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QUICK SEARCH AND SYNCHRONIZATION ALGORITHM FOR WIDEBAND NOISE-LIKE SIGNALS

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Abstract: Currently, one of the dominant types of information exchange is remote interaction between geographically distributed subscribers using a wide range of wireless telecommunication systems. One of the important requirements for such systems is the minimum processing time of received signals and the provision of their reliability required level. Meeting this requirement is actually impossible without the availability of effective devices for these signals search and synchronization. A particularly complicated process is the development of search and synchronization devices for high-orbit satellite telecommunication systems, since there is also a frequency mismatch in these systems caused by the Doppler Effect, along with the mismatch of received signals with reference signals by the time of their arrival.

In this regard, the article proposes the fast search and synchronization algorithm for high-orbit satellite telecommunication systems when they are used as the information carriers of broadband noise-like signals with linear frequency modulation. The developed algorithm is based on the consideration of development peculiarities for these signals.

Keywords: high-orbit satellite telecommunication systems, search and synchronization algorithm, broadband noise-like signals with linear frequency modulation.

I. INTRODUCTION

One of the promising areas in the field of broadband noise-like signal (NLS) development for modern high-orbit satellite telecommunication systems is the use of special codes and new methods of range spreading. However, the expediency of one or another class of signals application in any information and telecommunication system (ITS) is largely determined by the possibilities of efficient device development for their search and synchronization. Currently, there are various approaches to device design that reduces the search and synchronization time of received NLS delay [1-11], in which the spectrum is spread by the transmission of each element of the information sequence (“1” and “0”) differing from each other by pseudo-random sequences (PRS), which modulate the high-frequency oscillation by phase. Such classes of signals are called FM PRS signals in literature. However, FM PRS signals do not have the property of invariance to the Doppler mismatch in frequency [12]. This peculiarity does not allow minimizing the time costs of high-orbit satellite telecommunication systems to search for these signals by frequency.

In this regard, the article proposes the fast search and synchronization algorithm of NLS with linear frequency modulation, which allows minimizing the time costs of high-orbit satellite telecommunication systems for their search and synchronization by frequency and delay.

II. MATERIALS AND METHODS

The proposed class of NLS with linear frequency modulation was obtained by the comparison of each information symbol (0 or 1) and the set of elements of a linearly frequency-modulated basis, the amount of which are mutually simple numbers, and the slope of the modulation characteristics (μ) of the specified basis for zero and single information symbols transmission are the same. In mathematical form, the envelope of the developed class NLSKK with the elements of a linearly frequency-modulated basis, the number of which is mutually simple numbers (N1 and N0) for the transmission, of the single (Figure 1) and zero (Figure 2) information symbols (I0 = 0 and I1 = 1) can be written as follows:

$$S(t)=\begin{cases} S_0\cdot\sum_{l=1}^{N_1} I_1\cdot rect\left\{\dfrac{t-(l-1)\frac{T_{I_1}}{N_1}}{\frac{T_{I_1}}{N_1}}\right\}\cdot\exp\left(j\cdot\left(\omega_0\cdot\left(t-(l-1)\frac{T_{I_1}}{N_1}\right)+\dfrac{\mu\left(t-(l-1)\frac{T_{I_1}}{N_1}\right)^2}{2}\right)\right)+ \\ 0,\ npu\ T_{I_1}<t<0 \\ +S_0\cdot\sum_{l=1}^{N_0} I_0\cdot rect\left\{\dfrac{t-(l-1)\frac{T_{I_0}}{N_0}}{\frac{T_{I_0}}{N_0}}\right\}\cdot\exp\left(j\cdot\left(\omega_0\left(t-(l-1)\frac{T_{I_0}}{N_0}\right)+\dfrac{\mu\left(t-(l-1)\frac{T_{I_0}}{N_0}\right)^2}{2}\right)\right); \\ 0,\ npu\ T_{I_0}<t<0 \end{cases} \quad (1)$$

Where: S0 is the amplitude of the signal envelope, hereinafter a constant value equal to 1; rect (x) is a rectangular "cutting-off" function determined by the following expression:

$$rect(x)=\begin{cases}1, & at\ 0\le x\le 1;\\ 0, & atother\ x.\end{cases}$$

ω0 – the average frequency of the chirp radio pulse; T_{I_0} and T_{I_1}– the duration of I0 and I1 symbols; $\frac{T_{I1}}{N_1}$ and $\frac{T_{I0}}{N_0}$ the element duration of linearly frequency-modulated basis of single and zero symbols; μ - the slope of chirp radio pulse modulation characteristics (frequency change rate) associated with its frequency deviation ΔF and the duration T0 by the following ratio: $\mu=\frac{2.\pi.\Delta F}{T}$.

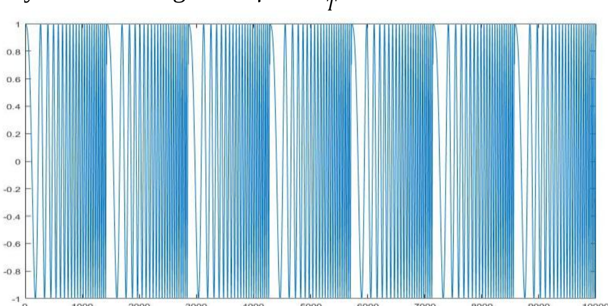

Figure 1 - NLS with linear frequency modulation and with the number of linearly frequency-modulated basis elements equal to N1 = 7 to transmit single information symbols I1 = 1

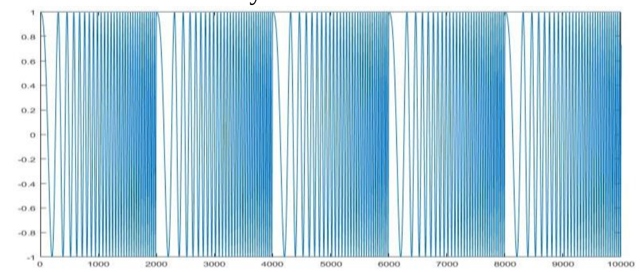

Figure 2 - NLS with linear frequency modulation and with the number of linearly frequency-modulated basis elements equal to N0 = 5 to transmit single information symbols I0 = 0.

As they noted above, during effective search and synchronization device development for high-orbit satellite telecommunication systems, it is very important to study the Doppler Effect influence on the characteristics of the signal structures used to transmit information.

As they know [13-14], in order to estimate the Doppler frequency shift, the uncertainty function (UF) is widely used, which can be represented by the following mathematical form:

$$\chi_i(\tau,F_\partial)=\frac{1}{2E}\int_{-\infty}^{\infty}S_i(t)\cdot S_i\cdot(t-\tau)\cdot\exp(j2\pi F_\partial t)dt \quad (2)$$

where: τ is the time shift between signals, Fд – the Doppler frequency shift, E - the signal energy, $S_i(t)$ - the envelope of the received i-th signal, $S_i(t-\tau)$ - the complex-conjugate envelope of the i-th signal.

On the basis of a large amount of experimental research, they found out that the nature of the envelope of UF NLS signal change with the linear frequency modulation for different values of the Doppler frequency shift and the magnitude of their base B= ΔF *T does not have any features determined by modulation and matches with UF envelope of the "ordinary chirp signal", which, as is known [13–14], is the invariant to the Doppler frequency error in the real limits of its variation (Fд from 0 to 50 kHz). The typical examples of UF NLS signals with linear frequency modulation are graphically presented by the Figures 3-4.

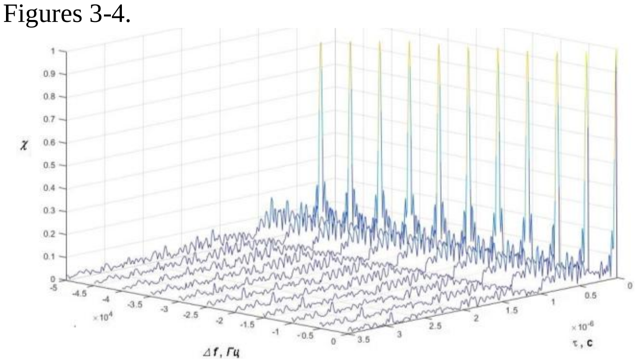

Fig. 3. UF values for NLS with linear frequency modulation, B = 600

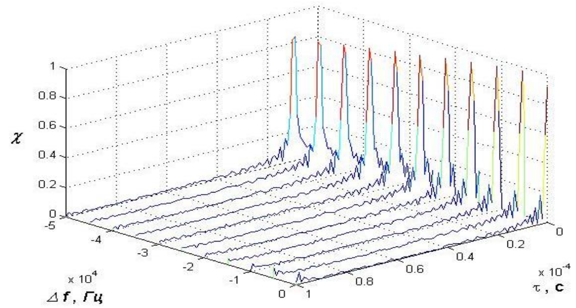

Fig. 4: UF values for NLS with linear frequency modulation, B = 1000

The analysis of envelope shape of NLS cross-ambiguity function (CAF) with linear frequency modulation is very important from the point of view of intra-system interference level evaluation arising from the implementation of multi-channel information transmission with the code division of addresses. The envelope of NLS CAF has the following form:

$$\dot{\chi}_{ij}(\tau,F_o)=\frac{1}{2E}\int_{-\infty}^{\infty}\dot{S}_i(t)\cdot\dot{S}_j^{\,*}(t-\tau)\cdot\exp(j2\pi F_o t)\,dt \qquad (3)$$

where $\dot{S}_j^{\,*}(t-\tau)$ is the complex conjugate envelope of the jth signal.

After a large number of experimental studies conducted with a different number of elements (N0 ≠ N1), it was proved that the maximum envelope level of CAF does not exceed the following value:

$$\frac{k}{\sqrt{N_0 N_1}} \qquad (4)$$

where k is the coefficient characterizing the number of coincidence concerning the equal value moment occurrence of linear frequency modulated basis of the single and zero information symbols among different NLS with linear frequency modulation.

The minimum level of the CAF envelopes can be obtained at k = 1, i.e. only if N0 and N1 are mutually prime numbers. Figures 5-6 show the examples of NLS CAF with linear frequency modulation and a mutually simple number N0 and N1.

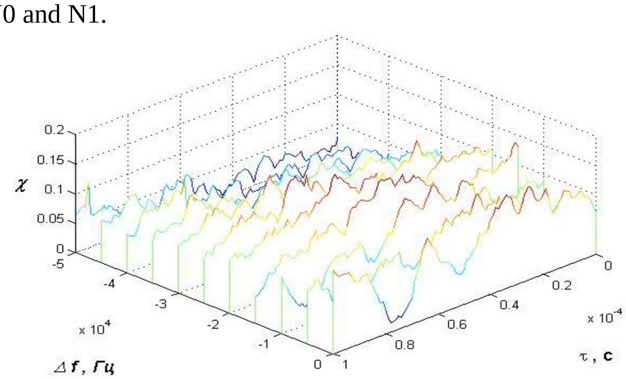

Fig. 5: CAF values for NLS with linear frequency modulation, N0=17, N1=13

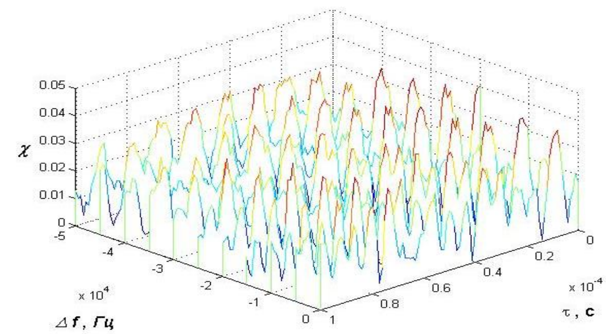

Fig. 6: CAF values for NLS with linear frequency modulation, N0=67, N1=61

Using the specified properties of NLS with linear frequency modulation, they developed a fast algorithm for their search and synchronization, the essence of which is the following one:

1) According to Figure 7, with the information symbol "1", using the first linear shift register, the binary code sequence from N1 (a simple number) elements is developed with the duration T_{I_1} and it is recorded in the memory register No. 1;
2) According to Figure 7, with the information symbol "0", using the second linear shift register, the binary code sequence from N2 (a simple number) elements is developed with the duration T_{I_0} and it is recorded in the memory register No. 2;
3) From the output of the memory register No. 1 the binary code sequence corresponding to the information symbol "1" is fed to the input of the generator No. 1 with linearly varying voltage. At that from the output of the memory register No. 2 the binary code sequence corresponding to the information symbol "0" is fed to the generator input of linearly varying voltage No. 2, the outputs of which have the pulses of various duration, the number of which is equal to N1 and N0, respectively, as can be seen from Figure 7;
4) the pulses from the linearly varying voltage generator output No. 1 are fed to the chirp signal generator input No. 1. At that, the pulses from the linearly varying voltage generator output No. 2 are fed to the chirp signal generator input No. 2;
5) the signals from the outputs of the chirp signal generator No. 1 and No. 2 enter the communication channel through high-frequency cascades;
6) at the receiving side the chirp signals are fed to the combined input of two parallel-connected channels designed for the processing of "1" or "0" information symbol, respectively. Each of these symbols includes a series-connected matched filter for the chirp signal processing and the recirculator, the feedback circuit of which includes a delay element, equal to T_{I_1} (in the channel for the information symbol "1" processing) and equal to T_{I_0} (in the channel for the information symbol "0" processing). The outputs of both channels are connected to the comparator input through the adder, the output of which will have signal when both outputs of both recirculator have signal that is during frame synchronization. The time of

entry into the frame synchronization mode is equal to the duration of one information package.

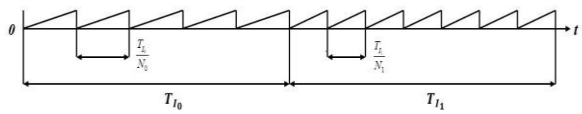

Figure 7: Temporary form of NLS signal with linear frequency modulation

III. RESULTS AND DISCUSSION

After theoretical and experimental research, they showed that one of the promising areas in the area of methods development for broadband noise-like signal generation in modern high-orbit satellite telecommunication systems is the use of special codes and new range spreading methods.

The new class of broadband noise-like signals with linear frequency modulation proposed in the article and obtained as the result of matching each information symbol (0 or 1) with a set of elements of a linearly frequency-modulated basis, the number of which is mutually prime numbers, has the following properties:

1. The change of envelope function uncertainty values of these signals at different values of the Doppler frequency shift and the value of their base B = ΔF *T does not have any features determined by modulation type and it coincides with the values of the envelope uncertainty functions of the "ordinary chirp signal", which, as we know [13–14], is the invariant to the Doppler frequency mismatch in real limits of its change (Fд from 0 to 50 кГц).
2. The maximum level of mutual uncertainty envelope functions for the proposed signals does not exceed the following value:

$$\frac{k}{\sqrt{N_0 N_1}},$$

Where, k is the coefficient characterizing the number of moment coincidences, the occurrence of equal elements of the linearly frequency-modulated basis of the single and zero information symbols among different NLS with linear frequency modulation.

The minimum level of mutual uncertainty envelope functions for the proposed signals can be obtained at k = 1, i.e. only if N0 and N1 are mutually prime numbers.

3. The obtained results of property studies for a new class of broadband noise-like signals allow us to offer this class of signals as data carrier if remote information exchange between geographically distributed subscribers is created using high-orbit satellite telecommunication systems.

IV. CONCLUSIONS

The proposed fast search and synchronization algorithm for NLS signals with linear frequency modulation, based on the consideration of this class of signal feature peculiarities, can significantly reduce search and synchronization period of high-orbit satellite telecommunication systems in comparison with the current approaches.

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