STUDY OF THE CHARACTERISTICS OF THE DEVELOPED BARKER-LIKE CODES

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Introduction. The synthesis of non-periodic signals with correlation properties, which have a linear structure of the spectrum and provide unequivocal measurement and high resolution, is relevant. Signals that satisfy this condition are called signals with the «no more R matches» property. The main requirement for signals with a selected compression ratio is the minimization of autocorrelation side lobes.

Among the most well-known and more frequently used signals in practice can be noted: Barker codes, M – sequences (Huffman codes), multiphase Frank codes, linear – and V -figuratively frequency modulated signals. When the signal analysis time is not long enough and the amount of analysed data is limited, the algorithms are not able to provide the necessary resolution in terms of delay time, which makes it impossible to detect and measure the parameters of two or more signals together. This problem is most relevant in the centimetre and millimetre wave radar [1].

Since the potential limit of resolution in terms of signal delay time is theoretically not limited and is determined by the spectrum width and the signal/noise ratio, the prospect opens for the development of algorithms that allow as close as possible to this theoretical limit in practice. The use of such algorithms for increasing the resolution is accompanied by energy losses relative to those existing in theory, but not implemented in practice. Minimization of energy losses is the main goal pursued in the development of new algorithms for increasing the resolution.Until now, there is no universal algorithm that ensures acceptable quality of signal processing in all radar tasks. In this regard, a modern radar station must contain a constantly updated set of algorithms and signals, which, when used together in a signal-algorithm pair, are able to provide solutions to a certain range of tasks. The importance of studying combinatorial configurations is particularly evident in the theory of coding during the synthesis of codes with high immunity to interference and discrete signals with good correlation properties, which have found application in radio engineering and communication [2].

Traditional methods of encoding information and converting signals, as well as methods that use classical combinatorial configurations, do not always make it possible to fully reveal the capabilities of coding systems [3].

Therefore, an important and urgent problem is the research and use of new effective models for improving information coding systems according to such indicators as immunity, ease of detecting and correcting errors.

Study of the autocorrelation and intercorrelation functions of the developed Barker-like codes. Autocorrelation or autocorrelation function -it is the correlation of the function with itself shifted by a certain value of the independent variable. Autocorrelation is used to find patterns in a series of data, such as periodicity [4]. Often-used in statistics and signal processing to analyze functions or data series.

Mathematically, the autocorrelation function is defined as:

$$R_f(\tau) = \int_{-\infty}^{\infty} f(t) f^*(t-\tau) dt , \qquad (1)$$

where the function $f(t)$ is integrated into the product with the complex conjugate and shifted by a certain amount τ (often τ time) function.

The graph of the autocorrelation function can be obtained by plotting the correlation coefficient of two functions (basic and shifted, shifted by the value τ) on the ordinate axis, and the value, on the abscissa axis τ . If the original function is strictly periodic, then the graph of the autocorrelation function will also be a strictly periodic function. Thus, from this graph it is possible to judge the periodicity of the basic function, and therefore its frequency characteristics. From the point of view of the autocorrelation function, the codes based on which signals with a low level of side lobes are constructed are of particular interest autocorrelation function. Among them are the so-called Barker codes. As is known, these signals ensure the achievement of a high value of the main petal of the autocorrelation function, if the level of the side petals is low [5].

By quasi-Barker or Barker-like we mean the code based on which Barker signals are built.

The subject of research is the autocorrelation function models of barker-like codes and methods of finding them. The main mathematical apparatus of research used in this work is the methods of combinatorial analysis, in particular the algebraic theory of knitted structures.

Barker codes are convenient to study and build with the help of numerical sequences, the elements of which are the code symbols 1 and -1, where the change of the sign $(+,-)$ before the unit corresponds to the change of the phase of the pulse signal $(0,\ \pi)$.

The main idea is to move from the narrow-band spectrum of the signal, which occurs during the usual potential coding, to a wide-band spectrum. This allows you to significantly increase the immunity of data [5].

With potential coding, information bits 0 and 1 are transmitted by rectangular voltage pulses. It is known that any function and, accordingly, any signal can be represented in the form of a discrete or continuous set of harmonics, approximately sinusoidal signals with weighting factors and frequencies selected in a certain way. Such representation is called Fourier transform. The frequencies of the harmonic signals themselves form the spectral decomposition of the function.

For example, when transmitting a rectangular pulse of duration *T*, the signal spectrum is described by the function:

$$\frac{\sin(\pi * f * T)}{\pi * f * T} \qquad (2),$$

where f -frequency of the spectral component.

In fact, the information bit, which is represented by a rectangular pulse, is divided into a sequence of smaller pulses-chips. As a result, the spectrum of the signal is significantly expanded, since the width of the spectrum can be considered with a good degree of accuracy to be proportional to the duration of one chip y.

In the general case, any regularity of the distribution of the weights of the digits can correspond to different digits of the barker-like code. However, the most interesting are the studies of distribution patterns that best satisfy the requirements related to information coding systems.

Recalling the advantages of a barker-like code, it should be noted that the effectiveness of any code is determined by many factors, including the possibility of coding for any code bit rate, the power of the coding method, sufficient immunity without excessive code redundancy, and finally, the availability of effective algorithmic means of building systems coding [4]. This requires conducting comprehensive studies of information encoding methods based on the above-mentioned approach.

Barker-like codes with a minimum level of the autocorrelation function. The choice of a pseudo-random code sequence in a radio-technical information transmission system is very important, since the enhancement of the system's processing, its immunity to interference, and its sensitivity depend on its parameters. With the same length of the code sequence, the system parameters may be different.

The well-known advantages of noise-like signals (NLS), such as high immunity to high-power narrowband interference, the possibility of separating subscribers by code sign, transmission stealth, high resistance to multipath propagation, and even high resolution in radar and navigation measurements, led to their use in various communication systems and location determination [1].

With the resolution of two signals with considerable, relative to the noise, equal energies, the condition for their mutually agreed resolution can be obtained:

$$\rho(\tau) \leq 0.5, \qquad (3)$$

where $\rho(\tau)$ – correlation coefficient of signals that differ from each other in delay time by the value τ

This condition is fulfilled when $\tau \geq \Delta\tau$, where $\Delta\tau$ -the width of the main petal of the ACF signal at the level of 0.5 from its maximum:

$$\Delta\tau = \frac{1}{\Delta f_c}, \qquad (4)$$

where Δf_c – signal spectrum width.

The task of resolving signals that differ from each other by an unknown parameter in advance τ by a value smaller in magnitude than $\Delta\tau$, and observed against the background of normal white noise, does not have a sufficiently effective practical solution.

It is urgent to search for a method that would allow resolution of signals when they differ from each other in magnitude $|\tau| \leq \Delta\tau$ and would provide resolution quality characteristics as close to potential as possible.

Code sequences used to expand the frequency band and create a broadband signal can be divided into two main classes: orthogonal (quasi-orthogonal) and pseudo-random with a low level of mutual correlation (Fig. 1).

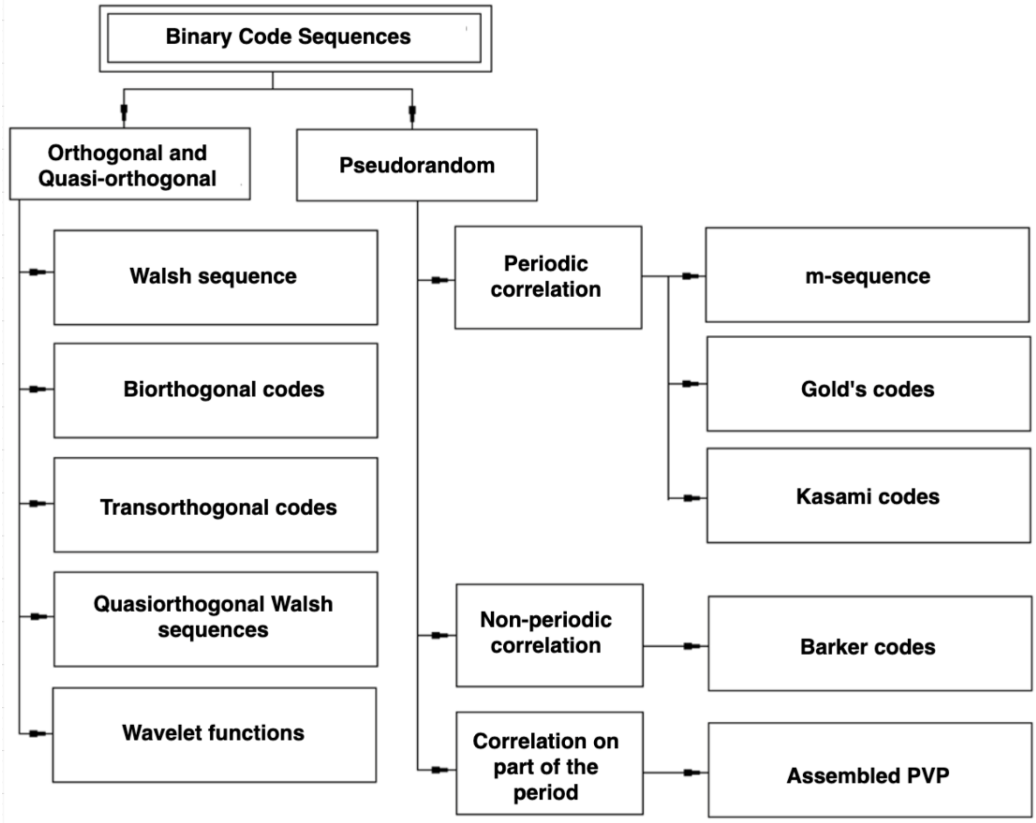

Fig.1. Classification of orthogonal sequences for the formation of broadband signals

An important parameter of the system using barker-like codes is the processing gain (processing gain). The processing gain shows the degree of improvement in the signal-to-noise ratio B_0 when converting the noise-like signal received by the receiver into the necessary information signal. This procedure was called compression or dispreading. According to the classical definition, B_0 is equal to:

$$B_0 = 10\lg[C_k / C_i], \quad (5)$$

where C_k – frequency of adherence of chips to a pseudo-random sequence, chip/sec;

C_i – information transfer rate, bit/sec.

According to this definition, a system that has an information transfer rate of 1 Mbit/second and a chip compliance frequency of 11 Mchip/sec (this means that each bit of information is encoded by a pseudorandom sequence of 11 bits) will have B_0, equal to 10.41 dB. This result means that the performance of the information transmission system will be preserved if the useful signal at the input is reduced by 10.41dB.

In commercial noisemakers, radio modems often place the greatest importance on the speed of information transmission, and not on stealth or immunity. Since the instructions of the Federal Communications Commission in the USA (FCC) for such devices provide a minimum value of B_0 10 dB, as well as a minimum allowable bandwidth of one channel (which imposes a limit on the maximum frequency of compliance of the chips C_k), the length of the pseudorandom code sequence must be at least 11 chips per bit. If we increase the length of the code sequence to 64 chips per bit (this is the maximum possible length for the well-known ShPS Z87200 processor from Zilog), then with the same chip frequency of 11 Mchip/sec, the processing gain will be 10Lg(64)=18.06dB, at the same time, the speed of information transmission will decrease by 64/11=5.8 times.

To be used in the SHPS system, code sequences must possess certain mathematical and other properties, the main of which are very good autocorrelation and intercorrelation properties. In addition, the code sequence must be well balanced, that is, the number of ones and zeroes in it must differ by no more than one character. The last requirement is important for excluding the constant component of the information signal.

The DSSS receiver compares the received code sequence with its exact copy stored in memory. When it detects a correlation between them, it switches to information reception mode, establishes synchronization and begins the operation of decoding useful information. Any partial correlations can lead to false positives and malfunction of the receiver, which is why the code sequence must have good correlation properties. Let's consider the concept of correlation in more detail.

Correlational properties of code sequences used in NLS systems depend on the type of code sequence, its length, the frequency of its symbols and its symbol-by-symbol structure [1].

In general, the autocorrelation function (ACF) is determined by the integral:

$$\Psi(\tau) = \int_{-\infty}^{\infty} f(t) f(t-\tau) dt \tag{6}$$

and shows the connection of the signal with a copy of itself, shifted in time by the amount τ . The study of ACF plays an important role in the selection of code sequences from the point of view of the least probability of establishing false synchronization.

The cross-correlation function (CCF), on the other hand, is of great importance for systems with code separation of subscribers, such as CDMA, and differs from the ACF only in that there are different functions under the sign of the integral, rather than the same one:

$$Y(\tau) = \int_{-\infty}^{\infty} f(t) g(t-\tau) dt \tag{7}$$

VKF shows, thus, the degree of correspondence of one code sequence to another.

To simplify the concepts of ACF and VKF, the value of one or another function can be represented as the difference between the number of matches A and non-matches B symbols of code sequences when comparing them symbol by symbol. To illustrate this example, consider the autocorrelation function of an 11-chip long Barker code sequence, which has the following form:

$$1\ 1\ 1\ 0\ 0\ 0\ 1\ 0\ 0\ 1\ 0 \tag{8}$$

A character-by-character comparison of this sequence with its copy is summarized in Tab.3.

Table 3

Results of symbol-by-symbol comparison of barker-like codes

Offset value	Sequence	Number of matches A	Number of mismatches B	The meaning of the difference
1	01110001001	5	6	-1
2	10111000100	5	6	-1
3	01011100010	5	6	-1
4	00101110001	5	6	-1
5	10010111000	5	6	-1
6	01001011100	5	6	-1
7	00100101110	5	6	-1
8	00010010111	5	6	-1
9	10001001011	5	6	-1
10	11000100101	5	6	-1
0	11100010010	11	0	11

Barker sequence is shown in Fig.2:

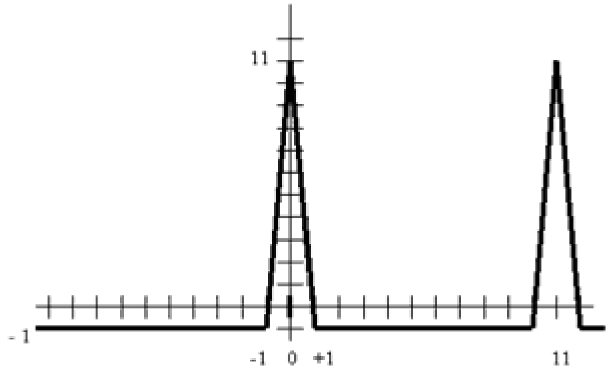

Fig.2. A graphic representation of Barker sequence ACF

Such an ACF can be called ideal, since it does not have side spears that could contribute to false signal detection.

As a negative example, you can consider any arbitrary code sequence, for example:

1 1 1 0 0 0 1 1 1 0 0 (9)

After carrying out the calculations corresponding to the previous example, we will get the following graphic image of the autocorrelation function, shown in the Fig. 3:

Side spears of 7 and 3 units can lead to false activation of the system in the case of using such a sequence for signal distribution.

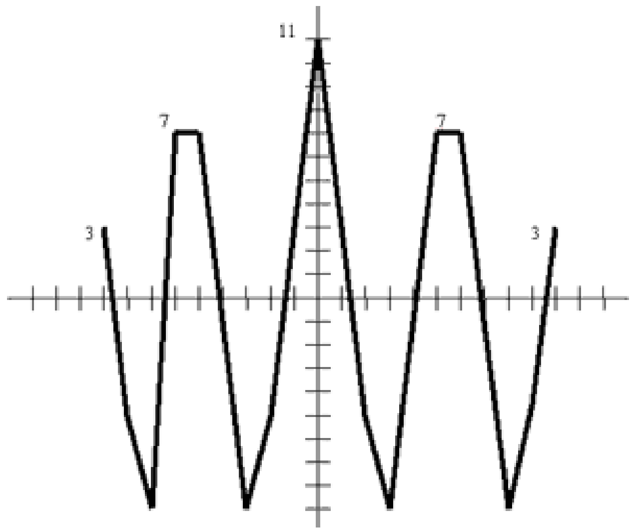

Fig.3. Graphical representation of the autocorrelation function

Barker codes, which have good autocorrelation properties, are usually used for high-speed NLS systems intended for information transmission, but not for code separation of subscribers. Barker code sequences longer than 13 symbols are unknown, therefore, to obtain a larger B, greater interference resistance, as well as for code separation of subscribers, longer sequences are used, a significant part of which are – sequences M .

One of the most famous phase-manipulated signals are signals whose code sequences are sequences of maximum length or m-sequence. Shift registers or delay elements of a given length are usually used to construct -sequences. M The length M of the sequence is equal to $2N-1$, where N is the number of digits of the shift register. Different options for connecting the outputs of the units to the feedback circuit give a certain set of sequences.

The ACF M of the sequence is equal -1 for all values of the delay, except for the region 0 ± 1 where its value changes from -1 to the value of $2N-1$. In addition, M – sequences have another interesting property: each sequence has one more ones than zeros. A lot of literature is devoted to the methods of formation and characteristics of M – sequences, so we will not dwell on this in detail.

To explore the possibilities of the new PRISMTM chip set by Harris Semiconductor conducted a practical study of short M – sequences and the Barker code in order to find the optimal ones from the point of view of the autocorrelation function [4].

As part of this study, a sequence of length 15 and having the following form was analysed:

111 1000 1001 1010

As it turned out, it has worse autocorrelation properties than the 13-character Barker sequence of the following form:

1 1111 0011 0101

A practical view of the ACF M sequence is shown in Fig.4:

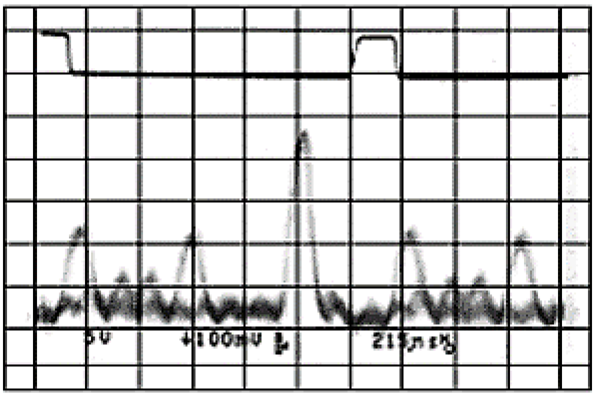

Fig.4. A practical view of ACF sequence

For comparison, the ACF of the Barker code sequence is 13 long (Fig.5).

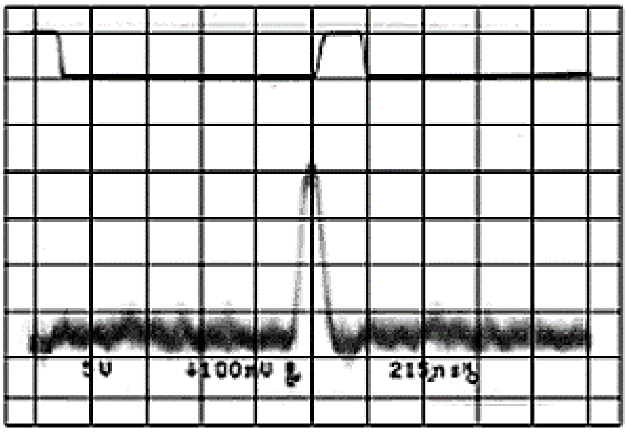

Fig.5. ACF of the Barker code sequence of length 13

The oscilloscope sync pulse is shown on the top of the photo. As can be seen from the photos, M the - sequence has several large side peaks, which can significantly degrade the reception qualities of the system's FMS, and sometimes can lead to false signal detection.

As it turned out in the course of further research, if two zeros are added to Barker's 13-character code sequence, then the ACF of the resulting sequence

001 1111 0011 0101

will be much better than the described ACF M sequence, which also consists of 15 symbols (Fig.6). ACF of the obtained sequence again:

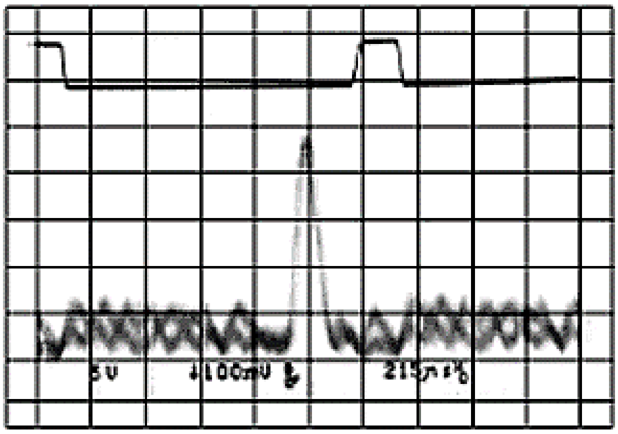

Fig.6. ACF is a sequence consisting of 15 characters

Short M – sequences are thus significantly inferior to Barker sequences in terms of autocorrelation properties, despite the better balance of zeros and ones.

In addition to M – sequences as such, composite code sequences, which are combinations of M – sequences and have some specific properties, have found use in communication systems. M The most famous and used of them are Gould sequences. Gould's code sequences are formed using a simple sequence generator based on two shift registers of the same bit size and have two advantages over M – sequences. First, the generator of code sequences, built on the basis of two shift registers of length N each, can generate M sequences of length, in addition to two output $2N-1$sequences N, i.e., the number of generated code sequences is significantly expanded.

Gould codes can be chosen so that the VKF for all code sequences received from one generator is the same, and the value of its side peaks is limited. For M – sequences, it cannot be guaranteed that the side spears of the VKF will not exceed a certain given value. Gould code sequences are used in global navigation systems, such as GPS. In addition to Gould's compound sequences, Kasami sequences are most often used.

Gould, Kasami sequences refer to sequences having a linear algorithm of formation. The main disadvantage of such sequences is their predictability and the associated lack of transmission secrecy.

Non-linear sequences are more unpredictable. Recently, a number of publications have appeared on the generation of noise-like signals using the phenomenon of dynamic chaos. The phenomenon of dynamic chaos consists in the fact that the movement of a deterministic dynamic system under certain conditions has all the properties of a broadband chaotic process. At the same time, the fundamental feature of the algorithms describing this phenomenon is their non-linearity, and the feature of the generated temporal process is -its non-periodicity. This opens up the possibility of finding a new class of random sequences for use in radio engineering systems for various purposes: wideband chaotic signals (BCCs), which more closely meet the requirements for pseudorandom sequences.

The method of synthesis of Barker-like codes with the minimum level of the autocorrelation function. In radar tasks, which deal with the selection of signals from targets against the background of possible interference, the synthesis of non-periodic signals with correlation properties, which have a linear structure of the spectrum and ensure unambiguous measurement and high resolution, is relevant. Signals that satisfy this condition are called signals with the «no more R matches» property. The main requirement for signals with a selected compression ratio is the minimization of autocorrelation side lobes. The most convenient for implementation are binary phase-manipulated signals, in which the phase manipulation of the continuous carrier is carried out at discrete moments of time that are multiples of the sampling interval τ_0. These signals consist of rectangular contour pulses, the duration of which is equal to the sampling interval, and the phase from pulse to pulse acquires a value of 0 or 180 degrees.

Consider the partial case of binary phase-manipulated signals – with a single-level periodic autocorrelation function. A single-level periodic autocorrelation function is called the autocorrelation function of one period of modulation of a binary phase-manipulated signal [2], built on the basis z of a -positional code μ_i, $i = 0,1,...,z-1$, if this function

$$r_\mu(m) = \sum_{i=0}^{z-1} \mu_i \mu_{i+m} , \qquad (10)$$

where $m = \frac{\tau}{\tau_0} \neq 0 \pmod z$ takes on only one value.

The mentioned discrete signals have a number of useful properties for radar tasks:

- the suppression of a weak signal by a strong one is practically excluded when two signals crossing each other in time arrive at the receiver input;
- the loss of reflected pulses is reduced (no more than one pulse is lost), which is associated with the problem of «blind» distances;
- the task of unambiguous measurement of distance and speed in the entire range of changes of these values is simplified;
- the problem of signal selection against the background of interference is solved more effectively.

Among the wide variety of such signals, signals with a low level of side lobes are of particular interest autocorrelation function. Among them are the so-called Barker signals. As is known, these signals ensure the achievement of a high value of the main petal of the autocorrelation function, if the level of the side petals is low. Barker's signals are convenient to study and build using numerical sequences, the elements of which are the code symbols 1 and -1, where the change of the sign $(+, -)$ before the unit corresponds to the change in the phase of the pulse signal $(0, \pi)$. The research results showed that there are no Barker signals with an odd number of positions greater than 13, for which the values of the autocorrelation function do not exceed unity (with the exception of the main lobe). Among Barker signals, the maximum ratio of the main petal to other petals is 13.

The method of constructing z-positional signals with a single-level periodic autocorrelation function is based on the use of properties of similarity and dependence of the field of elements $GF(p^\alpha)$, $z = \frac{p^\alpha - 1}{p - 1}$. At the same time, it is necessary to have initial irreducible $GF(p)$ polynomials over the field $f(x)$ to construct extended Galois fields $GF(p^\alpha)$. Then it is necessary to construct complete families of non-inverse -isomorphic difference sets, to find the best among them according to the minimum code length criterion, since all other conditions being equal, it is possible to obtain the maximum filling factor and, therefore, to increase the energy of the sounding signal. Based on the received code, we receive pulse signals with the «no more than R-coincidences» property.

To simplify and improve the results of solving the problem, it is important to develop a new approach to the synthesis of codes with good autocorrelation properties that approach Barker codes. One of these approaches is based on the use of the apparatus of the theory of numerical lines-bundles [4, 5].

The method of construction based on numerical lines-bundle (NLB) according to the criterion of the minimum value of the autocorrelation function of a discrete signal is as follows:

- using the algorithm of selective movements (at $2 < N < 16$), the algorithm of asymmetric branching (at $12 < N < 24$) or the algorithm of constructing a NLB based on ideal ring bundle (at $24 \leq N$), choose a variant of the NLB of a given order of N the required length L_N of multiplicity R;
- to build L_N – positional code μ_i with $i = 1, 2, ..., L_N$ a one-level periodic autocorrelation function based on the selected variant of the NLB $(k_1, k_2, ..., k_l, ..., k_N)$, where at N the positions of the code with ordinal numbers x_l, $l = 1, 2, ..., N$ which are determined from the formula

$$x_l \equiv 1 + \sum_{i=1}^{l} k_i \pmod{L_N}, \qquad (11)$$

place symbols "1", and in the remaining $L_N - N$ positions -symbols "-1".

The resulting sequence is an impulse sequence with the property «no more R -matches» and the minimum value of the autocorrelation function. By choosing another variant of the PHLV with such parameters (if it exists), we can obtain other pulse sequences with the property «no more R -matches» and the minimum value of the autocorrelation function. Let's consider an example of building according to the given method of pulse sequences based on IRB, $L_N = 28$, $N = 12$, $R = 5$:

- from the two existing variants of simple IRBs of the order $N = 12$, built according to the algorithm of selective movements, we choose, for example, the first variant of IRBs:

(1, 1, 3, 1, 1, 7, 2, 2, 3, 3, 3, 1);

— we build a sequence in which the length of the code is $L_N = 28$; in twelve positions $(N = 12)$ we place symbols $"1"$ according to formula (2), and fill the rest of the positions with symbols $"-1"$:

1, 1, 1, -1, -1, 1, 1, 1, -1, -1, -1, -1, -1, -1, 1, -1, 1, -1, 1, -1, -1, 1, -1, -1, 1, -1, -1, 1.

The resulting sequence is an impulse sequence with the property «no more R -matches», for which the value of the autocorrelation function does not exceed two (with the exception of the main petal):

28, -1, 0, 1, -2, 1, 2, 1, -2, 1, -2, 1, -2, 1, 2, -1, 2, -1, -2, -1, – 2, -1, 2, -1, -2, -1, 0, 1.

Here, the ratio of the main petal to the other petals is 14, which is more than Barker signals. By choosing other variants of IRB, we can similarly obtain variants of discrete signals with the specified properties.

Conclusions. Therefore, the use of ideal ring bundles for the synthesis of discrete signals makes it possible to simplify their construction, due to the exclusion of such operations as finding primitive irreducible polynomials $GF(p^{\alpha})$ over the field minimum length.

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ПРОФЕСІЙНА ПІДГОТОВКА ВЧИТЕЛІВ УКРАЇНСЬКОЇ МОВИ І ЛІТЕРАТУРИ ДО ВИКОРИСТАННЯ ОСВІТЯНСЬКИХ ЕЛЕКТРОННИХ РЕСУРСІВ В УМОВАХ ОСВІТНЬО-КОМУНІКАТИВНОГО ПРОСТОРУ ЗАКЛАДІВ ВИЩОЇ ОСВІТИ

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Вступ. Інформаційне суспільство вимагає формування комунікативних здатностей, культивування високих духовних ідеалів кожної особи на основі конструктивізму як життєвої позиції, утвердження культури толерантності стосовно представників інших культур. Сучасні виклики глобалізованого суспільства спонукають до переосмислення звичних характеристик і норм освітньої діяльності. Освіта стає основним показником інтелектуального, культурного, духовного, соціального, економічного розвитку суспільства та держави.

Завдання інноваційної освіти полягає в забезпеченні реальної, а не декларованої пріоритетності освіти. Ідеї й технології змінюються швидше, ніж покоління людей, тому потрібно насамперед забезпечити високу функційність людини в різних, часто непередбачуваних умовах. Найбільшої актуальності набувають інновації у сфері вищої педагогічної освіти, що спрямовані на формування особистості професіонала, здатності до інноваційної діяльності на основі соціального замовлення, оновлення змісту освітнього процесу, професійно-творчої діяльності. Освітню політику й діяльність усіх закладів вищої освіти (далі – ЗВО) потрібно спрямовувати на ґрунтовну соціально-економічну, комп'ютерну, досконалу мовну, педагогічну підготовку вчителів української мови і літератури.