


# ANTENNA THEORY

## Analysis and Design

CONSTANTINE A. BALANIS  
West Virginia University

1817  
 HARPER & ROW, PUBLISHERS, New York  
Cambridge, Philadelphia, San Francisco,  
London, Mexico City, São Paulo, Sydney

Sponsoring Editor: Carl McNair  
Project Editor: Pamela Landau  
Designer: Michel Craig  
Production Manager: Marion Palen  
Compositor: Science Typographers, Inc.  
Printer and Binder: The Murray Printing Company  
Art Studio: Vantage Art Inc.

**ANTENNA THEORY    Analysis and Design**

Copyright © 1982 by Harper & Row, Publishers, Inc.

All rights reserved. Printed in the United States of America. No part of this book may be used or reproduced in any manner whatsoever without written permission, except in the case of brief quotations embodied in critical articles and reviews. For information address Harper & Row, Publishers, Inc., 10 East 53d Street, New York, NY 10022.

Library of Congress Cataloging in Publication Data

Balanis, Constantine A., 1938 –  
Antenna theory.

(The Harper & Row series in electrical engineering)  
Includes bibliographical references and index.

1. Antennas (Electronics)    I. Title.    II. Series.  
TK7871.6.B353            621.38'028'3            81-20248  
ISBN 0-06-040458-2                            AACR2

# Contents

Preface xv

## Chapter 1 Antennas 1

- 1.1 Introduction 1
- 1.2 Types of Antennas 1  
*Wire Antennas; Aperture Antennas; Array Antennas; Reflector Antennas; Lens Antennas*
- 1.3 Radiation Mechanism 7
- 1.4 Current Distribution on a Thin Wire Antenna 11
- 1.5 Historical Advancement 15
- References 15

## Chapter 2 Fundamental Parameters of Antennas 17

- 2.1 Introduction 17
- 2.2 Radiation Pattern 17  
*Isotropic, Directional, and Omnidirectional Patterns; Principal Patterns; Radiation Pattern Lobes; Field Regions; Radian and Steradian*

vii

viii CONTENTS

2.3	Radiation Power Density	25
2.4	Radiation Intensity	27
2.5	Directivity	29
2.6	Numerical Techniques	37
2.7	Gain	42
2.8	Antenna Efficiency	44
2.9	Half-Power Beamwidth	46
2.10	Beam Efficiency	46
2.11	Bandwidth	47
2.12	Polarization	48
	<i>Linear, Circular, and Elliptical Polarizations; Polarization Loss Factor</i>	
2.13	Input Impedance	53
2.14	Antenna Radiation Efficiency	57
2.15	Antenna as an Aperture: Effective Aperture	59
2.16	Directivity and Maximum Effective Aperture	61
2.17	Friis Transmission Equation and Radar Range Equation	63
	<i>Friis Transmission Equation; Radar Range Equation</i>	
2.18	Antenna Temperature	67
	References	70
	Problems	71
	Computer Program—Polar Plot	75
	Computer Program—Linear Plot	78
	Computer Program—Directivity	80

**Chapter 3 Radiation Integrals and Auxiliary Potential Functions 82**

3.1	Introduction	82
3.2	The Vector Potential $\mathbf{A}$ for an Electric Current Source $\mathbf{J}$	83
3.3	The Vector Potential $\mathbf{F}$ for a Magnetic Current Source $\mathbf{M}$	85
3.4	Electric and Magnetic Fields for Electric ( $\mathbf{J}$ ) and Magnetic ( $\mathbf{M}$ ) Current Sources	86
3.5	Solution of the Inhomogeneous Vector Potential Wave Equation	88
3.6	Far-Field Radiation	92
3.7	Duality Theorem	93
3.8	Reciprocity and Reaction Theorems	94
	<i>Reciprocity for Radiation Patterns</i>	
	References	99
	Problems	99

**Chapter 4 Linear Wire Antennas 100**

4.1	Introduction	100
4.2	Infinitesimal Dipole	100
	<i>Radiated Fields; Power Density and Radiation Resistance; Near-Field (<math>kr \ll 1</math>) Region; Intermediate-Field (<math>kr &gt; 1</math>) Region; Far-Field (<math>kr \gg 1</math>) Region; Directivity</i>	

- 4.3 Small Dipole 109
- 4.4 Region Separation 112  
*Far-Field (Fraunhofer) Region; Radiating Near-Field (Fresnel) Region; Reactive Near-Field Region*
- 4.5 Finite Length Dipole 118  
*Current Distribution; Radiated Fields: Element Factor, Space Factor, and Pattern Multiplication; Power Density, Radiation Intensity, and Radiation Resistance; Directivity; Input Resistance; Finite Feed Gap*
- 4.6 Half-Wavelength Dipole 130
- 4.7 Linear Elements Near or on Infinite Plane Conductors 132  
*Image Theory; Vertical Electric Dipole; Horizontal Electric Dipole*
- 4.8 Ground Effects 148  
*Vertical Electric Dipole; Horizontal Electric Dipole; Earth Curvature*
- References 159
- Problems 159
- Computer Program—Linear Dipole: Directivity, Radiation Resistance, and Input Resistance 162

## Chapter 5 Loop Antennas 164

- 5.1 Introduction 164
- 5.2 Small Circular Loop 164  
*Radiated Fields; Small Loop and Infinitesimal Magnetic Dipole; Power Density and Radiation Resistance; Near-Field ( $kr \ll 1$ ) Region; Far-Field ( $kr \gg 1$ ) Region; Radiation Intensity and Directivity*
- 5.3 Circular Loop of Constant Current 176  
*Radiated Fields; Power Density, Radiation Intensity, Radiation Resistance, and Directivity*
- 5.4 Circular Loop with Nonuniform Current 184
- 5.5 Ground and Earth Curvature Effects for Circular Loops 188
- 5.6 Polygonal Loop Antennas 191  
*Square Loop; Triangular, Rectangular, and Rhombic Loops*
- 5.7 Ferrite Loop 196
- References 198
- Problems 199
- Computer Program—Circular Loop: Directivity and Radiation Resistance 201

## Chapter 6 Arrays: Linear, Planar, and Circular 204

- 6.1 Introduction 204
- 6.2 Two-Element Array 205
- 6.3  $N$ -Element Linear Array: Uniform Amplitude and Spacing 212

# Explore Litigation Insights

Docket Alarm provides insights to develop a more informed litigation strategy and the peace of mind of knowing you're on top of things.

## Real-Time Litigation Alerts



Keep your litigation team up-to-date with **real-time alerts** and advanced team management tools built for the enterprise, all while greatly reducing PACER spend.

Our comprehensive service means we can handle Federal, State, and Administrative courts across the country.

## Advanced Docket Research



With over 230 million records, Docket Alarm's cloud-native docket research platform finds what other services can't. Coverage includes Federal, State, plus PTAB, TTAB, ITC and NLRB decisions, all in one place.

Identify arguments that have been successful in the past with full text, pinpoint searching. Link to case law cited within any court document via Fastcase.

## Analytics At Your Fingertips



Learn what happened the last time a particular judge, opposing counsel or company faced cases similar to yours.

Advanced out-of-the-box PTAB and TTAB analytics are always at your fingertips.

## API

Docket Alarm offers a powerful API (application programming interface) to developers that want to integrate case filings into their apps.

## LAW FIRMS

Build custom dashboards for your attorneys and clients with live data direct from the court.

Automate many repetitive legal tasks like conflict checks, document management, and marketing.

## FINANCIAL INSTITUTIONS

Litigation and bankruptcy checks for companies and debtors.

## E-DISCOVERY AND LEGAL VENDORS

Sync your system to PACER to automate legal marketing.