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METHOD OF PROTECTING SPECIALLY IMPORTANT OBJECTS BASED ON THE APPLICATION OF THE BISTATIC RADIOLOCATION TECHNIQUE

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Abstract

The solution of the tasks assigned to the National Guard of the state implies the presence of certain forces and means with the appropriate technical equipment. A well-known place among such tasks is security of important state facilities. Various physical effects and methods, including radar, are used to create security systems.

The development of radar technology and technology made it possible to increase both the quantity and quality of the received information, as well as the use of radar stations for observing living objects.

The industry today produces bioradioradars for detecting people and controlling their movements. All samples are made in a single-position version and have a relatively high cost, the fact of their work is easily detected, which facilitates their suppression, including force.

In order to increase the secrecy of work, it is proposed to use the methods of separated, more precisely, bistatic location to control the area in front of particularly important objects.

The defining detection index is the effective reflective surface (ERS), which is about 1 m2 for a person. Equipment, weapons and protective equipment contributes to the increase in the ERS.

Given the small reflective surface of biological objects, it is proposed to limit the area of responsibility to the sector form in which, at a certain bistatic angle, the effect of a significant increase in the signal/(interference+noise) ratio is manifested. For a specific definition of the gain, it is necessary to choose the operating frequency of the bistatic system and its geometry.

For greater secrecy, it is advisable to use the transmitters of radio and television broadcasting, mobile communications, etc. The estimates found, for example, when using digital television transmitters (T2), indicate that the creation of a secretive bistatic system is quite possible – at least in a geometric interpretation.

Keywords: biolocation, bistatic RLS, bistatic angle, terrorism, effective reflective surface.

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1. Introduction

The issues of ensuring the security of various objects, first of all – especially important state ones, are highly relevant. One of the most important elements of almost any security system (informational, anti-terrorist, anti-criminal, etc.) is a physical protection complex (PPC). For the detection of unauthorized entry of the intruder, they usually use an alarm system as one of the important components of the PPC [1].

In developing and analyzing the effectiveness of such systems, the primary goal is achieving the required detection efficiency of the intruder. Efficiency increases with an increase in the residence time of the intruder in the zone. This implies the conclusion that it is necessary to increase the range of target detection in order to increase the response time. In solving this problem, it is necessary to take into account not only the specifics of choosing the type and location of detection tools (DT), but also possible methods of influencing the DT of a qualified intruder who has a priori knowledge of the principles of operation and parameters of the means, which reduces the possibility of its detection. In other words, it is necessary to hide the operation of the detection tool.

Various physical effects and methods are used to create security systems [2] – video and radar surveillance, perimeter security systems, security and fire alarm systems, and access control systems. Each system has its advantages and disadvantages. Let's note that further considered systems using only radar methods.

The development of radar technology and technology made it possible to increase both the quantity and quality of the information received, as well as the use of radar stations for observing living objects.

The industry today releases radars to detect people and control their movements. All samples are made in a single-position version and have a relatively high cost, the fact of their work is easily detected, which facilitates their suppression, including force.

In order to increase the secrecy of work, it is proposed to use the methods of separated (more precisely, bistatic) locations to control the territory remote from especially important objects.

For greater secrecy, it is advisable to use the radio and television broadcasting transmitters, mobile communications, etc. operating in the territory in question. Even if the offender has information about the presence of such a system, the fact of its functioning cannot be determined. Therefore, for example, let's find estimates, for example, when using digital television transmitters (T2), confirming that the creation of a secretive bistatic system is quite possible – at least in a geometric interpretation.

The defining detection index is the effective reflective surface (ERS), which is about 1 m^2 for a person. Equipment, weapons and protective equipment contributes to the increase in the ERS.

Given the small reflective surface of biological objects, it is proposed to determine the shape (circular, sector) areas of responsibility, in which, at a certain value of the bistatic angle, the effect of a significant increase in the "signal/(disturbance+noise)" ratio appears. For a specific definition of the gain, it is necessary to choose the operating frequency of the bistatic system and its geometry.

2. Literature review and problem statement

The continued development and intensive introduction of short-range radar methods indicates an expansion of their areas of application. They are used to develop systems for protecting important objects from intruders and blocking terrorist acts. Under these conditions, the object will be the person, i. e. biological object [2]. The tasks of the National Guard of many countries include the following:

– protection of objects protected by the National Guard (NG);

– prevention of the activities of illegal militarized or armed groups (formations), terrorist groups and criminals;

– participation in antiterrorist operations;

– participation in actions related to the cessation of armed conflicts and other provocations at the border, as well as in measures to prevent mass violations of the state border from the territory of neighboring states.

Similar tasks arise in states when it is necessary to ensure the security of a protected area. An example would be the protection from the infiltration of saboteurs on military bases (airfields in Syria), the advancement of terrorist groups into enemy territory in the Iran-Israel conflict, etc.

Let's consider briefly the characteristics of fixed assets represented by industry.

Currently, Ukraine uses radio location stations (RLS) for reconnaissance of ground targets 112L1 "Barsuk" (**Fig. 1**) and a station to monitor ground and low-speed low-flying targets 111L1 "Lis" (**Fig. 2**).

The radars 111L1 and 112L1 detect moving targets and equipment to ensure the protection or reconnaissance of the territory. "Barsuk" is wearable radar that provides detection of people, ground and surface transport objects [3]. The locator is built according to the classical active principle, in which significant power consumption from the power source (and cost) is determined by the presence of a transmitter, without which radar operation is impossible. "Barsuk" is used to detect moving people and equipment, to reconnoiter and ensure the protection of the territory [4], but it cannot detect fixed targets.

Fig. 1. "Barsuk" locator

a *b*

Fig. 2. "Lis" locator :
a – general view of the locator on the platform; *b* – under the hood on the car

Both radar continuous radiation, which allows the use of a transmitter with a very low radiation power – 200 mW and (30...40) mW, respectively. They operate in the millimeter wavelength range, the frequency is about 36 GHz.

Radars automatically detect objects and measure the distance to them at any time of the year, in case of bad weather – rain, dust, fog and no optical visibility. Target detection range with a radial speed of 2–50 km/h for the "Barsuk": a single person 600...800 m, vehicles – up to 1600 m. The same indicators for the "Lis" are a single person – 5.4 km, car, motor boat – 11.5 km, helicopter – 12 km. Marked characteristics will take as the source for later use.

"Jeb" equipment is mounted on a mobile chassis [5], which is not at all necessary for the protection of important stationary objects. In addition, to solve the tasks of observation in the area of the Jeb object, it is over-equipped with EW equipment, which increases the cost of manufacture and operation. Marked funds mastered in Ukraine.

The development of short-range radar is carried out in Russia – let's note the radar complex to monitor the situation in the zone of objects "Radeskan" [6]. In the complex "Radeskan" two working frequency ranges are used – video and radio, but the latter is characterized by the presence of special radiation, which is easily detected by the enemy to carry out counteraction.

Similar developments are carried out in different countries – AN/PPS-15, "Fallen", "Astrid" (USA), "Arabelle" (France), "Permagard" (Great Britain), "Isidore" (Sweden) [7, 8]. These radars provide a solution to a wide range of tasks, including locations and important objects along the perimeter, the ability to detect a moving person. For existing funds remain unresolved until the end of the task of increasing the range and accuracy of target detection, reduction of false positives (work behind the foliage of trees).

The common shortcomings of all ground reconnaissance radars include the detection of their work by the enemy at distances far exceeding the range of these radars. In addition, there is a large exposure to the effects of electronic suppression of the enemy.

When radar probing, traditional objects of location until recently were mostly non-living objects (targets), most often airborne [9, 10].

Thus, traditionally used monostatic radars for detecting moving objects in such conditions are ineffective due to the large number of interfering reflections (forest, buildings, rugged terrain) and low speed of movement of detected objects (people). The use of several such radars is impractical because of their relatively high complexity and cost. In addition, it is impossible to ensure the *secrecy of such detection systems*, which is an important condition for radar surveillance.

Currently, the so-called MIMO (Multiple Input Multiple Output) systems are being developed in radiolocation. This definition includes systems that have multichannel receiving and/or transmitting systems that use one of the methods for separating signals in channels, and joint processing of these signals is performed. The application of the principles of MIMO systems in the construction of multi-position forward-scattering RLS is a promising, but poorly understood direction.

For the described conditions, the construction of radar observation systems in the form of a forward-scattering multi-position (in particular, two-position, bistatic) radar system seems promising. The primary field in semi-active systems is created by the transmitter, which is not included in this system and is an external element with respect to it. In this case, the only element of the system itself is the receiver, but it functions in close cooperation with the transmitter external to the system.

An analysis of technical literature [3–10] shows that the use of the principles of separated (semi-active) radar for covert observation of biological objects in scientific periodicals is practically not discussed. Therefore, let's further consider how methods and means of biolocation can be implemented by separated systems.

Solving problems related to the research and development of ground-based radar detection of ground targets is of great scientific importance and should allow such systems to be used to solve problems of detecting, locating and classifying moving ground objects under the influence of passive interference, including from vegetation. This determines the relevance of the article.

Currently, the so-called MIMO (Multiple Input Multiple Output) systems are being developed in radiolocation. This definition includes systems that have multichannel receiving and/or transmitting systems that use one of the methods for separating signals in channels, and joint processing of these signals is performed. The application of the principles of MIMO systems in the construction of multi-position forward-scattering radar is a promising, but poorly understood direction.

Thus, the use of existing and newly developed means of protection of particularly important objects can ensure reliable and timely confrontation. Ensuring security in the immediate vicinity of the perimeter of the object is no longer a problem. At the same time, the issues of observing living objects in emergency conditions – covert surveillance of gangster or terrorist groups hiding on the ground at a considerable distance from the object, remained unsolved until the end.

Let's note that the limitations of the radar detection equipment with continuous radiation, adopted in the article, are explained by the intended use of the external over the illumination system from industrial radio and television broadcasting stations, which operate in continuous mode and thereby ensure the complete secrecy of the target illumination.

The aim of research is in identification of the possible ways to monitor biological objects using bistatic RLS methods. In addition, from geometric positions it is supposed to evaluate the possibility of implementing the "forward-scattering" mode on the example of the use of radiation from the transmitter of a digital television system based on land.

To achieve the aim, the following objectives are set:

– to ensure covert and early detection (in comparison with existing norms) of the fact of the infiltration of violators into protected areas;

– to monitor the movement of potential intruders, including on vehicles, in the direction of protected objects to issue a transition signal to high alert;

– taking into account the existing location of radio-emitting centers, determine rational geometry in open areas to achieve maximum responsibility based on the technical characteristics of the light sources.

3. Application of bistatic location methods for the detection of biological objects

By definition, a biolocation is a method of non-contact detection and diagnosis of people (animals), including behind opaque walls, based on the modulation of a radar signal by movements (movements) of a biological object.

Biolocator systems appeared as a result of work at the interface of radiophysics and biology – sciences far from each other. However, researchers have become interested in these systems, and then potential consumers in many countries around the world. The progress of radar technology and technology has allowed many times to increase both the quantity and the quality of information received from the facility, as well as the use of radar stations to monitor living objects.

The range of recorded movements determines the use of electromagnetic waves in bioradiolocator (BRL) up to a very high frequency range. Both emitted and continuous signals with complex modulation can be used as emitted. It is possible to use monochromatic signals.

Information received from biolocator systems can be used to supplement the information necessary for reliable operation of existing information management systems.

For BRL, the following technical characteristics are essential:

– autonomous food and operating time in this mode;

– ability to manually move the device, its weight and dimensions;

– ease of use and ease of image analysis;

– possibility of angular scanning of the area;

– time to detect a stationary (if possible) and a moving person;

– maximum allowable width of the barrier through which it is possible to still find a person;

– maximum distance to which a biolocator can detect a person;

– accuracy of determining the location of the person.

The above data indicate the operation of radio equipment in different frequency ranges. Let's note that when choosing the working range of wavelengths, it is necessary to take into account the general requirements for biolocators, the main of which is the detection range – this information is given in **Table 1**.

This shows (**Table 1**) that, firstly, biological objects can be targets. Secondly – ground and air vehicles (low-flying unmanned aerial vehicles for various purposes). A detailed description of the latter is beyond the scope of the issues addressed. Further consideration will be carried out specifically for biological objects, i. e., humans.

Table 1

Required detection range of ground targets

Radars (range)	Detection range		
	people		vehicle
	going	crawler	
Closer	130–1600	80–300	2000–3000
Small	1500–5000	200–500	5000–10000
Medium	4000–14000	up to 2000	12000–25000
Long	15000–26000	up to 7000	30000–60000

Let's note that a person, like any other target, is characterized, first of all, by the so-called effective reflecting surface (ERS). According to many sources, the reflecting surface is about 1 m^2.

If a person is put on a metal helmet, special shoes and equipment in the form of body armor, bullet-proof linings and plates, its image intensifier will increase significantly as equipment is equipped.

A further increase in this indicator is associated with equipping the fighters with metal rifle armament – an automatic rifle, a grenade launcher, a pistol and ammunition in the form of spare automatic horns, grenades and pistol holders. It is also necessary to take into account the presence of knives, optical and night vision devices, radio communications and navigation.

The task of single-station (monostatic) implementation of the detection of biological objects has now been successfully solved. The authors of these lines could not find any mention of another method - multi-position (in the simple case – bistatic) radar. Therefore, further briefly fill this gap. According to foreign experts [11], bistatic RLSs can be considered as cells of the MPRLS.

In practice, the following (already classical) formulation of the problem is most often considered [12, 13]. A coherent multi-static system consists of several transmitters and several receivers located separately at some distances. Transmitters with their signals should cover all monitored areas. Synchronization between individual transmitters or transmitters and receivers is not required, but it is necessary to know the exact position of both transmitters and receivers.

Of particular interest is the use of transmitters external to the planned radar system as sources of illumination. Such transmitters can be terrestrial and space-based radio and television transmission centers operating with analog and digital (which is better) signals, radio navigation system transmitters, etc. At the same time, the new system acquires undoubted advantages:

– eliminates costly transmitting device locator, because "free" radiation from other industrial systems is used;

– as a consequence of the first, the power consumption of the entire system is significantly reduced, since the main consumer is the transmitter;

– provides almost complete secrecy of the functioning of the new system, because the radiation of a specialized transmitter is excluded, and to detect the radiation of the heterodyne of the receiver, a significant increase in the sensitivity of the reconnaissance receiver of the opposing side will be required;

– a significant (almost all) part of the constituent elements of the new system can be built on the developed and widely manufactured products of the industry, which also reduces the development costs of the system many times.

The decisive role is played by the angle β between the directions from the transmitting and receiving positions to the object, which is called bistatic (**Fig. 3**). This is one of the main geometrical characteristics of bistatic RLSs [14, 15]. With moderate values of the bistatic angle β, according to the "equivalence theorem" and experimental data, the bistatic ERS σ_b is usually close to the one-position ERS of the same target σ_0 (taking into account the averaging over possible angles). However, as the angle β approaches 180°, the picture changes dramatically. Let's consider this circumstance in more detail.

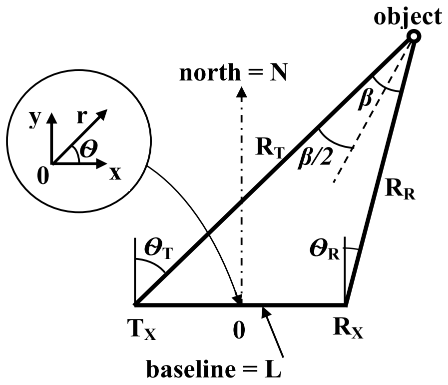


Fig. 3. Bistatic coordinate system for two positions: N – north direction; L – baseline; T_X, R_X – standing points of the transmitter and receiver, respectively; x, y – rectangular coordinate system; θ_T, θ_R – azimuth to the target from the transmitter and receiver; R_T, R_R – transmitter-target and receiver-target distances; β – bistatic angle

For example, for an ideally conducting ball with a radius r_c=20λ (λ is the wavelength), the single-position σ_o and bistatic σ_b at angles β less than 140...150° are 400 $\pi\lambda^2$. When scattering forward, the bistatic ERS is $\sigma_b(180°)=4\pi^3 \cdot 10^4 \cdot \lambda^2$. Therefore, σ_b (180°) is approximately 16,000 times, or 42 dB more. The sharp increase in the ERS of targets in the scattering of forward allows in certain conditions to reduce the energy potential of the radar. It is especially important that the "shadow" ERS σ_b simply can't be reduced [12].

In two-position (bistatic) radio location systems systems (BRLS) situations arise when the target can be observed within a narrow zone adjacent to the base of the system, i. e. the line between the receiving and transmitting positions of the system [16].

If in the path of the wave propagation place an absolutely certain body of large size compared to the wavelength, then a so-called stray field ("shadow" field) will appear behind the body. This field does not depend on the shape of the body surface and is completely determined by its illuminated external boundaries [17]. As a result, a sharp increase in the bistatic σ_b effective dispersion zone (EDZ) of objects is observed. This allows the same time to reduce the requirements for the energy potential of the radar at the same range.

Let's note that the magnitude of the "shadow" EDZ is not affected by radio-absorbing coatings, which are used to impede the location of airplanes and other objects.

Let's consider the characteristics of target detection in these conditions.

The EDZ dependence $\sigma_b(r)$ on the distance r in the far zone at bistatic angles β close to 180° is determined by the following expression, where A_t – the "radiating" aperture [2]:

$$\sigma_b(r) = \frac{4\pi}{\lambda^2} \cdot \left| \int_{A_t} \exp\left[j\frac{2\pi}{\lambda}\rho r \right] \right|^2, \quad (1)$$

here ρ – radius vector of an arbitrary point of the aperture A_t; λ – wavelength; r – ort, directed to the receiving position. The origin is in the conditional center of the aperture A_t.

From (1) it is seen that at β=180°, when r=ρ, EDZ σ_b reaches its maximum:

$$\sigma_b(180°) = 4\pi\left(\frac{S_t}{\lambda^2}\right). \quad (2)$$

In this expression, S_t – area of the aperture A_t. Imagine (2) in the form

$$\sigma_b(180°) = G_t \cdot S_t, \quad (3)$$

where by $G_t = 4\pi \frac{1}{\lambda^2}$ – the directional coefficient of the common-mode aperture A_t with area of S_t.

It can be seen that the EDZ σ_b of direct dispersion is greater than the geometric area of the aperture A_t by G_t times. Let's note in passing the condition under which we can expect a significant increase in bistatic EDZ:

$$S_t >> \lambda^2. \tag{4}$$

Fulfillment of this condition directly indicates the choice of the working wavelength and provides (for large compared with the wavelength dimensions of the object) $G_{t>>1 \text{ and } \sigma b}(180°)>>S_t$. Therefore, the EDZ $\sigma_b(180°)$ is much larger than the single-position EDZ σ_0. With a large excess of $\sigma_b(180°)$ over σ_0, a significant gain in the EDZ can also be maintained in the region of the side lobes of the DN of the aperture A_t.

At the same time, the EDZ σ_b, defined by (2), is preserved only in a relatively narrow sector around the base between the transmitting and receiving positions. For a specific definition of the gain, it is necessary to choose the operating frequency of the bistatic system and its geometry.

For example, let's select the decimeter wavelength range (500...800 MHz, λ=0.6...0.37 m), in which the transmitters of digital television of the T2 format operate. The location of the transmitters on the ground will be tied (also for example) to the Kharkiv region (Ukraine), then the size of the base can vary within 10...90 km. These values are selected according to the location of T2 transmitters in the Belgorod Region (Russian Federation) [18] and are shown for two (randomly selected) stationary points of receivers – in Zolochiv and Vovchansk (Ukraine). However, the number of receiving channels remains unclear – the use of illumination from all transmitters is likely to be redundant, and the very possibility of illumination needs to be determined. The latter is easily estimated by the well-known relationship [19]:

$$D_{ILL} = 3{,}57 \cdot \left(\sqrt{h_{TR}} + \sqrt{h_{OB}}\right). \tag{5}$$

In this formula, h_{TR} and h_{OB} are the height of the transmitter antenna and the height of the object, respectively. Many formulas use a coefficient of 4.12, which is suiTable for *meter* waves. In the formula (5), a factor of 3.57 is used, since waves above 1 GHz are practically not subject to refraction, and therefore do not penetrate beyond the horizon.

Using computer technology, for clarity, let's obtain a graph of dependence (5), presented in **Fig. 4**, for three standard antenna heights.

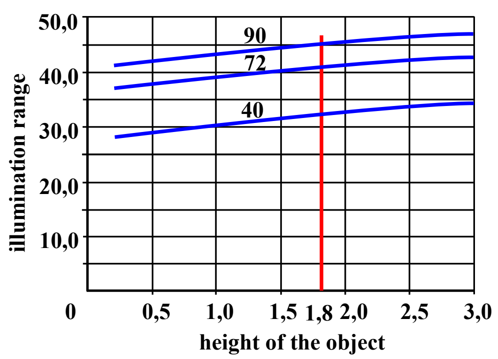
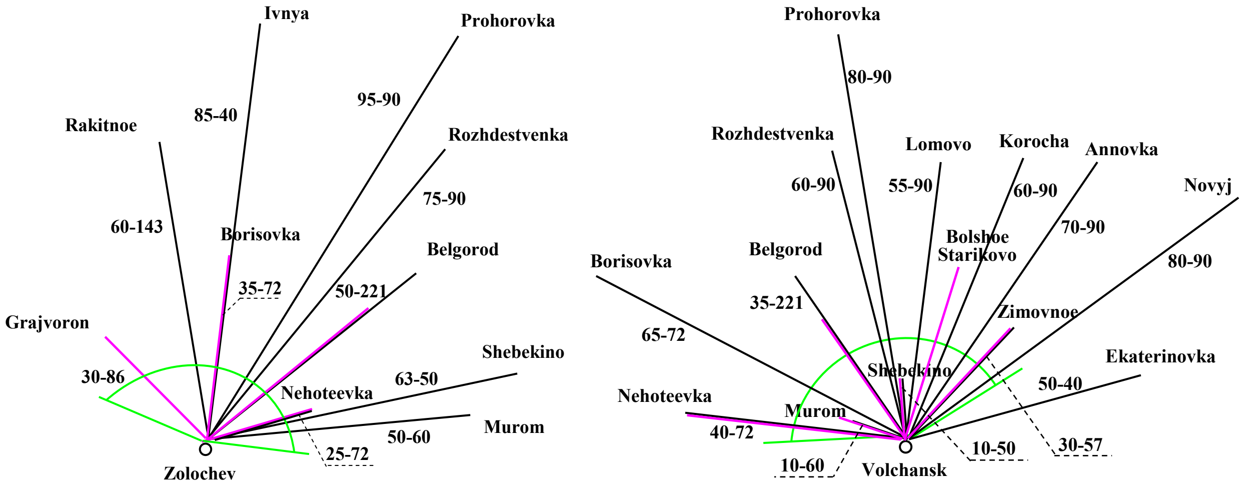


Fig. 4. Dependencies of the illumination range on the heights of the antenna and the object. The red line marks the height of the object – 1.8 m

From the analysis of the curves (**Fig. 4**), it can be seen that for the existing standard antenna suspension heights of the transmitters, the illumination range is 30...45 km, which is shown in **Fig. 5, *a*, *b*** is highlighted with *pink lines*. **Fig. 5, *a*** corresponds to the location of the receiver in Zolochiv, **Fig. 5, *b*** – in Vovchansk. The location of the names of settlements corresponds to the geographical map of the region. Recall that Zolochiv and Vovchansk are located in the northern part of Ukraine, and all other locations on the map are in the Russian Federation.



a *b*

Fig. 5. To the selection of Illumination transmitters: *a* – with a receiver in Zolochiv, *b* – with a receiver in Vovchansk. Numbers 00-00 mean: the first is the distance to the transmitter, the second is the height of the antenna suspension. Green shows service sector at receiver location

Let's now define the geometric relations and conditions for providing the specified – at least 150° – bistatic angle values. For simplicity, considering the surface of the Earth to be flat and using **Fig. 6**, simulating the motion of an object in a straight line *OB* at an angle γ, measured from the line of the base *OA*, let's obtain the following relations.

Let's find the third side:

$$AB = \sqrt{OB^2 + OA^2 - 2 \cdot OB \cdot OA \cos\gamma}; \tag{6}$$

and the desired bistatic angle:

$$\beta = \arccos\frac{OB^2 + AB^2 - OA^2}{2 \cdot OB \cdot AB}. \tag{7}$$

Let's find, ultimately, the width of the signal reception sector, in which the EDZ is increased by at least 20 dB. This value will be used for the subsequent assessment of the energy performance of a bistatic system with a particular source of external illumination. The calculation results are shown in **Fig. 7** for the three values of the bases – 10, 30 and 50 km.

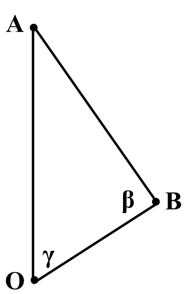


Fig. 6. To the calculation of the bistatic angle: *O* – a point of receiver standing; *A* – a point of transmitter standing; *B* – current position of the object; *OB* – variable (1st side); *OA* – 2nd side (base line); γ – internal angle (azimuth); β – bistatic angle (angle of base visibility)

An analysis of the course of the curves allows to conclude that an accepTable value of the observation sector of 50° is twice the deviation angle γ=25°. If now superimpose this sector on the base line in **Fig. 7**, it turns out that in both receiving positions, the approach paths are fully controlled. Let's note that the 60° sector is realized at a distance of up to 100 m.

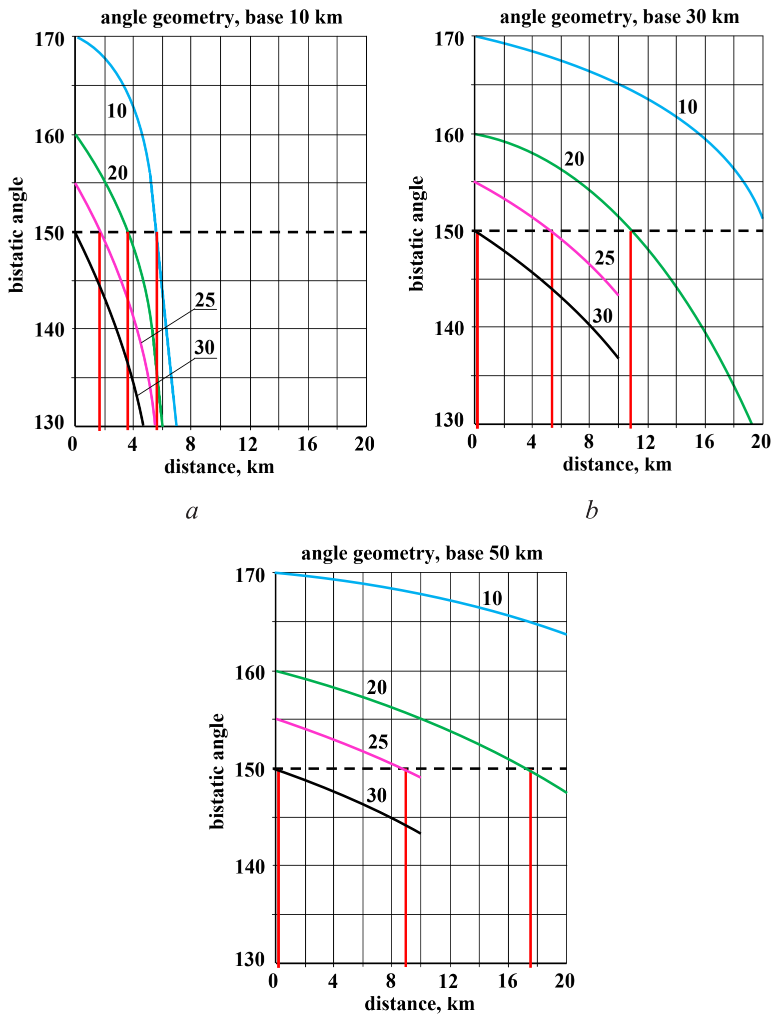


Fig. 7. The values of bistatic angles (vertical axis, degrees) depending on the object's removal from the receiver (horizontal axis, kilometers) and the angle of deviation from the base line (curve parameter, degrees): *a* – base 10 km; *b* – base 30 km; *c* – base 50 km, the scale in range is the same

In **Fig. 7**, the dashed line corresponds to the specified minimum value of the bistatic angle of 150°. Red vertical lines indicate the estimated (geometric) observation of the object.

Finally, to determine σ_b at $\beta \neq 180°$ in formula (1), let's turn to the Cartesian coordinates and obtain:

$$\sigma_b(\cos\Theta_x, \cos\Theta_y) = \frac{4\pi}{\lambda^2}\left| \iint_{A_t} \exp j\frac{2\pi}{\lambda}(x\cdot\cos\Theta_x + y\cdot\cos\Theta_y)\mathrm{d}x\mathrm{d}y \right|^2, \quad (8)$$

where x, y – the ρ projections on the X, Y axis in the plane of the aperture A_t; $\cos\theta_x$, $\cos\theta_y$ – direction cosines of the ort r with respect to the same axes. It is assumed that the positive direction of the wave incident on the target coincides with the Z axis.

If the receiving position is located in the XZ or YZ plane, then in (8) either $\cos\theta_y=0$ or $\cos\theta_x=0$and $\theta_x=\beta-\pi/2$, so $\cos\theta_y=\sin\beta$. Then the bistatic EDZ of the object can be calculated as follows:

$$\sigma_b(\beta)=\frac{4\pi}{\lambda^2}\left|\int_{x_{\min}}^{x_{\max}}\exp\left[j\frac{2\pi}{\lambda}x\cdot\sin\beta\right]\left[y_1(x)-y_2(x)\right]\mathrm{d}x\right|^2, \tag{9}$$

where $x_{\min,\, x\max}$ – side borders on the left and on the right; y_1, y_2 – vertical upper and lower boundaries of the aperture A_t.

The signal-to-noise ratio at the input of the receiving position for bistatic RLSs is calculated as:

$$q=\sqrt{\frac{P_i\tau_i G_0 G_t\sigma_b\lambda^2\eta}{(4\pi)^3 kT_{ef}\left|R_r-L\right|\left|R_{tr}-L\right|}}, \tag{10}$$

where P_i, τ_i – impulse power and pulse duration of the transmitting position; $G_{0,\, Gt}$ – the gains of the receiving and transmitting antennas; η – the total energy loss coefficient ($\eta<1$); k – Boltzmann constant; T_{eff} – effective noise temperature at the receiver input; R_r, R_{tr} – distance from the target to the receiving and transmitting positions; L – radius vector, which determines the location of the target.

To illustrate the increase in the signal-to-noise ratio from the bistatic angle, let's use the data from [20], which shows the signal-to-noise ratio versus the bistatic angle for the model of the Su-33 aircraft. The numerical data in the calculation of (10) used the technical characteristics of the radar "Casta-2" (made in Russia) [21]. Bistatic angle varies from 100° to 180°. The original graphs fluctuate quickly, so the figures show the envelopes of the signal-to-noise ratio. An analysis of the course of the curves in the graphs (**Fig. 8**) shows that in the range of 150°…180°, signal/noise 30...35 dB is provided (border – red line).

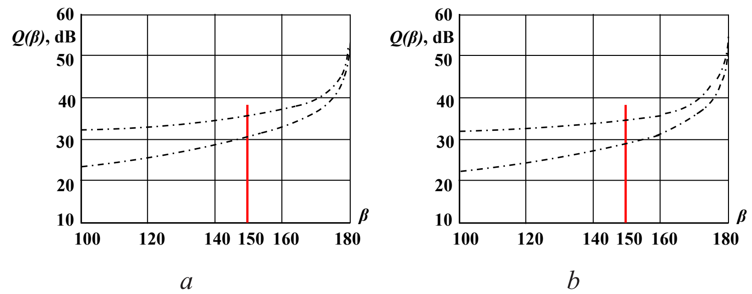


Fig. 8. The calculated dependences of the signal-to-noise ratio on the bistatic angle for the fighter model during scattering: *a* – forward "in full face"; *b* – forward "in profile"

Similar results were obtained by foreign researchers [14, 22].

6. Discussion of research results of covert observation of biological objects by means of bistatic RLS

Existing radar reconnaissance surface and surface objects are used, as a rule, for observation of land and water sections of the state border. Such devices can also be used to protect important military and economic objects (nuclear power plants, warehouses, consulates, etc.). The results of their work practically do not depend on weather conditions and the lack of optical visibility.

Earlier studies [11, 17] show that, in the approximation of physical optics, the shadow field of an object does not depend on the shape of the surface. The shadow field of the target is also not affected by the material of its surface (for example, plastic), or the radio-absorbing coatings, which drastically weaken the own diffuse field for the one-position variant.

The submissions indicate that the use of digital television transmitters to create a secretive bistatic system is quite possible – at least in a geometric interpretation in open areas. A wide network of television transmitters allows to choose from them the necessary warning to create a zone of intrusion into the protected area.

At the same time, it is possible to focus on using the reception sector of a single channel 50 degrees wide, which will ensure control of the territory at a distance of 1.5...5 km, depending on the size of the base. Full coverage of the frontal zone will require 4 receiving channels.

In addition, with low economic costs, it is possible to obtain a significant economic effect by significantly simplifying the multi-position and transition to bistatic RLS. The latter, with a certain configuration regarding the location object, allows observing objects that were not previously detected, which is confirmed by other works [23, 24].

At the same time, the well-known classical radiolocation formula requires clarification with reference to a change in the value of the bistatic angle depending on the changing location of the object in the geometric field of the system. Depending on the type and location of the radiation source, the geometry of the system varies significantly, which requires additional research. This is especially true of cosmic illumination from transponder satellites, and the main component will be played by the energy component, since there are no limitations on illumination in the area of the object.

The possibilities of the method are also limited in urban conditions, since it is not possible to distinguish the offender from the ordinary passer-by. In addition, the possibilities of organizing a circular area of responsibility, when the receiving device is located, for example, in the center of the protected object, have not been studied.

The application of the method for locating moving targets is considered, but the lower limit of the speed of movement is not defined, which requires further research on the possibility of distinguishing the signals reflected from violators and from the leaf cover of trees. Finally, it is possible to consider the possibilities of the method for detecting low-flying unmanned aerial vehicles for various purposes.

In the future, it is advisable to continue research on the use of methods of bistatic RLS (including secretive) with other illumination transmitters for solving problems of monitoring biological objects.

7. Conclusions

The found dependences of the signal-to-noise ratio $q(\beta)$ on the bistatic angle β allow to conclude that objects, including biological, are more reliable in the "forward-scattering" radar compared to the classical single-position, but in a smaller angular sector.

The use of digital radio and television broadcasting signals allows to focus on the size of the reception sector of a single channel 50 degrees wide, which will provide control over an area of 2...25 km^2 depending on the size of the base. Full coverage of the frontal zone will require 4 receiving channels.

If the geometry of the location of the position of the bistatic RLS and the object is such that during its movement the condition $\beta\approx180°$ is met, then it is possible to use the effect of increasing the ERS to observe objects. It is possible to save the energy potential of the radar.

On the whole, the article is of a staging nature, and the analysis performed indicates that it is expedient to use the "forward-scattering" radar method to detect ground (surface) moving objects, including biological ones.

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