



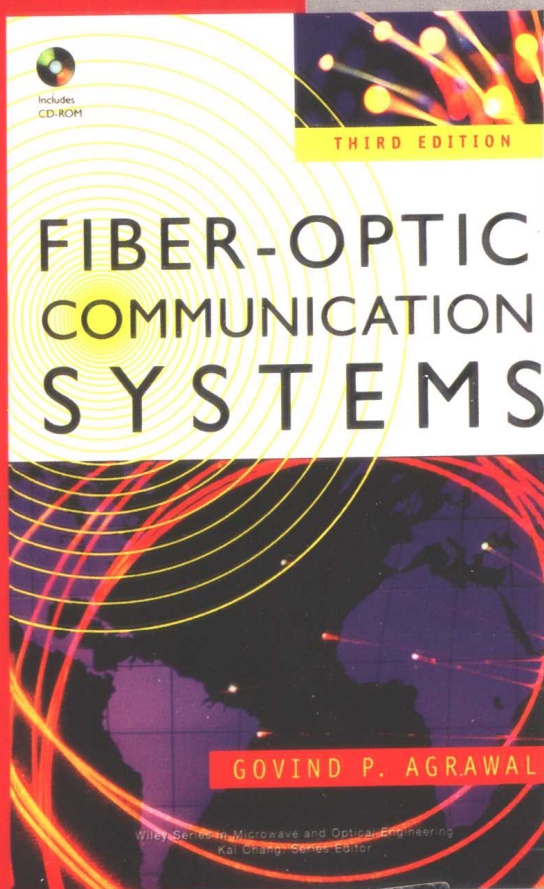
内附光盘

国外大学优秀教材 —— 通信系列 (影印版)

Govind P. Agrawal

光纤通信系统

(第3版)



清华大学出版社

国外大学优秀教材 —— 通信系列 (影印版)

光纤通信系统

(第3版)

**Fiber-Optic Communication
Systems**

Govind P. Agrawal

江苏工业学院图书馆
藏书章

清华大学出版社
北京

Govind P. Agrawal

Fiber-Optic Communication Systems(3rd Ed.)

Copyright © 2002 by John Wiley & Sons, Inc.

All Rights Reserved.

AUTHORIZED REPRINT OF THE EDITION PUBLISHED BY JOHN WILEY & SONS, INC., New York, Chichester, Weinheim, Brisbane, Singapore and Toronto. No part of this book may be reproduced in any form without the written permission of John Wiley & Sons, Inc.

未经出版者书面许可，不得以任何方式复制或抄袭本书的任何部分。

北京市版权局著作权合同登记号 图字：01-2003-8062

本书封面贴有清华大学出版社激光防伪标签，无标签者不得销售。

图书在版编目(CIP)数据

光纤通信系统 = Fiber-Optic Communication Systems: 第3版 / (美) 阿格拉瓦 (Agrawal, G. P.) 著. —影印本. —北京: 清华大学出版社, 2004

(国外大学优秀教材——通信系列(影印版))

ISBN 7-302-08749-0

I. 光… II. 阿… III. 光纤通信—通信系统—高等学校—教材—英文 IV. TN929.11

中国版本图书馆 CIP 数据核字 (2004) 第 052490 号

出版者: 清华大学出版社

<http://www.tup.com.cn>

社总机: (010) 6277 0175

地址: 北京清华大学学研大厦

邮编: 100084

客户服务: (010) 6277 6969

责任编辑: 邹开颜

印刷者: 清华大学印刷厂

装订者: 三河市新茂装订有限公司

发行者: 新华书店总店北京发行所

开本: 170×230 印张: 35.25

版次: 2004 年 7 月第 1 版 2004 年 7 月第 1 次印刷

书号: ISBN 7-302-08749-0/TN·188

印数: 1~3000

定价: 54.00 元 (含光盘)

本书如存在文字不清、漏印以及缺页、倒页、脱页等印装质量问题, 请与清华大学出版社出版部联系调换。联系电话: (010) 62770175-3103 或 (010) 62795704

Fiber-Optic Communication Systems(3rd Ed.)

影 印 版 序

自从 1970 年低损耗的石英光纤和在室温下连续工作的半导体激光器取得突破性进展以来, 光纤通信技术进入了一个迅猛发展的阶段。近 30 年来, 光纤通信系统从 1975 年的速率为 45Mb/s、传输距离为 10km 左右发展到如今单纤中最高累计速率为 10.92Tb/s、最长实验传输距离达到近 3 万 km, 系统的速率与传输距离的乘积 (BL) 一直以每年翻一番的趋势增长, 增长速度超过了著名的摩尔定律。光纤系统性能的巨大进展极大地提高了全球通信网络的容量和覆盖范围, 在“信息高速公路”的建设乃至全球信息化的进程中发挥了关键的作用。因此, 目前国内外许多大学的电子工程、物理和光学等领域的有关专业中都开设光纤通信课程, 相应的教材、参考书和专著已不胜枚举。美国罗彻斯特大学的 Govind P. Agrawal 教授的《光纤通信系统》一书在国内外享有盛誉。本书于 1992 年问世, 10 多年来一直受到光通信界的认可, 许多大学将它作为教材或参考书。本书再版于 1997 年。由于近年来光纤通信技术的快速发展, 作者又于 2002 年推出了目前的第三版。其主要目标依然与前两版一样, 即一方面能够作为教科书使用, 同时又能供光通信界科技工作者作参考。因此, 物理的理解是本书的重点, 但工程方面内容的讨论也贯穿各章的始终。

概括起来, 本书有如下特点:

(1) 内容系统全面。本书从最基本的光纤、光发射和光接收机讲起, 随后按章节分别讨论了系统设计、光纤损耗和色散管理所涉及的先进技术、光网络中的波分复用、时分复用及码分复用技术。光孤子, 以及相干光通信系统等。书中内容反映了到 2001 年为止光纤通信系统最新和全面的状况。

(2) 注重概念方法。从内容的整体编排到具体内容的叙述, 都体现了突出物理概念、强调基本分析方法的指导思想。为了便于读者理解概念, 本书采用了大量清晰的插图和内容详实的表格。

(3) 例题习题丰富。书中有大量的例题和习题。书后并附有一张由 Optiwave 公司提供的 CD 光盘, 其中包含了一个光纤通信系统设计用的软件包。光盘中有大量的例题, 读者能够利用这些例题了解该软件包的各种功能, 然后可使用该软件包求解本书各章结尾部分提供的习题, 这将有助于读者加深对光通信系统设计中重要难点的理解。

本书的作者从 1989 年起在美国罗彻斯特大学光学院讲授光纤通信系统课程,

且与工业界合作密切，因此本书的内容不仅适合教学，而且反映了工业界的最新发展。本书的主要用途是作为光通信专业研究生的教材，内容经适当筛选后也能用于高年级的本科生。书中的主干内容与国内教材基本一致，因此很适合作为国内光纤通信和光电子技术应用等相关课程的教学参考书。在当前高校中正大力推进采用外语讲学的形势下，本书更是英文版教材中一个较好的选择。

谢世钟教授
清华大学电子工程系光通信研究所
2004 年 5 月

Preface

Since the publication of the first edition of this book in 1992, the state of the art of fiber-optic communication systems has advanced dramatically despite the relatively short period of only 10 years between the first and third editions. For example, the highest capacity of commercial fiber-optic links available in 1992 was only 2.5 Gb/s. A mere 4 years later, the wavelength-division-multiplexed (WDM) systems with the total capacity of 40 Gb/s became available commercially. By 2001, the capacity of commercial WDM systems exceeded 1.6 Tb/s, and the prospect of lightwave systems operating at 3.2 Tb/s or more were in sight. During the last 2 years, the capacity of transoceanic lightwave systems installed worldwide has exploded. Moreover, several other undersea networks were in the construction phase in December 2001. A global network covering 250,000 km with a capacity of 2.56 Tb/s (64 WDM channels at 10 Gb/s over 4 fiber pairs) is scheduled to be operational in 2002. Several conference papers presented in 2001 have demonstrated that lightwave systems operating at a bit rate of more than 10 Tb/s are within reach. Just a few years ago it was unimaginable that lightwave systems would approach the capacity of even 1 Tb/s by 2001.

The second edition of this book appeared in 1997. It has been well received by the scientific community involved with lightwave technology. Because of the rapid advances that have occurred over the last 5 years, the publisher and I deemed it necessary to bring out the third edition if the book were to continue to provide a comprehensive and up-to-date account of fiber-optic communication systems. The result is in your hands. The primary objective of the book remains the same. Specifically, it should be able to serve both as a textbook and a reference monograph. For this reason, the emphasis is on the physical understanding, but the engineering aspects are also discussed throughout the text.

Because of the large amount of material that needed to be added to provide comprehensive coverage, the book size has increased considerably compared with the first edition. Although all chapters have been updated, the major changes have occurred in Chapters 6–9. I have taken this opportunity to rearrange the material such that it is better suited for a two-semester course on optical communications. Chapters 1–5 provide the basic foundation while Chapters 6–10 cover the issues related to the design of advanced lightwave systems. More specifically, after the introduction of the elementary concepts in Chapter 1, Chapters 2–4 are devoted to the three primary components of a fiber-optic communications—optical fibers, optical transmitters, and optical receivers. Chapter 5 then focuses on the system design issues. Chapters 6 and 7 are devoted to the advanced techniques used for the management of fiber losses and chromatic dis-

person, respectively. Chapter 8 focuses on the use of wavelength- and time-division multiplexing techniques for optical networks. Code-division multiplexing is also a part of this chapter. The use of optical solitons for fiber-optic systems is discussed in Chapter 9. Coherent lightwave systems are now covered in the last chapter. More than 30% of the material in Chapter 6–9 is new because of the rapid development of the WDM technology over the last 5 years. The contents of the book reflect the state of the art of lightwave transmission systems in 2001.

The primary role of this book is as a graduate-level textbook in the field of *optical communications*. An attempt is made to include as much recent material as possible so that students are exposed to the recent advances in this exciting field. The book can also serve as a reference text for researchers already engaged in or wishing to enter the field of optical fiber communications. The reference list at the end of each chapter is more elaborate than what is common for a typical textbook. The listing of recent research papers should be useful for researchers using this book as a reference. At the same time, students can benefit from it if they are assigned problems requiring reading of the original research papers. A set of problems is included at the end of each chapter to help both the teacher and the student. Although written primarily for graduate students, the book can also be used for an undergraduate course at the senior level with an appropriate selection of topics. Parts of the book can be used for several other related courses. For example, Chapter 2 can be used for a course on optical waveguides, and Chapter 3 can be useful for a course on optoelectronics.

Many universities in the United States and elsewhere offer a course on optical communications as a part of their curriculum in electrical engineering, physics, or optics. I have taught such a course since 1989 to the graduate students of the Institute of Optics, and this book indeed grew out of my lecture notes. I am aware that it is used as a textbook by many instructors worldwide—a fact that gives me immense satisfaction. I am acutely aware of a problem that is a side effect of an enlarged revised edition. How can a teacher fit all this material in a one-semester course on *optical communications*? I have to struggle with the same question. In fact, it is impossible to cover the entire book in one semester. The best solution is to offer a two-semester course covering Chapters 1 through 5 during the first semester, leaving the remainder for the second semester. However, not many universities may have the luxury of offering a two-semester course on optical communications. The book can be used for a one-semester course provided that the instructor makes a selection of topics. For example, Chapter 3 can be skipped if the students have taken a laser course previously. If only parts of Chapters 6 through 10 are covered to provide students a glimpse of the recent advances, the material can fit in a single one-semester course offered either at the senior level for undergraduates or to graduate students.

This edition of the book features a compact disk (CD) on the back cover provided by the Optiwave Corporation. The CD contains a state-of-the-art software package suitable for designing modern lightwave systems. It also contains additional problems for each chapter that can be solved by using the software package. Appendix E provides more details about the software and the problems. It is my hope that the CD will help to train the students and will prepare them better for an industrial job.

A large number of persons have contributed to this book either directly or indirectly. It is impossible to mention all of them by name. I thank my graduate students and the

students who took my course on optical communication systems and helped improve my class notes through their questions and comments. Thanks are due to many instructors who not only have adopted this book as a textbook for their courses but have also pointed out the misprints in previous editions, and thus have helped me in improving the book. I am grateful to my colleagues at the Institute of Optics for numerous discussions and for providing a cordial and productive atmosphere. I appreciated the help of Karen Rolfe, who typed the first edition of this book and made numerous revisions with a smile. Last, but not least, I thank my wife, Anne, and my daughters, Sipra, Caroline, and Claire, for understanding why I needed to spend many weekends on the book instead of spending time with them.

Govind P. Agrawal

Rochester, NY

December 2001

Contents

Preface	xv
1 Introduction	1
1.1 Historical Perspective	1
1.1.1 Need for Fiber-Optic Communications	2
1.1.2 Evolution of Lightwave Systems	4
1.2 Basic Concepts	8
1.2.1 Analog and Digital Signals	8
1.2.2 Channel Multiplexing	11
1.2.3 Modulation Formats	13
1.3 Optical Communication Systems	15
1.4 Lightwave System Components	16
1.4.1 Optical Fibers as a Communication Channel	17
1.4.2 Optical Transmitters	17
1.4.3 Optical Receivers	18
Problems	19
References	20
2 Optical Fibers	23
2.1 Geometrical-Optics Description	23
2.1.1 Step-Index Fibers	24
2.1.2 Graded-Index Fibers	26
2.2 Wave Propagation	28
2.2.1 Maxwell's Equations	29
2.2.2 Fiber Modes	31
2.2.3 Single-Mode Fibers	34
2.3 Dispersion in Single-Mode Fibers	37
2.3.1 Group-Velocity Dispersion	38
2.3.2 Material Dispersion	39
2.3.3 Waveguide Dispersion	41
2.3.4 Higher-Order Dispersion	42
2.3.5 Polarization-Mode Dispersion	43
2.4 Dispersion-Induced Limitations	45
2.4.1 Basic Propagation Equation	46

2.4.2	Chirped Gaussian Pulses	47
2.4.3	Limitations on the Bit Rate	50
2.4.4	Fiber Bandwidth	53
2.5	Fiber Losses	55
2.5.1	Attenuation Coefficient	55
2.5.2	Material Absorption	56
2.5.3	Rayleigh Scattering	57
2.5.4	Waveguide Imperfections	58
2.6	Nonlinear Optical Effects	59
2.6.1	Stimulated Light Scattering	59
2.6.2	Nonlinear Phase Modulation	64
2.6.3	Four-Wave Mixing	66
2.7	Fiber Manufacturing	67
2.7.1	Design Issues	67
2.7.2	Fabrication Methods	68
2.7.3	Cables and Connectors	70
	Problems	72
	References	74
3	Optical Transmitters	77
3.1	Basic Concepts	77
3.1.1	Emission and Absorption Rates	78
3.1.2	p - n Junctions	81
3.1.3	Nonradiative Recombination	83
3.1.4	Semiconductor Materials	84
3.2	Light-Emitting Diodes	87
3.2.1	Power-Current Characteristics	87
3.2.2	LED Spectrum	89
3.2.3	Modulation Response	90
3.2.4	LED Structures	91
3.3	Semiconductor Lasers	92
3.3.1	Optical Gain	93
3.3.2	Feedback and Laser Threshold	94
3.3.3	Laser Structures	96
3.4	Control of Longitudinal Modes	99
3.4.1	Distributed Feedback Lasers	100
3.4.2	Coupled-Cavity Semiconductor Lasers	102
3.4.3	Tunable Semiconductor Lasers	103
3.4.4	Vertical-Cavity Surface-Emitting Lasers	105
3.5	Laser Characteristics	106
3.5.1	CW Characteristics	107
3.5.2	Small-Signal Modulation	110
3.5.3	Large-Signal Modulation	112
3.5.4	Relative Intensity Noise	114
3.5.5	Spectral Linewidth	116
3.6	Transmitter Design	118

3.6.1	Source-Fiber Coupling	118
3.6.2	Driving Circuitry	121
3.6.3	Optical Modulators	122
3.6.4	Optoelectronic Integration	123
3.6.5	Reliability and Packaging	124
	Problems	126
	References	127
4	Optical Receivers	133
4.1	Basic Concepts	133
4.1.1	Detector Responsivity	133
4.1.2	Rise Time and Bandwidth	135
4.2	Common Photodetectors	136
4.2.1	p - n Photodiodes	137
4.2.2	p - i - n Photodiodes	138
4.2.3	Avalanche Photodiodes	142
4.2.4	MSM Photodetectors	148
4.3	Receiver Design	149
4.3.1	Front End	149
4.3.2	Linear Channel	150
4.3.3	Decision Circuit	152
4.3.4	Integrated Receivers	153
4.4	Receiver Noise	155
4.4.1	Noise Mechanisms	156
4.4.2	p - i - n Receivers	158
4.4.3	APD Receivers	159
4.5	Receiver Sensitivity	162
4.5.1	Bit-Error Rate	162
4.5.2	Minimum Received Power	164
4.5.3	Quantum Limit of Photodetection	167
4.6	Sensitivity Degradation	168
4.6.1	Extinction Ratio	168
4.6.2	Intensity Noise	169
4.6.3	Timing Jitter	171
4.7	Receiver Performance	174
	Problems	176
	References	178
5	Lightwave Systems	183
5.1	System Architectures	183
5.1.1	Point-to-Point Links	183
5.1.2	Distribution Networks	185
5.1.3	Local-Area Networks	186
5.2	Design Guidelines	188
5.2.1	Loss-Limited Lightwave Systems	189
5.2.2	Dispersion-Limited Lightwave Systems	190

5.2.3	Power Budget	192
5.2.4	Rise-Time Budget	193
5.3	Long-Haul Systems	195
5.3.1	Performance-Limiting Factors	196
5.3.2	Terrestrial Lightwave Systems	198
5.3.3	Undersea Lightwave Systems	200
5.4	Sources of Power Penalty	202
5.4.1	Modal Noise	202
5.4.2	Dispersive Pulse Broadening	204
5.4.3	Mode-Partition Noise	205
5.4.4	Frequency Chirping	209
5.4.5	Reflection Feedback and Noise	213
5.5	Computer-Aided Design	217
	Problems	219
	References	220
6	Optical Amplifiers	226
6.1	Basic Concepts	226
6.1.1	Gain Spectrum and Bandwidth	227
6.1.2	Gain Saturation	229
6.1.3	Amplifier Noise	230
6.1.4	Amplifier Applications	231
6.2	Semiconductor Optical Amplifiers	232
6.2.1	Amplifier Design	232
6.2.2	Amplifier Characteristics	234
6.2.3	Pulse Amplification	237
6.2.4	System Applications	241
6.3	Raman Amplifiers	243
6.3.1	Raman Gain and Bandwidth	243
6.3.2	Amplifier Characteristics	244
6.3.3	Amplifier Performance	246
6.4	Erbium-Doped Fiber Amplifiers	250
6.4.1	Pumping Requirements	251
6.4.2	Gain Spectrum	252
6.4.3	Simple Theory	253
6.4.4	Amplifier Noise	255
6.4.5	Multichannel Amplification	257
6.4.6	Distributed-Gain Amplifiers	260
6.5	System Applications	261
6.5.1	Optical Preamplification	261
6.5.2	Noise Accumulation in Long-Haul Systems	264
6.5.3	ASE-Induced Timing Jitter	266
6.5.4	Accumulated Dispersive and Nonlinear Effects	269
6.5.5	WDM-Related Impairments	271
	Problems	272
	References	273

7	Dispersion Management	279
7.1	Need for Dispersion Management	279
7.2	Precompensation Schemes	281
7.2.1	Prechirp Technique	281
7.2.2	Novel Coding Techniques	283
7.2.3	Nonlinear Prechirp Techniques	285
7.3	Postcompensation Techniques	286
7.4	Dispersion-Compensating Fibers	288
7.5	Optical Filters	290
7.6	Fiber Bragg Gratings	293
7.6.1	Uniform-Period Gratings	293
7.6.2	Chirped Fiber Gratings	296
7.6.3	Chirped Mode Couplers	299
7.7	Optical Phase Conjugation	300
7.7.1	Principle of Operation	300
7.7.2	Compensation of Self-Phase Modulation	301
7.7.3	Phase-Conjugated Signal	302
7.8	Long-Haul Lightwave Systems	305
7.8.1	Periodic Dispersion Maps	305
7.8.2	Simple Theory	307
7.8.3	Intrachannel Nonlinear Effects	309
7.9	High-Capacity Systems	310
7.9.1	Broadband Dispersion Compensation	311
7.9.2	Tunable Dispersion Compensation	313
7.9.3	Higher-Order Dispersion Management	315
7.9.4	PMD Compensation	317
	Problems	321
	References	322
8	Multichannel Systems	330
8.1	WDM Lightwave Systems	330
8.1.1	High-Capacity Point-to-Point Links	331
8.1.2	Wide-Area and Metro-Area Networks	334
8.1.3	Multiple-Access WDM Networks	336
8.2	WDM Components	339
8.2.1	Tunable Optical Filters	339
8.2.2	Multiplexers and Demultiplexers	344
8.2.3	Add-Drop Multiplexers	348
8.2.4	Star Couplers	350
8.2.5	Wavelength Routers	351
8.2.6	Optical Cross-Connects	354
8.2.7	Wavelength Converters	357
8.2.8	WDM Transmitters and Receivers	360
8.3	System Performance Issues	362
8.3.1	Heterowavelength Linear Crosstalk	363
8.3.2	Homowavelength Linear Crosstalk	365

8.3.3	Nonlinear Raman Crosstalk	366
8.3.4	Stimulated Brillouin Scattering	369
8.3.5	Cross-Phase Modulation	370
8.3.6	Four-Wave Mixing	372
8.3.7	Other Design Issues	374
8.4	Time-Division Multiplexing	375
8.4.1	Channel Multiplexing	375
8.4.2	Channel Demultiplexing	377
8.4.3	System Performance	380
8.5	Subcarrier Multiplexing	381
8.5.1	Analog SCM Systems	382
8.5.2	Digital SCM Systems	385
8.5.3	Multiwavelength SCM Systems	386
8.6	Code-Division Multiplexing	388
8.6.1	Direct-Sequence Encoding	388
8.6.2	Spectral Encoding	390
	Problems	393
	References	394
9	Soliton Systems	404
9.1	Fiber Solitons	404
9.1.1	Nonlinear Schrödinger Equation	405
9.1.2	Bright Solitons	406
9.1.3	Dark Solitons	409
9.2	Soliton-Based Communications	411
9.2.1	Information Transmission with Solitons	411
9.2.2	Soliton Interaction	412
9.2.3	Frequency Chirp	414
9.2.4	Soliton Transmitters	416
9.3	Loss-Managed Solitons	418
9.3.1	Loss-Induced Soliton Broadening	418
9.3.2	Lumped Amplification	420
9.3.3	Distributed Amplification	422
9.3.4	Experimental Progress	425
9.4	Dispersion-Managed Solitons	427
9.4.1	Dispersion-Decreasing Fibers	427
9.4.2	Periodic Dispersion Maps	429
9.4.3	Design Issues	432
9.5	Impact of Amplifier Noise	435
9.5.1	Moment Method	435
9.5.2	Energy and Frequency Fluctuations	437
9.5.3	Timing Jitter	439
9.5.4	Control of Timing Jitter	442
9.6	High-Speed Soliton Systems	445
9.6.1	System Design Issues	445
9.6.2	Soliton Interaction	447

9.6.3	Impact of Higher-Order Effects	450
9.6.4	Timing Jitter	452
9.7	WDM Soliton Systems	458
9.7.1	Interchannel Collisions	458
9.7.2	Effect of Lumped Amplification	461
9.7.3	Timing Jitter	461
9.7.4	Dispersion Management	463
	Problems	467
	References	469
10	Coherent Lightwave Systems	478
10.1	Basic Concepts	479
10.1.1	Local Oscillator	479
10.1.2	Homodyne Detection	480
10.1.3	Heterodyne Detection	480
10.1.4	Signal-to-Noise Ratio	481
10.2	Modulation Formats	482
10.2.1	ASK Format	483
10.2.2	PSK Format	484
10.2.3	FSK Format	485
10.3	Demodulation Schemes	487
10.3.1	Heterodyne Synchronous Demodulation	488
10.3.2	Heterodyne Asynchronous Demodulation	488
10.4	Bit-Error Rate	490
10.4.1	Synchronous ASK Receivers	490
10.4.2	Synchronous PSK Receivers	492
10.4.3	Synchronous FSK Receivers	493
10.4.4	Asynchronous ASK Receivers	493
10.4.5	Asynchronous FSK Receivers	495
10.4.6	Asynchronous DPSK Receivers	497
10.5	Sensitivity Degradation	497
10.5.1	Phase Noise	498
10.5.2	Intensity Noise	500
10.5.3	Polarization Mismatch	502
10.5.4	Fiber Dispersion	504
10.5.5	Other Limiting Factors	506
10.6	System Performance	507
10.6.1	Asynchronous Heterodyne Systems	507
10.6.2	Synchronous Heterodyne Systems	508
10.6.3	Homodyne Systems	508
10.6.4	Current Status	510
	Problems	511
	References	512
	Appendix A System of Units	518

Appendix B Acronyms	520
Appendix C General Formula for Pulse Broadening	524
Appendix D Ultimate System Capacity	527
References	528
Appendix E Software Package	529
Index	531

Chapter 1

Introduction

A communication system transmits information from one place to another, whether separated by a few kilometers or by transoceanic distances. Information is often carried by an electromagnetic carrier wave whose frequency can vary from a few megahertz to several hundred terahertz. Optical communication systems use high carrier frequencies (~ 100 THz) in the visible or near-infrared region of the electromagnetic spectrum. They are sometimes called lightwave systems to distinguish them from microwave systems, whose carrier frequency is typically smaller by five orders of magnitude (~ 1 GHz). Fiber-optic communication systems are lightwave systems that employ optical fibers for information transmission. Such systems have been deployed worldwide since 1980 and have indeed revolutionized the technology behind telecommunications. Indeed, the lightwave technology, together with microelectronics, is believed to be a major factor in the advent of the “information age.” The objective of this book is to describe fiber-optic communication systems in a comprehensive manner. The emphasis is on the fundamental aspects, but the engineering issues are also discussed. The purpose of this introductory chapter is to present the basic concepts and to provide the background material. Section 1.1 gives a historical perspective on the development of optical communication systems. In Section 1.2 we cover concepts such as analog and digital signals, channel multiplexing, and modulation formats. Relative merits of guided and unguided optical communication systems are discussed in Section 1.3. The last section focuses on the building blocks of a fiber-optic communication system.

1.1 Historical Perspective

The use of light for communication purposes dates back to antiquity if we interpret optical communications in a broad sense [1]. Most civilizations have used mirrors, fire beacons, or smoke signals to convey a single piece of information (such as victory in a war). Essentially the same idea was used up to the end of the eighteenth century through signaling lamps, flags, and other semaphore devices. The idea was extended further, following a suggestion of Claude Chappe in 1792, to transmit mechanically