FREQUENCY SHIFT KEYING SIGNALS APPLICATION POSSIBILITY IN IDENTIFICATION SYSTEMS

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Abstract

In this paper the possibility of creating a radio signals family with *M*-ary random frequency shift keying (FSK) modulation and the desired correlation properties for use in radiofrequency identification systems (RFID) was researched. The radio signal mathematical model, as well as the algorithm of the program, through which the desired selection of the signals family was realized, are described. Results of the research are clearly illustrated graphically.

I. INTRODUCTION

Identification is the process of object recognition (or classification) by its identifier. The object identifier is presented to a reader that reads and transmits object's individual code to the system of identification for the procedure of recognition. Identification object may be human, animal, vehicle, equipment, container cargo, goods, valuables, etc. Non-contact means of electronic identification (semiconductor devices and devices on surface acoustic waves) began to widespread recently. Applications for electronic identification are rapidly introducing in almost all spheres of human activity.

II. DATA ENCODING PRINCIPLES IN RFID SYSTEMS

Identifier's individual codeword is a set of symbols. Each symbol m_i, where $i = 1,\dots,M$, can be regarded as an element of a finite alphabet, containing M elements. When $M = 2$ the encoding is binary and each symbol carries one bit of information. When $M > 2$ encoding is called *M*-ary. The amount of information in bits, carried by one symbol of a finite alphabet, can be calculated by the formula: $b = \log_2 M$.

Data encoding in RFID systems is made through the modulation of radio signals. Currently a large number of modulation variants are used. There are three main groups among them: amplitude, phase and frequency modulation. Most of the used types of modulation are versions of ones listed above.

III. MATHEMATICAL MODEL OF INVESTIGATED RADIO SIGNALS

It is practically interesting to explore the possibility of using FSK modulation in RFID systems [1]. Radio signal with FSK modulation is a set of rectangular radio pulses with instantaneous frequency, abruptly changing from pulse to pulse by a certain law.

M-ary FSK modulation with random arrangement of radio pulses in the signal was considered. Random nature of the modulation increases the achievable amount of individual identifier's code words.

Let us consider a signal with *M*-ary random FSK modulation. It represents N rectangular radio impulses-symbols, closely adjoining to each other, having the same amplitude A_c and duration t_c. The frequency of the oscillations in the symbols changes in steps from a symbol to symbol in accordance with a certain code and takes one of the values from the range of frequencies (f_l ; f_u), where f_l and f_u - are the lower and upper frequencies of the active signal spectrum band respectively. Deviation between adjacent frequencies is the same and is determined from the condition: $\Delta f = \Delta F/M$, where ΔF – the signal's set active frequency band, M - total number of frequencies in the considered range. In general, there is a random ratio between M and N. In this work we studied $M = N$ case. The amount of information, carried by such a signal, can be calculated as follows: $b = N \cdot \log_2 M$. When $M = N = 16$ $b = 64$ bit.

The following demands are produced to the investigated radio signals:

1. Symbols, which make up the FSK signal, must be orthogonal to each other. The symbols orthogonal condition is the ratio: $\Delta f \cdot t_c = q$, where q is a natural number, t_c is the duration of the symbol.

This parity is valid for random initial phase of oscillations within the symbol. The minimum symbol duration for a given Δf is achieved with $q = 1$. In this case the orthogonality condition takes the form: $\Delta f \cdot t_c = 1$. [2]

2. Frequency manipulated codeword should be a random set of M integers. These numbers define the location of symbols in the signal. In this work we consider the equiprobable statistical law of symbols arrangement.

Taking requirements into account, complex envelope of the FSK signal can be represented as:

$$S_k(t) = \sum_{i=1}^{N} \Big\{ A(t-(i-1)\cdot t_c) \times \times \exp\left[j \cdot 2 \cdot \pi \cdot \Delta f \cdot \left(b_i - \frac{M+1}{2} \right) \cdot t \right] \Big\} \quad (1)$$

Here k is the serial number of the signal, i – the serial number of a symbol, b_i – a random value of the frequency manipulation codeword,

$$A(t) = \begin{bmatrix} A_c, 0 \le t \le t_c \\ 0, t > t_c \end{bmatrix}$$

Figure 1 shows the timing diagram of 6 symbols FSK signal.

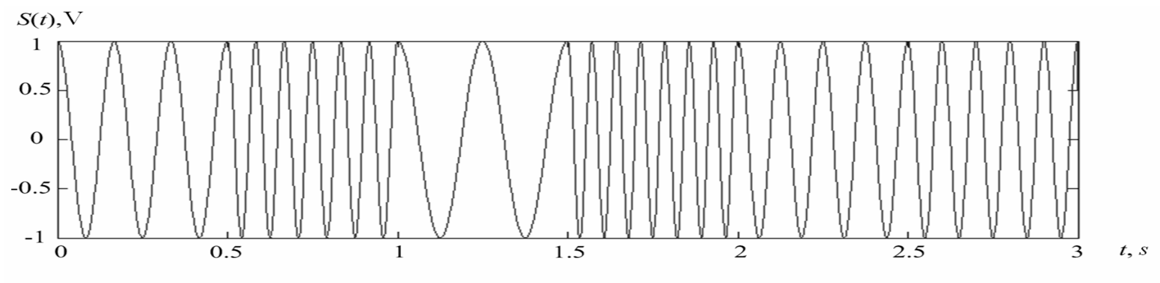

Fig. 1. FSK modulated signal

In the case under consideration as a radio signal carrier frequency we will consider the central frequency of FSK signal spectrum. The active frequency band of the complex envelope spectrum will occupy the band [-ΔF/2; ΔF/2].

IV. ALGORITHM OF THE DESIRED RADIO SIGNALS FAMILY SELECTION

In making decisions about ownership of the received signal for the classified object, the principle of matched filtering is used. If the received signal matches with the filter, the signal at the output reaches a maximum value (autocorrelation function (ACF) of received signal). If the received signal does not match with the filter, its value at the output is much smaller than ACF. Thus, by comparing the output signal with a given threshold, we can identify an object from a group of objects.

In this work it was studied the possibility of M-ary random FSK modulation applying to create a family of radio signals, within which cross-correlation function (CCF) of any pair of signals would not exceed a set level.

From signal theory we know, that the signal's ACF is defined by the expression:

$$B_s(\tau) = \int_{-\infty}^{\infty} s(t)s(t-\tau)dt, \quad (2)$$

and a CCF is defined by the expression: [3]

$$B_{12}(\tau) = \int_{-\infty}^{\infty} s_1(t)s_2(t-\tau)dt \quad (3)$$

The signals family is the set of FSK signals, satisfying the above requirements, as well as having a specified level of the CCF.

Searching of the desired FSK signals family was made by the method of mathematical modeling in the package MATLAB. Operator *randperm*, that implements a random set of numbers with equiprobable statistical law of their values, used to generate frequency manipulation codes. These numbers describe the order of symbols arrangement in the signal. Samples of these numbers, generated by the operator *randperm*, can be correlated, so we need to make their correlation assessment. When $M = N = 16$, the number of possible code sequences equal to the number of 16 symbols permutations (without repetitions of numbers in the sequence). This number is equal 16!, i.e. more $2\ 10^{13}$. Direct CCF calculation of all signals that can be implemented on the basis of these codes would require unacceptably long time. The algorithm was divided into two phases. At the first phase primary correlation assessment of frequency manipulation codes and selection of appropriate candidates to the array were carried out. A selection criterion was the maximum number of symbols matches in a random selected pair of signals. As matching of symbols we will name the fact of identical symbols, finding on the same position in signals. If the number of symbols matches exceeds a set level, the selected sequence was discarded. If not exceeded, the sequence enrolled in the family candidates. In the second stage cross-correlation functions of all family candidates are calculated by the *xcorr* operator. Normalization of the selected signals CCF level to the ACF level was performed, and they were compared with a specified threshold.

The maximum value of all signals ACF in the case $M = N$ is the same, because this maximum is determined by the signal energy, which does not vary from the symbols permutation.

V. RESEARCH RESULTS

In this work studies were carried out in the $M = N = 16$ case at an active bandwidth of the signal $\Delta F = 50$ MHz; the number of references to the operator *randperm* - 10^8; the maximum number of symbol matches by the first criterion - 4; the set maximum level of normalized CCF – 0.3. At such statement of the task it was possible to create the group of 237 signals. The calculations results are presented in the form of array, recorded in computer memory and containing the family of the selected signals; ACF and CCF graphs of several signals, as well as the correlation matrix. Correlation matrix is a three-dimensional histogram, in which the serial numbers of family members laid on the x and y axes, and at the intersection of family numbers the signals relative CCF level (for $x \neq y$) or the ACF level (for $x = y$) laid on the z axis. In this paper the results of calculations are presented for the $M = N = 12$ case at an active bandwidth of the signal $\Delta F = 50$ MHz; the number of references to the operator *randperm* – 10^4; the maximum number of symbol matches by the first criterion - 4; the set maximum level of normalized CCF – 0.3. In this case it was possible to create the group of 43 signals. Figure 2, as an example, shows graphs of the normalized CCF envelopes of two pairs of signals, randomly selected from the resulting family. The graph shows, that the relative level of the CCF actually does not exceed a set level 0.3. Figure 3 shows graphs of the normalized ACF envelopes of two signals, randomly selected from the group. It is evident, that the relative magnitude of the maximal ACF level is numerically equal to unity.Figure 4 shows the correlation matrix. The graph shows, that family signals ACF lies on the $x = y$ line; the family signals CCF are in the field $x \neq y$, and their relative level is less than 0.3.

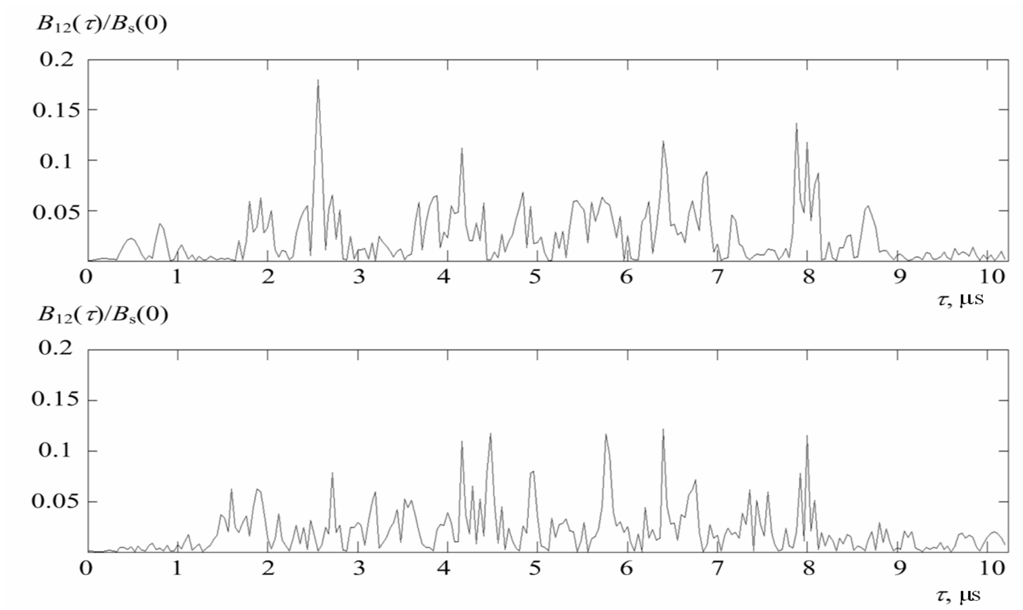

Fig. 2. Normalized CCF envelopes of two random signal pairs

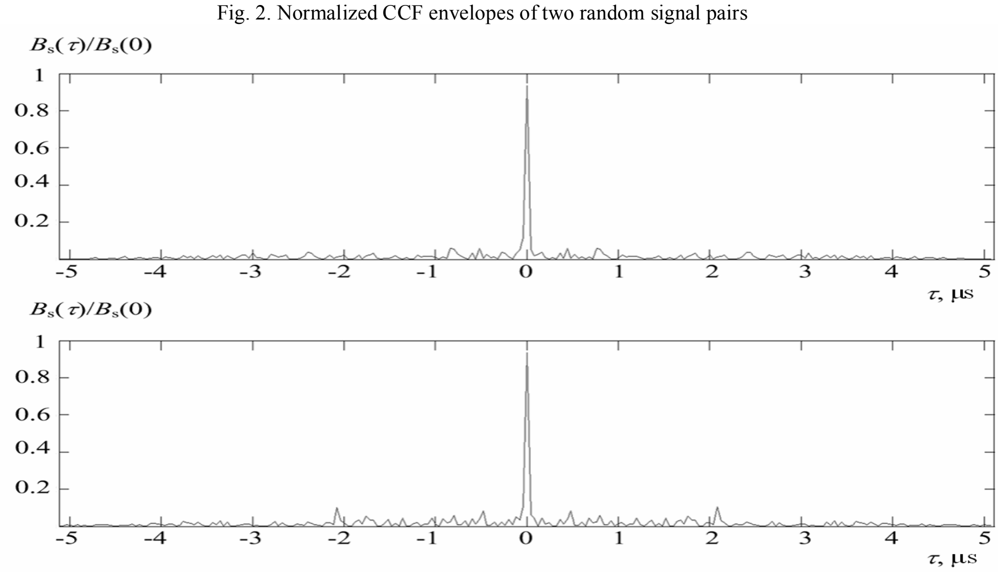

Fig. 3. Normalized ACF envelopes of two random signals

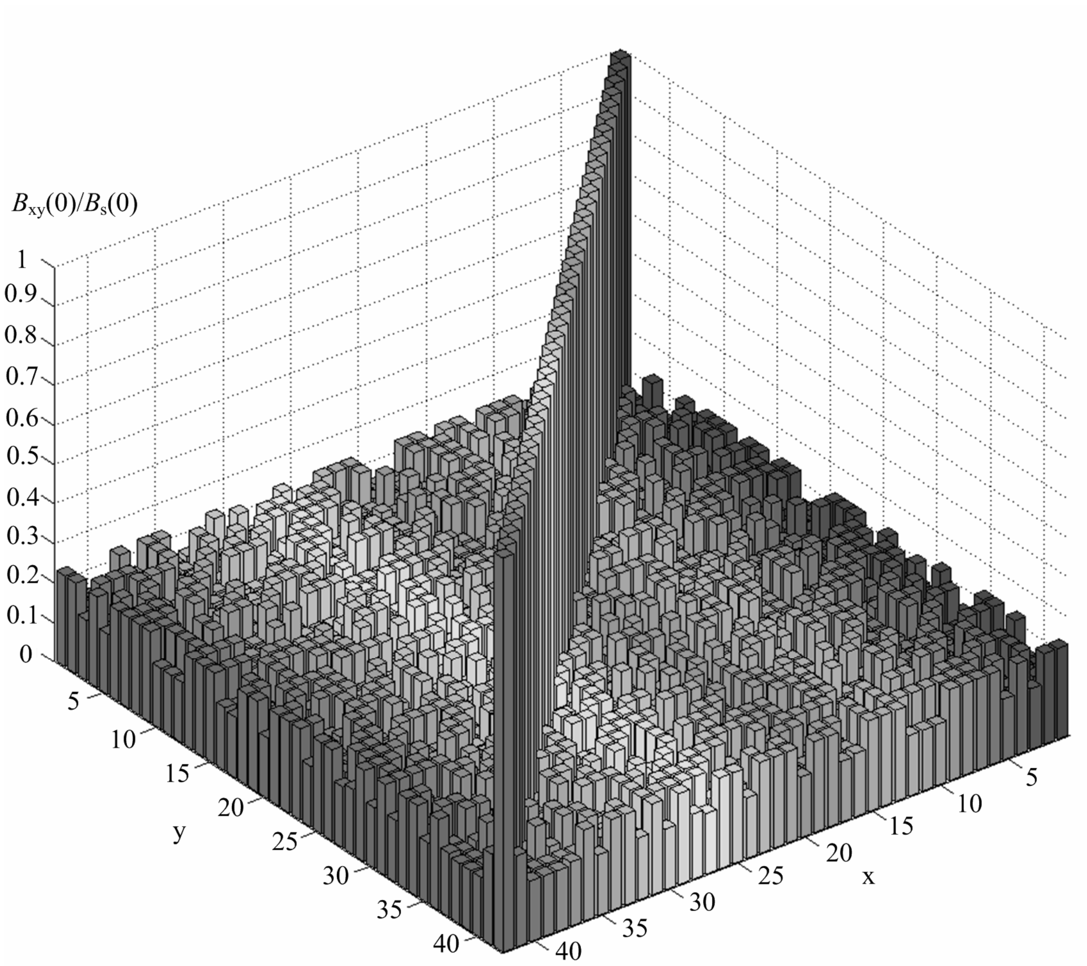

Fig. 4. Correlation matrix

VI. CONCLUSION

The study can be concluded that the application of *M*-ary FSK modulation is useful when creating a family of signals with a given level of cross-correlation. When $M = 16$ it was possible to create the group of 237 signals. When $M > 16$ you can significantly increase the amount of desired signals.

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