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SUBSTITUTION OF RESEARCH ON ANTENNA SYSTEMS IN SHORTWAVE AND ULTRASHORTWAVE RANGES

Abstract. To improve the short-wave antenna based on low-positioned vibrators, an analysis of current trends in the development of new and modernization of existing antenna systems for short-wave radio communications was conducted. The possibility of studying the use of low-positioned horizontal vibrators is due to the fact that it is possible to create rather complex antenna arrays with large gain coefficients from available materials at ionospheric wave antenna sites and not only for them. Approaches to improving antenna systems depending on the type of radio wave propagation, physical parameters of antenna-feeder devices and their directional properties were analyzed. In this regard, an approach to antenna synthesis and the use of this approach in further work to improve the antenna system and obtain the necessary directional characteristics for organizing stable radio communications were substantiated. It is proposed to develop a method of constructive synthesis based on the methods of induced electromotive forces and mirror reflection. At the same time, a set of scientific tasks has been defined to achieve new results, classical mathematical methods have been selected, with the help of which it will be possible to calculate the electromagnetic field created by an improved antenna system. To achieve the set goal, the main directions have been defined, such as: improving the mathematical model of the antenna system based on low-lying radiators; the next step is to improve the mathematical method for calculating the electromagnetic field taking into account the radial components of the electric and magnetic fields; and, as a result, to obtain a convenient tool, to develop a methodology for the constructive synthesis of an improved short-wave antenna system from low-lying radiators with the ability to change the direction of the antenna radiation pattern in the vertical and horizontal planes. The article has formed an objective function that determines the main parameters that need to be achieved. Controlled and uncontrolled variables have been determined, on which the objective function of the specified process directly depends. In conclusion, an approach to calculating the efficiency indicator for evaluating the obtained parameter value from their previous values is presented.

Keywords: mobile radio communication, short-wave antenna, low-lying vibrators, induced electromotive force method, mirror reflection method, antenna systems, gain.

Introduction

In conditions of maneuverable fast-paced modern combat with a sharp change in the situation and in the absence of a continuous line of contact of troops, reliable high-quality radio communication is a guarantee of stable and flexible command of troops.

The main trends in the development of military radio communication means of the tactical command link are a reduction in their weight and dimensions, an increase in the duration of autonomous operation, as well as an improvement in the main technical characteristics of such means, due to the improvement of systems and individual elements of these means. On the one hand, these trends meet the requirements for military radio stations, and on the other hand, the possibility of improving their characteristics due to the rapid growth of technologies in modern technology. Therefore, the creation of modern means of communication and the modernization of existing radio stations requires the development of new and if possible, improved standard antenna systems [1].

Statement of the problem

The search for the optimal variant of the antenna type, its parameters, design, technology, element base, metrological support, etc., which best meet the requirements, forms the basis of the design (synthesis) of promising antenna systems. Thus, in the theory of antenna technology, a number of scientific tasks arise that are related to the need to further improve the general theory of antennas, methods for their calculation, finding new ways to build antenna systems and solving no less important design and technological problems [2–4].

Design and construction of antennas according to the specified requirements, that is, the synthesis of antenna systems, is the main task of any process of developing such systems. The process of performing this task can be conditionally divided into two parts - the development of theoretical principles (mathematical methods) and practical implementation (design and technological implementation) of antennas (Fig. 1).

The theoretical (physical-mathematical) theory of antenna system synthesis usually consists of two separate tasks, namely: solving the external task – determining currents (electromagnetic fields) according to given directivity characteristics; solving the internal task – determining the elements of the antenna design, excitation device, distribution systems and others [5].

These two tasks are considered independently of each other in most cases. For the construction of antenna systems, it is advisable to use constructive synthesis of antennas. According to the views of well-known experts in the field of antenna technology, constructive synthesis is a process by which, based on the specified requirements for electrical characteristics, a design solution for an antenna with the appropriate technical characteristics is found [2, 6]. Tactical control link communications equipment in service has a standard set of antenna-feeder devices with limited technical characteristics. At the same time, these equipment cannot operate without changing the height of the antenna devices, which complicates the formation of the desired antenna beam pattern and does not provide control over it when the situation changes. Today, there is no method for forming the necessary beam pattern taking into account the antenna orientation and its height of suspension.

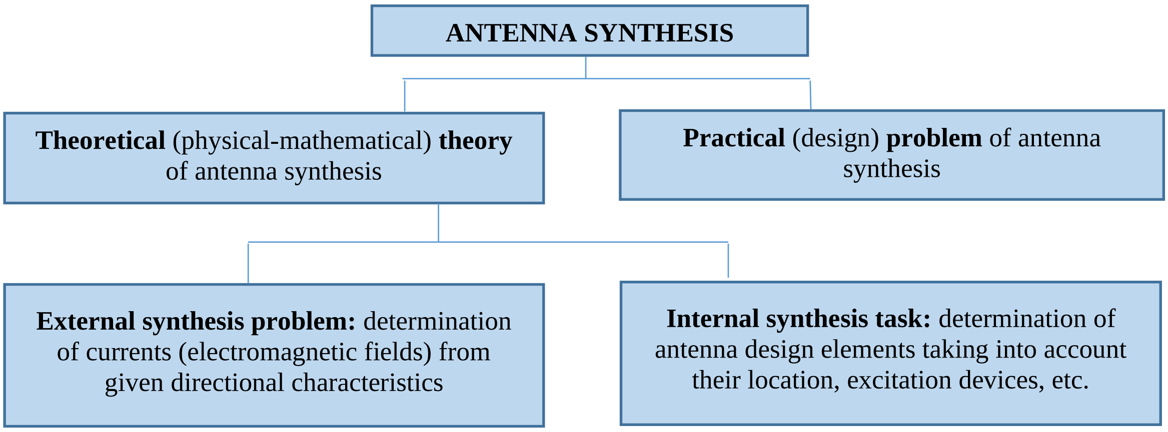

Fig. 1. The principle of antenna construction

Presentation of the main material

To achieve operational and economic benefits of modernizing mobile radio communications, it is advisable to pay attention not only to the development of new antenna systems, but also to the improvement of existing ones, which have a limited number of standard antenna-feeder devices, by improving the technical characteristics of the antenna to obtain the required width of the directivity diagram, as well as taking into account the direction of information transmission and the influence of the earth's surface on the propagation of radio waves. Currently, stationary speakers made from improvised materials are used for the shortwave (HF) and ultrashortwave (VHF) ranges. For example, for two parallel lines, one of which is shown in Fig. 2, with 10 vibrators in each, it is possible to obtain a gain of up to 12 dB. The line is a vibrator (conductors from the antenna cable) that are suspended above the ground on wooden poles (Fig. 2).

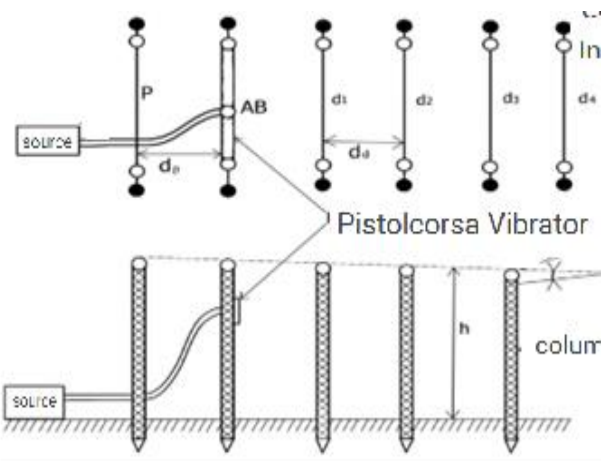

Fig. 2. Antenna system made of horizontal vibrators

Such antenna system can be installed because radio equipment can be moved approximately once every 2-3 days, and in territorial defense once a month (from the experience of practical application of communication systems).

Such AS can be used for both automobile communication stations and portable ones, the input/output impedance of which is 50 Ohms [3, 4].

Analysis of the design features of antenna systems of mobile radio communication equipment shows that for vibrator-type antennas with a width of the main lobe of the DS Θ=80o, a radio communication range of up to 50 km is provided. Under the conditions of reducing the width of the main lobe of the DS to 50o, the radio communication range increases to 70 km, with unchanged transmitter power.

Clarifying the essence of the processes of propagation of electromagnetic waves directly near the planet Earth and in its surrounding space plays an important role in organizing communication [3, 4].

Radio wave propagation is a spatial process that encompasses the propagation of electromagnetic waves of the radio range in the atmosphere, outer space and the Earth's interior, while electromagnetic waves can propagate along rectilinear trajectories, skirting the convex surface of the Earth, reflecting from the ionosphere, etc.

The methods of electromagnetic waves propagation significantly depend on the wavelength λ, the illumination of the atmosphere by the Sun, the location of radio paths relative to the Earth's surface.

A significant role in the process of electromagnetic waves propagation relative to the Earth's surface is played by a part of space that has the shape of an ellipsoid of rotation, at the foci of which the transmitter and receiver are located, while radio waves can be weakened or amplified.

In addition, since the Earth has a heterogeneous surface, when assessing the impact of the Earth's surface on the propagation of electromagnetic waves, it is advisable to take into account such physical effects and phenomena as the properties of the Earth's surface (type of soil, the presence of water, forest resources, urban developments, transport arteries, power lines, etc.); properties of natural and artificial objects and the boundaries of the distribution of boundaries between them and the multi-beam formation of the final signal; multi-beam formation of the weakened power of radio waves due to their absorption by rain, snow, dust; reflection of radio waves from rain, snow, dust, flocks of birds; curvature of the propagation paths of radio waves due to the heterogeneity of the layers of the atmosphere [3, 4].

Fig. 3 shows a typical diagram of a short-wave radio line taking into account reflection from the F2 ionosphere layer. The figure also shows that in short-wave radio communication, space and ground waves are necessarily present, and there is also a ring zone of silence around the receiver, when the ground wave is no longer possible, and the space wave is not yet possible. This is due to the significant attenuation of the ground wave along the earth's surface and the angles of incidence and reflection of the space radio wave from the ionosphere layers [7, 8].

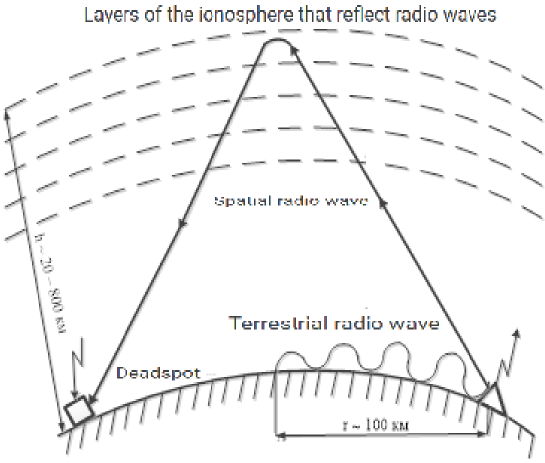

Fig. 3. Typical shortwave radio line diagram

Thus, an urgent scientific task arises regarding the constructive synthesis of an improved AC for short-wave radio communication and the development of an appropriate methodology that takes into account the design features of the AC, the direction of information transmission and the influence of the earth's surface on the propagation of radio waves, which will allow for the rapid construction of a short-wave antenna based on low-lying vibrators.

Therefore, the purpose of the research is to develop a methodology for the constructive synthesis of an improved AC for a mobile radio communication device, which will allow the head of the communication station to calculate a short-wave AC based on low-lying vibrators, in accordance with the specified technical characteristics, and the service personnel to quickly deploy the antenna.

To achieve the research goal, it is necessary to:

– improve the mathematical model of the antenna system based on low-lying emitters;

– improve the mathematical method for calculating the electromagnetic field taking into account the radial components of the electric and magnetic fields;

– develop a method for the constructive synthesis of an improved short-wave antenna system from low-lying emitters with the ability to change the direction of the antenna directivity diagram in the vertical and horizontal planes.

Existing programs for calculating the directivity characteristics of vibrator antennas are developed based on the theory of radiation of a symmetrical vibrator in the far zone, which has significant inaccuracies in the calculation of the components of the electromagnetic field.

Therefore, it is proposed to take into account the radial component of the electric field, which directly affects closely located wire segments.

To calculate the mutual influence of coupled vibrators, it is advisable to use the induced electromotive force method, which allows to find the induced and self-resistances of vibrators, as well as the amplitudes and phases of currents in passive vibrators.

To take into account the influence of real radiators and their mirror reflections on the antenna directivity characteristics in the induced induced electromotive force method, it is advisable to use the mirror reflection method, which allows to partially take into account the influence of real soil parameters on the antenna characteristics.

The essence of the mirror reflection method is that when determining the electromagnetic field generated by a vibrator located above a perfectly conducting surface, secondary currents are excluded from consideration by introducing a probable vibrator, which is a mirror image of the existing vibrator [1, 6].

To achieve the goal of the research, it is necessary to solve the following set of scientific tasks:

1. Analysis of the design features of existing antenna systems of radio communication facilities.

2. Analysis of mathematical methods for calculating the design, construction, modeling and modernization or improvement of antenna systems of radio communication facilities.

3. Development of a physical model of an antenna array of low-lying radiators based on the method of induced electromotive forces and the method of mirror reflection to a system of wire radiators of a special shape, taking into account their common relative location and the influence of the soil.

4. Improving the calculation method for creating a system of emitters in order to increase the energy of the radio line in the desired direction.

5. Developing technical proposals for the use of an antenna system from standard antenna-feeder devices of mobile radio communication equipment and a grounding system, taking into account soil parameters. Using the specified antenna system, form the necessary directivity diagrams in the vertical and horizontal planes, which can be quickly controlled.

6. Developing recommendations for the communications chief of the unit (station chief) for calculating the deployment of the antenna array based on the initial data: frequency, elements of the antenna system, the probable location of the correspondent and approximate soil parameters.

When using modernized vertically located antenna systems (this applies to VHF antennas), it is necessary to achieve the following characteristics:

1) The radiation pattern should change so that the width of the main lobe in the vertical plane is $\theta_0 \le 50^0$. For standard antennas, this parameter is 80º or more.

2) It is assumed that the antenna gain (G_a) will increase to 6 dB. Currently, this parameter is up to 3 dB.

3) Based on the width of the directional pattern in the vertical (θ_0) and horizontal (φ_0) planes and the antenna gain, the electric field E strength should increase accordingly, which at the reception point improves the quality of communication, or while maintaining the same quality of communication, the communication range will increase [9].

Thus, the objective function of this process will be:

$$R(x) = \max R\left(x^*\right); \;\; x^* \in \Delta,$$

where $R(x)$ – the main parameter of the objective function (communication range); x – parameters on which the objective function depends (controlled and uncontrolled variables); x^* – parameter values at the maximum value of the objective function; Δ – permissible range of parameter changes.

Limitations and assumptions:

– limitations on increasing the transmitter power and receiver sensitivity, which must remain unchanged;

– limitations on deployment time (the deployment time of the AS is equal to or less than the current one);

– the qualification of the performer corresponds to a certain position (station chief);

– other limitations may arise based on the direct operational task when developing a methodology for the station chief.

The controlled variables include: the number of antenna array elements (n), the location of the antenna array elements (the distance between the elements is r), the dimensions of these elements (the length of the element is l; the diameter of the element is d), the height of the antenna rise (h), the operating frequency (f), the wavelength (λ), and the antenna gain (G_a).

The controlled variables determine the main parameters of the objective function. The communication range is chosen as the main objective function.

The increase in the communication range is directly proportional to the antenna gain, i.e. $R = \sqrt{G_a}$.

The narrowing of the DS width is approximately 2 times.

Accordingly, the electric field strength must increase, which follows from the equation:

$$E = \frac{\sqrt{30 P_{пер} G_a}}{R}.$$

Uncontrolled variables: climatic conditions, such as season of the year, weather (heat, rain, etc.), soil parameters, maximum transmitter power, receiver sensitivity, type of signal encoding, etc.

The efficiency indicator has the form:

$$\eta = \left[\frac{\left(R_{нов} - R_{ст}\right)}{R_{ст}}\right] \cdot 100\%,$$

where $R_{нов}$ – the new received parameter value, $R_{ст}$ – the previous value of the parameter.

For example, when increasing the communication range from 50 to 70 km, we get:

$$\eta = \left[\frac{70-50}{50}\right] \cdot 100\% = 40\%.$$

Conclusions

The practical implementation of the research results should be an improved antenna system based on low-lying vibrators with the ability to change the direction of information transmission depending on the location of the correspondents. This will provide the technical possibility of improving the efficiency of performing HF and VHF communication and ground wave communication, and will also provide guaranteed radio communication at the required set distance between correspondents.

By modernizing the antenna system without changing the transmitter power and receiver sensitivity, it is expected to increase the communication range by 20–40% [1].

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Обґрунтування досліджень антенних систем в короткохвильових та ультракороткохвильових діапазонах

О. М. Бердников, С. Ю. Мазор, Т. В. Храновська, П. Є. Дімітров

Анотація. Для удосконалення короткохвильової антени на основі низькорозташованих вібраторів проведено аналіз сучасних тенденцій у розробці нових та модернізації існуючих антенних систем для короткохвильового радіозв’язку. Можливість дослідження застосування низькорозташованих горизонтальних вібраторів пов’язана з тим, що є можливість на стоянках для антен іоносферних хвиль і не тільки для них створювати з підручних матеріалів досить складні антенні решітки з великими коефіцієнтами підсилення. Проаналізовано підходи до удосконалення антенних систем у залежності від виду розповсюдження радіохвилі, фізичних параметрів антено-фідерних пристроїв та їх спрямованих властивостей. У зв’язку з цим обґрунтовано підхід щодо синтезу антен та використання даного підходу у подальшій роботі для удосконалення антенної системи й отримання потрібних характеристик спрямованості для організації стійкого радіозв’язку. Запропоновано розробити методику конструктивного синтезу на основі методів наведених електрорушійних сил та дзеркального відображення. Для досягнення поставленої мети визначено основні напрямки, такі як: удосконалення математичної моделі антенної системи на основі низькорозташованих випромінювачів; наступний крок – це удосконалення математичного методу розрахунку електромагнітного поля з врахуванням радіальних складових електричного та магнітного полів; та, як наслідок, для отримання зручного інструменту розробити методику конструктивного синтезу удосконаленої короткохвильової антенної системи із низькорозташованих випромінювачів з можливістю зміни напряму діаграми спрямованості антени в вертикальній та горизонтальній площинах. У статті сформовано цільова функція, що визначає основні параметри, які необхідно досягти. Визначені керовані та некеровані змінні, від яких напряму залежить цільова функція зазначеного процесу. Як підсумок, наведено підхід до розрахунку показника ефективності для оцінки отриманого значення параметрів від їх попередніх значень.

Ключові слова: мобільний засіб радіозв’язку, короткохвильова антена, низько розташовані вібратори, метод наведених електрорушійних сил, метод дзеркального відображення, антенні системи, коефіцієнт підсилення.