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RADAR TECHNIQUE FOR AIRCRAFT WITH AN ARTIFICIALLY REDUCED RCS UNDER CONDITIONS OF APPLICATION A RESONANT ELECTROMAGNETIC FIELD

The paper presents the results of a study of the radar technique for aircraft with an artificially reduced radar cross section (RCS) under the condition of using a resonant electromagnetic field. It is shown that the detection and tracking of air objects under conditions of artificially reduced RCS is carried out using radar information with resonant excitation of their radar absorbing coating. It is proposed to carry out tracking and detection of aircraft by a complex combination of an active radar channel with the formation of a resonant radio signal and a passive radar capable of receiving signals formed by an excited surface. It has been determined that by increasing the power level of the irradiating signal to 20-30%, it is possible to increase the area of the local conduction region of the dielectric by 10 times, which means that it will simplify the technical implementation of the method of locating aircraft. The proposed control methods make it possible to provide the necessary probability of detection accompanied by a radar target in a difficult jamming environment and thus increase the potential capabilities of the radar. In the course of the study, it was determined that the excitation and heating of the coating during enthalpy directly depends on the energy flux density of the electromagnetic microwave field per unit mass and area of the substance. It has been established that purposeful control of this effect makes it possible to substantiate the possibility of using enthalpy as a factor in excitation of air target coatings with an artificially reduced reflection area (RCS). The conditions for increasing the efficiency of radar targets with an artificially reduced RCS using a concentrated resonant electromagnetic field have been clarified. It is determined that the influence of such a field is accompanied by the concentration of the energy of the electromagnetic field in the crystal structure of the radio-absorbing coating of the aircraft due to the resonant irradiating signal, which causes temporary local conductivity and thermal radiation. Calculations of quantitative indicators characterizing the possibility of changing the electrically conductive properties of a carbon-type dielectric at a distance for the practical application of advanced radar systems are presented.

Keywords: radar, unmanned aerial vehicle, effective enthalpy, radio-absorbing, target tracking.

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МЕТОДИКА РАДІОЛОКАЦІЇ ЛІТАЛЬНИХ АПАРАТІВ ЗІ ШТУЧНО ЗНИЖЕНОЮ ЕВП ЗА УМОВ ЗАСТОСУВАННЯ РЕЗОНАНСНОГО ЕЛЕКТРОМАГНІТНОГО ПОЛЯ

В роботі представлено результати дослідження методики радіолокації літальних апаратів зі штучно зниженою ефективною площею відбиття (ЕПВ) за умов застосування резонансного електромагнітного поля. Показано, що виявлення та супроводження повітряних об’єктів за умов штучно зменшеної ефективної відбиваючої поверхні (ЕВП) здійснюється використанням радіолокаційної інформації за умов резонансного збудження їх радіопоглинаючого покриття. Запропоновано здійснювати супроводження та виявлення літальних апаратів шляхом комплексного поєднання активного радіолокаційного каналу із формуванням резонансного радіосигналу та пасивної РЛС яка здатна приймати сигнали утворені збудженою поверхнею. Визначено, що шляхом підвищення рівня потужності опромінюваного сигналу до 20-30 % існує можливість збільшення в 10 разів площі локальної області провідності діелектрика, а отже це дозволить здійснити спрощення технічної реалізації способу локації літальних апаратів. Запропоновані методики керування дозволяють забезпечити необхідну ймовірність виявлення та супроводження радіолокаційної цілі за умов складної завадової обстановки і таким чином підвищують потенційні можливості РЛС.

Ключові слова: радіолокація, безпілотний літальний апарат, ефективна ентальпія, радіопоглинаючий шар, супроводження цілі.

Problem Formulation

The problem for which the article is directed is the problem of obtaining information about an air target with an artificially reduced Radar Cross Section (RCS) [1] based on the resonant frequency-phase interaction of the microwave electromagnetic field (MEF) with the crystal structure of the composite material of the structure by antenna systems [2, 3] as part of the Unmanned Aerial Vehicle (UAV) direction-finding radio monitoring systems [4, 5].

The relevance and significance of the subject of the article for practice lies in the fact that the technique proposed in the article will increase the potential gain in signal-to-noise ratio (SNR) in the direction finding of both single aircraft objects and group-use aircraft (UAV group rows). Such a task is very relevant in the context of the introduction by a number of countries of a new strategy to combat UAVs for combat operations, explosive and terrorist activities, organizing drug trafficking, etc. In addition, a significant increase in requirements for radar, the need to raise the qualitative and quantitative indicators of the effectiveness of the operation of radar systems to the desired level. The non-orientation of the radar station to the detection and tracking of air targets with an artificially reduced RCS poses the task of developing a scientifically methodical approach to determining the directions for improving the efficiency of the radar of the latest UAVs. We need to formulate reasonable recommendations for improving the efficiency of UAV radar [2].

Thus, the currently existing approaches do not allow to fully reliably assess and predict the impact of the characteristics and capabilities of modern aircraft (UAVs) on the effectiveness of their radar. Therefore, it is necessary to develop methods for detecting and tracking air targets with an artificially reduced RCS, which are proposed in this article.

Main Part. Analysis of Current Sources

Modern technology is created using non-metallic materials in its design. This is understandable for a number of reasons, the main of which is the better characteristics of the substances used. Existing approaches to obtaining radar information about such objects are unsuitable, since they are based on the use of effects that occur in metals when they are irradiated with an MEF. Therefore, the task of creating conditions for a remote temporal change in the conductivity properties for the use of induced effects in existing radar methods and especially in the context of UAV location is relevant.

The scientific problem considered in the article is devoted to the calculation of quantitative indicators characterizing the possibility of changing the electrically conductive properties of a carbon-type dielectric at a distance with the practical use of existing radar systems.

An important circumstance contributing to the creation of local conductivity is the presence of electrons in atoms in the conduction band, which is typical for conductors. In semiconductors and dielectrics, the conduction and valence bands are separated by band-gap. For example, carbon, which is widely used in radio engineering, has a band gap of 5.4 eV [6].

If we assume that under certain conditions the electrons from the valence band of the carbon atom will be moved to the conduction band, then the specified substance will exhibit the properties of a conductor. This will make it possible to change the strategy for the use of carbon, its compounds and other dielectric and semiconductor materials in radar technology [7].

As is known, the transition of electrons to the conduction band occurs in the excited state of the atom [6]. It is possible to excite an atom when it is exposed to an external electromagnetic field of high power. The required power of the irradiation field P for the transfer of one electron from the valence band to the conduction band is determined by the dependence [6].

$$P = \frac{w}{\tau}, \tag{1}$$

where w is the band gap (for dielectrics >2 eV); τ is the time spent by an electron in the conduction band of an excited atom ($\tau = 10^{-5} ... 10^{-6}$ s).

For soot, the base of which is carbon, the required power is $8.64 \cdot 10^{-13}$ W. Considering Avogadro's law, the creation of a local conduction band in dielectrics and semiconductors requires an irradiating field power of 10^2 to 10^4 W, which has no practical meaning. But, if we take into account that the transfer of energy to excite the atom will occur when the frequency and phase resonance (oscillations) of the external source of electromagnetic radiation and natural oscillations of the atom are reached, then the energy costs are significantly reduced.

As practice shows [8], a typical surveillance radar (with radiation parameters: P_u=0.5 MW (pulse power), $\omega_н$=12 GHz (carrier frequency), τ_u= 0.5 μs (pulse duration) creates an oscillation amplitude at the frequency of resonant interaction with a soot-type dielectric $U_к$= 0.975 V). The oscillation amplitude of the irradiation signal at the frequency of resonant interaction with the carbon atom is determined by the dependence:

$$U_к = 2U_н \omega_н \tau_u \left| \frac{\sin\left(\frac{\varpi_к}{2}\tau_u\right)}{\frac{\varpi_к}{2}\tau_u} \right| \tag{2}$$

where $U_н$ is the amplitude of the irradiation signal at the carrier frequency $\omega_н$; $\varpi_к$ is the frequency of the *k*-th harmonic of the irradiation signal amplitude range (determined by the natural frequency of the carbon atom with a wavelength of 4700 Å).

Accordingly, the power of the irradiation signal at the working range of the station D=100 km will be P=2.5 10^{-16} W with the initial value P=0.94 W.

$$P = \frac{2P_1 G\sigma}{\left(4\pi D^2\right)^2} \tag{3}$$

where G is the radar antenna connection factor; σ is the surface area of the dielectric (semiconductor).

If we assume that at a certain distance there is a coincidence in phase and frequency, or their difference is an integer constant value of the irradiation signal and vibrations of dielectric (semiconductor) atoms, then such an interaction should be considered as coherent. In this case, the excitation of the atom occurs due to the transfer energy from the irradiation of the field an external source. In this case, electrons from the valence band pass into the conduction band, which is accompanied by the emission of a radio wave.

The duration of radiation is determined by the time of arrival of electrons in the band gap after the removal of the atom from equilibrium and is equal to 0.5 – 1 μs [9, 10]. The resulting energy of the electromagnetic radiation field is determined by the dependence:

$$E_p = \sqrt{E_e^2 + E_{U_к} + 2E_e E_{U_к} \cos\Delta\varphi} \tag{4}$$

where E_e is the electron energy; $E_{Uк}$ is the energy of the irradiation signal at the frequency of the resonant interaction; Δφ is the phase difference of the interacting oscillations.

Simple calculations show that at a distance of 100 km, when a carbon-based dielectric sample is irradiated with an electromagnetic field with characteristics noted for the initial power of the backward radio wave, it will be $1.602 \cdot 10^{-7}$ W.

In addition to the indicated effect, under the action of resonant irradiation, a local conduction region will be formed with a lifetime of up to 1 μs. The presence of this region is explained by the movement of electrons into the conduction band: that is, an electrical breakdown of the dielectric (semiconductor) occurs. That is, during the breakdown, it is possible to induce a secondary microwave electromagnetic field on the dielectric surface area and the accompanying reflection of a radio wave with an arbitrary carrier frequency.

In view of the foregoing, of practical interest is the possibility of determining the area of the local conduction region of a dielectric (semiconductor) when irradiated by a resonant electromagnetic microwave field. To do this, it is necessary to determine the intensity of the resonant radio emission material according to the formula:

$$I = \frac{\rho V U^2}{2} \tag{5}$$

where ρ is the density of the material; V is the speed of the radio wave; U is the amplitude of atomic vibrations.

In the case under consideration, the intensity of radio emission a carbon-type dielectric in an excited state is $16.2 \cdot 10^{-15}$ $W \cdot m^3$.

If we use the well-known formula [10],

$$S = \frac{E}{I} \tag{6}$$

where S is the area of the material sample; I is the intensity of radio emission; E is the energy of radio emission,

It can be argued that at a practical radar operating range of 100 km, it is possible to create a local conduction region with an area of 0.101 m^2 on the surface of a dielectric carbon coating.

This approach to remote control of the state of dielectric and semiconductor materials is of practical importance, since it expands the possibilities of locating aircraft (for our UAV study), marine and land objects, in the design of which nonmetals are increasingly used.

Until recently, it was believed that such phenomena as the excitation radio absorbers, the breakdown of insulators, the formation standing waves in impedance coatings are of a concomitant harmful nature and therefore were not purposefully reproduced in laboratory conditions and were not studied from the point of view technical implementation as an element weapon destruction [11-13].

Preliminary results of experimental studies are devoted to the study the phenomenon of excitation the internal crystal structure of radio-absorbing materials when they are irradiated with a microwave signal at a resonant frequency, opening up a wide space for further and deeper study of this phenomenon.

A number of experiments carried out on a laboratory basis and their metrological examination allow us to formulate a hypothesis. Its main is that in the case of irradiation a radio-absorbing material with a pulsed microwave electromagnetic signal with a carrier frequency that is a multiple the frequency of natural oscillations of an atom the crystal structure the substance under study (provided that the corresponding phases of the natural oscillations of an atom or the basic element for molecular structures coincide) and the initial phase of the irradiation signal, it is possible receive a response signal whose power is 4-16 times higher than the power consumed for excitation. This hypothesis is based on the provisions of the theory of Louis De Broglie, the Fabry-Perot theorem and the conditions for the emergence of multitone signals [14].

Thus, in order to develop a method for detecting a radar target with an artificially reduced RCS, it is necessary to analyze the phenomena that occur during exposure to microwave signals of radar absorbing materials and determine approaches to their practical application in practice.

According to experts, random phenomena accompanying the process of irradiation of radio-absorbing materials can be quite controllable, and most importantly, have sufficient validity for technical implementation.

From the basic ideas of modern radio physics, it is known that any materials are capable of accumulating microwave energy - the so-called resonant excitation, accompanied by the release of heat.

The effect of resonant excitation for each material is different (Table 1), but is accompanied by general patterns:

- radiation of energy by a substance during heating;
- ionization of the boundary layer of the coating;
- mechanical release of elementary particles from the crystal structure (coating assignment) [7].

Table 1

Indicators accompanying the effect of resonant excitation for some radio-absorbing and insulating materials

№	Material	H_{ef}, W/kg	T, ºC	Chemical formula	Carbon content, %	Scattering coefficient of radio waves
1.	Graphite	573.16	3447	C_2	100	0.01
2.	Silicon graphite	181.93	3227	SiC	50	0.02
3.	Soot	178.71	2227	CO_2	33	0.031
4.	AF	161	2127	nCFCl	25-27	0.06
5.	LHX	121.3	2100	$CF_2 \rightarrow$[CFCl- CF]	18	0.1
6.	TAS	67.4	2027	$2MgO{\cdot}Al_2O_3{\cdot}5SiC$	15	0.1
7.	Sital KPZh-9 (glass ceramic)	40.4	2000	$2H_2O{\cdot}Si_2{\cdot}Al_2O_5$	0	0.15

Table 1 draws attention to the carbon content to a greater or lesser extent in almost all radio absorbers and insulators. The presence of carbon in most screens can be explained from two points of view. First, according to the Bouguer-Lambert law, the high coefficient of absorption of electromagnetic field energy and a fairly high melting point makes this substance very practical in the synthesis of coatings in technologies of artificial reflection area reduction (RCS) [1]. Secondly, it can be assumed that the absence of carbon in the material of the last position of Table. 1 is explained by the use of sitals (glass ceramic) as radio-transparent radome. That is, the presence of carbon in the internal structure of the substance will shield the operation of radar systems covered by radome.

Improving the effectiveness of radar targets

The widespread use of various composite materials in microwave radar technology has proven itself well during their operation, but it was noted that their resource is small, and with intensive use in circulators and antenna equivalents, it is tens of hours or less [7]. In a number of published works [5] this is associated with the action of the enthalpy phenomenon (H_{ef})

It is proposed to increase the efficiency of radar targets with an artificially reduced RCS using a concentrated resonant electromagnetic field. This effect is accompanied by the concentration of electromagnetic field energy in the crystal structure of the radar-absorbing coating of the aircraft (UAV) due to the resonant irradiating signal, which causes temporary local conduction and thermal radiation. The effect is based on the purposeful creation of the enthalpy (7) effect, which manifests itself when irradiated with a resonant signal.

Thus, there is an interest in the analytical dependencies that relate the effective enthalpy to other parameters and characteristics:

$$H_{ef} = \frac{(h_1 - h_0) + \Gamma(h_2 + \psi(E))}{1 + \frac{h_3}{E} \cdot \frac{q_1}{q_2}} \quad (7)$$

where h_0 is the initial enthalpy of the substance; h_1 is the enthalpy of the ionized phase of the substance during the temperature heating of the substance T_p (Table 1); h_2 is the thermal effect of gasification of the components of the coating substance during microwave heating to T_p; Γ is the degree of ionization of the coating material; h_3 is the thermal effect of coating excitation; $\psi(E)$ – coating heating coefficient due to irradiation with microwave energy signals; q_1/q_2 is the ratio of specific heat fluxes before irradiation and during irradiation with a microwave signal.

If we take into account the components of the analytical dependence (7), then it can be argued that the excitation and heating of the coating during the enthalpy directly depends on the energy flux density of the electromagnetic microwave field per unit mass and area of the substance. As noted, enthalpy is a by-product of radio exposure and has been widely observed but not reproduced in the laboratory.

In the case of purposeful control of this effect, there is a reasonable possibility of using enthalpy as a factor in excitation of UAV airborne target coatings with an artificially reduced reflective area (RCS). Such excitation will be effective if the following conditions are met:

- creating sufficient power per unit mass and area on the impedance coating of the aircraft;
- the temperature accompanying the excitation of the coating must exceed the radiation temperature of the fuselage and bearing surfaces of the aircraft.

Calculations using well-known techniques of radar and electrodynamics [5] (Table 2) indicate that ground-based radar devices can create the indicated conditions for the occurrence of resonant excitation at ranges up to 100 km.

Considering the simulation results, it can be assumed that in practice the use of this effect can be quite effective either at high power, which means fundamental changes in the design of the radar [15], or when implementing frequency-phase resonant radar methods.

Thus, the article presents science-based assumptions about the possibility of remote control of the conductive properties of a dielectric (semiconductor) under the action of a resonant electromagnetic microwave irradiation field.

Table 2

Summary table of the results of modelling the conditions for the occurrence of resonant excitation of radio absorbing coatings

№	Device	Pulse power of radiation, MW	Distance, km	Effective enthalpy, W/kg	Coating temperature, °C
1.	surveillance radar	0.5	100	17	100
2.	tracking radar	0.5	91	53	153
3.	tracking radar	0.7	100	98	207
4.	surveillance radar	0.5(under resonance conditions)	110.1	184	850

Some results of a comparative assessment the effectiveness of the original radar and the control system synthesized on its basis with adaptive algorithms are shown in Fig. 1, Fig. 2.

In particular, in Fig. 1 shows the probability diagrams for detecting and taking on target tracking for the corresponding RCS values.

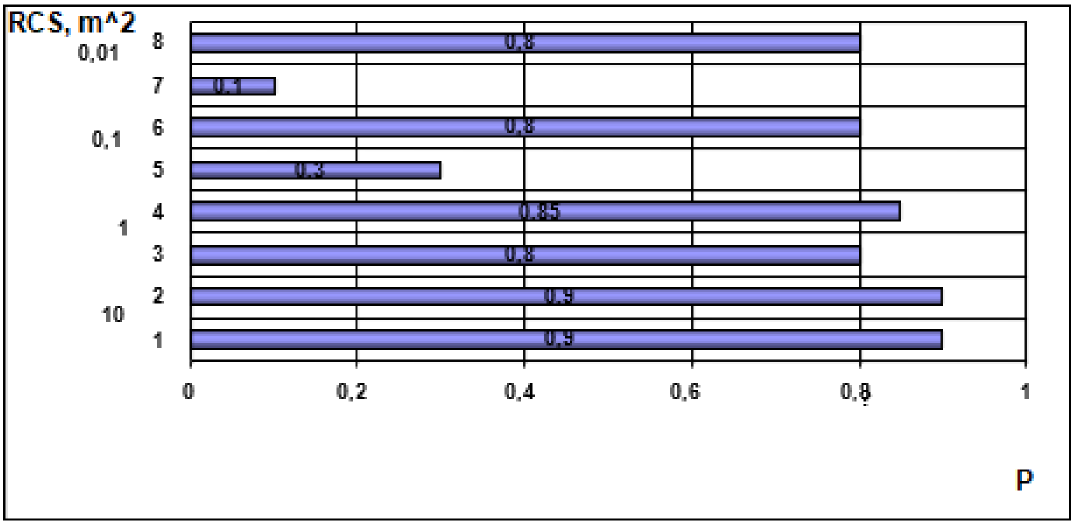

Fig. 1. Estimated probability of detecting and tracking a radar target with an artificially reduced RCS

On Fig. 2 shows a vertical section of the integrated radiation pattern of the improved radar at zero parameter.

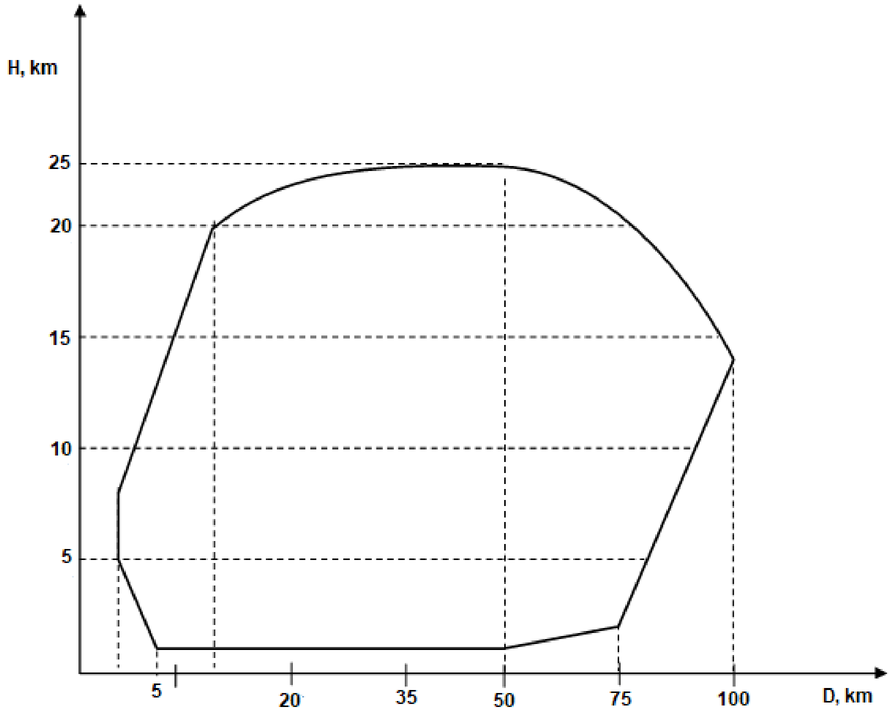

Fig. 2. Vertical section of the integral radiation pattern of the improved radar at zero parameter

Conclusion

Calculations make it possible to obtain practically sufficient results for the formation of the resonant excitation area and local conductivity of a carbon-type dielectric sample. The above calculations show that this area is ≈0.1 m^2, i.e., sufficient for inducing a secondary microwave field and processing both the excitation signal and the reflection in existing receiving systems with a sensitivity of $\geq 10^{-13}$ W. Recent advances in the technology of creating the element base of radio equipment make it possible to produce powerful and at the same time small-sized transmitters. Under these circumstances, an increase in the power of the irradiation signal by 20–30% will increase the area of the local conduction region of the dielectric by a factor of 10, which will simplify the technical implementation of the method for locating objects whose construction contains more than 10% non-metallic substances.

Guidance of a radar target with an artificially reduced reflection area is possible using an adaptive method based on adapting the antenna control system to the conditions of information uncertainty caused by fluctuation of the excitation signal of the radar target's radar absorbing coating. The evaluation of the parametric sensitivity of the synthesized antenna control system on a mathematical model implemented using a PC shows a sufficient degree of "rough estimate" to the measurement errors of the parameters of the radar target. The developed control algorithms make it possible to provide the necessary probability of detecting and tracking a radar target in the event of input information distortion due to fluctuations in the excitation signal of the radar-absorbing target coating, expanding the potential capabilities of the radar.

Based on the results of modeling and experimental studies, it can be reasonably argued that it is expedient to use the phenomenon of resonant excitation of radar absorbing substances as a factor in increasing the efficiency of radar for objects with an artificially reduced RCS.

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