CME LIVE OPEN ACCESS

Journal of
Advances in Civil and Mechanical Engineering

Research Article

Electrodynamic Modeling of a Four-Section Phased Antenna Array with a Wide Bandwidth and Provision of this Distributed Power Supply

Stanislav A. Karpukhin*

Pao Npo Almaz Leading Engineer Russia Moscow.

Corresponding Author: Stanislav A. Karpukhin, Pao Npo Almaz Leading Engineer Russia Moscow.

Received: 2024 Nov 14 **Accepted:** 2024 Dec 02 **Published:** 2024 Dec 11

Summary

This article is devoted to promising methods of detection of unmanned aerial vehicles by phased antenna array with a wide bandwidth and providing distributed power supply of this array using a controller in the power supply circuits. Range extension of this phased antenna array is achieved by differentiating the antenna web into sub-bands to which a particular antenna section corresponds. This method allows the antenna to work on aerodynamic targets of different configurations and having different effective scattering surface. In contrast to the modeling described in articles modeling of the proposed antenna was carried out in the frequency range of 1 GHz - 2 GHz [1,2]. The antenna circuit uses a single power supply and a controller that allows the antenna sections to operate algorithmically depending on the type of target, target acquisition, acquisition reset, etc. The developed antenna can be used both in military and space technology, but when used in space technology, there will be problems, the impact of rocket engine plasma on the electromagnetic radiation of the antenna as it was described in the article [3], but the analysis of the use of short radio pulse shows that this problem is solvable [4]. In this paper, electrodynamic modeling of frequency characteristics of the radiators of a four-section phased antenna array is carried out.

Keywords: Phased Antenna Array, Bandwidth, Power Supply, Pulse Sequential Scheme

1. Introduction

Nowadays there is a need for detection and tracking of various aerodynamic targets having different geometric dimensions, different dispersion surface, made of different, including composite, materials. The development of unmanned technology has dictated new requirements for the development of radar technology and the creation of fundamentally new means of detection of aircraft. As it is known from the course of radar detection of aircrafts is carried out by a number of features and characteristics, such as size, material, speed, temperature, noise, aerodynamic trace in the atmosphere. In unmanned technology there is a tendency to reduce a number of characteristics, which has become a certain difficulty in the detection of targets by conventional air defense means.

1.1 Problem Statement

Thus there was a need for universal means of detection, capable of operating at different frequencies, with different wavelengths and providing a wide operating range, capable of operating in the near and far detection zone, and the use of frequencies of UHF and EHF - ranges for the realization of the necessary functions makes increased demands on radio-electronic equipment and the rapid introduction of new design technical solutions. Also a number of problems in providing phased antenna arrays with power supply were revealed, such as the need to use very powerful power sources, which entailed a decrease in the reliability of antenna elements (cables, amplifiers, phase shifters) and a significant increase in the number of means that provide power supply to the phased antenna array, which in turn entailed an increase in the radio visibility of the antenna, as mentioned in the book [1-5].

1.2 Problem Solution

This problem can be solved by a four-section phased antenna array, which consists of four sections operating in different frequency ranges. Fig. 1 shows a four-section phased antenna array, which must be provided with a distributed power supply. The paper describes numerical modeling, but for our antenna it is more appropriate to perform electrodynamic modeling [6]. When analyzing the propagation and scattering of ultra-wideband signals in media with frequency dispersion, it is more advantageous (from the computational point of view) to use time-domain methods [7]. The presented four-section phased antenna array is patented by the author.

The presented phased antenna array consists of the following elements: section 1, section 2, section 3, section 4 and tripod 4 (Figure 1). Section 1 provides operation in the 1 GHz band, section 2 in the 1.3 GHz band, section 3 in the 1.6 GHz band

and section 4 in the 2 GHz band. The method of numerical modeling in an inhomogeneous medium proposed in explains the dependence of electromagnetic wave propagation on the dielectric constant of the inhomogeneous medium, but in our case the conditions are simplified, since the medium will be considered as homogeneous [8]. The antenna assembly is a structure that provides immobility of the antenna sections in the vertical and horizontal planes, provides a tight fit of the edges of the antenna sections to each other without a gap, which has a positive effect on the quality of transmission. Sections made of glass-textolite are resistant to climatic factors: ambient temperature from minus 50°C to plus 60°C, relative humidity up to 98% ± 2% at a temperature of plus 35°C. These antenna arrays can form phased array systems and can be used at spaced positions.

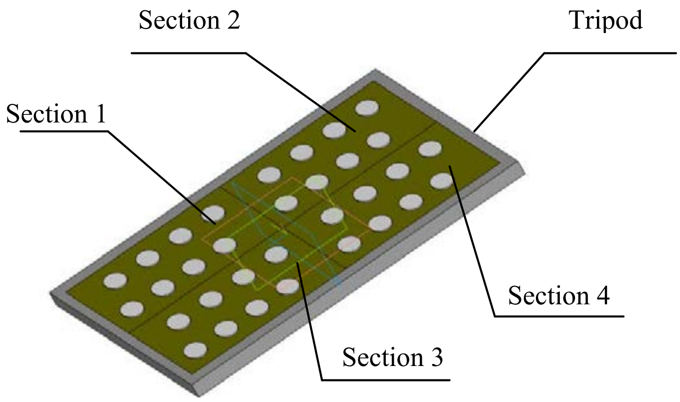

Figure 1: Four-Section Phased Antenna Array Assembly Installed in the Mounting Stand

The antenna geometry allows to reduce parasitic radiations by reducing the gap when connecting the sections, the labor intensity is reduced by using the slot method of connecting the antenna sections, the vibration resistance of the radiators is increased by changing their shape (round flat metal radiators), the phenomenon of interference is reduced by reducing the protruding elements (screw heads), the cost of production is reduced by using cheap materials (glass-textolite), and the bandwidth is wide enough. The peculiarity of this type of antennas is the use of impedance structures capable of supporting flat or cylindrical surface waves. In this case, the antenna is designed so that the reflection of the wave from the end of the structure is small, and the antenna establishes a mode close to the traveling wave mode.

2. The Comparative Analysis of the Proposed Phased Antenna Array shows that the Array Differs from the Antenna Arrays taken as a basis by the Fact that

• The sections in the four-section antenna are made of glass-textolite, which allows to reduce the cost of construction and considering that glass-textolite is well processed (milled, drilled, etc.), reduces the labor intensity and time of manufacture of sections.

• In the four-section antenna the radiators have a round flat shape, which positively affects the vibration resistance and allows to use it on a moving carrier.

• in the four-section antenna the assembly will be carried out with the help of groove joint, which allows to get rid of protruding surfaces, and this leads to the reduction of the phenomenon of interference (addition) of useful and side signals.

• in the four-section antenna feeding of round metal flat radiators is carried out with the help of coaxial feeders, which allows to reduce the influence of side signals on the feed line, as coaxial feeders have a protective screen in their composition.

2.1 The Sections are Made of Glass-Textolite by Copper Foil Etching Method According to the Protective Image (Printed Technology)

1. The first section of the antenna is connected to the second section by means of a slot connection.
2. The third section is connected to the first and second sections as follows: the projection of the third section is connected to the groove of the first section.
3. The fourth section is inserted into the groove on the right side of the antenna (from the end) with a protrusion and progressive movement to the left is aligned with the protrusion with the groove of the third section.

Antenna array is developed at the level of design sketch, which can be made a model for the realization of this technical solution. The principle of operation of the phased antenna array is as follows: first performs the antenna section with the longest wavelength. This section allows you to detect aerodynamic targets with a large effective scattering area and are at a considerable distance from the antenna. If the scattering area of the target is smaller, then the section with a shorter wavelength is activated, and so on. Thus, the target is detected by one of the antenna sections depending on the target scattering area and range. This scheme of phased antenna array construction allows to cover a significant operating range, in our case it is the octave range (1 GHz - 2 GHz) and allows to detect targets both at short range by sections with small wavelength and at long range by sections with long wavelength.

In the developed four-section antenna a pulse-sequential power supply scheme is applied, i.e. first the power supply is supplied to the first section of the antenna during time t, then to the second section, then to the third, and finally to the fourth. Power distribution will be accomplished by a controller and relays that will close the power supply circuits according to the signaling currents from the controller. The scheme of power supply distribution of the four-section antenna is shown in Figure 2. Electromechanical relays are used in the scheme, but in the future it is possible to use solid-state relays, which have a number of advantages, such as: smaller size, high performance, unlimited lifetime, etc. However, solid-state relays have their disadvantages such as: high resistance in the off state, tendency to overheat, the appearance of false alarms due to voltage surges.

Feeders used in antenna operation are defined as electrical circuits and auxiliary devices by means of which the energy of the radio frequency signal is brought from the radio transmitter to the antenna or from the antenna to the radio receiver. Feeder lines operate at lower power levels than hollow waveguides. To extend the operating range of the proposed antenna it is possible to use impedance materials, which were described in the article, but in our case, the range was extended by dividing the antenna web into sections [9]. As it was indicated the power supply of the antenna is pulse-sequential in nature. In combat operation it looks as follows: first the controller supplies current through circuit 1 (Figure 2), as a result of which triggers relay K1 and provides power to the first section of the antenna. The first section of the antenna scans the space with a signal with characteristics f = 1 GHz, λ = 300 mm for some fixed period of time t (the operation time is entered into the controller programmatically and will be about 2 - 5 min.). If no target marks are received during the operation of the first section, the controller turns off circuit 1 and energizes circuit 2.

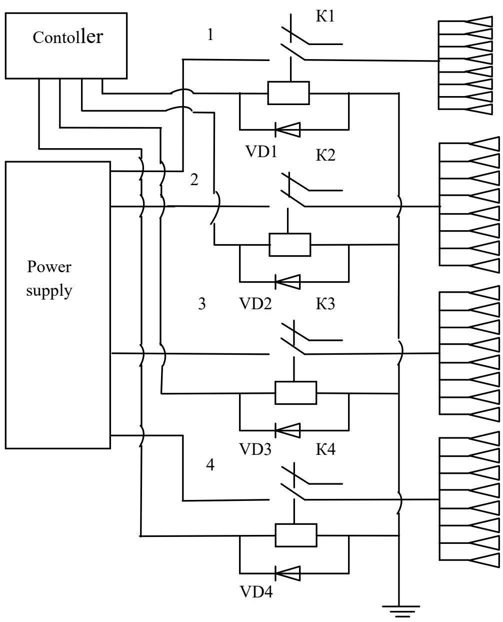

Figure 2: Scheme of Power Supply Distribution of a Four-Section Phased Array Antenna

As a result, the second section begins to scan the space with a signal with characteristics f =1.3 GHz, λ=223 mm, then after a time of 2 - 5 minutes, if no target marks are received, switches to circuit 3 and the third section scans the space with a signal with characteristics f =1.6 GHz, λ=181 mm, then if there are no marks is switched on the fourth section (f =2 GHz, λ=150 mm), and if there is no detection, the controller switches to circuit 1. If during the operation of one of the four sections the target detection marks are received, the operator sends a command to the controller to follow the target and further operation of the antenna is carried out by the antenna section that detected the target. In the case of failure of detection and disappearance of marks on the screen, the operator sends a command to the controller to remove the tracking of the target and the work of the antenna begins to be carried out in normal mode pulse-sequentially starting with the first section of the antenna and ending with the fourth. Thus, this scheme allows to detect drones of any form, as it allows to work in different modes and on different ranges. Also taking into account that the work in this antenna scheme is not the whole antenna web, but only a part of it, it is possible to spend more economically the power of power sources, that is, the power consumption we reduce four times, since only ¼ part of the antenna works.

2.2 The advantages of this Drone Detection Scheme are

1. Due to the fact that this phased antenna array has a sectional nature, the number of sections can be increased in any order, thereby increasing the range of radio scanning signals, which will detect unmanned aircraft with any effective scattering area, and using different guidance systems including inertial.
2. A failed antenna section can be easily dismantled and replaced with a serviceable one in the field.
3. The circuit uses a single power supply, which simplifies and reduces the cost of the antenna design.
4. The antenna can be mounted on a car chassis and quickly change the point of dislocation.
5. The antenna design has a relatively light weight, as it is made using composite materials (glass-textolite).
6. The antenna design is resistant to external influences (moisture, temperature, snow, vibration).

According to the method of feeding phased antenna arrays are divided into antennas with active, passive and mixed

Citation: Karpukhin, S. A. (2024). Electrodynamic Modeling of a Four-Section Phased Antenna Array with a Wide Bandwidth and Provision of this Distributed Power Supply. *J Adv Civil Mech Eng, 1*(1), 1-7.

power distribution. Passive feeding scheme has one common feed source and a group of passive phase shifters. The disadvantages of this scheme in transmission

- Utilization of a large amount of power by transmitting it through a single channel to the irradiator;
- High level of power operation of phase shifters.
- At reception.
- High noise level due to additional losses in phase shifters.

An active circuit has generators or power amplifiers in the supply channels for each transmitter.
The active power circuit has the following disadvantages

- The circuit is complex and expensive
- requires powerful power supplies

Compared to the passive scheme, the active scheme successfully realizes the problem of generating and transmitting high power, also the signal-to-noise ratio is much better. The power supply of such active phased arrays can be realized by different methods, having, for specific power supply systems of different importance, the conditions of which in general case are the following requirements

- Minimum mass of the power supply system (especially its part placed on the antenna web);
- Maximum reliability of the system;
- Maximum efficiency of the power supply system.

Many printed antennas are excited by symmetrical coupling devices that have a 180° phase shift and are fed from a power divider. In antennas, phase shifters with a constant phase shift are used. This is due to the fact that along the line of radiators a phase reset is used every 360°, which allows the use of “short” phase shifters that provide a phase shift of 360° or less. Various combinations of parallel-sequential, spatial and feeder methods of excitation of antenna elements are used. Let's consider some of them. The series circuit has in its composition one common feeder, which operates in the traveling wave mode.

➢ The Disadvantages of the Scheme are

1. Small level of transmitted power
2. High power losses
3. Phase shifters must be properly matched for their characteristics

➢ The Parallel Power Supply Circuit has Several Designs, and Compared to the Series Circuit, it has Several Advantages

1. High level of power throughput
2. Lower power losses

➢ Disadvantages of Parallel Circuits

1. Complex phase shifter control unit
2. Large phase shift is required to provide the required scanning sector

There is also a mixed power scheme in which the phase shifters are connected in parallel, but the power to the transmitter is supplied through a single feeder. The power supply methods are also classified as follows - centralized system, decentralized system, partially decentralized power supply system. In centralized system, there is one powerful power source which is supplied with energy from the input network through radio interference filter and converts it to supply power to the entire web. In a decentralized system, power is supplied from the on-board grid. In a partially decentralized system, the transmitters are grouped so that failure of a group of transmitters does not cause failure of the entire web.

Matrix power supply systems are a new stage in the development of phased array technology. The principle of matrix power supply is to distribute the power supply by means of integrated modules. The matrix structure of power supply modules arrangement allows to optimize the operation of individual antenna sections.

The simulation of a four-section phased array antenna has been carried out. Also, as in the article [10] the calculation of the antenna geometry was performed on a PC with a 3.7 GHz Intel Core i7 - 8700k processor and 16 Gbytes of RAM. All calculations and plotting of reflection coefficient, standing wave coefficient, impedance and total power were performed in the Antenna Magus software module. Directional diagram construction was carried out in the program module CST Studio Suite. The paper presents the diagrams of the frequency dependence of the standing wave coefficient and the radiation pattern for all four sections of the antenna. For the first section, an operating range with a frequency of 1 GHz and a wavelength of 300 mm was selected and the diagrams shown in Figures 3-4.

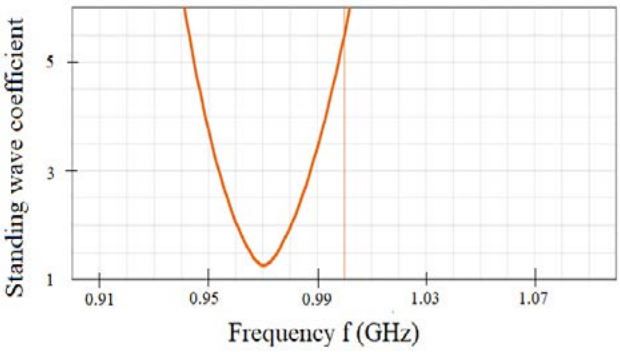

Figure 3: Diagram Showing the Frequency Dependence of the Standing Wave Coefficient for the First Antenna Section

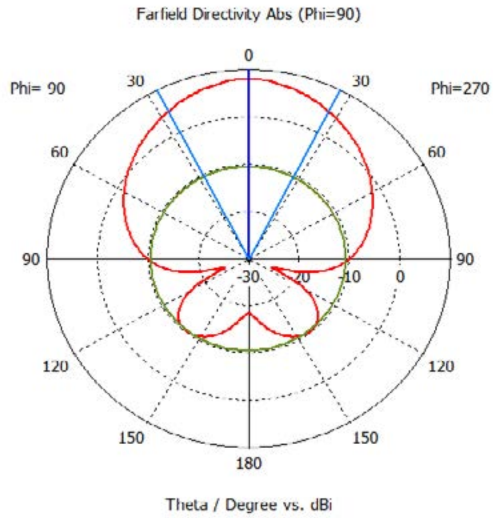

Figure 4: Directional Diagram for the First Section

For the second section, an operating band with a frequency of 1.3 GHz and a wavelength of 223 mm was selected and the diagrams shown in Figures 5-6.

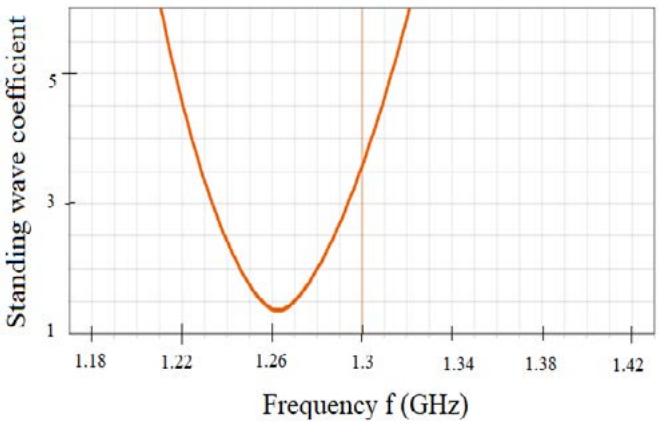

Figure 5: Diagram Showing the Frequency Dependence of the Standing Wave Coefficient for the Second Antenna Section

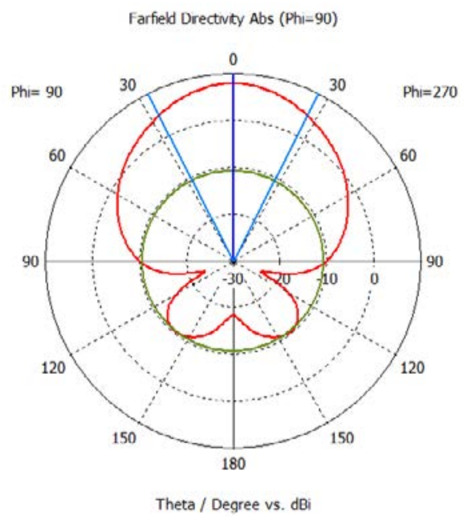

Figure 6: Directional Diagram for the Second Section

For the third section, an operating band with a frequency of 1.6 GHz and a wavelength of 181 mm was selected and the diagrams shown in Figs. 7 - 8.

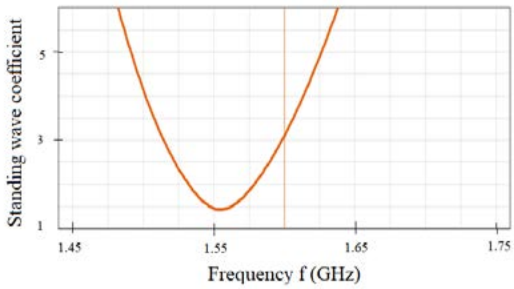

Figure 7: Diagram showing the Frequency Dependence of the Standing Wave Coefficient for the Third Antenna Section

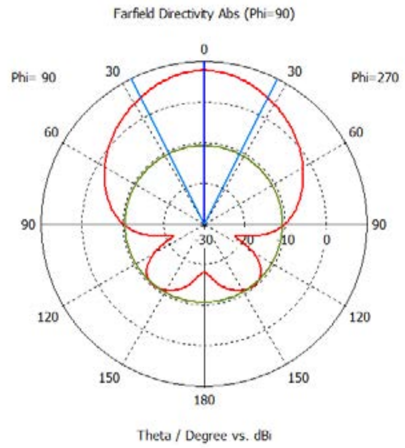

Figure 8: Directional Diagram for the Third Section

For the fourth section, an operating bandwidth of 2 GHz and a wavelength of 150 mm was selected and the diagrams shown in Figs. 9 - 10 were obtained.

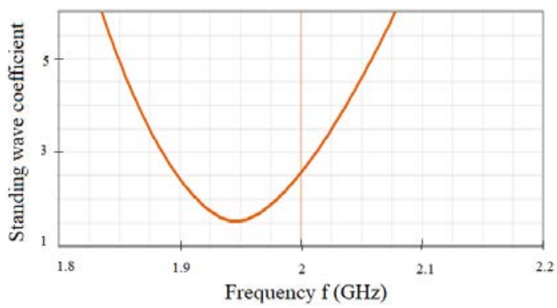

Figure 9: Diagram showing the Frequency Dependence of the Standing Wave Coefficient for the Fourth Antenna Section

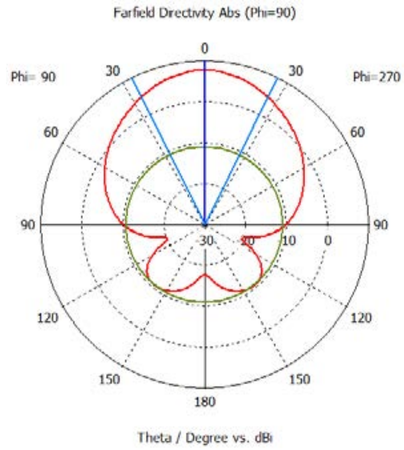

Figure 10: Directional Diagram for the Fourth Section

Analyzing the obtained graphs we can conclude that the standing wave coefficient has a low level, as in the article, and lies within 2.5 - 5, and the directional patterns are optimal for the selected frequency ranges, but never the less have pronounced side lobes to suppress which can be used method using the amplitude and phase distribution, which is described in the article [11,12]. It should be noted that such a design of phased antenna array allows to increase the available operating range of the antenna, by adding additional antenna sections to the design and increasing the total number of sections up to six, eight, etc. Further we would like to emphasize that the failure of one section of the antenna does not entail the failure of the entire antenna. Replacement of the failed section is easily done in the field, thereby reducing the time spent on antenna repair. The use of glass-textolite as the main material significantly reduces the cost of the antenna compared to analogs, and given that glass-textolite is strong enough, resistant to weather conditions, corrosion and is able to operate in a wide range of temperatures, we can note its clear advantage over metals.

3. Conclusion

Since the standing wave coefficient is low and lies within 2.5 - 5, and the radiation patterns are optimal for the selected frequency ranges, hence, the antenna characteristics satisfy the modeling conditions and this type of antennas can be used in military broadband equipment. The scientific novelty of the work consists in the fact that the modeled antenna array allows extending the detection range of unmanned aerial vehicles regardless of their geometric shapes and effective scattering surface, as well as providing detection in the near and far detection zones. Additionally, as an innovation, the paper proposes a distributed power supply system with a built-in controller, which allows to optimize the method of power supply of a given antenna, thereby allowing more economical consumption of the charge of power supply sources and reducing the load on power cables and antenna elements, and the failure of one section does not entail the loss of performance of the phased antenna array as a whole. This optimization allows to extend the service life of antenna parts (feeders, amplifiers, phase shifters), thereby increasing the durability of the entire phased antenna array.

References

1. Godin, A. S., Kruglov, A. I., & Klimov, K. N. (2016). Numerical electrodynamic analysis of the far-field patterns of the external Sestroretskii cube. *Journal of Communications Technology and Electronics, 61*(7), 776-782.
2. Godin, A. S., Tsai, A. B., & Klimov, K. N. (2015). Numerical electrodynamic analysis of the interior problem for a Huygens element that is an interior Huygens cube. *Journal of Communications Technology and Electronics, 60*, 329-334.
3. Konov, K. I., & Klimov, K. N. (2023). Using the Method of the Impedance Analog of the Sestroretskii Electromagnetic Space to Take Into Account the Influence of the Rocket Engine Plasma on the Radiation Pattern of the Onboard Antenna. *Journal of Communications Technology and Electronics, 68*(8), 836-842.
4. Konov, K., & Perfilyev, V. (2021, April). Analysis of the Propagation of a Short Radio Pulse in Media with Negative Permittivity. *In 2021 International Seminar on Electron Devices Design and Production* (SED) (pp. 1-4). IEEE.
5. Trevor S. B. Aperture Antennas in Application in *Fundamentals of Aperture Antennas and Arrays: From Theory to Design, Fabrication and Testing* , Wiley, 2015, pp.357-389,
6. Klimov, K., & Konov, K. (2019, April). Modification of the Integration Variable Selection Method in Numerical Simulation of Electromagnetic Wave Propagation in the Time Domain. *In 2019 International Seminar on Electron Devices Design and Production* (SED) (pp. 1-5). IEEE.
7. Klimov, K. N., Matsayan, M. S., Konov, K. I., Epaneshnikova, I. K., Serebryannikov, S. V., Serebryannikov, S. S., ... & Boldyreff, A. S. (2019, October). Electric field distribution modelling of the distributing system 5-beam APAR in time area. *In Emerging Imaging and Sensing Technologies for Security and Defence IV* (Vol. 11163, pp. 136-145). SPIE.
8. Klimov, K. N., Epaneshnikova, I. K., Belevtsev, A. M., Konov, K. I., Serebryannikov, S. V., Cherkasov, A. P., ... & Boldyreff, A. S. (2019, October). Development of the integration variable selection method in numerical simulation of electromagnetic wave propagation in the time domain mode. *In Millimetre Wave and Terahertz Sensors and Technology XII* (Vol. 11164, pp. 139-147). SPIE.
9. Klimov, K. N., Epaneshnikova, I. K., Belevtsev, A. M., Godin, A. S., & Drize, A. D. (2017, October). Synthesis of structures of electric small-sized radiators using impedance matching materials for millimeter waves. *In Millimetre Wave and Terahertz Sensors and Technology X* (Vol. 10439, pp. 49-58). SPIE.
10. Klimov, K. N., Konov, K. I., Belevtsev, A. M., Epaneshnikova, I. K., & Boldyreff, A. S. (2023, June). Electromagnetic Modeling of the Ultra-Wideband Antenna Array Radiator. *In 2023 Radiation and Scattering of Electromagnetic Waves* (RSEMW) (pp. 232-235). IEEE.
11. Godin, A. S., Tsai, A. B., & Klimov, K. N. (2015). Numerical electromagnetic investigation of patterns of the external problem for the Huygens element that is the external Huygens cube. *Journal of Communications Technology and Electronics, 60,* 737-746.
12. Klimov, K. N., Konov, K. I., Belevtsev, A. M., Epaneshnikova, I. K., Serebryannikov, S. V., Cherkasov, A. P., ... & Boldyreff, A. S. (2020, September). Method for suppressing side lobes of a linear phased antenna array using amplitude and phase distributions. *In Millimetre Wave and Terahertz Sensors and Technology XIII* (Vol. 11541, pp. 89-97). SPIE.

Citation: Karpukhin, S. A. (2024). Electrodynamic Modeling of a Four-Section Phased Antenna Array with a Wide Bandwidth and Provision of this Distributed Power Supply. *J Adv Civil Mech Eng, 1*(1), 1-7.