## SUMMARY AND LOOK FORWARD

In this chapter, we studied several main ideas about signals and information. We can represent a time-varying signal as either an *analog* (continuous) variation of voltage, or as a *digital* (discrete) variation of voltage. In the analog representation, the voltage directly follows the signal voltage. In the digital representation, the signal is *sampled*, or measured, at selected times and a number represents the value of each sample. In modern communication systems, the sampled values are represented using *binary* numbers. When data are transmitted across a communication channel, the sender and receiver must agree on a certain *protocol*—a set of rules by which the numbers will be formatted, sent, and interpreted.

We discussed analog and digital radio, both of which use the technique of frequency multiplexing to send separate streams of information using different channels. Broadcasting stations operate on different carrier frequencies. Each radio station is allowed a fixed band (or range) of frequencies. The width of the range of frequencies allocated is called the bandwidth of the allocated channel. The larger (wider) the bandwidth is, the larger the data rate can be. Signal bandwidth is the width of the spectral window occupied by the spectral recipe that is needed to represent a certain signal. A signal can be sent through a channel only if that channel has a bandwidth at least as large as the signal bandwidth.

Analog radio and digital radio both have certain advantages and disadvantages.

- **Advantages of analog radio broadcasting:**
  - Analog technology is simple.
  - It is usually not subject to interruptions.

- **Disadvantages of analog radio broadcasting:**
  - AM and FM radio systems can typically broadcast only over a small geographical region.
  - Radio broadcasts cannot easily include other content in addition to audio.
  - Radio spectrum (bandwidth) is a fixed and precious commodity, which limits the amount of information that can be carried.

- **Advantages of digital radio broadcasting:**
  - Can broadcast from anywhere in the world.
  - Can reach many areas that have poor analog radio reception.
  - Can include other content in addition to audio in the broadcast.
  - Can obtain better sound quality using a "fast" enough computer system.

- **Disadvantages of digital radio broadcasting:**
  - Subject to interruptions of Internet connections.
  - Sound quality may not be as good as with analog radio, because it depends on data rate ("speed") of Internet connection.
  - Data rate is not consistent across the Internet.

There is a physical limit to the total bandwidth that can be achieved in any channel medium. The limit is set by the highest carrier frequency in the band. For example, if we adopt a technology that uses carriers with frequencies up to 108 MHz (the top of the range for FM), then we could not have a bandwidth greater than 108 MHz. Indeed, this would include all frequencies from zero up to 108 MHz, and there are not any more megahertz to be had in this range. The only way to increase the data rate

is to use higher and higher carrier frequencies. This is the motivation behind using visible light as a carrier for communication systems. Recall that the frequencies of visible light are approximately $10^{14}$ Hz; that is, 100 million MHz. This is the reason that optical fibers can carry such large amounts of data per second, as we will discuss in later chapters.

## SUGGESTED READING

A popular account of radio and the Internet:
Naughton, John. *A Brief History of the Future.* Woodstock, NY: Overlook Press, 2000.

An excellent text on telecommunications, with discussions of bandwidth and signals, at the same level as the present text:
Rogers, Alan. *Understanding Optical Fiber Communications.* Boston: Artech House, 2001.

Goldsmith, Andrea. *Wireless Communications.* New York: Cambridge University Press, 2005.

History of radio, television, and the Internet, by the Federal Communications Commission (FCC) at http://www.fcc.gov/omd/history.

## KEY TERMS

*Amplitude modulation* (*AM*)
*Analog*
*Audio range*
*Baud*
*Bandwidth*
*Beats*
*Carrier wave*
*Channel*
*Channel bandwidth*
*Cross-talk*
*Data period*
*Data rate*
*Digital*
*Electromagnet*
*Electromagnetic wave*
*Frequency modulation* (*FM*)
*Frequency multiplexing*
*Frequency spectrum*
*Multiplexing*
*Protocol*
*Sampling*
*Sampling theorem*
*Signal bandwidth*
*Spectral recipe*

## ANSWERS TO QUICK QUESTIONS

Q8.1 The voltage sequence representing the four decimal numbers 2, 4, 0, 9 is 2 = (0010), 4 = (0100), 0 = (0000), 9 = (1001), or graphically: