DOI 10.53364/24138614_2022_26_3_35
УДК 621.396.67:629.73

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THE USE OF MICROSTRIP ANTENNA ARRAYS TO BUILD A RELIABLE SECURITY SYSTEM FOR AN UNMANNED AERIAL VEHICLE

ИСПОЛЬЗОВАНИЕ МИКРОПОЛОСКОВЫХ АНТЕННЫХ РЕШЕТОК ДЛЯ ПОСТРОЕНИЯ НАДЕЖНОЙ СИСТЕМЫ БЕЗОПАСНОСТИ БЕСПИЛОТНОГО ЛЕТАТЕЛЬНОГО АППАРАТА

ҰШҚЫШСЫЗ ҰШУ АППАРАТЫНЫҢ СЕНІМДІ ҚАУІПСІЗДІК ЖҮЙЕСІН ҚҰРУ ҮШІН МИКРО ҰШҚЫШСЫЗ АНТЕННАЛЫҚ ТОРЛАРДЫ ПАЙДАЛАНУ

Abstract. This article discusses the prospects for the use of unmanned aerial vehicles in the field of light cargo transportation. The author noted the problem according to which unmanned aerial vehicles are not protected from collisions with obstacles in the form of walls, trees, other drones in case of crossing routes. In this regard, the article describes the study of the electrodynamic characteristics of microstrip phased antenna arrays, emphasizing their advantage over the existing obstacle avoidance systems based on ultrasonic sensors. The structure of the MNG-substrate is considered, which makes it possible to reduce the size of the antennas for convenient and smaller-sized mounting in the body of an unmanned aerial vehicle without losing the effective values of the parameters.

Key words: unmanned aerial vehicle, drone, microstrip antenna, phased array antenna (PAA), security system, metamaterials.

Аңдатпа Бұл мақалада жеңіл жүктерді тасымалдау саласында ұшқышсыз ұшатын аппараттарды қолданудың келешегі талқыланады. Автор ұшқышсыз ұшатын аппараттардың жолдарды кесіп өту кезінде қабырғалар, ағаштар және басқа дрондар түріндегі кедергілермен соқтығысудан қорғалмаған проблемасын атап өтті. Осыған байланысты мақалада микрожолақты фазалық антенналық массивтердің электродинамикалық сипаттамаларын зерттеу сипатталған, олардың ультрадыбыстық сенсорларға негізделген кедергілерді болдырмау жүйелерінен артықшылығы атап өтілген. Параметрлердің тиімді мәндерін жоғалтпай ұшқышсыз ұшу аппаратының корпусында ыңғайлы және шағын өлшемді орнату үшін антенналардың өлшемін азайтуға мүмкіндік беретін субстрат құрылымы қарастырылады.

Түйін сөздер: отын деңгейін өлшегіш, потенциометриялық әдіс, отын багы.

Аннотация. В данной статье рассматриваются перспективы использования беспилотных летательных аппаратов в сфере перевозки легких грузов. Автор отметил проблему, согласно которой беспилотные летательные аппараты не защищены от столкновений с препятствиями в виде стен, деревьев, других дронов при пересечении маршрутов. В связи с этим в статье описано исследование электродинамических характеристик микрополосковых фазированных антенных решеток, подчеркнуто их преимущество перед существующими системами обхода препятствий на основе ультразвуковых датчиков. Рассмотрена структура подложки, позволяющая уменьшить размеры антенн для удобного и малогабаритного монтажа в корпусе беспилотного летательного аппарата без потери эффективных значений параметров.

Ключевые слова: беспилотный летательный аппарат, дрон, микрополосковая антенна, фазированная антенная решетка (ФАР), система безопасности, метаматериалы.

Inroduction. Currently, unmanned aerial vehicles open up a new field of use: transportation of light cargo according to flight tasks developed by operators of post offices, as well as by individuals in personal use, taking into account optimal solutions for operating a drone (flight time, taking into account climatic factors, etc.). Such a breakthrough technology can be implemented in Kazpost offices, realizing the principle of "Stepping over" of the state program "Digital Kazakhstan": a course towards the introduction of the most advanced technologies, without fear of ignoring proven solutions in favor of innovations of the day after tomorrow [1].

The use of the above technology is faced with rather high risks of accidents during the operation of drones. The most obvious reasons include the following examples:

– collision of drones with obstacles in the form of walls, trees, etc;

– collisions of drones with each other due to the occurrence of cross routes during mass use.

Drone repairs or total breakdowns cost a lot of budget to reduce the risk of such disastrous consequences. In our opinion, the following design solutions for this problem are quite respectable:

– development of a system for positioning the routes of flight missions of drones within the city;

– designing a system to identify and overcome obstacles through the control of the autopilot.

Methodology. In the course of the article, in the future, we will focus on the antenna array, but at the same time, without an adequate positioning system, the activity of unmanned aerial vehicles already with ready-made hardware and software complexes for overcoming obstacles does not guarantee protection against the harmful factor of inertia during braking at a relatively high flight speed. Therefore, it is advisable to combine the two design solutions to minimize accidents.

The American company Panoptes Systems is developing a system for overcoming obstacles by unmanned aerial vehicles. The structure of the system includes 4 ultrasonic sensors: 2 - on the sides, 1 - in front and one more located on top. The range of the sensors is 4.6 meters.

The system has limitations in the form of failure of work due to excess of the take-off weight provided by the manufacturer according to the technical characteristics. In order to improve the quality indicators of the system's operation, it is proposed to introduce passive phased antenna arrays of microstrip technology in the research project "Designing algorithms for the use of unmanned aerial vehicles in North Kazakhstan for the implementation of the state program" Digital Kazakhstan "in the field of agriculture, construction.

The range Rmax equal to 4.6 meters typical for a system with ultrasonic sensors is not enough for an adequate response to dynamic obstacles, therefore, to compensate for this gap, a retrofit kit based on PAR should increase this indicator to an acceptable level. In this case, calculation of the range of an antenna system operating in radar mode (formula 1) cannot be avoided without a mathematical analysis:

$$R_{max} = \sqrt[4]{\frac{Pt \cdot Ga \cdot Ae \cdot Seff \cdot N}{(4 \cdot \pi)^2 \cdot Pr \cdot Ls}}, \qquad 1)$$

where Pt is the peak power of the chirp pulse; Ga - antenna gain; Ae is the effective area of the antenna; λ is the wavelength (for the chirp frequency of 5.8 GHz); Seff - effective reflecting target area; N = n · Ei (n) = 1024 - accumulation parameter; n is the number of pulses; Ei (n) - an indicator of the efficiency of the operation of adding n pulses together; Pr - receiver sensitivity; Ls - system loss factor.

In order to determine the compromise values between the transmitter power and the receiver sensitivity, it is necessary to calculate the second parameter (formula 2):

$$Pr = k \cdot To \cdot F\text{п} \cdot \text{B} \cdot \left(\frac{S}{N}\right) \qquad 2)$$

where kT0B is thermal noise; B is the frequency bandwidth of the receiver; Fn is the receiver noise figure; (S/N) - signal-to-noise ratio.

According to the above formulas, it is possible to reveal the graphs of the dependence of the range on the transmitter power (Fig. 1), the range on the receiver sensitivity (Fig. 2) for different wavelengths of the probe signal of the PAA. According to Figure 2, curve "1" is typical for a wavelength of 3 mm., Curve "2" - 8 mm., Curve "3" - 30 mm., Curve "4" - 50 mm. To select the optimal ratio of transmitter power and receiver sensitivity (at Q = Rmax / Pr), Table 1 has been developed.

Table 1. Dependence of the transmitter power parameter on the receiver sensitivity.

	Transmitter power Rmax, W	**Receiver sensitivity Pr, pW**
$Q=10^{12}$	1	1
$Q=10^{13}$	1	0,1
	10	1
$Q=10^{14}$	1	0,01
	10	0,1
	100	1
$Q=10^{15}$	10	0,01
	100	0,1

Based on the mathematical analysis carried out according to formulas 1-2, it is possible to select a receiver-transmitter with a power of Rmax 1 W and a sensitivity of Pr 1 pW to provide an obstacle detection range at a distance of 500 meters with a phased array radiation frequency of 5.8 GHz.

To ensure the improvement of the quality parameters in the angular coordinates, the field of view of the PAA in the azimuthal plane θ = 30 degrees was chosen. Further, the beam pattern of a given PAA with the width of the main lobe F (θ) up to 30 degrees is scanned in space. After the full passage of the beam, two opposite direction planes F (θ) and F (-θ) are formed, which, according to formula 3, determine the direction finding characteristic (Fig. 3).

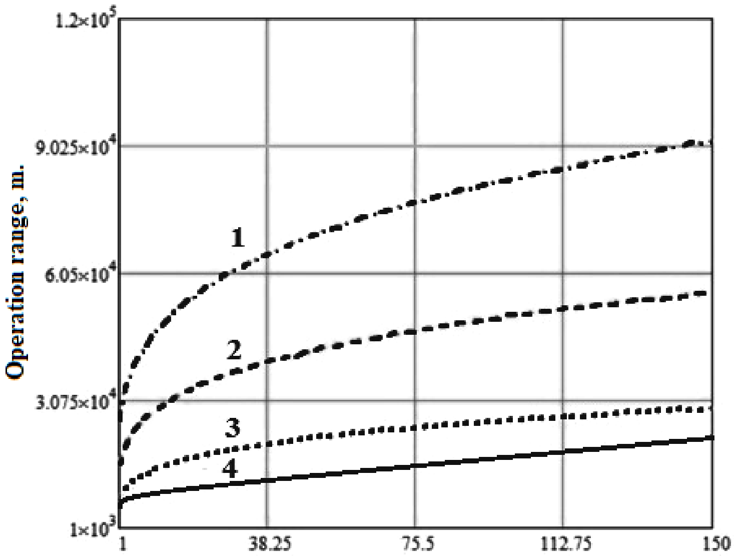

Figure 1 – Graph of the dependence of the transmitter power on the range of the phased array.

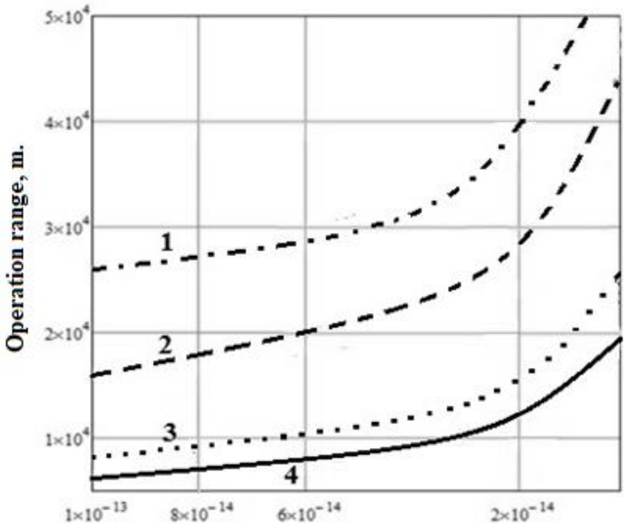

Figure 2 – Graphs of the dependence of the receiver sensitivity on the range of the phased array antenna.

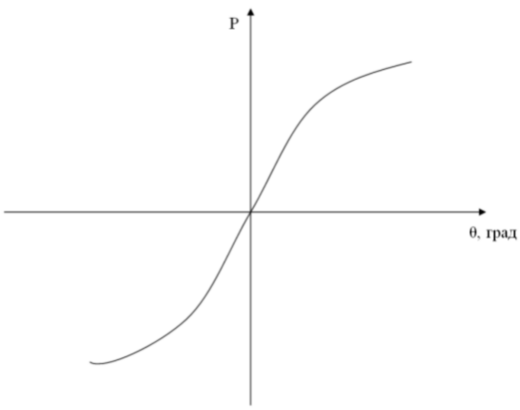

Figure 3 – Direction finding characteristic of PAA.

$$P = \frac{F(\theta) - F(-\theta)}{F(\theta) + F(-\theta)} \quad 3)$$

Such a correction of the parameters of the angular coordinates of scanning the complex for overcoming an obstacle by a drone will reduce the angle of the blind zones from 50◦ degrees to 1◦.

But a complete replacement of ultrasonic sensors with a phased array is still not done without taking into account the rather significant disadvantages of the new hardware:

– high price;

– large dimensions.

The latter index lends itself to correction when introducing metamaterials into the structure of a microstrip phased antenna array. Metamaterials in antenna technology today are mainly used for:

– fabrication of substrates and emitters in printed antennas to achieve;

– broadband and reduce the size of antenna elements;

– compensation for the reactivity of electrically small antennas in a wide frequency band, including those exceeding the fundamental limit;

– achieving a narrow spatial directivity of elementary emitters immersed in the meta-environment;

– manufacturing of surface wave antennas;

– reduction of mutual influence between elements of antenna arrays;

– matching horn and other types of antennas [2].

The structure of the metamaterial forming the substrate can be homogeneous or composite, formed from several types of media. For example, in Fig. 4 shows a μ-negative MNG substrate (magnetic permeability is negative) formed from vertical slit square frames immersed in a dielectric pad.

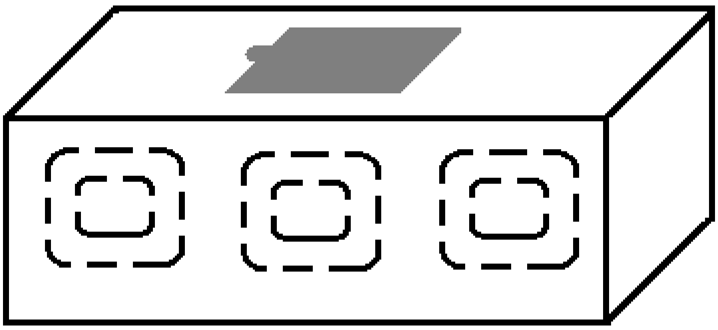

Figure 4 – μ-negative MNG substrate.

The structure of a passive phased antenna array of an unmanned aerial vehicle includes the following layers:

emitter consisting of a metal shield;

– a dielectric substrate located on a metal screen;

– a metal plate located on a dielectric substrate;

– feeder line for power supply, electrically connected through a hole in the metal screen and dielectric substrate with a metal pad;

– dielectric support located on the emitter, as well as the metamaterial located on the dielectric support, while the metamaterial is made in the form of a layered structure with identical transverse dimensions with the emitter and dielectric support, not exceeding the wavelength [3].

3. Experiment

In order to prove the effectiveness of using a phased antenna array based on metamaterials, an experiment was carried out in laboratory conditions. A matched 4x1 antenna array ("Inset-fed 4-by-1") from the set "Microstrip antennas in SDR" with parameters 10.44 cm x 25.82 cm x 0.88 cm (see Fig. 5).

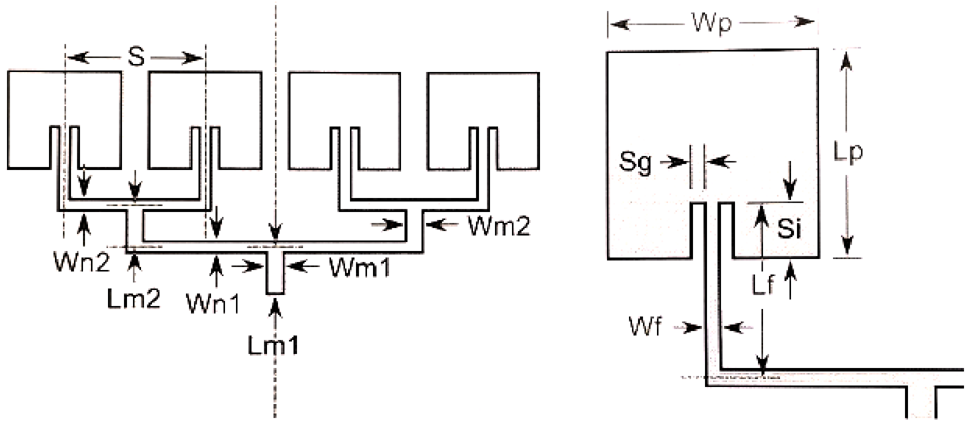

Figure 5 – Microstrip antenna array 4x1.

To obtain data on electrodynamic parameters, in addition to a rotating 4x1 antenna, a Vivaldi-type antenna is used as an antenna system of the transmitter module. The schematic of the experiment is shown in Figure 6.

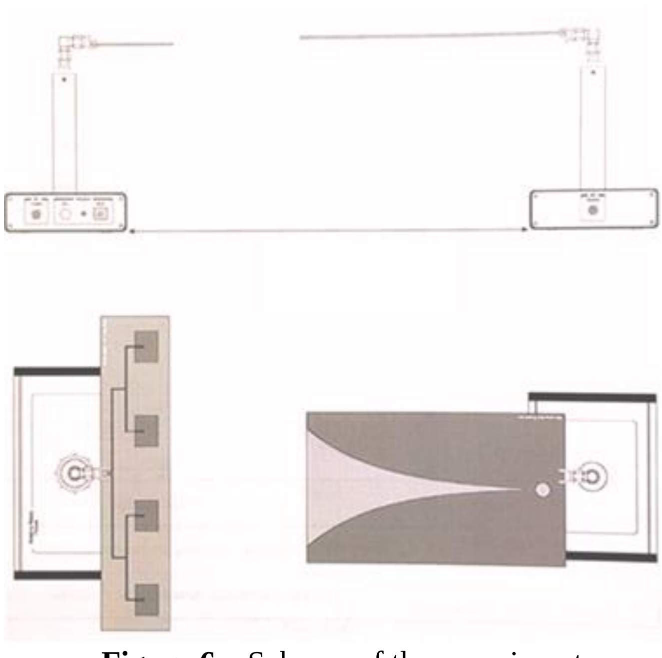

Figure 6 – Scheme of the experiment.

Before performing a laboratory study of microstrip antennas based on the NI USRP-2901 SDR software and hardware complex, it is necessary to install ARF and ASF devices in parallel at a distance of at least 1.5 m, ensuring maximum interference-freeness, and run the PCB Antennas Lab software. It is necessary to study the preliminary characteristics of the antennas in the Description section, selecting the antenna under study from the list [4]. Then, using the scaling tools, determine, calculate the antenna characteristics and fill in the corresponding cells of Table 3 (RL should be less than -10 dB, VSWR value in the range from 1 to 2).

The next stage of research is connecting the "Inset-fed 4-by-1" antenna to the ARF device, and the auxiliary "Microstrip-fed Vivaldi slot" antenna to the AST device according to Figure 6. In the main program window, go to the Measurement section to set the speed and rotation angle antenna, set the signal generator frequency, return loss coefficient, select the measurement plane (XY / XZ / YZ) and press the Start button [5]. Take measurements in 3 planes and make sure that the data collection is complete and the status slider is 100% loaded and save them. In the Compare section, load all measurements and display the radiation patterns (Fig. 7, 8). The measurements were performed at a frequency of 4222 MHz.

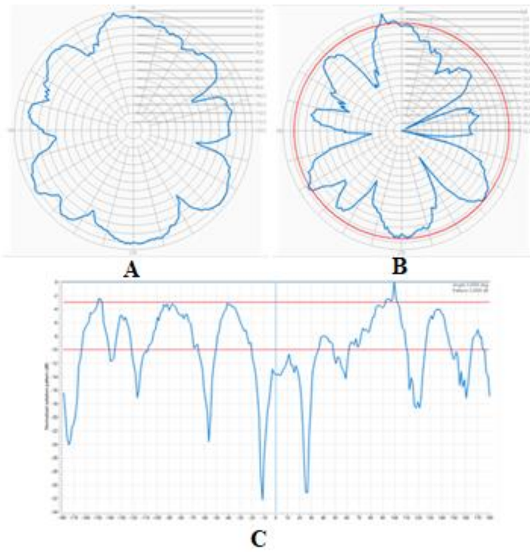

Figure 7 – a - radiation pattern, b - normalized radiation pattern, c - normalized radiation pattern in a Cartesian coordinate system in the XY Plane.

Based on the results of measurements in additional planes YZ, XZ, we construct a three-dimensional radiation pattern shown in Figure 8:

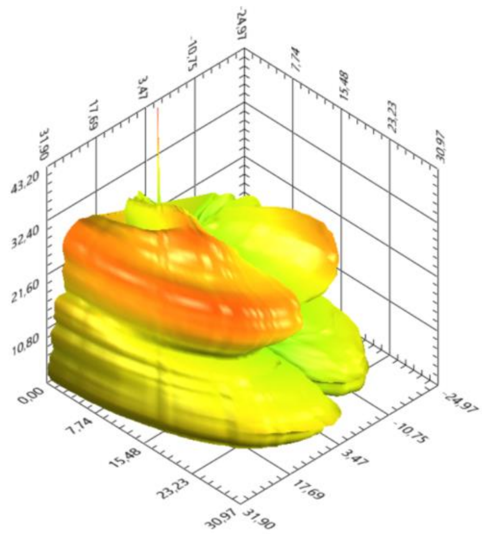

Figure 8 – 3D polar pattern.

In the second part of the experiment, a microstrip phased antenna array was designed in the ANSYS HFSS application as an analogue of "Inset-fed 4-by-1" based on metamaterial, for an unmanned aerial vehicle is presented (Fig. 9). Antenna dimensions: 4.16 cm × 10.4 cm × 0.16 cm in the plane of the electric field and 4.16 cm × 9.8 cm × 0.16 cm in the plane of the magnetic field. Rectangular patch antennas with a mutual distance of 2.6 cm are adopted as emitters [6].

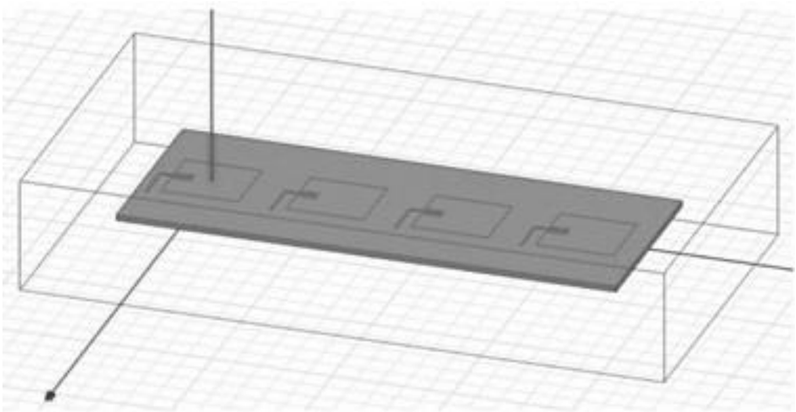

Figure 9 – Microstrip PAA of an unmanned aerial vehicle in the ANSYS HFSS application.

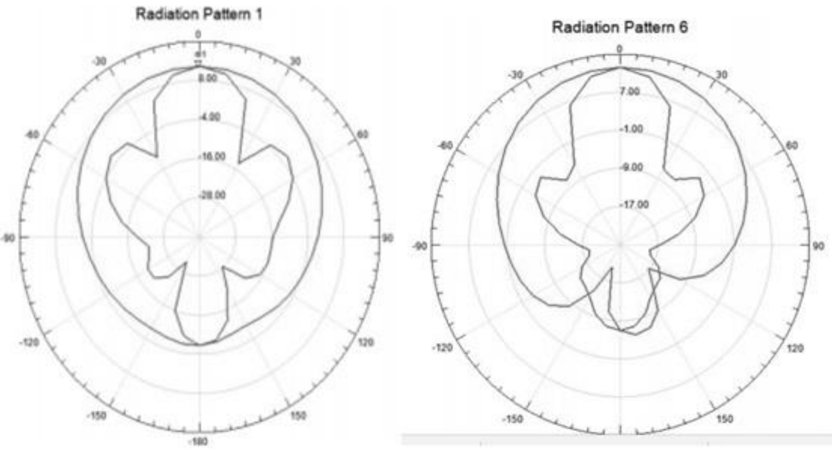

Figure 10 – UAV PAA radiation pattern in the meridian plane (left) and in the azimuthal plane (right).

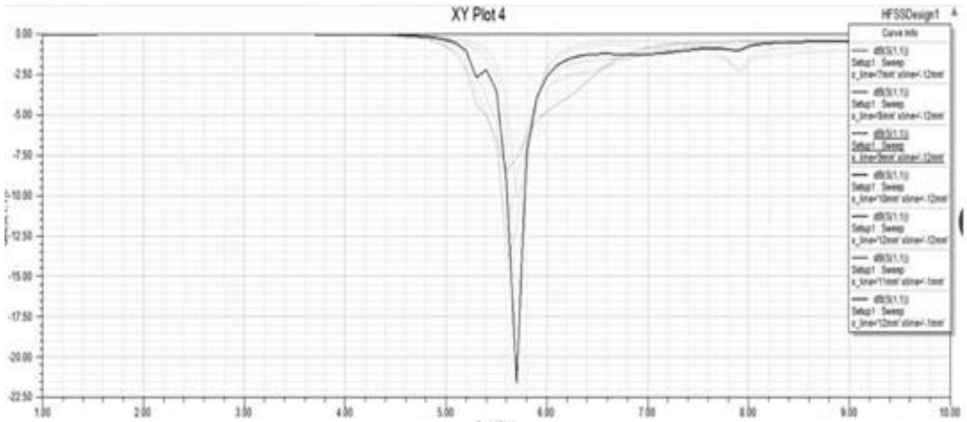

Figure 11 – Reflection coefficient S11 of the UAV microwave HEADLIGHT.

Figure 10 shows the radiation patterns of a passive phased antenna array of an unmanned aerial vehicle in the meridian and azimuthal planes. Figure 11 shows a graphical solution for the reflection coefficient S11 of a microwave antenna (-21.5 dB). The results of the experiment showed that the microstrip phased antenna array with metamaterial developed in the ANSYS HFSS application, taking into account the reduction in geometric and overall dimensions, surpasses its analogue from the laboratory stand "Microstrip antennas SDR" in directional properties.

Conclusion. The presented PAA model can be used in the modernization of the antenna complex for overcoming obstacles of the following drones:

– Geoscan 201;
– Geoscan 101;
– DJI Inspire;
– DJI Agro.

The phased array of microstrip technology, due to the gain in range, speed and scanning angles, will allow the aforementioned UAVs to perform flight tasks in the field of forestry (building orthophotomaps, revealing the normalized vegetation index NDVI), in the field of search operations of the Ministry of Emergency Situations (the antenna system will allow early identification of obstacles in the path of the drone) , delivery of goods from post offices to addressees (warns against collisions with each other), in geodetic activities.

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