Analysis of the current state and development prospects of radar system for guided weapons of air targets destruction

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Abstract: **The effectiveness of destruction of air objects (AO) largely depends on the excellence of radar devices, which are called radar homing heads (RHH) of the guided weapons systems (GWS). In the process of GWS AO development, several generations of RHHs were created: semi-active RHHs with a pulsed or continuous target illumination signal; RHHs providing combined guidance; RHHs, providing realization of inertial guidance with radio correction from the weapon control system of the GWS carrier, active guidance, a combination of semi-active and active modes, combined guidance, in which inertial guidance with radio correction, passive and active homing are consistently implemented. Currently, there is a need for an analytical generalization of information about the GHHs, published in various open scientific and technical sources of information. In the course of the analysis, it was found that the main directions for improving the RHHs are: the development of new, more flexible non-stationary homing methods and their information support, which provide the ability to intercept new types of AO in complex signal-jamming multipurpose situations. This predetermines the need to achieve a high level of RHHs protection from natural and intentional interference, the use of trajectory control of observation when aiming at radio-emitting and group objects, improvement of situational awareness, RHHs intellectualization and digitalization, improvement of RHH antenna systems.**

Keywords: **radar homing heads, guided weapons, air object, guidance system**

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Contents

1. INTRODUCTION

The radar homing heads (RHH), being one of the types of information-and-control systems of the guided weapons systems (GWS) **of air objects** (AO), provides the implementation of the homing method and its information support. All indicators of the complex perfection (efficiency, survivability, dynamism) for the destruction of the air objects largely depend on the quality of RHH functioning.

In the process of GWS AO development, several generations of RHHs were created. At the initial stage, semi-active RHHs with a pulsed or continuous target illumination signal were developed. In semi-active pulsed RHHs the AT was irradiated by the onboard radar of GWS carrier, and in the RHH, GWS guidance signals were generated based on information obtained as a result of receiving radio signals reflected from the AO.

To increase the launch range of GWS, GWSs were developed using various guidance methods at different parts of the flight path: at the initial stage inertial-corrected guidance was used, followed by proportional homing on the basis of semi-active RHH signals with AO capture on the path.

Subsequent efforts of the developers were aimed at creating GWS AO with active RHH. In active RHHs irradiation and target illumination were carried out by a transmitting device included into RHH composition. This allows to consider it as a special-purpose onboard radar.

The action range of such RHHs is less than that of semi-active ones, therefore, at the first stage of GWS guidance, an inertial mode with radio correction was used, and at the second stage – active homing. In this case the “launch and forget” principle was carried out but only at the last stage of GWS guidance. Active RHHs allowed to guide simultaneously several GWSs launched from one carrier to different air objects.

To increase the launching range, RHHs were also developed, in which three modes of their operation, implemented sequentially, were provided: inertial guidance with radio correction, semi-active guidance and active homing. There are also known RHHs in which there is no inertial guidance mode with radio correction, but semi-active homing and active homing are implemented sequentially. For GWS guiding at radio emitting objects passive RHHs were developed.

Subsequently RHHs appeared, with the help of which inertial guidance with radio correction, passive homing and active homing were consistently carried out. Such RHHs provide a possibility to destroy radio-emitting objects over long distances.

Currently, there is a need for an analytical generalization of information about RHHs, published in various open scientific and technical sources of information, which will allow us to get a general idea of the current state and development prospects of the RHH GWS AO.

The purpose of the paper is to analyze the stages of creation, the current state, prospects and trends in the development of RHH from the composition of controlled weapons for destroying air objects.

2. ANALYSIS OF THE DEVELOPMENT DIRECTIONS AND CURRENT STATE OF THE RHHS FROM THE COMPOSITION OF THE GUIDED MEANS OF AIR OBJECT DESTRUCTION

2.1. Analysis of the stages of development, design features and characteristics of existing radar homing heads

Let us consider the features and characteristics of RHHs, installed on different GWS AO, taking into account the chronology of their development, realization and practical application, as it is briefly indicated in the introduction.

Note, that in the general case the perfection of RHHs used in GWS AO, is characterized by the following indicators:

– a list of targets to be destroyed (aircraft, helicopters, missiles, etc.) with an indication of their features (maneuvering, non-manuevering, high-speed, low-speed, etc);
– working area, determined by the distance ranges (D_{pmax}, …, D_{pmin}), velocities (V_{max}, …, V_{min}), altitudes (H_{max}, …, H_{min}), interception aspects in which the GWS realizes its purpose;
– the homing method used (stationary, non-stationary, with anticipation, with re-aiming, etc.);
– type of information subsystem and its operating modes (pulsed, continuous, coherent, incoherent, active, passive, semi-active, etc.);
– the possibility of implementing the “launch-and-forget” principle;
– missing the possibility to destroy the target.

In the early 60-s of the last century GWSs AO with semi-active pulsed RHH P 8M (1962), P 4, P 98 (1965), P 3P (1966) were developed. To implement the target tracking procedure a conical scanning of the antenna was used in RHHs of these GWS AO, and the monopulse method of target direction finding was used in RHHs of GWS P 40 (1970) (**Fig. 1**).

The disadvantage of semi-active pulsed RHHs was impossibility of auto-tracking AO, flying at low altitude, since simultaneously with the pulsed signals from the AO, jamming signals were received, which were formed as a result of reflections from the earth’s surface of radio signals, emitted by the onboard radar of GWS carrier.

Fig. 1. *RHH GWS P-40.*

The first domestic GWS, capable of destroying an AO against the background of reflections from the ground, was created in 1973 (P-23P). The GWS launch range was 35 km, the flight speed was 3M. The AO capture in a semi-active Doppler RHH was made during the flight. Before launching, a target designation was introduced into the RHH from the onboard radar, equipped with a channel of continuous illumination signal , used for operation of a semi-active RHH after launching GWS. 3 seconds after the launch, the RHH started searching for the signal reflected from the AO and capturing it. The phase mono-pulse method of direction finding was used in RHH, which provided a higher noise immunity as compared to the amplitude mono-pulse method of AO direction finding. Note, that GWS with semi-active RHHs were used mainly for non-maneuvering AOs, thus, the range of coverage of such RHHs was comparatively low.

Subsequently, in order to increase the GWS launch range at the initial stage of the flight an inertial guidance mode was introduced, in the implementation of which the so-called pseudo-kinematic link was used, using the current parameters of GWS movement and parameters of AO movement, that entered the RHH at the moment of GWS launch. The pseudo-kinematic link provided the formation of predicted values of the GWS and AO relative motion parameters based on the known kinematic equations. This resulted in 30% increase of GWS launch range.

A distinctive feature of GWS P 27P and P 27E (1984-1985) is a combined guidance method, when various guidance methods are used at different parts of the flight trajectory: inertial-corrected guidance and proportional homing based on signals of semi-active RHH with AO capture in the path. The introduction of inertial control with correction from the onboard radar of the GWS carrier allowed to increase the GWS launch range significantly. These GWSs provide the effective AO destroying at any aspect angle. The detailed description of the construction principles of RHH GWS (**Fig. 2**) P 27P is given in [11].

It should be noted that the work on creating GWS AO with RHH was actively carried out abroad, primarily in the USA. Beginning from 1975 the development of the whole family of GWS "Sparrow" was completed.

The first version was GWS "Sparrow" AIM-7C with a semi-active pulsed RHH, which had a coverage range of 12 km. The next version was GWS "Sparrow" AIM 7D, in RHH of which a continuous illumination signal was used. The RHH GWS AIM 7F worked both with AO continuous illumination signal and with a signal of a pulsed-Doppler onboard radar of the carrier, which allowed to use GWSs from carriers equipped with various onboard radars. GWS "Sparrow" AIM 7F was the main means for destroying AOs until in early 90-s of the last century a new GWS AIM 120 with an active RHH appeared. In 1987 GWS "Sparrow" AIM 7P, having a communication line with the aircraft-carrier, appeared.

Fig. 2. *RHH GWS P-27P.*

The disadvantage of semi-active RHHs was impossibility of destroying AO by the "launch-and-forget" principle, since the AO had to be illuminated before the AO was destroyed or the GWS missed.

Hence, the development of GWS with active RHHs started.

GWS Foenix AIM 54A was developed abroad in 1973. The guidance system of this GWS is combined and consists of a semi-active radar pulsed-Doppler system working from onboard radar signals of GWS carrier at the initial and middle sections of the trajectories, and an active pulsed-Doppler RHH, switching on at GWS distance from AO of about 16 km. From the GWS carrier it is possible to carry out simultaneous guidance of 6 GWSs at 6 AOs. With further modernization the AIM–54C became completely autonomous. Most of the time GWS flies to the predicted point and at the end of the flight phase it is guided with the help of an active RHH (ARHH). This approach is most effective when aiming at rectilinearly flying AOs.

Domestic GWS PBB-AE (1994) with an active RHH (**Fig. 3**) ensures the defeat of aircraft, helicopters and cruise missiles as well as GWSs of air and ground objects. The RHH includes a monopulse direction finder and an onboard computer system. To increase noise immunity and ensure high guidance accuracy, space – time signal processing, Kalman filtering, continuous solution of kinematic equations were implemented in RHH with the ability to maintain the guiding process in case of temporary disruptions. A no-platform inertial system is installed on the GWS. A

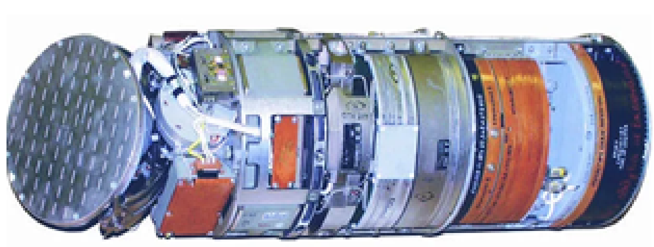

Fig. 3. *RHH GWS PBB-AE.*

modified proportional guidance method is used for control. In conditions of organized interference, in which the onboard radar of the carrier cannot provide the RHH with information about the range and speed of the approach to the AO, guidance is carried out along a special trajectory.

Later on, GWS with combined and passive guidance methods were developed.

Medium range GWS P 27П with passive RHH is designed to destroy radio-emitting airborne objects, including those which install jamming to cover their objects. At the same time the "launch-and-forget" principle is implemented. The range of application is 70 km, the minimum altitude of the airborne object to be destroyed is 20 m.

GWS AIM 120A (USA, 1991) has the range of application -180 km and 3 guidance modes: inertial-corrected, autonomous inertial and active radar. The GWS implements the "launch-and-forget" principle in case of the sequential use of the autonomous mode and the active mode. To destroy an AO, several GWSs can be used simultaneously. A control system with an active radar guidance and sufficiently long inertial section with radio-correction can significantly increase the effectiveness of AO destruction. At the same time a feature of the implementation of the combined guiding method is the dependence of the GWS combat use efficiency on the quality of radio correction channel functioning.

When the carrier is suppressed by the onboard radar interference after the GWS launch, information about the AO coordinates and parameters is not received via the radio correction channel. In this case the GWS guidance system can perform first inertial guidance without radio correction, and then homing using the RHH active operating mode. With a large difference between the coordinates and AO moving parameters, predicted on board of GWS, and their real values by the beginning of active homing, it is not possible to guarantee the possibility of successful interception.

GWS P 37M (RF) is designed to destroy AOs at the range of up to 300 km. The GWS guiding system is an inertial guidance with radio correction and active radar homing at the final section of GWS flight. The RHH includes a digital signal processor with a large memory content and increased processing speed [14].

Monopulse Doppler active RHH 9Б 1103M ensures the destruction of AOs, such as aircraft, helicopters (including hovering helicopters), cruise missiles and antiradar missiles. Modes of operation: completely autonomous according to preliminary target designation from the carrier, but without radar support in flight; inertial guidance mode with radio correction with the subsequent transition to active homing.

ARHH measures the AO angular coordinates and the angular velocities of the line of sight rotation, as well as the speed of approach to AO and provides:

– AO reception, capture and tracking;
– reception and decryption (decoding) of radio correction signals;
– generating GWS control signals and transmitting them to the GWS control system via a digital communication line.

The RHH consists of: a controlled coordinator with an antenna, a transmitting channel, a receiving channel a reprogrammable onboard computer system. The capture range of AO with an effective reflection surface (ERS) of 5 m^2 is not less than 20 km. The range of the radio correction channel is up to 50 km.

The GWS 9Б 1103M 150 («Kolibri») provides the capture of AO with ERS of 5 m^2, moving at speeds of 0.1-5 M, at a minimum altitude of 30 m at the range of not less than 13 km. The RHH operating band is Ku (10.7-12.75 GHz, 1.67-2.5 cm). ARHH is almost completely digital, the transition to digital processing (signal digitization) is carried out at the first intermediate frequency. The antenna has a diameter of 150 mm.

The active-semi-active RHH 9B 1103M 200PA is designed for information support

Fig. 4. *RHH 9B 1103M 200PS.*

for solving the problem of destroying aircraft, helicopters (including hovering helicopters), cruise missiles and antiradar missiles. The antenna of this RHH is combined: in the active mode the RHH operates in Ku band, using a waveguide-slot antenna, in the semi-active mode an array of 12-16 dipoles is used, installed on the front of the antenna surface, it is designed to ensure the RHH operation in a semi-active mode at lower frequencies. The RHH provides the capture range of AO with ERS of 3 m^2: in inertial – semi-active mode – 80-100 km, in active mode – 20 km. The operation band in the active mode is Ku.

The active-passive RHH 9B 1103M 200PS (**Fig. 4**) ensures destroying aircraft, helicopters, cruise missiles and antiradar missiles. The passive mode makes it possible to direct RHH to the source of interference and radio-emitting onboard radar of the AO. The capture range of AO with ERS of 3 m^2 in inertial-passive mode – 200 km, in active mode – 15 km. The operation band in the active mode is Ku.

2.2. Features of RHH functioning when solving problems of trajectory control and tracking

Evaluation of characteristics of known RHH GWS AO shows, that the principles of building RHH are largely determined by characteristics of intercepted AOs and conditions of their use.

This feature predetermines the need to solve two problems: the formation of a homing law (method) and algorithms for its information support. In this case, the GWS homing method is usually understood as the law of the formation of the required trajectory, the flight along which will allow it to hit the target.

In general, the guidance method (GM) should provide: minimum guidance time; maximum launch range; minimal instantaneous overloads; minimum energy consumption of control signals; practical feasibility and invariance of the radio control system for the conditions of use.

To meet the first four requirements, the guidance trajectory should be as straight as possible. Practical feasibility implies the possibility of forming estimates for all necessary coordinates of the relative and absolute movement of the target and GWS with existing information sensors (meters), real memory volumes, speed and bit capacity of onboard computers and real energy consumption for control. Invariance provides guidance in the entire range of ranges, speeds and altitudes regardless of the presence and speed of the wind and the direction (angle) of interception.

To characterize the homing method the following is usually used:

– the type of tracings that can be realized (with anticipation, without anticipation, restrictions on the angles of interception, etc.);

– a set of coordinates of the relative and absolute movement of the target and GWS, to be measured (evaluated), and requirements for their accuracy;

– restrictions on permissible GWS transverse overloads.

If in the process of interception control error transmission coefficients do not change, this method is considered to be stationary, if they change – then it is non-stationary.

As a rule, in tracing control by existing GWS AO, the proportional guiding method or its modification is used. To implement them it is necessary to know the angular velocity of the line of sight and the velocity of the approach to AO, the estimation of which is provided by appropriate meters and tracking systems. The effectiveness of their functioning largely depends on the type of RHH used (active, semi-active and passive), as well as on the type of AO and dynamics of approaching GWS to AO. Measurement of the approach speed to AO in semi-active RHHs is associated with certain difficulties, since the source of radio emission is located onboard the GWS carrier, while the reception of the signals, reflected from AO, is performed on the GWS. In passive goniometric GWSs direct measurement of the velocity of approaching the AO is impossible.

It should be noted, that modern RHHs have significant drawbacks, due to imperfection of homing methods and AO auto-tracking algorithms which can lead to decrease of the AO destruction effectiveness, as well as to disruption of GWS guidance process, especially in the situation of intercepting new types of highly maneuverable and high-speed AOs. As the analysis showed the known homing methods:

– do not ensure interception of AOs moving with the change of signs of derived angles and ranges;
– do not ensure interception of priority AOs in the conditions of their protection (low survivability);
– do not ensure interception of AO as part of a dense group;
– do not ensure redistribution of management functions in the process of guidance (first angular errors, then linear misses, first resolution in angles, then guidance, etc.);
– do not ensure retargeting in the tracing.

The information subsystems have the following disadvantages:

– lead angle constraints, defined by antenna angle sector;
– the need to stabilize the GWS lateral axes in space with semi-active guidance;
– low order of the astaticism of the tracking systems which predetermines the tracking disruption of intensively maneuvering AOs;
– do not ensure interception at 4/4 angles when using Doppler RHH;
– large dead zones because of angle noise;
– radome errors leading to appearance of significant synchronous errors in angular velocity and requiring the formation of purely individual matrices of direction finding errors;
– the influence of an “antipode” when intercepting low-flying targets against the earth background;
– tracking disruptions due to narrow linear sections of discriminatory characteristics of tracking meters.

Thus, in connection with the emergence of new types of AOs and the change in the conditions of using GWS, the solution of the interception problem has become significantly more complicated which requires further improvement of GWS guidance methods and AO tracking.

It should be noted that RHH provides the formation of GWS control signals, necessary for the implementation of the process of its guidance to the AO, as well as for creating conditions, required when performing the procedures for evaluating coordinates and parameters of the target movement in case of missing information from the GWS carrier onboard radar and if only AO angular coordinates can be measured. In the latter case the GWS trajectory control is also necessary to create favorable conditions for the functioning of AO tracking systems, therefore, it is often referred to as the trajectory observation control (TOC).

Moreover, the TOC is used to implement the RHH protection from intentional interferences. A version of the flight trajectory corresponding to one of heuristic or optimal TOC methods is given in [27].

Another promising direction for the use of TOC is its use when GWS is pointed at the object in a dense group composition [28].

The TOC signals can also be formed at simultaneous guidance of two GWSs. A method of destroying the target – a coherent jammer GWS with an active RHH described in [16] can be indicated as an example.

It is known that coherent interference causes distortion of the phase front of the electromagnetic radio wave reflected from the target. The impact of such interference on the RHH leads to unacceptable misses and a decrease in the probability of hitting the target. However, the possibilities of setting up coherent interference have fundamental physical limitations. Effective interference can only be created in a specific angular direction. The area of space, in which it is possible to create effective coherent interference, is limited and amounts to almost 0.001 radians. For this reason, coherent interference is not effective against multi-positional radars - bistatic radars, in particular. This property of resistance to coherent interference with spaced-apart points of transmission and reception of radio signals can be implemented in GWS due to a special operation of the process of simultaneous guidance of two GWSs and their interaction with each other. The essence of the method is that the radiation of the probe signal and the reception of the signal reflected from the AO are redistributed between the GWSs alternately. In this case the interval of signal emission by one GWS should correspond to the interval of reception of the reflected signal by the other GWS. In addition, GWS guidance is carried out along maximally diverging trajectories of the “pincers” type.

The GWS guidance along the most divergent parts in the initial and middle sections of the trajectory of the “pincers” type is aimed at ensuring that on most part of the flight trajectories the GWSs are maximally distant from each other and do not enter the area of space, in which the effect of coherent interference on the RHH is effective.

In conclusion, note, that the TOC methods behind radio emitting objects in two-position goniometric radar systems are considered in detail in [21].

2.3. Features of RHH functioning in the conduct of group actions and in the conditions of radio electronic countermeasures

A specific feature of the modern interaction of attack and defense means is their group use [24]. In a sufficiently long information and control chain of group confrontation, including the detection of targets and their tracking, the use of GWS, one of the most important and complicated tasks is the target distribution and guidance of GWS AO to the most important AO. Moreover, the practical implementation of these modes of RHH operation is significantly more complicated when the opposing side uses radio electronic countermeasures.

As the analysis has shown [25,26], the armed forces of the USA and European NATO countries have sufficiently powerful electronic warfare (EW) weapons that are capable of generating various jamming effects that pose a serious threat to RHH. In particular, to suppress the channels of detection, discrimination and recognition, as well as channels for measuring range and speed, means of radio electronic countermeasure (ECM) can generate the following types of interference: continuous noise, chaotic pulse, multiple synchronous pulse, simulating pulse and combined ones (retargeting active-passive and a combination of active-simulating and masking interference). To suppress goniometric channels ECM can create single-point interference for goniometric channels with linear scanning, single-point interference for monopulse goniometric channels, multi-point interference for goniometric channels, polarization interference. Moreover, to suppress goniometric channels it is envisaged to set up deliberate interference, acting along the side lobes of the radar antenna pattern.

Thus, the successful solution of the GWS homing problem largely depends on efficiency of the active pulse-Doppler radar operation under the conditions of EW. A serious threat to the normal functioning of the active RHH is posed by individual ECM equipment installed on the targets to be hit as well as EW equipment intended for group and collective (mutual) defense of AOs. The latter ones are capable to create multi-point (non-isotropic in space) active interference, which can be masking and imitating and act both along the main and side lobes of the antenna directional pattern. In this regard, special measures in an active radar must be taken to protect against multi-point interference in space.

In such a situation in RHH first of all it is necessary to assess the signal-interference environment. To do this, two processes must proceed in it practically in parallel: the first process is the assessment of interference environment (IE), the second is the AO radar surveillance with simultaneous compensation for various kinds of deliberate interference. AO radar surveillance should begin with IE assessment operations. Various algorithms have been developed to determine the number and angular coordinates of radiation sources which include interference providers (IP) as well. These algorithms together with the algorithms for synthesizing the directional patterns of the multichannel antenna system, make it possible to form a given number of reception channels, equal to the number of IPs and conduct IP radar surveillance in them. When implementing space-time processing of signals in radar systems, this procedure is usually divided into space and time procedures which implies separate construction of spatial (beams directed to IP) and temporal channels. In the formed reception channels, which number is determined by the number of IPs, algorithms are implemented that perform such operations as detecting interfering signals, measuring the angular coordinates of IPs with subsequent correction of beams position in space and recognizing the type of acting interference.

The output signals of the time channels, IP angular coordinates, the type of interference are fed to the device for analyzing the signal-interference situation, where the type of interference situation is assessed (recognized). The results of IP assessment serve as a basis for making a decision to start a space survey with a version of the noise protection scheme that meets the current situation. Each IE class corresponds to its own version of arranging jamming protection in the radar system and, thereby, its own scenario of its operation which ensures the maximum degree of GWS protection from the effects of deliberate interference.

In addition to the above, in order to ensure GWS guidance in such a situation, it is advisable and necessary to introduce into the RHH an additional mode of passive homing for radio emitting sources, creating interference signals in the operating range of the GWS carrier onboard radar. In this case the GWS guidance can be carried out either within the framework of a passive one-position goniometric guidance system, or a passive two-position goniometric system. The most preferable is the option of using two-position guidance system which includes the guided GWS and its carrier [21].

From the above it follows that in order to successfully solve the problem of AO interception when conducting group actions in the conditions of using EW means it is necessary to supplement the GWS control system with a two-position passive guidance mode. In this mode sufficiently reliable information about the AO coordinates and motion parameters is obtained which is necessary for GWS targeting, as it makes possible to sufficiently neutralize the effect of electronic suppression on the formation of estimates of coordinates and motion parameters in RHH.

In addition, it is advisable to use an active phase antenna array (APHAR) in an active RHH, as a multichannel antenna system, which makes it possible to optimize and implement the space-time processing of useful and interference signals and provide a given level of RHH noise immunity.

2.4 RHH operation features when implementing the passive guidance mode to a radio emitting air object

As it is indicated above, when implementing passive GWS guidance methods, it is advisable to use a two-position goniometric guidance system (GTPS), as part of, for example, GWS and its carrier from which it was launched, or as part of two GWSs which form receiving positions (RP). As it is known [21], in passive two-position goniometric systems on RP the bearings of a radio emitting AO (REAO), as well as their own coordinates and motion parameters are measured with the subsequent transition of the measurement results to interacting positions. Subsequently, the trajectory parameters of REAO movement are estimated in the selected coordinate system (rectangular, spherical, etc.).

Joint processing of information in GTPS which makes it possible to significantly improve the quality of radio-emitting target (RET) observation, is divided into three stages.

At the first stage single measurements coming from different positions are converted into a single coordinate system, e.g., a Cartesian one, the origin of which is tied to a certain geographic point (a conditional GTPS center). At the second stage the measured results are identified with each other and with the previously constructed trajectories. Since the data generated in GTPS are statistical estimates of AO parameters, the problem of their identification is also statistical in nature. At the third stage the actual construction of REAO trajectories is carried out, i.e., the assessment of their coordinates and parameters of their movement. Previously at the third stage in the process of intra-base processing on the basis of the measured values of REAO bearings in each mobile position and the coordinates of these positions, the so-called generalized single measurements (indirect measurements) of the radio emitting objects coordinates are calculated: rectangular REAO coordinates or distance to them. In other words, the primary assessment of the REAO location is carried out. The trajectory of each REAO in the GTPS is formed as a result of the secondary processing of direct and indirect single measurements of coordinates.

To create effectively functioning trajectory tracking systems it is necessary to have high-quality algorithms to estimate coordinates and parameters of the REAO movement, corresponding to the specific conditions of GTPS use. Currently estimation algorithms based on methods of linear and nonlinear filtering are widely used, in particular, methods and algorithms of estimating coordinates and parameters of RET motion based on using linear and expanded Kalman filters, as well as adaptive α, β-filter and linearized α, β-filter.

The effectiveness of GTPS application largely depends on the accuracy of determining the relative and absolute REAO coordinates and the parameters of their movement. A distinctive feature of the GTPS operation is the dependence of the errors in the location of radio emission sources on the spatial system configuration («geometry»), i.e., on the size of the base and REAO position relative to the base. This circumstance makes it possible to minimize the errors in estimating the REAO phase coordinates at the expense of intentional change of the receiving positions location, and thereby to increase the efficiency of using the GTPS.

In the general case, when using the GTPS it is necessary to solve two tasks, namely, the task of guiding one GWS to the REAO and the task of trajectory control of the second GWS to create the most favorable conditions for observing the REAO in which the errors of measuring its location are minimized. In this case one of the positions, for example, the one, closest to the REAO, solves the homing problem using one method or another, and the second one deliberately changes its position in space ensuring the highest possible accuracy in determining the radio emitting object location in both positions. The first position is usually called the leading position and the second one – the position of information support.

Currently orthogonal and gradient methods of trajectory observation control (TOC) in GTPS have been developed. When using the orthogonal TOC methods, the reduction of errors in estimating the REAO location is achieved by maintaining the angle of intersection of the lines of sight (bearings) of the REAO close to 90°. A common disadvantage of orthogonal guidance methods is the fact that prior to the GWS information support exit to an arbitrary point lying on the perpendicular to REAO line – the leading GWS, or to a given point of this perpendicular, essentially no requirements are imposed on the current values of the errors in determining the positions of the REAO. At the same time the process of guiding the leading GWS can end even before the GWS information support reaches the specified perpendicular, when the errors in determining the REAO position become minimal.

Since ensuring simultaneous exit of the leading GWS to the end point of guidance, and the GWS information support to a given line (or a given point) is a rather difficult task, the GWS information support control can be organized in such a way that the error in determining the REAO location at any time is as minimal as possible. To fulfill this condition the GWS information support must move along a special trajectory the parameters of which, for example, can be calculated using an algorithm obtained on the basis of the TOC gradient method.

3. THE MAIN DIRECTIONS AND TRENDS IN THE DEVELOPMENT OF RHHS WHICH REFER TO CONTROLLED MEANS FOR DESTRUCTING THE AIR TARGETS

When modernizing and developing new GWSs it is necessary to take into account a number of factors due to the current stage of aviation development as well as the state and prospects of avionics development in general.

These factors primarily include the following [9]:

- taking into account the state and development trends of aviation and air targets to be hit, including their means of protection (tactical factors);
- economy, determined by the total costs for the RHH development, application and maintenance;
- manufacturability, determined by the level of information technologies used, element base, depth and accessibility of technical condition monitoring, complexity of repair, as well as the ability to improve the efficiency indicators without changing the RHH constructing principles;
- a set of organizational measures for the development and implementation of the new RHH image.

Taking into account the above factors allows us to single out a number of aspects that directly affect the information and control side of the functioning of guidance systems.

These areas primarily include:

- qualitative complication of the laws of the aircraft mutual spatial movement;
- group use of both means of attack and defense;
- high dynamics and speed of air collisions;
- widespread use of control modes and information support on the verge of the loss of stability, typical for super-maneuverable AOs and tracking systems.

It is impossible to meet these requirements within the framework of traditional stationary guidance methods. In this regard the task of developing and applying non-stationary guiding methods becomes very urgent, taking into account the higher derivatives of linear and angular coordinates, the parameters of which change depending on the initial conditions of application and during the guidance process, providing higher indicators of the method perfection as a whole.

By now, four directions of synthesis of non-stationary homing methods can be distinguished based on the use of the mathematical apparatus of the statistical theory of optimal control [35,36] and the methods of dynamics inverse problems [37].

These areas include the synthesis of the following control laws:

– with parameters depending on the initial conditions of use;
– with redistribution of priorities in the process of control;
– taking into account the discrepancy between the AO dynamic properties and the guided GWS;
– with non-linear dependence on control errors.

It should be noted, that in each direction based on different approaches different variants of non-stationary guidance methods can be obtained.

In turn, these directions for improving homing methods predetermine the following main directions for improving the information subsystems of GWS AO:

3.1. Expansion of information support capabilities

Awareness of the state of the current tactical situation and the stability of information support are a prerequisite for solving the problem of AO interception. Modern RHH GWS AO operate in a complex signal and jamming environment. This is due to the fact that collisions can be of a group nature which significantly complicates the procedure for obtaining information about AOs, especially when they are flying in a group. The expansion of information capabilities implies an increase in the amount of information, extracted from radio signals, an improvement in the detection rates, resolution and accuracy of estimating the coordinates of the AO absolute and relative motion [9].

Within the framework of this direction the most important is to provide high-precision and uninterrupted tracking of intensively maneuvering objects including those moving with a change in signs of the derivatives of range and angular coordinates. Possible variants of the synthesis of such algorithms are considered in [38,39].

APHAR plays a significant role in improving the quality of the assessment in the current signal and interference situation in promising RHHs, since they allow the formation of the required number of spatial channels, in which it is possible to conduct radar observation of the AOs and sources of interference.

When creating RHHs more and more attention is paid to the issues of increasing their resolution, which contributes to the solution of VO recognition problem. For reliable AO recognition in the RHH it is recommended to use modulation features that allow to construct a Doppler AO picture based on the analysis of the spectrum of the received signal. A feature, characterizing individual belonging to a certain type of AO is the presence of relatively well-distinguished components in the Doppler spectrum due to the rotation of turbine blades or propeller blades of aircraft [9]. To recognize helicopters it is advisable to use the secondary modulation effect from its lifting propeller [8]. It is also advisable to use modulation signs when recognizing imitation noise, including when recognizing towed false targets. A promising direction for improving the resolution is the use of TOC [28].

3.2. Providing multi-range

First of all, the multi-range requirement refers to active-passive RHHs. Along with the active homing mode, a mode of passive homing on air objects on which radio emission sources operating in different frequency ranges are located, is implemented in these RHHs. In particular, onboard radars installed on aircraft of the USA tactical aviation, emit radio signals in the frequency range of 8-20 GHz [9], and onboard radars of aircraft for long-range radar surveillance and guidance - in the range of 3.175-3.425 GHz [19]. This circumstance complicates significantly the development of an antenna system for RHH.

Note, that abroad one of the main directions for improving RHH is the use of flat or conformal antenna arrays [8]. The main advantages of RHH with flat and conformal antenna arrays in comparison with modern reflector and slot antennas are: more efficient tuning out from natural and organized interference; electronic beam control of the antenna with a complete rejection of the use of moving parts with a significant reduction in weight and dimensions characteristics and power consumption; more efficient use of polarimetric mode and Doppler beam narrowing; increase in carrier frequencies (up to 35 GHz) and resolution, aperture and field of view; reducing the influence of the properties of radar conductivity and thermal conductivity of the radome causing its aberration and distortion. In such RHHs it is also possible to use modes of adaptive tuning of the equal-signal zone with automatic stabilization of antenna directional pattern characteristics.

In addition, the use of multiple ranges of emitted signals is an effective means for reducing the influence of angular noise on pointing accuracy [40].

3.3. Using methods of trajectory control of observation

In practice situations are possible when the measurement of the range and speed of approach to the AO in RHH active channel will be impossible when it is suppressed by the interference, and only the passive channel tracking the angular position of the interference source will be operational. In this case, in the absence of a priori information about coordinates and parameters of radio-emitting target movement it is necessary to organize the trajectory observation control to solve the guidance problem. A similar problem arises when monitoring radio-emission sources, located on air objects, in the absence of a priori information about the target coordinates in the GWS carrier onboard radar, which is necessary for transmission to the RHH in the process of target designation and radio correction. The trajectory control of observation can be carried out both in single-position and two-position systems of guiding to AO.

A specific area of TOC is the creation of negative algorithmic impacts on the enemy information systems [41].

3.4. Joint GWS guidance to a group air object

Currently, GWS AO carriers, as a rule, carry several GWSs which can be simultaneously guided to a group air object (GAO). In this case different objects for using GWS are provided. Situations are possible when either GWSs will independently choose their AOs for guidance or this process will be carried out centrally, but without the participation of the carrier. Therefore, when developing the GWS, it is necessary to provide for the need of AO resolution in a dense group [28] and organization of radio exchange of information between the GWSs as well as a two-way radio communication line with the GWS carrier.

3.5. Improving the RHH intelligent qualities

Intelligent RHHs are a new scientific and technical direction in radar systems engineering. To the greatest extent, the property of RHH intelligence is manifested when solving the problem of RHH adapting to rapidly changing external environment in order to ensure the optimal distribution of limited time, frequency, spatial and energy resources over a number of processed location objects. Besides, the level of intelligence acquires a fundamental importance at RHH action under the EW conditions when it is exposed to unpredictable in advance complex effect of various interferences with their equally unknown space-time dynamics. The RHH intelligence abilities are especially important when conducting a GWS group actions against an AO group in conditions of electronic countermeasures from the enemy.

Hence, it follows that at the present stage of RHH development the most important are the tasks of RHH organizing and algorithmic functioning as a whole (including in the conditions of interference), the tasks of optimal RHH resource management, the tasks of organizing and optimizing its functional modes.

The RHH functioning can be arranged using artificial intelligence methods. Thus, the intelligent RHH must provide an assessment of the signal – interference environment, determination of the interference type and method of protection against it, determination of the number and importance of targets, the choice of the homing method and information sources. This makes it possible to take effective decisions on methods of protection against interference, as well as to solve the problems of target allocation and GWS guidance.

3.6. Strengthening the role of digital information processing

The decisive role in ensuring RHH high information content and giving it intellectual qualities belongs to the system of digital processing of radar signals and data. Digital methods of information processing and control are used in RHH when solving the following tasks: beamforming and antenna array directivity control; adaptive spatial filtering of radio signals received by the antenna array, including in conditions of difficult interference environment; digital time-frequency coherent and incoherent processing of radar signals; detection and tracking of trajectories based on radar measurement data; AO recognition; provision of situational awareness; control of RHH operating modes and blocks, including the arrays. Moreover, there has also been a steady trend towards the introduction of digital methods for the formation of probing and reference signals.

Achievements in digital technologies of recent years significantly expand the information capabilities of promising RHHs, allowing by forming a set of probing signals with the required properties, to provide the flexibility of the system for processing radar signals and data, adjusting it to the specified conditions of radar observation using a programmable digital signal generator, broadband digital multichannel receiver and universal processor. Thus, digital technologies make it possible to solve the problem of RHH development, relying on new approaches and making the most of the advantages of digital representation of signals.

3.7. Improvement of antenna systems

Antenna systems largely determine the appearance of the new generation RHHs. One of the promising directions of RHH development is the use of active and passive phased antenna arrays in them. The space-time signal processing used in this case allows to expand significantly the RHH information capabilities and greatly increase their noise immunity. That is why the development of highly efficient APHAR samples is of paramount importance. The latter make it possible to provide flexibility in controlling the RHH operating modes, good adaptability under the influence of various kinds of interference and changing electromagnetic environments which is due to their ability to carry out the following: almost instantaneous beam overthrow; formation of the required antenna pattern (AP) and its rapid change; simultaneous RHH operation in several modes; creation of multi-beam AP; adaptive and flexible forming of the required number of APHAR beams with low side lobe levels; simultaneous emission of multi-beam AP signals at different carrier frequencies and repetition frequencies; reduction of radio reflection by the antenna array due to its rational, including conformal placement and control of the direction of scattering the signals incident on it by the antenna system; the use of one antenna array in the interests of several modes of RHH operation. However, note that in order to obtain all the advantages of using APHAR, a significant complication of its algorithmic support is required.

The implementation of the considered promising directions of the development in RHH design will contribute to increasing the potential and efficiency of GWS AO application.

4. CONCLUSION

The foregoing allows us to draw the following conclusions:

1. In the process of GWS AO development, several generations of these products were developed, equipped with radar homing heads. Nowadays RHHs are widespread providing inertial guidance with radio correction from the onboard radar of their carrier in the initial and middle sections of GWS flight and active homing in the final section. When using these RHHs, simultaneous guidance of several GWSs is possible. RHHs are very promising, in which the sequential implementation of three guidance modes is provided: inertial guidance with radio correction, passive guidance and active guidance. Using such RHHs radio-emitting targets can be intercepted.
2. In modern RHH the existing homing methods and algorithms for automatic target tracking and GWS trajectory control do not ensure successful GWS guidance with a given efficiency on new types of air objects. A similar disadvantage also occurs when it is necessary to intercept simultaneously a group of air objects by several RHHs. Therefore, the development of promising RHHs requires the introduction of new homing methods and tracking algorithms for AO.
3. The main directions for improving GWS AO are: the development of new, more flexible non-stationary homing methods and expansion of the possibilities for their information support. This predetermines the need to improve situational awareness, ensure multiband operation, achieve a high level of RHH protection from natural and intentional interference, using the trajectory control of observation when aiming at radio emitting objects, joint GWS guidance to GAO, intellectualization and digitalization of RHHs, improvement of antenna systems.

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