Journal of Physical Science, Vol. 34(3), 37–52, 2023

Issue of VHF Continuous Emission Radars Coordinate Measurement Discrepancy

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Published Online: 6 December 2023

To cite this article: Vasiliev, I. et al. (2023). Issue of VHF continuous emission radars coordinate measurement discrepancy. *J. Phys. Sci.*, 34(3), 37–52. https://doi.org/10.21315/jps2023.34.3.3

To link to this article: https://doi.org/10.21315/jps2023.34.3.3

ABSTRACT: *The research delves into the significance of continuous emission radars of very high frequency (VHF) range in detecting small unmanned aircraft and marine targets for navigation safety. Recognising the need for improved radars and reduced coordinate measurement errors, the study aims to analyse discrepancies in azimuth and range determination in radars with fixed-phased antenna arrays. By developing effective tools with low computational complexity for target azimuth determination, the research seeks to enhance radar performance. Employing analytical, classification, functional, and statistical methods, the study comprehensively examines the peculiarities and differences of radars. It meticulously analyses coordinate measurement errors and investigates their causes. The impact of these discrepancies on radar performance and their relevance in various applications, particularly maritime navigation, is carefully evaluated. The findings emphasise the critical role of continuous emission radars in ensuring shipping safety and economic efficiency. The recommendations derived from the study offer valuable insights for improving radar effectiveness, addressing operational limitations, and enhancing overall functionality. By tackling coordinate measurement errors and providing accurate azimuth determination tools, this research contributes to advancing continuous emission radar technology and its practical applications. Through its findings and recommendations, the study aims to optimise radar performance, enhance navigation safety, and improve economic efficiency in diverse sectors.*

Keywords: low-speed, safety, azimuth, antennas, unmanned aerial vehicles

1. INTRODUCTION

One important element in missile warning systems for detecting small, long-range targets, such as ballistic missile warheads, is continuous radiation radar. Issues in continuous emission radar's very high frequency (VHF) range are certain coordinate measurement errors, related to issues of definition and optimisation of performance in the stages of design, operation, and development. To solve some issues in terms of country security in many areas, and especially in the airspace, it is necessary to introduce the use of progressive and innovative intelligence and warning systems. These are VHF range continuous emission radar systems, which ensure the speed and precision of information. Following Karasev et al., Ship radar stations have an advantage over radio and satellite systems, since their usage does not require additional devices and satellites.[1] It is impossible to say that radars can replace other equipment. Radars are used in a variety of systems, especially in satellites and navigation systems. This device helps pinpoint the location of one object relative to the location of another object and recognises objects that could cause an accident.

Following Eaton et al., certain radar systems can find objects only at close range, while others have a broad range of object detection, they come in different sizes, both enormous and tiny.[2] Radar systems for various purposes can calculate the speed of an object using the frequencies of the signal. The trajectory of an object can be determined by calculating the coordinates over a certain period, this allows us to predict its next position. Following Vierinen et al., radar, optical, optical-electronic, radio- and laser-based equipment are optimal components that allow accurate data on objects in different areas, and even more so in outer space.[3] To get accurate measurement results, proper and proven methods, and algorithms are required. Moreover, many methods are needed to combine the research fragments into a unified result and to make predictions for detecting the location of hazards in outer space.

Dobroiu et al. note that modern radar systems, that utilise electromagnetic waves for various purposes, have made enormous progress in development due to their widespread use in various spheres.[4] It is important to research the problems of emissions in areas with increased forestation. This is necessary for an accurate prediction in radar systems and the correct composition of the algorithm. Following Michler et al., currently, there are few small radar systems, and they are mainly used for fast and accurate searches for unmanned aerial vehicles.[5] These radar systems are effective due to their emission power being very small compared to others, small-sized, low power consumption, and picking up continuous emission signals. But the main advantage is their small size, which makes them unique and easy to use, in the detection of unmanned aerial vehicles and more.[6–8] Most of the open articles of the last five years focus on the specific use of VHF in the study of certain objects and phenomena.[9,10] Occasionally, certain errors in measurements and methods of their improvement are highlighted.[11] Therefore, there is a need to study radar performance to optimise it, improve navigation safety, etc.

The research aims to perform an objective analysis to identify issues and errors in the coordinate measurement in radar at the present stage of development. This objective will provide an opportunity to develop effective methods for more accurate calculation and measurements, as well as minimise errors in the process. The study's findings and recommendations aim to optimise radar performance, enhance navigation safety, and improve economic efficiency in various sectors. It is important to delve into the theoretical aspect of the study, define the concept of "VHF radars" and analyse their characteristics and principles of operation. It is necessary to study the mechanism and identify the problems associated with the development and use of constant radiation radars. It is important to evaluate the potential of constant radiation radars in missile warning systems, study the introduction of new technologies to improve VHF constant radars, investigate methods to reduce errors in measuring coordinates and range when detecting unmanned aerial vehicles and assess the impact on national security and the effectiveness of their development. Based on the results of the theoretical and practical analysis, it is necessary to provide recommendations on the operation of the mechanism, with a special focus on VHF radars. This will provide a solid basis for further research, allowing for a deeper understanding and potential advancement in the field of VHF radars.

2. MATERIALS AND METHODS

The research was conducted in the field of coordinate measurement errors in continuous emission radars applying methods that determine the theoretical and practical content of the object. The analytical method allowed us to highlight the problems of constant emission radar, in the application of the search of small unmanned aerial vehicles, addressing coordinate measurement errors. With the help of statistical methods, the metrics that help analyse the number and causes for measurement errors in VHF range continuous emission radar were considered as well as the implementation of improvement schemes in radar in different areas, the prospects for using this object and development in the sectors of maritime shipping.

Empirical methods were also used, namely the method of modular survey. The causes of discrepancies in determining the azimuth and range in radars with fixed-phased antenna arrays and the efficiency of this mechanism development and its prospect were determined. Radar functional diagram drawings were also presented. The role and mechanism of continuous emission radars in different systems, especially in missile warning systems, their advantages and disadvantages, and their impact on national security were analysed by applying the functional method. The structural-functional method helped to analyse the trends, factors, and models of constant emission radar and to determine that to solve the problems with errors in coordinate measurements, to improve maintenance of constant emission radar and its components, to develop new formulas to reduce inaccuracies in measurements, define and optimise metrics in the design stages of constant emission radar, the increased government funding a new approach to control a system, and development of constant emission radars and its components alongside the improvement technology quality in the field is necessary. The deduction method allowed us to identify the concept of "constant emission VHF range radar" through the prism of highlighting its characteristic features for a complete analysis of the operation and its issues. Applying the method of synthesis, allowed us to summarise the results of theoretical and practical nature and identify recommendations that contribute to solving problems and improving efficiency, perspectives to reduce errors in coordinate and range measurements, development in modelling and design of radar components, namely for the VHF range constant emission radar systems for missile warning systems and in marine navigation systems.

As such, this research was conducted in several stages. The first stage consisted of disclosing the theoretical aspect of the research, namely in defining the concept of "VHF range constant emission radars" and analysing the characteristics and principles of this operation; in particular, in missile warning systems and maritime navigation. The second stage was based on the study of the mechanism and problems of the approach to the development and application of constant emission radars, their advantages and disadvantages, their operation, and the analysis of their functionality in various areas. An important step of this stage was to analyse the perspectives of the constant emission radars in missile warning systems, to implement the new technologies to improve VHF range constant emission radars, to study ways of reducing errors in measuring coordinates and range while searching for unmanned aircraft and to highlight the impact on national security and the effectiveness and prospects of its development. The third stage, based on the results of theoretical and practical analysis, provided an opportunity to highlight problems and recommendations for the mechanism operation, especially for the VHF range constant emission radar, which will contribute to the solution of these issues and development in different systems.

3. RESULTS

To ensure the safety of Kazakhstan's population, it is necessary to improve missile warning systems, especially in terms of accurate measurements of the VHF range constant emission radars, which are most often used. Long-term coherent signal accumulation and the ability to detect targets at short distances make the use of meter wave range constant emission radars useful for the detection of small unmanned aerial vehicles and maritime targets. Meter-wave radar systems have low environmental absorption, especially in the air, making them popular and optimal to use for many applications. An important issue that currently needs to be addressed is the errors in the measurement of coordinates and range in the VHF range constant emission radars and their simulation, the reliability of the measurement results, and the effectiveness of their operation and development in these areas. In the operation of radars with fixed-phased antenna arrays, it is necessary to find and address the causes of errors in determining the azimuth and range. Fixed phased array antennas allow communication in dynamic mode. When a plasma cloud appears, a conducting surface is formed, which is a transmitter, but if the cloud is not formed, the antenna has a small value of the effective scattering area. In most cases, the use of these antennas can greatly increase the stealth capabilities of radio communication.

The development of scientific methods to solve the problems of coordinate and range measurement errors in VHF range constant emission radar in various systems at the moment has huge progress and prospects. Computational dependencies are carried out to determine the maximum limits of the antenna system, allowing the determination of the azimuth of the targets by formulas with low computational complexity. If constant emission radars begin to use modern electronics and computerised data processing, this will greatly increase radar capabilities as an atmospheric research tool. The challenge of missile warning systems mode effective management, their usage problems, and the development of innovative radars are becoming increasingly relevant and practical. VHF range constant emission radar has traditionally been used in missile warning systems to detect small, long-range targets, such as ballistic missile warheads. This radar type uses a constantly transmitted pseudo-random signal and has many advantages over other radars. In this complex process, the revision of the measurement errors caused by constant emission radars and their solution is of particular importance since the development of this mechanism in Kazakhstan is one of the topical modern problems. The reason for this is the increased efficiency of the target scattering area at frequencies, at which the radio wavelength is comparable to the dimensions of the radio signal wavelength due to the resonant over-radiation of the radar station signals. Very often distance measurements in continuous emission radars have errors, which reduces the efficiency of the radar system. In general, the problem of optimising the error mitigation in coordinate measurements in constant emission radars is not completely solved.

An important reason for using constant emission radars in missile warning systems was the possibility of long-term coherent accumulation of radio signals reflected from targets. Radar systems are often used in a variety of applications for measurements. To improve data quality, it is necessary to improve reliability and reduce measurement errors. Currently, to detect small-sized long-range targets, VHF range constant emission radars are the most widespread and developed. A feature of constant emission radars is the ability to detect targets at short distances, as they do not block the receiver during the emission of the probing pulse, which happens in pulsed radar systems. These radars also allow finding the location and distance of objects in the sea, mainly ships. A prerequisite for the reliable operation of constant emission radar systems is ensuring stable operation, both of elements and the system as a whole. Many studies in this area have shown that long-term coherent accumulation of signals in the VHF range allows the detection of small boats at distances up to 20% greater than the radio horizon range. Specially designed radar systems help to accurately mark the size and shape of the object and to find differences between these objects.[12]

VHF range constant emission radar systems in the country have a huge potential for development and a longer implementation practice than other radar systems. It is important to study the peculiarities of using constant emission radar systems to detect unmanned aerial vehicles at ranges up to 150 m, to not make mistakes during the mechanism used. For the efficiency of measurements and operation in general, it is necessary to constantly improve this mechanism for the results to be more accurate and of higher quality.[13] The problem of optimisation and reduction of errors in coordinate measurements in constant emission radar systems is still relevant and unsolved due to the lack of attention to this issue. The research provides information on constant emission radar, which is the detection of unmanned aerial vehicles at a range of 500 m with a transmitter power of 10 watts. This has a huge advantage for the operation in various fields. It is possible to calculate field attenuation accurately and easily in different environments by conducting experiments, but it will be more difficult in the forest environment due to the heterogeneous structure, the huge vegetation, and the parameters of the soil.[14]

Addressing issues about reducing errors in coordinate and range measurements requires the introduction of effective simulation tools for VHF range constant emission radar and its elements. Almost all experiments with constant emission radars to detect drones are carried out in C, X, Ku and K bands. One of the promising projects to create a small-sized constant emission radar system is NanoSAR. These mechanisms operate on different frequency bands, which helps clear and quickly identify and detect objects at any time of day, in dusty and smoky conditions of the reconnaissance area. The rapid development of continuous-beam radar design at this time will help in effective problem-solving at greater speed and bring the quality of the obtained results to a new modern level. Conducting calculations that show the ability to detect unmanned aircraft at ranges up to the radio horizon in the VHF range is now of great relevance. Radar systems of direct detection are easy to design and simulate as well and in the calculation of the amplitude of the radio signal, their voltage is proportional to the signal power and distance, which has a significant influence.[15]

Constant emission radar systems require improvement in all directions, and it is especially necessary to increase the environmental and economic level of development. Based on calculations showing the possibility of detecting unmanned aerial vehicles at ranges up to the radio horizon in the VHF range, a scheme of building a constant emission radar of the meter wave range, for the detection of low-speed low-sized objects can be proposed. The mathematical description of the constant emission radar systems operation makes it possible to achieve the control of the emission characteristics of being possible not only by changing the resonant frequencies of the circuit material and antenna sizes but also by forming a multi-mode emission.[16] For accurate modelling and design of constant emission radar system elements, it is necessary to consider possible errors in coordinate and range measurements as most of the inaccurate results of the process occur because of this. The theoretical basis for building constant emission radar systems is described sufficiently, but there are some specific limitations in the design of VHF radars, related to the fact that large frequency changes cannot be used on these bands due to the restrictions on electromagnetic compatibility. Different ways, namely remote methods, reduce some errors in observing, which appear due to various flaws, deficiencies in the radars, and insufficient accuracy due to the great distance to the target.[17]

At the moment the problems of VHF range constant emission radar systems' element reliability are significant, and some experience in improving the reliability and perceptiveness of radar systems in different ways is currently available. This defines the need to closely analyse the limitations of meter-range radar systems at small scanning ranges. The transmitter, which is used to increase the power, generates some radio signals of small frequencies and algorithms according to the capabilities of a continuous-beam radar system, which is called the probing signal. There are certain complications in the calculation of VHF range continuous emission radar functioning processes, detection and identification of the most vulnerable elements, and finding the best method of solving these problems. The functional diagram of the considered radar system is shown in Figure 1. The transmitting antenna of the radar system (TX) is located on the same line with two receiving antennas (RX1, RX2), at an equal distance of them. The distance between the receiving antennas is L.

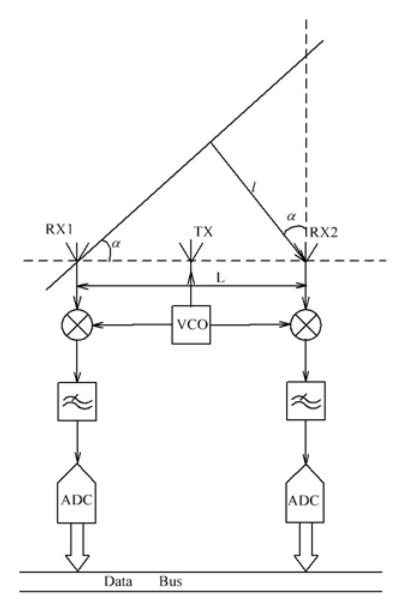

Figure 1: Functional scheme of radar system.

Note: ADC – analog-digital converter; VCO – voltagee-controlled oscillator.

The signal reflected from the target, located at an angle α concerning the normal to the line of antenna location, passes an additional path l, due to which there is an additional phase shift of the signal, carrying information about the azimuthal coordinates of the target. In the aspect of the impossibility of a controlled movement of the Earth's artificial satellites by the network of the radar system located above it, the large orbits are highly elliptical with apsis in the southern hemisphere. The task of reducing measurement errors is complicated by the fact that the objects in question are composed of expensive elements with improved parameters and innovative nature of the operation. When the start time of the measurement of the echo signal changes, the phase difference of the signals received by the receiving antennas should also change. Thus, if, during one frequency scanning period several measurements of the signal from the target will be consistently made, it is possible to eliminate the ambiguity of azimuth determination. Figure 2 demonstrates a timing diagram of the signal measurement process in constant emission radar systems.

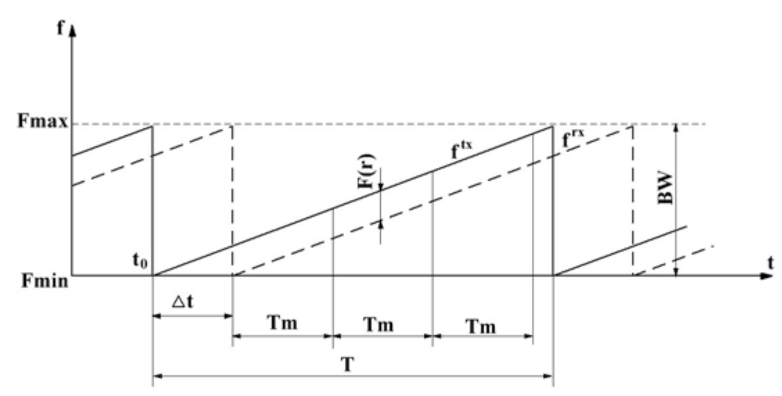

Figure 2: Change time cycle.

Note: F_{max} – maximum scan range frequency; F_{min} – minimum scan range frequency; t_0 – start of probing cycle; T – scan period; BW – band operating frequencies; F(r) – frequency of the received signal reflected from the target at a distance r from reder system; f^{tx} – transmitted signal; f^{rx} – received signal; T_m – minimum value of measurement duration; – target echo delay.

Measurements that are made at the same locations, but at different distances, will have different results. The results of the modern research on VHF range constant emission radar problems, which can be used in different fields, revealed the following conflicts: between new technologies for the design and simulation of reliability of constant emission radars and the lack of adequate means of organising this process; between the importance of training qualified personnel to ensure error-free operation of radar systems and the discrepancy of workplace organisation to ergonomic requirements and the insufficient number of qualified personnel to ensure error-free operation of radar systems and discrepancy in the organisation of quality education computer programs for effective implementation of the process. Existing radar systems for detecting short-range unmanned aerial vehicles have shown that the radars are built on the principle of direct conversion radar. Constant emission radar systems have short ranges and low power in terms of emissions, which is suitable for the use of close-range drones. The properties and features of these VHF range constant emission radar systems allow for finding ground and air objects, depending on the required conditions of different tasks.

4. DISCUSSION

The quality of research conducted by VHF range constant emission radars for detection of small, unmanned aircraft and marine targets and their effectiveness is one of the most topical issues of modern times, and some problems require immediate solutions. For example, the decline of the output signal level, if the distance is increased, allows the calculation of the ranges of constant emission radar systems, which are about 1–2 m. It is not particularly effective to study and solve some problems. The research on the operation of radar systems allowed a better understanding of the causes of errors in coordinate and range measurements, to assess the possibility of solving these problems and to identify at what stage they may appear. Due to the design features and radiation characteristics in radars, it is also possible to reduce the length of the transmitter.[18] It is worth noting that in the development of the design and modelling of constant emission radar systems, Kazakhstan has made a large step forward in the past few years. It is impossible to use only radar-bearing methods because many other methods will be more accurate and efficient in obtaining certain results and measurements.

During calculations of coordinates and range in radar systems and their elements for the detection of small, unmanned aircraft and maritime objects, the models must adequately describe the process, and be simple and implementable. One of the performance metrics of a VHF range constant emission radar is the average power of the emitted signal, sometimes there may also be peak power, but this is rare. Most constant emission radars have short pulses that are signals, as a result, some elements, namely antennas, can be applied in different modes, split time, transmit, and receive.[19,20] The primary role in ensuring the effectiveness of constant emission radar systems for the detection of small unmanned aerial vehicles and maritime targets is played by the professionalism of personnel and frequent diagnostics of equipment. According to recent studies by Gouveia et al., the increased forestation interferes significantly with the expansion of the VHF constant emission radar waves, mainly due to the average properties, which can be a weak field, which is appropriate for forested areas due to their vegetation soil cover and structure inside, and the polarisation of the emission.[21] Solving the problems with modelling and finding approximate values of the linear attenuation is not enough to isolate and compare the individual elements. The whole mechanism of constant emission radar systems was analysed, and in the end, it was decided that to apply different structures, especially theoretical ones, it is necessary to have accumulated basic knowledge to denote the physical devices and their number, which will help to understand the process of wave distribution in the forest environment under given conditions.

Some problems that are related to insufficient professionalism of personnel can be solved with the use of special programs for professional development, so improving the skills of working personnel is a priority in the training of specialists, which contributes to the professional development of communication workers and activates their regulatory framework for quality maintenance of radar systems. Following Ren et al., this mechanism is a complex processing algorithm in radio signal receivers despite the simple architecture of small-sized constant emission radar systems.[22] The results can improve the quality and accuracy of images but also can be proof of information about terrain sensing. Small-size radar systems can be used to obtain images and pictures of radar system surveys with very large measurement characteristics, which will help to create and modernise the plans of the topographic map, as well as the basis of cartographic maps.[23] This demonstrates that in the design and modelling of small-sized constant emission radar systems, it is necessary to consider all factors that affect the quality of radar imaging. As the fact that small-sized radar systems contribute to the solution of multiple tasks of the country, for example, accurately calculating the environment and terrain, providing and creating a three-dimensional picture of surfaces, and studying the ways in any environment and surface, especially the ground.[24–26]

Analysis of the factors determining the errors and their causes of occurrence in constant emission radars has identified the measurements in which the most errors occur, which include the determination of the azimuth and range. Researchers Liu and Liu determined that a heterodyne class receiver can be very susceptible, to the voltage output which is determined by the received signal and its amplitude, mixed with the heterodyne signal.[27] This receiver is used in a variety of applications, especially constant emission radars and radio communication systems. But when modelling the systems of matrix radio vision, even when the employment of a receiver of this class may complicate the process, due to the massive number of receiving elements and power distribution in many elements.[28,29] Therefore, it is important to consider the peculiarities of using this type of receiver: a timely study of data and possible causes of failures for further promising development of the receiver application in radar systems. The advantage of measurement error cause analysis lies in the fact that it will make it possible to design more influence-resistant elements of radar systems, based on the information about coordinate measurement errors in VHF range constant emission radars. Pfanner et al. determined that the comparison of the radiation characteristics for plasma antenna and aluminium di-field shows that the use of plasma antennas allows for saving all the most important characteristics of the transmitter, directivity, efficiency, and range of operating frequencies.[30]

The results of this performance comparison were analysed and more accurately investigated, which allows us to conclude about the effectiveness of plasma antennas, and how their usage allows for reducing radio noise.

The current state and complexity, a significant number of measurement errors, and constant emission radar systems require workers to constantly comprehend the modern challenges, and dynamic and flexible solutions, adjusting to the situation during the operational process. Michler et al. have demonstrated in their works, that for direction finding the mark must meet all the requirements, and then the distance can be calculated.[31] If the mark of the machine is suitable for calculating the distance to them, it is not suitable for direction finding. It is important to select only a few methods of ship location from a large number, either by visual bearing and radar ranging, by hook distance, and by some bearing and radar distances. This method may be modified to suit the properties of the observed mechanism. Other variations of the sighting and radio directional constant emission radar systems usage cannot be as useful and effective due to them having insufficient accuracy in contrast to the presented.[32,33] One of the challenges in recent years was to significantly improve the communication and implementation of new technologies, to improve the performance of the constant emission radar system, and to prevent a large number of measurement errors. As noted by Wang et al., receiver switches help one antenna to function on broadcast, preventing disturbances of a receiver during its pulse generation period, and on receive, bending this bounced signal to the receiver rather than to the transmitter.[34]

Furthermore, receivers in constant emission radar systems can also store energy while transmitting, as well as leave the energy of the bounced signals when received.[35–37] This works as a visual selection, providing angular expansion and similar system operation capabilities. It is necessary to increase the funding and qualification of workers, to start introducing new technologies to improve the design and modelling of constant emission radar systems and to reduce errors in azimuth and range measurements in these radars.

5. CONCLUSIONS

Based on the research findings, several important conclusions can be drawn. The main challenges faced by VHF range constant emission radars in detecting small unmanned aircraft and maritime targets include insufficient training, inadequate radar system modelling and design, and multiple errors in coordinate measurements. These issues are of ongoing relevance and require further investigation. The results indicate a viable approach to address the uncertainties in target azimuth calculations by conducting multiple measurements within a single repetition period of the probing signal. This research successfully identified effective tools for determining target azimuth using computationally efficient formulas.

To improve the signal-to-noise ratio when determining the target range, the Fourier transform can be performed for the full sample volume. In the second stage, the transform can be done on reduced samples to determine the phase change and, accordingly, to eliminate the ambiguity of azimuth determination. All set goals of issue research, namely, to describe problems of VHF range constant emission radar and analyse them more precisely. The solution to the measurement error issue was also proposed, which will allow employing the mechanism effectively. The condition, the fulfilment of which in the design of radar systems of continuous radiation allows for neglect of the quadratic term in the computational expressions and reduces the need for computing resources, is considered and analysed. Dissected modern approaches to the problems of constant emission radar networks will respond to modern needs for further perspective use. Further research will focus on identifying and solving radar transmitter problems and on developing a modern calculation methodology for numerical experiments in this area.

6. ACKNOWLEDGEMENTS

This research is made as a part of a study, funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan (Grant No. BR109009-0221).

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