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The Ohio State University

ElectroScience Laboratory

Department of Electrical Engineering
Columbus, Ohio 43212

Second Annual Report 710816-6

Contract N00014-78-C-0049

December 1979

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This report presents the second annual review of research at Ohio State sponsored by the Joint Services Electronics Program (JSEP). The research is in the area of electromagnetics and the specific topics are: (1) Diffraction Studies; (2) Hybrid Techniques; (3) Antenna Studies; (4) Time Domain Studies; and (5) Adaptive Array Studies.

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CONTENTS

I. INTRODUCTION

This report presents the second annual summary of research at Ohio State sponsored by the Joint Services Electronics Program (JSEP). The research is in the area of electromagnetics and the specific topics are: (1) Diffraction Studies; (2) Hybrid Techniques; (3) Antenna Studies, (4) Time Domain Studies; and (5) Adaptive Array Studies.

The following sections summarize the significant accomplishments of the program (Section II) and the research by work unit (Section III). Researchers and their publications are listed under each work unit. A listing of the present research programs at the Laboratory and all reports and papers published by the Laboratory during the past year are given in the Appendices.

II. SIGNIFICANT ACCOMPLISHMENTS

The diffraction coefficients and other parameters of the uniform Geometrical Theory of Diffraction (GTD) obtained by Kouyoumjian and Pathak and their associates have been employed in many computer codes for calculating the patterns of reflector antennas and antennas on aircraft, missiles, satellites, ships and in other environments. These codes have been widely used in both the U. S. and Western Europe; they have been found to give surprisingly accurate results. It is reasonable to expect that these codes will be updated, using the recent contributions described here, in order to increase both their versatility and accuracy. In the present period the contributions in diffraction theory of greatest importance are the uniform expressions for the fields diffracted at convex surfaces, where the source may be either on or off the surface, and at vertices. They have already been incorporated in the ElectroScience Laboratory codes. The diffraction coefficient for two closely-spaced edges was just developed this past summer; hence it is too early to assess the extent of its use. Also, the importance of a progressing wave version of the uniform GTD in the time domain has not been fully explored; however, it has been demonstrated to be useful in determining the early-time responses to EMP illumination. In addition to the oral and written papers, a further effort was made to disseminate the new uniform GTD results. Invited lectures were presented at two symposia and two book chapters were written.

Using combined GTD and Moment Method (hybrid) techniques, the very useful diffraction coefficient for a cylindrically truncated planar surface has been completed for both hard and soft boundary conditions and for a source either on or off the planar surface. This coefficient is particularly useful in the analysis and design of horn and reflector antennas with low side and back lobes.

Many practical antenna applications involve monopole-type antennas mounted near the edge of a surface or structure. Significant progress has been made during the present program in developing a useful mathematical model for a wire attached to a surface near the edge of the surface. Also, an improved representation of a nonrectangular surface in terms of polygon-shaped surface current patches has been obtained.

Perhaps the most significant accomplishment of our time domain research during the present contract period has been the establishment of a firm understanding of how the various methods for extracting parameters from a noisy transient waveform compare. The superiority of an eigenanalysis method was determined as was its relationship to the noise present in the signal. A method, using eigenanalysis, was also developed for finding that difference equation best suited to various signal records from a target. With this in hand, the needed preprocessing noise treatment can now be studied. A new geometrical method using signal flow graphs and the K-Pulse concept has been developed for obtaining the complex natural resonances of finite conducting objects. The geometrical approach has been applied to predict the resonances of spherical and wire objects. Oral papers have been presented and invited papers written to disseminate the results of our time domain work.

Adaptive antenna arrays are playing an increasingly important role in interference-resistant communications. During the past year an improved LMS loop has been developed to eliminate time constant variation with signal power and hence improve the dynamic range of an adaptive antenna system. Also, the problem of grating lobes, which normally occur for widely spaced elements, has been solved by properly selecting the element patterns in an adaptive array of widely spaced elements. Polarization flexibility has been studied and found to greatly enhance the performance of an adaptive antenna system. Polarization control can be used to make a communications system much more resistant to intentional interference. Significant improvement also has been made in acquisition of a desired signal in the presence of interference by using a power optimization algorithm.

III. RESEARCH SUMMARY

A. Diffraction Studies

Researchers: R. G. Kouyoumjian, Professor (Phone: (614)422-7302)
R. Tiberio, visiting Professor
P. H. Pathak, Senior Research Associate
N. Wang, Senior Research Associate
T. Jirapunth, Graduate Research Associate

Accomplishments

During the present contract period the work accomplished in extending the uniform geometrical theory of diffraction (UTD) has been substantial. This is composed of the research and writing which is detailed in the paragraphs to follow.

1. Diffraction at Convex Surfaces

a. Diffraction at the shadow boundary of a smooth convex surface

A paper entitled "A Uniform GTD Analysis of the Scattering of Electromagnetic Waves by a Smooth Convex Surface" has been written by P. H. Pathak, W. D. Burnside and R. J. Marhefka. This paper has been accepted for publication in the IEEE Transactions on Antennas and Propagation.

In this paper an approximate asymptotic high frequency result is obtained for the field scattered by a smooth, perfectly-conducting convex surface when it is excited by an arbitrary electromagnetic wavefront. This asymptotic result is uniform in the sense that it is valid within the transition regions adjacent to the shadow boundaries where the pure ray optical solution based on the geometrical theory of diffraction (GTD) fails, and it reduces to the GTD solution in terms of the incident, reflected, and surface diffracted rays exterior to the transition regions where the latter solution is indeed valid. This result employs the same ray paths as in the GTD solution, and it is expressed in the simple format of the GTD; therefore, it may be viewed as a uniform GTD solution for this problem. In that this solution is developed in the GTD format, it can be conveniently and efficiently applied to many practical problems. For example, it could be used to analyze the scattering effects of the mast on a ship, the fuselage of an aircraft, etc.

b. The radiation from sources on a convex surface

A paper entitled "A Uniform GTD Solution for the Radiation from Sources on a Perfectly-Conducting Convex Surface" written by P. H. Pathak, N. Wang, W. D. Burnside, and R. G. Kouyoumjian has been submitted for publication to the IEEE Transactions on Antennas and Propagation. An oral version of this paper was presented at the International IEEE/APS Symposium in Seattle, Washington held June 18-22, 1979.

A compact, approximate asymptotic solution is developed in this paper for the fields radiated by antennas on a perfectly-conducting smooth convex surface. This high-frequency solution employs the ray coordinates of the GTD. In the shadow region, the field radiated by the source propagates along Keller's surface diffracted ray path; whereas in the lit region, the incident field propagates along the geometrical optics ray path direct from the source to the field point. These ray fields are expressed in terms of Fock functions; they reduce to the geometrical optics field in the deep lit region and remain uniformly valid across the shadow boundary transition region into the deep shadow region. Surface ray torsion, which affects the radiated field in both the shadow and transition regions, appears explicitly in the solution as a torsion factor. The radiation patterns of slots and monopoles on cylinders, cones and spheres calculated from this solution agree very well with those obtained from exact solutions. In addition, the solution accurately predicts the measured radiation patterns of slots and monopoles mounted on a prolate spheroid.

c. Mutual coupling between antennas on a convex surface

A paper entitled "Ray Analysis of Mutual Coupling between Antennas on a Convex Surface," by P. H. Pathak and N. N. Wang is now in manuscript form and will be submitted for publication very shortly to the IEEE Transactions on Antennas and Propagation. An oral version of this paper was presented at the International IEEE/APS Symposium in Seattle, Wash. held June 18-22, 1979.

In this paper, an asymptotic high frequency solution is presented for the electromagnetic fields induced on an arbitrary smooth, convex conducting surface by an infinitesimal magnetic or electric current moment which is placed on the same surface. These surface fields propagate along Keller's surface ray paths, and their description remains uniformly valid along the rays including the immediate vicinity of the source. An important feature of this solution is that the effect of surface ray torsion on the surface ray fields is explicitly identified. This solution can be readily employed to calculate the mutual coupling between antennas on a convex conducting surface in an efficient and accurate manner. Numerical results for the mutual coupling between slots and also between short, thin monopoles which are located on a conducting cylinder, cone, and a prolate spheroid are presented to demonstrate this.

d. The radiation and scattering from conducting surfaces with a surface impedance loading

A paper entitled "Radiation from Sources on Perfectly-Conducting Convex Cylinders with an Impedance Surface Patch" is being written by L. Ersoy and P. H. Pathak and will be submitted for publication to the IEEE Transactions on Antennas and Propagation. An oral version of this paper was presented at the International IEEE/APS Symposium in Seattle, Washington held June 18-22, 1979.

This paper deals with an asymptotic high frequency analysis of the radiation patterns of a magnetic line source, or a magnetic line dipole, located on a uniform impedance surface patch which partly covers an electrically large, perfectly conducting convex cylinder. This work is relevant, for example, to the study of fuselage mounted airborne antennas for satellite communication purposes. In the latter application it is of interest to see if an impedance surface patch can be employed to increase the radiation intensity in the vicinity of the horizon over that which would ordinarily exist in the absence of such an impedance loading.

In the present analysis, the impedance surface patch is seen to constitute an equivalent aperture in the rest of the perfectly conducting convex cylinder. Approximate asymptotic expressions for the "equivalent aperture distribution"; i.e., for the "currents on the impedance surface patch" are developed in this work for the two source types; these expressions for the currents are valid in the neighborhood of each source. The radiation pattern of this configuration is then found in a straightforward manner by numerically integrating this current distribution in conjunction with a simple and accurate asymptotic high frequency form of the perfectly conducting, convex cylinder Green's function (rather than the usual free space Green's function). Since the cylinder Green's function is employed, one needs to integrate only over the currents which exist on the impedance surface patch (i.e., over the equivalent aperture) and not over the currents on the remaining, perfectly conducting portion of the cylinder.

Radiation pattern calculations based on this analysis are found to compare quite well with those of a moment method type solution and also with some presently available experimental results for this problem. It is seen that a moderately large increase in the radiation intensity can be obtained in the vicinity of the horizon for cylinders loaded by an impedance surface.

2. Extensions of Edge Diffraction

Consider a high-frequency EM field obliquely incident on the perfectly-conducting curved wedge as shown in Figure A-1. ES indicates the planes tangent to the convex surfaces of the curved wedge at the point of diffraction Q_E. The diffraction coefficients given by Kouyoumjian and Pathak[4] are valid in the exterior region away from the planes ES; in particular, they remain valid at and near the shadow boundary SB and the reflection boundary RB, where the earlier expressions given by Keller fail. However, the diffraction from surface rays S_r excited at Q_E must be included in the region near ES and in the region between ES and S_r. Thus a natural first step to improve the present GTD solution for the curved wedge is to determine these surface ray contributions. Additional improvements can be made by extending the present treatment of wedge diffraction to include the illumination by non ray-optical fields, such as transition region fields or the fields from sources very close to the edge. The accomplishments in the research on the edge diffraction of transition region fields will be described first.

a. Edge illumination by non ray-optical fields

A paper entitled "A Uniform GTD Solution for the Diffraction by Strips Illuminated at Grazing Incidence" by R. Tiberio and R. G. Kouyoumjian appears in the December 1979 issue of Radio Science.

The contents of this paper are related to the more general case of diffraction by a pair of nearby, parallel edges, where one edge lies on the shadow boundary of the other. The method of analysis is described in a paper entitled "An Analysis of Diffraction at Edges Illuminated by Transition Region Fields", which has been written by R. Tiberio and R. G. Kouyoumjian and will be submitted to Radio Science.

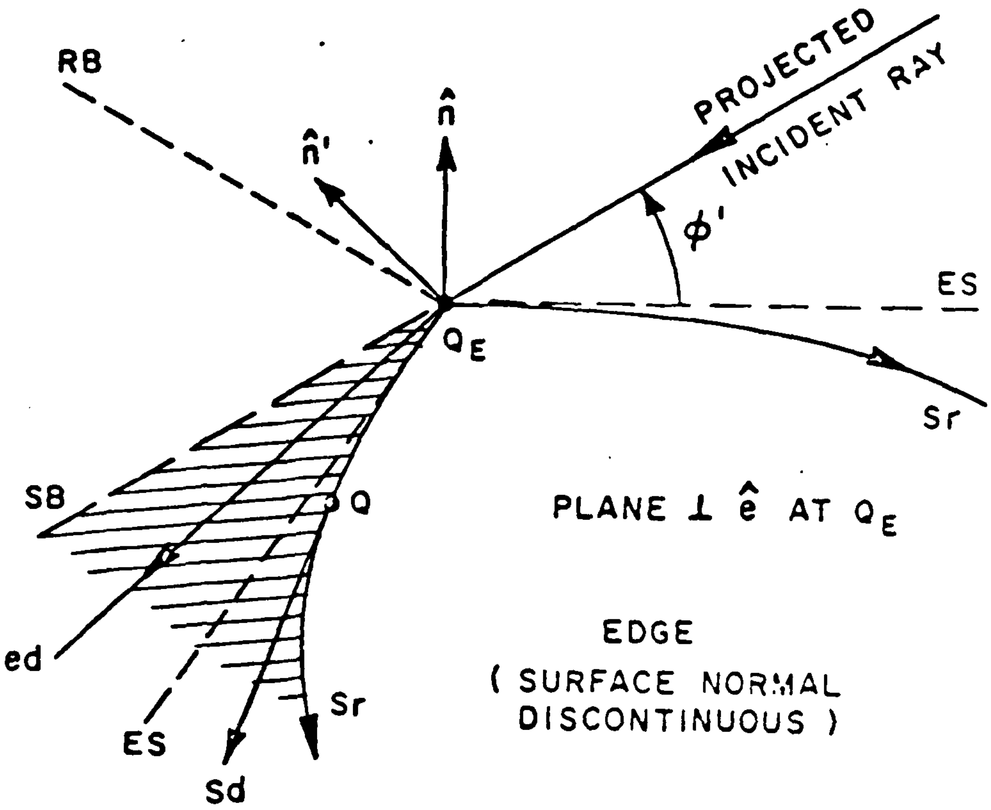

Figure A-1. Incident, reflected and diffracted rays and their associated shadow and reflection boundaries projected onto the plane normal to the edge at the point of diffraction Q_E.

In this paper a solution for the field of the doubly-diffracted ray is obtained by a spectral extension of the uniform GTD. Expressions for the diffracted field are given for plane, cylindrical and spherical wave illuminations. Incidence oblique to the edges is also considered. These expressions reduce to a closed form at the shadow boundaries and outside the overlapping transition regions where the results coincide with those obtained by the uniform GTD augmented by slope diffraction. The solutions to the scalar problems are then used to derive a dyadic diffraction coefficient for the doubly-diffracted field in the ray-fixed coordinate system.

To evaluate and test this solution, it has been applied to calculate the fields diffracted and scattered from a number of geometries involving interacting edges, which are illuminated at grazing incidence, e.g., the strip, staggered parallel plates, the thick edge, the rectangular cylinder, and the aperture in a thick screen. Comparisons with numerical results obtained by other methods are excellent even though the surface exposed to grazing incidence is no more than a few tenths of a wavelength wide. A paper describing these calculations (except for the strip and the aperture in a thick screen) is now in manuscript form.

The diffraction by a slit in a thick screen involves a pair of interacting thick edges. A paper entitled "Application of the Uniform GTD to the Diffraction by an Aperture in a Thick Screen" was presented by R. Tiberio and R. G. Kouyoumjian at the IEEE/APS Symposium in Seattle, Washington held June 18-22, 1979. A written version of this paper, which contains some additional analysis, is planned.

b. Edge-excited surface rays

Curved wedges occur as a part of many practical antenna and scattering shapes, e.g., the edge of a reflector antenna, the base of conical and cylindrical structures, and the trailing edge of wings and stabilizers. A curved wedge may have a plane surface; however, the edge-excited surface rays do not have to be introduced separately at this surface. They occur as part of the space ray system. At a concave surface forming a curved wedge, multiply-reflected waves and whispering gallery modes are excited.

In the case of the convex surface, outside the region where there is a confluence of the edge and curved surface shadow boundaries, the excitation of the surface rays S_r at Q_E in Figure A-1 has been determined from the GTD parameters which are presently available. A paper describing this research is in manuscript form.

3. Vertex Diffraction

In many practical antenna problems one encounters situations where an antenna radiates in the presence of finite, planar structures with edges which terminate in a vertex (or corner), e.g., an antenna radiating in the presence of a finite, rectangular ground plane. Also, flat plates with edges are used in the modeling of aircraft wings and vertical or horizontal stabilizers for analyzing on-aircraft antenna patterns. In the above problems, the antenna pattern is affected by the diffraction of electromagnetic waves not only by the edges but also by the vertices or corners.

The problem of electromagnetic vertex diffraction is rather complicated. A formally exact eigenfunction solution has been obtained earlier at the ElectroScience Laboratory[1]; however, this solution is not given in terms of simple functions and it is therefore quite difficult to implement in the GTD format. Some approximate, asymptotic high-frequency solutions to the vertex or corner diffraction problem have been presented for the acoustic case[2,3]. While these solutions constitute a first step in obtaining useful solutions, they are not uniform in that the vertex diffraction coefficient obtained is not valid along the vertex and edge shadow boundaries where the edge and vertex diffracted fields assume their greatest magnitude and importance. It is therefore desirable to begin a study of vertex diffraction with a view toward obtaining a vertex diffraction coefficient which remains valid at and close to these boundaries.

Presently, a vertex diffraction coefficient has been obtained via an asymptotic evaluation of the radiation integral which employs the equivalent edge currents that would exist in the absence of the vertex. The vertex diffraction term is then found by appropriately (but at present empirically) modifying the asymptotic result for the radiation integral which is characterized by a saddle point near an end point. This diffraction coefficient is still in the initial stages of its development. However, it has been shown to very successfully predict the corner effect for numerous plate structures. A paper describing this vertex diffraction coefficient is planned.

4. Time-domain GTD

The development of a time-domain version of the GTD in terms of progressing waves is of value because some of the advantages of the GTD in the frequency domain carry over directly to the transient analysis. For example, the method may be applied to complex shapes which occur in practice and the resulting solution in terms of ray contributions easily can be identified with the radiation mechanisms involved (reflection, edge diffraction, surface diffraction, etc.). These transient solutions may be used to determine the response of objects exposed to EMP or to study problems connected with target identification. Also, it is often possible to test and compare high-frequency solutions more conveniently by inversely transforming them to the time domain.

Recently the transient responses of currents and charges induced on a perfectly-conducting plane surface bounded by edges were considered. The responses in the early-time period, which can be found by inversely transforming the high frequency solutions, were of interest. The suitability of several asymptotic edge-diffraction solutions was examined. It was found that the uniform GTD[4] provides the best solution for early and intermediate times following the arrival of the edge-diffracted wavefront. The currents and charges on the plane surface are represented as the sum of a geometrical optics contribution and contributions from rays singly and doubly diffracted from the edges. The problem of a perfectly-rays do not have to be introduced separately at this surface. They occur as part of the space ray system. At a concave surface forming a curved wedge, multiply-reflected waves and whispering gallery modes are excited.

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Publications and Presentations

I. Articles

1. "Surface-wave Diffraction by a Truncated Dielectric Slot Recessed in a Perfectly-Conducting Surface", by P. H. Pathak and R. G. Kouyoumjian, J. Radio Science, vol. 14, No. 3, May-June 1979, pp. 405-418. (This work has been jointly supported by JSEP-Office of Naval Research Contract N00014-78-C-0049 and NASA Grant No. NGR 36-008-0144.)

2. "A Uniform GTD Solution for the Diffraction by Strips Illuminated at Grazing Incidence", by R. Tiberio and R. G. Kouyoumjian, J. Radio Science, pp. 933-941, November-December 1979. (This work has been supported by JSEP-Office of Naval Research Contract N00014-78-C-0049).

3. "A Uniform GTD Analysis of the Diffraction of Electromagnetic Waves by a Smooth Convex Surface", by P. H. Pathak, W. D. Burnside, and R. J. Marhefka, paper accepted for publication in IEEE Trans. on Antennas and Propagation (This work has been jointly supported by JSEP and NADC.)

4. "A Uniform GTD Solution for the Radiation from Sources on a Perfectly-Convex Surface", by P. H. Pathak, N. N. Wang, W. D. Burnside, and R. G. Kouyoumjian, paper submitted to IEEE Trans. on Antennas and Propagation. (This work has been jointly supported by JSEP and NASC Contract No. N00019-78-C-0524.)

5. "An Analysis of Diffraction at Edges Illuminated by Transition Region Fields", by R. Tiberio and R. G. Kouyoumjian, paper submitted to J. Radio Science. (This work has been jointly supported by JSEP and NOSC)

II. Book Chapters

1. "The Uniform Geometrical Theory of Diffraction and it's Application to Electromagnetic Radiation and Scattering", by R. G. Kouyoumjian, P. H. Pathak, and W. D. Burnside, in: Recent Developments in Classical Wave Scattering - Focus on the T-matrix Approach, eds. V. K. Varadan and V. V. Varadan, Pergamon, New York, pp. 373-397, in press.

2. "A Uniform GTD for the Diffraction by Edges, Vertices, and Convex Surfaces", by R. G. Kouyoumjian, P. H. Pathak, and W. D. Burnside, 65 pages in Theoretical Methods for Determining the Interaction of Electromagnetic Waves with Structures, ed., J. K. Skwirzynski, Sijthoff and Noordhoff, Netherlands, in press.

III. Theses and Dissertations

1. "Radiation by Sources on Perfectly-Conducting Convex Cylinders with an Impedance Patch" by L. Ersoy (Dissertation). (This work has been supported in part by JSEP and Air Force Cambridge Research Center Contract F19628-77-C-0107.

2. "Early-Time Response of Currents and Charges Induced on Perfectly-Conducting Wedge and Strips" by T. Jirapunth (Thesis). (This work has been supported in part by JSEP and Dikewood Industries, Inc. on subcontract DS-SC-77-01).

IV. List of Oral Papers Presented at the 1979 International AP-S/URSI Symposium in Seattle, Washington, June 18-22, 1979:

1. "A Uniform GTD Solution to the Radiation from Sources on a Perfectly-Conducting Convex Surface", P. H. Pathak, N. Wang, W. D. Burnside and R. G. Kouyoumjian.

2. "Application of the Uniform GTD to the Diffraction by an Aperture in a Thick Screen", R. Tiberio and R. G. Kouyoumjian.

3. "The Early-Time Responses of Currents and Charges on Wedges and Strips", T. Jirapunth and R. G. Kouyoumjian.

4. "An Analysis of the Mutual Coupling Between Antennas on a Smooth Convex Surface", P. H. Pathak and N. N. Wang.

5. "Radiation by Sources on Perfectly Conducting Convex Cylinders with an Impedance Surface Patch", L. Ersoy and P. H. Pathak.

V. Lectures

1. "The Uniform GTD and its Application to Electromagnetic Radiation and Scattering", by R. G. Kouyoumjian, at the International Symposium on: Recent Developments in Classical Wave Scattering - Focus on the T-matrix Approach, The Ohio State University, Columbus, Ohio, June 25-27, 1979.

2. "A Uniform GTD for the Diffraction by Edges, Vertices, and Convex Surfaces", by R. G. Kouyoumjian and P. H. Pathak, at the NATO-Advanced Study Institute on Interaction of EM Waves with Structures, Norwich, England, July 23-August 4, 1979.

B. Hybrid Techniques

Researchers: W. D. Burnside, Research Scientist and
Adjunct Associate Professor (Phone: (614)422-5747)
G. A. Thiele, Associate Professor (Phone: (614)422-1760)
C. Chuang, Senior Research Associate
S. Goad, Graduate Research Associate
L. Henderson, Graduate Research Associate

Accomplishments

1. GTD-MM Studies

The numerical solution for the diffraction coefficient for a cylindrically truncated planar surface has been completed for both the hard- and soft-boundary cases. The source may be either mounted on or moved off the planar surface. The receiver is in the far field of the structure. Using this solution, calculation of the complete radiation pattern is very efficient and the computation time is almost independent of the radius of the curved surface. An example comparing the numerically-derived diffraction coefficient with the corresponding half-plane solution and Senior's solution for the case where a magnetic line source is mounted on the planar surface is shown in Figure B-1. Some illustrations of the use of this diffraction coefficient solution are discussed in the following paragraphs.

In the first case, it is used to determine the pattern of an axial slot mounted on a two dimensional cylinder as shown in Figure B-2. The agreement between the measured and calculated results is excellent.

Next, it is used to analyze the E-plane pattern of the horn configuration shown in Figure B-3. Again, excellent agreement between the measured and calculated results is obtained in the region $0^\circ \leq \phi \leq 120^\circ$. The measured pattern for the region $120^\circ \leq \phi \leq 180^\circ$ exceeded the range capability such that one could not obtain accurate low level radiation values.

The application of this diffraction coefficient solution to the design of a modified horn is very significant because a properly designed horn terminated by curved surface sections has several important features: 1) Both the side lobe ripple and the back lobe are greatly reduced by the addition of the curved surface sections as can be seen from Figure B-3 where a measured E-plane pattern of the conventional horn was included for comparison. 2) The virtual source of radiation in the main beam remains fixed at the horn vertex. 3) The change in the pattern is small over a broad frequency band as shown in Figure B-4. 4) A very low SWR can be obtained.

The pattern of a corrugated horn also possesses the first two features. However, a corrugated horn is relatively frequency sensitive and expensive to design and build. In contrast, a horn terminated by curved surface sections is easier to build and, with this diffraction coefficient solution, designing such a horn is very inexpensive and straightforward.

Finally, the diffraction coefficient solution is applied to the calculation of the radiation pattern of a parabolic cylinder reflector antenna. The reflector is terminated by curved surface sections as shown in Figure B-5(a). The primary feed is placed at the focus and has a feed pattern of the form $e^{-\psi^2}$. Figure B-5(b) shows the resultant radiation pattern and Figure B-5(c) the radiation pattern of the same reflector antenna except that the curved surface termination is removed. Comparison of the two patterns shows that the addition of the curved surface sections slightly raises the side lobe level but significantly reduces the back lobe level. By using the technique employed in Reference 1, this numerically derived diffraction coefficient solution also can be applied to the calculation of the radiation pattern of a three-dimensional reflector antenna.

2. MM-GTD Studies

The MM-GTD technique has been successfully extended to the case where a wire antenna is mounted on a curved surface. Figure B-6 shows the effect of the curvature of a circular cylinder on the input impedance of a monopole.

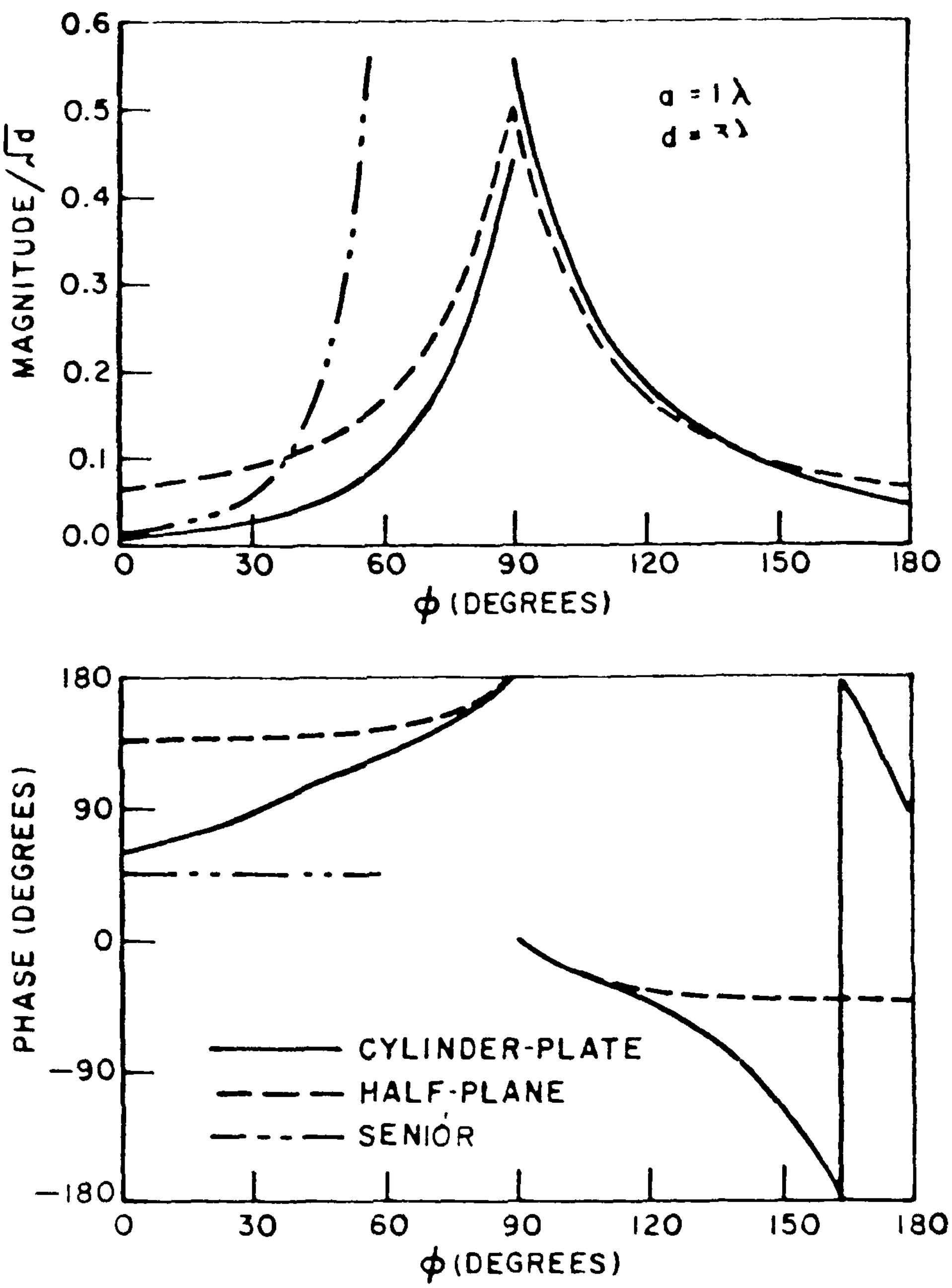


Figure B-1. An example of the numerically derived diffraction coefficient compared against the half-plane solution and Senior's solution. Note that a is the radius of the curved surface and d is the distance of the source from the plane-cylinder junction where $-90^0<\phi<90^0$ is the lit region and $90^0<\phi<270^0$ is the dark region.

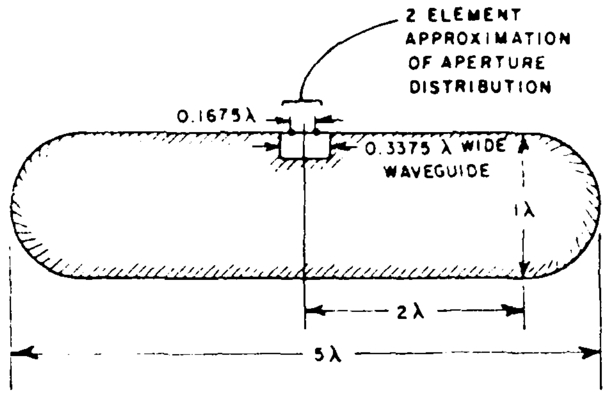


Figure B-2(a). Axial waveguide mounted on a two dimensional cylinder.

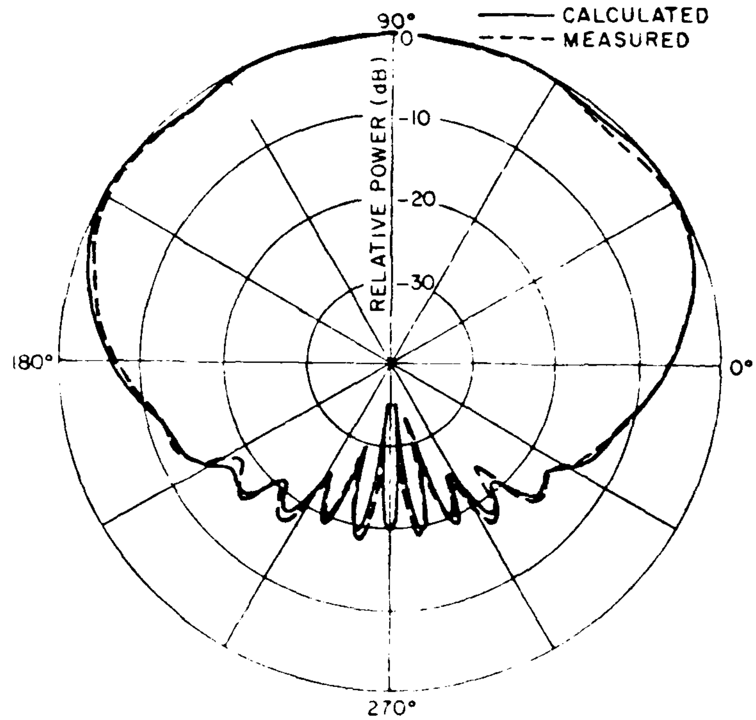


Figure B-2(b). Its radiation pattern.

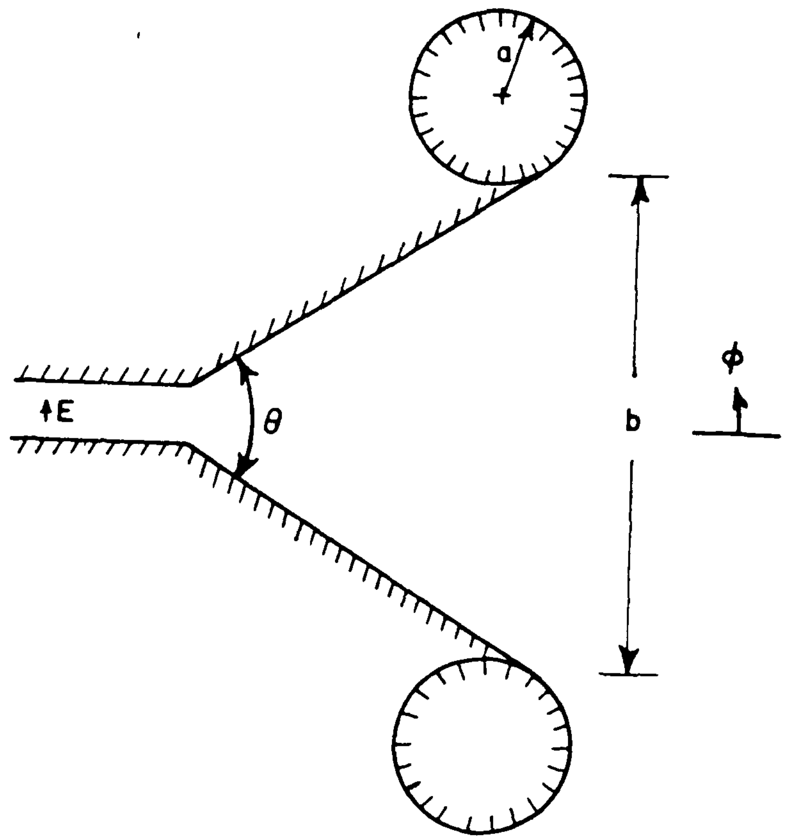


Figure B-3(a). Modified horn.

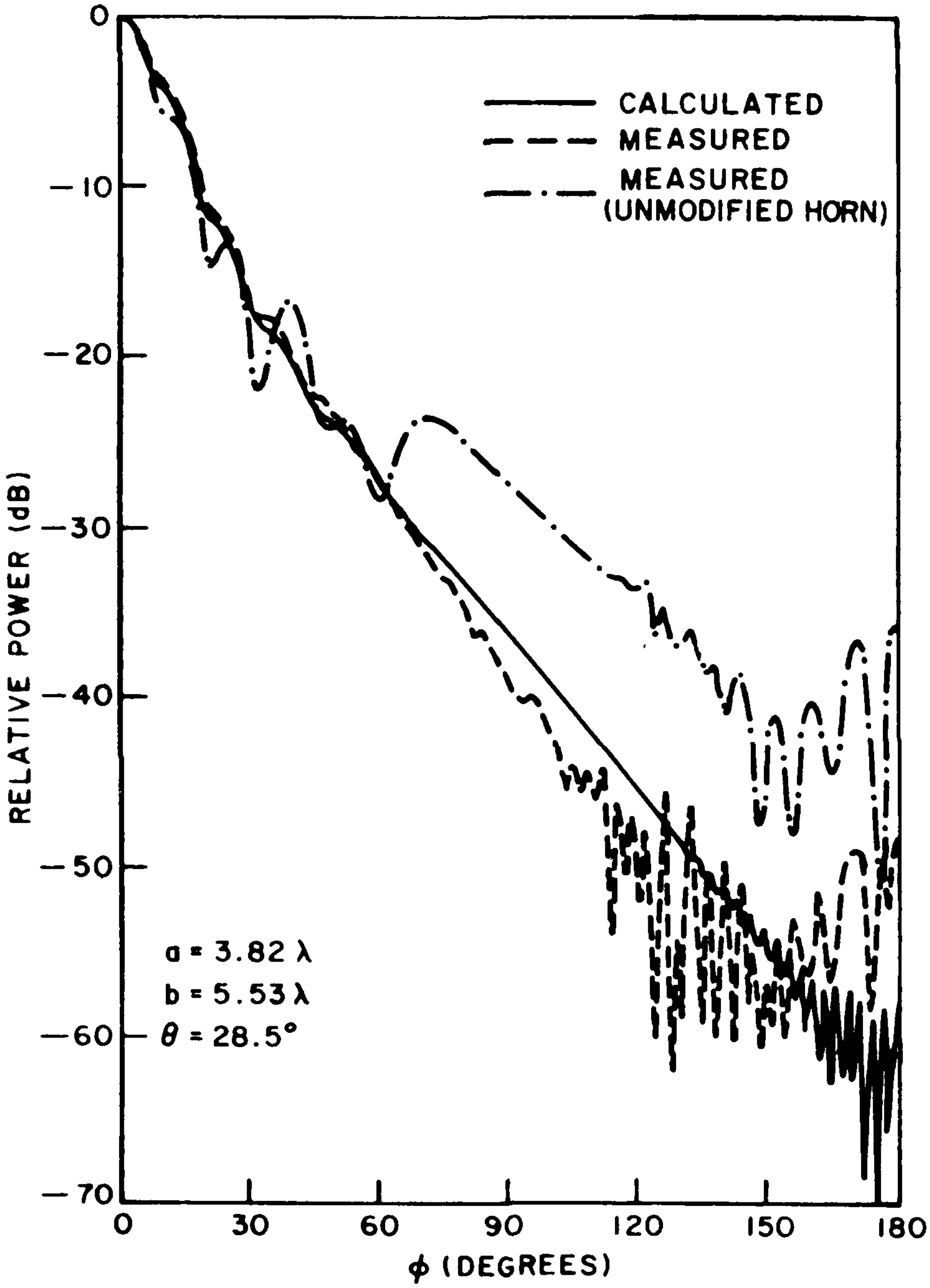


Figure B-3(b). E-plane pattern.

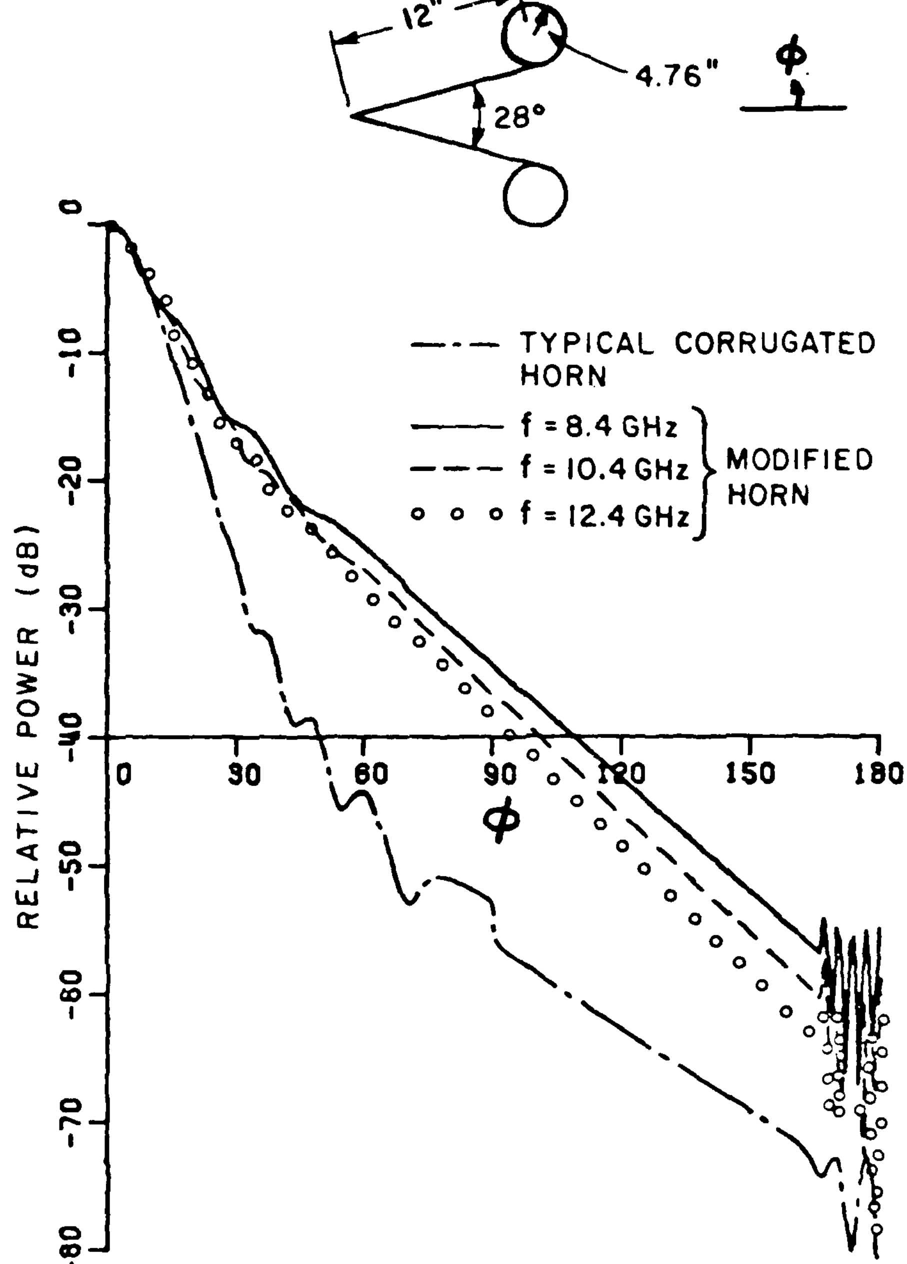


Figure B-4. Various calculated E-plane horn patterns.

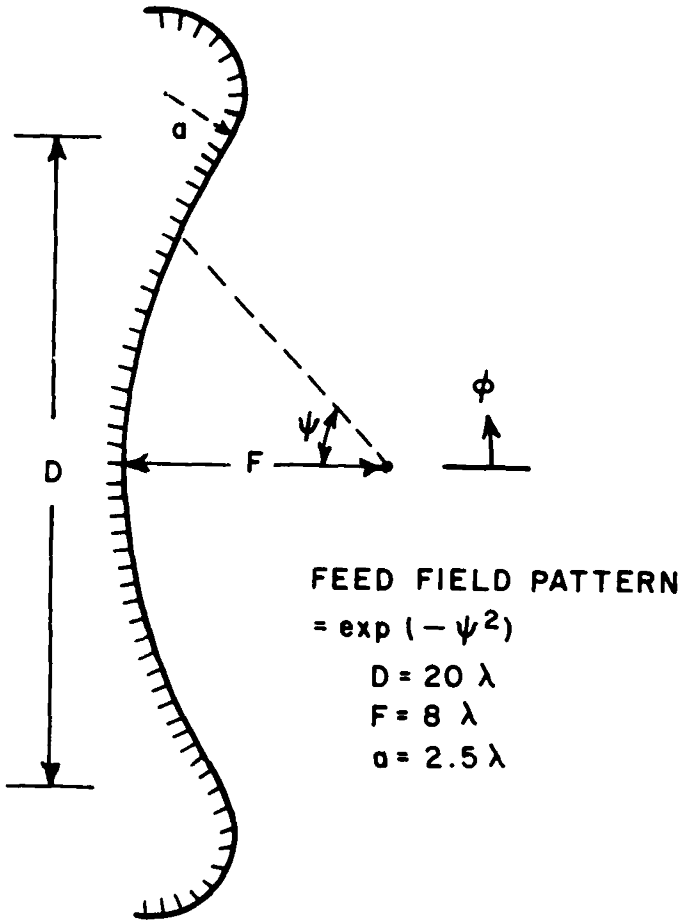


Figure B-5(a). Parabolic cylinder reflector antenna with curved surface terminations.

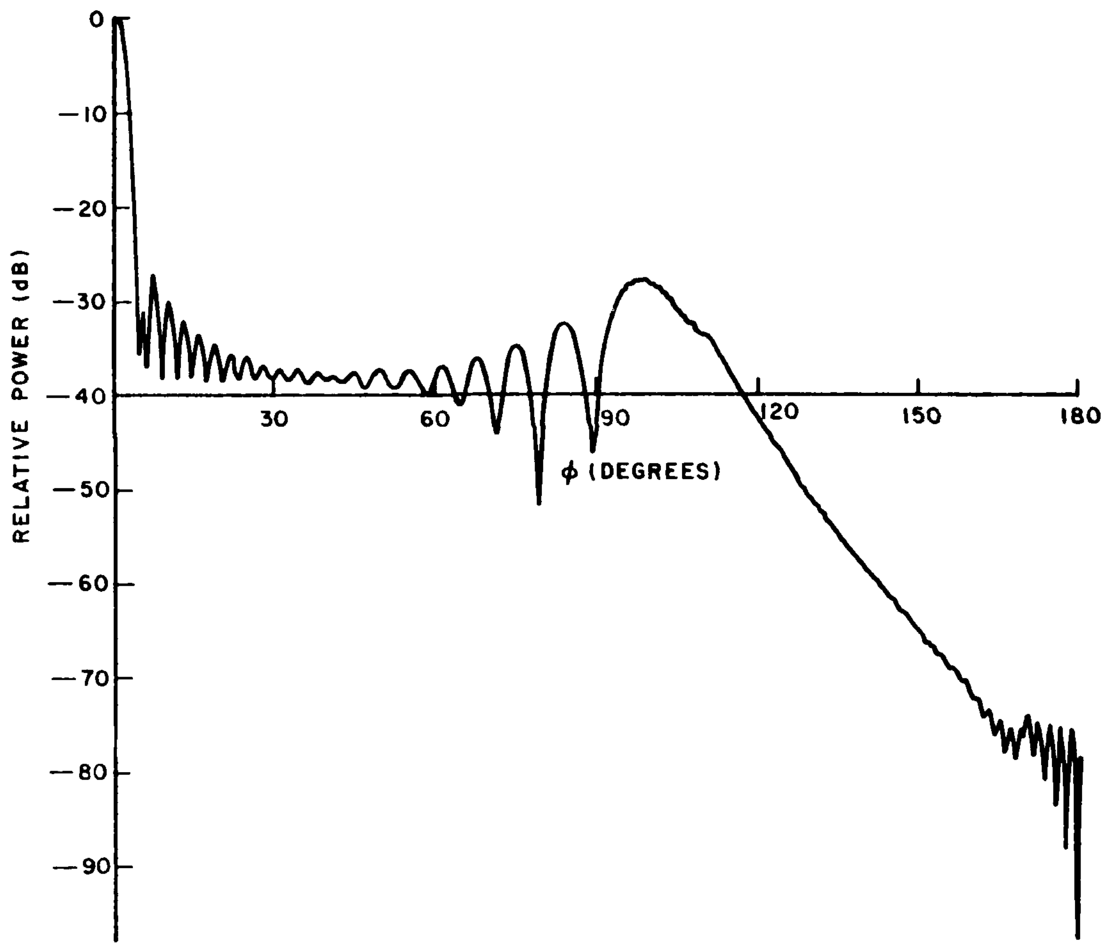


Figure B-5(b). Radiation pattern of the antenna shown in Figure B-5(a). Soft-boundary case.

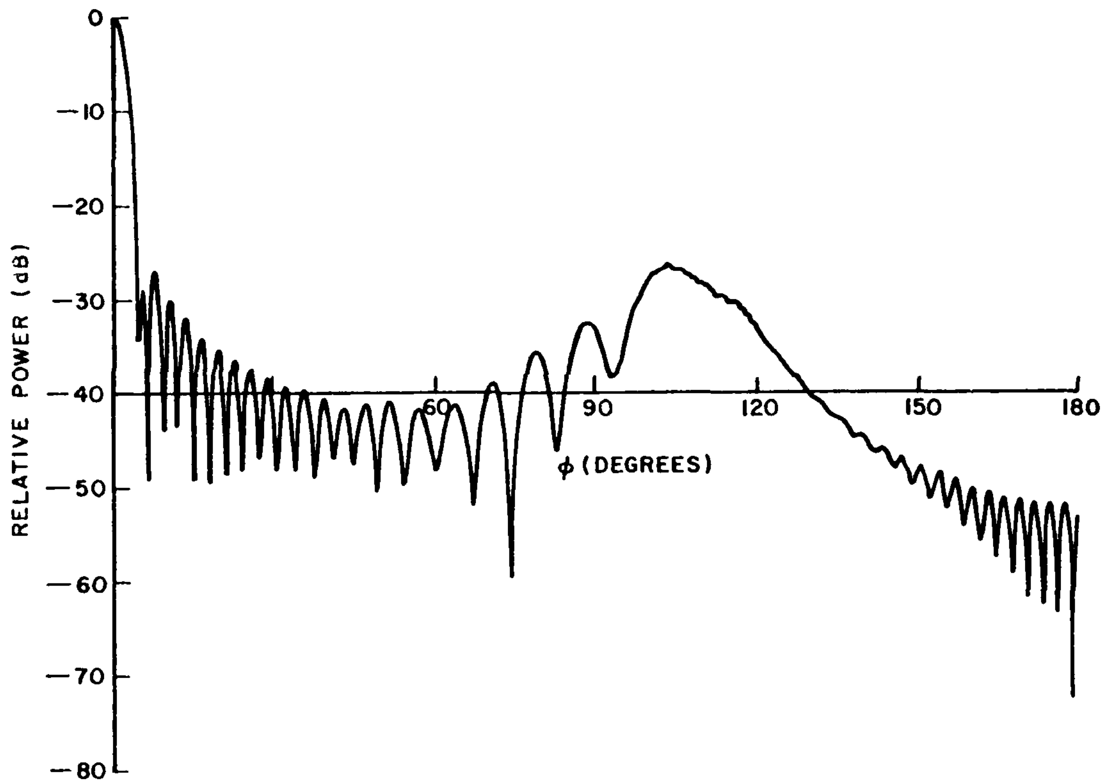
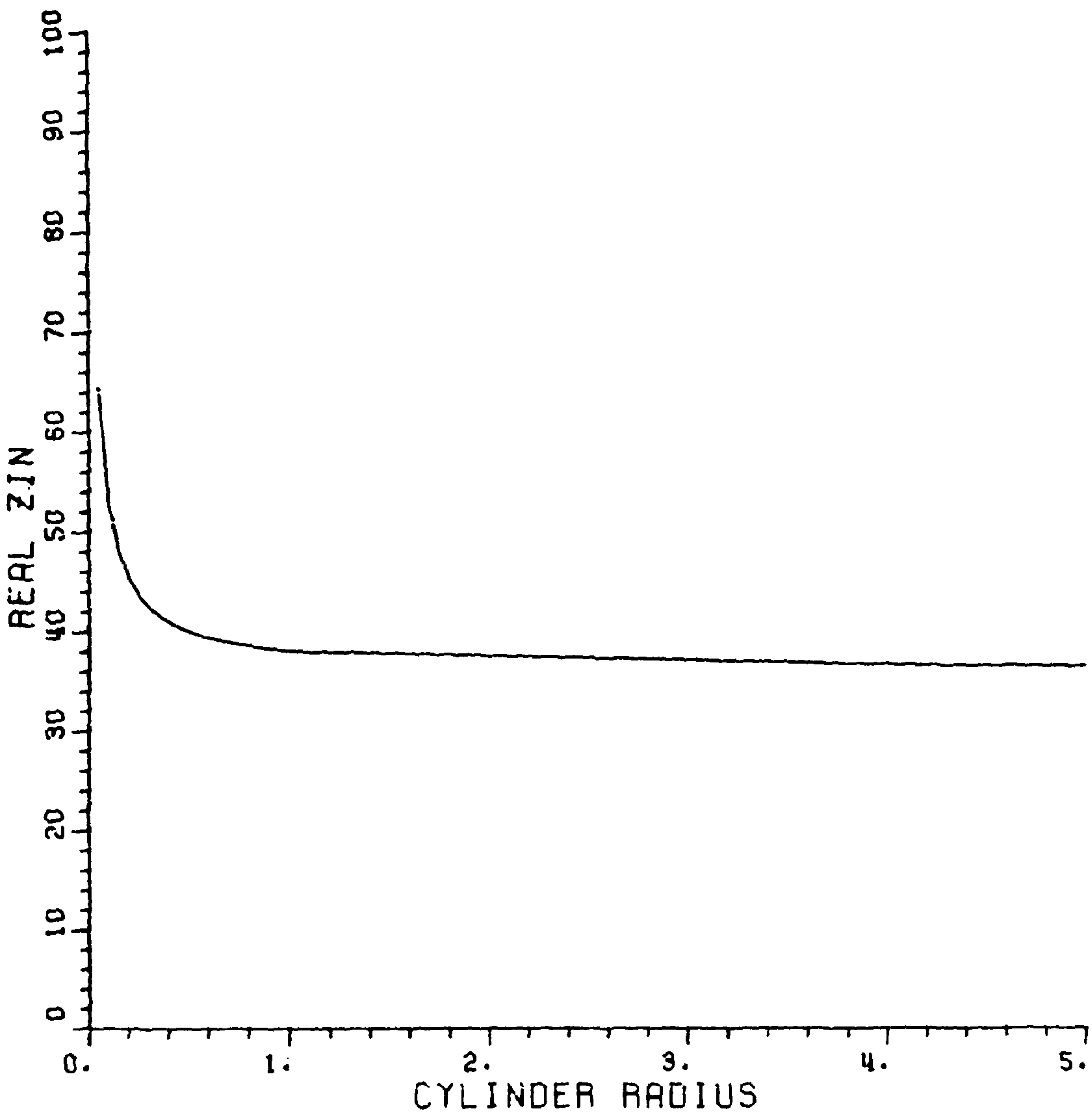
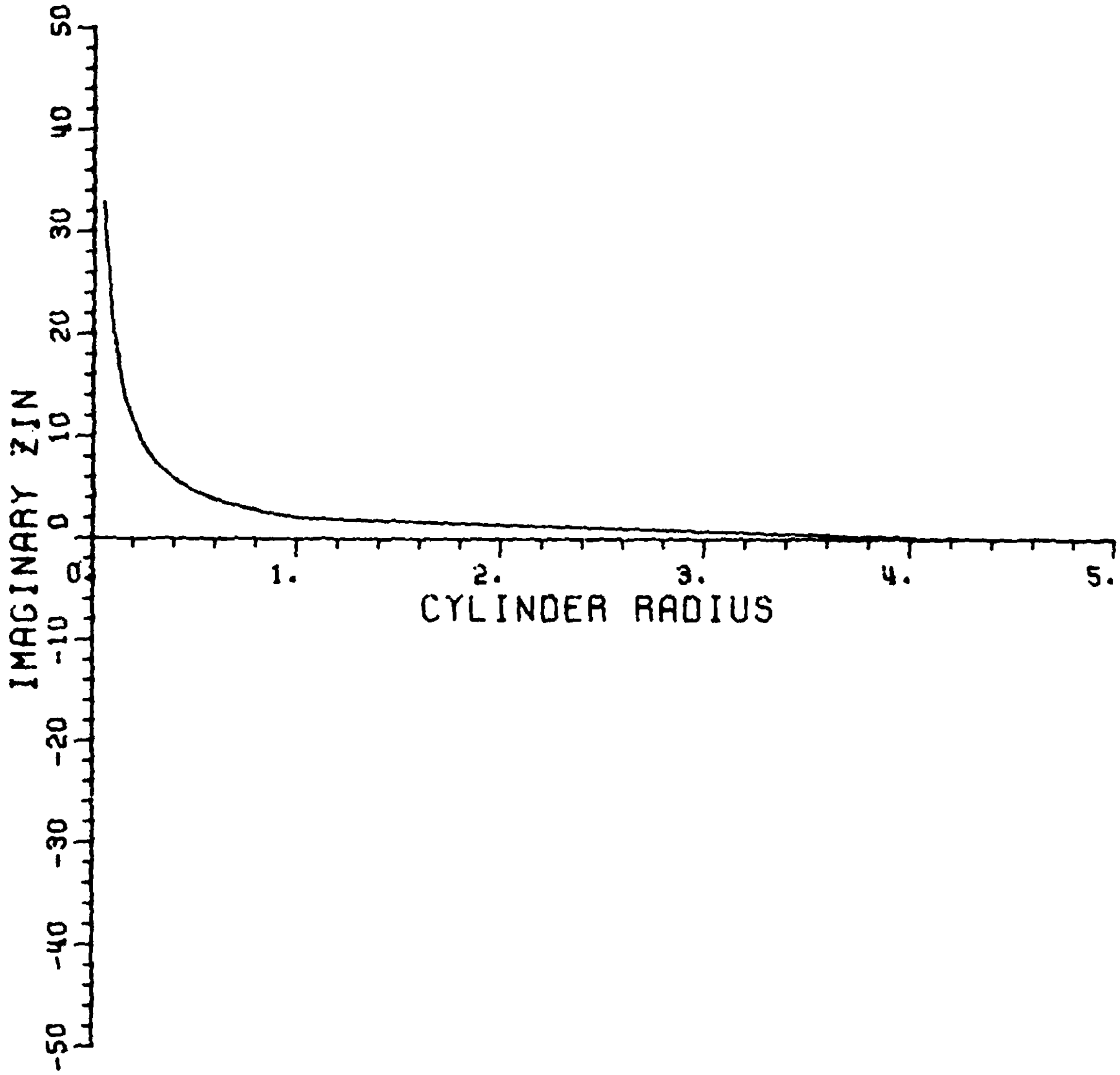


Figure B-5(c). Radiation pattern of the reflector antenna without the curved surface terminations. Soft-boundary case.



a) Resistance of monopole.

Figure B-6. Effect of cylinder radius on impedance of a monopole mounted on the cylinder.



b) Reactance of monopole.

Figure B-6. (Cont).

The work is continuing on to the case of two or more monopoles arbitrarily positioned on the cylinder so that mutual coupling can be studied. This work combines the UTD creeping wave theory with the momemt method.

References

1. R. A. J. Ratnasiri, R. G. Kouyoumjian, and P. H. Pathak, "The Wide Angle Sidelobes of Reflector Antennas", Report 2183-1, March 1970, The Ohio State University ElectroScience Laboratory, Department of Electrical Engineering; prepared under Contract AF 19(623)-5929 for Air Force Cambridge Research Laboratories, (AFCRL-69-0413) (AD 707105).

Publications

I. Papers

C. W. Chuang and W. D. Burnside, "A Diffraction Coefficient for a Cylindrically Truncated Planar Surface", has been accepted for publication in IEEE Transactions on Antennas and Propagation; also an oral paper was presented at the IEEE/APS Symposium in Seattle, Washington, 18-22 June 1979.

II. Reports

"An Improved Method for Calculating the Reflection Point on an Elliptic Cylinder", by Lee W. Henderson, Technical Report in preparation.

C. Antenna Studies

Researchers: E. H. Newman, Senior Research Associate
(Phone: (614)422-4999)

D. M. Pozar, Graduate Research Associate

P. Tulyathan, Graduate Research Associate

Accomplishments

The purpose of our research is to develop general-purpose low-frequency (i.e., applicable to structures not large in terms of a wavelength) computer techniques for designing and analyzing antennas, including their support structure. Specifically, this is being done by developing a general-purpose computer code using moment-method surface-patch modeling for analyzing composite wire and surface geometries. Previously a code to analyze combinations of rectangular plates and thin wires, including wire-to-plate and plate-to-plate junctions, has been developed[1,2]. Wire-to-plate junctions were required to be at least 0.1λ from a plate edge. This year work was done to improve the basic techniques in three areas:

1) Wire attachments near the edge of a half-plane.

2) Modeling of non-rectangular plates.

3) Improving the computational efficiency or speed of the computer code.

The progress made in these three areas will now be briefly reviewed.

1. Wire Attachments Near an Edge

The basic attachment mode, applicable to wire attachments away from the edge of a plate, enforces that the plate surface current density spreads out uniformly from the attachment point[1]. However, when the attachment point is close to an edge the current density no longer spreads uniformly. For example, for an attachment near the edge of a half-plane more current goes away from the edge than toward the edge.

Although the eventual goal is to treat attachments near the edge of a wedge, the initial effort was to analyze a wire attached near the edge of a half-plane. To gain familiarity, the initial problem studied was a two-dimensional one, the fields and currents induced by a vector electric line source near the edge of a wedge[3,4]. Next, the half-plane Green's function was studied to determine the nature or the form of the surface current density induced by a monopole near the edge of a half-plane. This investigation lead to the development of edge modes (to enforce the edge condition) and attachment modes (to enforce the non-uniform spreading of the surface-current density). The success of the surface patch solution is illustrated in Figure C-1 when the input impedance of a monopole near the edge of a half plane is computed using an exact MM/Green's solution, a MM/GTD solution, and the surface-patch solution[5,6]. The reason for the shift between the curve for the surface-patch solution and those for the MM/Green's function and MM/GTD solution is that the latter were computed for a finite plate while the former were for an infinite half-space plane. Next year this work will be extended to treat attachments near the edge of a wedge.

2. Non-Rectangular Plates

The original code models solid surfaces using rectangular plates[1]. This is sufficient to treat rectangular plates, rectangular corner reflectors, boxes with rectangular sides, etc. Non-rectangular flat surfaces can be modeled by polygon plates, and even a piecewise flat representation of a doubly curved surface can be made with polygon plates. Thus, the next generation code will use polygon rather than rectangular plates. The original code "covered" the rectangular plate with the rectangular surface-patch modes shown in Figure C-2(a). Polygon plates are better covered with either the trapezoidal modes of Figure C-2(b) or the quadrilateral modes of Figure C-2(c). At present we intend to use the trapezoidal modes, Figure C-2(b).

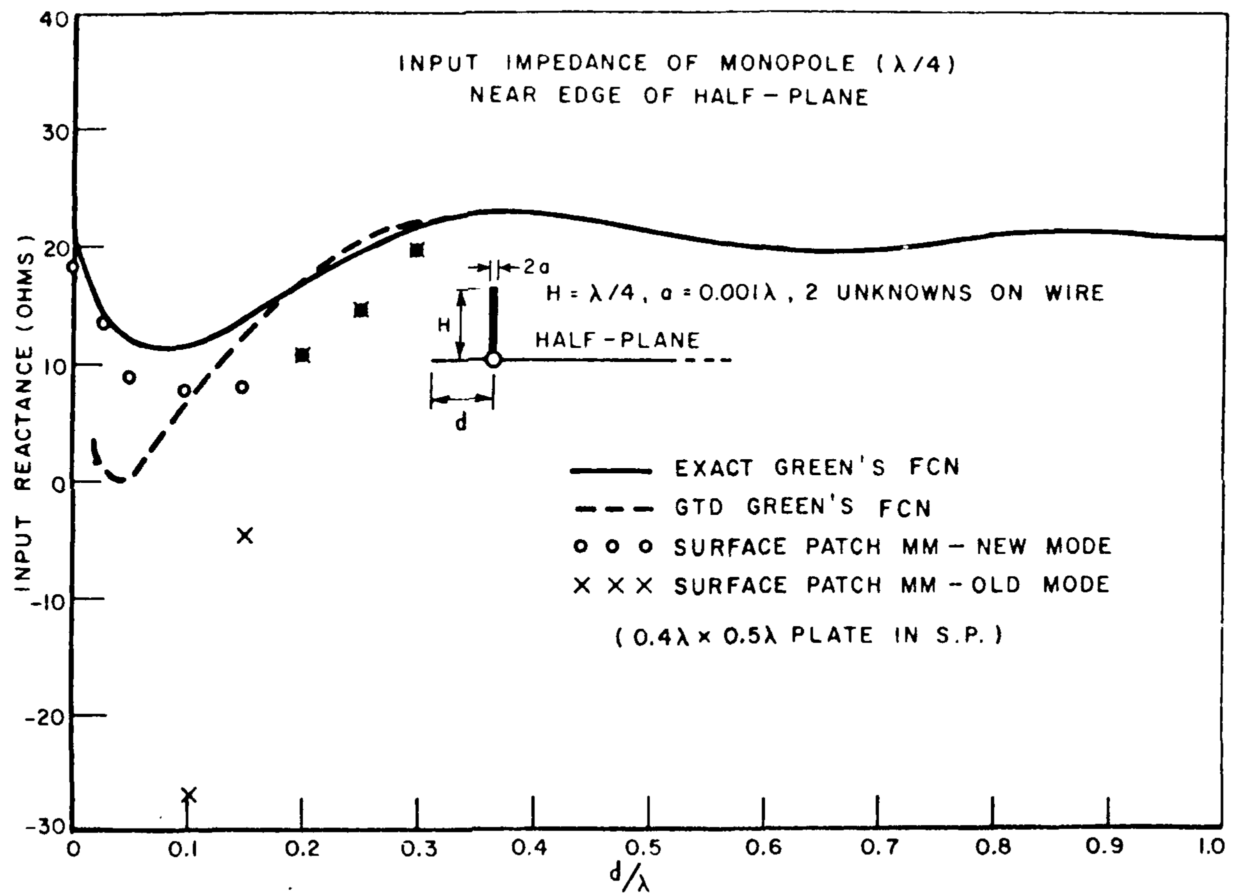


Figure C-1. Input reactance of a λ/4 monopole vs distance, d, from the edge of a half-plane computed using MM/exact Green's function, MM/GTD, surface patch with old att. mode, and surface patch with new att. mode.

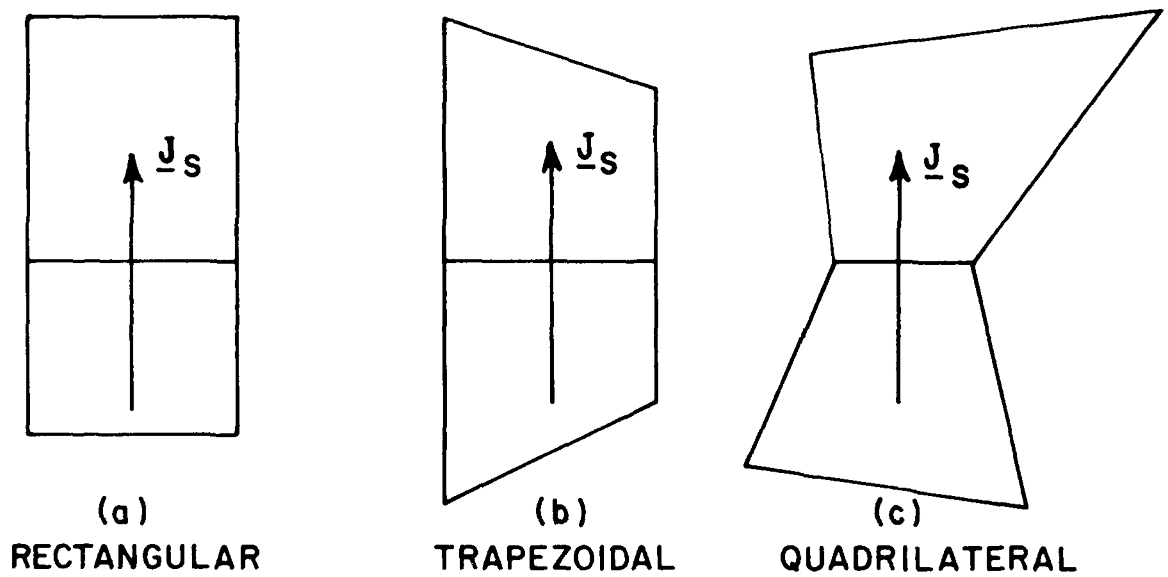


Figure C-2. Surface-patch modes.

Figure C-3 shows the trapezoidal modes "covering" an octagonal plate. (Note: only one current polarization is shown). At present we are able to compute the backscattering from polygon plates; however, the more difficult problems of plate-to-plate and wire-to-plate junctions will be addressed in the future.

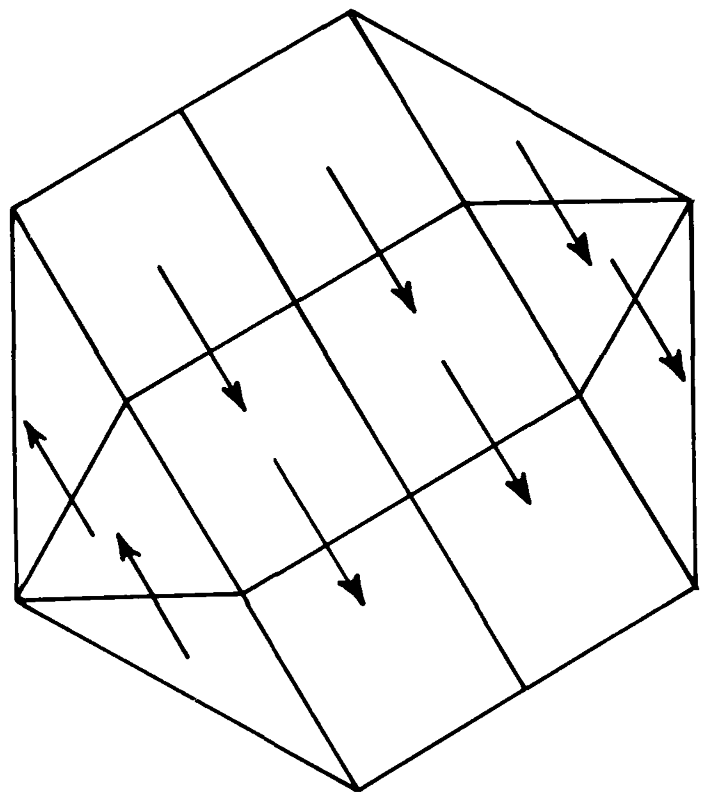


Figure C-3. Trapezoidal modes on octagonal plate.

3. Code Efficiency

In order to be useable, a code must run in a reasonable amount of time. In our surface patch code, and others using Galerkin's methods, a quadruple integration is required to find a general element in the impedance matrix. If one does not write an efficient and rapidly converging code, the run time can easily be on the order of hours, even for a relatively small problem involving less than a wavelength of surface area. Some of the techniques we employ to speed up our code have been published[7]. Rather than detail them here we will simply state that we can analyze a monopole on a one square wavelength plate with a run time of 115 sec. on the Datacraft 6024 (equivalent to 40 sec. on an IBM 370 or 20 sec. on an Amdahl 470).

References and Publications

1. E. H. Newman and D. M. Pozar, "Electromagnetic Modeling of Composite Wire and Surface Geometries," IEEE Trans. on Antennas and Propagation, Vol. AP-26, No. 6, November 1978, pp. 784-89.

2. E. H. Newman and D. M. Pozar, "Considerations for Efficient Wire/Surface Modeling," accepted for publication IEEE Trans. on Antennas and Propagation.

3. D. M. Pozar and E. H. Newman, "Near Fields of a Vector Electric Line Source Near the Edge of a Wedge," Report 784569-5, June 1978, The Ohio State University ElectroScience Laboratory, Department of Electrical Engineering; prepared under Grant DAAG29-76-G-0331 for U. S. Army Research Office. (ARO 14012.2-EL)(AD/A057403).

4. D. M. Pozar and E. H. Newman, "Near Fields of a Vector Electric Line Source Near the Edge of a Wedge," Radio Science, Vol. 14, No. 3, May/June 1979.

5. D. M. Pozar and E. H. Newman, "Analysis of Wire Antennas Mounted Near or at the Edge of a Half-Plane," Report 784569-9, August 1979, The Ohio State University ElectroScience Laboratory, Department of Electrical Engineering; prepared under Grant DAAG29-76-G-0331 for U. S. Army Research Office.

6. D. M. Pozar and E. H. Newman, "Analysis of Wire Antennas Mounted Near or at the Edge of a Half-plane," submitted to IEEE Trans. on Antennas and Propagation.

7. E. H. Newman and D. M. Pozar, "Efficient Wire/Surface Modeling Techniques," to be published January, 1980, IEEE Trans. Antennas and Propagation.

D. Time Domain Studies

1. Time Domain Concepts and Methods

Researchers: D. L. Moffatt, Associate Professor (Phone: (614)422-5749)
E. M. Kennaugh, Professor Emeritus
C. M. Rhoads, Graduate Research Associate
K. A. Shubert, Graduate Research Associate

Accomplishments

Theoretical and analytical studies of electromagnetic scattering and radiation by material objects have primarily addressed problems of steady-state response to monochromatic excitation. There is an increasing interest, however, in the transient response to aperiodic excitations where concepts, diagnostics and even new and unique applications are often simplfied. For example, fundamental work at this Laboratory on the identification of such targets as aircraft, subsurface objects, and ships from radar data was originally initiated from time domain visualizations.

This section deals with the application of time domain concepts and methods to electromagnetic scattering and radiation problems. The general goals of this research include:

1) Prediction of scattered and radiated waveforms from objects of increasing complexity for point or plane wave electromagnetic sources with arbitrary waveforms.

2) Investigation of target-dependent excitation waveforms and/or signal processing algorithms to identify and optimize electromagnetic response from specific targets.

3) Determination of the effects of system bandwidth and noise on recommended techniques for detection and identification of radar targets.

During the present program, significant progress has been made in both the development and extension of basic concepts. In addition, preliminary versions of methods for the identification of radar targets have been applied to widely diverse classes of targets with extremely encouraging results. This research is summarized in the following paragraphs. In most cases the summary is a slightly expanded version of the abstract of a paper published, accepted for publication or in preparation for publication.

a. Radar target identification

Research on the identification of an object using solely active (radar) remote sensing data on the object has taken two forms: 1) application of developed but incomplete prediction-correlation methods, used in conjunction with a finite set of excitation invariant target parameters, to particular classes of objects, and 2) studies to optimize both the techniques for finding the appropriate target parameters and the interrogating radar signals. Stated another way, the methods inherently invoke broadband signals because transients are needed but precisely how broadband and on what portion of the spectrum is as yet unknown. Only noncooperative targets are considered, although certain of the techniques would also appear to be attractive for cooperative targets. Another form of radar target identification which, given a ramp response waveform of an object produces isometric three-dimensional images of the object, has evoked some study. On this research program the interest arises because certain of the excitation invariant target parameters utilized in prediction-correlation may possibly lend new insight to radar imagery methods.

An initial paper "Radar Identification of Naval Vessels," by D. L. Moffatt and C. M. Rhoads has been accepted for publication as a correspondence by the IEEE Transactions on Aerospace and Electronic Systems. This paper presents a scheme for the identification of naval vessels using active multiple frequency radar amplitude data. A predictor-correlator processing using nominal substructure complex natural resonances of the vessels is applied to synthetically generated amplitude-only matched filter response waveforms. A major virtue of the method is the use of amplitude data only. The identification method is illustrated using measured model data on eight different vessels in situ. A correct identification probability of roughly 0.77 is obtained.

A paper "Update on Naval Vessel Identification" by D. L. Moffatt and C.M. Rhoads was presented at the International IEEE AP-S URSI meeting in in Seattle, Washington, June, 1979. In this paper it was demonstrated that the ship identification method, originally illustrated for aspects confined to bow-on, stern-on and abeam, could be extended to aspects in the proximity of these positions without seriously reducing the identification quality.

It has become increasingly evident that discrete frequency data spanning 10 harmonics will not permit, on good detail models of the ships, resolution of the actual substructures dominating the echo signals. To achieve this type of resolution, swept frequency measurements similar to those discussed later for aircraft models would be in order. That is, actual pulse response waveforms of the vessel in situ are needed. Unfortunately this type of measurement is relatively sophisticated, particularly with the ship on a ground plane, and therefore expensive both in terms of funding and personnel. There is some question, at this stage, as to the advisibility of continuing to work with experimental data. An analytical approach to predicting the echo signals from much simpler ship models on a sea surface may be a more reasonable alternative. Some initial study along this line has been made[1]. At this time a decision has not been made, but the increasing cost of technician-aided experimental measurements may force the analytical mode.

A paper "Ship Identification Via Radar"* by D. L. Moffatt and C. M. Rhoads has been accepted for publication in the IEEE Transactions on Antennas and Propagation, Special Issue on Inverse Scattering and Related Topics. This paper presents a scheme for the identification of naval vessels using discrete, harmonically- related, multiple-frequency radar amplitude data. A predictor-correlator processing is applied to synthetically-produced matching-filter-type response waveforms. Prediction is based on a finite set of difference equations unique to each vessel in the classes considered. A combination of the geometrical complexity of vessels and the sea environment dictates interrogating frequencies in the mid-resonance range of the vessel. Depending on vessel class, electrical hull lengths of (0.6-1.8) to (6.0-18.0) wavelengths are used. The difference equations can be viewed as being associated with substructure features of the vessels.

The identification method is demonstrated using measurements (30° elevation angle, aspects concentrated around bow-on, stern-on and abeam) of detailed models of specific vessel classes with model scales of 500:1 and 700:1. The ships are measured in a simulated natural environment thus sea-vessel interactions, an important scattering mechanism, are included. The effects of noise on the identification process, over and above that inherently present in the measured data, are demonstrated.

A paper "A Characterization of Subsurface Radar Targets" by Luen C. Chan, David L. Moffatt, and Leon Peters, Jr. was published in the Proceedings of the IEEE, Vol. 67, No. 7, July 1979. The capability of subsurface target identification at shallow depths has been demonstrated using an electromagnetic video or baseband pulse radar. Real radar measurements were collected for five targets at a depth of 5 cm for various ground conditions. These

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*As of the final preparation of this report, the papers identified by * or ** are to be combined into two invited papers in the IEEE Transactions on Antennas and Propagation, Special Issue on Inverse Scattering and Related Topics.

measurements were processed for target characterization and identification. Identification performance based on a single radar observation was evaluated. The identification process requires only simple algebraic operations and thus offers the potential of real-time on-location identification of subsurface targets.

A paper "Estimation of the Complex Natural Resonances. A Class of Subsurface Targets" by L. C. Chan, D. L. Moffatt, and L. Peters, Jr. was published in the Proceedings of the International Symposium and Workshop on Recent Developments in Classical Wire Scattering: Focus on the T-Matrix Approach, The Ohio State University, June, 1979. This paper is also scheduled to be published in a book by Pergamon Press. This paper summarizes a study of the characterization of subsurface targets by their complex natural resonances. The methodology in estimating the complex natural resonances of these targets is emphasized. A method for extracting the resonances from the backscattered waveforms is derived for completeness. The method is known as Prony's method and, when applied to measured data, it is extremely sensitive to the values of its parameters. An approach to solve certain of these problems is presented. Prony's method is applied to the measured backscattered waveforms and an analysis of the resulting resonances is presented.

A paper "Systematic Imaging Techniques for Subsurface Targets"** by L. C. Chan, D. L. Moffatt and L. Peters, Jr. has been accepted for publication in the IEEE Transactions on Antennas and Propagation, Special Issue on Inverse Scattering and Related Topics. This paper focuses on synthetic imaging techniques for subsurface targets from their backscattered fields and the special problems introduced by the ground. The ground is modeled as infinite, homogeneous and frequency-independent. The constitutive parameters, namely, conductivity, permittivity, and permeability, are assumed to be constant with respect to both location and frequency. Both 2- and 3-dimensional perfectly conducting targets are considered. The incident fields are assumed to be plane waves. In obtaining the backscattered fields from these targets, the physical optics approximation is used. Such an approximation enables the target geometry to appear explicitly in the expression for the time-domain backscattered field and thus greatly enhances the possibility of target imaging. The goal of this paper is to determine the extent that the profile function can be evaluated when loss is introduced. The solution is valid in the region where the high frequency approximation to the propagating factor may be used.

A paper "Improved Performance of a Subsurface Radar Target Identification System Via Antenna Design"** by L. C. Chan, L. Peters, Jr. and D.L. Moffatt has been accepted for publication in the IEEE Transactions on Antennas and Propagation, Special Issue on Inverse Scattering and Related Topics. In this paper a subsurface target identification radar is improved, primarily by modifying the antenna and its associated hardware. The identification capability of the improved design is compared with that of the original system and significant improvement noted. This improvement is obtained by a reduction in the signal-to-clutter ratio.

A paper "Measured Pulse Response Waveforms of Aircraft and Identification Potential"* by D. L. Moffatt, K. A. Shubert and E. M. Kennaugh has been accepted for publication in the IEEE Transactions on Antennas and Propagation, Special Issue on Inverse Scattering and Related Topics. Measured pulse response waveforms of five modern fighter aircraft, the F-104, F-4, F-5, F-15 and MIG-21, are reported. The measurements are for vertical polarization, i.e., polarization perpendicular to the plane of flight, and selected aspects in that plane. The measured pulse responses are synthetically produced from step-type swept frequency scattering measurements spanning the frequency range 30.0 to 56.0 MHz. Certain responses for the range 60.0 to 112.0 MHz for a larger cavity containing a cone-cylinder shape are also presented. An excitation invariant linear homogeneous difference equation is derived from multiple aspect pulse responses of a target. The implications of these results in terms of substructure complex natural resonances and the radar identification of aircraft in the frequency range 30.0 to 112.0 MHz are discussed.

Naval vessels, aircraft and subsurface objects clearly comprise three widely diverse classes of targets. Two of these classes also involve an ambient medium which makes identification a more perverse problem. In each case the actual interrogating signal waveforms were very different but the processing and identification techniques nearly identical. No claim can be made at this time that the signaling waveforms and processing are optimum either in terms of implementation or simplicity. Nevertheless the methods do work, and in the presence of moderate noise. A common factor, some subset of the excitation invariant parameters of the target, is involved in each of the methods.

b. Radar Imagery

A paper "A Chronological History of Radar Target Imagery at The Ohio State University" by D. L. Moffatt was presented at the International IEEE AP-S/URSI Symposium in Seattle, Washington in June, 1979. In this paper a chronological history of the development of radar target imagery methods at The Ohio State University was presented. This history dates from the late 1940's when Prof. E. M. Kennaugh and his colleagues first presented the physical optics approximation for electromagnetic backscattering as a function of target cross section along the radar line-of-sight and related the cross section to the time-dependent target response for an aperiodic ramp-type excitation. The first application of these results, to predict the axial backscatter of a 10:1 conducting prolate spheroid, was briefly reviewed with emphasis on what was known at that time about the target and on the target image which would have resulted.

The paper also reviewed the impulse response concept (formalized in 1965 by Kennaugh and Moffatt) and topics directly related to target imaging, namely, target cross sectional areas, frequencies of free or natural oscillations of an object and time domain interpretations of ray optics results. The nonphysical nature of certain geometrical theory of diffraction results and the use of such estimates in target image production was stressed and it was demonstrated that dielectric objects can be easily imaged, thereby circumventing the usual conducting target restriction. To the best of the author's knowledge, the first three-dimensional isometric "picture" of a finite object was produced by Young in 1970 using linear system concepts and a new limiting surface procedure. The limiting surface approach and a recent natural resonance addition were briefly reviewed. More recent imaging results using these concepts were illustrated and the use of a volume error criterion reviewed. The paper concluded with a discussion and illustration of the free oscillation frequencies of an object as related to a time-dependent ramp response waveform---the basic imaging quantity. From these results we postulate a correction to the limiting surface procedure which shows promise of improving object image resolution in the shadowed region of the target.

A summary of the results utilized in this paper is contained in References 2-7. A more complete picture is given in References 8 and 9 where some other approaches to the target identification problem are also presented.

A paper "Radar Imagery Spectral Content" by D. L. Moffatt has been accepted for publication in the IEEE Transactions on Antennas and Propagation, Special Issue on Inverse Scattering and Related Topics. In electromagnetics, the physical optics approximation is often employed as a direct scattering solution in the development of inverse scattering theories. This paper examines the consequences, in terms of image quality, of two decisions related to the physical optics assumption; the spectral span over which the resultant inversion algorithm is applied and the shadow boundary utilized. As shown, these decisions are most easily viewed in the time domain. The exact and approximate canonical response waves (impulse, step and ramp) of a conducting sphere, cone-sphere for axial incidence and circular disk are compared using several choices for the shadow boundary termination. From these results the spectral range over which one can safely exploit object area function relationships to the measured scattered field are deduced.

c. Difference equation processing

A general discussion of difference equation processing is given in Reference 10. An abstract of a paper "Least Square Difference Equations"* by D. L. Moffatt, E. M. Kennaugh and C. M. Rhoads has been accepted for publication in the IEEE Transactions on Antennas and Propagation, Special Issue on Inverse Scattering and Related Topics. In recent years the concept of electromagnetic, excitation invariant, complete natural resonances of an object has been coupled with a rediscovered technique for extraction of simple pole models of the resonances (Prony's method) to produce new results in the radar identification of targets.

In this paper it is demonstrated that extraction of the simple pole models necessarily involves the solution of an arbitrary Nth order linear homogeneous difference equation. It is shown that in a least-squared-error sense there are really N + 2 solutions for the difference coefficients, one of which is Prony's method. These solutions are compared, both in terms of total squared error and in terms of extracted simple pole loci, for various signal-to-noise ratios. An eigenanalysis procedure is defined which always yields the minimum total squared error under certain conditions and it is also shown that Prony's method is rarely optimum. A procedure for finding that difference equation which best "fits" several data records of the same target (aspect or polarization changes) is illustrated using the eigenanalysis method.

The solution comparisons are made using a simulated random process consisting of a finite sum of known exponentials with amplitudes and phases which are random variables plus a noise signal. Strictly speaking the amplitudes and phases are known if the object is known, but for an unknown target they are random variables. A final section of the paper applies the eigenanalysis procedure to measured multiple frequency scattering data and conjectures are made concerning the use of complex natural resonances and difference equations in imaging applications. The question of additional constraints on the eigenanalysis solution is also discussed.

2. The K-Pulse

Researcher: E. M. Kennaugh, Professor Emeritus (Phone: (614)422-9690)

Accomplishments

Considerable detail on the concepts and applications of the K-pulse is given in Reference 10 and will not be repeated here. In simplest terms, the K-pulse for a given object of arbitrary shape and composition is designed such that the response of the object to its K-pulse is of very brief duration, i.e., a nonoscillatory response. The concept of the K-pulse has permitted derivation of a simple relation between the complex natural frequencies of an object and its shape and composition. A paper "The K-Pulse Concept" by E. M. Kennaugh has been submitted to the IEEE Transactions on Antennas and Propagation, Special Issue on Inverse Scattering and Related Topics. In this paper a unique aspect-invariant excitation waveform (K-pulse) is postulated for an isolated scatterer. This waveform, of finite and minimal duration, then characterizes the pole spectrum of the scatterer, i.e., those employed in the singularity expansion method and for target identification.

The derivation of this excitation waveform and its relation to one or more surface waves is illustrated by several examples. The geometrical theory of diffraction is used to predict pole spectra for spheres and cylinders. The special properties of the scattered waveforms when the K-pulse is used for excitation are illustrated and applications to target identification are discussed.

3. The Thin Circular Disk

Researchers: D.B. Hodge, Professor (Phone: (614)422-5051)
D.P. Mithouard, Graduate Research Associate

Accomplishments

A report "Electromagnetic Scattering by a Metallic Disk" by Didier P. Mithouard and Daniel B. Hodge has been written. The scattering of electromagnetic waves by finite obstacles can be rigorously found for only two cases, the sphere and the disk. There exist two exact solutions to the scattering of an electromagnetic plane wave by a circular metallic disk. Flammer's and Meixner's exact approaches are successively considered and compared. In the former case, the fields are expanded in spheroidal vector wave functions, and the scattered field is uniquely determined by the boundary conditions on the surface of the disk and the edge condition. The purpose of the present work is to find a numerically useful solution valid everywhere; in particular, it is desired to obtain the surface current and near fields. A numerical test of the bistatic scattered far-field for normal incidence is presented. Problems encountered in Flammer's solution for arbitrary incidence are pointed out. The general form of the scattered field is derived from Meixner's vector potentials. This formulation is appropriate for near-field calculations. Another proof of Meixner's solution using dependence relations of the spheroidal vector wave functions is given.

The general far field computer programs which were developed in this study have proved extremely useful to other researchers. The value of a rigorous solution for the disk, both as a calibration standard to supplement or replace the sphere and as a test of postulated approximate theories involving an edge, cannot be overemphasized. It is postulated that similar programs for the surface currents and charges would be even more useful. For example, rigorous solutions for the complex natural resonances of an object with an edge should evolve. New insight into the noncausal nature of time-dependent asymptotic solutions would also be obtained. Unfortunately, support for the disk studies has terminated. Interest in the research, however, remains high and will hopefully lead to funding of future studies.

References

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E. Adaptive Array Studies

Researchers: R. T. Compton, Jr., Professor (Phone: (614)422-5048)
E. C. Hudson, Graduate Research Associate

Accomplishments

During the past year, JSEP funds have been used to support research on adaptive arrays in four areas:

1) Dynamic range and weight jitter with the improved LMS loop,

2) Element pattern effects on adaptive array performance,

3) Pointing accuracy requirements for a steered-beam adaptive array, and

4) The power optimization technique in adaptive arrays.

A short discussion of each of these subjects and our motivation for studying them is given below.

1. Dynamic Range and Weight Jitter with the Improved LMS Loop

During the previous JSEP program (1977-78), the adaptive array research effort was devoted to the problem of time constant variation with signal power in the LMS array. Time constant variation is a severe problem in the LMS array. Most communication systems can accept only a limited range of time constants in the array. As a result, time constant limits in the communication system become dynamic range limits in the adaptive array. Several alternatives to the LMS feedback loop were studied, and one in particular was selected as quite promising. We refer to it as the Improved LMS loop[1]. This loop, which eliminates time constant variation with signal power, is shown in Figure E-1.

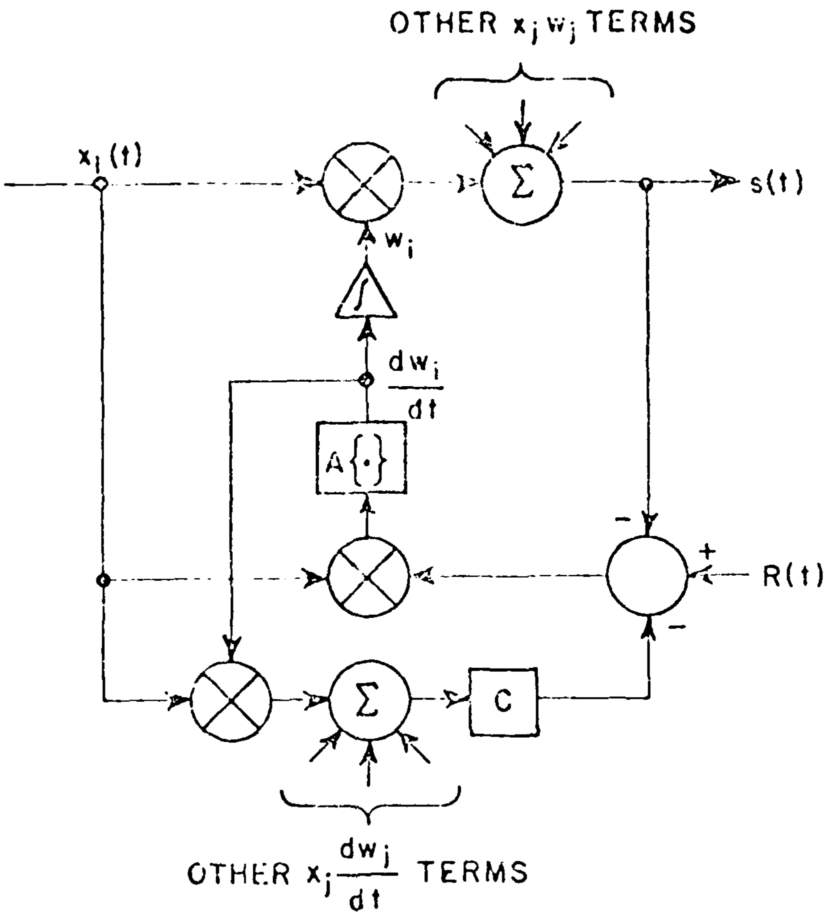

Figure E-1. The modified feedback loop.

Under the present JSEP program, studies on the performance of this loop have been continued. These studies have had two purposes. The first was to evaluate weight jitter (or variance) with the new loop. The second purpose was to evaluate the effects of multiplier and weight saturation on dynamic range, and to investigate the use of limiters and AGC circuits in this loop to improve dynamic range.

Studies on weight jitter in the improved loop have been essentially completed. These studies show that the improved loop holds the amount of weight jitter fixed, as well as the time constant, when signal power varies. Moreover, we have found that weight jitter in the improved loop is essentially the same as the jitter in an LMS loop whose fastest time constant is equal to the improved loop time constant. Since the time constant of the improved loop does not vary with signal power, this result means that weight jitter is much less of a problem in the modified loop than in the LMS loop.

Studies on dynamic range limitations due to saturation, and on the use of limiters and AGCs, are underway but have not yet been completed. We expect to finish this work during the beginning of the continuation contract.

2. Element Pattern Effects on Adaptive Array Performance

During the year a study was begun of the effects of antenna element patterns and spacing on adaptive array performance. Most adaptive array studies to-date have assumed isotropic elements. While this assumption is useful for many purposes, it obscures the effect of the elements on the overall performance. To develop an understanding of this subject, we have studied the performance of some small arrays using simple dipole elements. The purpose is to learn how to choose elements and element locations in a design problem and to determine what tradeoff's exist.

A case of special interest is the case where the patterns of the elements in the array are all unequal (i.e., all different from each other) and where the elements are widely spaced. This case is important because a designer may wish to locate elements somewhat arbitrarily on a structure, such as an aircraft. If this is done, the element patterns will usually be different and the elements may be spaced in an irregular manner, often more than a half wavelength apart.

During this study, we have examined two types of problems relating to this subject: the effects of element patterns on grating nulls, and the effect of element and signal polarization on array performance.

The first problem undertaken was to examine the effect of element patterns on grating nulls. It is well known that an array with elements more than a half wavelength apart is subject to grating lobe effects. In the context of adaptive arrays, grating lobe effects manifest themselves in the form of spurious nulls. That is, interference nulled by the array at one angle may cause additional nulls ("grating nulls") at other angles. If the desired signal is near a grating null, the output signal-to-noise ratio from the array will be poor.

In this study, we used simple arrays of dipoles to show several things. First, having unequal element patterns in the array tends to reduce the effects of conventional grating nulls. Second, however, unequal element patterns can create other spurious nulls in addition to conventional grating nulls. (We refer to these extra nulls as sign-reversal grating nulls.) Third, it turns out that for a two-element array with dipole patterns, it is impossible to avoid grating nulls for spacings greater than a half wavelength. Finally, however, we have shown that grating nulls can be avoided by using more than two elements, even with wide element spacing, if the element patterns are properly chosen. A paper has been written on this subject and has been submitted for publication[2].

The second problem we have investigated concerns the effects of element and signal polarization on the performance of the system. When realistic element patterns are assumed in an adaptive array, it is also necessary to consider the effect of signal polarization, since the subject of element patterns cannot be divorced from the subject of polarization in any but a few simple cases.

In this work, we have studied the performance of some simple adaptive arrays in which the elements have different polarizations. We find that adding polarization flexibility to the antenna system greatly enhances the performance of the system. For example, an adaptive array with polarization flexibility can null interference from the same direction as the desired signal, as long as the polarizations of the two signals are different. This capability greatly complicates the problem of designing an effective jammer against such an adaptive array.

Two papers on the performance of adaptive arrays with polarization flexibility are in preparation. One describes the performance of an array of two pairs of crossed dipoles and the other an array using three mutually perpendicular dipoles at one location. (We call this last antenna the "tripole antenna".)

The initial studies described above were done under JSEP funding. However, this work is now being continued under RADC Contract F30602-79-C-0068. At present we are studying the effects of element spacing and patterns in more general situations, i.e., with elements dispersed in a three-dimensional volume. The objective is to develop general design techniques for choosing patterns and geometries.

3. Pointing Accuracy in a Steered-Beam Array

A desired signal can be tracked with an adaptive array in two ways. One can either use a reference signal in the array feedback, with the LMS algorithm[3], or one can inject steering weights into the feedback loops, as originally suggested by Applebaum[4].

In the LMS array, using a proper reference signal (correlated with the desired signal) causes the array to maintain a strong pattern response (usually a beam maximum) in the desired signal direction. One does not need to know the desired signal direction to do this. However, generating a suitable reference signal can be a difficult task. Several problems exist. First, there must be some way to process the array output signal so the desired signal is preserved and the interference is decorrelated. Second, there is usually an acquisition problem. The frequency of the incoming desired signal and often the timing of a pseudonoise code or other tagging modulation are unknown and must be determined before reference signal generation can begin. Third, it must be possible to start reference signal generation in the presence of interference and before the array nulls the desired signal. Finally, generating the reference signal, even when possible, usually requires a great deal of electronic circuitry behind the array. Although suitable reference signal generation techniques have been found for a few types of communication systems[5,6], for many other types of system there simply does not appear to be any way to obtain a reference signal.

The second way to steer the beam in an adaptive array is to insert steering weights into the array feedback loops, as described by Applebaum[4]. This approach is vastly simpler, since no reference signal is required at all. The only difficulty with this approach is that the designer must know where to point the beam. He must know the desired signal arrival angle.

Because of the simplicity of the steered beam array, compared to the LMS array with a reference signal, it is certainly the most desirable approach if the desired signal arrival angle is known. However, in many design situation the signal direction may be known approximately, but not exactly. Or, it may be possible to estimate the signal direction[7], and the estimate may include estimation error. For this reason, it is of interest to determine how well a steered beam array will perform when the beam pointing angle is in error. That is the subject we have addressed under this study.

A study was done to determine the performance of a steered-beam adaptive array as a function of the beam pointing error. A paper has been written on this subject[8] and submitted for publication. The paper shows several things. First, to obtain full gain from the array, the beam angle must be extremely close to the correct direction when the signal power is high. Second, the beam pointing error that can be tolerated is essentially a question of dynamic range: the greater the desired signal dynamic range that must be accommodated by the array, the smaller the pointing error must be. Third, the paper compares the steered beam array performance with that of a power inversion array and an LMS array. It shows that the steered beam array performs better than the power inversion array even with quite large pointing errors, but poorer than the LMS array for any nonzero pointing error. Finally, the paper shows that with interference present, the performance of the steered beam array is less sensitive to pointing errors than without the interference.

4. The Power Optimization Technique in Adaptive Arrays

The final area in which research has been done concerns the problem of signal acquisition with an adaptive array. Before a desired signal has been acquired, it is not possible to generate a reference signal for the LMS adaptive array. Some alternative method must be used to allow the acquisition circuitry to acquire signal frequency, code timing, etc., during initial lockup. The study described here was done to address this problem. A different way of controlling the array weights was found that can protect a desired signal from an interfering signal without the need for a reference signal. The technique is based on a different weight control algorithm than the LMS algorithm. The new algorithm either maximizes or minimizes the array output power, subject to a constraint on the weights to prevent them from going to zero if infinity. If the desired signal is stronger than the interference, the algorithm is used to maximize output power. If the desired signal is weaker, it is used to minimize power. In either case, the output signal-to-interference-plus-noise ratio is maintained above a mimumim level. A paper describing this new weight control algorithm and its application has been written and submitted for publication[6].

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3. R. T. Compton, Jr., "An Improved Feedback Loop for Adaptive Arrays", to appear in IEEE Transactions on Aerospace and Electronic Systems.

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5. R. T. Compton, Jr., "On the Pointing Accuracy Required with a Steered Beam Adaptive Array", to appear in IEEE Transactions on Aerospace and Electronic Systems.

6. A. Ishide and R. T. Compton, Jr., "On Grating Nulls in Adaptive Arrays," to appear in IEEE Transactions on Antennas and Propagation.

APPENDIX I

PROJECT TITLES AND ABSTRACTS

Project 529081 Improvement of Antennas for Underground Radar (Terrascan)

The objective of this program is to improve the sensing head (antenna) of the Terrascan underground pipe detector developed previously for Columbia Gas and manufactured by Microwave Associates.

Project 784299 CTS/Comstar Communications Link Characterization Experiment

The objectives of this study are: a) continuation of angle of arrival measurements using the Comstar D-3 28.56 GHz beacon, and b) measurement of antenna gain degradation.

Project 784569 Analysis of Electrically Thin, Dielectric Loaded, Cavity Backed Radiators

During this third and final year of the program the objective has been to obtain a mathematical model and computer code to analyze dielectric filled cavity-backed antennas.

Project 784589 Technique for Optical Power Limiting

This is a classified program.

Project 784652 An Advanced Prototype System for Locating and Mapping Underground Obstacles

The objective of this program is to develop a portable video pulse radar system for locating and mapping underground objects to a depth of 10-15 feet. The emphasis is on improving signal processing techniques and optimizing system performance to improve target resolution.

Project 784673 Advanced Numerical Optical Concepts

The objective of this program is the development of the technology for optical computing systems.

Project 784701 A Synergistic Investigation of the Infrared Water Vapor Continuum

This study proposes a thorough 3-year investigation of the water vapor continuum absorption in the 8 μm to 12 μm and in the 3.5 μm to 4.0 μm atmospheric transmission windows. This absorption has been the topic of several previous studies. However, serious questions still remain and the need exists for a definitive study in order to answer questions related to laser radiation propagation through the atmosphere and also for optimization of infrared imaging and sensor systems which depend on 10 μm infrared radiation. The Contractor will use a multiline stabilized CO_2 laser and a spectrophone to perform precision measurements of the absorption by water vapor broadened by nitrogen, oxygen and N_2-O_2 mixtures, over a 17-27^{o} temperature range.

Project 784722 Electromagnetic Mine Detection and Identification

Research in this study is directed toward the special design of an impulse radar for the purpose of detecting buried mines.

Project 710816 Block Funded Support for Electromagnetic Research

This is research in the area of electromagnetic radiation and scattering including: (1) extension of the Geometric Theory of Diffraction (GTD) for convex surfaces, edges, vertices and time domain solutions; (2) the GTD combined with the Method of Moments (MM); (3) extension of MM codes utilizing polygon surface current patches and wire/patch attachment modes; (4) transient electromagnetic phenomena including target identification, radar imagery, K-pulse techniques and scattering from a thin, circular disk; and (5) adaptive array studies including dynamic range enhancement, beam pointing accuracy, and effects of element pattern and polarization on adaptive array performance.

Project 710964 Analysis of Airborne Antenna Patterns

The objectives of this program are to: (1) improve the aircraft model for far field pattern computations by considering a more realistic vertical stabilizer; (2) study various ways to model more general antenna types such as a monopole in the presence of directors; (3) examine various flat plate simulation codes; and (4) compare various calculated results with measurements supplied by NASA (Langley).

Project 711096 TWCM Effects

This is a classified program.

Project 711353 Extending the Geometrical Theory of Diffraction Using the Moment Method

This is a 3-year basic research program to develop the theory for further extensions of the GTD using the moment method and to implement that theory into computer programs so that the usefulness of the research in various scattering and antenna problems can be demonstrated.

Project 711510 Low Sidelobe Reflector Antenna Study

Far field patterns are to be calculated and compared with the measured patterns provided by AeroSpace Corporation for an available offset reflector and available feed horn. This will provide a verification of the theoretical models and computer codes to be used in developing antenna designs for the desired low sidelobe performance.

Project 711559 Study of Improved IFF Antennas

The objective of this research is to conduct a program that will lead to a low profile or flush mounted antenna capable of pointing a beam into each of the four quadrants in azimuth.

Project 711577 Application of the GTD to the Calculation of Acoustic Backscatter from Mine-Shaped Objects

The objective of this study is to prepare a summary report on the application of the Geometrical Theory of Diffraction (GTD) to the calculation of acoustic backscatter from mine-shaped objects.

Project 711587 Evaluation and Upgrading of the Antenna Calibration Facility at the Measurements Standards Laboratory

The following items of work are included in a twelve-month study:

(1) analyze the near field effects when measuring antenna gain at close range; (2) evaluate the facilities and procedures used at NAFS for antenna gain measurement; (3) recommend changes in procedures and/or equipment which will minimize the errors identified in (2); (4) fabricate a set of three similar corrugated horn antennas for evaluation as an improved gain standard; and (5) initiate work to determine the most suitable form for standard antennas for use in calibrating radiation hazard meters in the frequency range 1 to 18 GHz.

Project 711588 On-Aircraft Antenna Pattern Prediction Study

The objectives of this program are: (1) to produce a capability to analytically predict antenna patterns of on-aircraft mounted complex antennas which are both mechanically and electronically scanning; (2) to obtain predicted antenna patterns for several types of antenna arrays utilizing previously existing computer programs developed under Contract N62269-76-C-0554.

Project 711626 Investigation of Infrared Spectra of Atmospheric Gases to Support Stratospheric Spectroscopic Investigations

This research program employs infrared spectroscopy to determine the chemical composition of the stratosphere. Test gases include O_3, N_2O and CO_2. Infrared absorption spectra of the gases at stratospheric temperature and pressure conditions in absorption cells are recorded in digital form using a high resolution Fourier transform spectrometer system.

Project 711639 Superdirective Arrays

The objective of this study is the development of computer codes to analyze the performance of a circularly disposed super-directive array with the appropriate feed network.

Project 711679 Jam Resistant Communications Systems Techniques

The objectives of this program include (1) development and testing of a bit-synchronous time-division multiple-access digital communications system suitable for use by a large number of small (airborne) terminals in conjunction with larger ground stations, (2) the application of adaptive arrays for up-link antijam protection of this system, and (3) development of techniques, circuits and components for increased data rates, digital control, and interference rejection in high speed digital communications systems.

Project 711847 Communications Applications of Adaptive Arrays

Three areas of work are included in this study: 1) a study of the weight jitter and dynamic range properties of the new adaptive array feedback loop; 2) an extension of the work currently underway on FSK signals; and 3) continuation of the preparation of a monograph on adaptive arrays.

Project 711857 Digitization, Calibration and Analyses of GFE Analog Tapes

The objective of the program is to examine GFE analog tapes and oscillograph records, specify a digitization procedure compatible with the digitization facilities at AFWL, and analyze the digitized tapes. The digitization is to be performed at AFWL.

Project 711930 Radar Cross Section Studies

The objective is to establish the GTD techniques required to treat the radar cross section of missile and aircraft bodies.

Project 711964 Electrically Small Antennas

This three-year program of research into electrically small antennas has three phases: Phase 1 - a basic study to develop the theory, techniques and computer codes for electrically small antennas mounted on a general structure; Phase 2 - a study to develop the theory, techniques and computer codes for printed circuit antennas; and Phase 3 - a study to compare the K-Pulse concept with more conventional techniques for increasing the maximum data rate in pulse communications using small antennas.

Project 712242 Formulate Quasi-Optical Techniques for Antennas at UHF

The goal of this program is to increase the electromagnetic effectiveness of Navy ships by developing low cost, integrated, systematic EM design procedures.

Project 712257 Application of Optical Computing Techniques to Jet Engine Control

This program involves the following tasks: 1) survey and document control requirements for jet engines using information supplied by sponsor; 2) survey and document the field of optical computing as applied to jet engine controls; 3) generate a report listing the various schemes and comparing them for speed, information processing capability, and ability to withstand the necessary environmental conditions; and 4) make recommendations as to the scheme most likely to satisfy the requirements stated in 1).

Project 712331 Air-to-Ground Measurements, Processing and Analysis of Moving Tactical Ground Targets

An experimental study is proposed of the modulation induced by moving ground vehicles on the returns of a VHF airborne radar. Automatic target and classification procedures developed at the ESL using ground-based data will be extended to data obtained from the airborne radar.

Project 712351 Antenna Pattern Test of Low RCS Antenna Configuration

The objectives are to determine if: 1) the resonant slots introduced in a radome/antenna seriously distort the L and S band patterns of the antenna; and 2) the L and S band antenna scribed on the metallic radome seriously distorts the X band transmission properties of the radome.

Project 712352 Surface Ship Classification Using H.F. Multi-Frequency Radar

The objectives of this program are to: 1) investigate the development and testing of algorithms designed to provide automatic classification and identification of the surface ship targets;

2) make a quantitative appraisal of the effectiveness of the classification algorithms - the performance of these techniques as a function of the number (or granularity) of simultaneous interrogating radar frequencies will be studied; and 3) integrate this program with a program of full-scale multi-frequency measurements of ships to be made with the NRL Sea Echo HF radar.

Project 712384 Analysis of Aero-Optical Turbulence Measurements

The purpose of this program is to extend present data on altitude dependence of refraction index fluctuations pertinent to optical propagation. This will be done by analysis of AFWL airborne measurements of microthermal fluctuations.

Project 712398 Moment Method Antenna Analysis Techniques

The purpose of this project is to train Aerospace personnel on the use and operation of Richmond's computer codes.

Project 712527 Research on Near Field Pattern Effects

The objective is to continue present efforts on aircraft antenna computer code development in terms of combining the volumetric pattern analysis for the fuselage with the multiple plate solutions developed earlier. This solution must be efficient and of a form that it can be adopted to the fuselage-wing junction analysis treated previously.

APPENDIX II
ELECTROSCIENCE LABORATORY SPONSORING AGENCIES

OHIO STATE UNIVERSITY - ELECTROSCIENCE LABORATORY ACTIVE PROJECTS OCTOBER, 1979

PROJECT ENGINEER	PROJECT NUMBER	SPONSOR	CONTRACT OR GRANT NUMBER	STARTING DATE	ENDING DATE	AWARD AMOUNT	SOURCE
	Facilities Contract		AF 33(600)-31168				
YOUNG	523081	Gas Research Inst					
HODGE	784299	NASA/Goddard	NAS5-22575	09-02-75	02-28-80	484K	6.2
NEWMAN	784569	ARO	DAAG29-76-C-0331	09-24-76	09-23-79	90K	6.1
MEADORS	784589	AFSC	F33615-77-C-1011	10-18-76	11-22-79	191K	6.2
CALDECOTT	784652	EPRI	RP7856-1	01-01-77		237K	6.3
COLLINS	784673	BMD	DASG60-77-0645	03-01-77	10-01-79	193K	6.2
NORDSTROM/LONG	784701	ARO	DAAG29-77-C-0010	04-01-77	09-30-80	158K	6.1
PETERS	784722	Ft. Belvoir	DAAK70-77-C-0114	05-05-77	05-04-80	125K	6.2
WALTER	710816	ONR	N00014-78-C-0049	10-01-77	09-30-79	582K	6.1
BURNSIDE	710964	NASA/Langley	NSG 1498	01-16-78	01-15-81	119K	6.2
MEADORS	711036	AFAL	F33615-78-C-1431	04-16-78	12-31-79	125K	6.1
THIELE	711353	ESD	F19628-78-C-0198	09-01-78	08-31-81	42K	6.1
RUDDUCK	711510	Aerospace	P.O. 88318	09-01-78	10-01-79	49K	6.2
MUNK	711553	NRL	N00014-78-C-0855	09-30-78	10-01-79	82K	6.2
KOUYOUMJIAN/PATHAK	711577	NOSC	N61331-78-M-3152	09-25-78	10-30-79	9K	6.2
RUDDUCK	711587	WPAFB	N00014-76-A-0039-PZ01	09-28-78	12-04-79	83K	6.3
BURNSIDE	711588	NADC	N62269-78-R-0379	09-01-78	12-31-79	94K	6.2
SHAW	711626	NASA	NSG-7479	11-01-78	10-31-79	50K	6.1
NEWMAN	711639	NSA	MDA904-79-C-0497	10-24-78	10-23-79	99K	6.3
KSIENSKI	711679	RADC	F30602-79-C-0068	12-04-78	12-03-81	190K	6.2
COMPTON	711847	NASC	N00019-79-C-0291	12-01-78	03-31-80	70K	6.2
LEVIS	711857	Kirtland AFWL	F29650-79 M2507	03-12-79	09-30-79	10K	6.2
PETERS	711930	NASA/Langley	NSG 1613	05-01-79	04-30-80	50K	6.2
RICHMOND	711964	ARO	DAAG29-79-C-0082	05-01-79	04-30-82	49K	6.2
MARHEFKA/RUDDUCK	712242	NOSC	N00123-79-C-1469	08-01-79	07-13-82	124K	6.2
COLLINS	712257	NASA/Lewis	NSG 3302	08-01-79	07-31-80	40K	6.2
KSIENSKI	712331	Clarkson College	F30602-78-C-0102	08-14-79	09-30-79	35K	6.2
MUNK	712351	McDonnell Douglas	P.O. Y9E-189	08-28-79	09-30-79	3K	6.1
KSIENSKI	712352	ONR	N00014-79-C-0882	09-01-79	02-29-80	25K	6.1
LEVIS	712384	AF/Kirtland	F29650-79-M4553	09-11-79	09-30-79	7K	6.2
NEWMAN	712398	Aerospace	P.O. 10616	09-01-79	08-14-80	14K	6.5
BURNSIDE	712527	NASC	N00019-80-C-0050	11-29-79	11-28-80	60K	6.2

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