Chapter 3

Introduction To Physical Layer

Chapter 3: Outline

3.1 DATA AND SIGNALS

3.2 PERIODIC ANALOG SIGNALS

3.3 DIGITAL SIGNALS

3.4 TRANSMISSION IMPAIRMENT

3.5 DATA RATE LIMITS

3.6 PERFORMANCE

Chapter 3: Objective

- The first section shows how data and signals can be either analog or digital. Analog refers to an entity that is continuous; digital refers to an entity that is discrete.

- The second section shows that only periodic analog signals can be used in data communication. The section discusses simple and composite signals. The attributes of analog signals such as period, frequency, and phase are also explained.

- The third section shows that only non-periodic digital signals can be used in data communication. The attributes of a digital signal such as bit rate and bit length are discussed. We also show how digital data can be sent using analog signals. Baseband and broadband transmission are also discussed in this section.

Chapter 3: Outline

- The fourth section is devoted to transmission impairment. The section shows how attenuation, distortion, and noise can impair a signal.

- The fifth section discusses the data rate limit: how many bits per second we can send with the available channel. The data rates of noiseless and noisy channels are examined and compared.

3.1 Data and Signals

- A scenario between Alice and Bob
  - ✓ Alice working in Sky Research needs to have communication with Bob of Scientific Books to publish her research.
  - ✓ Five level communication between Alice and Bob
    - Application, Transport, Network, Datalink Layer – Logical communication
    - Physical Layer - Physical communication
  - ✓ Alice and Bob exchange data.
    - A signal is exchanged in physical layer.
  - ✓ Media have to change data to signals.
    - Data can be analog or digital
    - Signal can be analog or digital

3.1 Data and Signals

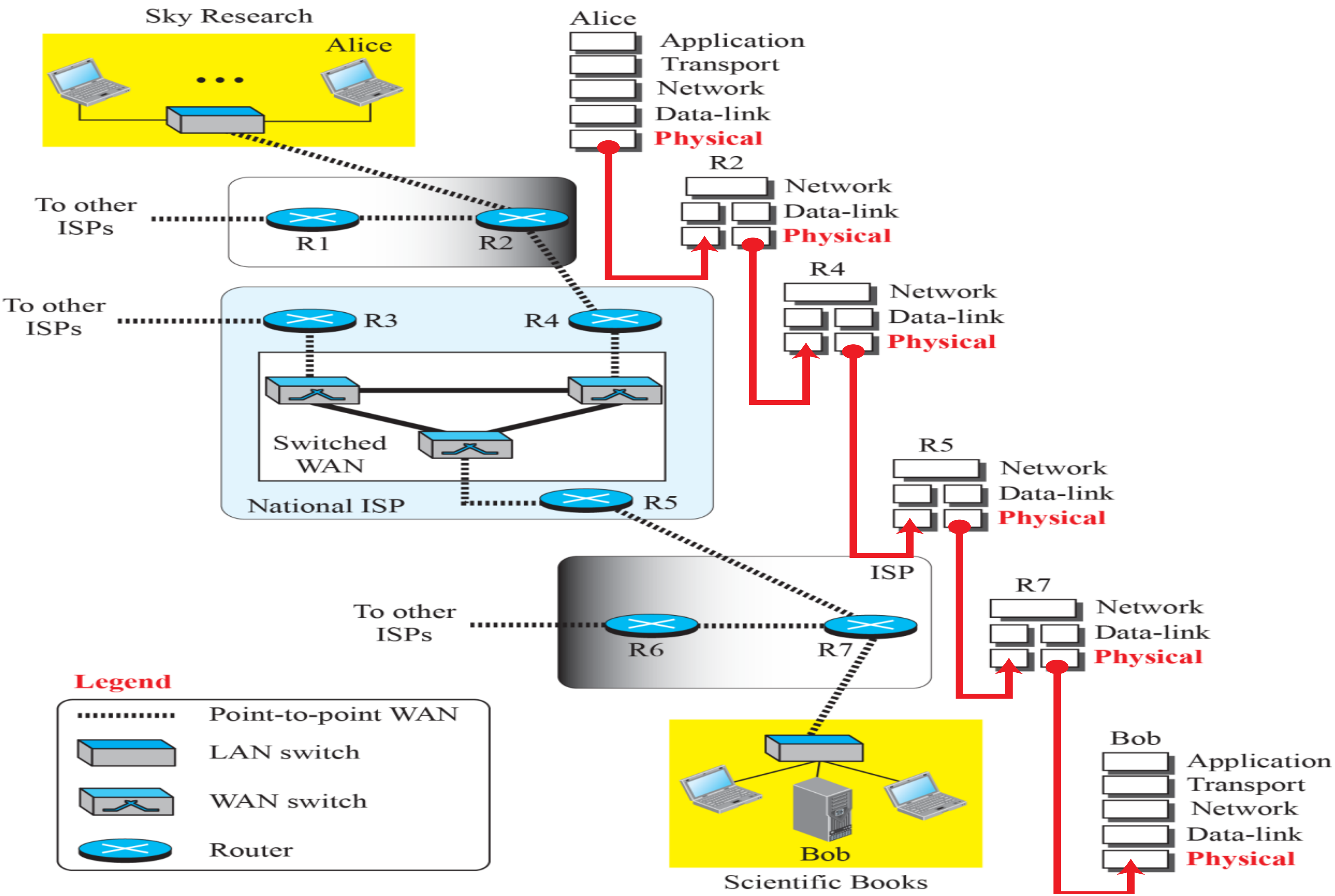


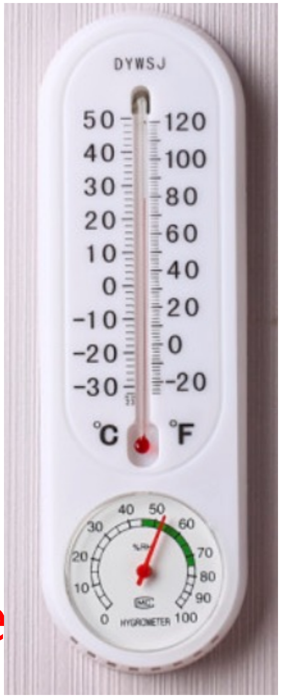
Figure 3.1: Communication at the physical layer

3.1.1 Analog and Digital Data

- Data can be analog or digital.

- Analog data refers to information that is continuo

  ✓ Ex : Voice, Temperature, Wave of Earthquake

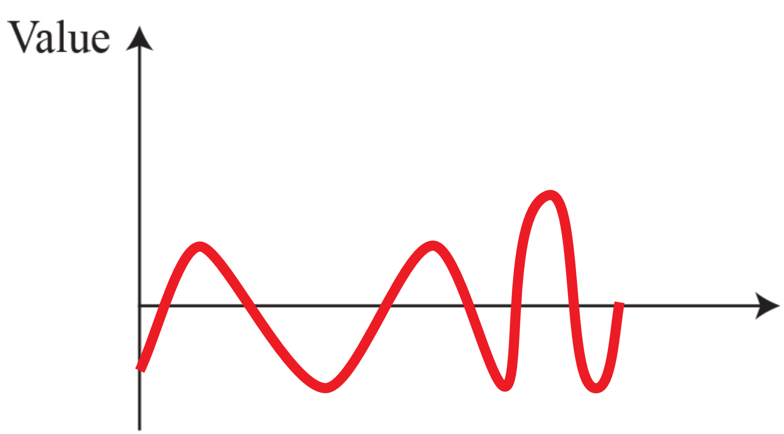


- Digital data refers to information that has discrete

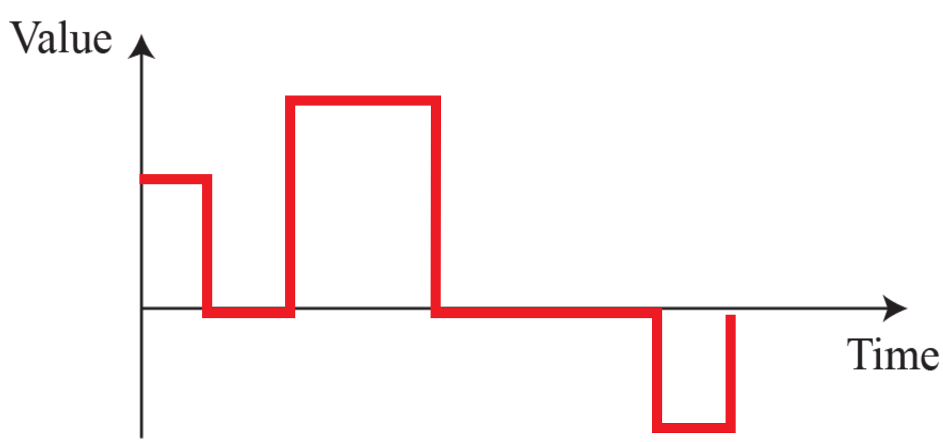
  ✓ Ex : 0 or 1, digital clock

3.1.2 Analog and Digital Signal

- Signals can be either analog or digital.
  - ✓ An analog signal has infinitely many levels of intensity over a period of time.
  - ✓ A digital signal can have only a limited number of defined values.
- Comparison of analog and digital signals



a. Analog signal



b. Digital signal

3.1.3 Periodic and Non-periodic Signal

- A periodic signal completes a pattern within a time frame, called a period, and repeats that pattern over subsequent identical periods.
  - ✓ The completion of one pattern is called a cycle.
- A nonperiodic signal changes without exhibiting a pattern or cycle.

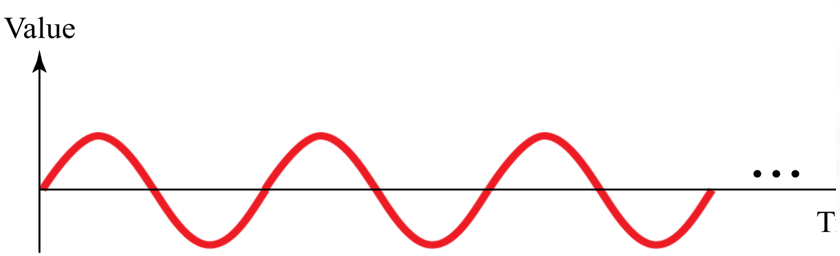
In data communications, we commonly use periodic analog signals and nonperiodic digital signals.

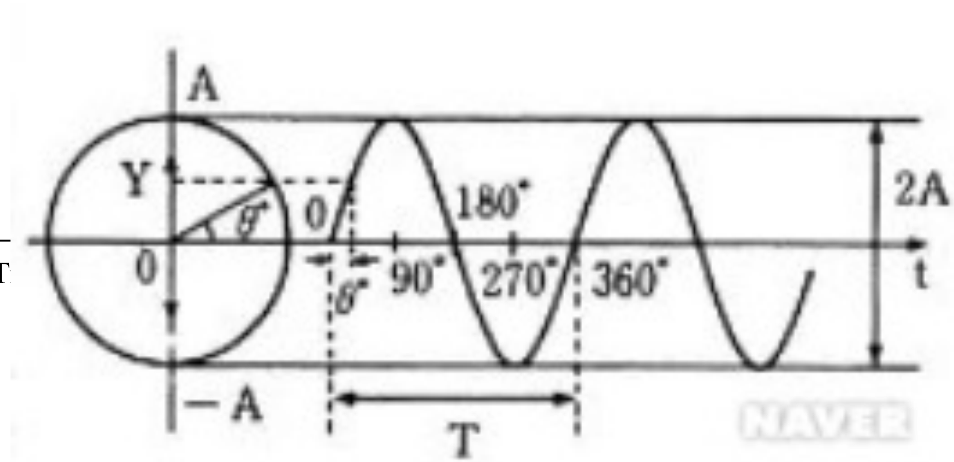
3.2 Periodic Analog Signals

- 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.

3.2.1 Sine Wave

- The sine wave is the most fundamental form of a periodic analog signal.
- A sine wave can be represented by three parameters : peak Amplitude, Frequency, Phase.



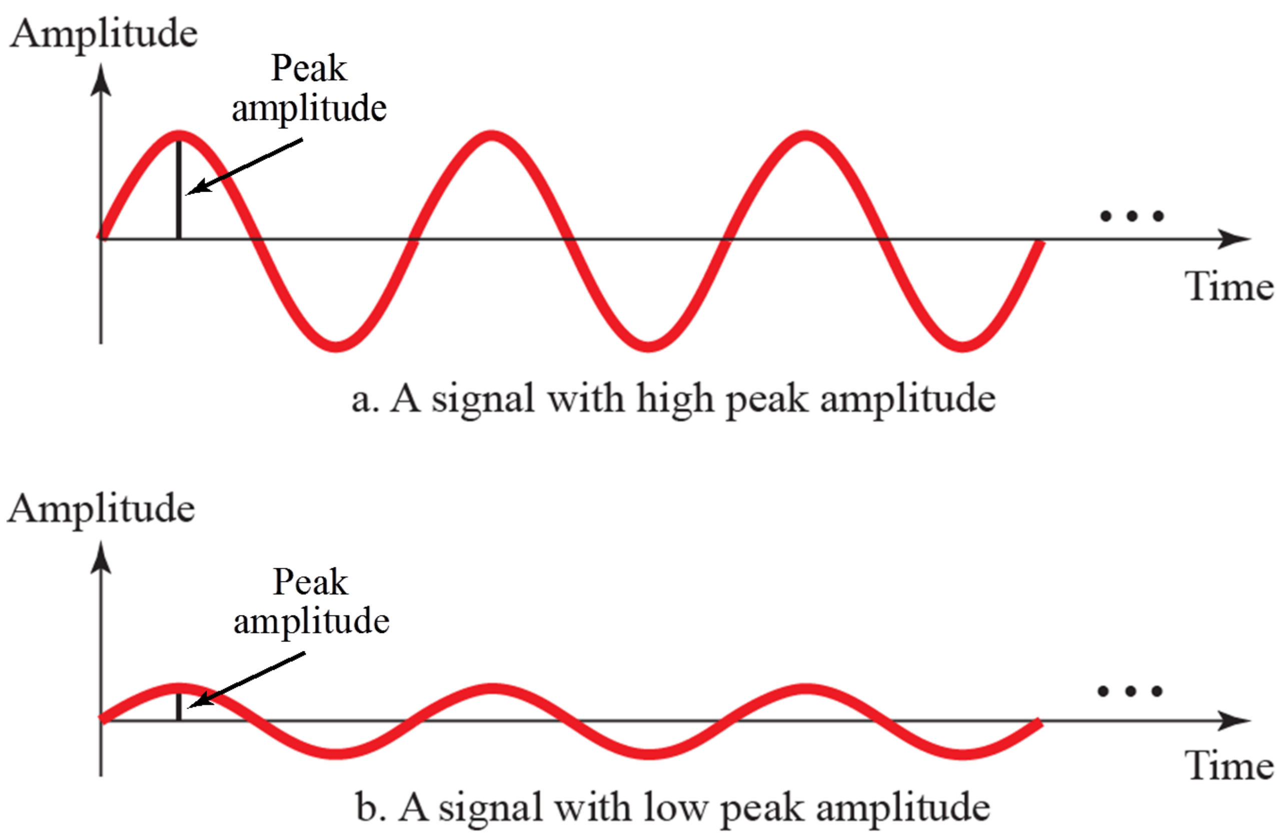


S(t) = A sin (2π f t + θ)

✓ *f is frequency*
✓ $\theta = 0 \sim 360$ *degree*

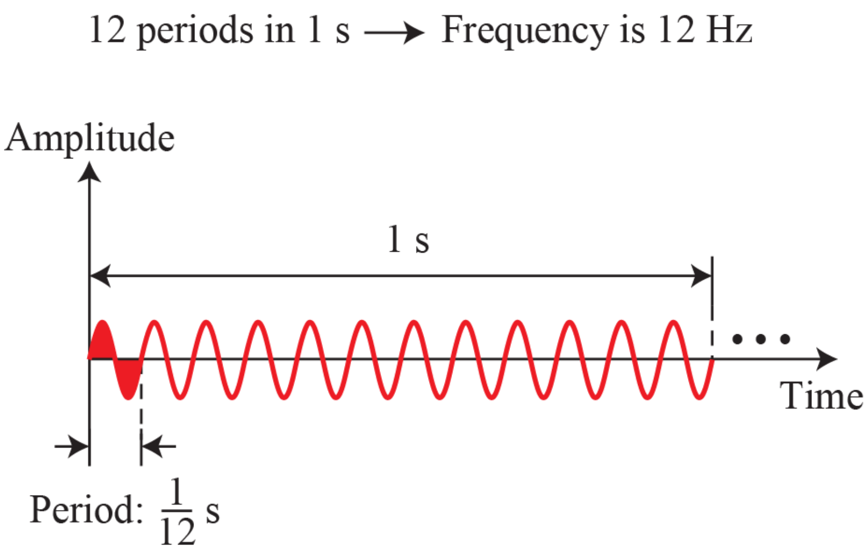
3.2.1 Sine Wave

- Two signals with two different amplitudes

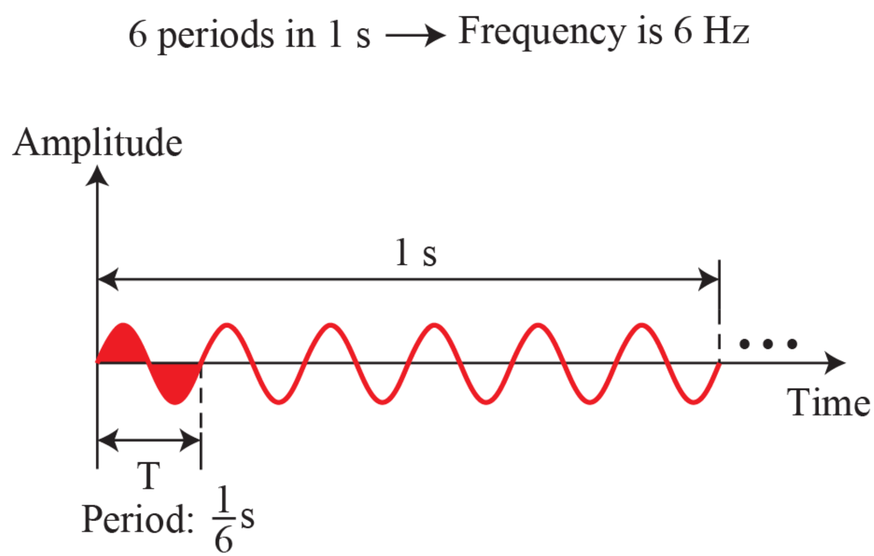


3.2.1 Sine Wave

- Two signals with the same phase and amplitudes, but different frequency.



a. A signal with a frequency of 12 Hz



b. A signal with a frequency of 6 Hz

If a signal does not change at all, its frequency is zero.
If a signal changes instantaneously, its frequency is infinite.

3.2.1 Sine Wave

- **Period** is the amount of time, in seconds, a signal needs to complete 1 cycle.
- **Frequency** is the number of period s in 1s.

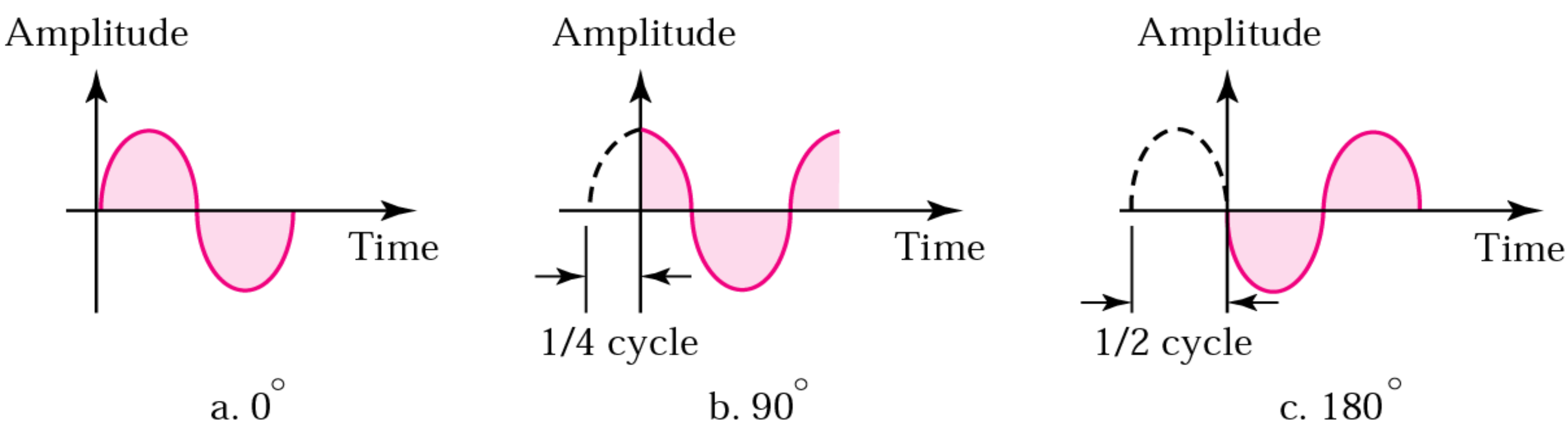
$$f = \frac{1}{T} \quad and \quad T = \frac{1}{f}$$ f is frequency and T is period.

- **Units of period and frequency**

Period		*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

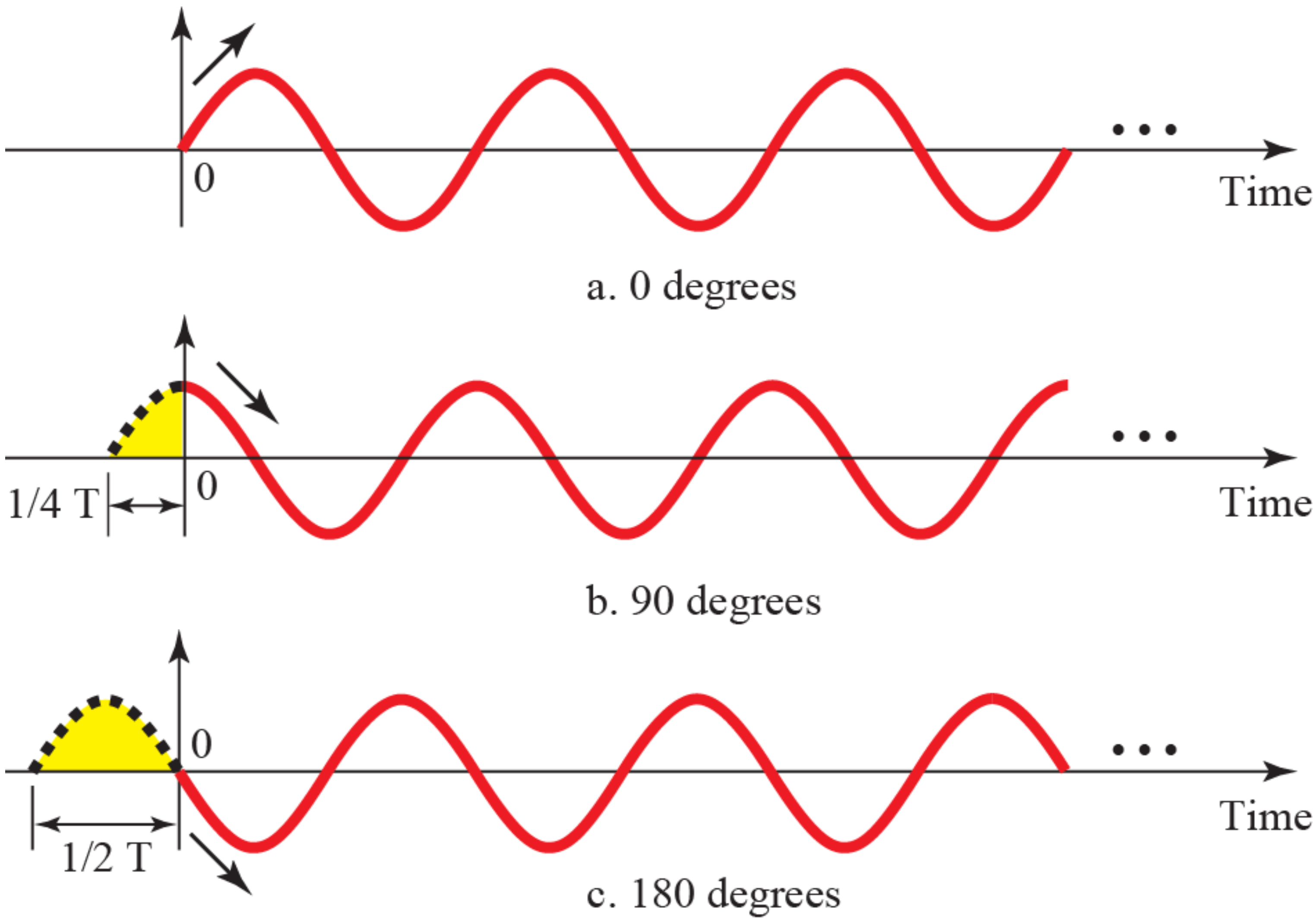
3.2.2 Phase

- The term phase describes the position of the waveform relative to time 0.
- If the wave is shifted backward or forward along the time axis, phase describes the amount of that shift.
- It indicates the status of the first cycle.



3.2.2 Phase

- Three sine waves with different phases



3.2.4 Time and Frequency Domains

■ Time Domain Plot

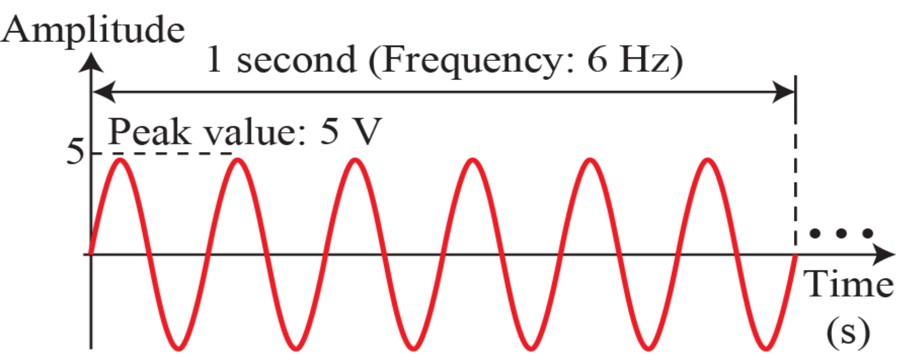
- ✓ It shows changes in signal amplitude with respect to time (it is an amplitude-versus-time plot).
- ✓ Phase is not explicitly shown on a time-domain plot.

■ Frequency Domain Plot

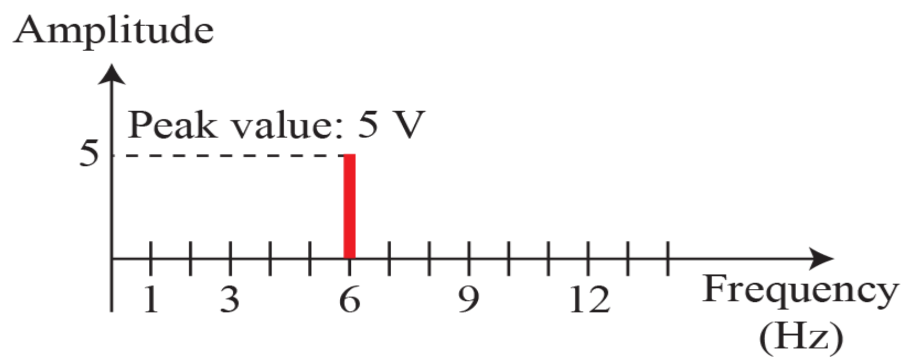
- ✓ It shows the relationship between amplitude and frequency.
- ✓ It is concerned with only peak value and frequency.
- ✓ Changes of amplitude are not shown.

3.2.4 Time and Frequency Domains

- Single sine waves



a. A sine wave in the time domain

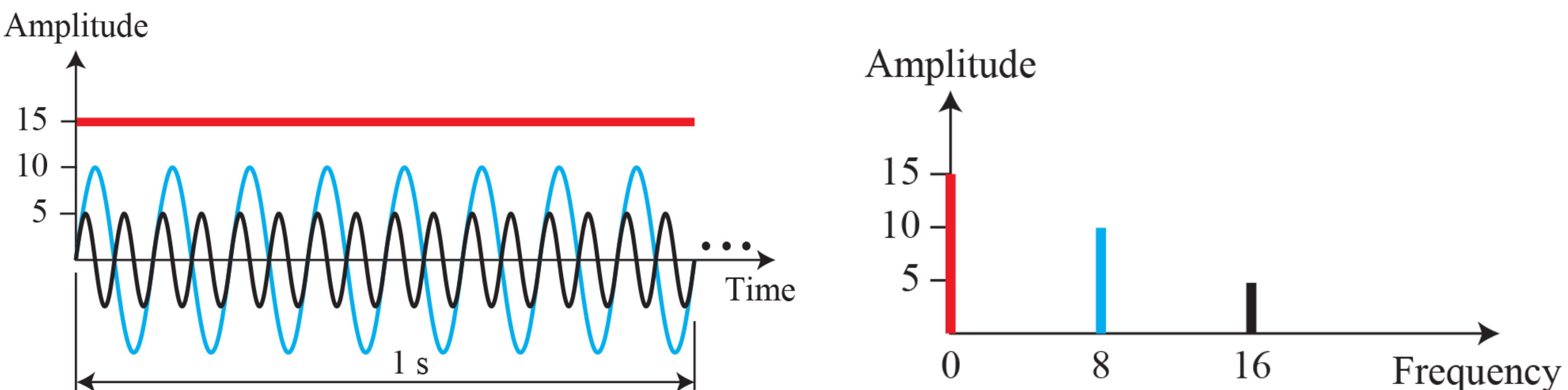


b. The same sine wave in the frequency domain

A complete sine wave in the time domain can be represented by one single spike in the frequency domain.

3.2.4 Time and Frequency Domains

- Three sine waves



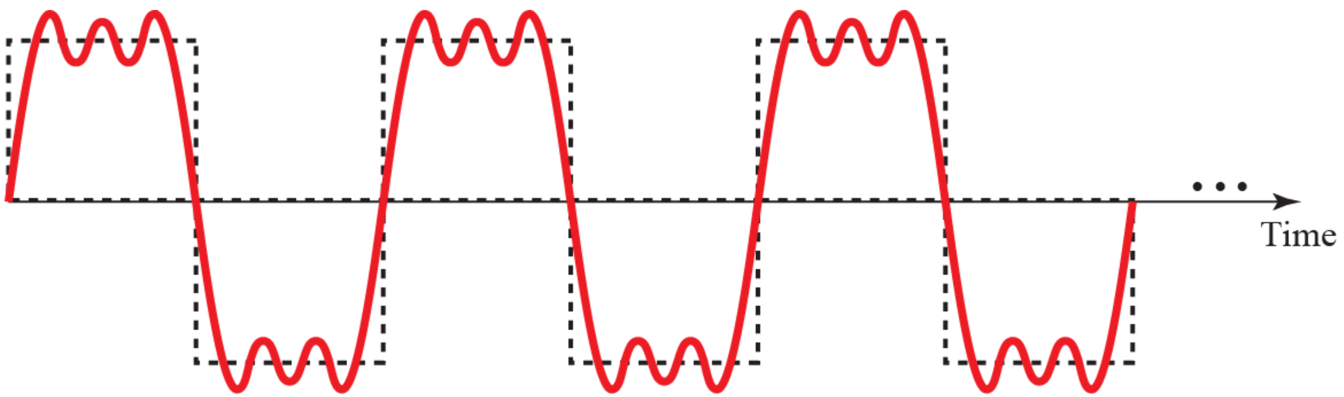
a. Time-domain representation

b. Frequency-domain representation

- ✓ ***A single-frequency sine wave is not useful in data communications;***
- ✓ ***we need to send a composite signal, a signal made of many simple sine waves.***

2.3.5 Composite Signals

- A periodic composite signal with frequency f.



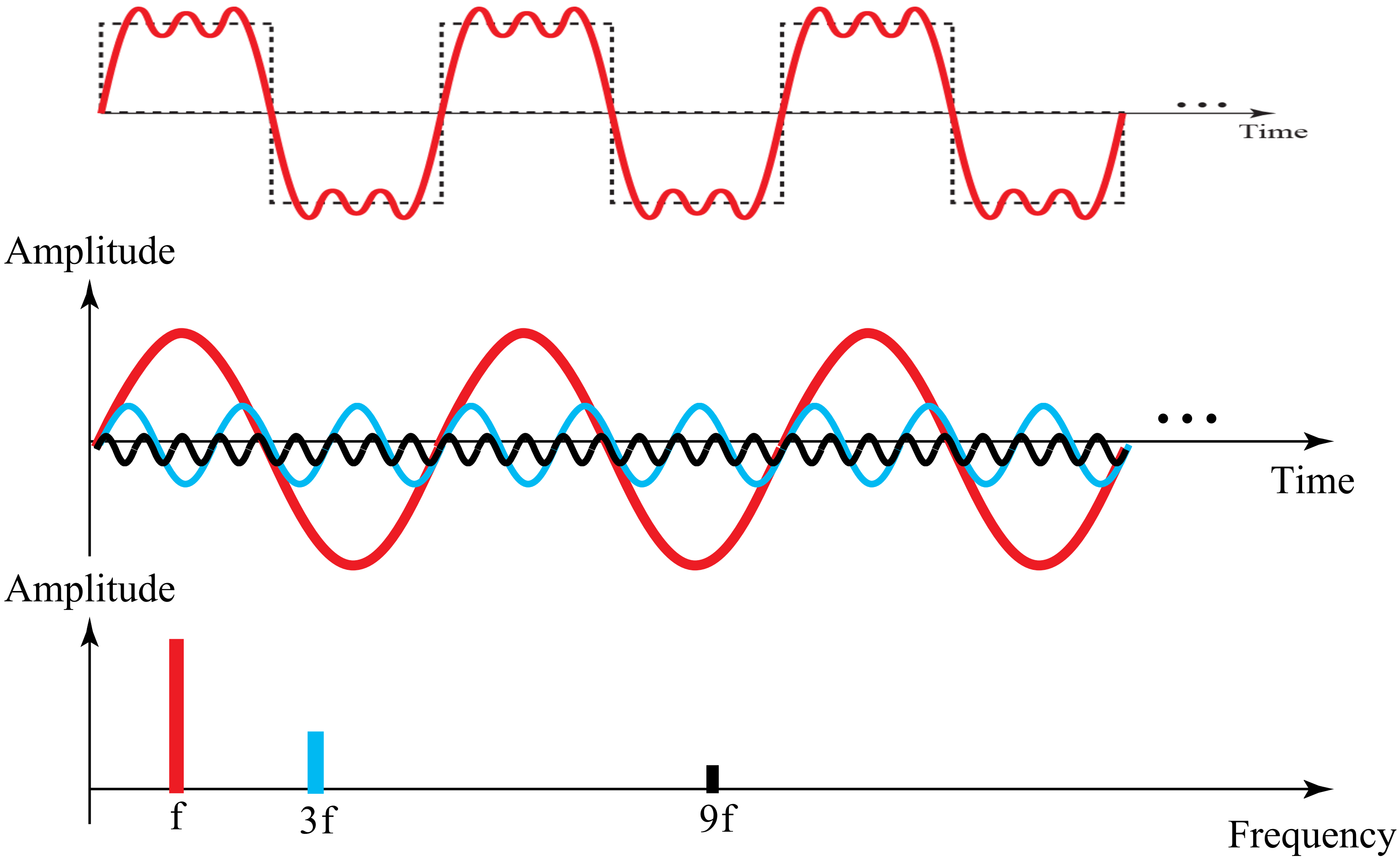
✓ It is very difficult to manually decompose this signal into a series of simple sine waves.

✓ **Fourier Series** http://jaeseo0519.tistory.com/127

According to Fourier analysis, any composite signal is a combination of simple sine waves with different frequencies, amplitudes, and phases.

Example 3.8

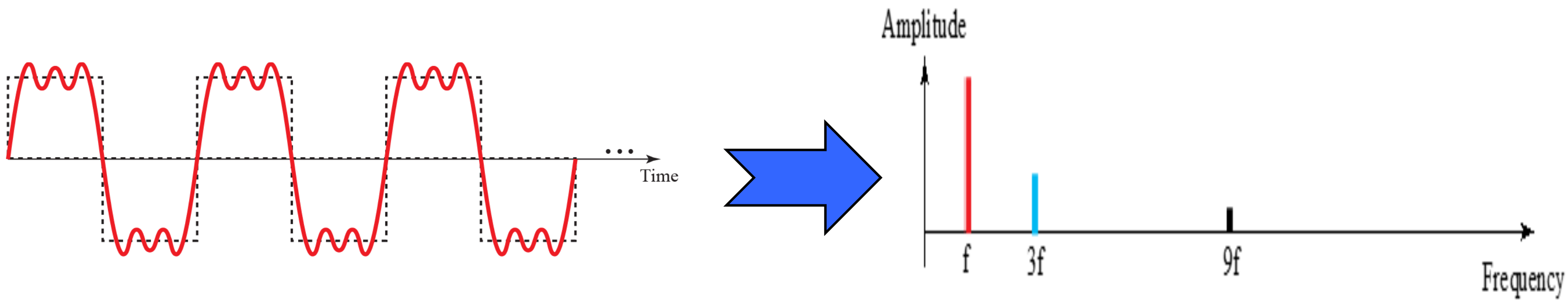
- Decomposition of a composite periodic signal



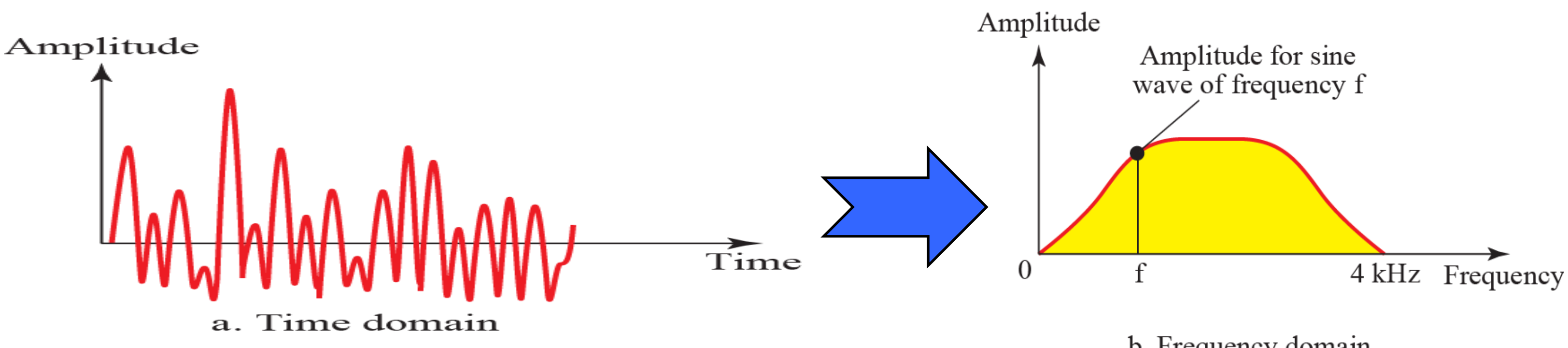
b. Frequency-domain decomposition of the composite signal

3.2.5 Composite Signals

- Decomposition of Periodic composite signal
  - ➔ a series of signals with discrete frequencies.



- Decomposition of Nonperiodic composite signal
  - ➔ a series of signals with continuous frequencies.



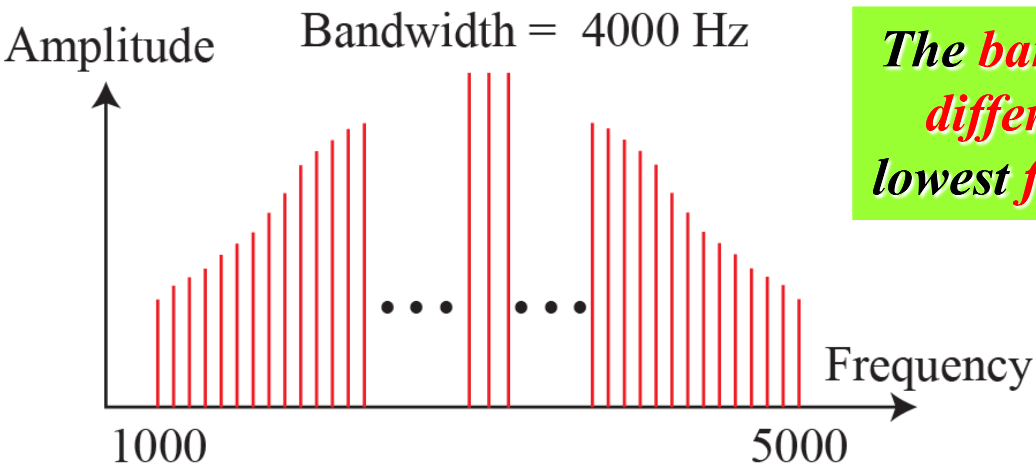
3.2.6 Bandwidth

- The range of frequencies contained in a composite signal is its bandwidth.
  - ✓ If a composite signal contains frequencies between 1000 and 5000, its bandwidth is 5000 − 1000 = 4000.

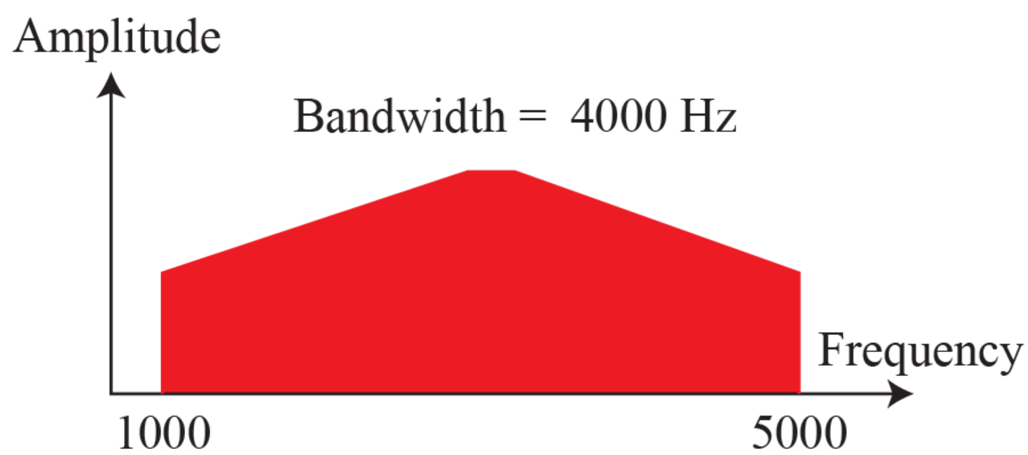
The bandwidth of a composite signal is the difference between the highest and the lowest frequencies contained in that signal.

3.2.6 Bandwidth

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



a. Bandwidth of a periodic signal



b. Bandwidth of a nonperiodic signal

***Figure 3.13:* The bandwidth of periodic and nonperiodic composite signals**

3.3 Digital Signals

- 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 3.17 shows two signals, one with two levels and the other with four levels.
- ***Topics discussed in this section:***

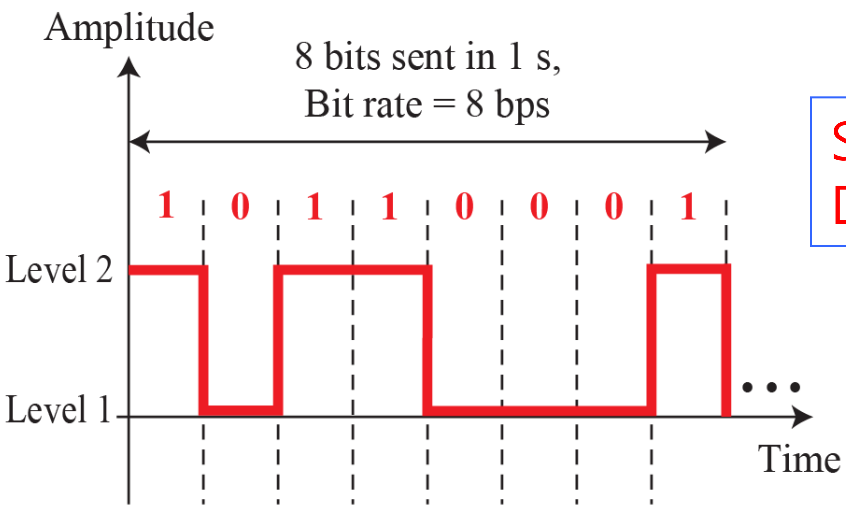
3.3.1 Bit Rate

3.3.2 Bit Length

3.3.3 Digital Signal as a Composite Analog Signal

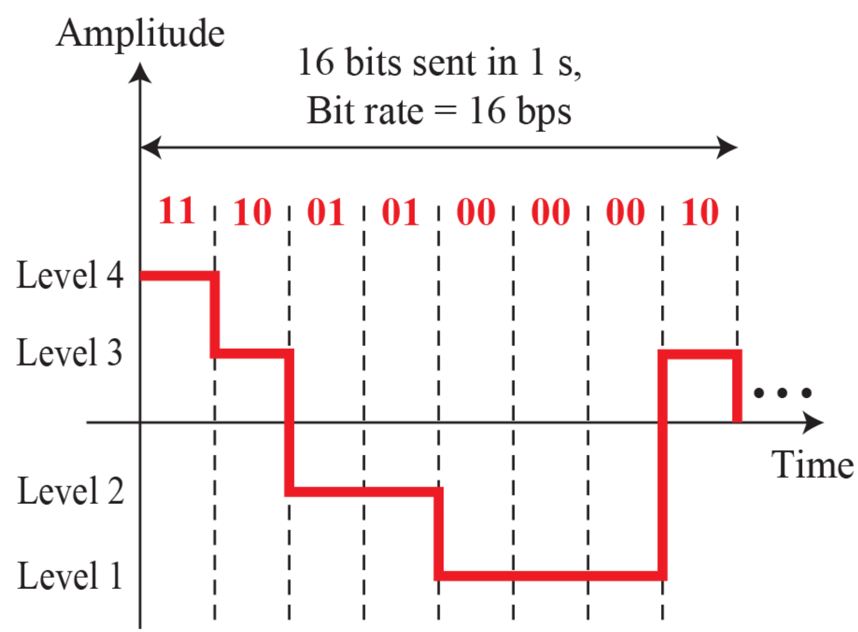
3.3.4 Transmission of Digital Signals

Figure 3.17: ***Two digital signals: one with two signal levels and the other with four signal levels***



a. A digital signal with two levels

Signal Rate : 8baud
Data Rate : 8bps



b. A digital signal with four levels

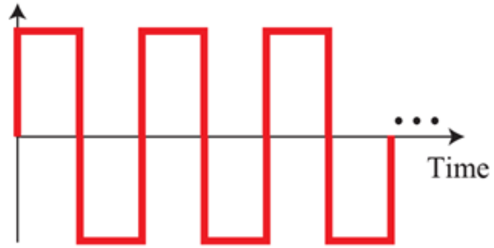
Signal Rate : 8baud
Data Rate : 16bps

3.3.3 Digital as Composite Analog

- A digital signal is a composite analog signal and it's bandwidth is infinite.

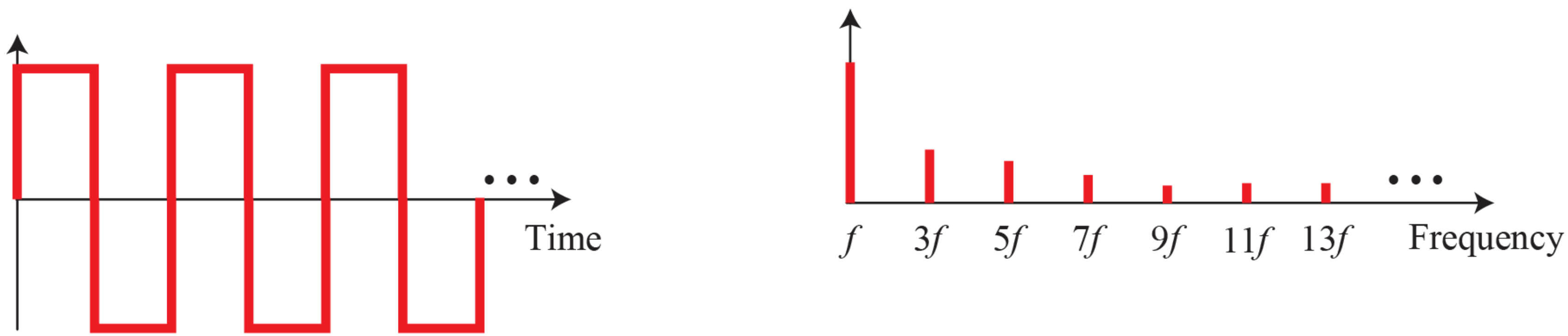
- A digital signal connect vertical and horizontal line segments in the time domain.
  - ✓ Vertical line means a frequency of infinity.
  - ✓ Horizontal line means a frequency of zero.

- Going from a frequency of zero to infinity implies all frequencies in between are part of the domain.

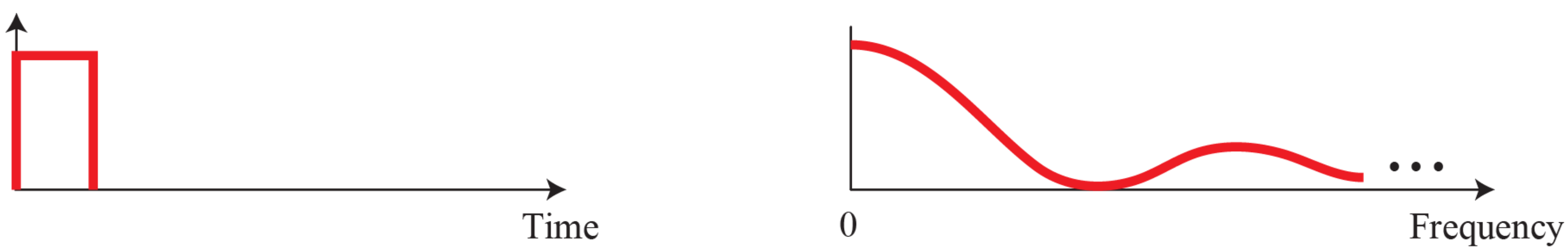


3.3.3 Digital as Composite Analog

- The time and frequency domains of periodic and nonperiodic digital signals



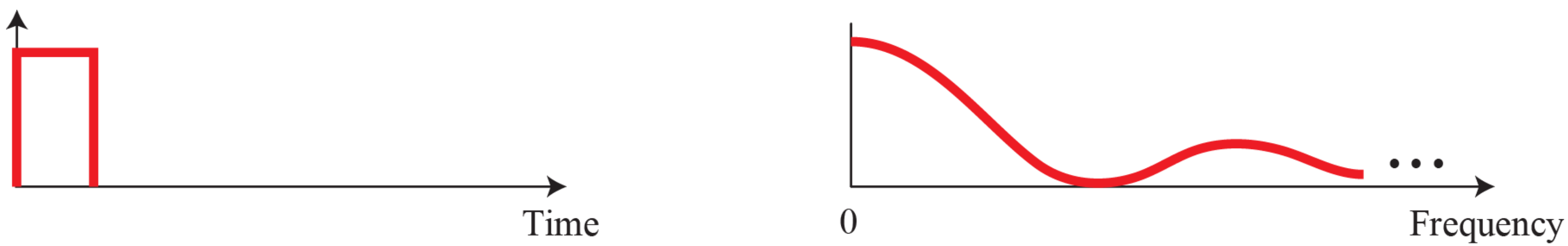
a. Time and frequency domains of periodic digital signal



b. Time and frequency domains of nonperiodic digital signal

3.3.4 Transmission of Digital Signals

- A digital signal is a composite analog signal with an infinite bandwidth.



b. Time and frequency domains of nonperiodic digital signal

- Transmission of Digital Signals
  - ✓ Baseband Transmission
  - ✓ Broadband Transmission

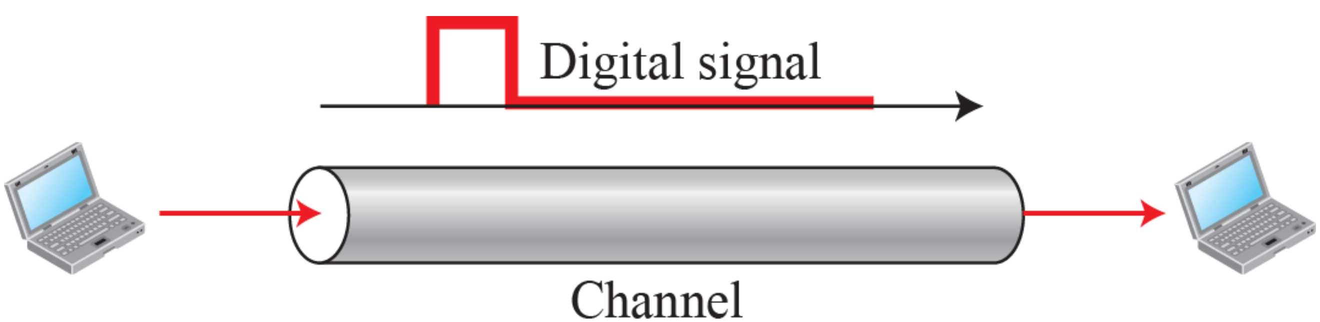
3.3.4 Transmission of Digital Signals

■ Baseband Transmission

- ✓ It means sending a digital signal over a channel without changing in modulation (the digital signal to an analog signal).

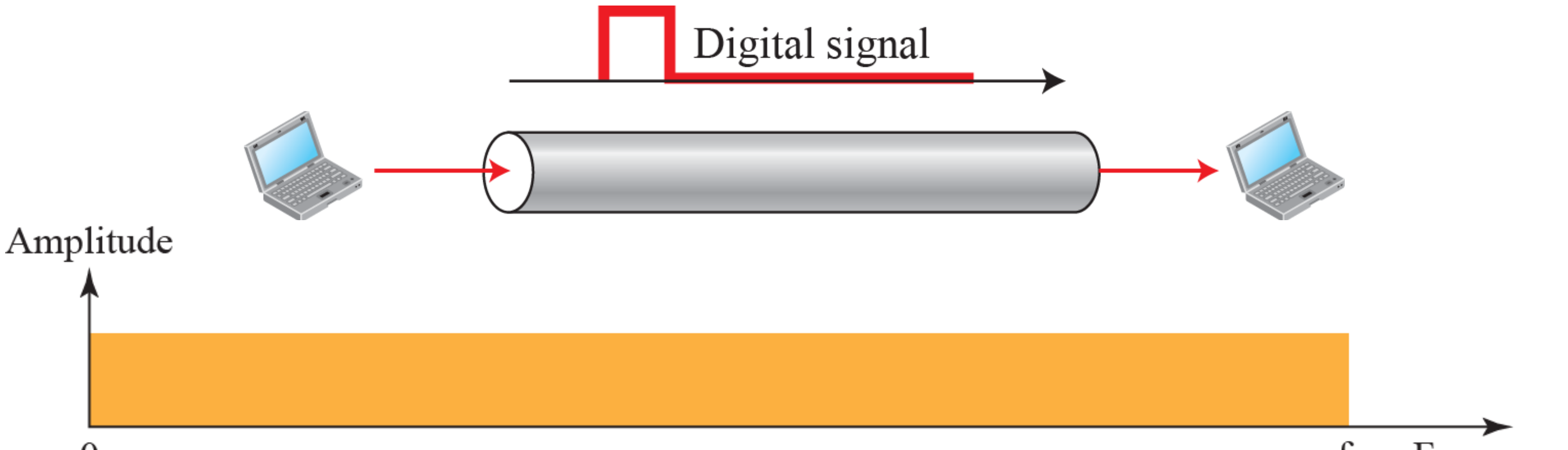
- ✓ Baseband transmission requires dedicated low-pass channel with a bandwidth that starts from zero.

- ✓ Baseband can be synonymous with low-pass or non-modulated

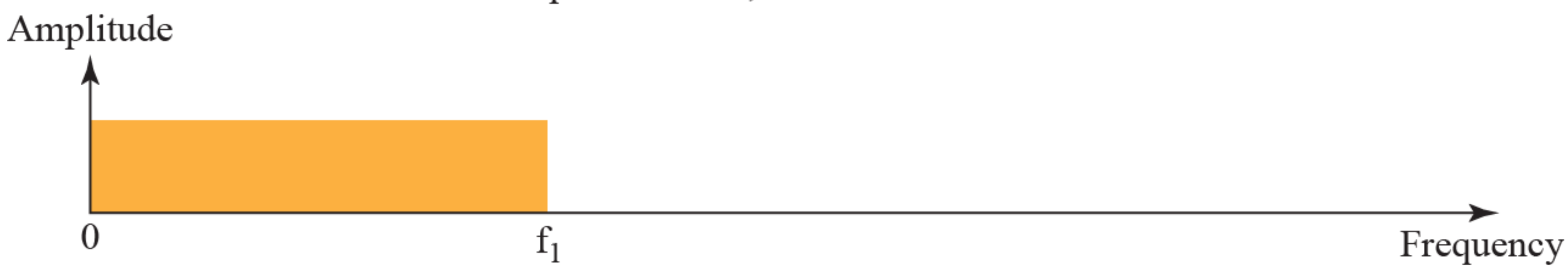


3.3.4 Transmission of Digital Signals

- Baseband transmission of a digital signal that preserves the shape of the digital signal is possible only if we have a low-pass channel with an infinite or very wide bandwidth.



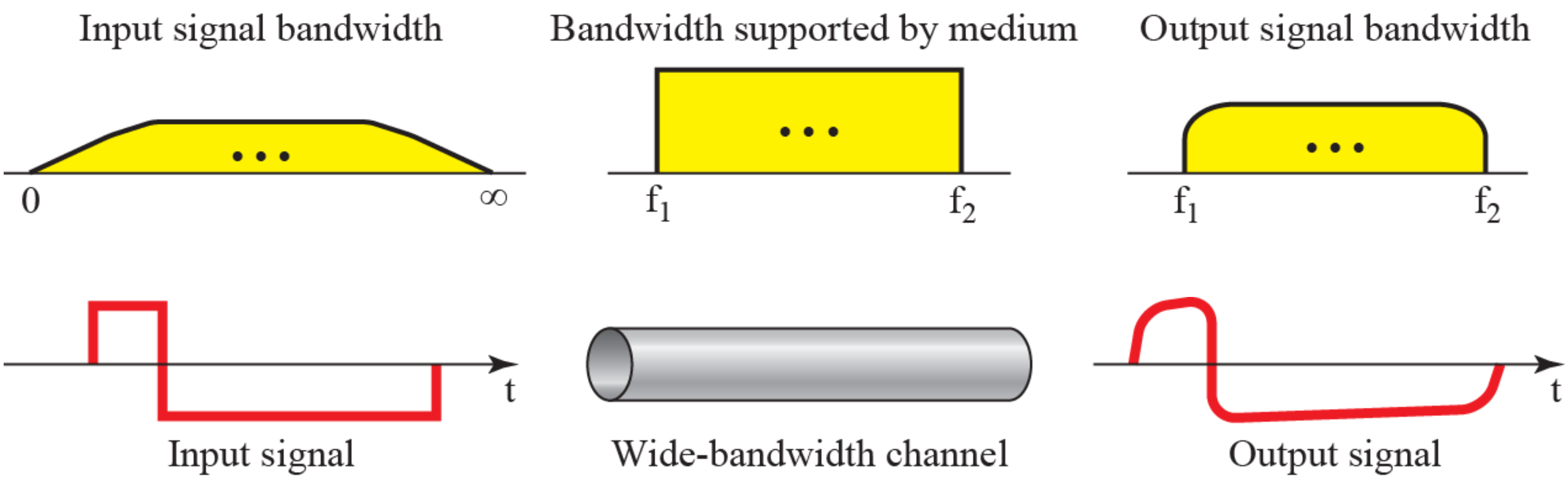
a. Low-pass channel, wide bandwidth



b. Low-pass channel, narrow bandwidth

3.3.4 Transmission of Digital Signals

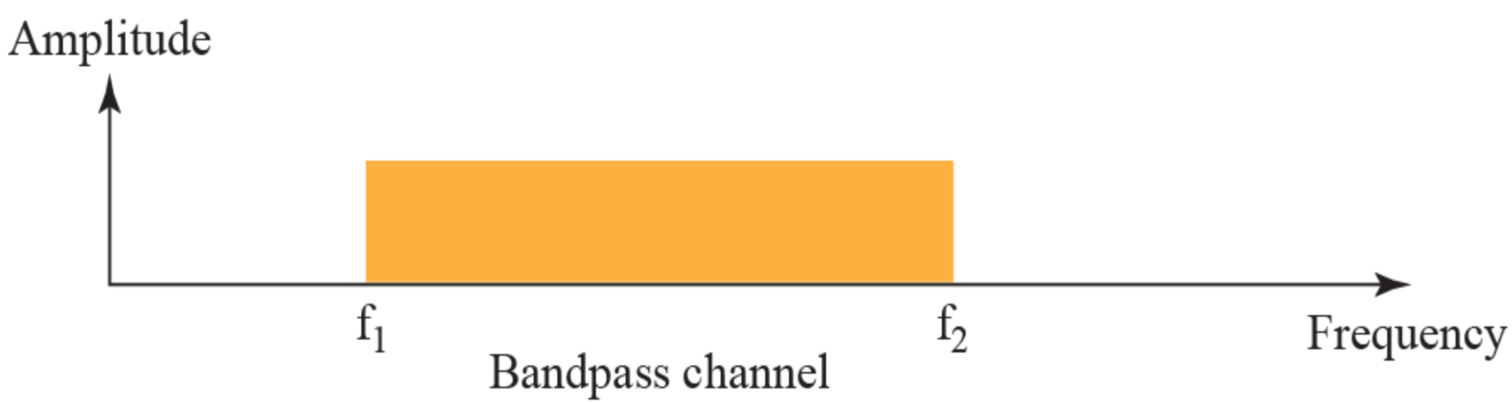
- Case 1: Low-pass Channel with Wide Bandwidth
  - ✓ Dedicated medium with an infinite bandwidth between sender and receiver



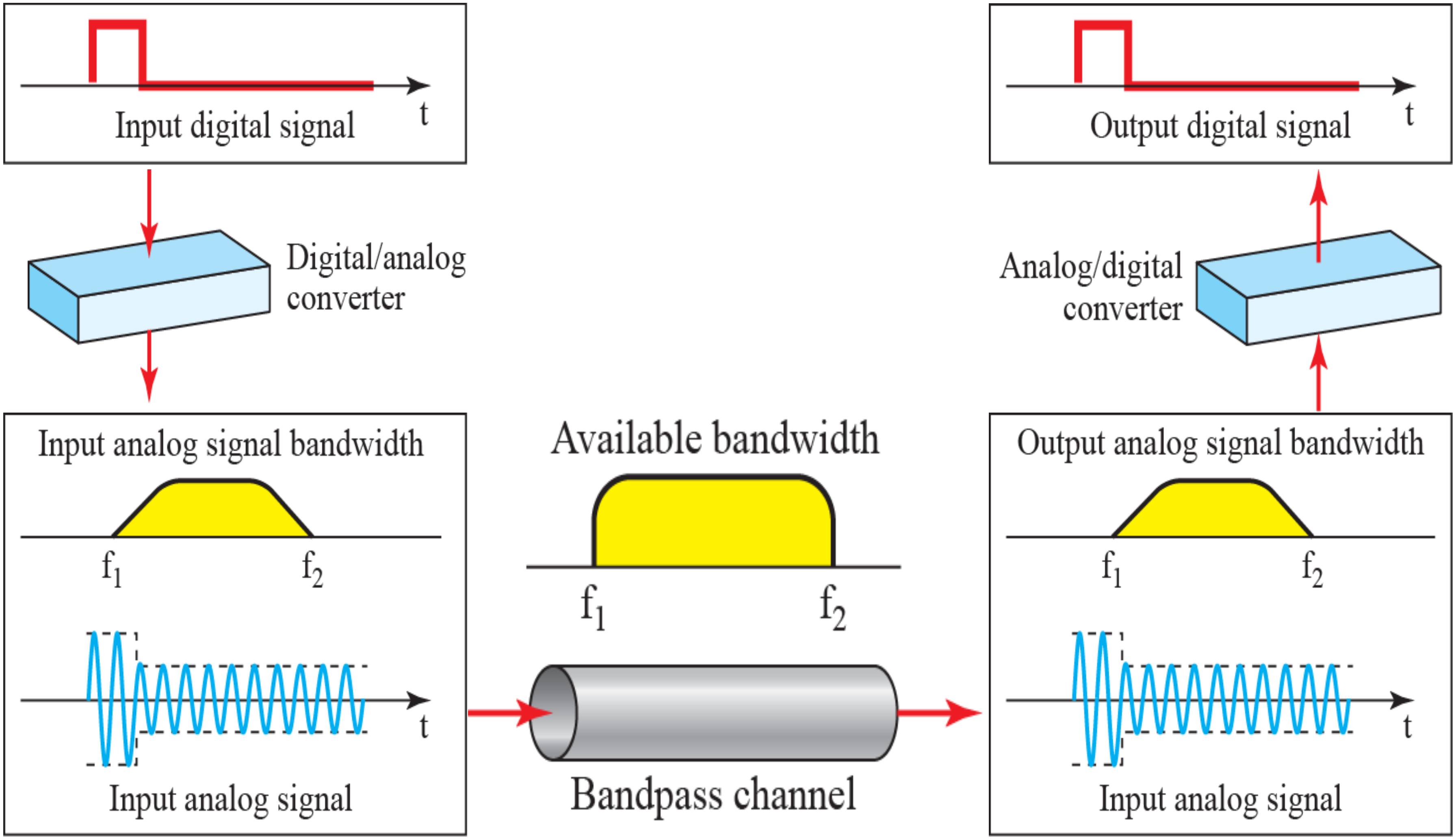
  - ✓ f1 is close to zero, and f2 is very high.
  - ✓ An example of a dedicated channel where the entire bandwidth is used as one single channel is a LAN.

3.3.4 Transmission of Digital Signals

- Broadband Transmission(Using Modulation)
  - ✓ If the available channel is a bandpass channel, we cannot send the digital signal directly to the channel;
  - ✓ we need to convert the digital signal to an analog signal before transmission. ➔ Modulation



3.3.4 Transmission of Digital Signals



Amlpitude Modulation

Figure 3.25: Modulation of a digital signal for transmission on band-pass channel

Example 3.25

■ Examples of Broadband Transmission

✓ The sending of computer data through a telephone line with a limited bandwidth

✓ Digital cellular telephone

- Digital cellular phones convert the analog voice signal to a digital signal.
- bandpass channel is available between caller and callee.
- We need to convert the digitized voice to a composite analog signal before sending.

Baseband & Broadband 영상

https://www.youtube.com/watch?v=Ph9N0XGmi-E

3.7 Summary

Q & A

- Analog & Digital
  - ✓ Data can be analog or digital
  - ✓ Signal can be analog or digital
- In data communication, we use periodic analog signal or nonperiodic digital signal.
  - ✓ Sine Wave - Frequency, Amplitude, Phase
  - ✓ Composite Signal - Bandwidth
- A digital signal is a composite analog signal with an infinite bandwidth.
  - ✓ Baseband Transmission is possible in a low-pass channel with a infinite or very wide bandwidth.
  - ✓ In a band-pass channel, a digital signal needs to be converted to an analog signal.

3.7 Summary

Q & A

- Bit Rate
  - ✓ Nyquist bit rate formula defines maximum bit rate for a noiseless channel.
  - ✓ Shannon capacity is used to find the maximum bit rate for a noisy channel.
- Transmission Impairment
  - ✓ Attenuation, distortion, and noise can impair a signal.
- Data Rate Limit
  - ✓ how many bits per second we can send with the available channel?
- Performance
  - ✓ bandwidth, throughput, latency, and jitter

3.7 Summary

- Bit Rate
  - ✓ Nyquist bit rate formula defines maximum bit rate for a noiseless channel.
  - ✓ Shannon capacity is used to find the maximum bit rate for a noisy channel.
- Attenuation, distortion, and noise can impair a signal.

Q & A