Chapter 3

Data and Signals

3-1 ANALOG AND DIGITAL

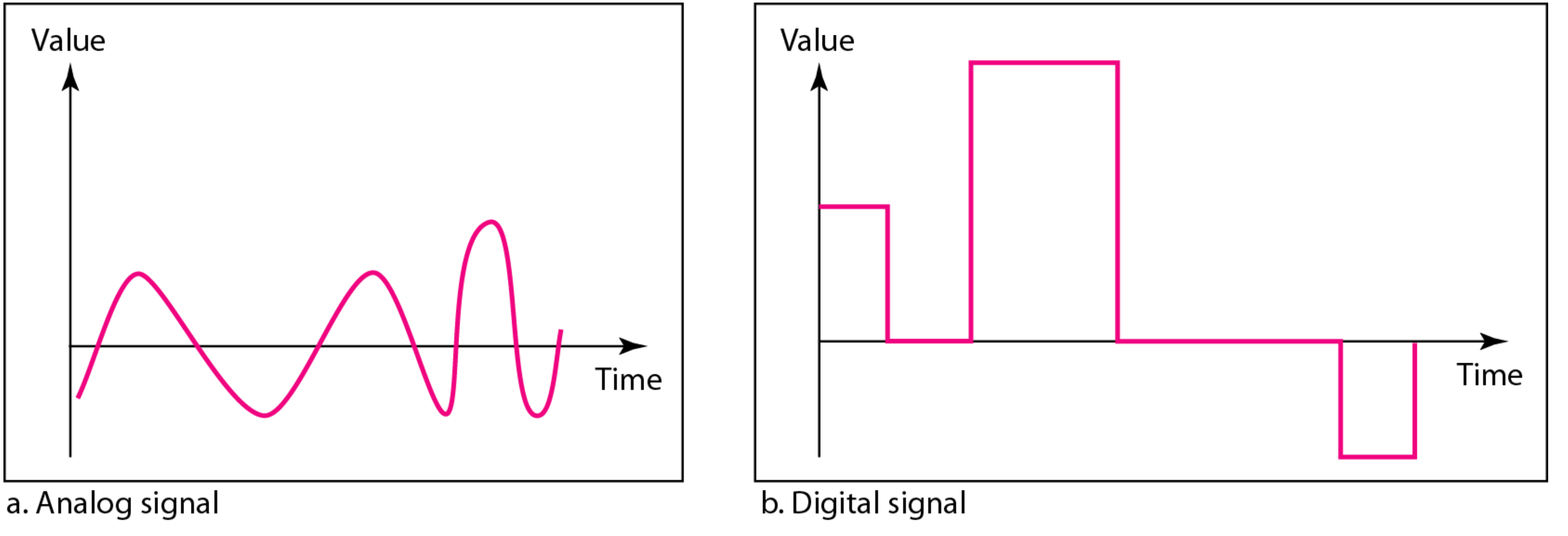
Data can be analog or digital. The term analog data refers to information that is continuous; digital data refers to information that has discrete states. Analog data take on continuous values. Digital data take on discrete values.

Analog and Digital Data
Analog and Digital Signals
Periodic and Nonperiodic Signals

Data can be analog or digital.
Analog data are continuous and take continuous values.
Digital data have discrete states and take discrete values.

Signals can be analog or digital. Analog signals can have an infinite number of values in a range; digital signals can have only a limited number of values.

Figure 3.1 *Comparison of analog and digital signals*



- A periodic signal completes a pattern within a measurable time frame. The completion of one full pattern is called a cycle.

- A nonperiodic signal changes without exhibiting a pattern that repeats over time.

In data communications, we commonly use periodic analog signals and nonperiodic digital signals.

3-2 PERIODIC ANALOG SIGNALS

Periodic analog signals can be classified as simple or composite. A simple periodic analog signal, a sine wave, cannot be decomposed into simpler signals. A composite periodic analog signal is composed of multiple sine waves.

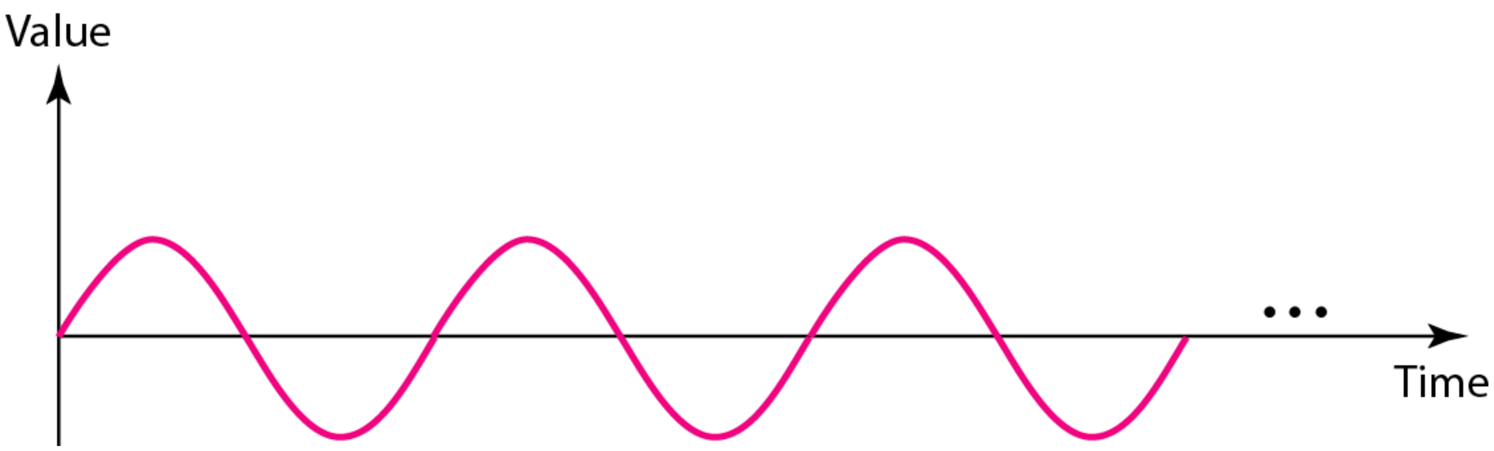
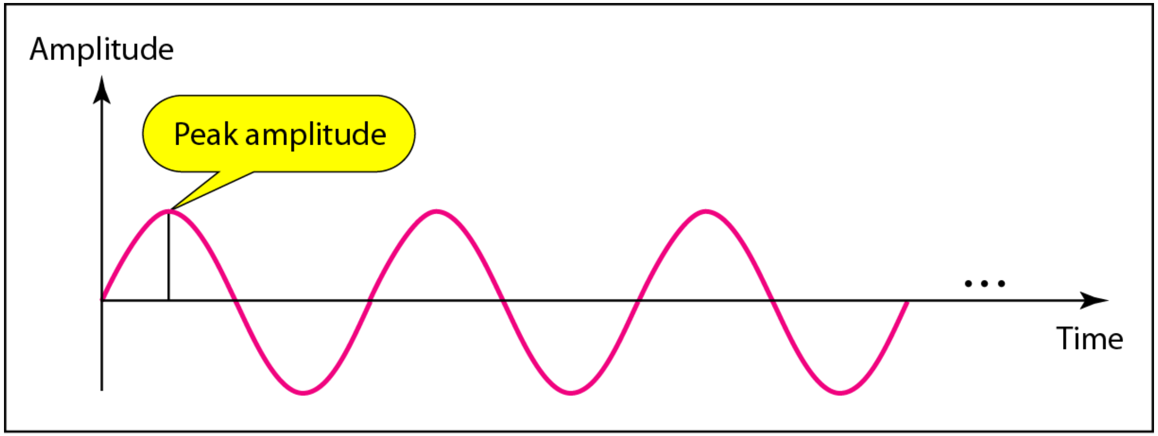
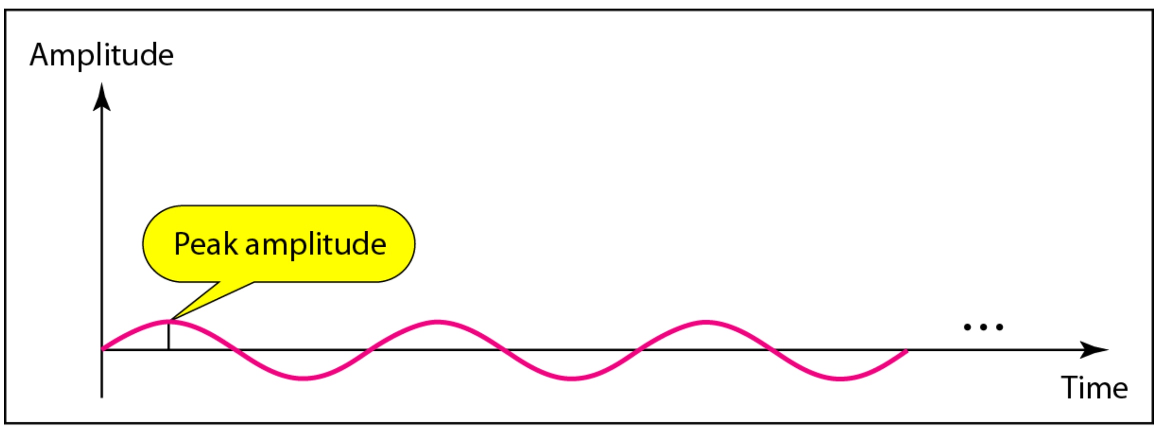


Figure 3.3 *Two signals with the same frequency, but different amplitudes*



a. A signal with high peak amplitude



b. A signal with low peak amplitude

Peak amplitude is the absolute value of its highest intensity

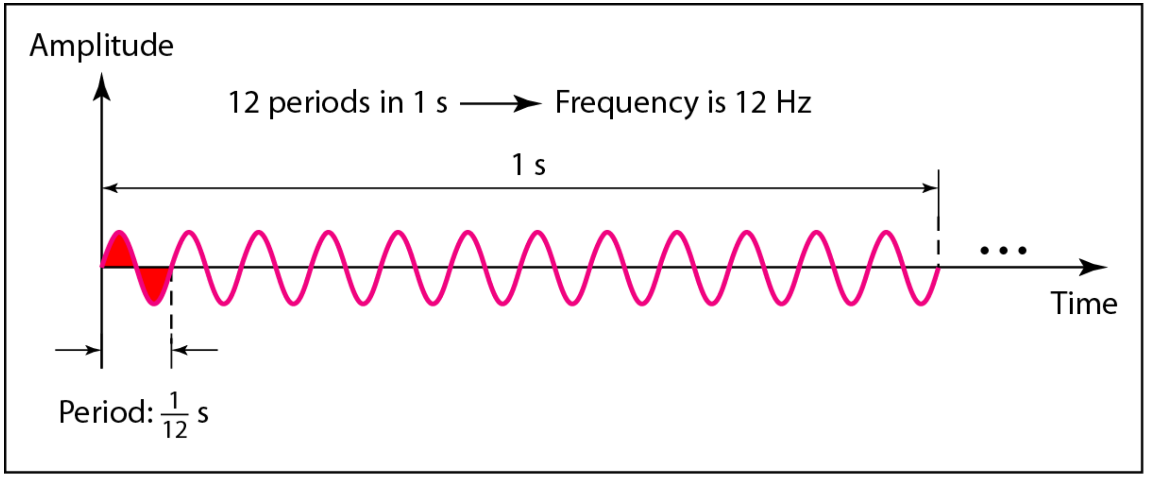
- Period refers to the amount of time (sec) a signal needs to complete 1 cycle

- Frequency refers to the number of periods in 1 second

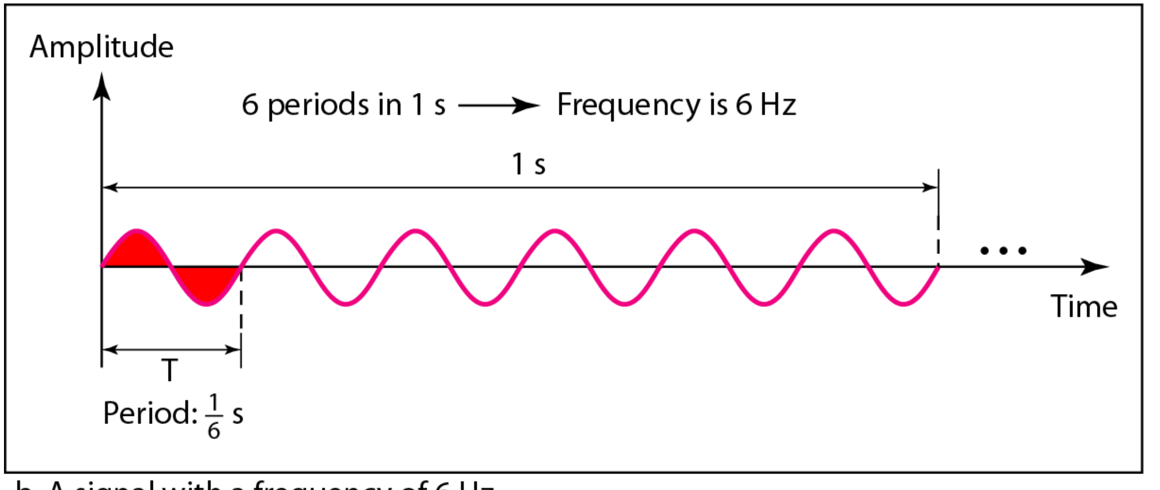
Frequency and period are the inverse of each other.

$$\boxed{f = \frac{1}{T} \qquad \text{and} \qquad T = \frac{1}{f}}$$

Figure 3.4 *Two signals with the same amplitude, but different frequencies*



a. A signal with a frequency of 12 Hz



b. A signal with a frequency of 6 Hz

Table 3.1 ***Units of period and frequency***

Unit	*Equivalent*	*Unit*	*Equivalent*
Seconds (s)	1 s	Hertz (Hz)	1 Hz
Milliseconds (ms)	10^{-3} s	Kilohertz (kHz)	10^{3} Hz
Microseconds (μs)	10^{-6} s	Megahertz (MHz)	10^{6} Hz
Nanoseconds (ns)	10^{-9} s	Gigahertz (GHz)	10^{9} Hz
Picoseconds (ps)	10^{-12} s	Terahertz (THz)	10^{12} Hz

Example 3.3

The power we use at home has a frequency of 60 Hz. The period of this sine wave can be determined as follows:

$$T = \frac{1}{f} = \frac{1}{60} = 0.0166 \text{ s} = 0.0166 \times 10^3 \text{ ms} = 16.6 \text{ ms}$$

Example 3.5

The period of a signal is 100 ms. What is its frequency in kilohertz?

Solution

First we change 100 ms to seconds, and then we calculate the frequency from the period (1 Hz = 10^{-3} kHz).

$$100 \text{ ms} = 100 \times 10^{-3} \text{ s} = 10^{-1} \text{ s}$$

$$f = \frac{1}{T} = \frac{1}{10^{-1}} \text{ Hz} = 10 \text{ Hz} = 10 \times 10^{-3} \text{ kHz} = 10^{-2} \text{ kHz}$$

- Wavelength binds the period or the frequency of a simple sine wave to the propagation speed of the medium

Wavelength = propogation speed X period = propogation speed / frequency

- A composite signal is a combination of simple sine waves with different frequencies and amplitudes

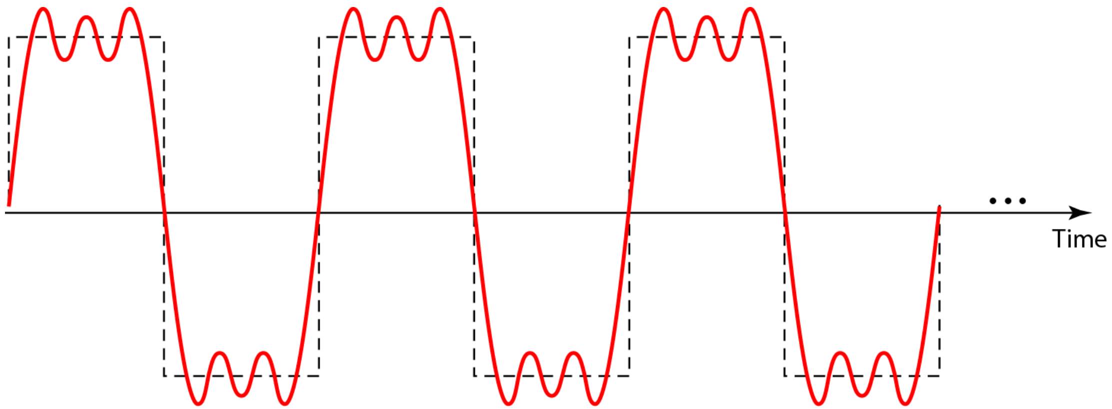
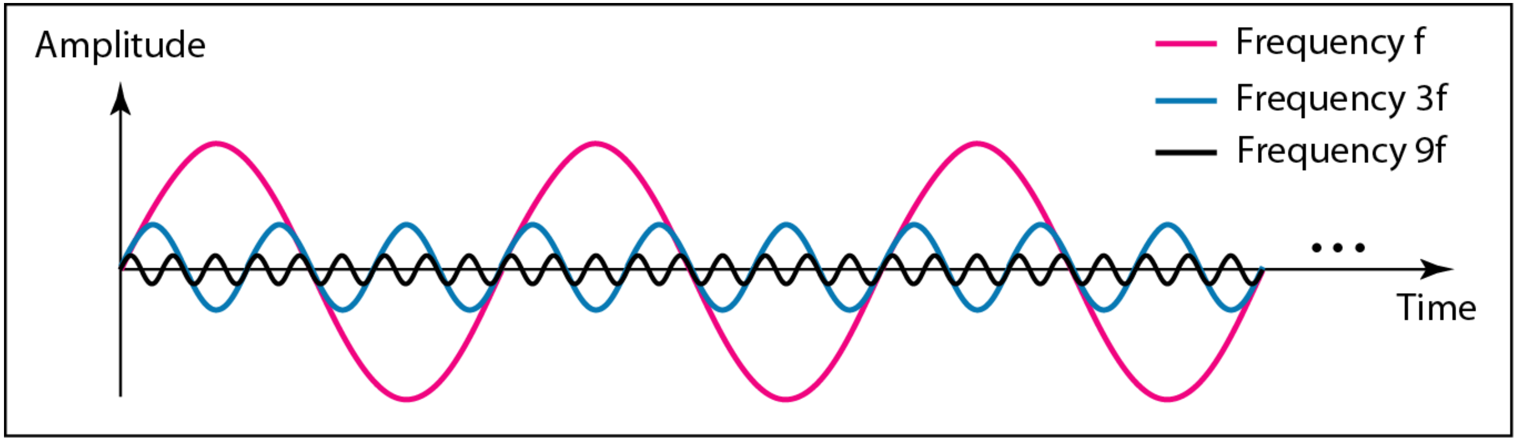
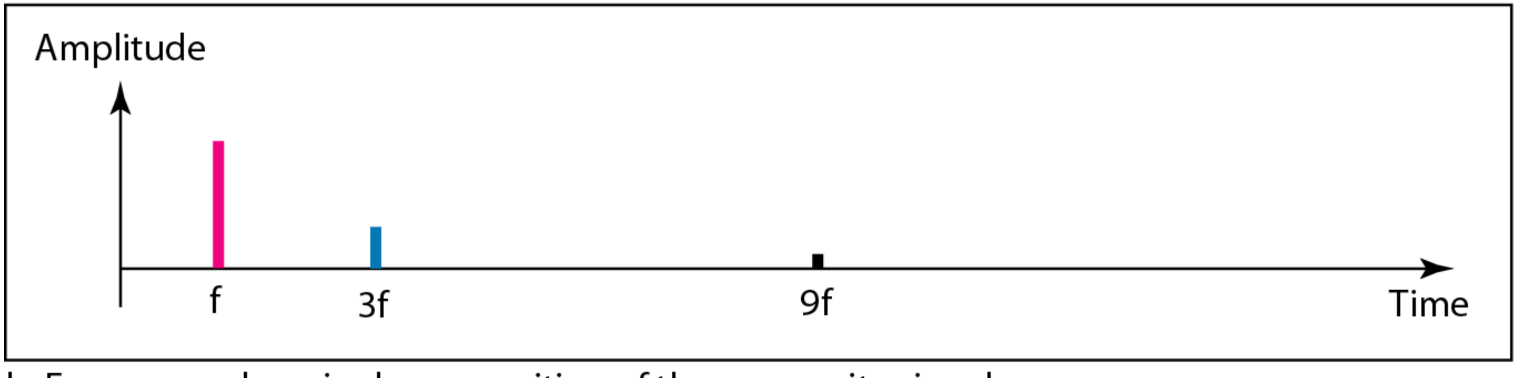


Figure 3.10 *Decomposition of a composite periodic signal in the time and frequency domains*



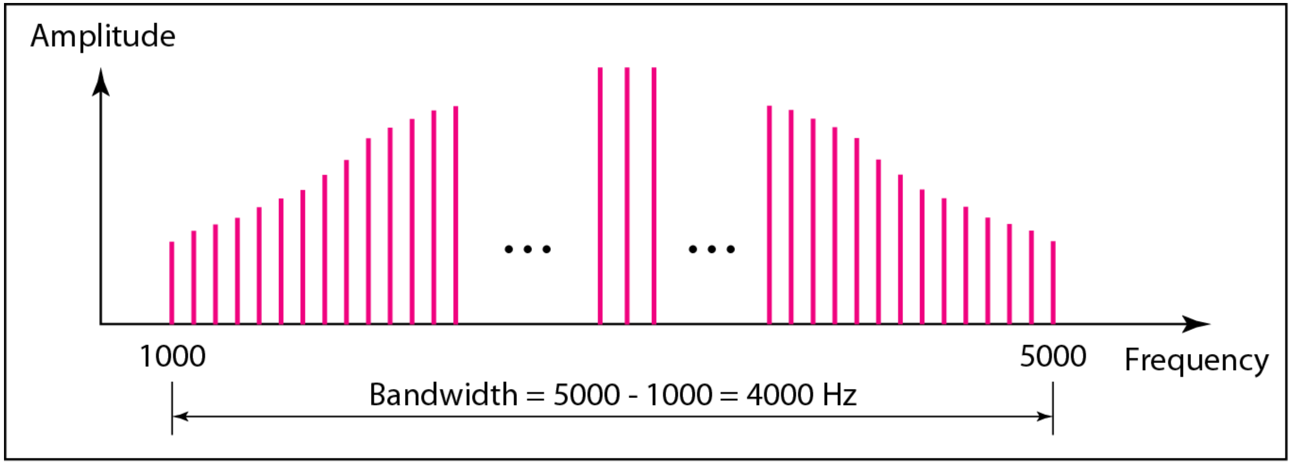
a. Time-domain decomposition of a composite signal



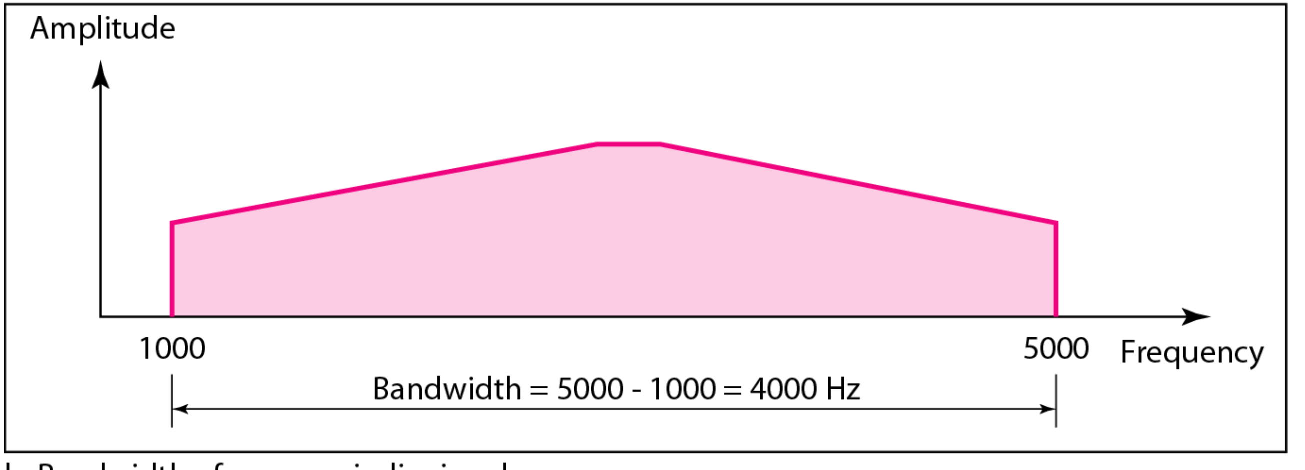
b. Frequency-domain decomposition of the composite signal

The bandwidth of a composite signal is the difference between the highest and the lowest frequencies contained in that signal.

Figure 3.12 *The bandwidth of periodic and nonperiodic composite signals*



a. Bandwidth of a periodic signal

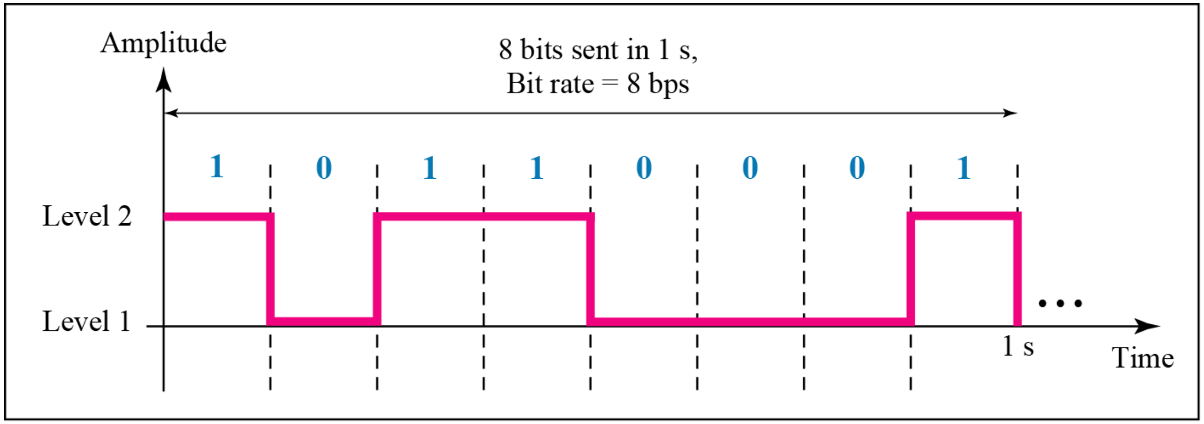


b. Bandwidth of a nonperiodic signal

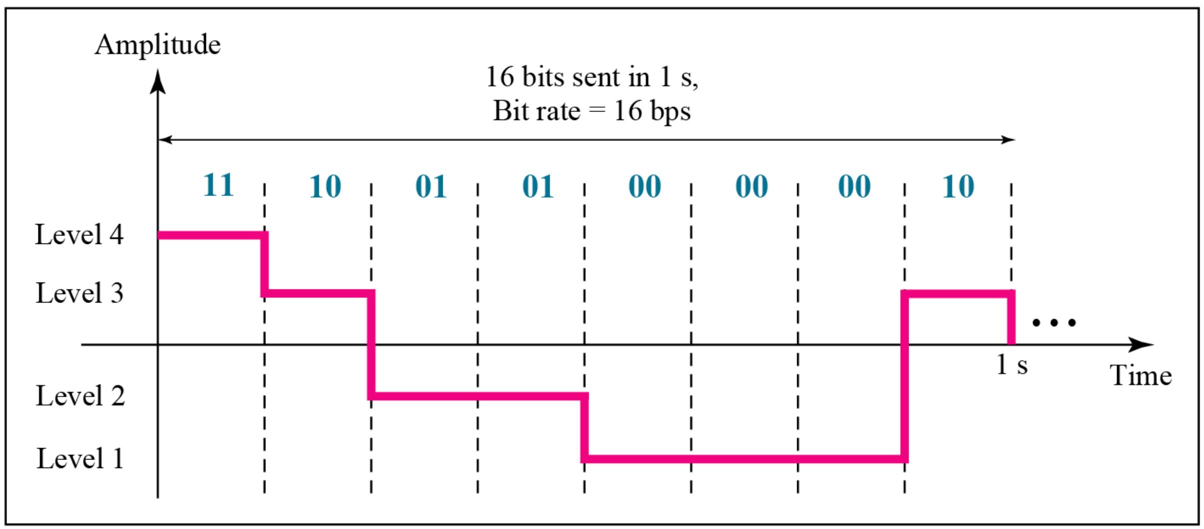
3-3 DIGITAL SIGNALS

In addition to being represented by an analog signal, information can also be represented by a digital signal. For example, a 1 can be encoded as a positive voltage and a 0 as zero voltage. A digital signal can have more than two levels. In this case, we can send more than 1 bit for each level.

Figure 3.16 *Two digital signals: one with two signal levels and the other with four signal levels*



a. A digital signal with two levels



b. A digital signal with four levels

Example 3.16

A digital signal has eight levels. How many bits are needed per level? We calculate the number of bits from the formula

$$\boxed{\text{Number of bits per level} = \log_2 8 = 3}$$

Each signal level is represented by 3 bits.

Example 3.18

- **The bit rate is the number of bits sent in 1 sec. It is expressed in bits per second (bps)**

Assume we need to download text documents at the rate of 100 pages per minute. What is the required bit rate of the channel?

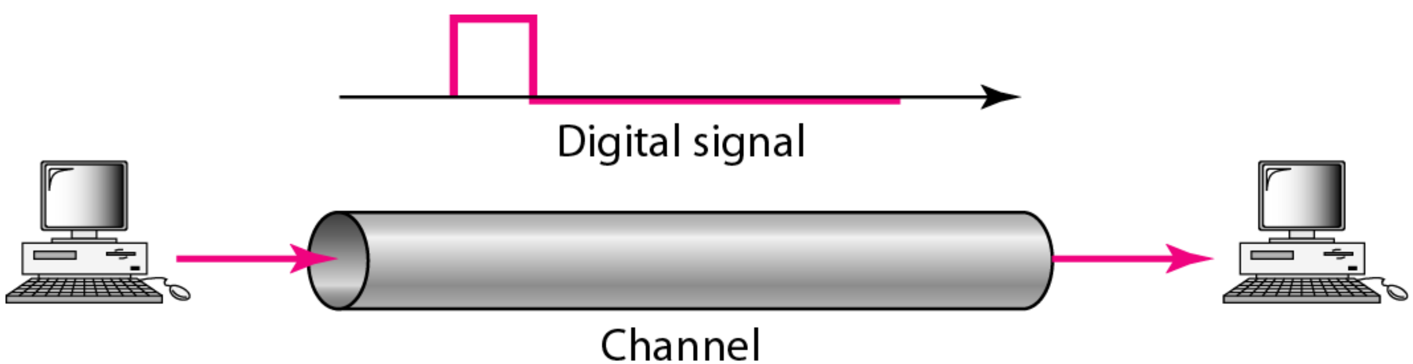
Solution

A page is an average of 24 lines with 80 characters in each line. If we assume that one character requires 8 bits, the bit rate is

$$\boxed{100 \times 24 \times 80 \times 8 = 1{,}636{,}000 \text{ bps} = 1.636 \text{ Mbps}}$$

Figure 3.18 *Baseband transmission*

- Baseband transmission means sending a digital signal over a channel without changing the digital signal to analog signal
- A digital signal is a composite analog signal with an infinite bandwidth



3-4 TRANSMISSION IMPAIRMENT

Signals travel through transmission media, which are not perfect. The imperfection causes signal impairment. This means that the signal at the beginning of the medium is not the same as the signal at the end of the medium. What is sent is not what is received. Three causes of impairment are attenuation, distortion, and noise.

Figure 3.25 *Causes of impairment*

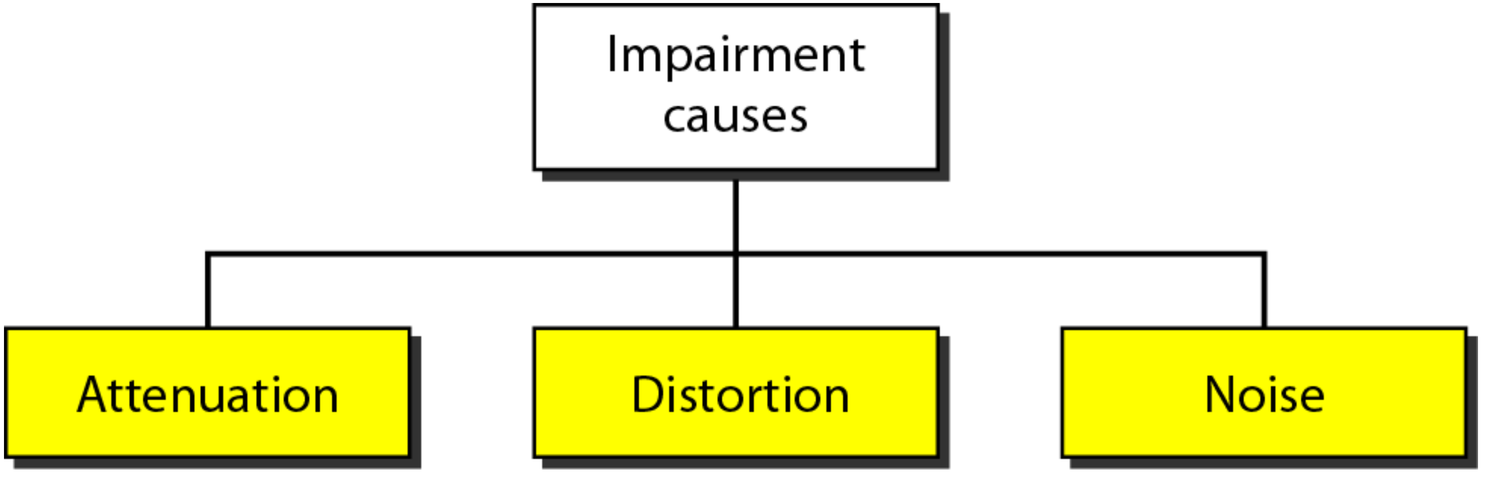


Figure 3.26 *Attenuation: loss of enengy*

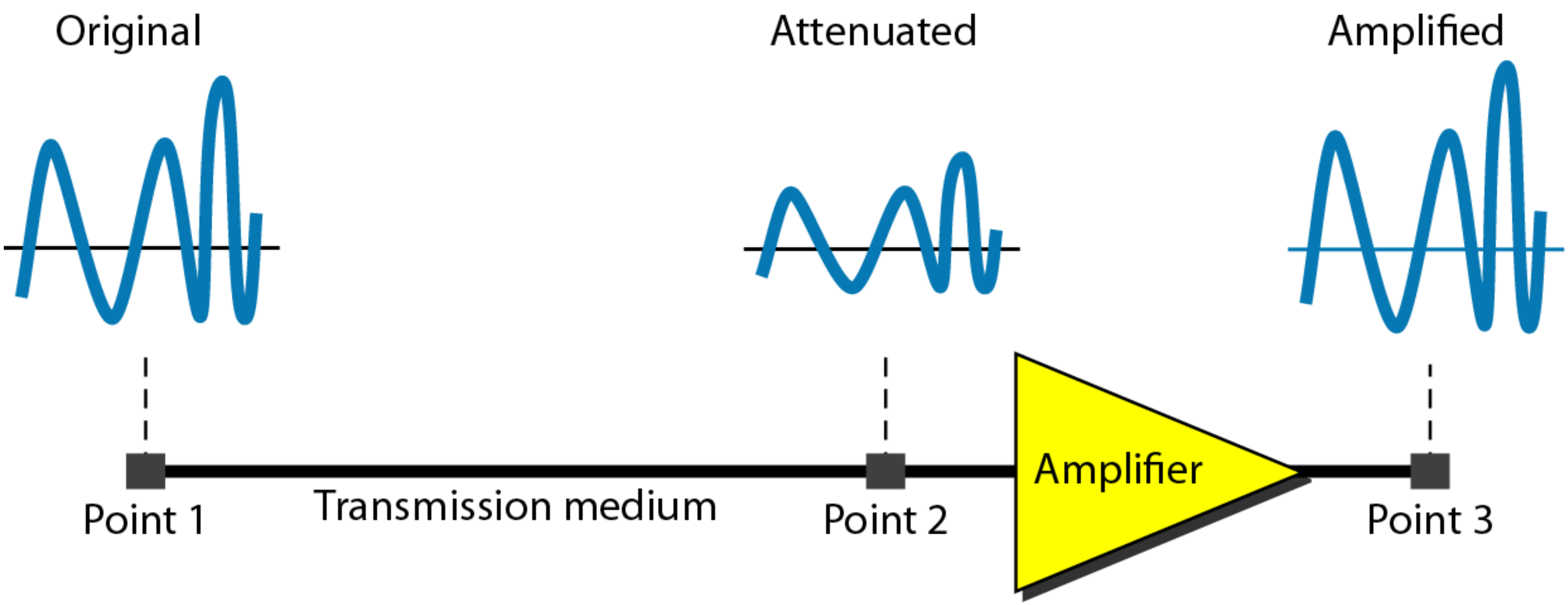


Figure 3.28 *Distortion: change in form or shape*

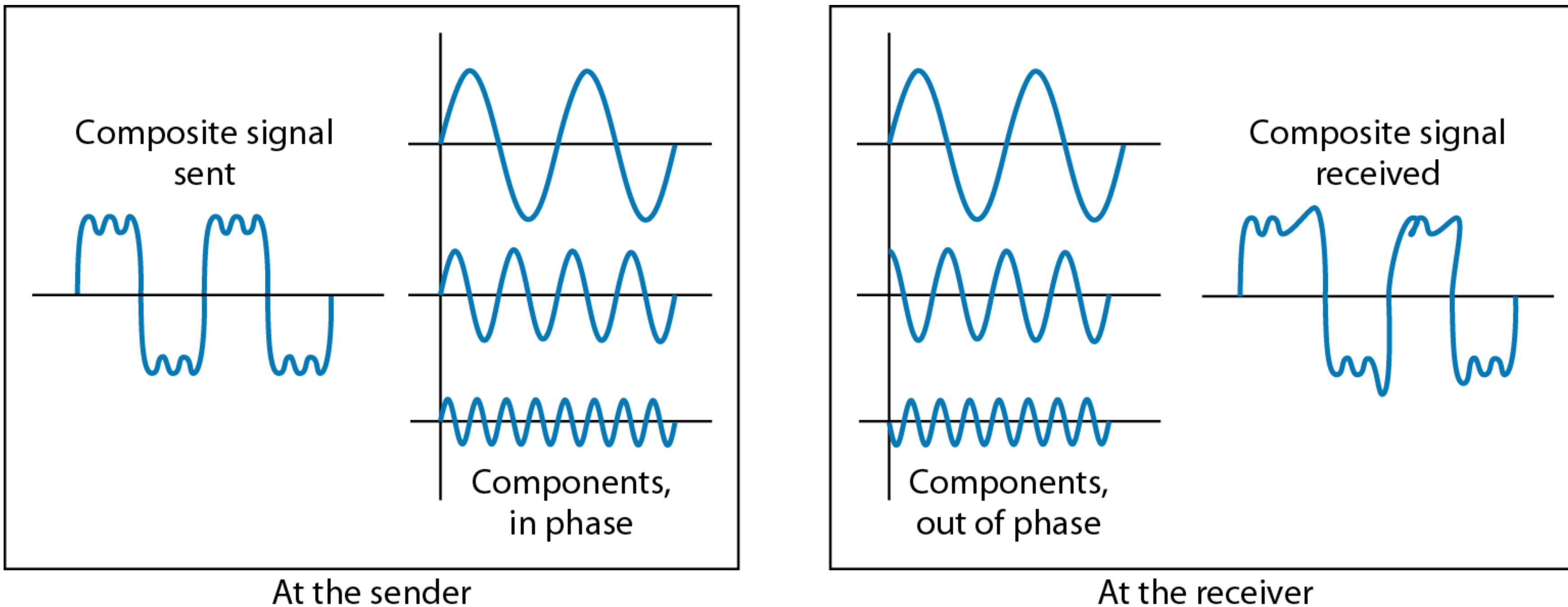
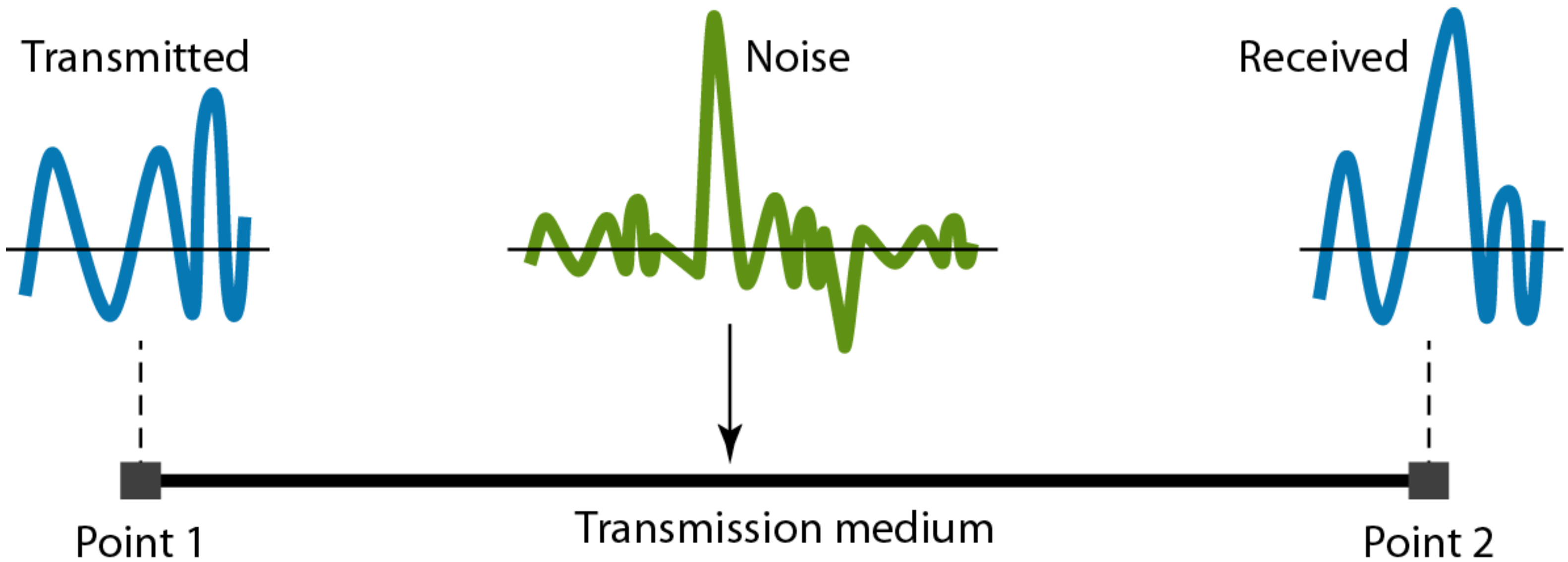


Figure 3.29 *Noise: corruption of signal by thermal, induced noise, crosstalk*



Signal to noise ratio (SNR) -
SNR = average signal power/average noise power

The power of a signal is 10 mW and the power of the noise is 1 μW; what are the values of SNR and SNR_{dB}?

Solution

The values of SNR and SNR_{dB} can be calculated as follows:

$$SNR = \frac{10{,}000\ \mu W}{1\ mW} = 10{,}000$$

$$SNR_{dB} = 10 \log_{10} 10{,}000 = 10 \log_{10} 10^4 = 40$$

3-5 DATA RATE LIMITS

A very important consideration in data communications is how fast we can send data, in bits per second, over a channel. Data rate depends on three factors:

1. ***The bandwidth available***
2. ***The level of the signals we use***
3. ***The quality of the channel (the level of noise)***

Noiseless Channel: Nyquist Bit Rate
Noisy Channel: Shannon Capacity

3-6 PERFORMANCE

One important issue in networking is the performance of the network—how good is it? We discuss quality of service, an overall measurement of network performance, in greater detail in Chapter 24. In this section, we introduce terms that we need for future chapters.

Bandwidth
Throughput
Latency (Delay)
Bandwidth-Delay Product

In networking, we use the term bandwidth in two contexts.

- **The first, bandwidth in hertz, refers to the range of frequencies in a composite signal or the range of frequencies that a channel can pass.**

- **The second, bandwidth in bits per second, refers to the speed of bit transmission in a channel or link.**

- **Bandwidth** refers to the number of bits per second a channel, link or network can transmit.
- **Throughput** is a measure of how fast actually send data through a network.
- Throughput <= Bandwidth (in terms of speed)
- **Latency** (Delay) - how long it takes for an entire message to reach the destination

Latency = propagation time + transmission time + queuing time + processing delay

- **Jitter** is a problem where different data packets encounter different delays and application is requiring time sensitive data (audio and video data)

4-3 TRANSMISSION MODES

The transmission of binary data across a link can be accomplished in either parallel or serial mode. In parallel mode, multiple bits are sent with each clock tick. In serial mode, 1 bit is sent with each clock tick. While there is only one way to send parallel data, there are three subclasses of serial transmission: asynchronous, synchronous, and isochronous.

Figure 4.31 *Data transmission and modes*

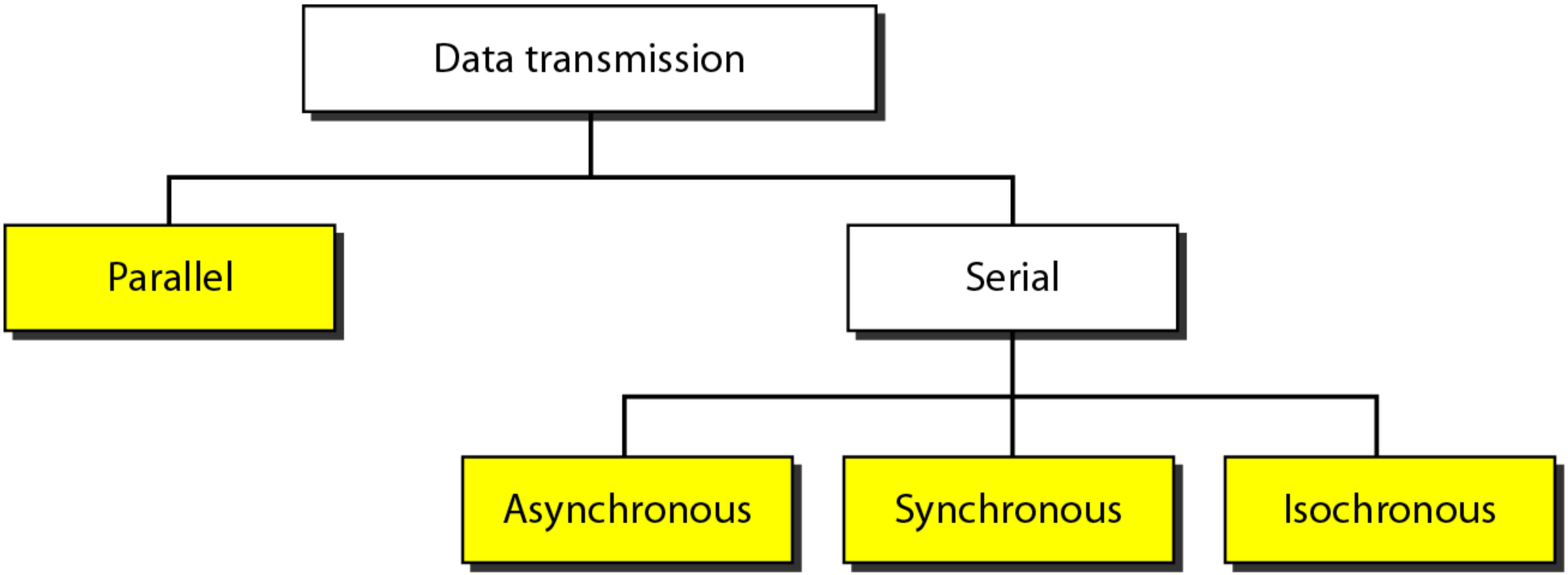
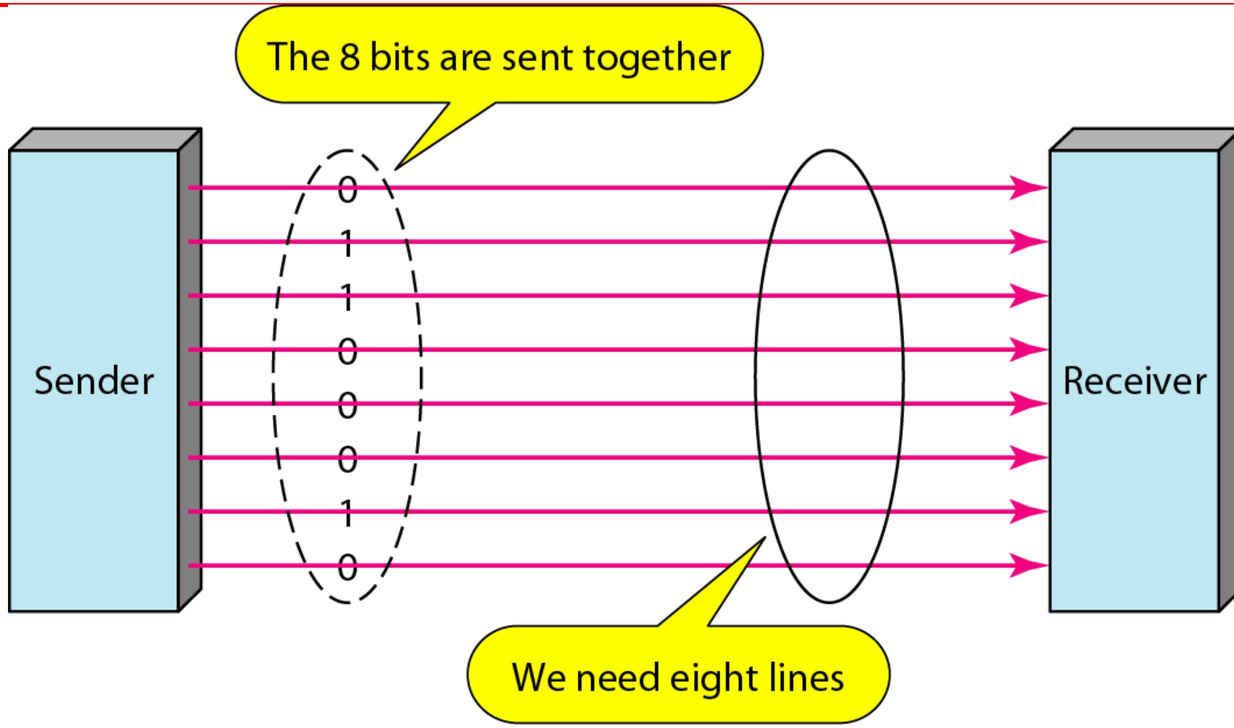
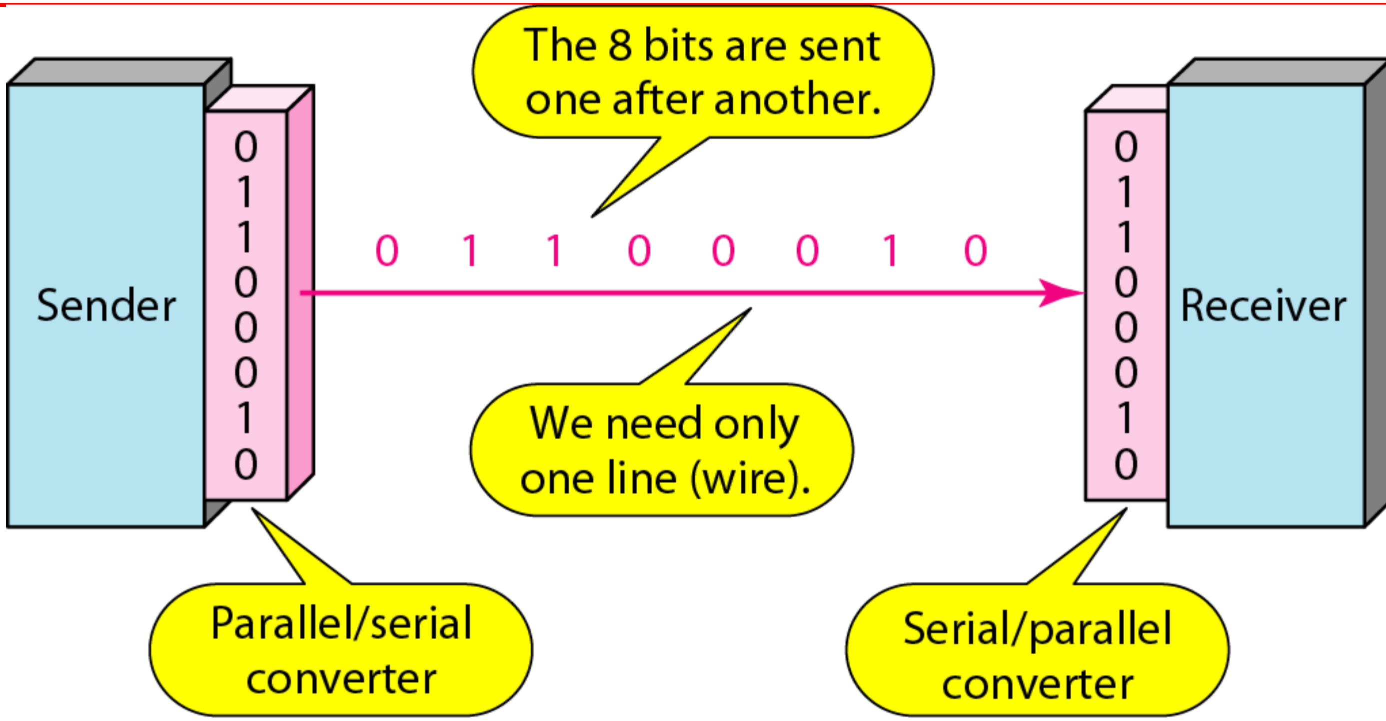


Figure 4.32 *Parallel transmission*



- Advantage of using parallel transmission is speed
- Disadvantage is cost as it requires n communication lines
- Only used for short distances

Figure 4.33 *Serial transmission*

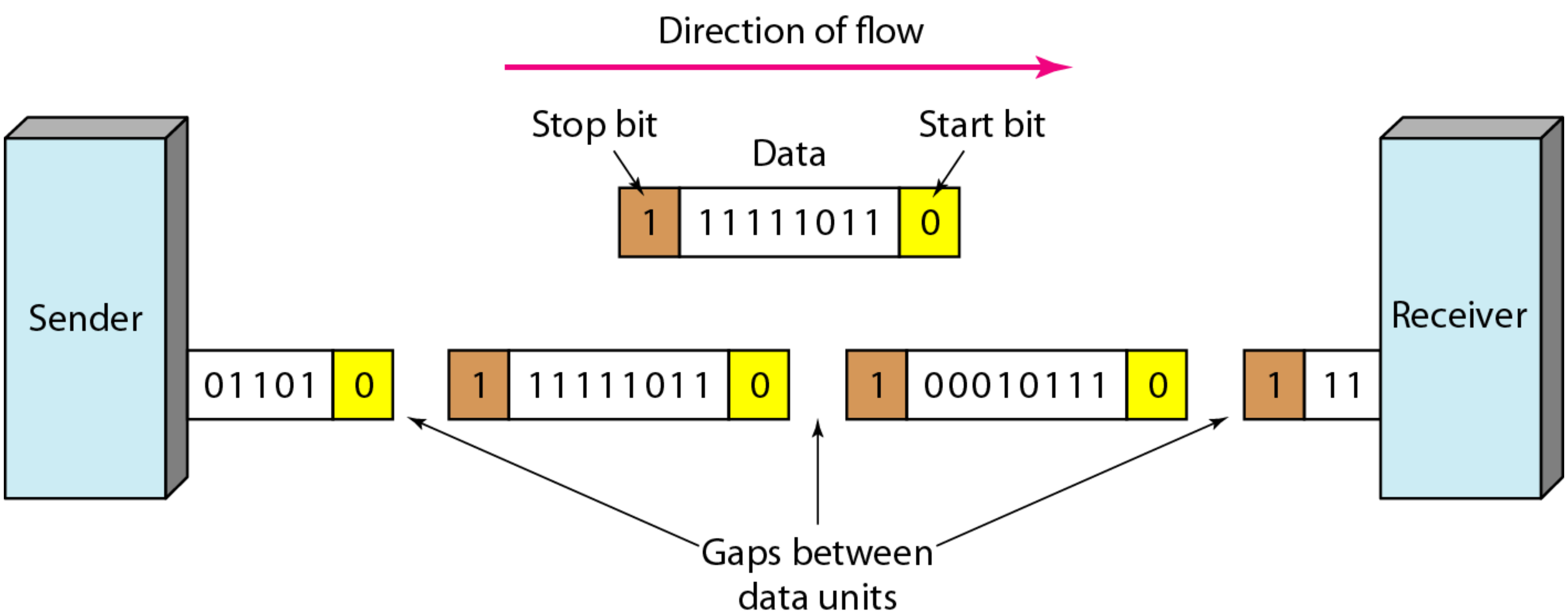


- Reduces the cost of transmission

In asynchronous transmission, we send 1 start bit (0) at the beginning and 1 or more stop bits (1s) at the end of each byte. There may be a gap between each byte.

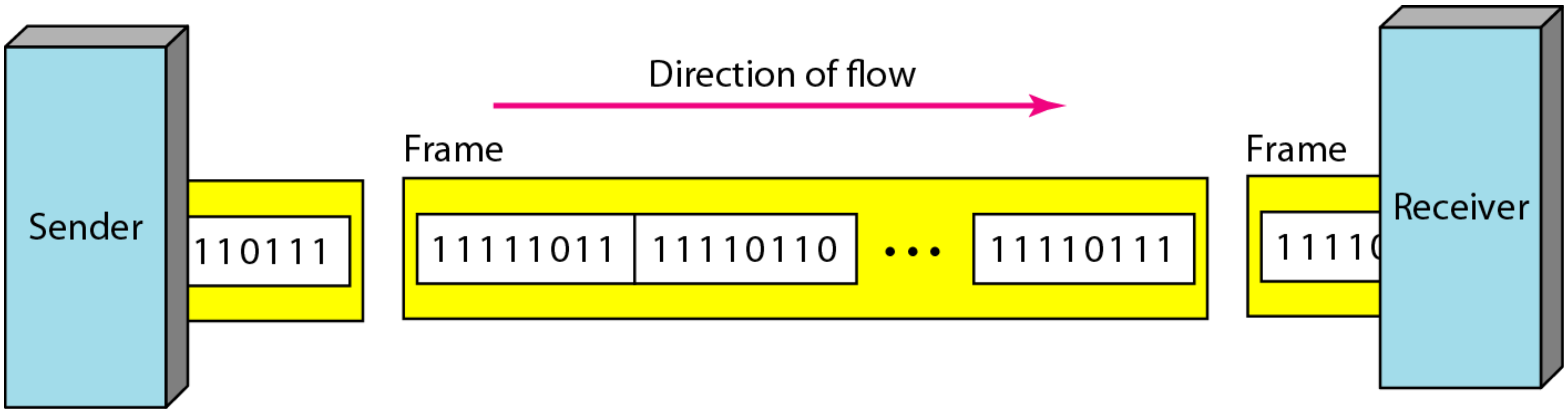
Asynchronous here means "asynchronous at the byte level," but the bits are still synchronized; their durations are the same.

Figure 4.34 *Asynchronous transmission*



In synchronous transmission, we send bits one after another without start or stop bits or gaps. It is the responsibility of the receiver to group the bits.

Figure 4.35 *Synchronous transmission*



- If sender wishes to send data in separate bursts, the gap between bursts must be filled with a special sequence of 0s and 1s.

Isochronous Transmission

- Uneven delay between frames are not acceptable in real time audio and video.
- Thus, synchronous transmission fails.
- For real time data, entire stream of bits must be synchronised.
- Isochronous transmission guarantees that data arrives at fixed rate.