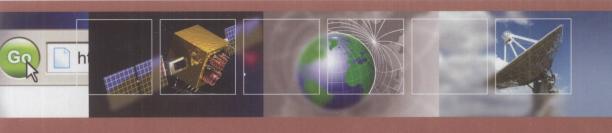
Louis J. Ippolito Jr.

Satellite Communications Systems Engineering

Atmospheric Effects, Satellite Link Design and System Performance



Wiley Series on
Wireless Communications
and Mobile Computing



TN927

Satellite Communications Systems Engineering

Atmospheric Effects, Satellite Link Design and System Performance

Louis J. Ippolito, Jr.

ITT Advanced Engineering & Sciences, USA, and The George Washington University, Washington, DC, USA







This edition first published 2008 © 2008 John Wiley & Sons Ltd

Registered office

John Wiley & Sons Ltd, The Atrium, Southern Gate, Chichester, West Sussex, PO19 8SQ, United Kingdom

For details of our global editorial offices, for customer services and for information about how to apply for permission to reuse the copyright material in this book please see our website at www.wiley.com.

The right of the author to be identified as the author of this work has been asserted in accordance with the Copyright, Designs and Patents Act 1988.

All rights reserved. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying, recording or otherwise, except as permitted by the UK Copyright, Designs and Patents Act 1988, without the prior permission of the publisher.

Wiley also publishes its books in a variety of electronic formats. Some content that appears in print may not be available in electronic books.

Designations used by companies to distinguish their products are often claimed as trademarks. All brand names and product names used in this book are trade names, service marks, trademarks or registered trademarks of their respective owners. The publisher is not associated with any product or vendor mentioned in this book. This publication is designed to provide accurate and authoritative information in regard to the subject matter covered. It is sold on the understanding that the publisher is not engaged in rendering professional services. If professional advice or other expert assistance is required, the services of a competent professional should be sought.

Library of Congress Cataloging-in-Publication Data

Ippolito, Louis J.

Satellite communications systems engineering: atmospheric effects, satellite link design, and system performance/Louis J. Ippolito.

p. cm. — (Wiley series on wireless communications and mobile computing)

Includes bibliographical references and index.

ISBN 978-0-470-72527-6 (cloth)

TK5104.I674 2008

621.382'5—dc22

2008013166

A catalogue record for this book is available from the British Library.

ISBN 978-0-470-72527-6 (HB)

Set in 10/12pt Times by Integra Software Services Pvt. Ltd, Pondicherry, India Printed in Singapore by Markono Print Media Pte Ltd

Satellite Communications Systems Engineering

Wiley Series on Wireless Communications and Mobile Computing

Series Editors: Dr Xuemin (Sherman) Shen, University of Waterloo, Canada Dr Yi Pan, Georgia State University, USA

The 'Wiley Series on Wireless Communications and Mobile Computing' is a series of comprehensive, practical and timely books on wireless communication and network systems. The series focuses on topics ranging from wireless communication and coding theory to wireless applications and pervasive computing. The books offer engineers and other technical professionals, researchers, educators, and advanced students in these fields invaluable insight into the latest developments and cutting-edge research.

Other titles in the series:

Mišić and Mišić: Wireless Personal Area Networks: Performance, Interconnection, and Security with IEEE 802.15.4, January 2008, 978-0-470-51847-2

Takagi and Walke: Spectrum Requirement Planning in Wireless Communications: Model and Methodology for IMT-Advanced, March 2008, 978-0-470-98647-9

Pérez Fontán and Mariño Espiñeira: *Modeling the Wireless Propagation Channel: A simulation approach with MATLAB*®, August 2008, 978-0-470-72785-0

Lin and Sou: Charging for All-IP Telecommunications, September 2008, 978-0-470-77565-3

Myung: Single Carrier FDMA: A New Air Interface for Long Term Evolution, November 2008, 978-0-470-72449-1

Hart, Tao, Zhou: IEEE 802.16j Mobile Multihop Relay, March 2009, 978-0-470-99399-6

Stojmenovic: Wireless Sensor and Actuator Networks: Algorithms and Protocols for Scalable Coordination and Data Communication, August 2009, 978-0-470-17082-3

Qian, Muller, Chen: Security in Wireless Networks and Systems, May 2009, 978-0-470-51212-8

Wang, Kondi, Luthra, Ci: 4G Wireless Video Communications, May 2009, 978-0-470-77307-9

Cai, Shen, Mark: *Multimedia for Wireless Internet – Modeling and Analysis*, May 2009, 978-0-470-77065-8

List of Acronyms

8ΦPSK 8-phase phase shift keying,

A

ACM adaptive coded modulation

ACTS Advanced Communications Technology Satellite

A/D analog to digital converter ADM adaptive delta modulation

ADPCM adaptive differential pulse code modulation

AGARD Advisory Group for Aeronautical Research and Development (NATO)

AIAA American Institute of Aeronautics and Astronautics

AM amplitude modulation AMI alternate mark inversion

AMSS aeronautical mobile satellite service
AOCS Attitude and Orbit Control System
ATS- Applications Technology SatelliteAWGN additive white Gaussian noise

Az azimuth (angle)

В

BB baseband BER bit error rate

BFSK binary frequency shift keying

BO backoff

BOL beginning of life BPF band pass filter

BPSK binary phase shift keying BSS broadcast satellite service

 \mathbf{C}

CBR carrier and bit-timing recovery
CDC coordination and delay channel
CDF cumulative distribution function

CDMA code division multiple access

CEPIT Coordinamento Esperimento Propagazione Italsat

CEPT European Conference of Postal and Telecommunications Administrations

C/I carrier to interference ratio

CLW cloud liquid water

cm centimeters

C/N carrier-to-noise ratio C/No carrier-to-noise density

COMSAT Communications Satellite Corporation

CONUS continental United States
CPA copolar attenuation
CRC cyclic redundancy check

CSC common signaling channel
CTS Communications Technology Satellite

CVSD continuously variable slope delta modulation

D

D.C. down converter DA demand assignment

DAH Dissanayake, Allnutt, and Haidara (rain attenuation model)

DAMA demand assigned multiple access

dB decibel dBHz decibel-Hz

dbi decibels above isotropic

dBK decibel-Kelvin
dBm decibel-milliwatts
dBW decibel-watt
DEM demodulator

DOS United States Department of State

DS digital signaling (also known as T-carrier TDM signaling)

DSB/SC double sideband suppressed carrier

DSI digital speech interpolation
DS-SS direct sequence spread spectrum

\mathbf{E}

Eb/No energy per bit to noise density extremely high frequency

EIRP effective isotropic radiated power

El elevation angle EOL end of life erf error function

erfc complimentary error function ERS empirical roadside shadowing

ES earth station

ESA European Space Agency E-W east-west station keeping

FA fixed access

FCC Federal Communications Commission

FDM frequency division multiplex

FDMA frequency division multiple access

FEC forward error correction FET field effect transistor

FH-SS frequency hopping spread spectrum

FM frequency modulation FSK frequency shift keying FSS fixed satellite service

FT frequency translation transponder

\mathbf{G}

GEO geostationary satellite orbits

GHz gigahertz

GSO geosynchronous satellite G/T, receiver figure of merit

H

HEO high elliptical earth orbit, high earth orbit

HEW Health Education Experiment

HF high frequency

HP horizontal polarization

hPa hectopascal (unit for air pressure, equal to $1 \text{ cm H}_2\text{O}$)

HPA high power amplifier

Hz hertz

I

IEE Institute of Electrical Engineers

IEEE Institute of Electrical and Electronics Engineers

IF intermediate frequency

INTELSAT International Satellite Organization

ISI intersymbol interference

ITU International Telecommunications Union

ITU-D International Telecommunications Union, Development Sector

ITU-R International Telecommunications Union, Radiocommunications Sector ITU-T International Telecommunications Union, Telecommunications Standards

Sector

J

K

K degrees Kelvin Kbps kilobits per second

kg kilogram

KHz kilohertz km kilometers

L

LEO low earth orbit LF low-frequency

LHCP left hand circular polarization LMSS land mobile satellite service

LNA low noise amplifier
LNB low noise block
LO local oscillator
LPF low pass filter

M

m meters

MA multiple access

MAC medium access control
Mbps megabits per second
MCPC multiple channel per carrier

MEO medium earth orbit MF medium frequency

MF-TDMA multi-frequency time division multiple access

MHz megahertz

MKF street masking function

MMSS maritime mobile satellite service

MOD modulator

MODEM modulator/demodulator
MSK minimum shift keying
MSS mobile satellite, service

MUX multiplexer

N

NASA National Aeronautics and Space Administration

NF noise figure (or noise factor)

NGSO non geosynchronous (or geostationary) satellite orbits

NIC nearly instantaneous companding

NRZ non return to zero

N-S north-south station keeping

NTIA National Telecommunications and Information Agency

NTSC National Television System Committee

O

OBP on-board processing transponder

OFDM orthogonal frequency division multiplexing

OOK on/off keying

P

PA pre-assigned access

PAL phase alternation line

PAM pulse amplitude modulation

PCM pulse code modulation PFD power flux density

PLACE Position Location and Aircraft Communication Experiment

PN pseudorandom sequence PSK phase shift keying

PSTN public switched telephone network

Q

QAM quadrature amplitude modulation QPSK quadrature phase shift keying

R

REC receiver

RF radio frequency

RFI radio frequency interference RHCP right hand circular polarization

RZ return to zero

 \mathbf{S}

SC service channel

SCORE Signal Communications Orbiting Relay Experiment

SCPC single channel per carrier
SDMA space division multiple access
SECAM SEquential Couleur Avec Memoire

SGN satellite news gathering
SHF super high frequency

SITE satellite instructional television experiment

S/N signal-to-noise ratio SS subsatellite point

SS/TDMA time division multiple access, satellite switched

SSB/SC single sideband suppressed carrier

SSPA solid state amplifier SYNC synchronization

T

TDM time division multiplex(ing)
TDMA time division multiple access
TDRS Tracking and Data Relay Satellite

TEC total electron content transmitter-receiver

TRANS transmitter

TRUST Television Relay Using Small Terminals

TT&C tracking, telemetry and command

TTC&M tracking, telemetry, command and monitoring

TTY teletype

TWT traveling wave tube

TWTA traveling wave tube amplifier

U

UHF ultra high frequency

USSR Union of Soviet Socialist Republics

UW unique word

V

VA voice activation (factor)
VF voice frequency (channel)
VHF very high frequency

VLF very low frequency VOW voice order wire VP vertical polarization

VPI&SU Virginia Polytechnic Institute and State University

VSAT very small antenna (aperture) terminal

W

WVD water vapor density

X

XPD cross-polarization discrimination

Y

 \mathbf{Z}

Preface

The book is written for those concerned with the design and performance of satellite communications systems employed in fixed point-to-point, broadcasting, mobile, radio-navigation, data-relay, computer communications, and related satellite-based applications. The recent rapid growth in satellite communications has created a need for accurate information on both satellite communications systems engineering and the impact of atmospheric effects on satellite link design and system performance. This book addresses that need for the first time in a single comprehensive source.

Significant progress has been made in the last decade in the understanding and modeling of propagation effects on radiowave propagation in the bands used for satellite communications, including extensive direct measurements and evaluation utilizing orbiting satellites. This book provides a single source for a comprehensive description and analysis of all the atmospheric effects of concern for today's satellite systems and the tools necessary to design the links and evaluate system performance. Many of the tools and calculations are provided in a 'handbook' form, with step-by-step procedures and all necessary algorithms are in one place to allow direct calculations without the need to consult other material.

The book provides the latest information on communications satellite link design and performance from the practicing engineer perspective – concise descriptions, specific procedures, and comprehensive solutions. I focus on the satellite free-space link as the primary element in the design and performance for satellite communications. This focus recognizes and includes the importance of free-space considerations such as atmospheric effects, frequency of operation, and adaptive mitigation techniques.

The reader can enter the book from at least three perspectives:

- for basic information on satellite systems and related technologies, with minimum theoretical developments and practical, useable, up-to-date information;
- as a satellite link design handbook, with extensive examples, step-by-step procedures, and the latest applications oriented solutions;
- as a textbook for a graduate level course on satellite communications systems the book includes problems at the end of each chapter and a solutions manual for the instructor.

Unlike many other books on satellite communications, this book does not bog down the reader in specialized, regional technologies and hardware dependent developments that have limited general interest and a short lifetime. The intent of the author is to keep the book relevant for the entire global wireless community by focusing on the important basic principles that are unique and timeless to satellite-based communications delivery systems.

xviii PREFACE

I would like to acknowledge the contributions of the many individuals and organizations whose work and efforts are reflected and referenced in this book. I have had the privilege of knowing and working with many of these researchers, some pioneers in the field of satellite communications, through my long affiliations with NASA, the ITU, and other organizations. The ideas and concepts that led to the development of this book were honed and enhanced through extensive discussions and interchange of ideas with many of the original developers of the technologies and processes covered in the book.

Finally, I gratefully acknowledge the support and encouragement of my wife Sandi who kept me focused on the project and whose patience I could always count on. This book is dedicated to Sandi, and to our children Karen, Rusty, Ted, and Cathie.

Louis J. Ippolito

Contents

List of Acronyms Preface		xi xvii	
Chapter 1	Introduction to Satellite Communications	1	
	1.1 Early History of Satellite Communications	3	
	1.2 Some Basic Communications Satellite System Definitions	8	
	1.2.1 Satellite Communications Segments	Ģ	
	1.2.2 Satellite Link Parameters	10	
	1.2.3 Satellite Orbits	11	
	1.2.4 Frequency Band Designations	12	
	1.3 Regulatory Process for Satellite Communications	14	
	1.4 Overview of Book Structure and Topics	16	
	References	17	
Chapter 2	Satellite Orbits	19	
	2.1 Kepler's Laws	20	
	2.2 Orbital Parameters	22	
	2.3 Orbits in Common Use	25	
	2.3.1 Geostationary Orbit	25	
	2.3.2 Low Earth Orbit	27	
	2.3.3 Medium Earth Orbit	28	
	2.3.4 Highly Elliptical Orbit	28	
	2.3.5 Polar Orbit	29	
	2.4 Geometry of GSO Links	30	
	2.4.1 Range to Satellite	3	
	2.4.2 Elevation Angle to Satellite	32	
	2.4.3 Azimuth Angle to Satellite	32	
	2.4.4 Sample Calculation	34	
	References	35	
	Problems	30	
Chapter 3	Satellite Subsystems	3'	
_	3.1 Satellite Bus	39	
	3.1.1 Physical Structure	39	
	3.1.2 Power Subsystem	40	
	3.1.3 Attitude Control	4	
	3.1.4 Orbital Control	4:	
	3.1.5 Thermal Control	4	
	3.1.6 Tracking, Telemetry, Command, and Monitoring	4.	

vi CONTENTS

	3.2 Satellite Payload	46
	3.2.1 Transponder	46
	3.2.2 Antennas	49
	References	50
		50
Chapter 4	The RF Link	51
	4.1 Transmission Fundamentals	51
	4.1.1 Effective Isotropic Radiated Power	53
	4.1.2 Power Flux Density	53
	4.1.3 Antenna Gain	54
	4.1.4 Free-Space Path Loss	57
	4.1.5 Basic Link Equation for Received Power	59
	4.2 System Noise	61
	4.2.1 Noise Figure	63
	4.2.2 Noise Temperature	65
	4.2.3 System Noise Temperature	68
	4.2.4 Figure of Merit	72
	4.3 Link Performance Parameters	73
	4.3.1 Carrier-to-Noise Ratio	73
	4.3.2 Carrier-to-Noise Density	74
	4.3.3 Energy-Per-Bit to Noise Density References	75
	Problems	75 75
	Troolens	/3
Chapter 5	Link System Performance	77
-	5.1 Link Considerations	77
	5.1.1 Fixed Antenna Size Link	78
	5.1.2 Fixed Antenna Gain Link	79
	5.1.3 Fixed Antenna Gain, Fixed Antenna Size Link	80
	5.2 Uplink	81
	5.2.1 Multiple Carrier Operation	83
	5.3 Downlink	84
	5.4 Percent of Time Performance Specifications	84
	References	86
	Problems	87
Chapter 6	Transmission Impairments	89
Chapter 0	6.1 Radiowave Frequency and Space Communications	89
	6.2 Radiowave Propagation Mechanisms	91
	6.3 Propagation Below About 3 GHz	93
	6.3.1 Ionospheric Scintillation	97
	6.3.2 Polarization Rotation	qq
		99 99
	6.3.3 Group Delay	99
	6.3.3 Group Delay 6.3.4 Dispersion	99 100
	6.3.3 Group Delay	99 100 102
	6.3.3 Group Delay6.3.4 Dispersion6.4 Propagation Above About 3 GHz	99 100

CONTENTS vii

6.4.7 Propospheric Scintillation 117 6.5 Radio Noise 121 6.5.1 Noseeffication of Radio Noise 121 6.5.2 Noise from Atmospheric Gases 123 6.5.3 Sky Noise due to Rain 124 6.5.5 Noise from Extra-Terrestrial Sources 129 References 136 Problems 137 Chapter 7 Propagation Effects Modeling and Prediction 139 7.1 Atmospheric Gases 139 7.1.1 Leibe Complex Refractivity Model 140 7.1.2 ITU-R Gaseous Attenuation Models 141 7.2 Clouds and Fog 153 7.2.1 ITU-R Cloud Attenuation Model 155 7.3 Rain Attenuation 163 7.3.1 ITU-R Rain Attenuation Model 155 7.3 Rain Attenuation 163 7.3.1 ITU-R Rain Attenuation Model 155 7.4.1 Rain Depolarization Modeling 190 7.4.2 Ice Depolarization Modeling 190 7.4.2 Ice Depolarization Modeling 190 7.5.1 Karasawa Scintillation 196 7.5.2 ITU-R Scintillation Model 190 References 103 References 103 Problems 204 Chapter 8 Rain Fade Mitigation 207 8.1 Power Restoral Techniques 207 8.1.1 Seam Diversity 207 8.1.2 Power Control 209 8.1.3 Site Diversity 214 8.1.2 Power Control 209 8.1.3 Site Diversity 214 8.1.2 Power Control 209 8.1.3 Site Diversity 214 8.1.4 Orbit Diversity 214 8.2.5 Signal Modification Restoral Techniques 215 8.2.1 Frequency Diversity 215 8.2.2 Bandwidth Reduction 216 8.2.3 Time-Delayed Transmission Diversity 216 8.2.4 Time-Delayed Transmission Diversity 217 References 217 Problems 218 Chapter 9 The Composite Link 21.1 Uplink 243 9.1.1 Uplink 243		6.4.4 Dan elemination	111
6.5 Radio Noise 6.5.1 Specification of Radio Noise 6.5.2 Noise from Atmospheric Gases 121 6.5.3 Sky Noise due to Rain 124 6.5.4 Sky Noise due to Rain 126 6.5.5 Noise from Extra-Terrestrial Sources 127 References 136 Problems 137 Chapter 7 Propagation Effects Modeling and Prediction 7.1 Atmospheric Gases 7.1.1 Leibe Complex Refractivity Model 7.1.2 ITU-R Gaseous Attenuation Models 141 7.2 Clouds and Fog 7.2.1 ITU-R Cloud Attenuation Model 7.2.1 ITU-R Cloud Attenuation Model 7.3.1 ITU-R Rain Attenuation Model 155 7.3 Rain Attenuation 163 7.3.1 ITU-R Rain Attenuation Model 7.3.2 Crane Rain Attenuation Models 164 7.3.2 Crane Rain Attenuation Model 17.3.1 ITU-R Rain Attenuation Models 177 7.4 Depolarization 189 7.4.1 Rain Depolarization Modeling 190 7.4.2 Lee Depolarization Modeling 191 7.5 Tropospheric Scintillation Model 7.5.2 ITU-R Scintillation Model 7.5.3 Wan De Kamp Cloud Scintillation Model 190 7.5.3 Van De Kamp Cloud Scintillation Model 201 References 203 Problems 204 Chapter 8 Rain Fade Mitigation 207 8.1 Power Control 208 8.1.2 Power Control 209 8.1.3 Site Diversity 208 8.1.2 Power Control 209 8.1.3 Site Diversity 214 8.2.1 Frequency Diversity 225 8.2.2 Bandwidth Reduction 226 8.2.3 Time-Delayed Transmission Diversity 227 8.24 Adaptive Coding and Modulation 228 Chapter 9 The Composite Link 9.1 Frequency Translation (FT) Satellite		6.4.4 Depolarization	
6.5.1 Specification of Radio Noise 6.5.2 Noise from Atmospheric Gases 123 6.5.3 Sky Noise due to Rain 124 6.5.4 Sky Noise due to Rain 126 6.5.5 Noise from Extra-Terrestrial Sources 129 References 136 Problems 137 Chapter 7 Propagation Effects Modeling and Prediction 7.1 Atmospheric Gases 7.1 I Liebe Complex Refractivity Model 7.1.1 Liebe Complex Refractivity Model 7.1.2 ITU-R Gaseous Attenuation Models 141 7.2 Clouds and Fog 153 7.2.1 ITU-R County Model 154 7.2.2 Slobin Cloud Attenuation Model 157 7.3 Rain Attenuation 163 7.3.1 ITU-R Rain Attenuation Model 164 7.3.2 Crane Rain Attenuation Models 17.4.1 Rain Depolarization Modeling 189 7.4.1 Rain Depolarization Modeling 190 7.4.2 Lee Depolarization Modeling 191 7.5.5 Tropospheric Scintillation 196 7.5.1 Karasawa Scintillation Model 197 7.5.2 ITU-R Scintillation Model 198 References Problems 204 Chapter 8 Rain Fade Mitigation 8.1 Power Restoral Techniques 8.1.3 Site Diversity 8.1.4 Orbit Diversity 8.1.5 Site Diversity 8.1.2 Power Control 8.1.2 Rain Fade Mitigation Restoral Techniques 8.2.3 Time-Delayed Transmission Diversity 235 8.2.2 Randwidth Reduction 236 8.2.3 Time-Delayed Transmission Diversity 247 8.2.4 Adaptive Coding and Modulation 248 Chapter 9 The Composite Link 9.1 Frequency Translation (FT) Satellite 9.1.1 Uplink 243			
6.5.2 Noise from Atmospheric Gases 6.5.3 Sky Noise due to Rain 6.5.4 Sky Noise due to Clouds 6.5.5 Noise from Extra-Terrestrial Sources 129 References Problems 137 Chapter 7 Propagation Effects Modeling and Prediction 7.1 Atmospheric Gases 7.1.1 Leibe Complex Refractivity Model 7.1.2 ITU-R Gaseous Attenuation Models 140 7.1.2 ITU-R Cloud Attenuation Models 141 7.2 Clouds and Fog 7.3 Rain Attenuation 145 7.3 Rain Attenuation 156 7.3 Rain Attenuation 167 7.4 Depolarization 7.4.1 Rain Depolarization Modells 177 7.4 Depolarization 178 7.5 Tropospheric Scintillation 179 7.5 Tropospheric Scintillation 189 7.5.1 Karasawa Scintillation Model 190 7.5.2 ITU-R Scintillation Model 190 7.5.3 Van De Kamp Cloud Scintillation Model 190 7.5.3 Van De Kamp Cloud Scintillation Model 190 8.1 Power Restoral Techniques 8.1 Beam Diversity 8.1.2 Power Control 8.1.3 Site Diversity 8.1.4 Orbit Diversity 8.2.5 Iman Modification Restoral Techniques 8.2.1 Fraquency Diversity 8.2.2 Bandwidth Reduction 8.2.3 Time-Delayed Transmission Diversity 8.2.3 Time-Delayed Transmission Diversity 8.2.3 Time-Delayed Transmission Diversity 8.2.3 Time-Delayed Transmission Diversity 8.2.4 Adaptive Coding and Modulation 8.3 Summary 8.6 Chapter 9 The Composite Link 9.1 Frequency Translation (FT) Satellite			
6.5.3 Sky Noise due to Rain			
Chapter 7 Propagation Effects Modeling and Prediction 139			
References 136 Problems 137 Chapter 7 Propagation Effects Modeling and Prediction 139 7.1.1 Leibe Complex Refractivity Model 140 7.1.2 ITU-R Gaseous Attenuation Models 141 7.2 Clouds and Fog 153 7.2.1 ITU-R Cloud Attenuation Models 154 7.2.2 Slobin Cloud Model 154 7.2.2 Slobin Cloud Model 155 7.3 Rain Attenuation 163 7.3.1 ITU-R Rain Attenuation Model 164 7.3.2 Crane Rain Attenuation Models 177 7.4 Depolarization 189 7.4.1 Rain Depolarization Modeling 190 7.4.2 Ice Depolarization Modeling 191 7.5 Tropospheric Scintillation 196 7.5.1 Karasawa Scintillation Model 196 7.5.2 ITU-R Scintillation Model 199 7.5.3 Van De Kamp Cloud Scintillation Model 190 7.5.3 Van De Kamp Cloud Scintillation Model 201 References 203 Problems 207 8.1.1 Beam Diversity 208 8.1.2 Power Control 209 8.1.3 Site Diversity 214 8.1.4 Orbit Diversity 232 8.2 Signal Modification Restoral Techniques 232 8.2.1 Frequency Diversity 235 8.2.2 Bandwidth Reduction 236 8.2.3 Time-Delayed Transmission Diversity 235 8.2.4 Adaptive Coding and Modulation 236 8.3 Summary 237 References 237 Problems 238 Chapter 9 The Composite Link 9.1 Frequency Translation (FT) Satellite 9.1.1 Uplink 243			
References Problems 136 137 137 137 137 137 137 138 139		*	
Problems 137 Chapter 7 Propagation Effects Modeling and Prediction 139 7.1 Atmospheric Gases 139 7.1.1 Leibe Complex Refractivity Model 140 7.1.2 ITU-R Gaseous Attenuation Models 151 7.2 Clouds and Fog 153 7.2.1 ITU-R Cloud Attenuation Model 154 7.2.2 Slobin Cloud Model 155 7.3 Rain Attenuation 163 7.3.1 ITU-R Rain Attenuation Model 164 7.3.2 Crane Rain Attenuation Models 177 7.4 Depolarization 189 7.4.1 Rain Depolarization Modeling 190 7.4.2 Ice Depolarization Modeling 191 7.5 Tropospheric Scintillation 196 7.5.3 Van De Kamp Cloud Scintillation Model 196 7.5.2 ITU-R Scintillation Model 199 7.5.3 Van De Kamp Cloud Scintillation Model 201 References 203 Problems 204 Chapter 8 Rain Fade Mitigation 207 8.1 Power Restoral Techniques 207 8.1.1 Beam Diversity 208 8.1.2 Power Control 209 8.1.3 Site Diversity 214 8.1.4 Orbit Diversity 235 8.2.2 Signal Modification Restoral Techniques 235 8.2.3 Time-Delayed Transmission Diversity 235 8.2.2 Bandwidth Reduction 236 8.2.3 Time-Delayed Transmission Diversity 235 8.2.3 Summary 237 References 237 Problems 238 Chapter 9 The Composite Link 9.1 Frequency Translation (FT) Satellite 243 9.1.1 Uplink 243 9.1.1 Iplink 243 9.1.1 Uplink 243 9.1.1 Iplink 243 9.1.2 Interval			
7.1 Atmospheric Gases 7.1.1 Leibe Complex Refractivity Model 7.1.2 ITU-R Gaseous Attenuation Models 141 7.2 Clouds and Fog 7.2.1 ITU-R Cloud Attenuation Model 7.2.2 Slobin Cloud Model 154 7.2.2 Slobin Cloud Model 155 7.3 Rain Attenuation 163 7.3.1 ITU-R Rain Attenuation Model 7.3.2 Crane Rain Attenuation Model 7.3.2 Crane Rain Attenuation Models 7.4.1 Rain Depolarization 189 7.4.1 Rain Depolarization Modeling 7.5.5 Tropospheric Scintillation 7.5.1 Karasawa Scintillation Model 7.5.2 ITU-R Scintillation Model 7.5.3 Van De Kamp Cloud Scintillation Model 199 7.5.3 Van De Kamp Cloud Scintillation Model References Problems 203 Problems 204 Chapter 8 Rain Fade Mitigation 8.1 Power Restoral Techniques 8.1.1 Beam Diversity 208 8.1.2 Power Control 209 8.1.3 Site Diversity 214 8.1.4 Orbit Diversity 214 8.1.4 Orbit Diversity 225 8.2.2 Signal Modification Restoral Techniques 8.2.1 Frequency Diversity 235 8.2.2 Bandwidth Reduction 236 8.2.3 Time-Delayed Transmission Diversity 237 8.2.4 Adaptive Coding and Modulation 236 8.2.3 Time-Delayed Transmission Diversity 237 References Problems 240 Chapter 9 The Composite Link 9.1 Frequency Translation (FT) Satellite 9.1.1 Uplink 241			137
7.1 Atmospheric Gases 7.1.1 Leibe Complex Refractivity Model 7.1.2 ITU-R Gaseous Attenuation Models 141 7.2 Clouds and Fog 7.2.1 ITU-R Cloud Attenuation Model 7.2.2 Slobin Cloud Model 154 7.2.2 Slobin Cloud Model 155 7.3 Rain Attenuation 163 7.3.1 ITU-R Rain Attenuation Model 7.3.2 Crane Rain Attenuation Model 7.3.2 Crane Rain Attenuation Models 7.4.1 Rain Depolarization 189 7.4.1 Rain Depolarization Modeling 7.5.5 Tropospheric Scintillation 7.5.1 Karasawa Scintillation Model 7.5.2 ITU-R Scintillation Model 7.5.3 Van De Kamp Cloud Scintillation Model 199 7.5.3 Van De Kamp Cloud Scintillation Model References Problems 203 Problems 204 Chapter 8 Rain Fade Mitigation 8.1 Power Restoral Techniques 8.1.1 Beam Diversity 208 8.1.2 Power Control 209 8.1.3 Site Diversity 214 8.1.4 Orbit Diversity 214 8.1.4 Orbit Diversity 225 8.2.2 Signal Modification Restoral Techniques 8.2.1 Frequency Diversity 235 8.2.2 Bandwidth Reduction 236 8.2.3 Time-Delayed Transmission Diversity 237 8.2.4 Adaptive Coding and Modulation 236 8.2.3 Time-Delayed Transmission Diversity 237 References Problems 240 Chapter 9 The Composite Link 9.1 Frequency Translation (FT) Satellite 9.1.1 Uplink 241	Chapter 7	Propagation Effects Modeling and Prediction	139
7.1.1 Leibe Complex Refractivity Model 7.1.2 ITU-R Gaseous Attenuation Models 141 7.2 Clouds and Fog 7.2.1 ITU-R Cloud Attenuation Model 154 7.2.2 Slobin Cloud Model 155 7.3 Rain Attenuation 163 7.3.1 ITU-R Rain Attenuation Model 164 7.3.2 Crane Rain Attenuation Model 7.4.1 Rain Depolarization Modeling 7.4.1 Rain Depolarization Modeling 7.4.1 Rain Depolarization Modeling 7.5.5 Tropospheric Scintillation 196 7.5.1 Karasawa Scintillation Model 7.5.2 ITU-R Scintillation Model 7.5.3 Van De Kamp Cloud Scintillation Model 197 7.5.3 Van De Kamp Cloud Scintillation Model References Problems 204 Chapter 8 Rain Fade Mitigation 8.1 Power Restoral Techniques 8.1.1 Beam Diversity 8.1.2 Power Control 209 8.1.3 Site Diversity 8.1.4 Orbit Diversity 8.2.2 Bandwidth Reduction 8.2.3 Time-Delayed Transmission Diversity 8.2.2 Bandwidth Reduction 8.2.3 Time-Delayed Transmission Diversity 8.2.4 Adaptive Coding and Modulation 236 8.3 Summary 8.6 Problems Chapter 9 The Composite Link 9.1 Frequency Translation (FT) Satellite 9.1.1 Uplink 243	Chapter 7		
7.1.2 ITU-R Gaseous Attenuation Models 7.2.2 Clouds and Fog 7.2.1 ITU-R Cloud Attenuation Model 7.2.2 Slobin Cloud Model 154 7.2.2 Slobin Cloud Model 155 7.3 Rain Attenuation 163 7.3.1 ITU-R Rain Attenuation Model 164 7.3.2 Crane Rain Attenuation Models 177 7.4 Depolarization 189 7.4.1 Rain Depolarization Modeling 190 7.4.2 Ice Depolarization Modeling 191 7.5 Tropospheric Scintillation 196 7.5.1 Karasawa Scintillation Model 7.5.2 ITU-R Scintillation Model 199 7.5.3 Van De Kamp Cloud Scintillation Model 199 7.5.3 Van De Kamp Cloud Scintillation Model 199 8.1 Power Restoral Techniques 204 Chapter 8 Rain Fade Mitigation 207 8.1 Power Restoral Techniques 208 8.1.1 Beam Diversity 208 8.1.2 Power Control 209 8.1.3 Site Diversity 214 8.1.4 Orbit Diversity 214 8.1.4 Orbit Diversity 225 8.2 Signal Modification Restoral Techniques 235 8.2.1 Frequency Diversity 235 8.2.2 Bandwidth Reduction 236 8.2.3 Time-Delayed Transmission Diversity 237 8.6 References 237 8.7 References 237 8.7 References 237 8.7 References 237 8.7 Problems Chapter 9 The Composite Link 9.1 Frequency Translation (FT) Satellite 9.1.1 Uplink 243			
7.2 Clouds and Fog 7.2.1 ITU-R Cloud Attenuation Model 7.2.2 Slobin Cloud Model 7.2.2 Slobin Cloud Model 7.3.3 Rin Attenuation 163 7.3.1 ITU-R Rain Attenuation Model 7.3.2 Crane Rain Attenuation Models 7.4.1 Peopolarization 189 7.4.1 Rain Depolarization Modeling 7.4.2 Ice Depolarization Modeling 7.5 Tropospheric Scintillation 196 7.5.1 Karasawa Scintillation Model 7.5.2 ITU-R Scintillation Model 7.5.3 Van De Kamp Cloud Scintillation Model References Problems 204 Chapter 8 Rain Fade Mitigation 8.1 Power Restoral Techniques 8.1.1 Beam Diversity 8.1.2 Power Control 8.1.3 Site Diversity 8.1.4 Orbit Diversity 8.2.2 Signal Modification Restoral Techniques 8.2.1 Frequency Diversity 8.2.2 Bandwidth Reduction 8.2.3 Time-Delayed Transmission Diversity 8.2.4 Adaptive Coding and Modulation 236 8.3 Summary References Problems 237 References Problems 248 Chapter 9 The Composite Link 9.1 Frequency Translation (FT) Satellite 243 9.1.1 Uplink 243			
7.2.1 ITU-R Cloud Attenuation Model 154 7.2.2 Slobin Cloud Model 155 7.3 Rain Attenuation 163 7.3.1 ITU-R Rain Attenuation Model 164 7.3.2 Crane Rain Attenuation Models 177 7.4 Depolarization 189 7.4.1 Rain Depolarization Modeling 190 7.4.2 Ice Depolarization Modeling 191 7.5 Tropospheric Scintillation 196 7.5.1 Karasawa Scintillation Model 196 7.5.2 ITU-R Scintillation Model 199 7.5.3 Van De Kamp Cloud Scintillation Model 201 References 203 Problems 204 Chapter 8 Rain Fade Mitigation 207 8.1.1 Beam Diversity 208 8.1.2 Power Restoral Techniques 207 8.1.3 Site Diversity 214 8.1.2 Power Control 209 8.1.3 Site Diversity 234 8.2 Signal Modification Restoral Techniques 235 8.2.1 Frequency Diversity 235 8.2.2 Bandwidth Reduction 236 8.2.3 Time-Delayed Transmission Diversity 236 8.2.3 English Modulation 236 <td></td> <td></td> <td></td>			
7.3 Rain Attenuation 7.3.1 ITU-R Rain Attenuation Model 7.3.2 Crane Rain Attenuation Models 7.4 Depolarization 7.4 Depolarization 7.4.1 Rain Depolarization Modeling 7.4.1 Rain Depolarization Modeling 7.5.1 Karasawa Scintillation 7.5.1 Karasawa Scintillation Model 7.5.1 ITU-R Scintillation Model 7.5.2 ITU-R Scintillation Model 7.5.3 Van De Kamp Cloud Scintillation Model 8 References 9 203 9 Problems 9 204 Chapter 8 Rain Fade Mitigation 8.1 Power Restoral Techniques 8.1.1 Beam Diversity 9 8.1.2 Power Control 9 8.1.3 Site Diversity 9 214 8.1.4 Orbit Diversity 9 225 8.2 Signal Modification Restoral Techniques 8.2.1 Frequency Diversity 9 235 8.2.2 Bandwidth Reduction 9 8.2.3 Time-Delayed Transmission Diversity 9 236 8.3 Summary 9 237 References 9 237 Problems 9 1 Frequency Translation (FT) Satellite 9 1.1 Uplink 9 1 Frequency Translation (FT) Satellite		e	154
7.3.1 ITU-R Rain Attenuation Model 7.3.2 Crane Rain Attenuation Models 1177 7.4 Depolarization 1189 7.4.1 Rain Depolarization Modeling 7.4.2 Ice Depolarization Modeling 190 7.4.2 Ice Depolarization Modeling 191 7.5 Tropospheric Scintillation 196 7.5.1 Karasawa Scintillation Model 196 7.5.2 ITU-R Scintillation Model 199 7.5.3 Van De Kamp Cloud Scintillation Model 201 References 203 Problems 204 Chapter 8 Rain Fade Mitigation 207 8.1 Power Restoral Techniques 207 8.1.1 Beam Diversity 208 8.1.2 Power Control 209 8.1.3 Site Diversity 214 8.1.4 Orbit Diversity 232 8.2 Signal Modification Restoral Techniques 235 8.2.1 Frequency Diversity 235 8.2.2 Bandwidth Reduction 236 8.2.3 Time-Delayed Transmission Diversity 236 8.2.4 Adaptive Coding and Modulation 236 8.3 Summary 237 References 237 Problems 238 Chapter 9 The Composite Link 241 9.1 Frequency Translation (FT) Satellite 243 9.1.1 Uplink 243		7.2.2 Slobin Cloud Model	155
7.3.2 Crane Rain Attenuation Models 7.4.1 Depolarization 7.4. Depolarization 7.4.2 Ice Depolarization Modeling 7.5. Tropospheric Scintillation 7.5.1 Karasawa Scintillation 7.5.1 Karasawa Scintillation Model 7.5.2 ITU-R Scintillation Model 7.5.3 Van De Kamp Cloud Scintillation Model References 203 Problems 204 Chapter 8 Rain Fade Mitigation 8.1 Power Restoral Techniques 8.1.1 Beam Diversity 8.1.2 Power Control 209 8.1.3 Site Diversity 214 8.1.4 Orbit Diversity 232 8.2 Signal Modification Restoral Techniques 8.2.1 Frequency Diversity 8.2.2 Bandwidth Reduction 235 8.2.1 Frequency Diversity 236 8.2.3 Time-Delayed Transmission Diversity 236 8.2.3 Time-Delayed Transmission Diversity 237 References 237 Problems 238 Chapter 9 The Composite Link 9.1 Frequency Translation (FT) Satellite 241 9.1.1 Uplink		7.3 Rain Attenuation	163
7.4 Depolarization 189 7.4.1 Rain Depolarization Modeling 190 7.4.2 Ice Depolarization Modeling 191 7.5 Tropospheric Scintillation 196 7.5.1 Karasawa Scintillation Model 199 7.5.2 ITU-R Scintillation Model 199 7.5.3 Van De Kamp Cloud Scintillation Model 201 References 203 Problems 204 Chapter 8 Rain Fade Mitigation 207 8.1 Power Restoral Techniques 207 8.1.1 Beam Diversity 208 8.1.2 Power Control 209 8.1.3 Site Diversity 214 8.1.4 Orbit Diversity 232 8.2 Signal Modification Restoral Techniques 235 8.2.1 Frequency Diversity 235 8.2.2 Bandwidth Reduction 236 8.2.3 Time-Delayed Transmission Diversity 236 8.2.4 Adaptive Coding and Modulation 236 8.3 Summary 237 References 237 Problems 238 Chapter 9 The Composite Link 241 9.1 Frequency Translation (FT) Satellite 243 9.1.1 Uplink 243		7.3.1 ITU-R Rain Attenuation Model	164
7.4.1 Rain Depolarization Modeling 7.4.2 Ice Depolarization Modeling 7.5.5 Tropospheric Scintillation 7.5.1 Karasawa Scintillation Model 7.5.2 ITU-R Scintillation Model 7.5.3 Van De Kamp Cloud Scintillation Model References Problems 203 Problems 204 Chapter 8 Rain Fade Mitigation 8.1 Power Restoral Techniques 8.1.1 Beam Diversity 8.1.2 Power Control 8.1.3 Site Diversity 8.1.4 Orbit Diversity 8.22 8.2 Signal Modification Restoral Techniques 8.2.1 Frequency Diversity 8.2.2 Bandwidth Reduction 8.2.3 Time-Delayed Transmission Diversity 8.2.4 Adaptive Coding and Modulation 236 8.2 Summary References Problems 237 References 237 Problems 241 9.1 Frequency Translation (FT) Satellite 9.1.1 Uplink 243		7.3.2 Crane Rain Attenuation Models	177
7.4.2 Ice Depolarization Modeling 7.5.1 Tropospheric Scintillation 7.5.1 Karasawa Scintillation Model 7.5.2 ITU-R Scintillation Model 7.5.3 Van De Kamp Cloud Scintillation Model References Problems 203 Problems 204 Chapter 8 Rain Fade Mittgation 8.1 Power Restoral Techniques 8.1.1 Beam Diversity 208 8.1.2 Power Control 209 8.1.3 Site Diversity 214 8.1.4 Orbit Diversity 222 8.2 Signal Modification Restoral Techniques 235 8.2.1 Frequency Diversity 235 8.2.2 Bandwidth Reduction 236 8.2.3 Time-Delayed Transmission Diversity 236 8.2.4 Adaptive Coding and Modulation 236 8.3 Summary 237 References 237 Problems 238 Chapter 9 The Composite Link 9.1 Frequency Translation (FT) Satellite 9.1.1 Uplink 243		7.4 Depolarization	
7.5 Tropospheric Scintillation 196 7.5.1 Karasawa Scintillation Model 199 7.5.2 ITU-R Scintillation Model 201 References 203 Problems 204 Chapter 8 Rain Fade Mitigation 207 8.1 Power Restoral Techniques 207 8.1.1 Beam Diversity 208 8.1.2 Power Control 209 8.1.3 Site Diversity 214 8.1.4 Orbit Diversity 235 8.2.1 Frequency Diversity 235 8.2.2 Bandwidth Reduction 236 8.2.3 Time-Delayed Transmission Diversity 236 8.2.4 Adaptive Coding and Modulation 236 8.3 Summary 237 References 237 Problems 238 Chapter 9 The Composite Link 243 9.1 Frequency Translation (FT) Satellite 243 9.1.1 Uplink 201			
7.5.1 Karasawa Scintillation Model 7.5.2 ITU-R Scintillation Model 7.5.3 Van De Kamp Cloud Scintillation Model References Problems 203 Problems 207 8.1 Power Restoral Techniques 8.1.1 Beam Diversity 208 8.1.2 Power Control 209 8.1.3 Site Diversity 214 8.1.4 Orbit Diversity 228 8.2 Signal Modification Restoral Techniques 8.2.1 Frequency Diversity 235 8.2.2 Bandwidth Reduction 236 8.2.3 Time-Delayed Transmission Diversity 237 References Problems 238 Chapter 9 The Composite Link 9.1 Frequency Translation (FT) Satellite 9.1.1 Uplink 201 202 203 204 205 207 207 208 209 209 209 209 209 209 209 209 209 209			
7.5.2 ITU-R Scintillation Model 199 7.5.3 Van De Kamp Cloud Scintillation Model 201 References 203 Problems 204 Chapter 8 Rain Fade Mitigation 207 8.1 Power Restoral Techniques 207 8.1.1 Beam Diversity 208 8.1.2 Power Control 209 8.1.3 Site Diversity 214 8.1.4 Orbit Diversity 232 8.2 Signal Modification Restoral Techniques 235 8.2.1 Frequency Diversity 235 8.2.2 Bandwidth Reduction 236 8.2.3 Time-Delayed Transmission Diversity 236 8.2.4 Adaptive Coding and Modulation 236 8.3 Summary 237 References 237 Problems 238 Chapter 9 The Composite Link 241 9.1 Frequency Translation (FT) Satellite 243 9.1.1 Uplink 243			
7.5.3 Van De Kamp Cloud Scintillation Model 201 References 203 Problems 204 Chapter 8 Rain Fade Mitigation 207 8.1 Power Restoral Techniques 207 8.1.1 Beam Diversity 208 8.1.2 Power Control 209 8.1.3 Site Diversity 214 8.1.4 Orbit Diversity 232 8.2 Signal Modification Restoral Techniques 235 8.2.1 Frequency Diversity 235 8.2.2 Bandwidth Reduction 236 8.2.3 Time-Delayed Transmission Diversity 236 8.2.4 Adaptive Coding and Modulation 236 8.3 Summary 237 References 237 Problems 238 Chapter 9 The Composite Link 241 9.1 Frequency Translation (FT) Satellite 243 9.1.1 Uplink 243			
References 203 Problems 204 Chapter 8 Rain Fade Mitigation 207 8.1 Power Restoral Techniques 207 8.1.1 Beam Diversity 208 8.1.2 Power Control 209 8.1.3 Site Diversity 214 8.1.4 Orbit Diversity 232 8.2 Signal Modification Restoral Techniques 235 8.2.1 Frequency Diversity 235 8.2.2 Bandwidth Reduction 236 8.2.3 Time-Delayed Transmission Diversity 236 8.2.4 Adaptive Coding and Modulation 236 8.3 Summary 237 References 237 Problems 238 Chapter 9 The Composite Link 241 9.1 Frequency Translation (FT) Satellite 243 9.1.1 Uplink 243			
Chapter 8 Rain Fade Mitigation 207 8.1 Power Restoral Techniques 207 8.1.1 Beam Diversity 208 8.1.2 Power Control 209 8.1.3 Site Diversity 214 8.1.4 Orbit Diversity 232 8.2 Signal Modification Restoral Techniques 235 8.2.1 Frequency Diversity 235 8.2.2 Bandwidth Reduction 236 8.2.3 Time-Delayed Transmission Diversity 236 8.2.4 Adaptive Coding and Modulation 236 8.3 Summary 237 References 237 Problems 238 Chapter 9 The Composite Link 241 9.1 Frequency Translation (FT) Satellite 243 9.1.1 Uplink 243			
Chapter 8 Rain Fade Mitigation 207 8.1 Power Restoral Techniques 207 8.1.1 Beam Diversity 208 8.1.2 Power Control 209 8.1.3 Site Diversity 214 8.1.4 Orbit Diversity 232 8.2 Signal Modification Restoral Techniques 235 8.2.1 Frequency Diversity 235 8.2.2 Bandwidth Reduction 236 8.2.3 Time-Delayed Transmission Diversity 236 8.2.4 Adaptive Coding and Modulation 236 8.3 Summary 237 References 237 Problems 238 Chapter 9 The Composite Link 241 9.1 Frequency Translation (FT) Satellite 243 9.1.1 Uplink 243			
8.1 Power Restoral Techniques 207 8.1.1 Beam Diversity 208 8.1.2 Power Control 209 8.1.3 Site Diversity 214 8.1.4 Orbit Diversity 232 8.2 Signal Modification Restoral Techniques 235 8.2.1 Frequency Diversity 235 8.2.2 Bandwidth Reduction 236 8.2.3 Time-Delayed Transmission Diversity 236 8.2.4 Adaptive Coding and Modulation 236 8.3 Summary 237 References 237 Problems 238 Chapter 9 The Composite Link 241 9.1 Frequency Translation (FT) Satellite 243 9.1.1 Uplink 243		Problems	204
8.1.1 Beam Diversity 208 8.1.2 Power Control 209 8.1.3 Site Diversity 214 8.1.4 Orbit Diversity 232 8.2 Signal Modification Restoral Techniques 235 8.2.1 Frequency Diversity 235 8.2.2 Bandwidth Reduction 236 8.2.3 Time-Delayed Transmission Diversity 236 8.2.4 Adaptive Coding and Modulation 236 8.3 Summary 237 References 237 Problems 238 Chapter 9 The Composite Link 241 9.1 Frequency Translation (FT) Satellite 243 9.1.1 Uplink 243	Chapter 8	Rain Fade Mitigation	207
8.1.2 Power Control 209 8.1.3 Site Diversity 214 8.1.4 Orbit Diversity 232 8.2 Signal Modification Restoral Techniques 235 8.2.1 Frequency Diversity 235 8.2.2 Bandwidth Reduction 236 8.2.3 Time-Delayed Transmission Diversity 236 8.2.4 Adaptive Coding and Modulation 236 8.3 Summary 237 References 237 Problems 238 Chapter 9 The Composite Link 241 9.1 Frequency Translation (FT) Satellite 243 9.1.1 Uplink 243		8.1 Power Restoral Techniques	
8.1.3 Site Diversity 214 8.1.4 Orbit Diversity 232 8.2 Signal Modification Restoral Techniques 235 8.2.1 Frequency Diversity 235 8.2.2 Bandwidth Reduction 236 8.2.3 Time-Delayed Transmission Diversity 236 8.2.4 Adaptive Coding and Modulation 236 8.3 Summary 237 References 237 Problems 238 Chapter 9 The Composite Link 241 9.1 Frequency Translation (FT) Satellite 243 9.1.1 Uplink 243		ANGENING CO. D. D. D. SANTEN CO. D. C. D. SANTEN CO. D. C.	
8.1.4 Orbit Diversity 232 8.2 Signal Modification Restoral Techniques 235 8.2.1 Frequency Diversity 235 8.2.2 Bandwidth Reduction 236 8.2.3 Time-Delayed Transmission Diversity 236 8.2.4 Adaptive Coding and Modulation 236 8.3 Summary 237 References 237 Problems 238 Chapter 9 The Composite Link 241 9.1 Frequency Translation (FT) Satellite 243 9.1.1 Uplink 243			
8.2 Signal Modification Restoral Techniques 235 8.2.1 Frequency Diversity 235 8.2.2 Bandwidth Reduction 236 8.2.3 Time-Delayed Transmission Diversity 236 8.2.4 Adaptive Coding and Modulation 236 8.3 Summary 237 References 237 Problems 238 Chapter 9 The Composite Link 241 9.1 Frequency Translation (FT) Satellite 243 9.1.1 Uplink 243		***************************************	
8.2.1 Frequency Diversity 235 8.2.2 Bandwidth Reduction 236 8.2.3 Time-Delayed Transmission Diversity 236 8.2.4 Adaptive Coding and Modulation 236 8.3 Summary 237 References 237 Problems 238 Chapter 9 The Composite Link 241 9.1 Frequency Translation (FT) Satellite 243 9.1.1 Uplink 243		ACCRECATE TO THE CONTROL OF THE CONT	
8.2.2 Bandwidth Reduction 8.2.3 Time-Delayed Transmission Diversity 8.2.4 Adaptive Coding and Modulation 236 8.3 Summary 237 References 237 Problems 238 Chapter 9 The Composite Link 9.1 Frequency Translation (FT) Satellite 9.1.1 Uplink 243			
8.2.3 Time-Delayed Transmission Diversity 236 8.2.4 Adaptive Coding and Modulation 236 8.3 Summary 237 References 237 Problems 238 Chapter 9 The Composite Link 241 9.1 Frequency Translation (FT) Satellite 243 9.1.1 Uplink 243			
8.2.4 Adaptive Coding and Modulation 236 8.3 Summary 237 References 237 Problems 238 Chapter 9 The Composite Link 241 9.1 Frequency Translation (FT) Satellite 243 9.1.1 Uplink 243			
8.3 Summary References Problems 237 Problems 238 Chapter 9 The Composite Link 9.1 Frequency Translation (FT) Satellite 9.1.1 Uplink 241 243			
References 237 Problems 238		- 1001	
Chapter 9 The Composite Link 241 9.1 Frequency Translation (FT) Satellite 243 9.1.1 Uplink 243			
9.1 Frequency Translation (FT) Satellite 243 9.1.1 Uplink 243			
9.1 Frequency Translation (FT) Satellite 243 9.1.1 Uplink 243	Charter	The Composite Link	241
9.1.1 Uplink 243	Chapter 9		
1			

viii CONTENTS

	9.1.3 Composite Carrier-to-Noise Ratio	245
	9.1.4 Performance Implications	249
	9.1.5 Path Losses and Link Performance	250
	9.2 On-Board Processing (OBP) Satellite	255
	9.2.1 OBP Uplink and Downlink	255
	9.2.2 Composite OBP Performance	256
	9.3 Comparison of FT and OBP Performance	258
	9.4 Intermodulation Noise	261
	9.5 Link Design Summary	263
	References	264
	Problems	264
Chapter 10	Satellite Multiple Access	267
chapter 10	10.1 Frequency Division Multiple Access	270
	10.1.1 PCM/TDM/PSK/FDMA	271
	10.1.2 PCM/SCPC/PSK/FDMA	273
	10.2 Time Division Multiple Access	274
	10.2.1 PCM/TDM/PSK/TDMA	276
	10.2.2 TDMA Frame Efficiency	277
	10.2.3 TDMA Capacity	278
	10.2.4 Satellite Switched TDMA	281
	10.3 Code Division Multiple Access	284
	10.3.1 Direct Sequence Spread Spectrum	287
	10.3.2 Frequency Hopping Spread Spectrum	291
	10.3.3 CDMA Processing Gain	292
	10.3.4 CDMA Capacity	294
	References	296
	Problems	296
Chapter 11	The Mobile Satellite Channel	299
	11.1 Mobile Channel Propagation	300
	11.1.1 Reflection	301
	11.1.2 Diffraction	301
	11.1.3 Scattering	302
	11.2 Narrowband Channel	304
	11.2.1 Path Loss Factor	307
	11.2.2 Shadow Fading	310
	11.2.3 Multipath Fading	317
	11.2.4 Blockage	324
	11.2.5 Mixed Propagation Conditions	329
	11.3 Wideband Channel	332
	11.4 Multi-Satellite Mobile Links	334
	11.4.1 Uncorrelated Fading	334
	11.4.2 Correlated Fading	336
	References	338
Appendix A	Satellite Signal Processing Elements	339
	A.1 Analog Systems	340
	A.1.1 Analog Basehand Formatting	340