RADIATION CHARACTERISTICS OF A WIRE ANTENNA WITH FINITE SIZE PLANE AND CORNER SCREENS

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Abstract

Based on the uniform geometric diffraction theory method the asymptotic solutions are obtained for 3-D problems of diffraction of the fields radiated by the arbitrary oriented electric dipole Hertz and half-wave resonant vibrator on the thin ideally conducting plane screen of the rectangular form and on the finite size corner reflectors of a various configuration. The carried out experiments confirm the accuracy of calculated radiation patterns of analyzed systems. There are also calculated the optimal tilt angles, positions of the vibrator, placed above the rectangular screen, and the reflector dimensions for producing the circularly polarized radiation in the main observation planes with maximum directive gains.

Keywords: directive gain, radiation patterns, Back to Front Ratio, circular polarization, resonant length of vibrator

1. FORMULATIONT OF THE PROBLEMS

In the present work our long-term researches on studying the influence of the diffraction effects on the radiation characteristics of the wire antenna with finite size plane and corner reflectors are generalized. A number of the basic results of researches have been submitted and published in the works of the previous ICATT [1–5]. The method of geometrical optics (GO) and the method of the uniform geometrical theory of diffraction (UGTD) which is advanced by us for solution of the three-dimensional problems of diffraction of the fields radiated by the arbitrary oriented dipole Hertz and half-wave resonant vibrator on the thin perfectly conducting plane screen of the rectangular form and also on the finite size corner reflector of a various configuration are used.

For the first time are obtained the asymptotic uniform on the observation angles in the far field zone expressions for a full field in the three-dimensional problems of diffraction of the fields radiated by the half-wave resonant vibrator on the following screens 1), 2), 3) with the sizes comparable with the wave length and big, (Fig. 1):

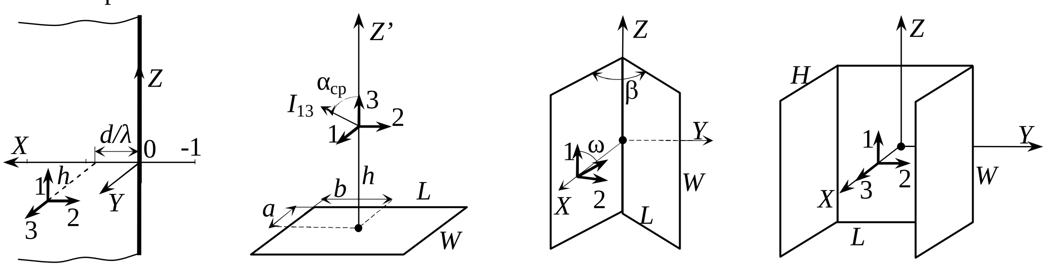

Fig. 1. The geometry of the problems

1) – the rectangular screen with the side sizes L and W for any distance and position of the electric vibrator concerning it (b);

2) – 90°-corner reflector and a symmetrically excited corner antenna with an aperture angle β and the side sizes L , W (c);

3) – the Π-figuration reflector with the side sizes L, W and H (d).

We consider independently three cases of excitation of analyzed reflectors by mutually orthogonal electric vibrators 1, 2, 3 (Fig.1).

Within the framework of the UGTD method the components of a full electric field intensity vector $\vec{E}(M)$ of the radiating system is determined in any observation point M as a superposition of the discontinues GO and diffracted fields components :

$$\vec{E}(M) = \vec{E}_{go}(M)\chi + \vec{E}^{*}_{go}(M)\chi^{*} + \vec{E}_{d}(M)\chi_{d} + \vec{E}^{*}_{d}(M)\chi_{d}^{*}. \quad (1)$$

For each problem 1), 2), 3) the electrodynamic model is constructed as system of the GO sources and virtual diffracted sources (VDS). The radiation pattern (RP) of VDS is adequate for radiation pattern of the wave diffracted on a perfectly conducting infinitely thin half-plane. The patterns of each source depend on orientation of a vibrator and geometry of a problem. The GO field is calculated by the method of mirror images as the sum of the wave incident $\vec{E}_{go}(M)$ and the waves reflected from the screen sides $\vec{E}^{*}_{go}(M)$, which are radiated by an electric vibrator and his mirror images. In formula (1) $\vec{E}_d(M)$, $\vec{E}^{*}_d(M)$ are the intensity vectors of the diffracted fields, excited by incident and reflected GO waves on the halfplane (VDS) accordingly. The uniform on the observation angle asymptotic expressions for the components of the VDS field corresponding to orientation of the dipole relative to the edge are obtained in [6]. Ones were represented through the integral of probability and can be used as close, and far from the light-shadow boundaries of GO waves.

Since the reflector sides are finite, for each GO and VDS source the illuminated and shadow regions in the observation space are formed. Coefficients χ, χ^{*}, χ_d, χ_d^{*} take a value of unity in the illuminated region and a value of zero in the shadow region corresponding waves. The key point in solution of the posed problems is determination of coefficients, i.e. the equations of the boundaries of illuminated and shadow regions of GO and diffracted waves. The algorithms for determining the equations of these boundaries throughout the observation space for each problems 1), 2), 3) are presented in [7–9].

Effective numerical algorithms and 3-D computer programs of calculation of amplitude, phase and polarizing characteristics of the radiation fields for investigated systems are developed and realized. There are investigated the influence of the reflector sizes, position and orientation of a vibrator concerning a reflector on the field structure and such radiation characteristics:

$$I_{\Sigma} = \int_0^{2\pi} d\varphi \int_0^{\pi} f^2(\theta,\varphi)\sin\theta d\theta\,, \qquad \left|\dot{f}\right|^2 = \left|\dot{f}_\theta\right|^2 + \left|\dot{f}_\varphi\right|^2,$$

$R_{\Sigma} = AI_{\Sigma}$, where $A=30\pi(l/\lambda)^2$ for the dipole Hertz; for the symmetrical vibrator with length $2l$ $A = 30/\pi$;

$$D(\theta,\varphi) = 4\pi f^2(\theta,\varphi)/I_{\Sigma},$$

$$D_{\max} = 4\pi f^2(\theta_{\max},\varphi_{\max})/I_{\Sigma}. \qquad G(\theta,\varphi) = 10\lg(D/D_{\max})$$

Here I_{Σ} is the integral of the radiation throughout the observation space, R_{Σ} is the radiation resistance, $D(\theta,\varphi)$ is the directive gain at the observation angles θ, φ, $G(\theta,\varphi)$ – the radiation power pattern.

2. POLARIZATION EFFECTS

In the three-dimensional diffraction problems of the wire vibrator radiation on the conducting bodies with sharp edges of various orientation in relation to the vibrator the problem of diffraction of an arbitrary oriented dipole Hertz radiation on a perfectly conducting half plane is model (Fig. 1a). From the calculation results follows, that at excitation of a half-plane by the dipole with an axis, perpendicular its edge, linearly polarized radiation of the dipole may be transformed in elliptically polarized due to appearance of nonsinphase orthogonal vector components of a diffracted field in the considerable regions of the observation space. As it seen from Fig. 2 the ellipticity value σ_2 of the

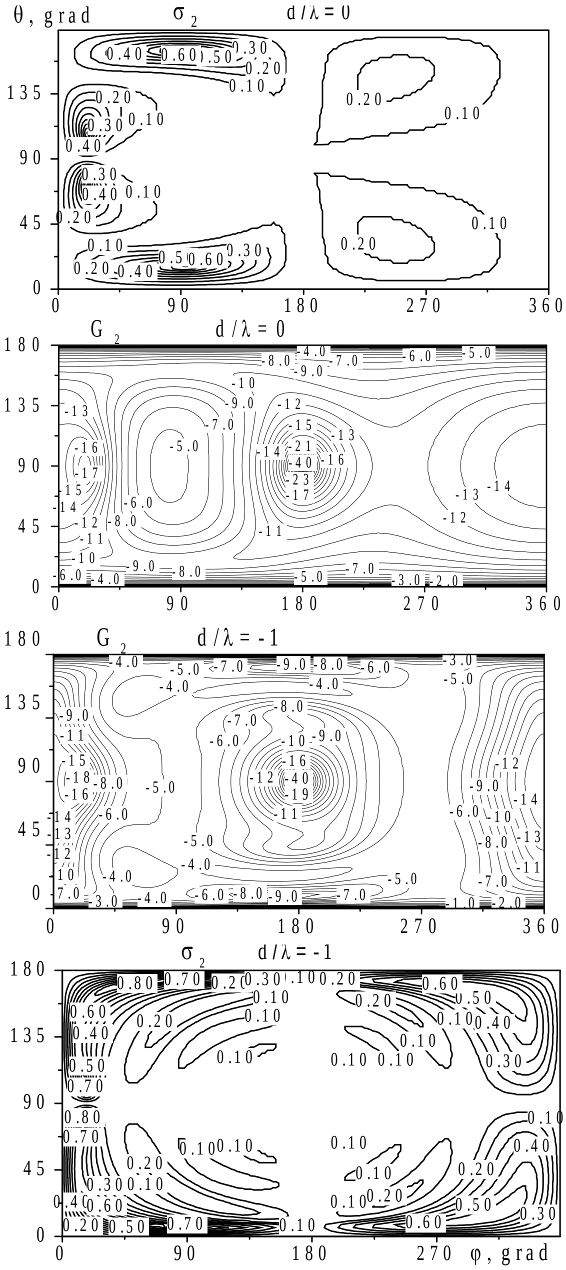

Fig. 2. Isolines of σ_2 and G_2 (in decibels) for dipole 2 in the coordinate system of observation angles θ, φ

polarization ellipse of the full field sufficiently depends on position dipole 2 in relation to a halfplane. The greatest values σ_2 at the considerable power density of radiation G_2 take place within interval of observation angles θ=2…20°, digitized from an edge of a halfplane at d/λ=0...-1 (Fig 2) and at d/λ=0.5…0 for dipole 3.
In the case of excitation of the rectangular screen by the dipoles 1 or 2 in definite sectors of the main observation planes in a far field zone the linearly *E* - or *H* - polarized radiation transformed in elliptically polarized, as well as in the case of a diffraction on a halfplane.

3. Results of Calculation of the Back to Front Ratio and Experiment

For an estimation of the accuracy of 3-D programs for calculation PR-s and determining the limits of applicability of the UGTD method at different vibrator orientation concerning the screen the experiments have been carried out. The purpose of the experiment includes the definition: first, whether we apply method GTD in a case when the screen sizes are less than wave length; second, suitability of designed algorithm for calculation the crosspolarized radiation; in the third, an opportunity to minimize of the attitude of antenna radiation in the directions along the normal lines "back" and "front" to the screen by means of choosing the optimum screen sides ratio *W/L*.
In Fig.3 the experimental and calculated RP-s of the λ/2-vibrator 1, located at height h=0,25λ above the middle of the rectangular screen with the side sizes L=0,47λ, W=0,63λ (a, b) and L=W=0,96λ (c-e) are presented. The experimental and calculated RP-s both in forward half space, and in a direction of observation "back" from the screen, differ no more than on 2 dB. Thus, the experiments have confirmed the deductions received earlier that UGTD is applied for calculation of RP-s for screens with the sizes down to half of wave length at excitation by the vibrator, parallel to the greater side of the screen.

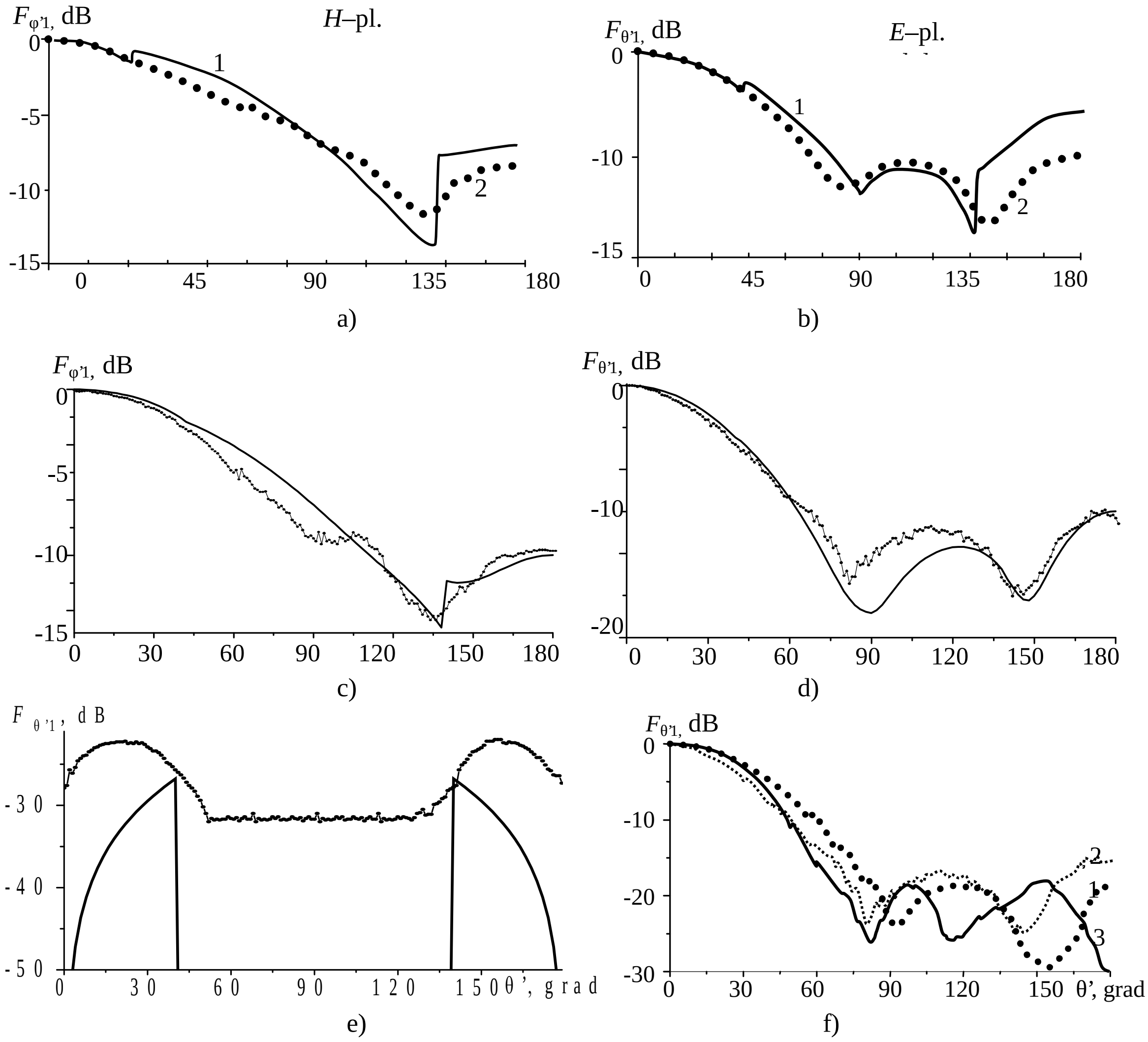

Fig. 3. The RP-s of the λ/2-vibrator above the screen with L=0,47λ, W=0,63λ (a, b) and L=W=0,96λ (c-e) in *H*-plane (a, c, e) and *E*- plane (b, d); calculation by method UGTD(—) and experiment (—•—); the RP-s in *E* -plane (f) for various *W/L* at h=0,25λ

From the analysis of a field structure of the radiating system vibrator-screen it is follows, that in the main observation planes, perpendicular to the vibrator, the crosspolarized field components are formed, that caused by a diffraction of the vibrator radiation on perpendicular edges to it.

The carried out experiment confirms also the calculated RP of the crosspolarized component, excited at a diffraction of radiation of the vibrator 1 on the transverse to it screen edges in the definite sectors of observation angles (Fig. 3e). The distinctions of the calculated and experimental RP-s are explained by a deterioration of the measuring precision at the small levels of a field.

From the analysis of the calculation results it follows, that at the fixed observation directions, distance h, the size L there is a certain interval of values W/L at which take place the interference oscillations of the diffracted radiation level [3]. This phisical effect enables to reduce the radiation capacity in the set direction by a choice optimum ratio W/L from this interval. In particular, by a choice of the corresponding sides ratio W/L of the rectangular screen it is possible to reduce rear radiation and also to increase the directive gain of the antenna, to reduce the maximal value of the crosspolarized radiation and to change the position of its maximum in the space.

The important parameter of the quality of the radiating systems is the Back to Front Ratio, $V= 20\lg(|E_{back}| / |E_{front}|$, where E_{front} and E_{back} are the electric field amplitude in the orthogonal to the screen directions in the front and back half-spaces. From the detailed analyses of the calculated dependences V when changing sizes of the screen over wide ranges there have been obtained dependencies of optimum ratios of screen sides $(W/L)_{opt,}$ providing minima of Back to Front Ratio, $V_{min.}$ The developed approximation program allows to compare the dependences $(W/L)_{opt}$ obtained by computerical experiment with the corresponding calculated elementary algebraical functions. Our calculation program has resulted in the calculated coefficients of correlation R between the above-mentioned values. As a result of the data obtained, it was found that the hyperbolic function $y=A+ B/x$ gained the advantage over others. So the approximation formula which models five dependences $(W/L)_{opt(n)}$ on L/λ is described by the hyperbolic multiple –valued function

$$(W/L)_{opt(n)} = A_n + B_n /(L/\lambda) \quad . \qquad (2)$$

The corresponding calculated coefficients A_n, B_n, R_n are given in table 1

Table 1. The coefficients for the approximation formula

n	1	2	3	4	5
A_n	1,05	1,16	1,06	1,06	1,09
B_n	0,85	2,60	4,81	6,79	8,70
R_n	1,00	1,00	1,00	1,00	1,00

To verify the obtained calculated dependences the experiment has been put at the choice of the ratio side screen $(W/L)_{opt}$, providing V_{min} at the given width of the screen L=0,96λ and h=0,25λ. From the formula (2) follows, that for providing V_{min} at the screen width L=0,96λ, it is necessary to take $(W/L)_{opt}$ = 1,9. In the experiment have been measured the RP-s of a λ/2-vibrator situated above the screens with L=0,96λ at different W/L, including $(W/L)_{opt}$. The experimental RP in E–plane for the vibrator situated above the screen with sizes L=0,96λ, W=0,72λ (curve 1); L=W=0,96λ (curve 2) and L=0,96λ, W=1,84λ (curve 3) at h=0,25λ are shown in Fig. 3. The comparison of the radiation levels back in the experimental RP-s proves effect of an optimum choice of the ratio screen sides, that convincingly confirms the theoretical analysis.

4. Synthesis of Circularly Polarized Field with Maximum Gain

The analysis of expressions for complex patterns of the electric field intensity vector components [3] reveals, that when the plane screen is excited by a tilted dipole I_{13} being a superposition of dipoles 1 and 3, the circularly polarized radiation may be obtained in the directions θ′=90°, φ′≠0 (Fig. 1b). The one may be formed in the directions φ′=0, θ′≠0° at exciting plane screen by a tilted dipole I_{23} being a superposition of dipoles 2 and 3 The circularly polarized radiation is generated for an arbitrary distance h, excluding those h when one or both orthogonal components are equal to zero by choosing the corresponding dipole tilt angle α_{cp}.

Let us consider a plane screen with finite dimensions. In [10] the algorithms are obtained to determine α_{cp} with account of diffraction effects for providing the circularly polarized radiation of the λ/2-vibrator-screen system in the main observation planes. The simultaneous calculation of the squared absolute value of the normalized total field E^2_{cp} makes it possible to provide for the conditions of the synthesis of the circular polarization and to optimize the directivity characteristic for the maximum gain in a given direction. All the computations have been performed for a screen with the side dimensions W=L=3λ and a vibrator located at h=0,25λ. The positions of the vibrator relative to the screen are determined by coordinates a and b of the screen‘s vertex (Fig. 1b). The values of a and b range within the interval –3λ ÷ 6λ with the step 0.05λ. From the obtained array of values σ(θ′,φ′), we choose maximum value σ_{max} and corresponding observation direction θ_{cp} and $E^2_{cp.}$ The computation have shown that the circularly polarized radiation cannot be synthesized in all angles θ′. The analysis of the conditions of the synthesis of a circularly polarized field with the maximum gain is illustrated in Fig. 4a-d (curves 1, 2 - at exciting by current I_{13} and I_{23} accordingly). In order to optimize the geometry of radiating system from the array of values E^2_{cp}, we select at each b maximum values E^2_{max} (a) and corresponding coordinates a_{max} (c), observation angle θ_{max} (b), and vibrator tilt angle $\alpha_{max.}$(d). In the case of the corner antenna diffracted on its edges fields bring the essential contribution to a full field in the direction of a normal «forward» to the antenna in the certain interval of the values *W/L* dependent on the corner aperture angle β, size *L* and distance from the interior corner edge *S*, and that the greater, than it is less angle β [2]. It enables to maximize the directive gain and the R_Σ for each aperture angle β by choosing an optimum combination of reflector dimensions, the vibrator orientation and distance *S*. In [11] is shown that the circularly polarized field can only be formed in the main planes for the corners with aperture angle β=π/*N*, when *N* is even, which are excited by the tilted dipole being the superposition of dipoles 1 and 2 (Fig. 1c). For the corners with β=90° and β=45° the optimum dimensions, L_{opt} and W_{opt}, and optimum vibrator tilt angle ω_{cp} for providing the circularly polarized radiation along the normal to the corner aperture with maximum directivity gain D_{cp} were determined for each *S*. In Fig. 4 the optimum values of D_{cp} (e) and corresponding radiation resistance R_{cp} (f) are shown as function of distance *S/*λ (curves 1, 2 - for β=90°; curves 3, 4 - for β=45°; curves 1, 3 correspond to the infinite corner and curves 2 and 4 correspond to the L_{opt} and W_{opt}).

Analyzing of the calculated values of D_{cp}, we plotted the maxima of D_{cp} versus width *L/*λ (Fig. 4g) for 90°corner (curve 1 - *S*=0,2λ, curve 2 - *S*=0,7λ) and for 45°corner (curve 3 - *S*=0,4λ, curve 4 - *S*=0,85λ). The behavior of the radiation resistance R_{cp} (Fig. 4h) as a function of width *L/*λ is similar to directive gain D_{cp}

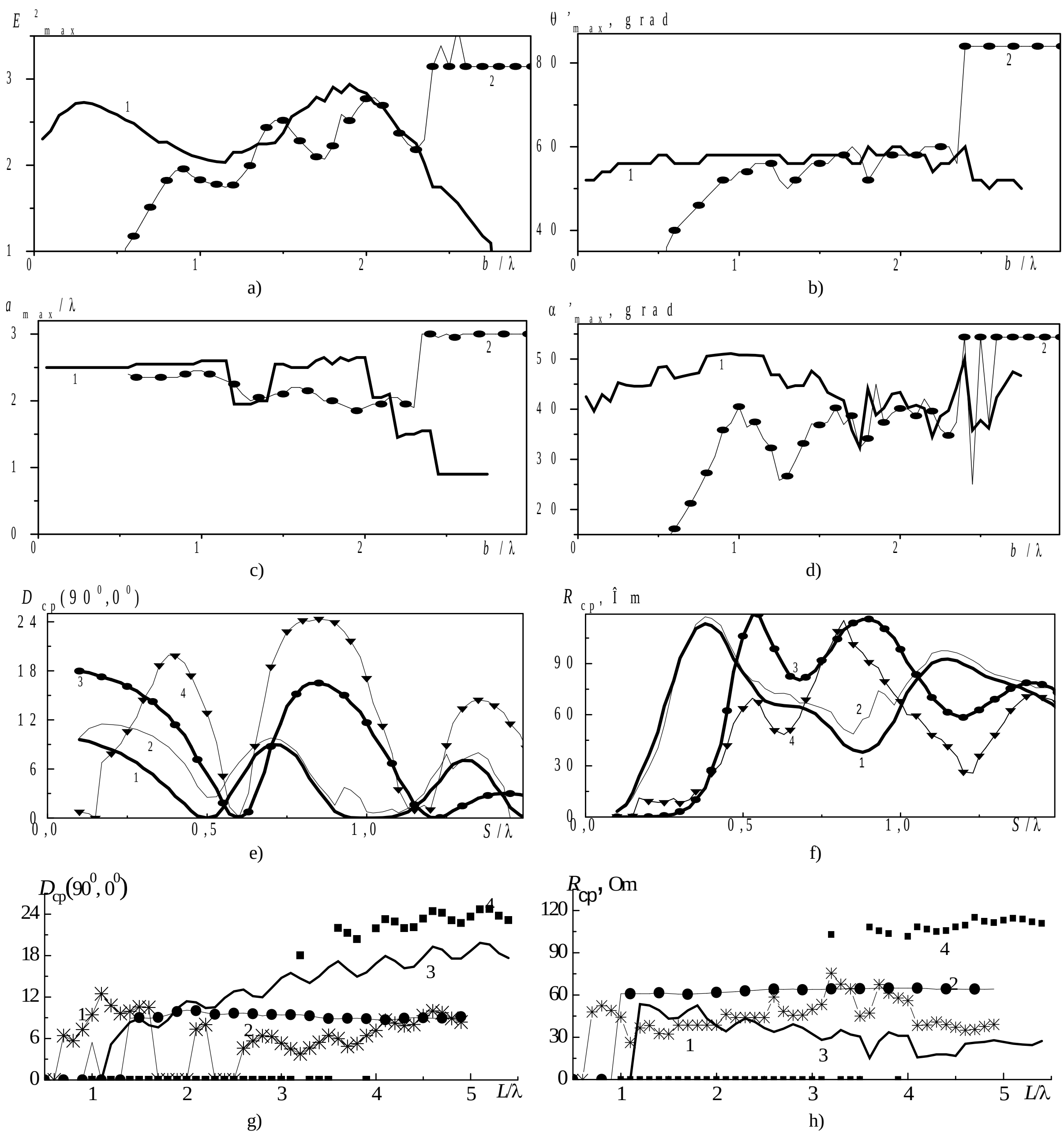

Fig. 4. Optimizing the directive gain of the λ/2-vibrator, placed above the rectangular screen (a-d), and the corner antenna with a circularly polarized radiation field (e-h)

Thus, the directive gain D_{cp} of 90° and 45° corner can be increased by 50% and 70%, respectively, upon optimizing the corner dimensions and the position and tilt angle of the vibrator.

5. Calculation of Resonant Length of Wire Antenna

On the basis of the induced electromotive forces method and the UGTD method a technique for calculating the input impedance of the symmetric vibrator with length 2*l*, placed above the metal infinitely thin rectangular screen is developed in [4]. With using this technique the shorting of the resonant vibrators 1 and 3 with account for influence of diffraction effects on the screen were calculated in the following way [12]. The isolines of real and jet part of the input impedance of the vibrators, placed at various distances *h* above the infinite screen and screens $W=L=0{,}5\lambda$ и $W=L=\lambda$ were calculated when changing the shoulder length of the vibrators l/λ in the limits from 0.21 to 0.245 and the relative thickness l/a from 10 до 700 (*a* – radius of the wire). The resonant shoulder length l_0/λ of the half-wave vibrators 1 and 3 at which the jet part of its input impedance is equal to zero is determined. The ones are presented in Fig. 5 as function of relative thickness l/a. Here the dependence l_0/λ for vibrator in free space is presented too. It is shown, that presence of the screen results in the greater shortening resonant length of the vibrator irrespective of its thickness, than in case of the vibrator in free space. In case of the screen of smaller sizes (curves 4, 6) the magnitude of shortening is more, as the amplitude of diffracted on screen edges waves is more. The shortening of resonant vibrators 1 above the screen with sizes $\lambda\times\lambda$ practically same, as well as in case of the infinite screen (curves 2, 5). Difference the calculated resonant length of the experimental vibrator 1 with given length and relative thickness $l/a=13$, placed above the screen with sizes $L=0{,}47\lambda$, $W=0{,}67\lambda$ at $h=0{,}25\lambda$, and measured makes 1,2%.

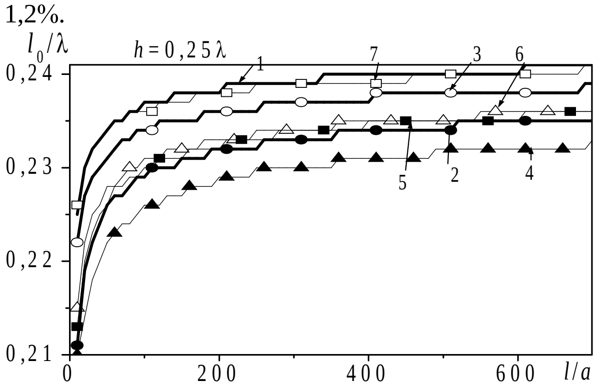

Fig. 5. Dependences of resonant shoulder length l0/λ on l/a for vibrator in free space (curve 1), vibrators 1 (curves 2, 4, 5) and 3 (curves 3, 6, 7), placed above the screen at h=0,25λ (curves 2, 3 for infinite screen, curves 4, 6 for W=L=0,5λ, curves 5, 7 for W=L=λ).

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