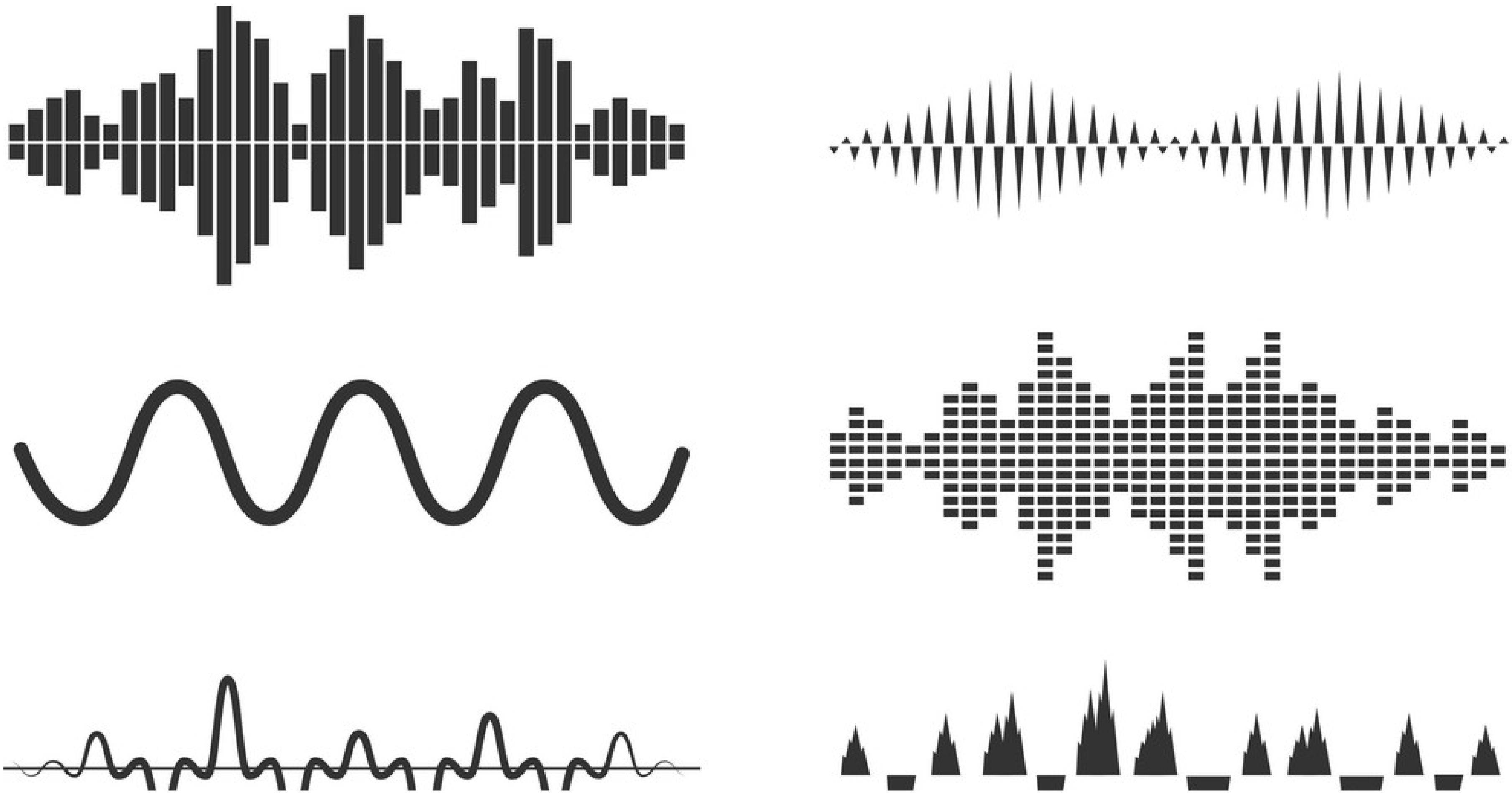


Chapter 6

Information Sources and Signals

Topics Covered

- 6.1 Introduction
- 6.2 Information Sources
- 6.3 Analog and Digital Signals
- 6.4 Periodic and Aperiodic Signals
- 6.5 Sine Waves and Signal Characteristics
- 6.6 Composite Signals
- 6.7 The Importance of Composite Signals and Sine Functions
- 6.9 Bandwidth of an Analog Signal
- 6.10 Digital Signals and Signal Levels
- 6.12 Converting a Digital Signal to Analog
- 6.14 Synchronization and Agreement About Signals
- 6.15 Line Coding
- 6.20 Encoding and Data Compression

6.1 Introduction

This chapter

- Begins exploration of data communications in more detail
- Examines the topics of information sources
- Studies the characteristics of the signals that carry information

Successive chapters

- continue the exploration of data communications by explaining additional aspects

6.2 Information Sources

- Communication system accepts input from one or more sources and delivers to a specified destination
- The source and destination of information can be a pair of application programs
  - that generate and consume data

- **Data communications theory concentrates on low-level communications systems**
  - it applies to arbitrary sources of information
  - conventional computer peripherals such as keyboards and mice
  - information sources can include microphones, sensors, and measuring devices, such as thermometers and scales
  - destinations can include **audio output devices** such as earphones and loud speakers as well as devices such as LEDs that emit light

6.3 Analog and Digital Signals

- Data communications deals with two types of information:
  - analog
  - digital
- An analog signal is characterized by a continuous mathematical function
  - when the input changes from one value to the next, it does so by moving through all possible intermediate values
- A digital signal has a fixed set of valid levels
  - each change consists of an instantaneous move from one valid level to another
- Figure 6.1 illustrates the concept

6.3 Analog and Digital Signals

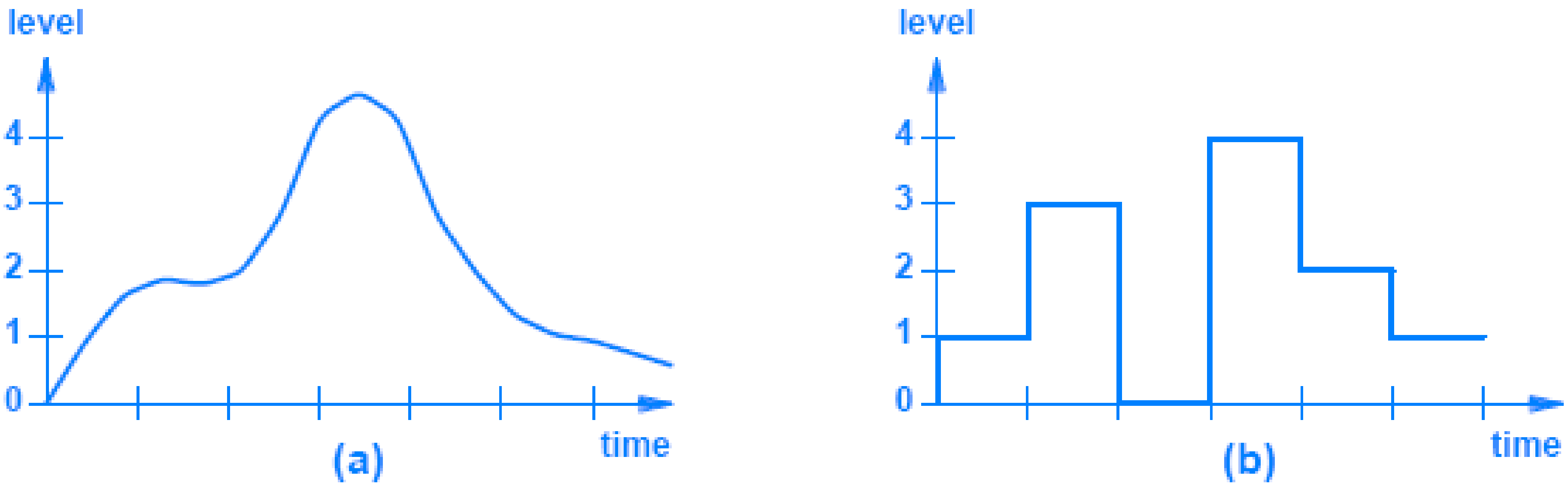


Figure 6.1 Illustration of (a) an analog signal, and (b) a digital signal.

6.4 Periodic and Aperiodic Signals

- Signals are broadly classified as
  - periodic
  - aperiodic (sometimes called nonperiodic)

- Figure 6.1a is aperiodic over the time interval shown because the signal does not repeat

- Figure 6.2 illustrates a signal that is periodic (i.e., repeating) - periodic signal repeats

6.5 Sine Waves and Signal Characteristics

- Much of the analysis in data communications involves the use of sinusoidal trigonometric functions
  - especially sine, which is usually abbreviated sin
- Sine waves are especially important in information sources
  - because natural phenomena produce sine waves
- When a microphone picks up an audible tone, the output is a sine
  - electromagnetic radiation can be represented as a sine wave
- We are interested in sine waves that correspond to a signal that oscillates in time

- Figure 6.2 shows a sine wave

6.5 Sine Waves and Signal Characteristics

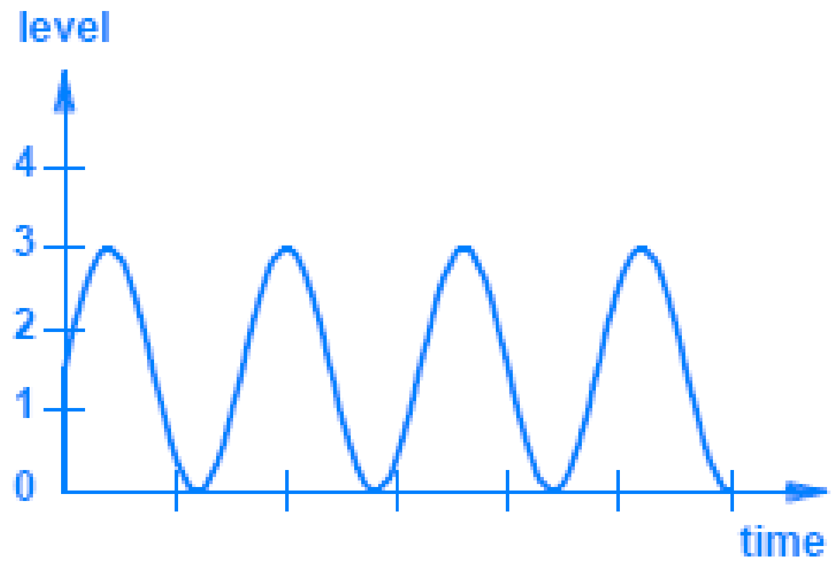
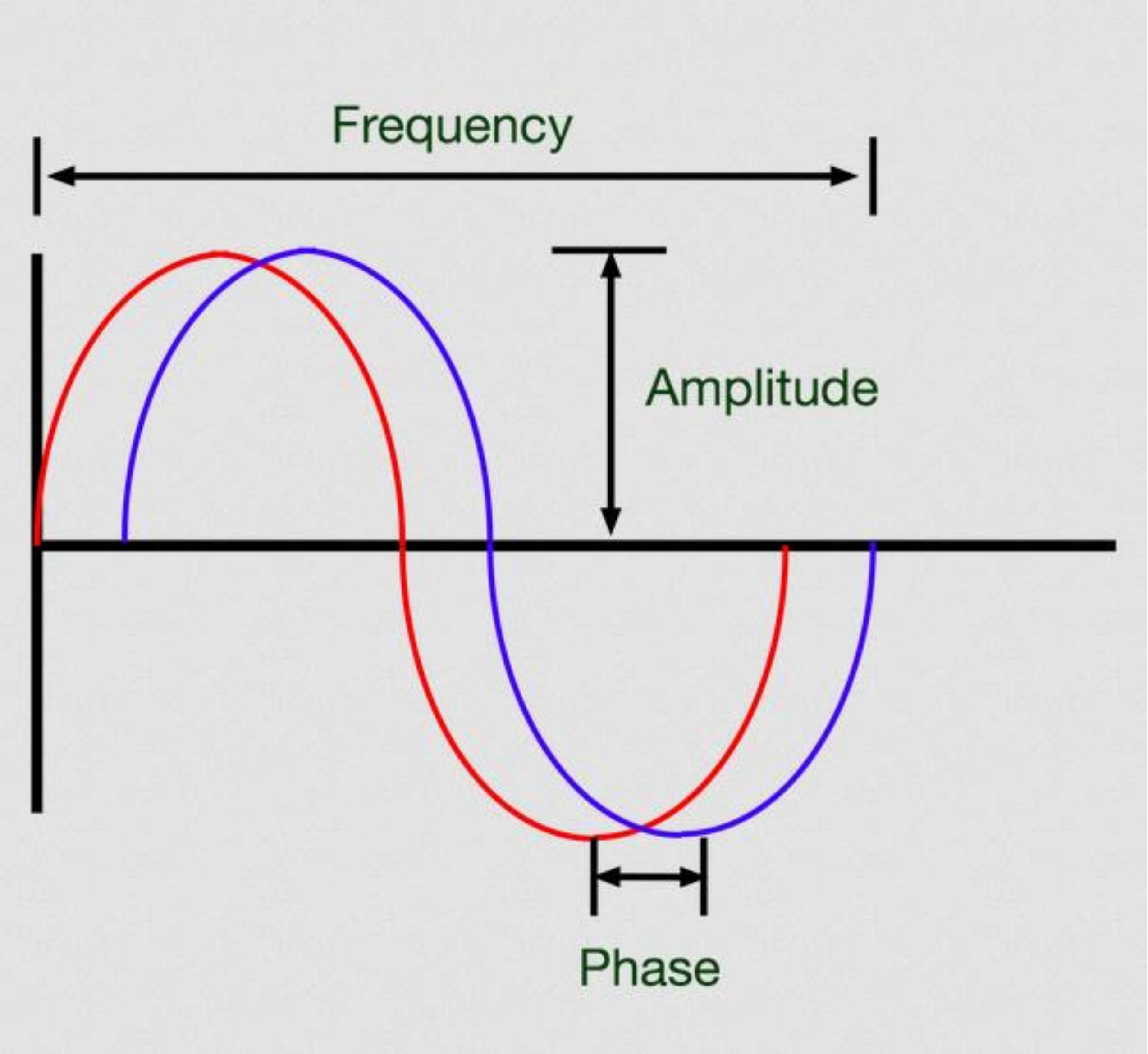


Figure 6.2 A periodic signal repeats.

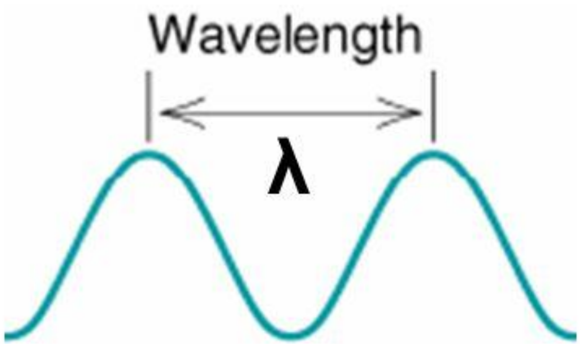
6.5 Sine Waves and Signal Characteristics

There are number of signal characteristics:

- Frequency:
  - the number of oscillations per unit time (usually seconds)
- Amplitude:
  - the difference between the maximum and minimum signal heights
- Phase:
  - how far the start of the sine wave is shifted from a reference time
- Wavelength:
  - The length of a cycle as a signal propagates across a medium
  - It is determined by the signal propagation speed
- These characteristics can be expressed mathematically
  - Figure 6.3 illustrates the frequency, amplitude, and phase characteristics


Frequency
Amplitude
Phase

Radio Signal Wavelength



$$\lambda = \frac{c}{f}$$

- EM waves travel at the **speed of light: c**
- c = 300,000,000 m/sec
- The relationship between wavelength and frequency for an EM wave is given as:

$$\lambda = \frac{c}{f}$$

- **λ** in meters, **f** in hertz and **c** = 300,000,000 m/sec

6.5 Sine Waves and Signal Characteristics

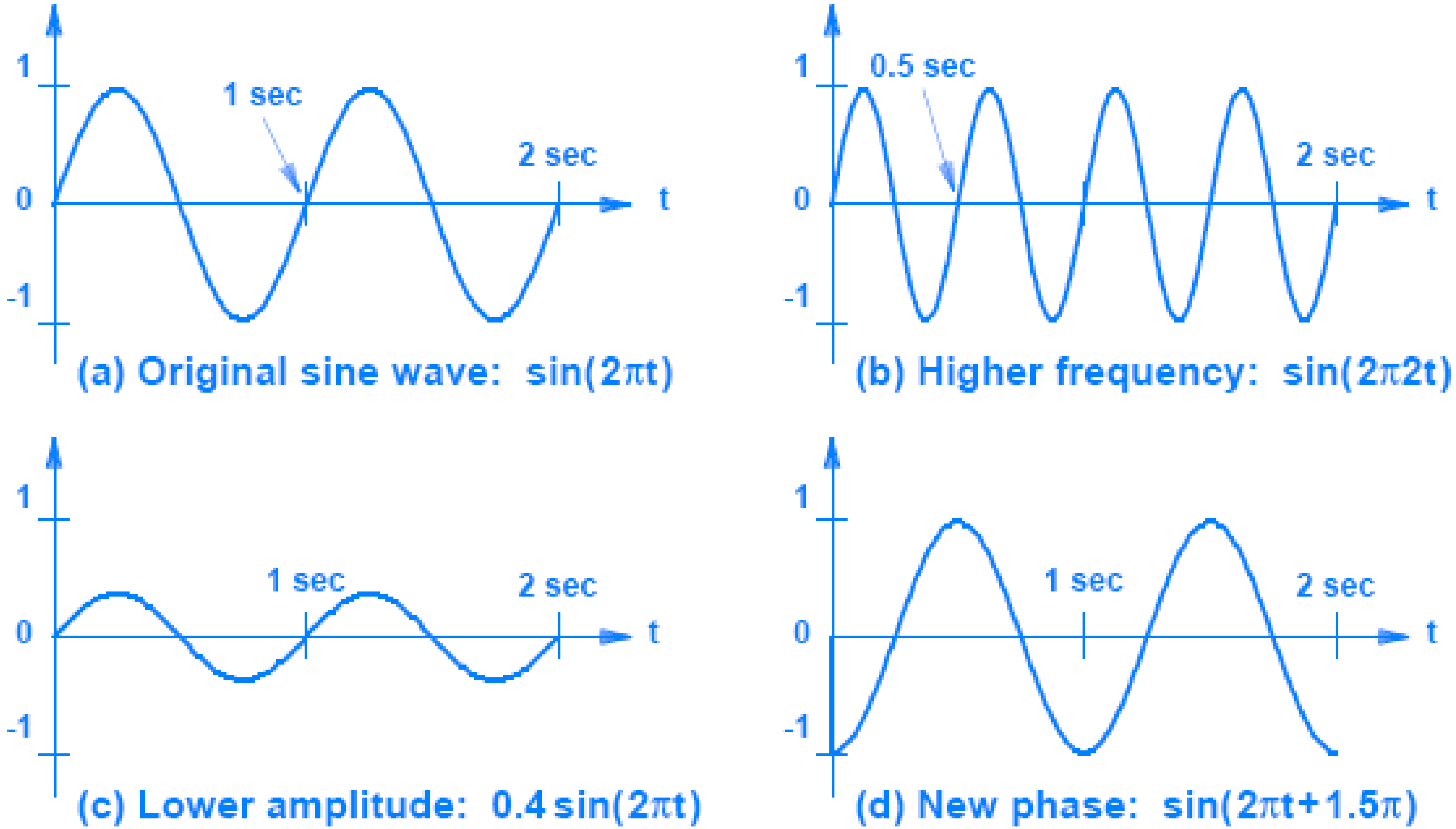
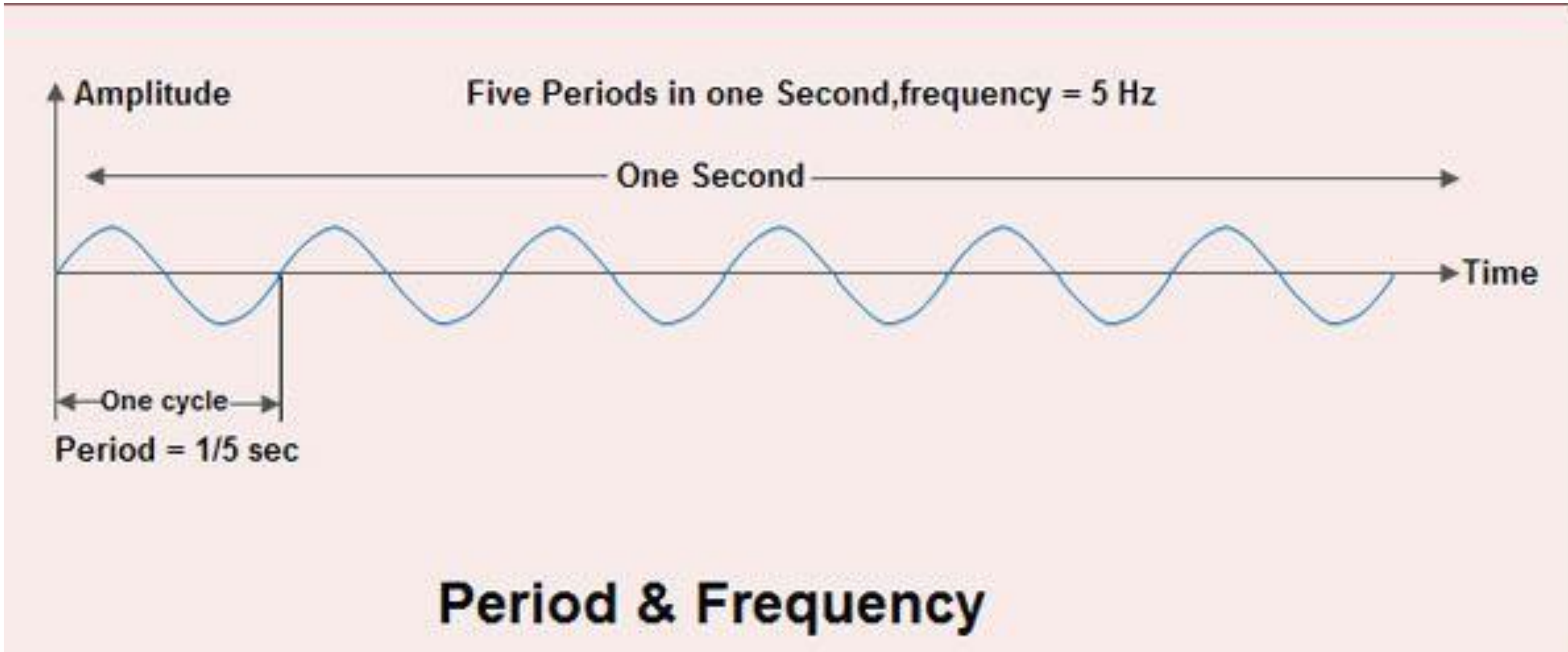


Figure 6.3 Illustration of frequency, amplitude, and phase characteristics.

6.5 Sine Waves and Signal Characteristics

- The frequency can be calculated as the inverse period.
- The period is known as time required complete one cycle
- The example sine wave in Figure 6.3a has
  - Period $T = 1$ seconds
  - Frequency is $1 / T$ or 1 Hertz
- The example in Figure 6.3b has
  - a period of $T = 0.5$ seconds
  - its frequency is 2 Hertz
- Both examples are considered extremely low frequencies
- Typical communication systems use high frequencies
  - often measured in millions (Mega) of cycles per second

- Figure 6.4 lists time scales and common prefixes used with frequency


Amplitude
Five Periods in one Second,frequency = 5 Hz
One Second
Time
One cycle
Period = 1/5 sec
Period & Frequency

6.5 Sine Waves and Signal Characteristics

Time Unit	Value	Frequency Unit	Value
Seconds (s)	10^{0} seconds	Hertz (Hz)	10^{0} Hz
Milliseconds (ms)	10^{3} seconds	Kilohertz (KHz)	10^{3} Hz
Microseconds (μs)	10^{6} seconds	Megahertz (MHz)	10^{6} Hz
Nanoseconds (ns)	10^{9} seconds	Gigahertz (GHz)	10^{9} Hz
Picoseconds (ps)	10^{12} seconds	Terahertz (THz)	10^{12} Hz

Figure 6.4 Prefixes and abbreviations for units of time and frequency.

6.6 Composite Signals

Signals like in Figure 6.3 are classified as simple

- because they consist of a single sine wave
- A single sine wave cannot be decomposed further

Most signals are classified as composite

- they can be decomposed into a set of simple sine waves

Figure 6.5 illustrates a composite signal

- formed by adding two simple sine waves

6.6 Composite Signals

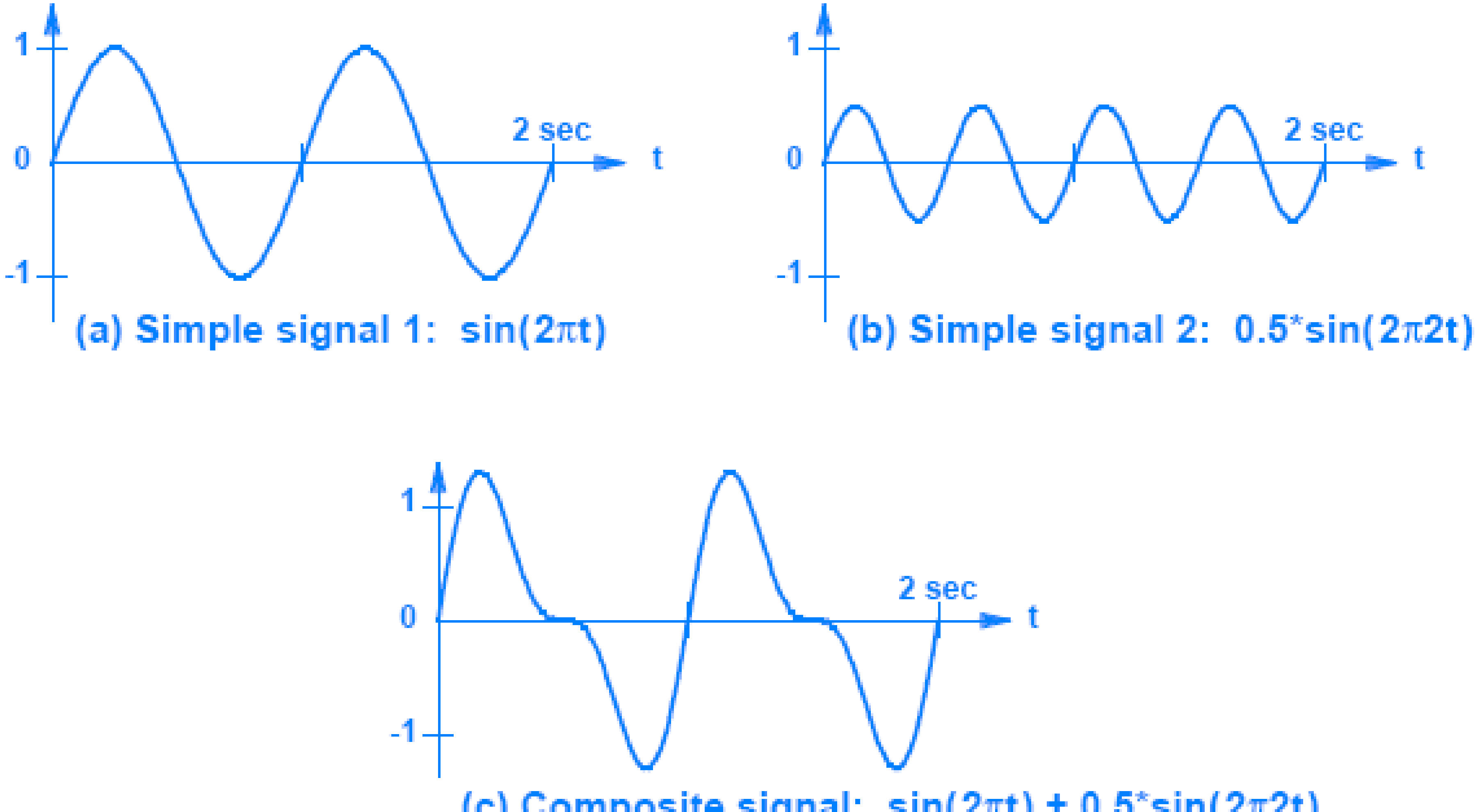


Figure 6.5 Illustration of a composite signal formed from two simple signals.

6.7 The Importance of Composite Signals and Sine Functions

- Fourier discovered that it is possible to decompose a composite signal into its constituent parts
  - a set of sine functions, each with a frequency, amplitude, and phase
- The analysis by Fourier shows that if the composite signal is periodic, the constituent parts will also be periodic
  - most systems use composite signals to carry information
  - a composite signal is created at the sending end
  - and the receiver decomposes the signal into the simple components

6.9 Bandwidth of an Analog Signal

- What is network bandwidth?
- In networking and communication, the definition of bandwidth varies; here we describe analog bandwidth
  - We define the bandwidth of an analog signal to be the difference between the highest and the lowest frequencies of the constituent parts (obtained by Fourier analysis)
- Figure 6.7 shows a frequency domain plot with frequencies measured in Kilohertz (KHz)
  - Such frequencies are in the range audible to a human ear
  - In the figure, the bandwidth is the difference between the highest and lowest frequency (5 KHz - 1 KHz = 4 KHz)

6.9 Bandwidth of an Analog Signal

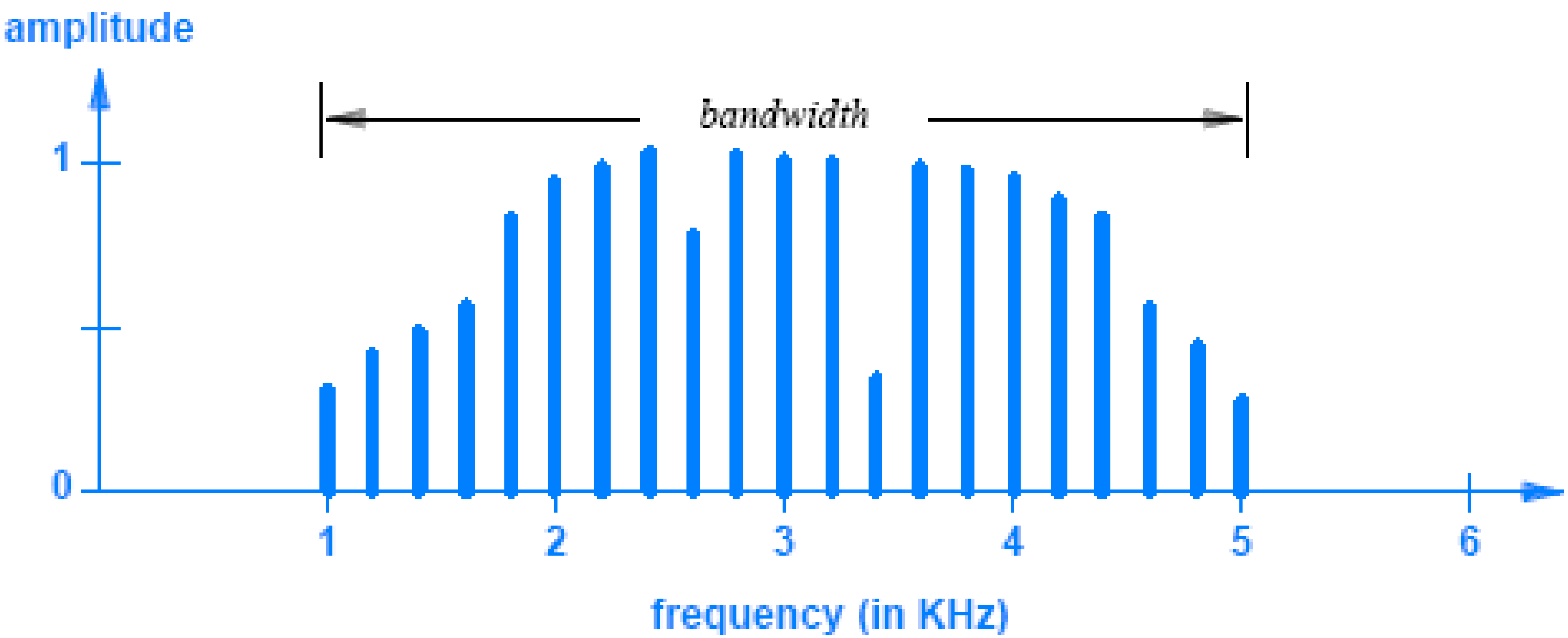


Figure 6.7 A frequency domain plot of an analog signal with a bandwidth of 4 KHz.

6.10 Digital Signals and Signal Levels

- Some systems use voltage to represent digital values
  - by making a positive voltage correspond to a logical one
  - and zero voltage correspond to a logical zero
- For example, ***+5*** volts can be used for a logical ***one*** and ***0*** volts for a logical ***zero***
- If only two levels of voltage are used
  - each level corresponds to one data bit (0 or 1).
- Some physical transmission mechanisms can support more than two signal levels
- When multiple digital levels are available
  - each level can represent multiple bits
- For example, consider a system that uses four levels of voltage:

  -5 volts, -2 volts, +2 volts, and +5 volts

  - Each level can correspond to two bits of data as Figure 6.8 illustrates

6.10 Digital Signals and Signal Levels

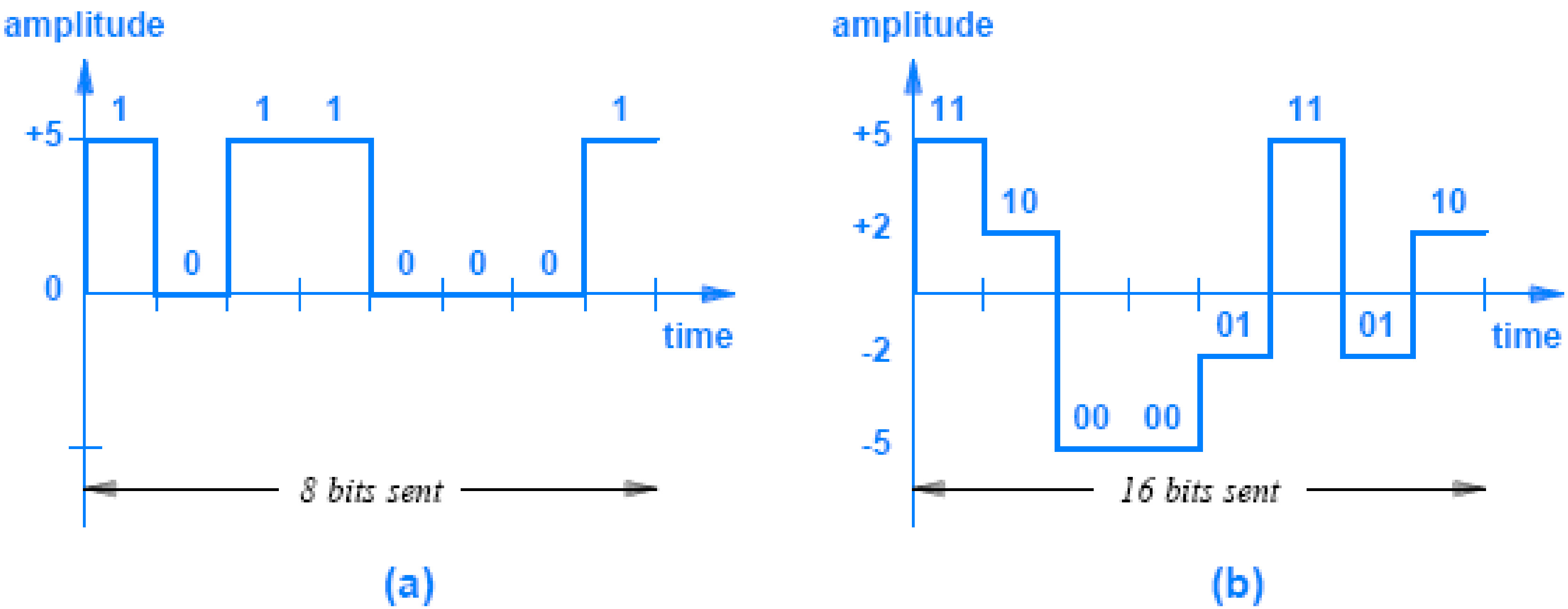


Figure 6.8 (a) A digital signal using two levels, and (b) a digital signal using four levels.

6.12 Converting a Digital Signal to Analog

- How can a digital signal be converted into an equivalent analog signal?
- According to Fourier, an arbitrary curve can be represented as a composite of sine waves
- Fourier's theorem also be applied to digital signals
- Conversion of a signal from digital to analog is approximate
  - approximation involves building a composite signal from only a few sine waves

- Figure 6.9 illustrates the approximation

6.12 Converting a Digital Signal to Analog

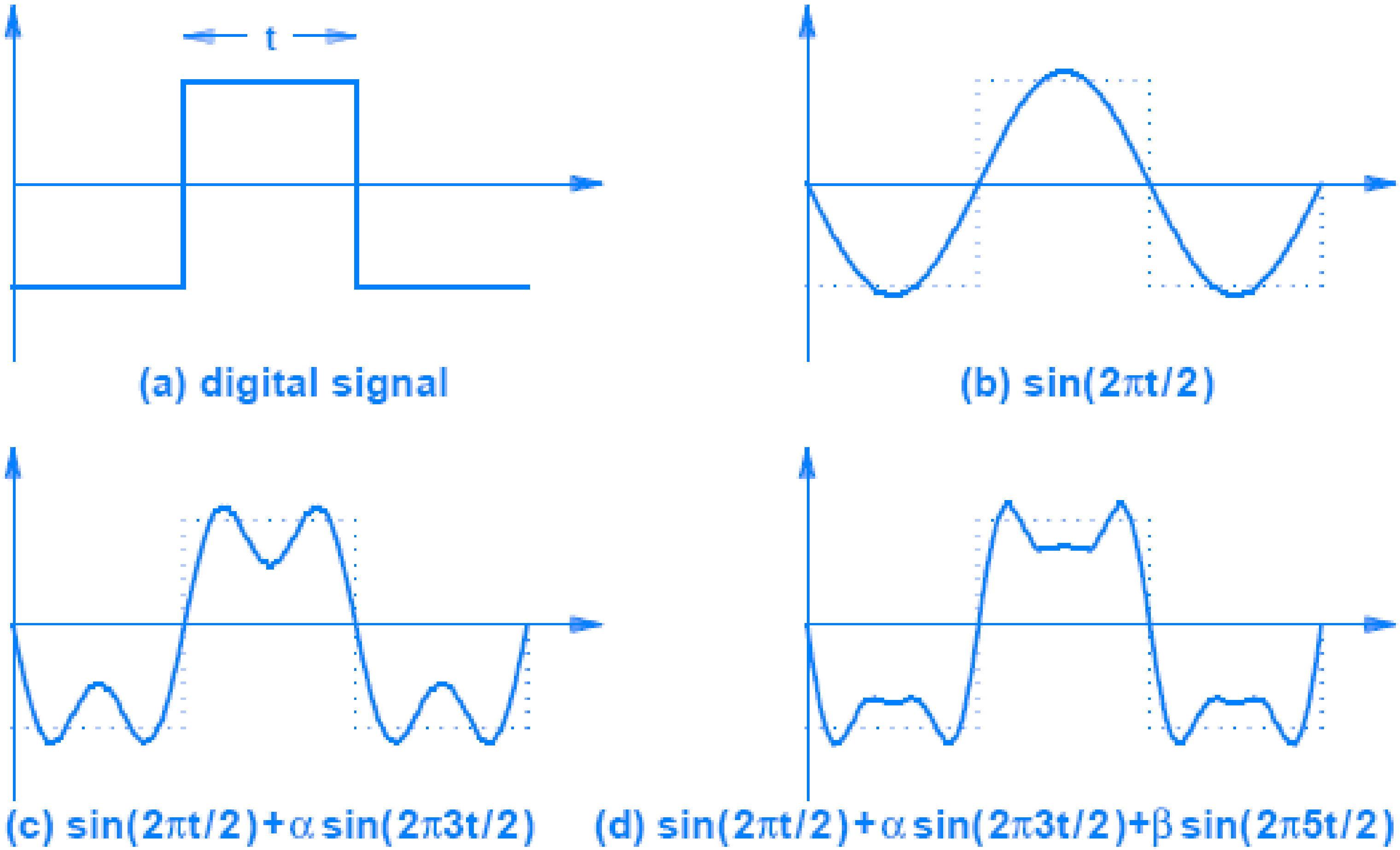


Figure 6.9 Approximation of a digital signal with sine waves.

6.14 Synchronization and Agreement About Signals

- The electronics at both ends of a physical medium must have circuitry to measure time precisely
- Building electronic systems that operate at the high speeds is extremely difficult
- A fundamental problem that arises from the way data is represented is synchronization issues between sender/receiver
- Suppose a receiver misses the first bit that arrives, and starts interpreting data starting at the second bit

- Figure 6.10 illustrates how a mismatch in interpretation can produce errors

6.14 Synchronization and Agreement About Signals

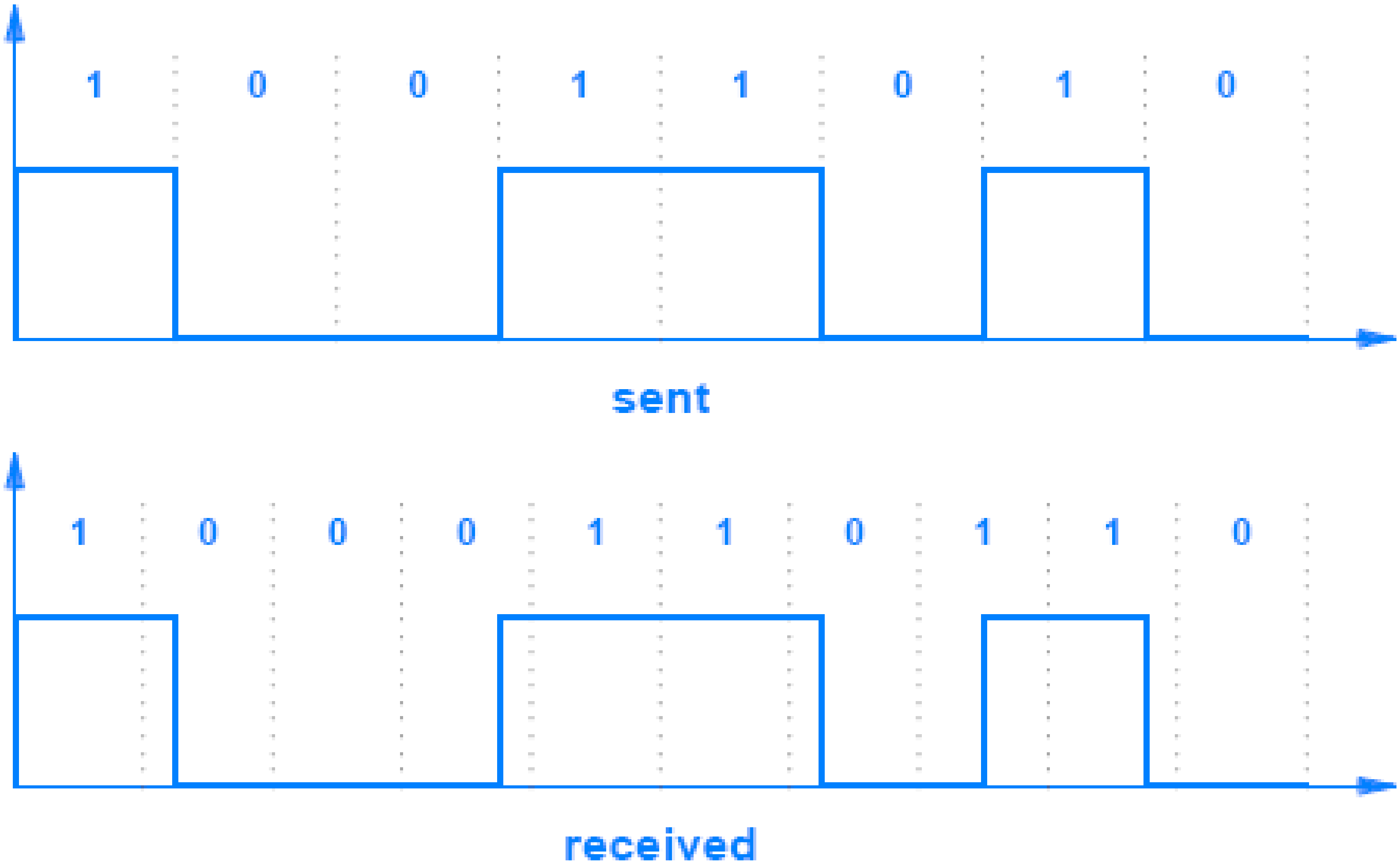


Figure 6.10 Illustration of a synchronization error in which the receiver allows slightly less time per bit than the sender.

6.15 Line Coding

- Several techniques have been invented that can help avoid synchronization errors
- In general, there are two broad approaches:
  1. Before transmitting, the sender transmits a known pattern of bits, typically a set of alternating 0s and 1s, for receiver to synchronize
  2. Data is represented by the signal in such a way that there can be no confusion about the meaning
- Line coding describes the way data is encoded

6.20 Encoding and Data Compression

Data compression

- reducing the number of bits required to represent data

Data compression is important in networking

- because reducing the number of bits used to represent data reduces the time required for transmission
- a communication system can be optimized by compressing data
- Esp in multimedia applications: See chapter 29

There are two types of compression:

- Lossy
  - some information may be lost during compression
- Lossless
  - all information must be preserved in the compressed version

6.20 Encoding and Data Compression

- **Lossy compression**
  - generally used with data that a human consumes
    - such as an image, video/audio
  - only needs to preserve details to the level of human perception
    - such as, JPEG (used for images) compression or MPEG-3 (abbreviated MP3 and used for audio recordings) employ lossy compression
- **Lossless compression**
  - preserves the original data without any change
  - can be used for documents or in any situation where data must be preserved exactly