An Efficient Finite Difference Time Domain (FDTD) Technique For Modeling a Reflector Antenna System with Partial Circular Symmetry

Dean Arakaki, Wenhua Yu, and Raj Mittra
Electromagnetic Communication Research Laboratory
The Pennsylvania State University
University Park, PA 16802

1. ABSTRACT

This paper presents an efficient method for solving a large body scattering problem *viz.*, a paraboloidal reflector antenna system with only partial circular symmetry. The asymmetry in the system is introduced by two factors, *viz.*, the microstrip feed and an inhomogeneous radome. The paper presents a novel approach, based on the Reciprocity Principle and the "equivalent aperture" theory, to handle the asymmetry problem and still take advantage of the circular symmetry of the large paraboloid of revolution to render the problem manageable.

2. INTRODUCTION

This paper uses the reciprocity approach, in conjunction with the "equivalent aperture" principle, to compute the radiation pattern of a large body with partial circular-symmetry. The solution of the circularly-symmetric portion of the problem is based on a 2½-D FDTD algorithm designed to handle Maxwell's equations for rotationally-symmetric geometries [1]. In the present problem, the lack of azimuthal symmetry is further exacerbated, over that introduced by the 4-element feed array system, by the azimuthal asymmetry of the inhomogeneous scatterer, *viz.*, a radome with a skirt that encloses the reflector antenna system. This additional complexity is dealt with by using an "equivalent aperture" field approach. It utilizes a 2½-D FDTD algorithm as a first step, then employs a 3-D FDTD algorithm to track the propagation of this field impinging upon the feed array. The Reciprocity Theorem is then invoked as in [2] to determine the radiation pattern of the reflector antenna system.

3. APPROACH

We consider the reflector antenna system, shown in Fig. 1, to outline the procedure.

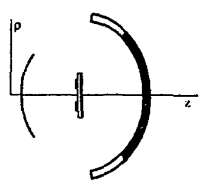

Fig. 1a Reflector Antenna System

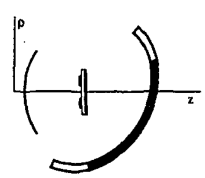

Fig. 1b Reflector Antenna System, Tilted

In Fig. 1, the structures to the left, middle, and right are the main reflector (paraboloid), microstrip feed array, and the radome structure (composed of two dissimilar materials), respectively. When the reflector antenna together with its feed system points at boresight (Fig. 1a), the reflector as well as the radome structures are both circularly-symmetric with respect to the *z*-axis, but the feed array perturbs this symmetry. When the reflector is tilted at an angle with respect to the axis of the radome, as in Fig. 1b, this introduces an additional asymmetry in the geometry. To address this problem, we first project the hybrid field pattern onto a plane perpendicular to the radome structure. This is illustrated in Fig. 2, in which the darker region denotes where the incident fields impinge upon a higher permittivity material (radome), while the lighter region indicates the corresponding region illuminated by the fields that are incident on a lower permittivity material (skirt). Since the radome structure is circularly-symmetric about the *z*-axis, it is sufficient to analyze the system with respect to one tilt angle, chosen to be in the elevation (*yz*) plane. A circular region is formed when the reflector system is aligned with the radome structure (normal incidence, top drawing), while an elliptical pattern results when the reflector system is tilted relative to the radome structure (bottom drawing) by an angle θ.

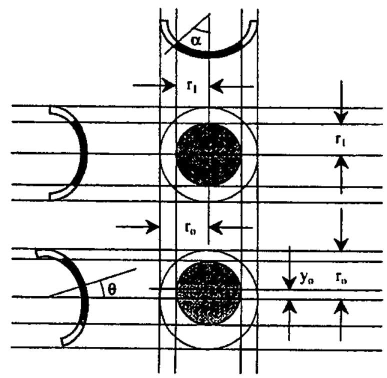

Fig. 2 Tilted Radome and Projected Field Distributions

The center of the ellipse (or circle, in the normal case) relative to the center of the pattern, is determined by

$$y_o = r_o \sin\theta \cos\alpha \tag{1}$$

which is the center point between the top and bottom edges of where the radome material begins. The angle α is the angular displacement of the radome material and θ is the tilt angle of the radome structure with respect to the reflector system. Since the system is tilted in the elevation plane only, the major axis of the ellipse remains fixed at a length of r_I (see Fig. 2). The minor axis is calculated by the formula $b = r_I \cos\theta$. With all of the parameters known, the equation of the ellipse can then be written

$$\left(\frac{x}{a}\right)^2 + \left(\frac{y - y_o}{b}\right)^2 = 1 \tag{2}$$

in which $a = r_I$.

Once the distribution has been determined in the manner described above, it must be projected onto the radiating aperture of the reflector system. An example is shown in Fig. 3.

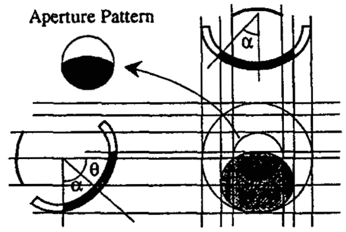

Fig. 3 Projection of distribution onto Radiating Aperture

The upper left drawing in Fig. 3 shows the resulting aperture distribution projected onto the main reflector. The area of this aperture field distribution must then be adjusted based on the distance separating the aperture and the main reflector (full-size if the aperture is located at the main reflector and zero area if located at the focal point of the main reflector). The next step is to use this distribution as an input source for a 3-D FDTD simulation to propagate the fields onto the surface of the feed dielectric substrate. These fields are subsequently used to calculate the far-zone fields by invoking the reciprocity principle.

4. NUMERICAL RESULTS

To illustrate the procedure, we calculate the field distribution in the focal region of a paraboloidal reflector antenna. We calculate the aperture fields for the radome in two steps; first for the higher permittivity material, and then for the lower one. For this analysis, the tilt angle of the radome with respect to the reflector system was 30°. The elliptical pattern is then projected onto the receiving aperture region.

As mentioned earlier, these aperture patterns were subsequently used as sources for the 3-D FDTD simulation to determine the fields on the surface of the feed dielectric. In accordance with the reciprocity procedure, a dot product of these fields and the surface currents on the four patches was evaluated to compute the far-zone electric field. Three different cases for the surface currents were considered, along with three different reflector system tilt angles. Table 1 shows the results.

Table 1 Far-Zone Electric Field Calculations

Gain (dB) relative to 0 degree tilt angle:						
Tilt Angle	Azim Diff		Elev Diff		Sum	
(degrees)	Co-pol	Cross-pol	Co-pol	Cross-pol	Co-pol	Cross-pol
30	0.208563	-0.58409	1.301668	-3.97905	0.003332	0.027922
40	-0.64326	-0.93849	-2.91202	-9.49989	0.051324	-0.05318
50	-3.14955	-0.56464	-15.6718	1.011048	-0.04897	-0.07703

As indicated in Table 1, the sum pattern for the surface currents shows very little change in the far-zone field magnitude for increasing tilt angles. This is due to the sum pattern having a peak in the normal direction. Therefore, a slight difference in the incident electric fields among the patches has almost no effect.

For the azimuthal difference pattern, a null exists along the *y*-axis (see Fig. 4). The tilt angle is in the *yz*-plane with respect to the *z*-axis (out of Fig. 4). As a result, this pattern is sensitive to differences in fields incident on patches 1 and 4 *vs.* those on patches 2 and 3. Since the aperture fields remain approximately the same for all tilt angles for patches 1 and 2, and also for patches 3 and 4, this case also shows only small changes in the far-zone electric fields.

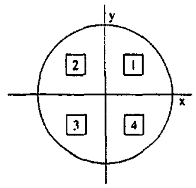

Fig. 4 Patches on Feed Dielectric Surface

For the elevation difference pattern, a null exists along the *x*-axis. Therefore, this pattern is sensitive to differences in the fields incident on patches 1 *vs.* 4 and 2 *vs.* 3. Since the tilt angle is in the *yz*-plane, slightly different fields are intercepted by these pairs of patches due to the different radome materials. The resultant far-zone fields thus vary considerably as the tilt angle increases, as shown in Table 1.

5. CONCLUSIONS

This paper has presented an efficient method for determining radiation patterns for an electrically large reflector antenna system with a microstrip patch feed and a dielectric radome/skirt combination that has only partial circular-symmetry. The paper shows how we can still take advantage of the existing symmetry of a large portion of the structure to reduce the CPU time and memory requirements significantly. The Reciprocity Principle described in [2] is combined with the "equivalent aperture" approach to compute the radiation pattern of the reflector antenna system. Numerical results for various current distributions were presented indicating the sensitivity of the system to tilt angles of the reflector system with respect to the radome.

REFERENCES

[1] Y. Chen and R. Mittra, "Finite-Difference Time-Domain Algorithm for Solving Maxwell's Equations in Rotationally Symmetric Geometries," *IEEE Trans. Microwave Theory Tech.*, vol. 44, pp. 832-839, June 1996.

[2] R. Mittra, S. Dey, S. Chakravarty, and N. V. Veremey, "Reciprocity Approach to Pattern Computation of a Microstrip Antenna Operating in a Complex Environment," *IEEE AP-S International Symposium*, Atlanta, 1998, pp. 1138-1141.