

Analysis and Modeling of Radio Wave Propagation

With this comprehensive guide you will understand the theory and learn the techniques needed to analyze and model radio wave propagation in complex environments. All of the essential topics are covered, from the fundamental concepts of radio systems to complex propagation phenomena. These topics include diffraction, ray tracing, scattering, atmospheric ducting, ionospheric ducting, scintillation and propagation through both urban and non-urban environments. Emphasis is placed on practical procedures, with detailed discussion of numerical and mathematical methods, providing you with the necessary skills to build your own propagation models and develop your own techniques. MATLAB functions illustrating key modeling ideas are available online.

This is an invaluable resource for anyone wanting to use propagation models to understand the performance of radio systems for navigation, radar, communications or broadcasting.

Christopher John Coleman is a Senior Visiting Research Fellow in the Department of Electronic and Electrical Engineering at the University of Bath, and a Visiting Research Fellow at the School of Electrical and Electronic Engineering at the University of Adelaide. From 1990 until 1999 he was a Principal Research Scientist on Australia's Jindalee Over the Horizon radar project. He is the author of the book *An Introduction to Radio Frequency Engineering* (Cambridge, 2004).

Cambridge University Press
978-1-107-17556-3 — Analysis and Modeling of Radio Wave Propagation
Christopher John Coleman
Frontmatter
[More Information](#)

Analysis and Modeling of Radio Wave Propagation

CHRISTOPHER JOHN COLEMAN

University of Bath and University of Adelaide



CAMBRIDGE
UNIVERSITY PRESS

Cambridge University Press
978-1-107-17556-3 — Analysis and Modeling of Radio Wave Propagation
Christopher John Coleman
Frontmatter
[More Information](#)

CAMBRIDGE UNIVERSITY PRESS

University Printing House, Cambridge CB2 8BS, United Kingdom

One Liberty Plaza, 20th Floor, New York, NY 10006, USA

477 Williamstown Road, Port Melbourne, VIC 3207, Australia

4843/24, 2nd Floor, Ansari Road, Daryaganj, Delhi – 110002, India

79 Anson Road, #06–04/06, Singapore 079906

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning and research at the highest international levels of excellence.

www.cambridge.org

Information on this title: www.cambridge.org/9781107175563

© Cambridge University Press 2017

This publication is in copyright. Subject to statutory exception and to the provisions of relevant collective licensing agreements, no reproduction of any part may take place without the written permission of Cambridge University Press.

First published 2017

Printed in the United Kingdom by TJ International Ltd. Padstow Cornwall

A catalogue record for this publication is available from the British Library

Library of Congress Cataloging-in-Publication Data

Names: Coleman, Christopher, 1950– author.

Title: Analysis and modeling of radio wave propagation / Christopher John Coleman, University of Adelaide.

Description: Cambridge, United Kingdom ; New York, NY : Cambridge University Press, [2017] |

Includes bibliographical references and index.

Identifiers: LCCN 2016045806 | ISBN 9781107175563 (Hardback ; alk. paper) |

ISBN 1107175569 (Hardback ; alk. paper)

Subjects: LCSH: Radio wave propagation. | Radio wave propagation—Mathematical models. | Electromagnetic waves.

Classification: LCC TK6553 .C635 2017 | DDC 621.3841/1—dc23 LC record available at <https://lcn.loc.gov/2016045806>

ISBN 978-1-107-17556-3 Hardback

Additional resources for this publication at www.cambridge.org/coleman

Cambridge University Press has no responsibility for the persistence or accuracy of URLs for external or third-party Internet websites referred to in this publication, and does not guarantee that any content on such websites is, or will remain, accurate or appropriate.

Contents

	<i>Preface</i>	<i>page ix</i>
1	Basic Concepts	1
	1.1 Waves	1
	1.2 Electromagnetic Waves	2
	1.3 Communications Systems	5
	1.4 Cellular Radio	7
	1.5 Radar Systems	8
	1.6 Complex Propagation	9
2	The Fundamentals of Electromagnetic Waves	15
	2.1 Maxwell’s Equations	15
	2.2 Plane Electromagnetic Waves	17
	2.3 Plane Waves in Anisotropic Media	22
	2.4 Boundary Conditions	27
	2.5 Transmission through an Interface	28
	2.6 Oblique Incidence	30
	2.7 Sources of Radio Waves	33
3	The Reciprocity, Compensation and Extinction Theorems	38
	3.1 The Reciprocity Theorem	38
	3.2 Reciprocity and Radio Systems	40
	3.3 Pseudo Reciprocity	42
	3.4 The Compensation Theorem	44
	3.5 The Extinction Theorem	46
4	The Effect of Obstructions on Radio Wave Propagation	50
	4.1 The Friis Equation	50
	4.2 Reflection by Irregular Terrain	53
	4.3 Diffraction	55
	4.4 Surface Waves	58
	4.5 The Geometric Theory of Diffraction	60
		v

vi	Contents	
	4.6 Propagation in Urban Environments	64
	4.7 The Channel Impulse Response Function	68
5	Geometric Optics	70
	5.1 The Basic Equations	70
	5.2 Analytic Integration	78
	5.3 Geometric Optics in an Anisotropic Medium	80
	5.4 Weakly Anisotropic Medium	86
	5.5 Fermat's Principle for Anisotropic Media	87
6	Propagation through Irregular Media	94
	6.1 Scattering by Permittivity Anomalies	94
	6.2 The Rytov Approximation	98
	6.3 Mutual Coherence	102
	6.4 The Rytov Approximation and Irregular Media	103
	6.5 Parabolic Equations for the Average Field and MCF	110
	6.6 The Phase Screen Approximation	114
	6.7 Channel Simulation	118
	6.8 Rough Surface Scattering	121
7	The Approximate Solution of Maxwell's Equations	129
	7.1 The Two-Dimensional Approximation	129
	7.2 The Paraxial Approximation	135
	7.3 Kirchhoff Integral Approach	139
	7.4 Irregular Terrain	145
	7.5 3D Kirchhoff Integral Approach	148
	7.6 Time Domain Methods	151
8	Propagation in the Ionospheric Duct	159
	8.1 The Benign Ionosphere	159
	8.2 The Disturbed Ionosphere	165
	8.3 Vertical and Quasi-Vertical Propagation	167
	8.4 Oblique Propagation over Long Ranges	177
	8.5 Propagation Losses	187
	8.6 Fading	191
	8.7 Noise	192
	8.8 Full Wave Solutions	194
9	Propagation in the Lower Atmosphere	204
	9.1 Propagation in Tropospheric Ducts	204
	9.2 The Effect of Variations in Topography	209

	Contents	vii
9.3	Surface Wave Propagation	211
9.4	Propagation through Forest	216
9.5	Propagation through Water	218
9.6	Propagation through Rain	219
10	Transionospheric Propagation and Scintillation	222
10.1	Propagation through a Benign Ionosphere	222
10.2	Faraday Rotation and Doppler Shift	225
10.3	Small-Scale Irregularity	226
10.4	Scintillation	227
Appendix A	Some Useful Mathematics	236
A.1	Vectors	236
A.2	Vector Operators	236
A.3	Cylindrical Polar Coordinates	237
A.4	Some Useful Integrals	238
A.5	Trigonometric Identities	239
A.6	Method of Stationary Phase	240
A.7	Some Expansions	240
A.8	The Airy Function	241
A.9	Hankel and Bessel Functions	242
A.10	Some Useful Series	245
Appendix B	Numerical Methods	247
B.1	Numerical Differentiation and Integration	247
B.2	Zeros of a Function	248
B.3	Numerical Solution of Ordinary Differential Equations	249
B.4	Multidimensional Integration	251
Appendix C	Variational Calculus	253
Appendix D	The Fourier Transform	259
Appendix E	Finding Stationary Values	263
E.1	Newton–Raphson Approach	263
E.2	Nelder–Mead Method	263
Appendix F	Stratified Media	265
F.1	Two-Layer Medium	265
F.2	Three-Layer Medium	270

viii	Contents	
	<hr/>	
	Appendix G Useful Information	273
	Appendix H A Perfectly Matched Layer	274
	Appendix I Equations for TE and TM Fields	276
	Appendix J Canonical Solutions	278
	<i>Index</i>	284

Preface

The aim of this book is to provide the reader with the techniques and theory that are required for the analysis and modeling of radio wave propagation in complex environments. It is designed for the reader who might need to model propagation in order to understand the performance of radio systems for navigation, radar, communications or broadcasting. The book brings together a range of topics that are often treated separately, but all of which are important in the comprehensive modeling of a radio system. In particular, the book includes an extensive discussion of propagation through irregularity, of importance to systems that suffer from scintillation. The book is not intended to be just a cookbook of propagation formulae, but rather to provide readers with sufficient insight to enable them to produce their own specialized theory and techniques when required. It is my experience that many propagation problems are not amenable to off-the-shelf black box solutions. A black box will often only provide part of the solution and the modeler will need to modify and/or add capability. To do this successfully, the modeler will need to have some insight into the basis of the black box in order to effectively incorporate his/her own modifications. It is the intention of the author to provide the reader with such insight. The book leverages on my experience, over several decades, in the development of techniques for the analysis and modeling of propagation in a variety of radar and communication systems. In writing this book, I have been heavily influenced by the work of Professor James Wait, Dr. G.D. Monteath, Dr. Jenifer Haselgrove, and Dr. Kenneth Davies. In particular, the reciprocity ideas that have been developed by Dr. Monteath have proven invaluable in the development of many propagation modeling techniques.

The book is designed to take the reader from very basic ideas concerning radio systems to advanced propagation modeling. The first chapter will be useful to someone new to radio systems and provide them with an idea of the technology and the challenges that radio wave propagation imposes. Obviously, this chapter can be skipped by those readers who are already familiar with radio technology. Chapters 2 and 3 introduce some important electromagnetic ideas that are used in the rest of the book. Readers specifically interested in ionospheric propagation will find Chapters 5 and 8 of most use, while those interested in scintillation will find Chapters 6 and 10 of relevance. For those interested in propagation across terrain and through the lower atmosphere, Chapters 4, 7 and 9 are of greatest relevance. The appendices contain extensive notes

on mathematics and numerical techniques that are used throughout the text. In addition, there are appendices in which important canonical solutions are derived.

I would like to thank Professor Christophe Fumeaux, Dr. L.J.Nickisch and Dr. Robert Watson for reading drafts of this book and providing useful feedback. I would also like to thank my wife, Marilyn, for her invaluable support and help in preparing this book.