DEPOLARIZATION AND SCATTERING
OF ELECTROMAGNETIC WAVES

FINAL REPORT

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# Depolarization and Scattering of Electromagnetic Waves

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**Abstract:** (see next page)  

**Key Words:**  
- Depolarization  
- Scattering  
- Equation of Transfer  
- Incoherent Specific Intensities  
- Stokes Parameters  
- Full Wave  
- Physical Optics  
- Perturbation  
- Diffuse Scattering  
- Co-polarized  
- Cross-polarized  
- Scattering Cross Sections  
- Extinction Cross Sections.
The principal purpose of the research is to investigate radio wave scattering and depolarization by conducting objects of irregular shape. To test the programs and in order to develop better physical interpretations of the results, scatterers with simple shapes are considered first. Thus, the full wave solutions for scattering and depolarization are compared with known solutions to the problem.

The second phase of this work is devoted to the problem of scattering and depolarization by irregularly shaped objects. Both one- and two-dimensional problems are considered. To account for medium losses the scatterer is characterized by a complex permittivity and permeability. Using the full wave approach it is not necessary to employ the approximate impedance boundary conditions.

Special attention is given to determining the normalized co-polarized and cross-polarized backscatter cross section. The full wave solutions for the scattering cross sections are compared with the perturbational and physical optics solutions. Special attention is also given to the polarization dependence of the scattering cross sections.

The third phase of this investigation is devoted to the solution of the equation of transfer for the incoherent specific intensities in a media consisting of random distributions of irregular shaped particles. The random rough surfaces of the particles are characterized by their surface height autocorrelation function. Both single scatter and multiple scatter results are presented.
TABLE OF CONTENTS

1. Introduction—Statement of the Problem ........ 1
2. Summary of Results ................................ 2
3. Description of Research .......................... 5
4. Personnel Supported by this Project .......... 6
5. Acknowledgments ................................. 7
6. List of Publications by the Principal Investigator During Period of Army Contract .......... 8
   (a) Publications in Technical Journals .......... 8
   (b) Abstracts and Summaries of Papers Presented at International Conferences .......... 9
   (c) Technical Reports ............................ 11
   (d) Ph.D. Dissertation ........................... 12
7. Appendices ....................................... 13
   (a) Semi-Annual Progress Reports Nos. 1-7 Item 6(c)
   (b) Reprints and Preprints of Publications in Technical Journals, Item 6(a)
   (c) Reprints and Preprints of Abstracts and Summaries of Papers Presented and International Conferences, Item 6(b)
1. INTRODUCTION - STATEMENT OF THE PROBLEM

The principal purpose of the research is to investigate radio wave scattering and depolarization by conducting objects of irregular shape. To test the programs and in order to develop better physical interpretations of the results, scatterers with simple shapes are considered first. Thus, the full wave solutions for scattering and depolarization are compared with known solutions to the problem.

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The third phase of this investigation is devoted to the solution of the equation of transfer for the incoherent specific intensities in a media consisting of random distributions of irregular shaped particles. The random rough surfaces of the particles are characterized by their surface height autocorrelation function. Both single scatter and multiple scatter results are presented.
2. SUMMARY OF RESULTS

Over the period of this contract the principal investigator submitted twenty-one manuscripts for publication in Scientific/Technical Journals, presented seventeen conference papers and submitted seven Semi-Annual Technical Reports. In addition, the research leading to a Ph.D. dissertation was supported by this contract (see Section 6 for a detailed list).

The topics of the publications and conference presentations can be classified into three main groups.

The first group is related to scattering and depolarization by rough surfaces* (1), (4), (5), (6), (8), (11), (12), (14), (18), (24), (27), (28), (30), (31), (33), (34), (35), (38). In this work the full wave approach based on the unified and two-scale models of the rough surfaces is used to determine the co-polarized and cross-polarized scattering cross sections. The full wave solutions which are based on complete expansions of the fields and the imposition of exact boundary conditions are shown to reduce to the physical optics solutions in the high frequency limit and the small perturbation solution in the low frequency limit. Surfaces with Gaussian as well as non-Gaussian surface height probability density functions are considered and the slope probability densities are assumed to be either isotropic and Gaussian or non-isotropic and non-Gaussian. The rough surface is characterized by its

*Reference numbers correspond to list given in Section 6.
surface height spectral density function (the Fourier transform of its autocorrelation function). Using the unified full wave approach, the inadequacy of employing the commonly used hybrid physical optics-perturbation approach to rough surface scattering has been established.

The second group of publications deals with scattering by finitely conducting objects with irregular shapes, such as cylinders and spheres and disks (flakes) with random rough surfaces: (2), (3), (7), (9), (10), (13), (15), (19), (21), (22), (23), (25), (26), (29), (32), (36). The mean square heights of the rough surfaces are assumed to be very large such that the familiar small perturbation approach is not suitable to analyze these problems. The particle rough surface is characterized by different surface height spectral density functions and complex permittivities. Thus, different scales of roughness are considered and the effects of varying the mean square height and the mean square slope (and the related correlation distances) are examined in detail. Special consideration is given to the derivations of the bistatic like- and cross-polarized cross sections as well as the albedos and extinction cross sections of the irregular shaped particles (for which no analytic solutions had yet been presented).

The third group of manuscripts deals with the solution of the equation of transfer for the co-polarized and cross-polarized incoherent specific intensities (Stokes parameters) in media consisting of random distributions of irregular shaped particles.
Both infrared and optical excitations are considered at normal and oblique incidence to parallel layers of particles. First order, single scatter as well as multiple scatter results are presented for particles with rough surfaces as well as particles with smooth surfaces. It is shown that the principal effect of the particle surface roughness is to make the incoherent specific intensities more isotropic, (thus smoothing out the large undulations in the specific intensities for the medium consisting of smooth particles and eliminating windows of transmission). In addition, the degree of polarization of the scattered specific intensities is significantly smaller for the particles with rough surfaces. Step by step progress on the research conducted over this period of the contract is reported in seven semiannual technical reports reproduced in this Final Report.
3. DESCRIPTION OF RESEARCH

Detailed description of the analytical and numerical techniques used in these investigations and their applications to engineering and technology are given in the reprints and preprints of the scientific manuscripts submitted with this Final Report (see list of publications, Section 6, and Appendix).
4. PERSONNEL SUPPORTED BY THIS CONTRACT

In addition to the principal investigator, Ezekiel Bahar, the main contributors to this research project are Mary Ann Fitzwater and Parveen Wahid (Post Doctoral Associates), and Swapan Chakrabarti (Graduate Research Assistant).

Mr. Swapan Chakrabarti's Ph.D. dissertation is based on the research conducted for this project. The Ph.D. thesis is submitted as an addendum to this Final Report.
5. ACKNOWLEDGMENTS

The author wishes to thank James Mink, Walter Flood, (ARO Durham, North Carolina), and Edward Stuebing and Robert Frickel (CRDC Aberdeen, Maryland), for their encouragement, suggestions and interest in these investigations.

The author also wishes to acknowledge the support he received from the University of Nebraska-Lincoln for use of its computing facilities. He is especially indebted to the National Science Foundation for the Engineering Supercomputer Grants ECS 8515794/5 he was awarded.
6. List of Publications by the Principal Investigator During Period of Army Contract

(a) Publications in Technical Journals


(14) "Full Wave Solutions for Electromagnetic Scattering and Depolarization in Irregular Stratified Media," Special Issue of Radio Science on Waves in Inhomogeneous Media--in press.

(15) "Scattering and Depolarization by Conducting Cylinders with Rough Surfaces," Applied Optics--in press.

(16) "Multiple Scattering by Irregular Shaped Particles of Finite Conductivity at Infrared and Optical Frequencies," Radio Science--in press.

(17) "Scattering and Depolarization of Linearly Polarized Waves with Finitely Conducting Particles of Irregular Shape," submitted for review.

(18) "Interpretation of Backscatter Cross Sections for Normal Incidence Using Unified and Two-Scale Full Wave Analyses of Rough Surfaces," submitted for review.


(20) "Extinction Cross Sections and Albedos for Particles with Very Rough Surface," submitted for review.

(21) "Co-Polarized and Cross-Polarized Incoherent Specific Intensities at Oblique Incidence for Particles of Irregular Shape and Finite Conductivity," submitted for review.

(22) "Computer Aided Graphics for Three Dimensional Objects Based on Full Wave Theory," submitted for review.


(b) Abstracts and Summaries of Papers Presented at International Conferences


(29) International Union of Radio Science (URSI) Meeting at the University of Colorado, Boulder, January 11-13, 1984, "Scattering and Depolarization by Large Conducting Spheres with Very Rough Surfaces."


(35) 1985 CRDC Scientific Conference on Obscuration and Aerosol Research, Aberdeen, Maryland, June 17-21, 1985, "Multiple Scattering in Media Consisting of Non-Spherical, Finitely Conducting Particles."


1985 Joint Meeting of the IEEE Geoscience and Remote Sensing Society and USNC/URSI Commission, October 7-9, 1985, University of Massachusetts, Amherst, Massachusetts, "Like and Cross Polarized Cross Sections for Random Rough Surfaces—Full Wave Theory and Experiment."


29th Midwest Symposium on Circuits and Systems, University of Nebraska-Lincoln, August 11-12, 1986, "Application of Full Wave Theory to Computer Aided Geometric Design."


(c) Technical Reports


(d) Ph.D. Dissertation

(55) "Scattering Cross Sections and Incoherent Specific Intensities for Particles of Irregular Shape and Finite Conductivity--Full Wave Approach," to be submitted to the Department of Electrical Engineering, University of Nebraska-Lincoln, May 1986, by S. Chakrabarti.