
**ELECTROMAGNETIC
WAVES** **PIER 14**

**Progress
In
Electromagnetics
Research**

No responsibility is assumed by the Publisher for any injury and/or damage to persons or property as a matter of products liability, negligence, or otherwise, or from any use or operation of any methods, products, instructions, or ideas contained in the material herein.

© 1996 EMW Publishing

All inquiries regarding copyrighted material from this publication, manuscript submission, and subscription orders should be directed to: EMW Publishing, P. O. Box 597, Kendall Square, Cambridge, Massachusetts 02142-0597, USA.

This publication is printed on acid-free paper.

ISSN 1070-4698

Manufactured in the United States of America

**ELECTROMAGNETIC
WAVES PIER 14**

Progress
In
Electromagnetics
Research

Chief Editor: J. A. Kong

Electromagnetic
Scattering by Rough
Surfaces and Random Media

Editors:
M. Tateiba and L. Tsang

EMW Publishing
Cambridge, Massachusetts, USA

ELECTROMAGNETIC SCATTERING BY ROUGH SURFACES AND RANDOM MEDIA

PREFACE

The technology of sensing using electromagnetic and optical waves requires the understanding of the interactions of electromagnetic waves with geophysical and biological media as well as new materials for various emerging applications. Since propagation problems are closely related to solving the scattering of electromagnetic waves by rough surfaces and random media, this PIER 14 includes recent new results for the study of such problems.

In the chapter by Ishimaru et al., a second-order Kirchhoff theory with shadowing corrections is applied to treat random rough surfaces with high slopes. It includes a good comparison with experimental results.

In the chapter by Kuga et al., experimental techniques in millimeter wave scattering are described. Such controlled laboratory experiments are important in the discovery of new physical phenomena such as backscattering enhancement and memory effects. They are also useful in verification of theoretical results.

In the chapter by Ogura and Takahashi, a stochastic functional method is discussed for scalar wave scattering by two-dimensional random rough surfaces, and numerical results are given for the case of slight roughness.

In the chapter by Au et al., the scattering and absorption in a vegetation canopy at microwave frequencies is treated with the wave approach. Unlike the approach of independent scattering and radiative transfer, the wave approach takes into account the structure of trees and vegetation which can contribute to the collective scattering and absorption effects of branches and leaves.

The chapter by Chen et al. applies the concept of collective scattering and absorption to trees generated by the stochastic Lindenmayer system. The advantage of the Lindenmayer system is that the computer growth procedure produces trees that are realistic in appearance and thus are able to simulate the collective scattering effects of such vegetation structure.

The chapter by Veysoglu and Kong derives the correlation functions rigorously for a random medium model. Such studies are useful to characterize scattering by highly inhomogeneous media.

The chapter by Tateiba and Meng presents an approach to the problem of wave scattering from a conducting body of arbitrary shape and size in a random medium. Numerical results of RCS of a cylinder surrounded by a turbulent medium are also presented.

M. Tateiba and L. Tsang

March 1996

CONTENTS

Chapter 1	POLARIMETRIC SCATTERING THEORY FOR HIGH SLOPE ROUGH SURFACES A. Ishimaru, C. Le, Y. Kuga, L. A. Sengers, and T. K. Chan	
	1. Introduction	1
	2. Formulation of the Mueller Matrix M and the Cross Section Mueller Matrix Σ	4
	3. First-Order Kirchhoff and Geometric Optics Approximation	6
	4. Evaluation of $\langle J_1 J_1^* \rangle$ in the Geometric Optics Approximation	10
	5. Second-Order Kirchhoff Approximation	14
	6. Evaluation of the Ladder Term $\langle J_2 + J_2^* \rangle$	16
	7. Evaluation of the Cross Section for the Ladder Term	21
	8. Evaluation of the Cyclical Term	23
	9. Numerical Examples and Comparison with Millimeter Wave Experiment	26
	10. Summary and Conclusion	34
	Acknowledgments	34
	References	34
Chapter 2	EXPERIMENTAL STUDIES OF MILLIMETER-WAVE SCATTERING IN DISCRETE RANDOM MEDIA AND FROM ROUGH SURFACES Y. Kuga and P. Phu	
	1. Introduction	37
	2. Random Media for Controlled Experiments	39
	3. Experimental Systems	55
	4. Experimental Results on Rough Surfaces and Discrete Random Media	65
	5. Conclusions	83
	References	84

Chapter 3	<p>SCATTERING, RADIATION, AND PROPAGATION OVER TWO- DIMENSIONAL RANDOM SURFACE H. Ogura and N. Takahashi</p>	
	1. Introduction	91
	2. Homogeneous Random Field and Shift Operator	93
	3. Form of the Stochastic Wave Field for Plane Wave Incidence	98
	4. Statistical Quantities of the Scattered Wave Field	104
	5. Approximate Method of Solution	108
	6. Scattering Characteristics	119
	7. Relations to Other Theories	132
	8. Green Function over a 2D Random Surface	135
	9. Radiation over a Random Surface - Far Field from the Source and the Surface	141
	10. Radiation Characteristics	145
	11. Propagation over a Random Surface - Far Field along the Surface	149
	12. Propagation Characteristics	166
	Appendices	170
	References	178
Chapter 4	<p>COLLECTIVE SCATTERING AND ABSORPTION EFFECTS IN MICROWAVE INTERACTION WITH VEGETATION CANOPIES W. C. Au, L. Tsang, R. T. Shin, and J. A. Kong</p>	
	1. Introduction	182
	2. Numerical Solution of Scattering by Clusters of Thin Dielectric Cylinders	184
	3. Vector Radiative Transfer Theory with Collective Scattering Behavior of Particles	196
	4. Applications to Active Remote Sensing	202
	5. Applications to Passive Remote Sensing	212
	6. Conclusion	228
	References	229

Chapter 5	APPLICATION OF STOCHASTIC LINDENMAYER SYSTEMS TO THE STUDY OF COLLECTIVE AND CLUSTER SCATTERING IN MICROWAVE REMOTE SENSING OF VEGETATION Z. Chen, L. Tsang, and G. Zhang	
	1. Introduction	234
	2. Modeling of Plants by Using L-Systems	236
	3. Scattering from Trees Generated by L-Systems Based on Coherent Addition Approximation	246
	4. Scattering from Trees Generated by L-Systems Based on Discrete Dipole Approximation	258
	5. Conclusions	273
	Appendices	274
	References	275
Chapter 6	MULTI-SCALE CORRELATION FUNCTIONS FOR RANDOM MEDIUM MODELS M. E. Veysoglu and J. A. Kong	
	1. Introduction	279
	2. Random Medium Model	281
	3. Computation of Correlation Functions	283
	4. Summary and Conclusions	309
	Appendices	310
	References	313
Chapter 7	WAVE SCATTERING FROM CONDUCTING BODIES EMBEDDED IN RANDOM MEDIA - THEORY AND NUMERICAL RESULTS M. Tateiba and Z. Q. Meng	
	1. Introduction	317
	2. Scattering Theory	319
	3. Numerical Results	331
	4. Concluding Remarks	350
	Appendices	252
	References	359