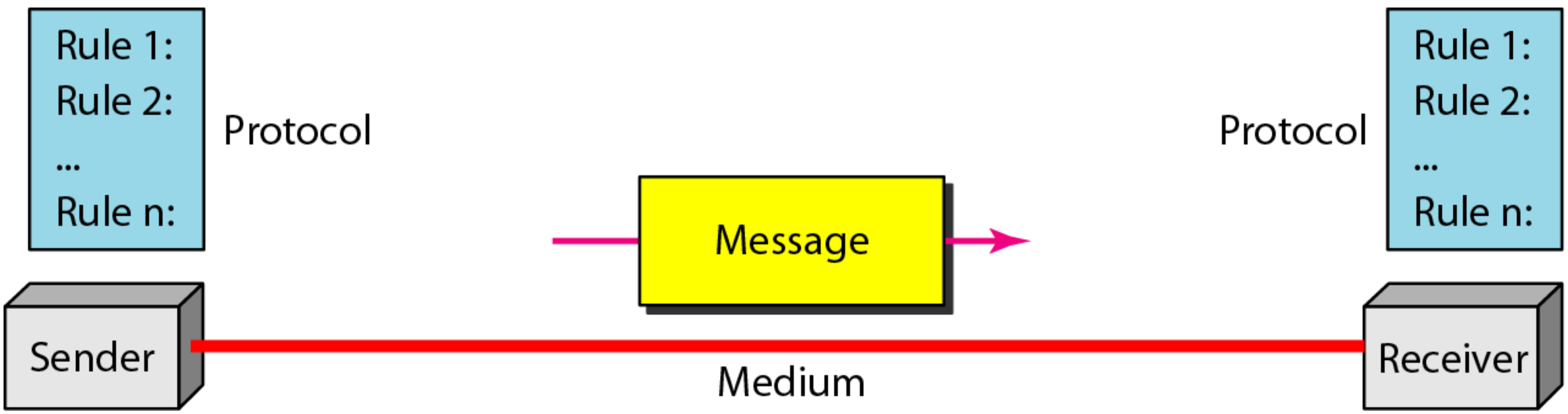
# OVERVIEW OF COMMUNICATION SYSTEM

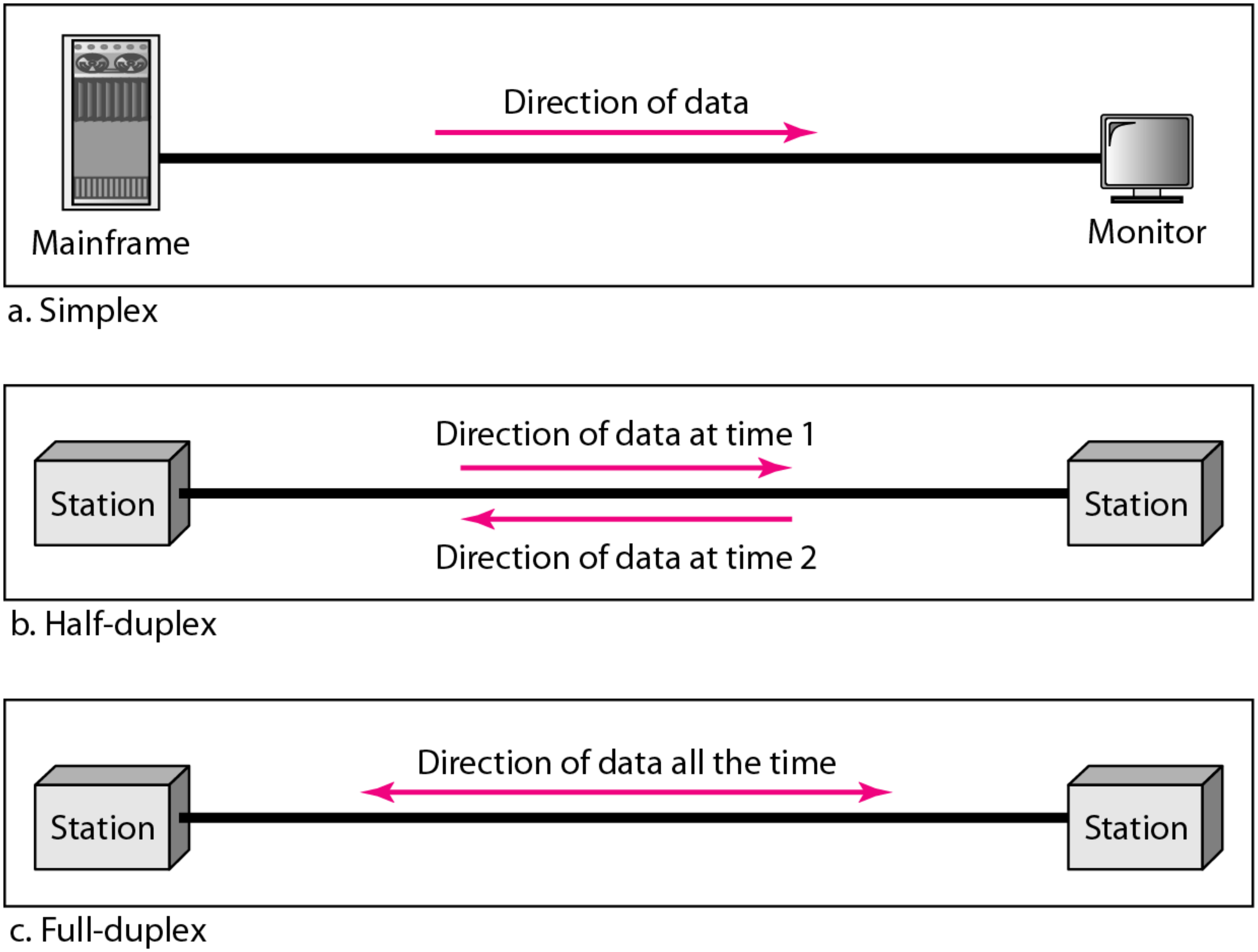
# Data Communication

- *The term telecommunication means communication at a distance.*
- *The word data refers to information presented in whatever form is agreed upon by the parties creating and using the data.*
- *Data communications are the exchange of data between two devices via some form of transmission medium such as a wire cable.*

# *Five components of data communication*



*Data flow (simplex, half-duplex, and full-duplex)*

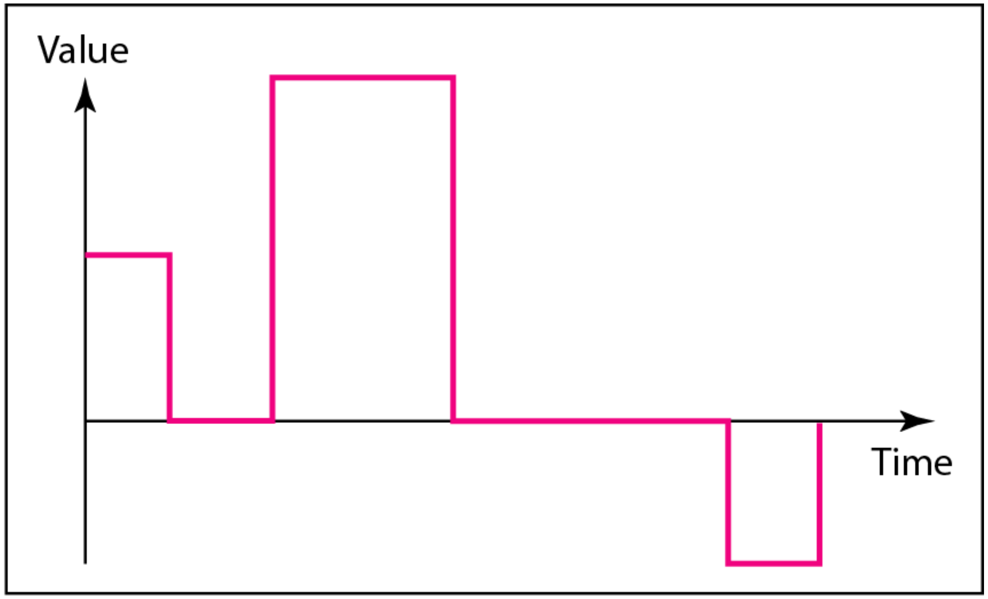


# Data and Signals

- 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.
- Periodic and Non periodic signals

# Comparison of analog and digital signals


a. Analog signal

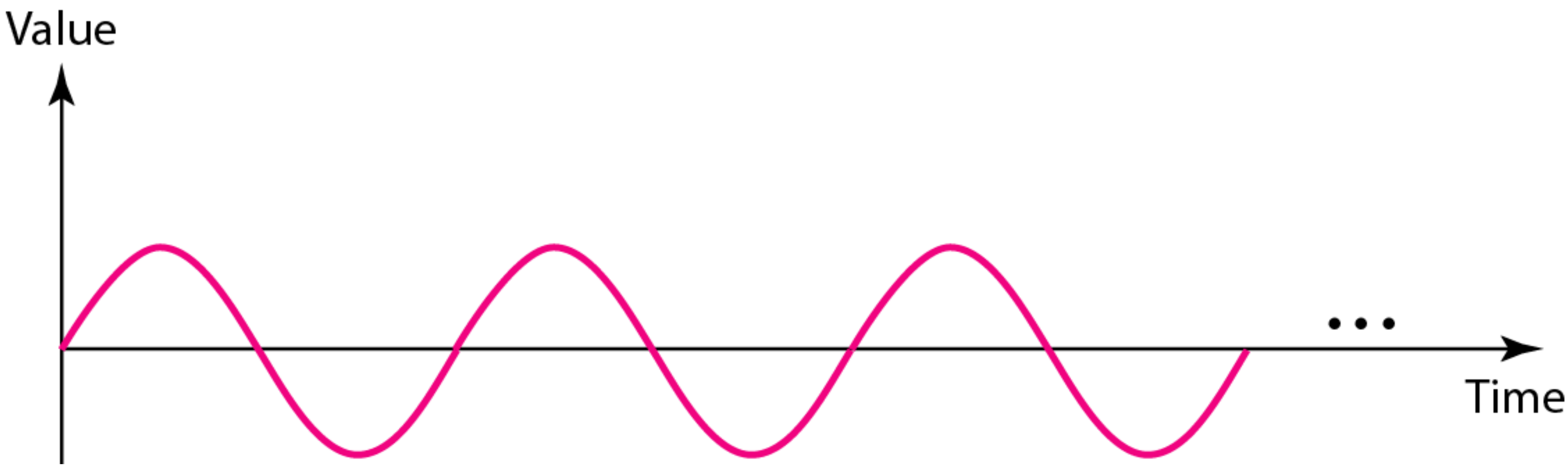



b. Digital signal

# PERIODIC ANALOG SIGNALS

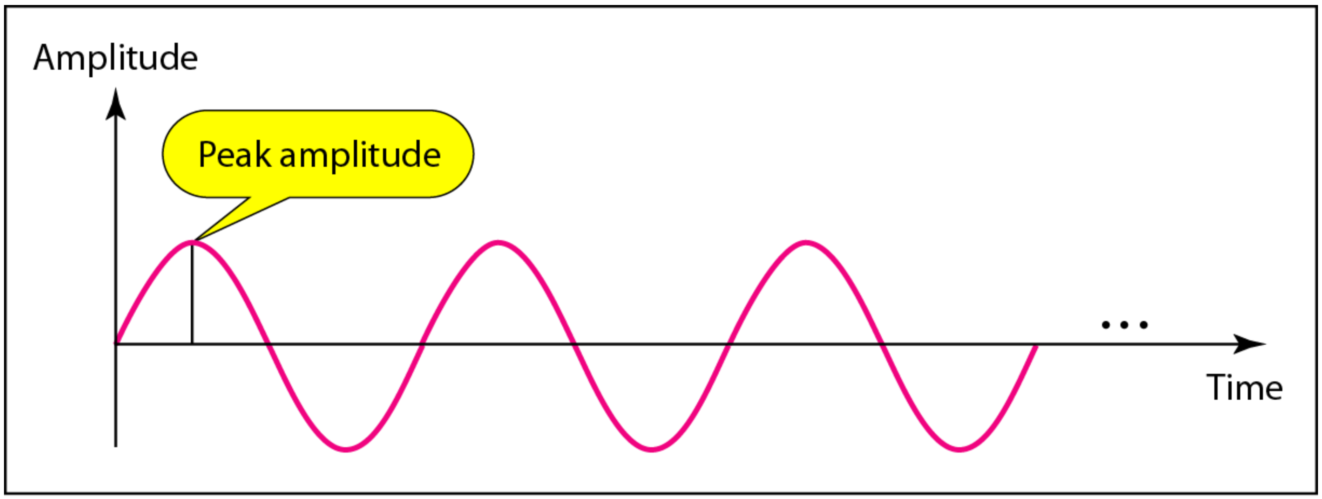
- Periodic analog signals can be classified as simple or composite. A simple periodic analog signal, a sine wave, cannot be decomposed into simpler signals.
- A composite periodic analog signal is composed of multiple sine waves.

# Sine Wave

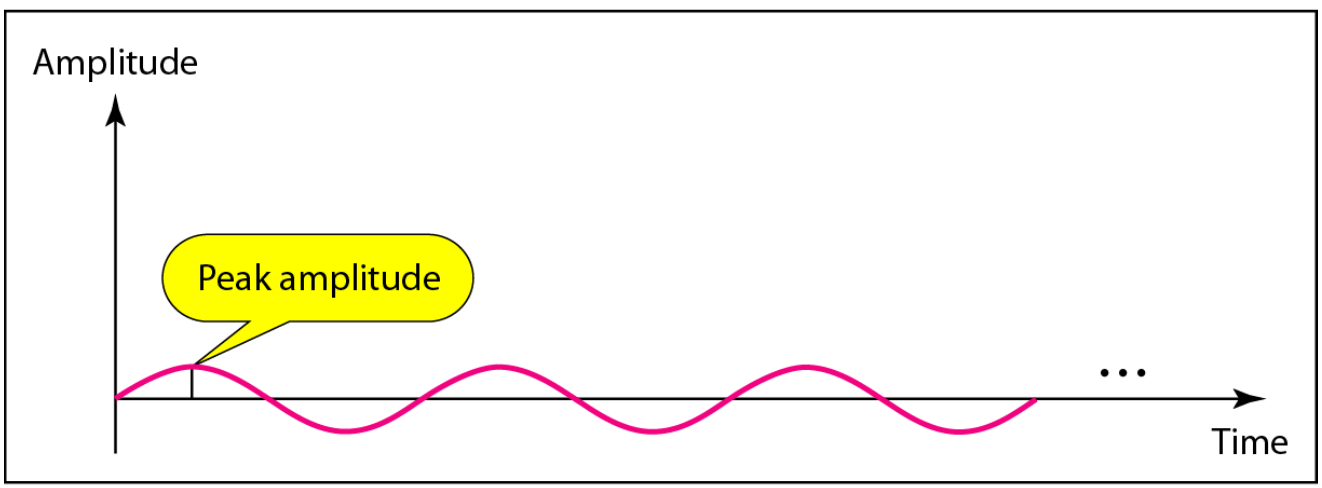



Phase
Amplitude
frequency

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




a. A signal with high peak amplitude




b. A signal with low peak amplitude

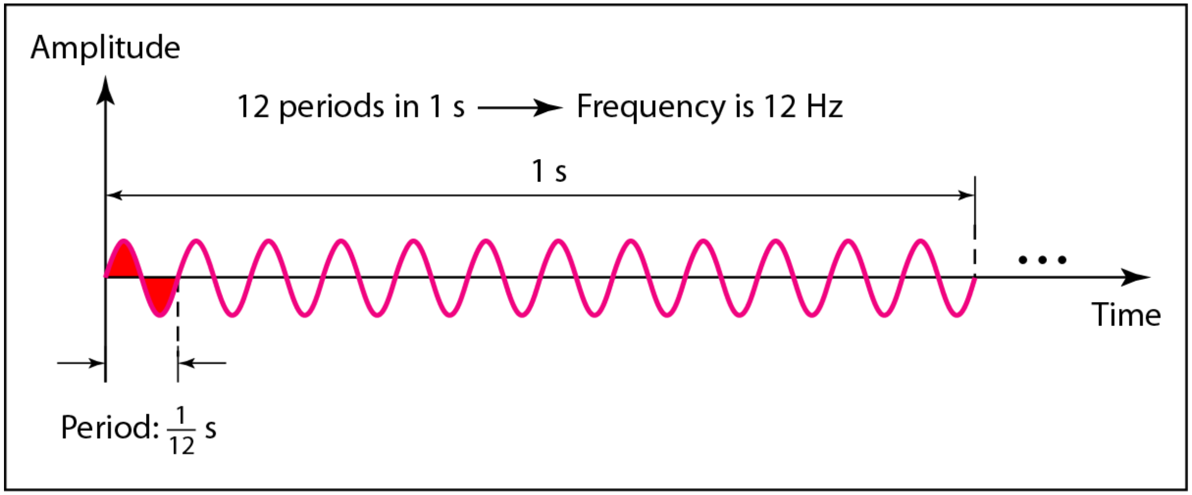
# Frequency and Periods

- Frequency and period are the inverse of each other.

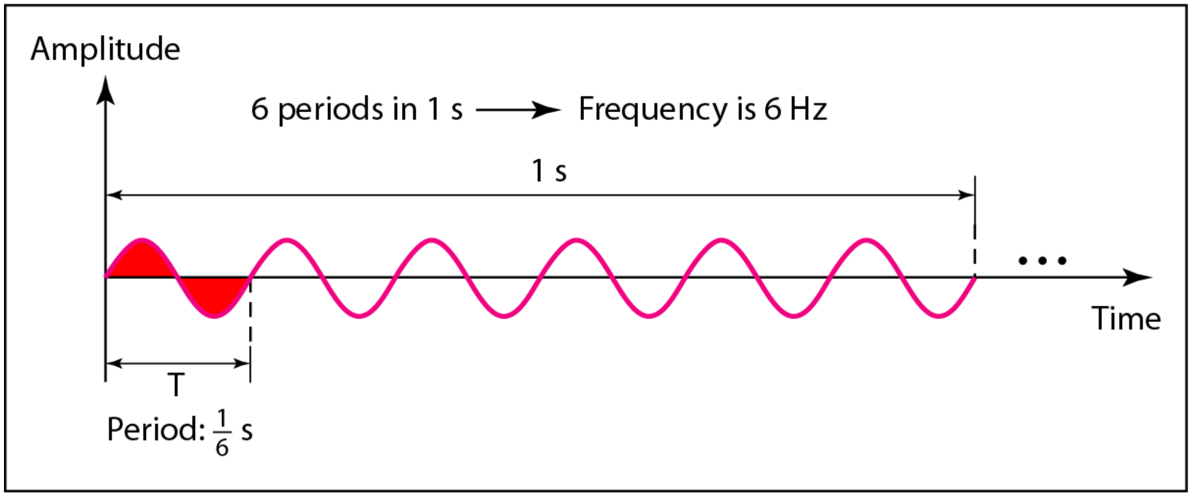
$$\boxed{f = \frac{1}{T} \qquad \textbf{and} \qquad T = \frac{1}{f}}$$

- 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.

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




a. A signal with a frequency of 12 Hz




b. A signal with a frequency of 6 Hz

# 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

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

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

- Express a period of 100 ms in microseconds.

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

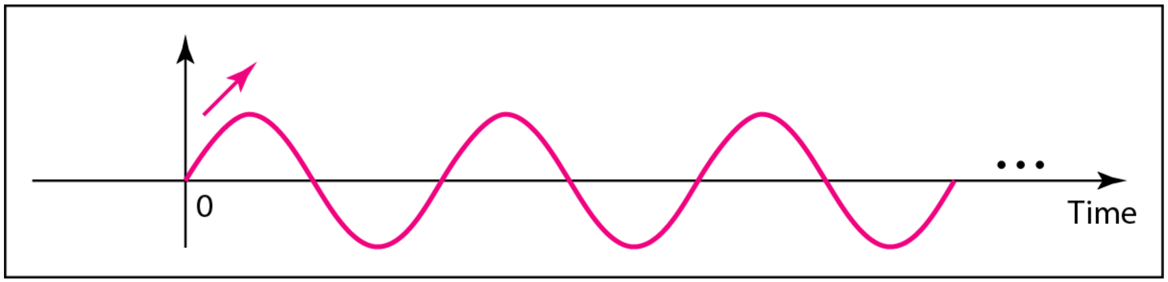
# Example

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

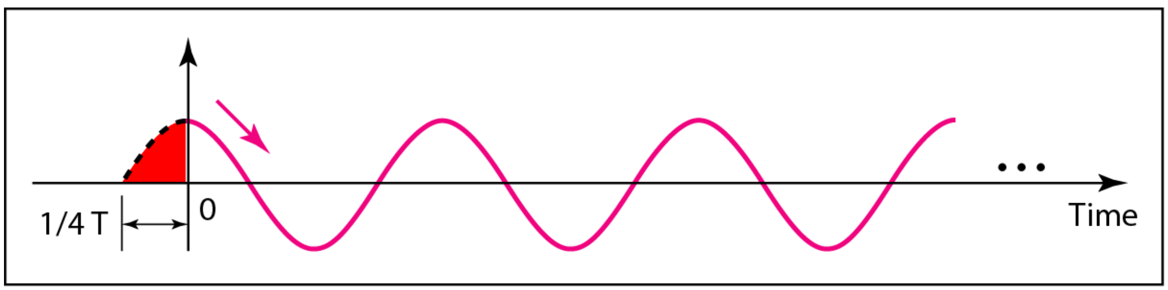
$$100 \text{ ms} = 100 \times 10^{-3} \text{ s} = 10^{-1} \text{ s}$$

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

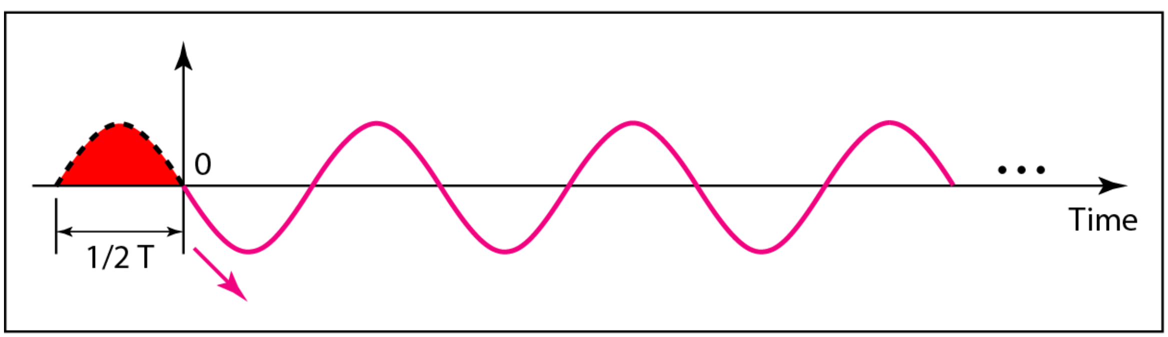
# Three sine waves with the same amplitude and frequency, but different phases




a. 0 degrees

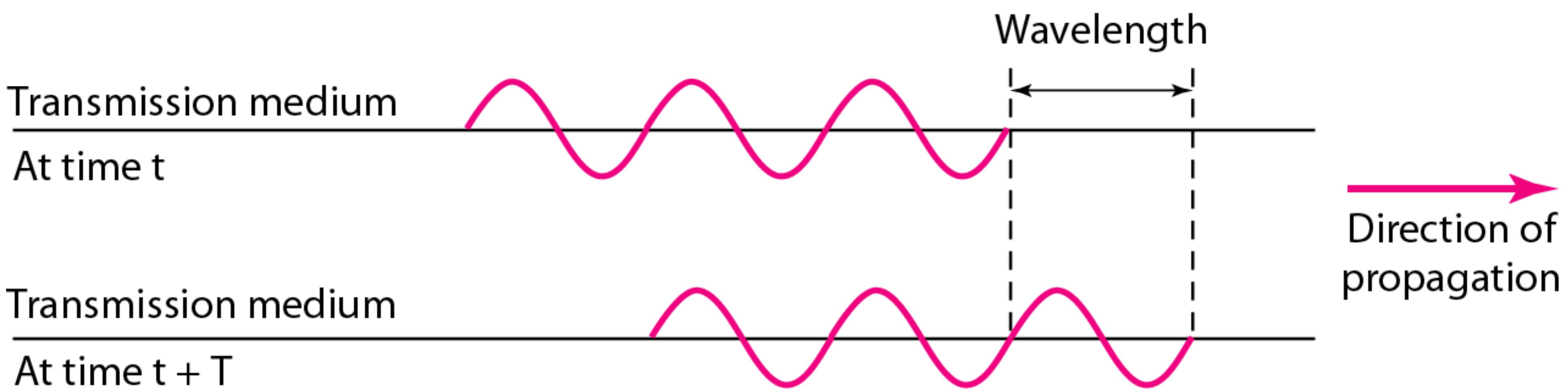



b. 90 degrees




c. 180 degrees

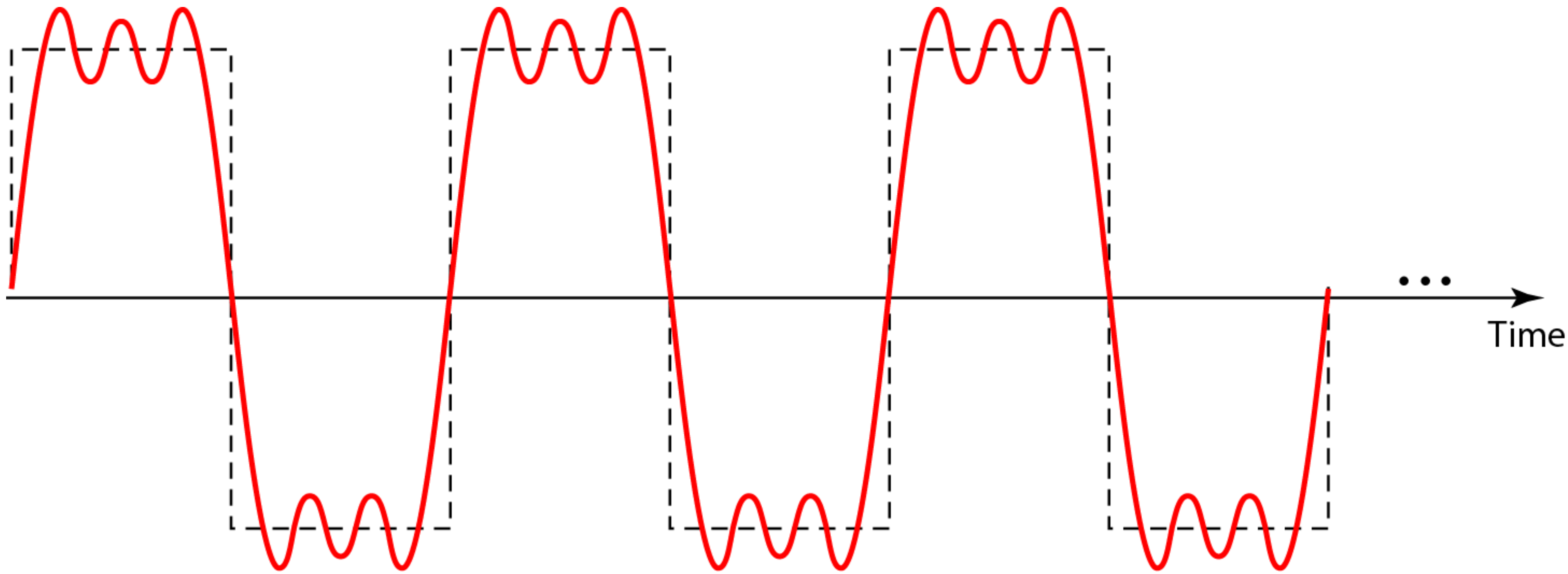
# Wavelength and period



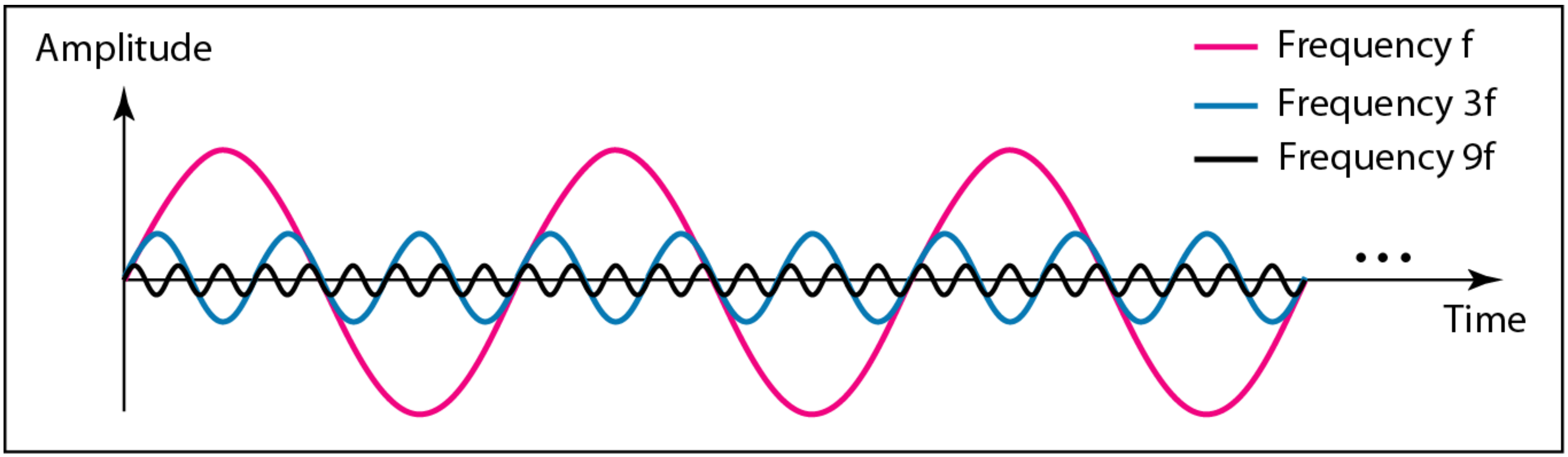
# Composite Signal

- 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.
- If the composite signal is **periodic**, the decomposition gives a series of signals with discrete frequencies;
- if the composite signal is **nonperiodic**, the decomposition gives a combination of sine waves with continuous frequencies.

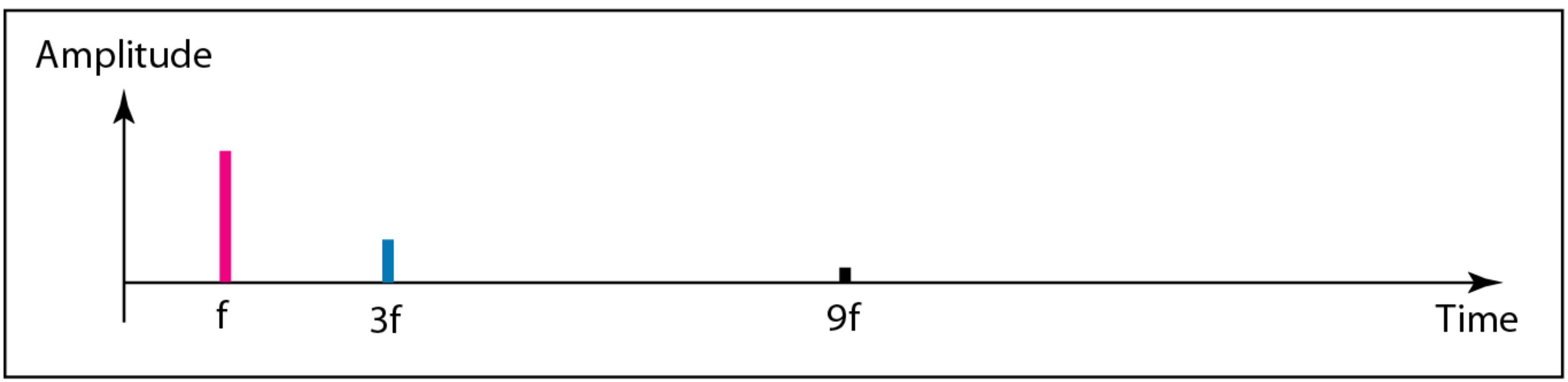
# A composite periodic signal



## Decomposition of a composite periodic signal in the time and frequency domains



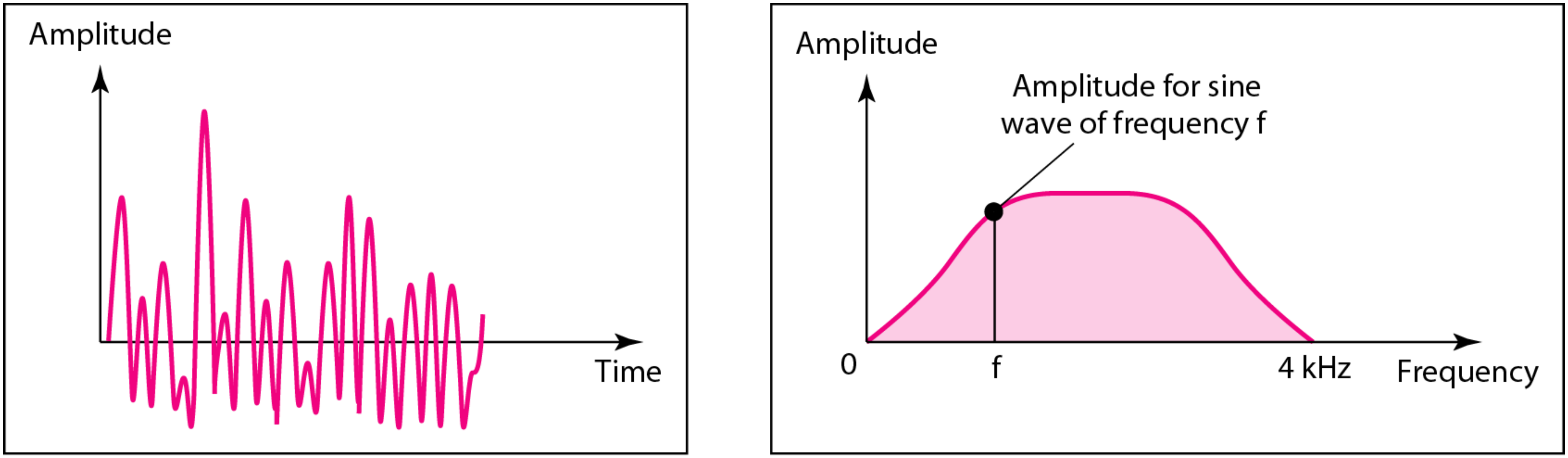

a. Time-domain decomposition of a composite signal




b. Frequency-domain decomposition of the composite signal

# The time and frequency domains of a nonperiodic signal

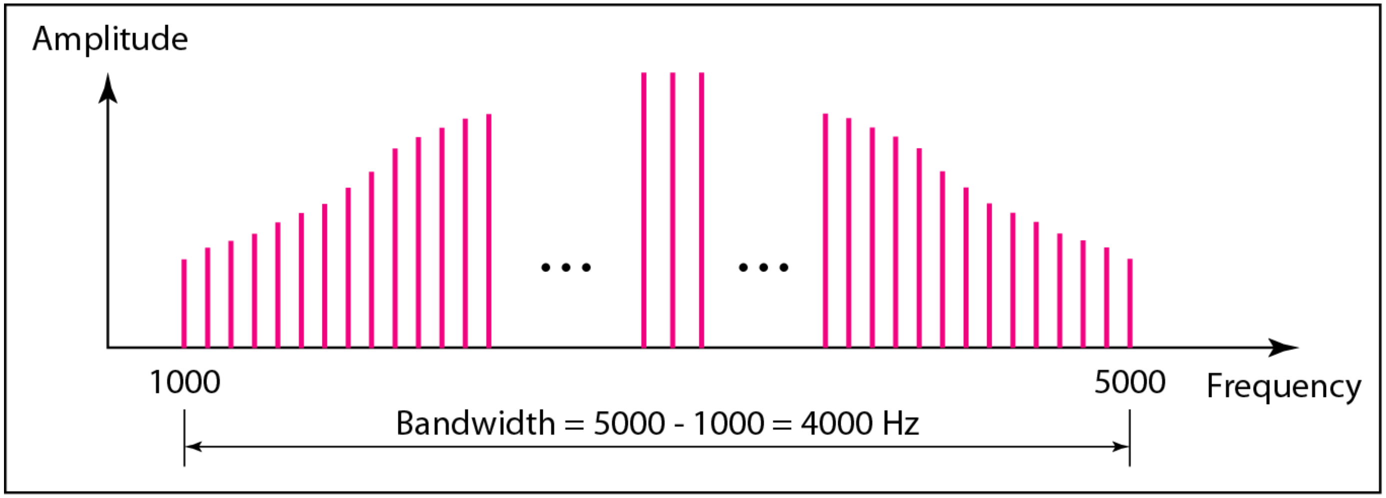
Figure below shows a nonperiodic composite signal. It can be the signal created by a **microphone** or a **telephone set** when a word or two is pronounced. In this case, the composite signal cannot be periodic, because that implies that we are repeating the same word or words with exactly the same tone.



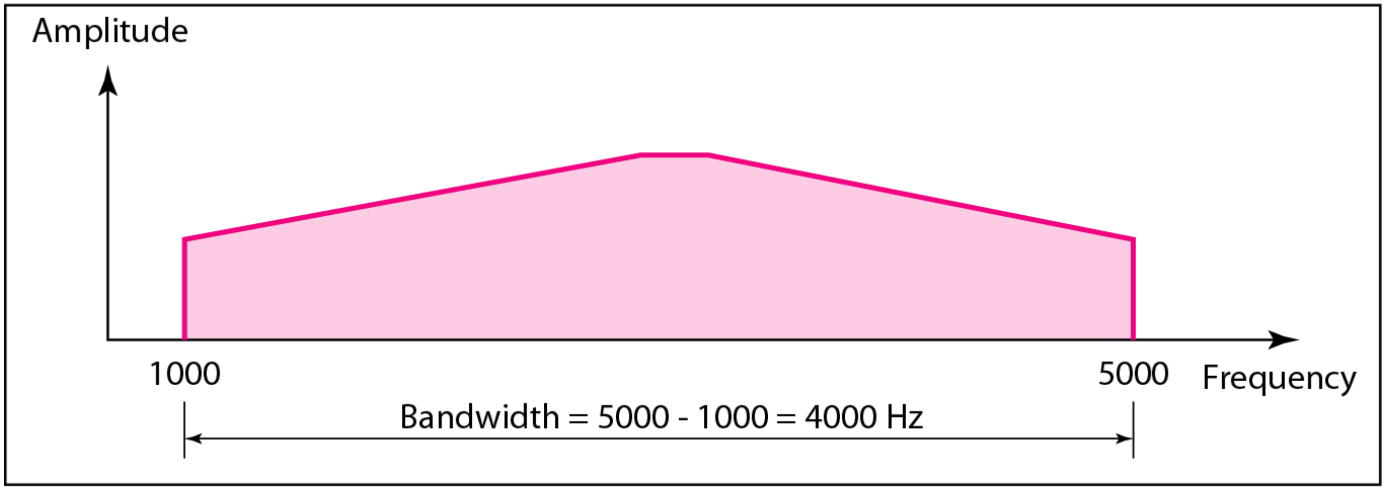

a. Time domain

b. Frequency domain

# The bandwidth of periodic and nonperiodic composite signals




a. Bandwidth of a periodic signal




b. Bandwidth of a nonperiodic signal

# Example

- 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

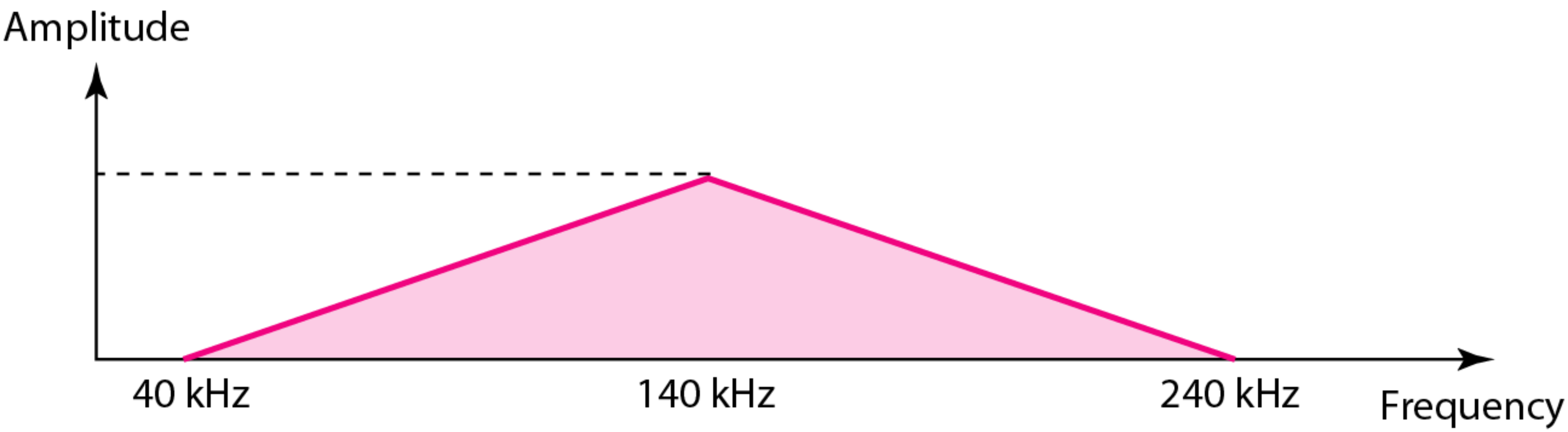
$$\boxed{B = f_h - f_l = 900 - 100 = 800 \text{ Hz}}$$

# Example

- 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.

- Solution
- The lowest frequency must be at 40 kHz and the highest at 240 kHz. Figure on the next page shows the frequency domain and the bandwidth.

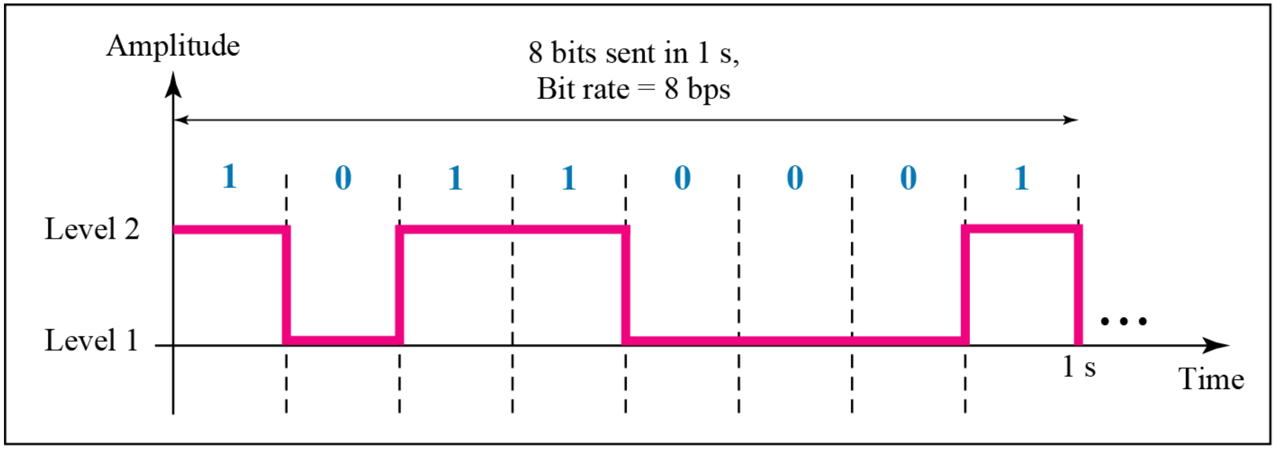
# Example (cont.)



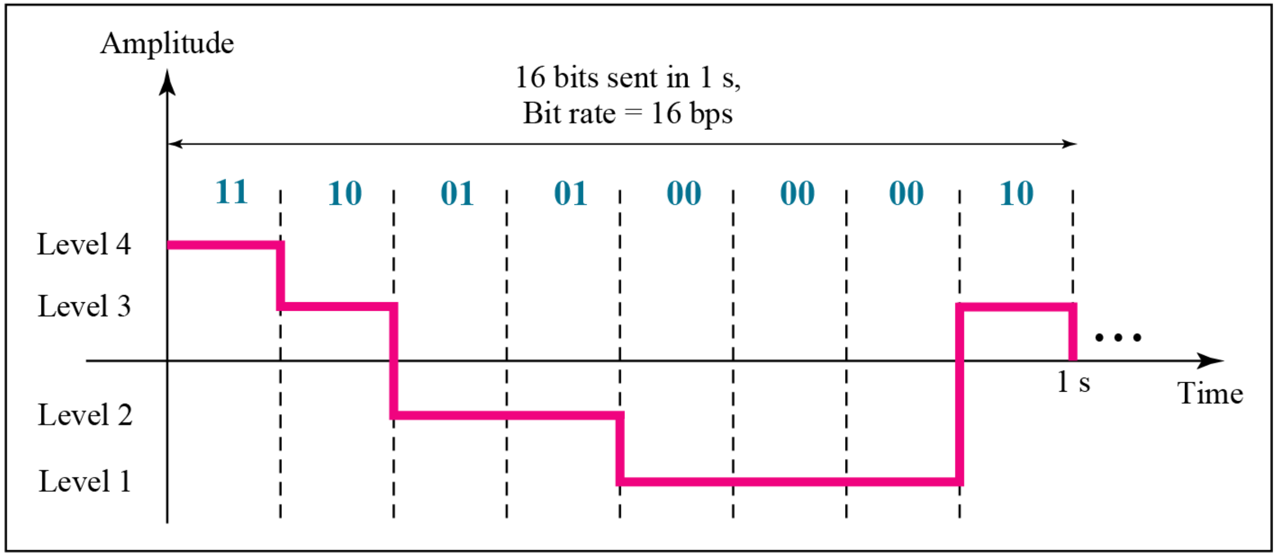
# Digital Signals

- 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.

# Two digital signals: one with two signal levels and the other with four signal levels




a. A digital signal with two levels

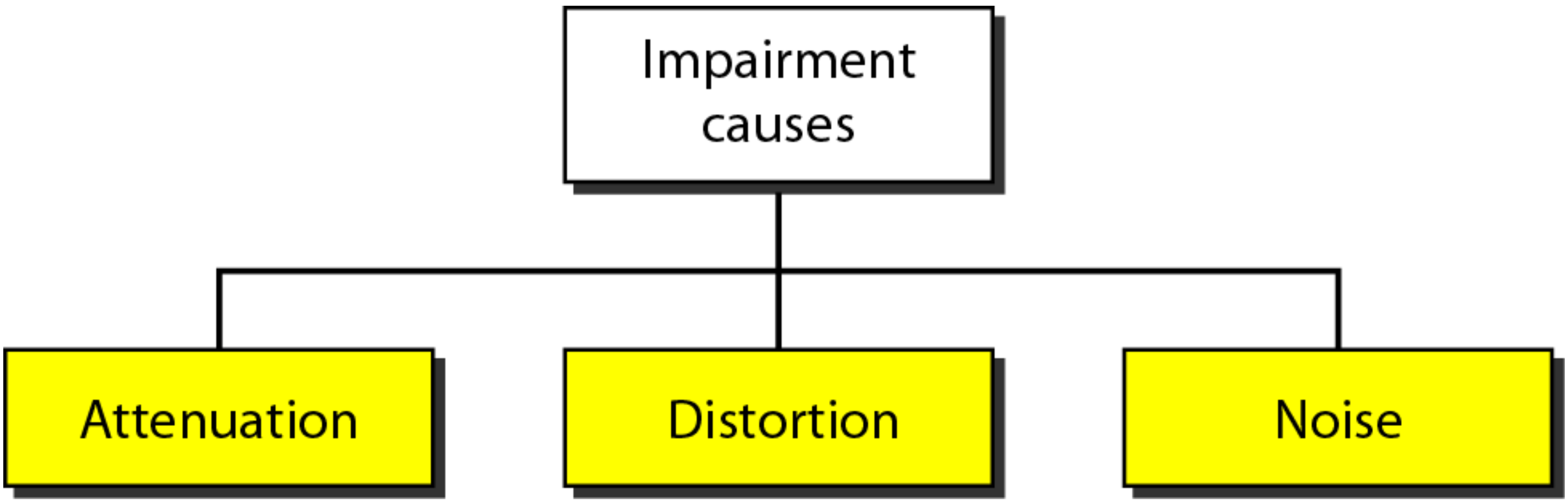



b. A digital signal with four levels

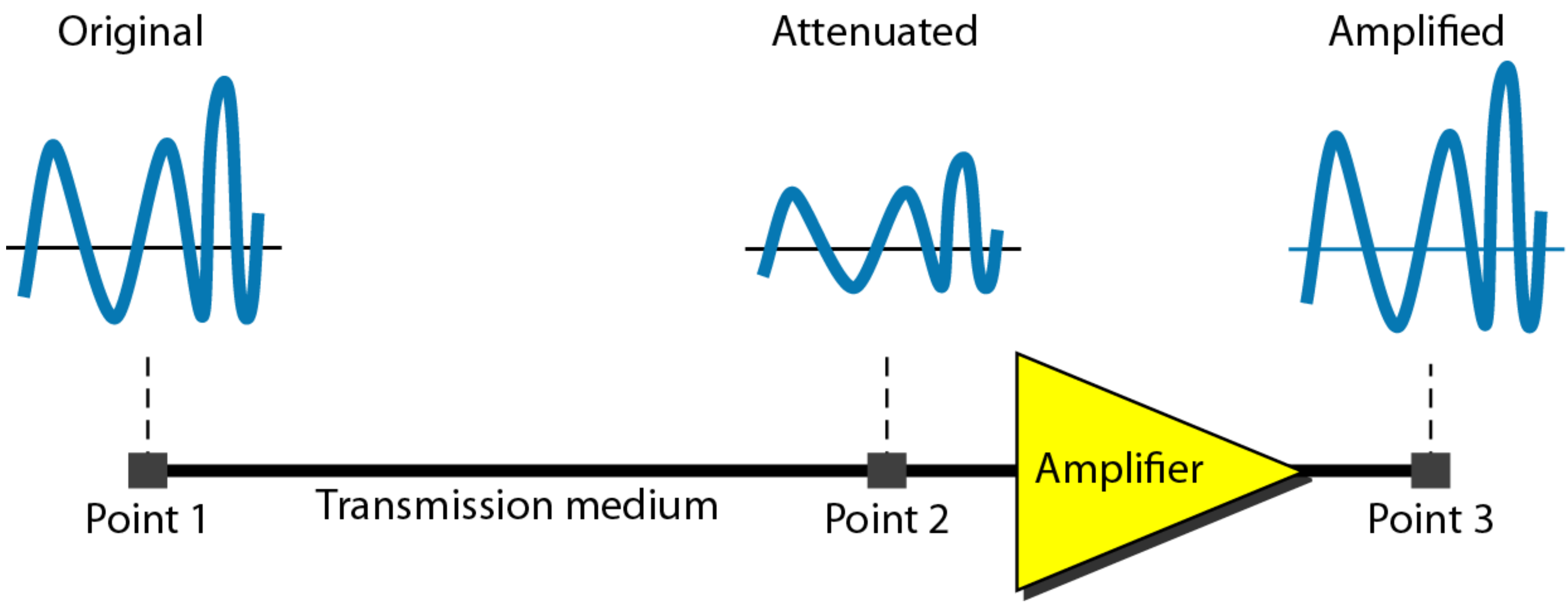
# Transmission Impairments

- 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.

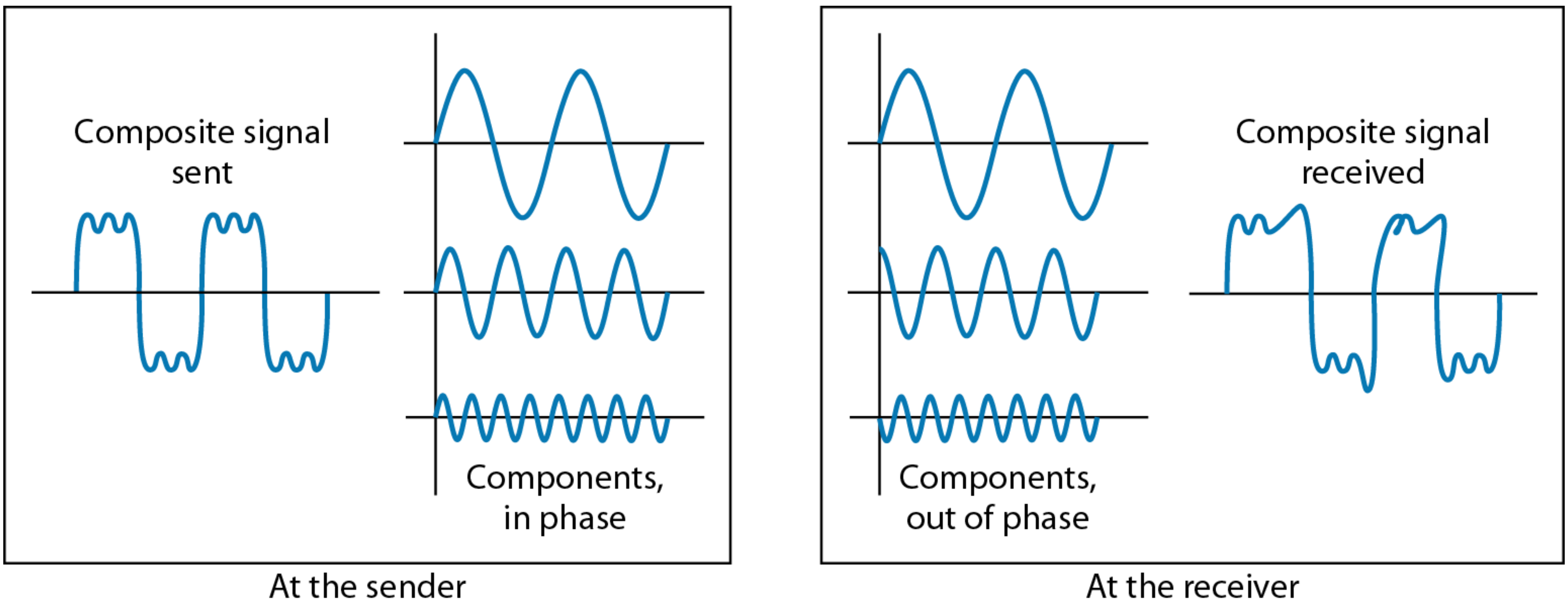
# Causes of impairment



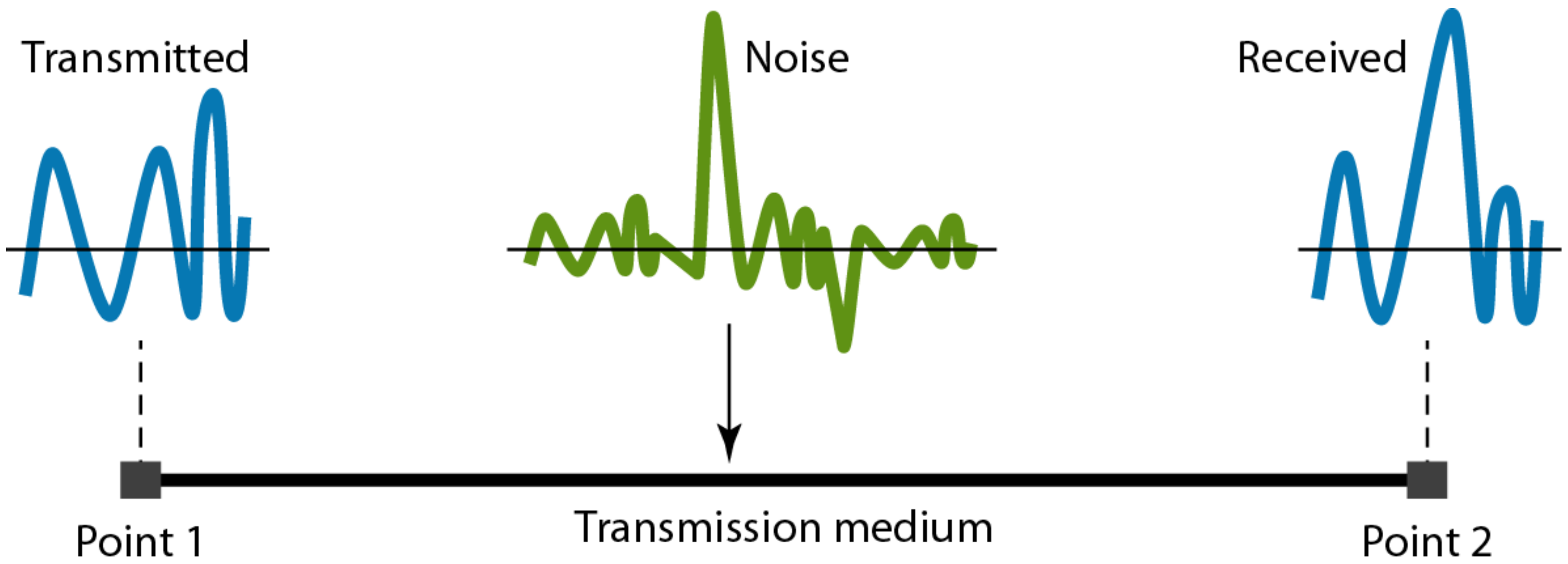
# Attenuation



# Distortion


Composite signal sent
Components, in phase
At the sender
Components, out of phase
Composite signal received
At the receiver

# Noise


Transmitted
Noise
Received
Point 1
Transmission medium
Point 2

# 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)

Topics discussed in this section:

Noiseless Channel: Nyquist Bit Rate
Noisy Channel: Shannon Capacity
Using Both Limits

# Data Rate Limits

- Noiseless channel: **Nyquist Bit Rate**
  - *Bit rate = 2 * Bandwidth * $\log_2 L$*
  - *Increasing the levels may cause the reliability of the system*
- Noisy channel: **Shannon Capacity**
  - *Capacity = Bandwidth * $\log_2(1 + SNR)$*

Note

Increasing the levels of a signal may reduce the reliability of the system.

# Data Rate: Noiseless Channels

Harry Nyquist
(1889-1976)

- *Nyquist Theorem*

$$\boxed{\text{Bit Rate} = 2 \times \text{Bandwidth} \times \log_2 L}$$

  - Bit rate in bps
  - Bandwidth in Hz
  - *L* – number of signal levels

# 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

$$\boxed{\text{BitRate} = 2 \times 3000 \times \log_2 2 = 6000 \text{ bps}}$$

# 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

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

# 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?

Solution

We can use the Nyquist formula as shown:

$$265{,}000 = 2 \times 20{,}000 \times \log_2 L$$

$$\log_2 L = 6.625 \qquad L = 2^{6.625} = 98.7 \text{ levels}$$

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.

# Data Rate: Noisy Channels

- *Shannon Capacity*

$$\boxed{\text{Capacity} = \text{Bandwidth} \times \log_2(1+\text{SNR})}$$

  - Capacity (maximum bit rate) in bps
  - Bandwidth in Hz
  - SNR – Signal-to-Noise Ratio

**Claude Elwood Shannon (1916-2001)**

# 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

$$\boxed{C = B \log_2 (1 + \text{SNR}) = B \log_2 (1 + 0) = B \log_2 1 = B \times 0 = 0}$$

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. The signal-to-noise ratio is usually 3162. For this channel the capacity is calculated as

$$C = B \log_2 (1 + \text{SNR}) = 3000 \log_2 (1 + 3162) = 3000 \log_2 3163$$
$$= 3000 \times 11.62 = 34{,}860 \text{ bps}$$

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 $SNR_{dB} = 36$ and the channel bandwidth is 2 MHz. The theoretical channel capacity can be calculated as

$$SNR_{dB} = 10 \log_{10} SNR \rightarrow SNR = 10^{SNR_{dB}/10} \rightarrow SNR = 10^{3.6} = 3981$$

$$C = B \log_2 (1 + SNR) = 2 \times 10^6 \times \log_2 3982 = 24 \text{ Mbps}$$

# 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?

## Solution

First, we use the Shannon formula to find the upper limit.

$$\boxed{C = B \log_2 (1 + \text{SNR}) = 10^6 \log_2 (1 + 63) = 10^6 \log_2 64 = 6 \text{ Mbps}}$$

# Example 3.41 (continued)

The Shannon formula gives us 6 Mbps, the upper limit. For better performance we choose something lower, 4 Mbps, for example. Then we use the Nyquist formula to find the number of signal levels.

$$\boxed{4 \text{ Mbps} = 2 \times 1 \text{ MHz} \times \log_2 L \quad \Longrightarrow \quad L = 4}$$

Note

The Shannon capacity gives us the upper limit; the Nyquist formula tells us how many signal levels we need.

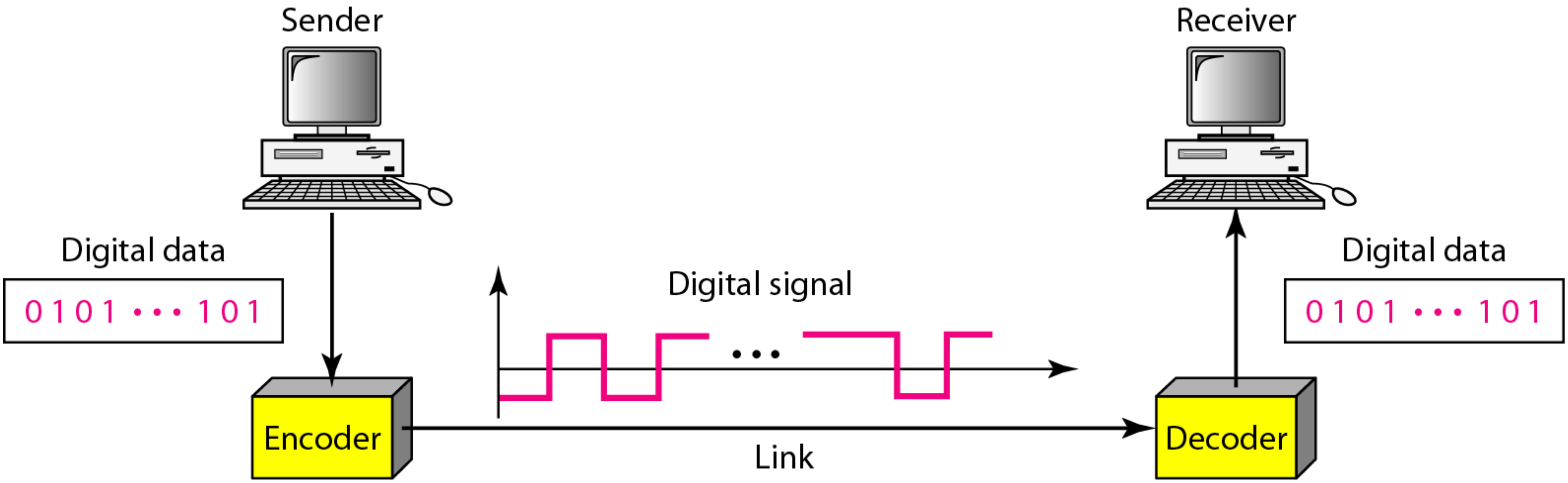
# 4-1 DIGITAL-TO-DIGITAL CONVERSION

*In this section, we see how we can represent digital data by using digital signals. The conversion involves three techniques: **line coding**, **block coding**, and **scrambling**. Line coding is always needed; block coding and scrambling may or may not be needed.*

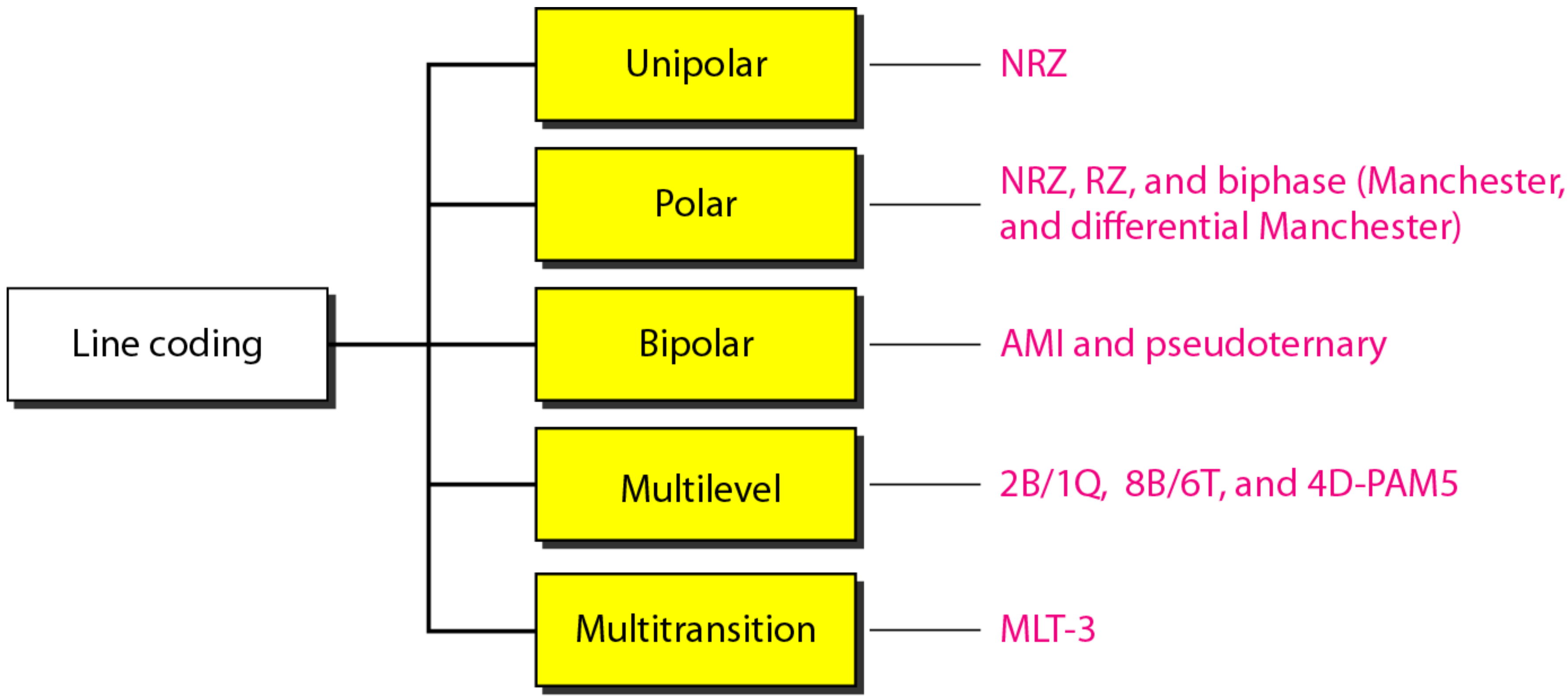
***Topics discussed in this section:***

**Line Coding**
**Line Coding Schemes**
**Block Coding**
**Scrambling**

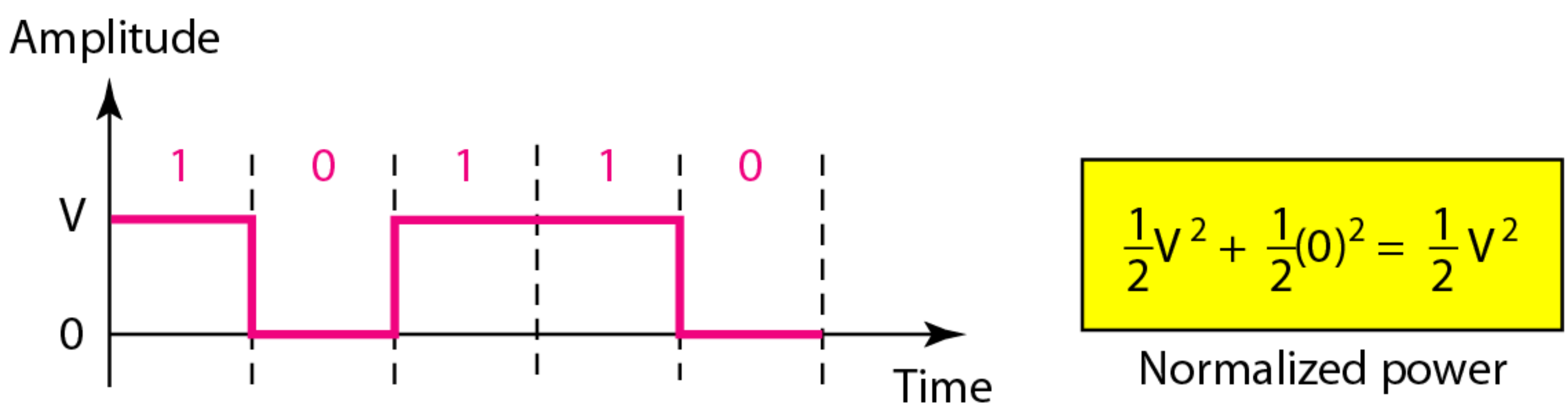
# **Figure 4.1** *Line coding and decoding*



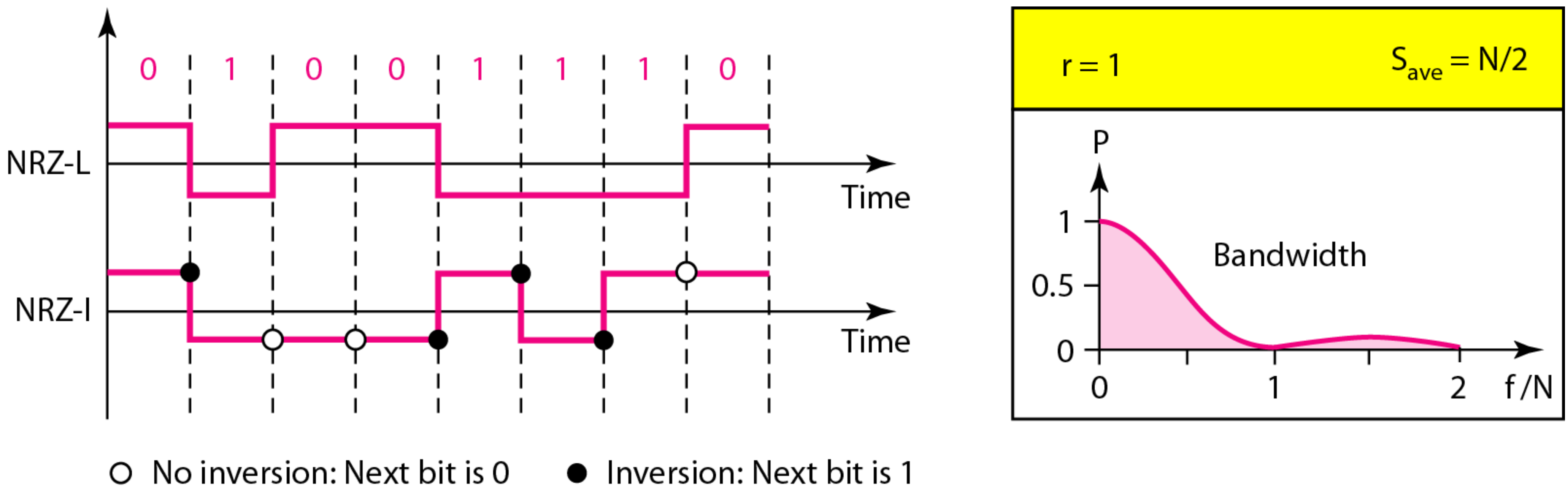
# Figure 4.4 *Line coding schemes*



# Figure 4.5 *Unipolar NRZ scheme*



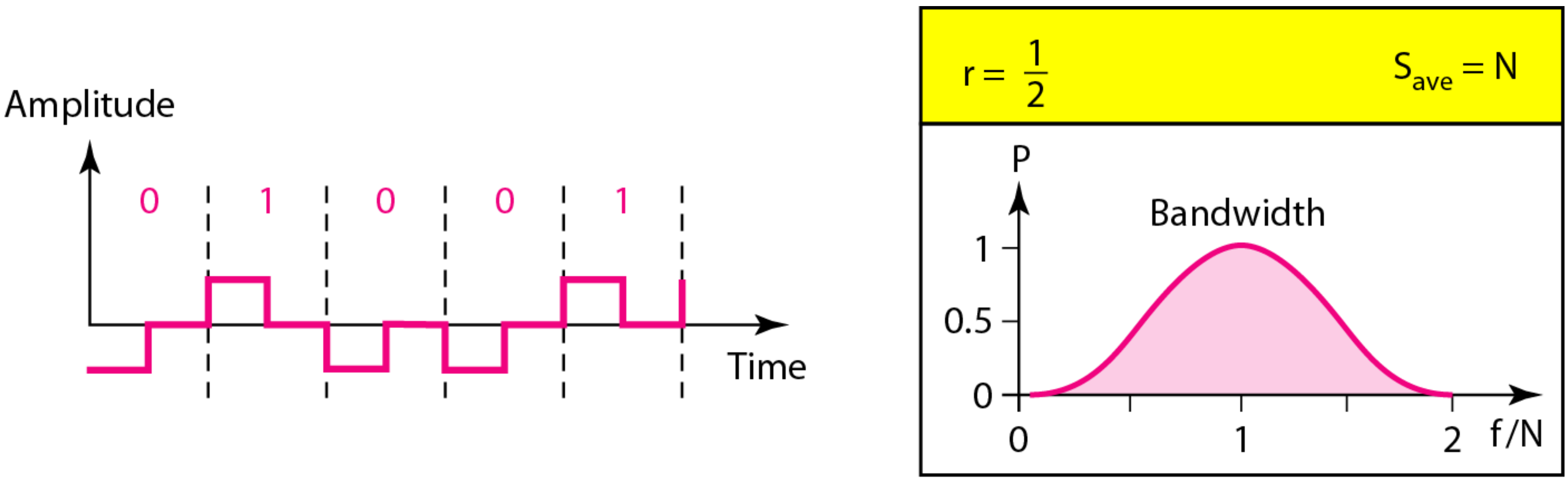
## Figure 4.6 *Polar NRZ-L and NRZ-I schemes*



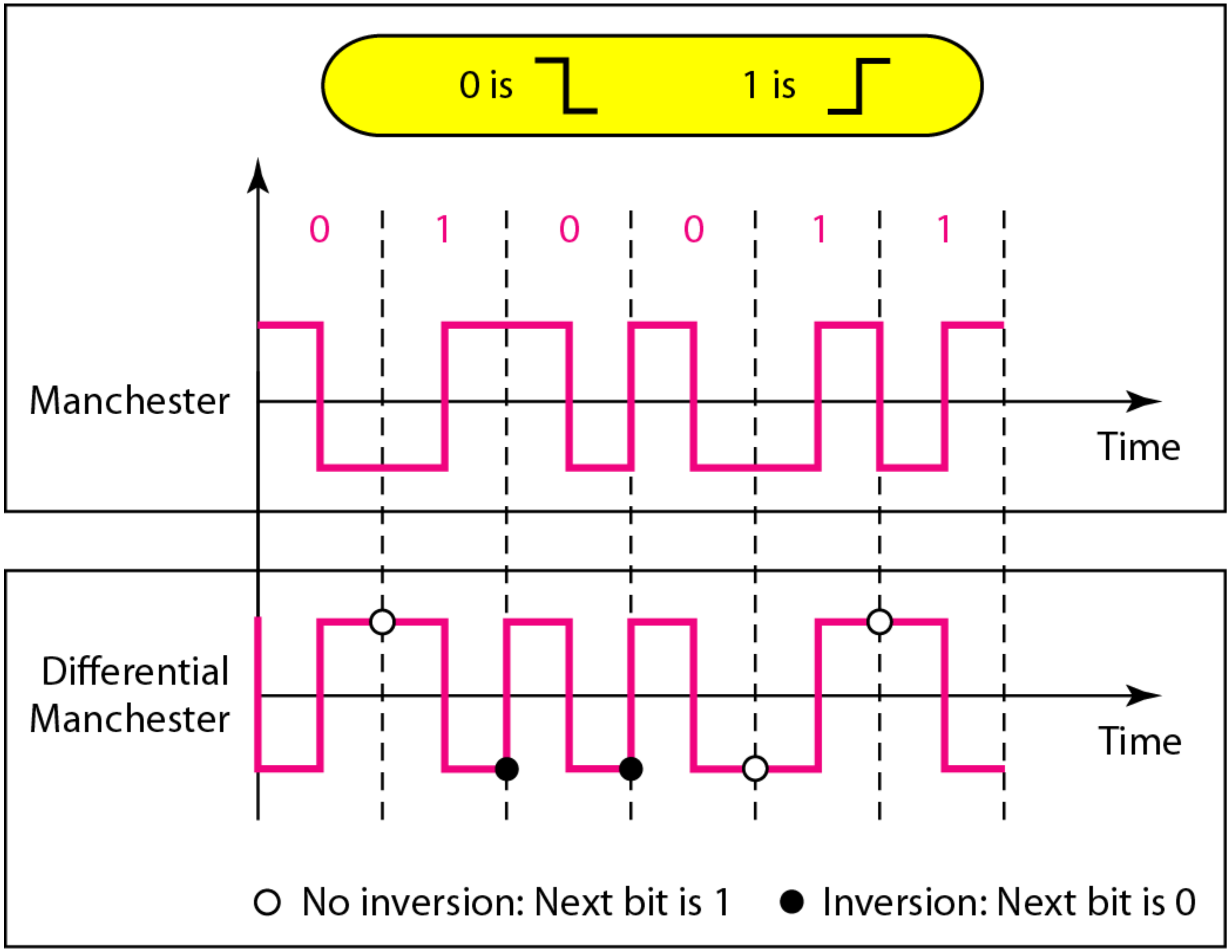
**Note**

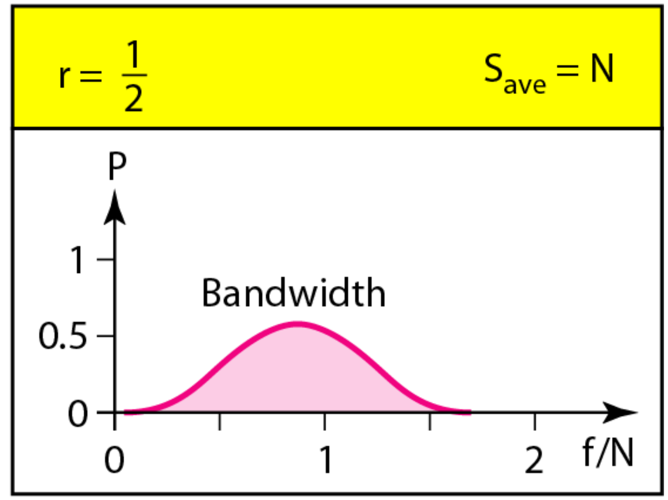
**In NRZ-L the level of the voltage determines the value of the bit. In NRZ-I the inversion or the lack of inversion determines the value of the bit.**

# **Figure 4.7** *Polar RZ scheme*



# **Figure 4.8** *Polar biphase: Manchester and differential Manchester schemes*



**Note**

**In Manchester and differential Manchester encoding, the transition at the middle of the bit is used for synchronization.**

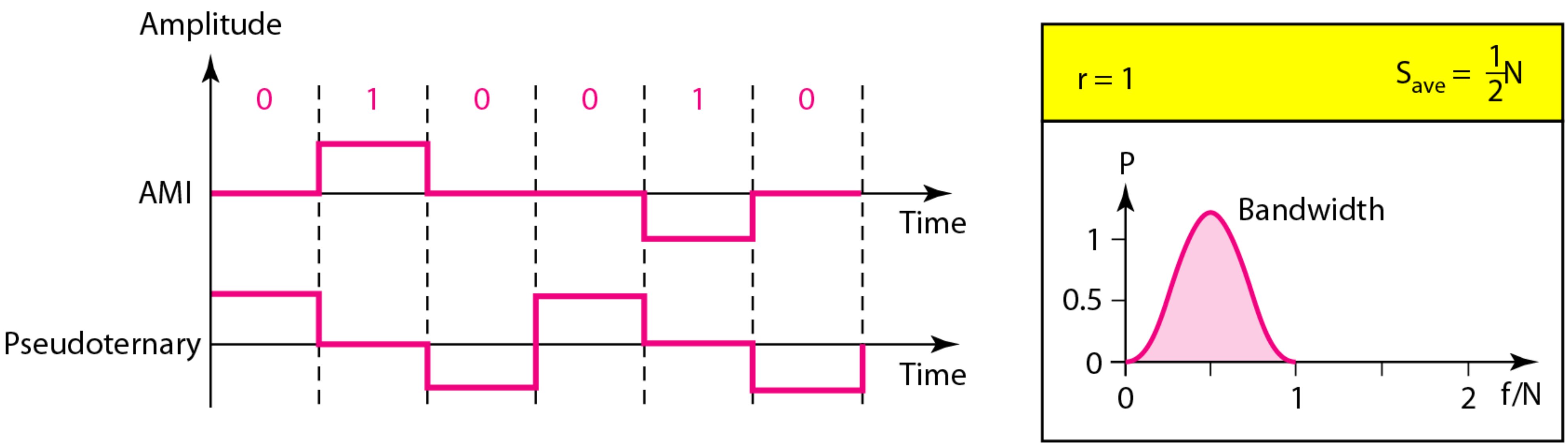
**Note**

**The minimum bandwidth of Manchester and differential Manchester is 2 times that of NRZ.**

***Note***

**In bipolar encoding, we use three levels: positive, zero, and negative.**

## Figure 4.9 *Bipolar schemes: AMI and pseudoternary*



# Good Luck ☺