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METHOD FOR THE DETECTION OF SMALL-SIZED AIR OBJECTS BY OBSERVATIONAL RADARS

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Запропоновано введення в існуючу однопозиційну оглядову РЛС додаткового режиму рознесенного прийому та об’єднання однопозиційного та рознесеного прийому сигналів. Удосконалено алгоритм виявлення повітряного об’єкта при його опроміненні декількома передавачами. Розроблена схема виявлювача забезпечує прийом, узгоджену обробку ехо-сигналів сторонніх джерел, компенсацію різниць в затримці та частоті Допплера відносно роздільного об'єму оглядової РЛС та некогерентне вагове підсумовування. Встановлено, що найбільш ефективним є об’єднання двох, максимум трьох каналів прийому

Ключові слова: малорозмірний повітряний об’єкт, виявлення, прийом сигналу, однопозиційна система, багатопозиційна система, канал обробки

Предложено введение в существующую однопозиционную обзорную РЛС дополнительного режима разнесенного приема и объединение однопозиционного и разнесенного приема сигналов. Усовершенствован алгоритм обнаружения малоразмерных воздушных объектов при его облучении несколькими передатчиками. Разработанная схема обнаружителя обеспечивает прием, согласованную обработку эхо-сигналов внешних источников, компенсацию разности в задержке и частоте Допплера относительно разрешающего объема обзорной РЛС и некогерентное весовое суммирование. Установлено, что наиболее эффективным является объединение двух, максимум трех каналов приема

Ключевые слова: малоразмерный воздушный объект, обнаружение, прием сигнала, однопозиционная система, многопозиционная система, канал обработки

1. Introduction

The emergence of small-sized unmanned air objects significantly complicates solving the task on building a reliable air defense system at present [1–3]. Small-sized air objects such as guided missiles (shells), guided air bombs, cruise missiles of different types of base, anti-radar missiles, unmanned air devices have specific flight-and-technical characteristics. First and foremost, these are small effective scattering surfaces (ESS), a wide range of motion speed and the capability to carry out hidden flights at low and ultra-low altitudes using terrain relief [3–5]. The specified features significantly complicate the task on detection of small-sized air objects by observation radars.

The use of traditional methods to increase effectiveness of detection of small-sized air objects leads to an increase in the number and energy potential of radar. Consequently, a need to solve the problem of detection of small-sized air objects emphasized a contradiction between trends in the development of small-sized air objects and capabilities of existing observation radar . Therefore, it is an important task to develop a method for detecting small-sized air objects by observation radar that would resolve the specified contradiction.

2. Literature review and problem statement

Paper [6] summarizes methods used to improve the effectiveness of radiolocation detection of small-sized air objects. They are:

– denser radar locations along dangerous directions (creation of zones of detection of small-sized air objects);

– using all frequency bands by radar;

– employing radar with a greater energy potential, etc.

Authors of papers [7–10] propose applying the following new information technologies to increase the efficiency of radiolocation detection of small-sized air objects:

– serial-parallel electronic monitoring of a zone along the angle of a site and a two-dimensional electronic scanning of a diagram of antennas orientation;

– phased antenna arrays that are active, semi-active and passive for transmission;

– digital synthesis of probing signals with different parameters: carrier frequency, type of modulation, bandwidth, duration, frequency of pulsing;

– digital diagramming of a phased antenna array for reception;

– automatic analysis of a noise situation and adaptive selection of means and modes of protection against interference;

– automatic topographic binding and orientation of radar based on information from space navigation systems;

– complexing of radar with means of secondary radiolocation;

– possibility of building up radar to an active-passive complex.

Applying the aforementioned known methods and new information technologies to increase the effectiveness of detection of small-sized air objects leads to an increase in the required number, capacity, and technological complexity of radars.

Papers [10–16] consider alternative ways to improve detection of small-sized air objects:

– use of multilocational systems;

– use of energy from third-party irradiation sources;

– use of the property to increase ESS at resonant reflection of electromagnetic waves from an air object;

– use of properties to increase bistatic ESS of secondary irradiation in comparison with ESS of reverse secondary irradiation.

Papers [11–13] consider detection of air objects by multistatic and bistatic systems of passive location. The works give practical recommendations for the construction of such systems and experimental data on detection of air objects.

Papers [14–16] present methods of multilocation radiolocation and their practical application to improve detection and determination of air objects coordinates. The feature of multiposition radiolocation systems is the use of spatial-temporal methods of processing signals, which are received simultaneously at spatially-dispersed reception points. In this case, both active and passive methods of reception are used. Article [15] describes a statistical theory of detection, determination of coordinates of objects, definition of principles of interposition identification of unit measurements and trajectories of air objects. Paper [16] develops methods of combination of radiolocation information by multipositional radiolocation systems. The main advantages of using multiposition radiolocation systems in comparison with one-position radar are as follows:

– increasing survivability of the system due to spatial dispersion of receiving and transmitting positions;

– possibility of formation and dynamic control of the required inspection area;

– possibility of increasing accuracy of the measurement of spatial coordinates of air objects by employing rangefinder methods;

– increasing reliability due to an excess number of receiving and transmitting positions, and others.

In multiposition systems, which operate according to the principle of active location, typical radar are used as system elements [14–16]. This requires an increase in the required number of radars and in the cost of a multiposition system.

The transmitter, which is not part of the system (external transmitter), is used in a multiposition system in papers [17–20]:

– LTE (Long-Term Evolution) signal transmitter – a wireless high-speed data transmission system for mobile phones and other terminals [17];

– transmitter of a signal from satellites located at a geostationary orbit [18];

– DVB-T (Digital Video Broadcasting – Terrestrial) broadcast transmitter of air digital television [19];

– transmitter of Wi-Fi technology (Wireless Fidelity) of the IEEE 802.11 standard [20].

Systems [17–20] ensure minimum energy costs for operation of a system. Authors of [17–20] consider principles of construction and options of practical implementation of dispersed radiolocation systems operating in the field of illumination of third-party transmitters in different wavelength ranges. They obtained expressions for estimation of a potential of dispersed radiolocation systems for detection and determination of coordinates of air objects, and derived dependences of characteristics of dispersed radiolocation systems on parameters of illumination signal.

The further development of radiolocation systems proceeds in the direction of combining of properties of certain types of radiolocation systems into unified active-passive multipositional radiolocation systems. Such complexes carry out cooperative processing of radiolocation information. Authors of papers [21, 22] consider an option of organization of cooperative processing of radiolocation information in an active-passive radiolocation system to increase probability of detection of air objects [21, 22].

Paper [23] investigates a possibility of increasing ESS of small-sized air objects in observation radar to increase the efficiency of detection of small-sized air objects. For this purpose, it utilizes the property of bistatic ESS of air object for a dispersed reception of signals from third-party irradiation sources. According to the results of the conducted studies [23] on the comparison of bistatic and monostatic ESS of air objects, the authors established:

– at values of bistatic angles less than 136 degrees, the value of bistatic ESS does not exceed, and in some cases, is less by 2–5 dB than the values of monostatic ESS, which leads to deterioration of radar capabilities for detection of air objects;

– at values of bistatic angles close to 180 degrees, a value of biased ESS exceeds a value of monostatic ESS significantly (up to 30 dB), which improves radar capabilities for detection of small-sized air objects;

– the brokenness of a bistatic dispersion diagram is less than that of a monostatic dispersion diagram, which reduces a flicker (noise) of an object and reduces its effect on a measurement error of coordinates of an object;

– for objects based on the “Stealth” technology, there is an increase in values of bistatic ESS compared with monostatic ESS.

Thus, the analysis of literature on the research subject showed that issues related to the construction and operation of an active observation radar during operation under modes of single-position and dispersed radiolocation of air objects remain insufficiently investigated. Also, known papers do not consider a possibility of comprehensive use of the possibility to locate air objects under monostatic and bistatic detection modes. The issue of combination of properties of monostatic and bistatic ESS of air objects remains unresolved. Solving it would increase the effectiveness in detection of small-sized air objects.

3. The aim and objectives of the study

The aim of present study is to improve effectiveness of detection of small-sized air objects by introducing an additional mode of dispersed reception to the existing one-position observation radar.

We must solve the following tasks to achieve the objective:

– to improve an algorithm for the detection of an air object at its irradiation by several transmitters;

– to develop structural scheme of a detector, which performs the detection of an air object using the illumination of an object by several transmitters, and to evaluate parameters of the quality of detection of an air object at its irradiation by several transmitters;

– to select the number of receiving channels that are combined;

– to construct a structural diagram of channels for processing echo signals from an observation radar at combination of methods of one-position and dispersed signal reception.

4. Improved algorithm for the detection of an air object at its irradiation by several transmitters

It is necessary to provide an implementation of an algorithm for detection of an object at its irradiation by several transmitters in radar to solve the problem of detection of an air object when introducing an additional mode of dispersed reception. To do this, we must implement appropriate channels in radar for processing echo signals, which emerge due to the irradiation of own and third-party transmitters:

– a channel for processing of echo signals reflected from an air object at its irradiation by a transmitter, which is combined with a receiving device;

– channels of processing echo signals reflected from an air object at its irradiation by external transmitters, which are dispersed in space.

We must implement a separate processing channel for processing echo signals from each transmitter at a receiving point. Signals irradiated by transmitters dispersed in space, in general, can be incoherent among themselves. Fluctuations of amplitudes of reflected signals under monostatic and bistatic modes correspond to different dispersions, and therefore they are independent.

We should construct an algorithm for optimal processing of signals reflected from an air object under a monostatic and bistatic mode based on the principle of incoherent summation of results of a coherent processing with an appropriate compensation of time and frequency shifts. Thus, to improve the detection of small-sized air objects due to the additional use of third-party irradiation sources in observation radar, it is necessary to improve a multichannel detection method with incoherent combining of channels.

When an air object is in the irradiation zone of several transmitting positions, we can present echo signals reflected from it at the location of a receiving position in the following form (1):

$$Y_k(t,\vec{\lambda})=\left\{S_{1k}(t,\vec{\lambda}_1),...,S_{ik}(t,\vec{\lambda}_i),...,S_{Nk}(t,\vec{\lambda}_n)\right\}, \tag{1}$$

where $Y_k(t,\vec{\lambda})$ is the aggregate signal at the location of a receiving position, which is conditioned by signals reflected from an air object, while an air object is in the k-th separate volume; $S_{ik}(t,\vec{\lambda}_i)$ is the i-th type of a signal, which is conditioned by the i-th transmitter and is reflected from an air object, while an air object is in the k-th separate volume; $\vec{\lambda}$ is the vector of informational parameters of an aggregate signal, which consists of vectors $\vec{\lambda}_i$; $\vec{\lambda}_i$ is the vector of informational parameters of an echo signal of the i-th type; i=1, 2, ..., N is the number of types of signals, which are conditioned by a number of transmitting positions that irradiate an air object.

Each $S_{ik}(t,\vec{\lambda}_i)$, signal that is a part of an aggregate signal (1) at the point of the receiving position is mutually uncorrelated and can be received and processed by the corresponding separate receiving channel. Therefore, to ensure possibility of processing the entire set of signals $Y_k(t,\vec{\lambda})$, the receiving point must consist of a set of specific processing channels. Each receiving channel operates according to algorithm (2):

$$\tilde{Z}_i=\int_0^T\left\{Y_k(t,\vec{\lambda})-\hat{D}_{ik}(t,\vec{\lambda}_i)\right\}X_{ik}(t,\vec{\lambda}_i)\mathrm{d}t, \tag{2}$$

where $\tilde{Z}_i$ is the result of a coherent processing of an echo signal of i-th type received from an air object, which is located in the k-th separate volume; $Y_k(t,\vec{\lambda})$ is the aggregate incoming signal at the output of a receiver reflected from an air object located in the k-th separate volume; $\hat{D}_{ik}(t,\vec{\lambda}_i)$ is the average square estimation of interference components of an incoming signal, it forms at the output of interference compensator for the i-th channel of processing and the k-th separate volume; $X_{ik}(t,\vec{\lambda}_i)$ is the expected (reference) signal of the i-th type for the k-th separate volume.

If we have one receiving channel, the optimal processing algorithm takes the form similar to (1) and (2) [15]:

$$L_1=\frac{1}{N_1^2}\left|\tilde{Z}_1\right|^2, \tag{3}$$

$$L_2=\frac{1}{N_1}\left|\tilde{Z}_1\right|^2, \tag{4}$$

where L_1, L_2 are the ratios of probability for weak and strong signals, respectively; N_1 is the one-way spectral density of white noise power in a receiving channel; $\tilde{Z}_1$ is the result of coherent processing of received signals in a receiving channel.

Expressions (3) and (4) represent the optimal processing algorithm based on the principle of incoherent summation of results of a coherent processing of corresponding echo signals in the case of m processing channels:

$$L_1=\sum_{i=1}^{m}\frac{A_{i1}^2}{N_i^2}\left|\tilde{Z}_i\right|^2, \tag{5}$$

$$L_2=\sum_{i=1}^{m}\frac{1}{N_i}\left|\tilde{Z}_i\right|^2, \tag{6}$$

where L_1, L_2 are the ratios of probability for weak and strong signals, respectively; $A_{i1}=\frac{P_i}{P_1}$ is the ratio of mean signal strengths in the i-th and first channels; N_i is the one-way spectral density of white noise power in the i-th channel; $\tilde{Z}_i$ is the result of coherent processing of received signals in the i-th channel; m is the number of incoherent processing channels.

Optimal processing (5) and (6), which ensures detection of an air object at its irradiation by several transmitters, reduces to coherent processing of received echo signals, quadratic detection in each processing channel and weight summation of outputs of detectors of all channels. Weight coefficients depend on a signal/noise ratio and spectral density of noise in processing channels.

Processing channels are at the same receiving point, but emitters of probing signals that determine echo signals of corresponding processing channels dispersed in a space. Consequently, echo signals reflected from one air object and conditioned by probing signals emanating from spatially dispersed positions will have different delay times and Doppler frequency in the receiving position. Therefore, in contrast to expressions (5) and (6), incoherent summation must proceed separately for each separate volume of observation radar. In this case, it is necessary to provide a preliminary compensation of a time delay and Doppler frequency in each receiving channel to a separate volume of observation radar. Taking this into account, expressions (5) and (6) take form (7) and (8), respectively:

$$L_1(d_k,\beta_k,\varepsilon_k,F_{D_k}) = \\ = \sum_{i=1}^{m}\left(\frac{A_{i1}^2(d_k,\beta_k,\varepsilon_k,F_{D_k})}{N_i^2(d_k,\beta_k,\varepsilon_k,F_{D_k})}\left|\tilde{Z}_i(d_k,\beta_k,\varepsilon_k,F_{D_k})\right|^2\right), \qquad (7)$$

$$L_2(d_k,\beta_k,\varepsilon_k,F_{D_k}) = \\ = \sum_{i=1}^{m}\left(\frac{1}{N_i(d_k,\beta_k,\varepsilon_k,F_{D_k})}\left|\tilde{Z}_i(d_k,\beta_k,\varepsilon_k,F_{D_k})\right|^2\right), \qquad (8)$$

where $L_1(d_k,\beta_k,\varepsilon_k,F_{D_k})$, $L_2(d_k,\beta_k,\varepsilon_k,F_{D_k})$ are the ratios of probability for weak and strong signals in the k-th separate volume with coordinates $(d_k,\beta_k,\varepsilon_k)$ and k-th Doppler frequency F_{D_k}, respectively; $d_k,\beta_k,\varepsilon_k$ are a distance, an azimuth and an angle of a location corresponding to the k-th separate volume of observation radar; F_{D_k} is the Doppler frequency, which corresponds to the k-th separate channel along Doppler frequency; $A_{i1}(d_k,\beta_k,\varepsilon_k,F_{D_k})$ is the ratio of mean signal capacities in the i-th and the first channel for the k-th separate volume and the k-th separate Doppler frequency of observation radar; $N_i(d_k,\beta_k,\varepsilon_k,F_{D_k})$ is the one-way spectral density of white noise power in the i-th channel in an element corresponding to the k-th separate volume and the k-th separate Doppler frequency of observation radar; $\tilde{Z}_i(d_k,\beta_k,\varepsilon_k,F_{D_k})$ is the result of a coherent processing of received signals in the i-th channel in an element that corresponds to the k-th separate volume and the k-th separate Doppler frequency of observation radar.

As we can see from expressions (7) and (8), each receiving channel of i-th signal type should be multichanneled for distance (delay time) and speed (Doppler frequency).

Thus, an improved algorithm for detection of an air object when it is exposed to several transmitters is reduced to:

– coherent processing of received signals in each processing channel in each element corresponding to the relevant separate volume and the relevant separate Doppler frequency;

– quadratic detection in each processing channel in each element corresponding to the relevant separate volume and the relevant separate Doppler frequency;

– mass summation of outputs of detectors for each processing channel in each element, which corresponds to the relevant separate volume and the relevant separate Doppler frequency.

5. Structural diagram of the detector of an air object at illumination of an object with several transmitters

We can see from the analysis of expressions (2), (7), (8) that each receiving channel of a signal of the i-th type must be a multichannel for distance (delay time) and speed (Doppler frequency). Fig. 1 shows structure diagram of the detector, which implements the algorithms for detection of an air object based on expressions (2), (7), (8) using illumination of an air object by several space-dispersed transmitters. The signal Y_k received by antenna of the i-th receiving channel enters the unit of components evaluation $\hat{D}_i$ (components are interferences for the i-th type signal) and units $t_{1i}...t_{Mi}$ of distance channels formation for signals of the i-th type.

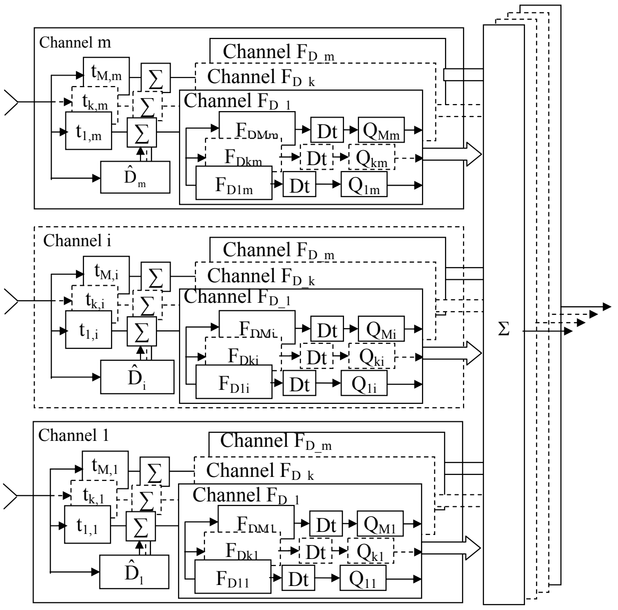

Fig. 1. Structure diagram of the detector that uses illumination of an air object by several space-dispersed transmitters

There are compensation operations of interference signals performed and $F_{D1i}...F_{DMi}$ channels of speed formed in each channel of distance. The result of a coherent processing of an echo signal of the i-th type received from an air object, which is located in the k-th separate volume for the k-th high-speed channel, forms at the output of high-speed channels after amplitude detection ("Dt" letters mark "a detector" in Fig. 1). Results of coherent processing of echo signals are employed in weight summation. Weight coefficients (Q_k) are formed for each type of the i-th type of a signal in each k-th channel of distance and speed. The outputs of each channel of a signal of the i-th type, which correspond to the same volume of the same name and the same channel of speed, proceed to the input of the adder.

Fig. 2 shows part of the structure diagram of the detector with a use of illumination of an air object by several space-dispersed transmitters, which corresponds to the same separate volume and a high-speed channel. Fig. 2 shows that an optimal detector for the construction of a radiolocation system consisting of one receiver and several transmitting positions is a multichannel detector. Receiving channel signals line up according to delay values *tk*, 1...*tk*, which is conditioned by different distances between receiving and transmitting positions. Signals lined up by delay proceed to coherent processing, Doppler filtration ($F_{Dk1}...F_{Dkm}$), detection and summation with weight coefficients ($Q_{k1}...Q_{km}$). Values of coefficients depend on the signal/noise ratio in processing channels.

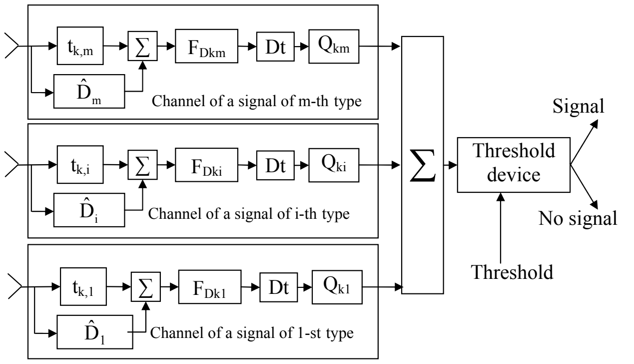

Fig. 2. Structure diagram of the detector that uses the illumination of an air object by several space-dispersed transmitters, which corresponds to one separate volume and one high-speed channel

From the output of the adder, the signal accumulated over channels (calculated likelihood ratio) arrives at the threshold device. There, it is compared with the threshold, the value of which depends on the selected detection criterion (a minimum of average risk, minimax, Neuman-Pearson, ideal observer, and others). Depending on an excess or no excess of the threshold, a system decides on the presence or absence of an air object in the *k*-th separate volume and the *k*-th high-speed channel.

Thus, to detect small-sized air objects in observation radar with a use of irradiation from third-party sources, it is necessary to provide reception, coherent processing of echo signals from third-party sources, compensation of differences in delay and Doppler frequency relative to a separate volume of observation radar and incoherent weight summation.

Let us evaluate efficiency of detection of an air object at its irradiation with several transmitters. We will use conditional probability of correct detection of an air object as an indicator of efficiency.

The following expression determines conditional probability of correct detection in the incoherent combining of m channels (9):

$$D = e^{-\frac{u_0}{2\left(1+\tilde{q}^2\right)}} \sum_{k=0}^{m-1} \frac{\left(\frac{u_0}{2}\right)^k}{k!\left(1+\tilde{q}^2\right)^k}, \tag{9}$$

where m is the number of incoherent combined channels; $\tilde{q}$ is the average signal/noise ratio at the output of the processing channel (taken as equal for all channels); u_0 is the normalized threshold level, which depends on the probability of false alarm, the following expression determines it (10):

$$F = e^{-\frac{u_0}{2}} \sum_{k=0}^{m-1} \frac{\left(\frac{u_0}{2}\right)^k}{k!}. \tag{10}$$

Fig. 3 shows detection characteristics constructed according to expressions (9), (10) at incoherent combining of two (indicated by number 3 in Fig. 3), three (indicated by number 4 in Fig. 3) and four (indicated by number 5 in Fig. 3) receiving channels. We constructed characteristics for the value of conditional probability of false alarms $F=10^{-5}$.

There are also detection curves for monostatic signal reception (indicated by number 1 in Fig. 3) and bistatic reception of signals (indicated by number 2 in Fig. 3) for comparison in Fig. 3.

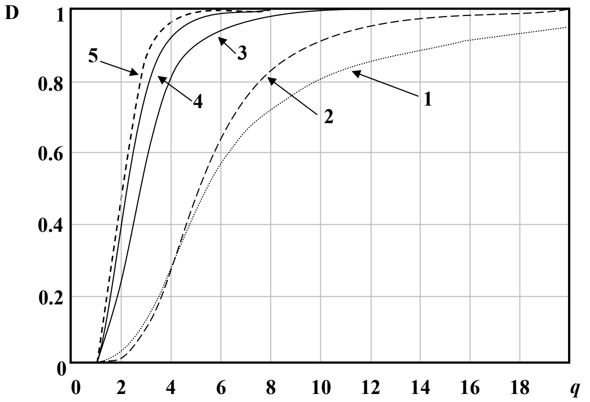

Fig. 3. Characteristics of detection of an air object in channels for conditional probability of false alarm $F=10^{-5}$: 1 — monostatic reception of signals; 2 — bistatic reception of signals; 3 — at incoherent combining of 2 channels; 4 — at incoherent combining of 3 channels; 5 — at incoherent combining of 4 channels

From the analysis of detection characteristics depicted in Fig. 3, it is evident that transition from single-channel detection of an air object (curves 1, 2) to detection of an air object at the incoherent combining of two channels (curve 3) leads to a significant shift of detection characteristics to the left. A further increase in the number of incoherently combined channels (curves 4, 5) does not lead to a significant shift in detection characteristics to the left comparing to detection characteristic when two channels are combined (curve 3).

6. Selection of the number of receiving channels, which are combined

To select an optimal number of reception channels for incoherent combining, let us evaluate a gain in terms of a signal/noise ratio at the incoherent combination of channels in comparison with one-position signal reception. We will evaluate such a gain according to expression (11):

$$K_m = 20\lg\left(\frac{q_1}{\tilde{q}_m}\right), \tag{11}$$

where K_m is the gain in a signal/noise ratio at the combining of m channels relative to one-position reception (with a signal/noise ratio q_1); q_1 is the signal/noise ratio at one-position reception, which is required to provide specified indicators of a quality of detection of an air object without a use of additional channels; $\tilde{q}_m$ is the signal/noise ratio required to provide specified indicators for detection of an air object at the incoherent combining of m channels.

Fig. 4 shows dependence of energy gain K_m in the desired signal/noise ratio to provide indicators of the quality of detection of an air object D=0.8; F=10^{-5} at incoherent combining of channels on the number of combined channels. We made calculations according to expression (11).

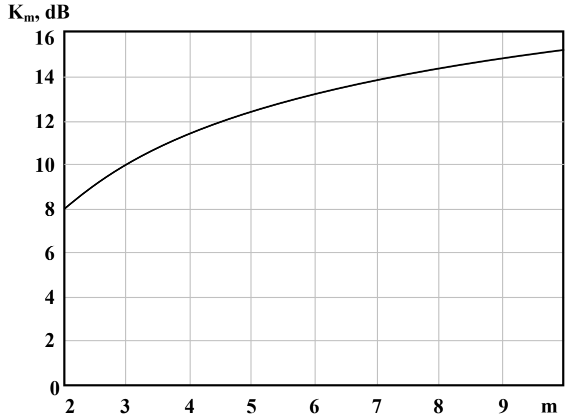

Fig. 4. Gain in a signal/noise ratio at in the incoherent combination of channels relative to a signal/noise ratio for one-position reception (for indicators of a quality of detection D=0.8; F=10^{-5})

From the analysis of gain in the signal/ noise ratio shown in Fig. 4, it is evident that the combining of two channels provides a gain of 8 dB (m=2; K_m=8dB). Adding a third channel will increase a gain by 2 dB only (m=3; K_m=10dB). A further increase in the number of combined channels results in an increase in a gain of less than 2 dB for each added channel. Therefore, based on the efficiency-cost criterion, the most effective is to combine two, at most three channels (for example, one-position channel and one or two bistatic ones).

To select the optimal number of receiving channels for incoherent combining, we will also make calculations for estimation of a gain in the signal/noise ratio at the incoherent combination of different number of processing channels on the given probability of correct detection. The calculations used expressions (9)–(11).

Fig. 5 shows dependence of K_m gain in the signal/noise ratio on the given conditional probability of correct detection at incoherent combining of different channels (m=2; 3; 4; 10) at F=10^{-5}.

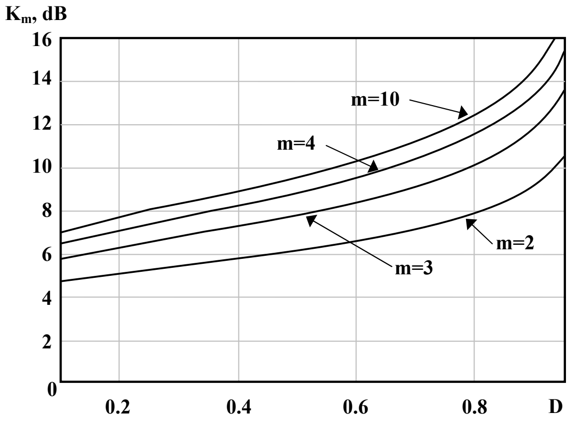

Fig. 5. Gain in a signal/noise ratio at the incoherent combining of m channels relative to a signal/noise value with one-position reception (at F=10^{-5})

From analysis of Fig. 5, it is evident that an increase in the probability of correct detection increases a gain in the signal/noise ratio. The increase in a gain for the signal/noise ratio reduces at m>3, which confirms the inexpediency of incoherent association of more than three channels.

In addition, the analysis of detection characteristics (Fig. 3) also indicates inexpediency of combining more than three channels. Fig. 3 shows that the further increase in the number of incoherent channels (curves 4, 5) does not lead to a significant shift in detection characteristics to the left comparing to detection characteristic when two channels are combined (curve 3).

7. Structural diagram of channels that process echo signals from an observation radar

To ensure the possibility of combining the modes of single-position and dispersed location in observation radars, it is necessary to ensure complexing of corresponding digital receiver devices and digital signal processing systems. One receiving device provides reception and processing of echo signals, which are caused by irradiation of a transmitter of an observation radar, this corresponds to the standard mode of operation of an observation radar. Another receiver provides the reception and processing of echo signals, which are caused by irradiation by external sources, this corresponds to implementation of the additional mode of dispersed location. The basic principle of complexing of the mentioned receiving devices should be the informational supplement without violating the standard modes of operation of an observatory radar. Fig. 6 shows structural diagram of channels that process echo signals from observation radar , which provides combining of modes of one-position and dispersed location.

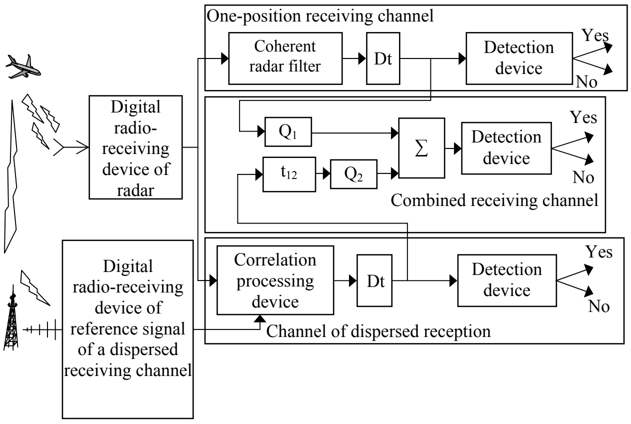

Fig. 6. Structural diagram of channels that process echo signals of an observation radar , which provides combining of modes of one-position and dispersed location

Designations in Fig. 6 above correspond to the designations in Fig. 1, 2. One-position receiving channel, which is shown in the upper part of Fig. 6, corresponds to a regular channel of reception and processing of echo signals of an observation radar . An additional channel, which is shown in the bottom of Fig. 6, corresponds to a channel of dispersed reception. It provides combining of single-position and dispersed modes in an observation radar. Signals received by the antenna of the observation radar and the antenna of the receiver of a reference signal of the channel of dispersed reception, arrive to the input of an additional channel. Based on the results of correlation processing of the signals, a decision is made to detect an air object in the mode of dispersed reception. A combined channel is for combining the modes of one-position and dispersed location. The combined channel receives results of processing of echo signals in the main and secondary channels. After combining of results of processing of echo signals of the main and secondary channels in the combined channel detection device, a system makes a decision to detect an air object at combining of single-position and dispersed modes.

7. Discussion of results of the introduction of an additional mode of dispersed reception to the existing one-position observation radar

We proposed the introduction of an additional mode of dispersed reception into the existing one-position observation radar in the study. This addition makes it possible to improve the efficiency of detection of small-sized air objects.

The benefits of present study are:

– improvement of the algorithm of detection of an air object at its irradiation by several transmitters;

– development of the structural diagram of the detector of an air object at illumination of an object by several transmitters. We managed to take into account the multichannel character of each receiving channel for distance and speed in this case;

– selection of the number of receiving channels, which are combined. We selected the number of receiving channels by analyzing a gain in the signal/noise ratio at incoherent combining of channels relative to the signal/noise ratio with one-position reception; by estimation of a gain in relation to the signal/noise ratio at incoherent combination of different number of processing channels by the given probability of correct detection and by estimation of characteristics of detection of an air object;

– a structural diagram of channels that process echo signals of an observation radar. There are possibilities of operation of an observation radar under a regular mode, under the mode of bistatic reception and under the mode of combining of receiving channels. An operator of radar can select an operation mode in dependence on air situation and tasks solved by radar.

We accepted the following main limitations and assumptions during the study:

– we considered operation of observation radar only;

– a signal/noise ratio is the same in all additional channels of dispersed reception;

– we did not take into account a type of interference components of an incoming signal;

– we ignored the influence of a direct signal from an external source of irradiation on the main receiving channel of an observation radar.

Development of the present study implies the following:

– it is necessary to conduct research into development of a direct signal auto-compensator to ensure functioning of an additional channel under the influence of a direct signal from external sources of irradiation;

– it is necessary to carry out research intp provision of Doppler filtration of echo signals using Doppler filters based on a fast Fourier transform to ensure selection of air objects against the background of local objects;

– to conduct research into ensuring the synchronization of operation of the main and additional channels of observation radar.

7. Conclusions

1. We improved the algorithm for detection of an air object irradiated by several transmitters. To do this, we implemented the appropriate channels for processing echo signals:

– a channel for processing echo signals reflected from an air object at its irradiation by a transmitter, which is combined with a receiving device;

– channels for processing echo signals reflected from an air object at its irradiation by external transmitters, which are dispersed.

We provided a preliminary compensation of a delay time and Doppler frequency in each receiving channel to a separate volume of an observation radar at upgrading the algorithm.

An improved algorithm for detection of an air object with its irradiation by several transmitters is reduced to:

– coherent processing of received signals in each processing channel in each element corresponding to the relevant separate volume and the relevant separate frequency Doppler;

– quadratic detection in each processing channel in each element corresponding to a relevant separate volume and the relevant separate Doppler frequency;

– a mass sum of the outputs of the detectors for each processing channel in each element, which corresponds to the relevant separate volume and the relevant separate frequency Doppler.

2. We constructed a structural diagram of the detector of an air object for the object illuminated by several transmitters. Each receiving channel of a signal is multichannel by distance and speed. The diagram provides reception, coherent processing of echo signals from third-party sources, compensation of delay differences and Doppler frequency relative to a separate volume of an observational radar and incoherent weight summation.

We carried out estimation of the efficiency of detection of an air object at its irradiation by several transmitters. We used the conditional probability of correct detection of an air object as an efficiency indicator. We constructed characteristics of detection of an air object with a different number of receiving channels. We established that transition from single-channel detection of an air object to detection of an air object at the incoherent combining of two channels results in a significant shift of detection characteristics to the left. A further increase in the number of incoherent channels does not lead to a significant shift in detection characteristics to the left, comparing to detection characteristic when two channels are combined.

3. We carried out selection of the number of receiving channels, which are combined. We established that the most effective is combining of two, at most three channels (for example, one-position and one or two bistatic ones).

4. We constructed a structural scheme of channels that process echo signals of an observation radar at combining of the methods of one-position and dispersed signal reception. For combination of one-position and dispersed location in observation radars we provided complexing of corresponding digital reception devices and digital signal processing systems. The main principle of the combining of the mentioned receiving devices is the informational supplement without violating the standard modes of operation of an observation radar.

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