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ANTENNA ARRAYS SYNTHESIS ACCORDING TO THE SECTOR PATTERN BY MULTIPARAMETRIC METHOD OF REGULARIZATION

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ABSTRACT

The synthesis problem of linear antenna arrays has been solved numerically by multi-parametric regularization method (MRM). The synthesis power directivity pattern was given by a sector pattern with prescribed width and direction of pattern main lobe, low level of side lobes. The investigations of the synthesis problem quasi-solutions and their properties have been carried out.

PROBLEM STATEMENT AND METHOD OF SOLUTION

As known, the nonlinear synthesis problems of radiation systems according to the prescribed amplitude or power directivity pattern (PDP) are the most complicated. These problems belong to the set of ill-posed inverse problems [1]. The field directivity pattern of radiation system with linear polarized radiators has the following view:

$$G(\theta,\varphi)=\sum_{m=1}^{N} a_m f_m(\theta,\varphi)\, e^{-ikr_m(\theta,\varphi)}, \tag{1}$$

where $f_m(\theta,\varphi)$ is the partial directivity pattern of radiator with Cartesian co-ordinates (x_m, y_m, z_m) of its phased center(with unit current on it). To registrate the mutual coupling we must calculate or measure directivity pattern, when other radiators are passive. N is the quantity of radiators, $k=2\pi/\lambda$ is the wave number, $r_m(\theta,\varphi)=x_m\sin\theta\cos\varphi+y_m\sin\theta\sin\varphi+z_m\cos\theta$, $\mathbf{a}=(a_1,a_2,...,a_N)$ is the excitation vector of radiation system, $(\theta,\varphi)\in W=\{(\theta,\varphi):0\le\theta\le\pi, 0\le\varphi\le 2\pi\}$. The PDP of radiation system is determined by the expression $F(\theta,\varphi)=|G(\theta,\varphi)|^2$. The sector function $S(\vartheta,\varphi,\varphi_{max},h)=\begin{cases}1, \varphi_{max}-h\le\varphi\le\varphi_{max}+h\\ 0, \varphi\in\left[-90^o,\varphi_{max}-h\right)\cup\left(\varphi_{max}+h,90^o\right]\end{cases}$ defines the directivity pattern in the plane $\theta=\pi/2$, where $2h(^o)$ is the width of sector and φ_{max} is the direction of the pattern main lobe.

According to the MRM we consider a system of control directions $\psi_i=(\theta_i,\varphi_i)$, i=1,2…,L. In our case all of the points are located in the plane $\theta=\pi/2$. Some of the points ψ_i, i=1,2,…,M (M<L) are in the region of main lobe V_1 ($|\varphi_i-\varphi_{max}|\le h$), and $\psi_i=(\theta_i,\varphi_i)$ for i=M+1,…,L are in the region of side lobes V_2 ($\varphi_i\in[-90^o,\varphi_{max}-h)\cup(\varphi_{max}+h,90^o]$). The tolerant values of PDP are given by the inequalities in the region of main lobe V_1:

$$d_i\le F_i(\mathbf{a})\le c_i \quad \text{for i=1,2,…,M,} \tag{2}$$

and in the region of side lobes V_2

$$F_i(\mathbf{a}) \le c_i \text{ for i=M+1,...,L,} \quad (3)$$

c_i, d_i are positive numbers, $F_i(\mathbf{a}) = F(\theta_i, \varphi_i) = (\mathbf{B}_i \mathbf{a}, \mathbf{a})$, $\mathbf{B}_i$ is a complex N-dimension Eremite matrix with elements $(\mathbf{B}_i)_{m,l} = \tilde{f}_m^*(\theta_i, \varphi_i) \cdot \tilde{f}_l(\theta_i, \varphi_i)$, where $\tilde{f}_m(\theta_i, \varphi_i) = f_m(\theta_i, \varphi_i) \cdot e^{-kr_m(\theta_i, \varphi_i)}$. Inequalities (2) and (3) define the tolerant set D of vectors $\mathbf{a} \in X_N$. The synthesis problem according to the prescribed PDP of the antenna array is formulated as minimization problem of smoothing functional:

$$R(\mathbf{a}, \mathbf{u}) = Q(\mathbf{a}) + \sum_{i=1}^{L} u_i F_i(\mathbf{a}), \quad (4)$$

where $Q(\mathbf{a}) = (\mathbf{A}(\mathbf{a} - \mathbf{a}_0), (\mathbf{a} - \mathbf{a}_0))$ is quadratic functional, u_i, $i = 1, ..., L$, are some real weight parameters, $\mathbf{a}_0$ is the given vector. We consider the next minimization problem

$$\min_{\mathbf{a} \in X_N} R(\mathbf{a}, \mathbf{u}) \text{ for } \mathrm{u} \in \mathrm{U}. \quad (5)$$

$R(\mathbf{a}, \mathbf{u})$ is the positive definite quadratic functional with respect to excitation vector a for all $\mathrm{u} \in \mathrm{U}$.

The quasi-optimal synthesis problem for antenna array is formulated in the next form:

$$\min_K P(\mathbf{a}), \quad \text{where } K = \overline{K}_0, K_0 = \bigcup_{\mathbf{u} \in \mathbf{U}} \arg \min_{\mathbf{a} \in X_N} \{R(\mathbf{a}, \mathbf{u})\}, \quad (6)$$

$P(\mathbf{a}) = \sum_{i=1}^{M} \max\{0, d_i - F_i(\mathbf{a}), F_i(\mathbf{a}) - c_i\} + \sum_{i=M+1}^{L} \max\{0, F_i(a) - c_i\}$. It is proved [2], that the problem (6) has solution even in the case, when tolerant set D is empty. Hence, there is a vector $\mathrm{a} \in \mathrm{K}$, which minimizes the function $P(\mathbf{a})$. We have convergent iterative process with respect to u [2], which minimizes errors of synthesis PDP in the control directions. On each step we may choose vector $\mathrm{u} \in \mathrm{U}$ by making use of well-grounded special way and must solve the minimization problem (5). As the synthesis PDP the sector directivity pattern $S(\theta, \varphi, \varphi_{\max}, h)$ is chosen. Inequalities (2) and (3) are given with the next parameters: $c_i = 1 + 0.01$, $d_i = 1 - 0.01$ for $\varphi_i \in V_1$, $c_i = 0.01$ for $\varphi_i \in V_2$.

NUMERICAL RESULTS AND DISCUSSION

The synthesis problems were solved for antenna arrays, which had different parameters. In particular, we considered various radiators, linear antenna arrays with different quantity of elements N and radiators distance. We changed the width of the sector and direction of the main lobe of PDP. As an example, the synthesis problem of antenna arrays with several isotropic radiators, where $f_i(\theta, \varphi) = 1$, was considered. In this case the gotten excitation vector a had the constant amplitude distribution and the linear phased distribution. The condition of existence of single main lobe with low level of side lobes fulfilled for sector of angles $\varphi \in \lfloor -40^o, 40^o \rfloor$. The maximum level of side lobes was equal to –25 dB.

Also, we considered antenna arrays when the distance between radiators was $d/\lambda = 0.2 < 0.5$. For some values of the scanning angles of main lobe the iterative process didn't converge to the single point in X_N. We got several quasi-solutions for different parts of this process. This example corresponded to the case, when the period T=2π/d of array directivity pattern is greater than interval of real angles [-k, k], where PDP was defined.

Directivity pattern with the narrowest main lobe for antenna arrays with parameters d/λ=0.6, $f_i(\theta,\varphi)=(\cos\varphi)^{5/2}$, N=21 is described in Figure 1(a). In Figure 1(b) the result of the PDP synthesis is represented for antenna arrays with parameters d/λ=0.6, $f_i(\theta,\varphi)=(\cos\varphi)^{5/2}$, N=20, h=0.14rad.

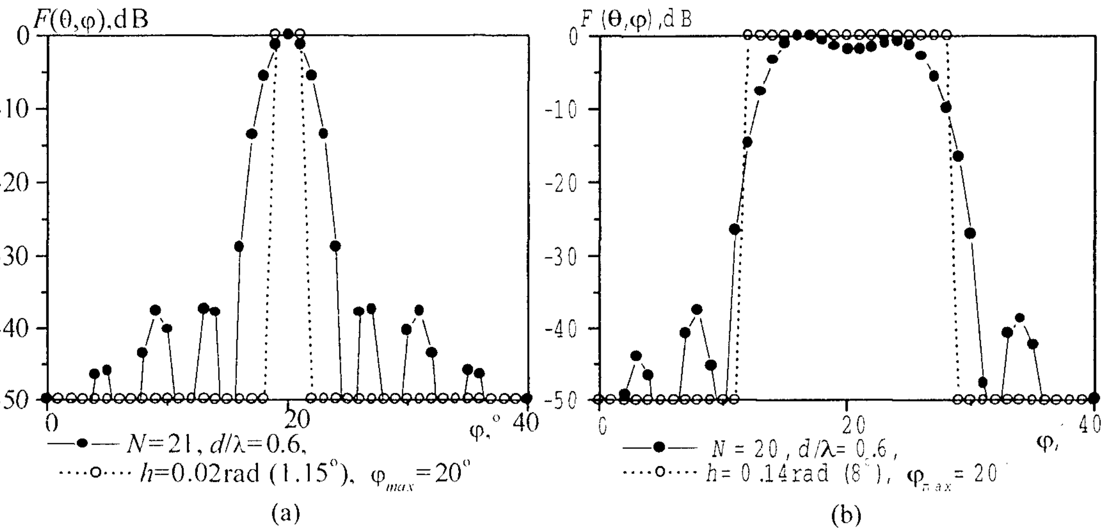

Figure 1. Sector PDP with the width of sector 2*h* in the plane θ=π/2 with direction of the main lobe φ_{max}=20° and synthesis PDP for the equidistant antenna arrays.

CONCLUSIONS

Computer codes for solving antenna array synthesis according to the prescribed PDP have been developed using multiparametric regularization method. These codes enable to find quasi-solutions of the synthesis problems for different types of antenna arrays with the given partial directivity patterns of radiators and the given geometry of the antenna arrays.

In spite of complication of the MRM for creating program codes we marked convenience in the application of this method and good convergence of the algorithm, especially, for the given sector patterns. We analyzed the class of quasi-solutions according to the sector power directivity patterns with different width and directions of main lobe. It was shown, that the synthesis problem had nonunique solution in the case, when radiators distance d/λ≤0.5. The examples of the synthesis will be presented. The arrived results prove high effectiveness of multiparametric regularization method.

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