International Journal of Applied Engineering and Technology

The Creation of a Hidden Radar Field for the Detection of Small Aerial Objects due to the Use of Signals from Telecommunication Systems

Hennadii Khudov, Kristina Tahyan, Vitaliy Lishchenko, Halyna Misiuk
Ivan Kozhedub Kharkiv National Air Force University, 2345kh_hg@ukr.net, madi_73@ukr.net, lvnpo43ta@gmail.com, galina_mis@ukr.net

Volodymyr Bashynskyi
Central Research Institute of the Armed Forces of Ukraine, bashynskyi_v_g_1968@gmail.com

Oleksii Fakadii
National Defense University of Ukraine named after Ivan Cherniakhovskyi, fakadey_1@meta.ua

Oleh Maslenko, Maksym Herda
Defence Intelligence Research Institute, oleh.maslenko_11@gmail.com, maxim.flame.work_1@gmail.com

Tetiana Lavrut
Hetman Petro Sahaidachnyi National Army Academy, lavrut_t_v_1@i.ua

Volodymyr Nedilskyi
National Academy of the National Guard of Ukraine, 05050555555@gmail.com

Date of Submission: 21st July 2023 Revised: 12th August 2023 Accepted: 24th August 2023

How to Cite: **Khudov, et. al. (2023), The Creation of a Hidden Radar Field for the Detection of Small Aerial Objects due to the Use of Signals from Telecommunication Systems, International Journal of Applied Engineering and Technology 5(3), pp. 9-17.**

***Abstract* - The paper is devoted to the creation of a hidden radar field for the detection of small aerial objects using the signals of telecommunication systems. The issues of geometric construction of the hidden radar field system, sources of information regarding the aerial object are considered. It was established that the creation of a hidden radar field allows to increase the capabilities of the existing radars. This allows for the detection of a small-sized and low-altitude aerial object at a line-of-sight range of 80-100 km. This, in turn, will ensure the possibility of prompt decision-making regarding a small-sized aerial object. In further research, it is necessary to estimate the energy characteristics of the radars of the hidden low-altitude radar field, as well as to solve the issue of optimizing the geometric construction of the system.**

***Index Terms* - Aerial object, hidden radar field, detection, signal, telecommunication system, digital TV, radar**

INTRODUCTION

Nowadays the air defense system construction is complicated by the appearance of small-sized air objects [1, 2].

Small-sized aerial objects have specific flight technical characteristics, namely [3-5]: a wide range of movement speeds, small effective scattering surfaces, stealth flights at medium, extremely low altitudes. Such altitudes use terrain relief.

When creating promising unmanned aerial vehicles, considerable attention is paid to reducing their radar visibility. This, in turn, reduces the probability of detecting small aerial objects by radars and increases the possibilities of such aerial objects to successfully overcome the air defense system [3-5].

The decrease in radar visibility of small air objects is inextricably linked to the decrease in their effective scattering surface. The main methods of reducing the effective scattering surface are reducing the size, giving objects special low-reflective forms, using active masking systems, radio-absorbing coatings and composite materials, etc. [3, 6, 7].

The use of traditional methods of improving the quality of detection of small aerial objects leads to an increase the number of radars, an increase the energy of radars and an increase in the cost of creating and maintaining a radar field.

Therefore, the search for new ways, methods to improve the quality of detection of small-sized air objects is an urgent task.

LITERATURE REVIEW AND PROBLEM STATEMENT

In [8], to improve the quality of aerial objects detection, a special survey of the radar zone by the angle of the location is used. The advantage [8] is a reduction in the time required to inspect the radar zone. The disadvantage [8] is the invariance of the indicators of the quality of aerial objects detection.

In [9], to improve the quality of aerial objects detection, it is proposed to change the parameters of probing signals. The frequency, bandwidth of the receiving device, pulse parameters, etc. are changed. The advantage [9] is the ability of radar to specify the coordinates of an aerial object. The disadvantage [9] is the impossibility of current changes in the parameters of the radar signal.

In [10], a phased antenna array with a change in operating mode (probing and receiving) is used to improve the quality of detection of aerial objects. The advantage [10] is the adaptability of radar operation. The disadvantage [10] is the impossibility of operationally changing the modes of operation of the phased antenna array of the radar.

In [11], to improve the quality of detection of aerial objects, the use of a phased antenna array and adaptation of its operation in conditions of interference is proposed. The advantage [11] is the high level of radar immunity. The disadvantage [11] is the impossibility of implementing the method on radar in the absence of a phased antenna array.

Taking into account the data [12], we will calculate the possibilities of detecting unmanned aerial vehicles by modern radars of the "Malachite" type (P-18MA) and radar 35D6 (19Zh6). The calculation of the detection zone of unmanned aerial vehicles will be carried out assuming the location of the radar in ideal positions. The vertical section of the detection zone is generally described by expression (1) [12]:

$$r(\varepsilon)=r_0 F_0(\varepsilon) F_E(\varepsilon), \quad (1)$$

where r_0 is the maximum detection range of a radar target in free space;
$F_0(\varepsilon)$ is the directivity diagram of the antenna in free space;
$F_E(\varepsilon)$ is the interference coefficient of the Earth.

The shapes and sizes of detection zones of unmanned aerial vehicles of radar "Malakhit" (P-18MA) are shown in Fig. 1, Fig. 2, and radar 35D6 (19Zh6) in Fig. 3.

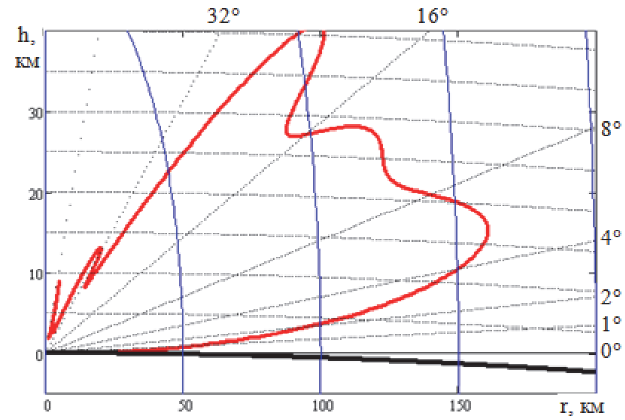

FIGURE 1 THE VERTICAL SECTION OF THE ZONE OF DETECTION OF THE UNMANNED AERIAL VEHICLE OF "MALACHITE" RADAR (P-18MA) WHEN WORKING WITH A STANDARD ANTENNA

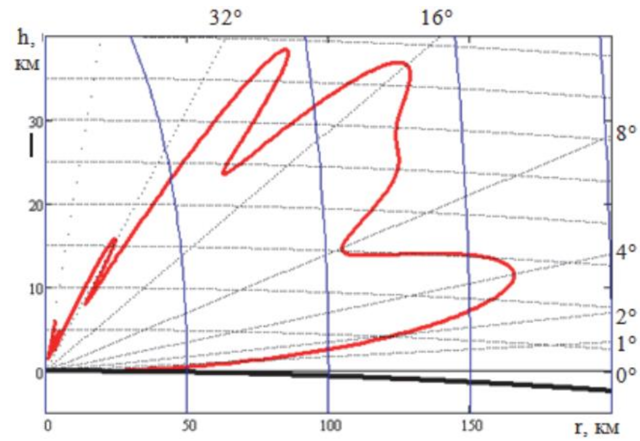

FIGURE 2 THE VERTICAL SECTION OF THE ZONE OF DETECTION OF THE UNMANNED AERIAL VEHICLE OF "MALACHITE" RADAR (P-18MA) WHEN THE ANTENNA IS RAISED IN TWO SECTIONS

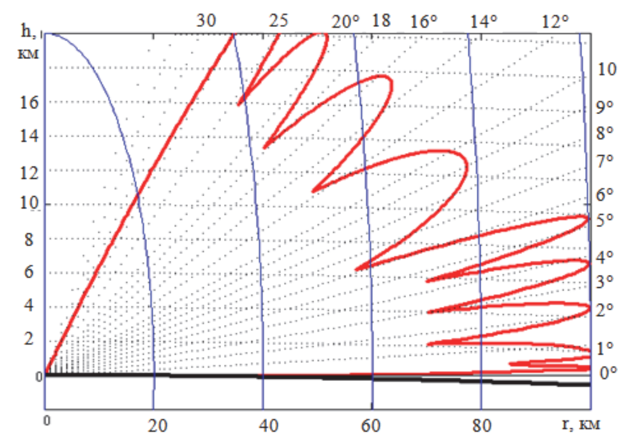

FIGURE 3 THE VERTICAL SECTION OF THE ZONE OF DETECTION OF THE UNMANNED AERIAL VEHICLE OF RADAR 35D6 (19ZH6) IN DUTY MODE FAMILIES OF

The calculations made it possible to determine that modern radars can provide detection of unmanned aerial vehicles of the "Orlan-10" type at heights of 100 m – at ranges of 15...30 km, at heights of more than 500 m – at ranges of 50...60 km, and at heights of more than 1000 m – at distances of 70...90 km.

In [13], distributed (multi-position) active radar systems are used to improve the quality of aerial objects detection. The advantage [13] is the increase of information sources regarding the detection of an aerial object. The disadvantage [13] is an increase in financial costs.

In [14, 15], various options for building distributed (multi-position) radar systems are proposed. The main advantages [14, 15] are:

- distribution in space of a multi-position system;
- ensuring the management of the radars in accordance with changes in the signal and jamming situation;
- increasing the accuracy of determining the coordinates of an aerial object, etc.

The disadvantages [14, 15] are the need to ensure the synchronous operation of all system elements.

In [16, 17], a system of active radars of the same type is used to improve the quality of aerial objects detection. Advantages of [16, 17] are increased detection range of aerial objects. Disadvantages of [16, 17] are the complexity of building a system of the same type of radars, especially if the radars are not digital.

In [18–21], the process of detecting inconspicuous air objects was investigated. It was established that modern small-sized aerial objects spend a small amount of time in the detection zone of existing radars. At the same time, there are also no target indications for providing a priori information regarding the detection of small-sized aerial objects, etc.

In [22], a passive location station with spatial diversity of the receiving system is used to improve the quality of aerial object detection. . The disadvantage of [22] is the lack of definition of the types of signals with which the proposed passive system can work.

In [23], several channels of passive reception are used to improve the quality of air object detection. One channel is defined as the main one, the others are normal. The advantage [23] is a low level of false alarms. The disadvantage of [23] is the lack of definition of the types of signals with which the proposed passive system can work.

In [24], an increase in the number of active radars is proposed. At the same time, different modes of operation of such radars are selected. The advantage [24] is a high level of the signal/noise ratio when detecting an aerial object. The disadvantage [24] is the high cost of the radar system.

In [25] is presented the methods for improving the quality of inconspicuous aerial objects detection through the use of external radiation sources. The advantages of [25] are the use of additional sources of information. The disadvantage of [25] is the weak signal level of additional radiation sources.

MATERIALS AND RESEARCH METHODS

Let's consider the use of radar systems that work on signals from third-party sources of the underworld. We will consider wireless telecommunication systems as third-party sources of underworld. The operation of such systems is associated with a number of problems that limit the range of action, as well as complicate the detection of airborne objects and reduce the accuracy of estimating their coordinates.

One of these problems is the low power of the sublight radiation source, which reduces the effective range of the radar system. To increase the range of the system, the signal reflected from the air object is accumulated, which, in turn, leads to a significant increase in computational complexity [26, 27].

Another problem is that the direct signal of the backlight source on the side lobe of the antenna pattern of the radar system enters the main channel of the radar system. At the same time, the power of the direct signal of the backlight source is several times higher than the power of the signal reflected from the aerial object [14].

A multi-position spaced radar system of the cellular communication system, ground-based and space-based radio and television broadcasting is shown in Fig. 4.

The system is built in several detection lines at a depth of 50-100 km along the front in a strip of 200-300 km and at an altitude of up to 1500 m.

Each detection line represents a sequence of detection zones. The zones are located between base stations. The detection zone is formed by a single-base spaced Doppler radar. Doppler radar is bistatic radar. Information from each detection zone is sent via GSM networks to the Information Collection and Processing Center. The Center can be located some kilometers away from the detection system. Identification of aerial objects is carried out by bearing, frequency and time features.

Let's consider the geometry options. construction of such systems. The geometry of the radars using telecommunication signals reflected from aerial objects is shown in Fig. 5.

The source of the backlight signal (Fig. 5) can be a base station of a mobile communication system, a digital broadcast television transmitter, a digital radio transmitter, and others. The operation of the passive radar system is carried out as follows: the source of the backlight signal emits a radio signal, which is reflected from the air object and enters the receiving channel of the passive radar system. In addition, the passive radar system receives a direct signal from the transmitter, which is necessary for synchronization and further processing. Spatial localization (detection) of an aerial object is carried out as a result of reception and processing of signals reflected from aerial objects, as well as direct signals from the transmitter.

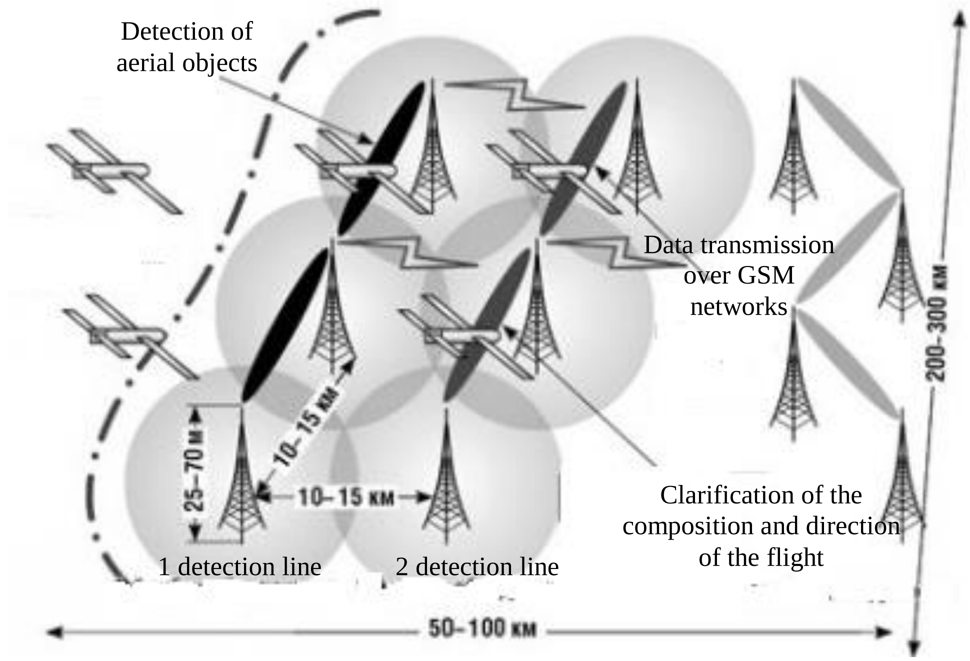

FIGURE 4 A MULTI-POSITION SPACED RADAR SYSTEM OF THE CELLULAR COMMUNICATION SYSTEM, GROUND-BASED AND SPACE-BASED RADIO AND TELEVISION BROADCASTING

A passive radar system can have a single-position or multi-position structure. The single-position passive radar system works on one source of the backlight signal (Fig. 5). With such a structure of a passive radar system, a direct signal and a signal reflected from an aerial object emitted by one source of the backlight signal are received. Spatial localization of an aerial object can be carried out using the range-finding method [28, 29].

A single-position passive radar system, which works on several sources of sublight, is shown in Fig. 6. In this case, the spatial localization of the aerial object can be carried out using signals reflected from the aerial object from several sources. The following methods can be used to estimate the coordinates of an aerial object: ranging and bearing, difference ranging [28, 30, 31].

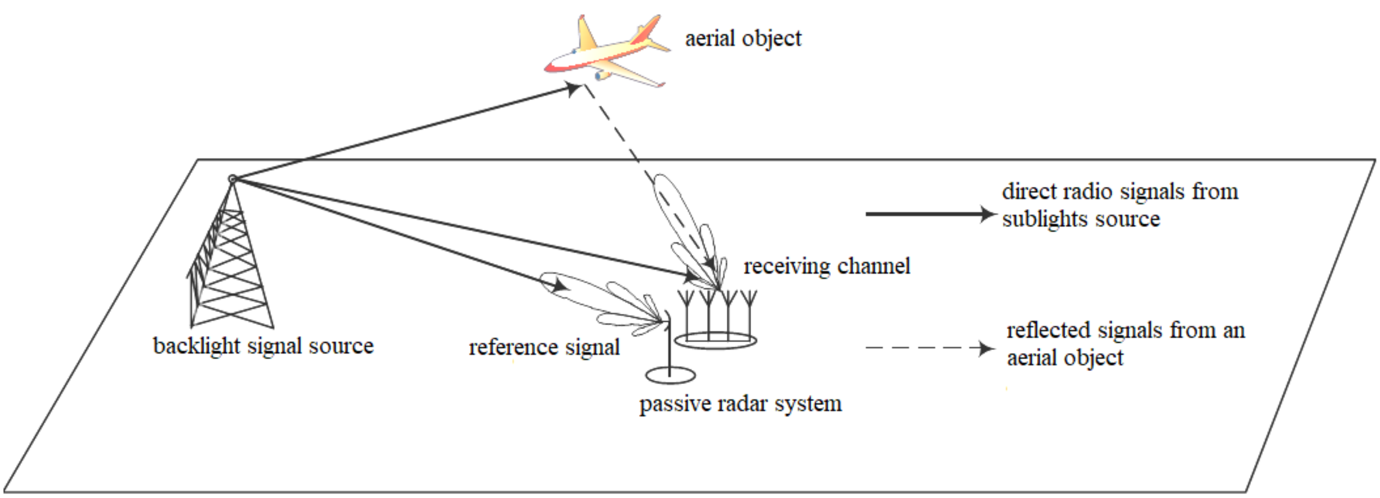

FIGURE 5 THE V THE GEOMETRY OF THE RADAR SYSTEM USING TELECOMMUNICATION SIGNALS REFLECTED FROM AERIAL OBJECTS

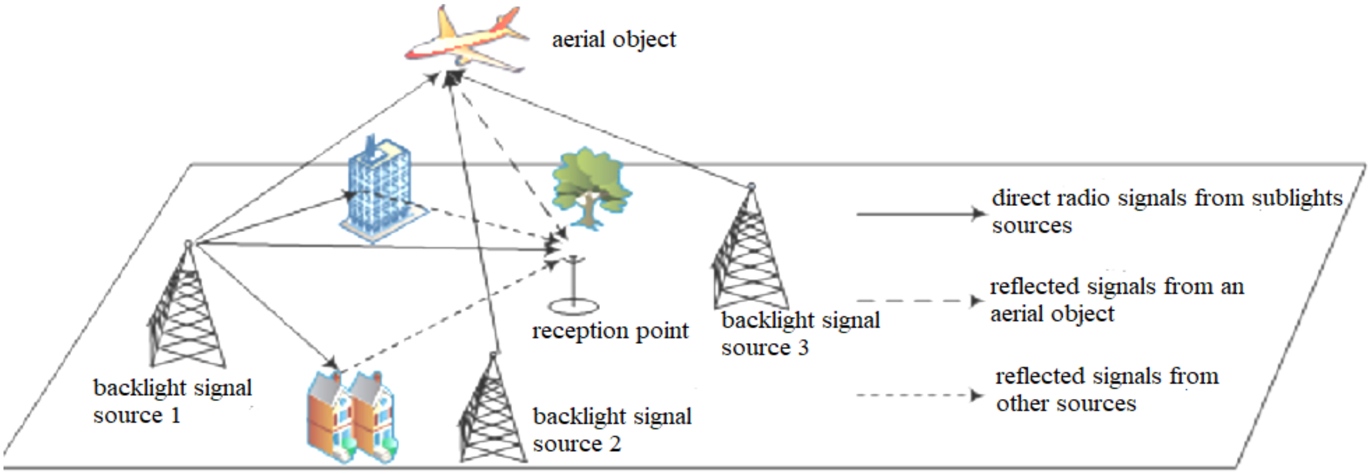

FIGURE 6 THE GEOMETRY OF A SINGLE-POSITION PASSIVE RADAR SYSTEM OPERATING ON SEVERAL SOURCES OF SUBLIGHT

A multi-position passive radar system operating on one source of the backlight signal is shown in Fig. 7. The signal from the source is received in several scattered receiving points. For spatial localization of an aerial object, the range-finding method and the difference-range-finding method are used [28, 30, 31].

A multi-position passive radar system that works on several sources of sub-light signals is shown in Fig. 8. Such a configuration of a multi-position system allows to estimate the coordinates of an aerial object with greater accuracy, because in this case all the above methods of determining the coordinates can be used together.

The main advantages of single-position passive radar systems:

- high mobility of system deployment;
- relatively low cost of the system;
- no need for synchronization.

Disadvantages of single-position passive radar systems:

- limited area of action;
- no reservation.

Advantages of multi-position passive radar systems:

- high reliability and reliability of the interpretation of radar data due to the processing of information received from several sources (different angles, polarization, frequencies);
- more effective detection and tracking of objects moving in a wide range of speeds in different directions (at different angles, from different distances);
- the possibility of using modes of the radar system that are unavailable or ineffective in monostatic configurations;
- the possibility of changing the observation parameters (mutual spatial position and direction of velocity vectors, frequency range, polarization, laws of signal modulation) and the processing algorithm for the most effective use;
- higher reliability.

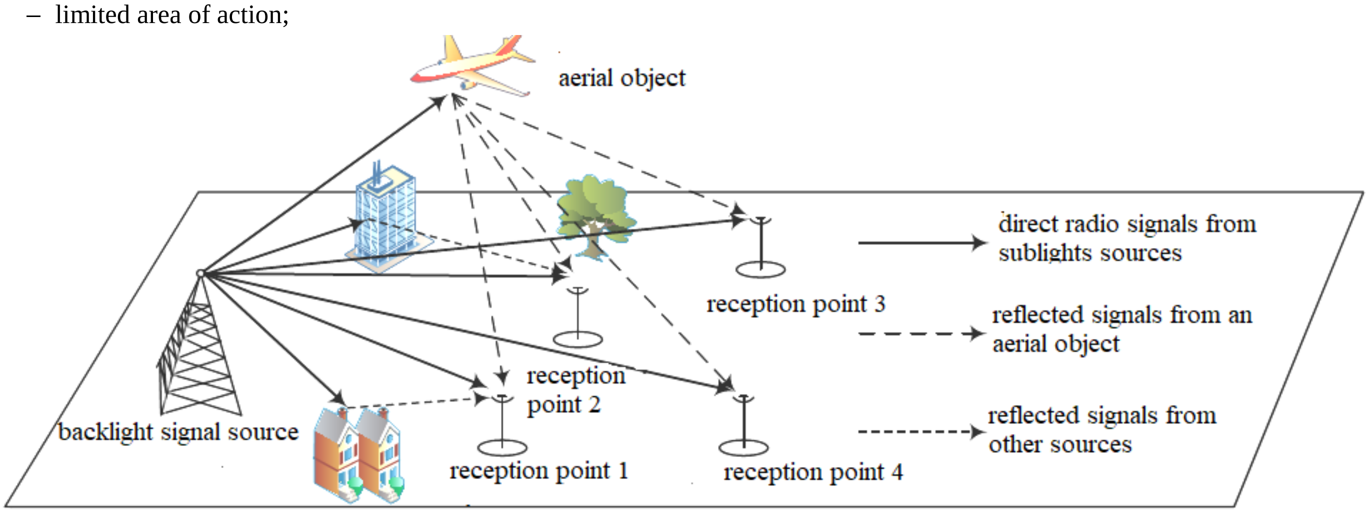

FIGURE 7 THE GEOMETRY OF A MULTI-POSITION PASSIVE RADAR SYSTEM OPERATING ON ONE SOURCE OF THE BACKLIGHT SIGNAL

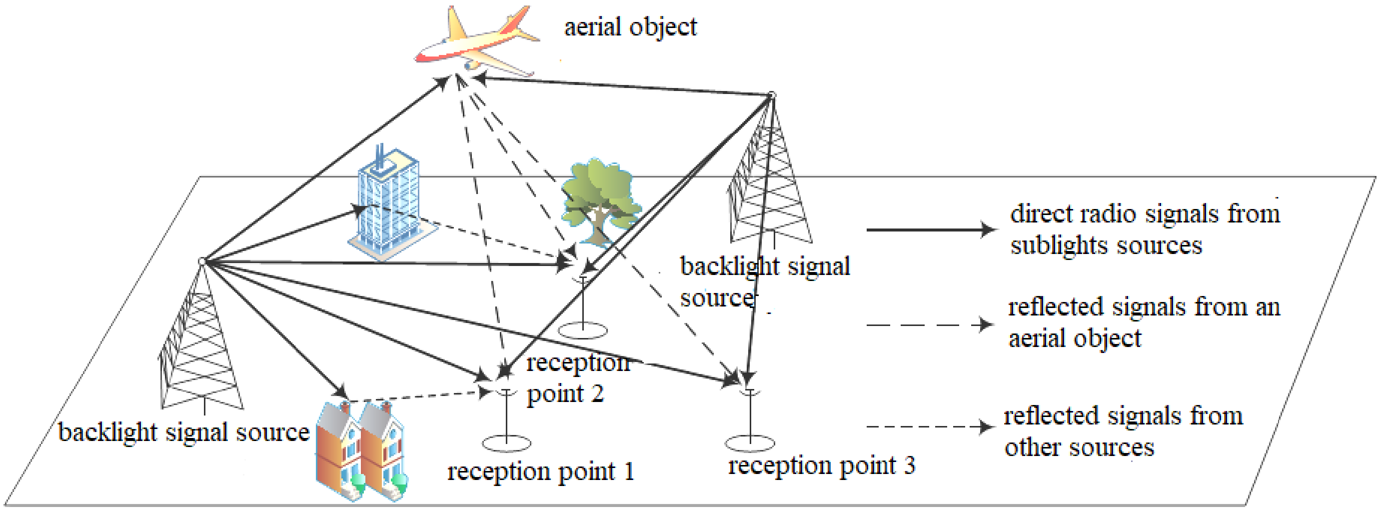

FIGURE 8 THE GEOMETRY OF A MULTI-POSITION PASSIVE RADAR SYSTEM OPERATING ON SEVERAL SOURCES OF SUBLIGHT SIGNALS

Disadvantages of multi-position passive radar systems:

– the need for mutual time and phase synchronization, determination of mutual position vectors;
– the need to use high-performance computing devices and the increased cost of the system.
– Consider, for example, the signals of modern telecommunication systems, which can be used as sources of sublight signals. Such signals must meet the following requirements:
– the power of the illumination source must be sufficient to determine the coordinates of the radar target at the required range;
– signals must have a sufficient bandwidth to achieve a certain range resolution;
– signal sources used in passive radar systems must have widely directed antenna systems;
– the coordinates of the sources of the backlight signals must be known with the required accuracy.

The Table 1 shows the main parameters of the backlight signal sources of modern telecommunication systems.

From the Table 1, it can be seen that according to the requirements for the power of the backlight signals, there are analog and digital television signals that meet the requirements.

In Fig. 9, for example, the dependence of the range of the passive radar system on the effective scattering surface of the aerial object when working on the signals of the 4G system (LTE) and the digital television system of the DVB-T2 standard is given. The results shown in fig. 6 obtained with the following initial data (Table 2 [19]).

From the Fig. 9, it can be seen that the most effective underlight system is the DVB-T2 digital television system.

TABLE I
THE MAIN PARAMETERS OF THE SIGNAL SOURCES OF THE UNDERLIGHT OF MODERN TELECOMMUNICATION SYSTEMS

Backlight signal source	Frequency, MGz	Bandwidth, MGz	Power, Wt	Modulation
FM and VHF	66-108	$(3\text{-}20)\cdot10^{-3}$	100-4000	analog FM
Analog TV	50-800	8	50000	analog AM та FM
Cellular communication systems GSM	900 1800	25	20	GMSK
Communication systems 3G	1920 2110	5	20	Code CDMA
Communication systems 4G (WiMAX, LTE)	2400 2500	1,4-28	20	Digital, OFDM
Digital TV	174-834	8	50000	Digital, OFDM

We will make approximate calculations of the direct line-of-sight range of the radar system using clearance location methods. The height of the placement of the antenna of the radar system, which works on the clearance, is from 100 to 250 m. At the same time, the underlight zone is inclined in the direction of the ground at an angle of 30 degrees. The flight height of small aerial objects is 50-250 m above the Earth's surface. Therefore, calculations according to expression (2)

$$D = 4{,}12\left(\sqrt{h_a} + \sqrt{h_{ao}}\right), \qquad (2)$$

where D is the line-of-sight range;
h_a is antenna lift height;
h_{ao} is target flight height,

Show that the line-of-sight range of a radar system operating in the clear is 70-120 km, which is unattainable for typical radar detection of small-sized and low-altitude aerial objects.

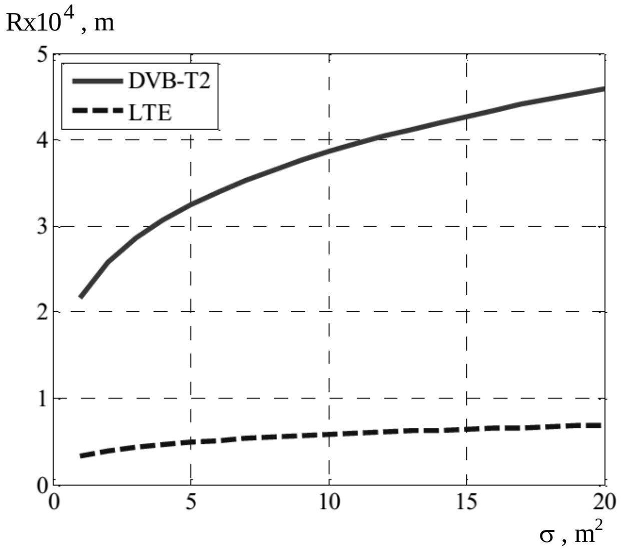

FIGURE 9 THE DEPENDENCE OF THE RANGE OF THE PASSIVE RADAR SYSTEM ON THE EFFECTIVE SCATTERING SURFACE OF THE AERIAL OBJECT WHEN WORKING ON THE SIGNALS OF THE 4G (LTE) SYSTEM AND THE DVB-T2 STANDARD DIGITAL TELEVISION SYSTEM

TABLE II
THE SIGNAL PARAMETERS OF LTE AND DVB-T2 SUBLIGHT SYSTEMS

Parameters of sublight systems	LTE	DVB-T2
Power, Wt	20	50000
The gain of the transmitting antenna, dB	15	10
The gain of the receiving antenna, dBe	10	10
Frequency, MGz	2500	800
Effective scattering surface of an aerial object, m^2	0,8-40	0,8-40
Noise band of the receiver, MGz	25	10
Accumulation time, s	0,01	0,01
Losses in the transmission path, dB	3	3
Losses in the receiving path, dB	3	3

Thus, the multi-position spaced radar system of the cellular communication system, radio and television broadcasting allows

– to create a continuous low-altitude radar field with multiple, multi-frequency overlapping of radiation zones created by various sources of sublight;
– to provide air and ground space control means of the area that are not overlapped by traditional means of radar;
– to significantly reduce the costs of placement and commissioning in comparison with our favorite similar systems;
– solve a wide range of tasks (building up the next low-altitude radar field in threatening directions, ensuring the safety of radars of state security objects, air traffic control (control of flights of light aircraft and unmanned aerial vehicles at low altitudes), anti-terrorist protection of strategically important objects, protection of the state border, monitoring of fire safety, search for aircraft in distress, etc.).

CONCLUSIONS

Thus, the creation of a hidden radar field makes it possible to increase the capabilities of the radar group, which will allow:

– to have a low-altitude radar field system on the territory of the country, which coincides with the coverage field formed by the underlight zones of television and radio broadcasting centers, cellular communication systems;
– accuracy characteristics of radar information allow to detect a small-sized target moving at a speed of 15-20 km/h, with a resolution of 150-200 m at a line-of-sight range, and issue target designations for the inclusion in combat of short-range weapons (portable anti-aircraft missile complexes or anti-aircraft small-caliber artillery);
– to reduce energy costs for signal emission. Electricity costs are limited only by the power of the equipment in reception mode;
– solve the environmental problem (absence of ultra-high-frequency radiation), absence of unpredictable impact on radio-electronic means of the local infrastructure;
– observe an air target from the flank, while the effective scattering surface is several times greater than the effective scattering surface in the front hemisphere;
– observe air targets by signals of onboard radiation sources using passive location methods.

In further research, it is necessary to estimate the energy characteristics of the radars of the hidden low-altitude radar field, as well as to solve the issue of optimizing the geometric construction of the system.

REFERENCES

[1] "Network centric warfare. vis-a-vis modern warfighting concepts". 2018. – Available at: https://futurewars.rspanwar.net/network-centric-warfare-vis-a-vis-modern-warfighting-concepts.

[2] Robb J. "Modern Militaries and a Network Centric Warfare Approach". 2022. – Available at: https://www.e-ir.info/2014/01/09/modern-militaries-and-a-network-centric-warfare-approach.

[3] "The Impact of Drones on Future of Military Warfare". 2023. – Available at: https://www.zenadrone.com/drones-impact-the-future-of-military-warfare.

[4] "The War in Ukraine Has Revolutionized Drone Warfare". 2023 – Available at: https://www.setav.org/en/the-war-in-ukraine-has-revolutionized-drone-warfare.

[5] Khudov H., Oleksenko O., Lukianchuk V., Herasymenko V., Yaroshenko Y., Ishchenko O., Ikaiev D., Golovchenko O., Volobuiev A., Drob Y., Solomonenko Y., Khizhnyak I. "The Determining the Flight Routes of Unmanned Aerial Vehicles Based on Swarm Methods". International Journal of Emerging Technology and Advanced Engineering. 2021. Vol. 11. Issue 09, pp. 23–32. DOI: 10.46338/ijetae0921_03.

[6] Zhu H., Wang C., Wang L. "A Target Detection Method of Distributed Passive Radar without Direct-Path Signal. Electronics". 2023. 12 (2):433. DOI:10.3390/electronics12020433.

[7] Tiwari S. "Ukraine War: Iran 'Modified' Shahed-136 Kamikaze Drones For Russia To Cause Max Destruction On Ukrainian Infra". Available at: https://eurasiantimes.com/ukraine-war-iran-modified-shahed-136-kamikaze-drones-for-russia.

[8] Richards M. A., Scheer J. A., Holm W. "A. Principles of modern radar". Volume I, Basic principles. Raleigh: SciTech Publishing. 2010. 924.

[9] Melvin W. L., Scheer J. A. "Principles of modern radar". Volume III, Radar applications. Raleigh: SciTech Publishing. 2014. 821.

[10] Melvin W. L., Scheer J. "A. Principles of modern radar. Volume II, Advanced techniques". Raleigh: SciTech Publishing. 2013. 872.

[11] Bezouwen J., Brandfass M. "Technology Trends for Future Radar". 2017 – Available at: http://www.microwavejournal.com/articles/29367-technology-trends-for-future-radar.

[12] "Radars 2020-2030: Technologies, Future Trends, Forecasts". 2020. – Available at: https://www.e-ir.info/2014/01/09/modern-militaries-and-a-network-centric-warfare-approach.https://hafenstrom.com/radars-2020-2030-technologies-future-trends-forecasts

[13] Majd M. N., Rarmard M., Chitgarha M. M., Bastani M. H., Nayebi M. M. "Detection-Localization Tradeoff in MIMO Radars". Radioengineering, 2017. 26, 2, 581–587.

[14] Khudov, H., Yarosh, S., Droban, O., Lavrut, O., Hulak, Y., Porokhnia, I., Yarovyi, S., Rogulia, A., Yuzova, I., & Khudov, R. "Development of a direct penetrating signal compensator in a distributed reception channel of a surveillance radar". Eastern-European Journal of Enterprise Technologies, 2021. 2(9) (110), 16–26. https://doi.org/10.15587/1729-4061.2021.228133.

[15] Lishchenko V., Khudov H., Tiutiunnyk V., Kuprii V., Zots F., Misiyuk G. "The Method of Increasing the Detection Range of Unmanned Aerial Vehicles In Multiradar Systems Based on Surveillance Radars", in 2019 IEEE 39th International Conference on Electronics and Nanotechnology (ELNANO), 2019. P. 559-562. DOI: https://doi.org/10.1109/ELNANO.2019.8783263

[16] Ruban I., Khudov H., Lishchenko V., Pukhovyi O., Popov S., Kolos R., Kravets T., Shamrai N., Solomonenko Y., Yuzova I. "The assessment of detection zones of radars with the additional use of external sources emission". Eastern-European Journal of Enterprise Technologies, 2020. 6/9 (108), 6–17. DOI: https://doi.org/10.15587/1729-4061.2020.216118.

[17] Oleksenko O., Khudov H., Petrenko K., Horobets Y., Kolianda V., Kuchuk N., Konstantinov A., Kireienko V., Serdiuk O., Yuzova I., Solomonenko Y. "The Development of the Method of Radar Observation System Construction of the Airspace on the Basis of Genetic Algorithm". International Journal of Emerging Technology and Advanced Engineering. 2021. 11, 8, 23-30. DOI: https://doi.org/10.46338/ijetae0821_04.

[18] Ruban I., Khudov H. Advances in Spatio-Temporal Segmentation of Visual Data, Chapter 2. "Swarm Method of Image Segmentation". Series Studies in Computational Intelligence (SCI), 876. Publisher Springer, Cham, 2020. 53-99. DOI https://doi.org/10.1007/978-3-030-35480-0.

[19] Khudov G.V. "Features of optimization of two-alternative decisions by joint search and detection of objects". Problemy Upravleniya I Informatiki (Avtomatika). 2003. 5. 51-59.

[20] Lishchenko V., Chaliy V., Khudov H., Zvonko A. "Proposals for Improving of Air Surveillance Informativity in MIMO Radar Systems Based on Two-Dimensional Radars", in Intern. Scient.-Pract. Conf. Problems of Infocommunications. Science and Technology (PIC S&T), 2018, pp. 153–156. DOI: https://doi.org/10.1109/infocommst.2018.8632052.

[21] Khudov H., Fedorov A., Holovniak D., Misiyuk G. "Method of Radar Adjustment with Automatic Dependent Surveillance Technology Use", in Intern. Scient.-Pract. Conf. Problems of Infocommunications. Science and Technology (PIC S&T), 2019, pp. 402–406. DOI:https://doi.org/10.1109/PICST47496.2019.9061245.

[22] Zaimbashi A. Greco M. A. "Multistatic Passive Radar Target Detection Under Uncalibrated Receivers With Direct-Path Interference". IEEE Transactions on Aerospace and Electronic Systems. 2022. 58. 6. 5443–5455. DOI: 10.1109/TAES.2022.3171532.

[23] Ma J., Jiang J. "Compressive Subspace Detectors Based on Sparse Representation in Multistatic Passive Radar Systems". IEEE Transactions on Signal Processing. 2022. 99. 1-13. DOI:10.1109/TSP.2022.3216385.

[24] Liu J., Gong M., Nie Z., Li H. "Subset Selection Strategies Based on Target Positioning Characteristics for Anti-Jamming Technology". Remote Sensing. 2022. 14 (24):6230. DOI:10.3390/rs14246230.

[25] Khudov H., Bashynskyi V., Kovalenko O., Tahyan K., Fakadii O. "The Methods for Improving the Quality of Detection of Inconspicuous Aerial Objects Through the Use of External Radiation Sources". International Journal of Emerging Technology and Advanced Engineering. 2023. Vol. 13. Issue 03, pp. 91–100. DOI: https://doi.org/10.46338/ijetae0323_09.

[26] Lishchenko V., Kalimulin T., Khizhnyak I., Khudov H. "The method of the organization coordinated work for air surveillance in MIMO radar", Paper presented at the 2018 International Conference on Information and Telecommunication Technologies and Radio Electronics, UkrMiCo, 2018. Proceeding. DOI: https://doi.org/doi:10.1109/UkrMiCo43733.2018.9047560.

[27] Khudov H., Diakonov O., Kuchuk N., Maliuha V., Furmanov K., Mylashenko I., Olshevskyi Y., Stetsiv S., Solomonenko Y., Yuzova I. "Method for determining coordinates of airborne objects by radars with additional use of ADS-B receivers". Eastern-European Journal of Enterprise Technologies. 2021. 4/9 (112), 54–64. DOI: https://doi.org/10.15587/1729-4061.2021.238407.

[28] Neyt X., Raout J., Kubica M., Kubica V., Roques S., Acheroy M., Verly J. "Feasibility of STAP for passive GSM-based radar". 2020. . – Available at: https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.158.2101&rep=rep1&type=pdf.

[29] Khudov H., Kovalevskyi S., Irkha A., Lishchenko V., Serdiuk O., Zots F. "The Proposals for Synchronization Positions of MIMO Radar System on the Basis of Surveillance Radars", in Intern. Scient.-Pract. Conf. Problems of Infocommunications. Science and Technology (PIC S&T), 2019, pp. 547–551. DOI: https://doi.org/10.1109/PICST47496.2019.9061284.

[30] Khudov H., Fedorov A., Holovniak D., Misiyuk G. "Improving the Efficiency of Radar Control of Airspace with the Multilateration System Use", in Intern. Scient.-Pract. Conf. Problems of Infocommunications. Science and Technology (PIC S&T), 2018, 680–684. DOI: https://doi.org/10.1109/infocommst.2018.8632141.

[31] Khudov H., Zvonko A., Kovalevskyi S., Lishchenko V., Zots F. "Method for the detection of smallsized air objects by observational radars", Eastern-European Journal of Enterprise Technologies, 2018. 2/9 (92). 61–68. DOI: https://doi.org/10.15587/1729-4061.2018.126509.

AUTHOR INFORMATION

Hennadii Khudov, Head of Department, Department of Radar Troops Tactic, Ivan Kozhedub Kharkiv National Air Force University, Ukraine

Kristina Tahyan, Senior Researcher, Department of Armament of Radars, Ivan Kozhedub Kharkiv National Air Force University, Ukraine

Vitaliy Lishchenko, Senior Lecturer, Department of Armament of Radars, Ivan Kozhedub Kharkiv National Air Force University, Ukraine

Halyna Misiuk, Senior Researcher, Department of Anti-Aircraft Missiles, Ivan Kozhedub Kharkiv National Air Force University, Ukraine

Volodymyr Bashynskyi, Chief Researcher, Central Research Institute of the Armed Forces of Ukraine, Ukraine

Oleksii Fakadii, Chief of Department, Department of the Command and Control, National Defense University of Ukraine named after Ivan Cherniakhovskyi, Ukraine

Oleh Maslenko, Senior Researcher, Defence Intelligence Research Institute, Ukraine

Maksym Herda, Leading Researcher, Defence Intelligence Research Institute, Ukraine

Tetiana Lavrut, Senior Researcher, Department of Military Management Systems, Hetman Petro Sahaidachnyi National Army Academy, Ukraine

Volodymyr Nedilskyi, Senior Researcher, Department of Research Laboratory, National Academy of the National Guard of Ukraine, Ukraine