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Pseudo-random code vocabulary extension using dual signal correlation processing

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Abstract: *The aim of research is the adaptation of code division multiple access (CDMA) technics for a radio frequency identification systems based on surface acoustic waves technology. The object of this research is a pseudo-random code of CDMA systems. The question of increasing the pseudo-random code vocabulary size, while maintaining good correlation characteristics is under consideration. The criterion for quality of pseudo-random code is the level of multiple access interference (MAI). This criterion is estimated by the maximum level of aperiodic correlation function between each pair of code words. The solution of the problem is achieved by signal processing and does not affect coding issues. A code is generated with necessary vocabulary size and a minimum level of MAI is achieved by using dual correlation processing. The concept of dual correlation processing is to seek a correlation function for two weakly dependent information features of the code. An additional informational sign is the amplitude spectrum of a code word. The correlation characteristics of the code after processing are modeled.*

Keywords: *CDMA, RFID, SAW, code extension, pseudo-random code.*

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Расширение словаря псевдослучайного кода с помощью двойной корреляционной обработки сигнала

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Аннотация: *Целью исследования является адаптация технологии множественного доступа с кодовым разделением (CDMA) для системы радиочастотной идентификации на поверхностных акустических волнах. Объектом исследования является псевдослучайный код системы CDMA. Рассматривается вопрос увеличения словаря псевдослучайного кода с сохранением приемлемых корреляционных характеристик. Критерием качества псевдослучайного кода является уровень помехи множественного доступа (ПМД), который оценивается по максимальному уровню апериодической корреляционной функции между каждой парой кодовых слов. Решение задачи достигается обработкой сигнала и не затрагивает вопросы кодирования. Генерируется код с тем размером словаря, который нужен, а минимальный уровень ПМД достигается с помощью двойной корреляционной обработки. Концепция двойной корреляционной обработки заключается в том, чтобы искать корреляционную функцию по двум слабо зависимым информационным признакам кода. Дополнительным информационным признаком является амплитудный спектр кодового слова. Промоделированы корреляционные характеристики кода после обработки.*

Ключевые слова: *CDMA, РЧИД, ПАВ, расширение словаря, псевдослучайный код.*

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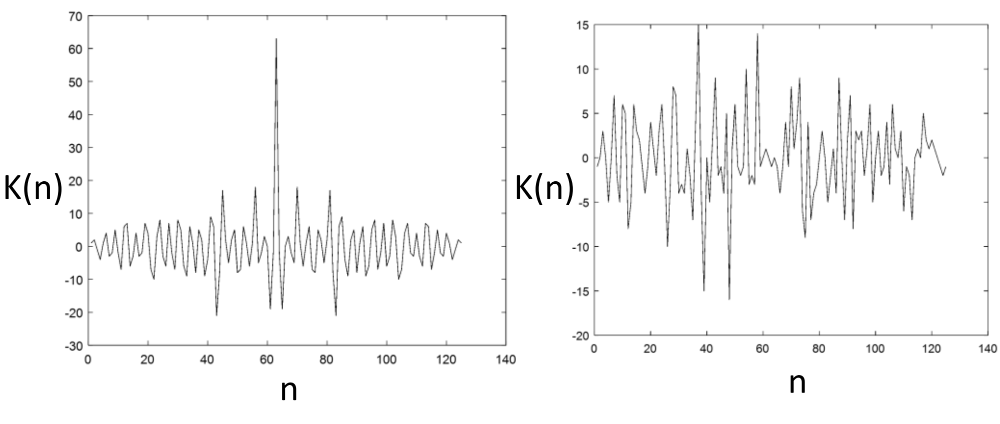
1. Introduction

Code Division Multiple Access (CDMA) systems are based on matched filtering and channel separation of information traffic using orthogonal or pseudo-random codes. The subject of the research is a pseudo-random code. The code must meet two requirements: to ensure maximum correlation when a signal passes through the filter of its "own" channel and to provide minimal, but non-zero emissions of the cross correlation function (CCF) when the signal passes through the filter of an "alien" channel. In practical applications pseudo-random binary codes of Gold and Kasami are currently used. The level of CCF between code words in them corresponds to the Sidelnikov's bound, defined as

$$\rho_{max} = \sqrt{\frac{2}{N}} \quad (1)$$

where N is a number of symbols in code [1].

The level of emissions corresponds to the bound (1) only if we calculate the periodic CCF. For an aperiodic CCF the emission level asymptotically approaches to the bound by increasing N. The level of the aperiodic CCF unambiguously determinates the level of multiple access interference (MAI), the main characteristic of a pseudo-random code [2]. A typical view of the response of matched filter to "own" and "alien" signal is shown in Fig. 1.



а б

Fig 1. The response of the matched filter to "own" (a) and "alien" (б) code.

Рис. 1. Реакция согласованного фильтра на «свой» (а) и «чужой» (б) код

A number of valid code words in the Gold and Kasami code vocabularies is a sequences of N and $N^{1.5}$ respectively. There are other applications in which CDMA technology may be used, but this vocabulary size is insufficient. An example of such application is a passive radio frequency identification system (RFID). The focus is on a fully passive RFID system with use of surface acoustic wave (SAW) technology [3]. The main feature of such system is an inability to change the channel code.

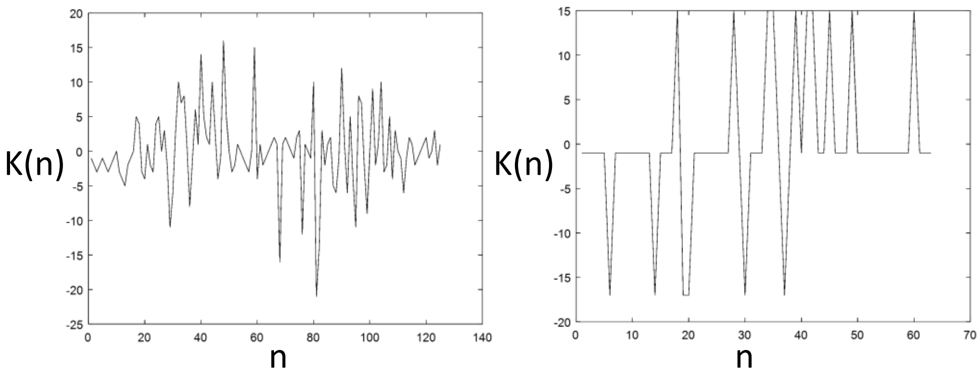
2. Statement of the problem

Study the possibility of pseudo-random code vocabulary extending is made in order to adapt CDMA technology for RFID systems. The RFID system has a number of important features which defines it from other CDMA systems. The main difference is that RFID system is not a data transmission system. It means that it does not transmit a continuous stream of data. As a result, there is no requirement to process data in real time, and for MAI analysis an aperiodic CCF will be used and not a periodic one which is applied to data transmission.

The task is to increase vocabulary size of pseudo-random code by no more than N^2 times compared to the Gold code. That is, the vocabulary size should be no more than N^3, where N is the number of symbols of a binary code. At the same time, the correlation characteristics of the code should be close to the Gold and Kasami codes, that is equal to bound (1). The task can be solved in one of two ways; either to generate a code with the required correlation characteristics to process the signal so that the level of the MAI had corresponded to a given bound while making decision. The pseudo-random code with the vocabulary size N^3 which CCF corresponds to the bound (1) and is currently unknown. This code can be found with a blind search. The algorithm of that is given in [4]. However, such kind of search requires completely unreasonable resources for calculating. Therefore, the signal processing shall be used.

There is a question how to estimate a MAI of pseudo-random code. Typically, in CDMA systems it is sufficient to estimate MAI basing on maximum level of a periodic CCF between a pair of code words. To make it clear the aperiodic and periodic CCF diagram of Gold code with a length of 63 symbols in Fig. 2 are stated below.

In figure above is shown that a periodic CCF of the Gold code can generally take only three possible values and looks the similar for any pair of code words. The maximum of these values corresponds to the bound (1). There is another pseudo-random code commonly used in CDMA, it is Kasami code in regard to the aperiodic CCF, its maximum value is located near the bound, but the CCF value between any specified code pair is unpredictable. It is necessary to analyze the entire code family to obtain reliable information about MAI. Obviously, it is impossible to do this using CCF diagrams because there will be too many of them. To simplify the analysis, we compose the matrix of CCF peak values between each code wordand use this matrix for further analysis. The matrix is shown in Fig. 3.



a b

Fig. 2. Aperiodic (a) and periodic (b) CCF of Gold code

Рис. 2. Апериодическая (а) и периодическая (б) ВКФ кода Голда

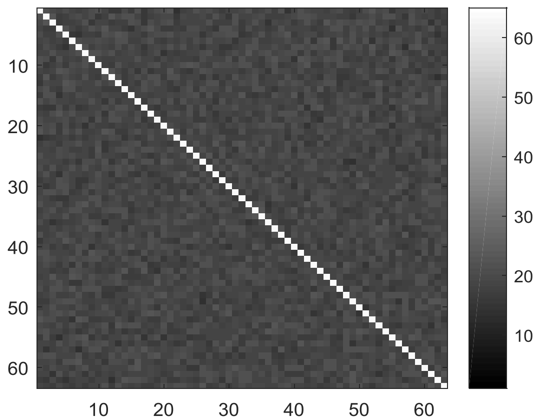


Fig. 3. Cross correlation matrix of Gold code.

Рис. 3. Матрица ВКФ кода Голда

Values of autocorrelation functions (ACF) are located on the main diagonal of matrix. All other elements can be normalized to ACF values.

In order to estimate the number of code pairs with each level of CCF it is necessary to construct a histogram of all matrix elements (Fig. 4)

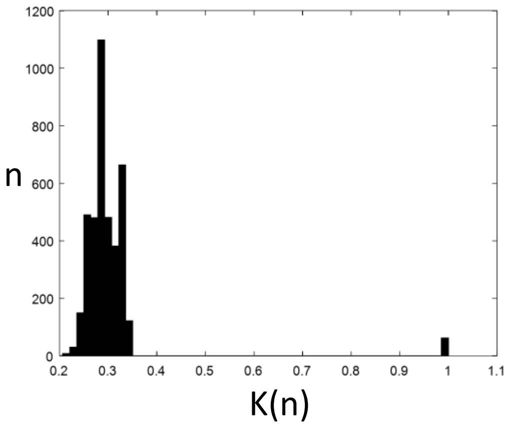


Fig. 4. The normalized cross correlation histogram of Gold code.

Рис. 4. Нормированная гистограмма максимумов ВКФ кода Голда

The position of the global extremum corresponds to the bound (1) on this histogram.

The cross-correlation matrix is formed to provide the ability to decisive device of the receiver to determine whether this channel is “own” or “alien” on the base of matrix CCF values. If we exclude the ACF column, then the histogram of these maxima will have the physical meaning of multiple access noise probability density, and can be described by the same parameters that usually describe the probability density of any other random value.

The Gold code with a length of 63 symbols has only 63 code words in vocabulary. Another popular pseudo-random code is Large Kasami sequence, which contains 441 code words for the same length. The CCF histogram of the Large Kasami sequence is shown in Fig. 5.

The periodic CCF of the Kasami large sequence code words is also strictly optimal along the bound (1).

Multiple access with low MAI and with extended code vocabulary will be provided by signal processing and not by coding. However, the extended code needs to be generated, which is quiet sophisticated task. It will be desirable; a code should still have MAI as low as possible in order to simplify further processing.

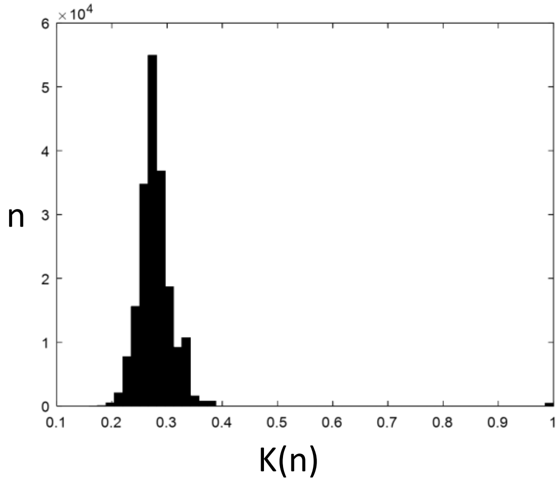


Fig. 5. The normalized cross correlation histogram
of Large Kasami sequence.

Рис. 5. Нормированная гистограмма максимумов ВКФ
Большого семейства Касами

There are several ways to generate code with a desired vocabulary size. The codes widely used for channel coding can be applied for solution of this task. For example, the Hamming code and derivatives of it. Several methods of obtaining the extended code were observed by experiment. The best correlation properties had code obtained in the following way:

At first stage, three pseudo-noise sequences (PN-sequences) PN1, PN2, PN3 of the same length N are formed [2].

Then, modulo-2 sum of each symbol of all three PN-sequences is produced. The resulting sequence is the first code word.

To performe a cyclic shift of all elements of the sequence PN3 and again, modulo-2 sum of elements in sequences PN1, PN2, PN3 are produced. The result is the second code word.

Repeat this operation with all possible cyclic shifts of mother's sequences PN2 and PN3.

As a result, it is a code with vocabulary of N^3 code words.

To obtain a code with a vocabulary of N^4 or N^5, it needs to generate 4 or 5 PN-sequences, respectively.

The correlation properties of codes with vocabulary of N^3, N^4 and N^5 code words are identical and have a form shown in the histogram on Fig. 6 [5].

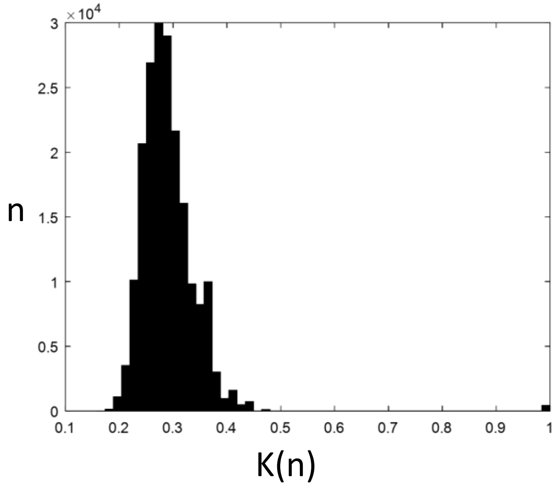


Fig. 6. The normalized cross correlation histogram of extended code.

Рис. 6. Нормированная гистограмма максимумов ВКФ расширенного кода

The CCF matrix hereinafter has been compiled for the first 441 code words for the extended code in a figure. This does not modify correlation characteristics of code, but it becomes possible to compare the numerical values on histogram with the Large Kasami sequence.

3. Method of dual correlation processing

The main idea of dual correlation processing method is a searching for correlation functions of two weakly correlated characteristics of complex signal. To make a conclusion about signal compliance to the code word from vocabulary by using two correlation functions jointly. If the signal passes through "own" filter, the maximum of the normalized ACF in any case will be equal to 1. If the signal passes through an “alien” filter, then the level of output MAI from at least one filter with high probability will not exceed (1). On the other hand, the decisive device will consider that the “own” signal has received only when the responses of both matched filters exceed the threshold. The first characteristic, which is used to calculate the correlation function, is the complex envelope of the encoded signal in the time domain, and the second characteristic is the discrete cosine transform (DCT) spectrum of this envelope. Instead of DCT spectrum, the Fourier amplitude spectrum can also be used. An illustration of the proposed method is shown in Fig. 7.

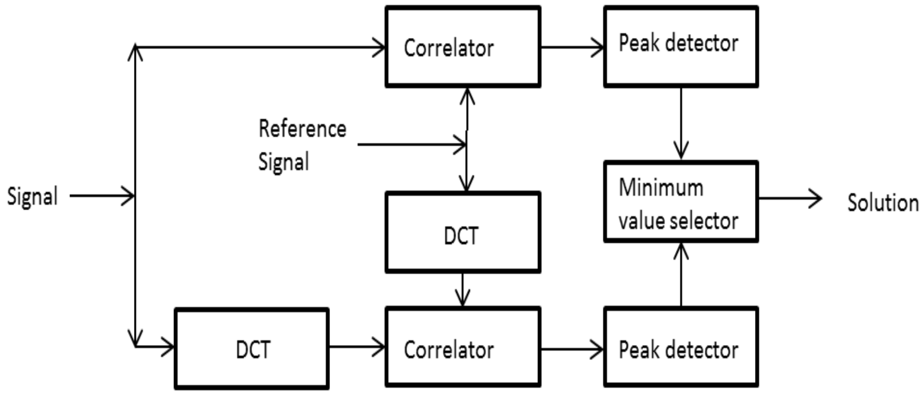


Fig. 7. Block diagram of dual correlation processing method.

Рис. 7. Структурная схема метода двойной корреляционной обработки

The cross correlation histogram of any code after DCT will look like it is shown in Fig. 8.

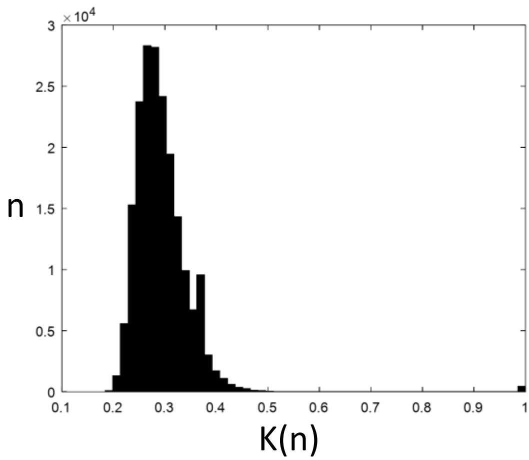


Fig. 8. The normalized cross correlation histogram of extended code after DCT.

Рис. 8. Нормированная гистограмма максимумов ВКФ
расширенного кода после ДКП

The CCF between each code pair of the extended code both before and after the DCT significantly exceeds the bound (1), but there are a few such pairs, and they are different for cases before and after DCT. In order to make a decision a minimum of the two correlation values is chosen. This value with a high probability will not exceed the typical value for the Gold and Kasami codes.

4. Modeling of dual correlation processing method and the results

Modeling of the method consists of extended code generation and afterwards CCF matrix code generation from it. Then, the DCT is produced with each line of the extended code, and for the resulting elements it also finds the cross correlation matrix. Finally, each element of two cross correlation matrixes is compared and we choose the smallest in modulus. The histogram of the resulting cross correlation matrix is shown in Fig. 9.

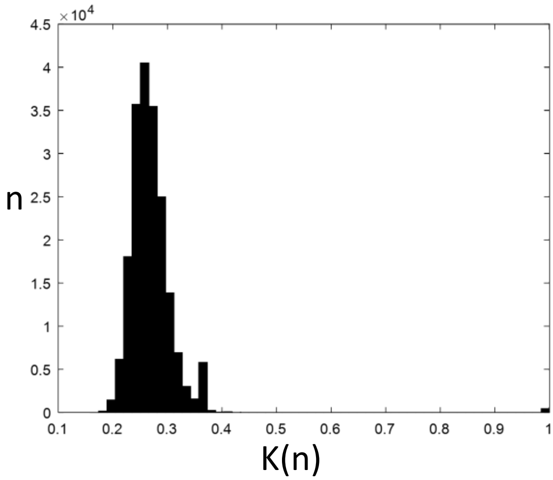


Fig. 9. The resulting cross correlation histogram of the extended code after the dual correlation processing.

Рис. 9. Результирующая гистограмма максимумов ВКФ расширенного кода после обработки методом двойной корреляции

We can compare histograms of Gold, Kasami and extended codes after processing in Fig. 4, 5 and 9 respectively. These codes have a length of 63 symbols and vocabularies of 63, 441 and 3969 code words. The figures show that the maximum values of code CCF after processing do not exceed those of the Kasami code. The average value of the extended code histogram is slightly higher than that of the Kasami code. However, it is worth noting that the Kasami code itself also has an average value on the histogram compared to the Gold code, and this parameter has a linear dependence on the number of words in vocabulary. Note that if the dual correlation method is applied to Gold and Kasami codes, it won’t have any significant effect because these codes are initially close to the optimal correlation characteristics.

5. Conclusion

Dual correlation processing allows to use pseudo-random code with a high level of MAI, but actually with the same properties as pseudo-random codes with the lowest possible level of MAI, in other words those codes that are widely used in CDMA systems. It allows to extend significantly the vocabulary of codes suitable for use in CDMA systems. Hence, CDMA technology can be applied to those tasks for which it has not previously been used, in systems which the identification code cannot be changed. An example of such system is a SAW RFID system.

The application of the dual correlation method is an important but not the only one step taken to solve a problem of adaptation a CDMA technology for SAW RFID systems. Another important step is the reduction of peak search area within the correlation function. This is possible due to the fact that RFID systems operate with no more than tens of meters distances. This step also reduces the level of MAI and complete the dual correlation method.

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