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# ELECTROMAGNETIC BACKSCATTERING BY CORNER REFLECTORS

Semiannual Report

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## ABSTRACT

The analysis of the backscatter cross section of a dihedral corner reflector, using GTD and PTD, is completed in the azimuthal plane, and very good agreement with experimental results is obtained. The advantages and limitations of the GTD and PTD techniques are discussed specifically for radar cross section applications. The utilization of GTD and PTD in oblique incidence diffraction from conducting targets is discussed. Results for equivalent current off-axis diffraction from the flat rectangular plate are presented using the equivalent currents of Knott, Senior, and Michaeli. The rectangular subdivision technique of Sikta, and its extension by Sunatara, alleviate some of the limitations of the equivalent current techniques. As yet, neither technique can be used in bistatic scattering or for multiple scattering of a complex target.

# I. INTRODUCTION

During the semiannual period beginning February 1, 1986 and ending July 31, 1986, significant progress has been made in the research funded under Grant No. NAG-1-562 entitled "ELECTROMAGNETIC BACKSCATTERING BY CORNER REFLECTORS". The research during this period investigated the accuracy and usefulness of the Geometrical Theory of Diffraction (GTD) and the Physical Theory of Diffraction (PTD) for analyzing backscattered cross sections of complex conducting targets, especially for those targets in which the multiple reflections and multiple diffractions are the dominating mechanisms. The GTD and PTD theories have become especially important tools in radar cross section work because of their accuracy, computational efficiency and versatility.

The progress on this project included completion of the analysis of the backscatter cross section of the dihedral corner reflector in the azimuthal plane using both the GTD and PTD techniques. This work led to the presentation of one conference paper [1] and to the submittal of two journal papers [2]-[3] which are currently under review. Both the GTD and the PTD predicted radar cross section patterns which compared well with experimental measurements for right, acute, and obtuse dihedral corner reflectors. The GTD research revealed many of the fundamental properties and limitations of the geometrical techniques. These properties, associated with radar cross section analysis, are not evident in most other GTD applications, including antenna pattern prediction. The PTD analysis uncovered the shortcomings of previous physical optics (PO) approximations, especially in terms of accuracy. Only through full utilization of the PO theory, without approximation, could the theory reliably match experimental measurements for all aspect angles and all reflector shapes.

The research progress, in addition, included investigations of the available techniques for determining oblique incidence backscattered fields using the Geometrical Theory of Diffraction. Published work on oblique incidence radar cross sections using GTD has only been available for a short time, and there is much interest in this topic. Equivalent current techniques and methods to apply these techniques have been proposed by several authors. The GTD's primary limitations are due to the singularities in the diffraction coefficients, and methods to avoid these singularities are sought. A related topic of concern is the method of choosing the edges upon which equivalent currents must be imposed for a general complex target.

In contrast, the PTD equivalent currents do not encounter the singularity problems associated with the GTD coefficients. The theory is well developed for single reflections and single diffractions from complex bodies which are formed of (or can be approximated by) flat surfaces and straight edges. The required calculations for the multiple reflections and multiple diffractions, however, tend to be much more difficult to perform. The major problems include the geometrical and mathematical complexity of the numerous surface and edge integrations of a given target. For multiple reflections, the surface integrations can only be performed using expensive numerical integrations. For corner reflectors especially, these multiple reflections and diffractions are of primary concern.

This report presents the status of the associated research in three sections: the analysis of the dihedral corner reflector in the azimuthal plane using GTD; the analysis of the dihedral corner reflector in the azimuthal plane using PTD; and the equivalent current techniques for oblique incidence diffraction using GTD. The progress and findings in each area are discussed.

## II. DIHEDRAL CORNER REFLECTOR BACKSCATTER ANALYSIS USING GTD

One of the most popular methods for determining approximate scattered fields due to surface reflection and edge diffraction is the Geometrical Theory of Diffraction (GTD) [4]-[9]. Originated by Keller [4], and refined as the Uniform Theory of Diffraction (UTD) by Kouyoumjian and Pathak [5], GTD supplements geometrical optics by adding contributions to edge diffraction at perfectly conducting edges. The theory has been used extensively, with much success, in many electromagnetic scattering problems [10]-[17]. GTD is especially useful because it provides good agreement with experimental results, it provides insight into specific scattering mechanisms, it involves common functions available on most computer systems, and solutions are relatively simple to construct in comparison to exact methods.

In this research, GTD is utilized to determine the backscatter cross section of dihedral corner reflectors in the azimuthal plane. Through the dihedral corner reflector analysis, the versatility and accuracy of the theory can be evaluated. The dihedral corner reflector was chosen because it exhibits many of the scattering mechanisms of more complex bodies; namely strong specular reflections from singly, doubly and triply reflected fields, along with significant first, second and third order diffracted fields. The dihedral corner reflector is analyzed when the interior angle is right, acute, and obtuse.

Several papers have dealt with the study of a dihedral corner reflector using geometrical and physical theories. Yu and Huang [13] have compared vertical polarization computed patterns with measurements in the forward 180° region of the dihedral corner reflector using GTD. Knott [18] studied the backscattered fields of the obtuse dihedral corner reflector using a combination of geometrical and physical optics over the first 70° on each side of the forward direction, without incorporating diffraction terms. Michaeli [19] utilized physical diffraction in a study of the 90° dihedral corner reflector only near grazing incidence to either plate.

In this work, the geometrical theory of diffraction is utilized to analyze in detail the entire backscatter cross section of right, acute, and obtuse dihedral corner reflectors in the azimuthal plane for both the horizontal and vertical polarizations. Extensive results from this research are available in [2]. All possible reflection-diffraction mechanisms of up to third order have been included in the analysis, and they are needed to achieve accuracies which compare well with measurements. The total cross section can be decomposed into individual components which explicitly show the dominant scattering mechanism at specific orientations. Understanding how the total cross section is built from individual mechanisms is very important for developing methods to reduce, enhance or synthesize particular backscatter characteristics of a particular target.

The problems associated with GTD (or UTD) in cross section analyses are not evident in other GTD applications, such as antenna pattern prediction. In RCS work, the UTD coefficients revert to Keller's original GTD forms as the distance of observation increases for the singly diffracted fields. The problems associated with the singularities of Keller's coefficients may be overcome if two mutually parallel edges exist on a planar surface, since the two singly diffracted fields together can produce finite cross sections. Ross [10] showed that for the rectangular flat plate the diffraction coefficients for each edge were infinite near normal incidence but the singularities from each edge cancelled against each other to yield finite cross sections at all aspects for the singly diffracted field. This occured because the edges of the rectangular plate are mutually parallel and the associated edge wedge angles are zero. Sikta [14], [16] used this property in his analysis of a general polygonal plate by subdividing each polygon into a number of rectangular strips to ensure continuity of the diffracted field near normal incidence. It is shown by Balanis and Griesser [2], [17] that the diffracted field singularities will mutually cancel regardless of the edge wedge angles provided the edges are parallel. This is an important result because it allows the subdivision of a general solid object into rectangular segments, which are not necessarily flat rectangular strips, to ensure continuity of the backscatter cross section.

It is computationally convenient to use the UTD coefficients at some finite, yet large observation distance to determine the diffracted fields. For a target formed of flat surfaces with mutually parallel edges, the UTD cross section will be nearly invariant with distance provided the distance is large. The cross section due solely to individual singly reflected fields or singly diffracted fields increases as the distance increases, however the total cross section will approach a finite value. The "far-field" criterion [20] can be used as a measure of the minimum distance required.

Although the diffracted field from a pair of parallel edges is continuous, cases may exist where both edges of a plate may not be visible near normal incidence. This normally occurs because another unrelated object passes in the line of sight from the target to the radar. Such is the case, for example, for the dihedral corner reflector when one plate obstructs the view of one of the edges of the second plate. Clearly in cases such as these, there is only one edge diffraction, and the field is no longer continuous near normal incidence.

Geometrically, under these circumstances, one portion of the plate is illuminated while another portion is shadowed. An abrupt discontinuity in the field incident upon the plate is created because of the shadow cast by the obstructing object. Since abrupt discontinuities must not exist, some diffraction mechanism should be introduced to assure continuity in the radar cross section pattern [13]. In the analysis of the dihedral corner reflector, an edge diffraction has been imposed exactly at the shadow edge to account for the field discontinuity. This edge position is a function of the dihedral orientation since the shadow edge moves as the dihedral corner reflector is rotated. This imposed edge diffraction was included if the aspect was such that the incident field was nearly normal to one of the two flat plates, and if at the same orientation, the second plate cast a shadow across the first.

The usefulness and accuracy of the geometrical theory of diffraction for targets which have dominant multiple reflections and diffractions can be evaluated through a study of the radar cross section of the dihedral corner reflector shown in Figure 1. This corner reflector is comprised of two rectangular flat conducting plates which are joined along an edge, forming an interior angle of $2\alpha$. The dihedral corner reflector is oriented such that its vertex is along the z-axis and the bottom edges lie in the x-y plane. The monostatic radar cross section is computed analytically in the azimuthal plane where $\theta = 90^\circ$ and $0^\circ \leq \phi \leq 360^\circ$. The two cases of vertical and horizontal polarization are considered, where the vertically polarized radar cross section is determined using the components of the incident and scattered electric fields which are parallel to the z-axis, and the horizontally polarized radar cross section is determined using the components of the incident and scattered electric fields which are perpendicular to the z-axis.

In Figures 2, 3 and 4, the vertically polarized radar cross section patterns of the dihedral corner reflectors found using GTD are compared with measured data for the $90^\circ$, $98^\circ$, and $77^\circ$ corner reflectors. The distance of observation was 200 $\lambda$ for these calculations to satisfy the far-field criterion, and the cross section is relatively independent of distance for larger distances. The RCS must be independent of distance for it to be a useful parameter in the radar range equation, since the basic motivation behind introducing cross sections as target parameters is to separate the effects of radar distance and configuration from the target specification. The GTD analytical results compare extremely well with the experimental data as the curves match many of the major and minor lobe structures of the measured cross sections. To achieve this accuracy, up to third order reflections and diffractions had to be included. While the GTD predicted patterns are symmetric about $\phi=0^\circ$, the measured data are not necessarily symmetric, especially near minor lobes. For this reason, the two cross sections may agree better on one side than on the other. Achieving perfectly symmetric measured cross sections, expecially at low levels, is an extremely demanding task.

Small angular misalignments in the lobe structures in Figures 2-4 will occur whenever the GTD cross section is evaluated at a finite distance. A major lobe should occur at $\phi = 45^\circ$ in the cross section of Figure 2, but occurs at $\phi = 44.2^\circ$ using GTD at a distance of 200 $\lambda$. The angular error can be reduced by choosing a larger distance for the GTD analysis; however higher precision would then be necessary when determining the GTD diffraction coefficients. The coefficients become very sensitive to angular inaccuracies near shadow boundaries as the distance of observation increases.

In the forward region, the choice of polarization has only a minor effect on the RCS of the $90^\circ$ corner reflector. For the $98^\circ$ corner reflector, a deep null at $\phi=0^\circ$ is present for vertical polarization but is absent for horizontal polarization. Effects such as this can be used as tools to design low RCS convex surfaces. For the $77^\circ$ dihedral corner reflector, the radar cross sections for the principle polarizations are markedly different, with the horizontal RCS generally exhibiting lower levels in this region. However, for all three corner reflectors, the horizontally polarized patterns tend to have higher sidelobes. In general, the GTD theory predicts no cross-polarized components in the azimuthal plane for either polarization.

## III. DIHEDRAL CORNER REFLECTOR BACKSCATTER ANALYSIS USING PTD

Physical Optics and the Physical Theory of Diffraction [21]-[28] compose a very important and very useful technique for the analysis of backscatter cross sections of complex targets. They are well suited for RCS evaluations because they can be readily applied in a wide variety of target configurations [6]-[9], [12], [17]-[19]. Physical Optics (PO) determines reflected fields and relies on an approximation of the induced surface current density on a conducting surface in proportion to the tangential incident magnetic field [28]. The Physical Theory of Diffraction (PTD), in one of its most useful forms, determines diffracted fields in terms of nonphysical equivalent currents on conducting edges [24]. Once the induced physical optics surface current density and physical diffraction edge current are approximated, the reflected and diffracted fields can be evaluated using standard electromagnetic techniques.

For backscatter analyses of conducting targets formed by flat polygonal surfaces, the physical optics and physical diffraction theories are especially convenient to use. When illuminated by a plane wave, the induced physical optics current varies linearly in phase across a flat surface, and when the surface is polygonal the fields due to this induced current can always be integrated to a closed form expression [24]. Similarly, under plane wave incidence, the physical diffraction edge currents vary linearly in phase along a straight edge, and the diffracted fields due to these edge currents can always be found in closed form. Hence, the backscatter cross section of bodies formed of perfectly conducting flat polygonal surfaces can be readily evaluated when only single reflections and single diffractions are important. In addition, the techniques are amenable to automated computer solution.

However, when multiple reflections dominate, as for a corner reflector, the physical optics theory becomes less convenient to use. The reflected field from one plate which impinges on a second plate is not planar and the problem is significantly more complicated. Typically, the second reflecting surface is in the "near-field" region of the first reflection and the conventional "far-field" approximations are not applicable. The induced current density at the second surface must then be found in terms of the "near-field" reflection from the first surface. Therefore the fields from the second reflection cannot generally be found in closed form, and costly numerical integrations must be performed.

One common simplification which has been used in the past [18] is to account for the initial reflections using geometrical optics (image) theory. The advantage of Geometrical Optics (GO) is that it maintains the planar nature of a wave upon reflection from a flat surface. Therefore the subsequent reflections, performed using PO, are then readily integrable in closed form over the GO illuminated portion of the second surface. For the cases considered, this geometrical optics simplification often degrades the analytical results, and an improvement is usually gained by using the more complicated PO expressions at every reflection. For the cases studied, the most improvement was noted in the forward region of the acute (77°) dihedral corner reflector and in the minor lobes of all the corner reflectors.

In this work, the backscatter cross sections of dihedral corner reflectors are analytically determined using the combination of physical optics and the physical theory of diffraction over the entire azimuthal plane. In previous papers by other authors, Knott [18] analyzed the radar cross section of a dihedral corner reflector in the forward region using physical optics for single reflections and the combination of physical optics and geometrical optics for double reflections. Michaeli [19] studied 90° dihedral corner reflectors using PTD near grazing incidence to one of the reflector faces, and Plonus [12] used PTD and GTD to evaluate the radar cross section of curved plate reflectors.

In this research, the examined dihedral corner reflectors have right, acute and obtuse interior angles and the RCS pattern is computed for vertical and horizontal polarizations. For vertical polarization, comparison of computed primary polarization RCS patterns are made with available experimental data. The physical diffraction equivalent currents, added in this work, refine the physical optics cross section to bring it more into agreement with experimental measurements.

The dihedral corner reflector, shown in Figure 1, is constructed of rectangular conducting plates of dimensions A and B. In this figure, the dihedral corner reflector is oriented such that its vertex is along the z-axis and the bottom edges lie in the x-y plane. The incident field arrives from the $\phi$ direction and is either vertically or horizontally polarized. The vertically polarized wave has an electric field which is parallel to the z-axis, and the horizontally polarized wave has an electric field which is perpendicular to the z-axis. The dihedral corner reflector interior angle is $2\alpha$.

The usefulness of the Physical Theory of Diffraction for radar cross section (RCS) prediction is evaluated by comparing analytical calculations with experimental measurements. The specific dihedral corner reflectors, for which experimental results were availble, were constructed of two square plates each with sides of 5.6088 $\lambda$. These experimental measurements, reported in [13], were conducted at 9.4 GHz using vertically polarized fields (i.e. the electric field vector was parallel to the longitudinal axis of the dihedral corner reflector). The backscatter cross section, as a function of azimuthal angle in a plane perpendicular to the dihedral corner longitudinal axis, was available for reflectors with $90^\circ$, $77^\circ$,, and $98^\circ$ interior angles.

The PTD backscatter cross sections of these three dihedral corner reflectors are compared with experimental measurements in Figures 2, 3 and 4. The analytical results, shown by the dotted lines, used only physical optics for the double reflected fields to achieve the best possible accuracy at the expense of severe complexity. For this method, the associated complex quadruple integrals were evaluated numerically.

From the RCS patterns exhibited in Figures 2, 3 and 4, it is evident that the combination of physical optics and the physical theory of diffraction agrees with many of the details of the measured cross section. The physical optics theory provides most of the dominant backscattering terms while the addition of the PTD diffraction coefficients tends to refine the analytical results and bring them more into agreement with the measurements.

## IV. GTD EQUIVALENT CURRENT TECHNIQUES FOR OBLIQUE INCIDENCE

The method of equivalent currents has been developed by several authors to allow the GTD diffraction coefficients to be used away from the Keller cone. Ryan and Peters [11] and Knott and Senior [8] both successfully used equivalent currents to extend the usefulness of the available GTD techniques. Michaeli [15] later developed a more rigorous equivalent current technique applicable for arbitrary incidence and scattering directions, but these coefficients have additional singularities. In these techniques, an equivalent non-physical current is introduced at the edges of a conducting body such that the fields induced by these currents approximates the actual field.

When the equivalent currents are used for backscatter cross section prediction, the principle problems encountered are due to the singularities of the GTD diffraction coefficients at normal incidence for the singly diffracted field. At normal incidence to either of the two surfaces which intersect to form the diffracting wedge, the currents become infinite and the cross section can not always be determined. The triangular and trapezoidal flat plates are examples of targets which are predicted to have infinite cross sections at normal incidence when equivalent currents are introduced at every edge. For targets which are formed of pairs of parallel edges, however, the radar cross section will converge to a finite value as normal incidence is approached. However this value happes to be twice the value predicted by the reliable physical optics (PO) techniques. Examples of flat plate targets for which this occurs include squares, rectangles, parallelograms, regular hexagons and regular octagons.

The cause of the problem stems from extending the GTD, derived from a two-dimensional canonical geometry, to the three-dimensional radar target problem. The GTD diffracted fields include the contribution of the PTD and PO fields at normal incidence for far field scattering. The PO fields, for flat surfaces, are proportional to the area of the surface, and hence the GTD fields can be said to account for the scattering from the area between two paired diffracting edges.

Considering the rectangular flat plate as an example, the diffraction from either pair of parallel edges accounts for all the surface area within, that is, the entire rectangular plate. Adding diffraction from all four edges accounts for the surface area twice and hence predicts fields which are twice the PO fields at normal incidence. In a principal plane, it is sufficient to consider diffraction from only the two diffracting edges in the plane, as Ross [10] has done. However in nonprincipal planes, for oblique incidence, it is not evident which combination of equivalent currents needs to be used to achieve the correct cross section pattern behavior away from normal incidence. Further research in this area is of much interest.

The equivalent current methods of Knott and Senior [8] and Michaeli [15] are compared with Physical Theory of Diffraction predictions in Figures 5-7 for a square flat plate. The square is oriented such that it lies in the x-y plane with edges parallel to the x and y axis. The radar cross section is shown for $\phi = 1^\circ$, $\phi = 30^\circ$ and $\phi = 45^\circ$ for $0^\circ < \theta < 90^\circ$ for the hard polarization. The square has sides of $5.0785\lambda$ and a frequency of 9.228 GHz is assumed. For backscattering, there are only minor differences between the choice of equivalent current. In these figures, the radar cross section for the equivalent current techniques has been reduced by 6 dB to match the PO radar cross section at normal incidence ( $\theta = 0^\circ$ ). These preliminary results show that the equivalent currents, if used on every edge, will predict a field which is twice the physical optics field at normal incidence. This is a property of targets formed of paired parallel edges. If parallel edges do not exist, imposing equivalent currents on every edge will yield infinite cross sections at normal incidence.

Sikta, *et al*. [14], [16] has been able to circumvent several problems by subdividing a general polygonal plate into rectangular strips. The strips are oriented so that they are illuminated only in a principal plane. This method allows the oblique incidence problem to be treated as a normal incidence problem and allows triangular and trapezoidal plates to be examined. Since Sikta only considers equivalent currents on two of the edges, the RCS matches the PO result at normal incidence. Sikta's method however does not define how the subdivision should be accomplished for targets other than flat plates or for bistatic cross sections. Sunahara, *et al*. [29] was able to apply the rectangular subdivision technique to polyhedrons by splitting the diffraction coefficients into two terms, each of which is associated with a particular surface of the wedge. This technique allows targets other than flat plates to be examined and gives good results for convex targets. As yet, no work has been done on concave targets for which multiple reflections and diffractions dominate. For multiple scattering, bistatic techniques are required but neither Sikta's nor Sunahara's method has been developed for bistatic scattering. Multiple reflections and diffractions are the dominant terms in the analysis of corner reflectors.

## V. CONCLUSION

During this semiannual period, the analysis of the dihedral corner reflector using GTD and PTD has been completed and investigations of GTD oblique incidence diffraction for radar cross section analysis have progressed.

In the first research area, the Geometrical Theory of Diffraction (GTD), is used to predict the backscatter cross sections of dihedral corner reflectors which have right, obtuse and acute included angles. GTD allows individual backscattering mechanisms of the dihedral corner reflectors to be identified and provides good agreement with experimental cross section measurements in the azimuthal plane. Multiply reflected and diffracted fields of up to third-order are needed and are included in the analysis for both horizontal and vertical polarizations. The coefficients of the Uniform Theory of Diffraction (UTD) revert to Keller's original forms in cross section analyses, but finite cross sections can be obtained everywhere by considering mutual cancellation of diffractions from parallel edges. Computationally, it is convenient to make analytic calculations at finite distances of observation using UTD coefficients; however the accuracy required in angular measurements is more critical as the distance increases. In particular, the analysis should not utilize the common "far-field" approximation that all rays to the observation point are parallel.

In the second research area, Physical Optics and the Physical Theory of Diffraction are used to determine the backscatter cross sections of dihedral corner reflectors in the azimuthal plane for the vertical and horizontal polarizations. The analysis incorporates single reflections, single diffractions, double reflections, triple reflections, and reflection-diffractions for perfectly conducting reflectors. The dominant double reflected fields are determined using two different techniques to determine the accuracy of the geometrical optics approximations which are commonly used for multiple reflections. In the first technique, geometrical optics is used at the first reflection to maintain the planar nature of the reflected wave, and consequently reduce the complexity of the analysis. In the second technique, physical optics is used at both reflections and the resulting backscattered field is found from a numerical integration of the resulting complex quadruple integral. The induced surface current densities and the resulting cross section patterns are investigated for these two methods. Experimental measurements confirm the accuracy of the analytical calculations for dihedral corner reflectors with right, acute and obtuse interior angles.

In the third research area, investigations of the oblique incidence GTD diffraction have been performed. Equivalent current techniques have been developed by several authors, but these techniques cannot be readily applied to RCS analysis. For flat plate polygonal structures, the radar cross section at normal incidence becomes infinite unless the target is formed of pairs of parallel edges. But if the target is formed of parallel edges, the equivalent current techniques predict the fields to be twice the physical optics value. This occurs because the equivalent currents account for the surface current density twice. To avoid these difficulties, targets can be divided into parallel rectangular strips as an approximation. The equivalent currents are then only imposed on one pair of edges on each strip. Further research in this area is of great interest in the technical community especially for oblique bistatic diffraction. The bistatic diffraction is necessary for analysis of complex targets when multiple scattering dominates.

Further research under this project will consider radar cross section prediction for corner reflectors and other complex targets in non-principal planes. Of particular interest are those complex targets for which multiple reflections and diffractions are the dominant mechanisms. In addition, the techniques will be extended to plates covered with dielectric material whose surfaces can be represented by impedance boundary conditions. Generally, surfaces coated with dielectric material have reduced radar cross sections in comparison to perfectly conducting surfaces of the same shape.

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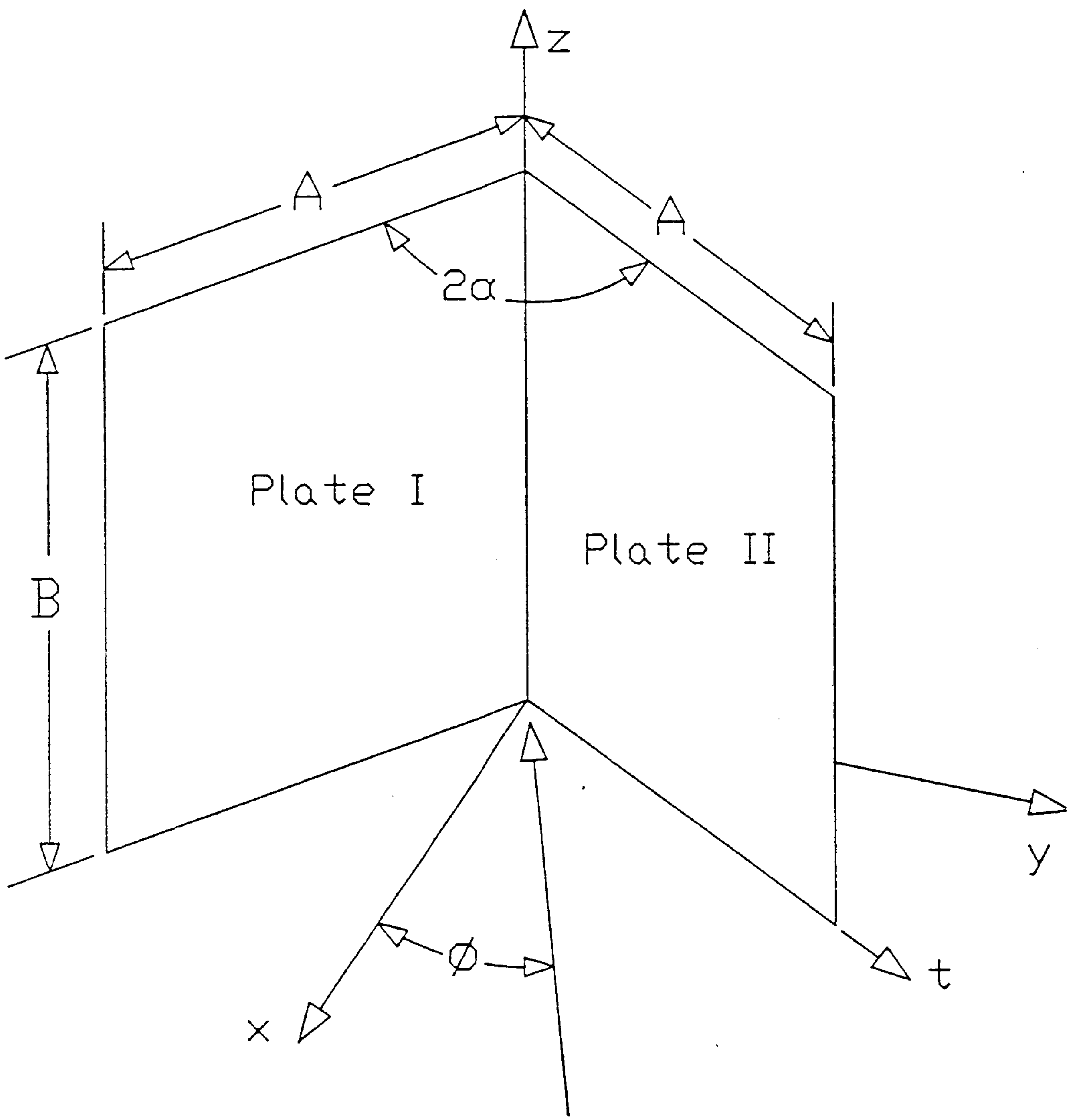


Figure 1. The dihedral corner reflector geometry.

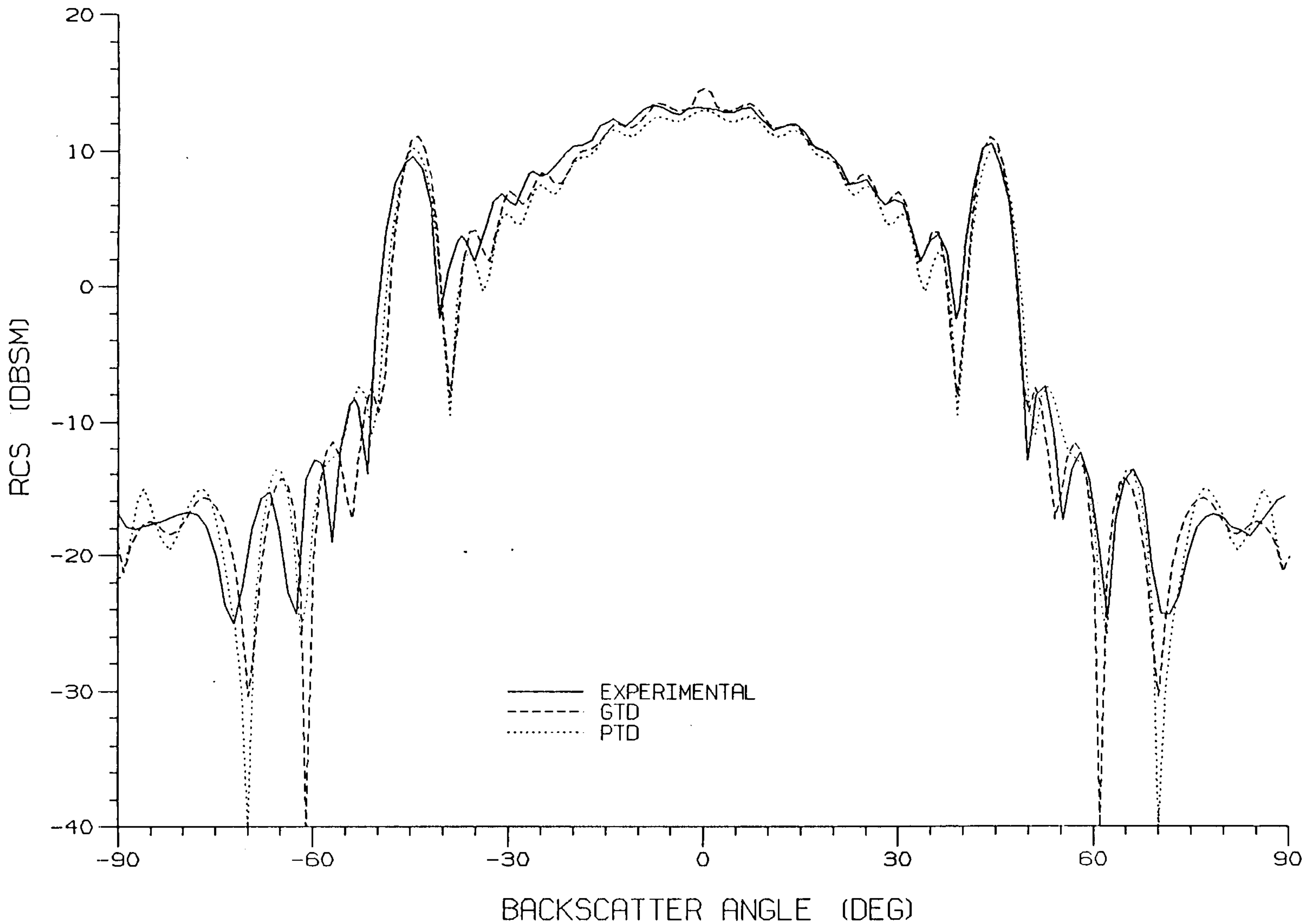


Figure 2. Experimental, Geometrical Theory of Diffraction, and Physical Theory of Diffraction cross sections for the 90° dihedral corner reflector. (A = B = 5.6088λ, vertical polarization, f = 9.4 GHz)

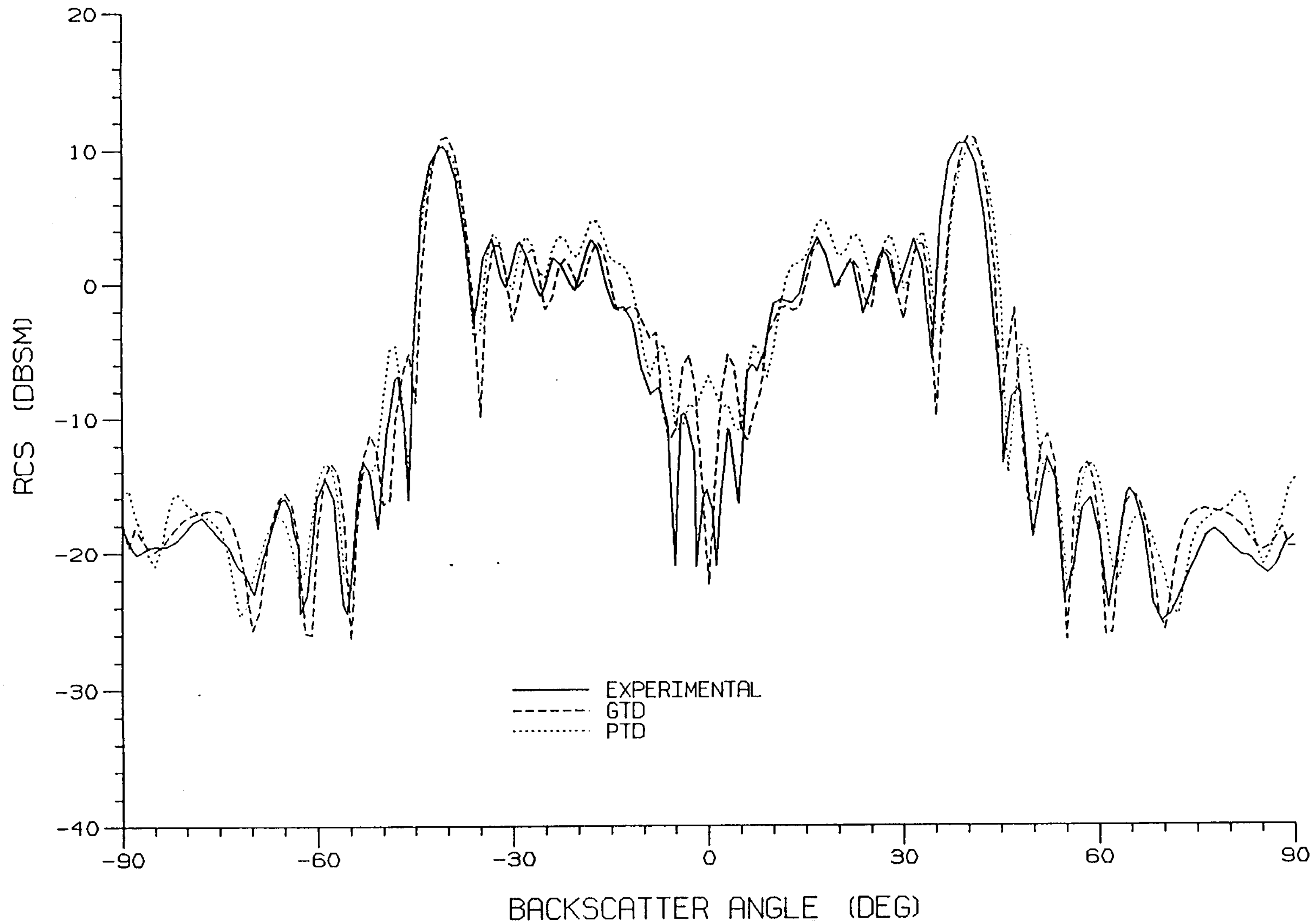


Figure 3. Experimental, Geometrical Theory of Diffraction, and Physical Theory of Diffraction cross sections for the 98° dihedral corner reflector. (A = B = 5.6088λ, vertical polarization, f = 9.4 GHz)

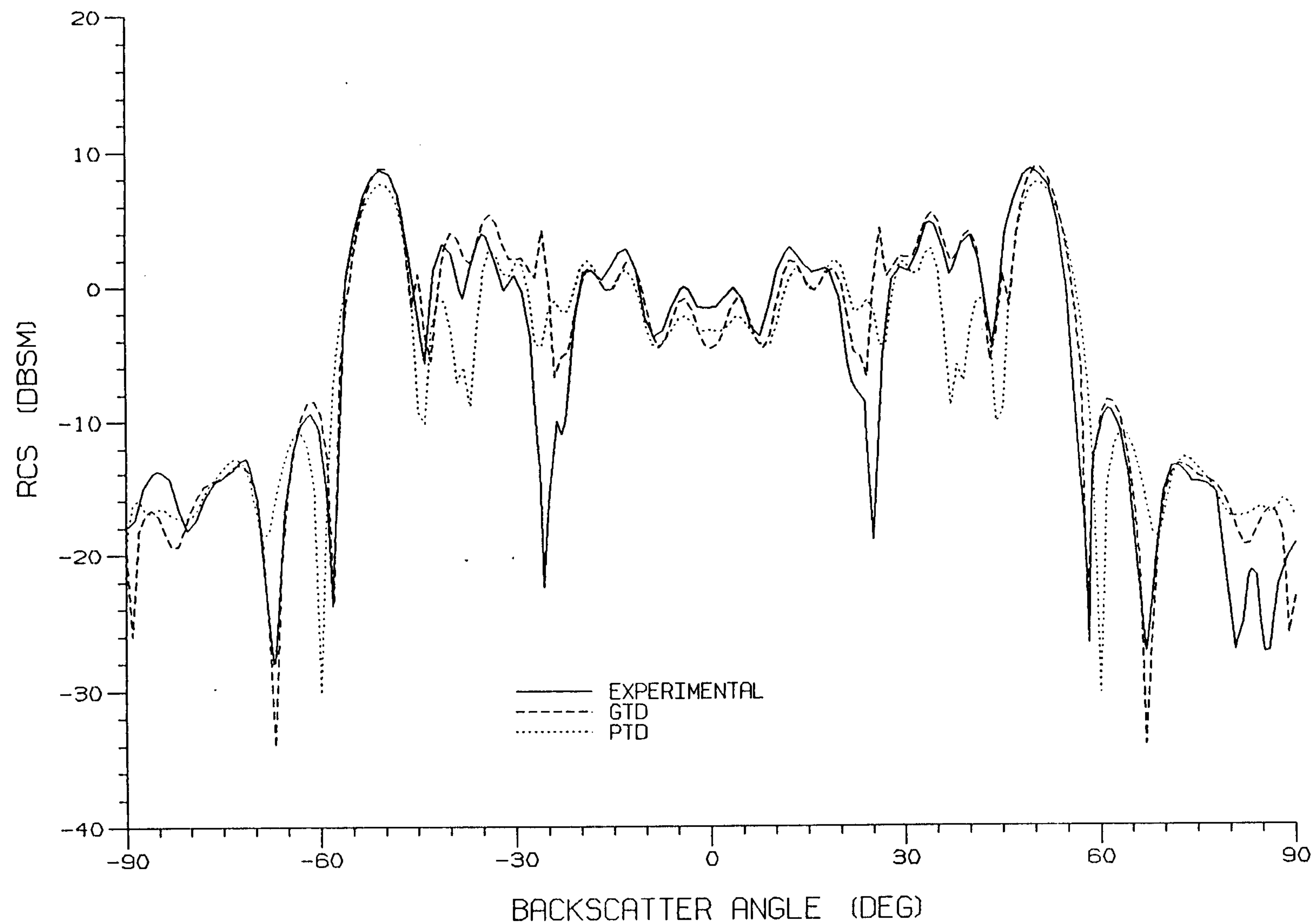


Figure 4. Experimental, Geometrical Theory of Diffraction, and Physical Theory of Diffraction cross sections for the 77° dihedral corner reflector. ($A = B = 5.6088\lambda$, vertical polarization, $f = 9.4$ GHz)

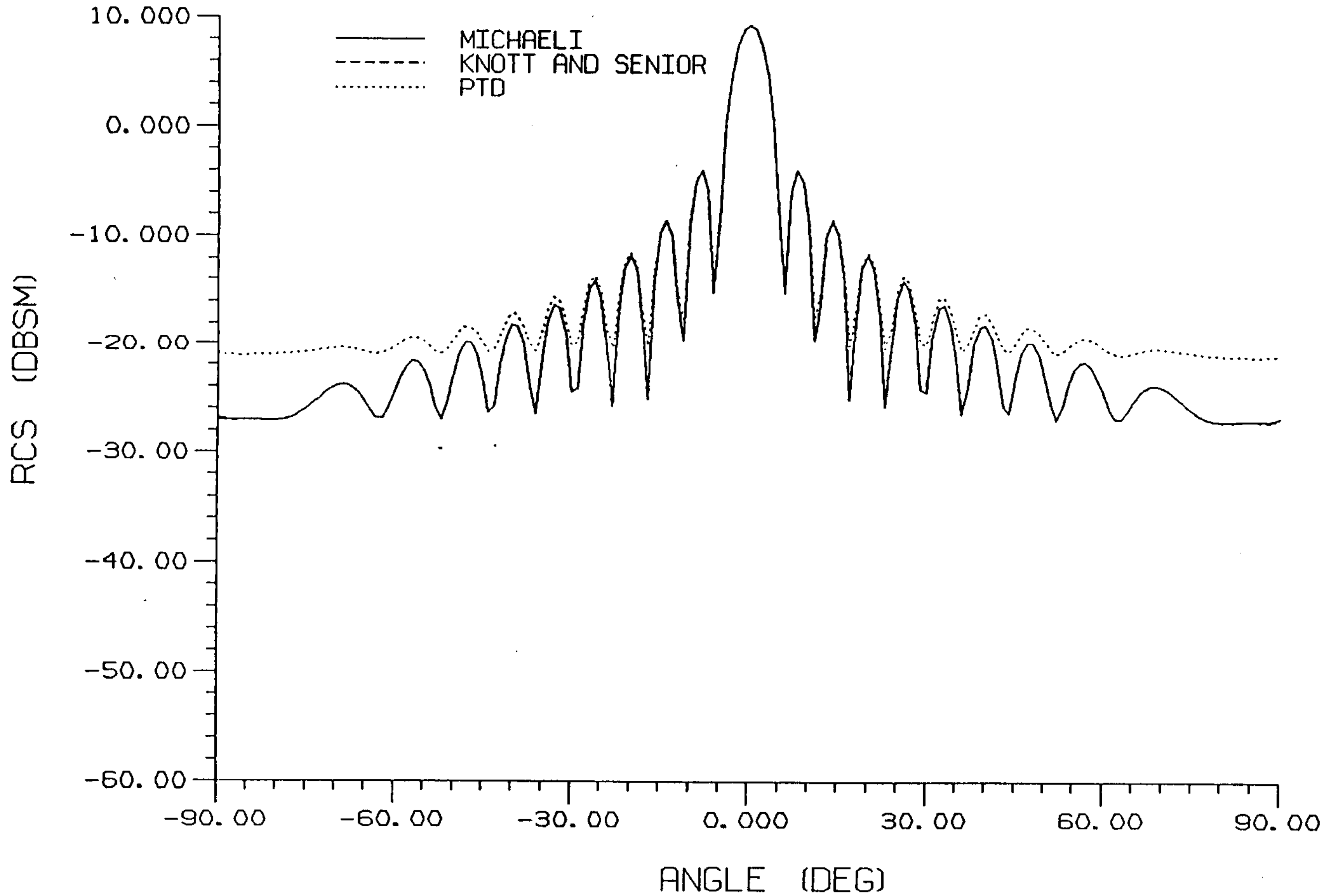


Figure 5. Cross section of a square plate using Knott and Senior's equivalent current, Michaeli's equivalent current, and the Physical Theory of Diffraction.
($A = 5.0785\lambda$, hard polarization, $f = 9.228$ GHz, $\phi = 1°$)

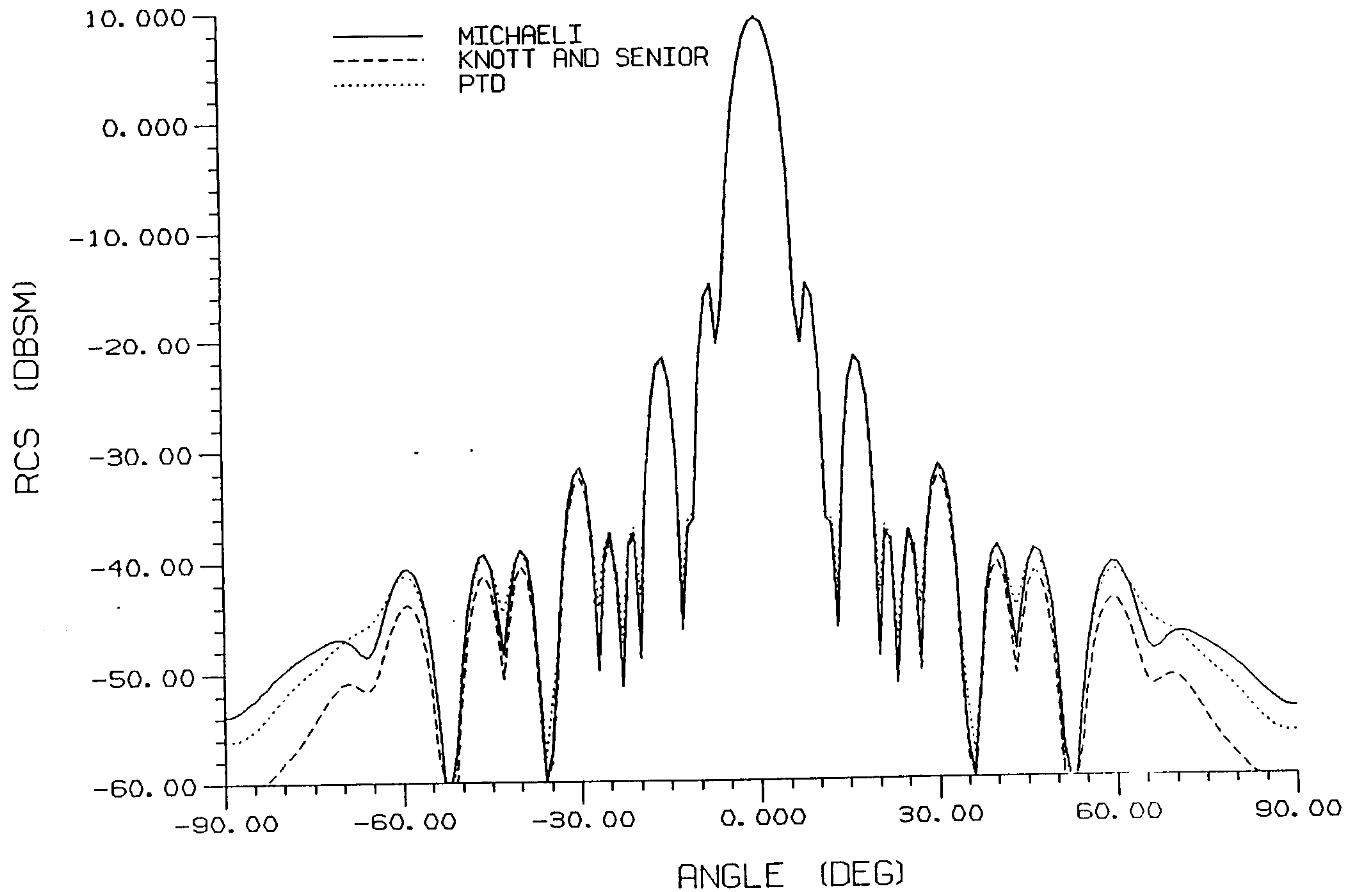


Figure 6. Cross section of a square plate using Knott and Senior's equivalent current, Michaeli's equivalent current, and the Physical Theory of Diffraction.
($A = 5.0785\lambda$, hard polarization, $f = 9.228$ GHz, $\phi = 30°$)

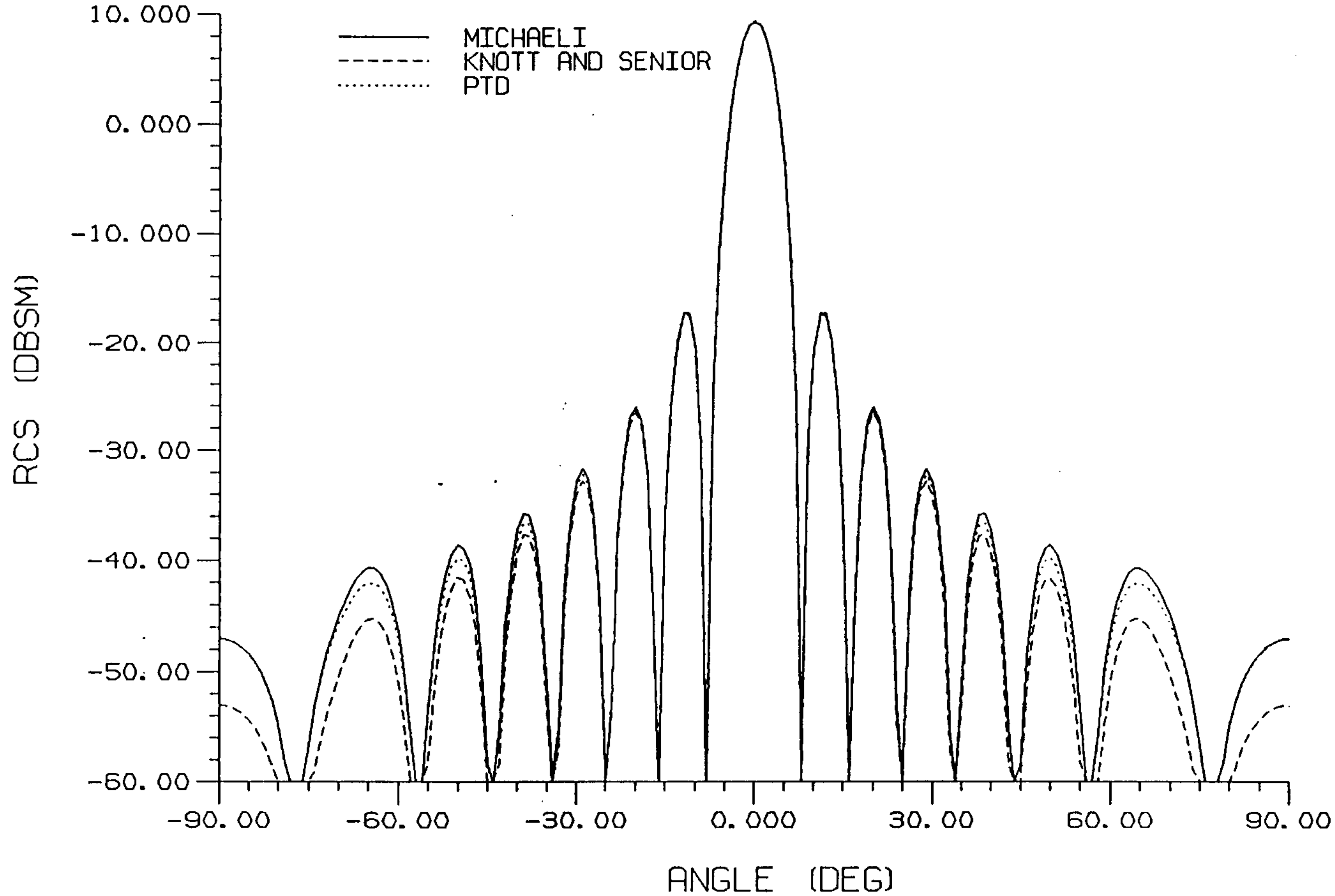


Figure 7. Cross section of a square plate using Knott and Senior's equivalent current, Michaeli's equivalent current, and the Physical Theory of Diffraction.
($A = 5.0785\lambda$, hard polarization, $f = 9.228$ GHz, $\phi = 45°$)