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Performance Study of Spread Spectrum Systems with Hard Limiters

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Abstract: Use of spread spectrum systems in telecommunications is studied. It is shown that spread spectrum techniques can substantially enhance noise and interference immunity in the currently deployed information transmission networks. Primitive polynomials are proposed to obtain respective spreading codes. A spreading code consisting of 1023 chips is synthesized and its characteristics are studied.

It is deduced that powerful interferences can exceed dynamic range of the receiving part of the system and, as a result, deteriorate information transmission. To overcome this problem, utilization of limiters is proposed, in which limitation level equals that of the internal noise of the receiving part. Computer simulation is employed to test the performance of the proposed solution. Performance of the spread spectrum system for information transfer is studied both without the limiter and with the limiter.

Research results show that, for binary modulation, performance of the system with limitation and without limitation is nearly identical while limiters can substantially reduce requirements for the dynamic range.

Compared to the existing approaches, it is proposed to use the synthesized spreading coding sequence with the limitation technique in practical implementations of those telecommunication networks, in which noise immunity and transmission concealment are required, such as in unmanned aerial vehicles. This can replace currently used approaches, such as frequency hopping, transmission power adjustment and antenna pattern changes.

Index Terms: Telecommunication networks, Primitive polynomials, Spreading coding sequences, Limiters, Computer simulation.

1. Introduction

Wideband signals find ample application in telecommunication networks to improve their performance in many ways. One of the main approaches to enlarge occupied signal spectrum is to use spreading coding sequences. This technique can provide higher interference immunity and transmission concealment characteristics in wireless telecommunication networks. Performance of this method is largely determined by the autocorrelation properties of the deployed spreading coding sequences. For this reason, research and development of the sequences with the required parameters is a very important task in itself.

Primitive polynomials are well-known to be used for synthesizing spreading coding sequences. Those sequences are the backbone of the third generation mobile networks, as the crucial part of CDMA technology. In this case, however, the spreading sequences are usually very long and used only to organize multi-access to the network in combination with the other coding sequences, such as Walsh codes.

In this paper, an attempt is made to study properties of much shorter spreading coding sequences based on primitive polynomials to improve specifically interference immunity and information concealment properties in telecommunication channels. Such properties are vital, for example, when it comes to control of unmanned aerial vehicles (UAV). Currently, to improve reliability of the UAV control channel, frequency hopping, transmission power adjustment and antenna pattern changes are used.

Additionally, it is well-known that interfering signals can exceed dynamic range of the receiver during wireless information transfer. This can lead to undesired and unpredictable consequences. One of the approaches to elimination of this problem is to use limiters that cut off the signal above a certain level.

Up until now, this problem has not been sufficiently addressed; therefore, this work aims to fill this gap and find out whether utilization of spreading coding sequences based on the primitive polynomials with additional application of the limiters can be used in practice to improve performance of telecommunication networks.

To find a solution to the problem, the research presented here involves a search of a primitive polynomial of a required degree, synthesis of the spreading coding sequence based on the polynomial and study of the characteristics of the telecommunication channel with interferences that includes the transmitted desired bits, spread by the coding sequence, in both the presence and the absence of the limiter.

2. Literature review

Design of control channels for UAV is considered in [1]. This book provides good coverage for many ways of practical implementation of these channels, but, unfortunately, it does not address the use of pseudo noise coding sequences for improving noise-immunity of the control channels.

Detailed description of spreading coding sequences that are used in third generation mobile networks is provided in [2-4]. In these books, one can find many spreading coding sequences, as well as their areas of implementation. Still, the main focus is made on securing multiple access to the networks and effective separation of the different subscribers. So, issues of using spreading coding sequences for designing of noise immune telecommunication channels are not entertained.

Papers [5-7] address the problems of using smart antennas to improve noise immunity of telecommunication channels and provide good insights into workings of the adaptive antennas. However, they do not offer to combine smart antennas with spread spectrum techniques to secure good performance of a telecommunication channel.

Reference [8] includes the most comprehensive information on theory and practice of using pseudo noise spreading coding sequences. It shows insights into generation of different coded sequences with help of many primitive polynomials. In addition, it has tables of the primitive polynomials of the different orders, which can be readily-used to generate respective sequences. On top of that, this book includes a lot of demonstrating materials and explanations. Nevertheless, problems of using of pseudo noise coding sequences for enhancing noise immunity of critically important telecommunication channels are not considered.

References [9,10] and [12,13,14] propose many ways to improve noise immunity of telecommunication channels with some original smart antenna algorithms and their implementation. Still, these books fail to combine those methods with spread spectrum techniques to improve efficiency. In addition, they do not contain comparative analysis of the proposed methods with the others available.

Books [11] and [15], papers [16-19] provide good insights into theory and practice of different coding techniques in wireless communications. They solidify the proposed approaches with good illustrating materials. Besides that, differentiation is made between spreading and scrambling techniques [20], as well as use of different codes for information ciphering and deciphering. Yet again, the issues of deploying pseudo noise coding sequences generated using primitive polynomials are not clarified and elaborated.

Thus, to the best knowledge of the paper authors, problems of using primitive polynomials to generate pseudo noise spreading coding sequences to enhance noise immunity and concealment properties of a telecommunication channels are not properly address in the available literature. At the same time, there is a well-elaborated theory of synthesis of these sequences using available and user-ready primitive polynomials of different orders.

3. Methodology of the Research

To study performance of the telecommunication channel, which deploys the synthesized spreading coding sequence, computer simulation was used. Due to its both universality and cost-effectiveness, this approach is ideally suited to verify the research objectives. The computer simulation was performed for the following conditions:

- complex additive mixture of the five bits of the desired signal sequence, internal channel noise and the interfering noise signal is created;
- the desired signal is represented as complex samples of the spreading sequence taken with account of the bit sign and assuming phase values of 0 or π;
- the internal channel noise is represented as complex samples with Gaussian probability distribution;
- the interfering signal is also formed as complex samples with Gaussian distribution;
- the internal noise power is set to unity;
- the interfering signal power assumes values of 1, 3, 7 and 15 relative units;
- the power of the desired signal is set to 0.25 relative unites;
- the bit sequence is formed from five bits: 1,1,-1,-1,1;

Created according to the above conditions, the signal mixture is passed through the despreading filter matching the spreading sequence.

Computer simulation was carried out with help of the software package Matlab.

Simulation results are expected to show that the useful signal can be extracted from the noise and the use of the limiters will not substantially compromise the gains obtained for the spreading-despreading technique without the limiters.

4. Studying Behavior of the Telecommunication Channel without the Limiter

4.1. Synthesis of the spreading coding sequence and evaluation of its correlation properties

Primitive polynomials have remarkable autocorrelation properties, what determines their wide use in telecommunications. Those polynomials can be deduced by using polynomial division, but there are some reference books that include user-ready primitive polynomials of different degrees. In this paper, it is proposed to use the primitive polynomial of the tenth degree. In [8] one can find that the tenth degree primitive polynomial over Galois field GF(2) can be presented as follows:

$$F(x) = x^{10} + x^{3} + 1 \quad (1)$$

Primitive polynomial (1) permits to synthesize pseudo noise spreading sequence that is illustrated in Fig.1.

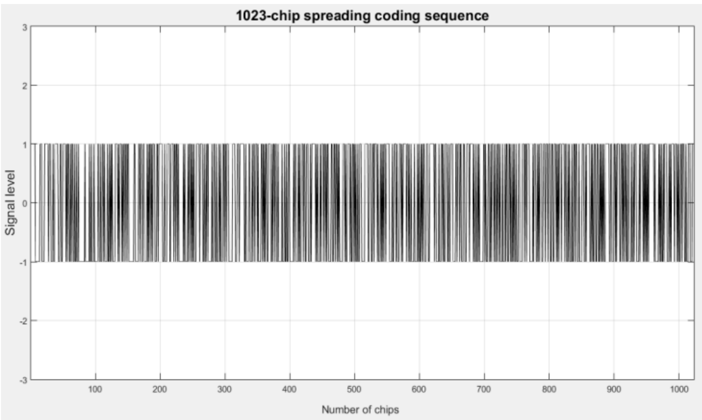

Fig.1. Spreading 1023-chip coding sequence based on the primitive polynomial (1)

Coding sequences in telecommunications can be presented both in «0» and «1» logic, and in «1» and «-1»; that in Fig. 1 is formed in the latter. Let us study autocorrelation properties of the spreading sequence in Fig. 1.

Correlational properties of pseudo noise spreading coding sequence in Fig.1 are illustrated by the graph in Fig.2. This graph demonstrates correlation function of the spreading sequence shown in Fig.1 and the bit sequence consisting from five following bits: 1,1,-1,-1,1. Each of these bits is spread by the same coding sequence shown in Fig.1. In other words, it is the result of consequent despreading of the spread sequence in the absence of a noise or interference.

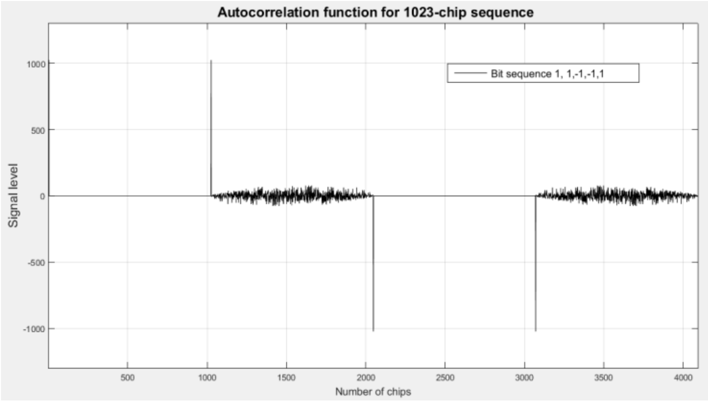

Fig.2. Spreading 1023-chip coding sequence based on the primitive polynomial (1)

Graph in Fig.2 illustrates unique autocorrelation properties of pseudonoise coding sequences derived from the primitive polynomial. Those properties imply that if the chip shift equals zero, the value of the autocorrelation function assumes the number of chips in the spreading sequence, which is 1023; in case of any shift of the sequence against itself, the value of the autocorrelation function equals -1.

It is important to notice, that if the bit sequence changes its sign, those unique properties degrade and the side lobes in the autocorrelation function become evident, as shown in Fig.2. One can suppose that those side lobes can, to a certain extent, compromise performance of the telecommunication network that deploys the spreading sequence shown in Fig.1.

4.2. Performance evaluation of the telecommunication channel with synthesized spreading sequence and without the limiter

Fig.3, Fig.4 and Fig.5 demonstrate modular, imaginary and real components of the signal mixture formed according to the above conditions and the relative interfering signal power equaling unity.

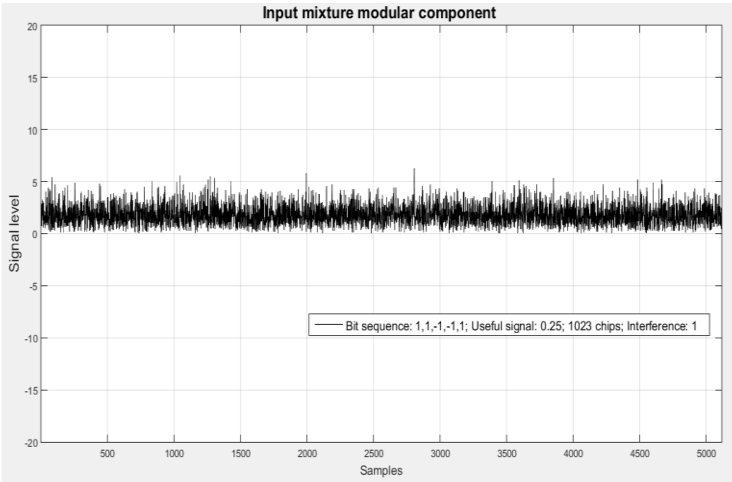

Fig.3. Modular component of the input signal mixture

In this case, total interfering signal and internal noise power exceeds the power of the desired signal 8 times or by 9 dBs.

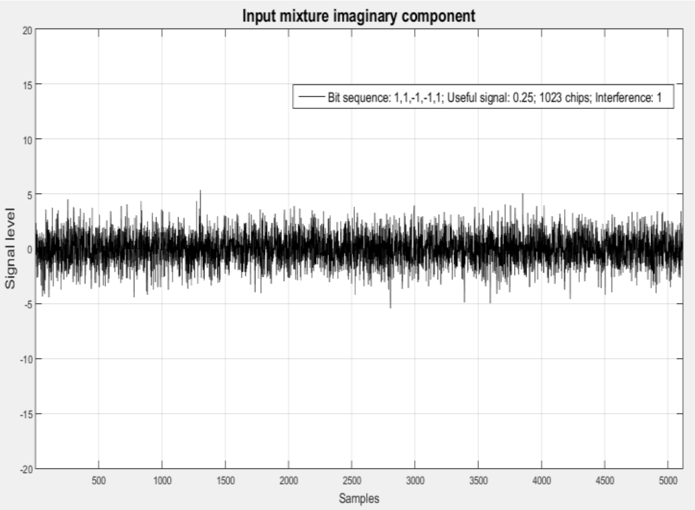

Fig.4. Imaginary component of the input signal mixture

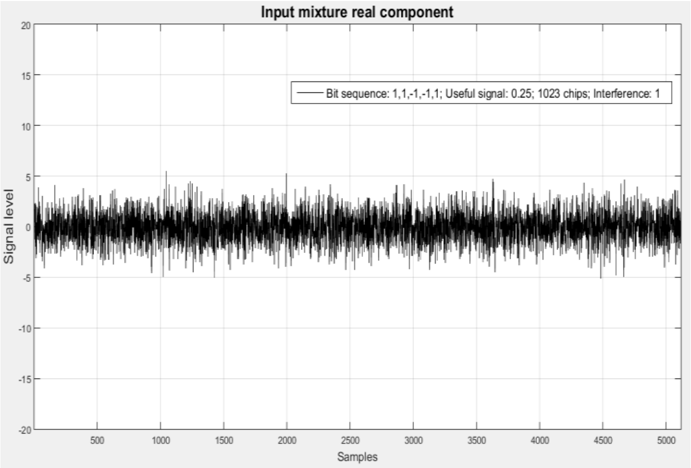

Fig.5. Real component of the input signal mixture

Data in these figures clearly show that desired signal is well-hidden in the noises and is considered to be difficult to extract without prior knowledge of the spreading code.

Fig.6, Fig.7 and Fig.8 illustrate modular, imaginary and real components of the mixture after despreading for the above conditions and when interfering signal has relative power 1. Analysis shows that the desired signal is clearly visible on the background of the noise signals and the bit sequence can be restored.

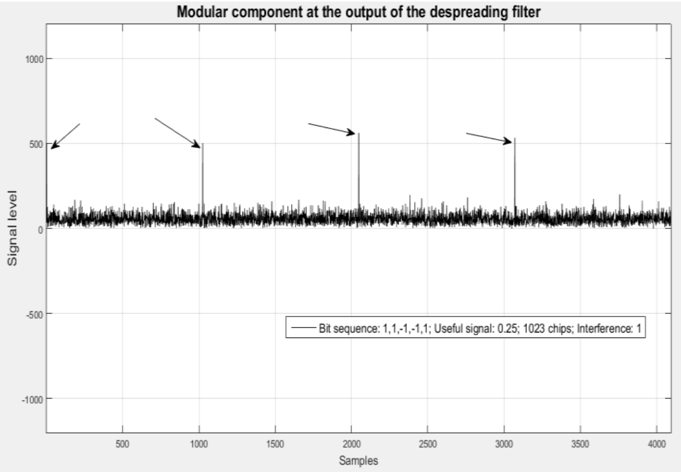

Fig.6. Modular component at the output of the despreading filter for interfering signal relative power 1

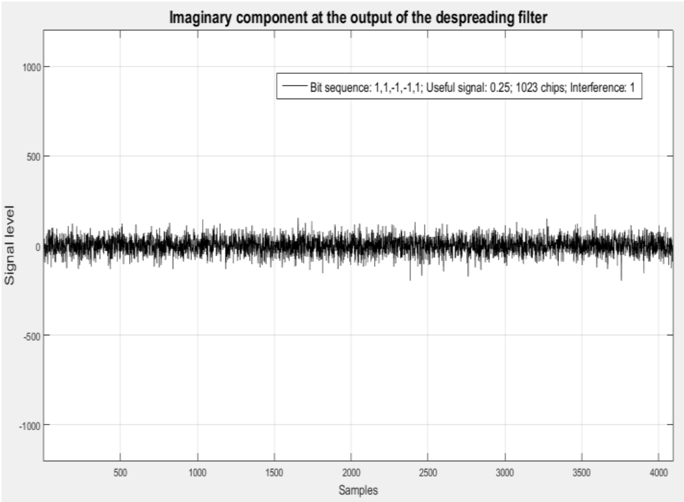

Fig.7. Imaginary component at the output of the despreading filter for interfering signal relative power 1

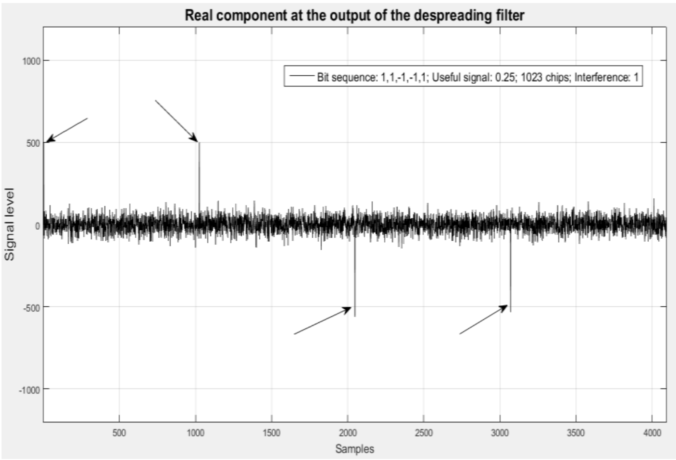

Fig.8. Real component at the output of the despreading filter for interfering signal relative power 1

The arrows in Fig.6, Fig.7 and Fig.8 indicate the desired signal bit sequence.

Fig.9, Fig10 and Fig.11 illustrate modular, imaginary and real components of the mixture after despreading for the interfering signal power equaling 3.

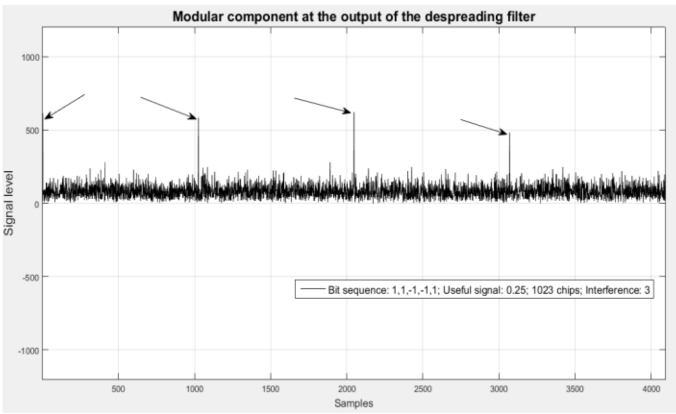

Fig.9. Modular component at the output of the despreading filter for interfering signal relative power 3

The arrows serve the same purpose as above. Yet again, the desired signal bit sequence is easily distinguishable on the background of the noise. Nevertheless, achieved gain in signal-to-interference ration is visibly smaller than in the previous case.

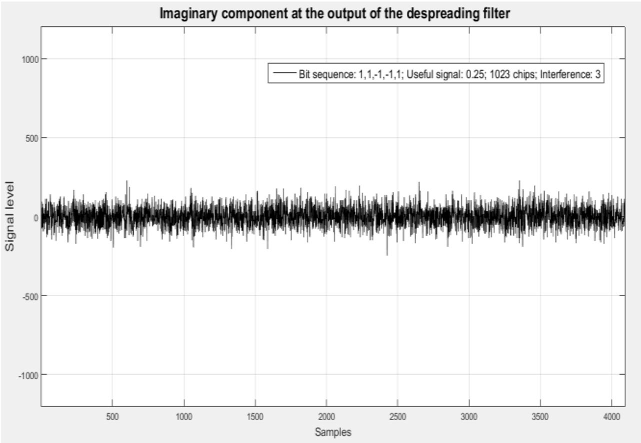

Fig.10. Imaginary component at the output of the despreading filter for interfering signal relative power 3

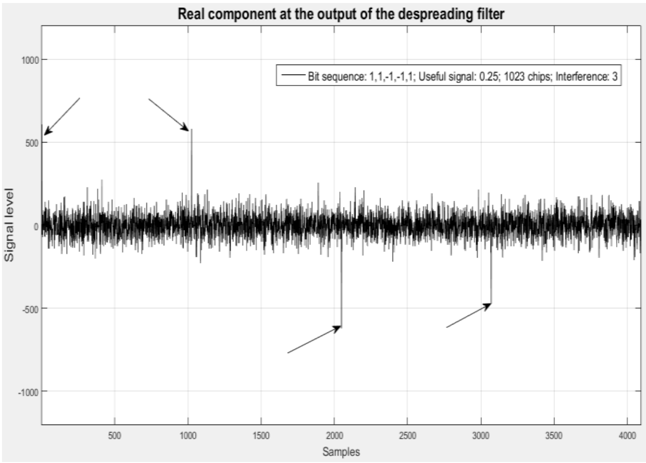

Fig.11. Real component at the output of the despreading filter for interfering signal relative power 3

Fig.12, Fig13 and Fig.14 represent modular, imaginary and real components of the mixture after despreading for the interfering signal power equaling 7. In this case, the combined noise exceeds desired signal 32 times or by 15 dBs.

Analysis of the data in these figures clearly indicates that the desired signal is confidently extracted from the noise mixture and the bit sequence can be restored. Still, residual noise level is visibly growing and in such a way that desired signal-to-interference ratio is decreasing as compared to the previous case.

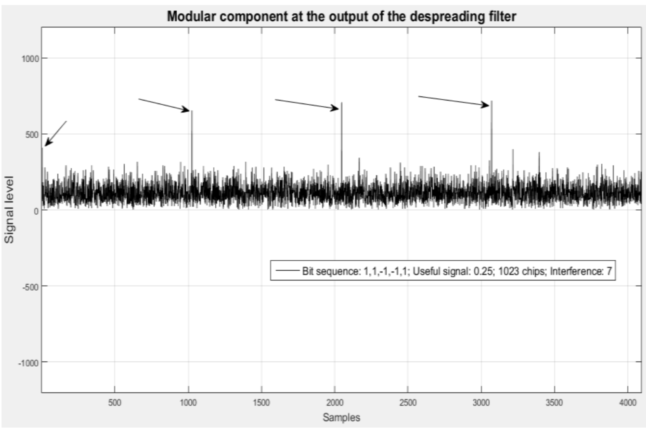

Fig.12. Modular component at the output of the despreading filter for interfering signal relative power 7

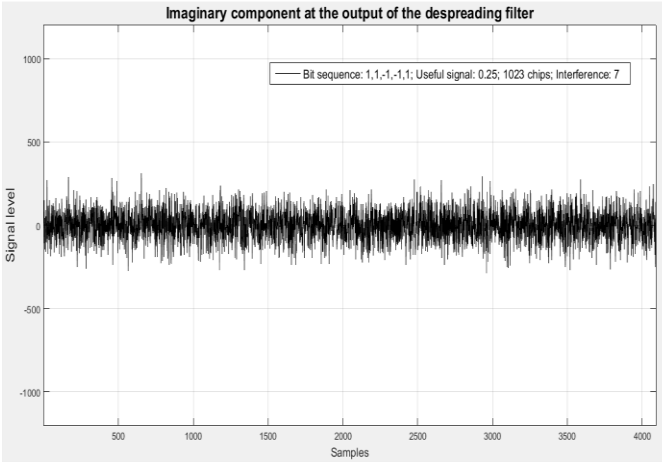

Fig.13. Imaginary component at the output of the despreading filter for interfering signal relative power 7

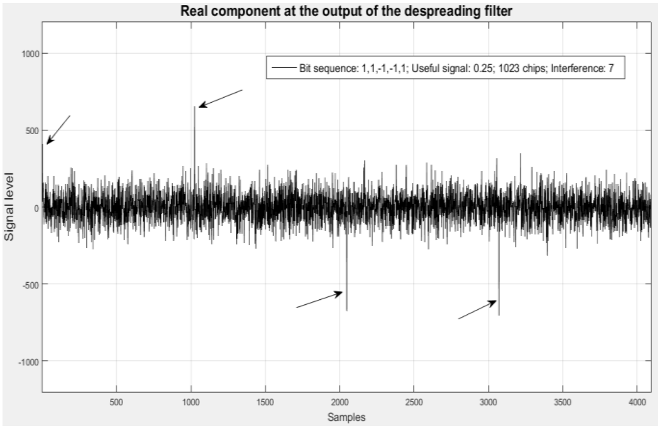

Fig.14. Real component at the output of the despreading filter for interfering signal relative power 7

Fig.15, Fig16 and Fig.17 demonstrate modular, imaginary and real components of the mixture after despreading for the interfering signal power equaling 15.

In this case, the combined noise exceeds desired signal 64 times or by 18 dBs.

Data in the Fig.15, Fig.16 and Fig.17 clearly show that although the desired bits are still visible on the background of the noise, there might be elevated bit-error rate as the level of the noise moves closer to the desired signal level.

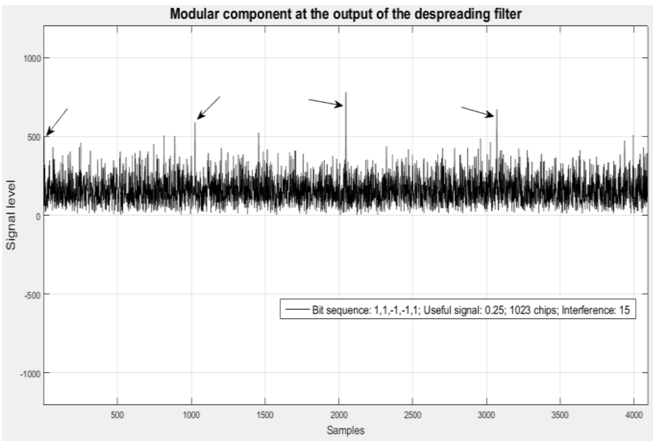

Fig.15. Modular component at the output of the despreading filter for interfering signal relative power 15

It looks certain that 18dB represents potential limit for the 1023-bit spreading code under consideration.

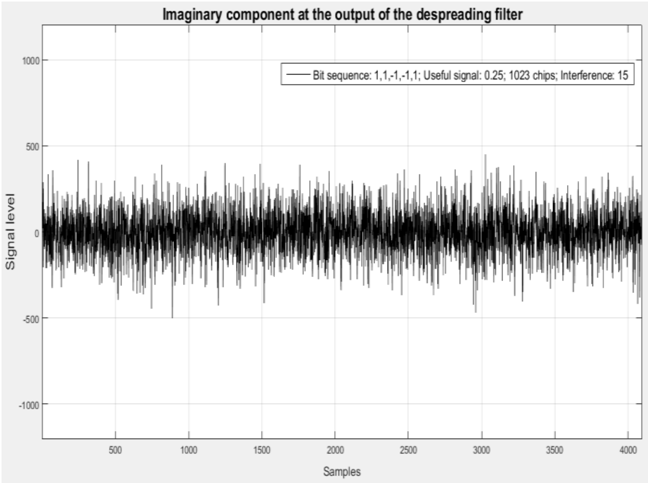

Fig.16. Imaginary component at the output of the despreading filter for interfering signal relative power 15

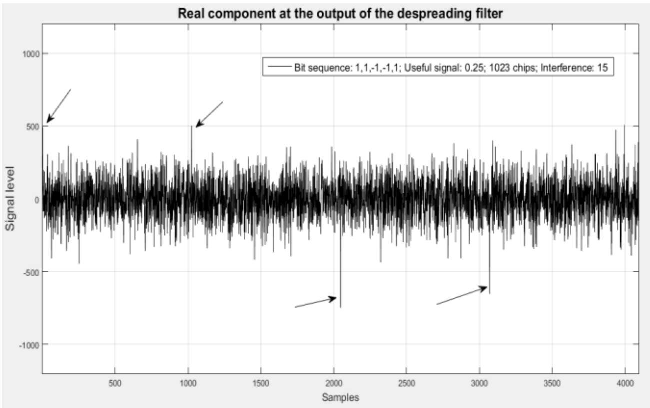

Fig.17. Real component at the output of the despreading filter for interfering signal relative power 15

5. Studying Behavior of the Telecommunication Channel with the Limiter

In the previous subsection, the situations were considered in which the signal mixtures can achieve big power levels. For example, Fig.18, Fig.19 and Fig.20 demonstrate the modular, imaginary and real components of the signal mixture for the interfering signal power of 15 relative units. It is useful to compare graphs in those pictures with the graphs in Fig.3, Fig.4 and Fig.5.

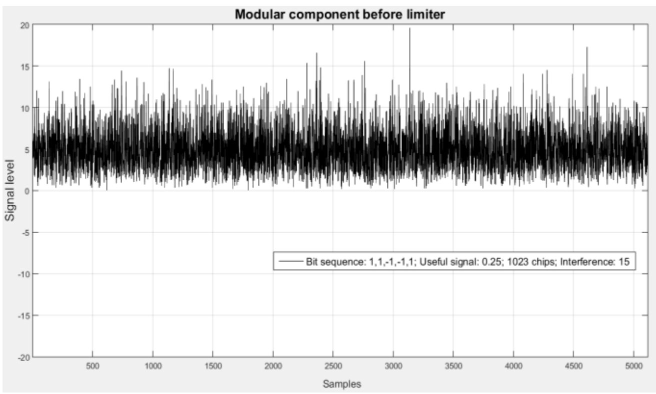

Fig.18. Modular component of the signal mixture before the limiter for interfering signal relative power 15

It is evidenced by the comparison that the relative power greatly increased and it can reach the limits posed by the dynamic range of the receiver.

To overcome the problem of the narrow dynamic range, it is proposed to use the limiter in the receiving unit before the despreading filter. The limitation level is chosen to be that of internal noise level. It is known as the hard limiter.

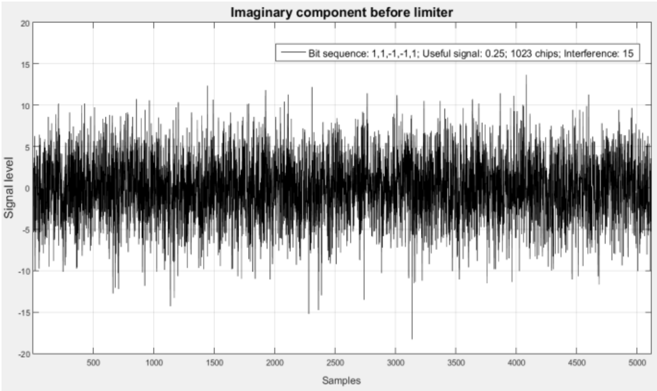

Fig.19. Imaginary component of the signal mixture before the limiter for interfering signal relative power 15

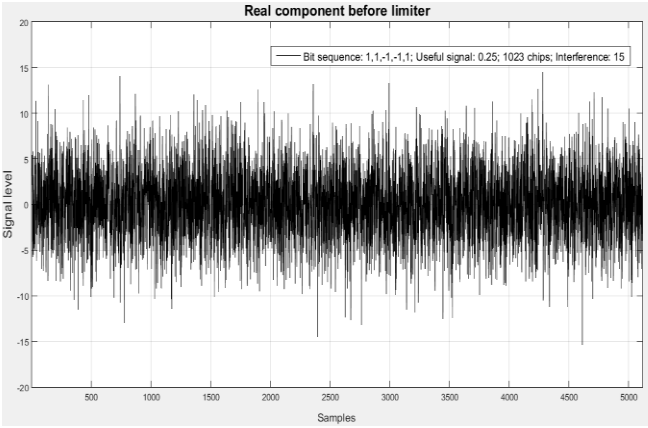

Fig.20. Real component of the signal mixture before the limiter for interfering signal relative power 15

Fig.21 Fig.22 and Fig.23 demonstrate modular, imaginary and real components of the signal mixture at the output of the limiter for the interfering signal relative power of 15 units.

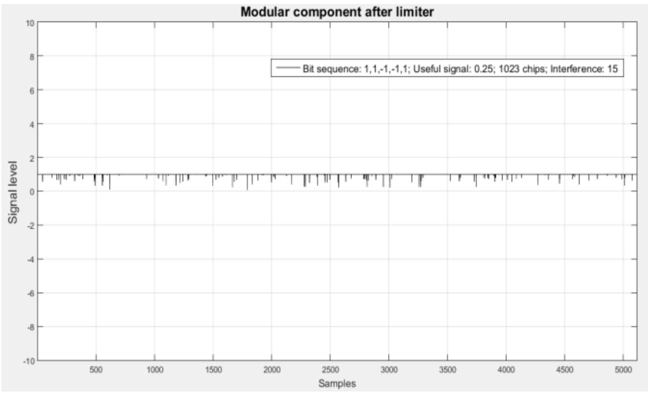

Fig.21. Modular component of the signal mixture after the limiter for interfering signal relative power 15

Data in Fig.21, Fig.22 and Fig.23 show that the limiter substantially reduces the range of the signal mixture.

To assess how the limitation process influences the despreading procedure, the signal mixtures for the interfering signal powers of 7 and 15, which are preprocessed by the limiter, are passed through the despreading filter.

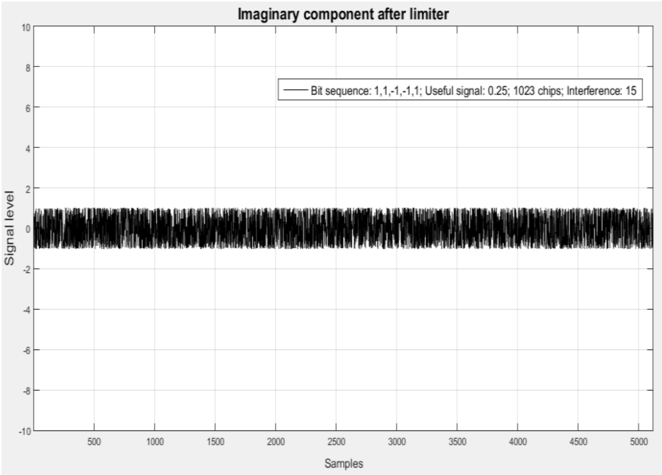

Fig.22. Imaginary component of the signal mixture after the limiter for interfering signal relative power 15

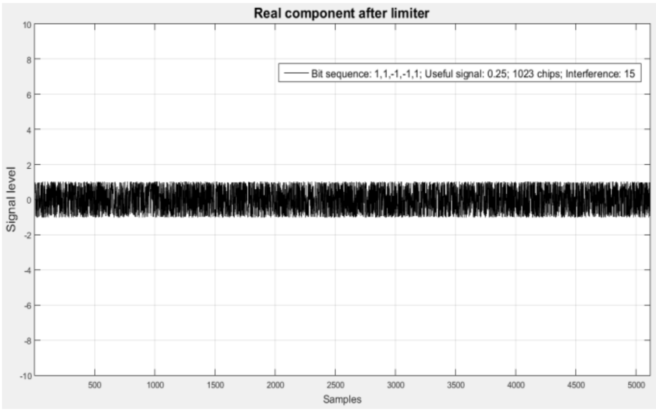

Fig.23. Real component of the signal mixture after the limiter for interfering signal relative power 15

Fig.24, Fig.25 and Fig.26 illustrate the modular, imaginary and real components of the signal mixture with account of the limitation process at the output of the despreading filter for interfering signal power 7.

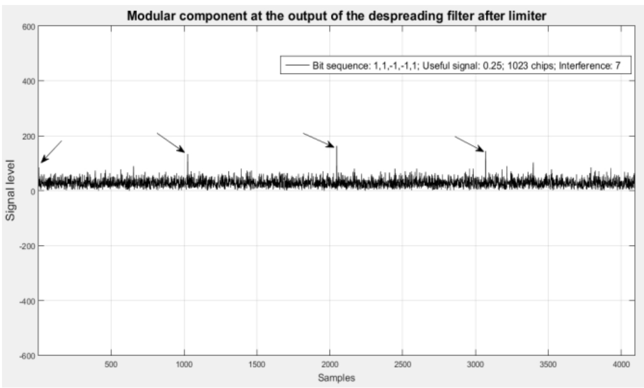

Fig.24. Modular component of the signal mixture at the output of the despreading filter with the limiter for interfering signal power 7

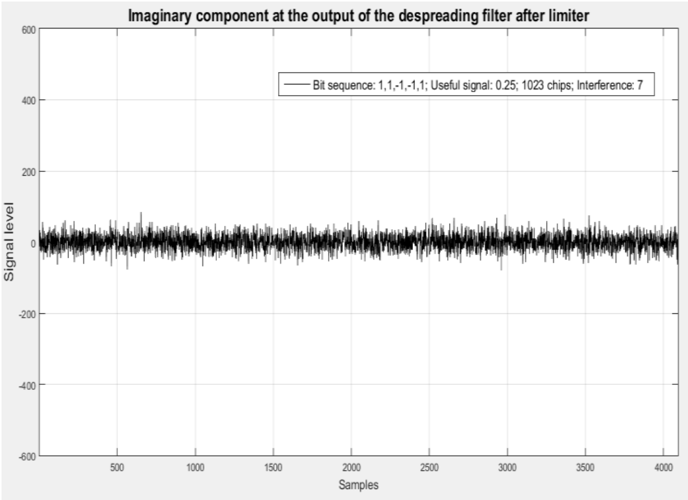

Fig.25. Imaginary component of the signal mixture at the output of the despreading filter with the limiter for interfering signal power 7

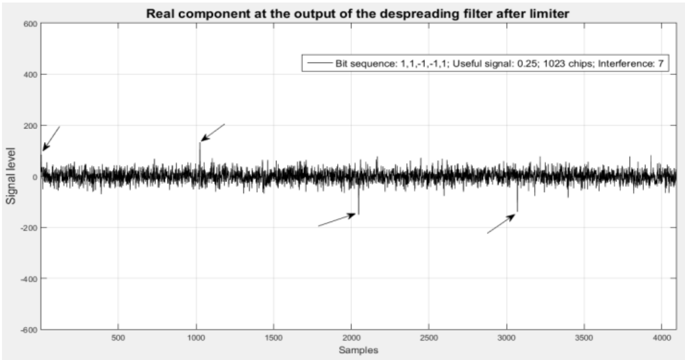

Fig.26. Real component of the signal mixture at the output of the despreading filter with the limiter for interfering signal power 7

The modular, imaginary and real components of the signal mixture with account of the limitation process at the output of the despreading filter for interfering signal power 15 are represented in the Fig.27, Fig.28 and Fig.29.

The arrows indicate the desired bit sequence.

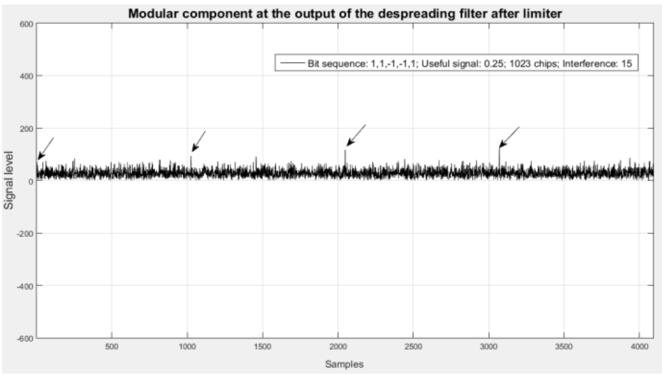

Fig.27. Modular component of the signal mixture at the output of the despreading filter with the limiter for interfering signal power 15

Information in Fig.27 and Fig.29 clearly shows that the desired signal can be extracted at the output of the despreading filter. Still, for the interfering signal relative power 15, as evidenced by the Fig. 29, the ability of the spreading code to secure extraction of the desired signal reaches its limit. This conclusion resonates with that about the data illustrated by the graph in Fig.17.

As a result, the limiter improves performance when the dynamic range is limited, and is equivalent to the performance of the system when the dynamic range is not limited and the limiter is not deployed.

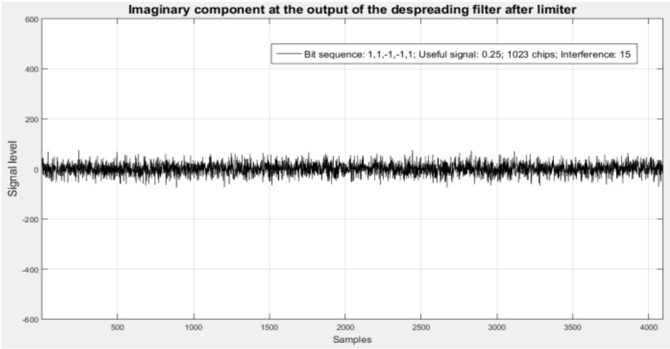

Fig.28. Imaginary component of the signal mixture at the output of the despreading filter with the limiter for interfering signal power 15

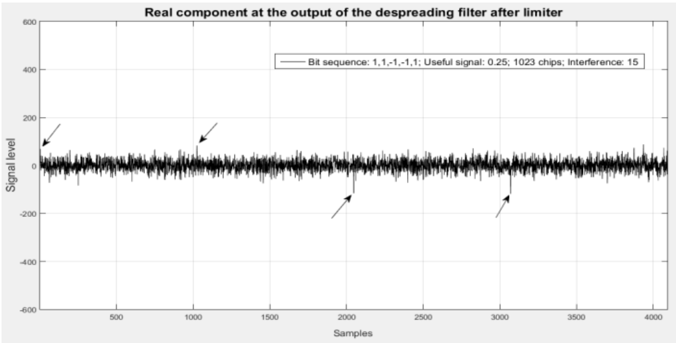

Fig.29. Real component of the signal mixture at the output of the despreading filter with the limiter for interfering signal power 15

Analysis of the computer simulation can give us following inferences:

1. Designed spreading pseudonoise coding sequence has very good correlational properties. When the desired bit sequence being transmitted is without change, those properties are ideal. When the desired bit sequence being transmitted changes signs, correlation properties degrade.
2. Preliminary spreading of the bit sequence with the synthesized pseudonoise coding sequence and with subsequent despreading of this sequence in the matched filter permits to extract the bit sequence that is transmitted in telecommunication channel with the internal noise and interference.
3. Obtained spreading coding sequence secures reception of the desired bit sequence in the channel in which combined level of the interfering signal and the internal noise exceeds the level of the desired signal by up to18 dB.
4. Utilization of the limiter in the telecommunication channel permits to match the dynamic range of the incoming signal mixture and that of the receiving part of the telecommunication channel. Use of the limiter preserves the ability of the technique to extract the bit sequence of the desired signal.

6. Conclusions

Some telecommunication applications, such as in UAV, require robust noise immune and concealed telecommunication channels. To solve this problem spectrum spreading technology is proposed. Spreading technology is a very powerful tool to enhance performance of information transmission in telecommunication systems. Synthesized on the base of tenth degree primitive polynomial, novel 2013-chip coding sequence possesses very good correlational properties and can be used for data spreading in telecommunication channels.

Interfering signals can exceed the dynamic range of the receiving part of the wireless link. In this case, it is offered to use limiters to match the dynamic range of the input signal mixture and that of the receiver. Computer simulation has been performed of the system that uses the synthesized coding sequence for spreading with and without limitation procedure. The simulation results indicate that for the chosen simulation conditions, the limiter does nor degrade the performance as compared to the situation without the limiter and secures desired signal bit sequence extraction from the noise mixture that exceeds the desired signal by up to 18 dBs.

In some cases, this is not enough. To achieve further performance improvement, one should increase the degree of the primitive polynomial and the corresponding length of the sequence. It specifies the area of further research.

Synthesized spreading sequence can be used both on its own and in combination with the limiter for spreading data bits in telecommunication networks.

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