Synthesis of the Radiation Pattern with Specified 3D Contour of the Main Lobe in Antenna Arrays with Complex Control

P. N. Bashlya, *, B. D. Manuilovb, and K. V. Derkachevb

a Russian Customs Academy (Rostov-on-Don Branch), Rostov-on-Don, 344002 Russia 
b Rostov-on-Don Research Institute of Radio Communication, Rostov-on-Don, 344038 Russia 
*e-mail: bpn973@mail.ru

Received April 16, 2015

Abstract—The problem of the matrix synthesis of an antenna array with complex control with the use of a generalized energy functional is solved. It is shown that the proposed solution of the synthesis problem is more general than well-known solutions and enables formation of a specified array complex pattern with required shape of the main lobe with consideration for local requirements on the phase pattern of the antenna array. Results of a numerical experiment performed by the example of a multielement antenna array with complex control, which confirm potentialities of the synthesis method, are presented.

INTRODUCTION

At present, radio-engineering systems most often use active phased array antennas (APAs) [1, 2]. Such arrays belong to the class of antenna systems with complex control, which allow control of not only phase but also amplitude distributions of the current in the array aperture.

Complex control of the amplitude—phase distribution of the array current opens considerable opportunities for control of the pattern shape in the interests of the radio-engineering system as a whole. Due to these opportunities, modern radio engineering involves now such concepts as multifunctional antenna system and integrated radio-engineering complex.

A new trend in the development of antenna technology, which is associated with application of antenna arrays with complex control, is intellectual antenna arrays capable of self-adjustment to dynamically varying external operating conditions by means of variation in the pattern shape [3, 4]. Such antennas are widely used in cellular radio systems of new generation.

A distinctive feature of antenna systems of integrated electronic complexes is their ability of simultaneous or sequential performance of two or more functions and the capability of optimal reallocation of its resources by means of reconfiguration depending on the sequence of realization of their intrinsic functions [5–7].

The problem of the optimal allocation of antenna resources is especially important for multielement antenna arrays with complex geometry their apertures, which have substantial power budget. Efficient control of such an antenna allows one to form the spatial pattern of a required shape for solution by the integrated radio–electronic complex of radar, communication, navigation, and control problems in conditions of the information conflict.

Development of the theory of synthesis of antenna systems in the direction of design of multifunctional antenna arrays is also important in view of application of digital antenna arrays in integrated electronic complexes. Such arrays can be attributed to antennas with complex control, because program-based signal processing in such an antenna is reached by weighting the signals with complex weighting coefficients.

High efficiency of the method of matrix synthesis of antenna systems, which allows one to synthesize an antenna array for its integral parameters, for example, the directive gain or the signal-to-noise-plus-interference ratio (SNIR) has been shown in [7].

The generalized energy functional proposed in [8] substantially extended capabilities of the matrix synthesis method. This functional was used in [9] to show the capability of the synthesis of an arbitrarily shaped pattern, including patterns with flat contour specified by two spatial coordinates. The possibility of the matrix synthesis of multilobe patterns with controlled levels and phases of the maxima of pattern lobes, i.e., the possibility of control of the pattern shape along the third spatial coordinate but at the points of local maxima has been shown in [10]. Thus, the need in generalization of the method of matrix synthesis of antenna
arrays with complex control and finding new solutions allowing one to form patterns of an arbitrary shape has arisen.

The objective of this study is the development of the matrix synthesis method for antenna arrays and antenna arrays with complex control enabling formation of array patterns with a specified 3D contour of the main lobe.

1. SELECTION OF THE FUNCTIONAL FOR SOLUTION OF THE ARRAY PATTERN SYNTHESIS PROBLEM

A generalized energy functional allowing one to synthesize antenna arrays with complex control for solution of a broad spectrum of problems, including synthesis of antenna arrays for monopulse sum—difference systems or synthesis of antenna arrays with controlled multilobe patterns, has been proposed in [8]:

\[
\chi(J) = \frac{\int \left\{ \sum_{n} f_n(u,v) J_n h_n \right\}^2 g_1(u,v) d\Omega}{\int \left\{ \sum_{n} f_n(u,v) J_n w_n \right\}^2 g_2(u,v) d\Omega}, \quad (1)
\]

where \( f_n(u,v) \) is the partial pattern obtained in the case of excitation of the \( n \)th array element by a wave with unit amplitude and zero phase; \( J_n \) is the complex excitation current of the \( n \)th array element; direction cosines \( u,v \in \Omega_{1,2} \); \( \Omega_1 \) is the angular sector occupied by the main lobe of the formed pattern; \( \Omega_2 \) is the antenna radiation region; \( h, w, \) and \( g_{1(2)}(u,v) \) are weighting functions determined according to requirements on the solved synthesis problem; \( n = 1, 2, ..., N \); and \( N \) is the number of array elements.

A synthesis problem for an antenna array with complex control was solved in [9]. In this paper, the main lobe of the radiation pattern was specified by a flat contour of an arbitrary shape. For this purpose, the generalized energy functional was modified to the following form, which was a particular case of generalized energy functional (1):

\[
\chi(J) = \frac{\Omega_1^{-1} \int \left\{ \sum_{n} f_n(u,v) J_n \right\}^2 \mu(u,v) d\Omega}{\Omega_2^{-1} \int \left\{ \sum_{n} f_n(u,v) J_n \right\}^2 d\Omega}, \quad (2)
\]

where \( \mu(u,v) \) is the weighting function determining the shape of the cross section of the pattern main lobe.

As was noted in [9], this formulation of the synthesis problem was called the power pattern synthesis problem [11] in which requirements on the phase pattern were not taken into account.

Transition to the synthesis of a contour field pattern [11], which was implemented in [9] with the use of a functional representing the ratio of the squared mean field intensity in the spatial sector of arbitrary shape \( \Omega_1 \) to the mean value of the array power pattern in the entire domain of real angles \( \Omega_2 \), allowed overcoming of the drawback of functional (2) consisted in restrictions on the possibilities of its application mentioned in [9].

A common drawback of known solutions consists in application of such solutions to control of only the shape of the cross section of the pattern main lobe, i.e., the shape specified by two coordinates \((u,v)\) by setting weighting function \( \mu(u,v) \) without a constraint on the pattern shape along the third coordinate.

In order to overcome this drawback of known solutions of the synthesis problem for arrays with contour patterns, we modify functional (2) to the following form:

\[
\chi(J) = \frac{\Omega_1^{-1} \int \sum_{n} f_n(u,v) J_n \mu(u,v,z) d\Omega}{\Omega_2^{-1} \int \sum_{n} f_n(u,v) J_n^2 d\Omega}, \quad (3)
\]

in which the complex weighting function is specified along three coordinates. This method allows one to specify a 3D contour of the main lobe of the formed pattern, i.e., synthesize an array pattern with 3D contour of the main lobe. Parameter \( z \) in weighting function \( \mu(u,v,z) \) determines the shape of the pattern main lobe at a given level.

2. SOLUTION OF THE PATTERN SYNTHESIS PROBLEM FOR AN ANTENNA ARRAY WITH COMPLEX CONTROL

The following transformations are valid for the numerator of functional (3):

\[
\left( \Omega_1^{-1} \int \sum_{n} f_n(u,v) J_n \mu(u,v,z) d\Omega \right)^2 = \left( \left( \hat{\mu}(u,v,z) J \right)^* \left( \hat{\mu}(u,v,z) J \right) \right) = J^* \mathbf{A}(z) J,
\]

where \( \mathbf{A}(z) \) is a symmetric matrix containing information on the energy distribution along \( z \) coordinates.