THE POTENTIAL AND REAL INTERFERENCE IMMUNITY OF THE COMMUNICATION SYSTEMS BASED ON THE ULTRA – WIDEBAND CODED SEQUENCES

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ABSTRACT

The generalized ambiguity function of aggregate ultra – wideband signal is considered and its properties and behaviour features are researched. The distance and velocity resolving power of aggregate ultra – wideband signals is calculated. The relationships for distance and velocity estimation variances are obtained. There was proposed a method of the subordinate maxima suppression of the ambiguity function of the aggregate ultra – wideband signals by means of its periodical modulation by Barker's code sequences and sequences with «no more than one coincidence» property.

Keywords: aggregate ultra – wideband signal, generalized ambiguity function, resolving power.

1. INTRODUCTION

The state-of-the-art radar, navigation and communication systems operate in difficult circumstances due to the wide hindrances set influence and other transmitting and receiving terminals operation in a different frequency ranges. So the researchers attention was attracted by the aggregate ultra – wideband (AUWB) signals – supernarrow pulse sequences without carrier –Ref. 1. These signals have a great interference immunity and obscurity (a small probability of acquisition and resistance), its can efficiently operate under the small average transmitter power.

Since the AUWB signals have no carrier, the conventional distance and velocity (time and clock rate) estimation performances aren't suitable for these signals. The generalized ambiguity function (GAF) of the AUWB signals was considered by the authors of given paper. The analysis of GAF demonstrated that it has extremely complicated multipeak structure, which is submitted to the set of rules. The GAF multipeak nature results in I and II sort anomalous errors appearance under the estimations of distance associated with signal time delay and velocity associated with received pulse sequence (PS) period. It could be the cause of aforementioned estimations unreliability. The significant suppression GAF subordinate maxima can be reached by the code modulation of the AUWB signal. Such modulation might be realized by exclusion of some pulses in regular PS by a certain code law. During the work the GAFs of sequences with periodical modulation by Barker's codes, optimal codes with «no more than one coincidence» property –Ref. 4 were researched. The distance and velocity resolving power of the AUWB signals is calculated, also the distance and velocity estimation variances are obtained.

2. THE SIGNAL MODEL AND THE ALGORITM OF ITS PROCESSING

Let the mixture of the AUWB desired signal $s\left(t|\tau_0,T_0\right)$ and additive white Gaussian noise $n(t)$ with zero mean and power spectral density $N_0/2$ proceeds on the received system input during the observation time $[0,T_H]$

$$x(t)=\sum_{k=0}^{\nu} a_k s_0\left(t-kT_0-\tau_0\right)+n(t) \qquad (1)$$

Here $\{a_k\}$, $k=\overline{0,\nu}$, $a_k=1,0$ - code sequence, modulating the source PS; $s_0(t)$ - primitive pulse shape which can be thought of as a Gaussian monocycle

$$s_0(t)=C\left(t/\tau_*\right)exp\left(-\left(t/\tau_*\right)^2\right), \qquad (2)$$

where τ_* - time constant, characterizing damping; pusle duration $\tau_u=2\pi\tau_*$. The pulses of such sort are implemented in ultra – wideband radars and pulse radio. The received PS period T_0 with time delay τ_0 can be thought of as information parameters subject to estimation.

The received desired signal $s\left(t|\tau_0,T_0\right)$ could be related either to infinite or finite PS class. The number of pulses $(\nu+1)$ in infinite PS is defined by the observation time T_H and could be vary in a wide range with the period T_0 variation. For the finite PS case the number of pulses $(\nu+1)$ is constant because the emitting device designates it. In radiolocation such signals are called pulse burst. Henceforward we shall consider only finite PS. The estimated parameters (τ_0,T_0) are defined in a priori region $[\lambda_1,\lambda_2;L_1,L_2]$, which we shall suppose significantly larger than the AUWB signal GAF main maximum subregion.

The optimal receiver forms the logarithm of the maximum likelihood ratio functional of the parameters (τ,T) in the region $[\lambda_1,\lambda_2;L_1,L_2]$

$$M(\tau,T)=\frac{2}{N_0}\int_0^{T_H} x(t)s\left(t|\tau,T\right)dt-\frac{1}{N_0}\int_0^{T_H} s^2\left(t|\tau,T\right)dt\,. \qquad (3)$$

Substituting the relationship (1) into the expression for $x(t)$ (3), we obtain the general statistics description at the optimal receiver output

$$M(\tau,T)=q_0^2\left(S\left(\Delta\tau,T_0,T\right)-\frac{1}{2}(\nu'+1)\right)+q_0N(\tau,T)\,, \qquad (4)$$

where $q_0^2=2e/N_0$ - power signal – to – noise ratio for one PS pulse having power e; $\Delta\tau=\tau-\tau_0$. The reference PS having period T contains $(\nu'+1)$ - pulse, where $L_1/T<1$, $L_2/T>>1$, and $\nu'=\left[\left(T_H-\tau_u\right)/T\right]$, where $[*]$ - whole part of number. In the expression (4)

$$S(\Delta\tau,T_0,T)=\frac{1}{e}\sum_{i=0}^{\nu'}\sum_{k=0}^{\nu}a_ia_k\int_0^{T_H}s_0(t-kT_0-\tau_0)\times$$
$$\times s_0(t-iT-\tau)dt=\sum_{i=0}^{\nu'}\sum_{k=0}^{\nu}a_ia_k\psi(kT_0-iT-\Delta\tau) \quad (5)$$

- periodical PS autocorrelation function (AKF), which can be thought of as a generalized ambiguity function (GAF) of the AUWB signal since it contains an information about the distance to object and its velocity –Refs. 1, 2. In relationship (5) function $\psi(\Delta\tau,T_0,T)$ can be considered as a normalized single pulse AKF. The surface $S(\Delta\tau,T_0,T)$ specified in a great mismatch range $(\Delta\tau,T/T_0)$ we denote as an ambiguity body. The component $N(\tau,T)=\sqrt{\frac{2}{eN_0}}\int_0^{T_H}n(t)s(t|\tau,T)dt$ is the statistics noise function at the AUWB signal optimal receiver output, respectively.

3. THE RESOLVING POWER OF THE AGGREGATIVE ULTRA – WIDEBAND SEQUENCES

The generalized ambiguity function of the periodical PS consisting of the Gaussian monocycles (2) has the following form

$$S(\Delta\tau,T_0,T)=\frac{1}{(\nu+1)}\sum_{i=0}^{\nu'}\sum_{k=0}^{\nu}exp\left(-\frac{2\pi^2}{\tau_u^2}\left((k-iN)T_0-\Delta\tau\right)^2\right)\left(1-\frac{2\pi^2}{\tau_u^2}\left((k-iN)T_0-\Delta\tau\right)^2\right), \quad (6)$$

where $N=T/T_0$. The GAF peaks structure is determined by the AKF shape of the single pulses $s_0(t)$ forming PS –Ref. 3. However, the direct calculation by relationship (5) shows that the general structure of the ambiguity body weakly depends on the primitive pulses shape under $Q>2$. The structure of the ambiguity body (6) of regular finite PS is represented at Fig. 1.

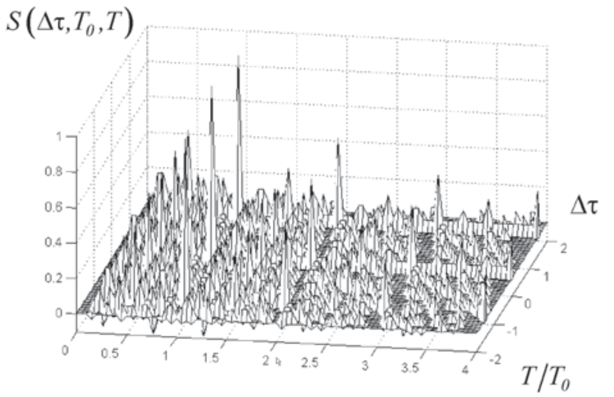

Fig. 1. The ambiguity body of regular finite PS consisting of 15 Gaussian monocycles. The sequence porosity is $Q=15$.

Let's calculate the potential resolving power of the AUWB signals. It could be determined through the correlation range of the period and time delay generalized ambiguity function sections in the main peak area.

$$\tau_{кор}=\left[-\frac{S(0,0)}{S''_{\tau\tau}(0,0)}\right]^{1/2}=1\Big/\sqrt{-\psi''(0)}\,; \quad (7)$$

$$T_{кор}=\left[-\frac{S(0,0)}{S''_{TT}(0,0)}\right]^{1/2}=\frac{1}{\sqrt{-\psi''(0)}}\left(\frac{\sum_{k=0}^{\nu}a_k}{\sum_{k=0}^{\nu}a_kk^2}\right)^{1/2}. \quad (8)$$

In the case of regular PS $\{a_k\}=1$, $k=\overline{0,\nu}$, which consists of the pulses with shape described by expression (2), it is not difficult to obtain

$$\tau_{кор}=\frac{\tau_u}{2\pi\sqrt{3}}\,;\ T_{кор}=\frac{\tau_u}{2\pi}\sqrt{\frac{2}{\nu(2\nu+1)}}\approx\frac{\tau_u}{2\pi\nu}. \quad (9)$$

Thus, the ambiguity function main peak section width along the time delay axis is $2\tau_{кор}$ and along the period axis is $2T_{кор}$. From aforementioned estimations of $T_{кор}$ follows that the increasing of the pulse number in the received sequence leads to ambiguity function peaks narrowing along the period axis.

The relationships (9) allows to obtain the estimations of the distance ΔR and velocity ΔV resolving power (in active location case) using the AUWB signals with the pulse shape (2) as a location signals

$$\Delta R=c\tau_{кор}=c\tau_u\big/4\pi\sqrt{3}\,;\ \Delta V=c/4\pi Q\nu \quad (10)$$

In real ultra – wideband radiolocation and communication systems the pulse duration makes up $0.1-20\,ns$ and the interval between them is $2-5000\,ns$. Therefore, at pulse duration $\tau_u=1\,ns$ we shall obtain the distance resolving power $\Delta R\approx 1.38\,см$. At PS porosity $Q=100$ and the pulse number $\nu=10^5$ (it corresponds to the observation time $T_H=10\,мсек$) the velocity resolving power will be $\Delta V\approx 2.39\,м/с$.

4. THE ANALYSIS OF THE GENERALIZED AMBIGUITY FUNCTION

The most complete research of the ambiguity body and its period and time delay sections behavior is carried out in –Ref. 3. Let's pay attention to some features of the GAF structure, which will be useful to us at the further analysis.

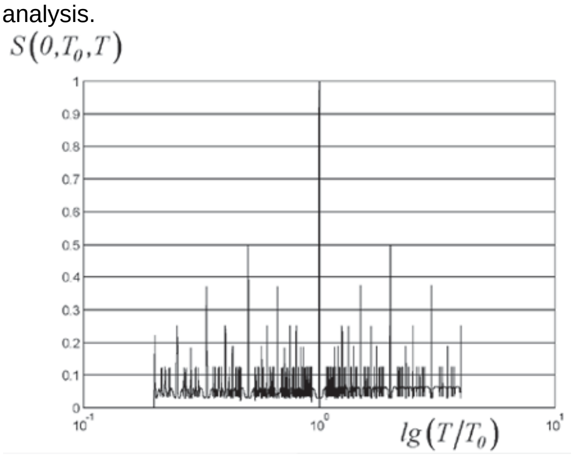

Fig. 2. The period section of the ambiguity body of the regular finite PS that consists of 15 Gaussian monocycles. The sequence porosity is $Q=10$.

Having assign in (6) $\Delta\tau=0$, we obtain the period section of the AUWB signal ambiguity body which is represented in Fig. 2.

The research of the given section has shown that it has a non – stationary component like a trend on which the narrow peaks of the main and subordinate maxima that appear under the condition fulfillment $kT_0 = iT$ in the expression (5) for AKF are imposed.

In the finite PS case the GAF period section that is plotted in semi-logarithmic scale has a symmetry by the subordinate maxima values relative to the main peak. The given section decomposes into separate peaks set if the PS porosity is $Q = T_0/\tau_u$ and the pulse number $(\nu + 1)$ is not great. The GAF peak width in the period section depends on true parameter T, T_0 values. Here the peaks satisfying the condition $N = T/T_0 \le 1$ have minimal width. The subordinate maxima width increase directly proportional N under the period ratio $N = T/T_0 = 2, 3, \ldots$.

We obtain GAF time delay section of the periodical PS if $T = T_0$. In given section the finite PS ambiguity body is represented as a set of $(2\nu + 1)$ peaks. The subordinate maxima values will decrease relative main peak value under the linear law with time delay mismatch increasing. The peaks structure in given section corresponds to AKF shape $\psi(\Delta)$ of the primitive pulses forming the PS.

The analysis of the ambiguity body structure in general allows to say that it has very complicated multipeak and normally ordered structure (Fig. 1). The detailed research of this 3D – surface shows that it could be thought of as a set of some scaling relative each other similar structures. The ambiguity body is represented as a pack of ridges that are situated under strictly defined angles to axes OT/T_0 and $O\Delta\tau$. Under the intersection these ridges fluently transform to a GAF peaks of different values, thus, forming the well-ordered system of the embedded in each other N - shaped structures. As a consequence the ambiguity body peaks are situated under the certain angles to axes OT/T_0 and $O\Delta\tau$, the pulse number increasing in received PS results in that angles tend to zero. It is typical for the correlated estimation case of the signal parameters. The pulse number increasing in the received PS leads to increasing the N - shaped structures number that results in complication of the ambiguity body structure.

4. THE GAF SUBORDINATE MAXIMA SUPPRESSION METHOD

It is obvious from Fig. 1 that the ambiguity body of the regular periodical PS has a great subordinate maxima number which presence leads to the II sort anomalous errors appearance during the distance and velocity estimation that in its turn significantly affects on the given estimations accuracy and reliability. The GAF subordinate maxima suppression could be realized by means of regularity imperfection of the AUWB signal by the way of its periodical modulation using some code sequence –Ref. 3. As a modulating code sequences Barker's codes –Ref. 2 and the sequences with «no more than one coincidence» property _Ref. 4 were considered.

The discrete codes with «no more than one coincidence» property are the sequences $\{a_k\}$, $k = \overline{0,\nu}$, $a_k = 1,0$, for which at any time shift at interval $\Delta > \tau_u$ no more than one coincidence of the source and shifted code pulses occurs. The given sequences elements are formed from the elements of sets that are obtained from extended Gaulle fields –Ref. 4. The subordinate peaks level of the normalized AKF of codes with «no more than one coincidence» property does not exceed $1/M_0$, where M_0 - code pulses number. Under the great values of M_0 и M it is true $M_0 \approx \sqrt{2M}$.

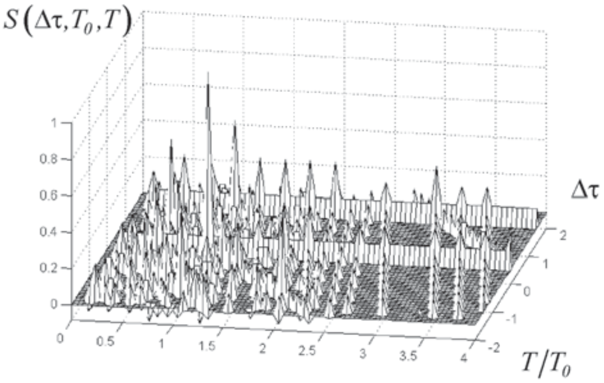

Fig. 3. The ambiguity body of the finite PS consisting of the 15 Gaussian monocycles and modulated by code sequence with «no more than one coincidence» property with $M = 7$ and $M_0 = 4$. The sequence porosity is $Q = 15$.

The received and reference AUWB signals regularity imperfection, first of all, results in subordinate maxima values reduction (Fig. 3, 4) and pulse number decrease in given signals. Due to this fact at the great PS porosity the GAF period section decomposes into separate peaks and the destruction of the the N - shaped structures of the ambiguity body takes place and their decomposition into rare ridges and peak groups (Fig. 3, 4). Moreover, the free region appears around the GAF main maximum that promotes the increasing of the accuracy and reliability of the information parameter estimations.

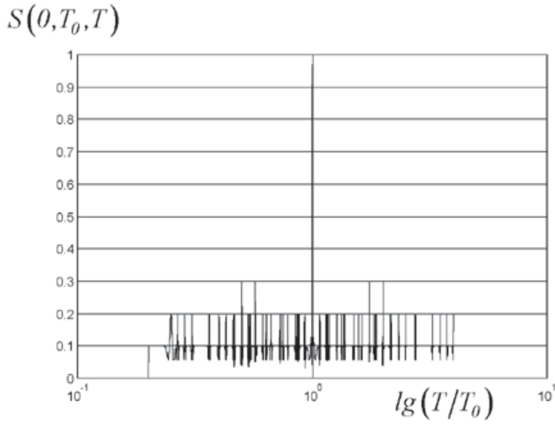

Fig. 4. The ambiguity body period section of the finite PS consisting of the 15 Gaussian monocycles modulated by code sequence with «no more than one coincidence» property with $M = 7$ and $M_0 = 4$. The sequence porosity is $Q = 10$.

The researches have shown that from all Barker's sequences the significant suppression of the GAF subordinate maxima provides the sequence with code positions number $M = 7$. For discrete sequences with «no more than one coincidence» property it is performed for all possible codes with $M_0 \geq 4$. The algorithm of codes generation with «no more than one coincidence» property allows to select the best code for regularity imperfection of PS of any length.

The comparative analysis of Barker's sequences and codes with «no more than one coincidence» property with the same pulses number and code positions number showed that the last are the optimal low for AUWB signals regularity imperfection in the sense of subordinate peaks values decreasing.

It should be noted that the implementation of the code sequences with «no more than one coincidence» property to AUWB signals results in decreasing of the GAF main peak absolute level in comparison with the case of regular PS. Furthermore, at reference and received PS regularity imperfection the pulses number in it decreases and so according to the relationship (8) the expansion of the GAF main maximum in the period section is occurred relative to the regular case. However, the essential difference between main and subordinate peak values is achieved that allows reducing the II sort anomalous errors influence on the distance and velocity estimations reliability.

The pulses number reduction in the reference and received sequences under the periodical modulation by codes with «no more than one coincidence» property leads to resolving power decreasing of AUWB signals. It is proved by the comparison of the expressions (7), (8) with the relationship for regular case (9). Nevertheless, it should be noted that the resolving power losses will be greater in the case of unreliable distance and velocity estimations than in the given case.

The research of the statistics at the periodic PS optimal receiver output allows drawing a conclusion about a dual nature of the information parameter T: the PS period displays the power parameter properties on a whole a priori interval $[L_1, L_2]$. Therefore, the reliability calculation of the object velocity estimation should be realized as for a power parameter. At the same time the PS period could be considered as non – power parameter at small subintervals of $T_{кор}$ order –Ref. 3. Consequently, the potential accuracy of the information parameters estimation (τ, T) could be characterized by Fisher inverse matrix –Ref. 2

$$\hat{K} = \frac{1}{q_0^2 \left(S''_{\tau\tau} S''_{TT} - S''^2_{\tau T} \right)} \begin{Vmatrix} -S''_{TT} & S''_{T\tau} \\ S''_{T\tau} & -S''_{\tau\tau} \end{Vmatrix}. \qquad (11)$$

Substituting in (11) the expressions for the GAF second derivatives (7), (8) with taking into account the code sequence type it is not difficult to obtain the explicit matrix $\hat{K}$ description

$$\hat{K} = \frac{\left(q_0^2 \left(-\psi''(0) \right) \right)^{-1}}{\left[\sum_{k=0}^{\nu} a_k \sum_{k=0}^{\nu} a_k k^2 - \left(\sum_{k=0}^{\nu} a_k k \right)^2 \right]} \begin{Vmatrix} \sum_{k=0}^{\nu} a_k k^2 & -\sum_{k=0}^{\nu} a_k k \\ -\sum_{k=0}^{\nu} a_k k & \sum_{k=0}^{\nu} a_k \end{Vmatrix}. \qquad (12)$$

In given matrix the diagonal elements can be thought of as PS period and time delay estimation variances, respectively, and the non – diagonal elements are the products of the estimations correlation coefficient on the appropriate root-mean-square deviations. It is apparent from expression (12), that the information parameters accuracy will be increase with the primitive pulse AKF duration $\left(-\psi''(0)\right)^{-1}$ reduction and with the summary signal-to-noise ratio $q_0^2(\nu + 1)$ increasing. In regular PS case with the pulses number increasing the time delay estimation variance is reduced $\sim 1/\nu$, and the period estimation variance $\sim 1/\nu^3$.

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