CHAPTER

1

An Introduction to Fiber Optics

About This Chapter

This chapter is a starting point to look around and see where you're going before you dig into details. The goal is to put fiber optics and communications into context and show how they go together. I start with a personal commentary about the turbulent times of the past several years, then explain the plan for this book. A brief history of fiber optics follows, which introduces some important concepts. Then a brief history of communications explains the need for bandwidth and how fiber optics filled that need, perhaps too well. Finally, I explain some of the terminology of the field to help you in your looking about.

A Personal View: Ups and Downs

Fiber revolutionized telecommunications by supplying tremendous bandwidth.

Fiber optics has come a long way in the nearly three decades I've been watching its development. For many years the field grew steadily, with new technology creating new applications, and new applications, in turn, supplying money to develop more new technology. The growth sped out of control in the late 1990s as the Internet fed a seemingly limitless thirst for bandwidth that only optical fibers could provide. The boom turned into a bubble, and the bubble into a bust as I watched in amazement.

We knew the bubble was too good to be true, but none of us wanted it to end. We told ourselves that the communications industry was in better shape than the dot-coms because it had real hardware, not just web sites. Then the industry ran right off a cliff and landed with an ugly splat. We traded grim jokes, noting that we would have done better to invest in cases of beer and return the empties in a state with a bottle-deposit law. Employment dropped nearly as badly. The industry seemed a vast, smoking crater.

Fiber-optic technology remains healthy.

That depressing view is as much of an exaggeration as was the euphoric overenthusiasm of the bubble. We'll never see that manic growth again, and that's just as well. But fiber-optic technology remains healthy, with advances continuing at a more sober rate. Fiber optics has become the backbone of the global telecommunications network, giving us instant access to Web sites and telephones around the world. That network continues to reach toward homes and businesses. Cable television companies, telephone companies, Internet providers, and power companies have their own fiber-optic networks. When you use a cell phone, your calls usually go wireless only to the tower, where a fiber-optic cable runs to the backbone telephone network. The demand for bandwidth continues to rise, although there's a lot of surplus fiber in the ground right now.

Fiber revolutionized telecommunications in the twentieth century, just as the railroads revolutionized transportation in the nineteenth century. Overbuilding of railroads caused spectacular busts in the latter half of the nineteenth century, but railroads remained the backbone of the national transportation network until the spread of the interstate highway system in the 1950s and 1960s. Railroads still carry people and freight today—especially in Europe.

The fiber-optic gold rush is over, and the field has had a roller-coaster ride of dramatic ups and downs. We've gained some experience and a few gray hairs in the process, but we've survived. Fiber has carved itself a vital niche in the communications world and will play a growing role around the world as other countries expand their own communications networks. Fiber is here to stay.

The Roots of Fiber Optics

Fiber optics did not begin as a communications technology. Optical fibers evolved from devices developed to guide light for illumination or displays, and were first used to look inside the human body. Bundles of optical fibers are still used to examine the stomach and the colon because they can reach into otherwise inaccessible areas. It's worth looking at how this idea began—it will teach you the basic ideas of light guiding in a fiber.

Piping Light

Light normally goes in straight lines, but sometimes we want it to go around corners.

Think of optical fibers as pipes that carry light. Lenses can bend light and mirrors can deflect it, but otherwise light travels in straight lines. The working of optical devices, from our eyes to giant telescopes and sensitive microscopes, depends on light going in straight lines. Yet sometimes it is nice to be able to pipe light around corners and look into inaccessible places. The first steps in that direction were taken in the nineteenth century.

In 1880, William Wheeler, a young engineer from Concord, Massachusetts, filed for a patent on a way to pipe light through buildings. Thomas Edison had already made the first incandescent light bulbs but hadn't gotten all the bugs out. Wheeler wanted to distribute light from an electric arc, a light source that was better developed at the time, but was blindingly bright. He planned to put arc lamps in the basements of buildings and

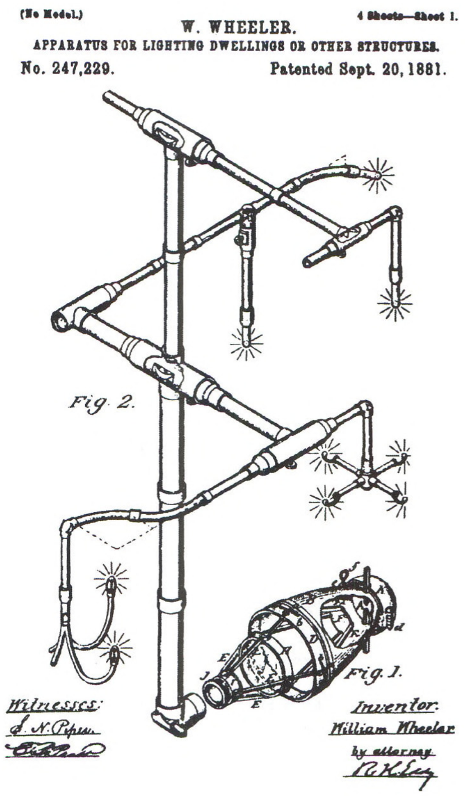

FIGURE 1.1
Wheeler's plan for piping light into rooms (U.S. Patent 247,229).

distribute the light to distant rooms through a set of pipes coated with a reflective layer inside, as shown in Figure 1.1. Diffusers at the ends of the pipes would spread the light out inside each room.

Wheeler was a solid engineer who became an expert in designing water works. He later founded a successful company that made reflectors for street lamps. His design was logical at the time since air seemed to be a much clearer medium than any known solid. But his light pipes never caught on, and Edison's incandescent bulbs eventually worked much better than arc lamps.

Total Internal Reflection

Even before Wheeler's time, scientists knew how to trap light inside a solid. A phenomenon called *total internal reflection*, described in Chapter 2, can confine light inside glass or other transparent materials. This phenomenon involves sending light through the material in such a way that it strikes the surface exposed to air at a glancing angle. Then the light is reflected back into the solid. You can see the effect in diamond or cut glass, in which one surface acts like a mirror to reflect light to your eye.

Total internal reflection can guide light along a glass rod or water jet.

Glassblowers may have been the first to realize this effect could guide light along a bent glass rod, but it wasn't widely recognized until 1841 when a Swiss physicist, Daniel Colladon, transmit separate signals through the same fiber at many wavelengths. WDM multiplies the capacity of individual fibers. The idea is similar to transmitting signals through the air at many separate radio frequencies, which allows many radio and television stations to transmit simultaneously to homes. Developers also began talking about *optical networking*, in which signals would be routed around the country optically without being converted into electronic form.

Eventually investment in fiber optics got out of hand, creating an economic "perfect storm," which survivors call "the bubble."

Understanding the Bubble

The rapid growth of the Internet and the proliferation of dot-com companies started pumping up the bubble in the late 1990s. A number of factors magnified its impact on the telecommunications industry.

For decades, the conventional wisdom of telecommunications engineers had been that you can't have enough bandwidth. Networks are designed around the assumption that everyone is not on the phone at the same time. The long-distance network can't handle all the country's phone lines at once, which is why you sometimes can't get a long-distance line on Mother's Day. As Internet demand started rising, telecommunications carriers installed more fiber to handle the demand. Extra fibers are cheap compared to construction projects, so the carriers added lots of fibers to make sure they had extra capacity in the future. They also planned on using wavelength-division multiplexing to multiply the capacity of every fiber. Nobody thought that they could ever have too much bandwidth.

Bandwidth was traditionally scarce in telecommunications.

But nobody fully grasped how fast the Internet was growing. For a brief period around 1996, Internet traffic seemed to be doubling every three months. Worldcom kept quoting that number for years until it became an Internet myth, widely believed although its origins were dubious. Telecommunications carriers looked at that tremendous growth rate and decided they'd need more fibers to handle the projected traffic. They didn't know that in reality Internet traffic was doubling only once every year, a fact hard to ascertain because the traffic was divided among many different carriers.

A gold rush started in technology stocks, focusing on the Internet, as new companies reported fast growth in sales. In reality, many of the numbers were fudged, and others looked deceptively large because they were starting from zero. Market analysts made wild projections of fantastic growth. A few people made fortunes selling promising new companies. Even when the first dot-coms began to fail, telecommunications looked good compared to selling dog food on the Internet, as I heard leading market analyst John Ryan say at a conference.

Venture capitalists kept pumping money into the optical industry. New companies popped up from nowhere. Some had solid ideas, but others seemed to have little more than fancy trade-show booths and a pitch to investors. Yet their valuations kept rising with the growth of the bubble. It was tempting to believe that this growth was real and everyone would get rich.

It wasn't. No one had realized how much market projections or corporate profits had been inflated by wishful thinking and fraud. When the collapse came, it was disastrous. Companies either folded or shrank to shadows of their former selves. Many fibers installed

The bubble badly hurt telecommunications and fiber optics.

THINGS TO THINK ABOUT

The Problem of the Bubble

The bubble created a tremendous amount of paper wealth that largely evaporated in its aftermath and left the telecommunications industry in shambles. Fortunes were made by a few people who sold stock near the peak; many more saw their holdings shrink.

The development of new technology requires investment, and the bubble distorted the entire pattern of investment. Cumulative losses are estimated to be in the hundreds of billions of dollars. Allegations of fraud abound, going far beyond the handful of criminal charges filed and regulatory actions taken. Both crooks and fools played roles, but we may never know which was more important, nor how we can avoid future bubbles.

The historical parallels with the rise of the railroads during the nineteenth century are striking. You might find it illuminating to read some of the excellent books that chronicle the age of robber barons and the lives of railroad tycoons such as Cornelius Vanderbilt, James J. Hill, Jay Gould, and Jim Fisk.

during the bubble remain unused. The industry is still nursing a massive hangover. Troubling questions remain about how telecommunications carriers can make a profit when the price of bandwidth keeps dropping.

Yet telecommunications remains a viable product, and the demand continues to grow. Fiber-optic technology is needed to meet that demand, and to help reduce costs so carriers can make a profit. Unused fibers are likely to be lit in the future as the demand for bandwidth continues to increase. That's why it's important to learn about fiber optics.

Fiber Terms: Terminology and Units

The appendixes include a glossary, tables listing important units, and other useful data. Many terms are standardized or widely accepted, but others are not. The communications industry is notorious for its many cryptic acronyms and sometimes puzzling buzzwords. I have tried to avoid unclear terms and all but the most widely accepted acronyms. I do use some designations set by international standards organizations, such as types of optical fiber specified by the International Telecommunications Union (ITU), because these labels have specific meanings and are widely used in the industry. Terms are explained the first time they appear. The terminology will continue to evolve as the field grows and changes.

I try to avoid proprietary terms. Many companies develop their own terminology, and different companies often have different names for the same technology. I do use a few trade names or trademarked terms that are widely used or are descriptive; they are capitalized as proper names to reflect their status.

Every writer has their own terminological preferences. I particularly despise meaningless market-speak, such as calling a product or system a "solution," because it tells nothing about what the thing is. I also prefer to spell out whole words rather than resort to acronyms. The latter conviction comes from reading too many specialized magazines that don't communicate clearly to readers who are not experts in the field. The acronyms I do use are well accepted.

In this introductory chapter, I have used both metric and Imperial units to help you get started. In the rest of the book I give virtually all measurements only in the metric units that are used throughout the telecommunications industry. You should get used to those units. Standard dimensions for most devices—starting with the fiber itself—are quoted in metric units. The American fiber industry uses Imperial units in only a few cases, usually for the lengths of cable runs. Appendix A lists the common metric prefixes for units.

Fiber-optic measurements are metric.

Because this book is published in the United States, it uses standard American spelling such as "meter" and "fiber" with few exceptions. The only important exception is in the "Fibre channel" set of standards for data transmission.

What Have You Learned?

1. Fiber optics has revolutionized telecommunications by supplying tremendous bandwidth, which previously was in short supply.
2. Fiber-optic technology remains healthy, but the business has suffered problems.
3. Light normally goes in straight lines, but optical fibers can guide it around corners.
4. Total internal reflection can guide light along a glass rod or water jet. An optical fiber guides light in a manner similar to a very thin glass rod.
5. Clad fibers were crucial in making fiber-optic imaging practical for examining the stomach and colon. The first practical application of fiber optics was gastroscopy.
6. An optical telegraph was invented in the 1790s in France. It was replaced by the electrical telegraph.
7. Optical fibers have very high bandwidth and can transmit signals farther than copper wires.
8. Glass fibers are inherently strong, allowing their use in outdoor cables.
9. Telecommunications means communications over a distance.
10. The telecommunications network is made of "pipes" and "switches" that distribute and transmit information.
11. Wavelength-division multiplexing transmits multiple signals through one fiber at different wavelengths.
12. The telecommunications bubble seriously disrupted the fiber-optics industry.
13. Fiber-optic measurements are made in metric units, although American companies often measure cable lengths in Imperial units (feet or miles).

What's Next?

In Chapter 2, you'll learn basic principles of physics and optics needed to understand fiber optics. Then you'll learn basic fiber-optic concepts.

Further Reading

On the evolution of fiber optics:

Jeff Hecht, *City of Light: The Story of Fiber Optics* (Oxford University Press, 1999 and 2004)

On the Internet bubble:

K. G. Coffin and A. M. Odlyzko, "Growth of the Internet," in I. P. Kaminow and T. Li, eds., *Optical Fiber Telecommunications IV B: Systems and Impairments* (Academic Press, 2002), pp. 17–56; available online at *http://www.dtc.umn.edu/~odlyzko/doc/oft.internet.growth.pdf*

On the development of communications in general:

Arthur C. Clarke, *How the World Was One: Beyond the Global Village* (Bantam, 1992)

Anton A. Huurdeman, *The Worldwide History of Telecommunications* (Wiley InterScience, 2003)

Irwin Lebow, *Information Highways & Byways: From the Telegraph to the 21st Century* (IEEE Press, 1995)

Laszlo Solymar, *Getting the Message: A History of Communications* (Oxford University Press, 1999)

Questions to Think About

1. For a bundle of optical fibers to transmit an image, the fibers must be arranged in the same pattern on both ends of the bundle. What limits the size of the smallest details that can be seen?
2. Devise an analogy using common implements found in a kitchen or cafeteria to show how a bundle of fibers transmits an image.
3. Most of the light lost in going through a glass window is reflected at the surface. Ignoring this surface reflection loss, suppose that a one-millimeter-thick window absorbs 1% of the light entering it and transmits 99%. Neglecting reflection, how much light would emerge from a one-meter-thick window?
4. If optical fibers transmit signals so much better than wires, why aren't they used everywhere?
5. During the bubble years, many people in the industry thought Internet traffic was doubling every three months. In reality, it was doubling about every year. How much difference in growth of Internet traffic would this make over a period of five years?
6. Why didn't anybody wonder how long Internet traffic could continue doubling every three months?

Chapter Quiz

1. Light can be guided around corners best in
   a. reflective pipes.
   b. hollow pipes with gas lenses.
   c. clad optical fibers.
   d. bare glass fibers.

2. The first practical use of optical fibers was
   a. in communications via optical telegraph.
   b. in Alexander Graham Bell's photophone.
   c. to illuminate flowing jets of water.
   d. in bundles to examine the inside of the stomach.

3. What is the principal requirement for a cladding on an optical fiber?
   a. It must have a refractive index lower than the core to produce total internal reflection.
   b. It must be opaque so light doesn't leak out.
   c. It must be made of plastic to keep the fiber flexible.
   d. It must have a refractive index lower than that of air.

4. Flexible bundles of optical fibers can be used to
   a. examine the inside of the stomach without surgery.
   b. examine the inside of the colon without surgery.
   c. illuminate hard-to-reach machinery.
   d. all of the above
   e. none of the above

5. A new automated control system costs $1 million. How much will it have to reduce annual operating expenses if company policy says the payback time has to be no more than four years? (Neglect interest rates.)
   a. $100,000
   b. $250,000
   c. $400,000
   d. $500,000
   e. $1 million

6. The elements of a fiber-optic data link must include
   a. light source, receiver, and fiber.
   b. light source and cable.
   c. fiber and receiver.

d. fiber only.
e. cable only.

7. You need to install a new cable to handle four years of growth on a transmission route. The traffic now fills one fiber, and traffic is doubling every three months. How many fibers will you need in four years?

a. 4
b. 16
c. 128
d. 65,536
e. over 1 million

8. As in Problem 7, you need to install a new cable to handle four years of growth on a transmission route where traffic is doubling every three months. All the traffic now fits in a signal that requires one wavelength in a fiber that can handle 32 wavelengths with wavelength-division multiplexing. How many fibers will you need to carry that traffic if you fill each one with 32 wavelengths?

a. 4
b. 16
c. 128
d. 2048
e. 65,536

9. Reality has set in, and you realize that traffic is doubling every year. How many fibers would you need if each fiber carried only one signal and the first fiber was already full?

a. 1
b. 4
c. 16
d. 128
e. 2048

10. How many fibers would you need to handle the transmission load in Problem 9 if each fiber could transmit signals at 32 wavelengths?

a. 1
b. 2
c. 4
d. 16
e. can't tell from data given