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EVALUATION OF NOISE IMMUNITY OF HIGH ORBITAL SATELLITE TELECOMMUNICATION SYSTEMS WITH BROADBAND NOISE-LIKE SIGN

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Abstract: It is known, when using narrow-band signals in high orbital satellite communication systems for organizing exchange of information, the efficiency of allocated frequency and time communication channel resource usage is reduced due to the large uncertainty in the frequency caused at the Doppler Effect and changes time of received signals arrival.

In this regard, currently one of the promising directions in the development of methods for constructing channel signals for use as information carriers in modern high-orbit satellite communication systems with code division of addresses, providing communication between remote subscribers in the Northern latitudes, is the use of broadband noise-like signals, which are the result of the use of special codes and new methods of spectrum expansion.

However, the priority of usage of one or another signal class in these systems is largely determined by their resistance to Doppler frequency shift. In with this regard article assesses the noise immunity of high-orbit satellite telecommunication systems with code division of addresses when using a number of broadband noise-like signals with linear frequency modulation as information carriers.

Keywords: satellite telecommunication systems, linear frequency modulated signal, a function of uncertainty, noise immunity, pseudo-random sequence.

I. INTRODUCTION

One of the most known classes of broadband noise-like signals that are widely used today in high-orbit satellite telecommunication systems with code-division addresses is the so-called FM PRS signals, obtained as a result of phase modulation of high-frequency harmonic oscillation according to the pseudo-random sequence (PRS) [1-6]. The reason to use such signals in these systems is based on large number of partially correlated forms, while it is known that they are not invariant to the Doppler frequency shift, which leads to large time-frequency expenses for searching and synchronizing of FM PRS signals. At the same time, there is a class of broadband noise-like signals with linear frequency modulation (LFM), that are invariant to the Doppler frequency shift and because of that such signals can be used for building of frequency-search less of high-orbit satellite telecommunication systems quite easily [7-8]. However, this class of signals has a small number of partially correlated forms, which does not allow using it in telecommunication systems with code-division of addresses. In works [9-10], it was shown that as carriers of information in satellite telecommunication systems with code-division of addresses it is much more efficient to use LFM FM or PR LFM signals, which combine the positive properties of both LFM and FM PRS signals. However, a very important aspect related to the quantitative assessment of the influence of the Doppler frequency shift (which, when satellites in high-elliptical orbits, reaches 50 kHz) on the noise immunity of satellite telecommunication systems with code division of addresses of these classes of broadband noise-like signals was not investigated in any of these works. In this regard, this paper analyzes the effect of this effect on the noise immunity of high-orbit satellite telecommunication systems with broadband noise-like signals.

II. EXPERIMENTS AND RESULTS

To estimate the Doppler frequency shift, as is known [4, 8], the uncertainty function (UF) is widely used, which in mathematical form can be represented as follows:

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

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

For LFM signals, the envelope of which, according to [4], is represented by the expression:

$$S(t) = S_0.\exp(j\mu\frac{t^2}{2}) \qquad (2)$$

where S0 is the amplitude of the signal envelope, hereinafter a constant value equal to 1, μ is the slope of the modulation characteristic of the LFM of the radio pulse (rate of change of frequency) associated with the frequency deviation ΔF and the duration of the signal T, ratio $\mu = 2\cdot\pi\cdot\Delta F / T$,

The UF graphically, for different values of the Doppler frequency shift (Fд from 0 to 50 kHz) and the magnitude of the signal base B=ΔF*T=1000, is shown in Figure 1.

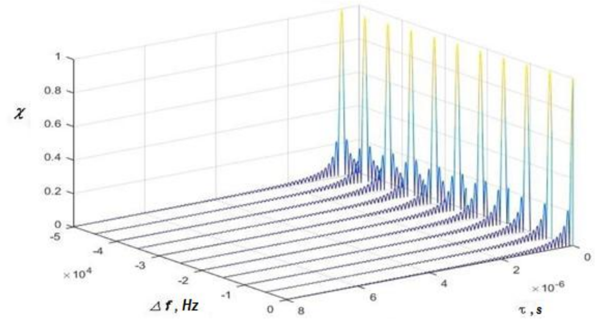

Figure 1: Values of UF for the LFM signal at B = 1000

For FM PRS signals, the envelope of which, according to [4], is representable by the expression:

$$S(t) = S_0\cdot\sum_{l=1}^{N}\nu_l\cdot rect\left\{\frac{t-(l-1)\cdot\tau_Э-\frac{T}{2}-\frac{\tau_Э}{2}}{\tau_Э}\right\} \qquad (3)$$

where τэ is the duration of the element PRS; N is the number of elements in the PRS; ν_l is the coefficient characterizing the state of the PRS, takes the values +1 or -1,

$rect(x) = 1,\ npu\ |x| \le \frac{1}{2}; rect(x) = 0,\ npu\ |x| > \frac{1}{2}$

is a rectangular "cutting off" function,

The UF graphically, for different values of the Doppler frequency shift (Fд from 0 to 50 kHz) and the value B = 1000, is shown in Figure. 2.

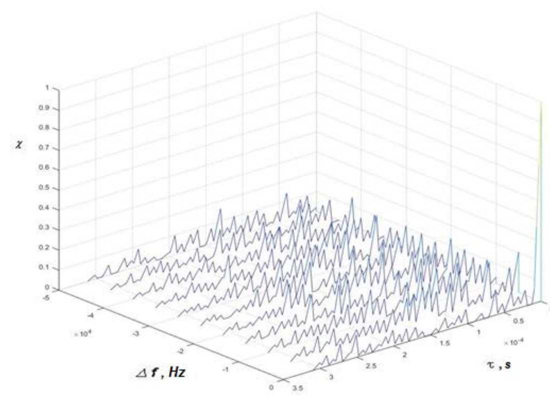

Figure 2: Values of UF for FM PRS signal at B = 1000, N = 31

For LFM FM signals, the envelope of which, according to [9], is represented by the expression:

$$S(t) = \begin{cases} S_0\cdot\sum_{l=1}^{N}\nu_l\cdot rect\left\{\frac{t-(l-1)\cdot\tau_Э-\frac{T}{2}-\frac{\tau_Э}{2}}{\tau_Э}\right\}\cdot\exp\left(j\mu\frac{t^2}{2}\right); & npu\ |t|\le\frac{T}{2} \\ 0; & at\ others\ t \end{cases} \qquad (4)$$

UF in graphical form for the value of the base signal B = 1000, various values of the Doppler frequency shift (Fд from 0 to 50 kHz) and the number of elements of the PRS 31 and 127, are presented in Figures 3 and 4.

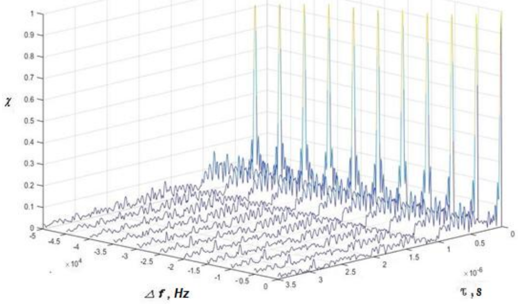

Figure 3: Values of UF for LFM FM signal at B = 1000, N = 31

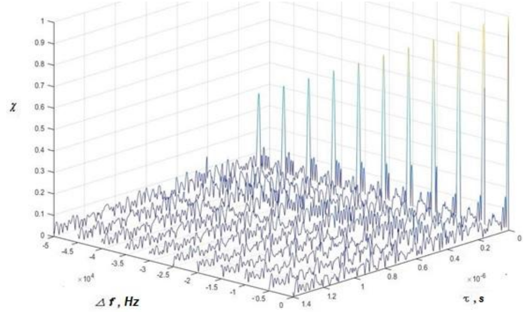

Figure 4.Values of UF for LFM FM signal at B = 1000, N = 127

For PR LFM signals, the envelope of which, according to [10], is representable by the expression:

$$S(t)=\begin{cases} S_0\cdot\sum_{l=0}^{N-1}\nu_{l+1}\cdot rect\left\{\frac{t-l\frac{T}{N}}{T_0}\right\}\cdot\exp\left(j\cdot\left(\omega_0\cdot\left(t-l\frac{T}{N}\right)+\frac{\mu\left(t-l\frac{T}{N}\right)^2}{2}\right)\right)+ \\ +S_0\cdot\sum_{l=0}^{N-1}(1-\nu_{l+1})\cdot rect\left\{\frac{t-l\frac{T}{N}-\tau_0}{T_0}\right\}\cdot\exp\left(j\cdot\left(\omega_0\left(t-l\frac{T}{N}-\tau_0\right)+\frac{\mu\left(t-l\frac{T}{N}-\tau_0\right)^2}{2}\right)\right); \\ 0,\ at\ \left[\frac{N-1}{N}\cdot T+T_0+(1-\nu_N)\cdot\tau_0\right]<t<0 \end{cases} \quad (5)$$

where: ν_{l+1} is a coefficient characterizing the state of the encoded sequence and taking values of +1 or 0; ω0- is the average frequency of the LFM radio pulse; T0-duration LFM radio pulse; τ0 is the delay between the beginning of the LFM of a radio pulse and the beginning of the PRS element corresponding to zero coefficient values ν_{l+1};

UF in graphical form for the magnitude of the signal base B=ΔF*T_0=1000, various values of the Doppler frequency shift (Fд from 0 to 50 kHz) and the number of elements of the PRS 31 and 127, are presented in Figures 5 and 6.

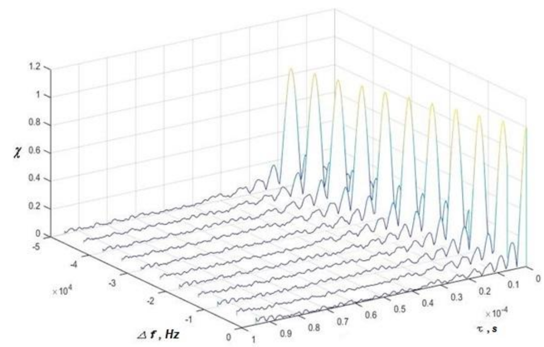

Figure 5: The values of the UF for the PR LFM signal at B = 1000, N = 31

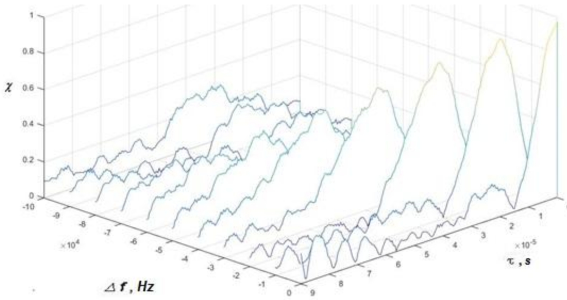

Figure 6: The values of the UF for the PR LFM signal at B = 1000, N = 127

When assessing the noise immunity of satellite telecommunication systems with code-division of addresses, when using the considered classes of signals as carriers of information, we will use the formula given in [11]:

$$P_{mist}=0,5\left[1-\Phi(h)\right] \quad (6)$$

Where, $\Phi(h)=\frac{2}{\sqrt{2\pi}}\int_0^h e^{-x^2/2}dx$ is the probability integral, $h=\sqrt{\frac{E}{N_0}}$ where E is the signal energy, N_0 is the power spectral density

The expediency of applying formula (6) is justified by the fact that the considered classes of signals, as shown by the results of experimental studies of their mutual uncertainty functions (Figure 7– Figure 10), are quasi-orthogonal, i.e. their values are close to zero.

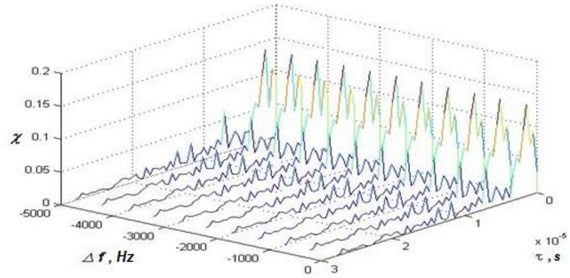

Figure 7: The values of the MUF for the LFM FM signal at B = 1000, N = 31

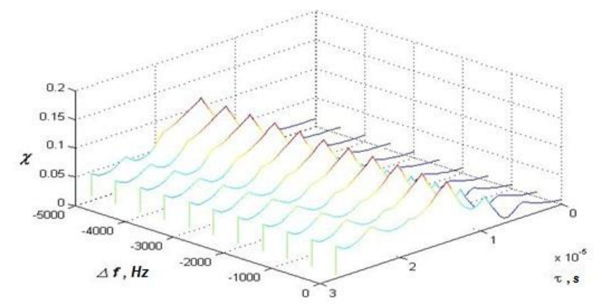

Figure 8: The values of the MUF for the LFM FM signal at B = 1000, N = 127

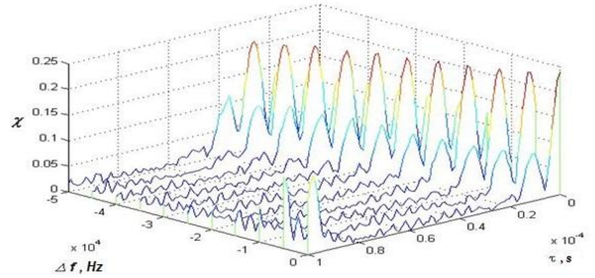

Figure 9: The values of the UF for the PR LFM signal at B = 1000, Ni=48,Nj=24

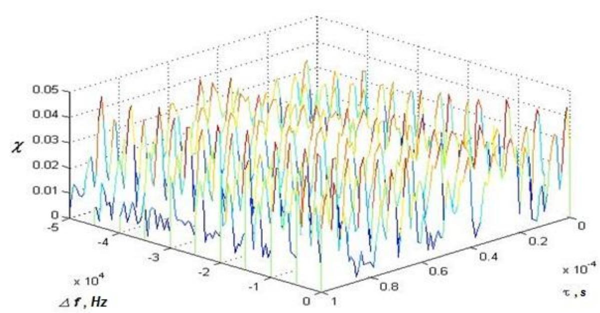

Figure 10: The values of the UF for the PR LFM signal at B = 100, Ni=31,Nj=27

To find the numerical values of the error probability, it is necessary to determine the argument of the integral of the probability h for all values of the Doppler frequency shift. To do this, we first find the maximum values of the UF for each of the considered classes of signals for all values of the Doppler frequency shift, and then multiply the found values of the UF (placed in Table 1) by the selected values of the signal energy to power spectral density (at Fд = 0). The values of the sought argument selected and obtained as described above, which take into account the effect of the Doppler frequency shift on the selected values of the ratio of the signal energy to the power spectral density, are presented in Table 2.

Table 1: Maximum values of the uncertainty functions for LFM, PR LFM, LFM FM, FM PRS signals for different values of Doppler frequency shifts:

The values of the Doppler frequency shift (kHz)	UF value for LFM signal	UF value for PR LFM N=31	UF value for LFM FM N=31	UF value for LFM FM N=127	The UF value for the FM PRS signal at N=31
5	0.9995	0.9889	0.9715	0.9374	0.05
10	0.999	0.9651	0.9513	0.8741	0.031
15	0.9985	0.9471	0.9466	0.811	0.061
20	0.998	0.9394	0.9354	0.748	0.0297
25	0.9975	0.9242	0.91	0.685	0.0294
30	0.997	0.9016	0.8962	0.6223	0.027
35	0.9965	0.883	0.8816	0.5596	0.013
40	0.996	0.874	0.8681	0.4971	0.024
45	0.9955	0.8592	0.8413	0.4348	0.004
50	0.995	0.8374	0.8358	0.3692	0.02

Table 2. Ratio of signal energy to noise power spectral density

The values of E/N_0 At F_d= 0	PR LFM, N=31 The values of E/N_0 At F_d=10, 30, 50 kHz			LFM FM, N=31The values of E/N_0 at F_d= 10, 30, 50 kHz			LFM FM, N=127 The values of E/N_0 atF_d=10, 30, 50 kHz		
	10 kHz	30kHz	50 kHz	10 kHz	30kHz	50 kHz	10 kHz	30kHz	50 kHz
1	0.965	0.901	0.837	0.951	0.896	0.835	0.874	0.622	0.369
2	1.930	1.803	1.674	1.902	1.792	1.671	1.748	1.244	0.738
3	2.895	2.704	2.512	2.853	2.688	2.507	2.622	1.866	1.107
4	3.860	3.606	3.349	3.805	3.584	3.343	3.496	2.489	1.476
5	4.825	4.508	4.187	4.756	4.481	4.179	4.370	3.111	1.846
6	5.790	5.409	5.024	5.707	5.377	5.014	5.244	3.733	2.215
7	6.755	6.311	5.861	6.659	6.273	5.850	6.118	4.356	2.584
8	7.720	7.212	6.699	7.610	7.169	6.686	6.992	4.978	2.953
9	8.685	8.114	7.536	8.561	8.065	7.522	7.866	5.600	3.322
10	9.651	9.016	8.374	9.513	8.962	8.358	8.741	6.223	3.692
11	10.616	9.9176	9.211	10.464	9.858	9.193	9.615	6.845	4.061
12	11.581	10.819	10.048	11.415	10.754	10.029	10.489	7.467	4.430
13	12.546	11.720	10.886	12.366	11.650	10.865	11.363	8.089	4.799
14	13.511	12.622	11.723	13.318	12.546	11.701	12.237	8.712	5.168
15	14.476	13.524	12.561	14.269	13.443	12.537	13.111	9.334	5.538
16	15.441	14.425	13.398	15.220	14.339	13.372	13.985	9.956	5.907
17	16.406	15.327	14.235	16.172	15.235	14.208	14.859	10.579	6.276
18	17.371	16.228	15.073	17.123	16.131	15.044	15.733	11.201	6.645
19	18.336	17.130	15.910	18.074	17.027	15.880	16.607	11.823	7.014
20	19.302	18.032	16.748	19.026	17.924	16.716	17.482	12.446	7.384

Based on the results obtained, Tables 3-5 of P_{mist} changes for PR LFM and LFM FM signals were compiled.

Table 3: Changes P_{mist} PR LFM signal at B = 1000, N = 31

F_d / h^2, dB	0	10 kHz	30kHz	50 kHz
5	$1.267*10^{-2}$	$1.4*10^{-2}$	$1.683*10^{-2}$	$1.903*10^{-2}$
10	$7.827*10^{-4}$	$9.462*10^{-4}$	$1.338*10^{-3}$	$1.903*10^{-3}$
15	$5.367*10^{-5}$	$7.068*10^{-5}$	$1.17*10^{-4}$	$1.96*10^{-4}$
20	$3.872*10^{-6}$	$5.55*10^{-6}$	$1.077*10^{-5}$	$2.121*10^{-5}$

Table 4: Changes of P_{mist} LFM FM signal, at B = 1000, N = 31

F_d / h^2, dB	0	10 kHz	30kHz	50 kHz
5	$1.267*10^{-2}$	$1.459*10^{-2}$	$1.714*10^{-2}$	$2.046*10^{-2}$
10	$7.827*10^{-4}$	$1.02*10^{-3}$	$1.378*10^{-3}$	$1.92*10^{-3}$
15	$5.367*10^{-5}$	$7.921*10^{-5}$	$1.23*10^{-4}$	$1.995*10^{-4}$
20	$3.872*10^{-6}$	$6.447*10^{-6}$	$1.15*10^{-5}$	$2.171*10^{-5}$

Table 5: Changes of P_{mist} LFM FM signal, at B = 1000, N = 31

F_d / h^2, dB	0	10 kHz	30kHz	50 kHz
5	$1.267*10^{-2}$	$1.828*10^{-2}$	$3.887*10^{-2}$	$8.712*10^{-2}$
10	$7.827*10^{-4}$	$1.556*10^{-3}$	$6.305*10^{-3}$	$2.734*10^{-2}$
15	$5.367*10^{-5}$	$1.467*10^{-4}$	$1.124*10^{-3}$	$9.304*10^{-3}$
20	$3.872*10^{-6}$	$1.45*10^{-5}$	$2.094*10^{-4}$	$3.29*10^{-3}$

III. DISCUSSION

Thus, the use of broadband noise-like signals LFM FM and PR LFM in high-orbit modern satellite telecommunication systems with code-division of addresses as the information carriers allows ensuring the stable functioning of these systems under the conditions of Doppler frequency mismatch in real limits of its change. In addition, due to the property of invariance to the Doppler mismatch in frequency within the limits of its real change, the use of the proposed classes of broadband noise-like signals reduces the number of required time-frequency resources of existing communication channels due to the minimum cost of their search and synchronization.

IV. CONCLUSION

From the data presented in tables 3-5, it can be seen that the change in the Doppler frequency shift in the real range of its change (from 0 to 50 kHz) leads to a decrease in noise immunity of high-orbit satellite telecommunications systems with code division of addresses [12], when used as information carriers FM PRS, LFM FM and PR LFM broadband noise-like signals.

However, it should be noted that the level of noise immunity of high-orbit satellite telecommunications systems when used as information carriers FM PRS signals even with small values of Doppler frequency mismatch is significantly reduced. At the same time, the level of noise immunity of high-orbit satellite telecommunications systems when used as information carriers LFM FM and PR LFM signals decreases slightly over the entire range of real changes in Doppler roassoglasovaniya frequency, which suggests the feasibility of the use of LFM FM and PR LFM broadband noise-like signals in high-orbit satellite telecommunications systems with code division channels.

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