РАДІОЕЛЕКТРОНІКА ТА ТЕЛЕКОМУНІКАЦІЇ

RADIO ELECTRONICS AND TELECOMMUNICATIONS

РАДИОЭЛЕКТРОНИКА И ТЕЛЕКОММУНИКАЦИИ

UDC 621.391

THE FORMATION METHOD OF COMPLEX SIGNALS ENSEMBLES BY FREQUENCY FILTRATION OF PSEUDO-RANDOM SEQUENCES WITH LOW INTERACTION IN THE TIME DOMAIN

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ABSTRACT

Context. The problem of forming complex signal ensembles on the basis of frequency band filtering and research of their properties is considered. The object of research is the process of synthesis of signal ensembles based on frequency filtering of pseudo-random sequences of short video pulses with low interaction in the time domain.

Objective. It is to form complex signal ensembles with satisfactory values of intercorrelation properties, which are close to the signals with minimal energy interaction.

Method. The results of the application of forming complex signal ensembles method by frequency filtering of pseudo-random sequences with low interaction in the time domain are presented. As a result of the spectral band selection of the studied pseudo-random short video pulse sequences due to the use of bandpass filters based on the Chebyshev filter of the first kind, new samples of sequences with spectrum restriction are obtained. By applying intercorrelation analysis to the obtained sequence samples, the values of the maximum emissions of the side lobes of the cross-correlation functions (CCF) for all possible signal pairs are estimated. If the values of the maximum emissions of the side lobes of the CCF signals exceed the limit values, the sequence of the analyzed pair with a smaller value of the number of pulses is removed from the ensemble. In case of satisfactory value – the received signals are accepted for the signal ensemble formation with the minimum power interaction. Thus, a new set of values of the maximum emissions of the side lobes of the CCF is formed. This approach increases the number of signals in ensembles with satisfactory values of statistical characteristics with limited signal spectrum width, and the correlation properties of such sequences approach the signals with minimal energy interaction, which reduces the level of multiple access interference. As a result, complex signal ensembles obtained by frequency filtering should be used in cognitive radio systems with code division multiplexing.

Results. Based on the software implementation of the method of forming complex signal ensembles by frequency filtering of pseudo-random sequences with low interaction in the time domain, signals with satisfactory values of statistical characteristics with limited signal spectrum width with intercorrelation properties close to signals with minimal energy interaction and higher ensemble volume were selected.

Conclusions. The application of frequency filtering to pseudo-random sequences of short video pulses with a low level of cross-correlation allows to obtain complex signal ensembles, which will be similar in correlation properties to sequences with minimal energy interaction. It will reduce the level of multiple access interference. The analysis revealed that the use of frequency filtering of sequences will slightly worsen the mutual correlation properties of signals, possibly due to suboptimal synthesis of values of maximum emission levels of side lobes of CCF signals, but, nevertheless, it is possible to use such signals in modern cognitive systems radio access multiple access with code division multiplexing.

KEYWORDS: complex signal, cross-correlation function, multiple access interference, videopulse, signal base, signal spectrum width, signal duration, duty cycle, impulse duration, minimal energy interaction.

DOI 10.15588/1607-3274-2020-4-1

ABBREVIATIONS

FR is a frequency response;

CCF is a cross-correlation function.

NOMENCLATURE

α is a coefficient;

B is a signal base;

E_i is energy of i-th signal;

ΔF is a signal spectrum width;

Δf is a filtering band width;

$\sigma_{R\max}$ is a standard deviation of the maximum emissions of the side lobes CCF;

$m_{R\max}$ is a mathematical expectation of maximum emissions of side lobes CCF;

N is a number of signal pairs interacting with each other;

n_i is a number of pulses in i-th sequence;

n_j is a number of pulses in j-th sequence;

Q_i is a duty cycle of i-th pulse sequence;

Q_j is a duty cycle of j-th pulse sequence;

R_k is a CCF of the sequence pair with serial number k;

$rect(\cdot)$ is a pulse of single amplitude and fixed impulse duration;

$S_i(t)$ is i-th pulse sequence;

T is a signal duration;

T_i is a pulse follow-up period in i-th sequence;

T_j is a pulse follow-up period in j-th sequence;

τ_i is a impulse duration of i-th sequence;

τ_j is a impulse duration of j-th sequence;

U_i is a value of the amplitude in the i-th sequence.

INTRODUCTION

Current trends in the development of multiple access radio systems and the impact of multiple access interference on them, especially in cognitive radio networks, require a further increase in the number of subscribers, provided that the specified quality of service in wireless networks. The study of the properties of complex signal ensembles based on pseudo-random sequences with minimal energy interaction allows to determine the statistical characteristics of complex signal ensembles obtained by applying the method of forming complex signal ensembles through frequency filtering of pseudo-random sequences with low interaction in the time domain due to which it is possible to significantly increase the volume of the signal ensemble by reducing the values of the maximum emissions of the side lobes of the CCF of such signals, while the level of multiple access interference remains within acceptable values. The received signals should be used in cognitive radio systems based on code division multiplexing, and increasing the number of signals in the ensemble allows you to increase the number of subscribers in such systems, while maintaining a high level of service quality.

The object of study is the process of synthesis of complex signal ensembles formed on the basis of frequency filtering of pseudo-random sequences of short video pulses. Given the limited frequency and time resources in modern cognitive radio systems, the urgent problem is to increase the volume of complex signal ensembles, in order to improve the quality of service and performance in such systems.

DOI 10.15588/1607-3274-2020-4-1

The subject of study is the method of forming complex signal ensembles by frequency filtering of pseudo-random sequences with low interaction in the time domain based on samples of pseudo-random sequences with minimal energy interaction. There are known methods of forming ensembles for phase-manipulated, amplitude-manipulated and other signals based on linear and nonlinear sequences [1, 2, 3, 4, 5], but the correlation properties of complex signal ensembles obtained by frequency filtering of sequences with low interaction in the time domain were not performed.

The purpose of the work is to develop a method for the synthesis of complex signal ensembles with limited spectrum width, the correlation properties of which are close to the signals with minimal energy interaction.

1 PROBLEM STATEMENT

Suppose a given sample of pseudo-random sequences with minimal interaction in time domain, with the parameters: $\tau_i = \tau_j$, $T_i \approx T_j$, $Q_i \approx Q_j >> 1$, $n_i \neq n_j$.

The task of forming complex signals ensembles by frequency filtering of pseudo-random sequences with low interaction in time domain is to choose the optimal value of Δf based on R_k analysis taking into account the limitations of $m_{R\max}$ and $\sigma_{R\max}$ to match the signals with minimal energy interaction, which in turn increase the number of received signals used to form ensembles.

2 REVIEW OF THE LITERATURE

Methods of forming complex signals are widely considered in the literature [3, 4, 7]. The value of the crest factor of such signals is close to 1 even taking into account the passage of the filters of the transmission paths [11, 12], and the maximum value of the cross-correlation coefficient of the signal ensemble is of such order that does not significantly reduce noise immunity and does not provide protection against multiple access interference under conditions of a significant dynamic range of received signals. When using recurrent sequences, it is quite difficult to obtain large complex signal ensembles with satisfactory correlation properties [1, 3, 6, 7, 10].

Statistical characteristics of signals obtained by frequency filtering of pseudo-random sequences of short video pulses with low energy interaction are considered insufficiently [2] and therefore require more detailed study to increase the number of complex signals in the ensemble.

3 MATERIALS AND METHODS

To evaluate the complex signals properties, pseudo-random sequences of short video pulses with a low level of cross-correlation were chosen, which are described by the expression [1, 2]:

$$s_i(t) = \sum_{k=1}^{n_i} U_{k_i} rect\left[t - (k \cdot Q_i - 1) \cdot \tau_i\right], \qquad (1)$$

the duty cycle of pulse sequence is defined as:

$$Q_i = \frac{T_i}{\tau_i}, \qquad (2)$$

to pulses of unit amplitude and fixed pulse duration the following restrictions are put forward [2]:

$$rect\left[t - (k \cdot Q_i - 1) \cdot \tau_i\right] = \begin{cases} 1, if\ (k \cdot Q_i - 1) \cdot \tau_i \le t \le k \cdot Q_i \cdot \tau_i; \\ 0, if\ (k \cdot Q_i - 1) \cdot \tau_i > t > k \cdot Q_i \cdot \tau_i. \end{cases} \qquad (3)$$

To increase the volume of ensembles using the method of forming complex signal ensembles through frequency filtering of pseudo-random sequences with low interaction in the time domain, a sample of pseudo-random sequences with minimal energy interaction was chosen.

In the analysis process, the frequency range of such sequences is divided into equal bands. The selection of spectrum parts from the common frequency band of complex signals is done using Chebyshev filter of the first kind. The use of such a filter is appropriate where it is necessary to provide with a small-order filter the necessary amplitude-frequency characteristics, in particular, proper suppression of frequencies from the suppression band.

As a result of the application of such filtering, pseudo-random sequences with minimal energy interaction in the frequency domain were subdivided into sequences characterized by constraints with equal intervals of frequency bands. Analysis of such sequences shows that the signals obtained by selection the frequency bands will differ in shape from each other and, moreover, will meet the condition of minimum similarity of signals (4).

The use of complex signals based on pseudo-random sequences with minimal energy interaction in cognitive systems with multiple access based on code division multiplexing provides a minimum level of multiple access interference, which can be estimated by determining the maximum allowable emissions of side lobes of CCF [3].

$$R_{\max} = \frac{\alpha}{\sqrt{B}}, \qquad (4)$$

the signal base is calculated as [3]:

$$B = \Delta F \cdot T. \qquad (5)$$

The calculation of the emissions values of the side lobes of the CCF, obtained as a result of permutations of the sequences, takes place in accordance with [3]:

$$R_{ij}(\tau) = \int_{-T}^{T} s_i(t) s_j(t - \tau) dt. \qquad (6)$$

Due to the different number of pulses in the sequences, and because the energies of the continuous signals will be different to estimate the CCF by expression (6) it is necessary to normalize the signal energy values [1]:

$$s_{i\,norm}(t) = \frac{s_i(t)}{\sqrt{E_i}}. \qquad (7)$$

The calculation of the CCF is performed for all possible pairs from the complex signal ensemble, checking the CCF of each pair of signals to meet the condition of ensuring a given maximum emission level of side lobes of mutual correlation. If the maximum emission values of the side lobes of the CCF signals exceed the limit values, the sequence of the analyzed pair with a smaller value of the pulses number is removed from the ensemble. In case of satisfactory value - the received signals are accepted for formation of a signals ensemble with the minimum power interaction. Determination of the optimal filter bandwidth is based on the analysis of the dependence of the maximum values of CCF $R(\tau)$ which depends on the number of elements in the involved sequences $\sqrt{n_i n_j}$ and the width of the filter band ΔF.

The dependence constructing of the maximum emission levels of the side lobes of the CCF on the filtration band width and the number of pulses in the sequences is based on the method described in [4, 5].

Statistical characteristics estimation of signal ensembles based on frequency filtering of short video pulse sequences with minimal energy interaction is performed using the calculation of mathematical expectation of maximum emissions of side lobes CCF signals $m_{R\max}$ when changing the values of filter bands in the range from 0.1% to 2% of the total spectral width at a constant value of duty cycle and signal duration [12]:

$$m_{R_{\max}}(\Delta F) = \frac{\sum_{k=1}^{N} \max\left|R_k(\Delta F)\right|}{N}. \qquad (8)$$

To estimate the standard error of the arithmetic mean from the mean value, the calculation of the standard deviation of the maximum emissions of the side lobes CCF $\sigma_{R\max}$ relative to the mathematical expectation is performed:

$$\sigma_{R\max}(\Delta F) = \sqrt{\frac{\sum_{k=1}^{N} \left(\max\left|R_k(\Delta F)\right| - m_{R\max}(\Delta F)\right)^2}{N}}. \qquad (9)$$

DOI 10.15588/1607-3274-2020-4-1

Thus, the study based on the proposed method for evaluating the correlation properties of complex signal ensembles by frequency filtering allows obtaining sequences with different waveforms, obtained even from the same sequence. The signals obtained by synthesizing different sequences are weakly correlated when they are located in different frequency bands, in addition, this method is relatively easy to implement and does not require significant computational resources.

4 EXPERIMENTS

To implement the proposed method of forming complex signal ensembles by frequency filtering of pseudo-random sequences with low interaction in the time domain, a software model was developed in the Matlab environment, which practically confirms the obtained theoretical results.

The original sample consists of 50 pseudo-random sequences with minimal energy interaction, on the basis of which, by band filtering, an ensemble of complex signals is formed.

As a result of searching all pairs of signals, the values of cross-correlation of pseudo-random sequences were calculated. Their estimation was carried out on the basis of the constructed models of each pair of sequences.

The selection of spectrum portions from the frequency band, on the basis of small-kind bandpass filters, which provide the necessary frequency response (FR), as well as the proper suppression of frequencies in the suppression band, was applied to the sampling. The frequency filtering band was selected in the range from 5 kHz to 200 kHz, in increments of 10 kHz. As a result of bandpass filtering of pseudo-random sequences on different frequency bands, signals differing in shape were obtained.

For further evaluation of the CCF of the filtered elements of the sequences, a necessary condition is the normalization of the received signals by energy, as due to the different number of pulses in the sequences and their continuity, the signal energies differ.

The next step is to determine the correlation properties of energy-normalized signals and build their models, on the basis of which further calculation of the maximum values of emissions of side lobes CCF signals for all possible pairs from the complex signal ensemble. The result is a dependence model of the maximum values of CCF, which depends on the number of elements in the involved pseudo-random sequences and the width of the filter band. After analyzing in each pair of sequences to meet the condition of ensuring a given level of maximum emissions of the side lobes CCF, only those sequences remain that meet the requirements for the limit values of the signals with minimal energy interaction.

After completing the analysis of the obtained signals that meet the requirements for the limit values of signals with minimal energy interaction, the statistical characteristics of ensembles are evaluated based on the calculation of mathematical expectations of maximum emissions of side lobes CCF signals $m_{R\max}$ to determine the mean value of the sample of the processed results, the calculation of the standard deviation of the maximum emissions of the side lobes CCF $\sigma_{R\max}$ relative to the mathematical expectation, to estimate the standard error of the arithmetic mean.

Based on the analysis of the statistical characteristics calculation, it is possible to ensure the effective formation of complex signals by filtering the spectrum bands of pseudo-random sequences with minimal energy interaction.

5 RESULTS

The statistical characteristics calculation of the maximum emissions values of the side lobes of the CCF is given in Table 1. To present the results, the following notations were used: $m_{R\max}$ – mathematical expectation of the maximum emissions of the side lobes of the CCF, $\sigma_{R\max}$ – standard deviation. The calculations were performed taking into account the frequency filtering band from 0.1% to 2% of the original spectrum width =of the studied sequences.

Comparing the values from the Table 1, the optimal results of solving the problem of complex signals synthesis by filtering bands of pseudo-random sequences of short video pulses with minimal energy interaction were obtained, provided that the condition fulfillment of required level compliance of maximum emissions the side lobes of the CCF with the limit values and at satisfactory values of the statistical characteristics of the studied signals.

Fig. 1 shows the results of the statistical characteristics calculating of the signals obtained by frequency filtering of pseudo-random sequences of short video pulses with minimal energy interaction. Fig. 1a shows the results of the limit values calculation of the side lobes maximum emissions of the CCF, taking into account the frequency filtering band. Obviously, not all calculated pairs satisfy the limit condition, which is shown as a slice. Pairs of sequences whose maximum value exceeds the allowable values must be re-analyzed in order to remove from the sequence signals ensemble that leads to exceeding the limit value. Fig. 1b presents the calculation results of large mathematical expectations of significant maximum emissions of the side lobes of the CCF, taking into account the standard deviation. Fig. 1c shows the dependence of the mathematical expectation of the maximum emissions of CCF side lobes on the frequency band, which shows the correspondence of the maximum values scatter of CCF side lobes to the calculated values, and its value does not exceed $\frac{1}{\sqrt{B}}$ at a filter bandwidth of 0.2%. From the obtained calculations we can conclude that the optimal filter band is equal to 0.2% of the total value of the sequences spectrum.

DOI 10.15588/1607-3274-2020-4-1

Table 1 – The calculation results of the statistical characteristics values of the maximum emissions level of the side lobes of the studied signals CCF

	ΔF(%)									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
$m_{R\max}$	0.584	0.211	0.182	0.146	0.121	0.118	0.116	0.114	0.112	0.110
$\sigma_{R\max}$	0.621	0.43	0.349	0.23	0.22	0.21	0.209	0.208	0.206	0.204
	ΔF(%)									
	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2
$m_{R\max}$	0.108	0.106	0.102	0.097	0.095	0.093	0.091	0.089	0.088	0.088
$\sigma_{R\max}$	0.2	0.198	0.196	0.194	0.189	0.186	0.183	0.179	0.178	0.177

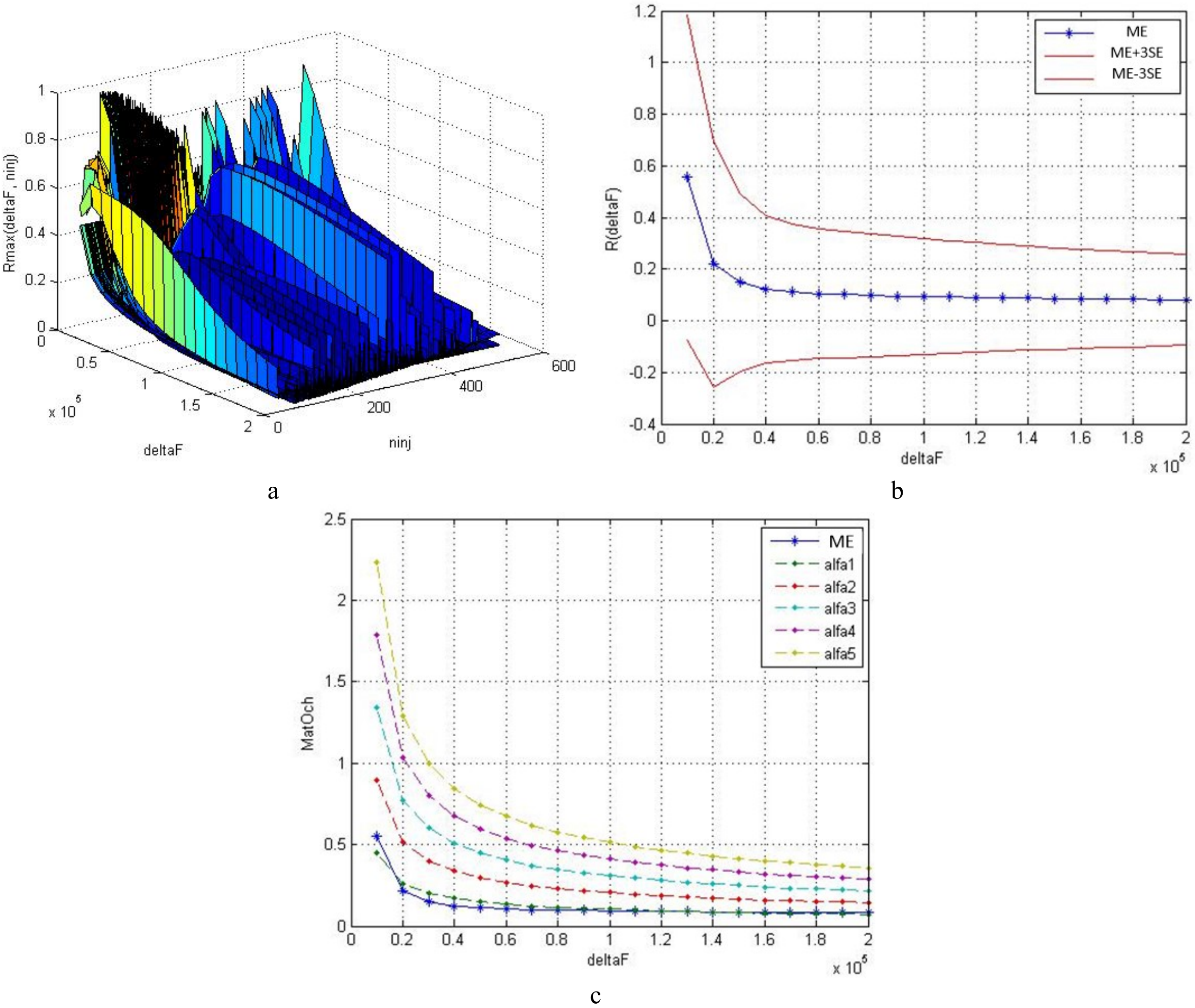

Figure 1 – Calculation results of statistical characteristics of short video pulses sequences with the minimum power interaction on the basis of frequency filtering:
a – limit values calculation of maximum emissions of CCF side lobes taking into account frequency filtration,
b – calculation of the mathematical expectation value of the maximum emission level of the CCF side lobes taking into account the standard deviation,
c – calculation of the mathematical expectation of the maximum emissions of the CCF side lobes at different values of α, depending on the frequency band

6 DISCUSSION

According to the data obtained when calculating of the statistical characteristics of the signals (Table 1) it is seen that based on the analysis of mathematical expectations of maximum emissions of CCF side lobes, depending on the frequency band, we can solve the problem of forming ensembles of complex signals from filtered frequency bands of the pseudo-random sequences of the short videopulses with minimal energy interaction.

The distribution of the maximum emissions values of the CCF side lobes depending on the number of pulses in the pairs of sequences and the filtration band width in Fig. 1a is limited in the form of a slice of the maximum values of the levels. Those pairs of sequences that exceed

DOI 10.15588/1607-3274-2020-4-1

these limits are re-analyzed to determine which of the sequences is not suitable for forming an ensemble of signals. Thus, after re-analysis, only those signals remain that satisfy the limit values of the constraints.

The choice of the optimal filtration band width is made on the basis of the analysis of the mathematical expectation dependence of the maximum emissions of the CCF side lobes (Fig. 1b) depending on the filtration band width. In comparison, condition (3) with different values of α was used (Fig. 1c). As a result, the mathematical expectation of the maximum emissions of the CCF side lobes does not exceed $\frac{1}{\sqrt{B}}$ at a filtration bandwidth of 0.2%.

It should be noted that with the filtration band expansion, the cross-correlation properties of the signals are improved, and, therefore, satisfy the condition of minimal signals similarity, with the disadvantage of a slight increase in the crest factor of such signals. Also, the application of frequency filtering by means of filters with equal frequency bands to the synthesized pseudo-random sequences with minimal energy interaction makes it possible to obtain a difference in the waveforms obtained even from the same sequence. The signals obtained by synthesizing different sequences are uncorrelated when they are located in different frequency bands.

CONCLUSIONS

Studies of the correlation properties of complex signal ensembles obtained by frequency filtering of pseudo-random sequences with minimal energy interaction allow forming much larger signal ensembles than existing complex signals used in modern radio systems with code division multiplexing.

The scientific novelty of obtained results lies in the development of a method for forming ensembles of complex signals by frequency filtering of pseudo-random sequences with low interaction in the time domain, which have a low level of multiple access interference. This approach simplifies the synthesis of complex signal ensembles based on pseudo-random sequences with minimal energy interaction and increases the number of received signals used to form ensembles with specified emission levels of CCF side lobes.

The practical significance of obtained results is that the possibility of using complex signals ensembles obtained by frequency filtering in cognitive radio systems with multiple access, which are affected by interference from multiple access.

Prospects for further research are to improve the selective capabilities of the proposed method and further modernization, taking into account the permutations of the filtration bands, as well as a deeper study of the ensemble properties of the signals obtained by the proposed method.

ACKNOWLEDGEMENTS

The work is supported by research work of the Ukrainian State University of Railway Transport on the topic: "“Study of national requirements for frequency allocation of Ukraine, the latest digital technological radio systems and development of a plan for the use of radio frequency resources of technological radio networks of the JSC “Ukrzaliznytsia” (agreement № 4/31 – 19).

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Received 25.09.2020.
Accepted 09.11.2020.

DOI 10.15588/1607-3274-2020-4-1

УДК 621.391

МЕТОД ФОРМУВАННЯ АНСАМБЛІВ СКЛАДНИХ СИГНАЛІВ ШЛЯХОМ ЧАСТОТНОЇ ФІЛЬТРАЦІЇ ПСЕВДОВИПАДКОВИХ ПОСЛІДОВНОСТЕЙ З НИЗЬКОЮ ВЗАЄМОДІЄЮ У ЧАСОВІЙ ОБЛАСТІ

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АНОТАЦІЯ

Актуальність. Розглянуто задачу формування ансамблів складних сигналів на основі фільтрацій смуг частот та дослідження їх властивостей. Об'єктом дослідження є процес синтезу ансамблів сигналів на основі частотної фільтрації псевдовипадкових послідовностей коротких відеоімпульсів з низькою взаємодією у часовій області.

Мета роботи. Формування ансамблів складних сигналів із задовільними значеннями взаємокореляційних властивостей, які наближаються до сигналів з мінімальною енергетичною взаємодією.

Метод. Наведено результати застосування методу формування ансамблів складних сигналів шляхом частотної фільтрації псевдовипадкових послідовностей з низькою взаємодією у часовій області. У результаті виділення смуг спектру досліджуваних псевдовипадкових послідовностей коротких відеоімпульсів за рахунок використання смугових фільтрів, побудованих на основі фільтра Чебишева першого роду, отримують нові вибірки послідовностей з обмеженням по спектру. Шляхом застосування взаємокореляційного аналізу до отриманих вибірок послідовностей здійснюють оцінку значень максимальних викидів бокових пелюсток функцій взаємної кореляції (ФВК) для усіх можливих пар сигналів. Якщо значення максимальних викидів бічних пелюсток ФВК сигналів перевищують граничні значення, то послідовність пари, що аналізується, з меншим значенням кількості імпульсів видаляється із ансамблю. В випадку задовільного значення – отримані сигнали приймаються для формування ансамблю сигналів з мінімальною енергетичною взаємодією. Таким чином формують новий ряд значень максимальних викидів бічних пелюсток ФВК. Завдяки такому підходу в ансамблях збільшується кількість сигналів із задовільними значеннями статистичних характеристик при обмеженій ширині спектра сигналу, а взаємокореляційні властивості таких послідовностей наближаються до сигналів з мінімальною енергетичною взаємодією, що призводить до зменшення рівня завад множинного доступу. У результаті ансамблі складних сигналів, отримані шляхом частотної фільтрації доцільно використовувати в когнітивних системах радіозв'язку з кодовим розділенням каналів.

Результати. На основі програмної реалізації методу формування ансамблів складних сигналів шляхом частотної фільтрації псевдовипадкових послідовностей з низькою взаємодією у часовій області було відібрано сигнали із задовільними значеннями статистичних характеристик при обмеженій ширині спектра сигналу, із взаємокореляційними властивостями, що наближені до сигналів з мінімальною енергетичною взаємодією та із збільшеним об'ємом ансамблю.

Висновки. Застосування частотної фільтрації до псевдовипадкових послідовностей коротких відеоімпульсів з низьким рівнем взаємної кореляції дозволяє отримувати ансамблі складних сигналів, які будуть подібними за взаємокореляційними властивостями до послідовностей з мінімальною енергетичною взаємодією, що дає можливість знизити рівень завад множинного доступу. У результаті проведеного аналізу виявлено, що застосування частотної фільтрації послідовностей незначно погіршить взаємні кореляційні властивості сигналів, за рахунок, можливо, неоптимального синтезу значень рівнів максимальних викидів бічних пелюсток ФВК сигналів, але, не зважаючи на це, існує можливість застосовувати такі сигнали в сучасних когнітивних системах радіозв'язку множинного доступу із кодовим розділенням каналів.

КЛЮЧОВІ СЛОВА: складний сигнал, функція взаємної кореляції, завада множинного доступу, відеоімпульс, база сигналу, ширина спектра сигналу, тривалість сигналу, шпаруватість, тривалість імпульсу, мінімальна енергетична взаємодія.

УДК 621.391

МЕТОД ФОРМИРОВАНИЯ АНСАМБЛЕЙ СЛОЖНЫХ СИГНАЛОВ ПУТЕМ ЧАСТОТНОЙ ФИЛЬТРАЦИИ ПСЕВДОСЛУЧАЙНЫХ ПОСЛЕДОВАТЕЛЬНОСТЕЙ С НИЗКИМ ВЗАИМОДЕЙСТВИЕМ ВО ВРЕМЕННОЙ ОБЛАСТИ

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DOI 10.15588/1607-3274-2020-4-1

АННОТАЦИЯ

Актуальность. Рассмотрена задача формирования ансамблей сложных сигналов на основе фильтрации полос частот и исследования их свойств. Объектом исследования является процесс синтеза ансамблей сигналов на основе частотной фильтрации псевдослучайных последовательностей коротких видеоимпульсов с низким взаимодействием во временной области.

Цель работы. Формирование ансамблей сложных сигналов с удовлетворительными значениями взаимокорреляционных свойств, которые приближаются к сигналам с минимальным энергетическим взаимодействием.

Метод. Приведены результаты применения метода формирования ансамблей сложных сигналов путем частотной фильтрации псевдослучайных последовательностей с низким взаимодействием во временной области. В результате выделения полос спектра исследуемых псевдослучайных последовательностей коротких видеоимпульсов за счет использования полосовых фильтров, построенных на основе фильтра Чебышева первого рода, получают новые выборки последовательностей с ограничением по спектру. Путем применения взаимокорреляционного анализа к полученным выборкам последовательностей осуществляют оценку значений максимальных выбросов боковых лепестков функции взаимной корреляции (ФВК) для всех возможных пар сигналов. Если значение максимальных выбросов боковых лепестков ФВК сигналов превышают предельные значения, то последовательность пары, которая анализируется, с меньшим значением количества импульсов удаляется из ансамбля. В случае удовлетворительного значения – полученные сигналы принимаются для формирования ансамбля сигналов с минимальным энергетическим взаимодействием. Таким образом формируют новый ряд значений максимальных выбросов боковых лепестков ФВК. Благодаря такому подходу в ансамблях увеличивается количество сигналов с удовлетворительными значениями статистических характеристик при ограниченной ширине спектра сигнала, а взаимокорреляционные свойства таких последовательностей приближаются к сигналам с минимальным энергетическим взаимодействием, что приводит к уменьшению уровня помех множественного доступа. В результате ансамбли сложных сигналов, полученные путем частотной фильтрации целесообразно использовать в когнитивных системах радиосвязи с кодовым разделением каналов.

Результаты. На основе программной реализации метода формирования ансамблей сложных сигналов путем частотной фильтрации псевдослучайных последовательностей с низким взаимодействием во временной области были отобраны сигналы с удовлетворительными значениями статистических характеристик при ограниченной ширине спектра сигнала, с взаимокорреляционными свойствами, приближенными к сигналам с минимальным энергетическим взаимодействием и с увеличенным объемом ансамбля.

Выводы. Применение частотной фильтрации к псевдослучайным последовательностям коротких видеоимпульсов с низким уровнем взаимной корреляции позволяет получать ансамбли сложных сигналов, которые будут сходными по взаимокорреляционным свойствам с последовательностями с минимальным энергетическим взаимодействием, что дает возможность снизить уровень помех множественного доступа. В результате проведенного анализа выявлено, что применение частотной фильтрации последовательностей незначительно ухудшит взаимные корреляционные свойства сигналов, за счет, возможно, неоптимального синтеза значений уровней максимальных выбросов боковых лепестков ФВК сигналов, но, несмотря на это, существует возможность применять такие сигналы в современных когнитивных системах радиосвязи множественного доступа с кодовым разделением каналов.

КЛЮЧЕВЫЕ СЛОВА: сложный сигнал, функция взаимной корреляции, помеха множественного доступа, видеоимпульс, база сигнала, ширина спектра сигнала, длительность сигнала, пик - фактор, скважность, длительность импульса, минимальное энергетическое взаимодействие.

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DOI 10.15588/1607-3274-2020-4-1