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Research on the Properties of Complex Signal Ensembles Obtained by Frequency Segments Permutation

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Abstract. *For cognitive telecommunication systems, the problem of reducing the level of multiple access interference (intrasystem interference), which occur during the simultaneous operation of different subscribers of one system in a common frequency band, is relevant. To this end, the formation methods of large ensembles of complex signals obtained by permutation of the frequency segments of the output sequences with a low level of interaction in the time domain, have been developed [1]. The cross-correlation level of the received signals shows the degree of signal interaction in the time domain and, thus, makes it possible to assess the level of multiple access problems in the cognitive telecommunication system. An important task is to determine the maximum emission level of the cross-correlation functions of the resulting complex signal ensembles depending on the filtering bands and, accordingly, their impact on the volume of the ensembles. Also, the dependence of multiple access interference level on the number and duration of pulses in the output sequences, which are used to form complex signal ensembles based on the frequency segments permutations, was interesting. The solution of these problems will make it possible to simplify the procedure for determining the width of the filter bands for the formation of complex signal ensembles by permutation of frequency segments.*

Keywords: *cognitive telecommunication systems, multiple access interference, cross-correlation function, complex signal, maximum emissions of side lobes of the cross-correlation function.*

V. Introduction and Problem Statement

Additional demand for bandwidth in existing radio communication systems in limited frequency-time resource conditions leads to the complexity of spectrum allocation procedures. To solve such problems, it is necessary to apply new methods that will ensure the efficient use of free frequency bands, including the sharing of frequency and time resources by secondary users of the cognitive radio network. The use of solutions based on dynamic access will help increase the efficiency of frequency and time resources using. In this case, for the implementation of such solutions it is necessary to solve a number of problems, the main of which is the implementation of new signal-code structures with a low level of multiple access interference. In cognitive radio systems based on multiple access, subscriber signals overlap in frequency and are shifted relative to each other in time randomly, resulting in multiple access interference (intra-system interference). Such interference have a significant impact on the quality of communication and the number of subscribers served simultaneously, and are embedded in the very principles of building a cognitive telecommunications system.

The results obtained in [2] show that the use of frequency elements permutations allows to obtain such signals, the level of maximum emissions of the side lobes of the CCF of time elements which satisfies the condition of minimum similarity. To further increase the volume of complex signal ensembles and, as a consequence, the optimal use of limited radio frequency resource, a method of permutation of frequency signal elements by complete search was proposed [3].

The essence of the method of permutations of the frequency signal elements is to compare the values of the maximum emissions of the side lobes of the CCF signals formed by frequency filtering of different output sequences in different frequency bands. The value of the comparison coefficient of the maximum emissions of the side lobes of the CCF signals is determined by the integral in the range from F_l to F_h in the product of the *i*-th and *j*-th signals [3]:

$$R_{ijmax}(\Delta f) = \int_{F_l}^{F_h} s_i(\Delta f) \cdot s_j(\Delta f - \Delta)\, d\Delta f \quad , \qquad (1)$$

where Δf – the filtration band;
Δ – the integration step.

Also, the obtained values must meet the condition of minimum similarity [2]:

$$R_{ijmax} \le \frac{2 \ldots 5}{\sqrt{B}} \quad , \qquad (2)$$

where B – the signal base.

The permutation of signals occurs by complete search. As a result, we obtain all possible permutation combinations: R12, R13, R14, R23, R24 and R34. This method of permutation can be described by expression:

$$\sum R_{ij} = \frac{R_{ij}^2 - R_{ij}}{2}, \qquad (3)$$

Of considerable interest is the research of the levels of maximum emissions of the CCF of the generated signals dependence on the bandwidth of the filtration, the number and duration of pulses in the output sequences. The results of the research will simplify the procedure for forming complex signal ensembles by choosing the optimal width of the filtering band for given conditions.

VI. Problem solution and Results

In accordance with the algorithm for implementing the method of forming complex signal ensembles based on sequences with improved cross-correlation properties obtained by bandpass filtering with permutations, shown in Figure 1, a complex signal ensemble was formed, consisting of 100 output sequences with the number of pulses ni in the range from 17 to 512. The sequence duration is T ≈ 0.8 ms, the pulse duration is τi = 1...10 ns, with a step 1 ns.

The total spectrum width of the source sequences is defined as:

$$\Delta F = 1/\tau i., \quad (4)$$

Accordingly, the filter band was changed in the range from 20 kHz to 2000 MHz, which is 0.1-1% of the total width of the spectrum of the output sequences, depending on the pulse duration.

The obtained results show that increasing the filter band leads to a decrease in the maximum emissions of the cross-correlation functions. In this case, increasing the duration obviously leads to an increase in these characteristics.

It is possible to determine acceptable values of pulse duration and bandwidth by fixing the values of the maximum emissions of cross-correlation functions in accordance with (2), and thus determining the limit parameters for the formation of signal ensembles.

Estimation of statistical characteristics of complex signal ensembles on the basis of sequences with the improved cross-correlation properties received by bandpass filtering with permutations can be carried out on the basis of random sizes statistical characteristics calculation technique which is resulted in [5-8] and includes calculation of the mathematical expectation of the maximum emissions of the side lobes of the CCF signals m_{Rmax} when changing the values of the filter bands in the range from 0.01% to 1% of the total width of the spectrum of the source sequences at a constant value of duty cycle and duration [4, 7, 8]:

$$m_{R_{max}} = \frac{\sum_{k=1}^{N} max\,|R_k(\Delta F)|}{N} \quad , \quad (5)$$

where N – the number of pairs of signals that interact with each other;

k – the serial number of CCF;

$max|R_k(\Delta F)|$ – the module of the maximum emissions of the side lobes of the CCF signals value depending on the width of the filter bands during the formation of signals (ΔF = 0.1, 0.2,…, 1% of the total width of the spectrum of the output sequences).

VII. Conclusions

As a result of research, it is possible to make a conclusion that in the general case the value of the mathematical expectation of the maximum emissions of side lobes of CCF does not exceed $3...5/\sqrt{B}$ at a filtration band to 0.2...0.5 % of the total frequency band of the original sequences. Therefore, under the given restrictions, the optimal value of the filter band will be a value equal to 0.4% of the total frequency band of the output sequences.

Thus, the application of bandpass filtering in different regions of the spectrum to sequences with improved cross-correlation properties with subsequent transfer of signals to the common band and the application of permutations to the obtained frequency elements can increase the volume of ensembles of complex signals by allowable reduction of cross-correlation characteristics.

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