РАДІОЕЛЕКТРОНІКА ТА ТЕЛЕКОМУНІКАЦІЇ

RADIO ELECTRONICS AND TELECOMMUNICATIONS

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METHOD OF SELF-DEFENSE OF GROUND (SURFACE) OBJECTS FROM HIGH-PRECISION RADAR MEANS OF AIR SURVEILLANCE

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ABSTRACT

Context it is caused by the need to search for scientific and technical ways to ensure the effectiveness of protecting ground (surface) objects from high-precision guided missile weapons.

Objective it is a necessity to ensure effective self-defense of objects from radar homing means.

Method. Electrodynamic modeling of Echo signals from spatially distributed objects, taking into account the features of their design and related operational limitations.

Results. Based on the analysis of the shortcomings of the well-known method of protecting stationary objects from radar surveillance and damage, based on the simulation of an effective reflection center outside the physical dimensions of the object, a new method of countering high-precision measurement of coordinates of stationary and mobile ground (surface) objects is proposed. The technique is based on the spatial deformation of the location of the effective target reflection center with dynamics that exceed the inertial capabilities of the auto-observation contour of the attacking missile (projectile). A structural and functional scheme of technical implementation of the methodology based on the first proposed relationship of simple design and technological solutions is proposed and justified.

Conclusions. The analytical model of Echo signals of spatially distributed ground (surface) objects was further developed, which takes into account the specifics of their design, and on its basis, for the first time, a universal method of self-defense of objects from radar home-leading devices was developed, which is implemented in a patented method and complex to exclude damage to protected objects.

KEYWORDS: radar home-leading head, electromagnetic wave scattering model, local reflection section, direction finding characteristic, angular reflector, polarization grating.

ABBREVIATIONS

CU is a control unit;
SGRH is a self-guided radar head;
SP is a scatter plot
LDA is a local display area;
CR is a corner reflector;
MC is a motor controller;
RD is a reduction drive;
RS is a radar station;
RCS is a radar cross-section;
SCS is a scattering cross-section
HLH is a home-leading head;
BSD is a Backscattering diagram
LDA is a local display area;
AR is an angle reflector;
RS is a radar set
RO is a radar objects;
ESS is an effective scattering surface;
ESC is an effective scattering center.

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NOMENCLATURE

α is an angle of view of the target by Yaw;

ε is a Pitch angle of view of the target;

$\vec{\gamma}$ is a vector that characterizes the observation conditions and object orientation;

A_i is an amplitude of the signal reflected from i LDA;

R_i is a radius-vector i LDA;

E is an electromagnetic field strength;

ω is a circular frequency;

λ is a wavelength of the probing signal;

$l_{\alpha,\varepsilon}$ is a geometric size of the target or a fragment of its structure in the "picture" plane;

$\Delta\theta_{\alpha,\varepsilon}$ is a width of the linear section of the direction finding characteristic by Yaw α and Pitch β;

Δf_e is an effective spectral band of the rocket control circuit;

$\sigma_{\alpha,\varepsilon}$ is an error of auto-tracking of the target by Yaw α and Pitch β.

INTRODUCTION

Radar means of air (space) observation is the only effective tool for highly informative remote monitoring of the Earth's surface in the interests of solving various general technical and special tasks in the absence of optical transparency of the surface layer of the atmosphere.

An urgent scientific and applied problem is minimizing the probability of high-precision weapons hitting ground (surface) equipment objects. There is a well-known method of self-defense of an object by installing a simulator outside it, for example, in the form of an angle reflector.

The disadvantages of this approach include:

– use only for stationary objects, since the AR ESS must be guaranteed to exceed the ESS of the protected object;

– a narrow corner protected area, which leads to an increase in the number of AR in conditions of a priori uncertainty in the direction of attack.

Taking into account the above, there is a scientific and technical task-the development of methodological and instrumental bases for electrodynamic simulation of Echo signals of stationary and moving objects in the radar home-leading channel, which exclude the defeat of the protected object regardless of the direction of attack, and optimal according to the criterion "efficiency/cost".

Thus, the topic that involves the search for scientific and technical ways to ensure effective protection of ground (surface) objects (targets) from high-precision missile weapons is relevant.

Object of research there is a process of forming echo signals from ground (surface) targets in the radar home-leading channel.

Subject of research is a analytical model of Echo signals for developing a method of self-defense of targets and a method of its practical implementation.

Purpose of the work is a ensuring effective self-defense of objects from radar home-leading means, for which it is necessary:

– perform an analysis of known approaches to describing echoes from spatially distributed targets;

– to develop and substantiate a model of scattering of electromagnetic waves in the radio range from the forming structure of observed objects in the form of a set of LDA and its analytical description;

– based on the LDA model, develop a methodology and method for self-defense of objects from homing means and perform a model experiment to analyze their effectiveness.

1 PROBLEM STATEMENT

It is known that the energy characteristics of the echo signal, which determine the maximum range of the homing section and potential accuracy, depend on the target'S EER, and the total guidance error is a function of the dynamics of missile-target movement [1–3]. At the same time, the missile's radar homing contour tracks the angular position of the target'S ESC [4–7].

The analytical criterion for stable operation of the homing circuit is the ratio

$$\sigma_{\alpha,\varepsilon} << \Delta\Theta_{\alpha,\varepsilon}\,. \tag{1}$$

To ensure the failure of auto wiring, artificial provision of the condition is necessary

$$\sigma_{\alpha,\varepsilon} > \Delta\Theta_{\alpha,\varepsilon} \tag{2}$$

per hour $t > \dfrac{1}{\Delta f_e}$.

For the first time, a complex is proposed as an instrumental basis for implementing this condition, which includes a set of AR that rotate asynchronously and provide a dynamic stochastic change in the BSD of the protected object.

2 REVIEW OF THE LITERATURE

In the radar surveillance channel, two approaches are used to model echoes from spatially distributed targets [8–13].

The phenomenological model is based on direct observations of the scattering process of the probing signal of the forming surface of the target. In practice, two types of phenomenological models are used:

– Radial model, which is the basis of the method of geometric optics and geometric diffraction theory. The radial representation of reflected waves is the main feature of the model. Secondary effects are diffraction and polarization. The model adequately describes the scattering process when the condition is met:

$$l_{\alpha,\varepsilon} > \lambda\,;$$

– a wave model based on the Huygens-Fresnel principle (physical optics method). The Shape of the object and the angle of the observation point relative to the observed object play a crucial role.

The analog model is based not on direct observations of the process of radio wave scattering, but on the results

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of studies of other phenomena that occur in a similar way to the simulated process. At the same time, as in the phenomenological model, the main features of the process are highlighted:

– the "shiny dots" model. It is based on observations of light reflection from polished target layouts. This model is used to analyze the field reflected from rough surfaces;

– facet model. It is based on the approximation of the target surface in the form of a set of flat reflectors that are normally oriented to the incident wave and on the observation of light reflection from the water surface.

The limited possibilities of applying the above models in practice are due to:

– the need to detail a priori information for a specific phono-target situation accompanying the homing of a missile (projectile);

– analytical complexity of obtaining the resulting expressions describing the echo signal from real objects that are observed;

– weak resistance to changes in observation conditions (in particular, the object's angle).

Therefore, the development of these models in the direction of universality of application while ensuring adequacy should be considered an urgent scientific and applied task.

3 MATERIALS AND METHODS

In order to ensure the adequacy of modeling the scattering process of sensing signals to real physical phenomena accompanying observations of ground (surface) objects in the radar channel, a model is proposed that combines the capabilities of the phenomenological and analog models discussed above – the LDA model [14–16].

The essence of the model is based on the following prerequisites:

– the field scattered by a spatially distributed object is formed by a small number of waves, the source of which is located on the "illuminated" part of its forming surface;

– the distances between LDA exceed the wavelength, and the geometric area that they occupy is small compared to the area of the entire "illuminated" part of the object's surface;

– LDA are partially coherent, but can contain pairs that are either completely coherent or completely incoherent;

– the location of the LDA is clearly related to the design features of the forming surface of the observed object.

Analytically, the field scattered by the LDA aggregate can be represented as

$$E(t,\omega,\vec{\gamma}) = \sum_{i=1}^{l} A_i(\omega\vec{\gamma}) e^{j\omega\frac{2R_i(\vec{\gamma})}{c}}. \quad (3)$$

The method of self-defense of a ground (surface) object provides for artificial provision of the condition (2). The latter can be achieved by asynchronously changing A_i in expression (3) due to the rotation of angular reflectors located along the perimeter of the protected object.

This leads to a chaotic change in the effective scattering center of the target with dynamics that exceed the capabilities of the missile (projectile) homing contour.

The practical implementation of the methodology is illustrated in Fig. 1 [17].

Structurally, the complex includes a set of an angular reflector with a polarization grating in the aperture to achieve polarization invariance. Asynchronous rotation of the angle reflector is provided by a controlled electric drive through a gearbox by connecting to the control unit.

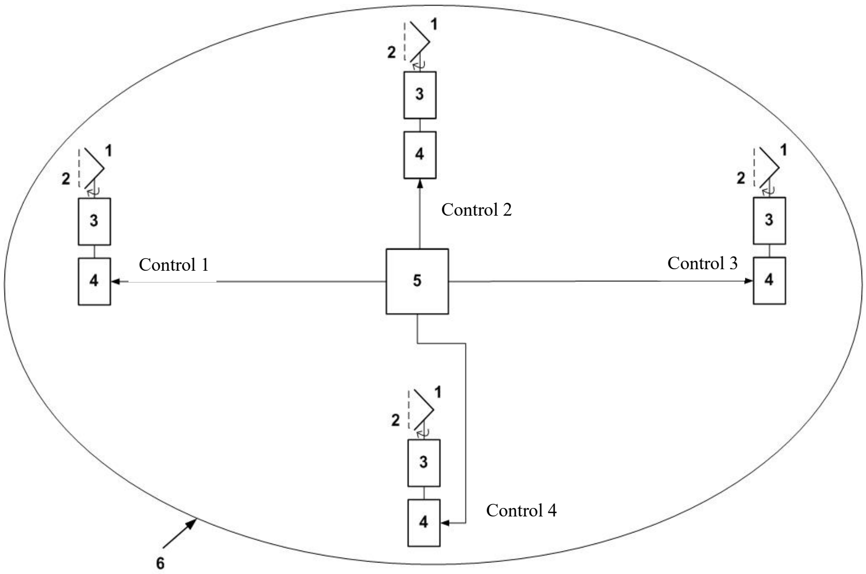

Figure 1 – The structural and functional diagram of a complex for simulating a ground (surface) object in a radar homing channel
1is an angle reflector; 2 is a polarizing grating; 3 is a gearbox; 4 is a controlled electric drive; 5 is a Control Unit; 6 is a geometric contour of the protected object

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4 EXPERIMENTS

A model experiment was performed [18] to prove the adequacy of the proposed LDA model to the real conditions for applying the developed method of self-defense of ground (surface) objects. The essence of the experiment is electrodynamic modeling of Echo signals of complex RO: a railway bridge, a missile system launcher, a helicopter (priority objects of destruction) in a radar home-leading channel. The inclined range was 10 000 m, ε = 75...85 angle degrees and α = 0...180 angle degrees, λ = 8 and 3 mm, and frequencies of 36 and 95 GHz.

To calculate the ratio of the ESS of complex RO when irradiated with an electromagnetic wave with a probing signal wavelength of 8 mm to the ESS of complex RO when irradiated with an electromagnetic wave with λ = 3 mm in the Maple 15 Medium, data arrays were created at Target viewing angles ε = 75...85 angle degrees and α = 0...180 angle degrees in increments of 1 angle degrees.

Polygonal models of the bridge, launcher, and helicopter are shown in Fig. 2–4.

5 RESULTS

The resulting BSD of these objects at wavelengths of 8 and 3 mm are shown in Fig. 5 – 7, respectively.

The obtained patterns allow for a clear physical interpretation.

A graphical representation of the ratio of the ESS of complex RO when irradiated with an electromagnetic wave with λ = 8 mm to the ESS of complex RO when irradiated with an electromagnetic wave with λ = 3 mm in a linear ratio is shown in Fig. 8, respectively.

Plots with a positive value of 10lg ($\sigma_{\lambda=8mm}$ / $\sigma_{\lambda=3mm}$) correspond to the case when the ESS of a complex RO when irradiated with an electromagnetic wave with λ = 8 mm is greater than the ESS of the same object when irradiated with an electromagnetic wave with λ = 3 mm (fig. 8).

Depending on the observation conditions, the value of this ratio can be either greater than 1 or less. Based on the dependence of the detection probability on the signal/noise ratio at the input of the linear detector, the probability of detection in each of these sections is determined with a false alarm probability of 10^{-6} and the fixed probability of detecting a complex RO as a whole is 0.9.

Under such conditions, the value of the signal/noise ratio at the input of the linear detector will be 15 dB, then in the section of the ESS ratio, where the ESS with λ = 8 mm is greater than the ESS with λ = 3 mm, the probability varies in the range of 0.9–1.

In the area where the ESS with λ = 8 mm is 2 times larger than the ESS with λ = 3 mm or less, the signal – to – noise ratio will be 13–15 DB, and the detection probability will be 0.7–0.9.

Figure 2 – Polygonal bridge model

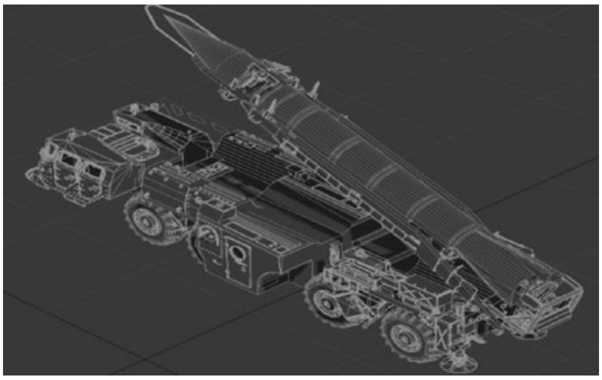

Figure 3 – Polygonal model of a rocket system launcher

Figure 4 – Polygonal helicopter model

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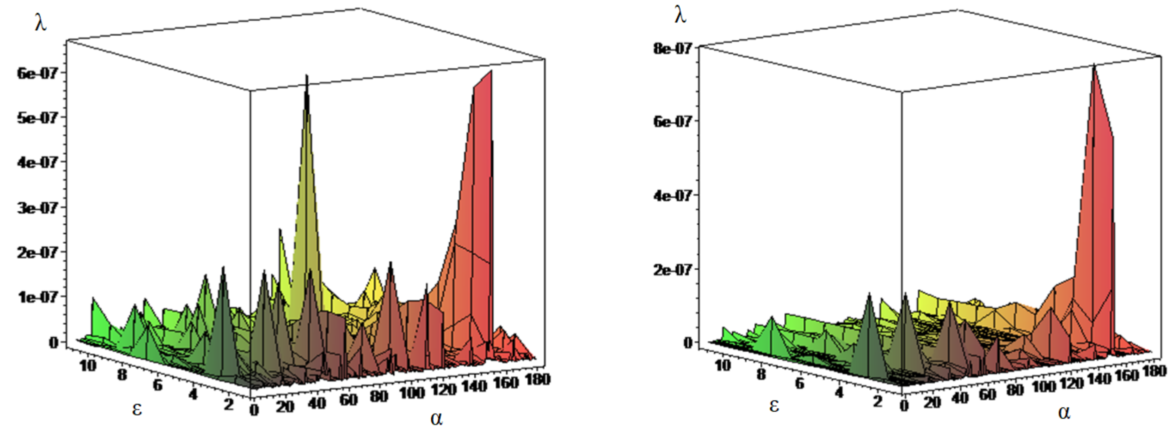
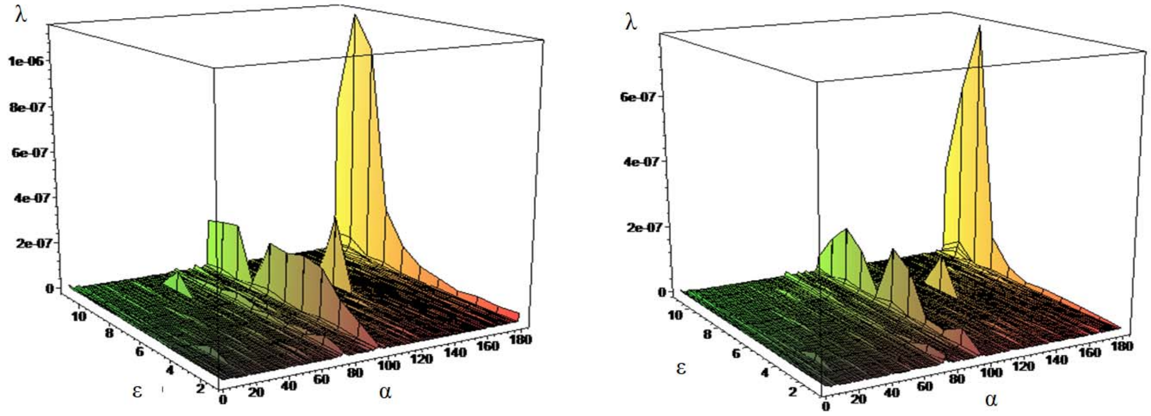


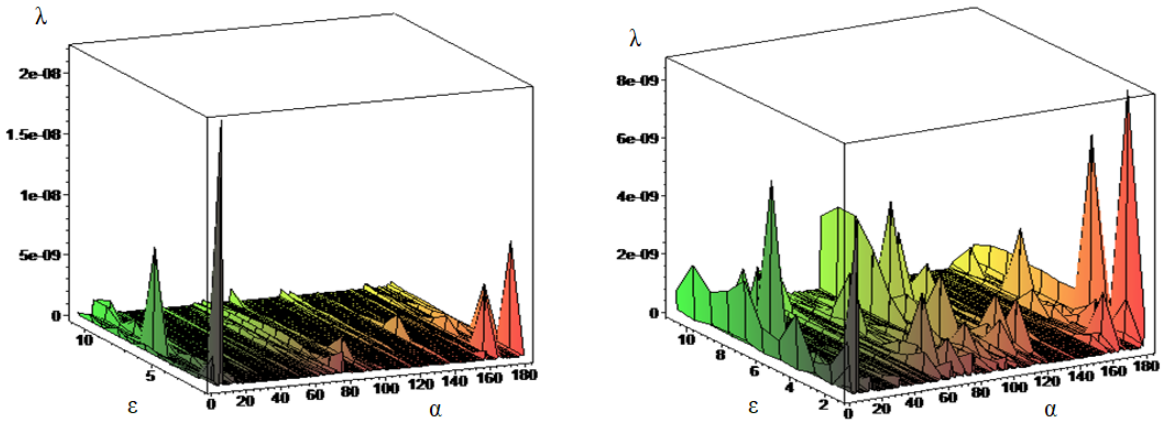
a b

Figure 5 – Bridge backscattering diagram: a – λ = 8 mm; b – λ = 3 mm;



a b

Figure 6 – Backscattering diagram of the launcher: a – λ = 8 mm; b – λ = 3 mm;



a b

Figure 7 – Helicopter backscattering diagram: a – λ = 8 mm; b – λ = 3 mm.

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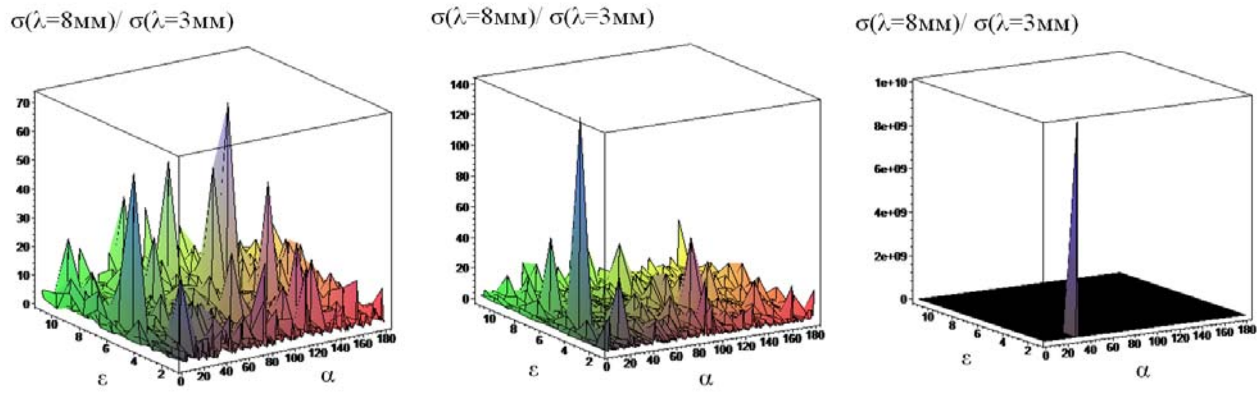

bridge launcher helicopter

Figure 8 – The ratio of the ESS of complex RO when irradiated with an electromagnetic wave with λ=8 mm to the ESS of complex RO when irradiated with an electromagnetic wave with λ=3 mm in a linear ratio

As can be seen from the nomogram (Fig. 8), Blue shows the area where the ESS with λ = 8 mm is larger, yellow shows the area where the ESS with λ = 8 mm is 2 times larger.

The results of the experiment confirm the initial prerequisites, namely:

– the total energy of target Echo signals is determined by a limited number of BSD extremes associated with the spatial distribution of LDA;

– since the HLH "works" on the ESC, an artificial dynamic change in its location is a universal means of self-defense of an object from self-guided means.

6 DISCUSSION

The method of the experiment provided for:

– approximation of the forming surface of targets observed in the radar channel in the form of an unbroken set of tangent triangles;

– formation of target Echo signals as a superposition of elementary Echo signals from triangles;

– obtaining backscattering diagrams of observed objects at an inclined range of 10,000 m at Target viewing angles of 75...85 angle. degrees in pitch and 0...180 angle. degrees at yaw.

The developed method, in comparison with the known ones, makes it possible to significantly expand the range of practical application conditions, removes restrictions on the type of protected object, its design, and the presence or absence of movement.

The reliability of the results obtained is confirmed by the possibility of their clear physical interpretation and modeling data. The possibility of wide application of the technique for protecting ground (surface) objects from radar home-leading means is based on the simplicity of technical implementation and low cost in comparison with known approaches

For the first time, an analytical description of the echo signal scattered by a complex object (3) was developed, together with the mandatory fulfillment of Condition (2), which gives an adequate description of the processes that accompany the observation of a spatially distributed target and is the basis of the developed method of its self-defense.

The practical implementation of the technique, in contrast to the known approaches, can technically be carried out in accordance with the proposed method for a wide range of external conditions and different dynamics of mutual movement of the protected and attacking objects.

It is important to note that the proposed method and method of self-defense are universal, since:

– invariant to the design and material of the forming surface of the protected object;

– effective for any trajectory and number of attacking objects;

– allow electrodynamic modeling to quantify the effectiveness of self-defense.

CONCLUSIONS

The scientific problem of methodological support of effective self-defense of ground (surface) objects from radar home-leading combat elements by stochastic change in the effective scattering surface of the protected object with dynamics exceeding the speed of the home-leading contour of attacking elements has been solved for that purpose:

– the analysis of the shortcomings of known approaches based on simulating the effective reflection center of the protected object beyond its physical dimensions is performed;

– for the first time, a universal model of a spatially distributed target observed in a radar home-leading channel in the form of a limited set of LDA is proposed and justified;

– based on the new model of a spatially distributed target, a system of self-defense of ground (surface) objects from radar homing means is proposed for the first time. It is based on the deformation of the location of the effective reflection center with dynamics that exceed the

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inertial capabilities of the home-leading contour of attacking means.

Practical significance the obtained results are determined by the proposed method and complex of self-defense of ground (surface) objects, the priority of which is confirmed by the patent for the invention, as well as the data of the model experiment.

Directions for further research there is an optimization of the number of AR based on the "efficiency/cost" criterion with reference to the volume (area) of the protected object.

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МЕТОДИКА САМОЗАХИСТУ НАЗЕМНИХ (НАДВОДНИХ) ОБ'ЄКТІВ ВІД ВИСОКОТОЧНИХ РАДІОЛОКАЦІЙНИХ ЗАСОБІВ ПОВІТРЯНОГО СПОСТЕРЕЖЕННЯ

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АНОТАЦІЯ

Актуальність зумовлена необхідністю пошуку науково-технічних шляхів забезпечення ефективності захисту наземних (надводних) об'єктів від високоточного ракетного керованого озброєння.

Метою роботи є забезпечення ефективного самозахисту об'єктів від радіолокаційних самонавідних засобів.

Метод. Електродинамічне моделювання ехо-сигналів від просторово розподілених об'єктів з урахуванням особливостей їх конструкції та супутніх експлуатаційних обмежень.

Результати. На основі аналізу недоліків відомої методики захисту стаціонарних об'єктів від радіолокаційних засобів спостереження і ураження, основаній на імітації ефективного центру відображення за межами фізичних розмірів об'єкту, запропонована нова методика протидії високоточному вимірюванню координат стаціонарних і рухомих наземних (надводних) об'єктів. Методика базується на просторовій деформації місцезнаходження ефективного центру відбиття цілі з динамікою, яка перевищує інерційні можливості контуру авто спостереження атакуючої ракети (снаряду). Запропонована і обгрунтована структурно-функціональна схема технічної реалізації методики на основі вперше запропонованого взаємозв'язку нескладних конструкторсько-технологічних рішень.

Висновки. Отримала подальший розвиток аналітична модель ехо-сигналів просторово розподілених наземних (надводних) об'єктів, яка враховує специфіку їх конструкції, та на її основі вперше розроблена універсальна методика самозахисту об'єктів від радіолокаційних засобів самонаведення, яка реалізована у запатентованому способі та комплексі для виключення ураження захищаємих об'єктів.

КЛЮЧОВІ СЛОВА: радіолокаційна головка самонаведення, модель розсіювання електромагнітних хвиль, ділянка локального відображення, пеленгаційна характеристика, кутовий відбивач, поляризаційна решітка.

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