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Микрополосковые антенны для бистатической радиолокационной системы, размещенной на БЛА

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Аннотация. ***Введение.*** Статья посвящена исследованию особенностей работы бистатической радиолокационной системы, установленной на беспилотном летательном аппарате, и обоснованию выбора оптимальной антенно-фидерной системы для неё. Подчёркнута важность учёта влияния корпуса беспилотного летательного аппарата, выполненного из токопроводящего материала, на характеристику направленности антенны и поляризацию излучаемых сигналов. Отмечено отсутствие в литературе достаточного количества информации и рекомендаций относительно подбора антенно-фидерной системы для бистатической радиолокационной системы, устанавливаемой на беспилотных летательных аппаратах, что определяет актуальность проводимого исследования. ***Цель.*** Цель работы состоит в разработке требований к выбору и расчёту, моделированию антенно-фидерной системы, удовлетворяющей условиям эксплуатации в составе бистатической радиолокационной системы. ***Материалы и методы.*** Представлены этапы разработки и тестирования выбранного решения, включающие определение технических требований к антенно-фидерной системе, оценка применимости известных конструкций антенн, расчёт и изготовление опытных образцов, проведение экспериментальных исследований. Для моделирования и оптимизации характеристик микрополосковых антенн использовался специализированный программный комплекс Antenna Designer пакета MATLAB. ***Результаты и обсуждение.*** По результатам проведённых исследований установлено, что использование микрополосковых антенн обеспечивает возможность создания однонаправленного излучения, стабильность электрических параметров в рабочем диапазоне частот и технологичность изготовления. Описаны конструктивные преимущества микрополосковых антенн, выявленные в ходе исследований. ***Заключение.*** Сделан вывод о целесообразности применения микрополосковых антенн для решаемых задач и предложено направление дальнейших исследований, связанное с созданием двухэлементных антенных решёток для повышения эффективности функционирования бистатической радиолокационной системы.

Ключевые слова: полосковая антенна, микрополосковая антенна, бистатическая радиолокационная система, зондирование земной поверхности, беспилотный летательный аппарат

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Research article

Microstrip antennas for a drone-mounted bistatic radar system

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Abstract. ***Introduction.*** This article examines the operational characteristics of a bistatic radar system installed on an unmanned aerial vehicle (UAV) and substantiates the selection of an optimal antenna-feeder system for it. The importance of considering the influence of the UAV body, made of conductive material, on the antenna directivity and polarization of emitted signals is emphasized. A lack of sufficient information and recommendations regarding the selection of an antenna-feeder system for a bistatic radar system installed on UAVs is noted, which determines the relevance of this study. ***Goal.*** The objective of this work is to develop requirements for the selection, calculation, and modeling of an antenna-feeder system that meets operating conditions within a bistatic radar system. ***Materials and methods.*** The stages of development and testing of the selected solution are presented, including determining the technical requirements for the antenna-feeder system, assessing the applicability of existing antenna designs, calculating and manufacturing prototypes, and conducting experimental studies. The specialized Antenna Designer software package in MATLAB was used to model and optimize the characteristics of microstrip antennas. ***Results and discussion.*** The results of the studies revealed that microstrip antennas provide unidirectional radiation, stable electrical parameters across the operating frequency range, and easy manufacturing. The design advantages of microstrip antennas identified during the studies are described. ***Conclusion.*** A conclusion is reached regarding the feasibility of using microstrip antennas for the tasks being solved, and a direction for further research related to the development of two-element antenna arrays to improve the efficiency of bistatic radar systems is proposed.

Key words: strip antenna, microstrip antenna, bistatic radar system, earth surface sensing, unmanned aerial vehicle

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Introduction. When implementing a bistatic (diversity) radar system (BRS) [1, 2], one of the primary challenges is selecting an antenna-feeder system (AFS), as the system's operation is sensitive to the antenna's radiation pattern (RP) and the polarization of the emitted wave. The antenna's RP shape is further distorted by the unmanned aerial vehicle (UAV) body, which is typically constructed from conductive materials to provide shielding for the electronic devices inside the UAV. Due to the nature of the research being conducted, the literature does not fully address the analysis and recommendations for selecting an AFS for BRS.

Thus, the decision on selection and calculation of the development of an AFU for UAVs, taking into account the specifics of their use in radar systems, is a pressing scientific challenge.

In this regard, the purpose of this article is to consider the operation of the radar from the point of view of the features of the radar system operation when placed on a UAV, the formation of requirements for the AFU, as well as the selection of the optimal design, calculations, modeling and study of the characteristics of the manufactured AFU for the radar.

Materials and research methods.

1. Formation of requirements for the AFU for the radar.

In a bistatic (diversity) radar system (BRS), two antenna systems with different functional purposes are used: transmitting and receiving (Fig. 1).

Requirements for antennas must be presented according to two groups of criteria:

1) required antenna characteristics and parameters;

2) required design, technological and operational features.

As a rule, the requirements for antennas in the first group are more important and decisive than the basic requirements for the parameters in the second group. In this case, the criteria of the second group are no less important than those of the first due to the specifics of antenna use onboard UAVs.

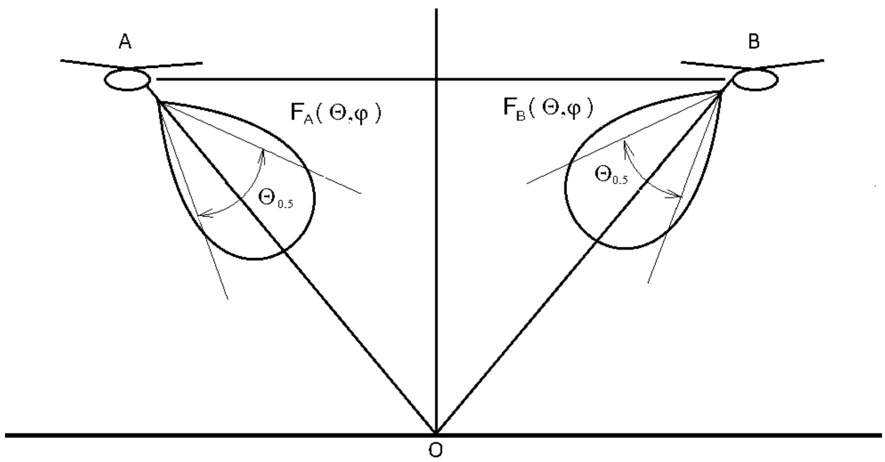


Figure 1 – To determine the requirements for antenna devices of a bistatic (diversity) radar system

Figure 1 shows that the problem being solved is geometrically symmetrical, and it makes no difference whether the radar transmitter and receiver are located at position A or B. This implies that the requirements for the radar transmitting and receiving antennas are identical. Antenna theory has proven that the fundamental electrodynamic parameters and characteristics of an antenna in transmitting and receiving modes are identical, so it is possible to use identical antennas for both receiving and transmitting in the bistatic radar system being developed [3, 4].

Requirements to antennas:

1) it is necessary to ensure radiation (reception) in a given sector of incidence (reflection) angles of 45...90 degrees with as uniform a dependence as possible on the angle of the directivity coefficient (DC) - i.e. to ensure a “sector” RP;

2) it is necessary to ensure horizontal and vertical polarization of the emitted (received) wave (for a transmitting antenna, simultaneous emission of waves of two polarizations is possible);

3) it is required that the antenna has acceptable matching (standing wave ratio (SWR) < 5 for transmitting and < 2 for receiving antennas) at a given operating frequency (in the frequency band).

So, of classes of medium-directional antennas with linear polarization, such as vibrator antennas, meet these requirements [4, 5].

2. Selecting the type of AFU for the radar

During the first stage of development, it was planned to use the standard vibrator antennas of the Stilsoft Skyron O UAV. For this purpose, studies were conducted on the electrical and electrodynamic properties of the carbon fiber composite from which the UAV body is made.

The conductivity (resistance) of a carbon fiber body cover sample from one of the UAV prototypes was measured along the surface in various directions using a DC current using an electronic multirange ohmmeter. The measured resistance values ranged from several tens of ohms to a few kilohms (the lowest measured resistance was 76 ohms; the highest was 1987 ohms), with significant randomness observed. No dependence of the resistance on the preferred directions or the path length between the extreme points of the carbon fiber cover was observed.

The studies of the electrodynamic properties of carbon fiber were carried out in laboratory conditions at a measuring range using a TK -450 S transmitter emitting an unmodulated carrier at a frequency of 469 MHz and equipped with a standard shortened antenna (A 1), as well as an Anritsu spectrum analyzer S 362E in power measurement mode with a shortened dipole antenna (A 2) from the National laboratory kit Instruments on the receiving part of the radio line.

Before measuring the carbon fiber composite parameters, the measurement site was evaluated to obtain calibration curves due to its limited physical dimensions and the presence of interfering reflections. For this evaluation, the field strength generated by the transmitter was measured at various distances from the transmitting antenna. Field strength values were recorded using an Anritsu 326 E instrument in spectrum analyzer mode (Fig. 2). Two experiments were conducted sequentially:

1) measuring the passage of electromagnetic waves through (through) the carbon fiber fragment of the body of the Stilsoft Skyron O UAV;
2) measurement of the level of electromagnetic wave reflection from the surface of a fragment of the body of the Stilsoft Skyron O UAV.

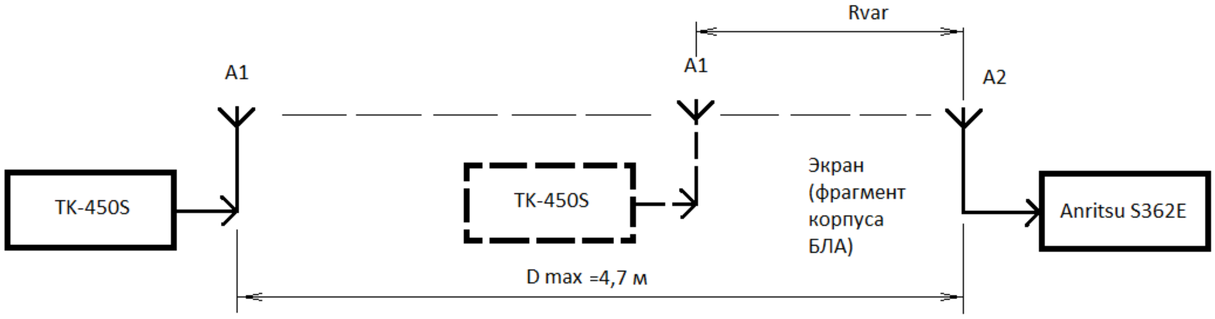


Figure 2 – Estimation of polygon error

Table 1 – Results of the experiment on studying the properties of carbon feeder

R , m	0.3	0.6	0.64	0.96	1.28	1.6	1.92	2.24
E_{free}, dB	-9.8	-10.1	-10.0	-9.8	-10.1	-10.0	-10.1	-9.9
E_{trans}, dB	-12.0	-13.0	-14.0	-10.7	-1 1 ,6	-10.1	-12.7	-11.7
E_{ref}, dB	-10.0	- 9.6	-12.0	-10.0	- 11,0	-9.8	-10.0	-9.1

Based on the measurement results, it was concluded that it is not possible to use antennas with a significant (commensurate with the level of the direct signal) level of rear and side radiation (for example, vibrator antennas) due to strong interference dips that will inevitably arise in the resulting RP (Fig. 3).

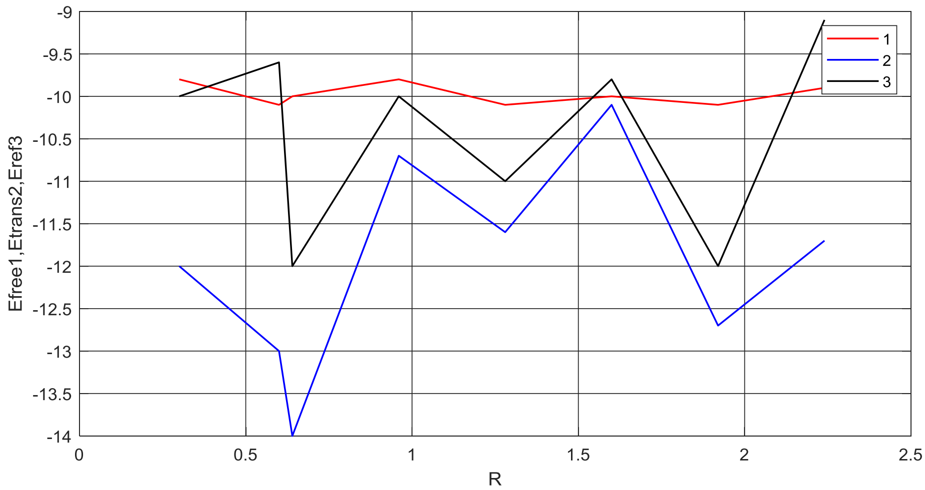


Figure 3 – Results of experiment studying the electrodynamic parameters of a carbon feeder casing: 1 – direct signal without a shield; 2 – transmission through a carbon feeder shield; 3 – reflection from a carbon feeder shield

To confirm this conclusion, the DD of an asymmetric (quarter-wave vibrator) vibrator antenna over a flat semiconducting screen with carbon fiber parameters was simulated using the MMANA program. GAL (Fig. 4).

For vertical polarization of the antenna in the vertical plane in the sector of angles of 45...89 degrees, the change (dips in the radiation pattern) amounted to $-15 \div -17$ dB relative to maximum.

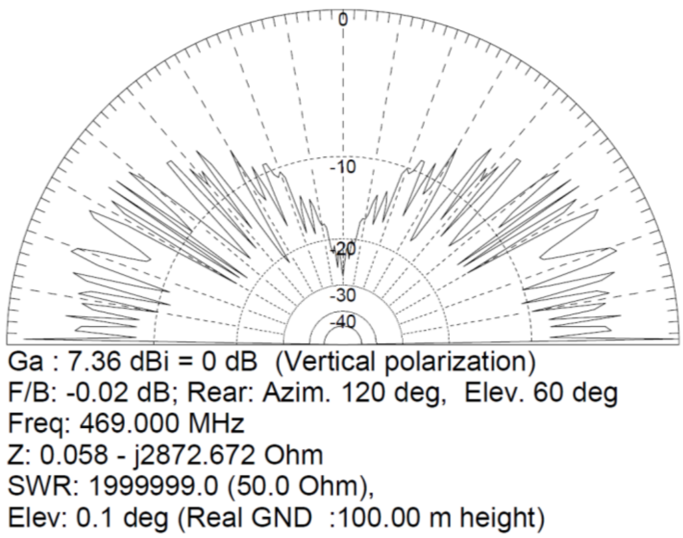


Figure 4 – The result of modeling a vibrator antenna over a semiconducting flat screen with carbon feeder parameters

Following the research, the use of the standard vibrator antennas of the Stilsoft Skyron O UAV had to be abandoned for the following reasons:

1) the dimensions of the standard antennas and the configuration of their placement do not allow obtaining acceptable directions of the main lobes of the radiation pattern and their width (Fig. 6);

2) the body and structural elements of the UAV are made of carbon fiber, which is a semi-conducting composite material with chaotically anisotropic electrodynamic parameters (

σ, ε_r); as a result of interference phenomena, the influence of the structural elements of the UAV on the RP becomes unpredictable;

3) the use of standard UAV antennas requires the integration of the radar into the UAV control system, which is impractical and highly undesirable due to the significant uncertainty and unpredictability of such a solution.

In the second stage, other antenna types with low backscatter radiation were investigated. The research showed that horn and reflector antennas, as low-backscatter antennas in the wavelength range used (0.6396 m), have unacceptably large longitudinal geometric dimensions. For traditional medium-directional antennas (vibrator, loop, etc.) with effective reflectors and screens (the screen dimensions must be equal to the operating $1,5 \div 2$ wavelength), the antenna system dimensions are also significant.

At the third stage, due to the fact that the antenna characteristics largely ensure the selection, calculation or setting of the characteristics and parameters of other functional parts of the radar (at least without knowing at least approximate values, it is impossible to set requirements for the required transmitter power and receiver sensitivity), a decision was made not to limit ourselves to general recommendations for choosing their type, but to develop a specific antenna for the radar.

The analysis showed the feasibility of choosing microstrip antennas, since significant achievements of recent decades in the field of microwave technology and microminiaturization have made it possible to develop efficient designs of such antennas manufactured using printed circuit board and integrated circuit technologies [6].

They are characterized by a simple design, small dimensions and weight, high manufacturability, good reproducibility of dimensions and electrical parameters, the ability to operate in dual- and multi-frequency modes, with linear and circular polarization, and with dual polarization. Stripline radiators are convenient as elements of antenna arrays (including conformal ones), and the use of printed technology significantly simplifies the implementation of various element power supply circuits, from the simplest series circuits to complex branched parallel circuits. The operating frequencies of stripline (SPA) and microstrip (MSPA) antennas and arrays range from hundreds of MHz to several tens of GHz [7, 8].

In addition, the MSPA are fundamentally shielded in the rear hemisphere of the RP, and the shielding effect is achieved with screen sizes significantly smaller than for other classes of antennas.

The main disadvantages of SPA and MSPA are low electrical strength, low permissible power of input oscillations; in the case of resonator-type antennas, narrowband (the relative operating frequency band is on average no more than 5%) [7, 8]. In the considered version of the bistatic radar system, these disadvantages are insignificant, since the required operating range does not exceed several meters, and narrowband signals are supposed to be used as probing radiation.

There are many strip and microstrip antennas, which can be conditionally classified into the following types [7, 8]:

- Vibrator antennas: with inductive and conductive excitation; loop vibrators; polyvibrator antennas;

– slot antennas: excited by strip and microstrip lines, with microstrip resonators; open ends of strip and microstrip lines;

– flat two-dimensional SPA and MSPA: resonant type; non-resonant type; with distributed connection to the power line;

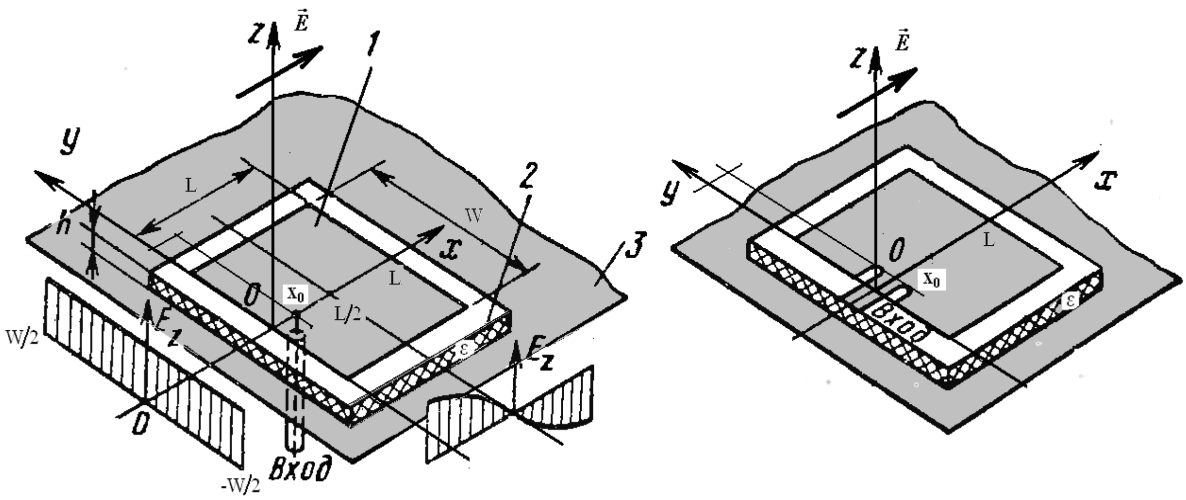
– volumetric (three-dimensional) SPA and MSPA;

– frequency-independent and multi-frequency SPA and MSPA: spiral, vibratory, log-periodic, etc.

The shape of stripline radiators is selected based on the required operating mode of the antenna, its frequency properties, the desired pattern shape, and the radiation polarization. In practice, rectangular, triangular, rhombic, elliptical, circular, and more complex radiator shapes—ring, circular sector, ring sector, etc.—are used [9].

3. Calculation of the microstrip antenna radiator

Printed strip antennas (PSA) of the resonant type based on rectangular radiators have become widely used as independent antennas and elements of antenna arrays [3, 7, 8]. PSAs of this type contain a radiator in the form of a rectangular metal strip 1, located on the outer surface of a dielectric substrate 2 above a metal screen 3 (Fig. 7) [7].



a) b)

Figure 5 – MSPA based on a rectangular resonator emitter with excitation by a coaxial line using a probe (a) and an asymmetric strip line (b)

Examples of excitation of resonant MSPAs are illustrated in Figure 5, a − using a coaxial transmission line and a probe; b − using an asymmetric strip line, the conductor of which is located on the surface of the substrate in the same plane as the emitter. Dielectrics with a relative permittivity and $\varepsilon = 2 \div 16$ a low dielectric loss tangent $tg\delta$ of no more than, are usually used as the substrate material $(1 \div 5) \cdot 10^{-3}$; the substrate thickness is $h \approx (0,01 \div 0,1)\lambda_0$ [10]. The antenna radiation is created by electric currents flowing along the surface of the plate and screen, as well as by bias currents in the dielectric substrate.

Typically, in such a structure, resonant electromagnetic oscillations of the lowest (fundamental) type are excited TM_{100}; the indices characterize the number of variations of the transverse wave in relation to the plane of the screen and the emitter components of the electric field strength vector E_z in the resonator cavity volume beneath the emitter along *the x* , *y,* and *z* *coordinate axes* . The entire structure is considered a cavity resonator without side walls, thereby ensuring radiation into the surrounding space.

In rectangular PAs, the lowest type of resonance occurs at the emitter length

$$L \approx \lambda_л / 2 , \tag{1}$$

where $\lambda_л \approx \lambda_0 / \sqrt{\varepsilon_r}$ is the length of the quasi- T wave in a strip line with a strip line width W . Note that the field component along the axis y is distributed uniformly, and along the axis x in the longitudinal direction, it is distributed sinusoidally with antinodes at the edges of the emitter at $x = 0, L$ and zero at the center under the emitter $x = L/2$ (Fig. 5).

At the resonant frequency, the antenna's input impedance becomes purely resistive and reaches values of several hundred ohms at the edges of the radiator parallel to the y-axis. Zero reactive input impedance facilitates matching of the radiator to the power line and ensures intense radiation.

To date, several methods have been developed for analyzing the characteristics of resonator SPAs, based on various mathematical models of the radiating structure [9]. In a rigorous formulation, the radiation problem is solved, for example, by the current method [11]. In this case, a boundary value problem is formulated and a system of integral equations is compiled for the scalar components of the vector distribution of the surface electric current density $J(z, y)$ on a conducting strip.

For a simplified approximate solution to the analysis problem, a simpler model is usually used, according to which the SPA is considered as a system of two equivalent slot radiators formed by the edges of a strip element (from one of which the exciting oscillations are supplied) and a screen. It is assumed that the radiation in the far zone is formed precisely by these slots, and radiation from the side slots is practically absent [12].

If the length of the emitter L is a multiple of an odd number of half-waves of the quasi- T wave, in particular, $L \approx \lambda_л / 2$, then the components of the field strength in slots 1 and 2 are out of phase (Fig. 5, a). The directions of the equivalent magnetic currents in the end slots and side slots are determined by the expression [8]

$$\dot{\;}_{M} \quad \lfloor \dots , \dot{-}_{z} \rfloor , \tag{2}$$

where $\vec{n}$ is the unit vector of the outer normal to the planes of the slits.

From (2) it follows that the equivalent magnetic currents of the end slots (open ends of the cavity resonator) are uniformly distributed and, most importantly, are in-phase. They generate maximum radiation in the direction normal to the screen plane, i.e., along the *z-axis*, with the far-field polarization of the vector parallel to the *x-axis* (Fig. 5). The equivalent magnetic currents in the side slots (parallel to the *x-axis*) are pairwise antiphase and contribute virtually nothing to the overall antenna radiation in the normal direction.

When the length of the strip radiator is a multiple of an even number of half-waves of the quasi-T wave, there is no radiation along the normal to the plane of the screen.

Directional pattern of the resonator MSPA within the upper hemisphere of space $(\theta = -90^\circ \ldots$ can be calculated with sufficient accuracy using the formula [13]

$$F(\theta,\varphi)=F(\theta)\cdot F(\varphi)=cos\theta\cdot cos\left(\frac{\pi L}{\lambda}sin\theta\right)\cdot\frac{sin\left(\frac{\pi W}{\lambda}sin\varphi\right)}{\frac{\pi W}{\lambda}sin\varphi}, \quad (3)$$

Where $F(\theta,\varphi), F(\theta), F(\varphi)$ – normalized radiation patterns: spatial, in planes θ and φ accordingly;

L,W – resonator dimensions MSPA according to Figure 5, a.

To calculate the radiation patterns, we used the Antenna Designer application from the Matlab package. The initial data for the calculation were: the operating frequency f (wavelength); the antenna patch dimensions; the angular coordinate (λ or) of one of the principal planes of the spherical coordinate system φ was used θ as a variable parameter. The second angular coordinate was fixed (Figs. 7, 8).

Radiation $F(\theta)$ patterns at $\varphi=0^{\circ}$ (blue color) and $F(\varphi)$ at $\theta=90^{\circ}$ (red color) are shown in Figure 6.

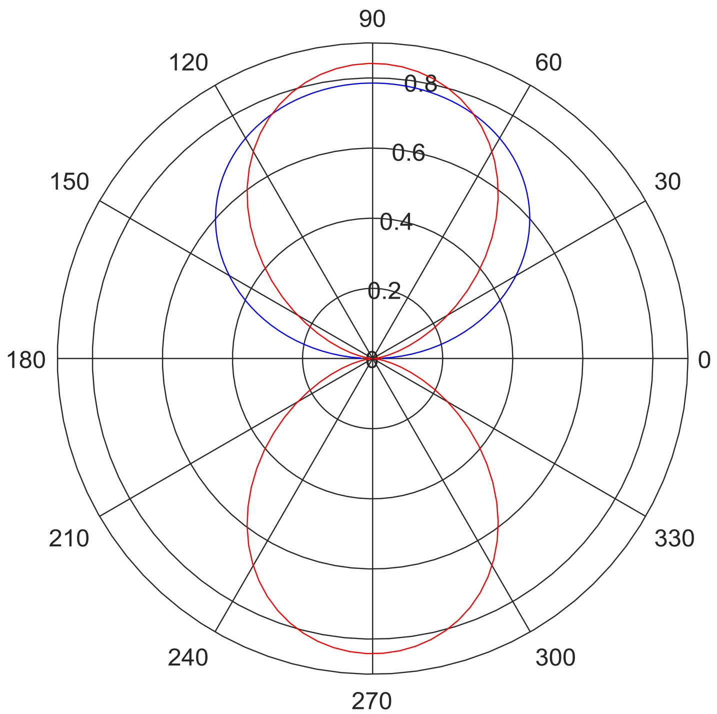


Figure 6 – MSPA RP graphs : calculation using formula (3) in Matlab

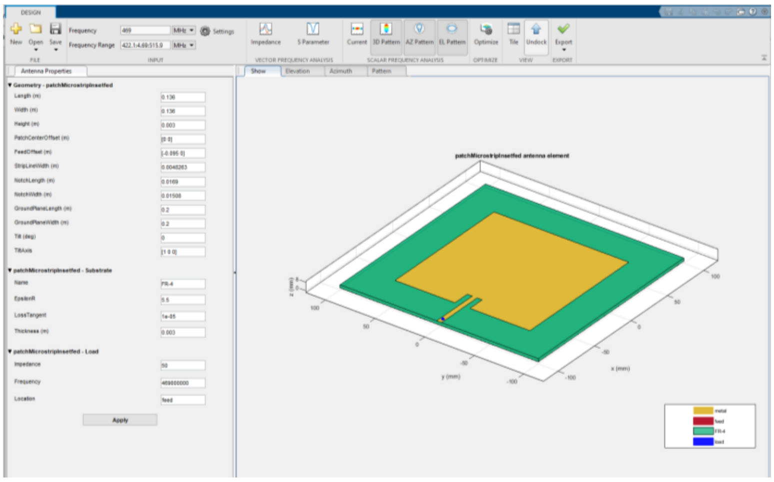


Figure 7 – Antenna Designer application interface

Calculated in *the Antenna app Designer* of the MSPA RP is presented in Figure 8.

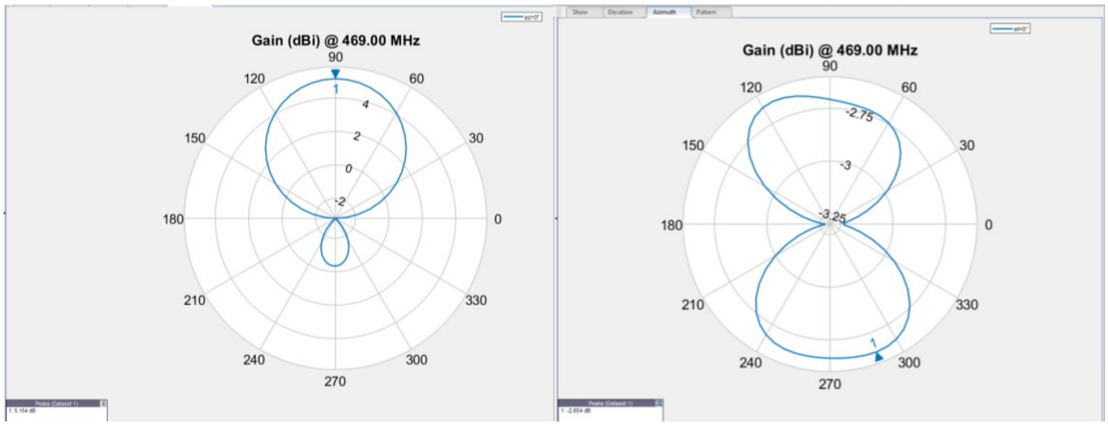
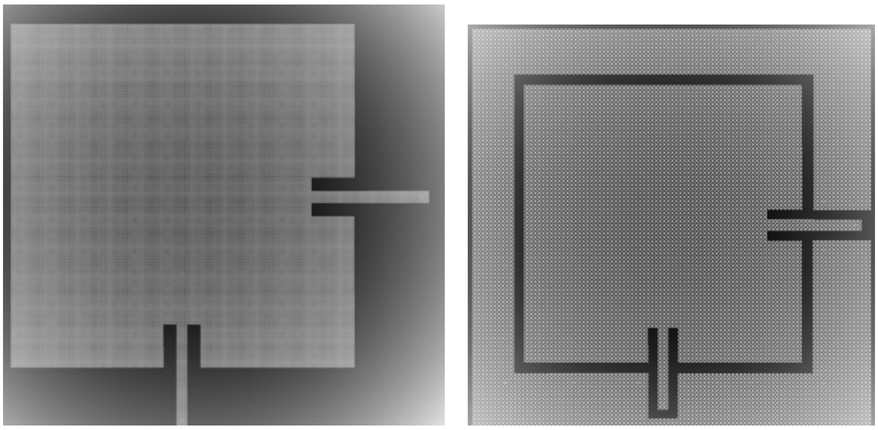


Figure 8 – MSPA RP graphs from the Antenna Designer application

It is clearly visible that the RP calculated using formulas (3) and in *The Antenna Designer application* are practically identical (Fig. 6 and 8).

FR4 fiberglass substrate was designed. A daisy-chain feeder from a coaxial-to-strip adapter, which also serves as the antenna connection point to the feeder via an SMA connector, was selected. Using the Sprint program the layout created a topology of the antenna resonator with a power supply loop in two versions - unshielded and shielded (Fig. 9).



a) b)

Figure 9 – The main resonator of the MSPA prototype, created in the Sprint Layout environment a) unshielded MSPA; b) shielded MSPA

The antenna prototype was manufactured by milling double-sided foil-clad fiberglass FR 4 from AB retail thickness 3 mm (Fig. 10).

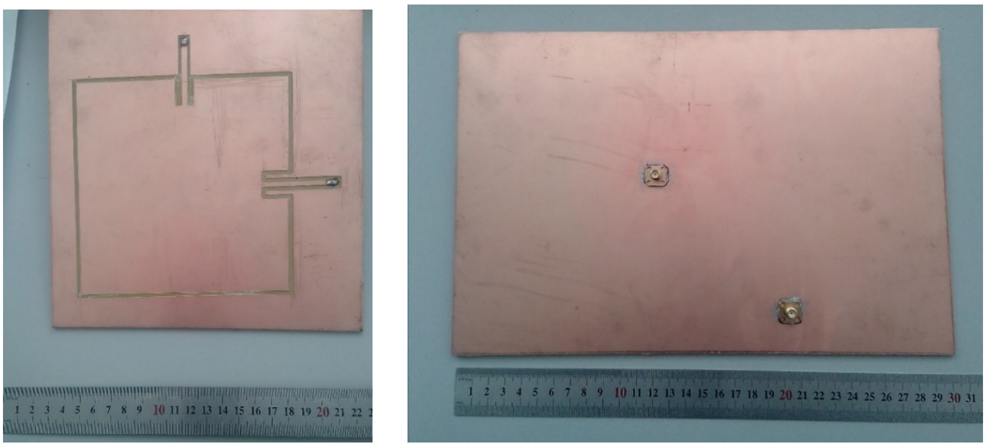


Figure 10 – A variant of the implementation of the MSPA prototype (working model) for measuring parameters

The actual permittivity of FR 4 fiberglass was lower than the manufacturer's stated value of 5.0–5.5 (the actual value was 4.4), necessitating precise tuning of the antenna to the selected frequency by adjusting its dimensions. To increase the antenna's resonant frequency, the antenna panel dimensions were reduced by trimming the resonator edge. To lower the frequency, narrow foil strips were soldered on. To significantly reduce the frequency, a section of the conductive shield on the active side of the antenna was used, connected to the antenna patch with shorting jumpers in several places (Fig. 11).

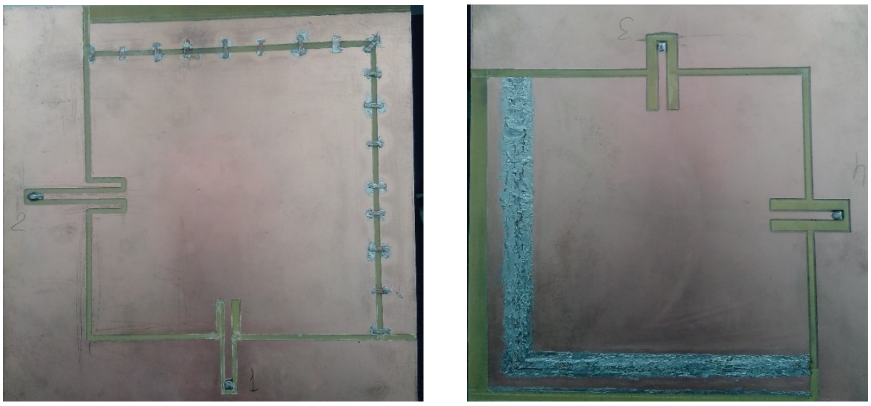


Figure 11 – Experimental models of MSPA with post - fine tuning to a frequency of 469 MHz

The resonant frequency was controlled using an Anritsu device. The S 362 E antenna and feeder line analyzer option measures the voltage standing wave ratio (VSWR) and input impedance in panoramic VSWR meter modes and using the Smith chart. For antenna and feeder line measurements, the Anritsu device The S 362E must be calibrated together with the connecting cable. Three types of loads are used for this procedure: open feeder, short-circuited load, and matched load.

An example of antenna tuning results for a bistatic radar system is shown in Figure 12. The MP antenna was tuned at input 2 for this antenna, and similar studies were conducted for the second antenna. The resulting VSWR is 1.23–2.05, and the bandwidth is approximately 10 MHz at a 3 dB level.

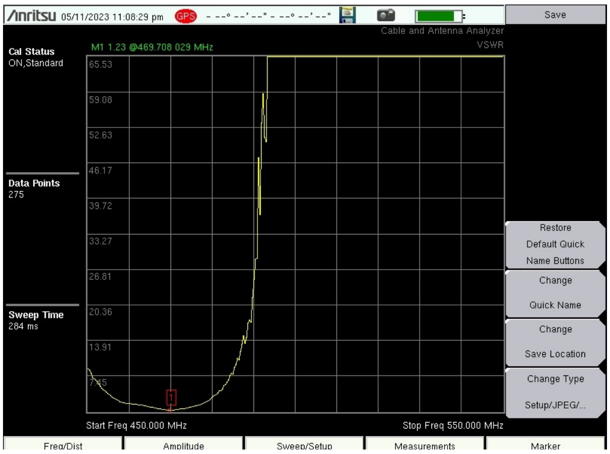


Figure 12 – Measuring the VSWR of the MSPA "1" at input 1

The measured gain factors of the experimental antenna models were:

– for model 1: vertical polarization 5.3 dB (1.84); horizontal polarization 4.9 dB (1.76);

– for layout 2: vertical polarization 4.8 dB (1.74); horizontal polarization 4.7 dB (1.72).

The results of measuring the antenna gains are in good agreement with those calculated in *The Antenna Designer*, which is 5.15 dB (1.81).

To calculate the power flux density of the transmitter signal and the sensitivity of the receiver, it is advisable to select the antenna gain value with a margin of 1.5 to compensate for random deviations in the radiation pattern.

Due to the lack of the correct conditions necessary for measuring the amplitude radiation pattern of the MSPA (there is no anechoic measuring chamber, it is impossible to move the stationary equipment to an open space for the arrangement of an antenna range), it was decided to use the method for measuring the radiation pattern proposed in the 90s of the last century at the Department of AFU of the Air Force Engineering Academy named after prof. N.E. Zhukovsky [14]. The essence of this method lies in the statistical processing of a large number of measurement results made under non-ideal conditions under the influence of random reflections from interfering objects.

A series of measurements with deliberately different reflection conditions (to ensure this, the auxiliary antenna—the transmitting one if the receive directivity characteristic is being measured, or the receiving one if the measurement is in transmit mode—is moved by distances multiples of a quarter-wavelength for each individual measurement) are then processed together: for each angular position of the antenna being studied, the average field amplitude is found. The resulting average values are normalized and presented graphically in the selected scale and the required coordinate system.

Two series of RP measurements were conducted for vertical and horizontal polarizations – 5 and 7 measurement sets, respectively. Each measurement set differed in the placement of the auxiliary antenna: in five (seven) sets, the auxiliary antenna was shifted transversely and longitudinally by a quarter-wavelength ($\lambda/4 = 16$ cm) from the initial position; in the other three sets (separately for each polarization), the auxiliary antenna was shifted vertically by half a wavelength ($\lambda/2 = 32$ cm). The results from all sets for each angle were averaged and then normalized. A total of 450 field strength measurements were performed in 18 measurement sets.

The averaged normalized characteristics of the RP, shown in Figures 13 and 14 (red color), coincide quite accurately with the calculated ones (blue color).

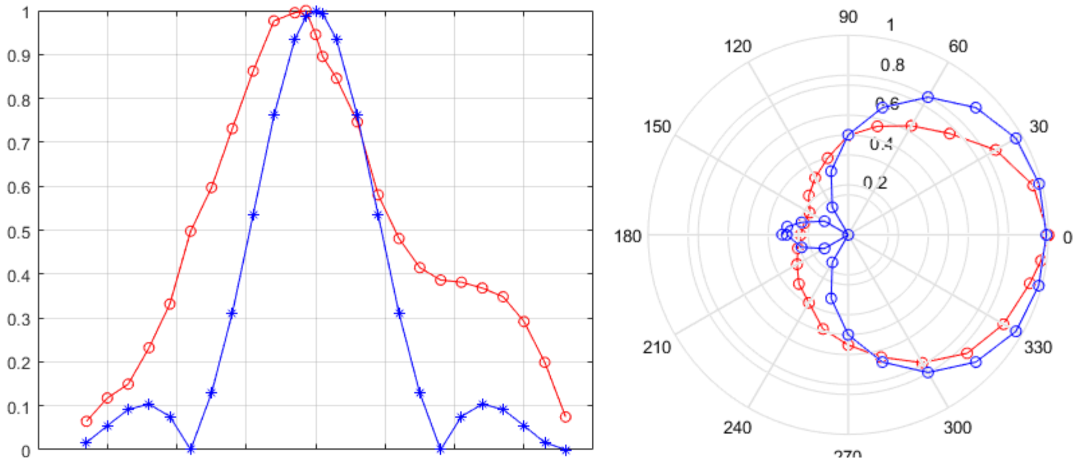


Figure 13 – RP of a vertically polarized antenna Fv(θ) in Cartesian and polar coordinates

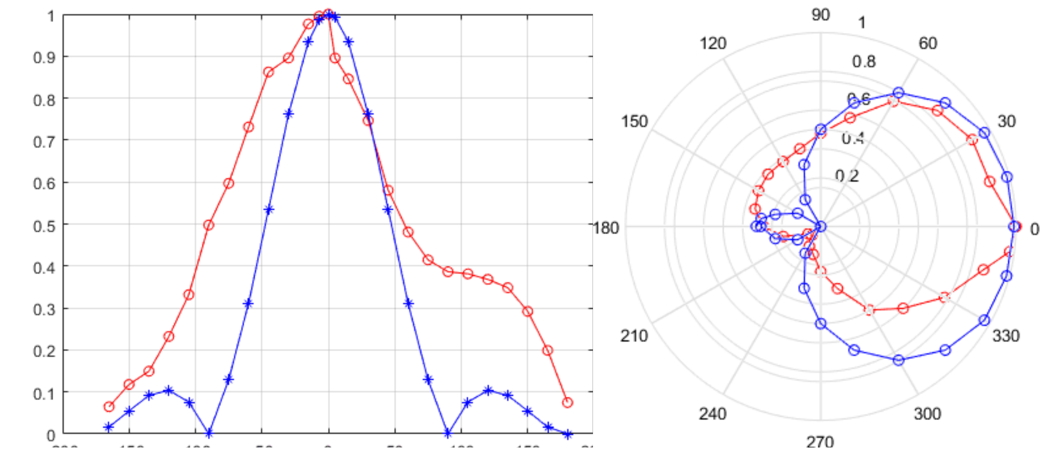


Figure 14 – RP of a horizontal polarization antenna Fv(θ) in Cartesian and polar coordinates

Rationale for the choice of transmission line type. Microstrip transmission lines are well matched to printed antennas in terms of their characteristic impedance and design. However, their use can only be achieved by using printed technology for all elements of the transmit-receive paths in the centimeter and millimeter wave bands. Furthermore, the transmission line lengths in the transmitting and receiving sections of the dual-position radar being developed are insignificant, and the anticipated hardware complexity of the devices being developed is low. Therefore, it is advisable to use coaxial flexible cables with a characteristic impedance of 50 ohms for the prototype. Joints between different transmission line types should preferably be implemented using a coaxial-to-strip transition.

It should be noted that the radar system's intended use requires the transmitter, transmitting antenna, and receiving and measuring device to be mounted onboard the UAV. This places special demands on the operational parameters of the radar system being developed. Specifically, the coaxial connectors must be tightly secured and secured with appropriate devices (safety wire, locking washers, etc.).

Research results and discussion. Experimental studies of antenna-feeder devices for UAV-based radars indicate that the use of MSPA is the most feasible option. This is due to the ability to generate unidirectional radiation, ensure stable electrical parameters across the operating frequency range, and ease of manufacture.

Conclusion. This article examines the operational features of a UAV-mounted radar and formulates requirements for the radar's antenna feeder. Based on the developed requirements, an analysis was conducted of the feasibility of using existing radar antennas for the radar system, which concluded that such a choice was impractical. A selection of micro-band antennas for the UAV-mounted radar was also conducted. The characteristics of the manufactured antenna feeder for the radar were calculated, modeled, and analyzed.

The direction of further research related to improving the operation of antennas for radars is the study of the possibility of using two-element antenna arrays for radar antenna feeds.

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