[4] Y. Kang and D. M. Pozar, "Correction of error in reduced sidelobe synthesis due to mutual coupling," *IEEE Trans. Antennas Propagat.*, vol. 33, pp 1025–1028, Sept. 1985.

[5] W. L. Stutzman and G. A. Thiele, *Antenna Theory and Design.* New York: John Wiley, 1981, pp 154–160.

[6] R. W. Lampe, "Design formulas for an asymmetric coplanar strip folded dipole," *IEEE Trans. Antennas Propagat.*, vol. 33, pp 1028–1030, Sept. 1985.

[7] R.F. Harrington, *Field computation by Moment Methods.* New York: Macmillan, 1968, ch. 4.

[8] H. K. Schuman, D. R. Pflug, and L. D. Thompson, "Infinite planar arrays of arbitrarily bent thin wire radiators," *IEEE Trans. Antennas Propagat.*, vol. 32, pp 364–377, Apr. 1984.

[9] K.M. Lee and R.S. Chu, "Analysis of mutual coupling between a finite phased array of dipoles and its feed network," *IEEE Trans. on Antennas Propagat.*, vol. 36, pp 1681–1699, Dec. 1988.

Small Efficient Axially Symmetric Dual Reflector Antennas

David C. Jenn, Nissan Vered, and Manuel Ordonez

Abstract—**Two efficient small dual reflector antenna designs are analyzed using the method of moments. One is based on the standard Cassegrain system and the other is a displaced axis design. Both incorporate a low-blockage feed consisting of a dipole radiating in the presence of parasitic elements. In the first case, efficiencies greater than 55% were obtained for 20 wavelength main reflectors; in the second, an efficiency greater than 67% was achieved for a 22-wavelength main reflector.**

I. Introduction

The advantages and disadvantages of dual reflecting systems are well known. They have shorter focal lengths than corresponding single-surface reflectors, but suffer performance degradation due to interference from the feed and subreflector. For axially symmetric reflectors, the subdish must be small enough to avoid excessive aperture blocking, yet large enough to be an efficient reflector. This usually requires that the main reflector diameter be greater than 50 wavelengths for classical Cassegrain and Gregorian configurations. However, several recent applications, such as direct broadcast satellites and passive sensors, have been cause to reexamine the capabilities of symmetric dual-reflector antennas with main-dish diameters less than 50 wavelengths, and perhaps as small as 20 wavelengths. Although suited for such applications because they are compact, lightweight, and simple, traditional designs have unacceptably low efficiencies in the range of 30–40%.

The analysis of reflectors of this size is more complicated than that for electrically large antennas. When the subreflector is small, its effective blocking area may be significantly different than its physical area, and the null-field hypothesis (i.e., optical shadowing) is not valid. In addition, the two reflectors and the feed are closely spaced, and therefore interactions are important. A further complication will result when a directive low-spillover feed is used. It may have an aperture size comparable to the subreflector's, and thus the subreflector may be in the near field of the feed. Consequently, many of the far-field and high-frequency approximations yield results that are significantly incorrect. The method of moments (MoM) is ideal for evaluating the performance of small reflectors. When basis functions are defined on all of the antenna surfaces, including the feed, then all of the important interactions mentioned above will be included. Such a solution has been implemented for dual reflector antennas with components consisting of surfaces of revolution and wires [1]. All of the data presented here are obtained using the method of moments.

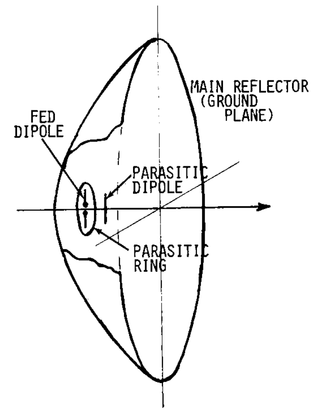
Manuscript received June 23, 1992; revised September 23, 1992.

D. C. Jenn is with the Naval Postgraduate School, Code EC/Jn, Monterey, CA 93943.

N. Vered is with the Israeli Navy.

M. Ordonez is with the U.S. Navy.

IEEE Log No. 9205481.



FED DIPOLE LENGTH=.5λ
FED DIPOLE HEIGHT ABOVE PARABOLOID=.25λ
PARASITIC DIPOLE LENGTH=.44λ
SEPARATION OF DIPOLES=.25λ
RING DIAMETER=1.65λ
RING DISTANCE IN FRONT OF FED DIPOLE=.2λ

Fig. 1. Low-blockage feed which uses the main reflector as a ground plane.

For dual reflectors there are two conflicting design requirements imposed on the feed that are increasingly difficult to satisfy as the electrical dimensions are reduced. First, the feed pattern must be as directive as possible to reduce subreflector spillover. Secondly, the feed size must be kept small to minimize the blocking of rays from the subreflector to the main reflector. The first implies a large feed aperture, while the second requires a small aperture. In this paper, two approaches to improving the efficiency of small symmetric dual reflectors are examined. One is to optimize the geometry and feed characteristics of the standard Cassegrain configuration. This primarily consists of choosing a low-blockage feed with high directivity and to tune the dimensions of the geometry to maximize gain. Using this approach, a maximum efficiency of 57% was achieved for a main reflector diameter of 20 wavelengths. A second approach is to use a displaced axis configuration as described in [2]. Based on the principles of ray optics, blockage is completely eliminated with such a design. Computed efficiencies of 67% and greater were obtained for a displaced axis design with a 22-wavelength main-reflector diameter.

II. Low-Blockage Feed Design

Cavity-backed dipoles are commonly used to feed reflector antennas. The cavity back serves as a ground plane for the dipole, and the sidewalls equalize the feed E- and H-plane beamwidths. For shallow cavities the improvement in beam symmetry is primarily due to the rim. The same effect is achieved when the entire sidewall is replaced with a parasitic ring at the same location as the rim [3].

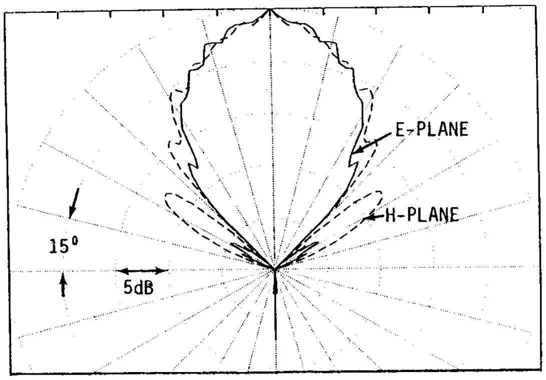


Fig. 2. Radiation patterns for the feed of Fig. 1.

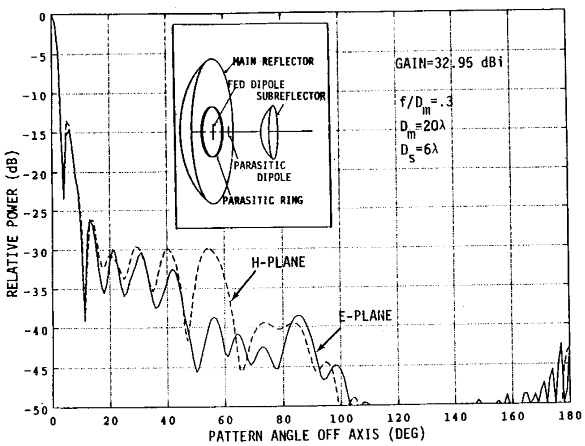


Fig. 3. Radiation patterns of a Cassegrain using the feed of Fig. 1.

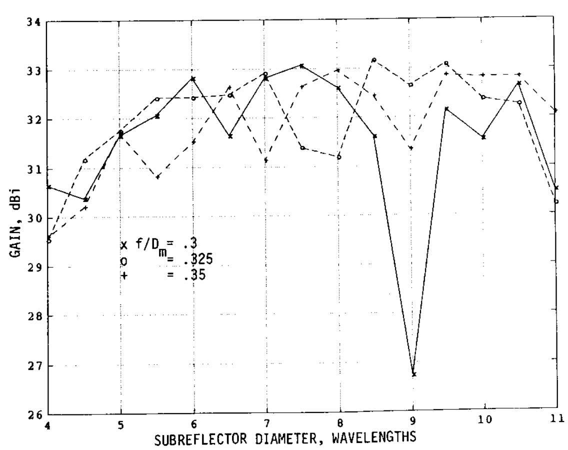


Fig. 4. Gain as a function of subreflector diameter. The eccentricity is adjusted to maintain a focus 0.25λ from the main reflector and $D_m = 20\lambda$.

A further increase in directivity occurs when a parasitic director is placed approximately 0.25λ in front of the fed dipole [4]. A feed comprised of the above components is shown in Fig. 1, in which the cavity ground plane has been replaced by a parabolic main reflector. The advantages of this design include:

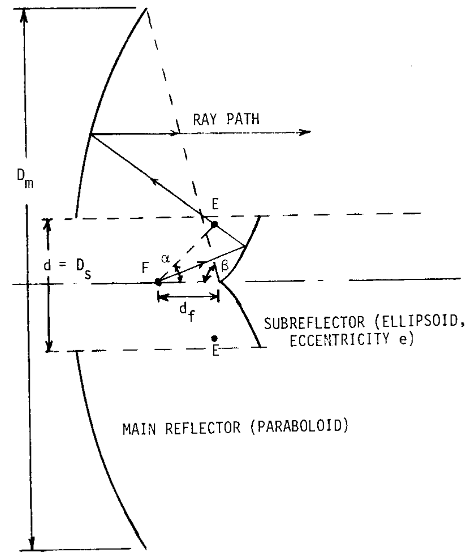


Fig. 5. Displaced-axis reflector geometry.

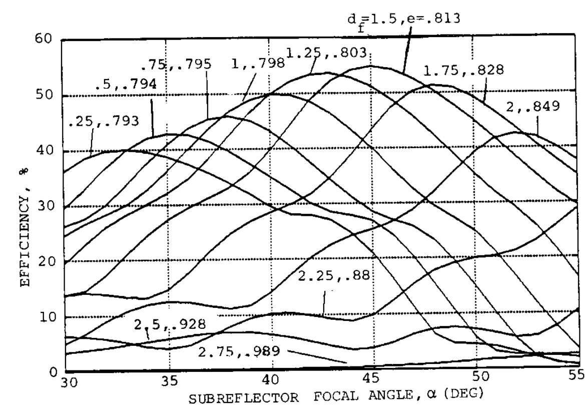


Fig. 6. Efficiency of various displaced-axis feed designs with an ideal $\cos^2\theta$ feed pattern. The parameters are eccentricity e and feed/subreflector spacing d_f. The main reflector diameter is 22λ.

1. a directive, symmetric feed pattern;
2. an accessible feed location;
3. the feed surface area is minimized (low blockage);
4. the feed/subreflector distance is maximized.

The E- and H-plane feed patterns computed using the MoM are shown in Fig. 2. The feed dimensions are:

- fed dipole length= 0.5λ;
- fed dipole height above paraboloid= 0.25λ;
- parasitic dipole length= 0.44λ;
- separation of dipoles= 0.25λ;
- ring diameter= 1.65λ;
- ring distance in front of fed dipole= 0.2λ.

The radiation patterns of a Cassegrain antenna with the feed incorporated are shown in Fig. 3. The MoM computer code is based on the Mautz and Harrington formulation for bodies of revolution, with appropriate modifications to include wires. The details of the solution are described in [5]. The efficiency is determined by computing the gain by integrating the radiation pattern obtained from the MoM currents, and then comparing the result to $4\pi A/\lambda^2$.

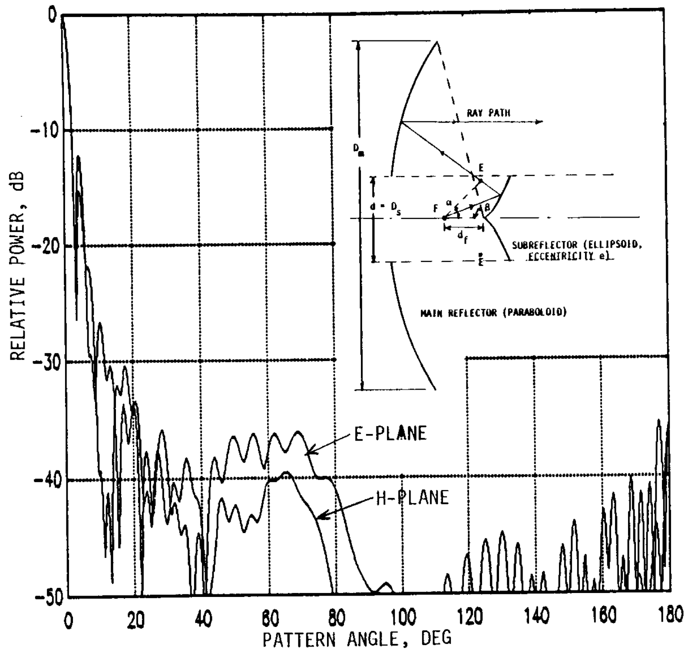


Fig. 7. Radiation patterns of a displaced-axis antenna with a low-blockage feed. A disc of diameter d is used as a ground plane for the dipoles and ring, and the feed geometry is the same as Fig. 1.

The efficiency as a function of subreflector diameter is shown in Fig. 4. The curve illustrates how the hyperboloid location can be used to "tune" the antenna, i.e., cause the interactions between the antenna structures to add constructively, rather than destructively, in the far field. In all cases, the main reflector diameter is $D_m = 20\lambda$, $f/D_m = 0.4$, and the focus is fixed at 0.25λ in front of the main reflector. For each D_s specified, the eccentricity of the subreflector is chosen so that the distance between the internal and external focii is $f - 0.25\lambda$. The efficiency of this particular design is 50%, but values 5% higher were achieved by moving the ring forward of the fed dipole about 0.2λ. A further slight increase occurred when two more parasitic dipoles were placed 0.25λ on each side of the fed dipole in the H-plane.

III. Displaced-Axis Dual Reflectors

Aperture blocking is eliminated using the displaced axis dual reflector configuration shown in Fig. 5 [2]. The generating curve of the main reflector is a displaced parabola, and that of the subreflector is a section of an ellipse. The subreflector focal angle is α, and the main reflector edge angle is β. Fig. 6 shows the computed efficiency of a 22λ antenna with an ideal $\cos^2\theta$ feed pattern. When the feed directivity is changed, the shapes of the curves remain essentially the same, but slide up or down the efficiency axis by an amount determined by the spillover (assuming a relatively constant amplitude illumination). Thus, the curves serve to identify the optimum combination of geometric design parameters.

The principal plane radiation patterns of a displaced axis antenna with a feed similar to the one described in Section II are shown in Fig. 7 for the optimum values of $\alpha = 45°$ and $\beta = 105°$. Because the feed point is more than 0.25λ in front of the main reflector, a circular disc is added to provide a ground plane for the dipoles and ring. The maximum computed gain was 67%, but the effect of small displacements in the parasitic element locations on the gain was not thoroughly investigated [6].

IV. Conclusions

A mechanically simple low-blockage feed for small dual-reflector antennas has been presented. When used in a standard Cassegrain configuration, efficiencies of more than 55% were computed for main-reflector diameters of 20λ. This appears to be about the maximum possible for traditional dual-reflector designs of this size [7]. An improvement in efficiency can be obtained by using a displaced-axis geometry that eliminates geometrical blocking. For a 22λ reflector of this type, an efficiency of 67% was obtained.

References

[1] D. C. Jenn and E. E. Barber, "Method of moments analysis of cavity-backed wire antennas," in Applied Computational Electromagnetics Symp., Mar. 1991, p. 432.

[2] A. C. Leifer and W. Rotman, "GRASP: An improved displaced-axis, dual-reflector antenna design for EHF applications," in 1986 AP-S Int. Symp. Digest, 1986, p. 507.

[3] P. S. Kildal and S. A. Skyttemyr, "Dipole disk antenna with beam-forming ring," *IEEE Trans. Antennas Propagat.*, vol. 30, no. 4, p. 529, July 1982.

[4] M. H. Hong, *et al.*, "Radiation fields of open-cavity radiators and a backfire antenna," *IEEE Trans. Antennas Propagat.*, vol. 18, no. 6, p. 813, Nov. 1970.

[5] J. F. Shaeffer and L. N. Medgyesi-Mitschang, "Radiation from wire antennas attached to bodies of revolution: The junction problem," *IEEE Trans. Antennas Propagat.*, vol. AP-29, no. 3, p. 479, May 1981.

[6] N. Vered, "Method of moments analysis of displaced-axis dual reflector antennas," M.S. Thesis, Naval Postgraduate School, Mar. 1992.

[7] Y. C. Chang, "A compact EHF/SHF dual-band reflector antenna," in 1989 AP-S Int. Symp. Digest, 1989, p. 1602.