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Adaptation of the CMS Radio Link to the Information Rate in the Presence of Interference

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Abstract. In modern command and measurement systems (CMS), phase-shift keyed signals are widespread, which, with relatively simple methods of formation, have a low level of side lobes of the autocorrelation function (ACF). Also, in recent years, a number of studies have been carried out on the implementation of the principle of constructing a CMS, based on the adaptation of processing algorithms to the properties of useful signals and interference.
On the basis of this principle, an algorithm for adapting the CMS radio link has been developed, which makes it possible to analyze information channels at various speeds and automatically connect the selected channel, which is an urgent task for controlling low-orbit spacecraft.
The article proposes a receiver scheme with parallel reception of several information channels with different information transfer rates. The analysis of autocorrelation and cross-correlation functions made it possible to conclude that the data obtained do not contradict the assumptions about the possibility of implementing an adaptive receiver with the choice of an information channel in terms of speed.
It is shown that the use of such a receiving device with an algorithm for selecting and switching information channels according to the reception rate provides a significant gain in information transmission time in comparison with traditional reception and switching of speeds by commands in conditions of complex interference environment.

Keywords: receiver, channel, radio link, interference, signal

Introduction

Currently space radio links are subject to various types of interference. Exposure to large amounts of interference can reduce the rate of information transmission and cause difficulties in signal reception and information extraction via radio-electronic equipment. Under the influence of interference, radio systems cease to be a source of information despite being serviceable. We can single out several main ways to counter interference [1]:

– increasing the radio link budget (transmitter power, antenna gain);
– decreasing the level of receiver noise;
– decreasing the level of external noise at the receiver input by its compensation;
– implementing joint processing of the interference and the signal based on determining the difference between the valid signal and the interference; and
– increasing the signal-to-noise ratio by using noise-immune modulation and coding methods.

The development of technical solutions providing protection from interference is advancing in the direction of the combined application of the abovementioned method with other techniques, yet the implementation of such solutions requires a certain complication of the equipment.

Single-frequency harmonic interference is cut out in a relatively narrow frequency band, while the useful information is fully restored from the "undamaged" parts of the spectrum. Any interference concentrated in the spectrum at the output of the correlation receiver is converted using pseudo-noise signals (PNSs) into broadband and is effectively suppressed.

The efficiency of receiver operation in the presence of interference depends on the choice of the type of modulation, coding and methods of signal processing in the receiver. The issues of coding and symbol interleaving are independent areas of research; hence, we will dwell only on the problems of receiving selected signals in the presence of interference.

Pseudo-noise signals (PNSs), which demonstrate a low side lobe level (LSL) of the autocorrelation function (ACF) at the relative simplicity of the ways of their shaping, have become widespread in modern command and measurement systems (CMSs). In addition, an array of studies have been conducted in recent years dedicated to the implementation of the CMS construction principle based on the adaptation of processing algorithms to the properties of useful signals and interference [2].

Based on this principle, an algorithm for adapting the CMS radio link that allows selecting the information channels by the results of their analysis at different rates and automatically connecting the selected channel, which is very important for controlling low-orbit spacecraft (SC), has been developed.

The modern development of hardware components and computer technology in line with the recommendations of the CCSDS [3] (Consultative Committee for Space Data Systems) will improve and boost noise-immunity as well as reduce the time of communication establishment in command radio links with PNSs.

Basic principles of operation of an adaptive receiver with parallel reception of several information channels with different data transmission rates

As noted in [4], "for radio links with complex spread spectrum signals, the combined effect of noise and structural interference is typical. In multichannel systems, structural interference is conditioned by the mutual influence of channels combined in one radio link, and in multi-satellite systems – by the mutual influence of inter-satellite radio channels operating in the allocated frequency band. Apart from this, radio channels with complex signals may be affected by intentional structural interference. The effect of noise and structural interference is the most complex in terms of assessing the noise-immunity indicators of data transmission and synthesizing the optimal processing of received signals."

The noise immunity of signal reception for broadband signals (BBSs) is determined by the bandwidth-duration product, which is equal to the ratio of the information signal band to the band of the broadband signal.

Interference at the receiver input can be several times higher than the useful signal. This can be a result of both naturally occurring noise, intentional interference and the receiver's own noise. In this regard, it becomes necessary to create reliable communication systems able to transmit information in the presence of interference with a given probability [5]. A correlation receiver based on pseudo-random sequences can be used as such a system.

In practice, a serial-parallel processing procedure is implemented during signal detection. Figure 1 demonstrates the structural diagram of the receiver performing parallel reception of signals at different information rates and automatic connection of the required channel.

Let us consider the principle of operation of the receiver under development. Command and program information (CPI) is fed into the input of the receiving path of the onboard equipment. The receiver selects the signal at multiple information rates in use. The input combination of signal and noise $y(t)$ enters m parallel operating channels (Fig. 1), each of which is tuned to its own reception clock frequency.

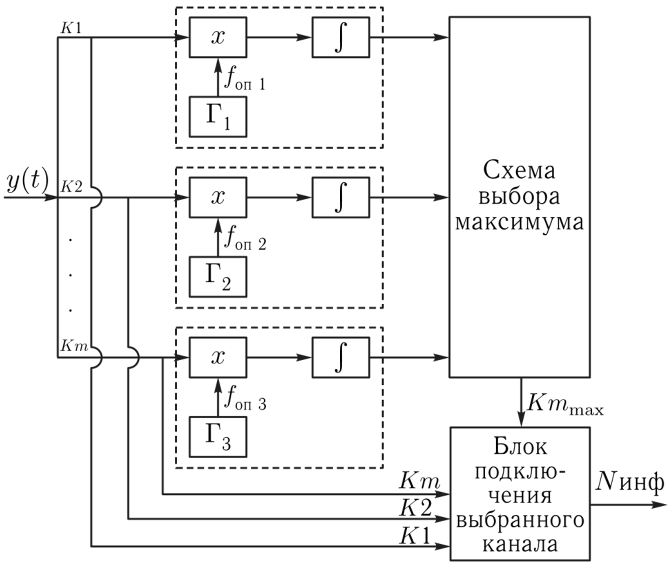

Fig. 1. Functional diagram of signal parallel reception with different information rates and automatic connection of the required channel.

The readings obtained from the correlation receivers are fed into the maximum selection circuit (MSC), where they are compared with the threshold. As a result of the comparison, a decision is issued as to which of the m signals is to be transmitted. The decision will be made based on the maximum level of the output signal in one of the assigned channels. The selected channel connection unit (SCCU) automatically connects one of the m-channels with the selected information rate for separating the required data.

The proposed method for receiving information allows the link to adapt to the information rate. The onboard receiver analyses all the m-channels and selects the channel of ground station operation. The fact of signal reception is reflected in the receipt signal.

This saves time for switching the CPI transmission rate. If the CPI is not accepted by the onboard equipment, then the ground station automatically switches to a lower rate (without commands).

Information channel selection algorithm

In radio links, CMSs can change the CPI transmission rates, for example, 1 kbit/s, 8 kbit/s, 16 kbit/s, 32 kbit/s, 128 kbit/s, 256 kbit/s. The external interference environment affecting the CMS radio link requires prompt delivery of the information volume to the SC.

As an example of CPI, Table 1 gives the structure of transmitted information in accordance with CCSDS [6] recommendations.

According to Table 1, each CPI block is preceded by the start sequence that is transmitted at the same clock frequency as the information. The detection of the start sequence can be used to judge the rate of the transmitted information. As an example, a start sequence was chosen that is an M-sequence (Fig. 2) with a period $M = 2^5 - 1 = 31$ with the corresponding fifth-degree generator polynomial given in Table. 2. The decision on channel selection and, consequently, the information transmission rate can be made by detecting the start sequence.

Table 1. Components of the data transmission unit

Command link transmission unit		
Start sequence	Encoded data	Tail sequence
31 symbols	Codeblock	Length of one codeblocka

Table 2. M-sequence

M-sequence	Generator polynomial $h(x)$
0000100101100111110001101110101	$h(x)= x^5 +x^2 + 1$

Using a program written in the C++ programming language, graphs for the correlation functions were calculated and plotted. The graphs obtained with the help of this program are shown in Figs. 2–5.

The analysis of the auto- and cross-correlation functions shows that the maximum side lobe level of the ACF sequence does not exceed the level of 0.3 relative to the normalized level 1. Figures 4 and 5 show that the outliers of the start sequence cross-correlation functions at rates of 8 and 16 kHz do not exceed a value of 0.48 of the normalized value, which will make it possible to select a channel with the required transmission rate.

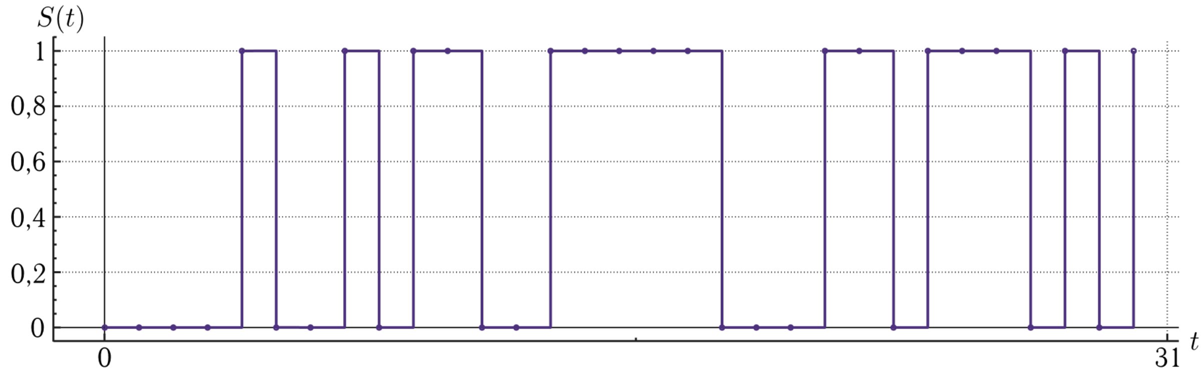

Fig. 2. M-sequence.

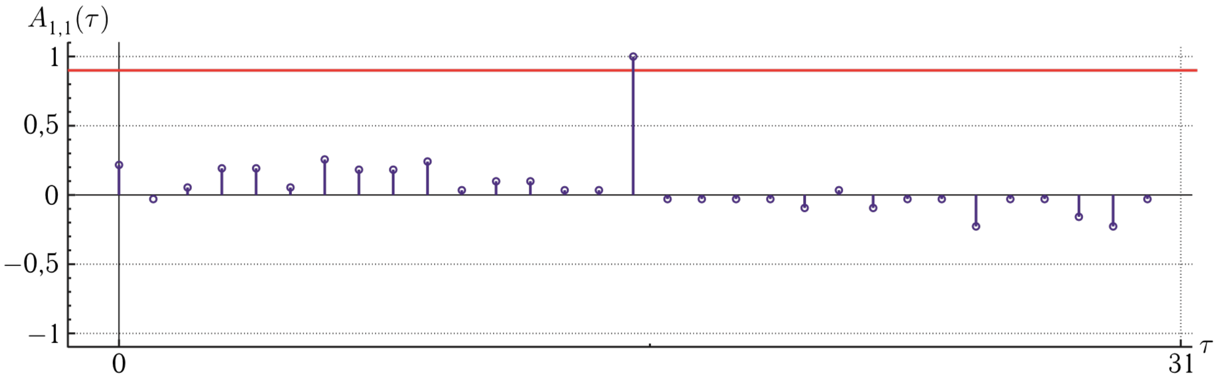

Fig. 3. Autocorrelation function for a clock frequency of 1 kHz in channel 1 (K1).

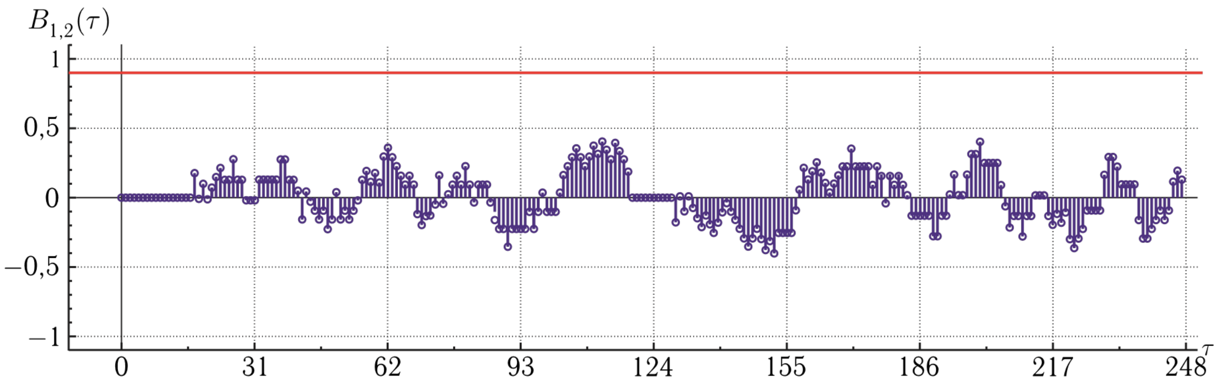

Fig. 4. Cross-correlation function for a clock frequency of 8 kHz in channel 2 (K2).

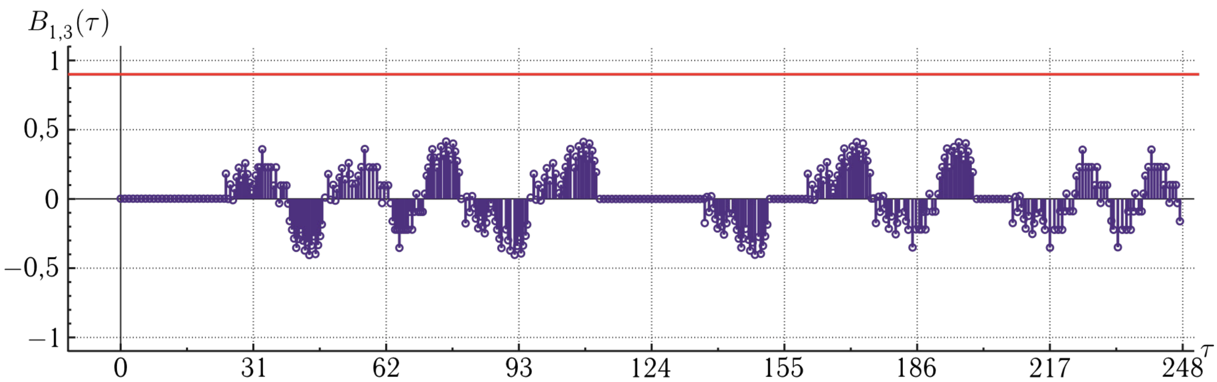

Fig. 5. Cross-correlation function for a clock frequency of 16 kHz in channel 3 (K3)

Conclusion

The analysis of autocorrelation and cross-correlation functions allowed us to conclude that the data obtained do not contradict assumptions concerning the possibility of implementing an adaptive receiver with rate-based selection of the information channel.

The use of such a receiving device with the capability to adapt the CMS radio link to the interference in terms of the information transmission rate in the presence of interference provides a significant gain in time of information transmission in comparison with traditional reception and switching of rates by commands.

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