Development of antenna system for use in meteorological and climatic control complexes

M A Kudryashov¹, O A Belousov¹, V I Tetyukhin¹, M M Kiryupin¹, V P Belyaev¹, I V Nagornova², E G Bezzateeva²

¹Tambov State Technical University, 106, Sovetskaya St., 392000, Tambov, Russia
²Moscow Polytechnic University, 38, B. Semenovskaya St., Moscow, Russia

E-mail: maximkudryashov969@gmail.com

Abstract. The synthesis of a cylindrical antenna array for ground-based mobile weather monitoring complexes, based on quadrifilar radiators, is considered. The basic mathematical expressions for determining the electrodynamic characteristics of both the radiator from the antenna array and the AA itself are presented. Various phenomenological models of these radiators are considered. The approach to the synthesis of phenomenological models of the radiator and antenna array as a whole is described. The results of such synthesis are given, and the main characteristics and values of DG, CG, SWR, RP for the given type of radiator and AA in the corresponding frequency range are obtained. Techniques for using phenomenological models for operational synthesis of electrodynamic structures such as cylindrical AA and quadrifilar radiator are developed and described in detail. The possibility of applying this approach to the synthesis of this type of structures for radar weather monitoring systems is shown.

1. Introduction

Currently, various upper-air sounding systems are available, such as, MARL-A, AVK-1, AIR-3A-RT2, RT-20, and MP3-3AT. Their characteristics are as follows: the operating frequency is 1680 MHz, 1790 MHz; antenna system characteristics (the type: mirror, passive antenna array (AA)); adaptive phased antenna array (APAA); azimuth scanning (electronic and electromechanical); elevation scanning (electronic and electromechanical) [1].

These complexes are quite cumbersome, and have a number of drawbacks, such as: a small number of radiosonde guidance (up to 5 targets simultaneously), a small range of tracking the probe (up to 20 ... 40 km), inability to quickly control the beam, in the horizontal plane it is of ± 180 degrees at a speed of 30 ... 40 rad/sec, and in the vertical plane from -30 to +140 degrees at 20 rad/sec. The key element of all airborne locators is the antenna system (antenna array). The performance quality of such complexes as a whole depends essentially on antenna array characteristics. Therefore, it is necessary to develop antenna systems without the above drawbacks in order to solve the problem. Such systems include adaptive antenna arrays, phased antenna arrays, adaptive phased antenna arrays, and arrays using artificial intelligence-based control algorithms.
2. Problem statement

Since the existing antenna systems cannot provide full operation in multi-channel mode with several radiosondes simultaneously, as well as have large mass and dimensions parameters, the main task is to modernize such antenna systems in order to eliminate these drawbacks.

The object of the work is to create an antenna array, which will significantly modernize the existing radar weather stations, operating at a frequency of 1687 MHz.

The main objectives of the work are:

- to develop mathematical and computer models of a quadrifilar helical radiator;
- to develop mathematical and computer models of an antenna array based on a quadrifilar helical radiator.

The developed antenna system should meet modern standards used in meteorological radar stations, have suitable electrodynamic characteristics, which will provide its effective use in such complexes, and show high reliability.

3. Theory

3.1. Radiator analysis

One important step in antenna array design is the selection or synthesis of a new radiator [2]. The most suitable radiators for aerological monitoring tasks are those based on moderating structures, and in particular, helical radiators [3]. The entire variety of helical radiators can be reduced to the two basic types: classical helical radiators and quadrifilar helical radiators. Quadrifilar radiators possess better characteristics than traditional helical antennas, such as electrodynamic and mass-dimensionality properties.

A quadrifilar helical radiator is an antenna system comprised of four radiators shifted relative to each other by 90 degrees. Each of these radiators is a metal conductor that is curved along a helical line. At the base of this antenna there are power cells that excite the radiators. The voltage on the antenna elements is formed by a special power supply circuit [4].

![Figure 1. Model of the QHA in the Matlab software package.](image-url)
Voltages must form with the same amplitudes, but phase-shifted by 90° in relation to each other so that this antenna radiates with circular polarization. Figure 1 shows a model of the simplest quadrifilar helical antenna formed by strip conductors. Such QHAs have free parameters, which can include α which is the winding angle and diameter D [5]. To control the radiation characteristics of the antenna, such as the radiation pattern and ellipticity factor, it is sufficient to change these parameters. The diameter of conductor d, if it has a circular cross section, or width w, when a metal strip is used as a conductor, can also be referred to free parameters, but these parameters do not affect the characteristics of a quadrifilar helical radiator, so these parameters can be disregarded [6-7].

It is necessary to determine the electrodynamic and geometric characteristics of the radiator for further synthesis.

The polarization coefficient can be determined using the following expression

\[ p = \sqrt{((m^2 \cos \theta)^2 + (m^2 \sin \theta)^2)(m^2 \cos \theta \sin \theta)} \]

where \( m = \frac{|E|}{|E|}, \theta = \arg E \sin \phi - \arg E \cos \phi \), \( \phi \) is the angle of preferential polarization [8].

The following sections describe the phase characteristics of the radiator. This term refers to the value of

\[ \Phi(\theta, \phi) = \Psi(0,0) - \Psi(\theta, \phi) \]

where \( \Psi(\theta, \phi) \) is the phase of the helix field at some point of the far zone with the coordinates \( R_0, \theta, \phi, \Psi(0,0) \) is the phase of the helix field at the point with coordinates \( R_0, 0, 0 \).

If we consider the phase response taking into account only one resonating harmonic, we obtain

\[ \Phi(\theta, \phi) = \gamma_0(\theta) - \gamma_0(0) \]

\[ \approx (\gamma_0(\theta) - \gamma_0(0)) \pi N + \phi + \Phi_0(\theta) \]

where

\[ \Phi_0(\theta) = \arctan (k \gamma_j \sin \theta) \]

Then, from (10) we know \( \gamma_0(\theta) = [\beta - k \cos \theta] \gamma_j \) and obtain the following

\[ \Phi(\theta, \phi) \approx \frac{k \gamma_j (1 - \cos \theta)}{2} + \phi + \Phi_0 \]

\[ \Phi(\theta, \phi) \approx \frac{k \gamma_j (1 - \cos \theta)}{2} + \phi_0 \]

where \( L_0 \) is the axial length of the radiator.

The above expression (5) describes the phase change of the field on a sphere centered at the origin, which is in fact the excitation point of the radiator. Following from the above conclusion, \( \Phi(\theta, \phi) \) shows the dependence of the initial phase of the current at the helix input on the direction to the electromagnetic field source. The expression (5) allows us to analyze the dependence of the phase at the helix input on the angles \( \theta, \phi \) on the geometric parameters of the helix and the wavelength.

The directional coefficient for an integer number of loops \( N \) can be described by the following expression

\[ D \approx \left\{ (\gamma_0 \gamma_j^2 (0) + 1) \right\} \left( \frac{\gamma_j^2 (\pi N \gamma_j (0)) - \gamma_j^2 (\pi N \gamma_j (0))}{B} \right) \]

where \( B = \{ \pi^2 (\pi N \gamma_j^2 (0)) \} \).
where $f_1(\theta, \phi)$ is the resulting radiation pattern of one radiator; $f_c(\theta, \phi)$ is the multiplier of the antenna array.

The vector $\mathbf{RP}$ of the radiator shows the following form

$$f_1(\theta, \phi) = f_0(ka \sin \theta) \cos \theta$$

where $f_0$ is Bessel function of zero order; $k$ is free space wave number; $a$ is the helix radius.

To determine the antenna array multiplier, we take $N_x$ and $N_y$ as the number of radiators in columns and rows, respectively. In the same way we will take $D_x$ and $D_y$ for the distance between adjacent radiators along the OX and OY axes, and $\theta_x$ and $\theta_y$ are the angles counted from the observation point from the OX and OY axes. Then we take each column of radiators as a linear antenna array, and the multiplier of such an antenna array can be written as

$$F_{C\chi}(\theta_x) = \frac{\sin[N_x(kd_x \cos \theta_x - \alpha_x)]}{N_x \sin[N_x(kd_x \cos \theta_x - \alpha_x)]}$$

(10)

In this case, by equivalently replacing each column of the planar antenna array with a radiator with its own RP, we obtain a linear antenna array that is oriented along the OY axis. Then, using the multiplication theorem for radiation patterns, we obtain

$$F_c(\theta_x, \theta_y) = F_0(\theta_x)F_{C\chi y}(\theta_y),$$

(11)

where $F_0(\theta_x)$ is the transmitter RP; $F_{C\chi y}(\theta_y)$ is the multiplier of the antenna array consisting of radiators. In this case $F_{C\chi y}(\theta_y)$ takes the form

$$F_{C\chi y}(\theta_y) = \frac{\sin[N_y(kd_y \cos \theta_y - \alpha_y)]}{N_y \sin[N_y(kd_y \cos \theta_y - \alpha_y)]}$$

(12)

Next, let us introduce the notation of generalized angular coordinates

$$U_x = kd_x \cos \theta_x - \alpha_x; \quad U_y = kd_y \cos \theta_y - \alpha_y.$$  

(13)

Substituting (13) into (10) and (12), we determine the multiplier of the planar antenna array

$$F_c(U_x, U_y) = \frac{\sin[N_x(U_x)]}{N_x \sin[N_x(U_x)]} \frac{\sin[N_y(U_y)]}{N_y \sin[N_y(U_y)]}.$$  

(14)

However, it is necessary to take into account the multiplier of the antenna array in the spherical coordinate system which is not a function of the angles $\theta_x$ and $\theta_y$. In this case, we determine the relationship between the angles $\theta_x$, and $\theta_y$, and the angles $\theta$ and $\phi$. If we consider that $\cos \theta_x$ and $\cos \theta_y$ are projections of the unit vector $\mathbf{e}_0$ which is oriented in the direction of the OX and OY axes, we obtain

$$\mathbf{e}_0^x = \sin \theta \sin \phi; \quad \mathbf{e}_0^y = \sin \theta \sin \phi.$$  

(15)

Then, given the relationship between the spherical and rectangular coordinate systems, we can express the projections of the unit vector $\mathbf{e}_0^\theta$ through the angles $\theta$ and $\phi$:

$$\mathbf{e}_0^\theta = \sin \theta \cos \phi; \quad \mathbf{e}_0^\phi = \sin \theta \sin \phi.$$  

(16)

Taking into account all of the above, we obtain an expression for the antenna array multiplier in the spherical coordinate system

$$F_c(\theta, \phi) = \frac{\sin[N_x(kd_x \sin \theta \cos \phi - \alpha_x)]}{N_x \sin[N_x(kd_x \sin \theta \cos \phi - \alpha_x)]} \frac{\sin[N_y(kd_y \sin \theta \sin \phi - \alpha_y)]}{N_y \sin[N_y(kd_y \sin \theta \sin \phi - \alpha_y)]}.$$  

(17)

By determining the antenna array multiplier and substituting the expressions (16) and (17) into the expression (8), we obtain the resulting radiation pattern of the quadrifilar helical radiator [5, 6].

$$F(\theta, \phi) = (J_0(ka \cdot \sin \theta) \cdot \cos \theta) \times$$

$$\frac{\sin[N_x(kd_x \sin \theta \cos \phi - \alpha_x)]}{N_x \sin[N_x(kd_x \sin \theta \cos \phi - \alpha_x)]} \frac{\sin[N_y(kd_y \sin \theta \sin \phi - \alpha_y)]}{N_y \sin[N_y(kd_y \sin \theta \sin \phi - \alpha_y)]}.$$  

(18)

The resulting radiation pattern for this radiator indicates the sufficient linearity of its basic electrodynamic characteristics.

In order to obtain the basic characteristics of this radiating structure, we use a method based on the construction of phenomenological models. It allows us to determine the parameters of the newly synthesized antenna structure and analyze the characteristics of this structure.
The method of building phenomenological models will allow synthesizing complex antenna systems and complexes without using methods of in-situ modeling and without building physical models, since this approach shows results as close to the real physical model as possible, in which the discrepancy with the physical model is less than five percent. In turn, the use of the proposed method makes it possible to promptly synthesize antenna structures that will have good repeatability and linearity of electrodynamic characteristics when transforming phenomenological models into physical ones. Based on the above approach, the antenna array for the meteorological support complex will also be synthesized [9].

Several quadrifilar radiator models will be synthesized for more variable sampling.

3.2. Antenna array analysis

The objective of this work is to design and develop such a type of antenna array, which meets the following requirements: the ability to work in multi-channel mode, the ability to work with several radiosondes simultaneously, a high range of tracking radiosondes, stability when working in rough meteorological conditions, and optimal mass-dimensional characteristics.

The geometrical structure will represent a cylindrical antenna array, which consists of $N$ radiators and $M$ rings, the quantitative value of which determines the resolving power of the system. A cylindrical antenna array is a system of radiators placed on a cylindrical surface. The spatial orientation of the radiators is such that the direction of the RP maximum for each of them coincides with the radius direction of the corresponding antenna array at the radiator location.

![Spatial orientation of the radiators.](image)

The main advantages of convex ring AA are:

- the possibility of wide-angle (up to 360°) scanning with a beam of unchanged width and shape in the azimuthal plane (in the arc plane). The cylindrical AA also allows scanning in an elevation plane (up to ±50°);
- weak compared to planar and linear AA, mutual coupling of the radiators due to the spatial rotation of their axes;
- practical convenience of placing convex AA on a number of objects (missile body, aircraft skin, etc.).
Their disadvantages include the complexity of the radiator excitation system and some redundancy in their number. Most often, the AA convex radiators are located on a well-conducting metal surface. The shielding effect of this surface will result in engaging only part of the radiators of the entire array in the formation of the highly-directional radiation, namely those of them located on the illuminated (in terms of geometric optics) section of the AA relative to the antenna radiation direction. Multiple beams can be formed on a convex arrays and they can scan independently by creating the appropriate number of isolated radiating sections. However, this mode of antenna operation is difficult to implement, and it requires special radiator excitation devices [15-17].

The formation of a narrow beam and wide-angle electric scanning in space requires independent adjustment of the amplitude and excitation phase in each radiator of the array.

Two ways of microwave energy distribution between the radiators of cylindrical and circular PHA are known, they are the feeder and spatial ones. With feeder excitation, energy is supplied to the radiators by transmission line segments (waveguide, coaxial, strip, etc.) and power dividers.

To form a beam in a given direction \( \theta_0, \varphi_0 \) on the radiating section of the cylindrical PAR, it is necessary to create such a phase distribution in which the fields transmitted by each radiator are added in phase in the specified direction.

In particular, for a ring array located in the plane \( z = 0 \)

\[
P_{0,n}(\theta_0 \varphi_0) = -(2\pi \lambda [R \sin \theta_0 \cos(\varphi_0 - \alpha_0)] \pm 2\pi k),
\]

where \( k = 0,1,2, \ldots \) is an integer.

The required phase is:

\[
P_{ph0,n}(\theta_0 \varphi_0) = P_{0,n}(\theta_0 \varphi_0) - P_{0,n'}(\theta_0 \varphi_0) + P(\theta_0 \varphi_0) - P_{fid0,n'}(\theta_0 \varphi_0) + 2\pi k.
\]

The radiation patterns of ring AA, in addition to the main polarization component of the radiated field, possess a spurious (crosspolarization) component. The spurious component is absent only when the AA is formed from longitudinal rulers and when the RP is considered in the equatorial plane (\( \theta = \pi/2 \)) [10-13].

Calculation of the RP of ring arrays is significantly complicated both because of the need to take into account diffraction phenomena on the antenna surface, and because the characteristics of each radiator of the array must be found in the presence of all the others, i.e., taking into account their interaction.

As in planar APH, due to the effect of interaction, the characteristics of individual radiators in a convex AA (input impedance, RP, polarization, etc.) can differ markedly from the same characteristics of a solitary radiator. That can lead to deterioration of the expected electrical characteristics of the designed AA [14].

Direct calculation of the RP of cylindrical and ring PHA is cumbersome, it requires computing, and its performance is justified at the stage of specifying the characteristics of the final version of the antenna.

At the stage of selecting and evaluating the variants of the designed PHA, it is advisable to reduce and simplify the calculations without significantly reducing their accuracy. For this reason, the following assumptions are introduced:

Within the radiating section, a ring AA with discrete radiators is replaced by one with a continuous current distribution \( I(\alpha) \), equal to the real amplitude distribution at the radiator placement points, and with a sufficiently smooth current distribution between these points.

The partial RP of the radiator and the amplitude distribution on the radiating section are approximated by elementary functions.

Taking into account the above assumptions, the RP of the ring array in the arc plane during beam formation in the direction of \( \theta_0 = \pi/2, \varphi_0 = 0 \) to the accuracy of the normalized multiplier \( A \)

\[
F_r(\varphi) = A \int_{-\beta}^{\beta} I(\alpha) F_{\alpha}(\varphi) \exp \left\{ -\frac{2\pi}{\lambda} R[\cos \varphi - \cos(\varphi - \alpha)] \right\} d\alpha,
\]

where \( F_{\alpha}(\varphi) \) is the RP in the azimuthal plane of the independent radiator with the coordinate \( \alpha \) [1].

The equivalent linear radiator method is convenient for approximate calculation of the RP by (19). Its essence is that the RP of the ring antenna is calculated as the RP of the in-phase linear antenna, in which the amplitude distribution corresponds to the projection of the amplitude distribution over the ring (within the radiating section) on a linear antenna of the length \( l_{equ} \), located perpendicular to the direction of the formed beam. In an equivalent linear antenna, the amplitude distribution
\[ e\!qu(y) \approx I \left( \arcsin \frac{y}{R} \right) F \left( \arcsin \frac{y}{R} \right) \frac{1}{\sqrt{R^2 - y^2}}. \]

Taking this into account the RP of the ring antenna in the azimuthal plane

\[ F(\varphi) = A \int_{-y_2}^{y_1} I_{eqi}(y) \exp \left( -i \frac{2\pi}{\lambda} y \sin \varphi \right) dy, \quad (20) \]

where \( y_1 = y_2 = R \sin \beta \).

The range of admissible angles \( \varphi \), within which it is possible to calculate the RP by (20) with an error not exceeding a few percent, is determined by the inequality

\[ |\varphi| \leq \arccos \left[ 1 - \frac{\lambda}{4R(1-\cos \beta)} \right], \]

Maximum DG of the ring array

\[ D_{kmax} \approx D_0 \sum_{m=-N_1}^{N_1} F_{0,n}^2(\varphi_0), \]

where \( D_0 \) is the DG of the radiator at the maximum of its RP; \( F_{0,n} \) is the value of the radiator RP with coordinate \( \varphi = \alpha_n \) in the direction of \( \varphi = \varphi_0 \).

In turn, in the case of an amplitude distribution of the current \( |I_{m,n}| = |I_{m,0}||I_{n,0}| \) in the \( z \) and \( \alpha \) coordinates, which is important for practice, the RP of the cylindrical PHA can be represented as the product of the RP of the ring AA lying in the plane \( z = 0 \), by the multiplier of the linear system \( f_z(\theta) \) of radiators located on the cylinder element [1]:

\[ F(\theta, \varphi) = F_k(\theta, \varphi) f_z(\theta), \]

where:

\[ F_k(\theta, \varphi) = \frac{\sum_{m=-M_1}^{M_1} |I_{m,0}| F_{m,0}(\theta, \varphi) \exp \left[ -i \frac{2\pi}{\lambda} \left( \sin \theta \cos (\varphi_0 - \alpha_n) - \sin \theta \cos (\varphi_0) \right) \right]}{\sum_{m=-M_1}^{M_1} |I_{m,0}| F_{m,0}(\theta_0, \varphi_0)}, \]

\[ f_z(\theta) = \frac{\sum_{m=-M_1}^{M_1} |I_{m,0}| \exp \left[ -i \frac{2\pi}{\lambda} \cos (\theta_0 - \cos \theta) \right]}{\sum_{m=-M_1}^{M_1} |I_{m,0}|}. \]

4. Experimental results

Using the expressions (1) ... (18), we build a phenomenological model in the electrodynamic simulation software program.

To synthesize the radiators and the antenna array, we selected the method of constructing phenomenological models. This method is used to design antenna structures without in-situ modeling, which reduces the time to verify and analyze the results. This method in comparison with the method of full-scale modeling shows discrepancies in electrodynamic characteristics of not more than 5\%, which is an admissible value for the primary design of antenna systems [18-20].

Figure 3 shows the results of the simulation.
Let us construct the basic electrodynamic characteristics of this radiator: the radiation pattern in the polar and Cartesian coordinate systems, reflection coefficient, standing wave coefficient, and wave impedance shown in figures 4...8.

**Figure 3.** 3D model of a closed QHA in the Altair FEKO software environment.

**Figure 4.** Radiation pattern of the QHA in the Altair FEKO software environment
Figure 5. RP of a closed quarter-wave QHA in a Cartesian coordinate system.

Figure 6. Reflection coefficient of a closed quarter-wave QHA.
Figure 7. Coefficient of the standing wave of the closed quarter-wave QHA.

Figure 8. Wave resistance of a closed QHA.

Consider another type of a radiator. It is designed as an open-end quadrifilar helical antenna. Its model is shown in figure 9.
Figure 9. 3D model of an open QHA.

For this type of radiator, the main characteristics are shown in figures 10...14.

Figure 10. Radiation pattern of the QHA in the Altair FEKO software environment.
Figure 11. Radiation pattern of the QHA in the Cartesian coordinate system.

Figure 12. Reflection coefficient of the open QHA.
Analysis of the basic electrodynamic characteristics of the radiators given in table 1 shows that both radiators have good directivity, they exhibit rotational symmetry and are mutual, since they have no non-reciprocal media, have a sufficiently distinct main lobe, with virtually no side lobes.
The comparative indices of the electrodynamic characteristics (on the central frequency) of the simulated radiators are shown in table 1.

Table 1. Comparison of the electrodynamic characteristics of phenomenological models qha.

| Indicator                  | Closed QHA | Open-end QHA |
|----------------------------|------------|--------------|
| Gain                       | 3 dBi      | 2.8 dBi      |
| Standing wave coefficient  | 1.4        | 1.7          |
| Reflection coefficient     | -20 dB     | -15 dB       |
| Wave resistance            | 40 ohm     | 50 ohm       |

The results of the performed synthesis of moderating electrodynamic structures, such as quadrifilar closed and open antennas, can be used as elements of an intelligent phased antenna array [20]. Then, on the basis of the obtained analytical dependences for a particular case, we synthesize the antenna array based on the above simulated QHA (Fig. 15).

Figure 15. Antenna array model.

Based on the obtained data, we simulate the operation of this array on the frequency of 1.67 GHz (Fig. 4...6), in order to obtain the basis of the electrodynamic characteristics, for their subsequent analysis.
Figure 16. 3D radiation pattern of AA.

Figure 17. Radiation pattern of the radiator in the polar coordinate system.
Figure 18. Radiation pattern of the radiator in the polar coordinate system.

5. Results discussion

The results show that the developed antenna system can solve the problem. This system forms multiple beam pattern, which provides an operation in multichannel mode without loss of quality, and also has a high gain of 14 dBi.

The result of AA modeling suggests that the use of such an antenna array in meteorological radar complexes will improve the following characteristics of the airborne radar:

- electronic scanning within 360 degrees in azimuth;
- electronic control of the radiation pattern beam position in azimuth and tilt;
- control of the APAA beam in the vertical plane is performed by forming the desired phase distribution of the field in the antenna aperture;
  - the normal to the array forms an angle of 30° with the horizon;
  - the deviation of the beam from the normal in the vertical plane can be from minus 50° to 85° (from minus 5° to 120° relative to the horizon);
- control of APAA beam in the horizontal plane is performed electronically by adjusting the phase distribution of the field in the antenna aperture, the electronic beam rotation sector is at least ±360°;
- the measurement of angular coordinates is performed by the quadrant scanning method. In this case, the radiation pattern (RP) of the APAA periodically occupies one of four positions: the beam is deflected by half the width of the RP upwards, to the left, downwards, to the right, etc. The specified RP intersect along the center line. Displacement of the radiosonde from the center line leads to amplitude modulation of the received signal with the scanning frequency. The depth of modulation is proportional to the current angular error, and the phase of modulation corresponds to the direction of the radiosonde shift from the center line:
  - it is possible to track several radiosondes, up to 25 simultaneously;
  - the inclined range of automatic (semi-automatic) tracking of the radiosonde and reception of telemetry information is minimum of 35 m (to the radiosonde release point) and maximum of more than 300,000 m.
- maximum altitude of radiosonde measurement: for tilts up to 70° it is 60,000 m; for tilts from 70° to 90° it is 35,000 m.
The results of the study confirm that this antenna system has good electrodynamic characteristics. This enables its use at radar stations for upper-air sounding, as well as the modernization of existing complexes. This antenna system, due to its mass and dimensions, as well as the sweep speed can be used as a mobile unit, which increases its versatility and allows its use not only in civilian objects, but also in the military sector.

6. Summary and conclusion
The considered method, based on the concept of creating phenomenological models, provides a quick construction of electrodynamic models and their analysis in real time during the synthesis of antenna structures, in particular antenna arrays and radiators. The results of such a study prove that the adequacy of the obtained models (AA and quadrifilar radiator) is quite high, which is confirmed by the main results of such synthesis (values of DG, CG, SWR and others). Thus, the developed antenna array on the basis of the above approach allows using it as part of the existing radar complexes of meteorological and climatic control, as well as to use it in newly developed monitoring systems, which can significantly reduce development time and increase the qualitative and quantitative characteristics of the system as a whole. The developed antenna array can form a multiple beam pattern in real time, it gives an opportunity to significantly improve the technical characteristics of existing monitoring complexes, and namely, there is an opportunity to simultaneously track several targets (probes), which allows a higher level of assessment of the existing weather situation by increasing the resolving power of the antenna system. The concept of this approach can be applied not only to climate monitoring systems, but also to radar, navigation and radio communication systems.

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