Analysis of Blended Rolled Edge Reflectors Using Numerical UTD

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***Abstract*—The uniform geometrical theory of diffraction (UTD) concept is used to predict the scattered fields in the target zones of compact range blended rolled edge reflectors. Since the necessary diffraction coefficients are not known in a closed form, a numerical method to calculate the diffraction coefficients is described. In the numerical method, the problem is reduced to two dimensions, and physical optics (PO) line integration is used to compute the diffraction coefficients. Thus, the method is computationally efficient. The method is used to analyze two compact range reflectors. The results obtained using the numerical UTD (NUTD) show a good agreement with the scattered fields obtained using a corrected physical optics surface integration.**

I. Introduction

Modern compact range reflectors may use rolled edge terminations to reduce the edge-diffracted fields in the target zone. To analyze these fields, it is desirable to have a method which is both accurate and computationally efficient. If the surface curvature of the reflector is discontinuous across the edge of its paraboloidal surface, then the uniform geometrical theory of diffraction (UTD) [1] can be used. However, some recent reflector designs utilize "blended" surfaces, for which the surface curvature is continuous across the rolled edge junction [2]; UTD diffraction coefficients are not available for these higher order discontinuities. To overcome this problem, the authors have developed a numerical method for computing the necessary uniform diffraction coefficients. In the numerical method, the problems is reduced to two dimensions and physical optics (PO) line integration is used to compute the diffraction coefficients. The method is applicable to junction discontinuities of any order. In this communication, the numerical method is described and using the numerical diffraction coefficients (NUTD), the scattered fields in the target zones of two compact range reflectors are computed. The computed results are compared with the scattered fields obtained using a corrected physical optics surface integration technique. It is shown that NUTD accurately predicts the fields in the target zones of blended rolled edge reflectors with arbitrarily shaped rims, and is much more efficient. NUTD is also advantageous in that it provides diagnostic information on the various contributions to the total scattered fields. The NUTD method is outlined in the following section.

II. Methodology

The NUTD method for obtaining uniform diffraction coefficients proceeds as follows.

1) At a diffraction point on the junction contour (the curve defining the junction between the paraboloidal surface and the rolled edge), the cross section of the reflector in a plane perpendicular to the junction contour is determined. Since the diffracted fields emanating from a single point of diffraction are of interest, the opposite rolled edge in the cross-sectional contour is replaced by a continuation of the paraboloidal surface such that no other discontinuities are present.

2) A two-dimensional geometry is defined by finding the orthogonal projections of the source and field points in the perpendicular plane, and multiplying the wavenumber k by $\sin \beta_0$, where β_0 is the acute angle between the tangent to the junction contour and the diffracted ray. By defining the 2-D problem in this way, the diffraction coefficients for the 2-D case will be related to the desired (3-D) coefficients by a factor of $\sqrt{\sin \beta_0}$ [3].

3) The total scattered field for the 2-D problem are found using PO for transverse magnetic (TM) as well as transverse electric (TE) incidence; i.e., the illumination is assumed to be an electric line source (TM incidence) or a magnetic line source (TE incidence) at the source point.

4) The junction-diffracted fields for the 2-D geometry are computed. This is done by noting that the PO fields calculated in the above step have the following contributions:

a) specular reflection from the reflector surface;
b) end point contributions originating from the endpoints of integration; and
c) junction diffraction.

Specular reflection is calculated using geometrical optics; while, the integral endpoint contributions are calculated using a method proposed by Gupta and Burnside [5]. These contributions are subtracted from the PO fields calculated in the previous step to obtain the junction-diffracted fields.

5) By equating the UTD expressions for the diffracted field to the calculated diffracted field values, the diffraction coefficients for the 2-D geometry are obtained.

6) Given the 2-D diffraction coefficients, the desired (3-D) diffraction coefficients are obtained simply by dividing by $\sqrt{\sin \beta_0}$, exploiting the relationship noted above.

The above procedure is repeated for each diffraction point on the junction contour. Once the diffraction coefficients for all the diffraction points are found, the UTD is used to compute the total scattered fields at the field point. For more details of the numerical method, one is referred to [4].

It should be pointed out that the NUTD method has two limitations. First, the method is valid only for field points near the specular direction; in this case, directly in front of the reflector. This is a consequence of the PO approximation. Second, this method may become invalid if the incident field pattern becomes highly directional. This is due to the fact that a line source illumination has been assumed in the 2-D geometry (see step 3). It will be seen in the next section that this method works quite well for compact range application.

III. Results

The first reflector analyzed using NUTD is shown in Fig. 1. The reflector uses a linearly blended [2] rolled edge. The focal length of the reflector is 15 ft. The rolled edge was designed using the method proposed by Gupta *et al.* [6]. The rolled edge and reflector parameters are given in the Appendix. The linearly blended rolled edge ensures that the surface curvatures are continuous across the junction. In this analysis, the feed is assumed to be vertically polarized Huygens source located at the focus, and the frequency of operation is 2 GHz. Fig. 2 shows the total scattered fields in the principal ($x = 0$) and $y = 6.5$ ft planes at a 25-ft downrange (z) distance

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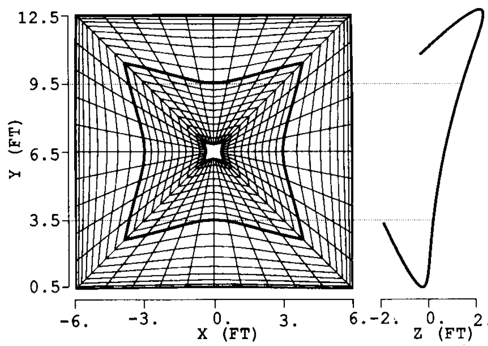

Fig. 1. Linearly blended rolled edge reflector. A front view and cross section in the $x = 0$ plane are shown. The dark line in the front view is the junction contour.

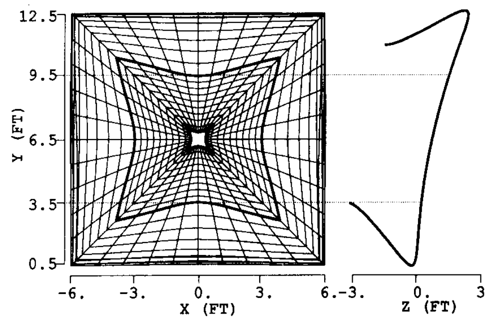

Fig. 3. Cosine-blended rolled edge reflector. A front view and cross section in the $x = 0$ plane is shown. The dark line in the front view is the junction contour.

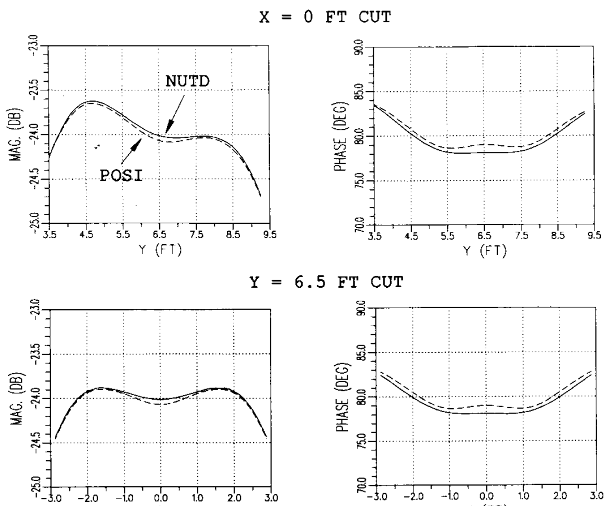

Fig. 2. Total fields at 2 GHz in the $x = 0$ and $y = 6.5$ ft cuts for the linearly blended rolled edge reflector shown in Fig. 1.

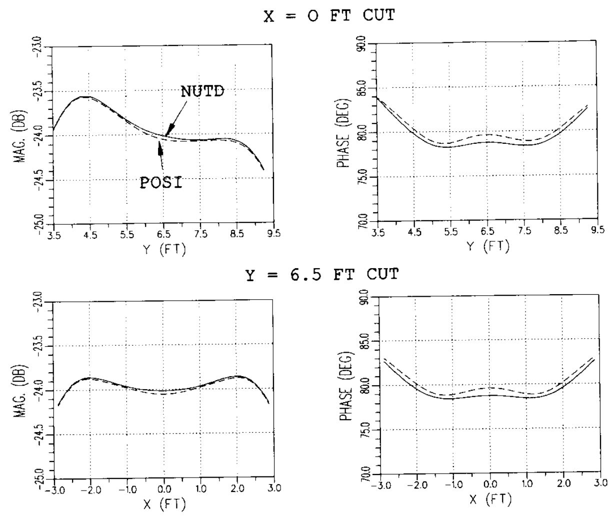

Fig. 4. Total fields at 2 GHz in the $x = 0$ and $y = 6.5$ ft cuts for the cosine-blended rolled edge reflector shown in Fig. 3.

from the vertex of the reflector. In the figure, the scattered fields obtained using physical optics surface integration (POSI) are also shown. In the POSI results, the endpoints correction proposed by Gupta *et al.* [7] is applied. The phase as well as magnitude of the co-polarized (vertical) component of the scattered fields is shown in the figure. Note that the magnitudes of the scattered fields obtained using the two methods agree to within 0.1 dB; while their phase agrees to within a degree. Thus, the NUTD provides a good estimate of the true scattered fields.

The second reflector used for illustrations has a cosine blended rolled edge [2]. All other parameters of the reflector are the same as those of the previous reflector. Cosine blending ensures that surface curvature and its first derivative are continuous across the junction. Thus, the reflector surface is smoother than the previous reflector. Fig. 3 shows the front view and a cross section of the reflector. The rolled edge for this reflector was also designed using the method proposed by Gupta *et al.* and the rolled edge parameters are given in the Appendix. The rolled edge was designed to meet the same overall size constraints. To compute the scattered fields, a Huygens source feed at the focus is used and the operating frequency is 2 GHz. The resulting scattered fields in the target zone are as shown in Fig. 4. The POSI scattered fields are also shown in the figure. Once again, note that the NUTD and POSI results agree to within 0.1 dB in magnitude and within a degree in phase.

In addition to providing a good estimate of the total scattered fields in the target zone, the NUTD also provides one with the contributions from individual scattering mechanisms. For example, in the case of the two reflectors discussed here, the total scattered fields consist of the specular reflection (geometrical optics term) and four diffraction terms originating from four diffraction points, one diffraction point on each side of the junction contour. Figs. 5 and 6 show the contributions from these scattering mechanisms for the linearly blended rolled edge reflector in the principal ($x = 0$ ft) and $y = 6.5$ ft planes, respectively. Note that in the principal plane the scattered fields from the top and bottom edge of the junction contour dominate the diffracted fields. The contributions from the left and right edges are exactly equal. The diffraction from the bottom edge decreases with an increase in y; while the reverse is true for the top edge. In the $y = 6.5$-ft plane, the diffraction from the left and right edges is dominant. Also, since the reflector has a vertical offset, the diffractions from the top and bottom edges are not equal. The left edge diffraction is dominant for the negative values of x, while the right edge diffraction is dominant for the positive values of x. This behavior is consistent with the physics of the reflector system. Thus, the NUTD works quite well.

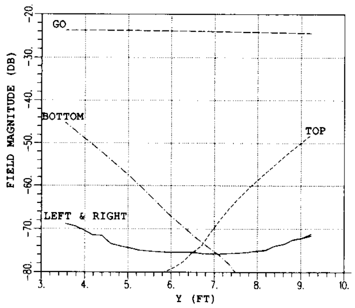

Fig. 5. Contributions to the fields in the $x = 0$ plane for the linearly blended rolled edge reflector.

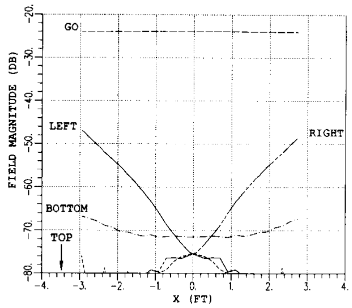

Fig. 6. Contributions to the fields in the $y = 6.5$ ft plane for the linearly blended rolled edge reflector.

Another advantage of the NUTD is computational efficiency. Since the NUTD requires PO line integrations, the total CPU time required to carry out the integration is directly proportional to frequency. POSI, on the other hand, requires surface integration; thus, the CPU time is proportional to the frequency squared. For the software used to generate the results appearing here, running on a VAX 8550 computer, it was found that POSI (using one-tenth-wavelength patches) required about 150 CPU-s per field point, while the NUTD required about 3 CPU-s. In fact, practical considerations often make it necessary to perform the POSI calculations on a supercomputer, even at the lowest frequencies of interest. The NUTD method offers considerable improvement in this respect.

IV. Conclusion

In this communication, an efficient technique for analyzing the performance of compact range reflectors with blended rolled edges was presented. The technique is based on the UTD concept, where the diffraction coefficients are obtained numerically using a corrected PO line integration method. It was shown that this approach yields results which are in good agreement with the corrected POSI method for the fields in the target zone. Furthermore, the numerical UTD is much more efficient than the POSI method. The numerical UTD method also provides diagnostic information on the effects of individual scattering mechanisms.

Appendix

For completeness, the various parameters of the reflectors considered here are given in the following. For a more detailed explanation of these parameters, the reader is referred to [6]. For both the linearly and cosine-blended rolled edge reflectors, the junction contour dimensions are $r_e = 3.0$ ft, $x_{\text{left}} = -3.0$ ft, $x_{\text{right}} = 3.0$ ft, $y_{\text{bottom}} = 3.5$ ft, and $y_{\text{top}} = 9.5$ ft. The feed tilt angle for both reflectors is $\alpha = 24.45°$. The parameters for the linearly blended rolled edge are $a_e = 0.500$ ft, $b_e = 1.395$ ft, $x_m = 11.151$ ft, and $\gamma_m = 120°$. For the cosine-blended rolled edge, $a_e = 0.500$ ft, $b_e = 2.204$ ft, $x_m = 10.983$ ft, and $\gamma_m = 120°$. The rolled edge parameters were assumed to be the same for all points along the junction contour.

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Mutual Coupling Compensation in Small Array Antennas

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***Abstract*—A technique to compensate for mutual coupling in a small array is developed and experimentally verified. Mathematically, the compensation consists of a matrix multiplication performed on the received signal vector. This, in effect, restores the signals as received by the isolated elements in the absence of mutual coupling. The technique is most practical for digital beamforming antennas where the matrix operation can be readily implemented.**

Introduction

The radiation pattern of an array of identical antenna elements is usually taken to be the product of an element factor and an array factor, based on the presumption that all elements have equal radiation patterns. Unfortunately, this may not be true for a practical array, where, due to mutual coupling, each element "sees" a different environment. The nature of the error thus incurred can be displayed by expressing the individual array element pattern $f_n(u)$

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