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Optimum circular-coverage gain of multimode horns with specified peak cross-polarization and sidelobe levels

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1 Introduction

Dual mode horns [1] and choked horns [2] can be used as an antenna for circularly covering a wide area. However, it is difficult to control radiation property like directivity synthesis in reflector antennas, in which sidelobe level due to the sub-reflector was optimized based on quadratic programming approach [3]. In this paper, we demonstrate that an optimum circular-coverage gain of multimode horns with specified peak cross-polarization and sidelobe levels can be presented by using the quadratic programming approach. The gain of the horns is numerically evaluated by comparing with uniformly illuminated gain.

2 Formulas for quadratic programming

Since an aperture distribution of an axially symmetrical horn can be expanded by multiple TE_{1n} and TM_{1m} modes, its universal radiation pattern for circular polarization is obtained by linear combination of radiation pattern $f_{k,i}(u)$ $(k = 1, 2)$ of i-th mode with coefficient c_i normalized by an equal power, where $u = D/\lambda \sin\theta$, D is the aperture diameter and $k = 1$ or 2 denote co-polar or cross-polar components, respectively. The gain is also given by $G_k(u) = 4\pi|F_k(u)|^2/P_t \quad (k = 1, 2)$, where P_t is total power. Hence, for maximizing the gain $G_1(u)$ over a circular coverage $0 \le u \le u_e$ with specified sidelobe level $|R|$ and peak cross-polarization level $|X|$ (see Fig. 1), we now consider an optimization maximizing $G_1(u_e)$ subject to $F_1(u_e) = 1$ and

$$F_1(u) \ge 1 \ \ (0 \le u \le u_e) \qquad (1)$$

$$-R \le F_1(u) \le R \ \ (u_0 \le u \le u_s) \qquad (2)$$

$$-X \le F_2(u) \le X \ \ (0 \le u \le u_x) \qquad (3)$$

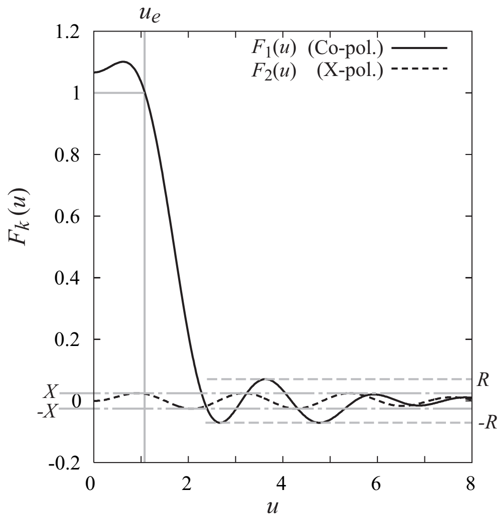

Fig. 1. Parameters for quadratic programming.

with

$$F_k(u) = \sum_i c_i f_{k,i}(u) \quad (k = 1, 2), \qquad G_1(u_e) = 4\pi/P_t, \qquad P_t = \sum_i c_i^2. \qquad (4)$$

Where u_e denotes the edge of the coverage, and $u_0 \le u \le u_s$ denotes the sidelobe region. When the aperture distribution of the conical horn is represented by superposition of cylindrical waveguide modes, $f_{k,i}(u)$ in the far-field region is given by the real function [4]. Therefore the real coefficient c_i of each mode is solved by minimizing the quadratic objective function P_t subject to the linear equality/inequality constraints based on the quadratic programming approach. The mode coefficient C_i for the multimode horns excited by unit power is finally determined by $C_i = c_i/\sqrt{P_t}$.

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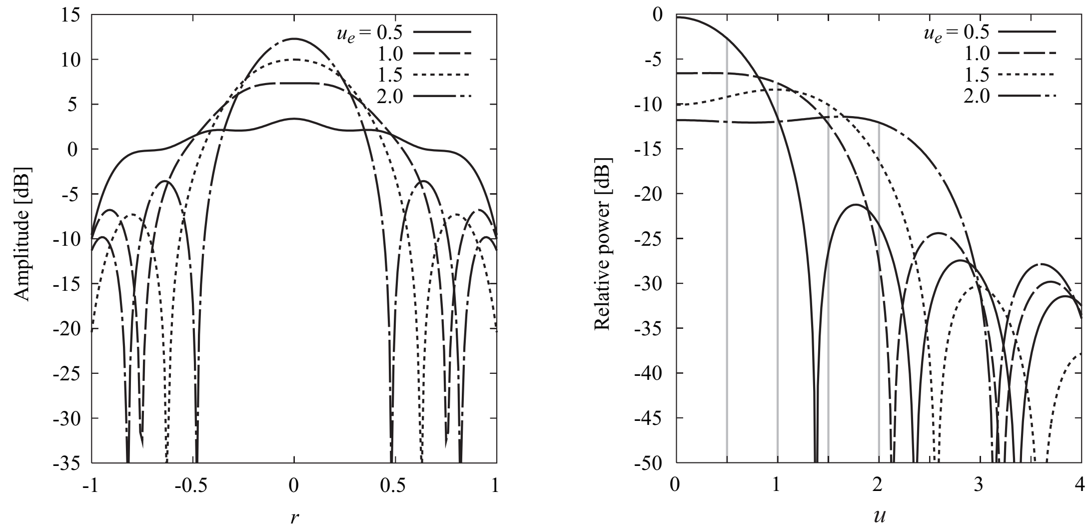
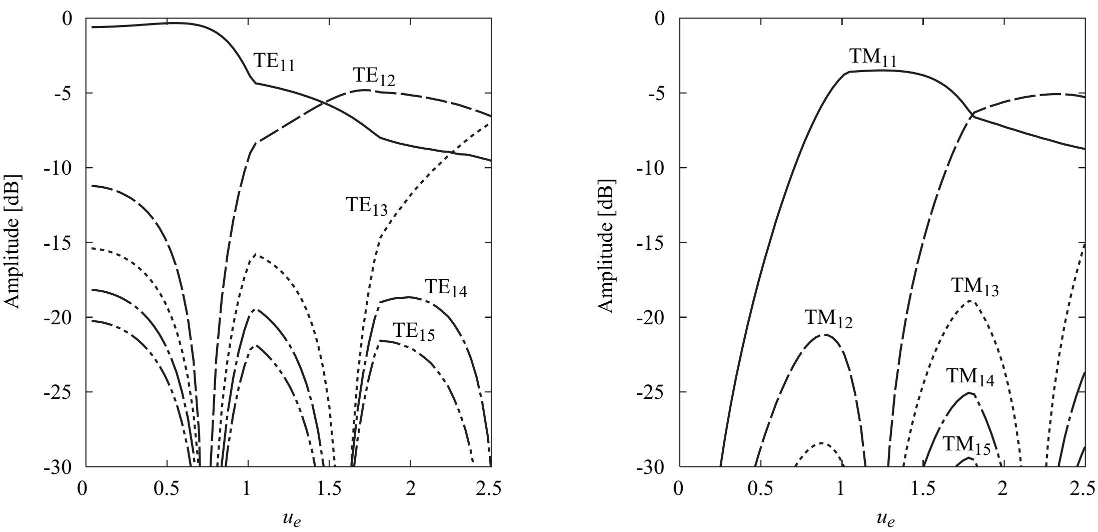
3 Numerical results and evaluation

Figure 2 (a) shows the aperture distributions of circularly polarized multimode horns with maximum gain over the circular area, where r denotes the coordinate in radius direction at the aperture. These distributions are illustrated for various parameters of $u_e (= D/\lambda \sin\theta_e)$, where θ_e denotes the direction at the edge of the circular coverage. Figure 2 (b) also shows various universal patterns radiated by the aperture distributions in Fig. 2 (a). These patterns are normalized by the peak gain due to the uniform aperture distribution. Figures 3 (a) and (b) show excitation coefficients of cylindrical TE_{1n} and TM_{1m} modes at the aperture of the horn as shown in Fig. 2, respectively. These results are obtained by the quadratic programming for each parameter u_e.



(a) Aperture distribution. (b) Universal radiation pattern.

Fig. 2. Field distribution of multimode horns for covering circular area.

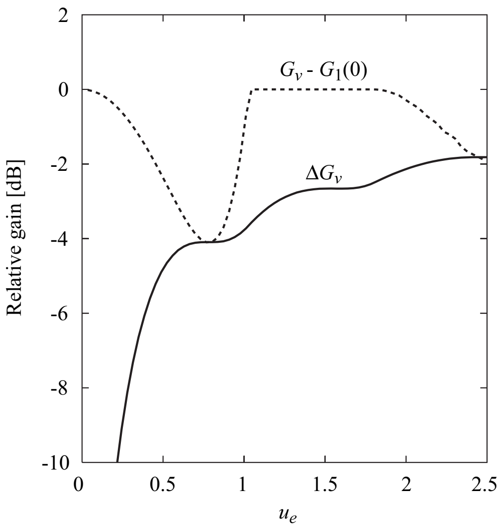


(a) TE_{1n} modes. (b) TM_{1m} modes.

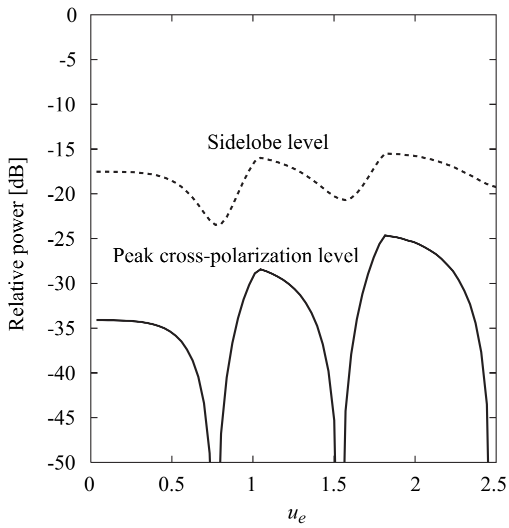
Fig. 3. Cylindrical mode coefficients of multimode horns for covering circular area.

Figure 4 (a) shows the relative gain ($\theta_e << 1$) at $u = u_e$ normalized by the gain at $u = 0$ and also shows ΔG_v to evaluate capability of the horns with modes in Fig. 3. $\Delta G_v = G_v - G_i$ [dB] is defined by an ideal gain G_i [dBi] when the coverage is uniformly illuminated, and the minimum gain $G_v = G_1(u_e)$

[dBi] over the circular coverage [5]. As shown in Fig. 4 (a), ΔG_v becomes higher as the diameter D/λ increases. However, in the horns with about $u_e < 0.5$, its aperture diameter is too small to obtain the desired beamwidth similar to a simple horn. On the other hand, Fig. 4 (b) shows the peak level of the cross-polarization component together with the first sidelobe level. It is found that these levels take periodically the local minima depending on the parameter u_e. The aperture diameter D/λ minimizing the cross polarization component is determined from null points $u_e \simeq 0.77, 1.53$ and 2.47. Especially, the first null point is produced by first two modes as shown in Fig. 3 (a), so it corresponds to dual-mode horns. On the contrary, the horns with $u_e \simeq 1.04$ and 1.81 have peak values of these levels. Thus, we have performed the optimization to suppress the peak cross-polarization level.



(a) Relative gain.



(b) Sidelobe and peak cross-polarization levels.

Fig. 4. Radiation characteristics of multimode horns optimized for covering circular area.

Figure 5 (a) shows the co- and cross-polarization components of the universal pattern excited by a circular polarization in the case of $u_e = 1.04$, and the specified cross-polarization level is -40 dB. It is confirmed from Fig. 5 (b) that rotationally symmetrical co-polar field is achieved by sufficiently suppressing the cross-polarization component. In this case, ΔG_v is -3.6 dB and the first sidelobe level is -16.9 dB. Furthermore, we have optimized the radiation patterns to achieve the low sidelobe level less than -30 dB. Figures 6 (a) and (b) show the aperture distribution and the universal pattern, respectively, including the comparison between the linear and circular polarization for $u_e = 1.53$. The ΔG_v is -2.7 dB, the first sidelobe level is -30 dB and also the cross-polarization level is less than -50 dB.

4 Conclusions

The optimum circular-coverage gain of the multimode horns with specified peak cross-polarization and sidelobe levels has been solved by the optimization based on the quadratic programming approach. The detail discussion for the capability to cover circular area will be presented at the talk.

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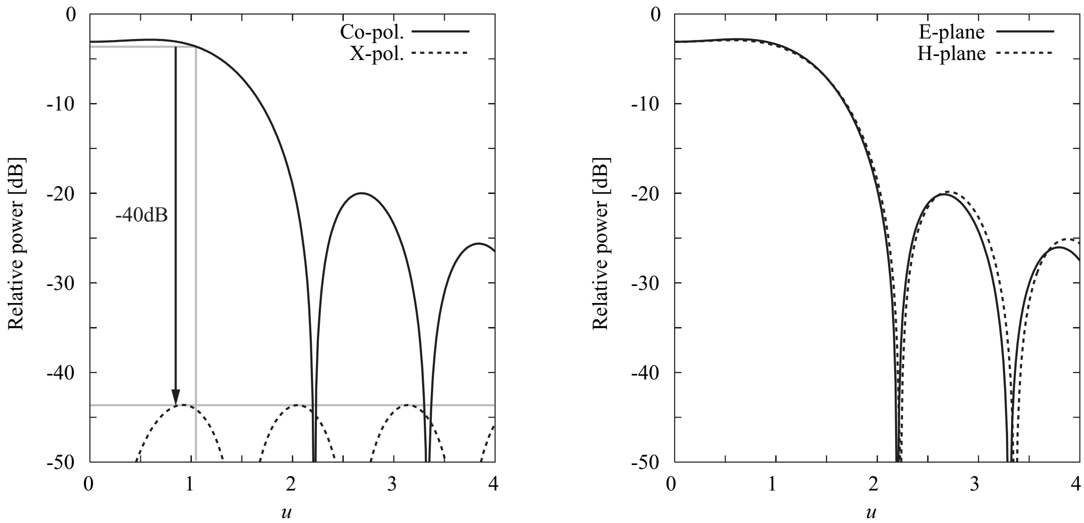
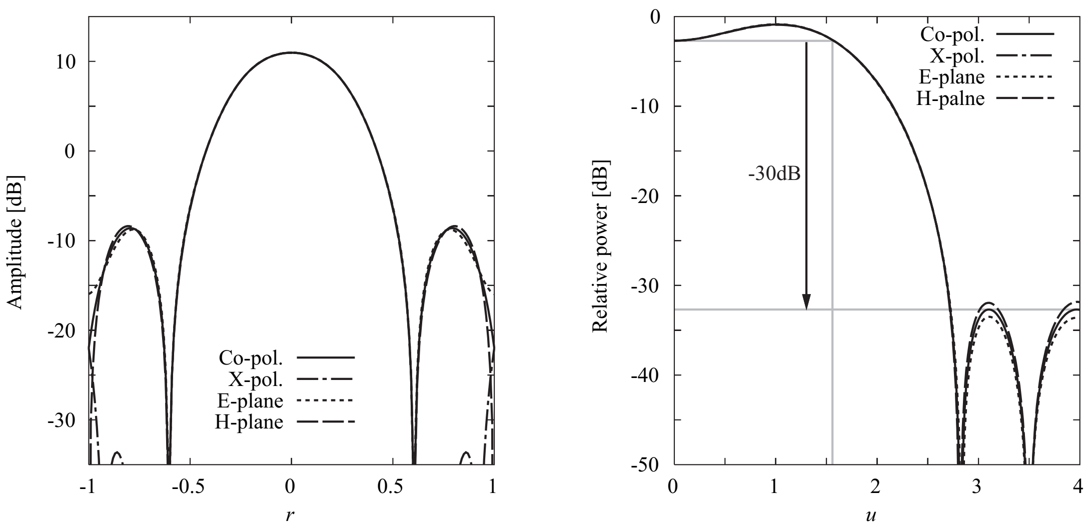


(a) Circular polarization. (b) Linear polarization.

Fig. 5. Unversal radiation pattern with low cross polarization less than -40 dB for $u_e = 1.04$.



(a) Aperture distribution. (b) Universal radiation pattern.

Fig. 6. Low cross-polarization horn with specified sidelobe level for $u_e = 1.53$.

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