

ABSTRACT

the topic dissertation work:

«Research of methods for analyzing signals and determining the location of RES for radio monitoring systems based on low-orbit SSC»

submitted for the degree of Doctor of Philosophy (PhD) in
the specialty «6D071900 - Radio engineering, electronics and
telecommunications»

KULAKAYEVA AIGUL YERGALIEVNA

Relevance of the topic and scientific problem of investigation. In the epoch of fast technological development for improving of citizens welfare and the socio-economic stability of country, the formation and establishment of digital economy in the Republic of Kazakhstan gains a peculiar significance. So, in accordance with the State program «Digital Kazakhstan» approved by the Act of the Government of the Republic of Kazakhstan from December, 12th, 2017 №827 and the Strategic plan of development of the Republic of Kazakhstan until 2025 approved by the Decree of the President of the Republic of Kazakhstan from February, 15th, 2018 №636, one of the key directions is the communication network coverage extension and development of information-communication infrastructure and also the creation of «Smart» cities. In addition, the development and implementation of the standard of the 5th generation mobile connection (5G) apart from the wide-band access imply the possibility of support of different kinds of sensor devices providing the collection of various information in the framework of realization of the technical concept of the Internet of things. Development of the directions mentioned will require a collection, transmission, and treatment of the enormous volume of various information which will lead to the active implementation and growth of new wireless (radio) technology. Such a tendency will certainly increase the demand for using the radio-frequency spectrum (RFS) both for the acting at present time and new being implemented radio electronic facilities (REF). This in its turn will significantly complicate the electromagnetic situation in the conditions of RFS's deficiency and require improvement of functions and mechanisms of RFS radio monitoring. The RFS is the important national limited nature resource which requires the rational and effective use, and it has a great social and economic significance for every country. In connection with that the problem of increasing of the effectiveness of radio monitoring system does not lose its relevance.

The management of radio frequency spectrum and radio monitoring are closely bound to each other. The results of the radio monitoring are very important when managing the RFS on the national and international levels. The main application of the system of radio monitoring is the periodic or permanent monitoring of RFS use. In the Republic of Kazakhstan with accordance with the article 28.5 of the Law «About communication» of the Republic of Kazakhstan from July, the 5th, 2004 the functions of problems of radio monitoring are attached to the Service of exploiting of the system of radio monitoring at the Republican State Enterprise «State radio frequency service» (RSE «SRFS») of the Ministry of digital development, innovation, and aerospace industry of the Republic of Kazakhstan (MDDIAI). The service of exploiting of the system of radio monitoring is the main assistant of the authorized agency on

management of RFS use in its work on distribution, extracting and assignment of the RFS. In connection with that the role of the results of work of monitoring system is very important. In addition, the international telecommunication union (ITU) recommends RFS radio monitoring for 24 hours a day since the majority of the REF use the RFS virtually continuously.

The acting at the present time national system of radio monitoring in the Republic of Kazakhstan realizes its functions and objectives only on the base of the ground-based radio monitoring system consisting of:

- 24 stationary (19 – being serviced sites and 5 – non-serviced sites);
- 15 moving measuring and positioning sites;
- 2 mobile measuring complexes realized on the base of the apparatus and software tools of Russian production («IRCOS» CJSC and «STC» LLC), operating in the frequency range from 30 MHz to 3 GHz;
- 4 mobile complexes for measuring of signals of wireless communication (Rohde&Schwarz, Ascom);
- 3 mobile complexes for measuring of signals of television and radio broadcasting (Rohde&Schwarz, Promax).

However, the ground-based systems of radio monitoring have a range of disadvantages, for instance:

- limited zone of radio accessibility of the radio monitoring system due to the peculiarities of various frequency radio waves propagation, the ground relief, the electromagnetic situation and so on;
- workload and complexity of radio monitoring procedures in the unfavorable climate conditions, particularly in the northern regions of country;
- insufficient quantity of radio monitoring sites all over the territory of country (2724.9 thousand km) and also technical obsolescence of radio measuring equipment;
- ground-based radio monitoring systems are mainly located in big cities and region centers and hence in an under-populated places virtually there is an absence of periodic or permanent radio monitoring of the electromagnetic situation and use of RFS;
- insufficient automation of the radio monitoring system processes.

In addition, it is worth to notice that the deficiency of RFS is observed in big cities where it is complicated to use the radio monitoring ground-based facilities to monitor the RFS occupancy and workload. Using the radio monitoring ground-based facilities the provision with complete and operational trustful information about the real state of RFS in the conditions of megacities is difficult to realize and the management of RFS use in the scale of country is more difficult.

Besides there is an urgent question to the acting national system of ground-based stations of satellite communication (GSSC), for instance, in the most widely used traditional Ku-range (10.7-12.5 GHz, 12.75-14.5 GHz), what is due to the peculiarities of the diagram of ground-based stations antenna's directivity. So, according to the preliminary data of RSE «SRFS» through the group of national communication satellites «KazSat-2» and «KazSat-3» in the Republic of Kazakhstan there are more than 10 thousand GSSC due to Kazakhstani communication operators, and also there

are difficulties with the determination of the number of ground-based stations working through foreign communication satellites on the geostationary orbit.

At the present time the MDDIAI of the Republic of Kazakhstan considers the possibility of using new foreign non-geostationary communication satellite systems like Starlink, OneWeb, SES for providing the Kazakhstani users with the broadband access to the internet. Also in April, 2021 the JSC «Republican center for space communication», the subordinate enterprise of the Aerospace committee of the MDDIASI and the operator SES signed a memorandum about mutual understanding. In the framework of the memorandum it is planned to carry out a joint work in the field of service for satellite communication using a system O3b mPOWER. In the structure of such systems there will be hundreds and thousands of satellites, and also an enormous number of central stations and customer terminals which can provide with various services of broadband communication in much more higher band of frequencies 17,7- 20,2 GHz (space – Earth), 27,5 – 30,0 GHz (Earth – space), which are difficult to monitor using ground radio monitor facilities.

Thus, one of the optimal ways of solution of the problem of increasing the effectiveness and extension of monitoring zone of radio monitoring systems in the Republic of Kazakhstan is the implementation of radio monitoring satellite systems on the base of low-orbiting small spacecraft (SSC). Satellite systems of radio monitoring on the base of low-orbiting SSC possess such advantages like broad visibility and absence of inaccessible parts of earth surface for radio monitoring. Also, it is worth to notice that such systems can be useful for solving of problems with border countries which are bound to each other by the provision with electromagnetic compatibility, and carrying out procedures of international coordination of frequency assignment. In addition, such systems can be used in any climate conditions and with any ground relief not depending on the daytime and season.

Using such systems one can make measurements and obtain the following information:

- about the number of REF which operate in the frequency range under consideration;
- about whether the parameters of the REF correspond to the requirements of normative documents and permission for using the REF;
- search for REF operating illegally.

When conducting the radio monitoring procedure, the parameters subjected to radio monitoring are the range and width of frequency band, field strength, power flux density, radio emission source coordinates, modulation parameters, parameters of unwanted emissions and so on. These data can to any extent help to solve many problems which are related to the rational use and regulation of the national RFS.

Degree of development of scientific problem. The questions of regulation and monitoring of use of radio frequency spectrum and methods of radio emission source locating were considered by such scientists like Rembovsky A.M., Makarov V.V., Volodina E.E., Nozdrin V.V., Kizima S.V., Ashikhmin A.V., Koz'min V.A., Slobodyanyuk P.V., Blagodarny V.G., Andreyev R.N., Konkin V.V., Mukhin I.E., Khmelevskaya A.V., Babanin I.G., Lipatnikov V.A., Tsarik O.B., Kharchemko I.P., Bakulev P.A., Belotserkovsky G.B., Voroshilin E.P., Mironov M.V., Gromov V.A.,

Tikhvinsky V.O, Mazar H., Navarro A., Restrepo J., Souryal M., Zhang J., Chen D., Dexiu H.U., Musicki D., Koch W., Ho K.C., Lu X., Chang D.C., Zhang, Hurtado W., Wang M., Li C., Zhao M.L., Yao G., Mark J.W. and others. Also, the significant contribution to study of problem of use of low-orbiting SSC in the system of radio monitoring were made by the following scientists: Pikul' A.I., Khegay D.K., Shpak A.V., Voznyuk V.V., Zaitsev S.A., Inchin A.S., Aitmagambetov A.Z., Chen X., Wang M., Zhang L., Ellis P., Dowla F. and others.

However, in these scientific works the questions of regulation and monitoring of radio frequency spectrum are considered mainly on the base of ground-based system of radio monitoring and all the studies carried out are related to the use of low-orbiting SSC as a system of radio monitoring and were considered fragmentarily.

The object of investigation is the system of satellite radio monitoring on the base of one low orbiting SSC for the Republic of Kazakhstan.

The subject of investigation is the development of methods of signal analyzing and radio emission source locating by the system of satellite radio monitoring on the base of one low orbiting SSC.

The boundaries of investigation are defined by the fact that the system of satellite radio monitoring on the base of one low orbiting SSC is under the study to estimate the correspondence of the emission parameters of ground-based radio electronic facilities to the norms of approval documents on the use of radio frequency spectrum, and to detect the REF operating illegally on the territory of the Republic of Kazakhstan.

The main idea of the work is to develop requirements for a satellite radio monitoring system based on a single low-orbit SSC, to develop a method for determining the location of the RES and its simulation model to assess the compliance of the radiation parameters of ground-based electronic means with the norms of permits for the use of the radio frequency spectrum, as well as to identify illegally operating REF in the territory of the Republic of Kazakhstan.

The aim of the dissertation: on the base of analysis of the possibility of application of the low orbiting SSC for realizing the radio monitoring of RFS on the territory of the RK, to develop and substantiate the methods of analyzing of signals from radio emission sources, methods of radio monitoring source locating and to develop the simulation model for ground-based radio emission sources locating using the systems of satellite radio monitoring.

For achieving the set aim it is required to solve the following problems:

- to define problem questions and substantiate the necessity of creation of the system of satellite radio monitoring on the base of low orbiting SSC basing on the analysis of the modern state of the radio monitoring system;
- to estimate the energy budget of radio-frequency lines for the system of radio monitoring on the base of low orbiting satellites and to substantiate the necessity of creation of the system of radio monitoring;
- to make an analysis of methods of radio emission source locating;

- to develop new methods for locating of radio emission sources on the base of one low orbiting SSC;
- to estimate the real level of radio signals from low orbiting satellites on the example of existing low orbiting satellite systems for substantiation of creation of radio monitoring satellite systems;
- to develop and substantiate the technical requirements to the radio monitoring system on the base of low orbiting SSC;
- to analyze the existing methods of detection of deterministic signal against the background of noises and to choose the most appropriate one among them for solution of problems of satellite radio monitoring;
- to develop and substantiate the simulation model of the system of satellite radio monitoring for locating of radio emission sources.

Methodology and methods of investigation.

For solution of the set problems the analytical methods, instrumental examinations, methods of mathematical and computer simulation were used.

For experimental verification of theoretical studies in the dissertation work and for estimation of signal level there were taken the results of radio channels monitoring (in the directions Uplink/Downlink) of the satellite system of remote probing of the Earth of the «NC «Kazakhstan Garysh Sapary»» JSC.

Scientific novelty of the dissertation. The scientific novelty of the dissertation work is the proposed and substantiated original method of modernization of the domestic system of radio monitoring on the base of application of one low orbiting SSC, the developed ways of locating of radio monitoring sources on the base of SSC, the developed simulation model of radio monitoring system on the base of one SSC.

Practical importance of the work is confirmed by:

- the act of implementation into the educational process at the International Information Technology University, the department of Radio Engineering, Electronics and Telecommunication, where the investigation results obtained in the framework of the dissertation are applied in the laboratory classes of the following disciplines: «Satellite systems», «Methods of regulation of RFS» for the educational programs 6B06201 – «Telecommunication systems and networks» and 6B06202 – «Radio engineering systems of information transmission» within the preparation direction 6B062 – «Telecommunication»;
- the act of implementation at «Geysler-Telecom» LLC when carrying out the investigation work on the subject «Development of conditions of cooperative use and regulation of interaction on exploiting in the frequency bands 23,6 – 24,0 GHz and 24,25 – 27,5 GHz of REF of the State corporation «Roscosmoc» and REF of standard 5G/IMT-2020 of mobile operators joined to the cooperative enterprise of 5G operators».

The particular theoretical and methodological statements and the developed models proposed in the dissertation have practical importance for the authorized body of the Republic of Kazakhstan with purpose of improving the effectiveness of radio monitoring system for regulation of the national radio frequency spectrum and can be

used for estimation of the correspondence of parameters of ground-based radio electronic facilities to the norms of approval documents about use of radio frequency spectrum, and for detection of ground-based radio electronic facilities operating illegally and improving the electromagnetic situation on the territory of the Republic of Kazakhstan.

Fundamental issues put forward for defense. The following issues are put forward for dissertation defense:

- the possibility of application of the low orbiting SSC for realization of radio monitoring on the territory of the RK is substantiated on the base of studies carried out with real data;

- new methods are developed for radio emission sources locating using one low orbiting SSC, and they are based on angle measuring method with use of scanning antennas on the board of SSC;

- the method is developed for deterministic signal detection using the system of radio monitoring on the base of one low orbiting SSC with application of probabilistic model;

- conceptually new simulation model is developed for ground-based radio emission sources locating using the system of satellite radio monitoring and algorithm of radio emission sources coordinate locating using one satellite.

Description of the main results of the study:

- the increasing role of the radio frequency spectrum in the national economy of the country as an irreplaceable limited natural resource has been revealed, increasing the efficiency of using the radio frequency spectrum as a limited natural resource requires the use of effective methods of its regulation and management and modernization of the current national radio monitoring system;

- it is proved that taking into account the territory of the country, the existing national radio monitoring system of the Republic of Kazakhstan on the basis of ground-based radio control points is currently ineffective;

- an analysis of the energy budget of radio lines was performed, which showed the possibility of using low-orbit small spacecraft for radio monitoring;

- an analysis of the signal levels at the input of the receiver of the radio monitoring system was carried out, which showed that for most of the considered ground-based radio electronic means, the signal/interference ratio is greater than 10 dB, which is acceptable for radio monitoring. However, for the effective operation of the radio monitoring system based on the SSC, it is necessary to use special methods for processing weak signals, the use of on-board receivers with increased sensitivity and antennas with increased gain;

- a method has been developed for determining the location of radio emission sources using a single low-orbit SSC, based on the angle-measuring method, using APAA-type scanning antennas on board the SSC, the coordinates of the location of radio emission sources are determined based on the analysis of geometric ratios of distances and angles between the SSC, radio emission sources and the center of mass of the Earth, bearings on the radio emission source using iterations;

- algorithms and programs have been developed to determine the coordinates of the RES according to the proposed method;

- the sources of errors and errors in determining the coordinates of radio emission sources for the developed method of determining the location of radio emission sources using a single low-orbit SSC are determined;

- the possibility of increasing the accuracy of determining the coordinates of radio emission sources by repeatedly measuring the coordinates of a ground-based radio emission source, where the bearings are determined at several (at least two) points of the orbit of a low-orbit spacecraft, is substantiated;

- the assessment of the levels of real radio signals of the telemetry of the KazEOSat-2 remote sensing satellite on the basis of the national company «Kazakhstan Garysh Sapary» was carried out in order to confirm the theoretical conclusions on the creation of a satellite radio monitoring system and improve the reliability of detection and recognition of radio signals from radio sources. The measurements showed that the maximum level of telemetry radio signals at the input of the on-board measuring receiver is in the range of -85 dBm to -120 dBm, which is acceptable for satellite radio monitoring based on a single low-orbit SSC;

- studies and calculations of the reliability index have shown that the proposed method of signal detection using Kalman filters can make the right decisions with very high accuracy;

- the influence of the Kalman filter decision-making speed on the results of radio signal processing was evaluated;

- preliminary technical requirements have been developed for the characteristics of the radio equipment of the radio monitoring system based on the low-orbit SSC;

- the characteristics of the trajectory of the low-orbit SSC were determined and the coverage (radio availability) of the satellite radio monitoring system based on one low-orbit SSC was analyzed, and the area of radio monitoring of the territory of the Republic of Kazakhstan was determined;

- a simulation model of a radio monitoring system based on a single low-orbit SSC has been developed for educational and research purposes;

- the proposed satellite system will significantly expand the radio monitoring area and accelerate the acquisition of data necessary for analyzing the use of the radio frequency spectrum and can integrate with the existing terrestrial radio monitoring network of the Republic of Kazakhstan and with the ITU international radio monitoring network.

Justification and validity of scientific issues, conclusions and recommendations are confirmed by the publications in journals included in the list of scientific issues recommended by the Committee on control in the sphere of education and science of the Ministry of Education and Science of the Republic of Kazakhstan (MES RK) and indexed in Scopus database; by approving in the domestic and foreign international scientific and practical conferences and forums; by the patents for useful model in the Republic of Kazakhstan and by the certificate about

implementing of the information into the state register of rights for objects copyrighted by authorship for virtual laboratory work.

Also, the proposed technical solutions were used when developing the digital education platform for distance conduction of virtual laboratory works on study of the modern radio systems of super high frequency and extremely high frequency ranges within the grant project №AP08857146 financially supported by the MES RK.

Approbation of work. Basic issues of the dissertation were presented and discussed at the following conferences and scientific seminars:

- scientific seminars of department of Electronics, Telecommunication and Space technology at Satbayev University (2018 – 2021);

- scientific seminars of department of Radio Engineering, Electronics and Telecommunication at the International Information Technology University (2020 – 2021);

- International conference Satbayev readings: «Innovation technology – a key to successful solution of fundamental and applied problems in ore and oil-gas sectors of the economy of the RK, Kazakhstan, Almaty city (2019);

- II International scientific and technical forum: The modern technology in science and education – MTSE-2019, the Russian Federation, Ryazan' city (2019);

- IV International scientific conference: Priority directions of innovation activity in industry, Russia, Kazan' city (2020);

- XXXIII International scientific and practical conference: The issues of technical, physical and mathematical science in the light of the modern investigations, Russia, Novosibirsk city (2020);

- International scientific conference: «Digital Technology in Education, Science and Industry 2020» (DTESEI 2020), Kazakhstan, Almaty (2020);

- International scientific forum: Science and Innovation – modern concepts, Russia, Moscow city (2021);

- LIV International scientific and practical conference «Technical sciences: problems and solutions, Russia, Moscow city (2021);

- International Scientific and Practical Conference: Problems and prospects in the international transfer of innovative technology, Russia, Orenburg city (2021).

Publications on the dissertation.

On the subject of the dissertation work there are 3 patents for useful model in the Republic of Kazakhstan; certificate about implementing of the information into the state register of rights for objects copyrighted by the authorship on virtual laboratory work «Study of principles of radio monitoring system on the base of one small space apparatus», 13 works are published, among them 4 articles in journals included in the list of scientific issues recommended by the Committee on control in the sphere of education and science of the MES RK; 9 articles at International forums and conferences, among them 1 article is indexed in Scopus database; 1 article is published in the journal indexed in Scopus database.

Personal contribution of the author.

The dissertation is an independent study, all results of scientific investigation are obtained by the author personally and independently. The statement of investigation problems, defining the methods of solution and analysis of investigation results are carried out in cooperation with the scientific supervisor and foreign scientific consultant. Also, the author participated as a member of a delegation of the Republic of Kazakhstan at work of group 1C EC-1 Management of spectrum use (working group 1C - Control of spectrum use) of the International Telecommunication Union from the Administration of communication of the Republic of Kazakhstan. The author is a member of the executing group on program «Grant financing for scientific investigations» in the framework of project №AP08857146 on subject «Development of digital educational platform for distance conduction of virtual laboratory work on study of the modern radio systems of super high frequency and extremely high frequency ranges using the technology of virtual reality» supported financially by the MES RK.

The structure and volume of the dissertation.

The dissertation work consists of an introduction, 4 chapters, a conclusion, a list of references of 137 names. The general volume of the dissertation is 135 pages, 74 figures, 10 tables, 7 appendices.