THE ANALYSIS AND DESIGN OF A BROADBAND CONSTANT BEAM WIDTH REFLECTOR DISH ANTENNA

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Abstract—This paper presents the design and analysis of a broadband constant beam width reflector dish antenna for use with a multi-frequency scatterometer. The scatterometer physical and electrical antenna requirements are very strict. The far-field analysis used in the design is presented. The reflector shape is discussed including a optimization technique for the reflector shape. The simulated antenna patterns before and after optimizing the reflector shape are included.

Introduction

In order to further remote sensing research, a multi-frequency scatterometer will be developed through the Brigham Young University Microwave Earth Remote Sensing Laboratory (MERS). This instrument will be useful in making backscatter measurements from the ocean surface at frequencies between 2 and 20 GHz. The data set collected by this instrument will be useful in wind estimation applications. For example, the data could be used to improve the algorithms which are currently applied to satellite scatterometer data for estimating wind speed and direction.

The antenna design which is presented in this paper is an elliptically shaped reflector antenna. Figure 1 shows a three dimensional plot for different views of the basic antenna structure. The reflector will be fed with a commercially available broad beam, broad band antenna. This paper will present the methods of analysis which were used in the design of the antenna for this scatterometer.

Antenna Specifications

The reflector antenna must meet certain electrical and physical specifications in order to satisfy the needs of the scatterometer. From an electrical standpoint, the antenna beam must be as narrow as possible in range (5° is feasible) and 60° in azimuth. For the data collected by the scatterometer to be useful, the beam should maintain a relatively constant shape and size over the entire frequency band. This ensures that the backscatter measurement made by the scatterometer is from the same portion of ocean for all frequencies. The antenna will also need to operate with dual polarizations. This requirement, however, only impacts the choice of feed for the dish and does not effect the dish design.

The physical requirements of the antenna are dictated primarily by structural concerns. Due to the nature of the scatterometer, the antenna must be able to withstand high winds without flexing or breaking. Thus, the antenna is limited to 1 meter in its maximum dimension. Due to the required radiation pattern, the antenna will tend to have one physical dimension significantly smaller than the other. However, structural considerations dictate that this dimension be a minimum of 25 cm, resulting in a 4:1 aspect ratio. Also for structural stability, the feed antenna cannot be more than 60 cm from the center of the dish.

Design Strategy

Far Field Analysis

This section will present two different analysis tools which were developed to facilitate the design of the reflector antenna. Both analysis methods require integration of the currents on the dish surface to produce a far field pattern. The physical optics method, for calculation of the currents on the reflector surface, will be described first and then the Ludwig

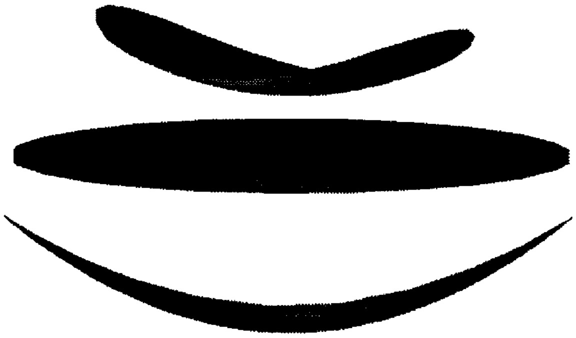

Figure 1: Reflector antenna off angle, top, and side views

method and Jacobi-Bessel expansion method for calculating the far-field patterns will be described.

Physical Optics

This section presents the physical optics method for computing currents on the reflector dish. The currents on an infinite ground plane with an incident plane wave are given by

$$\vec{J} = 2\hat{n} \times \vec{H} \tag{1}$$

where $\hat{n}$ is the normal vector of the ground plane and $\vec{H}$ describes the incident wave. When this method of calculating the surface currents is applied to a surface which is not flat or finite in extent, the currents are only an approximation and are not entirely accurate. In order for the approximation to be good, the radius of curvature of the surface must be large with respect to the wavelength. Even with this constraint the far-field pattern that is generated using the PO currents is only be valid for the main beam and first several sidelobes [Franceschetti and Mohsen, 1986]. This is due to the diffraction effects which are not entirely included in the PO approximation. A second requirement when using the PO approximation is that the dish be in the far-field of the feed antenna such that the incident radiation behaves like a plane wave when reflecting off the dish surface. The currents on the dish surface can be calculated using the equation given above if these constraints are satisfied.

Numerical Integration Methods

Two different techniques were used to calculate the far-field radiation pattern for a specific dish geometry. The first which will be presented is the Ludwig method and the second is the Jacobi-Bessel expansion method. Both of these methods involve computing a numerical solution to the radiation integral given as

$$\vec{E}(\vec{r}) = 2jw\mu\frac{e^{-jkr}}{4\pi r}\left(\bar{\bar{\mathrm{I}}} - \hat{r}\hat{r}\right)\cdot\vec{T}(\theta,\phi) \tag{2}$$

$$\vec{T}(\theta,\phi) = \int_{\Sigma'} \vec{J}(\vec{r}')\, e^{jk\hat{r}\cdot\vec{r}'} d\Sigma' \tag{3}$$

where $\bar{\bar{\mathrm{I}}}$ is the unit dyad and Σ' represents the reflector surface. The $\vec{r}'$ vector goes from the origin to a point on the reflector surface. The vector $\hat{r}$ points in the direction of the observation point and introduces the θ and ϕ dependence into the equation. Our main concern is the solution of the integral in equation 3. Because it must be evaluated for every observation point, an efficient integration scheme must be utilized to avoid excessive computational costs.

The Ludwig method, described in [Ludwig, 1968], approximates the exponent, $k\hat{r}\cdot\vec{r}'$, and $\vec{J}(\vec{r}')$ shown in equation 3 as linear functions. This allows the integral to be broken into pieces which can be solved analytically. The solution is then reduced to simply finding a linear approximation for the two functions.

The Jacobi-Bessel method which was presented for an elliptical aperture in [Rahmat-Samii, 1987], uses a Taylor series expansion and a Jacobi-Bessel expansion on different parts of the integral. Performing these expansions allows the the observation angles to be taken outside the integral. Thus, the pattern can be computed for many observation angles with only a few numerical integrations necessary. The disadvantage is that the expansions performed make the solution accurate only in the area around the main lobe. If many points in the radiation pattern must be computed near the main lobe the Jacobi-Bessel method should be used for the computation. However, if only a few points in the radiation pattern are needed but these points are not near the main lobe, the Ludwig method would be preferable.

During the design of this antenna, both of these methods were implemented in C++ computer code. This code allowed for the computation of the far-field pattern given a dish geometry and made possible the surface optimization which will be described in the following section.

Reflector Design

In this section, the basic reflector surface shape will be described and then the optimization techniques which were used on the surface will be presented.

Basic Reflector Shape

For a reflector antenna, the antenna beam width is nominally determined by the aperture size. For example, the small beam which is required in the azimuth direction dictates a large antenna aperture in that direction. The large antenna beam in the range direction dictates a small antenna aperture. A reflector whose edge is shaped as an ellipse will be used to meet these constraints (see the top view in figure 1).

Achieving the narrowest possible beam from a given reflector size dictates the use of a paraboloid conic-section for the antenna curvature. However, the constraint that the antenna have a fairly constant beam width over the frequency range dictates the use of a different shape. An ellipsoidal curvature tends to

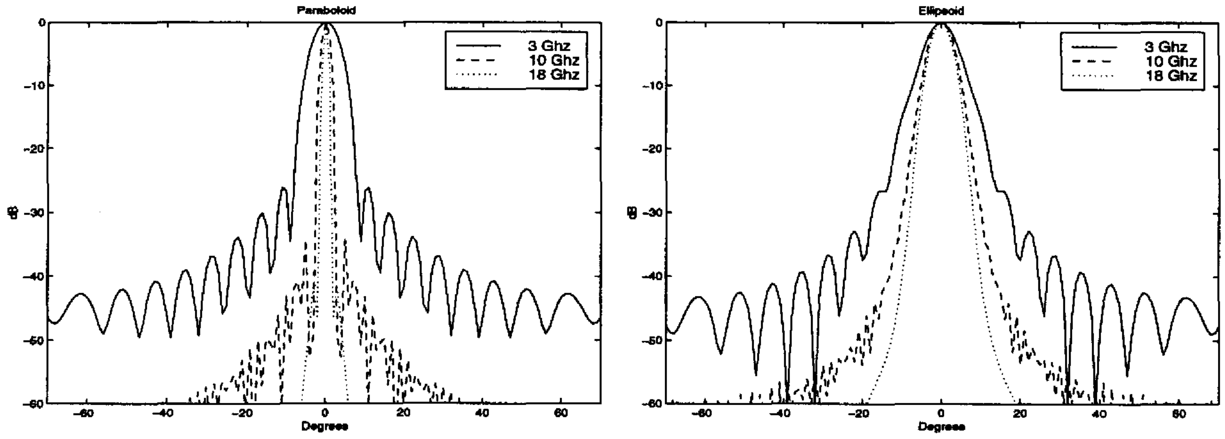

Figure 2: Parabolic reflector and ellipsoidal reflector far-field patterns

provide a more constant beam with variations in frequency than a parabolic curvature. Figure 2, which compares patterns generated by a parabolic reflector and an elliptical reflector, illustrates this principle.

As previously mentioned the largest allowable dimensional aspect ratio for the antenna is four to one. Since the ratio of the beam widths is twelve to one (60° to 5°) the narrow physical dimension of the antenna will be larger than necessary. In order to keep the beam in the range direction from being too small an ellipsoidal curvature which does not focus the beam in this direction is used.

In summary, the basic reflector shape will be an elliptical section cut from a three dimensional ellipsoid, as shown in figure 1. The following subsection will describe how this shape will be used as the starting point for the surface optimization.

Reflector Surface Optimization

The optimization discussed in this section is performed on the reflector shape which was described in the previous section. The optimization of the reflector surface is done in two steps. First, the several parameters which describe the ellipsoidal curvature are optimized. The equation describing an ellipsoid in terms of its focal point and eccentricity is found in [Jamnejad-Dailami and Rahmat-Samii, 1980]. Figure 3 shows the radiation pattern of the starting surface for the ellipsoid parameter optimization. Although the azimuth pattern has a fairly constant 3 dB beam width, the range pattern is not acceptable because the beam width at 3 Ghz is too small and the higher frequencies have over 6 dB of variation in the main beam. Figure 4 shows the radiation pattern generated by the final surface after the parameter optimization was performed. The second step in the optimization is to describe the surface in terms of a Jacobi-Bessel expansion and then optimize the coefficients of this expansion as described in [Rahmat-Samii and Mumford, 1989]. This second step will allow the surface to deform into a shape which is not a true ellipsoid. Figure 5 shows the radiation pattern generated from the final reflector shape after the Jacobi-Bessel surface coefficient optimization. Notice that this optimization has resulted in a flatter main beam in the range pattern.

The first step in the optimization is necessary since optimization routines have difficulty finding global minima when local minima are present. By finding the ellipsoidal shape that is needed, the starting point for the Jacobi-Bessel coefficient optimization is close to the desired global minimum. Furthermore, even with the efficient far-field computation techniques described in the preceding section the optimization procedure is quite computationally intensive. By optimizing the few ellipsoidal parameters much time can be saved over optimizing the many Jacobi-Bessel parameters.

Conclusion

The design and analysis of a broad band reflector dish antenna is facilitated by using proper far-field analysis techniques. The structural constraints of the antenna are taken into account when choosing an antenna size. The design is initiated by choosing an ellipsoidal shape which gives a fairly constant beam antenna. This shape is optimized using a Jacobi-Bessel expansion of the surface. The stringent requirements imposed by the remote sensing use of the antenna can be met fairly well by using the design techniques outlined in this paper.

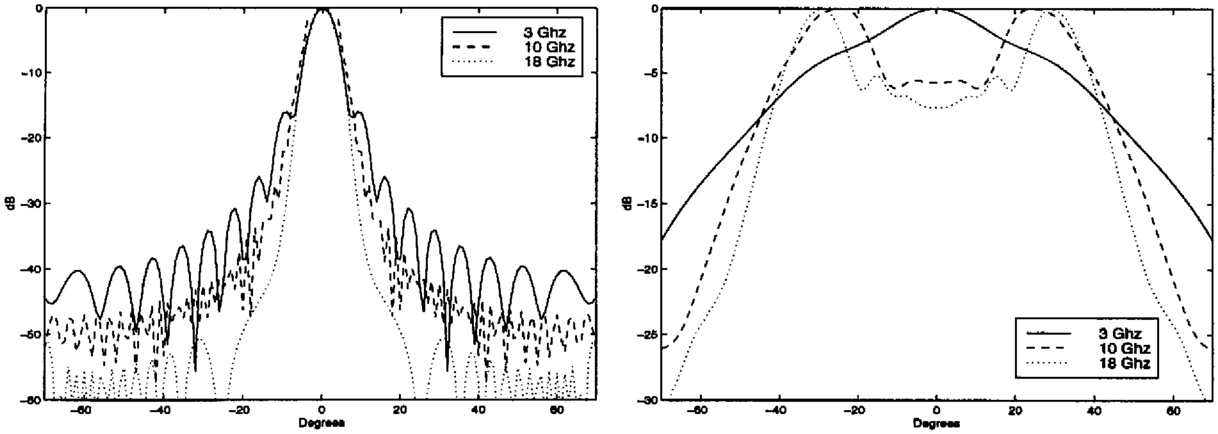

Figure 3: Azimuth and range radiation patterns from surface before optimization

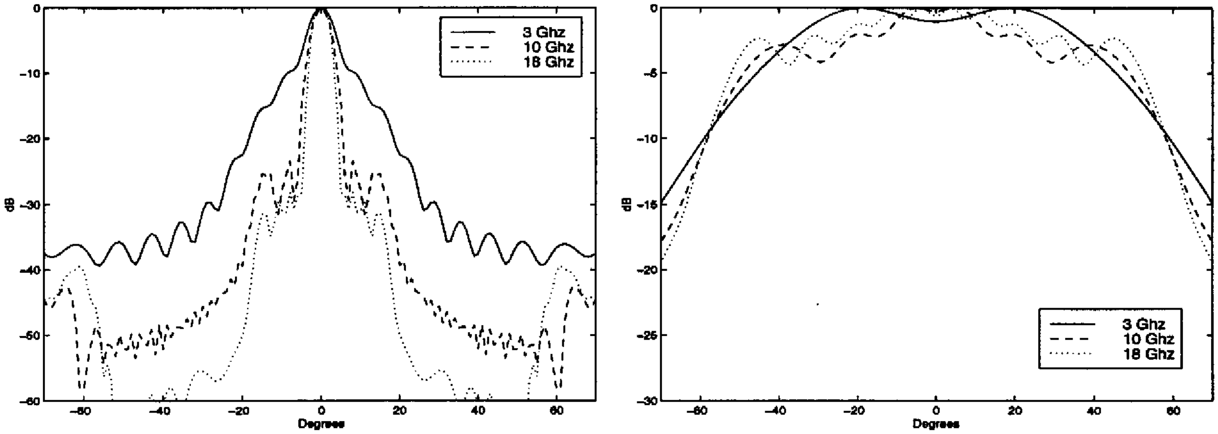

Figure 4: Azimuth and range radiation patterns from surface after ellipsoid parameter optimization

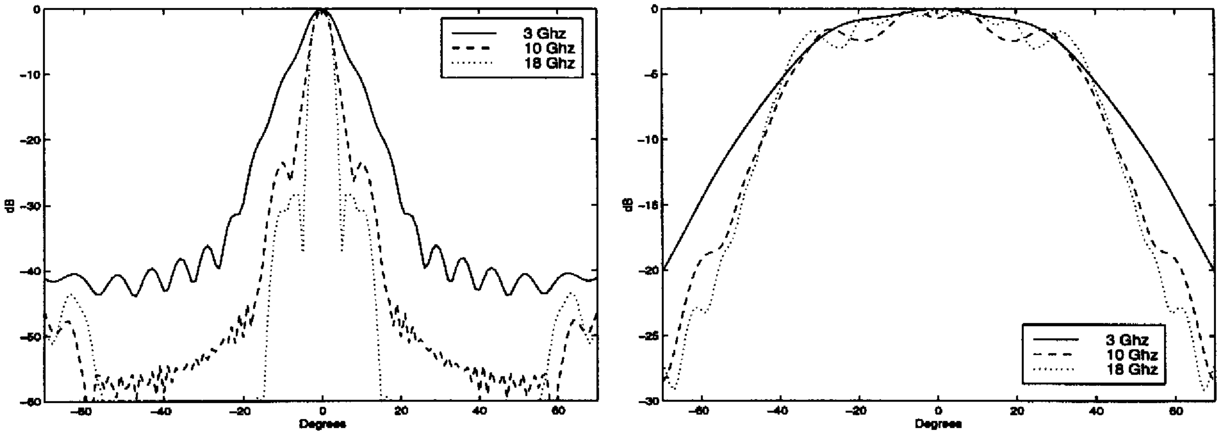

Figure 5: Azimuth and range radiation patterns from surface after Jacobi-Bessel coefficient optimization

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