S.Y.B.Sc.IT SEM III

COMPUTER NETWORKS (PUSIT303)

BY,

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UNIT II

2. Introduction to Physical layer
3. Introduction to the Data Link Layer
4. Wireless LANs

2. Introduction to Physical layer

INTRODUCTION TO PHYSICAL LAYER

- One of the major functions of the physical layer is to **move data in the form of electromagnetic signals across a transmission medium.**
- Generally, the data usable to a person or application are **not in a form that can be transmitted over a network**.
- For example, a photograph must first be **changed to a form that transmission media can accept.**
- Transmission media work by conducting energy along a physical path. For transmission, **data needs to be changed to signals**.

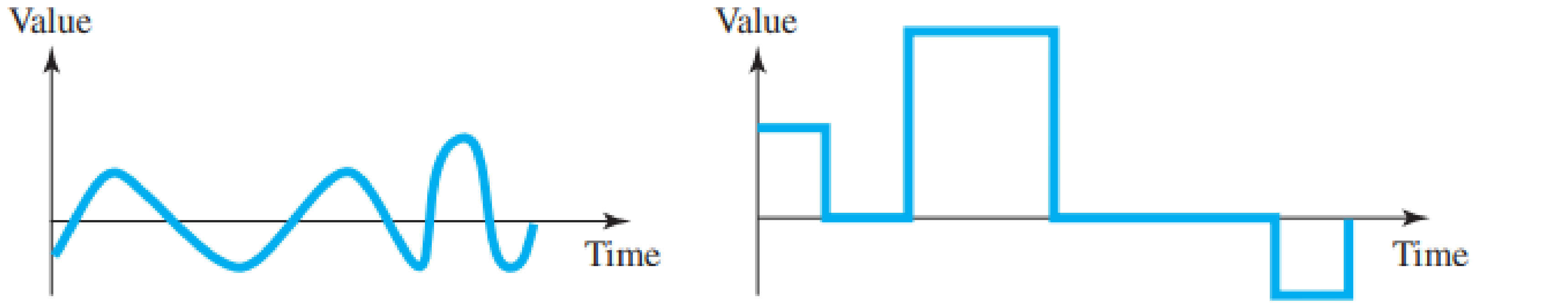
ANALOG AND DIGITAL DATA

- To be transmitted, **data must be transformed to electromagnetic signals.**
- **Data can be Analog or Digital**.
- 1. **Analog data** refers to **information that is continuous**;
- ex. An analog clock that has hour, minute, and second hands gives information in a continuous form; the movements of the hands are continuous , sounds made by a human voice
- 2. **Digital data** refers to **information that has discrete states**. Digital data take on discrete values.
- ex. A digital clock that reports the hours and the minutes will change suddenly from 8:05 to 8:06. And data are stored in computer memory in the form of 0s and 1s

SIGNALS

- Signals can be of two types:
- 1. Analog Signal: They have **infinite number of values in a range.**
- 2. Digital Signal: They have **limited number of defined values**

Figure 3.2 *Comparison of analog and digital signals*



a. Analog signal

b. Digital signal

PERIODIC & NON PERIODIC SIGNALS

- **Signals** which **repeat itself after a fixed time period** are called **Periodic Signals**.
- A periodic signal **completes a pattern within a measurable time frame, called a period**, and **repeats that pattern over subsequent identical periods**. The **completion of one full pattern is called a cycle**.
- A <u>non-periodic signal changes without exhibiting a pattern or cycle that repeats over time</u>.
- <u>Signals which do not repeat itself after a fixed time period</u> are called <u>Non-Periodic Signals</u>.
- In **data communications**, we **commonly use periodic analog signals** and <u>non- periodic digital signals</u>.

PERIODIC ANALOG SIGNALS

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

1. Sine Wave

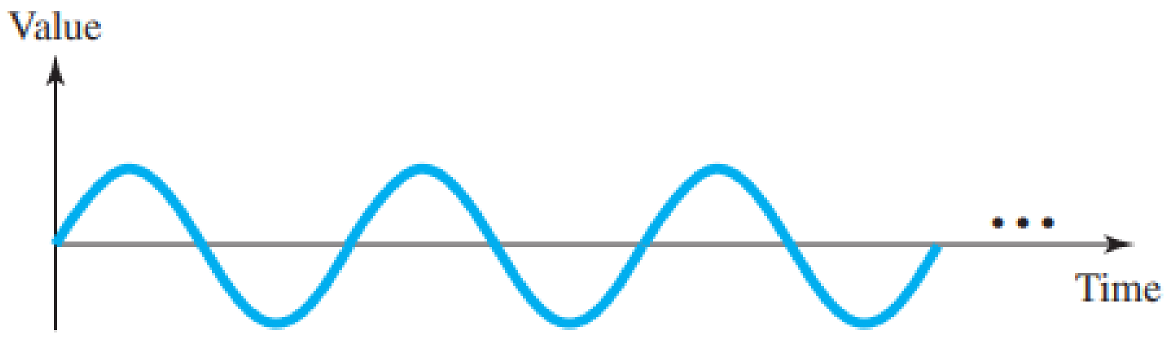
- A sine wave can be **represented by three parameters:**

➢peak amplitude

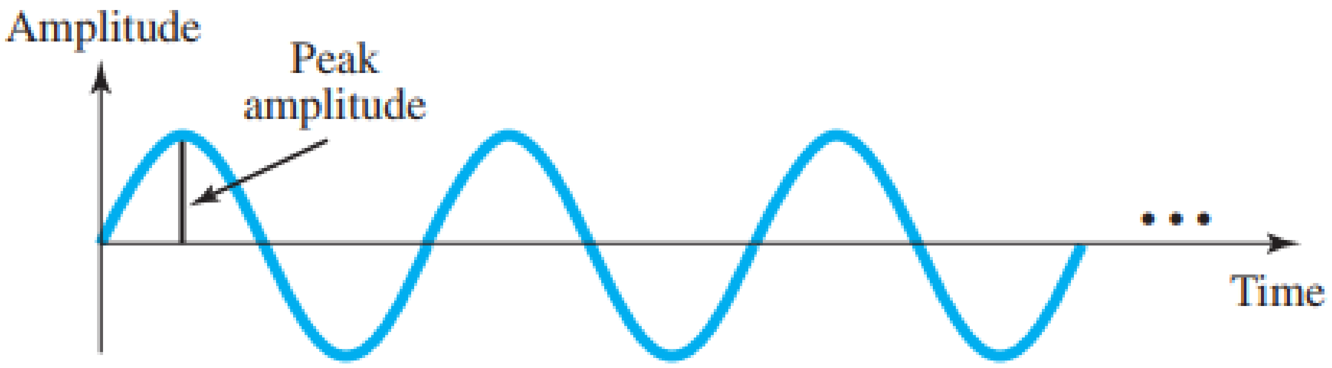
➢frequency

➢phase

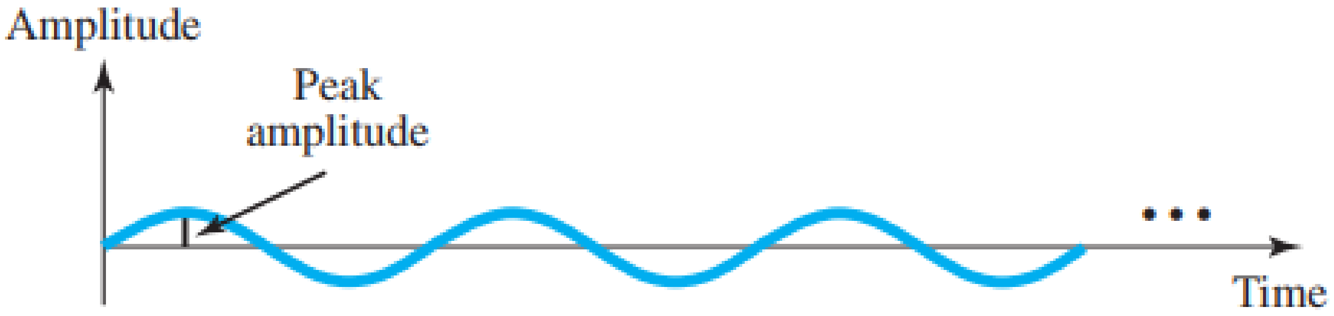
Figure 3.3 *A sine wave*



- **A. Peak Amplitude**
- The peak amplitude of a signal is the **absolute value of the highest intensity.**
- For electric signals, peak amplitude is **normally measured in volts.**



a. A signal with high peak amplitude



b. A signal with low peak amplitude

- **B. Period and Frequency**
- **Frequency** refers to the **number of cycles completed by the wave in one second.**
- **Frequency** is formally **expressed in Hertz** (Hz), which is cycle per second.
- ***Period*** refers to the ***time taken by the wave to complete one cycle***.
- ***Period*** is formally ***expressed in seconds***.

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

Frequency and period are the inverse of each other.

- Two signals with the same amplitude and phase, but different frequencies

Figure 3.5 *Two signals with the same amplitude and phase, but different frequencies*

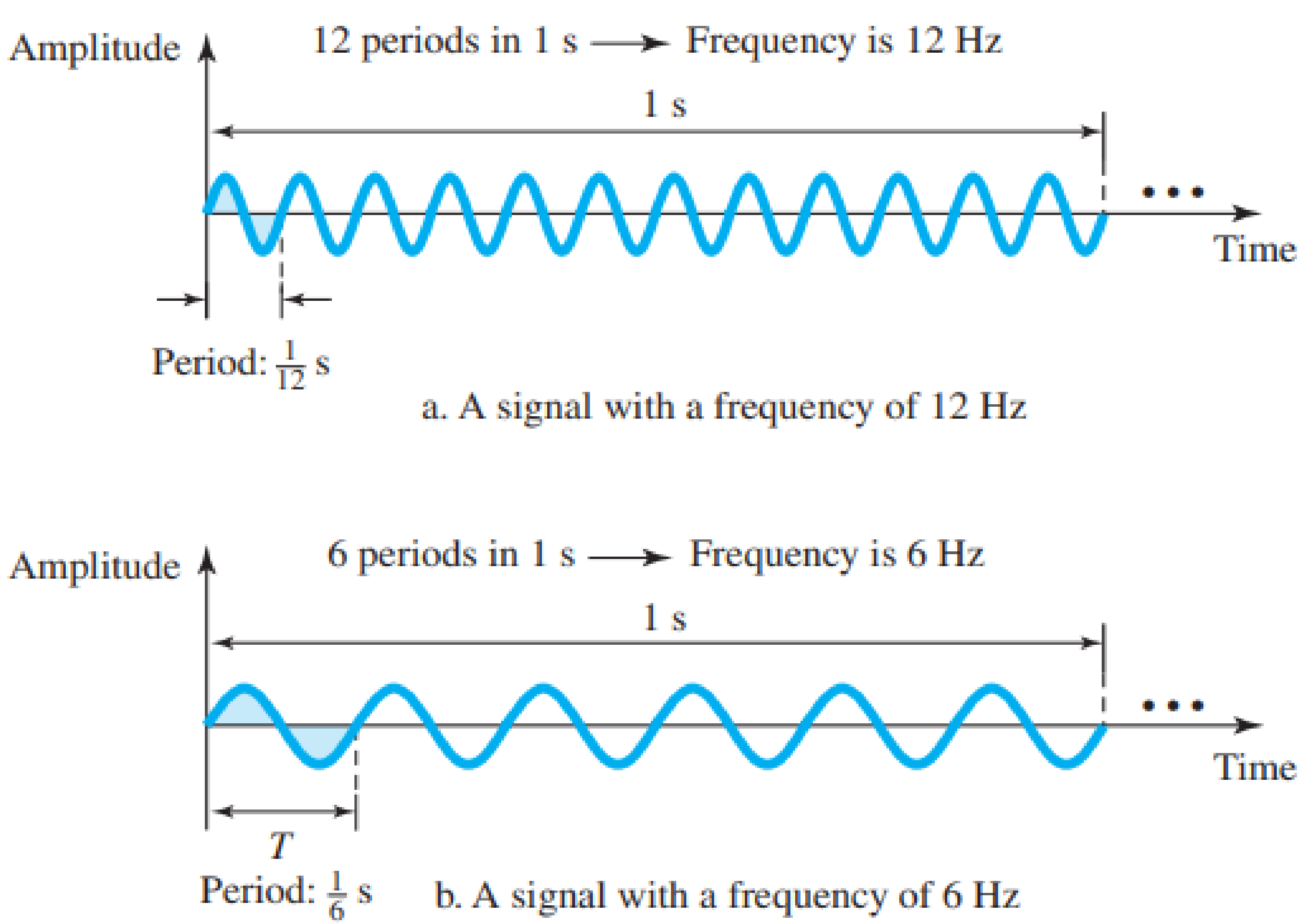


Table 3.1 *Units of period and frequency*

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

- **Example 3.3**
- The power we use at home has a frequency of 60Hz. The period of this sine wave can be determined as follows:

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

Q. frequency = 60 Hz

$T = 1/f = 1/60 = 0.0166 s$

$1 s = 10^3 ms$

$0.0166 \rightarrow ? ms$

$= 0.0166 \times 10^3 ms$

$= 16.6 ms$

Answer → 0.0166 seconds

OR

16.6 ms

- **Solve**
- Calculate the period of a wave whose frequency is 50 Hz

Q. frequency = 50 Hz

$T = 1/50 = 0.02\ s$

$1\ s = 10^3\ ms$

$= 0.02 \times 10^3\ ms$

$= \boxed{20\ ms}$

Answer = 0.02 s

OR

20ms

- **Solve**
- Calculate the frequency of a wave whose time period is 0.002 s

Q $T = 0.002\ s$

frequency = ?

$F = 1/T$

$= \frac{1}{0.002}$

$= \boxed{500\ Hz}$

- **Example 3.4**
- Express a period of 100 ms in microseconds.

Solution

From Table 3.1 we find the equivalents of 1 ms (1 ms is 10^{-3} s) and 1 s (1 s is 10^{6} µs). We make the following substitutions:

$$100\ \text{ms} = 100 \times 10^{-3}\ \text{s} = 100 \times 10^{-3} \times 10^{6}\ \mu\text{s} = 10^{2} \times 10^{-3} \times 10^{6}\ \mu\text{s} = 10^{5}\ \mu\text{s}$$

Q. 100 ms → ? µs

1] Convert ms in s

1 ms → 10^{-3} s

100 ms → ?

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

$= 10^{2} \times 10^{-3}$ s

$= 10^{-1}$ s

2] Convert s in µs

1 s → 10^{6} µs

10^{-1} s → ? µs

$= 10^{-1} \times 10^{6}$ µs

$= 10^{5}$ µs

$\boxed{100\ \text{ms} = 10^{5}\ \mu\text{s}}$

- **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).

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

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

Q. $T = 100$ ms
$f = ?$ kHz

1) convert ms → s
$1 \text{ ms} = 10^{-3} \text{ s}$
$100 \text{ ms} = ?$
$= 100 \times 10^{-3} \text{ s}$
$= 10^{2} \times 10^{-3} \text{ s}$
$= 10^{-1} \text{ s}$

2) Find frequency
$F = 1/T = 1/10^{-1} = 10 \text{ Hz}$

3) Convert Hz → kHz
$1 \text{ Hz} = 10^{-3} \text{ kHz}$
$10 \text{ Hz} = 10 \times 10^{-3} = \boxed{10^{-2} \text{ kHz}}$

- **Solve**
- The period of a signal is 100 ms. What is its frequency in megahertz?

Q. $T = 100\ ms$

$f = ?\ MHz$

1) convert $ms \rightarrow s$

$1ms \rightarrow 10^{-3} s$

$100ms \rightarrow ?\ s$

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

$= 10^{2} \times 10^{-3} s$

$= 10^{-1} s$

2) find frequency

$f = 1/T = 1/10^{-1} = 10\ Hz$

3) convert $Hz \rightarrow MHz$

$1\ Hz = 10^{-6}\ MHz$

$10\ Hz = ?\ MHz$

$= 10 \times 10^{-6} = \boxed{10^{-5}\ MHz}$

Frequency is the rate of change with respect to time. Change in a short span of time means high frequency. Change over a long span of time means low frequency.

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

- **C. Phase**
- Phase describes the **position of the waveform with respect to time** (specifically relative to time 0).
- If we think of the **wave as something that can be shifted backward or forward along the time axis, <u>phase describes the amount of that shift</u>.**
- It indicates the **status of the first cycle**.
- Phase is **measured in degrees or radians**
- ***[360º is 2π rad; 1º is 2π/360 rad, and 1 rad is 360/(2π)].***
- A phase shift of **360º** corresponds to a **shift of a complete period;**
- a phase shift of **180°** corresponds to a **shift of one-half of a period;**
- and a phase shift of **90º** corresponds to a **shift of one-quarter of a period**

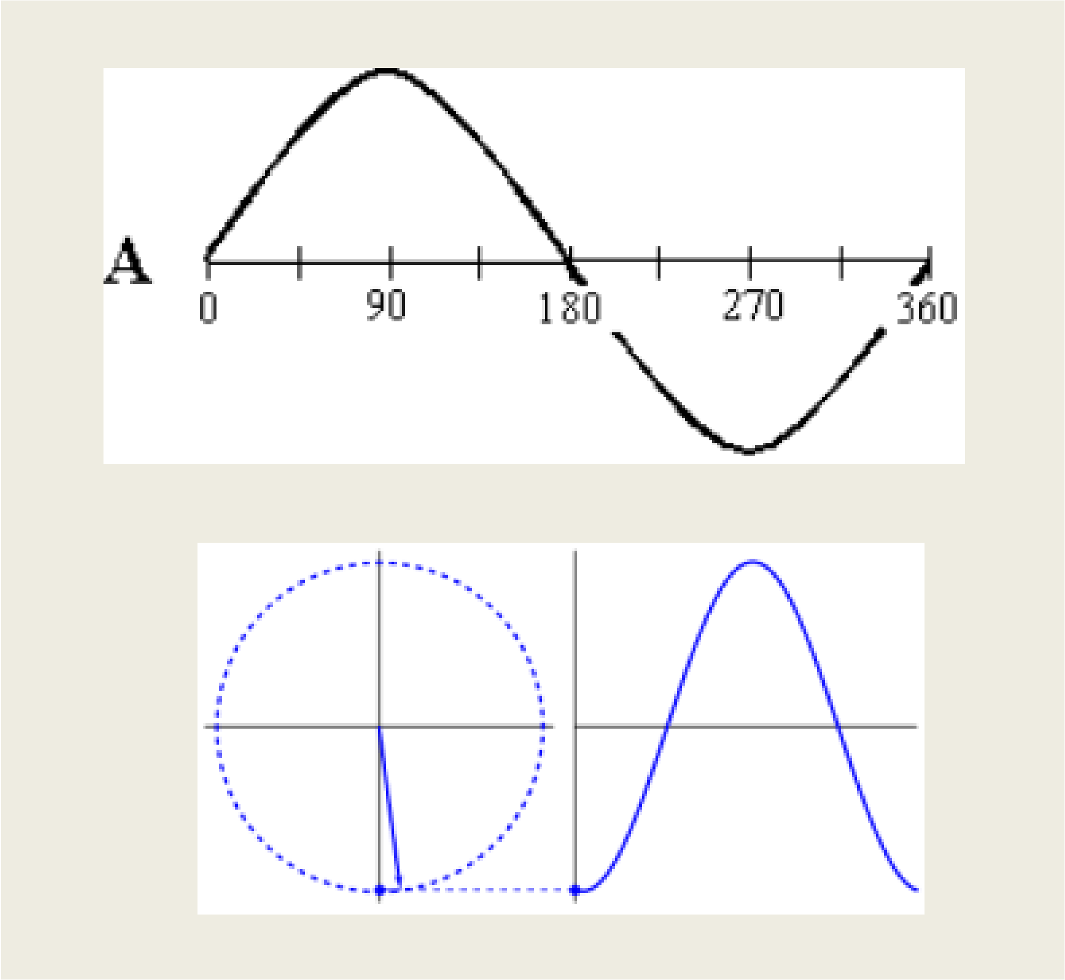
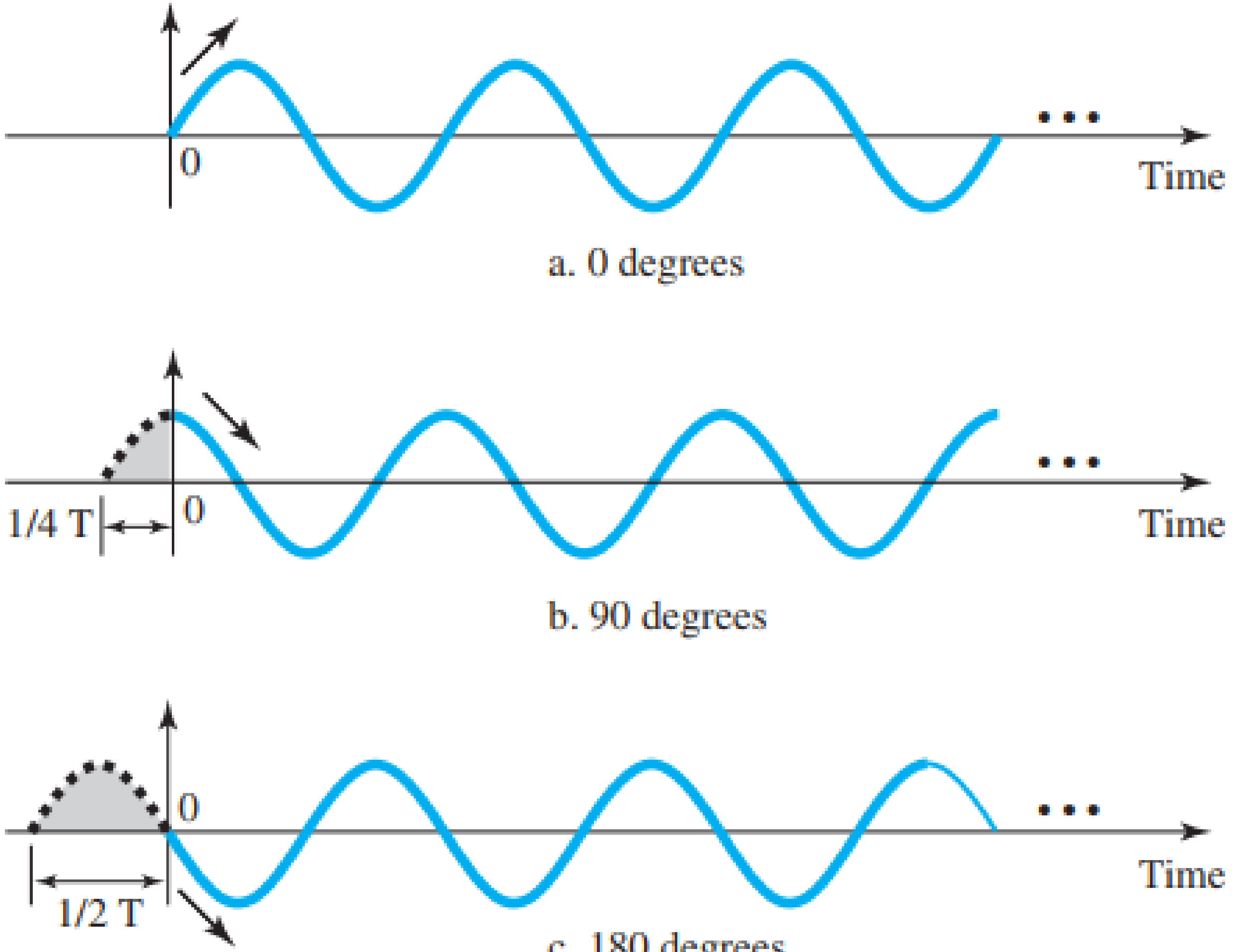

A
0
90
180
270
360

Figure 3.6 *Three sine waves with the same amplitude and frequency, but different phases*



a. 0 degrees

b. 90 degrees

c. 180 degrees

- Looking at Figure 3.6, we can say that
  - a. A sine wave with a **phase of 0° starts at time 0** with a **zero amplitude**. The amplitude is increasing.
  - b. A sine wave with a **phase of 90° starts at time 0** with a **peak amplitude**. The amplitude is decreasing.
  - c. A sine wave with a **phase of 180° starts at time 0** with a **zero amplitude**. The amplitude is decreasing.
- Another way to look at the phase is in terms of shift or offset. We can say that
  - a. A sine wave with a **phase of 0° is not shifted**.
  - b. A sine wave with a **phase of 90° is shifted to the left by cycle**.
  - c. A sine wave with a **phase of 180° is shifted to the left by cycle**.

- **Example 3.6**

- A sine wave is offset cycle with respect to time 0. What is its phase in degrees and radians?

Solution

We know that 1 complete cycle is 360°. Therefore, $\frac{1}{6}$ cycle is

$$\frac{1}{6} \times 360 = 60^\circ = 60 \times \frac{2\pi}{360} \text{ rad} = \frac{\pi}{3} \text{ rad} = 1.046 \text{ rad}$$

Q. 1/6 cycle = ? Degree
? radians

→ 1 Cycle = 360°

$= \frac{1}{6} \times 360^\circ$

$\boxed{= 60^\circ}$

→ $1^\circ = 2\pi/360$ rad

$60^\circ = ?$ radian

$= 60 \times \frac{2\pi}{360}$

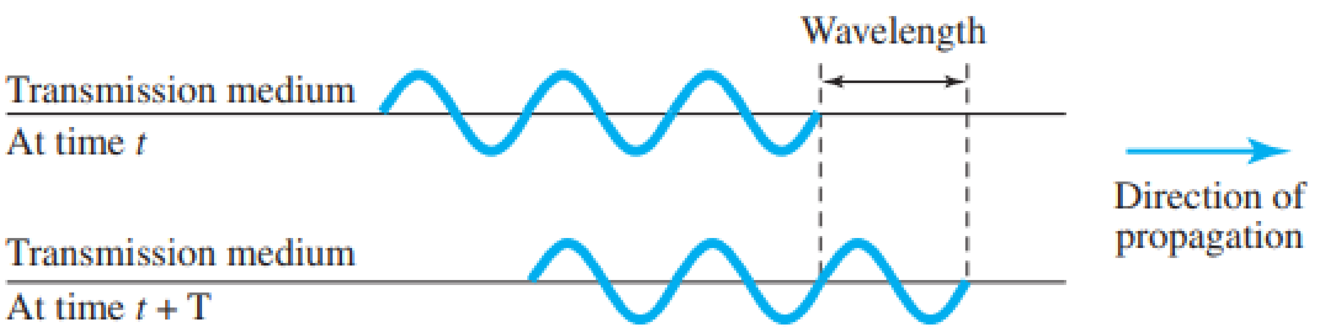
$= \frac{2\pi}{6} = \frac{\pi}{3} = \frac{3.14}{3}$

$\boxed{= 1.046 \text{ rad}}$

Wavelength

- The wavelength of a signal refers to the relationship **between frequency (or period) and propagation speed of the wave through a medium**.
- The wavelength is the **distance a signal travels in one period**.

Figure 3.7 *Wavelength and period*



- It is given by
- Wavelength = Propagation Speed * Period

OR

- Wavelength =Propagation Speed / Frequency

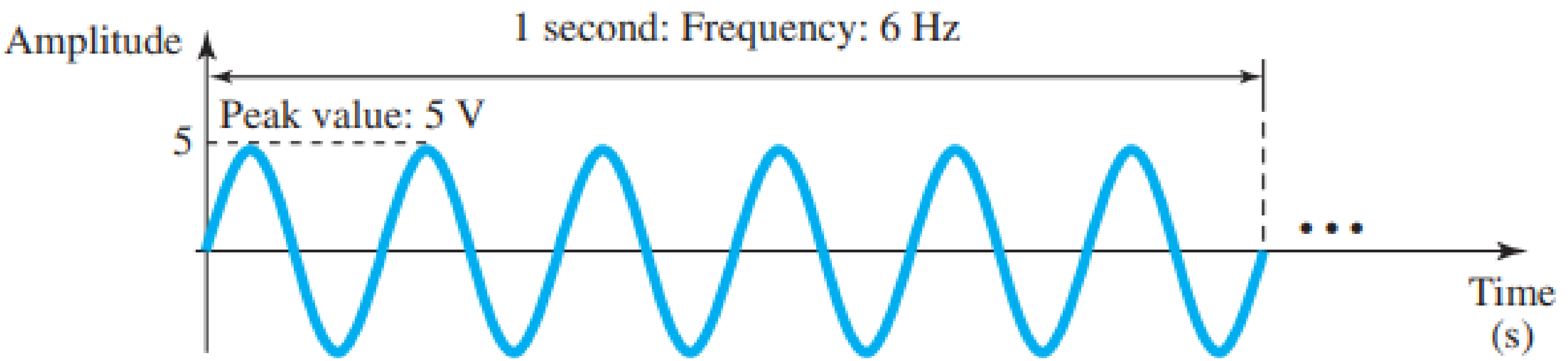
- It is **represented by the symbol : λ** (pronounced as lamda)
- It is **measured in micrometers** .
- Wavelength depends on **both the frequency and the medium**

Time and Frequency Domain

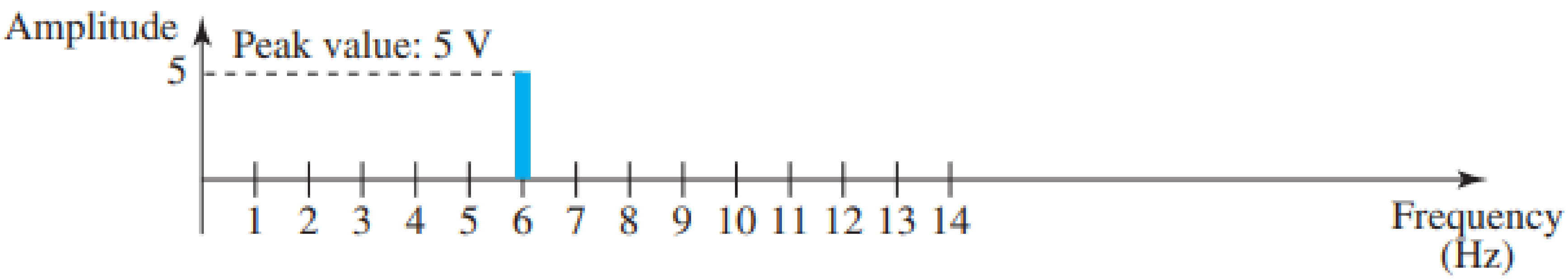
- A sine wave **can be represented either in the time domain or frequency domain.**
- The **time-domain plot** shows **changes in signal amplitude with respect to time**. It indicates time and amplitude relation of a signal.
- The **frequency-domain plot** shows the **relationship between signal frequency and peak amplitude**.

- The figure below show time and frequency domain plots of three sine waves.

Figure 3.8 *The time-domain and frequency-domain plots of a sine wave*

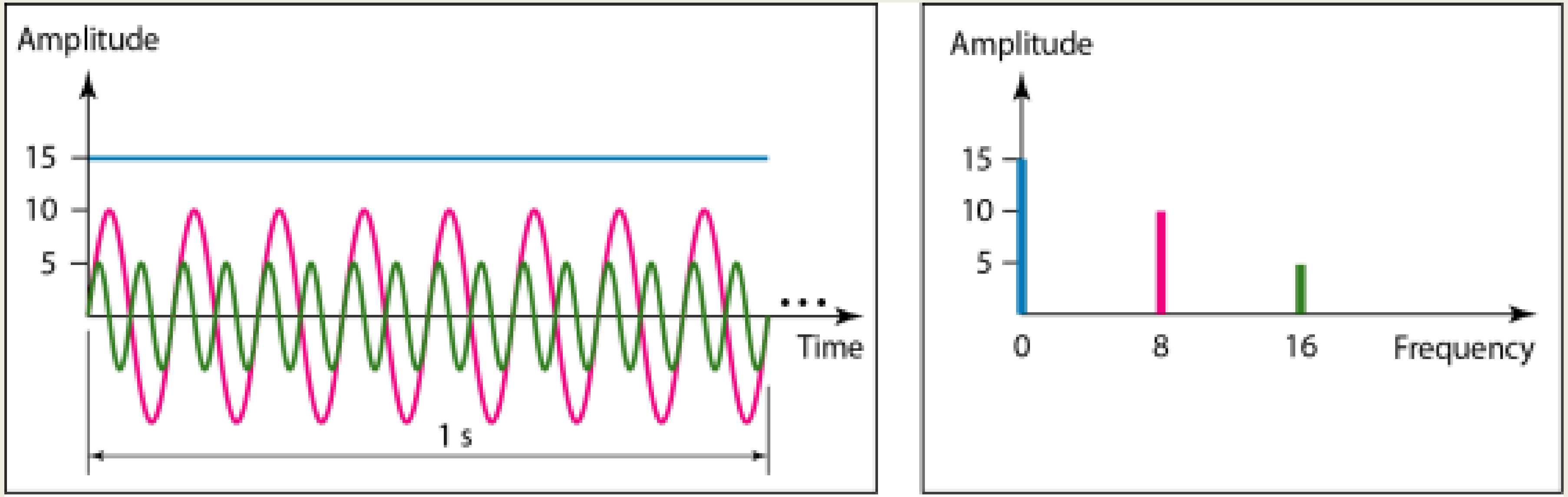


a. A sine wave in the time domain (peak value: 5 V, frequency: 6 Hz)



b. The same sine wave in the frequency domain (peak value: 5 V, frequency: 6 Hz)

- The **frequency domain** is **easy to plot and conveys the information that one can find in a time domain plot**.
- The **advantage** of the **frequency domain is that we can immediately see the values of the frequency and peak amplitude**.
- A **complete sine wave in** the **time domain** is **represented by one spike in frequency domain**.



a. Time-domain representation of three sine waves with frequencies 0, 8, and 16

b. Frequency-domain representation of the same three signals

2. Composite Signal

- A composite signal is a **combination of two or more simple sine waves with different frequency, phase and amplitude**.
- According to Fourier analysis, any composite signal is a combination of **simple sine waves with different frequencies, amplitudes, and phases**
- If the *composite signal is periodic*, the *decomposition gives a series of signals with discrete frequencies*;
- If the ***composite signal is non-periodic***, the ***decomposition gives combination of sine waves with continuous frequencies***.
- 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

Figure 3.10 *A composite periodic signal*

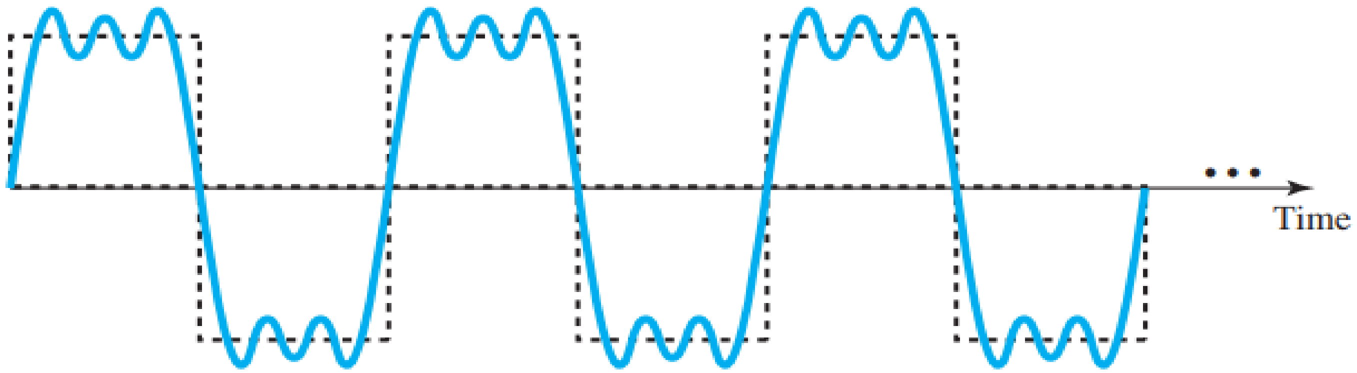
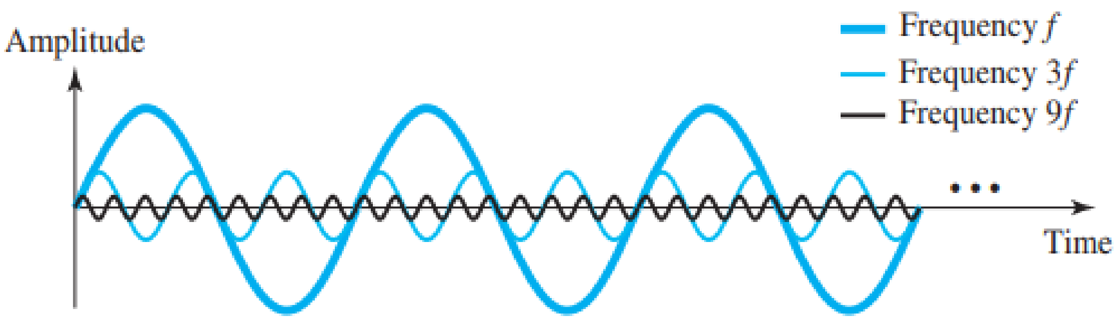
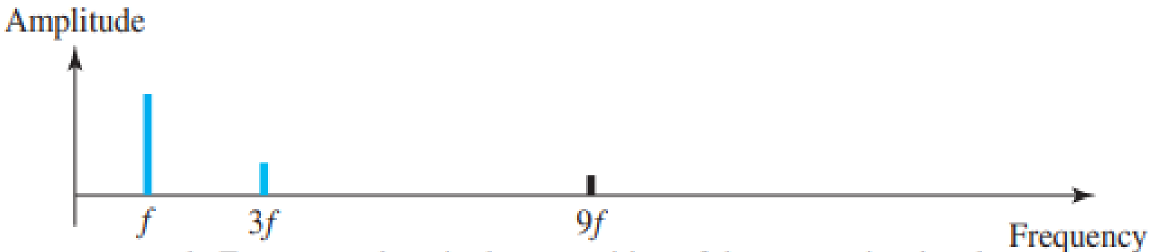


Figure 3.11 *Decomposition of a composite periodic signal in the time and frequency domains*

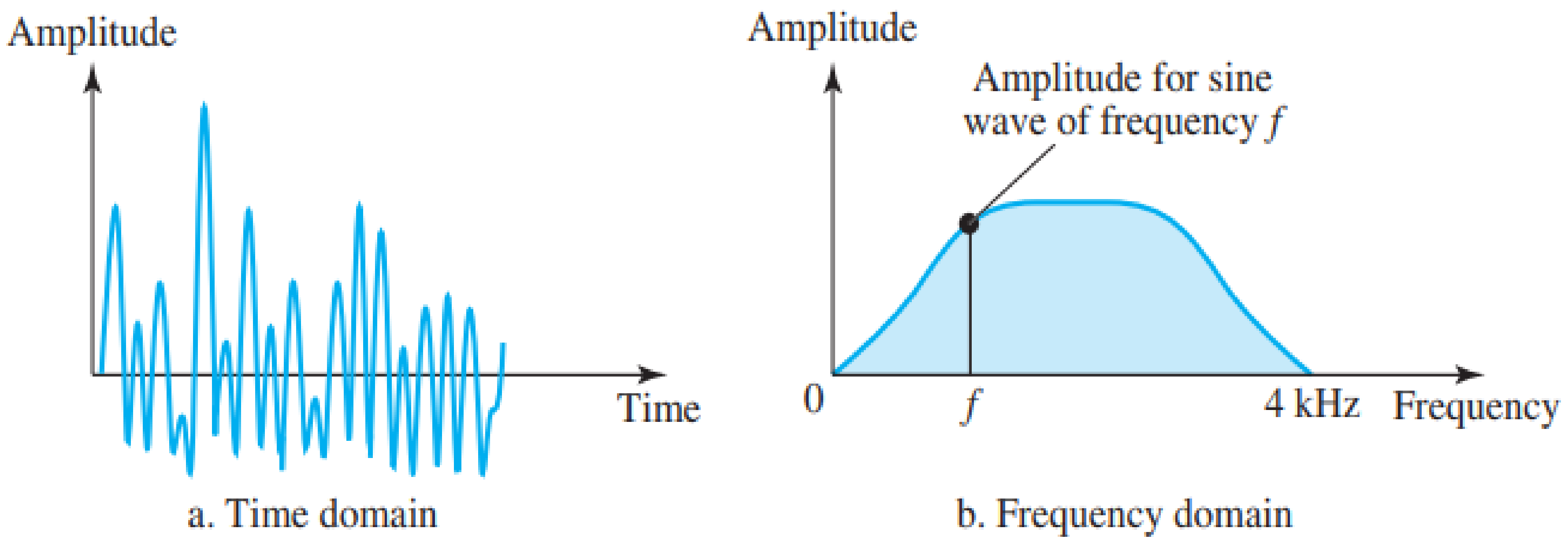


a. Time-domain decomposition of a composite signal



b. Frequency-domain decomposition of the composite signal

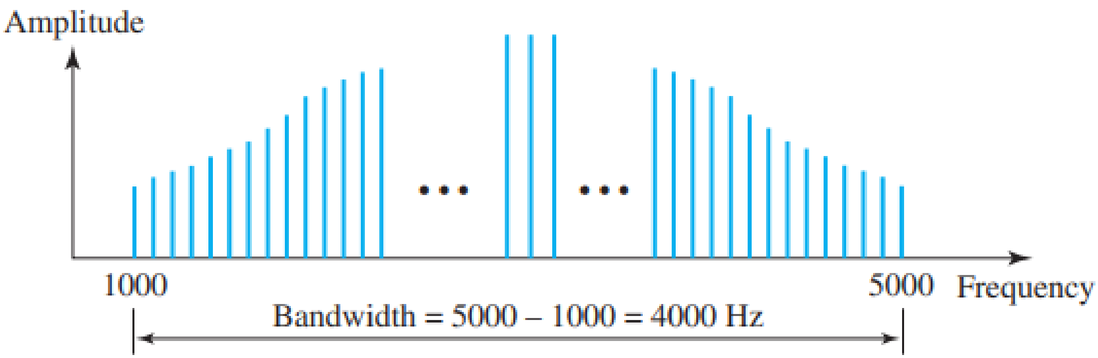
Figure 3.12 *The time and frequency domains of a nonperiodic signal*



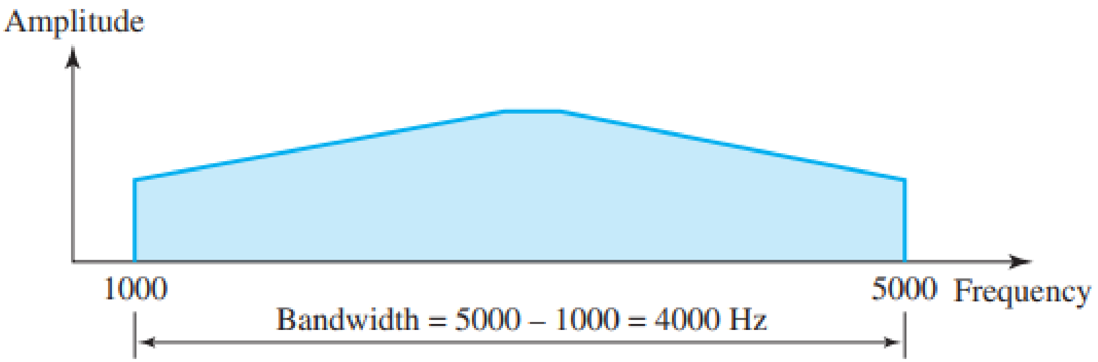
Bandwidth

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

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



a. Bandwidth of a periodic signal



b. Bandwidth of a nonperiodic signal

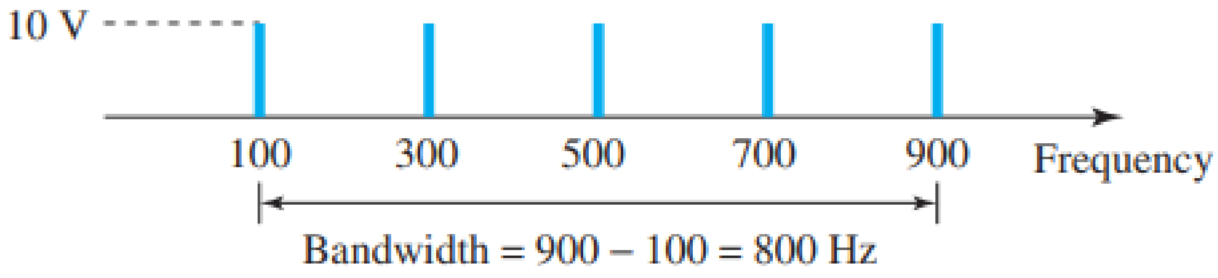
- **Example 3.10**
- If a periodic signal is decomposed into five sine waves with frequencies of 100, 300, 500, 700, and 900 Hz, what is its bandwidth? Draw the spectrum, assuming all components have a maximum amplitude of 10 V

Solution

Let f_h be the highest frequency, f_l the lowest frequency, and B the bandwidth. Then

$$B = f_h - f_l = 900 - 100 = 800 \text{ Hz}$$

Figure 3.14 *The bandwidth for Example 3.10*



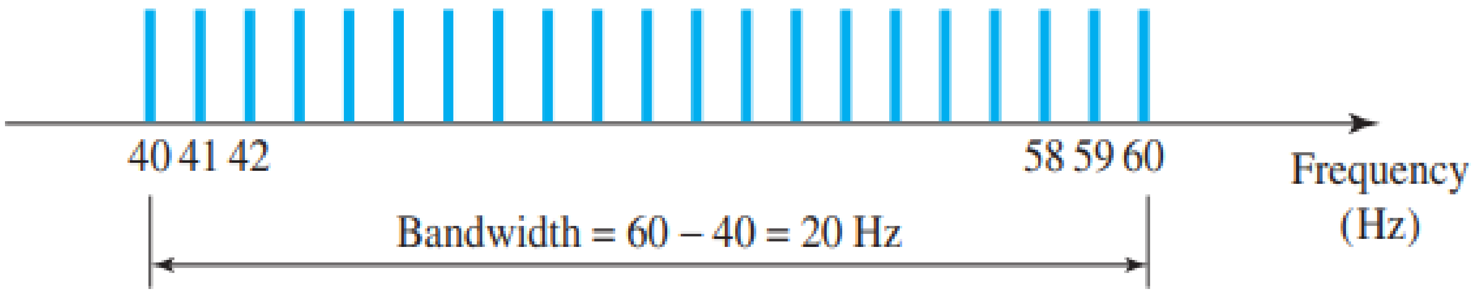
- **Example 3.11**
- A periodic signal has a bandwidth of 20 Hz. The highest frequency is 60 Hz. What is the lowest frequency? Draw the spectrum if the signal contains all frequencies of the same amplitude.

Solution

Let f_h be the highest frequency, f_l the lowest frequency, and B the bandwidth. Then

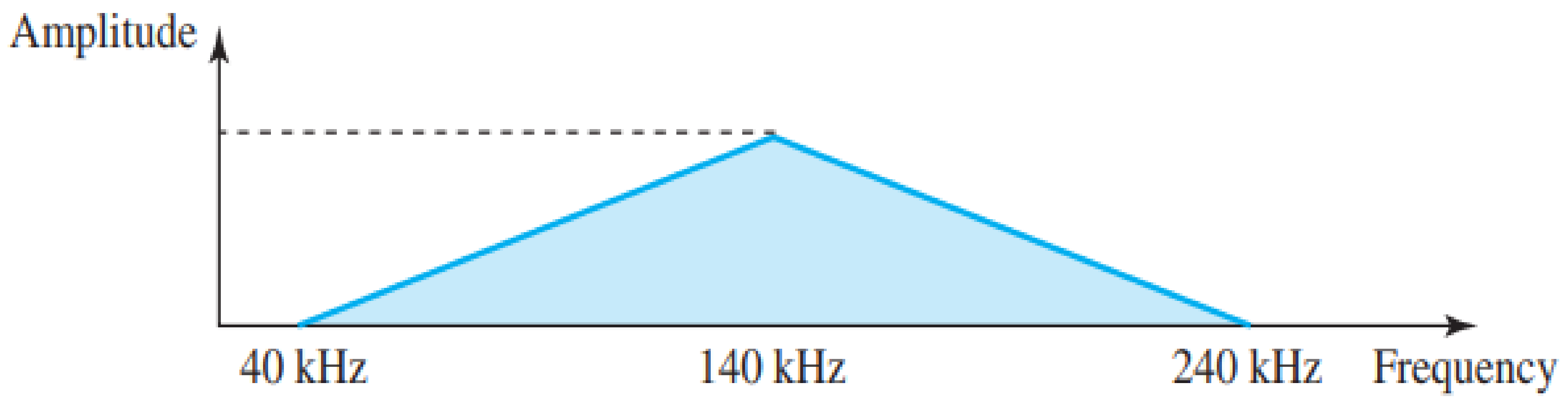
$$B = f_h - f_l \longrightarrow 20 = 60 - f_l \longrightarrow f_l = 60 - 20 = 40 \text{ Hz}$$

Figure 3.15 *The bandwidth for Example 3.11*



- **Example 3.12**
- A nonperiodic composite signal has a bandwidth of 200 kHz, with a middle frequency of 140 kHz and peak amplitude of 20 V. The two extreme frequencies have an amplitude of 0. Draw the frequency domain of the signal.

Figure 3.16 *The bandwidth for Example 3.12*



Q. Bandwidth = 200 KHz
Mid Value = 140 KHz

→ Let l be lowest frequency &
h be highest frequency

→ Bandwidth = $h - l$

$$200 = h - l \quad \text{--- (1)}$$

→ Mid value = $\frac{h+l}{2}$

$$140 = \frac{h+l}{2} \quad \text{--- (2)}$$

$$140 \times 2 = h + l$$

$$280 = h + l \quad \text{--- (3)}$$

→ from eq (1)

$$200 = h - l$$

$$h = 200 + l$$

Substitute h value in eq 3

$$280 = (200 + l) + l$$

$$280 = 200 + 2l$$

$$2l = 280 - 200$$

$$2l = 80$$

$$l = 80/2 = 40\text{KHz}$$

$$\boxed{l = 40\text{KHz}}$$

Substitute l in eq (1)

$$200 = h - 40$$

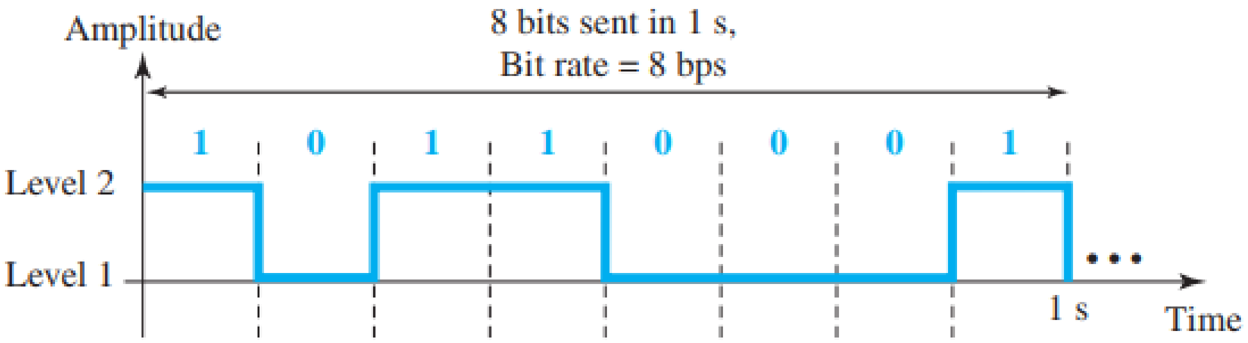
$$h = 200 + 40 = 240$$

$$\boxed{h = 240}$$

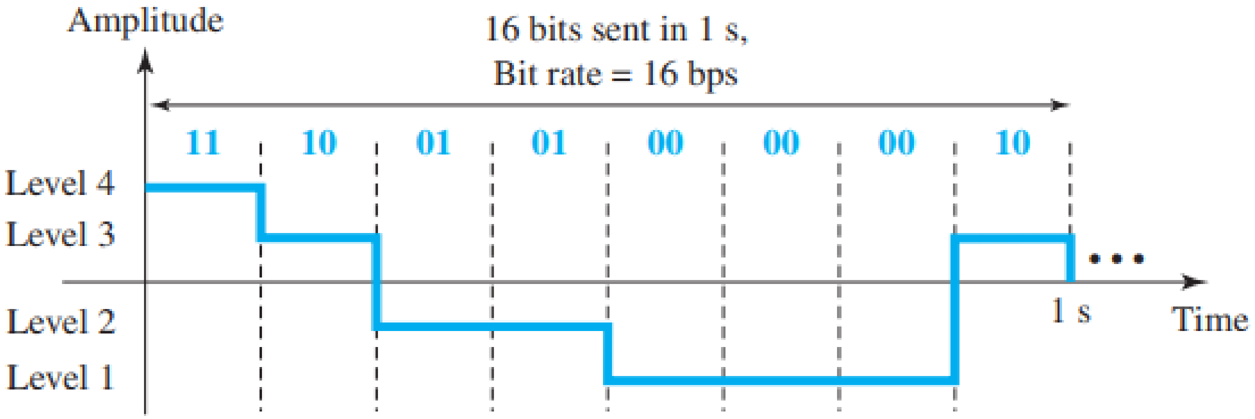
Digital Signal

- A digital is a signal that has discrete values.
- The signal will have value that is not continuous.

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



b. A digital signal with four levels

- **Relation between levels of signal and bit rate**

$$\text{Number of bits per level} = \log_2 \textit{Level}$$

- **Example 3.16**
- A digital signal has eight levels. How many bits are needed per level?

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

- **Example 3.17**
- A digital signal has nine levels. How many bits are needed per level?

Each signal level is represented by 3.17 bits. However, this answer is not realistic. The number of bits sent per level **needs to be an integer** as well as a **power of 2**. For this example, <u>**4 bits can represent one level**</u>.

Bit Rate

- It is the **number of bits transmitted in one second**.
- It is expressed as **bits per second (bps).**
- Relation between bit rate and bit interval can be as follows
- Bit rate = 1 / Bit interval

- **Note:** similar to the frequency for Analog

Bit Length

- The bit length is the **distance one bit occupies on the transmission medium.**
- It is the **time required to send one bit**.
- It is **measured in seconds**.
- Bit Length= Propagation speed * bit duration
- **Note:** Similar to wavelength for Analog.

Transmission of digital signals

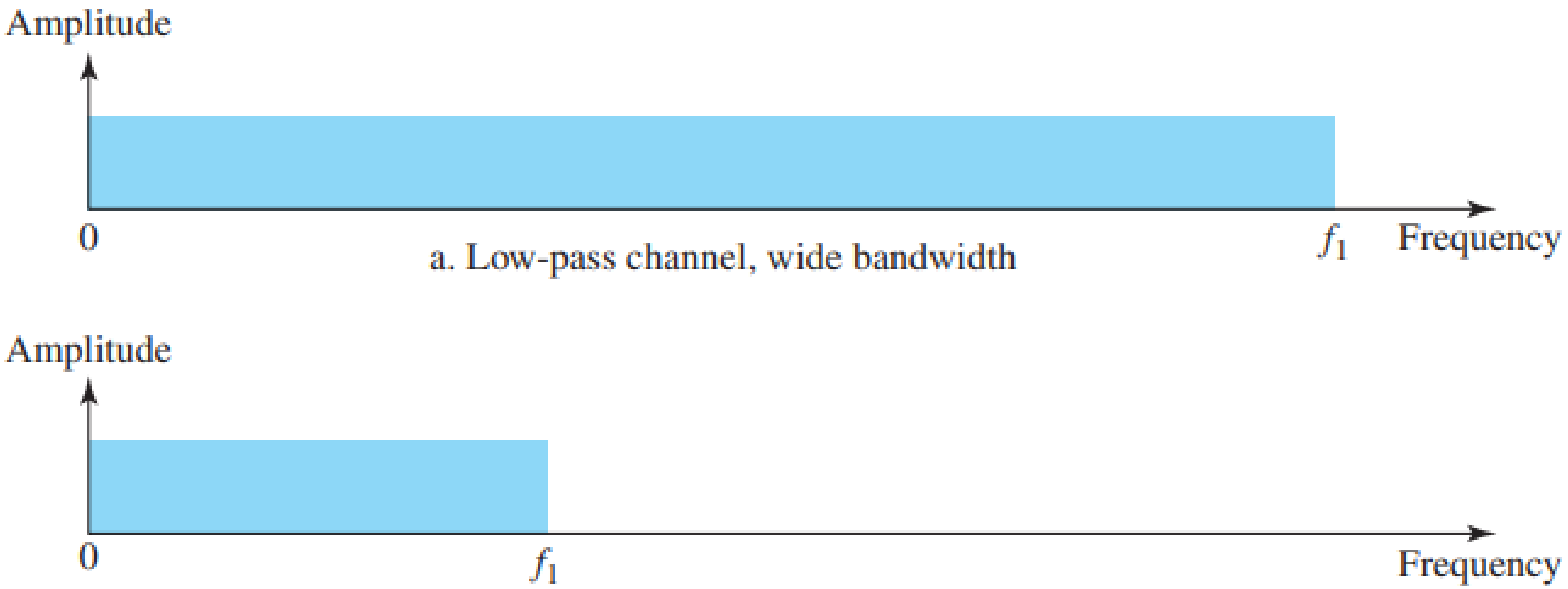
- We can transmit a digital signal by using one of two different approaches:
- 1.Baseband transmission or
- 2.Broadband transmission(using modulation).

- From the point of view of transmission, there are two types of channels:

- **1. Low pass Channel**
- This channel has the **lowest frequency as ‘0‘ and highest frequency as some non-zero** frequency ‘f1‘.
- This channel can pass all the frequencies in the **range 0 to f1**.

- **2 .Band pass channel**
- This channel has the **lowest frequency as some non-zero frequency ‘f1‘ and highest frequency as some non-zero frequency ‘f2‘.**
- This channel can pass all the frequencies in the **range f1 to f2**.

Figure 3.20 *Bandwidths of two low-pass channels*

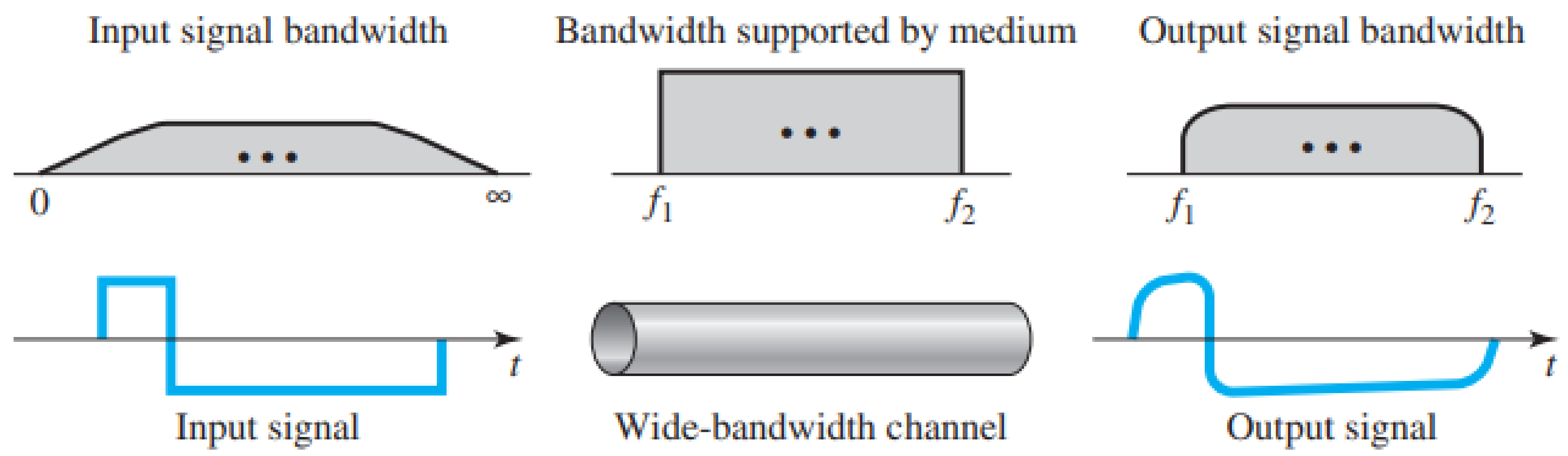


a. Low-pass channel, wide bandwidth

b. Low-pass channel, narrow bandwidth

- **1.Baseband transmission**
- Baseband transmission means **sending a digital signal over a channel <u>without changing</u> the digital signal to an analog signal**.

Figure 3.21 *Baseband transmission using a dedicated medium*



- Baseband transmission **requires a low-pass channel.**
- In baseband transmission, the **bandwidth of the signal to be transmitted has to be less than the bandwidth of the channel**.

- Ex. Consider a Baseband channel with lower frequency 0Hz and higher frequency 100Hz, hence its bandwidth is 100 (Bandwidth is calculated by getting the difference between the highest and lowest frequency).
- We can easily transmit a **signal with frequency below 100Hz**, such a channel whose **bandwidth is more than the bandwidth of the signal** is called **Wideband channel**
- Logically a signal **with frequency say 120Hz will be blocked resulting in loss of information**, such a **channel whose bandwidth is less than the bandwidth of the signal** is called **Narrowband channel**

- **2. Broadband transmission**
- Broadband transmission or modulation means **changing the digital signal to an analog signal for transmission**.
- Modulation allows us to **use a bandpass channel-a channel** with a bandwidth that does not start from zero.
- 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

Figure 3.24 *Bandwidth of a bandpass channel*

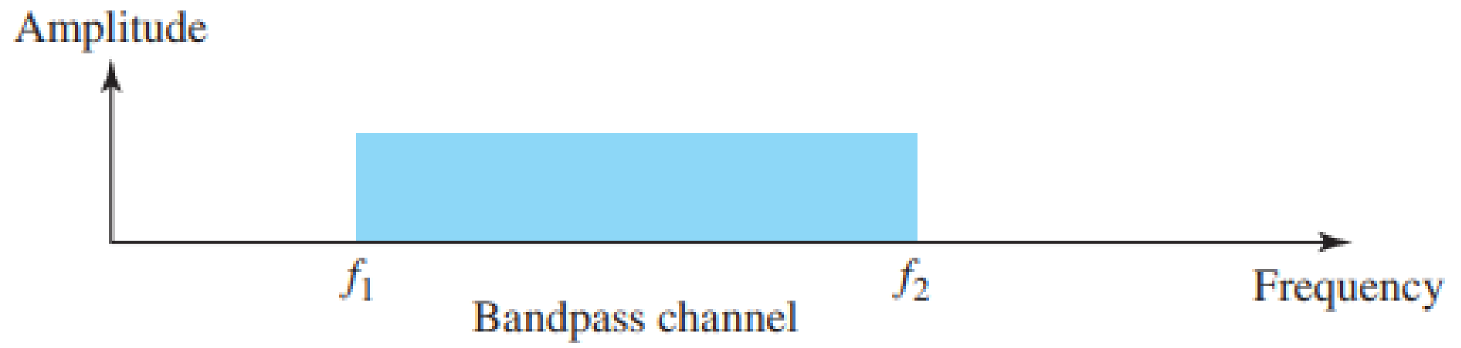
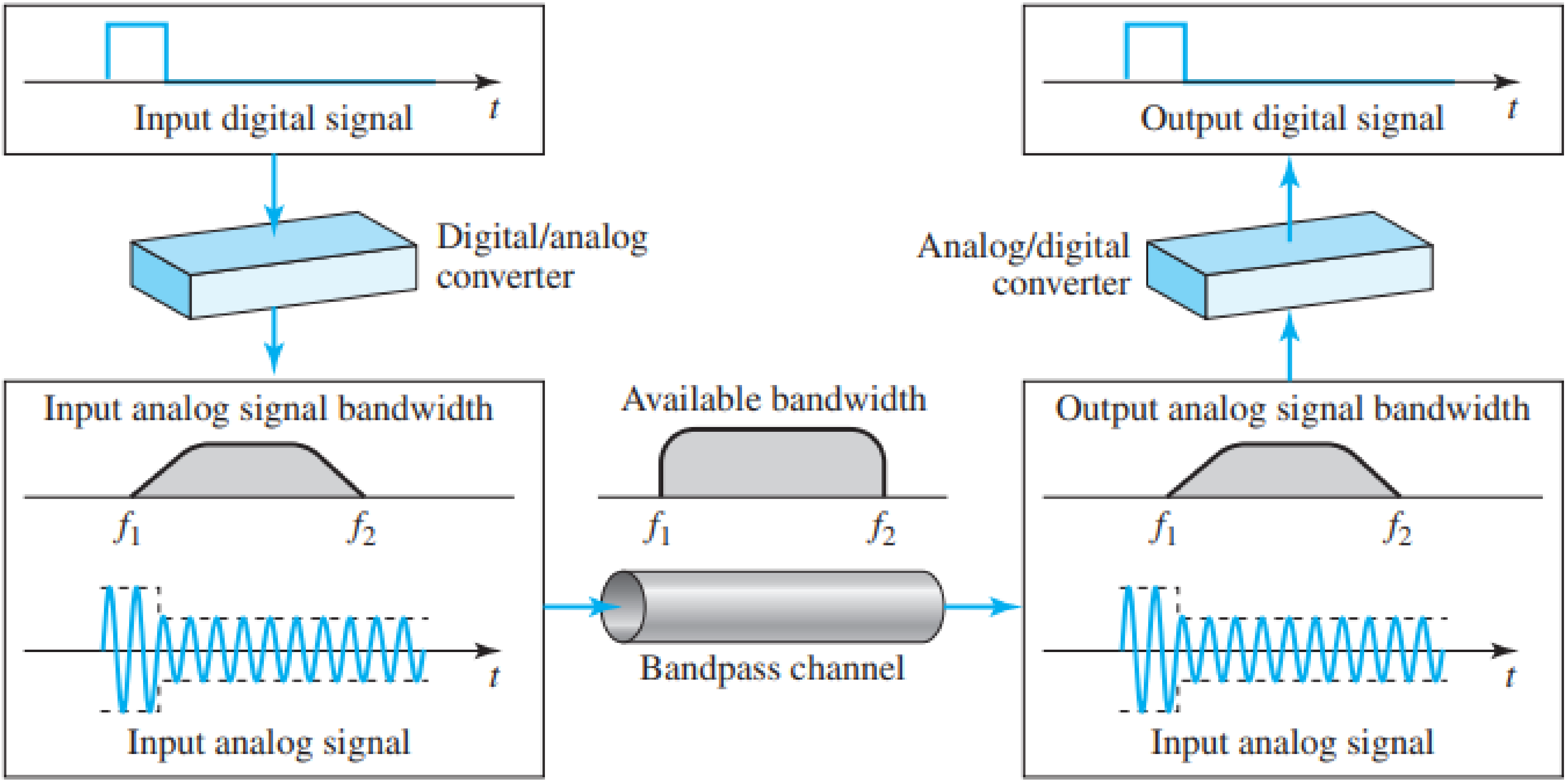


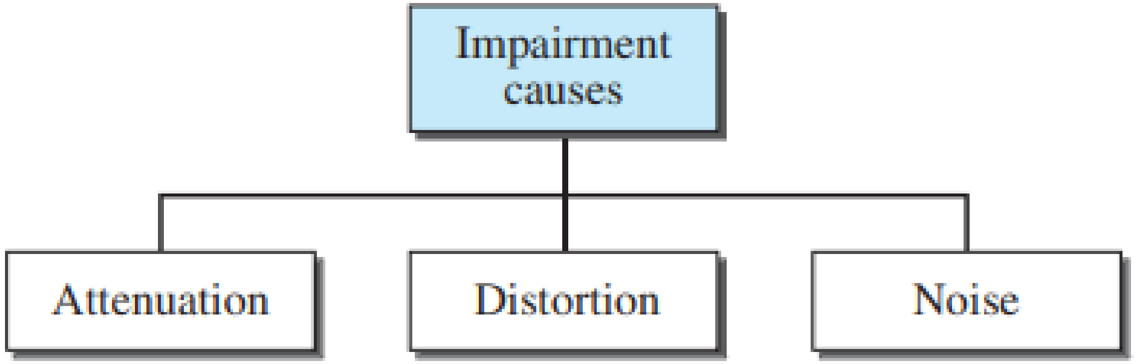
Figure 3.25 *Modulation of a digital signal for transmission on a bandpass channel*



Transmission Impairment

- **Impairment** : the state of being diminished, weakened, or damaged, especially mentally or physically
- **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.

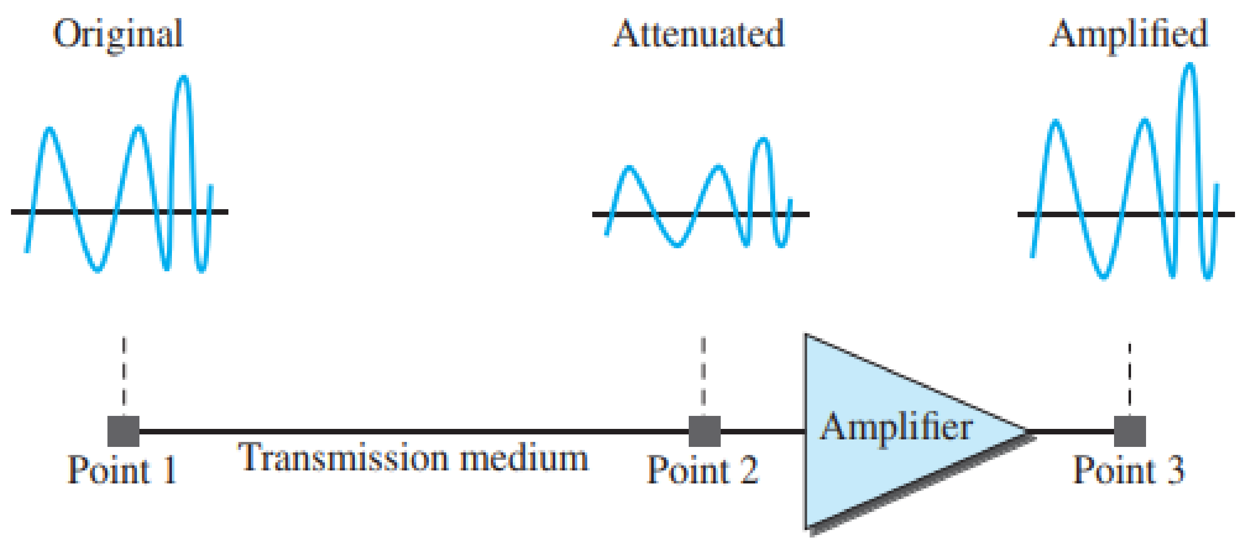
Figure 3.26 *Causes of impairment*



❖1. Attenuation

- Means **loss of energy -> weaker signal**
- When a **signal travels through a medium it loses energy** overcoming the resistance of the medium
- **Amplifiers** are **<u>used to compensate for this loss of energy by amplifying the signal.</u>**
- An amplifier is an electronic component that can increase the power of signal.

Figure 3.27 *Attenuation*



❖ **Measurement of attenuation**

- To show the **loss or gain of energy the unit “decibel” is used**.
- The **decibel (dB)** measures the **relative strengths of two signals or one signal at two different points**.
- Note that the **decibel is *negative* if a *signal is attenuated*** and **positive if a signal is amplified**.

➢ $dB = 10\log_{10} P2/P1$

- Where,
- P1 –power of **input signal at point 1**
- P2 –power of **output signal at point 2**

- **Example 3.26**
- Suppose a signal travels through a transmission medium and its power is reduced to one-half. This means that P2 is $\frac{1}{2}$ P1. In this case, the attenuation (loss of power) can be calculated as

Given : $P_2 = \frac{1}{2} P_1$

$\therefore P_2 = 0.5 P_1$

Formula : $dB = 10 \log_{10} P_2/P_1$

To find : $dB = ?$

Solution :

$$dB = \cancel{10 \log_{10}}\ 10 \log_{10} \frac{0.5 P_1}{P_1}$$

$$= 10 \log_{10} 0.5 \qquad \because [\log_{10} 0.5 = -0.3]$$

$$= 10 (-0.3)$$

$$= \underline{-3\ dB}$$

→ Negative value indicates loss of power

∴ A loss of 3dB (−3dB)

- **Example 3.27**

- A signal travels through an amplifier, and its power is increased 10 times. This means that P2 = 10P1. In this case, the amplification (gain of power) can be calculated as

Given : $P_2 = 10P_1$

Formula : $dB = 10 \log_{10} \frac{P_2}{P_1}$

To find : $dB = ?$

Solution : $dB = 10 \log_{10} \frac{10P1}{P1}$

$= 10 \log_{10} 10 \quad \because [\log_{10} 10 = 1]$

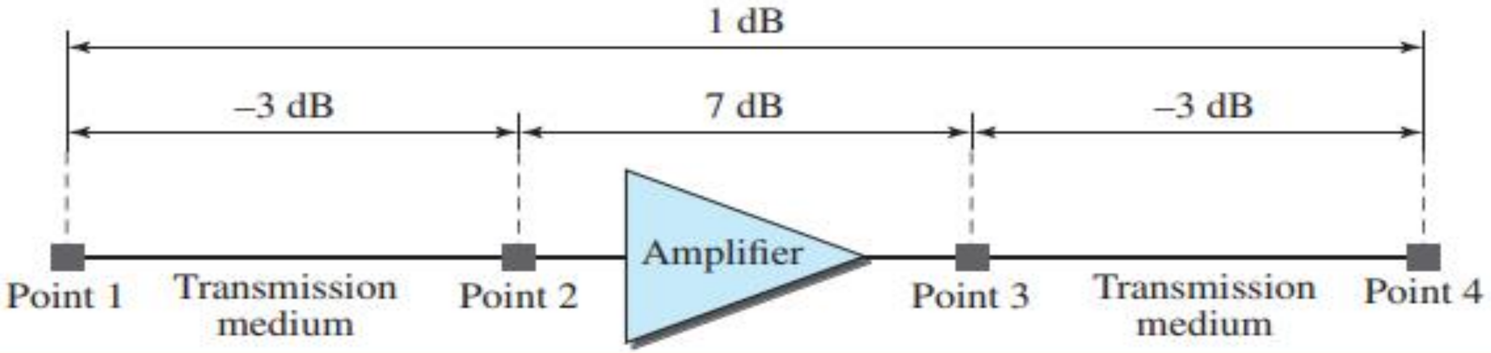
$= 10 (1)$

$= \underline{\underline{10 \; dB}}$

→ Positive value indicates gain of power

$\therefore$ 10 dB gain of power

- **Example 3.28**
- One reason that engineers use the **decibel to measure the changes in the strength of a signal is that decibel numbers can be added** (or subtracted) when we are **measuring several points** (cascading) instead of just two.
- In Figure 3.28 a signal travels from point 1 to point 4. The signal is attenuated by the time it reaches point 2. Between points 2 and 3, the signal is amplified. Again, between points 3 and 4, the signal is attenuated. We can find the resultant decibel value for the signal just by adding the decibel measurements between each set of points.



In this case, the decibel value can be calculated as

$$\mathbf{dB = -3 + 7 - 3 = +1}$$

The signal has gained in power.

- **Example 3.29**

- Sometimes the decibel is used to measure signal power in milliwatts. In this case, it is referred to as dBm and is calculated as dBm = 10 $\log_{10}$Pm, where Pm is the power in milliwatts. Calculate the power of a signal if its dBm = −30.

Given: $dB_m = 10 \log_{10} P_m$

where,

P_m is power in milliwats

$dB_m = -30$

Find: Power of signal, P_m = ?

Solution:

$$dB_m = 10 \log_{10} P_m$$

$$-30 = 10 \log_{10} P_m$$

$$10 \log_{10} P_m = -30$$

$$\log_{10} P_m = \frac{-30}{10}$$

b, a, c

$$\log_{10} P_m = -3$$

$\therefore$ $P_m = 10^{-3}$ mW ….. $\left[\begin{array}{l} \log_b a = c \\ a = b^c \end{array} \right]$

NIKITA MADWAL

- **Example 3.30**
- The loss in a cable is usually defined in decibels per kilometer (dB/km). If the signal at the beginning of a cable with −0.3 dB/km has a power of 2 mW, what is the power of the signal at 5 km?
- The loss in the cable in decibels is

$5 \times (-0.3) = -1.5$ dB

We can calculate the power as

$$dB = 10 \log_{10}(P_2/P_1) = -1.5 \, dB$$

$$\therefore \log_{10}(P_2/P_1) = \frac{-1.5}{10}$$

$$\therefore \log_{10}(P_2/P_1) = -0.15$$

$$\therefore \frac{P_2}{P_1} = 10^{-0.15} \quad \ldots \left[\log_b a = c, \; a = b^c \right]$$

$$\therefore \frac{P_2}{P_1} = 0.71$$

$$\therefore P_2 = 0.71 \, P_1$$

$$\therefore P_2 = 0.71 \times 2 \, mW$$

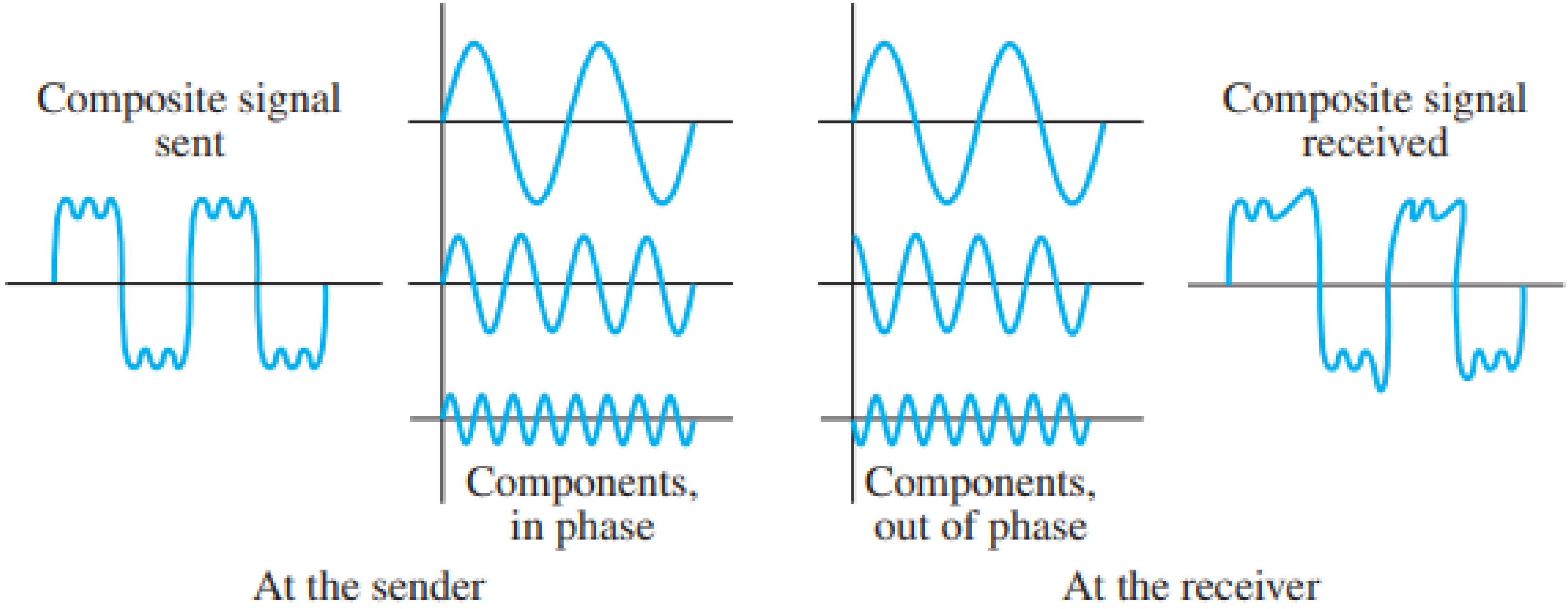
$$= \cancel{1.4 \, mW}$$

$$= 1.42 \, mW$$

❖ 2. Distortion

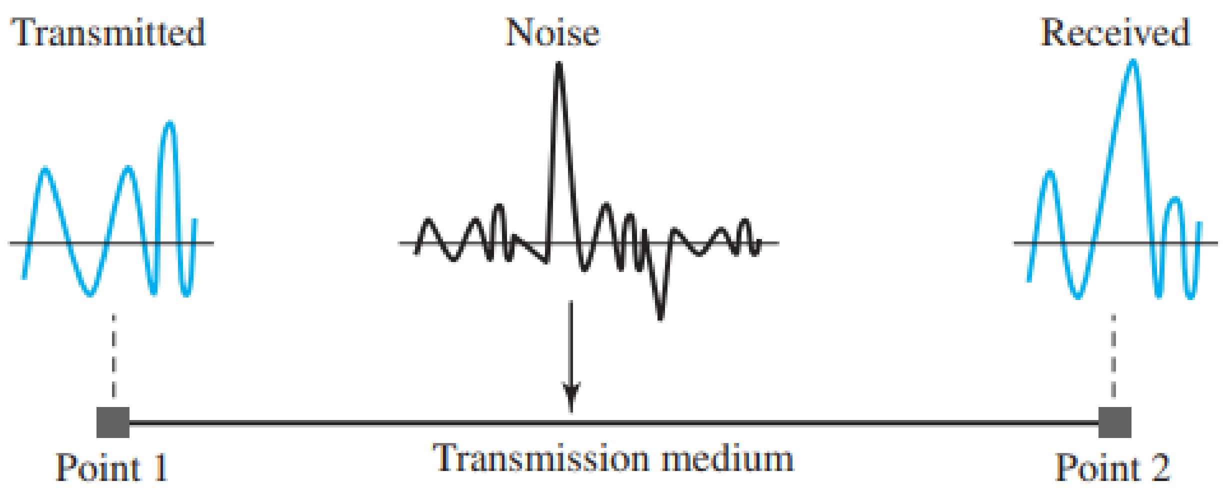
- Means that the **signal changes its form or shape**.
- Distortion **occurs in composite signals**.
- Each Signal component has its own propagation speed traveling through a medium.
- The different **components therefore arrive with different delays at the receiver.**
- That means that the **signals have different phases at the receiver than they had at the sender**. The **shape of the composite signal is therefore not the same**

Figure 3.29 *Distortion*



- **3. Noise**
- There are different types of noise which may corrupt the signal
- Thermal
- Induced
- Crosstalk
- Impulse

Figure 3.30 *Noise*

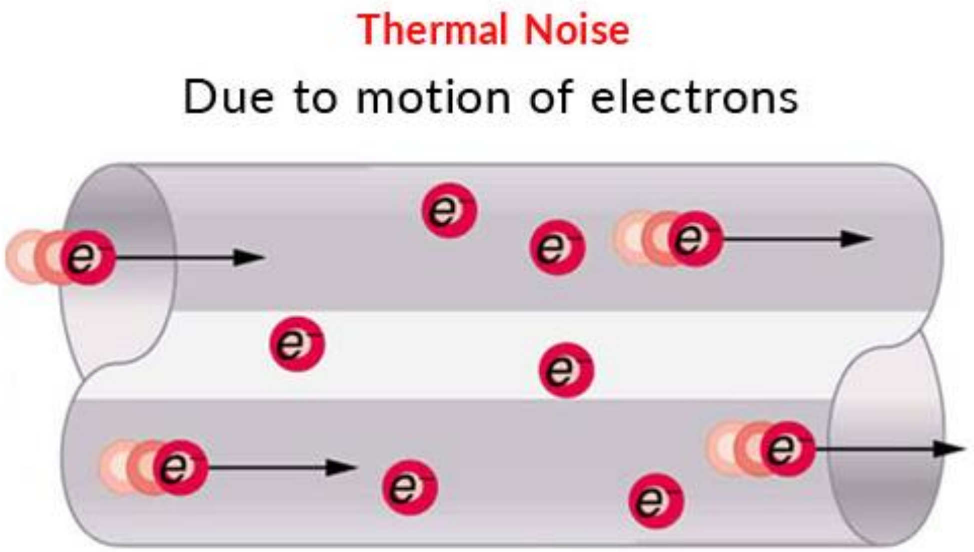


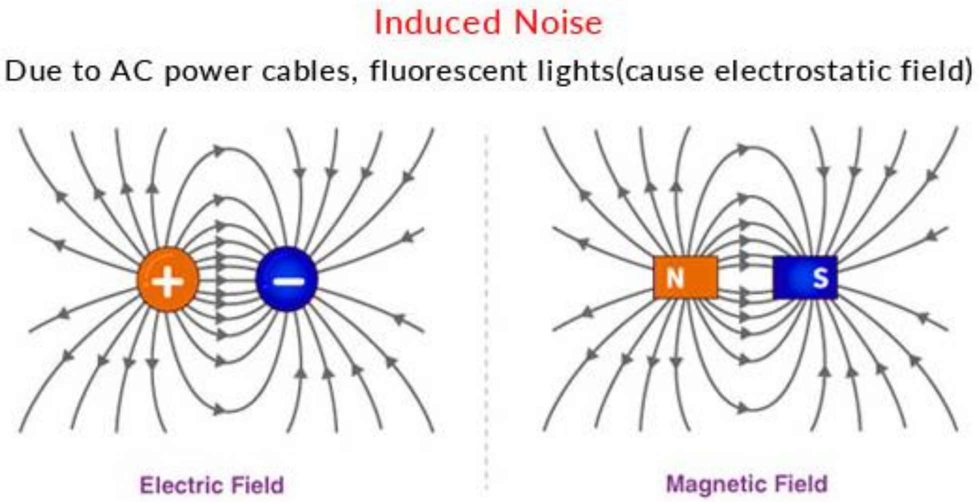
➢Thermal noise

- It is the **random motion of electrons in a wire**, which **creates an extra signal not originally sent by the transmitter**.

➢Induced noise

- **It comes from sources such as motors and appliances**.
- These **devices act as a sending antenna, and the transmission medium acts as the receiving antenna.**



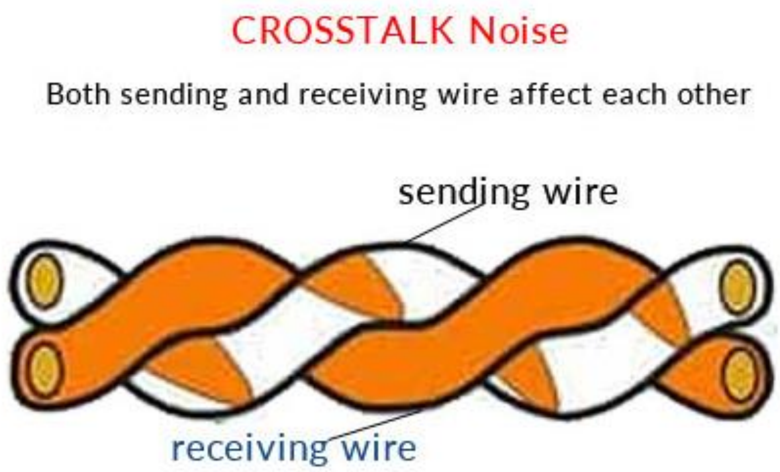


➢Crosstalk

- It is the effect of **one wire on the other**.
- One **wire acts as a sending antenna and the other as the receiving antenna.**

➢Impulse noise

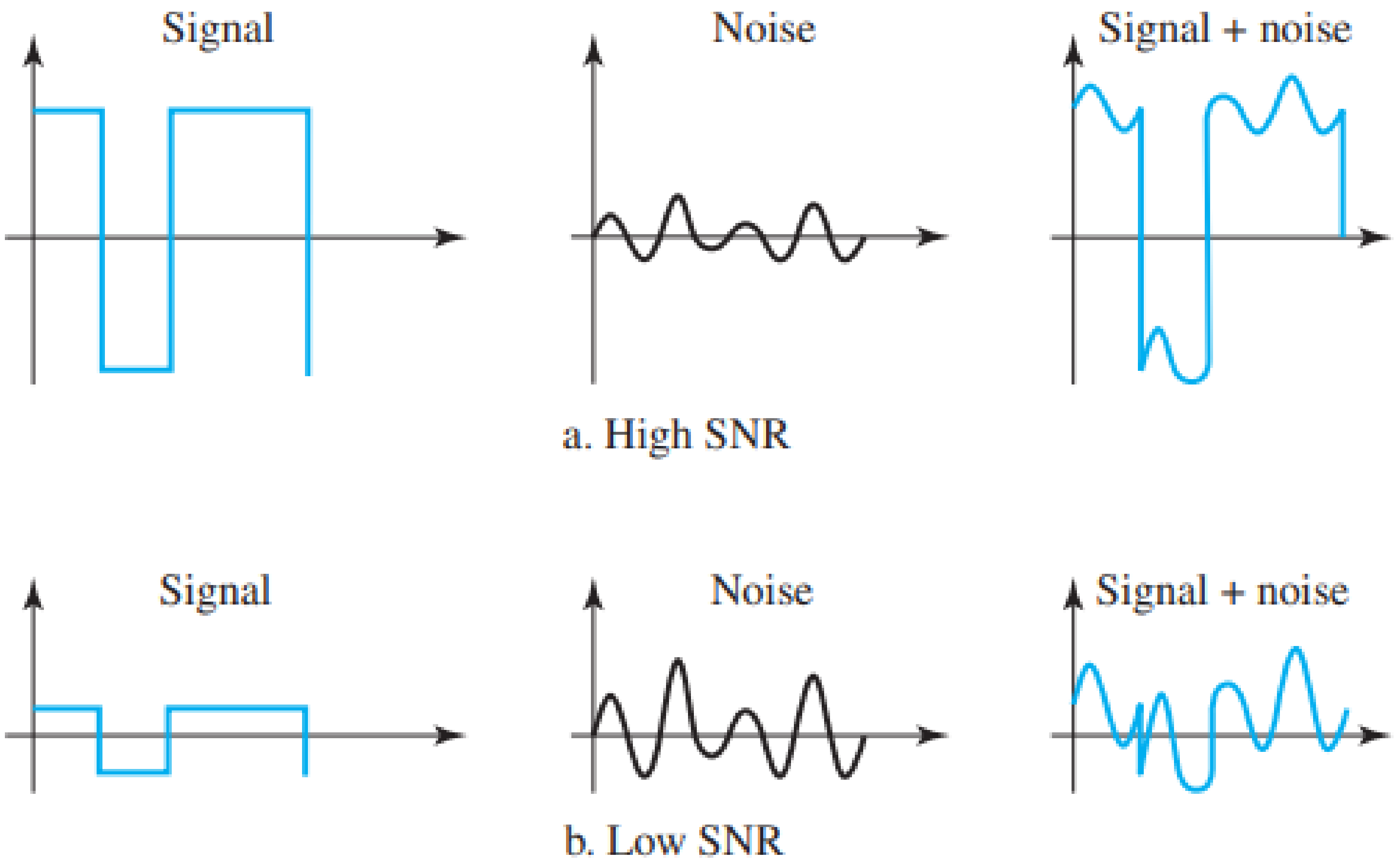
- It **is a spike** (a **signal with high energy in a very short time**) that comes from power lines, lightning, and so on.



Measurement of noise

- Signal to noise ratio (SNR)
- To **measure the quality of a system the SNR is often used**.
- It indicates the **strength of the signal with respect to the noise power in the system.**
- It is the **ratio** of the **signal power to the noise power**.
- The signal-to-Noise ratio is defined as $\mathrm{SNR} = \frac{\text{average signal power}}{\text{average noise power}}$
- SNR is the ratio of **what is wanted(signal) to what is not wanted(noise).**
- A **High SNR** means the **signal** is **less corrupted by noise**; a ***low SNR*** means the ***signal*** is ***more corrupted by noise***.
- Because SNR is the ratio of two powers, it is often **described in decibel units, $\mathrm{SNR}_{\mathrm{dB}}$**
- $\mathrm{SNR}_{\mathrm{dB}} = 10 \log_{10}\mathrm{SNR}$

Figure 3.31 *Two cases of SNR: a high SNR and a low SNR*



- **Example 3.31**

- 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}?

Given: Power of signal

$= 10mW = 10 \times 1000 = 10000\ \mu W$

.... $\left[\begin{array}{l} 1mW = 1000\mu W \\ 10mW = ? \end{array}\right]$

Power of Noise

$= 1\ \mu W$

Find: SNR (Signal-Noise-Ratio) = ?

$SNR_{dB} = ?$

Formula: $SNR = \dfrac{\text{average signal power}}{\text{average noise power}}$ — ①

$SNR_{dB} = 10 \log_{10} SNR$ — ②

Using ①

$SNR = \dfrac{10000\ \mu W}{1\ \mu W} = 10000$

Using ②

$SNR_{dB} = 10 \log_{10} 10000$

$= 10 \log_{10} 10^4$

$= 4 \times 10 \log_{10} 10$

$= 40 \log_{10} 10$

$= 40(1)$ ∵ $[\log_a a = 1]$

$= 40$

- **Example 3.32**
- The values of SNR and SNR_{dB} for a noiseless channel are

$$SNR = \frac{\text{signal power}}{0} = \infty$$

$$SNR_{dB} = 10 \log_{10} \infty = \infty$$

- We can never achieve this ratio in real life; it is an ideal.

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)
- **Two theoretical formulas** were developed **to calculate the data rate**: one by **Nyquist for a noiseless channel**, another by **Shannon for a noisy channel**

❖ **1.Noiseless Channel**

❖ **Nyquist bit rate**

- For a noiseless channel, the Nyquist bit rate formula **defines the theoretical maximum bit rate**
- BitRate=2 * bandwidth *$\log_2 L$
- In this formula, **bandwidth** is the *bandwidth of the channel*, **L** is the number of *signal levels* used to represent data, and **BitRate** is the *bit rate in bits per second*.
- According to the formula, we might think that, given a specific bandwidth, we can have any bit rate we want by increasing the number of signal levels.
- Although the **idea is theoretically correct, practically there is a limit**. When **we increase the number of signal levels, we impose a burden on the receiver.**

- If the number of levels in a signal is just 2, the receiver can easily distinguish between a 0 and a 1.
- If the level of a signal is 64, the receiver must be very sophisticated to distinguish between 64 different levels.
- In other words, **increasing the levels of a signal reduces the reliability of the system.**

- **Example 3.34**
- Consider a noiseless channel with a bandwidth of 3000 Hz transmitting a signal with two signal levels. The maximum bit rate can be calculated as

Given:

Bandwidth = 3000 Hz

Signal levels = 2

To find:

BitRate = ?

Formula:

$$\text{BitRate} = 2 \times \text{Bandwidth} \times \log_2 L$$

Solution:

$$\text{BitRate} = 2 \times 3000 \times \log_2 2$$

$$= 6000 \times 1$$

$$= \underline{\underline{6000 \text{ bps}}}$$

- **Example 3.35**
- Consider the same noiseless channel transmitting a signal with four signal levels (for each level, we send 2 bits). The maximum bit rate can be calculated as

$$\text{BitRate} = 2 \times 3000 \times \log_2 4 = 12{,}000 \text{ bps}$$

- **Example 3.36**
- We need to send 265 kbps over a noiseless channel with a bandwidth of 20 kHz. How many signal levels do we need?

Given:

BitRate = 265 kbps = 265 × 1000 = 265000 bps

Bandwidth = 20 KHz = 20 × 1000 = 20000 Hz

To Find:

Signal Level = ?

Solution:

$$\text{BitRate} = 2 \times \text{Bandwidth} \times \log_2 L$$

$$265000 = 2 \times 20000 \times \log_2 L$$

$$265000 = 40000 \times \log_2 L$$

$$\log_2 L = \frac{265000}{40000}$$

$$= \frac{265}{40}$$

$$\log_2 L = 6.625$$

$$L = 2^{6.625}$$

$$L = 98.7 \text{ levels}$$

Since this result is not a power of 2, we need to either increase the number of levels or reduce the bit rate.
If we have 128 levels, the bit rate is 280 kbps. If we have 64 levels, the bit rate is 240 kbps.

- **2. Noisy channel**
- **Shannon capacity**

- **In reality, we cannot have a noiseless channel; the channel is always noisy.**
- In 1944, **Claude Shannon introduced a formula**, called the Shannon capacity, **to determine the theoretical highest data rate for a noisy channel**
- Capacity =bandwidth $*\log_2(1 + SNR)$
- In this formula, **bandwidth** is the *bandwidth of the channel*, **SNR** is the *signal-to noise ratio*, and **capacity** is the *capacity of the channel in bits per second*.
- Note that in the **Shannon formula there is <u>no indication</u> of the signal level**, which means that **no matter how many levels we have**, we **cannot achieve a data rate higher than the capacity of the channel**.
- In other words, the **formula defines a characteristic of the channel**, not the method of transmission.

- **Example 3.37**
- Consider an extremely noisy channel in which the value of the signal-to-noise ratio is almost zero. In other words, the noise is so strong that the signal is faint. For this channel the capacity C is calculated as

Given : SNR = 0

To Find : Capacity , C = ?

Formula :

$$C = B\log_2(1 + SNR)$$

Solution

$$C = B\log_2(1+0)$$
$$= B\log_2 1$$
$$= B(0)$$
$$= \underline{\underline{0}}$$

This means that the capacity of this channel is zero regardless of the bandwidth.
In other words, we
cannot receive any data through this channel.

- **Example 3.38**
- We can calculate the theoretical highest bit rate of a regular telephone line. A telephone line normally has a bandwidth of 3000 Hz (300 to 3300 Hz) assigned for data communications. The signal-to-noise ratio is usually 3162. For this channel the capacity is calculated as

Given: Bandwidth, B = 3000
SNR = 3162

To find: capacity, C = ?

Formula:

$$C = B \log_2 (1 + SNR)$$

Solution:

$$C = (3000) \log_2 (1 + 3162)$$
$$= 3000 \log_2 3163$$
$$= 3000 \times 11.62$$
$$= \underline{\underline{34860 \text{ bps}}}$$

This means that the highest bit rate for a telephone line is 34.860 kbps.
If we want to send data faster than this, we can either increase the bandwidth of the line or improve the signal-to-noise ratio.

- **Example 3.39**
- The signal-to-noise ratio is often given in decibels. Assume that SNR_{dB} is 36 and the channel bandwidth is 2 MHz The theoretical channel capacity can be calculated as

Given: $SNR_{dB} = 36$

Bandwidth $= 2\,MHz = 2 \times 10^6\,Hz$

To Find:

Capacity, $C = ?$

Formula:

$\rightarrow SNR_{dB} = 10 \log_{10} SNR$

$\rightarrow C = B \log_2 (1 + SNR)$

Solution:

$\rightarrow 10 \log_{10} SNR = SNR_{dB}$

$$\log_{10} SNR = \frac{SNR_{dB}}{10}$$

$$SNR = 10^{SNR_{dB}/10}$$

$$SNR = 10^{36/10}$$

$$SNR = 10^{3.6}$$

$$\underline{SNR = 3981}$$

$\rightarrow C = B \log_2 (1 + SNR)$

$$= 2 \times 10^6 \log_2 (1 + 3981)$$

$$= 2 \times 10^6 \log_2 3982$$

$$= 2 \times 10^6 \times 11.95$$

$$= 23.9 \times 10^6$$

$$= \underline{24\,Mbps}$$

- Example 3.41
- We have a channel with a 1-MHz bandwidth. The SNR for this channel is 63. What are the appropriate bit rate and signal level?

$$1\text{Mhz} = 10^6 \ Hz$$

Given: Bandwidth $= 1MH_2$

SNR $= 63$

To Find: BitRate $= ?$

Signal Level $= ?$

~~Solution~~

Formula: $C = B \log_2(1+SNR)$

BitRate $= 2 \times$ Bandwidth $\times \log_2 L$

Solution:

→ $C = 10^6 \log_2(1+63)$

$= 10^6 \log_2 64$

$= 10^6 (6)$

$= 6$ Mbps

→ BitRate $= 2 \times$ Bandwidth $\times \log_2 L$

$\cancel{6 = 2\times}$

$6\text{Mbps} = 2 \times 1MH_2 \times \log_2 L$

$6 = 2 \times \log_2 L$

$6/2 = \log_2 L$

$3 = \log_2 L$

$\log_2 L = 3$

$L = 2^3$

$L = 8$

Performance

- One important issue in networking is the performance of the network—how good is it?
- The performance measurement terms for the **overall measurement of the network performance**.
- Bandwidth = capacity of the system
- Throughput = no. of bits that can be pushed through
- Latency (Delay) = delay incurred by a bit from start to finish
- Bandwidth-Delay Product

❖1. Bandwidth

- One characteristic that measures network performance is bandwidth.
- However, the term can be used in two different contexts with two different measuring values:
- 1) bandwidth in hertz
- 2) bandwidth in bits per second.

- **1) bandwidth in hertz**
- Bandwidth in hertz is the **range of frequencies contained in a composite signal or the range of frequencies a channel can pass**.
- For example, we can say the bandwidth of a subscriber telephone line is 4 kHz.

- **2) bandwidth in bits per second**
- The term bandwidth can also **refer to the number of bits per second that a channel, a link, or even a network can transmit.**
- For example, one can say the bandwidth of a Fast Ethernet network (or the links in this network) is a maximum of 100 Mbps. This means that this network can send 100 Mbps.

❖2. Throughput

- The throughput is a **measure of how fast we can actually send data through a network.**
- A link may have a bandwidth of B bps, but we can only send T bps through this link with **T always less than B**.
- In other words, the **bandwidth is a potential measurement of a link**; the **throughput is an actual measurement of how fast we can send data**.
- For example, we may have a link with a bandwidth of 1 Mbps, but the devices connected to the end of the link may handle only 200 kbps. This means that we cannot send more than 200 kbps through this link.
- Imagine a highway designed to transmit 1000 cars per minute from one point to another. However, if there is congestion on the road, this figure may be reduced to 100 cars per minute. The bandwidth is 1000 cars per minute; the throughput is 100 cars per minute.

- **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? Formula (msg size/time)

Solution

We can calculate the throughput as

$$\textbf{Throughput} = (12{,}000 \times 10{,}000) / 60 = 2 \text{ Mbps}$$

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

❖3. Latency

- The latency or delay **defines how long it takes for an entire message to completely arrive at the destination from the time the first bit is sent out from the source.**

- latency is made of **four components**: propagation time, transmission time, queuing time and processing delay.

$$\textbf{Latency} = \textbf{propagation time} + \textbf{transmission time} + \textbf{queuing time} + \textbf{processing delay}$$

- **1. Propagation Time**
- Propagation time **measures the time required for a bit to travel from the source to the destination.**
- The propagation time is calculated **by dividing the distance by the propagation speed.**
- The propagation speed of electromagnetic signals **depends on the medium and on the frequency of the signal.**
- For example, in a vacuum, light is propagated with a speed of 3 x 10^8 m/s. It is lower in air; it is much lower in cable.

$$\textbf{Propagation time} = \textbf{Distance} / (\textbf{Propagation Speed})$$

- **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 2.4×10^8 m/s in cable.

Propagation time = (12,000 × 10,000) / (2.4 × 2^8) = 50 ms

Given :→ Distance

$= 12000$ Km

$= 12000 \times 1000$ m

$= 12000\,000$ m

→ Propogation Speed

$= 2.4 \times 10^8$ m/s

To Find: Propogation Time = ?

Formula =

$$\text{Propogation Time} = \frac{\text{Distance}}{\text{Propogation Speed}}$$

$$= \frac{12000000}{240000000} = \frac{12}{240}$$

$$= 0.05 \text{ s} = 0.05 \times 10^3 = 50 \text{ ms}$$

- **2. Transmission Time**
- In data communications we don't send just 1 bit, we send a message.
- The first bit may take a time equal to the propagation time to reach its destination; the last bit also may take the same amount of time.
- However, there is a **time between the first bit leaving the sender and the last bit arriving at the receiver.**
- The first bit leaves earlier and arrives earlier; the last bit leaves later and arrives later.
- The **time required for transmission of a message depends on the size of the message and the bandwidth of the channel.**

$$\boxed{\textbf{Transmission time} = (\textbf{Message size}) / \textbf{Bandwidth}}$$

- **Example 3.46**
- What are the propagation time and the transmission time for a 2.5-KB (kilobyte) message (an email) 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 2.4×10^8 m/s.

Solution

We can calculate the propagation and transmission time as

$$\textbf{Propagation time} = (12{,}000 \times 1000) / (2.4 \times 10^8) = 50 \text{ ms}$$

$$\textbf{Transmission time} = (2500 \times 8) / 10^9 = 0.020 \text{ ms}$$

- **Example 3.47**
- What are the propagation time and the transmission time for a 5-MB (megabyte) 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

$$\textbf{Propagation time} = (12{,}000 \times 1000) / (2.4 \times 10^8) = 50 \text{ ms}$$

$$\textbf{Transmission time} = (5{,}000{,}000 \times 8) / 10^6 = 40 \text{ s}$$

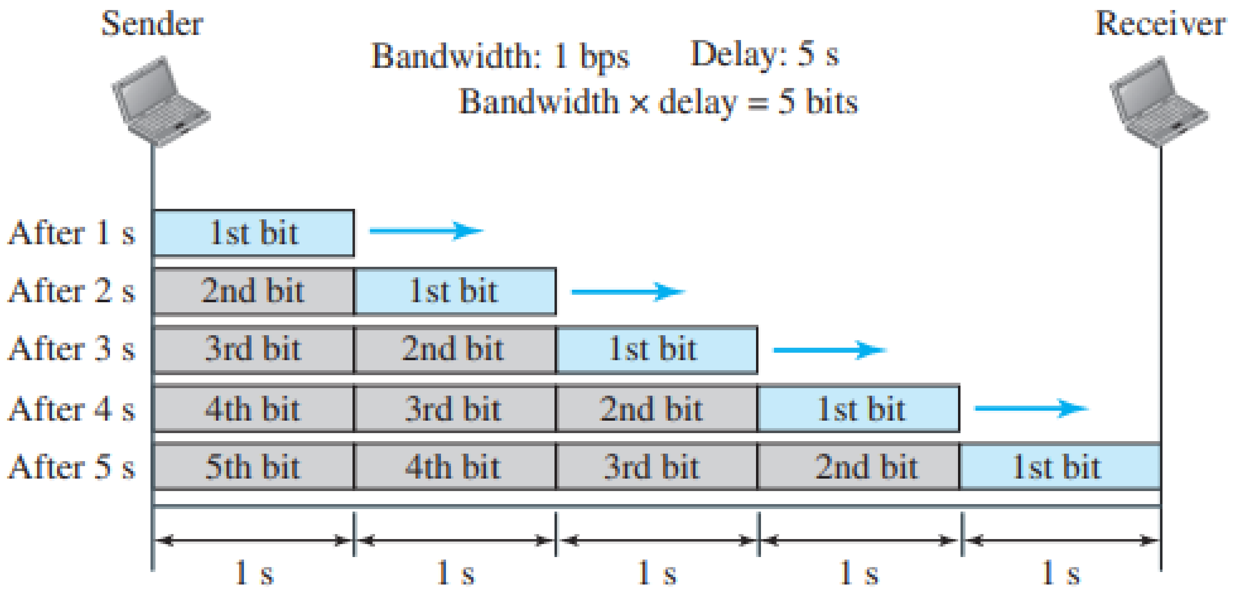
- **3. Queuing Time**
- The third component in latency is the queuing time, the **time needed for each intermediate or end device to hold the message before it can be processed.**
- The queuing time is **not a fixed factor**; it **changes with the load imposed on the network.**
- When **there is heavy traffic on the network, the queuing time increases**.
- An **intermediate device**, such as a router, **queues the arrived messages and processes them one by one.**
- **If** there are **many messages**, **each message will have to wait**.

❖4. Bandwidth Delay Product

- Bandwidth and delay are two performance metrics of a link.
- In data communications is the product of the two, the bandwidth-delay product is very important
- Bandwidth delay product is **a measurement of how many bits can fill up a network link**.

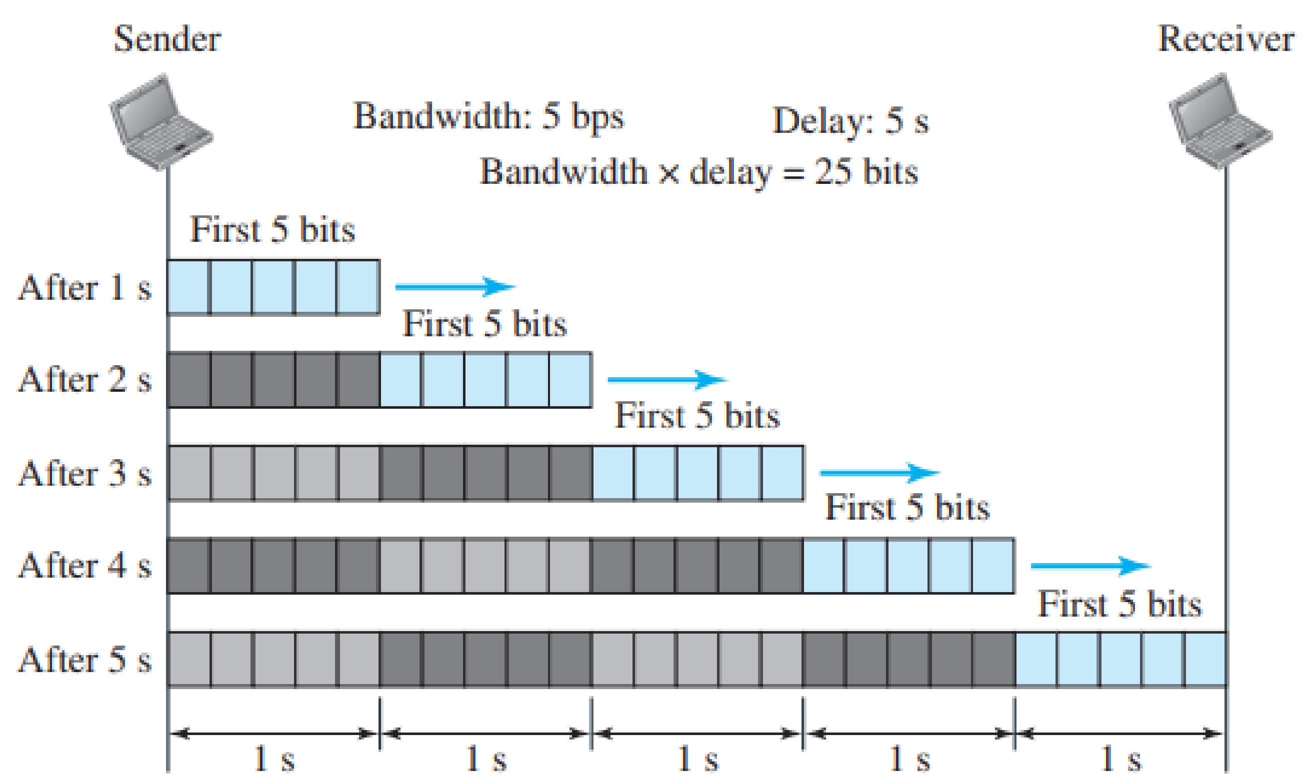
❑ **Case 1.** Figure 3.32 shows case 1.

Figure 3.32 *Filling the link with bits for case 1*



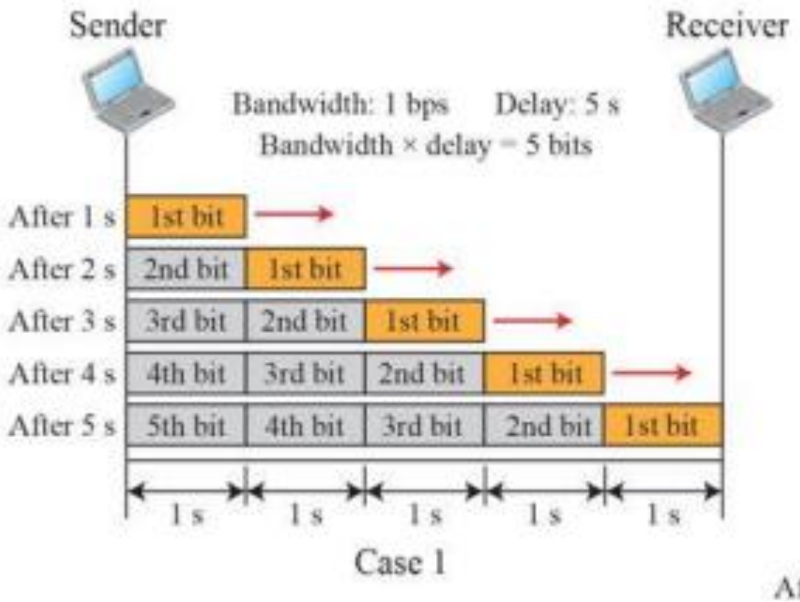
- Let us assume that we have a link with a bandwidth of 1 bps. We also assume that the delay of the link is 5.
- We want to see what the bandwidth-delay product means in this case.
- we can say that this product 1 x 5 is the maximum number of bits that can fill the link. There can be no more than 5 bits at any time on the link.

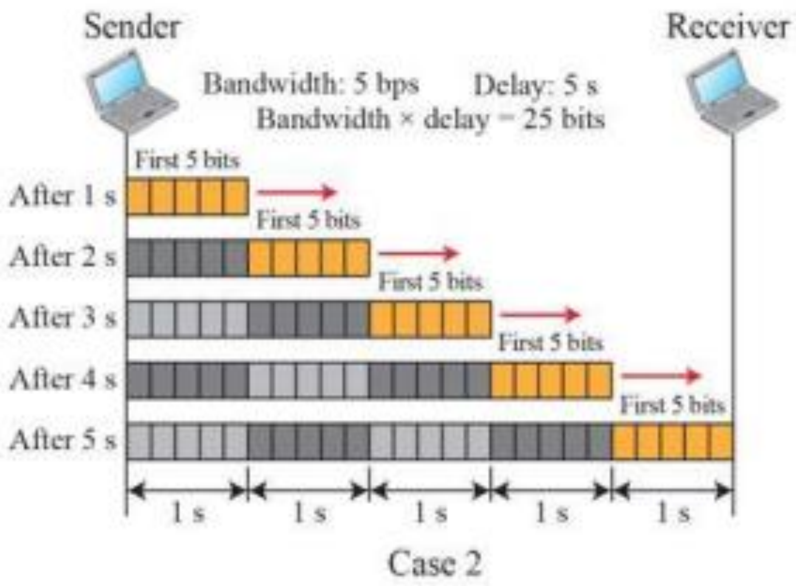
Figure 3.33 *Filling the link with bits in case 2*



- Now assume we have a bandwidth of 5 bps. Figure 3.33 shows that there can be maximum 5 × 5 = 25 bits on the line. The reason is that, at each second, there are 5 bits on the line; the duration of each bit is 0.20 s.

Figure 7.17: Filling the link with bits for cases 1 and 2





❖5. Jitter

- Another performance issue that is **related to delay is jitter**.
- ***Jitter or packet delay variance*** *is the* ***term used to refer to the fluctuation in delay as packets transfer across a network***
- 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.