Processing of Ultra Wideband LFM Signals Using Correlation-Filtering Method

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Abstract

The principles of processing the superposition of reflected ultra wideband chirp Signals by a correlation-filter method are considered; as a result, a transformation occurs in the spatial "window" in the range of the compressed LFM signals and is proportional to their frequency shift. At the same time, the frequency band of the reflected signals is reduced in proportion to the transformation coefficient, so that their further processing can be carried out in digital form, thereby ensuring high stability and identity of the processed signals necessary for more reliable recognition of radar targets with allowance for superresolution in the distance. A method is proposed for compensating frequency detuning compressed and frequency-shifted superposition of reflected LFM signals, which makes it possible to carry out their weight processing using standard methods and to limit the spectral band. Thus, the signal-to-noise ratio increases, and the correlation filtering method of processing, taking into account the compensation of frequency detuning of the transformed and compressed LFM signals, approaches the optimal method. This makes it possible to provide detection at longer distances, about 0.8 times the maximum detection, and, if necessary, take appropriate measures. It is shown that, regardless of the size of the spatial window, energy losses remain minimal, and the frequency of discrete samples of compressed pulses decreases in proportion to the transformation coefficient, while ensuring high resolution and saving phase information about the brilliant points in the spatial image.

Keywords: Correlation-filter method, Radar, Frequency-time transformation, Recognition, Weight processing.

Introduction

Ultra wideband (UWB) radar has become increasingly popular in both commercial and defense industries. UWB radars (whether impulse, LFM, noise, or OFDM-based) are defined as having a bandwidth of greater than 0.5 GHz, or more than 20% of their center frequency, and are regulated by FCC rules that allow UWB technology to coexist with existing radio services without causing interference. In the presence of the enemy a large number of unmanned aerial vehicles (UAVs), as well as limited ammunition of surface-to-air missile (SAM), which means new tasks are set using radar. Along with traditional characteristics, such as finding a target, determining its coordinates and trajectory, it is necessary to know to which class this target belongs. The presence of such information allows you to separate from a large amount of data the most important targets on which you should focus maximum attention, and in case of need to make a decision to destroy the most dangerous of them [1], [2].

To determine the class of a target, it is necessary to set a number of distinctive features by which recognition is performed. For recognition can be used: temporal, spectral, correlation, energy, spatial, polarization characteristics of the reflected signals, as well as features of the trajectory of targets [3]. The information content of individual recognition features is not the same, but an increase in their number reduces the probability of an error. Recognition methods, as a rule, use information contained in the structure of reflected signals or the entire object as a whole. Unlike the two and multi frequency [4], [5] recognition methods, the best quality indicators are achieved with the use of wideband probing signals [6], [7], which provide for obtaining radar images of airborne objects. At the same time, the presence of trace information about airborne objects, which is recorded in each radar, allows you to perform as close as possible to optimal accumulation in order to increase the signal-to-noise ratio and compare the accumulated information with the reference images given their angle, direction of movement and speed, thus increasing the probability of correct recognition.

In this case, the probing signals must have a high resolution that allows you to resolve individual "brilliant" points of the probed target in range. At the same time, the processing of broadband signals is associated with some difficulties, such as the complexity of implementing a broadband path and working with compressed signals of short duration, which, in turn, requires a high processing speed of the processing equipment and a large amount of memory. Of all the most widely known methods of processing wideband echo signals is the correlation-filter method [8]-[11]. This method assumes in the waiting interval of the reflected ultra-wideband LFM signal to change the reference frequency of the local oscillator by a frequency varying linearly. Then the heterodyning result is processed in a compression filter. This makes it possible to reduce the requirement for further processing equipment and maintain a high resolution in the range.

Statement of the problem

Along with the listed advantages, in comparison with other methods of processing ultra-wideband LMF signals, the correlation-filtering method also has several disadvantages. For example, when processing ultra-wideband signals from extended objects in order to isolate amplitude-phase dependence in range, i.e. proper images of these objects, the path band should be somewhat larger than the optimum, therefore the signal-to-noise ratio declines. In addition, in order to minimize these losses, it is necessary to coordinate as accurately as possible the switching time of the reference oscillator frequency to a linearly varying frequency with the time of receiving of the reflected signal, i.e. improve the accuracy of target designation, in order not to expand the pathway. Finally, the level of side lobes of LFM signals after a compression operation is about − 13 dB [12], which is clearly not enough to identify images of targets, because their high-level mask image features and makes these images indistinguishable. In addition, the known methods of reducing side lobes in this case are not applicable due to the presence of frequency detuning.

The purpose of this work is to develop working models using a weight filter and an auxiliary local oscillator, which operates synchronously with the main local oscillator. Allows you to quickly change the bandwidth of the correlation filter channel at the input, while providing at the output of the path a low level of side lobes and the approximate SNR to the optimum value.

Theory

The principle of the correlation filtering method of processing LFM radio pulses is to reduce the frequency deviation of the processed ultra-wideband signals by using a local oscillator with linear modulation and their subsequent compression. This leads to the transformation of the time intervals between the compressed pulses in proportion to the narrowing of the band of reflected LFM signals. This allows us to significantly reduce the requirements for such a basic parameter as the bandwidth frequency of the channel for further processing, without compromising the resolution of the system. Thus, the correlation-filtering method of processing ultra-wideband radio pulses have a significant advantage over other known methods.

Signal transformation with correlation filter processing method

From the literature, it is known [13] that the spectral density of the chirp signal is determined by the equation

$$S(\omega) \cong V_0\sqrt{\frac{\pi}{2\mu}} \cdot exp\left\{-j\left[\frac{(\omega-\omega_0)^2}{2\mu} - \frac{\pi}{4}\right]\right\} \qquad -\frac{\Delta\omega}{2} \leq \omega \leq \frac{\Delta\omega}{2} \qquad (1)$$

Where $V_0 -$ the amplitude of the radio pulse;

$\omega_0 -$ the average frequency;

$\mu = (\Delta\omega / T)$ is the frequency deviation equal to the ratio of the band to the duration of the radio pulse.

Moreover, the modulus of the spectral density is close to a rectangular shape for large values of the base of the chirp signal $D = (T \times \Delta\omega) >> 1$, which is just necessary for the realization of a very high resolution in range.

But when processing a superposition of signals overlapping in time, besides reducing the deviation in each of these signals, they will differ from each other by central frequencies [14].

So, for example, taking into account the duration (T_h) of the heterodyne LFM signal, its band ($\Delta\omega_h$), as well as the duration (T_0) and band ($\Delta\omega c$) of the probing signal, the maximum change in the center frequency of the transformed $i - th$ reflected signal from its position relative to the heterodyne signal to its extreme points is determined by the equation

$$\delta(\omega_i) = (1 - m)\mu_{tr} \cdot \delta t_i \; , \qquad (2)$$

Where: $m = (\Delta\omega_c / \Delta\omega) -$ transformation ratio, equal to the ratio of the band of the reflected probe signal from brilliant point to the transformed band;

$\delta t_i -$ Is the time shift of the reflected signal from a brilliant point relative to the center of the heterodyne signal;
$\mu_{tr} = (\Delta\omega / T_0)$ is the frequency deviation of the transformed signal, equal to the ratio of its band to the duration.

Accordingly, the spectral density of the transformed LFM signal reflected from a random $i - th$ brilliant point, of which there may be a large number in the long-range image, will have the following form

$$S_i(\omega) \cong V_0\sqrt{\frac{\pi}{2\mu_{tr}}} \cdot exp\left\{-j\left[\frac{(\omega-\omega_0-\delta\omega_i)^2}{2\mu_{tr}} - \frac{\pi}{4}\right]\right\} \qquad (3)$$

And the result of compression in the filter of the $i - th$ reflected and transformed chirp signal can be represented by an equation

$$V_i(t) = V_0\sqrt{D}\,\frac{\sin\frac{\Delta\omega}{2}(t-t_0-m\cdot\delta t_i)}{\frac{\Delta\omega}{2}(t-t_0-m\cdot\delta t_i)} \cdot \cos\left[(\omega_0 + \delta\omega_i)\cdot(t - t_0 - \delta t_i) + \frac{\delta\omega_i{}^2}{2\mu_{tr}}\right] \qquad (4)$$

In this equation, the parameter t_0 describes a constant delay in the compression filter, which in further considerations can be taken into account by a simple shift of coordinates along the time axis. The energy of the compressed $i - th$ chirp signal is concentrated at the point $t_i = m \cdot \delta t_i$, and the response time, including the transitional oscillatory process of forming the side lobes of the compression filter for each reflected and transformed $i - th$ chirp signal, will be within

$$m \cdot \boldsymbol{\delta t_i} - (T_0 - T_f)/2 \leq t \leq m \cdot \boldsymbol{\delta t_i} + (T_0 - T_f)/2, \qquad (5)$$

Where: T_0 is the duration of the probing LFM signal ;

$T_f -$ is the response duration of the compression filter to the delta disturbance.

Frequency Offset Compensation of the compressed LFM signals reflected from the brilliant points with the correlation filter processing method

Determined by the equation (2) dependence of the frequency offsets as a result of reducing the deviation and transformation of the time responses in the compression filter, which is linear, allows for compensation of offset data with subsequent narrowing of the bandwidth of the processing path of the ultra-wideband LFM signals by the correlation-filtering method and its approximation to the optimal form while maintaining the above advantages.

To transfer the center frequencies of the compressed LFM signals to a certain frequency corresponding to the center frequency of the weight filter, it is enough to use an auxiliary local oscillator which operates synchronously with the main local oscillator, the rate of change of the frequency of its reference signal varies linearly, and the sign of the deviation is opposite to the linearly varying offset of the frequencies of the compressed LFM signals reflected from the brilliant points. In this case, the frequency deviation of the auxiliary local oscillator can be expressed through the frequency deviation of the transformed signals in accordance with the relation.

$$\mu_{lo} = \left(1 - \frac{1}{m}\right)\mu_{tr} \quad (6)$$

Linear dependence of central frequency offsets ($\boldsymbol{\omega_{i1}}, \boldsymbol{\omega_{i2}}, \boldsymbol{\omega_{i3}}$) and the transformation of compressed signals at time ($\boldsymbol{\tau_{i1}}, \boldsymbol{\tau_{i2}}, \boldsymbol{\tau_{i3}}$) illustrated in Figure 1.

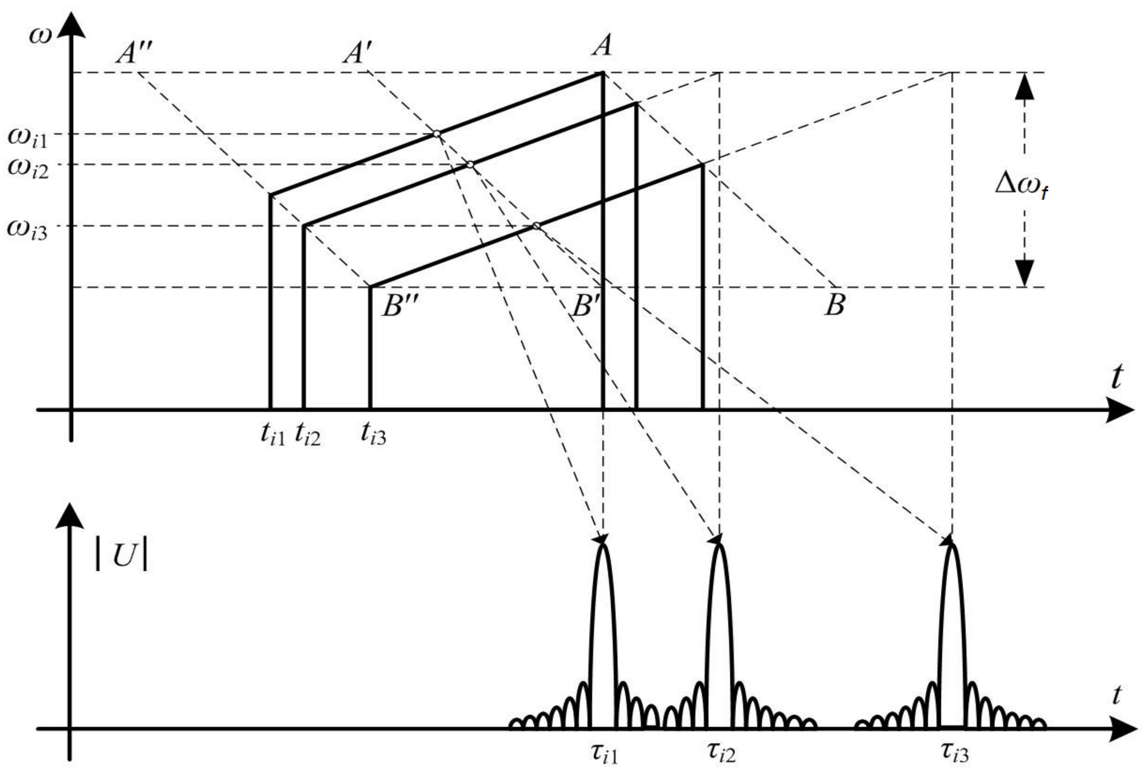

Fig. 1 Reflected and transformed LFM signals as a result of heterodyning (above) and their module after matched filtering (below).

Let us make sure that the assumption is correct, for this we will perform this operation, i.e. The transformed and compressed LFM signal with a random frequency offset from the value of $\boldsymbol{\omega_0}$ is multiplied by the signal of the auxiliary local oscillator, which center frequency is $\boldsymbol{\omega_1}$, and the deviation is determined by the equation (6). Then we select the useful part of the signal in the spectral region of the sum of frequencies$(\boldsymbol{\omega_0} + \boldsymbol{\omega_1})$. As a result of this operation, the signal will have the following analytical form,

$$V_i(t) = \frac{A_0 \cdot V_0}{2} \sqrt{D} \frac{\sin\frac{\Delta\omega}{2}(t - m\cdot\delta t_i)}{\frac{\Delta\omega}{2}(t - m\cdot\delta t_i)} \cdot \cos\left\{[\omega_1 + \omega_0 + (1-m)\mu_{tr} \cdot \delta t_i].t + \frac{\mu_{tr}\cdot t^2}{2}\left(1 - \frac{1}{m}\right) + \left[\frac{\delta\omega_i^2}{2\mu_{tr}} - (\omega_0 + \delta\omega_i)\cdot\delta t_i\right]\right\} \qquad (7)$$

Where: $A_0 -$ is the amplitude value of the auxiliary local oscillator.

To determine the center frequency of a compressed LFM signal with a random frequency offset after the described operation, it is sufficient to calculate the partial derivative of its phase with respect to time and perform an analysis in the region of the central lobe where the main energy of the reflected signal is concentrated. As a result of this, we will have

$$\frac{\partial \mathrm{p(t)}}{\partial t}\Big|_{t_i = m\cdot\delta t_i} = \omega_1 + \omega_0 + (1-m)\mu_{tr} \cdot \delta t_i + \mu_{tr} \cdot \left(1 - \frac{1}{m}\right)\cdot t \Big|_{t_i = m\cdot\delta t_i}$$
$$= \omega_1 + \omega_0 \qquad (8)$$

Due to the fact that the analytical test was performed for a random value of the frequency offset of the rating value, this statement is effective for all values satisfying the condition that the reflected LFM signal completely overlaps with the main local oscillator signal. Otherwise, the edge effect will be observed, at which the frequency offset rate increases, and the resolution decreases.

Reduction of side lobes of compressed LFM signals reflected from brilliant points with a correlation filter processing method

To reduce the level of side lobes you can perform weight processing. In this case, any weight processing leads to the expansion of the central lobe and energy losses. In this case, the most acceptable is the hamming-weight window [12], which ideally allows reducing the level of side lobes to the level of $-42.8\ dB$ with the extension of the central lobe 1.47 times, while the losses amount to $-1.34\ dB$. In this case, if we use a rectangular window the width of which corresponds to the band of a single reflected and transformed LFM signal, the level of side lobes will remain the same, but the signal-to-noise ratio will increase and such processing will be optimal.

Considering that the form of a compressed weighted pulse is strongly affected by the spectrum of the LFM signal [9], which as a result of correlation filtering processes and auxiliary local oscillator could be distorted, we will determine it from the relation,

$$S(\omega) = \frac{A_0\cdot V_0}{2}\sqrt{D}\int_{m\cdot\delta t_i - T_{\ni}/2}^{m\cdot\delta t_i + T_{\ni}/2} \frac{\sin\frac{\Delta\omega}{2}(t - m\cdot\delta t_i)}{\frac{\Delta\omega}{2}(t - m\cdot\delta t_i)} \times \cos\left\{\frac{(1-m)\mu_{tr}}{2m}\cdot t^2 + (\Omega + \delta\omega_i).t + \left[\frac{\delta\omega_i^2}{2\mu_{tr}} - (\omega_0 + \delta\omega_i)\cdot\delta t_i\right]\right\} e^{-j\omega t}\,dt = A_{oi}\int_{-T_{\ni}/2}^{T_{\ni}/2} \frac{\sin\frac{\Delta\omega}{2}\cdot X}{\frac{\Delta\omega}{2}\cdot X} \exp j\cdot\left[\frac{\mu_{lo}}{2}\cdot X^2 + (\Omega - \omega)\cdot X\right] dX \qquad (9)$$

Where $A_{oi} = \frac{A_0\cdot V_0}{4}\sqrt{D}\exp j\cdot\left[(\Omega - \omega)\cdot m\cdot\delta t_i - \left(\omega_0 + \frac{\delta\omega_i}{2}\right)\cdot\delta t_i\right]$; $T_{\ni} = T_0 + T_f$

$X = (t - m\cdot\delta t_i)\ and\ \Omega = (\omega_1 + \omega_0)$

To solve equation (9), we can transform it to the following form,

$$I = A_{oi}\int_{-T_э/2}^{T_э/2}\frac{\sin\frac{\Delta\omega}{2}\cdot X}{\frac{\Delta\omega}{2}\cdot X}\exp j\cdot\left[\frac{\mu_{lo}}{2}\cdot X^2+(\Omega-\omega)\cdot X\right]dX = \frac{A_{oi}}{j\Delta\omega}\left\{\int_{-T_э/2}^{T_э/2}\exp j\cdot\left[\frac{\mu_{lo}}{2}\cdot X^2+\left(\Omega-\omega+\frac{\Delta\omega}{2}\right)\cdot X\right]\frac{dX}{X}-\int_{-T_э/2}^{T_э/2}\exp j\cdot\left[\frac{\mu_{lo}}{2}\cdot X^2+\left(\Omega-\omega-\frac{\Delta\omega}{2}\right)\cdot X\right]\frac{dX}{X}\right\} = \frac{A_{oi}}{\Delta\omega}\{I_1(B)-I_2(B)\} \qquad (10)$$

Where

$$I_{1,2}(B) = \frac{1}{j}\int_{-T_э/2}^{T_э/2}\frac{\exp j.\left(\frac{\mu_{lo}}{2}\cdot X^2+BX\mp\frac{\Delta\omega}{2}\cdot X\right)}{X}\,dX\;,\; B=\Omega-\omega.$$

Then differentiate the equation (10) by the parameter B

$$\frac{\partial I(B)}{\partial B} = \frac{A_{oi}}{\Delta\omega}\left\{\int_{-T_э/2}^{T_э/2}\exp j\cdot\left[\frac{\mu_{lo}}{2}\cdot X^2+\left(\mathrm{B}+\frac{\Delta\omega}{2}\right)\cdot X\right]dX-\int_{-T_э/2}^{T_э/2}\exp j\cdot\left[\frac{\mu_{lo}}{2}\cdot X^2+\left(\mathrm{B}-\frac{\Delta\omega}{2}\right)\cdot X\right]dX\right\}, \qquad (11)$$

Then, assuming the first integral $Y=\sqrt{\frac{\mu_{lo}}{2}}\cdot\left(X+\frac{\mathrm{B}+\frac{\Delta\omega}{2}}{\mu_{lo}}\right)$, and in the second integral $Z=\sqrt{\frac{\mu_{lo}}{2}}\cdot\left(X+\frac{\mathrm{B}-\frac{\Delta\omega}{2}}{\mu_{lo}}\right)$, then equation (11) is transformed to a known form

$$\frac{\partial I(B)}{\partial B} = \frac{A_{oi}}{\Delta\omega}\sqrt{\frac{2}{\mu_{lo}}}\cdot\left\{exp\left[-j\cdot\frac{\left(\mathrm{B}+\frac{\Delta\omega}{2}\right)^2}{2\mu_{lo}}\right]\cdot\int_{-Y_1}^{Y_2}exp\left[j\cdot\frac{\pi}{2}Y^2\right]dY - exp\left[-j\cdot\frac{\left(\mathrm{B}-\frac{\Delta\omega}{2}\right)^2}{2\mu_{lo}}\right]\cdot\int_{-Z_1}^{Z_2}exp\left[j\cdot\frac{\pi}{2}Z^2\right]dZ\right\} \qquad (12)$$

In this equation, each term is represented by the product of the exponential function and the complex Fresnel integral [15], the value of these integrals on a certain interval is close to unity, and outside it is zero. In this case, these intervals are limited by the band of the auxiliary local oscillator, which is determined by the condition of $\Delta\omega_{lo} = \mathrm{T}_э\cdot\mu_{lo}$.

Taking into account the above, after integrating with respect to the parameter B, we again obtain the difference of the Fresnel integrals, the arguments of which differ by the value of $\Delta\omega$, therefore in this interval their difference is close to unity, and outside this interval to zero.

From this it follows that the modulus of the spectral density of the LFM signal with the base D >> 1 after the transformation and auxiliary local oscillator has a rectangular shape. Therefore, the operation to reduce the level of side lobes can be implemented using the Hamming window without additional correction.

The block diagram of the correlation filtering method of processing LFM signals with an auxiliary local oscillator and a weight filter is presented in Figure 2.

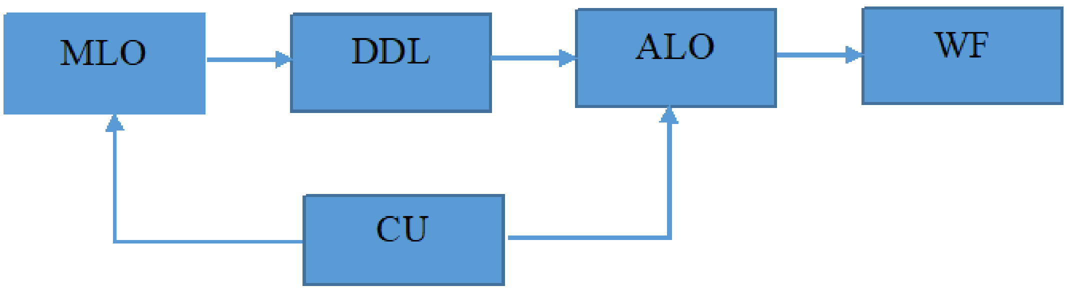

Fig. 2 Block diagram:

MLO - the main local oscillator; DDL - dispersive delay line (consistent with chirp signal); ALO-auxiliary local oscillator; WF - weight filter; CU - control unite.

Simulation results

The simulation of the processing of reflected ultra-wideband signals in the receiving correlation filter path with an auxiliary local oscillator and weight filter were performed in Matlab with the synthesis of the reflected ultra-wideband LFM signal from four brilliant points transformed as a result of heterodyning and compression. The characteristics of the probing signal and the parameters of the correlation filter track were set of conditions as close to real as possible, which simply can be implemented in the radar centimeter range.

For example, the duration of the probing LFM signal is given by $T_0 = 30\ \mu s$, and the band $\Delta f_C = 75\ MHz$. The duration of the main LFM local oscillator $T_{MLO} = 30.61\ \mu s$, which allows in the spatial "window" ΔL = 92 m, with a resolution of less than 3 m, fix a large number of resolved brilliant points and correlatively compare their amplitude-phase characteristics with radar images of selected classes of targets corresponding to a given angle and speed, taking into account the phase relationships between the brilliant points. In this case, the linear variation of the local oscillator frequency for a duration of 30 µs is 73.5 MHz, which determines the transformation coefficient, which in this case is equal to $m = 50$, and its full deviation at the duration of the heterodyne signal will be $\Delta f_{LO} = 75$ MHz. The characteristics of the compression filter are selected so that the reflected signal after transformation, regardless of its temporal position for the duration of the heterodyne LFM signal, compressed without distortion, then the response time of the filter to the delta disturbance should be $T_f = 60\ \mu s$, and the band $\Delta f_f = 3\ MHz$.

Spatial analysis was subjected to a long range of the target with four pronounced brilliant points. Moreover, the distance between the first and second points is 18.6 m, between the second and third is 2.4 m, and between the third and fourth is 6 m, while the power of the reflected signals is the same, and the center of the reflected LFM signal from the third point matches with the center of the LFM main local oscillator.

As a result, the correlation filtering processing overlapping in time superposition of LFM signals, reflected from the four brilliant points, compression is performed with transformation, the modulus of this signal at the output of the compression filter is shown in Figure 3.

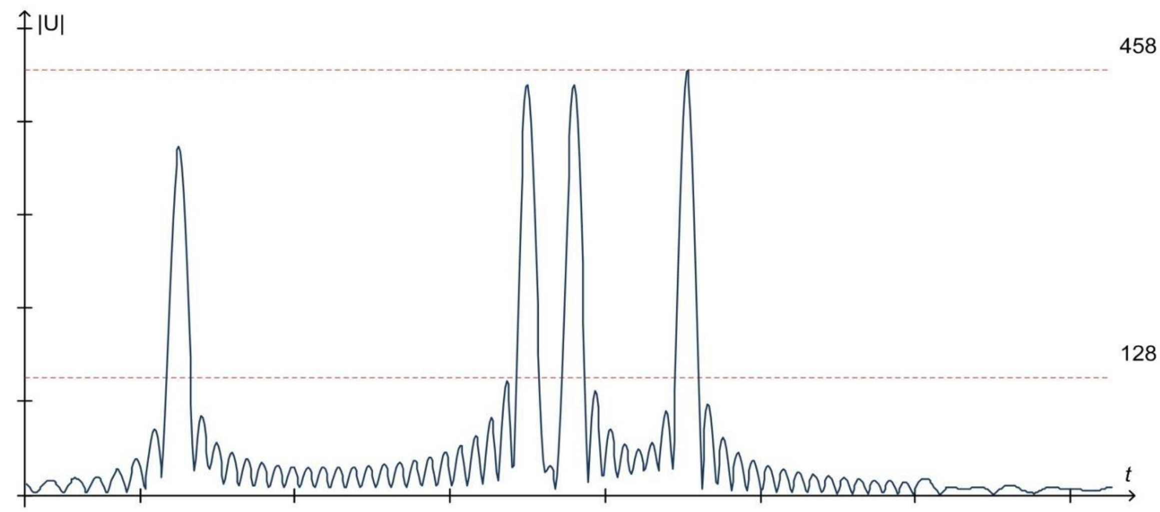

Fig. 3 Module of compressed LFM signal reflected from four brilliant points

From this figure, it is clear that the level of side lobes is about $-11\ dB$, which in the ideal case should be $-13.2\ dB$. But as a result of a closely located impulse, their side lobes interfere, and therefore this level may change in either direction, and the amplitude of this uncertainty in the total signal depends on the level of side lobes of each. In order to reduce the side-lobe level and increase the signal-to-noise ratio, the compressed signals separated by frequency as a result of the transformation are multiplied by the LFM signal of the auxiliary local oscillator, after which weighting is performed. The amplitude value of the signal at the output of the weighting filter is shown in Figure 4.

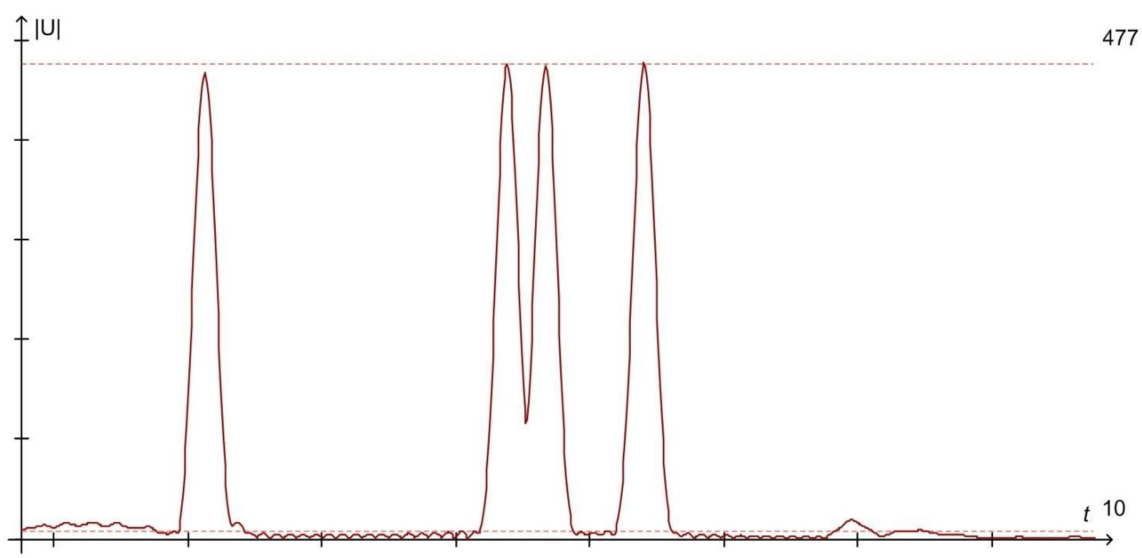

Fig. 4 Amplitude of four compressed LFM signals after weight processing.

In this figure, four peaks are clearly pronounced, which correspond to the spatial position of the four brilliant points located in an extended range target. The level of side lobes is no more than $-33\ dB$, and the weight filter limits the path band. The level of the signal-to-noise ratio (20 dB) after auxiliary local oscillator and weight processing for a given spatial window is greater than before local oscillator with weight processing, as shown in Figure 5.

It can be seen from this figure that the maximum values of all four peaks after weight processing exceed these same peaks before auxiliary local oscillator with weight processing at equal values of noise. This is explained by the fact that in this model, the band of the dispersive delay line in the correlation filter path is twice as wide as the band of a single reflected and transformed signal from a single brilliant point, i.e. mismatch loss is − 3 db. After compensation of the frequency detuning and limiting the noise band, taking into account the losses for weight processing, the total loss is 1.66 dB, independently of the length of the spatial window will remain unchanged.

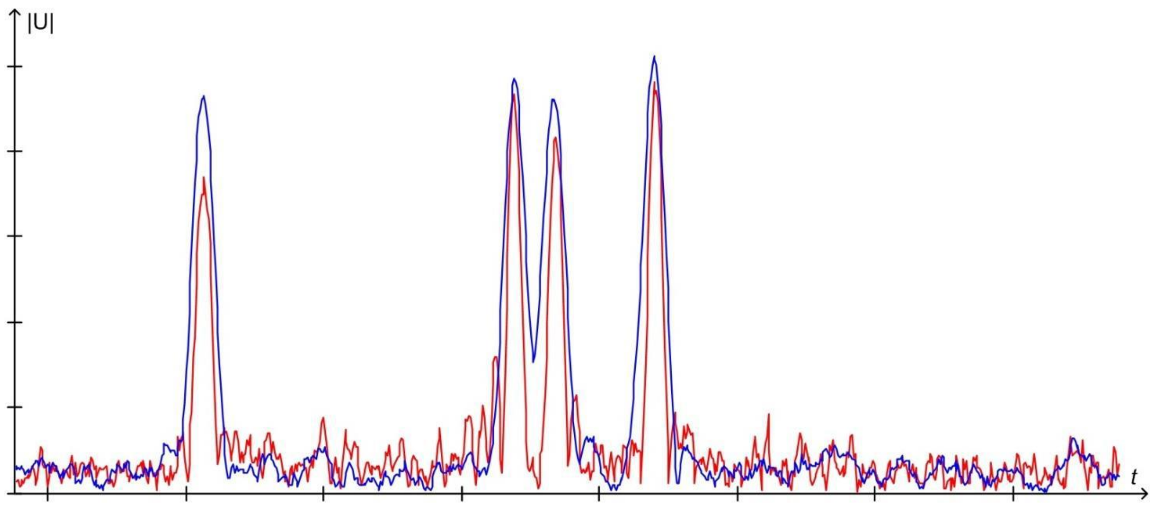

Fig. 5 Amplitude values of normalized to noise signals: after matched filtering (red) and auxiliary local oscillator with weight processing (blue).

It should also be noted that, in addition to the high resolution of individual brilliant points with a low level of side lobes and minimal energy losses during correlation filtering process, phase information is preserved. This can also be used to identify target images by comparing the reflected information with amplitude-phase reference. The quadrature signal components, in which is present as amplitude and phase information, are presented in Figure 6.

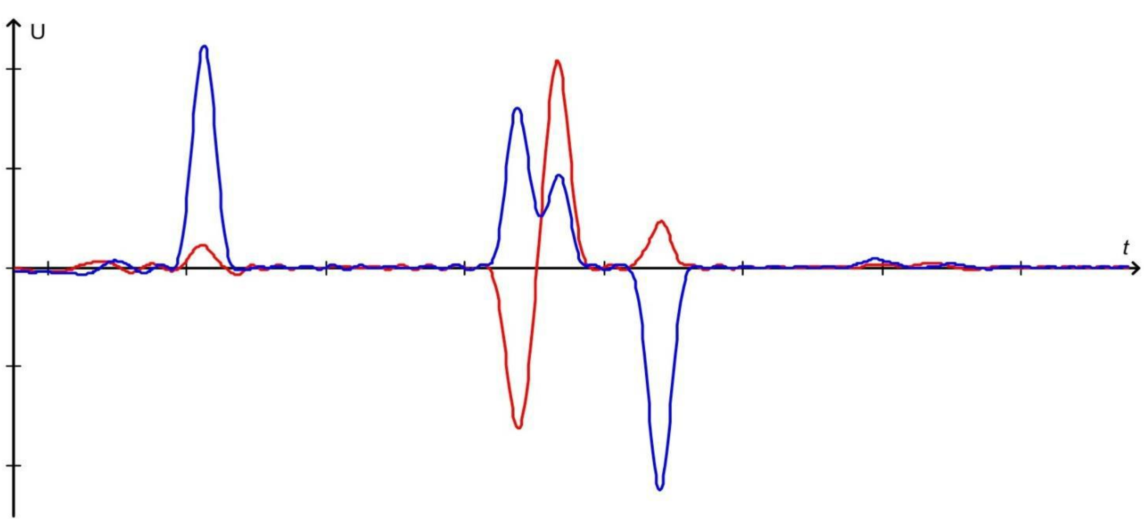

Fig. 6 the quadrature components of the four-compressed LFM signals after the weight processing.

Conclusions

The dependence of the characteristics of the correlation filter path is determined: the deviation and duration of the main and auxiliary local oscillators, as well as the spectral characteristics of the compression filter from the parameters of the spatial window, the resolution in the range and transformation coefficient.

Shown the independence of the energy losses of the linear dimensions of the spatial window in the range, which in this case are mainly determined only by the characteristics of the weight filter.

Simulation results using a correlation filter path with an auxiliary local oscillator and a weight filter show a significant decrease in the side lobe level of compressed LFM signals.

The frequency of discrete samples of compressed LFM pulses at the same time is reduced in proportion to the transformation coefficient, and the resolution of the system corresponds to the spectrum of a broadband probe pulse.

CONFLICT OF INTERESTS.

- There are no conflicts of interest.

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معالجة اشارات تضمين التردد الخطي فائقة النطاق العريض بأستخدام طريقة مرشحة الترابط

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الخلاصة

تم دراسة مبادئ معالجة التراكب لانعكاس اشارات تضمين التردد الخطي فائقة النطاق العريضة من خلال طريقة المرشح المترابط، ونيجة لذلك، يحدث التحويل في "النافذة" المكانية ضمن مدى اشارات التضمين الترددي الخطي المضغوطة ويتناسب مع ازاحة ترددها. وفي نفس الوقت، ان نطاق التردد للاشارات المنعكسة يتناقص بما يتناسب مع معامل التحويل، بحيث يتم اجراء المزيد من المعالجة بشكل رقمي، مما يضمن استقرارًا كبيرًا وهوية للإشارات المُعالجة، وهو أمر ضروري لتحقيق تمييز أكثر موثوقية بأهداف الرادار فيما يتعلق بالدقة الفائقة في المدى. هذه الطريقة اقترحت لتعويض الترددات الموهنة المضغوطة والمزاحة بواسطة الترددات المتراكبة المنعكسة لاشارات التضمين الترددي الخطي، مما يجعل من الممكن بواسطة الطرق القياسية إجراء معالجة الوزن والحد من النطاق الطيفي. وبالتالي، تزداد نسبة الإشارة إلى الضوضاء، طريقة معالجة مرشح الترابط، مع الأخذ في الاعتبار تعويضات ترددات الإشارات التضمين الترردي الخطي المحولة والمضغوطة، تقترب من الطريقة المثلى. وهذا يجعل من الممكن توفير الكشف عند مسافات أطول، حوالي 0.8 مرة كحد أقصى للكشف، وعند الضرورة، اتخاذ التدابير المناسبة. يتبين أنه، بغض النظر عن حجم النافذة المكانية، تبقى خسائر الطاقة ضئيلة، وتردد العينات المنفصلة للنبضات المضغوطة يتناقص بالتناسب مع معامل التحويل، مع ضمان دقة عالية وحفظ معلومات الطور حول النقاط اللامعة في الصورة المكانية.

الكلمات الدالة: طريقة مرشح – الترابط، رادار، تحويل التردد – الزمن، التمييز، معالجة الوزن.