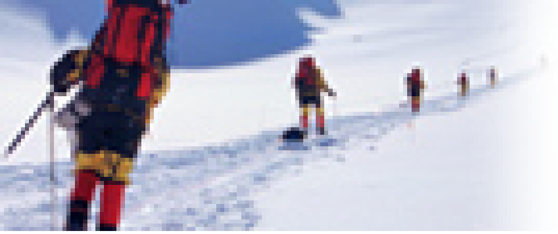


Chapter 3

Data and Signals

Summary of Data Communications

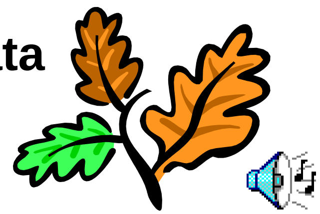
- What is communication?
  - The exchange of information between individuals using a common set of symbols, signs, behavior or language.
- What is data communication?
  - The exchange of data between two devices via some form of transmission medium such as a wire cable
- What is Computer Network?
  - A set of devices connected by communication links
    하드웨어와 소프트웨어, 케이블링의 조합으로 여러 컴퓨터 장치들이 서로 통신할 수 있게끔 하는 것 (의미)
- What is basic components of data communication system?
  - Message/Sender/Receiver/Medium/Protocol
- What is the difference between Data Communication and Network?
  - Computer Network=데이터 통신 + network Intelligence (topology)
- Protocol: A set of rules that governs data communication 다른 종류의 정보기기(entity) 사이의 원할한 통신을 가능하게 하는 약속된 통신 규약 (format, order of messages, actions)

Objectives

- analog or digital
- periodic analog signals
  - period, frequency, and phase
- non-periodic digital signals
  - Baseband and broadband
- transmission impairment
- Performance parameters
  - data rate
  - bandwidth, throughput, latency, and jitter

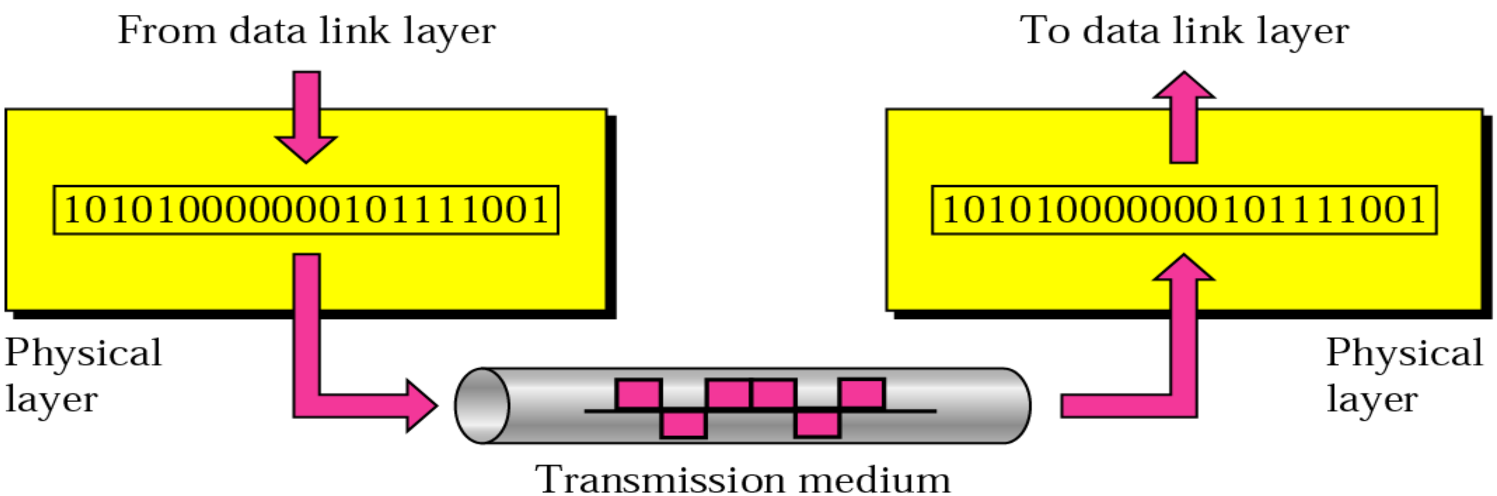
Data & Signal

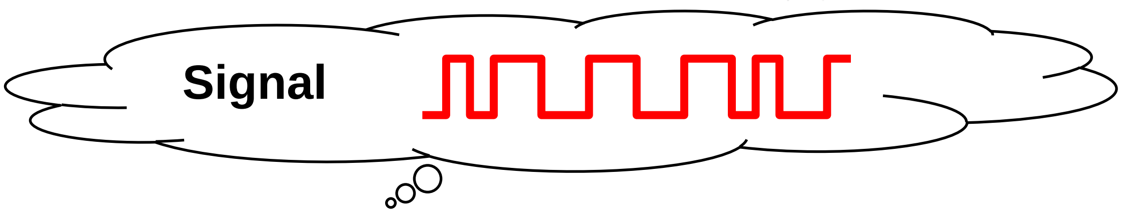
Data



Note:

To be transmitted, data must be transformed to electromagnetic signals.

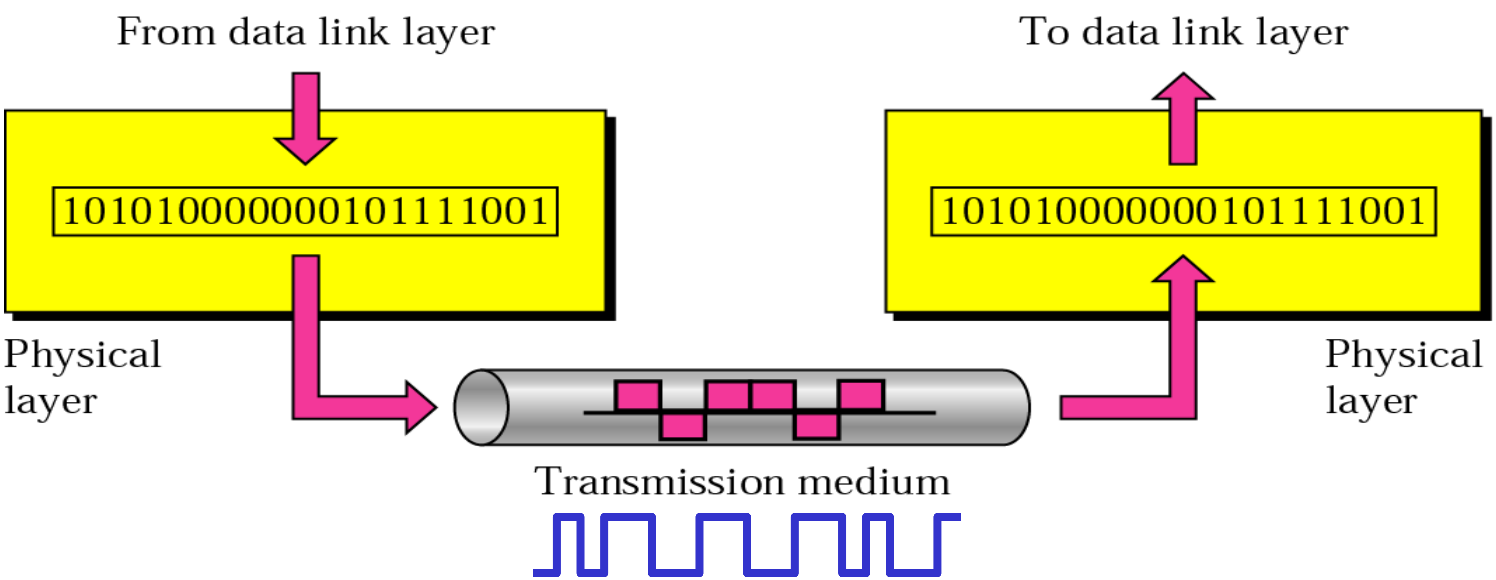




- **Why we have to use signal as well as data?**

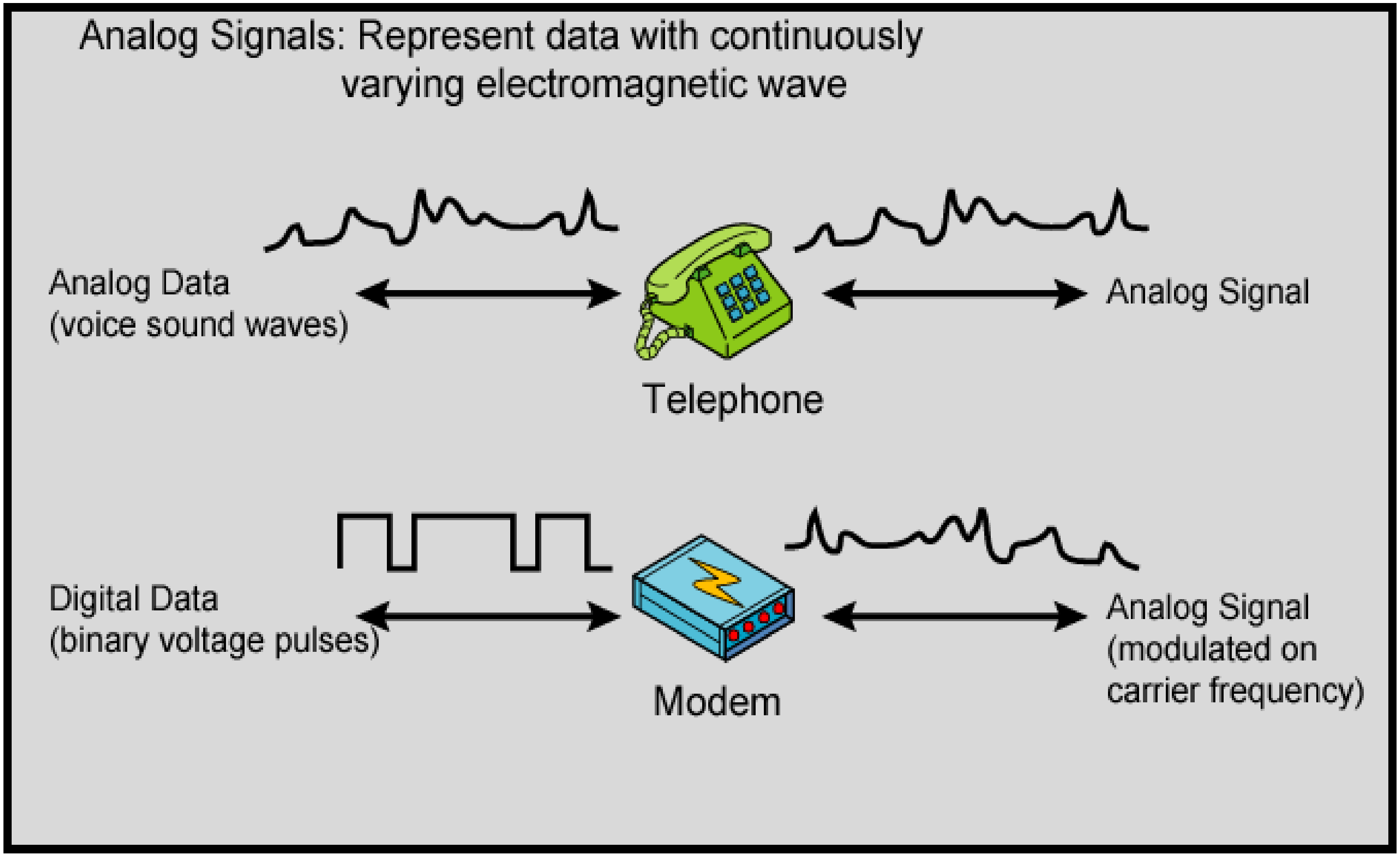
Data & Signal

Signal Encoding



Analog and Digital Data
Analog and Digital Signals
Periodic and Aperiodic Signals

Analog Signals Carrying Analog and Digital Data



Digital Signals Carrying Analog and Digital Data

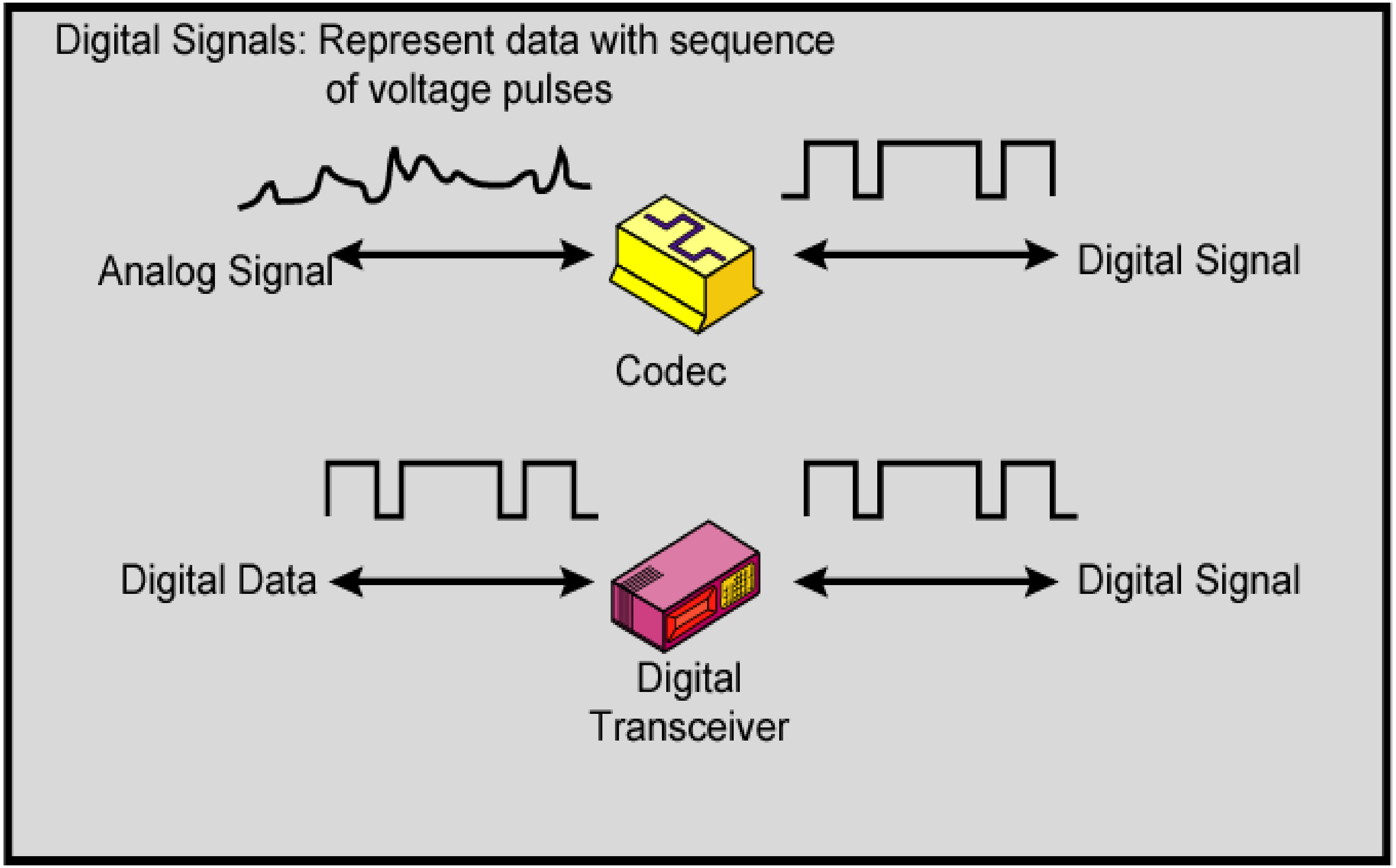
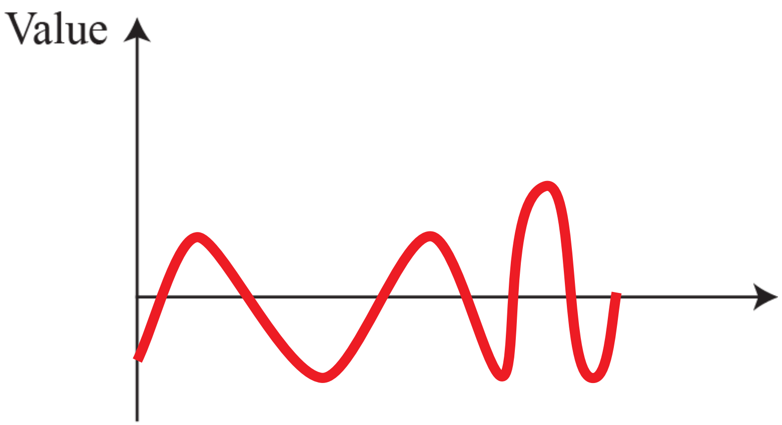
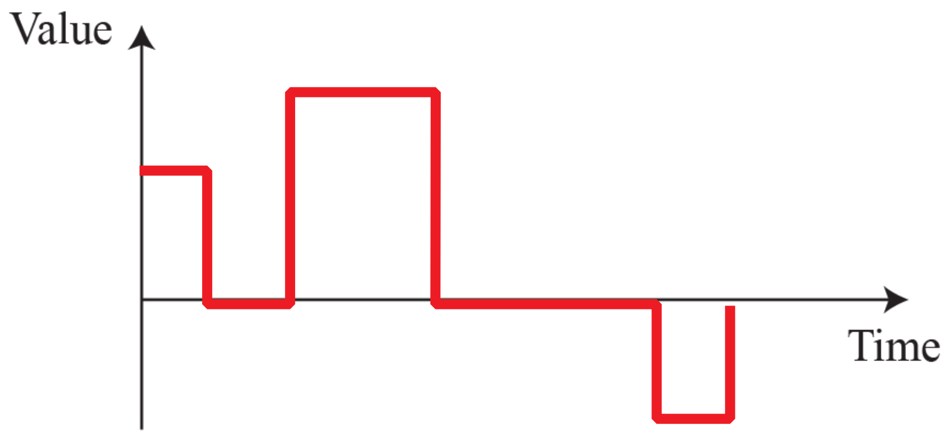


Figure 3.2: Comparison of analog and digital signals



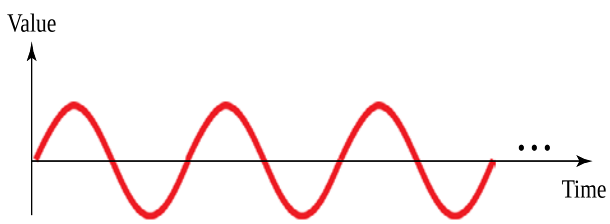
a. Analog signal

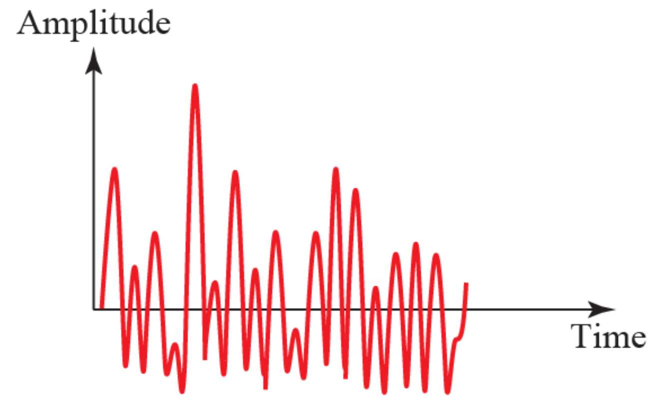


b. Digital signal

Periodic vs. Non-periodic

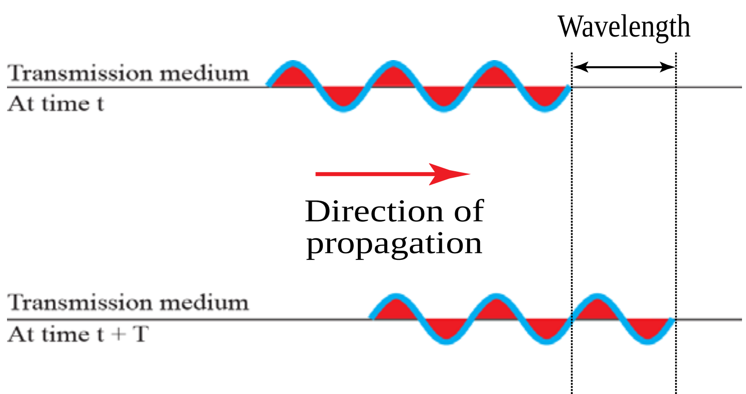
- Figure 3.3: A sine wave vs. non-periodic signal





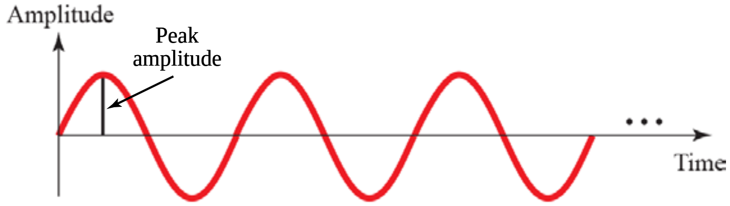
a. Time domain

- Figure 3.7: wavelength propagation

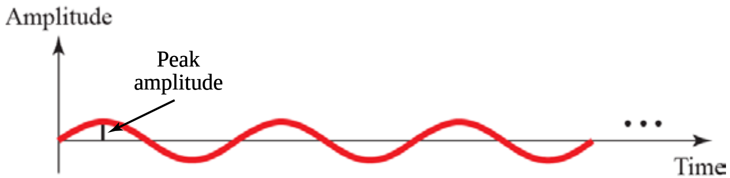


3.2.1 Sine Wave (Amplitude & Frequency)

- Figure 3.5 Electric signal



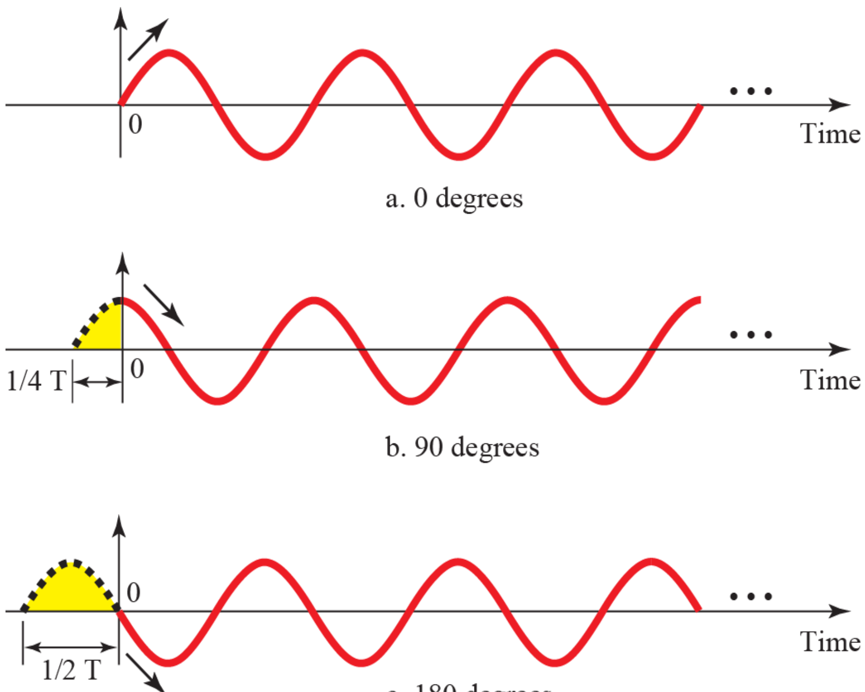
a. A signal with high peak amplitude



b. A signal with low peak amplitude

Phase

- Figure 3.6: Three sine waves with different phases



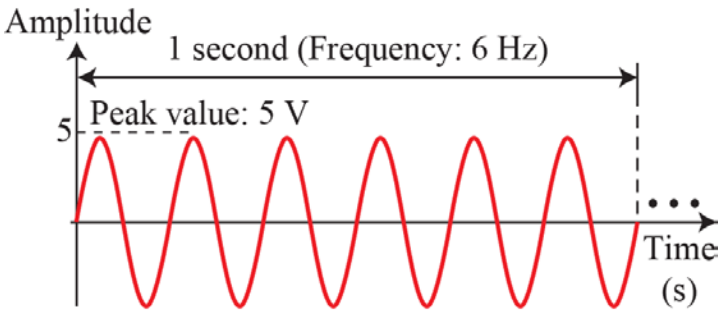
a. 0 degrees

b. 90 degrees

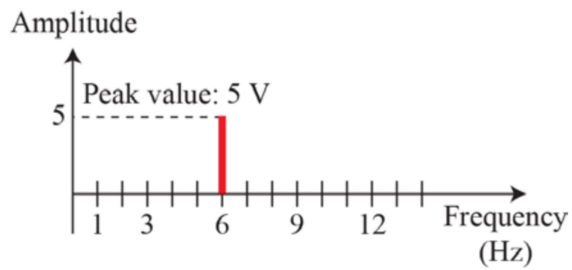
c. 180 degrees

Period vs. Frequency

- Figure 3.8/3.9: The time-domain and frequency-domain plots of a sine wave

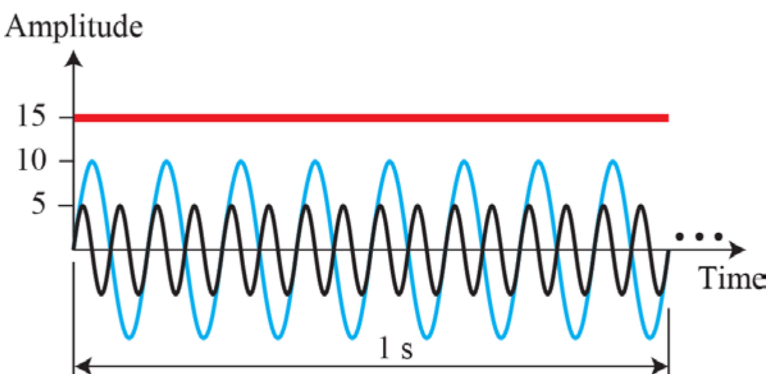


a. A sine wave in the time domain

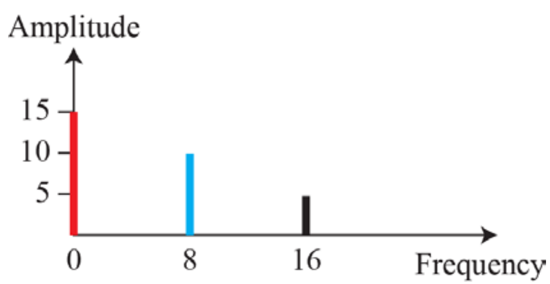


b. The same sine wave in the frequency domain

Period	
Unit	*Equivalent*
Seconds (s)	1 s
Milliseconds (ms)	10^{-3} s
Microseconds (μs)	10^{-6} s
Nanoseconds (ns)	10^{-9} s
Picoseconds (ps)	10^{-12} s



a. Time-domain representation

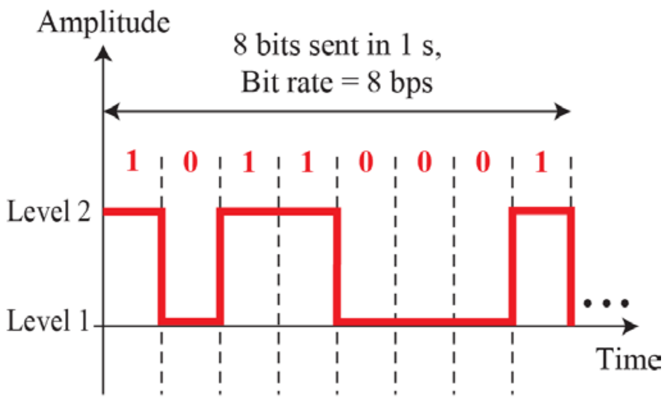


b. Frequency-domain representation

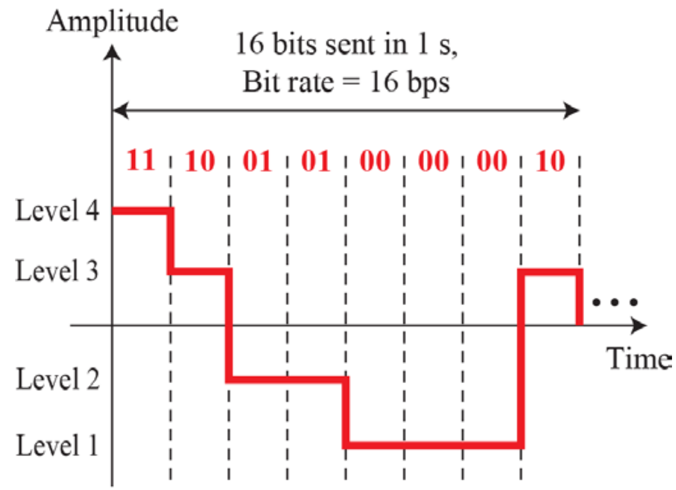
Frequency	
Unit	*Equivalent*
Hertz (Hz)	1 Hz
Kilohertz (kHz)	10^{3} Hz
Megahertz (MHz)	10^{6} Hz
Gigahertz (GHz)	10^{9} Hz
Terahertz (THz)	10^{12} Hz

3-3 DIGITAL SIGNALS

- Figure 3.17: Two digital signals



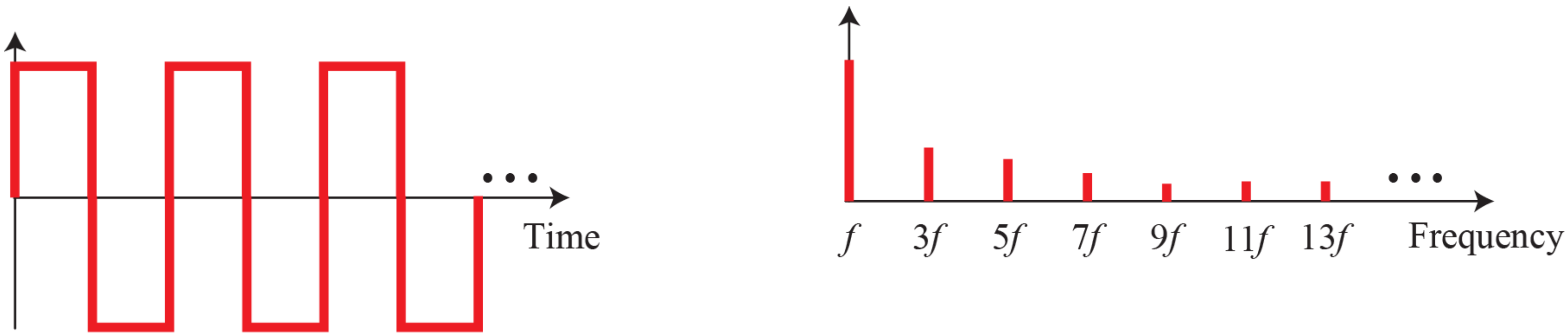
a. A digital signal with two levels



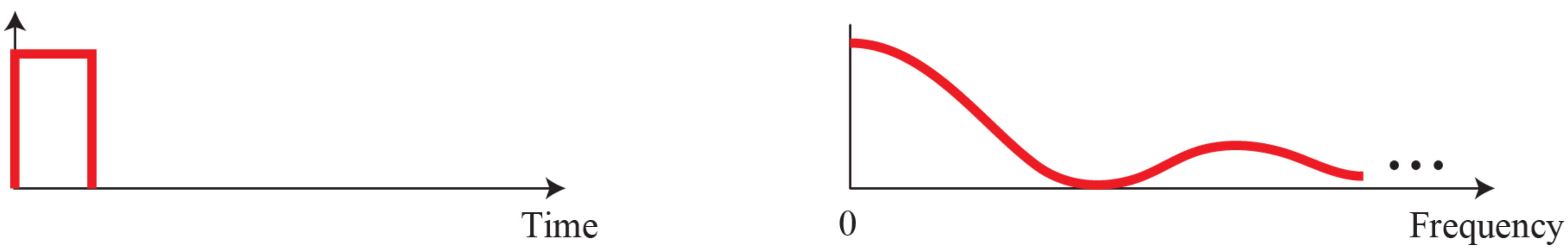
b. A digital signal with four levels

- 3.3.1 Bit Rate
  - bps= the number of bits sent in 1s

Figure 3.18: The time and frequency domains



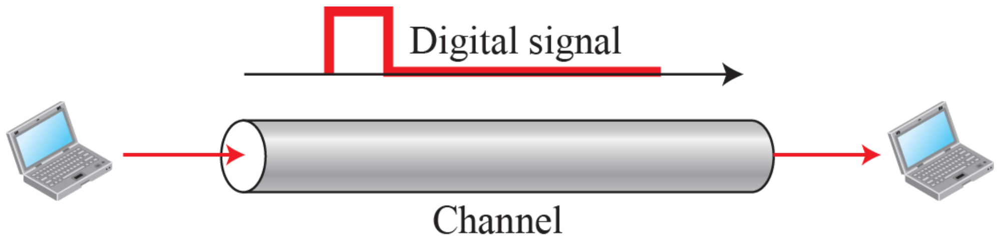
a. Time and frequency domains of periodic digital signal



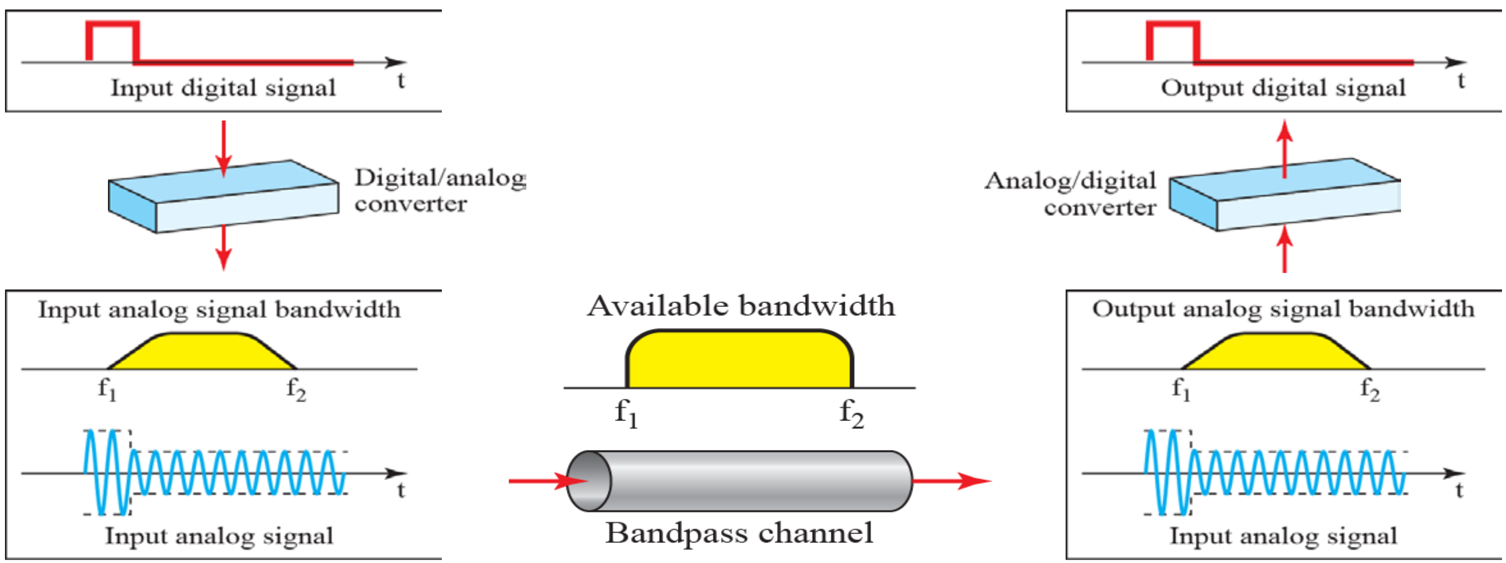
b. Time and frequency domains of nonperiodic digital signal

Baseband vs. broadband

- Baseband

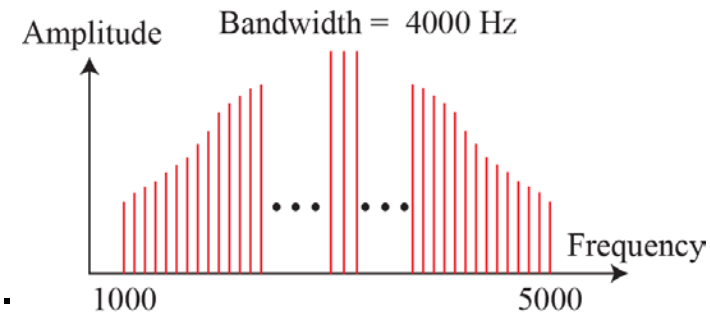


- broadband



3.6 Performance

- In networking, we use the term.
  - 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.



a. Bandwidth of a periodic signal

  - The second, bandwidth in bits per second, refers to the speed of bit transmission in a channel or link.
- Throughput
  - a measure of how fast we can actually send data through a network
- Latency
  - how long it takes for an entire message to completely arrive at the destination

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

Example 3.44

A network with bandwidth of 10 Mbps can pass only an average of 12,000 frames per minute with each frame carrying an average of 10,000 bits. What is the throughput of this network?

Solution

We can calculate the throughput as

$$\text{Throughput} = \frac{12{,}000 \times 10{,}000}{60} = 2 \text{ Mbps}$$

The throughput is almost one-fifth of the bandwidth in this case.

Example 3.45

What is the propagation time if the distance between the two points is 12,000 km? Assume the propagation speed to be 2.4 × 108 m/s in cable.

Solution

We can calculate the propagation time as

$$\text{Propagation time} = \frac{12{,}000 \times 1000}{2.4 \times 10^8} = 50 \text{ ms}$$

The example shows that a bit can go over the Atlantic Ocean in only 50 ms if there is a direct cable between the source and the destination.

Example 3.46

What are the propagation time and the transmission time for a 2.5-kbyte message (an e-mail) if the bandwidth of the network is 1 Gbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at 2.4 × 108 m/s.

Solution

We can calculate the propagation and transmission time as shown on the next slide:

$$\text{Propagation time} = \frac{12{,}000 \times 1000}{2.4 \times 10^8} = 50 \text{ ms}$$

$$\text{Transmission time} = \frac{2500 \times 8}{10^9} = 0.020 \text{ ms}$$

Note that in this case, because the message is short and the bandwidth is high, the dominant factor is the propagation time, not the transmission time. The transmission time can be ignored.

Example 3.47

What are the propagation time and the transmission time for a 5-Mbyte message (an image) if the bandwidth of the network is 1 Mbps? Assume that the distance between the sender and the receiver is 12,000 km and that light travels at 2.4×10^8 m/s.

Solution

We can calculate the propagation and transmission times as shown on the next slide.

$$\text{Propagation time} = \frac{12{,}000 \times 1000}{2.4 \times 10^8} = 50 \text{ ms}$$

$$\text{Transmission time} = \frac{5{,}000{,}000 \times 8}{10^6} = 40 \text{ s}$$

Note that in this case, because the message is very long and the bandwidth is not very high, the dominant factor is the transmission time, not the propagation time. The propagation time can be ignored.

3.6.4 Bandwidth-Delay Product

- Bandwidth and delay are two performance metrics of a link. However, as we will see in this chapter and future chapters, what is very important in data communications is the product of the two, the bandwidth-delay product. Let us elaborate on this issue, using two hypothetical cases as examples.
- Figure 3.32: Filling the links with bits for Case 1

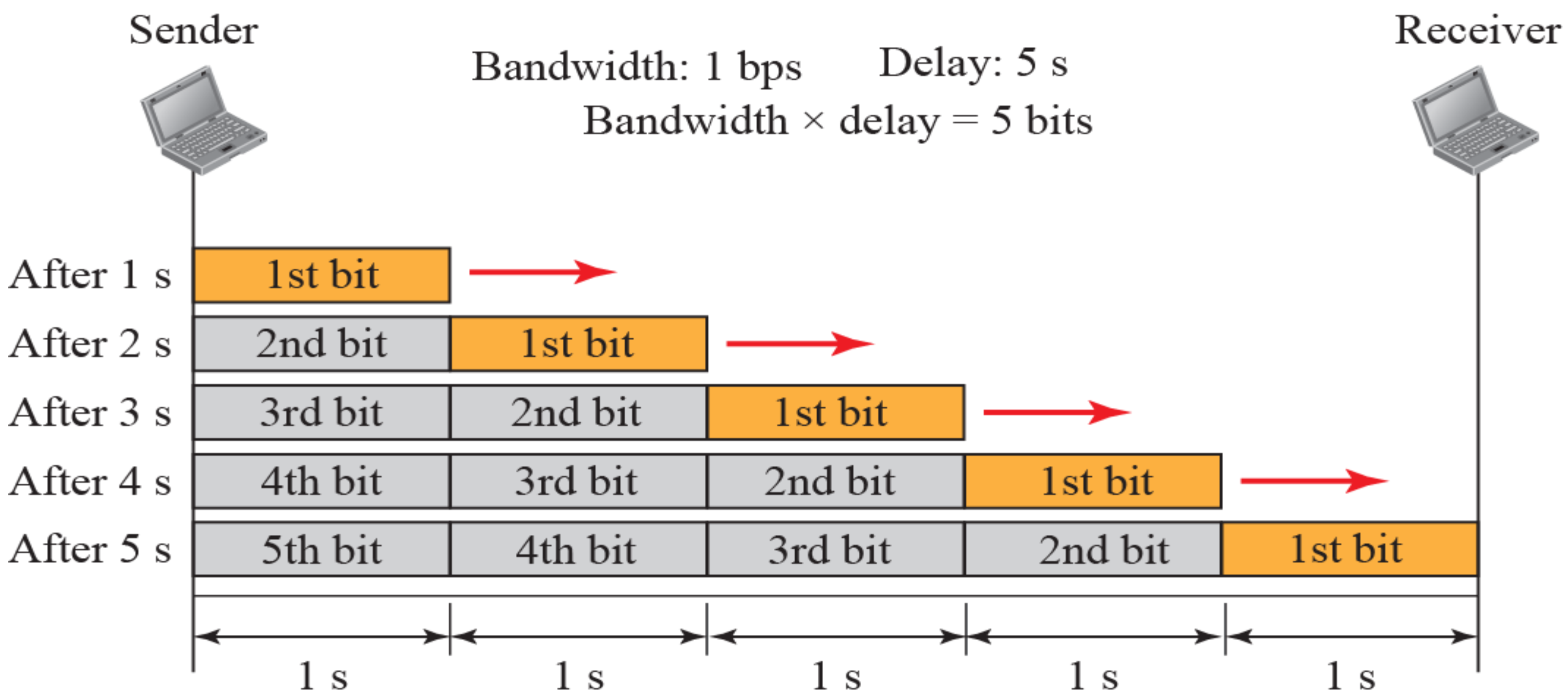
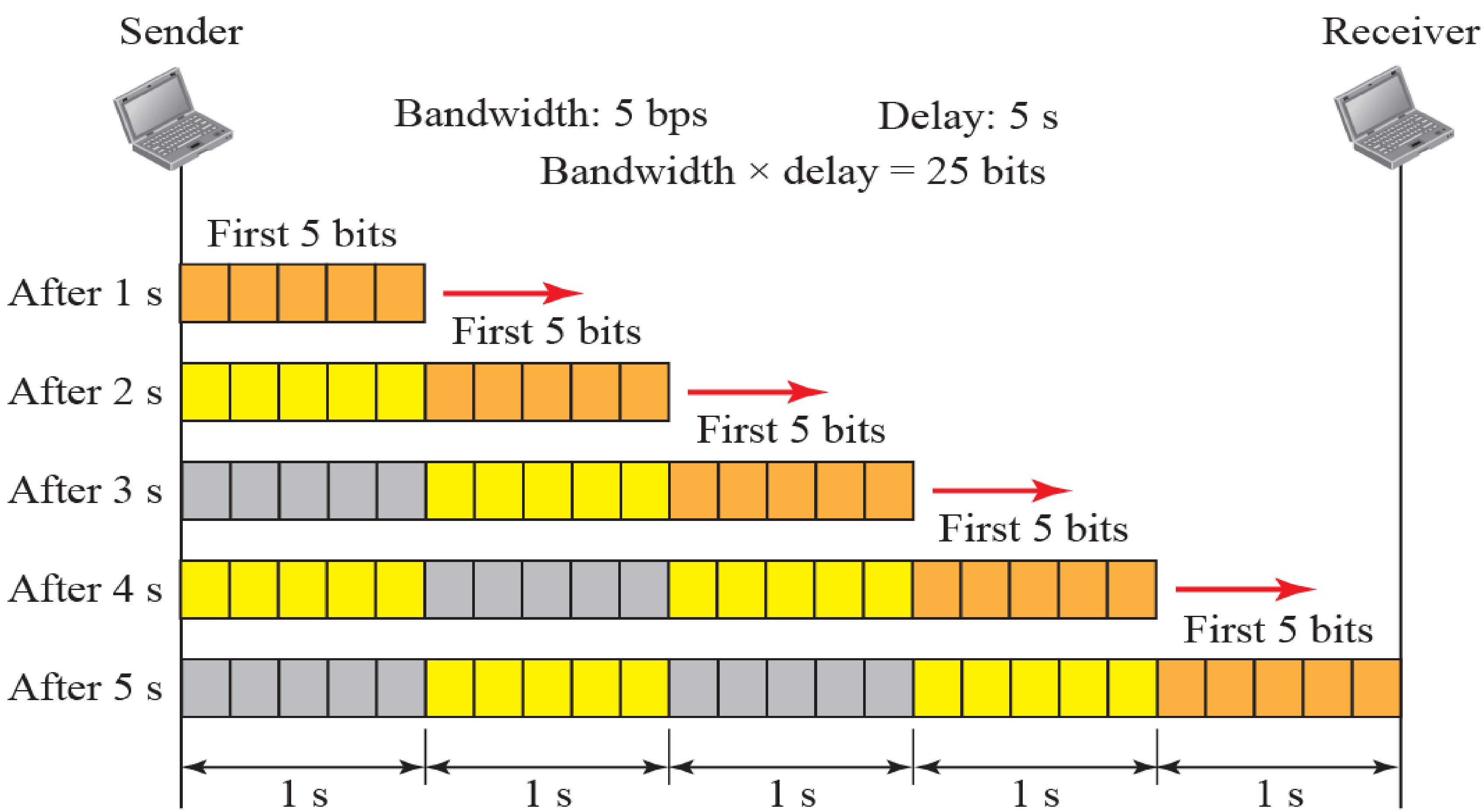
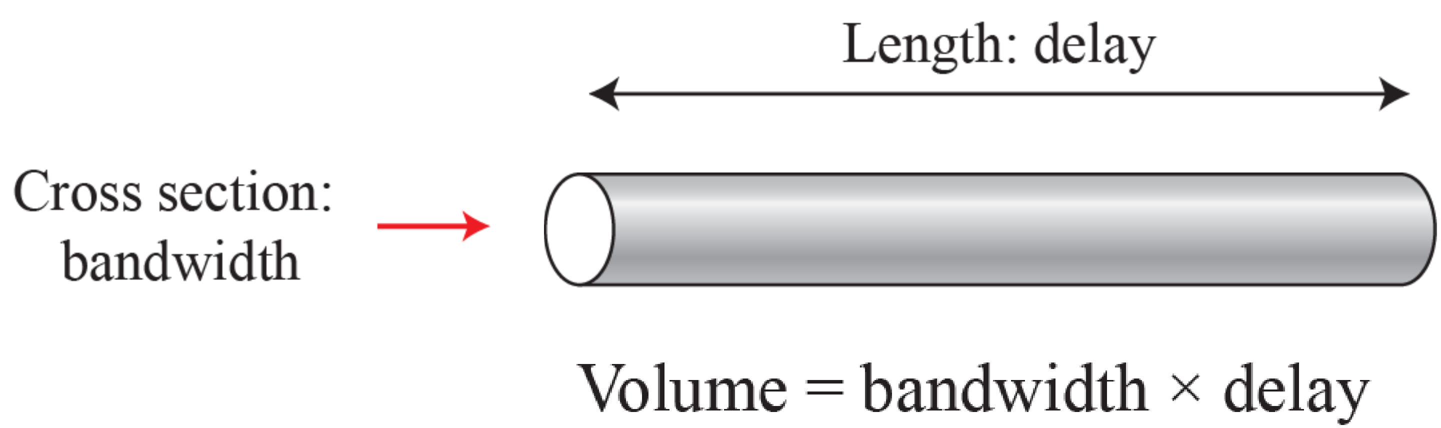


Figure 3.33: Filling the pipe with bits for Case 2



Example 3.48

We can think about the link between two points as a pipe. The cross section of the pipe represents the bandwidth, and the length of the pipe represents the delay. We can say the volume of the pipe defines the bandwidth-delay product, as shown in Figure 3.34.



3.6.5 Jitter

Another performance issue that is related to delay is jitter. We can roughly say that jitter is a problem if different packets of data encounter different delays and the application using the data at the receiver site is time-sensitive (audio and video data, for example). If the delay for the first packet is 20 ms, for the second is 45 ms, and for the third is 40 ms, then the real-time application that uses the packets endures jitter. We discuss jitter in greater detail in Chapter 28.