

Understanding Fiber Optics

Fifth edition, revised

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Preface to the Laser Light Press Edition

About This Edition

Except for this preface, the front matter, and the errata that follows, this Laser Light Press edition reprints the fifth edition of *Understanding Fiber Optics* published in 2006 by Pearson Education, Inc. I am planning a sixth edition, but because that will take a while to prepare and with the Pearson edition is no longer available, I am reprinting the fifth through Laser Light Press. It may not cover the cutting edge of fiber optics, but it does cover the fundamentals you need to understand the field.

This edition also is an experiment. I want to see how reducing the book's price will affect sales and make *Understanding Fiber Optics* more accessible to students. Thus Laser Light Press offers a low-cost PDF electronic version and a relatively inexpensive print-on-demand paperback. The many diagrams make an e-reader version more difficult.

Whether you are an instructor, a student or a general reader, I would appreciate your comments and suggestions. If you are teaching a course based on the book, please contact me at jeff@jeffhecht.com for an instructor's manual. You can find more information on the book's status and on associated material at through <http://www.understandingfiberoptics.com> or through <http://www.jeffhecht.com>.

About Fiber Optics

Fiber optics has come a long way since I wrote the first edition of *Understanding Fiber Optics* in 1987. Optical-fiber communications was a radical new technology then, used mostly for high-capacity, long-distance transmission of telephone signals. I used a 1200-baud modem to send text messages from my computer through proprietary networks. Today a fiber-optic cable to my home provides a broadband connection to the Internet. A global network of fiber-optic cables links my phone and my computer to every continent except Antarctica, and a new cable is being laid through the Arctic Ocean.

Fiber optics has revolutionized telecommunications in the same way the railroads revolutionized land transportation in the years my great-great-grandfather worked for one. Like the railroad business, the fiber-optic business has had its spectacular booms and busts. The telecommunications bubble brought dreams of riches, but the bust that followed left nightmares of ruin and grim jokes about the stocks of once high-flying companies. Yet the bubble and its aftermath are reminders that fiber optics is a technology that may be too good for its own good. Like the railroads and the Internet, fiber optics was something so good that the stock market wildly overvalued it; and like the Internet, fiber optics will be part of our future.

I wrote the first edition of this book mainly for self-study, but it is now used widely in classroom settings. My goal is to explain principles rather than to detail procedures. When you finish, you should indeed understand fiber optics. You should be able to understand what the field is all about, comprehend what you read in trade journals such as *Lightwave* or *Laser Focus World*, make sense of what people in the field are saying, and explain fiber optics to your Aunt Millie or your niece. You won't be ready to design a brand new system, but you will be literate in the field.

Think of it as Fiber Optics 101, a foundation for your understanding of a growing technology.

To explain the fundamentals of fiber optics, I start with ideas that may seem basic to some readers; the details will follow. To make concepts accessible, I include drawings to show how things work, limit math to simple algebra, and step through some simple calculation to show how they work. I compare fiber optics with other common technologies and highlight similarities and differences. I have organized the book to facilitate cross-referencing and review of concepts, and made a point of adding a thorough index to make its contents accessible. I also include some information on the business side of the technology, and boxes that talk about key issues that the fiber-optics community needs to think about.

The book introduces basic concepts first, then digs deeper into hardware and applications. The chapters are organized as follows:

- The first three chapters are an introduction and overview. Chapter 1 tells how fiber optics are used and how the technology developed. Chapter 2 introduces optics, light, and the concept of light guiding. Chapter 3 introduces other basic concepts of communications and fiber-optic systems. They assume no background in optics or telecommunications.

- Chapters 4 through 8 cover optical fibers, their properties, and how they are assembled into cables. The material is divided into five chapters to make it easier to digest. Chapters 4 through 6 explain the fiber concepts used in the rest of the book. Chapter 7 covers special-purpose fibers used in optical amplifiers and fiber gratings, photonic-crystal or microstructured fibers, and planar waveguides. Chapter 8 is an overview of cabling.

- Chapters 9 to 12 cover laser and LED light sources including diode and fiber lasers, optical transmitters, optical detectors, receivers, optical amplifiers, and electro-optic regenerators. Chapter 12 compares and contrasts the operation of optical amplifiers and electro-optic regenerators.

- Chapters 13 to 16 cover other components. Chapter 13 covers connectors and splices that join fibers. Chapter 14 covers optical couplers and other passive components in simple fiber systems and describes integrated optics. Chapter 15 covers optics that send signals at many separate wavelengths through the same fibers. Chapter 16 covers optical modulation and switching for optical networking.

- Chapter 17 covers fundamentals of optical and fiber-optic measurements and explains the quirks of optical measurements. Chapter 18 describes fiber-optic testing.

- Chapters 19 to 22 cover general principles of fiber communication. Chapter 19 describes fundamental concepts of fiber-optic systems and optical networking and how they work in practice. Chapter 20 describes communication standards. Chapter 21 outlines design of point-to-point single-wavelength systems, with sample calculations, so you can understand their operation. Chapter 22 describes the design of optical networks.

- Chapters 23 to 27 explain how fiber optics fit into networks used for global and regional telephone and Internet transmission, cable television, and data networks. These chapters focus on different levels and aspects of the global network to keep concepts manageable. Chapter 28 covers special systems that don't fit elsewhere, such as networks in cars, military systems, and aircraft.

- The final two chapters describe non-communication applications. Chapter 29 explains the principles and operation of fiber-optic sensors. Chapter 30 covers imaging and illumination with fiber optics.

The glossary at the back of the book gives you quick translations of specialized terms and acronyms.

Appendices tabulate useful information, including values of important physical constants, conversion factors, and a few key formulas. They're all in one place to make them easier to find. They also include an annotated list of resources, in addition to the suggestions for further reading in each chapter. So many resources are available on the Internet that I can't hope to compile a thorough list; I encourage you to use search engines creatively. I welcome your comments, questions, and suggestions at jeff@jeffhecht.com.

Acknowledgments

Over the years many members of the fiber-optics community have given generously of their time to patiently answer my questions. I owe special thanks to John Jay, Shane Nipple, Craig Kegerise, Jerry Jackson, Eric Udd, Dana McEntire, and Joel Orban for feedback on draft chapters of this edition. Thanks to Kevin Able, Bill Chang, David Charlton, Marc Duchesne, Erich Dzakler, Robert Gallawa, Jim Hayes, Dennis Horwitz, Larry Johnson, Jim Masi, Nick Massa, Mike Pepper, Jim Refi, John Schlager, and Wayne Siddal for help on earlier editions and other material. Thanks to Jeffrey Rankinen, Pennsylvania College of Technology; Richard Windley, FCPI College of Technology; and Dave Whitmore, Champlain College for their helpful reviews. Any errors that remain are my own.

This book draws on a series of articles on optical networking that I wrote for *Laser Focus World*. I thank Steve Anderson for commissioning and editing them, Carol Settino for ably steering them into print, and the magazine's readers for feedback. I thank the Optical Society of America and SPIE - The International Society for Optical Engineering for inviting me to teach short courses based on *Understanding Fiber Optics*.

I owe special thanks to the editorial and production staff at Pearson Education for their excellent work and their assistance in making this book possible. Thanks also to Lisa Cohen for updating me on the changing world of book publishing.

Jeff Hecht, Auburndale, MA
March 2015

Errata

What have you learned? item 6 on page 35 should read:

Refractive index (n) of a material is the speed of light in a vacuum divided by the speed of light in the material. It is always greater than 1.0 at optical wavelengths.

Figure 14.12 on page 356 does not correctly show the operators performed on light of different polarizations in an optical circulator.

Figure 15.1 on page 365 should have an * on λ_4 on the right side of the drawing to show that wavelength comes from the local transmitter at the bottom.

Table A.3 on page 764 should give the value of Planck's constant in J-s (joule-seconds) or eV-s (electronvolt-seconds), not J/s or eV/s. The numerical values are correct, but the units are not.

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*This book is dedicated to the memory of Heather Williamson Messenger,
gifted editor, good friend, and victim of domestic violence.*