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CLUTTER COMPENSATION PROBLEM IN THE LPI RADAR

S.Y. SEDYSHEV, S.A. GORSHKOV, AND M.N. VORONTSOV

Noise probing signals and noise radar technology is one of perspective directions in the radar systems theory and techniques. Detection of moving targets in background clutter environment by noise radar is discussed in this paper. Some questions of pseudorandom quasi-continuous signals processing in surveillance radar are also considered.

Keywords: LPI Radar, clutter, noise-like signals, autocorrelation function, cross-correlation function, «range-rate» matrix.

1. INTRODUCTION

Lowing of radar signal interception probability is an important way to improve the noise interference immunity and survivability of radars. Radars with the low level of the signals interception probability are called as Low Probability of Intercept Radar (LPI Radar) [1], [2], [3], [9], [12], [15]. Usually the time-frequency structure of radar signals is to be rather close to that of the noise waveform to provide improvement of radar LPI performance [5], [8], [9], [15].

Digitally generated random signals are to be called as noise-like signals (NLS). The term «noise-like signals» is due to their random properties, but actually these signals are generated with the help of mathematical algorithms. Noise-like signals are also called as pseudo-random signals (PRS) or pseudo-noise ones.

Number of theoretical and practical problems of the LPI radar has been solved [1], [2], [3], [5]. At present the following issues have been studied:

Formation rules for coherent sequences of pseudo-random signals [5], [8], [9], [12], [15];

Generation methods for high power probing pseudo-noise signals;

Pseudo-random signals compression principles.

Use of the sophisticated probing signals (PS) in radar made it possible to resolve the conflict between radar resolution and radar operation range, improve their immunity, and reduce the radiation peak power of the transmitters. Application of the pseudo-random sequences for complex noise-like signals formation allowed increasing of radar electromagnetic compatibility, improving the efficiency of the radio spectrum use by the code separation of PS.

There is one more important issue in the active LPI radar design to be studied in more details: the moving targets detection on the background clutter. Random modulation law (ML) of the NLS has a different structure of compressed pulse sidelobes at different pulse repetition periods. In this case the clutter correlation rate may decrease from period to period and, as a result, the quality of clutter suppression may reduce.

Mathematical modeling results of pseudorandom signals and device for their processing in surveillance radar at the presence of passive interferences are presented in the paper.

2. APPLICATION OF QUASI-CONTINUOUS SIGNALS IN LPI SURVEILLANCE RADAR LIGHTING

Improving of the quality of the passive interferences suppression can be achieved by increasing the pulse repetition frequency (PRF) of the radar. Furthermore, coherent integration (CI) of the reflected signals (RS) will reduce probability of the radar radiation interception [5]. Use of the quasi-coherent sequences NLS with ML change from pulse to pulse (Fig. 1) allows to save the unambiguous range r_{unq} with simultaneous expanding of the unambiguous determination range of radial velocity V_{runq} [13], [14].

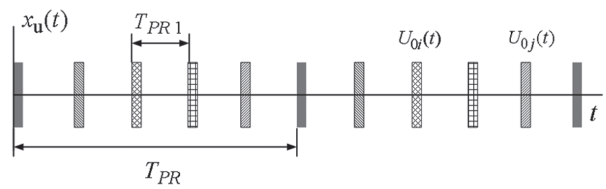


Fig. 1. Real component of the infinite coherent sequence of five mutually orthogonal signal

According to Fig.1 infinite coherent sequence of composite ML $U_0(t)$

$$U(t) = \sum_{k=-\infty}^{+\infty} U_0(t - kT_{PR}), \tag{1}$$

contains N repetitive mutually orthogonal signals

$$U_0(t) = \sum_{j=0}^{N-1} U_{0j}(t - kT_{PR1}), \tag{2}$$

$$\int_{-\infty}^{+\infty} U_{0i}(t) U_{0j}^*(t) dt = 0 \quad \forall i \neq j \quad i, j = \overline{0, N-1}. \tag{3}$$

The unique range for the probe sequence (1) with (2) and (3) is defined by the pulse repetition period T_{PR}:

$$r_{unq} = 0.5 c T_{PR}, \tag{4}$$

and unique radial velocity range is defined by the repetition period T_{PR1}:

$$V_{r_{unq}} = \pm\lambda / 4T_{PR1}, \tag{5}$$

where c is a light velocity, λ is a wavelength.

The ambiguity function of signal (1) is shown in the Fig. 2, b in comparison with the ambiguity function of the conventional PS sequence (without mutual orthogonality) (Fig. 2, a).

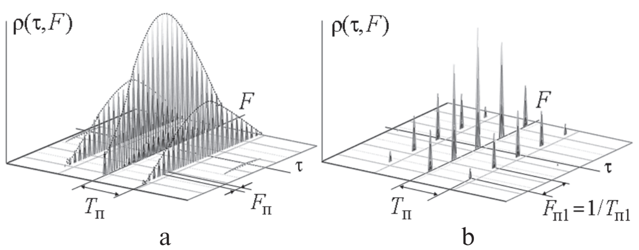


Fig. 2. Ambiguity function: a – conventional PS sequence; b – sequences of three PS consisting of five mutually orthogonal LNS

3. SIGNAL PROCESSING WITHIN THE PERIOD IN CASE OF COMPOUND MODULATION LAW

The impulse response of the matched filter (MF) is described by the mirror image of the complex-conjugate PS ML $U_0(t)$ [10], [11]. For the compound ML (2)

$$v_0(t) = U_0^*(t_0 - t) = \sum_{j=0}^{N-1} U_{0j}^*(t_0 - t - kT_{n1}), \qquad (6)$$

where t_0 is minimum delay value that is to be taken from the condition of the filter implementation assumption [9].

Digital implementation of the device (6) for processing within the period of the compound modulation law (PPML) will be considered further. The structural scheme of this device with the buffer random access memory (RAM) for the case $N = 5$ is shown in the Fig. 3.

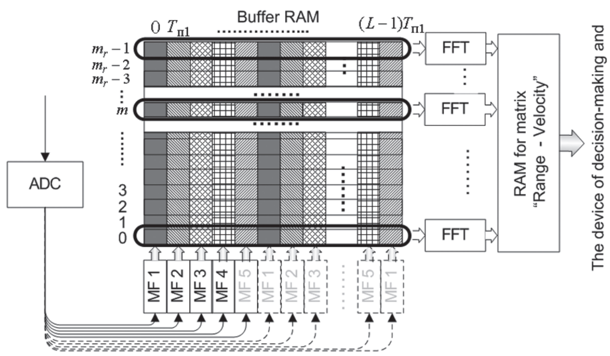


Fig. 3. Processing device of the compound ML

In figure (3) L is the number of coherently accumulated complex samples over a period T_{PR1} in every m radar resolution element for the range; m_r is the number of the range radar elements,

$$m_r = r_{unq} / \Delta r\ , \qquad (7)$$

where Δr is the radar range resolution of the radar.

4. PULSE-TO-PULSE SIGNAL PROCESSING

Pulse-to-pulse signal processing of the received radar returns consists of the following three stages [10], [11]:

Coherent compensation of the clutter;

Coherent integration of the signals;

Incoherent integration of the reflected signals.

Coherent compensation of the clutter is realized with the help of the following hardware :

Devices of the subtraction through a period (STP) or notch filters with fixed parameters;

Clutter adaptive automatic compensators with the correlation feedback;

Adaptive lattice filters (ALF);

Other ways of the coherent compensation.

STP is used for the coherent compensation of the clutter in this article. Coherent integration of the L complex samples through a period T_{PR1} is realized by the discrete Fourier transform (DFT) application for every m-th column of the buffer memory (Fig. 3). In case of L is defined by the number of power 2, then fast Fourier transform (FFT) may be used instead DFT.

The results of the DFT algorithm are stored in the output 2D memory buffer having $m_r \times L$ elements (RAM of the «Range-Velocity» matrix), which contains the square modules of the coherently integrated signals complex amplitudes in radar range resolution cells. It enables to evaluate the radial velocities of targets detected in these range elements within unambiguous velocity range (5). Examples of the coherent integration parameters have been considered in [5], [13], [14], [16].

Thus, the coherent integration of the matched filtration results in every m-th line of the buffer RAM (Figure 3) allows to organize a radar space surveillance over both range and radial velocity.

5. THE MODELING RESULTS

Mathematical model of the quasi-continuous sequences of five mutually orthogonal cyclically recurring ML based on Gold codes was used as an input signal for processing devices (Fig. 3). Mismatch function and mutual mismatch function of the Gold codes are shown in Fig. 4, 5.

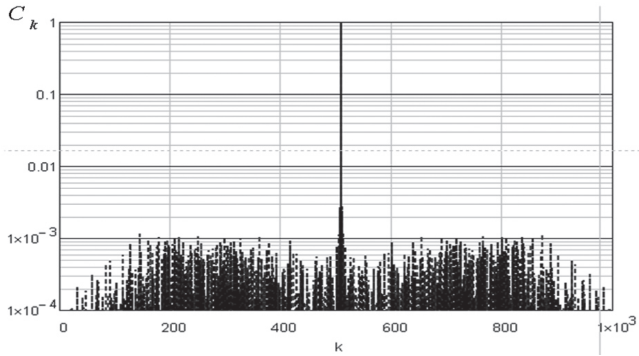


Fig. 4. Autocorrelation function of the Gold code sequences LM

L =16 repetition periods with T_{PR1} = 200 μs were used for modeling. The following PS characteristics were used: wavelength is $\lambda = 0.23$ m, discrete value duration is $T_d = 0.15 \cdot 10^{-6}$ s, discrete value amount is $N_d = 255$, sampling step in the model is $\Delta t = T_d / 2$. To reduce amount of computation the processing sample was modeled for 2048 range samples.

Clutter with zero Doppler frequency, ΔF_n =50 Hz spectrum width of the inter period fluctuations and clutter/noise ratio γ_{cl} = 30 dB (or γ_{cl} =37 дБ) held samples for the range with numbers 510-th up to 660-th after MF. Reflected signal with output MF signal/noise ratio $\gamma = 10$ dB and Doppler frequency F_D =2.4 kHz ($V_r = 280$ m/s) was located on 555-th sample for the range.

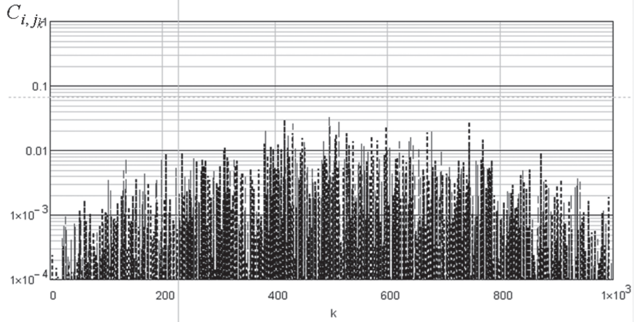


Fig. 5. Cross-correlation function of the Gold code sequences LM

Square modulus of the received signal MF result are shown in Figure 6 in dashed line. Solid line in Fig. 6 shows the output signal square modulus of the MTD device.

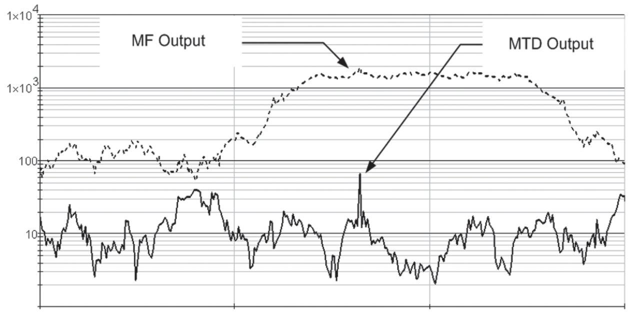


Fig. 6. Output signals of the MF and MTD device

Usual sequence clutter suppression coefficient on the output MTD device is defined as [10]:

$$K_{cl} \approx 0.023(F_{PR1} / \Delta F_{cl})^3 = 2.3\times10^4 \approx 44 \text{ дБ}, \quad (8)$$

where $F_{PR1} = 1/T_{PR1} = 5000$ Hz.

Coherent sequence of mutually orthogonal probing signals leads to the reduction of the interperiod clutter correlation coefficient. Partial clutter decorrelation is caused by amplitude-phase differences of compressed pulses sidelobes in adjacent repetition periods. It was found in the mathematical modeling process of the clutter coherent compensation for mutually orthogonal PS sequences and different ratios interference/noise, that output clutter suppression coefficient of the STP device can be represented as:

$$K_{cl1} \approx \left(\frac{1}{K_{cl}} + \nu_{sb} \right)^{-1}, \quad (9)$$

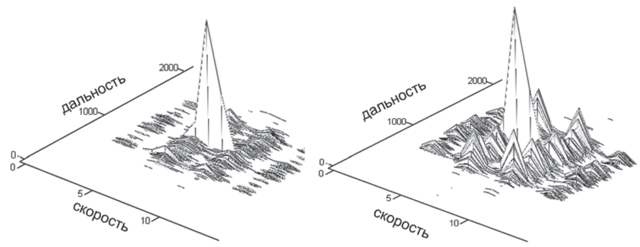
where ν_{sb} is the sidelobe average level of mutually orthogonal PS ML mismatch functions.

The sidelobe average level of Gold codes sequences used in the mathematical modeling is –30 dB. The resulting output clutter suppression coefficient of the twice STP device with (8) and (9) is

$$K_{cl1} = (10^{-4} / 2.3 + 10^{-3})^{-1} \approx 960 \approx 30 \text{ дБ}. \quad (10)$$

Thus, the influence of the sidelobe average level of the mutually orthogonal PS ML begins to affect when ratio interference/noise is $\gamma_{cl} > 1/\nu_{sb}$.

The coherent signal storage results after STP device for different ratio values interference/noise are shown in the Figure, a, b. In both cases the output ratio signal/noise of the MF devise was set = 4 dB.



a b

Fig. 7. CA results in the «range-rate» matrix:
a – ratio signal/noise is γ_{cl} =30 dB;
b – ratio signal/noise is γ_{cl} =37 dB

Fig. 7, b shows the growth of clutter compensation balances in «range-velocity» matrix in Figure 7,b compared with the Figure 7. This is due to the fact that the receiver internal noise level is less then sidelobes of the compressed signals.

6. CONCLUSIONS

The modeling results of the processing of the signals sequence reflected from target and clutter in the form of Gold codes sequence with ML change from pulse to pulse in the device shown in Figure 3 confirm the decreasing of the passive interference inter period correlation coefficient because the pseudorandom modulation law varies from period to period. For Gold codes sequence considered in the paper, the clutter suppression coefficient is less than the value inverse to sidelobes average level of the correlation function, i.e. -30 dB level.

Further quality improvement of the clutter coherent compensation can be achieved by:

Increasing number of QPSK signal discrete with simultaneous spectrum expansion at preserving PS duration $T_0 = T_d N_d$. «Blind» range sizes are not increased in this case;

Selecting of the better ways to form mutually orthogonal modulation law based on Frank and , Welch-Costas codes, signals with orthogonal frequency of channels division [3], etc.

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Проблема компенсации мешающих отражений в LPI РЛС обзора / С.Ю. Седышев, С.А. Горшков, М.Н. Воронцов // Прикладная радиоэлектроника: науч.-техн. журнал. – 2013. – Том 12. – № 1. – С. 137–140.

Случайный закон модуляции шумоподобных сигналов обладает случайной структурой боковых лепестков сжатого импульса. В этом случае происходит снижение коэффициента межпериодной корреляции пассивных помех, и, как следствие – снижается качество их подавления. В настоящей статье рассматривается возможность обнаружения движущихся целей на фоне пассивных помех. Приводятся результаты математического моделирования квазинепрерывной последовательности из пяти взаимно ортогональных циклически повторяющихся кодов Голда и устройств их обработки на фоне пассивных помех для РЛС обзора.

Ключевые слова: LPI РЛС, шумоподобные сигналы, пассивные помехи, коэффициент подавления, матрица «дальность-скорость».

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Проблема компенсації відбитків, що заважають, у LPI РЛС огляду / С.Ю. Седишев, С.А. Горшков, М.Н. Воронцов / / Прикладна радіоелектроніка: наук.-техн. журнал. – 2013. – Том 12. – № 1. – С. 137-140.

Випадковий закон модуляції шумоподібних сигналів має випадкову структуру бічних пелюсток стисненого імпульсу. У цьому випадку відбувається зниження коефіцієнта міжперіодної кореляції пасивних перешкод, і, як наслідок – знижується якість їх заглушення. У цій статті розглядається можливість виявлення рухомих цілей на фоні пасивних перешкод. Наводяться результати математичного моделювання квазі-неперервних послідовностей з п’яти взаємно ортогональних циклічно повторюваних кодів Голда і пристроїв їх обробки на фоні пасивних перешкод для оглядових РЛС.

Ключові слова: LPI РЛС, шумоподібні сигнали, пасивні перешкоди, коефіцієнт заглушення, матриця «дальність-швидкість».

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