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ESTIMATION OF MUTUAL COUPLING IN FINITE ARRAY OF DIPOLES

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Mathematical modeling of the mutual coupling in finite phased array of dipoles with complex shape reflector is developed. The complete set of equations of the mathematical model is formulated as Pocklington integral equation for dipoles current distributions and integral equation of II kind for the scattering field of reflector. Offered compact form of the mathematical model as the set of the functional matrix equations includes special iterative procedure for obtaining the required accuracy and stability of the numerical solution.

Keywords: pattern, amplitude-phase distribution, antenna array, reflector, optimization, integral equation.

The mutual coupling of the dipoles in phased array antennas is discussed in Ref. [1, 2]. The mutual coupling causes mismatch of the antenna array input impedance in given frequency band, decreasing of gain for some angular regions in scan sector. Analysis of the mutual coupling of the dipoles becomes difficult to determine the antenna array radiating field in case of finite complex shape reflector. In this case we must consider the appropriate boundary problem to determine current distribution on reflector surface and function of dipoles excitation. Note, we will determine the mutual coupling not only for dipoles, but for general electromagnetic system array – screen.

Well-known approaches for analysis the mutual coupling of the dipoles which dispose in an infinity periodic array can localize some angular directs of array's pattern. These angular direct characterize effect of array blindness caused of surface wave resonant [2]. This is the main feature of the infinity periodically modulated ribbed structure. For such model of array we can obtain some characteristics – reflection from inputs of dipoles, gain due to vector space modes, but only for the same amplitude and linear phase functions of the array excitation. Note, for large-size array these approaches is very effective and provides methods of cancellation the surface waves and improvement of mismatching for given frequency band.

It is important: for small-size arrays (volume of numerical data limited capabilities of computer modeling) we must determine the exact electromagnetic fields of the boundary dipoles, because their current distributions most heavily exposed inhomogeneous mutual coupling. Then we also must consider the current distribution on the near edge of the reflector. Note, the practice reflectors may be conformal, having curvilinear or stepped boundaries. It means, well-known mathematical model as aperiodic array of short-cut input dipoles [2] can not used for finite antenna array of dipoles.

Widely used method for solving of the scattering problems is approach the infinitely thin and unlimited perfect conducting surface [3]. Many important practice results we can obtain due to this approach. But for finite-thickness reflector (often reflector is a part of the array construction, Fig. 1) it is necessary general approach for boundary problem formulation of the mathematical model for reflector with given geometrical characteristics (perhaps, inhomogeneous), finite conductivity, arbitrary excitation of the dipoles.

We can consider the case for arbitrary complex shape and perfect conductive reflector. Note, the case of finite conductive reflector requires using the impedance boundary conditions, but it leads to similar set of integral equations. In the mathematical model of the array we introduce function of array's excitation – vector $\dot{U}_i$, $i=\overline{1,N}$, where N is a number of vibrators. The mostly used radiators for practice antenna systems is dipoles, therefore results of mathematical modeling can obtain the array's pattern and changes of the array excitation caused the mutual coupling dipoles and reflector. It leads to mismatch of the dipoles, but now we can to correct the excitation of dipoles based on results of modeling.

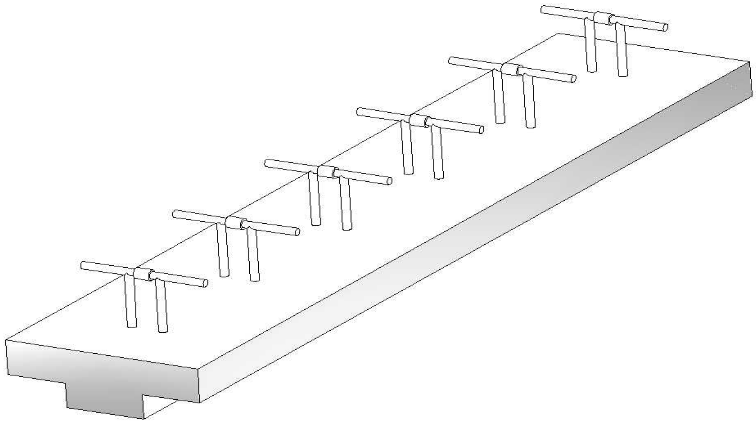

Fig. 1. Linear array, reflector as a part of the module construction

The radiating field of the array we determine due to solving of Pocklington integral equation. Choice of this equation based on convenient form to describe the excitation function as an electrical vector of distribution. Determination of such function as an external source use own functions of excitation, current distributions of other dipoles and the reflector surface current distribution. We can consider the case the dipoles axis focused parallel to x axes, therefore a set of integral equation in compact form describes:

$$\int_{-h}^{h} I_{\nu}\left(x_q\right)K\left(x_p, x_q, a\right)dx_q + \sum_{\mu\neq\nu}^{N}\int_{-h}^{h} I_{\mu}\left(x_q\right)P_{\mu}\left(r_{pq}\right)dx_q + \int_{S}\mathbf{B}^t\cdot\mathbf{j}_s\,ds_q = E_{\nu}^{i}\left(x_p\right), \tag{1}$$
$$p\in dip_{\nu};\ \nu=\overline{1,N}.$$

In this set $I_{\nu}\left(x_q\right)$ – current distribution of the dipole number $\nu, \nu=\overline{1,N}$; p,q – coordinates of points of view and source (integrand); $K\left(x_p, x_q, a\right)$ – kernel of Pocklington integral equation; a – radius of the conductor, h – a half length of the dipole; $\mathbf{j}_s=[j_x\ \ j_y\ \ j_z]^t$ – matrix of current distribution on reflector surface S ; $E_{\nu}^{i}\left(x_p\right)$ – excitation function of dipole number ν. Features of function $P_{\mu}\left(r_{pq}\right)$ and matrix $\mathbf{B}$ depend on distance between points of view and integrand and the role of each dipole relative of all other dipoles and current distribution on reflector surface.

Determination of current distribution on reflector surface requires the properties of continuity and regularity of S. We can consider surface S satisfy the Hoelder-continuous condition – for each points $p,q\in S$ exist normal vectors $\mathbf{n}_p, \mathbf{n}_q$, which $\left|\mathbf{n}_p-\mathbf{n}_q\right|\leq c\left|p-q\right|^{\alpha}$, where c, $0<\alpha\leq 1$ – an arbitrary numbers. Define of the surface current distribution $\mathbf{j}_s$ due to solving integral equation of II kind for magnetic field. Note, the integral equation of II kind mostly used for extensive conductive objects with regular surface and can not directly used for thin-thickness reflectors, because kernel of the equation haves some features and behaves as weakly oscillated function. Values of this function comparable with accuracy of the numerical procedures. The integral equation of II kind very convenient for the iterative procedure of numerical solution, especially for large-size reflectors. It is important: the integral equation of II kind after decomposition of S surface and moment method processing lead to matrix equation with dominant general diagonal which provides stability of numerical solution [3]. Some numerical results in case not thin-thickness reflector (thickness of screen more then $\lambda/18...\lambda/20$, λ – wave length) shows that the integral equation of II kind can successfully used to define current distribution $\mathbf{j}_s$. In case not flat screen the thickness may be reduced.

The minimal thickness of reflector which provides stability of numerical solution of integral equation of II kind can obtain due to following procedure: the first step is input to the mathematical model real shape and thickness of the reflector. Then we obtain numerical solution of the set of integral equation. We analyze results of solving as the array's pattern, current distributions of dipoles, mismatch in given frequency band. The second step is input a new thickness of the reflector, thickness slightly increased (numerical results gives a value of increasing about $\lambda/80$), then we compare results of modeling obtained at first and second steps. If these results satisfy given accuracy of modeling, it means the thickness of the screen appropriate to criteria of stable and correct of numerical solution. However, if requirements of stability not satisfy the reflector thickness we must increase on the basis of proposed iterative procedure. When a stable numerical results is obtained we analyze the compliance of the thickness estimation and the real reflector thickness. Note, in case of very thin-thickness reflector is used methods of solving the integral equation of I kind [3]. It is important: they gives many practice estimation and numerical results for comparing efficiency of solving integral equation of II kind and integral equation of I kind.

Determination of the surface current distribution $\mathbf{j}_s$ used the compact form of the integral equation of II kind:

$$\sum_{\nu=1}^{N}\int_{-h}^{h} I_\nu\left(x_q\right)\cdot \mathbf{D}\,dx_q + \mathbf{j}_s + \int_S \mathbf{F}\cdot \mathbf{j}_s\,ds_q = 0\,,\, p\in S\,, \quad (2)$$

where $\mathbf{D}, \mathbf{F}$ – matrix-column function of the incidence electromagnetic fields and matrix-kernel of the integral equation. Features of these matrix depend on mutual coupling in general electromagnetic system dipoles – reflector.

Thus, the integral equations (1) and (2) is the complete mathematical model to analyze the mutual coupling and pattern of the finite phased antenna array of dipoles and complex shape reflector. We consider some real antenna system and proposed mathematical model is very useful. For example, Fig. 2 depicts results of modeling antenna system as four dipoles and reflector as flat rectangular screen, length of the screen $2,6\lambda$, width $0,6\lambda$, thickness $0,056\lambda$. Distances between centers of the dipoles is $0,59\lambda$. In this case we use the equal amplitude and phase distribution.

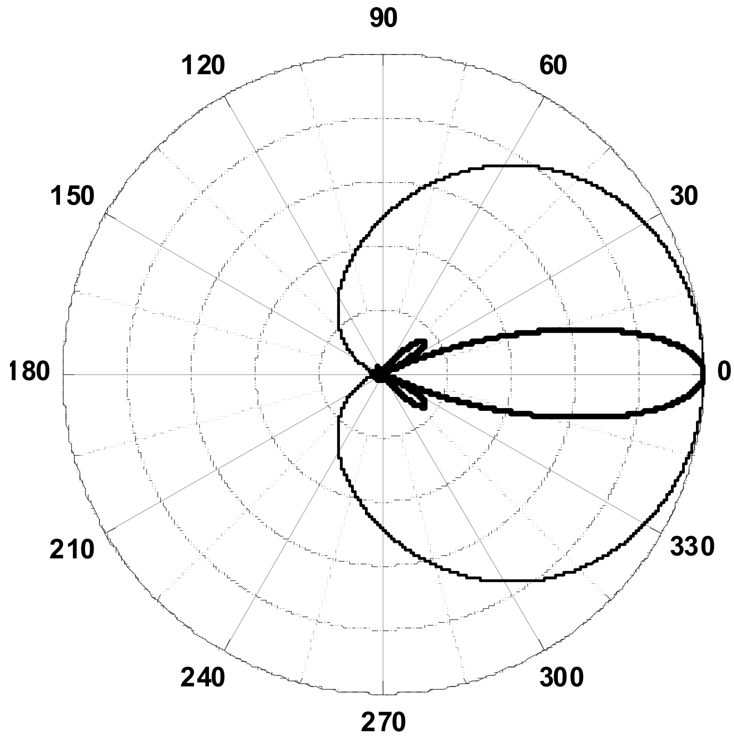

Fig. 2. Antenna system pattern on *E* plane and *H* plane

Comparing obtained results with the same results for flat infinity screen shown satisfactory compliance for vector $\mathbf{E}$ plane. However, results notably differ for vector $\mathbf{H}$ plane. It means, that exact mathematical modeling would be use to design of the antenna system for precision radio equipments.

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ОЦЕНКА ВЗАИМНОГО ВЛИЯНИЯ В ВИБРАТОРНОЙ АНТЕННОЙ РЕШЕТКЕ КОНЕЧНЫХ РАЗМЕРОВ

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Разработан метод математического моделирования взаимного влияния вибраторов в фазированной антенной решетке конечных размеров с рефлектором сложной формы. Полная система уравнений математической модели формулируется как система интегральный уравнений Поклингтона для токовых распределений вибраторов и интегрального уравнения II рода для поля рассеяния рефлектора. Предложена компактная форма математической модели в виде системы функциональных матричных уравнений, включающая в себя специальную итеративную процедуру, обеспечивающая заданную точность и устойчивость численного решения.

Ключевые слова: диаграмма направленности, амплитудно-фазовое распределение, антенная решетка, рефлектор, оптимизация, интегральное уравнение.

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