ANNOTATION

of dissertation for the Philosophy Doctor (PhD) degree in specialty "6D071900 – Radioengineering, electronics and telecommunications" by Meirambekuly Nursultan on the topic

"MULTI-BAND ANTENNA FOR SMALL REMOTE SENSING AND EARTH OBSERVATION SPACECRAFTS"

The work is devoted to the development and research of new antenna systems for small Earth remote sensing spacecraft (SC) using methods of theoretical calculations, modeling, creation of experimental models and laboratory research. In the development process, the anisotropic Zhanabaev's fractal (ZhF), a method of integrating antennas with other subsystems, by means of aperture alignment, was used. The results of laboratory experiments and computer modeling are described and compared by a theoretical model. Two types of antennas have been developed, having the function of integration with a remote sensing nanosatellite camera, a patch antenna based on ZhF and a cone-shaped spiral antenna. The impact of this integration technology on the responsiveness and energy security of the spacecraft was also assessed.

Relevance of the topic

CubeSat is a small spacecraft (SSC) standard proposed at the end of the last century. Due to the small size, the launch of such nanosatellites is often carried out on rockets that, according to the plan, put other, bulkier spacecraft into orbit. This significantly reduces the cost of obtaining a modern satellite with great functionality.

The peculiarity of CubeSats is fixed dimensions, which vary by multiples, that is, a CubeSat 1U is a space cube 10×10×10 cm, 2U is two cubes (10×10×20 cm). 1U, 3U and 6U are the three most common and current modifications. Today, the scope of application of nanosatellites is very wide – from educational missions to space observations and communications. Remote sensing occupies a special place among them.

Despite the effectiveness, the small size of CubeSats forces scientists all over the world to look for new ways to solve these problems. To fit full–fledged scientific instruments in a small device is not an easy task. Therefore, the development of new circuit solutions and the miniaturization of onboard systems, modules and their optimal locations, including antenna devices, make it possible to effectively use the limited space on board the spacecraft.

Many nanosatellites in operation or at the design stage use different types of antennas for data transmission (telemetry, imaging, etc.), depending on the mission, spacecraft capabilities and communication range. Wire and ribbon monopole, dipole antennas are widely used for telemetry with low data transmission rates in the VHF

and UHF bands due to the ease of manufacture. The usual monopole or dipole sizes for these ranges exceed the CubeSat surface.

Patch antennas, mainly operating in the L and S bands, are the second most popular due to the low profile, low weight and lack of an additional deployment mechanism.

It is also not uncommon to use fractal geometries to miniaturize and achieve the desired antenna characteristics. These are broadband, multi-band, antenna size reduction, etc.

To date, in practice, remote sensing nanosatellites for antennas and the base of the lens of optical instruments, mainly use separate places on the surface of the SC. This fact means that the antenna systems in the mentioned SSC occupy a separate place on its surface, which could be used to generate solar energy for the system. To solve these problems, antenna systems integrated with other subsystems of the SC are proposed, such as solar panels, an optical shooting system, etc., although there is an underestimation of this technology and is rarely used in practice. At the same time, the integration of the antenna system with solar panels often leads to the shading of the second, which leads to a decrease in the efficiency of solar panels.

The analysis of literature sources shows that the search for the creation and introduction of new types of antennas, miniaturization, and increasing their efficiency is an urgent task, and the use of antenna system integration technology and the use of fractal geometry to solve this problem is promising and research in this direction is carried out by the scientific community working in this direction.

The research done in this paper is related to promising areas of modern radio engineering and telecommunications, where new ideas for the development of antenna systems for the SC are used.

The aim of the work is the development, modeling and experimental study of new antenna systems with the function of integration with an optical system designed for the SC used in remote sensing.

Research objectives

1. to carry out calculations and computer simulation of theoretical models describing the frequency characteristics of new antenna systems;
2. to make experimental models of antenna systems based on calculations and simulation;
3. conduct a study of the electrodynamic characteristics of antennas and compare them with the results of computer simulation;

Objects of research: ZhF-based patch antenna integrated with the nanosatellite camera, cone-shaped spiral antenna with the function of integration with the nanosatellite camera by aperture alignment.

Subject of research:

Electrodynamic characteristics of antennas, such as S11, Voltage Standing Wave Ratio (VSWR), radiation pattern (RP), gain and polarization.

Research method

1. theoretical and numerical methods for the development of antenna systems for remote sensing;
2. computer and simulation simulations in the CST Microwave Studio software environment;
3. experimental study of the electrodynamic characteristics of antennas using a laboratory complex consisting of high-frequency equipment and devices;
4. analysis and comparison of the obtained results of theoretical calculations, computer simulation and experimental measurements.
5. Calculations of the influence of the integration system, by means of aperture alignment, on the SC system.

The main provisions submitted for protection

1. Patch antenna integrated with the camera and corresponding to the dimensions of the side of the CubeSat standard nanosatellite, with a dielectric substrate thickness of 1.6 mm, the radiating element of which is based on the geometry of the first hierarchy of the Zhanabaev fractal (ZhF) has two resonant frequencies in the S band with center frequencies of 2.04 GHz and 2.45 GHz.

2. A dual-band conical helix antenna with an integration function with a nanosatellite camera, where a springy brass wire with a diameter of 1 mm is used as a radiating element, operates in the L- and S bands, at frequencies of 1.7 GHz, 2.45 GHz, where at the corresponding frequencies gain 6.8 dBi and 7.4 dBi.

3. The antenna system integrated with the nanosatellite camera by using one plane due to the combination of shooting and data transmission modes allows avoiding the spacecraft energy consumption when orienting to switch from the shooting mode to the data transmission mode and increases the speed of the nanosatellite orientation by a factor of 2.11 in terms of the nutation angle along compared with the case of a perpendicular arrangement and by a factor of 2.14 in terms of the angle of own rotation compared with the mutually opposite arrangement of the antenna and camera.

The scientific novelty of the work is that for the first time

1. A dual-band patch antenna based on the Zhanabaev's fractal (ZhF), integrated with a remote sensing nanos atellite camera, was developed and investigated by means of aperture alignment;

2. A cone-shaped spiral antenna integrated with a remote sensing nanosatellite camera with operating frequencies in the L- and S-bands has been developed and investigated;

3. Calculations of the influence of the integration system on the work of the spacecraft were carried out.

Theoretical and practical significance of the work

The results obtained in the dissertation work make a significant contribution to the development of the field of space technology and technology, the development of effective antenna systems based on the ZhF, improving the efficiency of SC.

The personal contribution of the author is that the main results of theoretical calculations, computer modeling and physical experiment were obtained personally by the applicant. The task statement and discussion of the results were conducted jointly with scientific consultants.

Reliability of the results

The reliability of scientific results is confirmed by the consistency of theoretical calculations with the results of computer simulation and experimental measurements.

Approbation of the work

9 printed works have been published on the topic of the dissertation.

Articles with a high impact factor on the Web of science database or in publications included in the international Scopus database:

1. Meirambekuly, N., Temirbayev, A. A., Zhanabaev, Z. Z., Karibayev, B. A., Namazbayev, T. A., Khaniyev, B. A., Khaniyeva, A. K. Dual-band optical imaging system-integrated patch antenna based on anisotropic fractal for earth-observation CubeSats // Ain Shams Engineering Journal. -2022. –v. 13(2), doi:10.1016/j.asej.2021.07.010.
2. Meirambekuly N, Karibayev, B.A., Namazbayev, T., Ibrayev G.E., Orynbassar S.O., Samsonenko A.I., Temirbayev A.A. A High Gain Deployable L/S Band Conical Helix Antenna Integrated with Optical System for Earth Observation CubeSats // IEEE Access. -2023. -v. 11. -p. 23097-23106, doi: 10.1109/ACCESS.2023.3253556.

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

1. Мейрамбекұлы Н., Темирбаев А.А., Карибаев Б.А., Намазбаев Т.А. Анизотропты фрактал негізінде жасалған кіші ғарыш аппараттарына арналған S-диапазонды патч антенна //ҚазҰТЗУ хабаршысы. –2020. –№ 3 (139). –С. 325-330.
2. Мейрамбекұлы Н., Карибаев Б.А., Темирбаев А.А., Иманбаева А.К S и X диапазонная патч антенна для наноспутников CubeSat. // Вестник. Серия Физическая (ВКФ). -2021. -v. 78, -n. 3, -p. 90-96.
3. Мейрамбекұлы Н., Карибаев Б.А., Темирбаев А.А. Многодиапазонная антенна на базе второго поколения анизотропного фрактала для малых космических аппаратов дистанционного зондирования и наблюдения Земли. // Известия НАН РК. Серия физика-математическая. –2021. –№5. – С. 42-50.

Publications in collections of abstracts:

1. Мейрамбекұлы Н. Кіші ғарыш аппараттарына арналған S-диапазонды антенна // Материалы международной конференции студентов и молодых ученых «Фараби Әлемі». –Алматы. –2020, -с. 293.

2. Мейрамбекұлы Н., Ханиева А.К. UniSat наноспутнигінің антенна жүйесі // Материалы международной конференции студентов и молодых ученых «Фараби Әлемі». –Алматы, –2021. –С. 208.
3. Мейрамбекұлы Н. Опыт моделирования антенн для малых космических аппаратов. Анизотропный фрактал Жанабаева // Труды Международного научно-технического форума СТНО. –Рязань, 2022. –С. 5-8.
4. Karibayev B., Meirambekuly N., Namazbayev, T., Temirbayev A.A., Kadylbekkyzy E., Yessentaeva A. S band TT&C antennas integrated with optical camera system for nanosatellites. // International Conference on Electrical, Computer, and Energy Technologies, ICECET 2022. –2022, 20-22 July 2022.

Connection of the thesis topic with the plans of scientific works

The dissertation work was carried out within the framework of research in accordance with the plans of applied research works of the science committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan on the topic "Development and creation of S and X band antennas for CubeSat nanosatellites for remote sensing of the Earth", No. AP09057984 on priority: "Information, communication and space technologies"

Structure and scope of the dissertation

The dissertation consists of an introduction, four sections, a conclusion, a list of sources used and contains three appendices. The work is presented on 107 pages of typewritten text, illustrated with 87 figures, 56 formulas, 11 tables are given, and the list of sources used contains 117 titles.