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国外优秀信息科学与技术系列教学用书

光纤通信

第三版　影印版

Optical Fiber Communications

Third Edition

■ Gerd Keiser

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McGraw-Hill Companies

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ABOUT THE AUTHOR

GERD KEISER has been involved with the research, development, and application of optical networking technology and digital switch development for 25 years. The majority of this time was spent at the GTE Systems and Technology Corporation. His current interest is the architectural design and implementation of high-performance telecommunication networks. As a side activity, he has served as an adjunct professor of electrical engineering at Northeastern University and Tufts University, and was an industrial advisor to the Wentworth Institute of Technology. He is a Fellow of the IEEE and is the author of the book *Local Area Networks* (McGraw-Hill). He received his B.A. and M.S. degrees in mathematics and physics from the University of Wisconsin in Milwaukee and a Ph.D. degree in solid-state physics from Northeastern University in Boston.

PREFACE

TELECOMMUNICATION NETWORKS BASED on optical fiber technology have become a major information-transmission system, with high-capacity optical fiber links encircling the globe in both terrestrial and undersea installations. In the early days of optical fiber communications, the applications involved basically only the optical fiber, a light source, and a photodetector. Now, there are numerous passive and active optical devices within a light-wave link that perform complex networking functions in the optical domain, such as signal restoration, routing, and switching. Along with the need to understand the functions of these devices comes the necessity to measure both component and network performance, and to model and simulate the complex behavior of reliable high-capacity networks.

This book presents the fundamental principles for understanding and applying optical fiber technology to such sophisticated modern telecommunication systems. This text methodically examines the fundamental behavior of the individual optical components, describes their interactions with other devices in an optical fiber link, discusses the behavior of basic analog and digital optical links, and examines the performance characteristics of complex optical links and networks. Key features of the text for accomplishing this are as follows:

- A comprehensive treatment of the theory and behavior of basic constituents, such as optical fibers, light sources, photodetectors, connecting and coupling devices, and optical amplifiers.
- The basic design principles of digital and analog optical fiber transmission links.
- The operating principles of wavelength-division multiplexing (WDM) and the components needed for its realization.

- Descriptions of the architectures and performance characteristics of complex optical networks for connecting users who have a wide range of transmission needs.
- Discussions of advanced optical communication techniques, such as soliton transmission, optical code-division multiple access (optical CDMA), and ultra-fast optical time-division multiplexing (OTDM).
- An entire chapter devoted to measurement standards, basic test equipment, and techniques for verifying the operational characteristics of components in optical fiber communication links.
- A modeling and simulation program on a CD-ROM.

The modeling and simulation program on the CD-ROM is an abbreviated version of the *Photonic Transmission Design Suite®* (PTDS) from Virtual Photonics, Inc. This program is called PTDSlite, and is intended for student use. The software on the CD-ROM will allow students to examine the performance of key components (e.g., laser diodes, optical couplers, optical amplifiers, and photodetectors) and basic links consisting of these components. There are predefined parameter sets for each component, but, using Windows-based input screens, the user can vary any of these parameters (e.g., fiber length) and can turn them on and off to see their effect on link performance. This is a Windows-based program, so it can run on any standard PC that has the appropriate random-access memory and disk size.

This book provides the basic material for an introductory senior-level or graduate course in the theory and application of optical fiber communication technology. It will also serve well as a working reference for practicing engineers dealing with optical fiber communication system designs. The background required to study the book is that of typical senior-level engineering students. This includes introductory electromagnetic theory, calculus and elementary differential equations, basic concepts of optics as presented in a freshman physics course, and the basic concepts of electronics. To refresh readers' memories, concise reviews of several background topics, such as optics concepts, electromagnetic theory, and basic semiconductor physics, are included in the main body of the text. In this edition, various sections dealing with advanced material (e.g., the application of Maxwell's equations to cylindrical waveguides and the mathematical theory of optical receivers) are designated by a star and can be skipped over without loss of continuity. To aid readers in learning the material and applying it to practical designs, numerous examples are given throughout the book. A collection of 266 homework problems is included to help test the reader's comprehension of the material covered, and to extend and elucidate the text. Instructors can obtain the problem solutions from the publisher.

The original concept of this book is attributable to Tri T. Ha, Naval Postgraduate School, who urged me to write it when we were colleagues at GTE. His suggestions for the first two editions were most helpful. For this edition, I am greatly indebted to Ira Jacobs, Virginia Polytechnic Institute, and Don Nicholson, Syracuse University, for critical reviews of the manuscript and suggestions for enhancing and clarifying the material. In addition, I am grateful to Lian-kuan Chen, The Chinese University of Hong Kong; Walter Johnstone, University of Strathclyde, Scotland; and Winston I. Way, National Chiao-Tung University, Taiwan, for critical reviews of material in the newer chapters. Special thanks go to Dirk Seewald, Kay Iverson, Arthur Lowery (also of the University of Melbourne, Australia), and Stefan Georgi of Virtual Photonics for supplying the CD-ROM with the modeling tool and for reviewing the manuscript. Numerous people have helped directly or indirectly with various aspects of this book and its previous editions. Among them are Bert Basch, Joanne LaCourse, and Bill Nelson, GTE Laboratories; Sonia Bélanger, EXFO; C. T. Chang, San Diego State University; Emmanuel Desurvire, Alcatel Alsthom Researche, France; Paul Green, Jr., Tellabs; Katie Hall, MIT Lincoln Laboratory; Mark Jerabek, West Virginia University; Mohsen Kavehrad, University of Pennsylvania; Nishla Keiser, MIT; Arnie Michelson, GTE; Fred Quan, Corning; Don Rice, happily retired from GTE and Tufts University; Paul Schumate, Jr., Telcordia Technologies; Ramakant Srivastava, University of Florida; and Dan Yang, AFC Technologies. Particularly encouraging for doing the third edition were the many positive comments on the previous editions received from users and adapters at the numerous institutions worldwide. This edition especially benefited from the expert guidance of Betsy Jones, Michelle Flomenhoft, and Christina Thornton-Villagomez of McGraw-Hill. As a final personal note, I am grateful to my wife Ching-yun and my daughter Nishla for their patience and encouragement during the time I devoted to writing and revising this book.

Further information on new developments and reference material related to the book can be found on the following McGraw-Hill Web site for this book: http://www.mhhe.com/engcs/electrical/keiser/.

Gerd Keiser

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CHAPTER 1

OVERVIEW OF OPTICAL FIBER COMMUNICATIONS

Ever since ancient times, one of the principal needs of people has been to communicate. This need created interest in devising communication systems for sending messages from one distant place to another. Many forms of communication systems have appeared over the years. The basic motivations behind each new form were either to improve the transmission fidelity, to increase the data rate so that more information could be sent, or to increase the transmission distance between relay stations. Before the nineteenth century, all communication systems operated at a very low information rate and involved only optical or acoustical means, such as signal lamps or horns. One of the earliest known optical transmission links, for example, was the use of a fire signal by the Greeks in the eighth century B.C. for sending alarms, calls for help, or announcements of certain events.[1]

The invention of the telegraph by Samuel F. B. Morse in 1838 ushered in a new epoch in communications—the era of electrical communications.[2] In the ensuing years, an increasingly larger portion of the electromagnetic spectrum, shown in Fig. 1-1, was utilized for conveying information from one place to another.[3] The reason for this trend is that, in electrical systems, the data are usually transferred over the communication channel by superimposing the information onto a sinusoidally varying electromagnetic wave, which is known as the *carrier*. At the destination, the information is removed from the carrier wave and processed as desired. Since the amount of information that can be transmitted is directly related to the frequency range over which the carrier operates, increasing

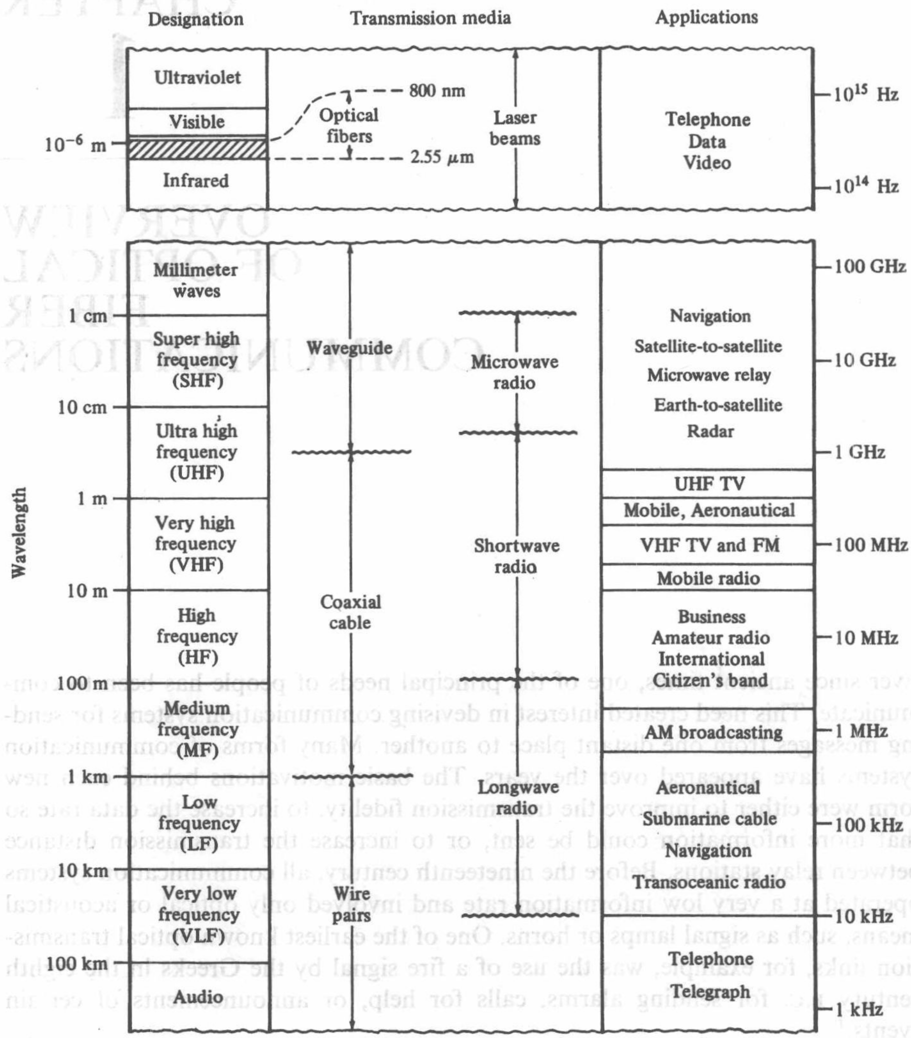

FIGURE 1-1
Examples of communication systems applications in the electromagnetic spectrum. (Used with permission from Carlson,[3] © 1986, McGraw-Hill Book Company.)

the carrier frequency theoretically increases the available transmission bandwidth and, consequently, provides a larger information capacity. Thus, the trend in electrical communication system developments was to employ progressively higher frequencies (shorter wavelengths), which offer corresponding increases in bandwidth or information capacity. This activity led to the birth of radio, television, radar, and microwave links.

Another important portion of the electromagnetic spectrum encompasses the optical region shown in Fig. 1-1. In contrast to electrical communications,