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Improving the Security and Reliability of Information-Exchange in Telecommunication Systems with Mobile Objects

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Abstract

Based on the analysis of existing approaches to ensuring the security and reliability of information exchange in telecommunication systems with mobile objects, the article notes that the most promising approach to ensure the required performance of these features is the use of signal method. This method is based on the use of combined channel signals as information carriers, created on the basis of special codes and new spectrum spreading methods.

It is shown that a sufficiently large number of different classes of channel signals have been developed today, the use of which as information carrier in the telecommunication systems with mobile objects allows somehow solving the problem of ensuring a given level of security and reliability of information exchange in these systems. At the same time, it is too early to say that this task has already been fully resolved.

In particular, the results of time-frequency features obtained in the research process of a new class of combined signal-code constructions, created on the basis of special sets of radio pulses with linear frequency modulation as the basis designs, allow making a statement that their use as information carriers in telecommunication systems with mobile objects allows providing greater security and reliability of information exchange in these systems compared to the existing classes of combined channel signals, since the developed class of combined channel signals has both the property of invariance to Doppler frequency mismatch and the high level of noise immunity.

Keywords

Immunity, Telecommunication Systems, Doppler Effect.

Introduction

The current stage of social development is characterized by a continuous increase in remote interaction between subscribers and user requests for various types of multiservice services with the required quality, regardless of their location, which is currently mainly implemented on the basis of telecommunication systems with mobile objects, one of which is satellite telecommunication systems (STCS). The importance of these systems for the information transmission has significantly increased after the adoption of appropriate decisions on the development of the Arctic latitudes.

However, an intensive increase in the number of these systems, simultaneously transmitting information through the communication channels with limited time-frequency resources, leads to the appearance of interference noise. In addition, a significant decrease in the quality of multiservice services provided using the STCS is facilitated by the systems developed in recent years, designed to generate intentional noise in the communication channel or unauthorized access to the transmitted information.

Thus, it is necessary to ensure an appropriate level of noise immunity for the effective functioning of satellite telecommunication systems in a complex electronic environment.

Currently, various approaches have been created to ensure the security and reliability of information exchange in the STCS, among which it is customary to single out organizational, spatial, energy and signal methods in the qualification essence [1].

At the same time, an analytical review of a large number of references [1-22] made it possible to establish that the use of digital processing methods for channel signals in the modern STCS, allowing adaptively changing their time-frequency features, the development of new types of modulation and demodulation have led to the greatest use of signal methods in these systems to increase the security and reliability of information exchange.

In this regard, the article considers the possibility of using a new class of combined signal-code structures obtained when using special sets of radio pulses with linear frequency modulation as the basis structures, with an aim of using them as information carriers in the STCS to increase the reliability and security of information exchange in these systems.

Main Parts of Research

Material and Methods

The developed class of broadband noise-like signals is a combined signal, which is based on the use of a time-frequency matrix, each element of which is a linear frequency-modulated pulse with a different value of the frequency change rate (LFM-FWM signal). Such a class of signals can be written as follows in mathematical form:

$$S(t)=\begin{cases} S_0\cdot\sum\limits_{l=1}^{L} rect\{t-(l-1)\cdot\tau_u\}\cdot\exp\left(j\cdot\left(\omega_0\cdot(t-(l-1)\cdot\tau_u)+(N_k-N_n)\cdot\dfrac{\mu(t-(l-1)\cdot\tau_u)^2}{2}\right)\right) \\ at\, 0<t<L\cdot\tau_u \\ 0\ at\ \text{other}\ t \end{cases} \quad (1)$$

where: S_0 – amplitude of signal envelope, hereinafter a constant value equal to 1; L – number of numerical sequence elements; ω_0 – signal carrier frequency;

N_k – number of number sequence from 1 to L;

μ – steepness of the modulation feature of the LFM radio pulse (frequency change rate) associated with the frequency deviation ΔF_j and the duration

of number sequence element τ_u with a ratio $\mu=\dfrac{2\cdot\pi\cdot\Delta F_j}{\tau_u}$;

N_n – constant number, *rect (x)* - rectangular “cutting” function defined by the expression:

$$rect\{t-(l-1)\cdot\tau_u\}=\begin{cases}1\ at\,(\mathrm{k}-1)\cdot\tau_u\le t\le k\cdot\tau_u, \\ 0\ \ at\ \ (\mathrm{k}-1)\cdot\tau_u>t>k\cdot\tau_u.\end{cases}$$

In the future, we will assume that $N_n=(L+1)/2$ leads to a symmetric arrangement of the LFM-FWM signal spectrum relative to the carrier frequency ω_0. It should be noted that various options for the formation of numerical sequence N_k and modulating functions as a whole are possible [1].

Figure 1 shows the structural diagram of one of the options for devices that allows formulating the proposed class of signals of FWM with LFM.

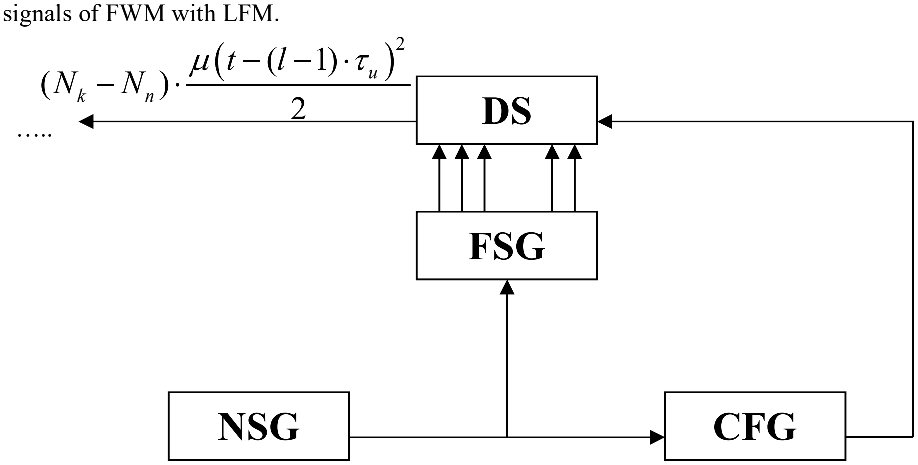

Figure 1: FWM with LFM Signal Generating Device

(where DS - Digital Switch, FSG - Frequency Spectrum Generator, CFG - Clock Frequency Generator, and NSG - Numerical Sequence Generator)

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The operation principle of the proposed scheme is as follows. The clock frequency generator (CFG) generates a signal with a clock frequency ω_{τ_u} that determines the clock frequency of a numerical sequence generator (NSG) based on a linear feedback shift register, the state of which is characterized by a binary number determined by the state (1 or 0) of each trigger included in the shift register, at each clock cycle.

As is known, there are $L = 2^n - 1$ states that provide all numbers N_k from *1 to L* for a shift register that generates a maximum length sequence [1-3].

The frequency spectrum generator (FSG) generates a spectrum of linear frequency-modulated pulses with different slopes for each element of the frequency-time matrix.

$$\omega_0 \cdot \left(t-(l-1)\cdot\tau_u\right)+(N_1-N_n)\cdot\frac{\mu_1\left(t-(l-1)\cdot\tau_u\right)^2}{2}+\omega_0 \cdot \left(t-(l-1)\cdot\tau_u\right)+(N_2-N_n)\cdot\frac{\mu_2\left(t-(l-1)\cdot\tau_u\right)^2}{2}$$
$$+\ldots+\omega_0 \cdot \left(t-(l-1)\cdot\tau_u\right)+(N_k-N_n)\cdot\frac{\mu_k\left(t-(l-1)\cdot\tau_u\right)^2}{2}. \tag{2}$$

All signals of the frequency spectrum are supplied to the corresponding first inputs of the digital switch (DS), the second input of which is supplied with a digital code from the NSG output. The digital switch associates each number N_k with a predetermined signal from the frequency spectrum with linear frequency-modulated pulses $\omega_0 \cdot \left(t-(l-1)\cdot\tau_u\right)+(N_i-N_n)\cdot\frac{\mu_i\left(t-(l-1)\cdot\tau_u\right)^2}{2}$ and only this signal is passed to the output.

The LFM-FWM signal thus obtained will have a duration equal to $T_c = L\cdot\tau_u$, and the width of the frequency band occupied by it can be determined from the following expression $\Delta F_c = (L-1)\cdot\Delta F_j$.

Hence, the base value of such a signal can be written in mathematical form as follows:

$$B_s = L\cdot\tau_u\cdot(L-1)\cdot\Delta F_j. \tag{3}$$

The number of different element movements of the thus formed square matrix of *L* size will be equal to:

$$N = 1\cdot 2 \ldots L = L! \tag{4}$$

When using the developed class of signals as information carrier in high-orbit STCS, it is very important to know the degree of their invariance to Doppler frequency mismatch, since this parameter largely determines the time-frequency costs of the indicated telecommunication systems for the search and synchronization of the signals used.

As is known [15], the uncertainty function is widely used as a quantitative estimate of invariance degree of a particular class of channel signals to Doppler frequency mismatch, which can be represented by the following formula in general form:

$$\dot{\chi}_{ii}\left(\tau, F_d\right) = \frac{1}{2E}\int_{-\infty}^{\infty}\dot{S}_i\left(t\right)\cdot\dot{S}_i^{*}\left(t-\tau\right)\cdot\exp\left(j\cdot 2\pi\cdot F_d\cdot t\right)dt \tag{5}$$

where: τ - time shift between signals, F_D - Doppler frequency mismatch, E – signal energy, $\dot{S}_i\left(t\right)$ - envelope of the received *i-th* signal, $\dot{S}_i^{*}\left(t-\tau\right)$ - complex conjugate envelope of *i-th* signal.

An analysis of the results of experimental studies of the cross sections of envelope LFM-FWM signals obtained at different values of the time shift between the signals (τ) and Doppler frequency mismatch (F_D), a typical example of which is presented in Figure 2, allowed establishing that the developed classes of channel signals for a certain selection of frequency change rates for each of the LFM pulses, which are the time-frequency matrix elements, provide complete invariance to Doppler frequency mismatch (F_D) within the limits of its real change (from 0 to 50 kHz).

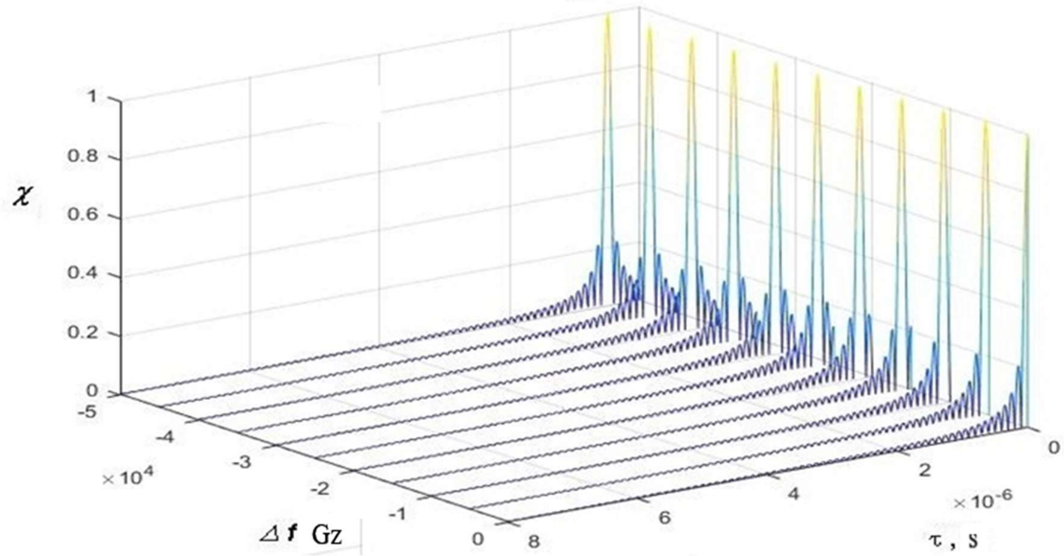

Figure 2: Values of LFM-FWM Signals

Conclusions

The presence of such a large volume of different LFM-FWM signals can significantly increase the noise immunity of satellite telecommunication systems for various types of attempts to unauthorized access to information transmitted by these systems.

It should also be noted that when implementing information exchange using high-orbit satellite telecommunication systems, the use of the developed class of LFM-FWM signals as information carriers in these systems, with a certain selection of the frequency change rate of each of the LFM pulses, which are the time-frequency matrix elements, will ensure complete invariance to Doppler frequency mismatch (F_D) within its real change (from 0 to 50 kHz).

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