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EVALUATION OF THE POSSIBILITIES OF PROVIDING THE NECESSARY ACCURACY OF THE RADIAL VELOCITY MEASURING OF A TARGET BY COHERENT-PULSE RADARS OUTSIDE THE LINE OF SIGHT

Abstract. The purpose of the article. The article estimates the possible values of the components of the mean-square error of measuring the radial velocity of the target which appear as a result of fluctuations of the phase of the radio signal outside the radar line of sight. The expediency of using a coherent burst of radio pulses to provide the necessary detection range with specified quality indicators is substantiated. Consideration is carried out for a model of a signal with a random amplitude and an initial phase. It is assumed that phase fluctuations are distributed according to the normal law with zero mean, and their correlation decreases with an increase in the interval between the radio bursts of the packet alternating. **Results.** The results show that due to the phase fluctuations of the radio pulses of the received pack, the mean-square measuring error of the target radial velocity can exceed the values determined by the tactical requirements for coherent-pulse radars. **Conclusions.** The performed numerical analysis allows to determine the degree of reduction of the quality of the radio pulses burst time-frequency processing in coherent-pulse radars and evaluates the degree of reduction of the effectiveness of the further secondary processing of the radar information.

Keywords: radar line of sight; radar surveillance; radial velocity; coherent-pulse radar; burst of radio pulses; phase fluctuations.

Introduction

Problem statement. Providing the necessary range radar subtle, pinpoint and maneuvering targets are connected to obtain the greatest possible signal-to-noise ratio at the output coherent processing of the received signal. When radar such purposes, the use of features in troposphere propagation radio wave can significantly increase the range of the radar.

The ability of modern aerodynamic purposes in the course of assigned tasks the implementation sudden maneuvers necessitates the estimation of the maximum radial velocity with high accuracy. To solve this problem a coherent pulse radar as a probing signal using coherent packet radio pulses. The actual conditions of distribution and reflection of the radar signal outside the range of sight significantly limit its temporal coherence and quality of time-frequency processing.

These conditions can be considered: the impact of atmospheric irregularities Doppler noise objectives and reflection of radio waves from the earth's surface with a complex terrain or rough sea surface. Danny conditions give rise to phase fluctuations of radio pulses adopted by the packs that reduce measurement accuracy of frequency and how to radial velocity targets. Until today coherent pulse radar imposed strict enough requirements for a given accuracy characteristics. So, radar, performing trajectory radar data processing error measurement targets radial velocity should not exceed 1 m/s. It is therefore necessary to analyze the components mentioned radial velocity measurement errors objectives and assess the extent of the contribution of individual factors in reducing the quality of time-frequency radio pulses packs processing of coherent-pulse radar.

Analysis of recent research and publications. Improvement and development of modern radar aerodynamic objects causing increasing requirements for means of identification and tracking.

In today's coherent pulse radar algorithms implemented digital coherent integration pachkovoho the received radio signal. Therefore, a practical benefit assessment of possible measurement errors radial target velocity based on the statistical characteristics of phase fluctuations of radio pulses adopted by the packs.

Radar targets and measuring their coordinates and motion parameters in a complex environment devoted a significant amount of work.

Phase fluctuations arising from atmospheric irregularities and use of radio systems in these conditions are described in the works [1–4]. In addition, the phase distortion of the received signal which are caused by complex form goals and its ability to perform sudden maneuvers, causing her walk radar center and as follows, the emergence of high-speed noise targets [1, 5, 6]. In the case of radio signal propagation with radar targets moving at small angles place as it appears additional phase distortion, as described in [3, 5–7].

Said demonstrates the need for assessing the impact of these factors on the quality of the measurement coordinates and motion parameters purposes, capable of sudden maneuvers by the radial velocity, including attack helicopters. Given the method described in [8], the results of which are shown in [9] indicate that the detection range of the helicopter outside the range of sight in terms of its location by the sea can be increased in 7 ... 10 times. However, with a significant impact exercise phase fluctuations of the received radio signal.

Problems ranging and radial velocity of targets in the circumstances considered in [10]. However, the conclusions were obtained for the case of radar signal. Providing the required detection range and accuracy radial velocity measurement objectives involves using as a probing signal radar coherent bundles of radio pulses. In [11–24] the method of calculating the error rate measurement packs resulting from the influence of phase fluctuations of radio pulses.

Assumptions statistical characteristics of reflected signals confirmed results of experimental studies that covered in [25].

Therefore, the urgent task is to find ways deterioration degree estimation accuracy radial velocity measurements of complex maneuvering targets beyond line of sight and radar analysis of the impact of the deterioration in their highway further processing. **The purpose of the article:** is the calculation of the component errors of the radial velocity measurement of the target and the analysis of their contribution to the resulting error for typical parameters of coherent-pulse radar.

Main material

Ensuring the sustainability radar complex maneuvering purposes directly related to maximizing the ratiosignal-to-noise ratio, which determines need-range radar quality radar detection and accurate measurement of their coordinates. This is achieved coherent accumulation packs received radio pulses.

For models with random signal amplitude and initial phase conditional probability of correct detection described by [26]

$$D = F^{1/(1+q^2/2)} \tag{1}$$

and depends only on the conditional probability of false alarm F and signal-to-power ratio q^2 (detection parameter).

Thus, to increase the conditional probability of correct detection, it is necessary to increase the signal-to-noise ratio, which can be ensured by the use of a coherent pack with as many radio pulses as possible.

The accepted implementation is considered to be the sum of the useful radio signal reflected and the intrinsic noise of the receiving device

$$y(t, \Omega) = x(t, \Omega) + n(t), \tag{2}$$

where $y(t, \Omega)$ - implementation of the accepted oscillation; $x(t, \Omega)$ - implementation of a useful signal; $n(t)$ - implementation of internal Gaussian noise; Ω - the Doppler cyclic frequency of the received radio signal.

As the signal seenpack having n radio pulses with random amplitude and initial phase. By phases of radio pulses packs attached fluctuation components φ_i ($i = 1, 2, \dots, n$) That due to the above terms of its distribution and reflection

$$\dot{X}(t, \Omega) = b \sum_{i=1}^n \dot{X}_i(t, \Omega) \exp[j(\beta + \varphi_i)], \tag{3}$$

where $\dot{X}_i(t, \Omega)$ - complex amplitude i -th radio pulse; b - the random amplitude of a radio signal distributed by Rayleigh's law; β - a random initial phase of a radio signal, distributed according to a uniform law; φ_i - fluctuation component of the initial phase i -th radio pulse; i - the number of the radio pulse that is counted from the beginning of the pack; n - the number of radio pulses in the pack.

Fig. 1 presents graphs of the conditional probability of correct detection (1) of the number of coherently accumulated radio pulses in the process of processing the received signal.

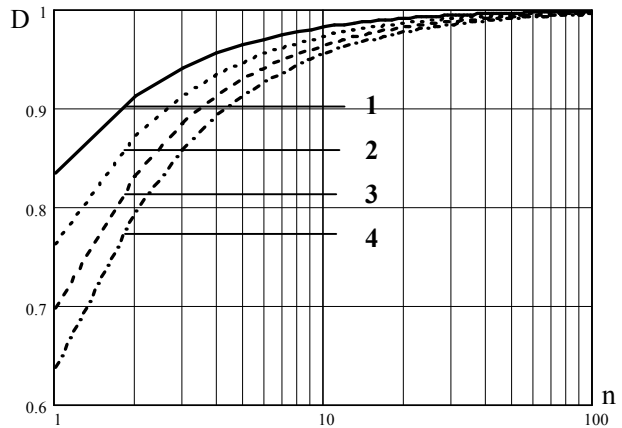


Fig. 1. The conditional probability dependence correct detection from the number of radio pulses the number of radio pulses

The results obtained in $q^2 = 100$ for cases: $F = 10^{-4}$ (graph 1) $F = 10^{-6}$ (graph 2) $F = 10^{-8}$ (graph 3) $F = 10^{-10}$ (graph 4).

These values characterize the quality of radar detection radar for different purposes, like viewing radar, as radar and support.

The dependences indicate that the accumulation of coherent radio pulses packs adopted zinachno able to improve the quality of radar detection. However, most efket observed during the transition from one treatment to radioimpulsu coherent processing 10 radio pulses. Increase the conditional probability of detection pravilnoho D depending on the conditional probability of false alarm $F = 10^{-4} \dots 10^{-10}$ makes up 15 ... 30 percentage. The transition from coherent accumulation 10 of radio pulses to coherent accumulation 100 the radio pulse causes an increase D only on 1,6 ... 4 percentage.

The above indicates that when solving the problem of high-quality radar surveillance, it is necessary to provide in-phase addition of 10 ... 30 received radio pulses.

Due to the effect of the troposphere radio waveguide, it is possible to detect targets at distances that far exceed the line of sight. This is confirmed by the results of the experiment given in [9]. During its conducting, a coherent pulse radar located on the coast of the Azov Sea was used as a radar meter 35. However, there were significant random distortions of the phase structure of the radar signal, which reduced the accuracy of measuring its time-frequency parameters.

According to the results of the experiment, in the conditions of anomalous refraction, the amplitude and the initial phase of radar signals are distributed according to the normal law at the propagation of electromagnetic waves over the sea. In this case, the normalized correlation function of the phase of the reflected signal is oscillating. For a packet of radio pulses with a rectangular scan and an even number of radio pulses, the vari-

ance of the measurement error parameter Ω only internal noise of the receiving device is evaluated according to the expression [11]

$$\frac{1}{\sigma_{\Omega_s}^2} = \frac{q^2(4m^2 - 1)T^2}{12} \quad (4)$$

and it looks

$$\sigma_{\Omega_s}^2 = \frac{12}{q^2(4m^2 - 1)T^2}, \quad (5)$$

where T – period of packet radio pulse tracking; m – the number of pairs of radio pulses symmetric about the center of the pack.

The presence of phase fluctuations peak signal is expanding body of uncertainty for time-frequency parameters and their deviation from the center, leading to deterioration of measurement accuracy radial velocity targets. If the phase fluctuations of radio pulses adopted by the packs described oscillatory correlation function, the dispersion parameter measurement error Ω Only the presence of phase fluctuations estimated by the expression obtained in [11]

$$\begin{aligned} \sigma_{\Omega}^2 &= 18\sigma_{\varphi}^2 \left/ \left(m^2(4m^2 - 1)^2 T^2 \right) \times \right. \\ &\times \left(\sum_{j=1}^m (2j-1)^2 (1 - \exp\left(-\frac{T}{\tau}(2j-1)\right)) \cos((2j-1)\gamma T) \right) + \\ &+ 2 \cdot \sum_{l=1}^{m-j} \exp(-\frac{T}{\tau}l) \sum_{j=1}^{m-1} (2j-1)(2j+2l-1) \times \\ &\times \left(\cos(j\gamma T) - \exp\left(-\frac{T}{\tau}(2j-1)\right) \cos((2j+l-1)\gamma T) \right), \end{aligned} \quad (6)$$

where σ_{φ}^2 – variance of phase fluctuations; τ – correlation interval phase fluctuations; γ – frequency oscillations correlation coefficient phase.

Relevant components of the mean square error (MSE) measure the radial velocity of targets can be calculated according to the expressions:

$$\sigma_{v_s} = \frac{\lambda}{4\pi} \sigma_{\Omega_s}, \quad \sigma_v = \frac{\lambda}{4\pi} \sigma_{\Omega}, \quad (7)$$

where λ – wavelength radar.

The principal feature of the radar tracking is that this class is designed for radar-guided weapons of destruction (missiles) to the target. It is technically ensured by the use of a radar tracking target image, including range and radial velocity. Modern radar-guided anti-aircraft missiles is trykoordynatnym coherent-pulse radar centimeter range, which provides automatic detection and capture aerodynamic and ballistic targets, while their maintenance, start-up and restore them to anti-aircraft missiles.

Such packs probing radar used signals from radio pulses repetition rate of 20 ... 100 kHz [27].

It has practical benefits get the possible values of components measuring radial velocity MSE aims with respect to signal noise in power $q^2 = 1000$ for cases of

short coherent integration $n = 8$, medium $n = 16$ and long $n = 32$ packs of radio pulses.

Using expressions (5) and (7) can be calculated component MSE radial velocity measurement purposes, due to internal noise receiver σ_{v_s} for packs of $n = 8, 16$ and 32 .

In the case of propagation in random heterogeneous environment, in [1, 2] given the magnitude of dispersion of phase fluctuations of radio σ_{φ}^2 which has passed through the Earth's disturbed troposphere. Interval correlation phase fluctuations may be $\tau = 0,1...1$ s.

For tracking radar target detection at ranges of 50 ... 150 km heterogeneity troposphere size 100 m can cause fluctuations of the phase dispersion $\sigma_{\varphi}^2 = 4,8...9,7$ rad² at $\lambda = 0,3...0,5$ cm.

For the data, using expressions (6) and (8) can be calculated component MSE radial velocity measurement purposes, due to phase fluctuations of radio pulses adopted by the packs σ_v for $n = 8, 16$ and 32 .

The calculation results constituents MSE radial velocity measurements for radar tracking targets are shown in Table 1.

Table 1 – Components measuring radial MSE rate targets for radar tracking, m/s

n	σ_{v_s}	σ_v
8	0.66	1.85 ... 6.9
16	0.33	1.3 ... 4.82
32	0.16	0.91 ... 3.4

The results obtained indicate that the values of the components of the MSE measurement of the radial speed of the target, due to the phase fluctuations of the radio-pulses of the received pack, can several times exceed the components due to the influence of the intrinsic noise of the receiving device.

In addition to the influence of troposphere heterogeneities, the effect of target Doppler noise and multipath propagation of the signal causes an additional increase in the fluctuation component of the MSE measurement of the radial velocity of the target to several units of m / s or more.

Thus, the phase distortion of the radar signal influences the operation of the radar tracking, causing the risk of disruption of the target from auto tracking at radial speed.

Conclusions

The conducted evaluation shows the necessity of using special methods of reducing the influence of these factors in radar measurement of radial velocity of the target both within and outside the radar line of sight.

The results obtained allow us to determine the degree of deterioration in the quality of the time-frequency processing of a bundle of radio pulses in coherent pulse radars and to evaluate the degree of decrease in the efficiency of further secondary processing of radar information.

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Оцінювання можливостей забезпечення заданої точності вимірювання радіальної швидкості цілі когерентно-імпульсними РЛС за межами дальності прямої видимості

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Анотація. У статті оцінюються можливі значення складових середньоквадратичної помилки вимірювання радіальної швидкості цілі, які виникають внаслідок флуктуацій фази радіосигналу за межами дальності прямої видимості РЛС. Обґрунтована доцільність використання когерентної пачки радіоімпульсів для забезпечення необхідної дальності виявлення із заданими показниками якості. Розгляд проводиться для моделі сигналу з випадковою амплітудою та початковою фазою. Вважається, що фазові флуктуації розподілені за нормальним законом з нульовим середнім, а їхня кореляція збуває зі збільшенням інтервалу між радіоімпульсами пачки за знаковим законом. Результати вказують на те, що внаслідок фазових флуктуацій радіоімпульсів прийнятої пачки, середньоквадратична помилка вимірювання радіальної швидкості цілі здатна перевершувати значення, які визначаються тактичними вимогами до когерентно-імпульсних РЛС. Проведений чисельний аналіз дозволяє визначати ступінь погіршення якості часо-частотної обробки пачки радіоімпульсів в когерентно-імпульсних РЛС та оцінювати ступінь зниження ефективності подальшої вторинної обробки радіолокаційної інформації.

Ключові слова: дальність прямої видимості; радіолокаційне спостереження; радіальна швидкість; когерентно-імпульсна РЛС; пачка радіоімпульсів; фазові флуктуації.

Оценивание возможностей обеспечения заданной точности измерения радиальной скорости цели когерентно-импульсными РЛС за пределами дальности прямой видимости

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Аннотация. В статье оцениваются возможные значения составляющих среднеквадратической ошибки измерения радиальной скорости цели, которые возникают вследствие флуктуаций фазы радиосигнала за пределами дальности прямой видимости РЛС. Обоснована целесообразность использования когерентной пачки радиоимпульсов для обеспечения необходимой дальности обнаружения с заданными показателями качества. Рассмотрение проводится для модели сигнала со случайной амплитудой и начальной фазой. Предполагается, что фазовые флуктуации распределены по нормальному закону с нулевым средним, а их корреляция убывает с увеличением интервала между радиоимпульсами пачки по знакопеременному закону. Результаты указывают на то, что вследствие фазовых флуктуаций радиоимпульсов принятой пачки, среднеквадратическая ошибка измерения радиальной скорости цели способна превышать значения, которые определяются тактическими требованиями к когерентно-импульсным РЛС. Проведенный численный анализ позволяет определять степень ухудшения качества время-частотной обработки пачки радиоимпульсов в когерентно-импульсных РЛС и оценивать степень снижения эффективности дальнейшей вторичной обработки радиолокационной информации.

Ключевые слова: дальность прямой видимости; радиолокационное наблюдение; радиальная скорость; когерентно-импульсная РЛС; пачка радиоимпульсов; фазовые флуктуации.