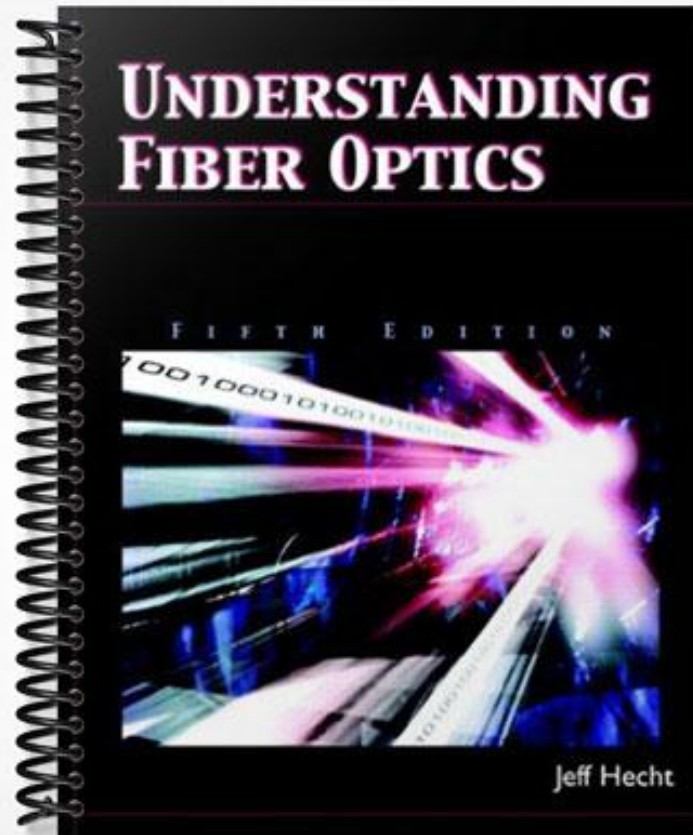# UNDERSTANDING FIBER OPTICS

FIFTH EDITION

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Chapter 2
Fundamentals of Fiber-Optic Components
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This chapter explains the basic principles of optics, optical fibers, and fiber-optic components that are essential to understanding later chapters. This is the starting point for your "meaty" lectures. You should open with the basics of refraction, and show how those principles lead to total internal reflection. Then you should cover light guiding in fibers (using the total internal reflection model), and other properties of fibers and optical components.

Overview

The starting point is basic optics, because students must understand light and its properties before they consider fiber optics. Much of this information may not be new to students who have had a good introductory physics course, but you can't count on that. This review focuses upon the parts of optics relevant for fiber optics.

I start with the ideas of the electromagnetic spectrum, wavelength, frequency, and photons. Then I introduce refraction and refractive index, which leads to total internal reflection, and how it can explain light guiding in a multimode step-index optical fiber. That explanation of light guiding takes the traditional optical perspective of tracing the paths of light rays, rather than the more accurate treatment of an optical fiber as a waveguide, because the ray model is more intuitive for students. The waveguide model is introduced in Chapter 4, which also introduces the graded-index and single-mode fibers.

This chapter also introduces fiber properties, including attenuation coupling losses, pulse dispersion and transmission bandwidth. These are fundamental concepts that appear throughout the book, and are described in more detail in later chapters. They are introduced here to give students a working background for later chapters. You can refer students who want more details to the index.   A brief final section introduces optical transmitters, receivers, amplifiers, and repeaters.

Students should finish this chapter with a general knowledge of fiber optic components, adequate to explain the subject to the proverbial man on the street, and to comprehend more detailed descriptions.

Questions to Think About for Chapter 2

1. Interference seems to be a strange effect. The total light intensity from two bulbs is the sum of the two intensities. Yet the light intensity is really the square of the amplitudes, and if the two waves are in phase, you double the amplitude, which when squared means the intensity should be four times the intensity of one bulb. Don't these

views contradict each other?

Answer: Not really because interference varies from place to place. If the bulbs emitted identical light waves, they would interfere constructively in some spots but destructively in others. Averaged over space, they're halfway between completely in phase (where intensity would be four times that of one bulb) and completely out of phase (where intensity would be zero), so intensity would average to that of two bulbs. If you scanned over the whole volume with a detector small enough to see the variations on the scale of a wavelength, you would see intensity varying continually between total darkness and peak light.

2. One photon is a wave packet that doesn't last very long. A continuous light source emits a steady or continuous wave. How is the continuous light source emitting photons?

Answer: In a steady stream. If the light source emits a steady amount of energy per second, it emits a constant number of photons each second.

3. The sun emits an energy of about 3.8×10^{33} ergs per second. A photon with wavelength of 1.3 micrometers has an energy of about 1.6×10^{-12} erg. If you assume the sun emits all its energy at 1.3 µm, How much attenuation in decibels do you need to reduce the sun's entire output to a single 1.3-µm photon per second?

Answer: The ratio is 2.375×10^{45}, which corresponds to 454 dB.

4. If an entire galaxy contains a billion stars, each one as luminous as the sun, how much attenuation does it take to reduce its entire output to a single 1.3-µm photon per second.

Answer: The ratio is 2.375×10^{54} or 544 dB.

5. Suppose window glass has attenuation of 10 dB/meter at 1.3 micrometers (not an actual value). How thick a block of glass would you need to reduce the sun's entire output to a single photon as in problem 3?

Answer: Divide 454 dB by 10 dB/m to get 45.4 meters.

6. Medical imaging fiber has attenuation of 1 dB/meter at optical wavelengths. If the attenuation is the same at 1.3 µm, and you don't have to worry about the sun's energy melting the fiber, how long a fiber would reduce the sun's output in problem 3?

Answer: Divide 454 dB by 1 dB/m, giving 454 meters.

7. Atoms and molecules in the atmosphere scatter light in the same way that atoms in glass scatter light in an optical fiber. The shorter the wavelength in the visible spectrum, the stronger the scattering. Where do you think the sky gets its blue color from and why?

Answer: Blue and violet light have the shortest wavelengths in the visible spectrum, but the eye isn't very sensitive to violet. The blue light is scattered much more than longer wavelengths. The blue light you see is scattered sunlight.

8. Diamond has a refractive index of 2.4. What is its critical angle in air and what does that have to do with its sparkle.

Answer: The critical angle is 28°, so it reflects light by total internal reflection over a wider range of angles than glass. Diamonds are cut so the facets at the back of the stone will reflect light back to your eye.

Worked Quiz Problems

Problem 7:
The problem implicitly assumes the zircon is in air. The critical angle is

$$\theta_{crit} = \arcsin\left(\frac{n_{air}}{n_{zircon}}\right) = \arcsin\left(\frac{1}{2.1}\right) = 31.6°$$

Problem 9:
First calculate total loss in decibels:

$$Loss = 0.3db/km \times 100km = 30dB$$

Then convert that loss back to a percentage:

$$Ratio = 10^{\left(\frac{lossin\,dB}{-10}\right)} = 10^{\left(\frac{30}{-10}\right)} = 10^{-3} = 0.1\%$$

Answers to Quiz for Chapter 2

1. e
2. e
3. c
4. b
5. c
6. d
7. c
8. c
9. a
10. d
11. a
12. b

Supplemental Material and Suggestions

Illustrations showing light refraction and the operation of lenses, if available.

Shine a laser pointer through a cloud of chalk dust to show how light travels in straight lines. (Cigar smoke also works well.)

Chart of the optical spectrum to illustrate wavelengths and colors. Point out that most fiber-optic transmission is at 850, 1300 and 1550 nm.

Plot of fiber loss to show fiber transmission windows; see Figure. 5.2.

David Falk, Dieter Brill, and David Stork's *Seeing the Light: Optics in Nature, Photography, Color, Vision, and Holography* (Wiley, 1986) is a wonderful nonmathematical treatment of optics.

J. Warren Blaker and Peter Schaeffer, *Optics: An Introduction for Technicians and Technologists* **(Prentice Hall, 2000) is a short primer on optics for technicians, with some math, which goes into more detail on optical components other than fibers.**