ СИСТЕМАХ

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THEORETICAL BASIS OF SYNTHESIS OF COMPLEX SIGNAL QUASIORTOGONAL SYSTEMS

Introduction

In modern telecommunication systems and networks the task of providing the necessary indicators of noise immunity (noise immunity and secrecy functioning) at the level of the source of signals – physical carriers of information is traditionally solved on the basis of increasing the ratio of signal power to the power of interference at the reception of the receiving device, as well as improving the directivity of the antennas of the transmitter and receiver. Signal intensity or signal-to-noise ratio is a key parameter that determines the characteristics of any receiving task. However, the energy parameters of the system may be limited. Among the main directions for improving the noise immunity and secrecy of the telecommunications network one can identify the directions associated with the use of channels with high redundancy, high spatial, structural, energy and time secrecy. One of the ways to solve this problem is to use radio channels with frequency redundancy [1 – 4]. To provide this type of redundancy, discrete signals are now widely used at the physical level, in which manipulated parameters (amplitude, phase, frequency) are changed at strictly fixed time intervals. Rules for changing the parameter being manipulated are specified by discrete sequences, which completely determine the properties of the discrete signals and are often identified with them. That is why the attention of scientists has been focused on the analysis, synthesis and processing of discrete sequences.

In the systems of radar, sonar, navigation, communication and transmission of information the use of the discrete sequences for the formation of complex wideband and ultrawideband signals as manipulating sequences made it possible to resolve the contradiction between the throughput and range of the systems operation, to increase their noise immunity and electromagnetic compatibility, increase radio bandwidth efficiency use due to code division of channels, to improve the ecology in the radio coverage area by reducing the peak radiation power, create satellite-based radar, radio navigation and communication systems, providing for observation, determination of coordinates and transmission of information to any point on our planet, to implement hidden location and communication using noise-like signals and much more. Today a large number of the discrete sequences classes are known. All of them differ from each other by the rule and the coding power, the priority qualitative characteristic (sequences with perfect periodic autocorrelation function, orthogonal, quasi-orthogonal, trans-orthogonal, maximally trans-orthogonal, optimum in minimum-maximal, or in some other kind, noise-like sequences, periodic, impulse, regular, irregular impulse sequences, etc.); they differ in a number of essential parameters (characteristics): period (length), peak factor, degree of equilibrium, uncertainty function, autocorrelation, reciprocal and butt-correlation functions, etc.

The main results of the research

To date, there is no unified theory for the synthesis of discrete signal (DS) systems with predetermined auto-, mutually-, joint correlation properties. Moreover, it is not possible to answer the question: how signals with a large period close to optimal ones are known. Therefore, it is relevant to search for effective methods of the discrete signals (DS) search with the necessary (for certain applications) correlation, ensemble, statistical and structural properties. One such method is based on the use of iterative algorithms [5]. Relatively good in this sense signals can be obtained with the appropriate choice of the initial approximation and the use of integer optimization by the minimum or medium degree criteria. However, the disadvantage of the iterative methods is the dependence on the initial approximation, a sharp increase in the search time of the signal as the signal period increases. Other methods include finding the necessary conditions for the existence of discrete sequences with the given parameters. It is known [6] that discrete sequences with a good aperiodic autocorrelation function (APFAC) can be found only among sequences with a good periodic autocorrelation function (PFAC). In the first stage, many sequences of candidates with good PFAC are formed. In the second stage, an exhaustive search is carried out for the criterion of the lowest level of the maximum of the side lobes of the APFAC among all cyclic shifts of one-period segments of the candidate sequences. The search result is a sequence with a minimum value of the APFAC side lobes. The method of the discrete sequences synthesis by homomorphic mapping of multiplicative groups of simple and extended Galois fields with k-valued character. Studies have shown that with the increase in the field characteristics and the number of classes, the amount of computations in the directional search is increasing dramatically [7]. Known methods of the discrete sequences synthesis with the given correlation functions are based usually on the operation of sorting multiple options to select the best result, and with a significant period of the discrete sequence application of such methods becomes problematic.

Let us formulate the problem of synthesis of one class of signals with given correlation, ensemble and structural properties. We will require that such signal systems have a "fuzziness" property in correlation properties. This property means that increase or decrease in the duration of the discrete signal does not change the correlation properties inherent in the output signal.

Under the problem of signal synthesis we will understand the task of constructing dictionaries (subsets) of vectors (signals) $(W_m^q), q=\overline{1,N},\ \ m=\overline{1,M}$, the whole set of which forms a system of uniform quasi-orthogonal signals (UQOS) of $M_k = N \times M_x$ dimension such that the following conditions are fulfilled in each of the dictionaries.

1. The mathematical model for the periodic autocorrelation function of each W_m^q of discrete signals (DSs) satisfies the system of nonlinear parametric inequalities (SNPI)

$$R_{a_1}^q(l) \le \sum_{i=1}^{L-1} W_i^q (W_{i+c}^q)^* \le R_{a_2}^q(l),\ \ l=\overline{1,L-1},\ \ q=\overline{1,N}, \tag{1}$$

where $R_{a_1}^q(l)$ and $R_{a_2}^q(l)$ are specified (such as required) values of the side lobes of the PFAC.

2. The mathematical model for the joint function of mutual correlation (JFMC) (W^q, W^p) of discrete signals (DSs) with joining words W^{qp} and W^{pq} satisfies a set of systems of nonlinear parametric inequalities:

$$\begin{aligned}
R_{b_{1,1}}^{qp}(l) &\le \sum_{i=0}^{L-K} W_i^q \times (W_{i+l}^p)^* + \sum_{i=L-K+1}^{L-1} W_i^q \times (W_{i-l+K}^p)^* \le R_{b_{2,1}}^{qp}(l);\\
R_{b_{1,2}}^{qp}(l) &\le \sum_{i=0}^{L-K} W_i^q \times (W_{i+l}^q)^* + \sum_{i=L-K+1}^{L-1} W_i^q \times (W_{i-l+K}^p)^* \le R_{b_{2,2}}^{qp}(l);\\
R_{b_{1,3}}^{qp}(l) &\le \sum_{i=0}^{L-K} W_i^q \times (W_{i+l}^p)^* + \sum_{i=L-K+1}^{L-1} W_i^q \times (W_{i-l+K}^q)^* \le R_{b_{2,3}}^{qp}(l);\\
R_{b_{1,4}}^{qp}(l) &\le \sum_{i=0}^{L-K} W_i^p \times (W_{i+l}^p)^* + \sum_{i=L-K+1}^{L-1} W_i^p \times (W_{i-l+K}^q)^* \le R_{b_{2,4}}^{qp}(l);\\
R_{b_{1,5}}^{qp}(l) &\le \sum_{i=0}^{L-K} W_i^p \times (W_{i+l}^q)^* + \sum_{i=L-K+1}^{L-1} W_i^p \times (W_{i-l+K}^p)^* \le R_{b_{2,5}}^{qp}(l);
\end{aligned} \tag{2}$$

moreover, $l=\overline{1,L-1}$, for various combinations q and p, $q=\overline{1,N}$, $p=\overline{1,N}$, $q \ne p$, where $R_{b_{1,j}}^{qp}(l)$ and $R_{b_{2,j}}^{qp}(l)$ - are specified (required) PFMC (Periodic Function of Mutual Correlation) and JFMC (Joint Function of Mutual Correlation) implementation.

3. Studies show that significant difficulties in overcoming the hidden functioning of radio channels can be created by giving “fuzziness” properties to signals. Let us introduce the concept of fuzziness. Moreover, we first formulate the problem of synthesis of a single signal W^q having the fuzziness in cyclic convolution. Let us define the fuzziness interval Δx by duration

$$L - x_2 \le \Delta x \le L + x_1, \tag{3}$$

Considering that, in the general case $|x_1| \ne |x_2|, |x_1|, |x_2| < L$, the fuzziness interval Δy relative to the true values of the cyclic frequency in the form

$$L - y_2 \le \Delta y \le L + y_1 , \tag{4}$$

and $|y_1| \ne |y_2|, |y_1|, |y_2| < L$.

Let us assume that based on the processing of the signal flow either signal

$$W^{\vartheta}_{x_L} = W^{\vartheta}_{L-\delta} W^{\vartheta}_{L} W^{\vartheta}_{x_1 - L - \delta}, \tag{5}$$

or signal

$$W^{\vartheta}_{x_1} = W^{\vartheta}_{L-\delta} W^{\vartheta}_{X_1+\delta} \tag{6}$$

is accepted as true

with $\Delta x \ge L$, either signal

$$W^{\vartheta}_{x_2} = W^{\vartheta}_{L-X_2}, \tag{7}$$

or signal

$$W^{\vartheta}_{x_{21}} = W^{\vartheta}_{\delta} W^{\vartheta}_{L-x_2-\delta} , \tag{8}$$

with $\Delta x < L$, where indices x_1 i x_2, δ, L, $x_1 + \delta - L$, $L - \delta$, $x_1 + \delta$, $L - x_2 - \delta$ indicate the number of characters of the truncated W^{ϑ} signal (the first or last, according to the arrangement of its characters $W^{\vartheta}_{X_1}$ or $W^{\vartheta}_{X_2}$). Then the fuzziness of the signals given by (5 – 8) is a set of systems of nonlinear parametric inequalities:

$$\begin{aligned} R_{a_1}(k) \le & \sum_{i=\delta}^{L-K} W_i^{\vartheta} \left(W^{\vartheta}_{i+k}\right)^* + \sum_{i=L-k+1}^{L} W_i^{\vartheta} \left(W^{\vartheta}_{i-L+K}\right)^* + \sum_{i=1}^{L-K} W_i^{\vartheta} \left(W^{\vartheta}_{i+k}\right) + \sum_{i=L-k+1}^{L} W_i^{\vartheta} \left(W^{\vartheta}_{i-L+K}\right)^* + \\ & + \sum_{i=1}^{x_1-L+\vartheta} W_i^{\vartheta} \left(W^{\vartheta}_{i+k}\right)^* \le R'_{a_2}(k);\ k = \overline{0, L + x_2}, \end{aligned} \quad \text{a)}$$

$$R_{a_1}(k) \le \sum_{i=\delta}^{L-K} W_i^{\vartheta} \left(W^{\vartheta}_{i+k}\right)^* + \sum_{i=L-k+1}^{L} W_i^{\vartheta} \left(W^{\vartheta}_{i-L+K}\right)^* + \sum_{i=1}^{L-K} W_i^{\vartheta} \left(W^{\vartheta}_{i+k}\right) + \sum_{i=L-k+1}^{L} W_i^{\vartheta} \left(W^{\vartheta}_{i-L+K}\right)^* \le R'_{a_2}(k); \quad \text{b)}$$

$$R_{a_2}(k) \le \sum_{i=1}^{L-x_1} W_i^{\vartheta} \left(W^{\vartheta}_{i-k}\right)^* \le R'_{a_2}(k), k = \overline{0, L - x_2}, \quad \text{c)}$$

$$R_{a_1}(k) \le \sum_{i=L-\delta}^{L-K} W_i^{\vartheta} \left(W^{\vartheta}_{i+k}\right)^* + \sum_{i=L-k+1}^{L} W_i^{\vartheta} \left(W^{\vartheta}_{i-L+K}\right)^* + \sum_{i=1}^{L-x_2+\vartheta} W_i^{\vartheta} \left(W^{\vartheta}_{i+k}\right)^* \le R'_{a_2}(k);\ k = \overline{0, L - x_2}, \text{d)} \tag{9}$$

where $R'_{a_1}(k)$ and $R'_{a_2}(k)$ – are various implementations of the PFAC that are specified in the synthesis of signals. In the case of “fuzziness” in the duration of sequences of characters in the interval Δx, which is defined as:

$$L - x_2 \le \Delta x \le L + x_1,$$

the mathematical model of fuzziness can be specified by a set of nonlinear inequality systems:

$$\begin{aligned} R^{'}_{b_1}(k) \le \sum_{i=\delta}^{L-K} W_i^q \left(W_{i+k}^{\vartheta_1}\right)^* + \sum_{i=L-k+1}^{L} W_i^q \left(W_{i-L+K}^{\vartheta_2}\right)^* + \\ +\sum_{L=1}^{L-K} W_i^p \times \left(W_{L+k}^{\vartheta_2}\right)^* + \sum_{i=L-K+1}^{L} W_i^p \left(W_{i-L+K}^{\vartheta_3}\right)^* + \\ +\sum_{i=1}^{L-K} W_i^r \times \left(W_{i+K}^{\vartheta_3}\right)^* \le R^{'}_{b_2}(k);\ k=\overline{0, L+x}, \end{aligned} \quad \text{a)}$$

$$\begin{aligned} & R^{'}_{b_1}(k) \le \sum_{i=\delta}^{L-K} W_i^q \left(W_{i+k}^{\vartheta_1}\right)^* + \sum_{i=L-k+1}^{L} W_i^q \left(W_{i-L+K}^{\vartheta_2}\right)^* + \\ & +\sum_{L=1}^{L-K} W_i^p \times \left(W_{L+k}^{\vartheta_2}\right)^* + \sum_{i=L-K+1}^{L} W_i^p \left(W_{i-L+K}^{\vartheta_3}\right)^* \le R^{'}_{b_2}(k); \\ & k=\overline{0, L+x}, \end{aligned} \quad \text{b)}$$

$$R^{'}_{b_2}(k) \le \sum_{i=L-\delta}^{L-K} W_i^q * (W_i^{\vartheta_1} + k)^* \le R_{b_2}(k), k=\overline{0, L-x_{2,}} \quad \text{c)}$$

$$\begin{aligned} & R^{'}_{b_1}(k) \le \sum_{i=L-\delta}^{L-K} W_i^q \left(W_{i+k}^{\vartheta_2}\right)^* + \sum_{i=L-k+1}^{L} W_i^q \left(W_{i-L+K}^{\delta_2}\right)^* + \\ & + \sum_{i=1}^{L-x_2+\delta} W_i^p \left(W_{i+k}^{\vartheta_2}\right)^* \le R^{'}_{b_2}(k); k=\overline{0, L-x_2}, \end{aligned} \quad \text{d) (10)}$$

Thus, the condition that must be fulfilled for the signals W_m^q synthesized system can be formulated as follows: the dictionary $\{W_m^q\}$ satisfies the set of systems of nonlinear parametric inequalities (9) – (10), i.e. the dictionary $\{W_m^q\}$ has in intervals Δx and Δy a blur in duration and cycle frequency.

4. In each of the M dictionaries there are signals $W_{m_1}^{q_1}$ and $W_{m2}^{q_2}$, auto – and mutual convolution of which will satisfy the set of inequalities of the form (1) and (2);

5. The law of signal W_m^q formation has perfect structural secrecy.

6. The mathematical model for the normalized APFAC of signal W_m^q satisfies the system of nonlinear inequalities

$$\begin{gathered} r_{a_1}^q(l) \le \sum_{i=1}^{L-m} W_i^q \left(W_{i+1}^q\right)^* \le r_{a_2}^q(l); \\ l=\overline{1, L},\ \ m=\overline{1, L}, \end{gathered} \quad (11)$$

where $r_{a_1}^q(l)$ and $r_{a_2}^q(l)$ – are the specified implementations of the APFAC.

7.The mathematical model for the aperiodic function of mutual correlation (APFMC) satisfies two systems of nonlinear parametric inequalities

$$\begin{aligned} & r_{b_{1,1}}^{qp}(l) \le \frac{1}{L-m} \sum_{i=0}^{L-m} W_i^q \left(W_{i+1}^q\right)^* \le r_{b_{1,2}}^{qp}(l); \\ & l=\overline{1, L}, m=\overline{1, L}, \\ & r_{b_{2,1}}^{qp}(l) \le \frac{1}{L-m} \sum_{i=0}^{L-m} W_i^p \left(W_{i+1}^q\right)^* \le r_{b_{2,2}}^{pq}(l); \\ & l=\overline{1, L}, m=\overline{1, L}, \end{aligned} \quad (12)$$

8. The objective function

$$Int(E)=\sum_{j=1}^{n}C_jS_j \tag{13}$$

belongs to the interval (A,B), where S_j – is the value of the implementation of the functions of the information transmission system, describing the laws of distribution of values of aperiodic and periodic correlation functions, which determine the structural secrecy of signals, algorithms for the construction of the discrete signals (DSs), etc and C_j – are the penalties corresponding to them.

Let us formulate the problem of the signal system synthesis, taking into account the main difference from the signal system considered earlier: the durations of some (all) vectors (signals) W^q in each of the dictionaries differ from the average duration L_{cp} by $\pm\Delta L$ value. Let such a system is termed the system of non-uniform quasi-orthogonal signals (NUQOS).

Let the source of the DS Q_m give L_j-valued with maximum entropy $H(Q_m=\log p^{L_{cp}})$ sequence such that for some or all signals the condition: $L_i\neq L_j$, $i,j=\overline{1,N}$, $i\neq j$), is fulfilled, then under the problem of synthesis of the NUQOS systems we will understand the problem of constructing dictionaries (subsets) of vectors $\{W_m^q\}$, $q=\overline{1,H}, m=\overline{1,M}$, the totality of which forms the NUQOS system of signals that meet these conditions.

1. The mathematical model for the periodic autocorrelation function of each W_m^q of the DS satisfies the system of nonlinear parametric inequalities of the form (1).

2. The conditions (11 – 12) are true.

3. The mathematical model for mutual convolution or joint function of mutual correlation (JFMC) of the DS $W^q(W^p)$ with joint dictionaries $W^{pp}(W^{qq}), W^{qp}, W^{pq}$, provided that $L_q<L_p$ satisfies the set of systems of nonlinear parametric inequalities:

$$\begin{cases} R_{b_{1,1}}(0)\le W_1^qW_1^p+W_2^qW_2^p+\ldots+W_\delta^qW_\delta^p+\ldots+\quad W_{Lq}^qW_{Lq}^p\le R_{b_{2,1}}(0), a)\\ R_{b_{1,1}}(1)\le W_1^qW_2^p+W_2^qW_3^p+\ldots+W_\delta^qW_{\delta+1}^p+\ldots+\quad W_{Lq}^qW_{Lq+1}^p\le R_{b_{2,1}}(1), б)\\ R_{b_{1,1}}(2)\le W_1^qW_3^p+W_2^qW_4^p+\ldots+W_\delta^qW_{\delta+2}^p+\ldots+\quad W_{Lq}^qW_{Lq+2}^p\le R_{b_{2,1}}(2), в)\\ R_{b_{1,1}}(\xi)\le W_1^qW_{\xi+1}^p+W_2^qW_{\xi+2}^p+\ldots+W_\delta^qW_{\xi+\delta}^p+\ldots+W_{Lq}^qW_{\xi}^p\le R_{b_{2,1}}(\xi), г)\\ R_{b_{1,1}}(Lp)\le W_1^qW_{Lp}^p+W_2^qW_1^p+\ldots+W_\delta^qW_{\xi-1}^p+\ldots+W_{Lq}^qW_{Lp-1}^p\le R_{b_{2,1}}(Lp), д) \end{cases} \tag{14}$$

$$\begin{cases} R_{b_{2,1}}(1)\le W_1^qW_2^q+W_2^qW_3^q+\ldots+W_\delta^qW_{\delta+1}^p+\ldots+\qquad +W_{Lq}^qW_1^p\le R_{b_{2,2}}(1), a)\\ R_{b_{1,2}}(2)\le W_1^qW_3^q+W_2^qW_4^q+\ldots+W_\delta^qW_{\delta+2}^p+\ldots+\qquad +W_{Lq}^qW_2^p\le R_{b_{2,2}}(2), б)\\ R_{b_{1,2}}(3)\le W_1^qW_4^q+W_2^qW_5^p+\ldots+W_\delta^qW_{\delta+3}^q+\ldots+\qquad +W_{Lq}^qW_3^p\le R_{b_{2,2}}(3), в)\\ R_{b_{1,2}}(\xi)\le W_1^qW_{\xi+1}^p+W_2^qW_{\xi+2}^p+\ldots+W_\delta^qW_{\xi+\delta}^p+\ldots+\qquad +W_{Lq}^qW_{\xi}^p\le R_{b_{2,2}}(\xi), г)\\ \ldots\qquad\qquad\qquad\qquad\qquad\qquad\qquad\qquad \ldots\\ R_{b_{1,2}}(Lq-1)\le W_1^qW_{Lp}^p+W_2^qW_1^p+\ldots+W_\delta^qW_{\delta-1}^p+\ldots+ +W_{Lq}^qW_{Lq-1}^p\le R_{b_{2,2}}(Lq-1), д) \end{cases} \tag{15}$$

$$R_{b_{1,3}}(0)\le W_1^qW_1^p+W_2^qW_2^p+\ldots+W_\delta^qW_\delta^p+\ldots+W_{Lq}^qW_{Lq}^p\le R_{b_{2,3}}(0),$$

$$R_{b_{1,3}}(1)\le W_1^qW_2^p+W_2^qW_3^p+\ldots+W_\delta^qW_{\delta+1}^p+\ldots+W_{Lq}^qW_{Lq+1}^p\le R_{b_{2,3}}(1),$$

$$R_{b_{1,3}}(Lp-Lq+1) \le W_1^q W_{Lp-Lq+2}^p + W_2^q W_{Lp-Lq+3}^p + \ldots + W_\delta^q W_{Lp-Lq+\delta-1}^p + \ldots + W_{Lq}^q W_1^q \le R_{b_{2,3}}(Lp-Lq+1),$$
$$R_{b_{1,3}}(Lp) \le W_1^q W_{Lp}^p + W_2^q W_1^p + \ldots + W_p^q W_{\delta-1}^p + \ldots + W_{Lq}^q W_{Lq-1}^q \le R_{b_{2,3}}(Lp),$$
$$R_{b_{1,3}}(Lp) \le W_1^q W_{Lp}^p + W_2^q W_1^p + \ldots + W_p^q W_{\delta-1}^p + \ldots + W_{Lq}^q W_{Lq-1}^q \le R_{b_{2,3}}(Lp),$$

for all kinds of combinations q and p, where $q, p = \overline{1, N}$, $q \ne p$ and where $R_{b_{1,1}}(l), R_{b_{1,2}}(l), R_{b_{1,3}}(l), R_{b_{2,1}}(l), R_{b_{2,2}}(l),$ and $R_{b_{2,3}}(l),$ – are the values of the PFMC and JFMC implementations.

4. Conditions (14) and (15) are satisfied for aperiodic auto – and mutual correlations for all W^q, $q = \overline{1, N}$ and any combination of the DS W^q and W^p, $q, p = \overline{1, N}, q \ne p$, the objective function (14) fits the interval (A, B).

We emphasize that the stated formulation of problems of the NUQOSs synthesis is more general than the formulation of the uniform quasi-orthogonal signals (UQOS) synthesis tasks. Both the formulation of the problem of synthesis of UQOS (UNQOS) signal systems and the proposed approach are new. Therefore, obtaining even partial solutions makes it possible to move further towards solving the problems of synthesis of the discrete signals (DS) with the specified correlation, ensemble and structural properties.

It is shown in [8] that the improvement of the ensemble, structural and correlation properties of the DS in case of insignificant complication of algorithms and devices of their formation, can be achieved based on the use of the so-called compound signals (CS). Thus components will be called signal systems for two reasons. First, the law of formation of complex elements in a composite signal may change, and secondly, complex elements forming the CS have identical (close) auto – and mutually correlating properties, so their mutual combination does not lead to deterioration of correlation properties and, at the same time, makes it possible to improve the ensemble properties, to increase the structural secrecy and to implement the mode of change of correspondence: m bits of the message – 2^m CS, without much complication of mechanisms of formation and processing of such signals.

Let us formulate the problem of synthesis of compound quasi-orthogonal signals (CQOS). Let the DS source form the UQOS or NUQOS systems each with the volume N_j. For such signal systems, conditions (1) – (2), (11) – (12), and (14) – (15) are satisfied. Then, by the task of building the CQOS system, we will understand the procedure of combining compound elements, which are UQOS or NUQOS. In this case, each CQOS contains 2^m CS and the following conditions are fulfilled:

1. The objective function of the form (13) for a given (pre-selected) penalty matrix belongs to the interval (A_C, B_C);

2. Auto – and mutual CQOS convolutions $W_i^{q_c}$ (PFAC, PFMC) in terms of maximum permissible lateral emissions and dispersion σ_R do not depend on the configuration type of the CS formation.

3. The law of all 2^m CS formation changes in each of the constituent elements.

In this formulation, the task of constructing compound quasi-orthogonal signals is reduced to a step-by-step solution of the problems of synthesis of the UQOS or NUQOS signal systems.

The conducted analysis showed that the solution of the problems of synthesis of the UQOSs, NUQOSs and CQOSs signal systems is primarily related to the study of the algebraic structure of systems of nonlinear parametric inequalities (1) – (2), (11) – (12), the development of approaches and theoretical basis for their solution.

Let us first consider the theoretical basis for the synthesis of two UQOSs signals x^p and x^q, without imposing restrictions on the blur of the form (10) and (11), and then make a series of generalizations to the synthesis case of N discrete signals, which also have blurred properties. At the same time, we will require that the UQOS signals have perfect structural properties, that is, such structural secrecy that during the interception and element-wise processing of any number of l symbols of UQOS signals, one cannot unambiguously predict the type of $L-l$ remaining symbols. This can be done if the symbols in the UQOS signals are independent and appear with equal probability.

Taking into account the systems of the form (1) – (2), for the case of synthesis of two discrete signals, the set of systems of nonlinear inequalities has the form:

$$\xi^1 a_1(l) \le \sum_{i=1}^{L} x_i^q \times (x_{i+l}^q)^* \le \xi^1 a_2(l),\ l=\overline{0,L-1} \qquad \text{a)}$$

$$\xi^2 a_1(l) \le \sum_{i=1}^{L-K} x_i^p \times (x_{i+l}^p)^* \le \xi^2 a_2(l),\ l=\overline{0,L-1} \qquad \text{b)}$$

$$\xi^1 b_1(l) \le \sum_{i=0}^{L-K} x_i^q \times (x_{i+l}^p)^* + \sum_{i=L-K+1}^{L-K} x_i^q \times (x_{i-L+K}^p)^* \le \xi^1 b_2(l),\ l=\overline{0,L-1} \qquad \text{c)}$$

$$\xi^2 b_1(l) \le \sum_{i=0}^{L-K} x_i^p \times (x_{i+l}^p)^* + \sum_{i=L-K+1}^{L-1} x_i^p \times (x_{i-L+K}^p)^* \le \xi^2 b_2(l),\ l=\overline{0,L-1} \qquad \text{d)}$$

$$\xi^3 b_1(l) \le \sum_{i=0}^{L-K} x_i^q \times (x_{i+l}^q)^* + \sum_{i=L-K+1}^{L-1} x_i^q \times (x_{i-L+K}^p)^* \le \xi^3 b_2(l),\ l=\overline{0,L-1} \qquad \text{e)} \qquad (16)$$

$$\xi^4 b_1(l) \le \sum_{i=0}^{L-K} x_i^q \times (x_{i+l}^p)^* + \sum_{i=L-K+1}^{L-1} x_i^p \times (x_{i-L+K}^p)^* \le \xi^4 b_2(l),\ l=\overline{0,L-1} \qquad \text{f)}$$

$$\xi^5 b_1(l) \le \sum_{i=0}^{L-K} x_i^p \times (x_{i+l}^p)^* + \sum_{i=L-K+1}^{L-1} x_i^p \times (x_{i-L+K}^q)^* \le \xi^5 b_2(l),\ l=\overline{0,L-1} \qquad \text{g)}$$

$$\xi^6 b_1(l) \le \sum_{i=0}^{L-K} x_i^p \times (x_{i+p}^q)^* + \sum_{i=L-K+1}^{L-1} x_i^p \times (x_{i-L+K}^p)^* \le \xi^6 b_2(l),\ l=\overline{0,L-1}. \qquad \text{h)}$$

The algebraic structure of systems (16) is established by the statements below.

Statement 1. The real or complex sequence of L – symbols X^{δ}, whose values of a commutative auto convolution are limited by functions $\xi a_1^i(l)$ and $\xi a_2^i(l), i=\overline{1,2}$, $l=\overline{1,L-1}$, has $L/2-1$ degrees of freedom in the case if L even and $L-1/2$ degrees of freedom in the case if L is odd. By the number of degrees of freedom we will mean the number of nonlinear inequalities that coincide with each other in the commutativity of convolution operations.

Statement 2. In systems of inequalities (16a) and (16b) for even $L,\ l=1,\ L/2$, and for odd L ,- $l=\overline{1,\dfrac{L+1}{2}}$. That is, this statement answers the question: how many inequalities in (16) coincide. From the statement it follows that the presence of the specified number of degrees of freedom determines the multiplicity of the solutions of system (16a) and (16b).

Statement 3. A mutual commutative convolution X^q with a cyclic sequence X^p extension, symbols that are defined by $\mathrm{mod}\,L$, up to the number of the mutual convolution element W^p, coincides with a cyclic elongated sequence X^q whose symbols are defined by $\mathrm{mod}\,L$.

It follows from Statement 3 that the systems (16c) and (16g) coincide, and the bilinear forms included in them differ only in the order of their location in the systems. Therefore, one of (16c) or (16g) systems is excessive.

Statement 4. Various bilinear forms obtained by calculating the time convolution of a sequence X^q with component sequences $X^q X^p (X^p X^q)$ or sequence X^p with component sequences $X^q X^p (X^p X^q)$ are different.

Statement 4 makes it possible to find out the algebraic structure of systems of nonlinear inequalities (16c), (16f), (16g), (16h). From Statement 4 it follows that in systems (16e) and (16h) all nonlinear inequalities are different and there is no redundancy.

Statement 5. Various bilinear forms that are included in the system of nonlinear inequalities (16e), (16a), for $l=0$, are different.

In the above statement, the task of synthesizing the vocabularies of one class of signals is the most generalized one, since it sets out the task of synthesizing signal systems with given correlation properties, formation laws, structural and ensemble properties. In particular, in our view, it is necessary to study the algebraic structure of systems of non-linear parametric inequalities of the form (16).

It is known that, to date, there is no mathematical apparatus for solving the second-order system of nonlinear parametric inequalities (SNPI). The only mathematical apparatus used to solve this problem is the apparatus of the theory of operations research, in particular, methods of nonlinear, dynamic and scholastic integer programming. Indeed, the set of systems of nonlinear inequalities (16) are functions of the consumption of permissible resources.

Analysis of possible solutions to the problem of synthesis of the UQOS signals shows that they must relate to tasks such as "packing a backpack", the procedure of repetition of the solution for which requires considerable and, in some conditions, endless resources. With this in mind, let us formulate more rigorously the problem of synthesis of the UQOS signal systems with blurred properties using the language of the operations research. To do this, let's go to the objective function E_j with the appropriate values of penalties C_j. Then the problem of synthesis of the UQOS signals in the language of the theory of operations research is the task of ensuring the interval value of the objective function

$$\operatorname{int}(E)=\sum_{j=1}^{n} C_j S_j \tag{17}$$

subject to the limitations (without blurring). Aanalytical expressions for determining constraints of the objective function (17) are as follows:

$$\begin{cases}
\xi_{a_1}^{1}(l)\le \sum_{i=1}^{L} x_i^1 \times (x_{i+l}^1)^* \le \xi_{a_2}^{1}(l),\ l=\overline{0,L'} \\
\xi_{a_1}^{2}(l)\le \sum_{i=1}^{L} x_i^2 \times (x_{i+l}^2)^* \le \xi_{a_2}^{2}(l),\ L'=\dfrac{L-1}{2},\ if\ L\ is\ odd \\
\qquad\qquad \dots \\
\xi_{a_1}^{j}(l)\le \sum_{i=1}^{L} x_i^j \times (x_{i+l}^j)^* \le \xi_{a_2}^{j}(l),\ L'=\dfrac{L}{2},\ if\ L\ is\ even \\
\xi_{a_1}^{N}(l)\le \sum_{i=1}^{L} x_i^N \times (x_{i+l}^N)^* \le \xi_{a_2}^{N}(l).
\end{cases} \tag{18}$$

$$\begin{cases} \xi_{b_1}^{1}(l) \le \sum\limits_{i=1}^{L} x_i^1 \times (x_{i+l}^2)^* + \sum\limits_{i=L-k+1}^{L} x_i^1 \times (x_{i-L+k}^2)^* \le \xi_{b_2}^{1}(l); \\ \xi_{b_1}^{1}(l) \le \sum\limits_{i=1}^{L-k} x_i^1 \times (x_{i+l}^3)^* + \sum\limits_{i=L-k+1}^{L} x_i^1 \times (x_{i-L+k}^3)^* \le \xi_{b_2}^{2}(l); \\ \qquad\qquad \dots \\ \xi_{b_1}^{1}(l) \le \sum\limits_{i=1}^{L-k} x_i^1 \times (x_{i+l}^j)^* + \sum\limits_{i=L-k+1}^{L} x_i^1 \times (x_{i-L+k}^j)^* \le \xi_{b_2}^{j}(l); \\ \qquad\qquad \dots \\ \xi_{b_1}^{1}(l) \le \sum\limits_{i=1}^{L-k} x_i^1 \times (x_{i+l}^N)^* + \sum\limits_{i=L-k+1}^{L} x_i^1 \times (x_{i-L+k}^N)^* \le \xi_{b_2}^{N}(l). \end{cases} \quad l = \overline{0, L-1}. \tag{19}$$

$$\begin{cases} \xi_{b_1}^{2}(l) \le \sum\limits_{i=1}^{L-k} x_i^2 \times (x_{i+l}^3)^* + \sum\limits_{i=L-k+1}^{L} x_i^2 \times (x_{i-L+k}^3)^* \le \xi_{b_2}^{2}(l); \\ \xi_{b_1}^{3}(l) \le \sum\limits_{i=1}^{L-k} x_i^2 \times (x_{i+l}^4)^* + \sum\limits_{i=L-k+1}^{L} x_i^2 \times (x_{i-L+k}^4)^* \le \xi_{b_2}^{3}(l); \\ \qquad\qquad \dots \\ \xi_{b_1}^{j+1}(l) \le \sum\limits_{i=1}^{L-k} x_i^2 \times (x_{i+l}^{j+1})^* + \sum\limits_{i=L-k+1}^{L} x_i^2 \times (x_{i-L+k}^{j+1})^* \le \xi_{b_2}^{j+1}(l); \\ \qquad\qquad \dots \\ \xi_{b_1}^{N}(l) \le \sum\limits_{i=1}^{L-k} x_i^2 \times (x_{i+l}^N)^* + \sum\limits_{i=L-k+1}^{L} x_i^2 \times (x_{i-L+k}^N)^* \le \xi_{b_2}^{N}(l). \end{cases} \quad l = \overline{0, L-1}. \tag{20}$$

$$\begin{cases} \xi_{b_1}^{\upsilon}(l) \le \sum\limits_{i=1}^{L-k} x_i^{\upsilon} \times (x_{i+l}^{\upsilon+1})^* + \sum\limits_{i=L-k+1}^{L} x_i^{\upsilon} \times (x_{i-L+k}^{\upsilon+1})^* \le \xi_{b_2}^{\upsilon}(l); \\ \xi_{b_1}^{\upsilon+1}(l) \le \sum\limits_{i=1}^{L-k} x_i^{\upsilon} \times (x_{i+l}^{\upsilon+2})^* + \sum\limits_{i=L-k+1}^{L} x_i^{\upsilon} \times (x_{i-L+k}^{\upsilon+2})^* \le \xi_{b_2}^{\upsilon+1}(l); \\ \qquad\qquad \dots \\ \xi_{b_1}^{m}(l) \le \sum\limits_{i=1}^{L-k} x_i^{\upsilon} \times (x_{i+l}^{\upsilon+m})^* + \sum\limits_{i=L-k+1}^{L} x_i^{\upsilon} \times (x_{i-L+k}^{\upsilon+m})^* \le \xi_{b_2}^{m}(l); \\ \qquad\qquad \dots \\ \xi_{b_1}^{N}(l) \le \sum\limits_{i=1}^{L-k} x_i^{\upsilon} \times (x_{i+l}^N)^* + \sum\limits_{i=L-k+1}^{L} x_i^{\upsilon} \times (x_{i-L+k}^N)^* \le \xi_{b_2}^{N}(l). \end{cases} \quad l = \overline{0, L-1}. \tag{21}$$

$$\begin{cases} \xi_{b_1}^{1}(l) \le \sum\limits_{i=1}^{L-k} x_i^{N-2} \times (x_{i+l}^{N-1})^* + \sum\limits_{i=L-k+1}^{L} x_i^{N-2} \times (x_{i-L+k}^{N-1})^* \le \xi_{b_2}^{1}(l); \\ \xi_{b_1}^{2}(l) \le \sum\limits_{i=1}^{L-k} x_i^{N-2} \times (x_{i+l}^{N})^* + \sum\limits_{i=L-k+1}^{L} x_i^{N-2} \times (x_{i-L+k}^{N})^* \le \xi_{b_2}^{2}(l); \\ \xi_{b_1}^{1}(l) \le \sum\limits_{i=1}^{L-k} x_i^{N-1} \times (x_{i+l}^{N})^* + \sum\limits_{i=L-k+1}^{L} x_i^{N-1} \times (x_{i-L+k}^{N})^* \le \xi_{b_2}^{1}(l). \end{cases} \quad l = \overline{1, L-1}. \tag{22}$$

$$\begin{cases} \xi_{b_1}^1(l) \le \sum_{i=1}^{L} x_i^1 \times (x_{i+l}^1)^* + \sum_{i=L-k+1}^{L} x_i^1 \times (x_{i-L+k}^1)^* \le \xi_{b_2}^1(l); \\ \xi_{b_1}^2(l) \le \sum_{i=1}^{L-k} x_i^1 \times (x_{i+l}^2)^* + \sum_{i=L-k+1}^{L} x_i^1 \times (x_{i-L+k}^2)^* \le \xi_{b_2}^2(l); \\ \ldots \\ \xi_{b_1}^3(l) \le \sum_{i=1}^{L-k} x_i^2 \times (x_{i+l}^2)^* + \sum_{i=L-k+1}^{L} x_i^2 \times (x_{i-L+k}^2)^* \le \xi_{b_2}^3(l); \\ \ldots \\ \xi_{b_1}^4(l) \le \sum_{i=1}^{L-k} x_i^2 \times (x_{i+l}^1)^* + \sum_{i=L-k+1}^{L} x_i^2 \times (x_{i-L+k}^1)^* \le \xi_{b_2}^4(l). \end{cases} \tag{23}$$

$$\begin{cases} \xi_{b_1}^1(l) \le \sum_{i=1}^{L} x_i^1 \times (x_{i+l}^1)^* + \sum_{i=L-k+1}^{L} x_i^1 \times (x_{i-L+k}^j)^* \le \xi_{b_2}^1(l); \\ \xi_{b_1}^2(l) \le \sum_{i=1}^{L-k} x_i^1 \times (x_{i+l}^j)^* + \sum_{i=L-k+1}^{L} x_i^1 \times (x_{i-L+k}^1)^* \le \xi_{b_2}^2(l); \\ \ldots \\ \xi_{b_1}^3(l) \le \sum_{i=1}^{L-k} x_i^j \times (x_{i+l}^j)^* + \sum_{i=L-k+1}^{L} x_i^j \times (x_{i-L+k}^1)^* \le \xi_{b_2}^3(l); \\ \ldots \\ \xi_{b_1}^4(l) \le \sum_{i=1}^{L-k} x_i^j \times (x_{i+l}^1)^* + \sum_{i=L-k+1}^{L} x_i^j \times (x_{i-L+k}^j)^* \le \xi_{b_2}^4(l). \end{cases} \tag{24}$$

$$\begin{cases} \xi_{b_1}^1(l) \le \sum_{i=1}^{L} x_i^1 \times (x_{i+l}^1)^* + \sum_{i=L-k+1}^{L} x_i^1 \times (x_{i-L+k}^N)^* \le \xi_{b_2}^1(l); \\ \xi_{b_1}^2(l) \le \sum_{i=1}^{L-k} x_i^1 \times (x_{i+l}^N)^* + \sum_{i=L-k+1}^{L} x_i^1 \times (x_{i-L+k}^1)^* \le \xi_{b_2}^2(l); \\ \ldots \\ \xi_{b_1}^3(l) \le \sum_{i=1}^{L-k} x_i^N \times (x_{i+l}^N)^* + \sum_{i=L-k+1}^{L} x_i^N \times (x_{i-L+k}^1)^* \le \xi_{b_2}^3(l); \\ \ldots \\ \xi_{b_1}^4(l) \le \sum_{i=1}^{L-k} x_i^N \times (x_{i+l}^1)^* + \sum_{i=L-k+1}^{L} x_i^N \times (x_{i-L+k}^N)^* \le \xi_{b_2}^4(l). \end{cases} \tag{25}$$

$$A_{2,j},\ j = \overline{j, N}; l = \overline{1, L-1}; \tag{26}$$

$$A_{3,j},\ j = \overline{4, N}; l = \overline{1, L-1}; \tag{27}$$

$$A_{\upsilon,j},\ j = \overline{\upsilon+1, N}; l = \overline{1, L-1}; \tag{28}$$

$$\begin{cases} \xi_{b_1}^1(l) \le \sum_{i=1}^{L} x_i^{N-1} \times (x_{i+l}^{N-1})^* + \sum_{i=L-k+1}^{L} x_i^{N-1} \times (x_{i-L+k}^{N})^* \le \xi_{b_2}^1(l); \\ \xi_{b_1}^2(l) \le \sum_{i=1}^{L-k} x_i^{N-1} \times (x_{i+l}^{N})^* + \sum_{i=L-k+1}^{L} x_i^{N-1} \times (x_{i-L+k}^{N-1})^* \le \xi_{b_2}^2(l); \\ \qquad \dots \\ \xi_{b_1}^3(l) \le \sum_{i=1}^{L-k} x_i^{N} \times (x_{i+l}^{N-1})^* + \sum_{i=L-k+1}^{L} x_i^{N} \times (x_{i-L+k}^{N-1})^* \le \xi_{b_2}^3(l); \\ \qquad \dots \\ \xi_{b_1}^4(l) \le \sum_{i=1}^{L-k} x_i^{N} \times (x_{i+l}^{N-1})^* + \sum_{i=L-k+1}^{L} x_i^{N} \times (x_{i-L+k}^{N})^* \le \xi_{b_2}^4(l). \end{cases} \tag{29}$$

Ensuring the interval value of the objective function (17) and the restrictions associated with x_1, x_2, y_1 and y_2 fuzziness:

$$\xi_{b_1}^1(k) \le \sum_{i=\delta}^{L-k} x_i^q \times (x_{i+k}^{\nu_1})^* + \sum_{i=L-k+1}^{L} x_i^q \times (x_{i-L+k}^{\nu_2})^* + \sum_{i=1}^{L-k} x_i^p \times (x_{i+k}^{\nu_2}) + \\ + \sum_{i=L-k+1}^{L} x_i^p \times (x_{i-L+k}^{\nu_3})^* + \sum_{i=L-k+1}^{L-k} x_i^r \times (x_{i-L+k}^{\nu_3})^* \le \xi_{b_2}^1(k), k = \overline{1, L + x_1}; \qquad \text{a) (30)}$$

$$\xi_{b_1}^2(k) \le \sum_{i=\delta}^{L-k} x_i^q \times (x_{i+k}^{\nu_1})^* + \sum_{i=L-k+1}^{L} x_i^q \times (x_{i-L+k}^{\nu_2})^* + \sum_{i=1}^{L-k} x_i^p \times (x_{i+k}^{\nu_2}) + \\ + \sum_{i=L-k+1}^{L} x_i^p \times (x_{i-L+k}^{\nu_3})^* \le \xi_{b_2}^2(k), k = \overline{0, L + x_2}; \qquad \text{b)}$$

$$\xi_{b_1}^3(k) \le \sum_{i=L-\delta}^{L-k} x_i^q \times (x_{i+k}^{\nu_1}) \le \xi_{b_2}^3(k), k = \overline{0, L - x_2}; \qquad \text{c)}$$

$$\xi_{b_1}^4(k) \le \sum_{i=L-\delta}^{L-k} x_i^q \times (x_{i+k}^{\nu_1}) + \sum_{i=L-k+1}^{L} x_i^q \times (x_{i-L+k}^{\nu_2})^* + \sum_{i=1}^{L-x_2-\delta} x_i^p \times (x_{i+k}^{\nu_2}) \le \xi_{b_2}^2(k), k = \overline{0, L + x_2}; \qquad \text{d)}$$

Moreover (30) is a collection of systems whose number is determined by all possible combinations of indices in the joint words $x_{x_1}^{qp}$, $x_{x_2}^{qp}$, $x_{x_2}^{q}$, $x_{x_2}^{p}$ and $x_{x_1}^{\upsilon_1\upsilon_2\upsilon_3}$, $x_{x_1}^{\upsilon_1\upsilon_2\upsilon_3}$, $x_{x_2}^{\upsilon_1}$ and $x_{x2}^{\upsilon_1\upsilon_2}$, that is, for

$$q, p, r, \upsilon_1, \upsilon_2, \upsilon_3 = \overline{1, N}. \tag{31}$$

Thus, the solution of the problem of synthesis of the UQOS systems with fuzziness properties can be reduced to solving the set of the SNPI of the form (18) – (31).

The statement formulated below defines sufficient conditions for the existence of P-th UQOSs with fuzziness properties, which provides interval (required) values of the objective function $\operatorname{int}(E)$.

Statement 6. Suppose that $\{x^j\}$, $j = \overline{1, N}$ is a dictionary (set) of P signals in a temporal or generalized theoretical representation, then, in order for the dictionary $\{x^j\}$ to belong to the UQOS system with fuzziness of order x_1, x_2, y_1, y_2, it is sufficient that each of x_i^j signals satisfies (is a solution)

$$C_1 = \frac{N}{2}(5N - 3) \tag{32}$$

the set of the SNPI of the form (18), and the joimt words of the form (19) – (22), respectively

$$C_2 = [(N(N-1)(N-2))]^2 (L - x_1)L, \tag{33}$$

$$C_3 = [(N(N-1))]^2 L(L - x_1), \tag{34}$$

$$C_4 = Nx_2 (L - x_2), \tag{35}$$

$$C_5 = [(N(N-1))]^2 x_2 (L - x_2). \tag{36}$$

the set of the SNPI of the form (30).

Statement 7. The number of the SNPI of the form (30), which provides sufficient conditions x_1 and x_2 of fuzziness of the dictionary $\{x^j\}$, is determined by the expression

$$C = [(N(N-1))]^2 L(L - x_2)((N-2)^2 + 1) + x_2 (L - x_2) N(N-1)^2 + 1. \tag{37}$$

Expression (36) makes it possible to estimate the total number of the SNPI that need to be analyzed both in the synthesis and in the attempts to disclose the signals forms and order x_1 and x_1 of the blur. It should be emphasized that the number of unknowns in (29) is less than the number of nonlinear inequalities.

Let us formulate a number of provisions, the conclusions of which will be used in the development of algorithms for the synthesis of the NUQOSs, UQOSs, and CQOS signal systems.

Statement 8. Let the maximum (minimum) values of the realizations of functions ξ'_{a_1} and ξ'_{a_2} (18) be such that the value Δ is defined as

$$\Delta = \left|\xi'_{a_1}(l) - \xi_{a_1}(l)\right|, \text{ or } \left|\xi'_{a_2}(l) - \xi_{a_2}(l)\right| \; \Delta \neq 0,1,2,3\ldots P-1, P, \tag{38}$$

is more than P, and w^j signal is defined above the field $GF(P)$ or above the ring of numbers modulo P, then many values of the cyclic convolution $\xi_{a_2}(l)$ may belong to the interval

$$(\min \xi_{a_1}(l) - \max \xi_{a_2}(l)). \tag{39}$$

At least when rejecting Q of the latter and adding Q of the first w^j signal characters where $Q = \frac{\Delta}{P}$, if $\frac{\Delta}{P}$ and $Q = \frac{\Delta + t}{P}$, if $\frac{\Delta}{P}$.

Statement 9. If $N_j^v \in GF(P)$, then $Q = \frac{\Delta}{2}$, if Δ - is even, and $Q = \frac{\Delta + t}{P}$, if Δ - is odd.

Statement 10. Suppose that the subspace $\{x^j\}$ is a set of signals of L duration over $GF(2)$, then the necessary conditions n-equality on cyclic auto-convolution with k levels, each of x^j is a condition of not more than Δ-imbalance (unbalance) in the number of characters $1 - k^1$ and $(-1) - k^{-1}$, in this case

$$\Delta = \left|k^1 - k^{-1}\right| \leq \sqrt{L + \sum_{i=1}^{n} n_i R_i} \,. \tag{40}$$

To determine the existence of optimal steps and their values, we formulate the following statement.

Statement 11. Suppose that x^j is a vector whose symbols in the temporal representation take values over $GF(P)$, and the imbalance in the number of symbols defined in terms of the value Q

as $\Delta i = |k_i - Q|$ is corresponding $\Delta_1, \Delta_2, \ldots, \Delta_Q$, then vector x^j satisfying the necessary conditions can be formed only by rejecting and adding, at least,

$$\upsilon = \frac{1}{q}\sum_{i=1}^{Q} \Delta i \tag{41}$$

symbols.

Thus, the solution of the problem of synthesis of the UQOSs signals with fuzziness properties can be reduced to solving the set of the SNPI of (18) – (31) form.

Conclusions

The efforts of the researchers are aimed at finding ensembles of complex signals whose characteristics with increasing duration approach the boundary of "dense packing" [2], that is, an ensemble, whose representatives have zero constant component, an ideal periodic autocorrelation function (PFAC), periodic mutual correlation function (PFMC), and have the largest possible volume. A widespread criterion for such an approximation is the minimum criterion, which focuses on ensemble synthesis by minimizing maximum values for the set of all undesirable correlations. Ensembles that have correlation peak values that reach the boundaries defined by the lower boundaries of Welch and Sidelnikov [6] are optimal and are sometimes called minimal ones. The problems of synthesis of a number of classes of signals with given correlation, ensemble and structural properties, including such systems of signals, which have "blurring" properties on correlation properties, are formulated in the general form. The said property means that increasing or decreasing the length of the discrete signal does not change the correlation properties of the discrete sequence on the basis of which the signal that is synthesized is formed. Theoretical bases of synthesis of quasioptimal uniform, nonuniform, complex signal systems with given auto -, mutually correlation, ensemble and structural properties are given. The use of many of these signal systems in modern information and communication systems will make it possible to improve the performance of such systems, first of all, noise protection, secrecy of operation, information security, noise immunity of receiving signals.

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