Simulation Model and Practical Realization of Barker-Like Codes

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Abstract. In the work we presented method of getting barker-like codes. It was implemented on the basis of numerical lines, that is, knots. The presented algorithm was realized on FPGA EP3C16F484N6, Altera. We have reviewed the main advantages, areas of use and peculiarities of barker-like codes. Besides, it was given functional diagram of the DS-SS system. The barker-like code generator and its frequency domain simulation were performed in VHDL language.

Keywords: Autocorrelation function, Barker code, Barker-like code, DS-SS, FPGA, Hardware implementation, Numerical ruler-bundle.

1 Introduction

The noise immunity and sensitivity of the pseudorandom code sequence primarily depends on its parameters. The length of the code may be the same, but the sequence parameters are different. Therefore, in the radio system of transmission information selecting pseudorandom code sequence is very important [1].

We propose to consider Barker's signals, because they are the ones that cause the greatest interest among scholars. They are also referred to as signals with a low level of side lobes of the autocorrelation function (ACF). It's interesting that a low level of side lobes provides a high value of the main lobe of the ACF. Basically, these signals will be built and researched on a numerical sequence from -1 to 1 [2].

However, it is known [3] that when the value of ACF does not exceed unit (excluding the main petal), and Barker's signals occupy odd positions that are more than 13, then they simply disappear, that is, they do not exist. Among the known Barker sig-

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nals, the maximum ratio of the main petal to other petals is 13. But in the course of research, the ratio of barker-like code signals equal to 14 or more was found [4]. Therefore, it makes sense to continue research in this direction.

So far there is no universal algorithm that provides an acceptable quality signal processing in all radar tasks [5]. In connection with this, the task of each modern radar station is to provide a constantly updated set of algorithms and signals that, when they are used jointly, are capable of solving certain tasks [6]. The electronic properties of materials to radar systems can be calculated by methods from first principles [7].

The paper presents the development of methods for synthesizing noise-like codes with the use of barker-like sequences for encoding and decoding data [8]; the development of simulation model of the synthesis of noise-like codes according to different criteria (by the functions of autocorrelation, by the length of the sequence and by the number of detected and corrected errors) [9]; realization of received sequences on FPGA [10]. The subject of research is the ACF-function of the model of barter-like codes and methods for its finding [11].

2 Review of the Literature

An urgent problem in our time is the protection of real-time data transmission with onboard systems, protection of their impedance and secrecy, and the general increase of strong cryptography. After all, these systems must meet the requirements for energy consumption, prices and general parameters in general. It is for this purpose that there are noise-like signals. They have a fairly high impedance over high-bandwidth interference with high power, can split subscribers by codes, have high protection against multi-beam propagation, provide secrecy of data transmission. In addition, noise signals have high resolution, even when positioned in radar and navigational measurements.

Many scientists have been working on the development of methods and means of silent coding in their time. Most of them used noise-like codes based on Barker sequences. For instance: M. Kelman and F. Rivest - the algorithm of encoding and decoding in real time with the use of sequences Barker [12]; P. Kim and E. Jang - research noisy codes are presented on the basis of sequences Goley and Barker; R. Nilawar and D, Bhalerao [13] - wireless data protection and data transmission systems that works in real time with certain parameters; S. Omar and F. Kassem - the solution of the problems of the ambiguity using methods with links to a Barker sequence [14]; S. Matsuyuki and A. Tsuneda - examples of the application of noise-coding codes in control systems, communication codes (the auto-collegial function is minimal) [15] and others.

After analyzing the scientific materials presented above, we concluded that it is impossible to find the Barker code for lengths greater than 13. Moreover, we found that the construction of barker-like sequences of any length is still an unresolved problem in our time. Regular methods of their construction were not yet developed. It follows that the known Barker codes can be used only for signals having a small base [16].

Since finding sequences longer than 13 that are similar to the Barker sequence, with the lowest possible value of the lateral petals is a major problem in our time, the regular method of constructing these codes proposed by us is actual. The method is based on ideal ring nodes. With its help, it is possible to realize the implementation of software and hardware components in order to synthesize small-scale real-time data transmission systems [17].

3 Problem Statement

We use Barker codes in communication networks with its extended range. After comparative analysis, it was found that Barker codes have more advantages than other pseudo-noise (PN) codes. In addition, they are well befit for Direct Sequence-Spread Spectrum (DS-SS). In systems DS-SS in each of the transmitted bits is embedded a certain sequence of chips. It is called a noise-like code. This is done in order to expand the spectrum of the narrowband signal. Each chip is represented as a rectangular pulse line with a duration that is one time smaller than the duration of the information bit. Figure 1 rep-presents the expansion of the spectrum for two information bits [18].

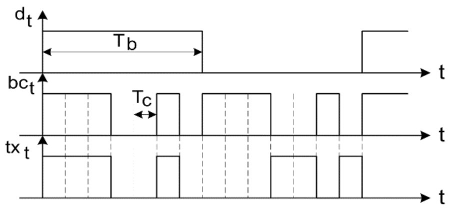


Fig. 1. The extension of the signal spectrum Barker code whose length is *N*=7.

Here, the Barker code is used instead of the pseudo-noise code. Its length is *N*=7. On this figure is marked: d_t – information signal (two bits), T_b – period of each bit, bc_t – Barker code, T_c – the period of each chip, tx_t – the converted signal which is generated when the transmission of signals d_t and bc_t through an XOR element with a denial.

The transmitter is governed by regenerating the signal of txt. This is done using the Binary Phase Shift Keying (BPSK) method. A method of demodulation of BPSK restores the modulated signal in the receiver [19]. Functional diagram of the system DS-SS are shown in Fig. 2.

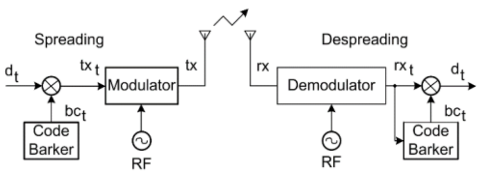


Fig. 2. The figuration of the functional scheme of the DS-SS system.

The PN-sequence generator is one of the main blocks in each DS-SS system. A range consisting of N of elements of a_j for $1 \le j \le N$, which taking values +1 and -1, make Barker's sequence. They must alternate so that the condition has being fulfilled:

$$\left| \sum_{j=1}^{N-i} a_j a_{j+i} \right| \le 1, \tag{1}$$

where $1 \le i \le N$.

Barker codes provide optimal reception, because they have minimum level of side lobes ACF. Well-known sequences of Barker have a length $2 \le N \le 13$ [20].

Sequence the ACF of the Barker code is a finite discrete sequence, which is formed by performing convolution on the sequence and its own copy:

$$R_j = \sum_{i=1}^{N-j} a_i a_{i+j}^{*}, \tag{2}$$

where the discrete index between the sequence and its copy in time is indicated.

This designation indicates a complex conjugate value. From the general properties of the autocorrelation function, it follows that it is symmetric with respect to the main lobe.

The mainlobe level (ML) is a module for the ACF coefficient for zero's displacement $j = 0$. The level of the main petal has the greatest value and is equal to own length. Peak sidelobe level (PSL) is defined as the maximum absolute value among the coefficients of the autocorrelation function for a non-zero shift $1 \le j < N$ [21]:

$$\mathrm{PSL} = \max \left\{ \left| \sum_{i=1}^{N-j} a_i a_{i+j} \right| \right\}. \tag{3}$$

In the Barker codes, the side petals never exceed 1. The ratio of the side lobes to their peak ratio has become a widespread application in our time. It is measured in decibels:

$$\mathrm{PSLR} = 20 \log_{10} \left(\frac{\mathrm{PSL}}{\mathrm{ML}} \right). \tag{4}$$

As an example, consider the Barker code which length is N=13 (+1, +1, +1, +1, +1, -1, -1, +1, +1, -1, +1, -1, +1), for which PSL=1, ML=13 i PSLR=-22.279 dB. Its ACF is depicted in the Fig. 3.

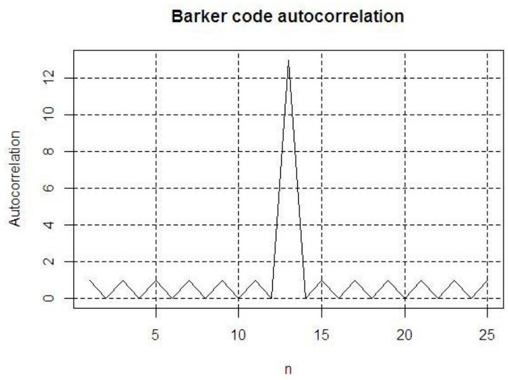


Fig. 3. Autocorrelation of Barker sequence whose length is *N*=13.

4 Algorithm of Synthesis of Barker-Like Codes

In the general case, a sequence $K_N = (k_1, k_2, ..., k_N)$ is called a simple numerical ring bundle (SNRB) of order of *N* on a sequence of N numbers. On it all the amounts dial the values of all L_N numbers starting from the given one. In a simpler version, these amounts exhaust the values of the natural range numbers 1, 2, …, L_N [22].

Provided that the range of successive values of the amounts discussed above begins with *a*, then the total sum of all numbers in this range will be determined as the ratio [23]:

$$S_N = \frac{K(K+2a-1)}{2} . \qquad (1)$$

The relationship between the number of the K methods for realizing the sums on the N - sequence, the multiplicity of R, and the sum of L_N all numbers is expressed by the formula [24]:

$$(L_N - 1)R = K - 1. \qquad (6)$$

Sealing procedure is an important parameter of a system that uses barker-like codes. It consists in transforming the noise-like signal received by the receiver into the required information signal. In this case, the processing factor shows the degree of improvement of the signal-to-noise ratio. In the general case, B_0 is equal to:

$$B_0 = 10\log_{10}\left(\frac{C_k}{C_i}\right), \qquad (7)$$

where C_k – the frequency of receiving pseudorandom sequence chips (chip / sec), C_i – speed of information transmission (bit/sec). For the system with C_i =1 Mbit/sec and

C_k =13 MChip/sec, each bit of information is encoded by a pseudo-random sequence of 13 bits. When processing, the advantage will be B_0 =11.14 dB. In this case, the efficiency of the information transmission system will be maintained if the useful input signal is reduced by 11.14 dB.

In addition, the algorithm for the synthesis of barker-like codes on the basis of numerical ring bundles (NRB). It consists in using the minimum value of the autocorrelation function of the discrete signal [25]. This algorithm is as follows:

- it is necessary to choose a variant of the NRB of the given order N. It should be necessary length L_N and multiplicity R. To do this, you need to apply the algorithm of selective displacements (for $2 < N < 12$), then the asymmetric branching algorithm (for $12 < N < 18$) *f, j* and the algorithm for constructing the NRB on the basis of ideal ring joints (for $18 \le N$);
- •to construct an L_N-position code μ_i, *i*=1, 2, …, L_N with a one-level periodic autocorrelation function based on the selected NRB variant $(k_1, k_2, ..., k_N)$, where in the N positions of the code with sequence numbers x_l, $l = 1,2,...,N$ to place the symbols "1", and in the other $L_N - N$ positions - the symbols "-1".

The sequence numbers x_l is determined from the formula:

$$x_l \equiv 1 + \sum_{i=1}^{l} k_i \cdot \left(\mathrm{mod}\, L_N\right). \tag{8}$$

The sequence we received defines a pulse sequence that has a property called "no more *R*-matches." It is also the minimum value of the auto-correlation function. If you choose another variant of the NRB with the same parameters (if it exists), then we will receive other pulse sequences with the same property.

The paper [26] presents barker-like codes, whose lengths are L_N =14 … 40. For each of the lengths L_N of these codes, the level of the side lobes of the normalized correlation function is minimal. The calculation of unique codes for each L_N length was carried out with the help of the NRB.

For an example, we will consider building a barker-like code based on the above algorithm. The construction will be carried out for $L_N = 21$, $N = 12$, $R = 7$ [27]. First, you need to do the following steps:

- there are only four variants of the shortest simple NRB of order $N = 12$. All of them are based on the algorithm of selective movements [28]. We need to choose the first version of the NRB, for which: (1, 1, 1, 1, 1, 2, 4, 2, 1, 4, 1, 2);
- carry up a sequence in which the length of the code is $L_N = 21$.

To do this, you must place the "1" characters in twelve positions ($N = 12$). We calculate these positions by the formula (4). The remaining positions need to be filled in with "-1" characters: 1, 1, 1, 1, 1, 1, -1, 1, -1, -1, -1, 1, -1, 1, 1, -1, -1, -1, 1, 1, -1.

Received a barker-like code for which PSLR=-20.42, its ACF is depicted in Fig. 4. From this figure, we see that PSL=2, the level of the main petal is equal to ML=21. Number of variants with a minimum level of ACF - 12.

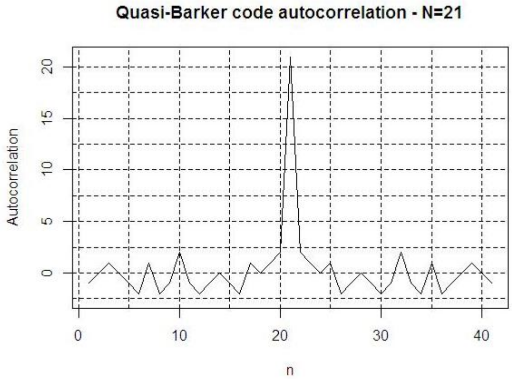
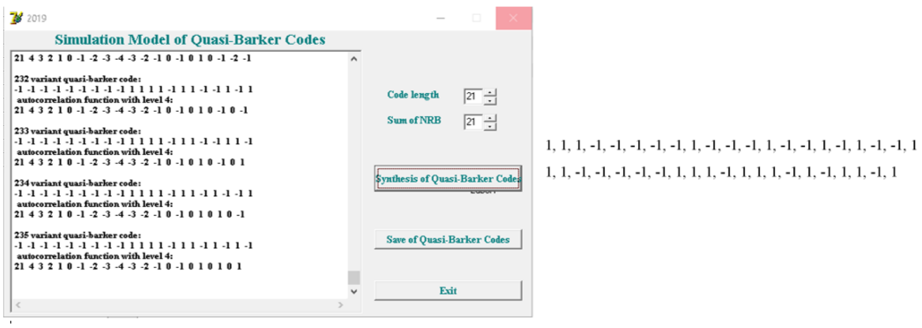


Fig. 4. Autocorrelation of Barker sequence whose length is *N*=21.

Software that simulates the operation of NRB-based barker-like codes has been developed. The general layout of the program and the results when the sum of the entered NRB is greater than or equal to the length of the code similar to the barker-like code is shown in Fig. 5a and Fig. 5b.



a b

Fig. 5. A general view of a program and results that simulates the work of barker-like codes based on NRB.

5 Realization of Barker-Like Codes on FPGA

In the course of the research, the FPGA EP3C16F484N6 of the Cyclone III family of the Altera company, which is part of the DE0 booth [29], was used. With its help, barker-like codes and Barker codes had been implemented. The development was done in VHDL hardware programming language in Quartus II development environment using development libraries. We needed to perform parallel computing with a large amount of data, so we used FPGA. They have a fairly large number of hardware on their crystal. For example, the FPGA EP3C16F484 includes 15,484 logical elements (LEs), 56 M9K units, 56 multipliers 18x18, a large number of implemented IP cores [30]. FPGA supports high-speed interfaces with external memory.

LE is the smallest element of logic in the architecture of the family Cyclone III. Each LE has four inputs, a four-inputs conversion table (LUT), a register, and an output logic [31].

The sequential parallel shift register determines the basis of the barker-like code generator. The scheme of its generation is depicted in Fig. 6. The dimension of the barker-like code is *N*=28.

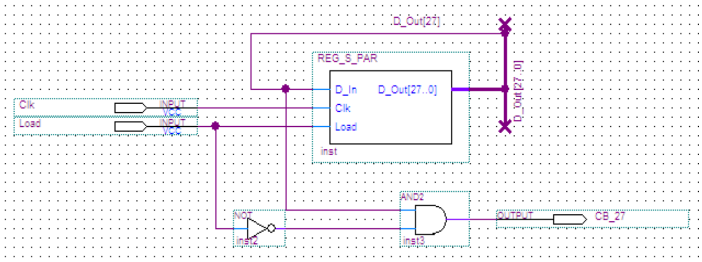


Fig. 6. Figuration of the barker-like code generation scheme (*N*=28).

This register stores the value 0x9FB2B94 (1001111110110010101110010100B). It is the initial value for the offset.

The character generator barker-like codes of length N=28 (CB_28) shown in Fig. 7.

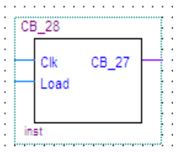


Fig. 7. The appearance of the symbol CB_28.

Input of the generator of the barker-like code which dimension is $N = 28$: Clk – the input of register of pulses to the case of a sequential parallel shift; Load (active signal level "1") – a signal to load the source data into a register. The output of the CB_28 generator is a barker-like code with a dimension of *N*=28. During each Clk synchronization pulse, the off-set is executed for one bit to the left of the D_Out array [27..0] and record the input value of the D_In register REG_S_PAR to the lower grade D_Out [0]. Timing diagrams of the generator are shown in the Fig. 8 [32].

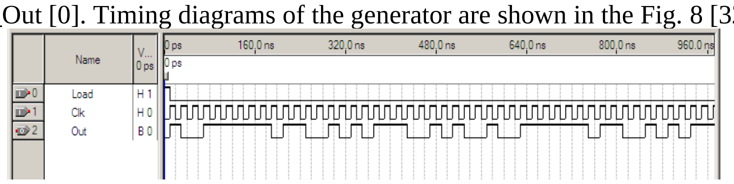


Fig. 8. Time charts of the barker-like code the dimension of which is *N*=28.

As for barker-like codes of arbitrary dimension $N = 14...40$, they can be realized in a similar way. However, you must keep in mind that the hardware resources that are needed for this will change. For example, in order to implement a barker-like code generator with dimension $N = 28,29$ (out of 15,408) logical elements, 28 registers and 3 (out of 347) FPGA EP3C16F484 outputs are required [33].

6 Conclusion

Thus, in the course of the work, an algorithm for the synthesis of barker-like codes, having a dimension $N = 14...40$, was developed. Autocorrelation functions for these codes were investigated. Barker-like codes were implemented on the Altera firmware of the FPGA family of EP3C16F484 Cyclone III and modeling their work in a time sequence.

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