ABSTRACT

of the dissertation work on the topic:

"**RESEARCH AND DEVELOPMENT OF SPECTRAL-CORRELATION METHODS FOR DELAY ESTIMATION AND DIRECTION FINDING OF RADIO SIGNALS**",

submitted for the degree of Doctor of Philosophy (PhD)

speciality 8D06201 - "Telecommunications"

SABIBOLDA AKEZHAN MURATULY

Purpose of the work.

The aim of this thesis work is to investigate spectral-correlation methods for delay estimation and direction finding of radio signals by developing a mathematical software model.

Objectives of the study:

- analysing the current state of existing methods for estimating the delay and bearing of radio signals;
- development of a digital spectral-correlation method for determining the delay and bearing of radio signals;
- development of software mathematical model of spectral-correlation method for measuring delay and bearing of radio signals;
- Analysing the speed and accuracy of the developed method for determining the delay and bearing of radio signals.

Based on the research work carried out, the methods presented and the tasks to be solved in this thesis aim to achieve the overall objective set out above

The **object of research** is the process of signal processing in difference-distance radar systems.

Research Methods

The main research methods and analyses applied in carrying out the thesis work include:

The first section uses methods of comparative analysis and evaluation of potential characteristics of modern passive and semi-active radar systems, methods of estimation of radio signal parameters and navigation parameters of air targets. The second section uses methods of digital temporal, spectral and spatial analysis of radio signals, methods of statistical evaluation of the accuracy characteristics of measuring signal parameters, methods of mathematical modelling of radio systems and signals. The third chapter uses mathematical and software modelling, methods of statistical evaluation of measurement results.

Main points (proven scientific hypotheses and other conclusions that constitute new knowledge) put forward for defence

- the results of research on studying the spectral-correlation method of radio direction finding, providing an increase in speed and productivity;

- results of a software model to investigate a digital spectral-correlation method for determining the delay and bearing of radio signals with minimum cost;

- results of theoretical and experimental studies of the error of the digital spectral-correlation method of measuring the delay and bearing of radio signals for different conditions of radio monitoring;

- results of analytical and experimental accuracy characteristics of the digital spectral-correlation method for measuring the delay and bearing of radio signals;

- experimental confirmation of the effectiveness of the software model of the developed methods and tools and their main characteristics, allowing to optimise the parameters of signal processing in accordance with the given conditions of radio monitoring.

Justification of the need to conduct research work

Modern radio monitoring systems face the challenges of a highly dynamic air environment and an increasing number of radio-electronic devices. In such an environment, it is necessary to ensure effective target parameterisation with high accuracy and minimal hardware costs. This is particularly relevant for semi-active and passive radar systems (PARLS), which provide stealthy operation and high survivability, unlike active systems.

Positional methods, such as difference-dalimeter methods, are promising for determining the position of targets. When using them, it is important to take into account not only the accuracy but also the speed of signal processing, which is especially important in conditions of high interference saturation. Spectral-correlation methods allow to determine time delays and directions of radio signals with minimum hardware costs, but require high computing power. To solve this problem, we propose a new digital spectral-correlation method, which provides estimation of delay and bearing of radio signals in one iteration, thus significantly increasing the system performance.

Description of the main results of the study

1. The first section reviews modern methods and means of passive and semi-active radar. The methods of construction of semi-active systems, different approaches to measurement of parameters in such systems are considered, and also existing PARLS and methods of calculation of mutual uncertainty function are analysed, which allows drawing conclusions about optimal methods for direction finding.

2. In the second section, a digital spectral-correlation method for measuring the delay and bearing of radio signals in difference-dalimeter systems is developed. Triangulation methods, difference-dalimeter methods, and angle-measuring methods are described in detail. As a result of the analysis, the feasibility of the spectral-correlation method is proved to improve accuracy and speed. An algorithm has been developed that provides the ability to accurately determine the direction and delay of radio signals at low signal-to-noise ratio.

3. In the third section, an experimental study of the developed method using mathematical modelling is carried out. A software model is presented, the functionality of which allows to investigate the accuracy characteristics of the method. In the course of the experiments, the dependences of RMS errors in direction and delay on various parameters, such as signal-to-noise ratio, type of "window" for spectral analysis, and antenna base, were investigated. The obtained results confirmed the high efficiency of the method under various radio monitoring conditions.

Justification of the novelty and importance of the results obtained

The novelty of the work lies in the development of a high-performance digital spectral-correlation method for determining the delay and direction of radio signals in semi-active and passive systems. As a result:

- For the first time a method is proposed that provides estimation of signal parameters in one iteration, which significantly improves the speed of performance.
- Studies have been carried out showing high accuracy and immunity to interference in complex electromagnetic environments.
- A software model has been developed and tested, which can be used in radio monitoring systems to improve their efficiency.

Technological novelty of the research: The proposed method is characterised by the use of a digital antenna array and adaptive spectral signal processing, which allows achieving high direction finding accuracy and reducing hardware costs. These results can be applied to real-world radio monitoring and radar applications to improve performance and noise immunity.

The practical value of the work is as follows:

– In the development and implementation of a new method of spectral-correlation analysis to improve the accuracy and speed of radio direction finding in complex electromagnetic conditions, thus improving the performance of radio monitoring systems.

– In creating and testing a software model for digital radio signal processing that adapts to low signal-to-noise ratio conditions, which provides system immunity to interference and improves the accuracy of radio navigation parameter determination.

– In the development of an experimental technique to determine the dynamic characteristics of signals and their influence on the parameters of direction finding, which allows a more accurate assessment of measurement errors in real conditions.

– In the proposal of design solutions for the use of digital antenna arrays in radio monitoring systems, which allows to increase their efficiency and reduce hardware costs.

– In the development of recommendations on the practical application of spectral-correlation analysis methods in real radio monitoring systems to improve their noise immunity and performance, which is especially relevant for operational surveillance systems in complex electromagnetic environment.

Relevance to science development directions or government programmes

The topic of the thesis corresponds to the priority direction of science development "Advanced manufacturing, digital and space technologies" and specialised scientific direction "Information and computing technologies" of the National Scientific Council under the Government of the Republic of Kazakhstan. The field of research in accordance with the Classifier of Scientific Directions refers to "Engineering and Technology; Electrical Engineering, Electronics, Information Technology; Telecommunications".

Author's personal contribution

The author's personal contribution consists in a comprehensive analysis of modern methods and means of radio direction finding for semi-active and passive systems, as well as in the development and implementation of a digital spectral-correlation method for determining the delay and bearing of radio signals. The author independently performed modelling and laboratory studies, developed software algorithms, participated in the experimental verification of the proposed techniques, and analysed the obtained data. The results of the research were presented at international conferences, formalised in the form of scientific articles and reports, which confirms the significance of the work at the international level. The total personal participation of the author in each publication was 100%.

Approbation of the work

On materials of dissertation work 6 printed works are published, from them 2 articles in the international peer-reviewed scientific journals, included in DB Scopus/Web of Science:

1. Smailov N., Tsyporenko V., Sabibolda A., Tsyporenko V., Kabdoldina A., Zhekambayeva M., Kuttybayeva A., Bektilevov A., Kassimov A., Abdykadyrov A. Improving the accuracy of a digital spectral correlation-interferometric method of direction finding with analytical signal reconstruction for processing an incomplete spectrum of the signal //Eastern-European Journal of Enterprise Technologies. - 2023. - Т. 125. - №. 9. DOI: https://doi.org/10.15587/1729-4061.2023.288397
2. Sabibolda A., Tsyporenko V., Tsyporenko V., Smailov N., Zhunussov K., Abdykadyrov A., Baigulbayeva M., Duisenov N. Improving the accuracy and performance speed of the digital spectral-correlation method for measuring delay in radio signals and direction finding. Eastern-European Journal of Enterprise Technologies ISSN 1729-3774 1/9 (115) 2022. DOI:10.15587/1729-4061.2022.252561.

Articles in publications recommended by the Committee for Quality Assurance in Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan:

1. Digital spectral-correlation method of measurement of radio signal reception delay and direction finding. Scientific Proceedings of the Military Engineering Institute of Radio Electronics and Communications, No. 3 (49), (September) 2022.https://drive.google.com/file/d/1G9vIQggbB2nvROBxDORqvvFeDod0RM1c/view

2. Investigation of noise immunity of search-free spectral correlation-interferometric radio direction finder for broadband signals. Scientific Proceedings of the Military Engineering Institute of Radio Electronics and Communications, No. 3 (49), (September) 2022. https://drive.google.com/file/d/1G9vIQggbB2nvROBxDORqvvFeDod0RM1c/view

Proceedings of international scientific-practical conferences:

1. Sabibolda, A., Tsyporenko, V., Smailov, N., Tsyporenko, V., Abdykadyrov, A. (2024). Estimation of the Time Efficiency of a Radio Direction Finder Operating on the Basis of a Searchless Spectral Method of Dispersion-Correlation Radio Direction Finding. In: Tuleshov, A., Jomartov, A., Ceccarelli, M. (eds) Advances in Asian Mechanism and Machine Science. Asian MMS 2024. Mechanisms and Machine Science, vol 167. Springer, Cham. https://doi.org/10.1007/978-3-031-67569-0_8

2. Digital spectral-correlation method for measuring radio signal reception delay and direction finding. International Satbayev Conference (2023), Volume 4, 596-603. ISBN 978-601-323-376-5 https://conference.satbayev.university/index.php/journal/issue/view/4/4