The Proposal to Choosing a Rational Number of Elements in the Multiradar System Structure

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ABSTRACT

The subject of research in the paper is the problem of choosing a rational number of elements in the structure of a multiradar system of the same type of two-coordinate surveillance radars with mechanical rotation. The purpose of the paper is determination a rational number of multiradar system elements, which will provide an optimal improvement in the quality of detecting air objects according to the cost-effectiveness criterion. To improve the quality of detection of small-sized objects, surveillance radar stations are combined into a spatially separated multiradar system. An assessment of the characteristics of detecting air objects in a multiradar system with a matched signal reception is carried out. The calculations were carried out for systems that consist of a different number of elements. The calculations show that the addition of second radar, regardless of the degree of signal coherence, showed the greatest efficiency in terms of signal-to-noise ratio, the rational number of radars in a multiradar system is no more than four. In a multiradar system of four radars, the threshold signal-to-noise gain can be up to eighteen decibels for a system with coherent signals and up to eleven decibels for a system with incoherent signals. More than four radars are impractical.

Key words :rational Number, element, radar, multiradar system, structure, signal-to-noise ratio

1. INTRODUCTION

The analysis of the experience of airspace control in the last decade, especially in modern local wars, including in conditions of hybrid hostilities, such as in Syria and Nagorno-Karabakh, showed that reliable radar detection of air objects is significantly complicated by the appearance of small-sized (with low radar signature) [1]–[4].

It is known that small unmanned aerial vehicles (UAVs) in most cases were not detected by the available standard radars [5]–[13], which previously successfully coped with the tasks of air traffic control and aircraft detection without identification signals.

Manufacturers of radar equipment around the world are implementing the latest advances in science and technology: serial-parallel electronic scanning of space in the vertical plane and two-dimensional electronic scanning of the antenna directional pattern, adaptive phased antenna arrays, digital synthesis of probing signals with various parameters, digital pattern formation [14]–[32].

Currently, the radar equipment is being updated, the newest and modernized models of radar stations appear, including those that use wideband phased signals and digital phased antenna arrays, but this process is gradual and expensive. Therefore, in general, the existing equipment does not provide a complete solution to the tasks set, especially in terms of detecting an inconspicuous airborne object.

At the same time, airspace monitoring provides a large number of two-dimensional surveillance radars of the P-18 type and its numerous modernized modifications. These radars are not capable of ensuring the detection of a modern, inconspicuous airborne object with specified quality indicators [26], [28], [31], [33]–[34].

Thus, at present, when solving the problem of detecting an inconspicuous airborne object, the discrepancy

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The number of radars to create an effective system will be determined by the specific gravity of the gain that each radar adds when calculating the signal-to-noise ratio. Each additional radar will add additional energy to the system and increase the synthetic aperture of the antenna. However, it is necessary to calculate the rational number of system elements at which the maximum effect will be ensured by the quality-cost criterion.

An important point when creating a multiradar system is the possibility of creating a synchronous coherent multiradar system in the presence of spatially separated radars. The creation of coherence necessitates the fulfilment of the following conditions: frequency synchronization, phase synchronization, time synchronization, review of the same area of space simultaneously by all radars. Figure 3 shows an example of building a multiradar system.
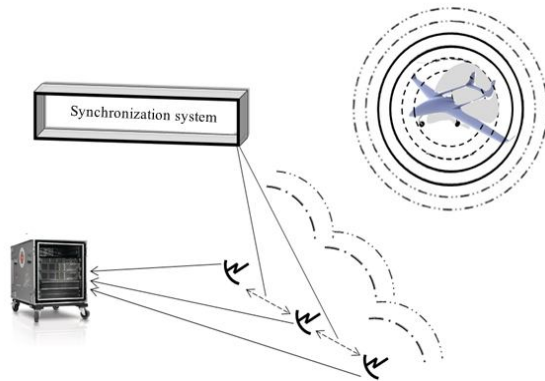
Figure 2. Forming an agreed inspection area small-base multiradar system of the surveillance same type radar
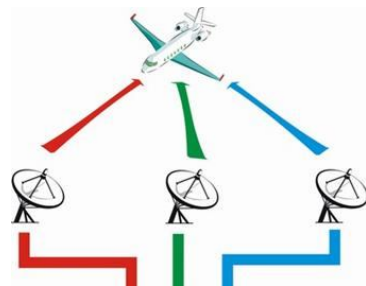
Figure 3. Multiradar system on the example of a synchronous small-base system with three radars

Each element of the system, and we have a radar, emits its own transmission signal, which does not correlate with the transmission signal of other radars. All radar signals are transmitted synchronously. Non-correlation (orthogonality) can be ensured: frequency diversity (frequency); signal coding (code). All system radars receive reflected signals:
– its emitted signal is reflected from an airborne object;
– reflected from an airborne object, transmitting a signal from neighbouring radars.

Depending on the design of the synchronization system of the multiradar system, the signals emitted by the radar can be mutually coherent or incoherent. Therefore, in a multiradar system, methods for processing mutually coherent or mutually incoherent signals can be implemented. We will consider the coherent case; for our calculations, it will not fundamentally differ from the incoherent case.

Method of processing coherent signals in a multiradar system. Consider a multiradar system in which each radar emits mutually orthogonal signals. These signals are reflected from an air object of complex shape. If the size of the air object is much larger than the wavelength, the signals received by each radar fluctuate. As a rule, amplitude fluctuations are described by Rayleigh law, and phase fluctuations are evenly distributed in the interval $(-\pi, \pi)$. The nature of the fluctuations of the signals received by different radars depends on the degree of their spatial correlation, which is determined by the size of the effective base (distance) between the radar (expression (1)):

$$\frac{L_{ef}}{R} > (0.8...1)\frac{\lambda}{l_{AO}} . \qquad (1)$$

where $L_{ef}=L \sin(\theta)$ – effective base between spatially spaced radars (θ – the angle that determines the direction of the air object); R – range to the air object from the middle of the effective base; λ – radar wavelength; l_{AO} – transverse size of the air object (parallel to the effective base).

At full spatial correlation, the complex amplitudes and initial phases of the signals at the inputs of different positions are strongly connected and fluctuate amicably. Therefore, such signals are spatially coherent. At small bases between receiving positions rigid communication between complex amplitudes of echo signals in various positions (full time correlation) is possible.

At the input of the radar receiver in each position receives signals emitted by all radar. If all radars emit the same signals in such a way that their in-phase summation on the air object is ensured, then at the input of the receiving positions there will be only one echo signal. The effective value of the amplitude of the echo signal in this case will be equal to the sum of the effective values of the echo signals formed by all transmitting positions [22].

In this case, the processing is performed on M implementations of independent Gaussian processes. The average value of these processes in each receiving position is equal to the phased sum of M echo signals. The initial value of the signal-to-noise is determined by expression (2):

$$q_{out}^2 = NM^2 q_{out0}^2 . \qquad (2)$$

where q_{out0}^2 – signal-to-noise ratio at the output of a single-position radar; N – the number of radars operating in transceiver mode; M – implementations of independent Gaussian processes.

The additional gain in M times is explained by the fact that at in-phase addition of signals on air object noises of the receiver do not take part, and at coherent addition in receiving devices together with signals incoherent noise develops.

The method of processing coherent signals in a multiradar system of the same type of two-coordinate survey radars with mechanical rotation is proposed in the form shown in Figure 4.
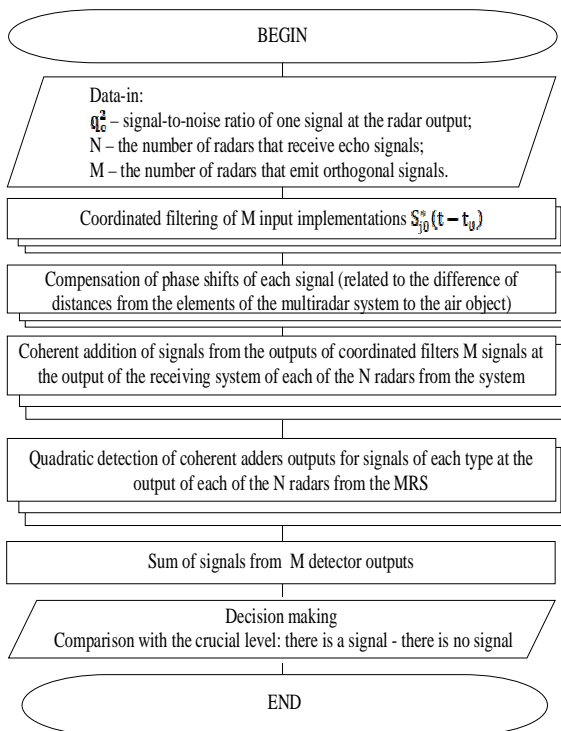
Figure 4. The method of processing coherent signals in a multiradar system

In the case of coherent signal summation and linear detection, the original statistics has a Rayleigh distribution, and in the case of quadratic detection, it has an exponential probability distribution.

If the radar system is able to communicate with the same signals in such a rank, so that they are not in phase with the software, then there will be only one reflected signal at the inputs of the correct positions. An ineffective value of the amplitude of the reflected -signal will, in all cases, provide the sum of the effective values of the reflected -signals, approved by all the transmission positions.

To construct detection curves in both cases, it is convenient to use a known expression for the probability of correct detection and false alarm (expression (3)):

$$P_D = P_F^{1/\left(1+\overline{q_{out}^2}\right)} . \qquad (3)$$

where P_D – probability of correct detection; P_F – probability of false alarm; q_{out}^2 – signal-to-noise ratio at the input of a threshold device, which is determined depending on the features of the construction of a spatially coherent multiradar system.

Figure 5 shows the detection curves for a small-base spatially coherent multiradar system. Figure 5 shows the case when all the same type of radar small-base spatial-coherent multiradar system uses the same signals so that their in-phase summation on the air object and at the input of the receiving positions we get only one echo signal. Calculations are given for the operation of one autonomous radar and for the use of a multiradar system with several radars for the probability of false alarm $P_F=10^{-6}$.

From the analysis of the detection characteristics shown in Figure 5 shows that the transition from a stand-alone radar (curve 1) to a combination of two or three radars (curves 2, 3) leads to a significant shift in the detection characteristics to the left. Increasing the number of coherently combined radars by more than three (curves 4, 5) does not lead to a significant shift in the detection characteristics to the left compared to the detection characteristics when combining three radars (curve 3).
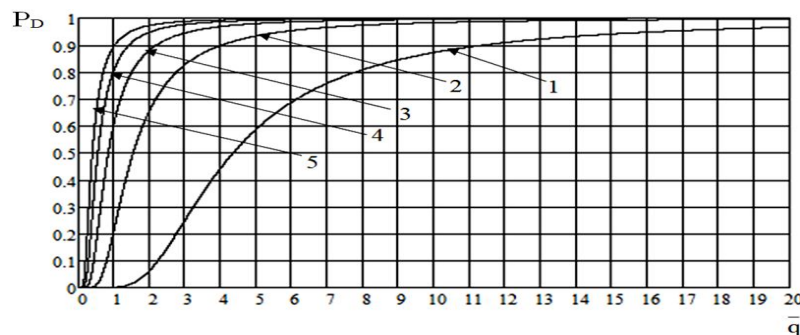
Figure 5. Characteristics of detection of multiradar system: 1 – for autonomous radar; 2 – when using 2 radars in a multiradar system; 3 – when using 3 radars in a multiradar system; 4 – when using 4 radars in a multiradar system; 5 – when using 5 radars in a multiradar system

In Figure 6 shows the dependence of the win K(m) in the desired signal-to-noise ratio in a system with m radar relative to a stand-alone radar to ensure quality indicators of air object detection (P_D=0,5, P_F=10^{-6}) for coherent combining radars.

From the analysis of the dependence of the gain on the signal-to-noise ratio, shown in Fig. 6, it can be concluded that for the case when all similar radars of a small base of a spatially coherent multiradar system use the same type of orthogonal signals, the gain is about 10 dB when two radars are combined and about 5 dB with the addition of a third radar, and an increase in gain of only 2.5 dB with the addition of a fourth radar and additional radars also provide an increase in gain, but the rate of this growth is much lower, which reduces practical significance and economic feasibility. So, summarizing the above, we can conclude that the highest efficiency in terms of si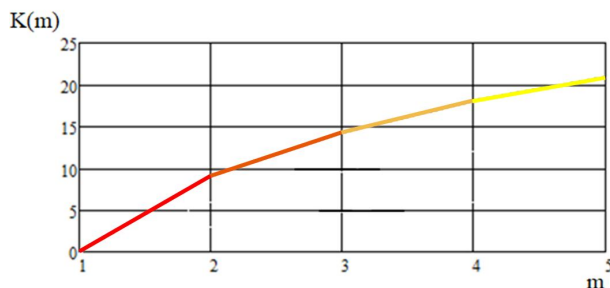gnal-to-noise ratio when combining the same spatially distributed radar into a multiradar system is observed when switching from one autonomous radar to a multiradar system with two or three radars.

Figure 6. The dependence of winnings in relation signal / noise in a multiradar system in the case when all radars use orthogonal coherent signals

A further increase in the number of radars in each of the two cases is accompanied by a decrease in efficiency due to the addition of each subsequent radar, and it is practically impractical to use in a multiradar system more than four radars with a maximum possible gain of close to 2 dB with the addition of the last radar from one radar to a multiradar system with two radars.

The addition of second radar for processing coherent and incoherent signals showed the greatest efficiency in terms of signal-to-noise ratio, and in all cases it was shown that the rational number of radars in a multiradar system is no more than four.

Therefore, according to the criterion of efficiency-cost, the most effective is the creation of a spatially coherent multiradar system by combining two to four identical radars.

Thus, in order to improve the quality of detection of an unobtrusive airborne object, it is advisable to create a spatially coherent multiradar system by combining four surveillance radars. Then the expected gain in signal-to-noise ratio can reach 18 dB if coherent orthogonal signals are used in a small-base system. The use of more than four radars is impractical, since it does not lead to a significant increase in the gain.

5. CONCLUSION

Thus, it can be argued that in a multiradar system, you can get the maximum benefit level in terms of signal-to-noise ratio when adding second radar to the system, and the rational number of elements in a multiradar system will be no more than four modules. This is the result of evaluating the system according to the quality-cost criterion. Moreover, this conclusion does not depend on whether the created system is a spatially coherent multiradar system or there will be a case of processing incoherent signals.

Thus, when forming a small-base multiradar system from existing radars to improve the quality of detecting small-sized air objects, it is advisable to create a spatially separated small-base synchronous multi-user system, combining from two to four surveillance radars. If more than four radars are included in the system, then the quality will certainly increase, but this is impractical, because there is no significant increase in the gain. For example, the expected gain in the threshold signal-to-noise ratio when using the proposed signal processing methods in a coherent multiradar system of 4 elements can reach 18 dB, and the use of the fifth radar will add about 3 dB of gain increase.

The direction of further research is to consider reliable methods for forming a coherent system in the spatial and temporal domains when using spatially separated two-coordinate radars as elements of a synchronous small-sized multiradar system with compatible signal processing

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