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BROADBAND PARABOLIC ANTENNA WITH SPIRAL RADIATOR FOR UAV COMMUNICATION SYSTEM

Introduction

The operational efficiency of ground control stations for unmanned aerial vehicles (UAVs) directly depends on the characteristics of the antenna system, which acts as the physical interface between the station's electronic units and the radio wave propagation environment. When analyzing ground-based antennas, the following critical parameters [1, 2] can be identified.

1. Gain is a key indicator that determines the ability of an antenna to concentrate electromagnetic energy in a particular direction. In the ground control segment, high-gain antennas are predominantly used to compensate for free-space path loss, which is critical for ensuring communication ranges exceeding 50–100 km. However, increasing gain narrows the antenna's radiation pattern, requiring precise antenna positioning relative to the UAV.

2. Selecting a radiation pattern for the ground control segment is an important compromise between the required coverage area and communication range. Omnidirectional antennas provide 360-degree coverage, but are vulnerable to interference in all directions. Directional antennas have a clear main lobe, which improves the system's interference immunity by "ignoring" electronic warfare signals outside the main beam.

3. Wave polarization can constantly change during active UAV maneuvering due to changes in antenna orientation. The ground segment must minimize these polarization losses. Linear polarization (vertical/horizontal) is simple to implement, but signal attenuation can be as low as 20–30 dB when the UAV tilts. Circular polarization (RHCP/LHCP) is more stable for mobile objects, as it allows communication to be maintained regardless of the UAV's roll angle and better mitigates the effects of multipath signal reflection.

4. Antenna matching is characterized by the voltage standing wave ratio (VSWR) and determines the efficiency of power transfer from the

transmitter to the antenna unit. Low VSWR (ideally < 1.5) minimizes reflection losses, which prevents overheating of the ground control system's power amplifier output stages and ensures the highest possible useful signal amplitude.

5. For ground-based antennas, the influence of the earth's surface and Fresnel zones is a critical factor. Increasing the antenna's mounting height on the mast allows for a wider radio horizon and extends the first Fresnel zone beyond the interference limits, which is crucial for operation at critical distances.

Analysis of recent research and publications

Numerous developments by various manufacturers and research papers have been published on the design principles, modeling, and evaluation of antennas of various designs for UAV communication systems [3]. Most of these publications propose antenna arrays [4] for the ground control segment, consisting of antenna elements of various designs.

The article [5] presents the design of 2×2 microstrip patch antenna array (AA) for a frequency of 3.8 GHz, which has a half-power beamwidth (HPBW) of 33 degrees with a gain of 13.2 dBi. The paper [6] proposes a two-element AA design operating at 2.4 GHz with a gain of 9.14 dBi at HPBW of 60 degrees in the E-plane and 65 degrees in the H-plane. The scientific paper [7] presents the implementation of four linear AA for the frequency range from 2.62 GHz to 2.69 GHz, consisting of microstrip rectangular antennas and operating with the gain of up to 12.2 dBi.

Axial-radiating antenna arrays are often used for ground control systems. Paper [8] proposes compact Yagi-Uda antenna on Rogers RO4003 substrate for the 1.9, 2.5, and 3.5 GHz frequency bands with gains of 6.29, 4.63, and 6.77 dBi, respectively. The objective of paper [9] is to develop compact planar Yagi-Uda antenna on FR-4 substrate for 2.4 GHz WLAN applications with maximum gain of 4.34 dBi. As a result of modeling and experi-

mental study of wideband microstrip log-periodic antennas (LPAs) for frequencies of 2–5 GHz in the paper [10], a gain of more than 6 dBi was obtained across the entire frequency range. Research in the paper [11] demonstrated the design of an LPA for WLAN/LTE/UWB applications in a wide bandwidth from 1.4 to 12 GHz with an average gain of 4.51 dBi.

Quite often, spiral antenna designs are used for such systems. A combination of helical elements of varying lengths allows the construction of a dual-band helical antenna [12] with right-hand circular polarization (RHCP) for frequencies of 1.227 GHz and 1.575 GHz. For these frequencies, gains of 4.44 and 3.87 dBi were obtained at HPBWs of 96 degrees and 122 degrees, respectively. The design principles of wire and microstrip four-element helical antennas for a frequency of 1268.52 MHz are given in the work [13].

The narrowest radiation pattern, and therefore the highest gain and best spatial selectivity, can be formed by parabolic antennas. The purpose of paper [14] is to analyze the performance evaluation of parabolic reflector with horn antenna for communication with frequency operating between 2 GHz and 3 GHz. In paper [15], helical antenna which is used as helical feeder for parabolic reflector is designed and simulated.

Problem statement

One effective solution for generating highly directional, high-gain radiation is the use of parabolic reflector antennas. These antennas are widely used in radio relay systems, satellite communications, and long-distance data transmission systems. The main advantage of parabolic antennas is their ability to achieve high gain with relatively small dimensions.

An important design element of the reflector antenna is a feed source, which determines the reflector aperture filling efficiency, operating frequency range, and polarization characteristics of the antenna. Various antenna types can be used as feed antennas, including horn antenna, microstrip antenna, and helical antenna.

Helical antennas are attractive for use as feed antennas due to their ability to generate circular polarization and relatively wide operating frequency band. Using the helical radiator with reversed radiation pattern allows for efficient irradiation of a parabolic reflector and ensures the required electromagnetic characteristics of the antenna system.

Study aim

The aim of this work is to develop and study the broadband circularly polarized parabolic antenna for the frequency range of 5.7–6.7 GHz using the helical antenna as feed source.

Materials and methods

A parabolic (reflector) antenna consists of the reflector with special profile (parabolic) and the feed antenna, which is weakly directional antenna and is located at the focal point of the reflector [16]. The main task of the parabolic reflector is to transform the spherical wavefront of the feed antenna into flat wavefront (Fig. 1) while forming very narrow radiation pattern. This operation principle of the reflector antennas is based on the properties of revolution paraboloid.

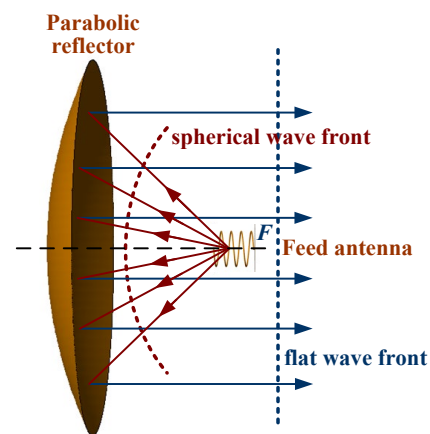


Fig. 1. The principle of field formation by single-mirror axisymmetric parabolic antenna

The feed antenna is positioned at the focal point of the reflector – point F (Fig. 10.1, a). The antenna aperture is shaped like a circle bounded by the edges of the reflector. The distance from the apex of the reflector to the focal point F is the focal length f . If the reflector is parabolic, then the cross-section with any plane containing the axis of symmetry will be parabolic.

A field source at point F creates radiation with spherical wave front. Let a beam be incident from point F onto the reflector surface at an arbitrary point. After reflection, to create narrow radiation pattern, this reflected beam must propagate parallel to the optical axis. This is possible provided that the reflector profile has the parabola shape:

$$\rho = \frac{2f}{1 + \cos \varphi}.$$

The parabolic reflector (Fig. 2) has axisymmetric circular aperture design with the diameter of $D = 313$ mm. The focal length of the reflector is approximately $F = 73.7$ mm, which corresponds to a ratio of $F/D \approx 0.24$. This ratio is typical for deep parabolic reflectors and allows to reduce the overall dimensions of the antenna system while maintaining a high gain.

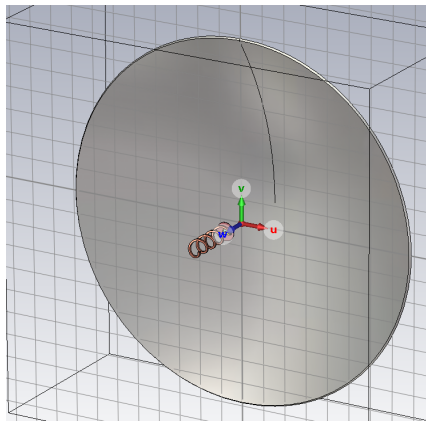


Fig. 2. Design of the proposed parabolic antenna

In the proposed antenna design, the spiral antenna with reverse radiation was chosen as the feed antenna (Fig. 3).

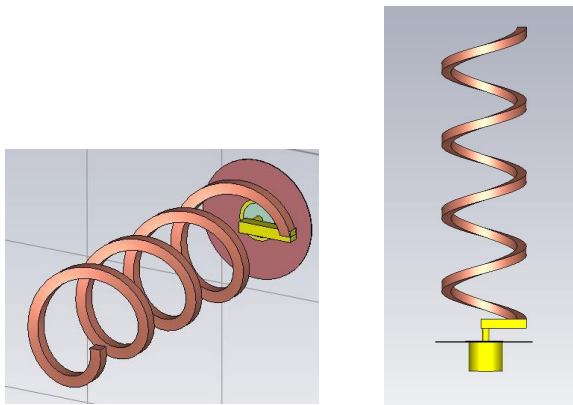


Fig. 3. The spiral antenna design with reverse radiation

Helical antennas are structurally shaped like a spiral, with one end free and the other attached to the central conductor of a coaxial cable. The outer sheath of the cable is connected to a disk, which serves as the antenna's counterweight. The disk can also act as a reflector, reducing radiation in the rear half-space if necessary. Cylindrical helical antenna (Fig. 4) is characterized by a turn length L , a turn diameter $2a$, a helical winding pitch S , and a number of turns n . The antenna length $l = nS$.

When the antenna is fed, different types of waves appear in the helix. The waves in the helix are denoted by the symbol T_q , where q is the number of wavelengths accommodated in one turn.

Wave type T_0 propagates with a phase velocity equal to the speed of light c and exists in the spiral with small turn length satisfying the condition

$$\frac{L}{\lambda} < \frac{L}{\lambda_{\min}},$$

where $\frac{L}{\lambda_{\min}} = \frac{\cos \alpha}{1 - \sin \alpha}$; λ is wavelength;

$\alpha = \arctg \frac{S}{2\pi a}$ is spiral angle.

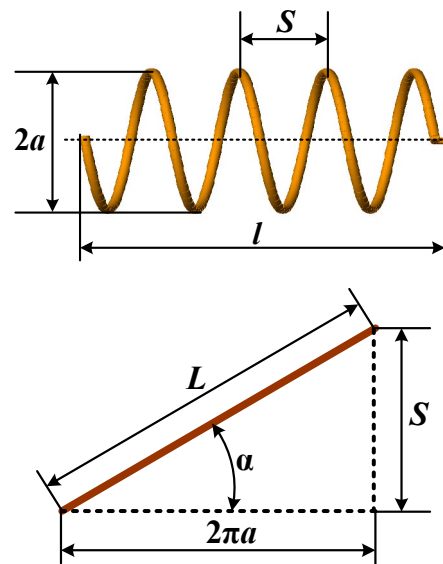


Fig. 4. Geometry of epy helical antenna

Along with the wave T_0 , the wave T_1 propagates, the phase velocity of which is less than the speed of light and depends on the ratio L/λ . The reflected wave T_1 has a very small amplitude, so traveling current wave is established in the helix. This is the axial radiation mode (the most important mode), which exists under the condition that $L/\lambda \approx 1$ or

$$0,25\lambda \leq 2a \leq 0,45\lambda .$$

As the oscillation frequency increases ($L/\lambda > 1$), higher types of waves T_2, T_3 , etc. arise in the spiral. This mode in the spiral is accompanied by practically unused conical radiation.

The main dimensions of the proposed spiral feed are:

- number of turns – 4;
- turn diameter – 11 mm;
- turn pitch – 12 mm;
- spiral counterweight diameter – 11 mm.

The feed's phase center is located at the focus of the parabolic reflector, 73.7 mm along the optical axis, which ensures efficient irradiation of the reflector aperture.

The main results of modeling the characteristics of the proposed parabolic antenna are presented in Fig. 5–12.

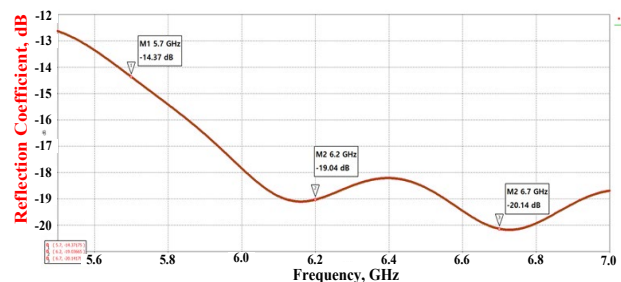


Fig. 5. Dependence of the reflection coefficient of the proposed parabolic antenna on the frequency

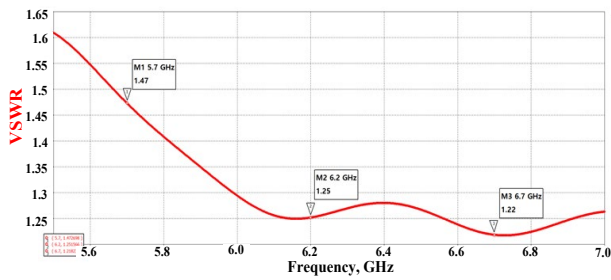


Fig. 6. Dependence of the VSWR of the proposed parabolic antenna on the frequency

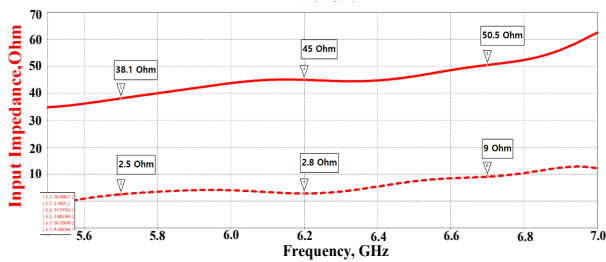


Fig. 7. Dependence of the real and imaginary components of the input impedance of the proposed parabolic antenna on the frequency

Simulations showed that the antenna's operating frequency range reaches over 1 GHz with VSWR < 1.5 (correspondingly, the reflection coefficient less than -14.4 dB). The real part of the input impedance varies between 40 and 50 Ohms, while the imaginary part ranges from 2.5 Ohms to 9 Ohms (Fig. 7).

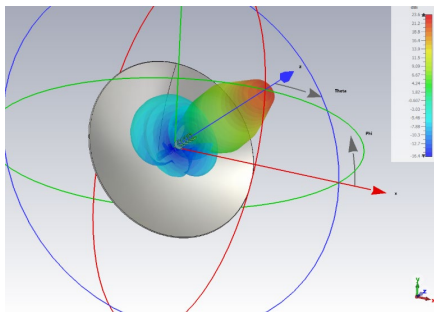


Fig. 8. 3D radiation pattern of the proposed parabolic antenna at the frequency of 6,2 GHz

Simulation results for the parabolic antenna with the helical feed demonstrated the feasibility of forming radiation pattern symmetrical about the optical axis (Fig. 8) with fairly narrow HPBW (Fig. 9 and Fig. 10). The HPBW level was 12.3 degrees for the lower frequency of the range (5.7 GHz) and 9.6 degrees for the upper frequency of the range (6.7 GHz). The sidelobes level does not exceed -15 dB.

The parabolic antenna's gain reaches 23.5 dBi at the lower frequency limit and 23.6 dBi at the upper frequency limit. The axial ratio remains consistently below 2 dB across the entire operating frequency range of 5.7–6.7 GHz.

After modeling the parabolic antenna with a helical feed, a prototype (Fig. 13) was manufactured for the next stage of the study. The experimentally measured matching characteristics are presented in Fig. 14.

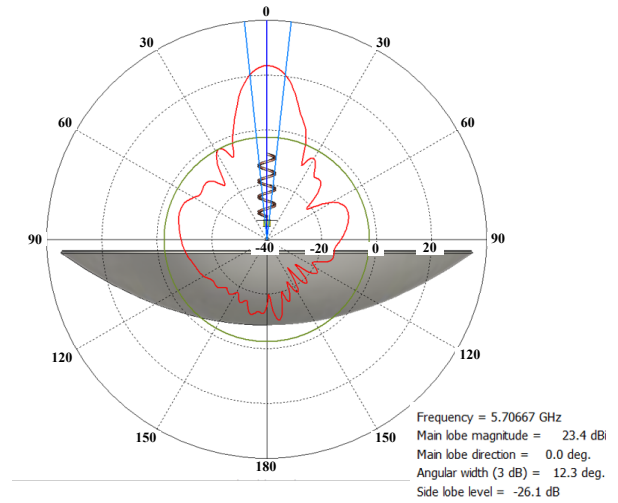


Fig. 9. Radiation patterns of the proposed parabolic antenna at the frequency of 5,7 GHz

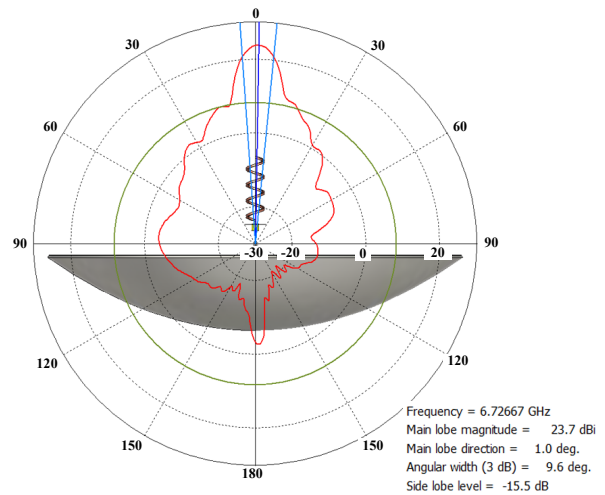


Fig. 10. Radiation patterns of the proposed parabolic antenna at the frequency of 6,7 GHz

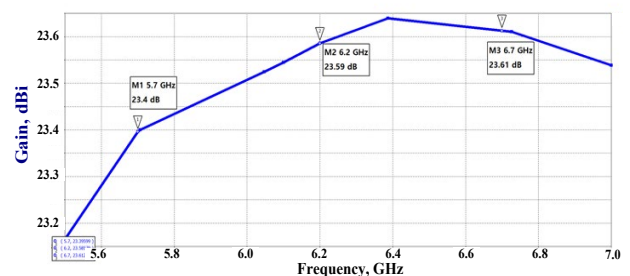


Fig. 11. Dependence of the gain of the proposed parabolic antenna on the frequency in the direction of maximum radiation

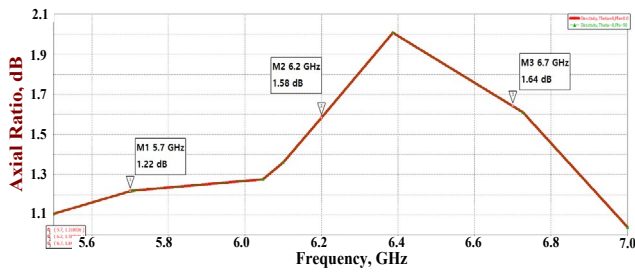


Fig. 12. Dependence of the axial ratio of the proposed parabolic antenna on the frequency in the direction of maximum radiation

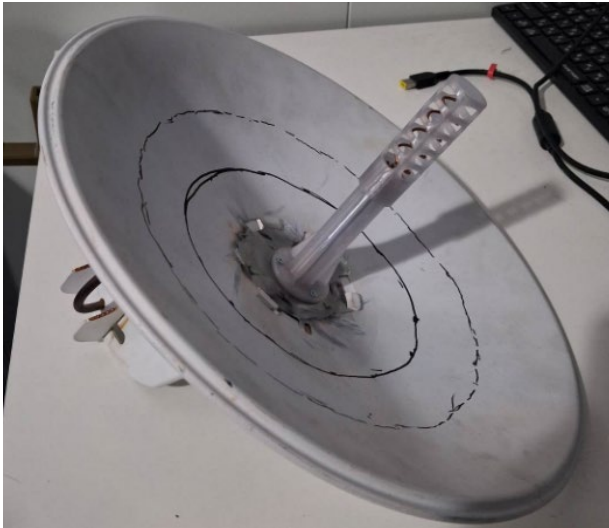


Fig. 13. Prototype of the proposed parabolic antenna

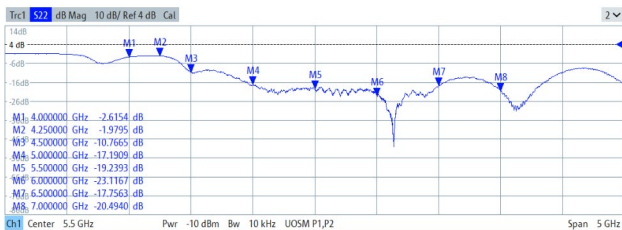


Fig. 14. Experimental dependence of the reflection coefficient of the proposed parabolic antenna on the frequency

The experimental study of the prototype parabolic antenna (Fig. 13) confirmed the modeling results and showed that the antenna's operating frequency range is 1 GHz (5.7 – 6.7 GHz) with VSWR < 1.5 ($S_{11} < -15$ dB).

Conclusions

Antennas are among the most important electronic devices in any UAV communication system, as their performance determines the quality and reliability of communications between the aircraft and other onboard and ground systems. UAV antennas must have a simple, robust, and compact design, easily mounted on both the onboard and ground segments of the UAV system.

This article examined in detail the design principles of a parabolic antenna with a helical feed for the

ground segment of UAV communications. Modeling and experimental study of radiation characteristics and matching of the developed antenna were also carried out.

The results of modeling and research of the experimental sample showed that the operating frequency range of the antenna reaches more than 1 GHz with VSWR < 1.5 (reflection coefficient less than -15 dB), including the required operating frequency range from 5.7 GHz to 6.7 GHz.

Simulation results for the parabolic antenna with helical feed demonstrated HPBW of 12.3 degrees for the lower frequency of the operating range and 9.6 degrees for the upper frequency, which meets the requirements for ground-segment antenna of UAV control system. Sidelobe levels do not exceed -15 dB across the entire operating frequency range.

The gain of the developed parabolic antenna obtained as a result of modeling reaches an average of 23.5 dBi in the operating frequency range. The axial ratio remains consistently below 2 dB throughout the entire operating frequency range of 5.7–6.7 GHz.

Acknowledgement

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REFERENCES

- [1] C.A. Balanis, *Antenna Theory: Analysis and Design*: 4th Edition, New Jersey: John Wiley & Sons Inc., 2016, 534 p.
- [2] T. A. Milligan, *Modern antenna design*, New Jersey: John Wiley & Sons, Inc., 2005, 614 p.
- [3] Shcherbyna O., Zadorozhnyi O. and Katushonok F. Antennas Combination for Ground and Airborne Segments of UAV Communication Systems. *Ostroumov, I., Marais, K., Zaliskyi, M. (eds) Advances in Civil Aviation Systems Development. ACASD 2025. Lecture Notes in Networks and Systems*, 2025, Vol. 1418, pp. 231-250. DOI:10.1007/978-3-031-91992-3_15.
- [4] Shcherbyna O., Zadorozhnyi O. and Stetsyshin O. Passive Antenna Arrays in UAV Communication Systems. *International Journal of Computer Network and Information Security (IJCNIS)*, 2024, Vol. 16, No. 4, pp. 31–51. DOI:10.5815/ijcnis.2024.04.03.
- [5] Sajjad H., Sethi W. T., Zeb K. and Mairaj A. Microstrip Patch Antenna Array at 3.8 GHz for WiMax and UAV Applications. In: *International Workshop on Antenna Technology: Small Antennas, Novel EM Structures and Materials, and*

- Applications (iWAT)*, Sydney, Australia, 2014, pp. 107–110. DOI:10.1109/IWAT.2014.6958609.
- [6] Chuang T. Y., Liao W. J., Ma T. G., Lee Y., and Ho M. C. Compact Directive Array Antenna Design for UAV Application. In: *International Symposium on Antennas and Propagation (ISAP)*, Phuket, Thailand, 2017, pp. 1–2. DOI:10.1109/ISANP.2017.8228780.
- [7] Ruiz P. M., Begaud X., Magne F., Leder E. and Khy A. Microstrip Antenna Array Design for Unmanned Aerial Vehicles Detection Radar. *Advanced Electromagnetics*, 2023, Vol. 12, No. 3, pp. 1–9. DOI:10.7716/aem.v12i3.2066.
- [8] Cheong P., Wu K., Choi W.-W. and Tam K.-W. Yagi-Uda Antenna for Multiband Radar Applications. *IEEE Antennas and Wireless Propagation Letters*, Vol. 13, 2014, pp. 1065–1068. DOI:10.1109/LAWP.2014.2328991.
- [9] Tanti R. K., Warathe S. and Anveshkumar N. Planar Yagi-Uda Antenna with Mirrored Ground Plane for WLAN. In: *11th International Conference on Computing, Communication and Networking Technologies (ICCCNT)*, Kharagpur, India, 2020, pp. 1–5. DOI:10.1109/ICCCNT49239.2020.9225278.
- [10] Shcherbyna O. and Zadorozhnyi R. The Log-periodic Dipole Array Antenna for Monitoring. In: *14th International Conference on Advanced Trends in Radioelectronics, Telecommunications and Computer Engineering (TCSET)*, Lviv-Slavske, Ukraine, 2018, pp. 583–586. DOI:10.1109/TCSET.2018.8336270.
- [11] Pojang K. and Raklua P. The Design of Log Periodic Dipole Array Antenna for WLAN/LTE/ UWB Applications. In: *18th International Symposium on Communications and Information Technologies (ISCIT)*, Bangkok, Thailand, 2018, pp. 66–69. DOI:10.1109/ISCIT.2018.8587918.
- [12] Yang Y.-H., Guo J.-L., Sun B.-H. and Huang Y.-H. Dual-Band Slot Helix Antenna for Global Positioning Satellite Applications. *IEEE Transactions on Antennas and Propagation*, 2016, Vol. 64, No. 12, pp. 5146–5152. DOI:10.1109/TAP.2016.2623647.
- [13] Shcherbyna O. and Kozhokhina O. Construction Principles of Quadrifilar Helical Antenna. *Telecommunications and Radio Engineering*, 2020, Vol. 79, No. 16, pp. 1441–1453. DOI:10.1615/TelecomRadEng.v79.i16.30.
- [14] The Lwin and Aung Wynn. Analysis of S-band Parabolic Antenna Performance for Microsatellite Communication Systems. *American Journal of Electromagnetics and Applications*, 2025, Vol. 13, No. 1, pp. 8–14. DOI:10.11648/j.ajea.20251301.12.
- [15] Khin Ei. Design of Helical Feed Parabolic Reflector Antenna in Satellite Communication. *Journal of Research and Innovation*, 2019.
- [16] Baars J. The Paraboloidal Reflector Antenna in Radio Astronomy and Communication. Theory and Practice. NY: Springer New York, 2007, 348 p. DOI:10.1007/978-0-387-69734-5.

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ШИРОКОСМУГОВА ПАРАБОЛІЧНА АНТЕНА ЗІ СПРАЛЬНИМ ВИПРОМІНЮВАЧЕМ ДЛЯ СИСТЕМИ ЗВ'ЯЗКУ БПЛА

Сучасний розвиток безпілотних літальних апаратів (БПЛА) вимагає стабільного каналу зв'язку на великих відстанях. Головною проблемою при керуванні БПЛА є необхідність підтримки високої пропускну здатності та стійкості до перешкод при маневруванні апарата. Використання параболічної антени в поєднанні зі спіральним опромінювачем є одним із найбільш ефективних рішень для наземних станцій керування, оскільки така конструкція поєднує високий коефіцієнт підсилення з перевагами кругової поляризації. Основою системи є параболічне дзеркало, яке виконує роль фокуруючого елементу. Вибір параболоїда зумовлений його здатністю формувати вузьку діаграму спрямованості, що критично важливо для збільшення радіусу дії. Однак ключовим елементом новизни в даній конфігурації є використання спіральної антени як опромінювача параболічного рефлектора. На відміну від лінійної поляризації, кругова поляризація дозволяє уникнути завмирання сигналу, коли БПЛА виконує маневри. Спіральна антена усуває потребу в точному узгодженні площин поляризації антени передавача та приймача. Також спіральні структури мають здатність працювати у широкому діапазоні частот без суттєвої зміни імпедансу. Антени з круговою поляризацією ефективно відсікають сигнали, що відбилися від землі або будівель, оскільки при відбитті напрямок обертання поляризації змінюється на протилежний, і вона не сприймається основною антеною. У роботі розраховано розміри параболічного дзеркала і спірального опромінювача для досягнення оптимального співвідношення «підсилення/рівень бічних пелюсток». Результати моделювання та дослідження експериментального зразка показали, що робочий діапазон частот розробленої антени сягає понад 1 ГГц з КСХН < 1,5 (робочий діапазон частот від 5,7 ГГц до 6,7 ГГц).

Результати моделювання для параболічної антени зі спіральним опромінювачем продемонстрували ширину діаграми спрямованості за половинною потужністю випромінювання (HPBW) 12,3 градуси для нижньої частоти робочого діапазону та 9,6 градуси для верхньої частоти, що відповідає вимогам до наземного сегменту системи керування БПЛА. Рівні бічних пелюсток не перевищують -15 дБ у всьому робочому діапазоні частот. Коефіцієнт підсилення розробленої антени, отриманий в результаті моделювання, досягає в середньому 23,5

дБі в робочому діапазоні частот. Осьове співвідношення залишається стабільно нижче 2 дБ у всьому робочому діапазоні частот 5,7–6,7 ГГц. Така антенна система є ідеальною для тактичних комплексів, де надійність зв'язку є пріоритетом.

Ключові слова: параболічна антена, спіральна антена, правогвинтова кругова поляризація, опромінювач, безпілотні літальні апарати, наземний сегмент системи керування.

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BROADBAND PARABOLIC ANTENNA WITH SPIRAL RADIATOR FOR UAV COMMUNICATION SYSTEM

The modern development of unmanned aerial vehicles (UAVs) requires stable communication channel over long distances. The main challenge in UAV control is maintaining high throughput and eliminating interference during aircraft maneuvers. Using parabolic antenna in combination with helical feed is one of the most effective solutions for ground control stations, as this design combines high gain with the advantages of circular polarization. The system is based on parabolic reflector, which serves as a focusing element. A paraboloid was chosen for its ability to form narrow beam pattern, which is critical for increasing range. However, the key innovation in this configuration is the use of the helical antenna as the parabolic reflector's feed. Unlike linear polarization, circular polarization prevents signal fading when the UAV maneuvers. The helical antenna eliminates the need for precise alignment of the polarization planes of the transmitter and receiver antennas. Helical structures also have the ability to operate over wide frequency range without significantly changing impedance. Circularly polarized antennas effectively reject signals reflected from the ground or buildings, since the polarization rotation direction reverses upon reflection, preventing it from being received by the main antenna. The paper calculates the dimensions of the parabolic dish and the helical feed to achieve optimal gain/sidelobe ratio. Simulation and experimental design studies demonstrate that the developed antenna has operating frequency range of over 1 GHz with a VSWR < 1.5 (operating frequency range from 5.7 to 6.7 GHz). Simulation results for the parabolic antenna with helical feed demonstrated the half-power beamwidth (HPBW) of 12.3 degrees for the lower frequency of the operating range and 9.6 degrees for the upper frequency, which meets the requirements for the ground segment of the UAV control system. Sidelobe levels do not exceed –15 dB across the entire operating frequency range. The antenna gain, obtained through simulation, averages 23.5 dBi across the operating frequency range. The axial ratio remains consistently below 2 dB across the entire operating frequency range of 5.7–6.7 GHz. This antenna system is ideal for tactical systems where communication reliability is a priority.

Keywords: parabolic antenna, spiral antenna, right-handed circular polarization, feed antenna, unmanned aerial vehicles, ground segment of the control system.

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