SIMPLIFIED EVALUATION FOR CROSS-POLAR FIELD DUE TO INDUCED CURRENT ALONG PARABOLA-AXIS

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1 Introduction

In an offset parabolic reflector illuminated by vertically polarized waves, an induced current component along the parabola-axis may cause cross-polar field in the radiating region. For achieving ultralow-cross-polarization characteristics, it is important to evaluate effects due to such an induced current. In previous, however, the copolar field has been mainly evaluated by comparing between aperture-field and physical optics (PO) methods [1, 2]. In this paper, formulation representing the secondary radiation patterns for the offset parabolic reflector is derived by means of the PO methods. Furthermore a simplified technique based on the beam modes expansion method [3] for evaluating the cross-polar field is presented.

2 Formulation

Consider an offset parabolic reflector illuminated by linearly polarized spherical waves which have the cross polarization component given by the third definition in [4]. Fig. 1 shows coordinate systems and unit vectors for the offset reflector. The phase center of the primary pattern $\mathbf{E}_1$ is located at the focal point. The field components along vectors $\mathbf{u}_{\xi 1}$ and $\mathbf{u}_{\eta 1}$ correspond to vertically and horizontally polarized excitations, respectively. Also the secondary pattern $\mathbf{E}_2$ is defined by the same way as follows [5].

$$\mathbf{E}_i = E_{ix}\mathbf{u}_{\xi i} + E_{iy}\mathbf{u}_{\eta i} \qquad (i=1,2) \tag{1}$$

$$\mathbf{u}_{\xi i} = \cos\varphi_i \mathbf{u}_{\theta i} - \sin\varphi_i \mathbf{u}_{\varphi i}, \qquad \mathbf{u}_{\eta i} = \sin\varphi_i \mathbf{u}_{\theta i} + \cos\varphi_i \mathbf{u}_{\varphi i} \tag{2}$$

where $\mathbf{u}_{\theta i}$ and $\mathbf{u}_{\varphi i}$ denote unit vectors along θ_i and $\varphi_i (i=1,2)$ in the polar coordinate systems, respectively. The secondary pattern $\mathbf{E}_2$ observed at the point $(r_2, \theta_2, \varphi_2)$ consists of $\mathbf{E}_{2s}$ due to the induced current along the parabola-axis and $\mathbf{E}_{2t}$ due to the normal component to its axis. The final expression for the $\mathbf{E}_{2s}$ by the PO methods is

$$\mathbf{E}_{2s} = -\frac{j}{\lambda}\frac{e^{-jkr_2}}{r_2}\iint_S \mathbf{F}_s e^{-jk(r_a - r_2)} dS, \tag{3}$$

$$\mathbf{F}_s = \frac{\eta}{2}(\mathbf{I} - \mathbf{u}_{r2}\mathbf{u}_{r2}) \cdot (\mathbf{J}\cdot\mathbf{s})\mathbf{s} = (\mathbf{n}\cdot\mathbf{E}_{1r})[(\mathbf{u}_{z2}\cdot\mathbf{u}_{\xi 2})\mathbf{u}_{\xi 2} + (\mathbf{u}_{z2}\cdot\mathbf{u}_{\eta 2})\mathbf{u}_{\eta 2}], \tag{4}$$

where $j=\sqrt{-1}$, λ is wavelength, k is the wavenumber, $\mathbf{J}$ is the induced current, $\mathbf{s}(=\mathbf{u}_{z2})$ is the unit vector along the ray reflected by the reflector, $\mathbf{n}$ is normal vector on the reflector, $\mathbf{E}_{1r}$ is the reflected electric field, $\eta(=\sqrt{\mu/\epsilon})$ is the wave impedance of free space, S is the reflector surface, and the dyadic $\mathbf{I}$ is an idem factor.

If θ_0 of the angular aperture is small, the radiation patterns $\mathbf{E}_{2t}$ and $\mathbf{E}_{2s}$ are approximately obtained for $\theta_i/2 << 1 (i=1,2)$ as follows.

$$\mathbf{E}_{2t} \simeq [\tilde{E}_2(E_{1x}) - \tan\frac{\alpha}{2}\tilde{E}_2(E_{1y}\sin\theta_1\sin\varphi_1)]\mathbf{u}_{\xi 2} + [-\tan\frac{\alpha}{2}\tilde{E}_2(E_{1x}\sin\theta_1\sin\varphi_1) + \tilde{E}_2(E_{1y})]\mathbf{u}_{\eta 2}, \quad (5)$$

$$\mathbf{E}_{2s} \simeq -\sin\theta_2[\tan\frac{\alpha}{2}\tilde{E}_2(E_{1x}) + \frac{1}{2}(1+\tan^2\frac{\alpha}{2})\tilde{E}_2(E_{1x}\sin\theta_1\cos\varphi_1) + \frac{1}{2}(1-\tan^2\frac{\alpha}{2})\tilde{E}_2(E_{1y}\sin\theta_1\sin\varphi_1)]\mathbf{u}_{\theta 2}, \quad (6)$$

where

$$\tilde{E}_2(\tilde{E}_1) = -\frac{j}{\lambda}\frac{e^{-jkr_2}}{r_2}\iint_S \tilde{E}_1 e^{-jkr_b} r_1^2 \sin\theta_1 d\theta_1 d\varphi_1. \quad (7)$$

In the cross-polar field due to the current along the parabola-axis, the effect for horizontally polarized excitation is negligibly small, even if the offset angle σ becomes large.

Further because $\tilde{E}_2(\tilde{E}_1)$ can be expanded by the beam modes [3], the cross polarization component for vertically polarized excitation, $E_{2s,X}$, is approximately obtained by

$$E_{2s,X}(\theta_2,\varphi_2) \simeq -\tan\frac{\sigma}{2}\sin\theta_2\sin\varphi_2 E_{2,C}(\theta_2,\varphi_2), \quad (8)$$

where $E_{2,C}$ denotes the scalar component of the copolar field by the beam modes expansion method. As the edge level of the illumination distribution becomes small, the formulation is simplified by using the dominate beam mode. As a result, the peak value of the cross polarization component, $P_{s,X}$(dBi), and its direction $\Theta_{s,X}$(rad) are expressed by

$$P_{s,X} \simeq K_P + 20\log_{10}\left(\tan\frac{\sigma}{2}\right), \quad (9)$$

$$\Theta_{s,X} \simeq K_\Theta \frac{\lambda}{D} \quad (10)$$

where $K_P = 1.7$, K_Θ is constant value determined by the edge level, and D is the aperture diameter. Beside, for the uniform illumination distribution, $P_{s,X}$ and $\Theta_{s,X}$ are obtained by $K_P = 1.4$ and $K_\Theta = 0.59$.

3 Calculated results and evaluation

The cross polarization components of radiation patterns due to the induced current along the parabola-axis are numerically analyzed for an offset parabolic reflector. Table I shows parameters of the offset parabolic reflector antenna. Fig. 2 shows radiation patterns of the cross-polar field in plane of asymmetry ($\varphi_2 = 90°$) dut to the current components along the parabola-axis. The observation distance r is defined by a parameter $t(=\frac{D^2}{8\lambda}\frac{1}{r})$. It was found that components for horizontally polarized excitations are negligibly small. Also peak level of the cross-polar field for vertically polarized excitations decreases according to the copolar field.

Fig. 3 shows comparisons between radiation patterns of cross-polar field in planes of symmetry ($\varphi_2 = 0°$) and asymmetry ($\varphi_2 = 90°$) calculated by the PO method and beam modes with (8). The corrected beam mode analysis provides sufficient accuracy in the far-field region. Fig. 4 shows peak value of the cross-polar field for vertically polarized excitations, where the phase is normalized by the copolar field. The peak value by the presented formulation(—) successfully agrees with results calculated by the PO method for the edge level $P_e = -10$dB ($\cdot\cdot\circ\cdot\cdot$) and -20dB ($--\times--$), therefore validity of the formulation was confirmed. In conclusions, the peak power(dBi) due to the induced current component along the parabola-axis is independent of the aperture diameter and is mainly determined by the offset angle.

References

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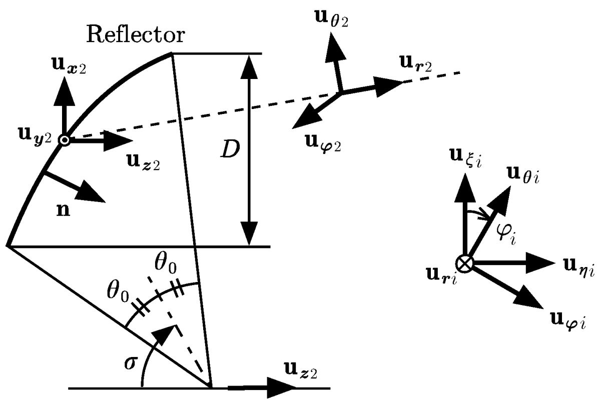
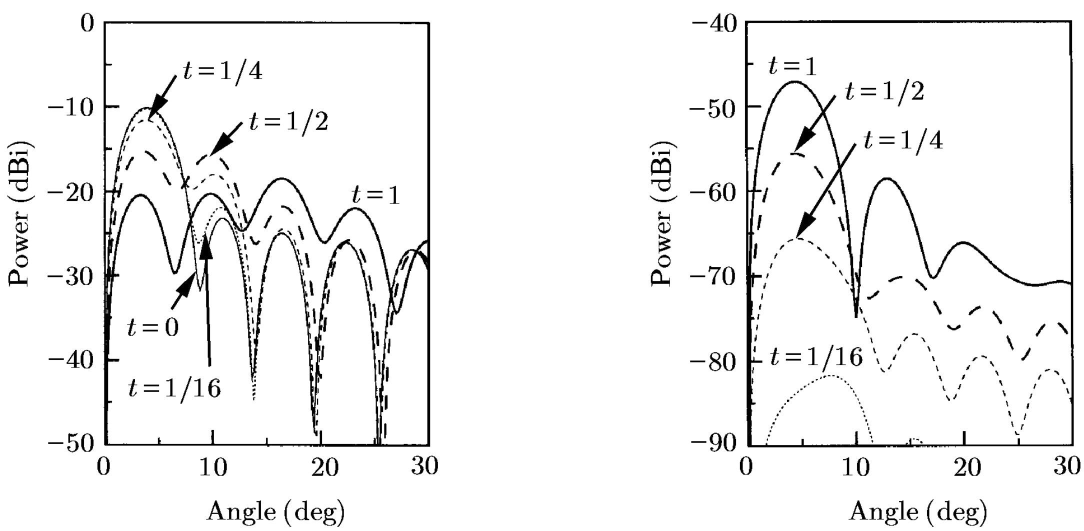


Figure 1: Coordinate systems and unit vectors for an offset parabolic reflector.

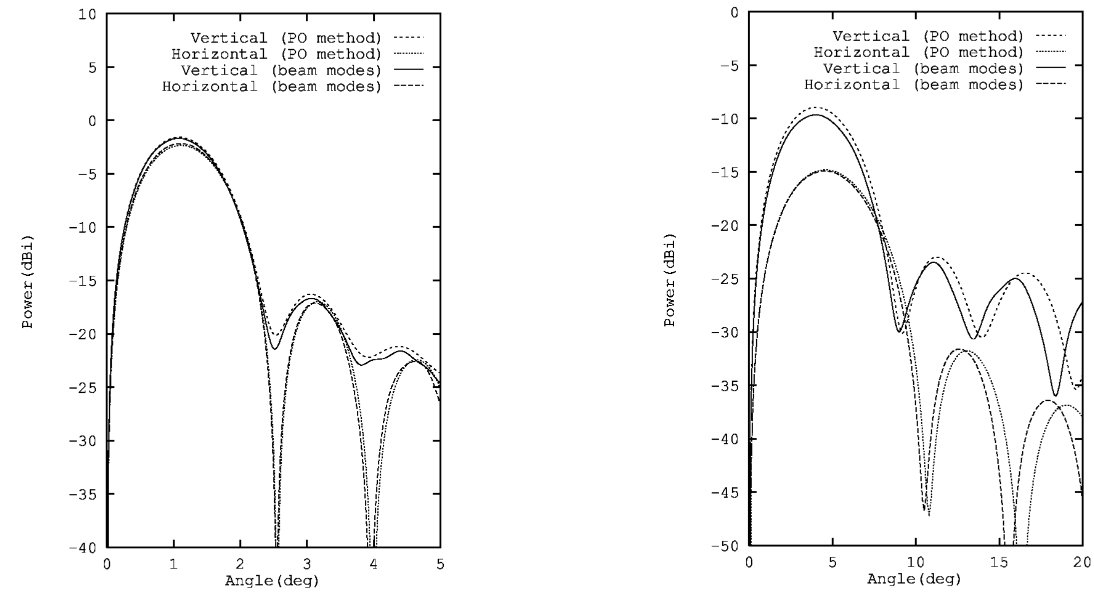
TABLE I
Parameters of an offset parabolic reflector antenna.

Mode excited by a primary radiator	EH_{11}-mode
Edge level on the aperture (dB)	-10
Aperture diameter D	10λ
Frequency f(GHz)	1
Angular aperture $2\theta_0$(deg.)	10
Offset angle σ(deg.)	30



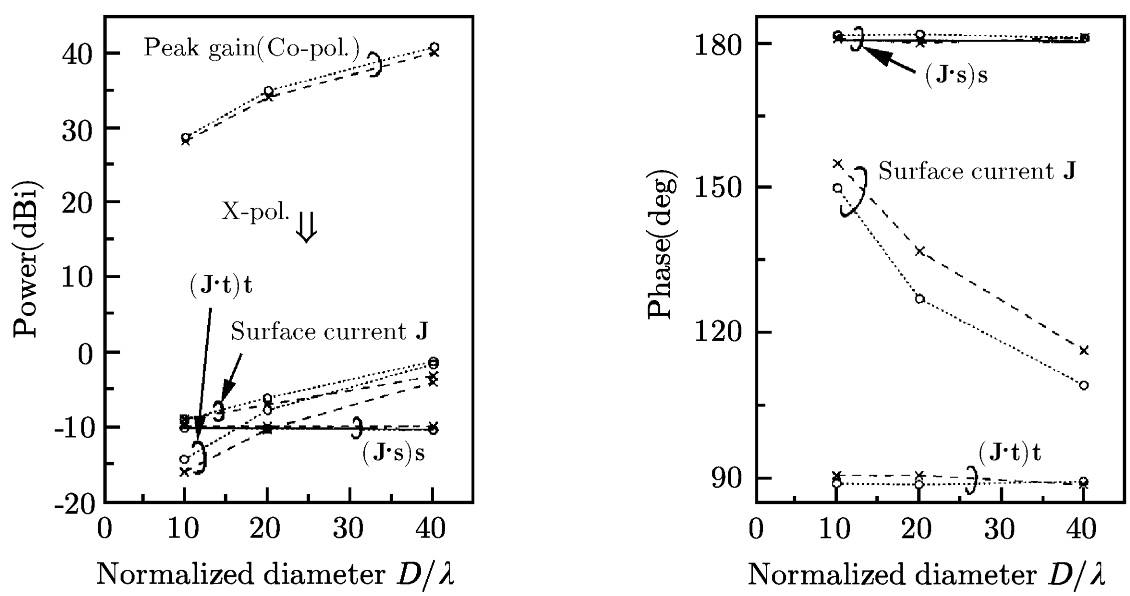
(a) Vertically polarized excitation. (b) Horizontally polarized excitation.

Figure 2: Radiation patterns of cross-polar field in plane of asymmetry ($\varphi_2 = 90°$) calculated by using the induced surface current components along the parabola-axis, where $t = \frac{D^2}{8\lambda}\frac{1}{r}$, D is the aperture diameter, λ is wavelength, and r is the observation distance.



(a) 1GHz. (b) 4GHz.

Figure 3: Comparisons between radiation patterns of cross-polar field in planes of symmetry ($\varphi_2 = 0°$) and asymmetry ($\varphi_2 = 90°$) calculated by the PO method and the presented beam modes analysis, where the distance r is infinity.



(a) Power (b) Phase

Figure 4: Peak value of the cross-polar field for vertically polarized excitations, where $\mathbf{s}(= \mathbf{u}_{z2})$ is the unit vector along the ray reflected by the reflector and $\mathbf{t}$ is the unit vector along the normal current to the vector $\mathbf{s}$.