Low-Sidelobe Reflector Synthesis and Design Using Resistive Surfaces

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Abstract—**A procedure is presented for determining the resistivity of a paraboloid's reflecting surface to obtain a desired sidelobe level. The only requirement is that the normalized aperture distribution due to the feed be greater than the corresponding normalized low sidelobe distribution at every point on the reflector (i.e., the reflection coefficient of the surface ≤ 1). In the synthesis procedure blockage is ignored and an ideal feed is assumed. In spite of this, computation of the secondary patterns of a resistively corrected antenna including the feed using the method of moments show that a -40 dB sidelobe level is achievable. In principal there is no limit in the sidelobe reduction for the field scattered from the reflector. In practice, blockage, feed illumination errors, errors in the surface resistivity and the feed backlobe will limit the sidelobe level.**

I. Introduction

Reflectors are the antennas of choice in many low sidelobe radar and communication systems because they are generally simpler and less expensive that phased arrays. However, low sidelobes (-30 to -40 dB relative to the main beam) are not always achieved without difficulty. In this paper a method of synthesizing low sidelobes based on geometrical optics (GO) is described. The GO field in the aperture is compared to the target low sidelobe distribution. The ratio of the two provides the surface reflection coefficient required to make the two distributions the same shape. This technique allows a low sidelobe secondary pattern without requiring a narrow beamwidth and hence large aperture feed antenna.

II. Synthesis Procedure

A problem commonly encountered in the design of low-sidelobe reflectors is that the feed illumination does not have the required shape for a low-sidelobe distribution such as a Taylor [1]. If the feed illumination (normalized to its peak value) is greater than the low-sidelobe distribution (normalized to its peak value) as illustrated in Fig. 1, then the two can be made equal by allowing some of the incident feed energy to pass through the reflector surface. A resistive film, or equivalently a mesh [2], is one way of achieving a transparent reflector surface. The amount of resistance required to give the feed illumination the same shape as the low sidelobe distribution is referred to as the resistive correction.

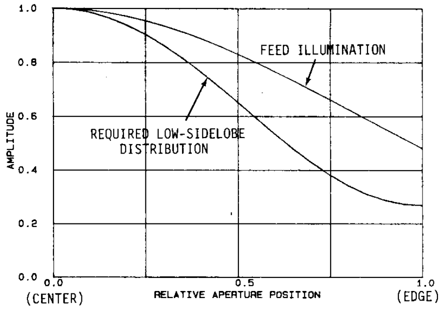

Fig. 1. Typical feed illumination compared to a low-sidelobe Taylor distribution.

The steps involved in determining the resistivity at each point on a surface of the paraboloidal reflector are described in [3]. The procedure ignores feed errors and blockage, and for simplicity, only rotationally symmetric reflectors will be considered, in particular a paraboloid. Consequently the resistive corrections will also be axially symmetric. Rotational symmetry is not a restriction inherent in the synthesis procedure.

The first step is to determine the aperture illumination due to the feed using geometrical optics. For a normalized feed pattern with a shape given by $F_n(\psi)$ and the reflector geometry defined in Fig. 2, the aperture distribution is

$$a(\rho) = F_n(\psi) f / r. \tag{1}$$

If the normalized low-sidelobe distribution is $a_o(\rho)$, then the reflection coefficient required to make them the same shape is

$$\Gamma(\rho) = a_o(\rho) / a(\rho) \tag{2}$$

and the surface resistivity having this reflection coefficient is [2]

$$R_s(\rho) = \frac{1}{2}\left(\frac{1}{\Gamma(\rho)} - 1\right). \tag{3}$$

III. Practical Design

Several important considerations are neglected in synthesizing the surface resistivity. For a nonidealized feed there will be some azimuthal asymmetry resulting in a phase and amplitude variation over the aperture. Feed blockage and scattering will also contribute to higher sidelobes. Other factors include the feed backlobe level, illumination of the ground and support structure through the surface and the ability to maintain tolerances on the resistivity.

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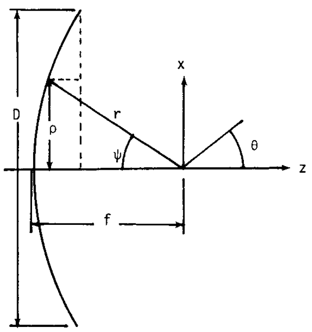

Fig. 2. Coordinate system and geometry for an axially symmetric paraboloid.

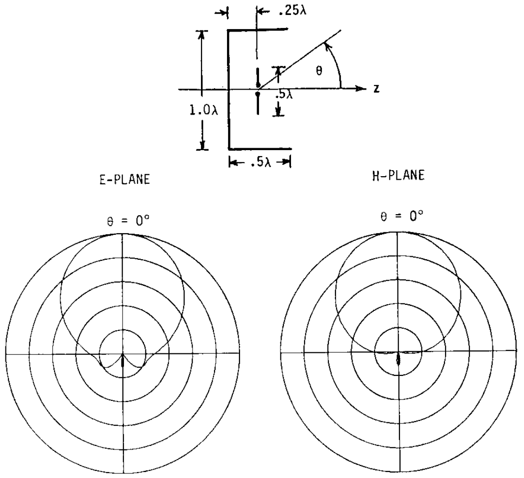

Fig. 3. The cavity-backed feed and its principal plane radiation patterns computed using MM. (Peak gain is 11.4 dBi and the scale is 5 dB/division.)

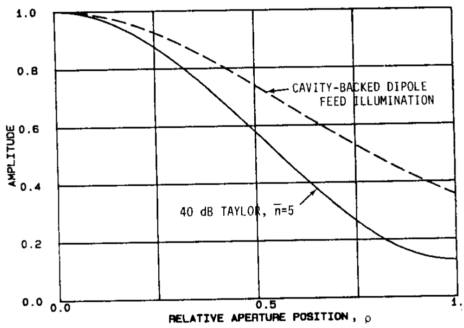

Fig. 4. Comparison of the cavity-backed dipole feed illumination and the target 40 dB Taylor distribution.

To assess the impact of these factors on the sidelobe level, the secondary radiation pattern of a resistively corrected reflector with a cavity-backed dipole feed was calculated using the method of moments. Current basis functions are defined on all of the antennas surfaces. The reflector and cavity basis functions are those for bodies of revolution developed by Mautz and Harrington [4]. The imperfect conductivity of the surface is accounted for by adding a load matrix to the method of moments (MM) impedance matrix as described in [5]. Triangular basis functions are used on the dipole and the thin wire approximation is assumed.

The calculated principal plane feed patterns are shown in Fig. 3 for a 0.5λ dipole in a 1λ cavity. The target sidelobe level of the secondary pattern is −40 dB relative to the peak gain. The *E*-plane pattern was used to calculate the resistive correction, since the beamwidth is slightly broader in this plane. A comparison of the feed illumination and a 40 dB Taylor, $\bar{n} = 5$ is shown in Fig. 4.

The far-field secondary radiation patterns ($D = 30$ λ, $f/D = 0.55$) for the uncorrected and corrected reflectors are given in Fig. 5 and 6, respectively. Since MM is used on all of the antenna surfaces, blocking, diffraction and feed and reflector interactions are included. The −40 dB target was met in the *E*-plane, but the *H*-plane sidelobes rise to −38.8 dB. Some *E*-plane beam broadening is also noticeable due to a 26° feed phase error in this plane. The cross-polarized field component remained below −50 dB.

The antenna gain performance is summarized in Table I. The additional loss in gain for the corrected reflector relative to the perfectly conducting reflector with the same feed is 1.7 dB. About 0.7 dB is due to the difference in aperture efficiency and the rest primarily due to increased radiation in the rear hemisphere. (This "transmission loss" can be estimated by integrating $\Gamma(\rho)$ over the reflector surface.) A negligible amount of ohmic loss occurs in the resistive material itself.

The success of the synthesis approach depends on the GO current being close to the actual current on the reflector. Fig. 7 is a comparison of the two for a 10λ paraboloid with an ideal feed having a $\cos^2\theta$ pattern. Both components of the actual current (computed using MM) generally oscillate about the GO values. (The singularity in the component tangential to the edge is missed due to the large segment size.) Based on the high-frequency assumptions of GO, it is expected that the agreement would be better for larger reflectors.

The effect of minor fluctuations in the resistivity was investigated using a piecewise linear approximation to the exact correction. Three linear segments were used to represent the resistivity profile from the center to the edge, resulting in a average error of approximately 5%. The current was assumed to be continuous across the surface. The change in the pattern was less than 1 dB at the −40 dB level. The tolerances required to maintain a given sidelobe level can be computed using the standard formulas for average sidelobe level versus RMS amplitude and phase error [6].

In principle ultra-low sidelobes can be achieved if the feed illumination errors and backlobe are small enough. Figs. 8 and 9 show that −50 dB sidelobes are possible for an ideal feed. In the first case the feed gain pattern is $\cos^{1.5}\theta$. This broad pattern requires high surface resistivity on the outer regions of the reflector because of the large difference between the distributions. This is the reason for the large lobe in the rear hemisphere ($90° < \theta < 180°$). In the second case a narrower feed pattern ($\cos^{2.8}\theta$) provides an edge taper that almost matches that of the low sidelobe distribution. The

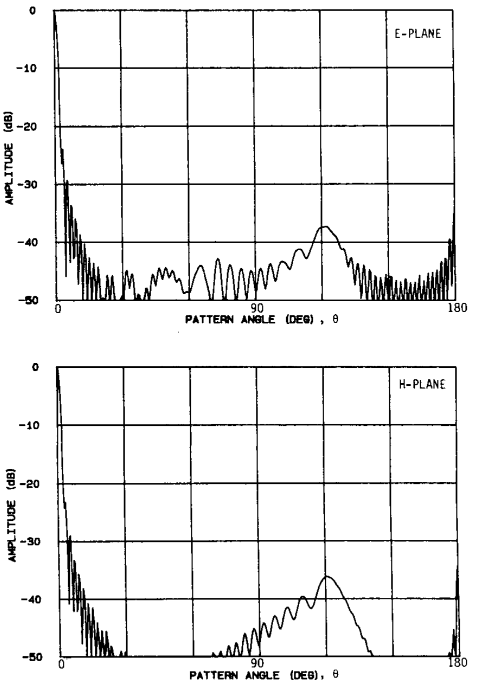

Fig. 5. Radiation patterns of a PEC reflector with a cavity-backed dipole feed computed using MM. ($D = 30\ \lambda$, $f/D = 0.55$.)

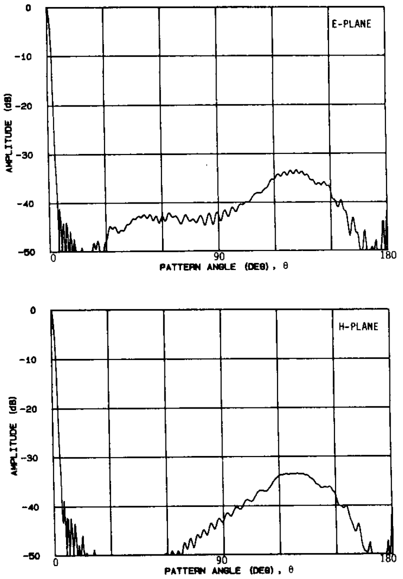

Fig. 6. Radiation patterns of a resistively corrected reflector with a cavity-backed dipole feed computed using MM. ($D = 30\ \lambda$, $f/D = 0.55$.)

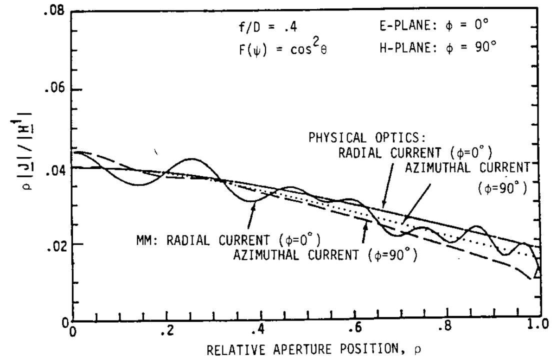

Fig. 7. Surface current induced on a 10λ paraboloidal reflector.

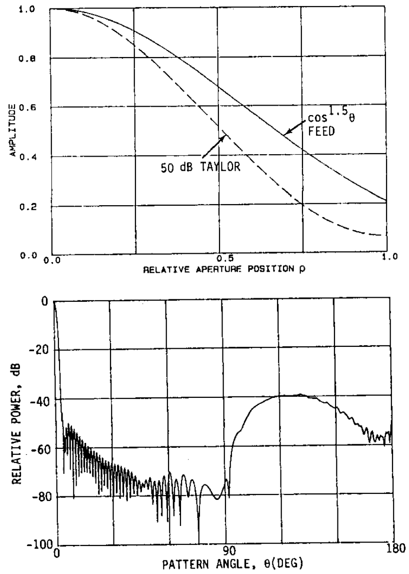

Fig. 8. A −50 dB sidelobe design based on a feed that provides a moderate edge taper. ($D = 40\ \lambda$, $f/D = 0.4$.)

TABLE I

Comparison of Estimated Gain with that Computed Using Pattern Integration Based on the MM Current

	Uncorrected (PEC)	Resistively Corrected
Directivity of a Uniformly Illuminated Aperture	39.5 dB	39.5 dB
Spillover Loss	−1.6	−1.6
Aperture Efficiency	−0.4	−1.1
Transmission Loss	.0	−0.9
Estimated Gain (Total)	37.5	35.9
Computed Using Pattern Integration	37.7	36.0

secondary radiation patterns of the two are nearly identical in the forward hemisphere, but the spillover and transmission lobe in the rear hemisphere are smaller in the second case. For an ideal feed it appears that the second design has an advantage. However, the feed size necessary for the edge level in Fig. 9 is substantially larger than that for Fig. 8, and consequently the effects of blockage will be more severe.

IV. Summary

A method of determining the surface resistivity of a reflector to obtain low sidelobes has been described. In prac-

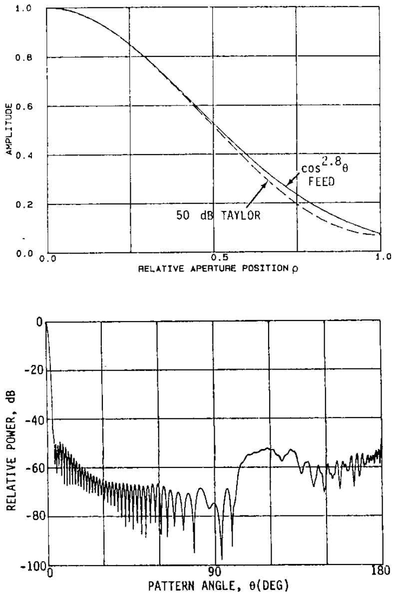

Fig. 9. A −50 dB sidelobe design based on a feed that provides a strong edge taper. ($D = 40\ \lambda$, $f/D = 0.4$.)

tice, the best way to vary the resistivity is to use a film. These films are commercially available; however, shapes more complicated that exponential or quadratic tapers have not been reported. Films are lightweight and can be layed out on a low-density foam or honeycomb that has a parabolic or other specified shape. Since the resistivities are usually less that 200 Ω/square, these support materials should not significantly change the antenna's performance.

The example presented here shows that −40 dB levels can be achieved even when nonidealized feeds and blockage are included. The biggest limitation for small reflectors appears to be the feed backlobe. For sidelobe levels below −40 dB other errors such as feed asymmetry, aperture phase, and amplitude errors and blockage will surely become significant.

ACKNOWLEDGMENT

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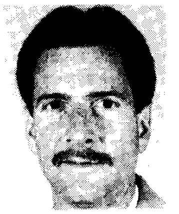

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