SINGLE REFLECTOR ANTENNAS WITH STABLE RADIATION PATTERNS

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A new class of single reflector antennas having a specific stability in radiation patterns with respect to small changes (deformations) of reflector surface and feed displacements is investigated. The "stability" means that in the case of the distortions above the deviations in energy radiation distribution in peaks gain and sidelobes are sufficiently less then those of usual parabolic antennas. In certain domain of distortion values any deviations in radiation pattern of such antennas are slightly dependent on the antenna system disturbances.

The results of wave catastrophes theory [2,3] are the basis for synthesis of such antenna systems . The solution of problem involved is to choose a certain form of reflector that supplies the radiation pattern described (at least in the main part) by the special function of wave catastrophe (SWC) of stable type. The list of stable type catastrophes (singularities) first has been published by V.I.Arnold and R.Thom. Nowadays one can find it in numerous publications on Catastrophes Theory (see for example [1,6,7]).

The first step of our investigations is the well known fact that radiation pattern of any antenna system may be presented by the following integral:

$$D(\theta,\varphi) = \mathbb{C} \iint_G \exp[ik\Phi(x,y,\theta,\varphi)]*f(x,y,\theta,\varphi)dxdy \qquad (1)$$

Here D is the radiation pattern of given antenna system in polar coordinates, Φ and f are the phase and the amplitude functions respectively, determined by the geometry and the construction of antenna, G is some surface with respect to which the functions Φ and f can be determined (or established), k is the wave number ($k=2\pi/\Lambda$) and $\mathbb{C}$ is the normalizing constant.

In case of single reflector antenna with point radiation source (Fig.1)

$$\Phi(x,y,\theta,\varphi)=[(z_0-h(x,y))^2+x^2+y^2]^{1/2}-Sin\theta*(x*Cos\varphi+y*Sin\varphi)-h(x,y)*Cos\theta$$

$$f(x,y,\theta,\varphi)=j_{x,y}(x,y)*[(z_0-h(x,y))^2+x^2+y^2]^{-1/2}*f_{0x,y}(x,y,\theta,\varphi)$$

where $h(x,y)$ is the reflector profile function, $(x=0,y=0,z=z_0)$ are the feed position coordinates, $j_{x,y}$ are the components of surface currents, induced by the primary field of radiation source on surface M, $f_{0x,y}$ is some slowly varying function (in Λ scale), taking into account the radiation diagrams of surface currents.

Using unknown function h , we desire the phase function Φ to coincide (up to normalizing constant γ) with universal unfolding of Σ-type stable singularity. It gives the following equality:

$$k\Phi(x,y,\theta,\varphi) = \gamma\, F_\Sigma(\xi_1,\xi_2,\bar{\lambda},\bar{a}) + \Theta(\theta,\varphi) \qquad (2)$$

Here F_Σ is the universal unfolding ξ_1, ξ_2 and $\bar{\lambda}$, $\bar{\alpha}$ being the internal and external variables respectively. The variables ξ_1, ξ_2 are the functions of x.y and θ, φ, while $\bar{\lambda}, \bar{\alpha}, \theta$ are the functions only θ and φ. For any values θ, φ and $(x,y) \subset G$

$$\det \left\| \frac{\partial(\xi_1 \ \xi_2)}{\partial\ (x \ \ y)} \right\| \neq 0$$

This condition supplies the singularity Σ to be the only singularity of function Φ on G (it's possible for Σ to contain all subordinate singularities it comprises). When $kR >> 1$ (R is the characteristic reflector size, or domain G size) and the solutions of following equations:

$$\frac{\partial \Phi}{\partial x}\ (x,y,\theta,\varphi) = 0\ ; \qquad \frac{\partial \Phi}{\partial y}\ (x,y,\theta,\varphi) = 0 \tag{3}$$

are fare from the boundaries of G **for any given** θ, φ the main part of integral (1) asymptotic is determined by the SWC of Σ singularity [2]:

$$I^{\Sigma}\ (\bar{\overset{*}{\lambda}}\ ,\ \bar{\overset{*}{\alpha}}\ ) = \iint \exp[iF_\Sigma(\xi_1, \xi_2, \bar{\overset{*}{\lambda}}, \bar{\overset{*}{\alpha}})] d\xi_1 d\xi_2 \tag{4}$$

Here $\bar{\overset{*}{\lambda}}$ and $\bar{\overset{*}{\alpha}}$ are the external parameters normalized by γ (see (6) in example below). If the condition above is not true we have to choose as universal unfolding that one of singularity with restrictions (see [3,4]).

In a view of great number of singularities types the analysis of equality (2) and the results followed seems to be too large for given article. Hence we'll restrict our consideration by only one example. Let Σ be the elliptic umbilic singularity D_4^-. In this case F_Σ has the following form (we use a symmetrized normal form of unfolding [5,6]):

$$F_{D_4^-}(\xi_1, \xi_2, \lambda_1, \lambda_2, \lambda_3) = \xi_1 * \xi_2^2 - 1/3\ \xi_2^3 + \lambda_3 * (\xi_1^2 + \xi_2^2) + \lambda_1 * \xi_1 + \lambda_2 *\ \xi_2 \tag{5}$$

Substituting (5) in equality (2) and considering strong directed radiation diagram (that is $\theta << 1$), we can find the following conditions giving rise to (2) :

$$\xi_1 = x, \qquad \xi_2 = y$$

$$\lambda_1 = \lambda_1^o - \gamma^{-1} k\ [\theta \ Cos\ \varphi], \qquad \lambda_2 = \lambda_2^o - \gamma^{-1} k\ [\theta\ Sin\ \varphi], \qquad \theta = 0$$

and in (4)

$$\overset{*}{\lambda}_1 = \gamma^{2/3}\ \lambda_1, \quad \overset{*}{\lambda}_2 = \gamma^{2/3}\ \lambda_2, \quad \overset{*}{\lambda}_3 = \gamma^{1/3}\ \lambda_3 \tag{6}$$

and in addition we have the obvious expression for reflector profile function h(x,y):

$$h(x,y) = \frac{x^2+y^2}{2(Z_o + k^{-1}\gamma\ F_{D_4^-})} \ + \ 1/2\ (Z_o - k^{-1}\gamma\ F_{D_4^-}) \tag{7}$$

The parameters λ_1^o, λ_2^o and λ_3 are arbitrary and we can use them for the choice of angle radiation desired. An amount of γ determines as the scale of diffraction pattern, described by SWC (4), so as whole width of radiation diagram. Z_o parameter in (7) is analog to focus distance of reflector, and it should be

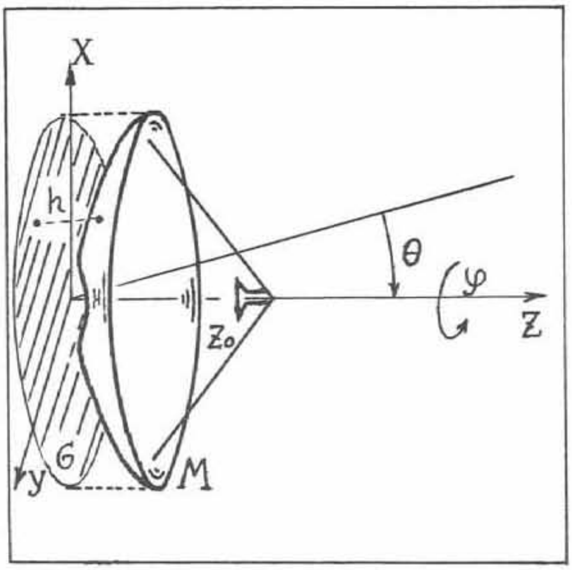

Fig.1

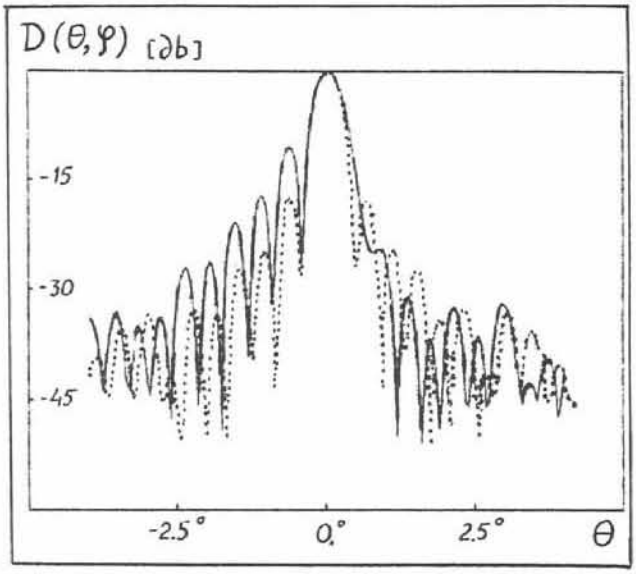

Fig.2

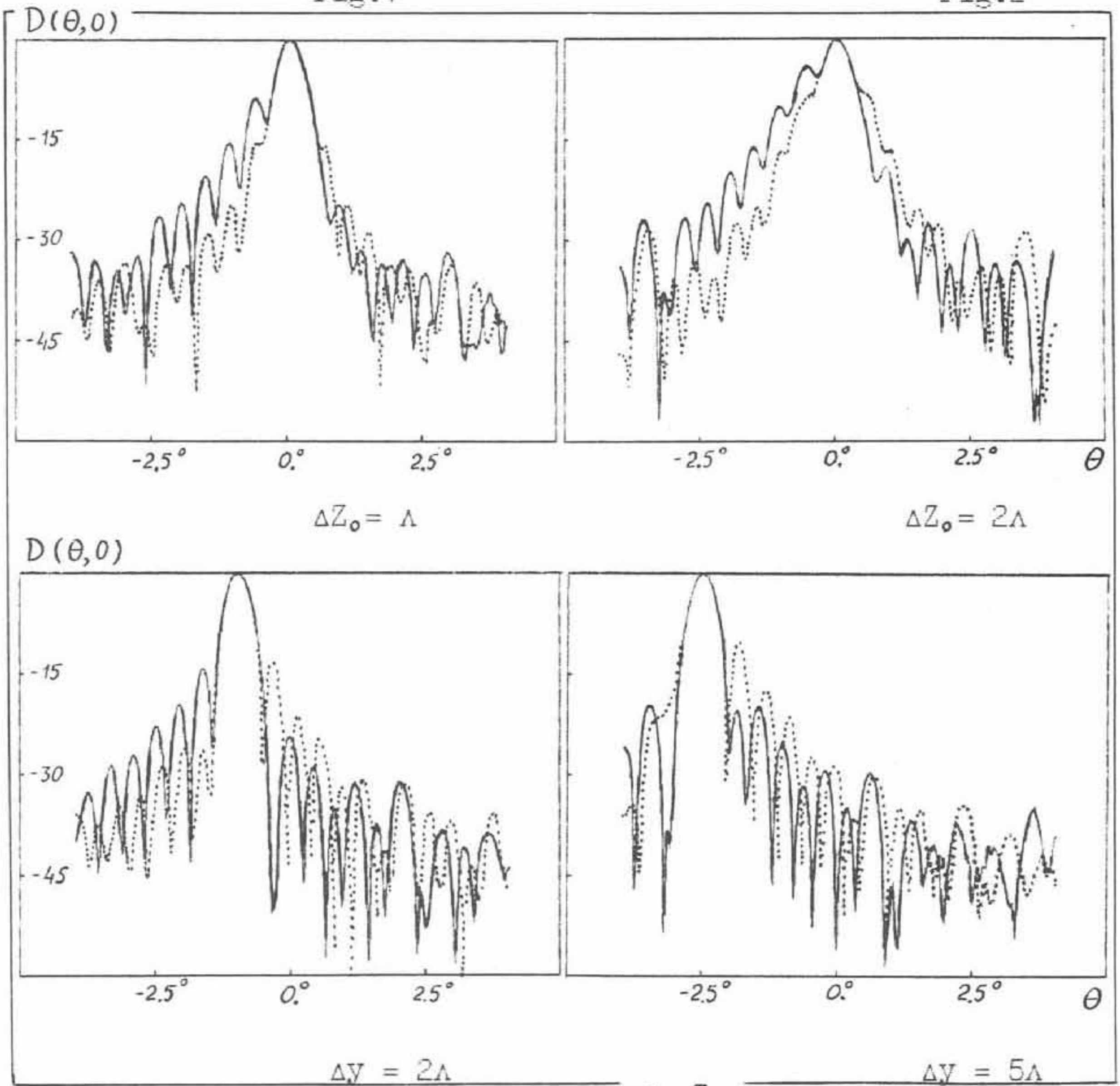

Fig.3

determined in dependence of antenna size, so that the condition (3) would be true.

If $\lambda_3 = 0$, the diagram pattern (as SWC structure [5,6]) has the main lobe of triangular form; and if $|\lambda| > 1$, it has a multilobes structure of triangular configuration with several peaks gain.

Fig 2 shows some numerical results of reflector antenna radiation pattern modeling when the reflector profile is determined by the formula (7) with the following parameter:

$k = 500$, $\Lambda \approx 1$cm, $R = 1.8$ m, $z_o = 1.$m, $\gamma = 5.$, $\lambda_3 = \lambda_1^o = \lambda_2^o = 0.$

Fig.2 represents some cuts trough radiation pattern for different planes $\varphi = const$. The triangular shape of radiation pattern is obvious because the angle radiation distribution does not change when φ is replaced by $\varphi \pm 120^{\circ}$ (the corresponding plots coincide with each other). For comparison the radiation pattern of parabolic reflector antenna of the same size is presented there by dotted line. The main lobe width by the level of -3 ∂b is approximately the same of parabolic antenna, but the sidelobes levels are 6-8 ∂b greater.

The results presented in Fig.3 illustrate the radiation pattern stability of the antenna under consideration. Here one can see the radiation patterns for the case of feed displacements varying from Λ to 2Λ in Z-axis and from Λ to 5Λ in y axis. The sidelobes energy distribution of given antenna is more stable then that one of parabolic antenna (dotted line).

In conclusion we note that it is possible to consider not only the common type stable finitely determinate singularities Σ but so the nonfinitely determinate singularities and the singularities having another restrictions but those connected with the boundaries of G (for example any symmetry of antenna).

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