MIMO TECHNOLOGY IN MULTI-RADAR SYSTEMS FOR DETECTING STEALTHY AIR OBJECTS

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Abstract: The main trends in the development of air objects are analyzed (the means of air attack in the conduct of the Russian-Ukrainian war are taken as a basis). It has been established that the increase in the efficiency of radar surveillance of airspace is currently being carried out due to the quantitative increase in radar stations. In this paper, to improve the quality of detection of subtle air objects, the use of multi-position location (based on MIMO systems) is proposed. The principle of operation of a spatially coherent MIMO system is considered. The set of spaced positions of a spatially coherent multi-position system is considered as a single sparse antenna array. The possibility of increasing the resolution in planar coordinates in a MIMO system compared to the resolution of a single autonomous radar station is shown. The calculated ratio for increasing the resolution of such a system is given. Detection curves are given for the case of a spatially coherent MIMO radar system for the case when the radar stations of the system operate simultaneously in the transceiver mode. It has been established that the transition from an autonomous radar station to a MIMO system leads to a significant shift in detection characteristics to the left. It has been established that an increase in the number of radar stations in the system leads to a less significant shift in the detection characteristics to the left, which indicates a decrease in the effect. The radar systems proposed by MIMO can be built on the basis of existing radar stations of a predominantly new fleet. It is especially advantageous to use radar facilities based on phased antenna arrays for these purposes. It is advisable to use such systems in particularly dangerous areas to cover important military, government and critical infrastructure facilities.

Keywords: Radar, MIMO technology, multi-radar system, air object, radar cross section, detection, radar information.

1. Introduction

The intensive development of science and technology in recent decades dictates a constant increase in the requirements for the quality of radar information. This is primarily due to the increase in the number and intensity of use of small unmanned aerial vehicles and high-precision missile weapons, which can be used in the entire range of altitudes [1–6].

From the experience of conducting military operations in the Russian-Ukrainian war (Russian aggression against Ukraine), it is known that various factors are used to reduce the visibility of air attack means, namely [2–4]:

– radar visibility of an aircraft in different frequency bands (unmanned aerial vehicles);

– flight path parameters that ensure the most efficient use (cruise missiles use riverbeds on their route, approach from the sea at extremely low altitude, "holes" and "corridors" of a low-altitude radar field), their speed characteristics (ballistic missiles);

– electronic environment conditions in which radar detection must be provided.

A qualitative increase in the efficiency of radar surveillance of airspace in such conditions is carried out not so much by increasing the intensity and quantitative increase in radar facilities, but by combining the radar information of individual autonomous existing radar stations [2–7].

2. Materials and Methods

One of the ways to improve the quality of detection of air objects is to combine existing radar reconnaissance equipment into systems with joint information processing [4]. In multiposition systems, information can be obtained from several spatially separated sections of the stray field of an air object [4–9]. One of the modern directions in the development of multi-position radar is MIMO radar (multiple input-multiple output – "multiple input - multiple output") borrowed from communication (**Fig. 1**) [9–14].

It is most advantageous to use spatially coherent systems. Such systems have mutual phase shifts of signals in paths of spaced positions and communication lines. The set of spaced positions of a spatially coherent multiposition system can be considered as a single sparse antenna array [7, 9–14].

A MIMO system can determine all three coordinates of an air object using only range measurements from different positions. Using broadband signals and sufficiently large base distances between positions, it is possible to obtain coordinate accuracy much higher than when measuring angular coordinates with a single-position radar station, which is an additional advantage of the MIMO system. By improving the signal-to-noise ratio, the detection range of air objects also increases [12–15].

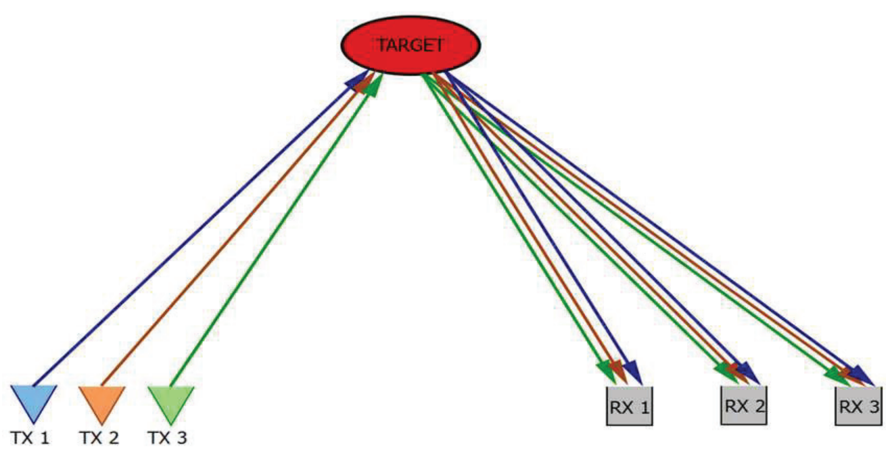

Fig. 1. An example of building a MIMO radar system

3. Results

In a MIMO system, it is possible to increase the resolution of the system in planar coordinates in comparison with the resolution of a single autonomous radar station of the system. This is achieved by the implementation of multi-position methods of information processing. The principle of increasing the resolution when using the rangefinding method is shown in **Fig. 2**.

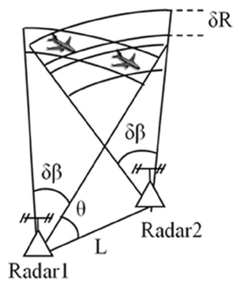

Fig. 2. Increasing the resolution in planar coordinates in a MIMO radar system

Two air objects are not resolved by Radar1 because they are in the same bin in azimuth (δβ) and range (δ*R*). At the same time, Radar2 can resolve them by range. This can be viewed as the ability of a MIMO radar system to resolve air objects by angular coordinates in the main beams of the radar beam. The equivalent resolution of a two-position active ranging system is determined by expression (1):

$$\delta\theta \approx \frac{\delta R}{L\sin(\theta)} = \frac{c}{2\Delta f_c L\sin(\theta)}, \quad (1)$$

where Δf_c – the width of the signal spectrum, L – the distance between positions (base), c – the speed of light in vacuum.

Increasing the signal-to-noise ratio in the MIMO system provides an increase in the detection range of an air object with the remaining observation conditions and object parameters unchanged. **Fig. 3** shows detection curves for the case of a spatially coherent MIMO radar system for the case where the radar stations of the system operate simultaneously in a transceiver mode.

From the analysis of the detection characteristics (**Fig. 3**), it can be seen that the transition from an autonomous radar station (curves 1) to a MIMO radar system (curves 2, 3) leads to a significant shift in the detection characteristics to the left. Increasing the number of radars in the system results in a smaller shift in detection performance to the left, indicating a reduced effect.

4. Discussion

The radar systems proposed by MIMO can be built on the basis of existing radar stations of a predominantly new fleet. It is especially advantageous to use radar facilities based on phased antenna arrays for these purposes. As a refinement, it will be necessary to install a synchronization system in time, frequency, and the initial phase of individual separated elements of the system. This system is favorably distinguished by the absence of the need to manufacture receiving and transmitting positions, but only the use of existing single-position radar stations with the above refinement. It is advisable to use such systems in particularly dangerous areas to cover important military, government and critical infrastructure facilities. When the danger is removed, the system can be dispersed and again work element by element autonomously by each radar station.

5. Conclusions

The efficiency of using a multi-position radar system based on MIMO can be quite high in the search mode. Joint signal processing can not only compensate for the energy loss of each radar, but can lead to an increase in the total energy in the system. Therefore, the signal-to-noise ratio increases, which provides an increase in the detection range.

The plane coordinates of an air object can be determined with higher accuracy, and the resolution in angular coordinates can also be increased using multi-position information processing methods.

Thus, MIMO radar systems are promising for various applications and offer many advantages. At the same time, MIMO systems can be created on the basis of existing radar stations and used situationally in dangerous directions or used autonomously by individual radar stations again.

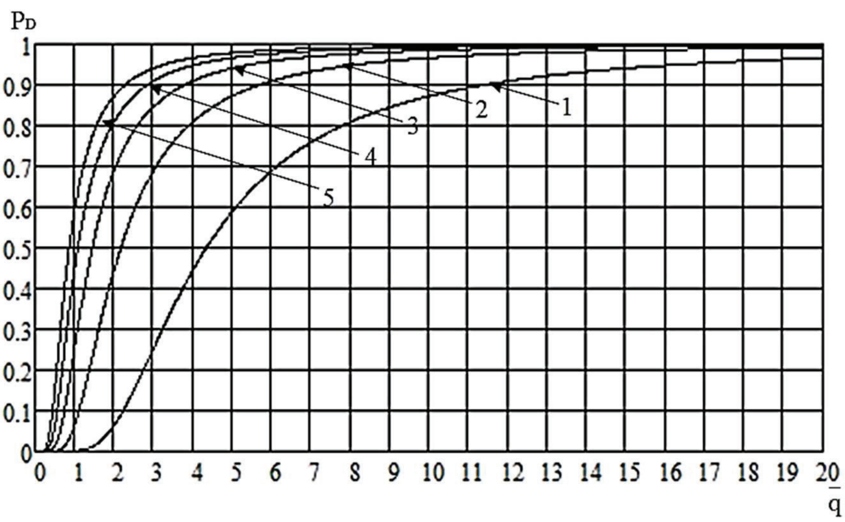

Fig. 3. Detection characteristics of an autonomous radar station in comparison with a spatially coherent MIMO radar system for the case when the radar stations of the system operate simultaneously in a transceiver mode with a false alarm probability P_F=10^{-6}:
1 – for an autonomous radar station; 2 – when using 2 radar stations in the system; 3 – when using 3 radar stations in the system; 4 – when using 4 radar stations in the MRS; 5 – when using 5 radar stations in MRS

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Manuscript has no associated data.

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