3D MICROWAVE ANTENNA SYNTHESIS TAKING INTO ACCOUNT DIELECTRIC COATING AND THE DESIRED RADIATION PATTERN

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Abstract

The problems of microwave antenna synthesis with a dielectric coatings, which use the desired radiation pattern characteristics as input information, are very important. Based on the method of auxiliary sources and integro-functional equations, a solution of the three-dimensional direct and inverse problems for excitation of microwave antenna array, which consists of a few slot emitters under a finite-size dielectric layer, is introduced. The results of research for the antennas radiation pattern with a given the distribution of the sources and synthesis of the amplitude and phase voltage distribution for the slot antenna array according to the desired radiation pattern are discussed.

Keywords: Slot antenna, amplitude-phase distribution, a dielectric coating, the method of auxiliary sources, integro-functional equations

Introduction

In many applications, slot antenna covered with a dielectric layers to provide protection against climatic and environmental hazards. Dielectric layers can seriously affect the characteristics of the antennas, such as the resonance frequency, input resistance, radiation pattern, gain, etc. The problem of exciting covered of finite size with different configuration of edges is of considerable interest. In this case, the field can be found as a superposition of an exciting field, and the field reflected from the edges of the dielectric layer. For designing a small element antenna arrays under the dielectric cover requires implementation of complex schemes of excitation (implement complex amplitude-phase relations between its elements) with a high degree of isolation between the elements, which can be used slot antenna with separate excitation scheme, located inside the resonator. This design allows to provide high isolation between the feed lines and contains sufficient elements for independent adjustment of amplitude and phase.

Development of methods for designing antennas with consideration for their placement is a very important and yet difficult problem. It can be divided into problem of synthesis of antennas in inhomogeneous space and the problem of implementing the obtained amplitude-phase distribution of the radiation sources. The problem of the synthesis given the heterogeneity of outer space in the traditional approach requires the construction of Green's function of the inhomogeneous space, i.e. the need to deal with a complex boundary value problems. In the case of arbitrary form inhomogeneous this can be done only by numerical methods and synthesis equation cannot be explicitly written.

The purpose of the paper is direct and reverse solution three-dimensional problems of excitation of microwave antenna array, which consists of a few slot emitters under a finite-size dielectric layer and synthesis of the amplitude and phase voltage distribution of the slot antenna array according to the desired radiation pattern..

Main Text:

Calculation of radiation field for slot antennas with dielectric coating causes considerable difficulty even using modern modeling tools based on packet Microwave Office, Advanced Design System (ADS), CST Microwave Studio (CST MWS), High Frequency System Simulator (HFSS), etc. In the present work, we introduce a solution, based on the method of auxiliary sources and integro-functional equations, of the three-dimensional direct and inverse problems for excitation of microwave antenna array, which consists of a few slot emitters under a finite-size dielectric layer.

Three dimensional analogue of functional equations for solving the two-dimensional problem of excitation of a dielectric cylinder is the equation for a single dielectric body, located in the volume V_i with the boundary S and external normal $\vec{\nu}$:

$$ik_i \oint \{[\vec{r}_0 [\vec{E}_e \vec{\nu}]] - W_i [\vec{r}_0 [\vec{r}_0 [\vec{H}_e \vec{\nu}]]]\} e^{ik_i(\vec{r}_0 \vec{r}_S)} dS = \vec{F}_{0i} \qquad (1)$$

where $k_i = \omega\sqrt{\varepsilon_i \mu_i}$,$k_i, \varepsilon_i, \mu_i$: respectively the propagation constant, dielectric and magnetic permeability of the dielectric, $\vec{r}_0 = \overrightarrow{x_0} x + \overrightarrow{y_0} y + \overrightarrow{z_0} z$ - the unit vector directed to the observation point on a sphere of infinite radius from the origin of coordinates, $(\overrightarrow{x_0}, \overrightarrow{y_0}, \overrightarrow{z_0})$ – unit vectors of the Cartesian coordinate system, $\vec{E}_e, \vec{H}_e -$ the boundary values of the external field on the surface S, $W_i = \sqrt{\mu_i / \varepsilon_i}$ – the wave impedance of the dielectric, $\vec{F}_{0i}$- radiation pattern for the electric field of internal excitation sources. The solution of this equation can be reduced to the problem of calculating the slot antenna cut into an infinite, perfectly conducting screen with a dielectric coating Fig.1, as the double-layer dielectric thickness of excitation of magnetic current, the plane of symmetry, that coincides with the plane of the screen, and in parallel to it. In this case, the solution will automatically satisfy the boundary conditions on the surface of the screen. In this paper, for simplicity, we will considered the thin slot antennas.

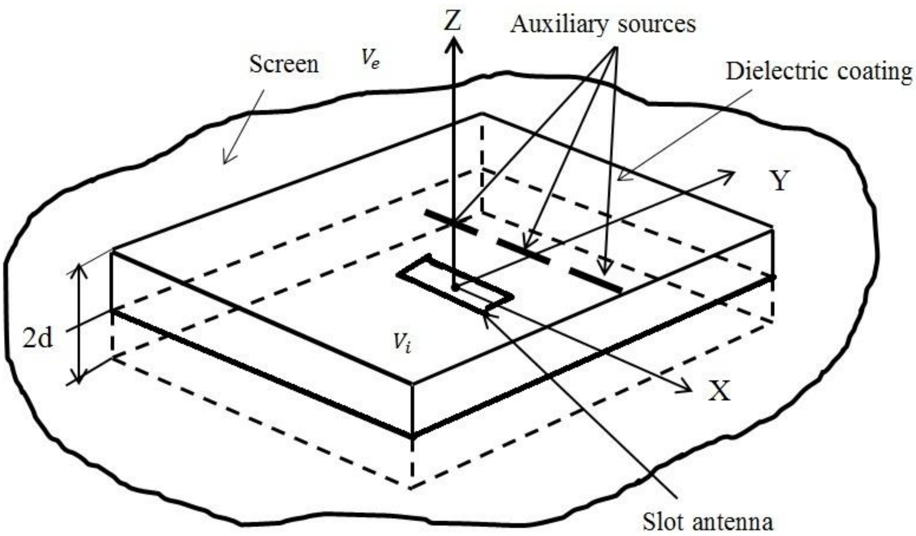

Fig. 1. Slot antenna with a dielectric coating.

❖ Field of internal excitation sources

In according with the field of internal undisturbed sources of excitation is a field created by a given linear magnetic current distribution along the slot, directed tangentially. Linear density magnetic current within the aperture of the slot is determined by the voltage distribution:

$$\vec{J}_m = \vec{\tau}_0 U(\vec{r}_l) \qquad (2)$$

where the unit vector $\vec{\tau}_0$ is through the unit vector $\vec{e}(\vec{r}_l)$, directed along the electric field intensity at the aperture of the slot and determined by the polarity of the specified voltage U, and the unit vector normal to the surface slot, coinciding with the coordinate vector $\vec{z}_0$, as $\vec{\tau}_0 = [\vec{z}_0 \vec{e}(\vec{r}_l)]$.

Magnetic vector potential associated with the current (2) can be represented as:

$$\vec{A}_m = \int \vec{J}_m(\vec{r}_l) G_i(|\vec{r} - \vec{r}_l|) dl \qquad (3)$$

where $G_i(|\vec{r}-\vec{r}_l|)=\frac{e^{-ik_i|\vec{r}-\vec{r}_l|}}{4\pi|\vec{r}-\vec{r}_l|}$ – the Green's function of a free space with the parameters of the dielectric coating. The field associated with the potential (3) can be represented as follows:

$$\vec{E}_{0i} = -rot\,\vec{A}_m \quad (4)$$

$$\vec{E}_{0i} = \int \left(ik_i + \frac{1}{|\vec{r}-\vec{r}_l|}\right) G_i(|\vec{r}-\vec{r}_l|)[\vec{r}_{l0},\vec{J}_m(\vec{r}_l)]dl \quad (5)$$

where $\vec{r}_{l0} = \frac{\vec{r}-\vec{r}_l}{|\vec{r}-\vec{r}_l|}$ – unit vector, directed from the point of integration $\vec{r}_l$ into point of observation $\vec{r}$. When $|\vec{r}| = r \to \infty$ the field $\vec{E}_{0i}$ can be represented as:

$$\vec{E}_{0i} = G_i(r)\vec{F}_{0i} \quad (6)$$

where $\vec{F}_{0i}$ – the radiation pattern of undisturbed internal original sources, the right part of the equation (1), can be written in the form:

$$\vec{F}_{0i}(\vec{r}_0) = ik_i \int [\vec{r}_0,\vec{J}_m(\vec{r}_l)]\, e^{ik_i(\vec{r}_0\vec{r}_l)}dl \quad (7)$$

❖ **Field of auxiliary sources**

For presentation of the required external field, excited by a slot antenna taking into account the property of symmetry of the magnetic and electric fields on the screen. Therefore, we are looking for a solution in the form of ancillary source fields that have the same property. One of the possible options is the use of auxiliary sources in the form of short items magnetic current $\vec{a}_n U_n l$ ($U_n l = P_{mn}$-magnetic moment source), $\vec{a}_n = \overrightarrow{x_0} a_{x_n} + \overrightarrow{y_0} a_{y_n}$ is a unit vector in the plane of the screen that specifies the orientation of the source, parallel to this plane.

Magnetic vector potential source related with singular magnetic moment can be represented as:

$$\vec{A}_n = \vec{a}_n\, G_e(R_n) \quad (R_n = |\vec{r}-\vec{r}_n|). \quad (8)$$

The electric field auxiliary source is calculated by the formula:

$$\vec{E}_{en} = -rot\vec{A}_n = \left(ik_e + \frac{1}{R_n}\right) G_e(R_n)[\vec{r}_{n0},\vec{a}_n] \quad (9)$$

where $\vec{r}_{n0} = \frac{\vec{r}-\vec{r}_n}{|\vec{r}-\vec{r}_n|}$ – is the unit vector from the source to the observation point. The magnetic field is from the following:

$$\vec{H}_{en} = \frac{1}{i\omega\mu_e}\left(graddiv\vec{A}_n + k_e{}^2\vec{A}_n\right). \quad (10)$$

$$\vec{H}_{en} = \frac{G_e(R_n)}{i\omega\mu_e}\left\{(3(\vec{r}_{n0},\vec{a}_n)\vec{r}_{n0} - \vec{a}_n)\left(\frac{ik_e}{R_n} + \frac{1}{R_n^2}\right) + k_e^2(\vec{a}_n - \vec{r}_{n0}(\vec{r}_{n0},\vec{a}_n))\right\} \quad (11)$$

We introduce the following notation:

$$\left(\vec{E}_{enx}, \vec{H}_{enx}, P_{nx}\right) = \left(\vec{E}_{en}, \vec{H}_{en}, P_n\right)_{(\vec{a}_n=\vec{x}_0)},$$

$$\left(\vec{E}_{eny}, \vec{H}_{eny}, P_{ny}\right) = \left(\vec{E}_{en}, \vec{H}_{en}, P_n\right)_{(\vec{a}_n=\vec{y}_0)},$$

The external field is represented as decomposition:

$$\vec{E}_e = \sum_{n=1}^{N}(P_{nx}\vec{E}_{enx} + P_{ny}\vec{E}_{eny}) \quad (12)$$

$$\vec{H}_e = \sum_{n=1}^{N}(P_{nx}\vec{H}_{enx} + P_{ny}\vec{H}_{eny}) \quad (13)$$

Coefficients of the decomposition P_{nx}, P_{ny} shall be determined using the equation (1). After their definitions, the internal field scatter can be calculate using integral relation:

$$\vec{E}_{pi} = -ik_i \oint\{\left(1 + \frac{1}{k_i R}\right)\left(\frac{(\vec{E}_e\vec{v})}{\varepsilon_r}\vec{r}_{s0} - \left[[\vec{E}_e\vec{v}]\vec{r}_{s0}\right]\right) - \sqrt{\frac{\mu_i}{\varepsilon_i}}[\vec{H}_e\vec{v}]\}G_i(R)dS \quad (14)$$

Where $\varepsilon_r = \varepsilon_i/\varepsilon_e$ –relative permittivity of the dielectric coating. $(k_e, \varepsilon_e, \mu_e)$: accordingly, constant propagation, dielectric and magnetic permeability of free space.

Complete field in the dielectric coating shall be determined as the sum of the primary field slot (5) and field scatter (14):

$$\vec{E}_i = \vec{E}_{0i} + \vec{E}_{pi}\,. \quad (15)$$

❖ **Numerical solution of integral-functional equations**

Substituting into equation (1) presentation of the external field (12), (13) we obtain the equation for the coefficients of P_n:

$$\sum_{n=1}^{N} P_{nx}\vec{F}_{inx}(\vec{r}_0) + P_{ny}\vec{F}_{iny}(\vec{r}_0) = \vec{F}_{0i}(\vec{r}_0) \quad (16)$$

$$\vec{F}_{inx,y}(\vec{r}_0) = ik_i \oint\{[\vec{r}_0[\vec{E}_{enx,y}\ \vec{v}]] - W_i[\vec{r}_0[\vec{r}_0[\vec{H}_{enx,y}\vec{v}]]]\}e^{ik_i(\vec{r}_0\vec{r}_s)}dS \quad (17)$$

To solve the equation (16) difficult to apply any preferred methods, in view of the fact that the system functions (17) quite arbitrary properties. However, these functions are orthogonal $\vec{r}_0$ and consequently has only two components. For simplicity, we use the spherical coordinates and represent (16) in the form of two scalar equations:

$$\sum_{n=1}^{N} P_{nx}F_{inx\vartheta}(\theta,\varphi) + P_{ny}F_{iny\vartheta}(\theta,\varphi) = F_{0i\theta}(\theta,\varphi) \quad (17)$$

$$\sum_{n=1}^{N} P_{nx}F_{inx\varphi}(\theta,\varphi) + P_{ny}F_{iny\varphi}(\theta,\varphi) = F_{0i\varphi}(\theta,\varphi) \quad (18)$$

Where

$$F_{inx,y\vartheta}(\theta,\varphi) = ik_i \oint\{-([\vec{E}_{enx,y}\ \vec{v}]\vec{\varphi}_0) + W_i([\vec{H}_{enx,y}\vec{v}]\vec{\theta}_0)\}e^{ik_i(\vec{r}_0\vec{r}_s)}dS \quad (19)$$

$$F_{inx,y\varphi}(\theta,\varphi) = ik_i \oint\{([\vec{E}_{enx,y}\ \vec{v}]\vec{\theta}_0) + W_i([\vec{H}_{enx,y}\vec{v}]\vec{\varphi}_0)\}e^{ik_i(\vec{r}_0\vec{r}_s)}dS \quad (20)$$

The right parts (17), (18) can be represented in the form:

$$F_{0i\theta}(\theta,\varphi) = -ik_i \int \left(\vec{J}_m(\vec{r}_l)\vec{\varphi}_0\right) e^{ik_i(\vec{r}_0\vec{r}_l)} dl \quad (21)$$

$$F_{0i\varphi}(\theta,\varphi) = ik_i \int (\vec{J}_m(\vec{r}_l)\vec{\theta}_0) e^{ik_i(\vec{r}_0\vec{r}_l)} dl \quad (22)$$

where $\overrightarrow{\theta_0} = \overrightarrow{x_0}\cos\theta\cos\varphi + \overrightarrow{y_0}\cos\theta\sin\varphi - \overrightarrow{z_0}\sin\theta$

$\overrightarrow{\varphi_0} = -\overrightarrow{x_0}\sin\varphi + \overrightarrow{y_0}\cos\varphi$

To transform the equations (17), (18) to the system of linear equations we will demand many points on a sphere (θ_q,φ_q) $(q = \overline{1,Q})$. Number of auxiliary sources is $2N$ and limited computing resources. Each point (θ_q,φ_q) corresponds to the system of two complex equations with $2N$ unknowns. When $Q = N$ the system of algebraic equations has the lowest dimension, but this raises the difficulty of point selection (θ_q,φ_q) due to few number. Therefore, a more rational method of least squares, when the number of equations is greater than the number of unknowns, which corresponds to the condition $Q > N$. In the system of equations (17),(18) move on to the matrix notation:

$$Fe\,P = Fi \quad (23)$$

where $Fi -$ matrix-column dimension $2Q$ the right parts of the system (17),(18), $Fe -$ the system matrix with dimension $2Q \times 2N$, $P -$ matrix-column values of the sought magnetic moments sources. In accordance with the method of least squares solution can be written as [6]:

$$P_0 = (\overline{Fe}^t Fe)^{-1}\overline{Fe}^t Fi \quad (24)$$

where $\overline{Fe}^t$ - matrix obtained from the matrix Fe complex conjugation of the elements and transposing.

❖ Synthesis of antenna array of slot emitters with a dielectric coating

In the present work uses the integral-functional equation (1) for the synthesis of antennas taking into account the dielectric shelter is applied to the problem of synthesis of the array antenna of the short slotted emitters placed under dielectric cover final dimensions. The algorithm of solving the problem will take the left part (1) as an integral operator that displays the value of the external field $\{\vec{E}_e, \vec{H}_e\}$ near the border shelter S in the radiation pattern of the undisturbed third-party sources located inside the shelter, i.e. in the radiation pattern of slot radiators $\vec{F}_{0i}$ in a homogeneous space with parameters ε_i, μ_i. Radiation pattern of separate short slotted emitter length l and the voltage on the slot U, oriented along the unit vector $\vec{a}_s$ and hosted at $\vec{r}_s$ can be obtained from the general equations for arbitrary radiation pattern of thin slot (7) and presented in the form of:

$$\vec{F}_{0is}(\vec{r}_0) = ik_i[\vec{r}_0, \vec{a}_s]Ule^{ik_i(\vec{r}_0\vec{r}_s)} = ik_i[\vec{r}_0, \vec{P}_s]e^{ik_i(\vec{r}_0\vec{r}_s)} \qquad (25)$$

where $\vec{P}_s = \vec{a}_s Ul$ – the magnetic moment of the slotted emitter.

In general form, synthesis equation arrays of slot emitters can be represented as:

$$\sum_{m=1}^{M} \vec{F}_{0ism}(\vec{r}_0) = \vec{F}_{0i}(\vec{r}_0) \qquad (26)$$

after the decision of which, depending on the specific formulation of the problem, magnetic moments can be defined $\vec{P}_s$ and the coordinates of the emitters $\vec{r}_{sm}$.

Obtained the radiation pattern taking into account the requirements to formed as the location of the antenna, the size of the placement of emitters. Therefore, the synthesis problem is solved in two independent stages. At the first stage, the problem of approximation of a given radiation pattern chart the direction of the auxiliary sources, which placed in an area under the surface of the dielectric layer is solved by using the given vector radiation pattern and the method of auxiliary sources. Obtained at this stage a field of the point sources in the form of magnetic dipoles, follows in the outer region of the Maxwell equations and the conditions of the radiation and thus can be physically realized. The radiation pattern of these sources is implemented. If the result of solution of this problem is acceptable to the developer, i.e. implemented radiation pattern is nearest to the required using equation (1) and the next of it of equation (26) solve the problem of synthesis of the slot emitters array. Validation solution for the problem of synthesis is carried out by forward problems, methods which use equations (16)-(24). The problem of synthesis of array of emitters in a free space is solved in two stages. In the first stage by using the auxiliary sources in the screen under the dielectric cover and the desired vector direction diagram $\vec{F}_{\text{втр}}(\vec{r}_0)$ is defined. The system of equations to determine the radiation pattern is similar to the system (17), (18):

$$\sum_{n=1}^{N} P_{nx}F_{\text{в}nx\vartheta}(\theta,\varphi) + P_{ny}F_{\text{в}ny\vartheta}(\theta,\varphi) = F_{\text{втр}\theta}(\theta,\varphi) \qquad (27)$$

$$\sum_{n=1}^{N} P_{nx}F_{\text{в}nx\varphi}(\theta,\varphi) + P_{ny}F_{\text{в}ny\varphi}(\theta,\varphi) = F_{\text{втр}\varphi}(\theta,\varphi) \qquad (28)$$

Radiation pattern auxiliary source in the form of a magnetic dipole located in the plane of the screen and the unit vector along $\vec{a}_n$, parallel to the screen is represented in the form:

$$\vec{F}_{en} = (ik_e)[\vec{r}_0, \vec{a}_n]e^{ik_e(\vec{r}_0\vec{r}_n)} \quad (29)$$

Projection $\vec{F}_{en}$ on spherical coordinates are of the form:

$$F_{en\vartheta} = -(ik_e)(\vec{\varphi}_0, \vec{a}_n)e^{ik_e(\vec{r}_0\vec{r}_n)} \quad (30)$$

$$F_{en\varphi} = (ik_e)(\vec{\theta}_0, \vec{a}_n)e^{ik_e(\vec{r}_0\vec{r}_n)} \quad (31)$$

Included in (27), (28) functions can be expressed in terms of (30), (31), as follows:

$$F_{enx\vartheta}(\theta,\varphi) = F_{en\vartheta}(\theta,\varphi)_{(\vec{a}_n=\vec{x}_0)} = (ik_e)sin\varphi e^{ik_e(\vec{r}_0\vec{r}_n)} \quad (32)$$

$$F_{eny\vartheta}(\theta,\varphi) = F_{en\vartheta}(\theta,\varphi)_{(\vec{a}_n=\vec{y}_0)} = -(ik_e)cos\varphi e^{ik_e(\vec{r}_0\vec{r}_n)} \quad (33)$$

$$F_{enx\varphi}(\theta,\varphi) = F_{en\varphi}(\theta,\varphi)_{(\vec{a}_n=\vec{x}_0)} = (ik_e)cos\theta cos\varphi e^{ik_e(\vec{r}_0\vec{r}_n)} \quad (34)$$

$$F_{eny\varphi}(\theta,\varphi) = F_{en\varphi}(\theta,\varphi)_{(\vec{a}_n=\vec{y}_0)} = (ik_e)cos\theta sin\varphi e^{ik_e(\vec{r}_0\vec{r}_n)} \quad (35)$$

The transition to matrix equations for systems (27),(28) is similar to systems (17),(18) in the form (24). Finally, the solution of the equation for synthesis is reduced to a system of two scalar equations from system (27),(28) by changing the wave number k_i in place k_e.

Discussion of results:

Below are the results of the calculation of radiation pattern ($f = 2.67\ GHz$) with the following parameters of slot and dielectric layer: The slot's length $l_s = 30mm$, width $w_s = 3mm$, the unit vector $(a_{x_n} = 1, a_{y_n} = 0)$. The voltage between the edges of the slot $U = 1$ V. Rectangular dielectric layer: length and width are the same and equal L_D, thickness $d = 32mm$, $\varepsilon_r = 3.5$, the dielectric loss tangent $tg\delta = 0.0018$.

The tables 1-3 shows the location, voltage distribution of the slot antenna array (the amplitude and phase of auxiliary sources).

Element	Position	Amplitude and phase
P_{00}	$(-L_D/4, -L_D/4, 0)$	$0.013\angle 30^\circ$
P_{01}	$(-L_D/4, L_D/4, 0)$	$0.013\angle 30^\circ$
P_{10}	$(L_D/4, -L_D/4, 0)$	$0.013\angle 47^\circ$
P_{11}	$(L_D/4, L_D/4, 0)$	$0.013\angle 47^\circ$

Table1. Auxiliary sources array (2×2), (L_D =56mm).

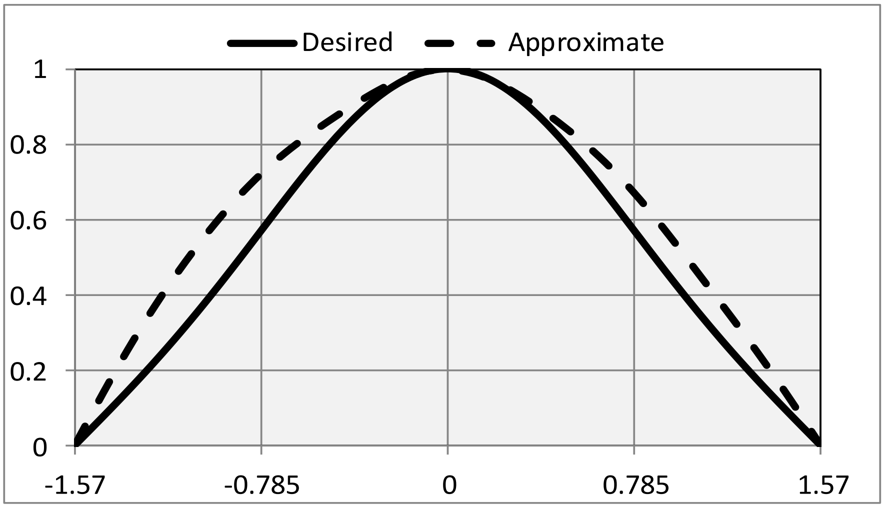

Fig. 2. Amplitude radiation pattern for the undisturbed internal sources $F_{0i}(\theta,\varphi)$ and the approximate with the auxiliary sources table1.

Element	Position	Amplitude and phase
P_{00}	$(-L_D/4,-L_D/4,0)$	$0.01\angle 63^{\circ}$
P_{01}	$(-L_D/4,L_D/4,0)$	$0.01\angle 63^{\circ}$
P_{10}	$(L_D/4,-L_D/4,0)$	$0.012\angle 71^{\circ}$
P_{11}	$(L_D/4,L_D/4,0)$	$0.012\angle 71^{\circ}$

Table2. Auxiliary sources array (2×2), (L_D =84 mm).

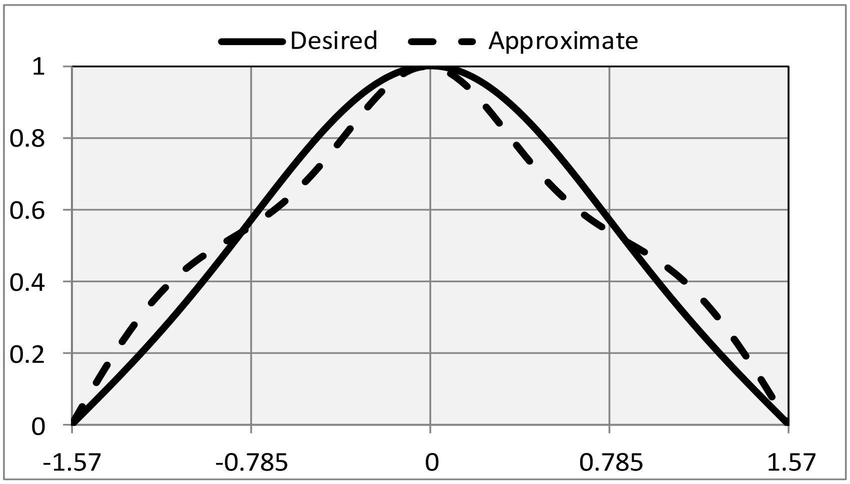

Fig. 3. Amplitude radiation pattern for the undisturbed internal sources $F_{0i}(\theta,\varphi)$ and the approximate with the auxiliary sources table2.

Element	Position	Amplitude and phase
P_{00}	$(-L_D/4,-L_D/4,0)$	$0.003\angle -173^{\circ}$
P_{01}	$(-L_D/4,0,0)$	$0.031\angle 161^{\circ}$
P_{02}	$(-L_D/4,L_D/4,0)$	$0.003\angle -173^{\circ}$
P_{10}	$(0,-L_D/4,0)$	$0.008\angle 59^{\circ}$
P_{11}	$(0,0,0)$	$0.057\angle -14^{\circ}$
P_{12}	$(0,L_D/4,0)$	$0.008\angle 59^{\circ}$
P_{20}	$(L_D/4,-L_D/4,0)$	$0.003\angle -177^{\circ}$
P_{21}	$(L_D/4,0,0)$	$0.127\angle 57^{\circ}$
P_{22}	$(L_D/4,L_D/4,0)$	$0.035\angle 162^{\circ}$

Table3. Auxiliary sources array (3×3), (L_D =84 mm).

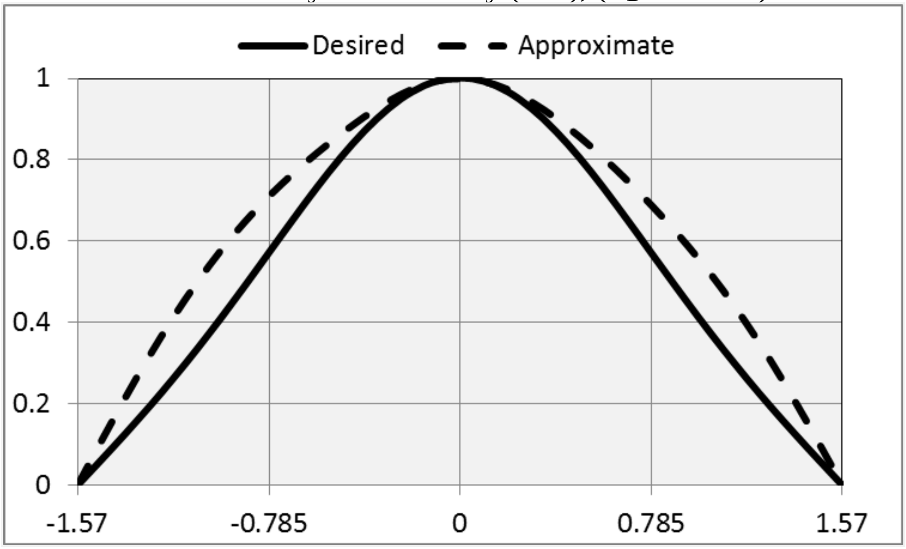

Fig. 4. Amplitude radiation pattern for the undisturbed internal sources $F_{0i}(\theta,\varphi)$ and the approximate with the auxiliary sources table3.

In Figures (2-3-4) the radiation pattern are calculated in E-plane ($\varphi = 0, \theta \in [-\pi/2, -\pi/2]$) with different number of auxiliary sources, shows that the form of the radiation pattern accurately reproduced with a relatively small number of auxiliary sources (N=4). The error rate in the calculation of the approximate with the auxiliary sources ~3%.

Numerical results are presented on the example of the synthesis of the five slot emitters under a dielectric coating (one in the center and 4 as symmetric matrix relative to the center, located along the x-axis) fig 5, using radiation pattern microstrip slot antenna as a desired radiation pattern, which is represented as:

$$F_{зад\vartheta} = -(ik_в)L_s \sin\varphi \left[\cos\left[k_в \frac{L_S}{2}\sin\theta\cos\varphi\right] \Big/ \left[\frac{2\left(k_в\frac{L_S}{2}\sin\theta\cos\varphi\right)}{\pi}\right]^2 - 1\right]$$

$$F_{зад\varphi} = (ik_в)L_s \cos\theta\cos\varphi \left[\cos\left[k_в \frac{L_S}{2}\sin\theta\cos\varphi\right] \Big/ \left[\frac{2\left(k_в\frac{L_S}{2}\sin\theta\cos\varphi\right)}{\pi}\right]^2 - 1\right]$$

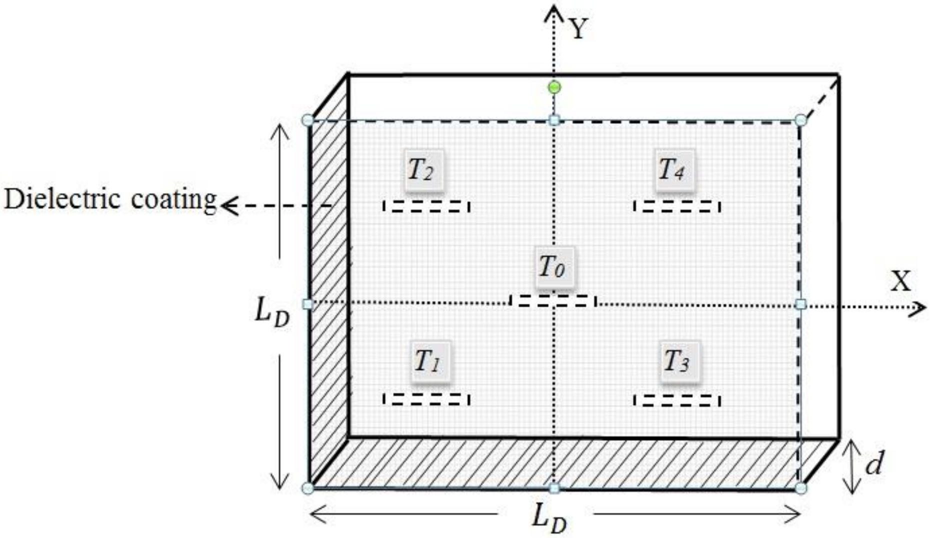

Fig. 5. Slot emitters array under a dielectric coating.

Table 4 shows the location, voltage distribution of the five slot emitters under a dielectric coating fig.5.

Element	Position	Amplitude and phase
T_0	$(0,0,0)$	$1.218\angle 180^\circ$
T_1	$(-L_D/4, -L_D/4, 0)$	$15.112\angle 0^\circ$
T_2	$(-L_D/4, L_D/4, 0)$	$15.112\angle 0^\circ$
T_3	$(L_D/4, -L_D/4, 0)$	$0.248\angle 0^\circ$
T_4	$(L_D/4, L_D/4, 0)$	$0.248\angle 0^\circ$

Table4. Slot emitters array (L_D =56 mm).

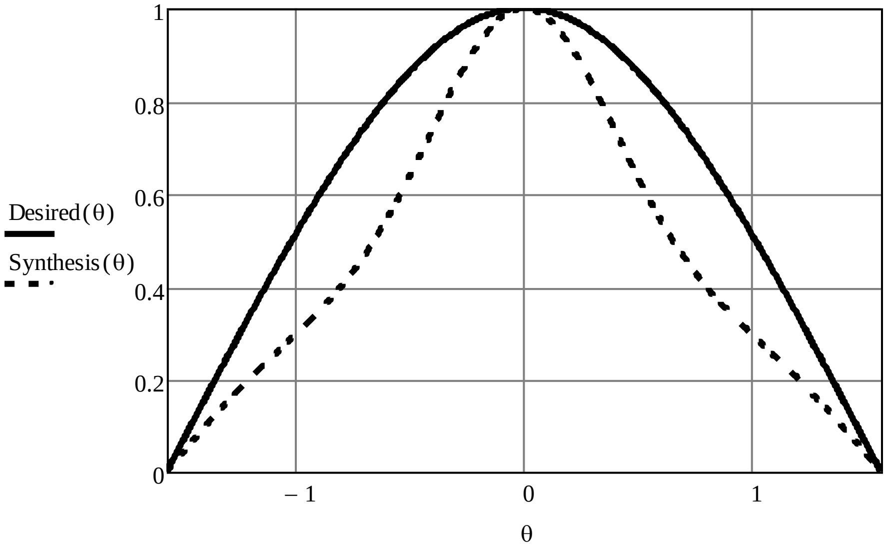

Fig. 6. Normalized radiation pattern desired and synthesis in E-plane ($\varphi = 0, \theta \in [-\pi/2, -\pi/2]$).

Fig.6 shows good agreement between the synthesis of the slot emitters array with a dielectric coating and the desired radiation pattern of microstrip slot antenna.

Conclusion

The results for solving of the problem of synthesis show the possibility of analysis and design for small element antenna arrays using the proposed approach for the acceptable time. The results of the synthesis listed for the given radiation pattern microstrip slot antenna, demonstrate the existence of solutions with different location of the slot emitters relative to the coordinate axes. It gives the possibility to choose in some cases, the solution corresponding to the smallest antenna dimensions.

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