Analog & Digital Signals

Course Code: COE 3201

Course Title: Data Communication

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Lecture No:	**3**	**Week No:**	**3**	**Semester:**	**Spring 23-24**
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Lecture Outline

- Analog and Digital Data
- Analog and Digital Signals
- Time and Frequency Domains
- Composite Signal
- Bandwidth
- Transmission Impairment
- Signal-to-Noise Ratio (SNR)

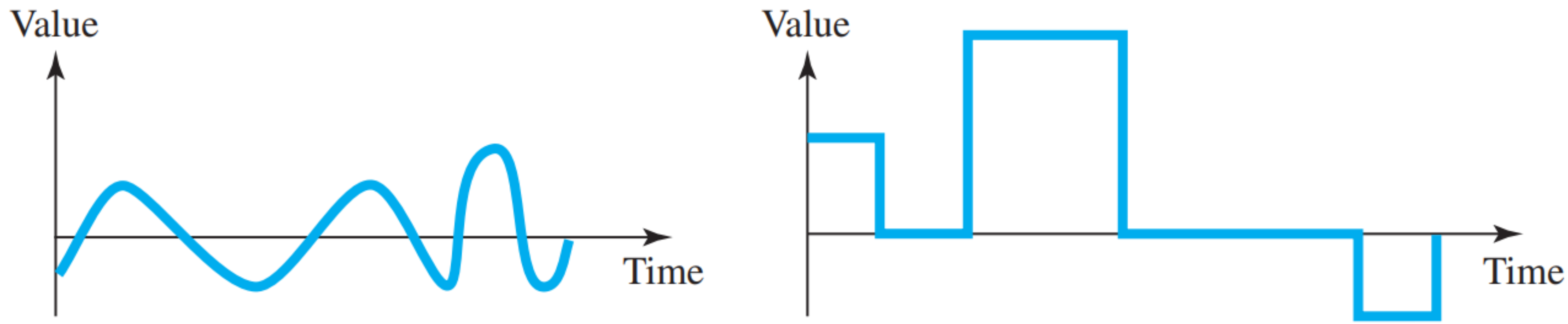
Analog and Digital Data

Data can be

- **Analog data →** information that is continuous
  - Example: voice and video are continuously varying patterns of intensity. Most data collected by sensors, such as temperature and pressure, are continuous valued.
- **Digital data →** information that has discrete states
  - Example: data stored in computer memory (Os and 1s), text and integers

Analog and Digital Signals

- Like the data they represent, signals can be either
- **Analog signals** can have an infinite number of values in a range.
- **Digital signals** can have only a limited number of values.



a. Analog signal

b. Digital signal

Periodic and Non-periodic Signals

- Both analog and digital signals can take one of two forms:
  - Periodic
  - Nonperiodic → Refer to as aperiodic, prefix a in Greek means "non“
- Periodic signal
  - completes a pattern within a measurable time frame, called a period, and
  - repeats that pattern over subsequent identical periods
- Completion of one full pattern is called a cycle
- **Nonperiodic signal** changes without exhibiting a pattern or cycle
- Both analog and digital signals can be periodic or nonperiodic

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

Periodic Analog Signals

Periodic analog signals can be classified as

- Simple or
- Composite

- **Simple** periodic analog signal cannot be decomposed into simpler signals → a sine wave

- **Composite** periodic analog signal is composed of multiple sine waves

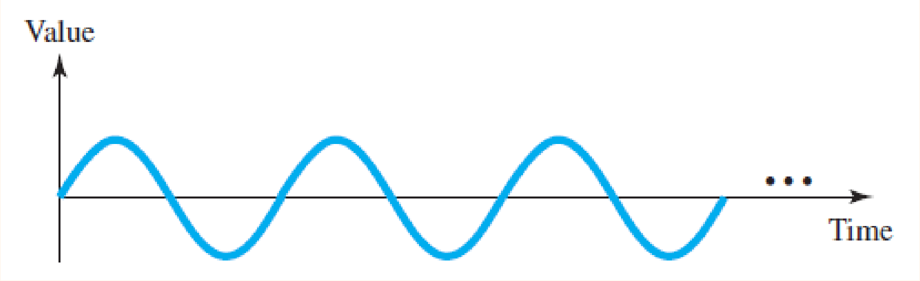


Fig: Simple signal

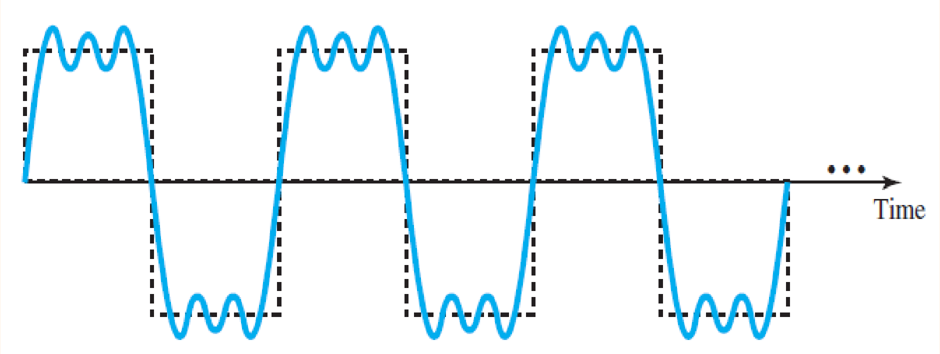


Fig: Composite signal

Sine Wave

- Sine wave is the most fundamental form of a periodic analog signal
- Its change over the course of a cycle is smooth and consistent, a continuous, rolling flow
- A **sine wave** can be represented by three parameters: the *peak amplitude,* the *frequency,* and the *phase*

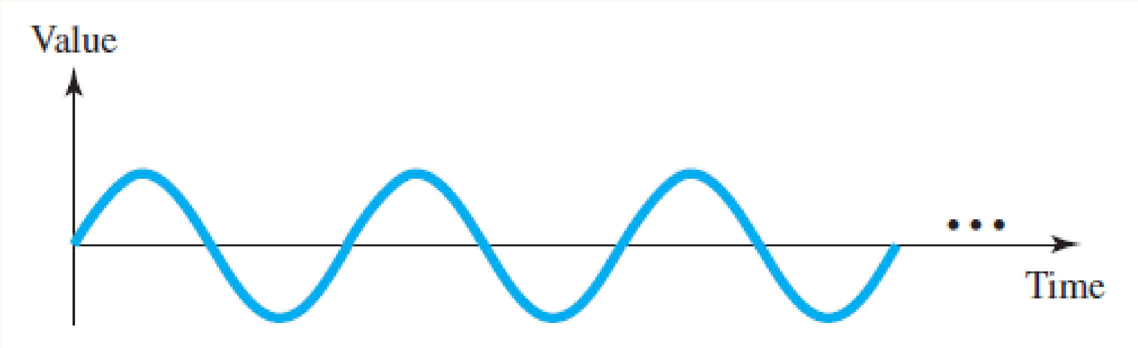


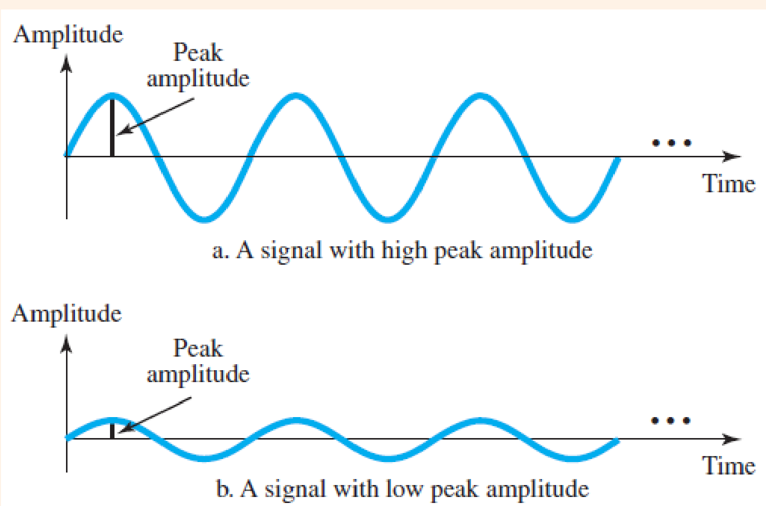
Fig: Sine wave

- **Peak Amplitude**
  - is the absolute value of its highest intensity
  - proportional to the energy it carries

- **Frequency** refers to the number of periods in 1 s. **Frequency** is formally expressed in Hertz (Hz), which is cycle per second.

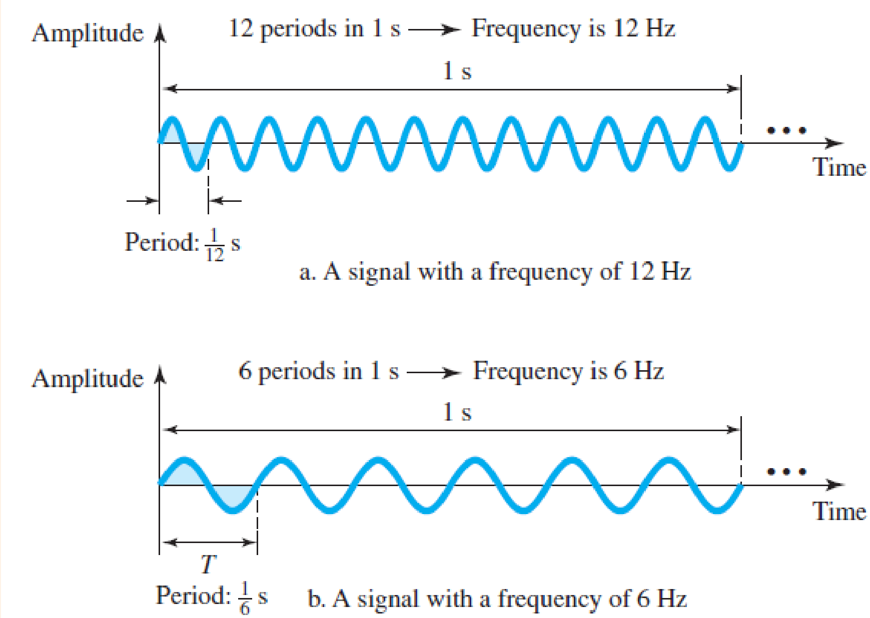
Note that period and frequency are just one characteristic defined in two ways. Period is the inverse of frequency, and frequency is the inverse of period

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



a. A signal with high peak amplitude

b. A signal with low peak amplitude



a. A signal with a frequency of 12 Hz

b. A signal with a frequency of 6 Hz

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 60 Hz (50 Hz in Europe). The period of this sine wave can be determined as follows:

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

This means that the period of the power for our lights at home is 0.0116 s, or 16.6 ms. Our eyes are not sensitive enough to distinguish these rapid changes in amplitude.

Period and frequency

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).

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

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

Phase

Phase describes the position of the waveform relative to time 0. It is also termed as phase shift.

- Phase can be measured in distance, time, or degrees.
- Phase is measured in degrees or radians [360° is 2π rad; 1° is 2π/360 rad, and 1 rad is 360/(2π)]
- A phase shift of 360° corresponds to a shift of a complete period;
- A phase shift of 180° corresponds to a shift of one-half of a period
- A phase shift of 90° corresponds to a shift of one-quarter of a period

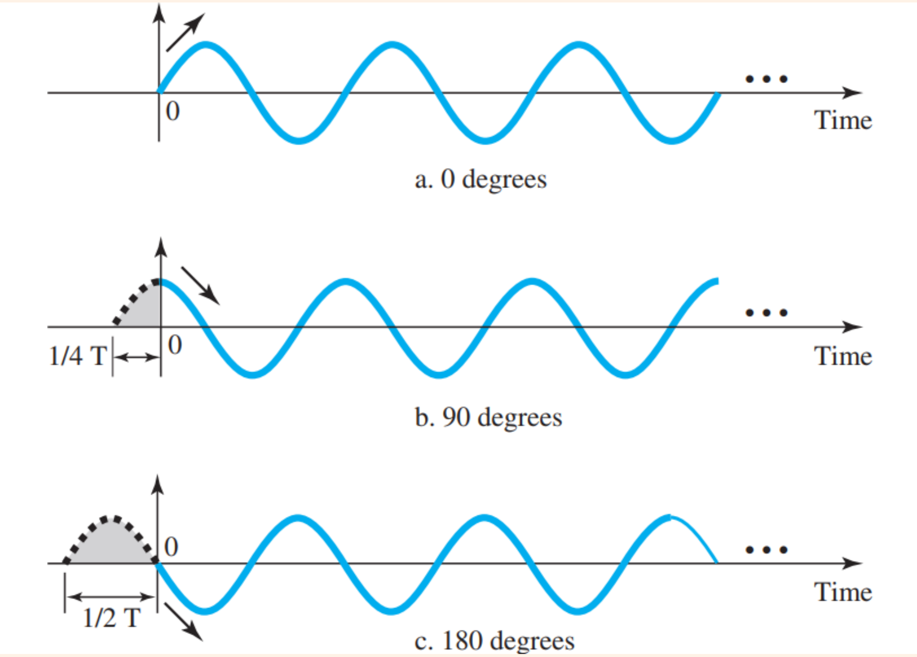
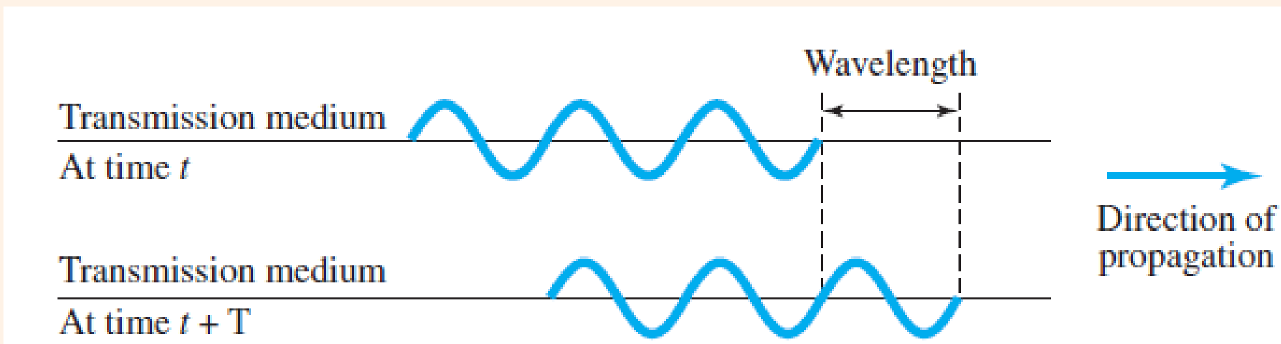


Fig: Three sine waves with the same amplitude and frequency, but different phases

Wavelength

Wavelength binds the period or the frequency of a simple sine wave to the propagation speed (the speed of Light) of the medium.

The wavelength is the distance a simple signal can travel in one period.



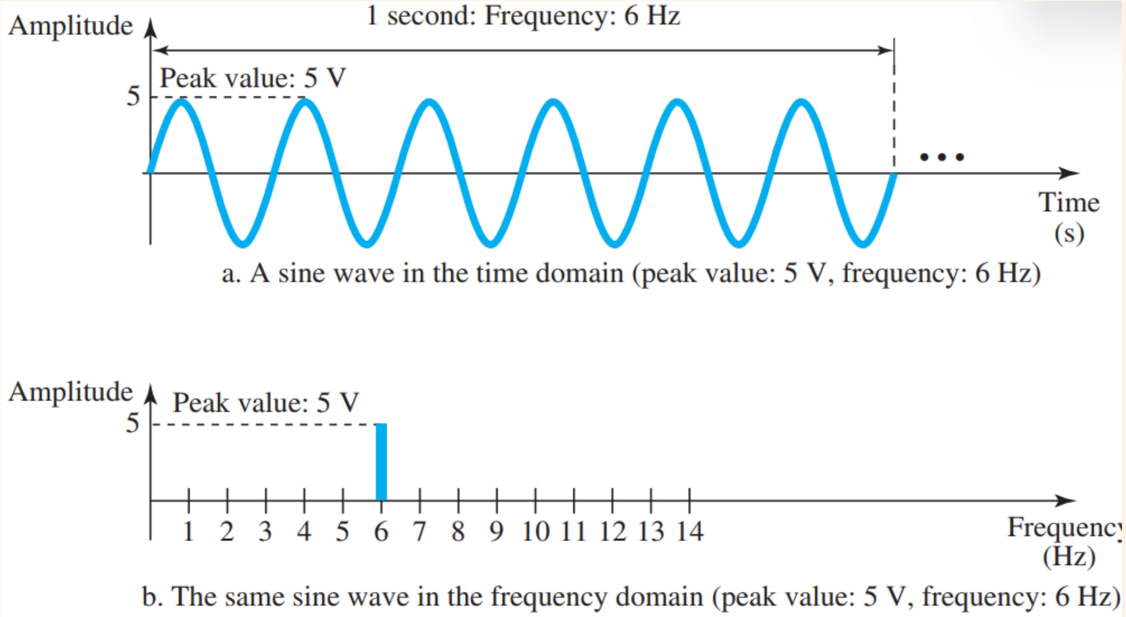
$$\textbf{Wavelength} = (\textbf{propagation speed}) \times \textbf{period} = \frac{\textbf{propagation speed}}{\textbf{frequency}}$$

$$\lambda = \frac{c}{f}$$

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 × 108 m/s. That speed is lower in air and even lower in cable.

Time and Frequency Domains

- Time-domain plot
  - Shows changes in signal amplitude with respect to time (amplitude-versus-time plot)
  - Phase is not explicitly shown on a time-domain plot
- Frequency-domain plot
  - To show the relationship between peak amplitude and frequency
  - Changes of amplitude during one period are not shown



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)

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

Time and Frequency Domains (contd.)

Example 3.7 :

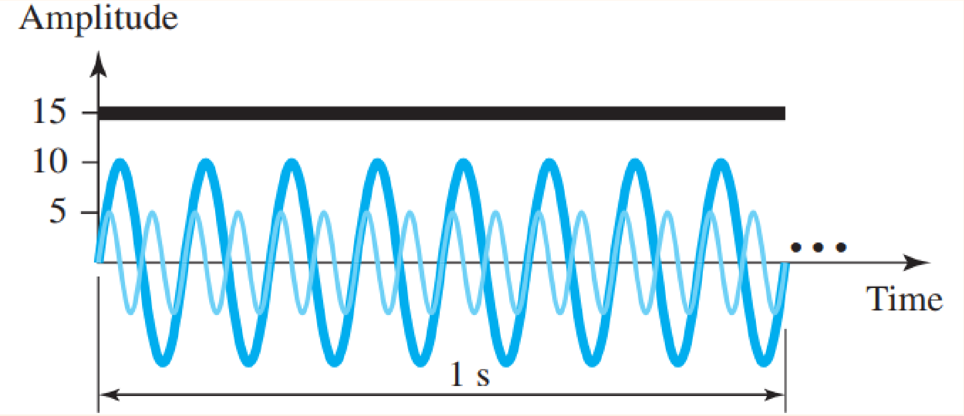


Fig: Time-domain representation of three sine waves with frequencies 0, 8, and 16.

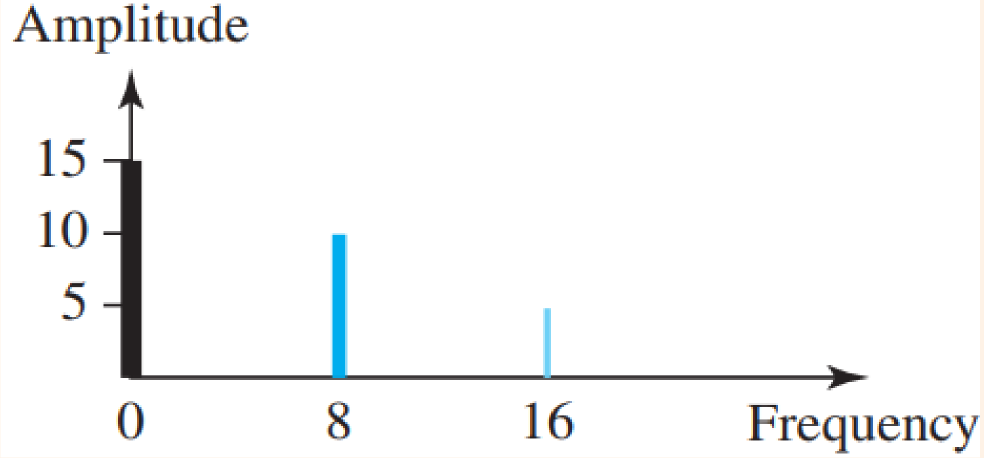


Fig: Frequency-domain representation of the same three signals

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
- 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 nonperiodic**, the decomposition gives a combination of sine waves with continuous frequencies

Periodic Composite Signal: can be decompose**d** into a number of signals with discrete frequencies in the frequency domain.

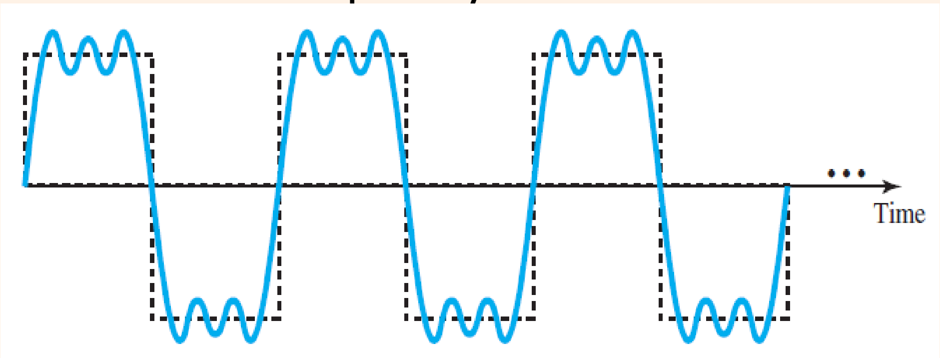


Fig: A composite periodic signal

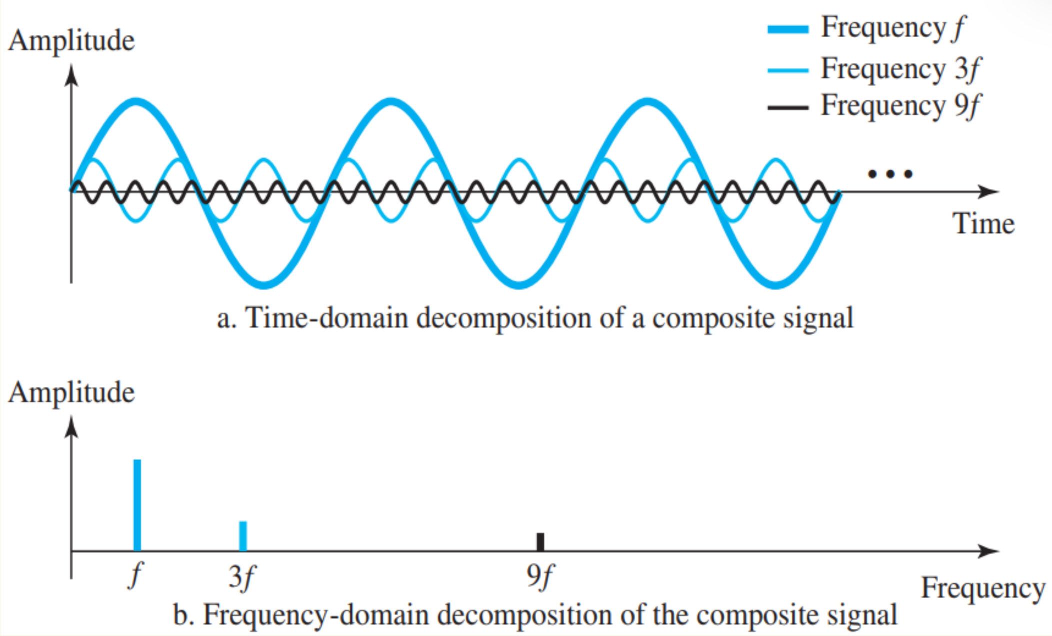


Fig: Decomposition of a composite periodic signal in the time and frequency domains

Nonperiodic Composite Signal: In a time-domain representation of this composite signal, there are an infinite number of simple sine frequencies

Example 3.9:

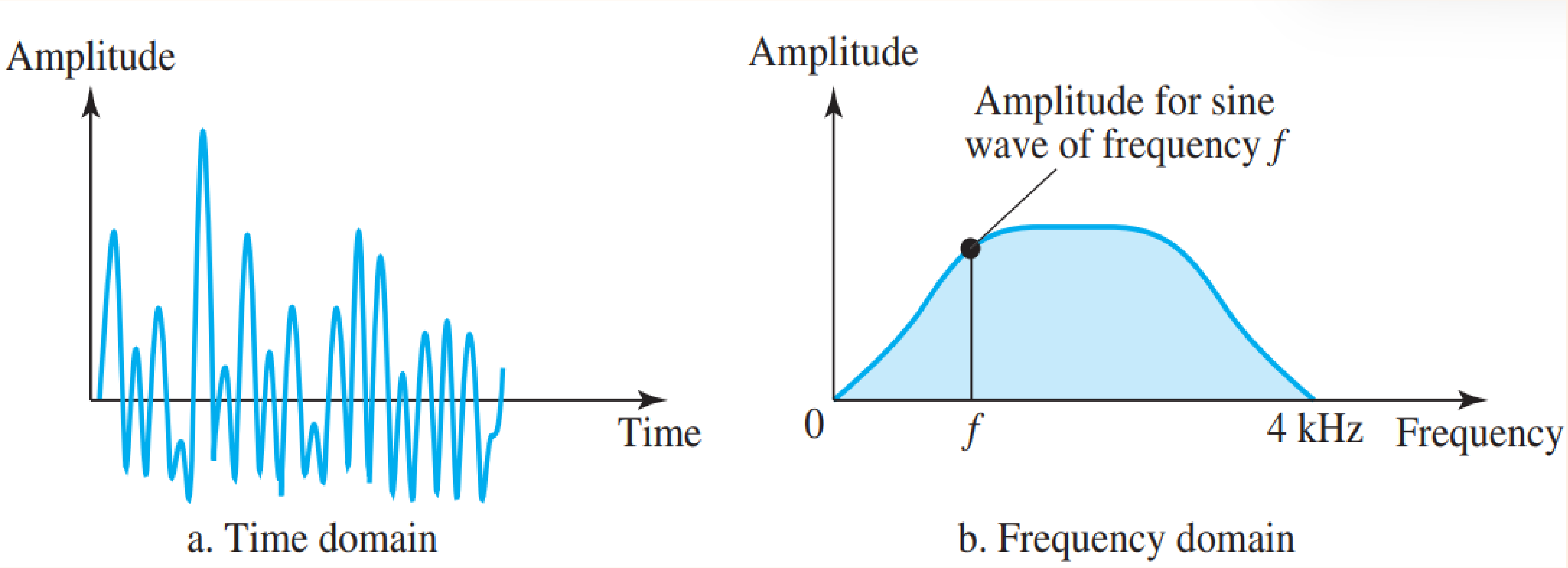


Figure 3.12: The time and frequency domains of a nonperiodic signal

Bandwidth

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

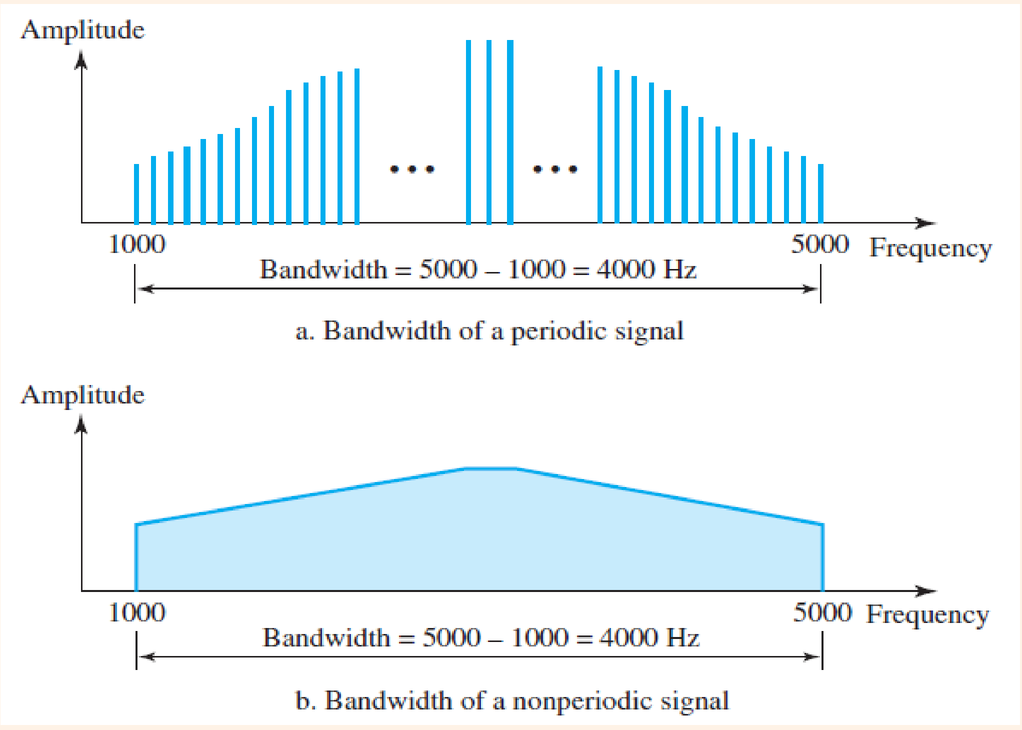


Fig: The bandwidth of periodic and nonperiodic composite signals

Bandwidth (contd.)

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

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

The spectrum has only five spikes, at 100, 300, 500, 700, and 900 Hz

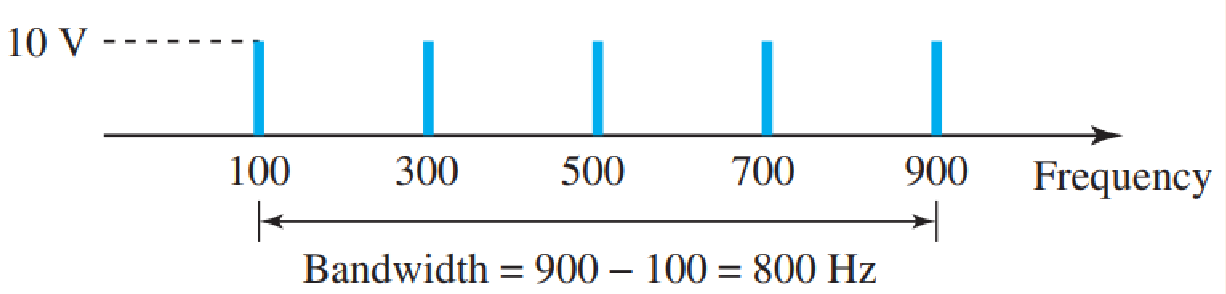


Figure 3.14: The bandwidth for Example 3.10

Transmission Impairment

Signals travel through transmission media, which are not perfect. The imperfection causes signal impairment.

This means that the signal at the beginning of the medium is not the same as the signal at the end of the medium. **What is sent is not what is received**.

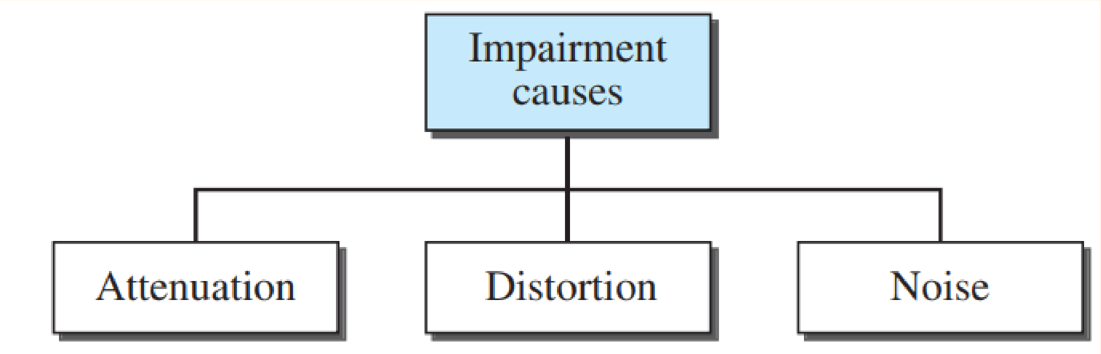


Figure 3.26 Causes of impairment

Attenuation

Attenuation means a loss of energy.

When a signal, simple or composite, travels through a medium, it loses some of its energy in overcoming the resistance of the medium.

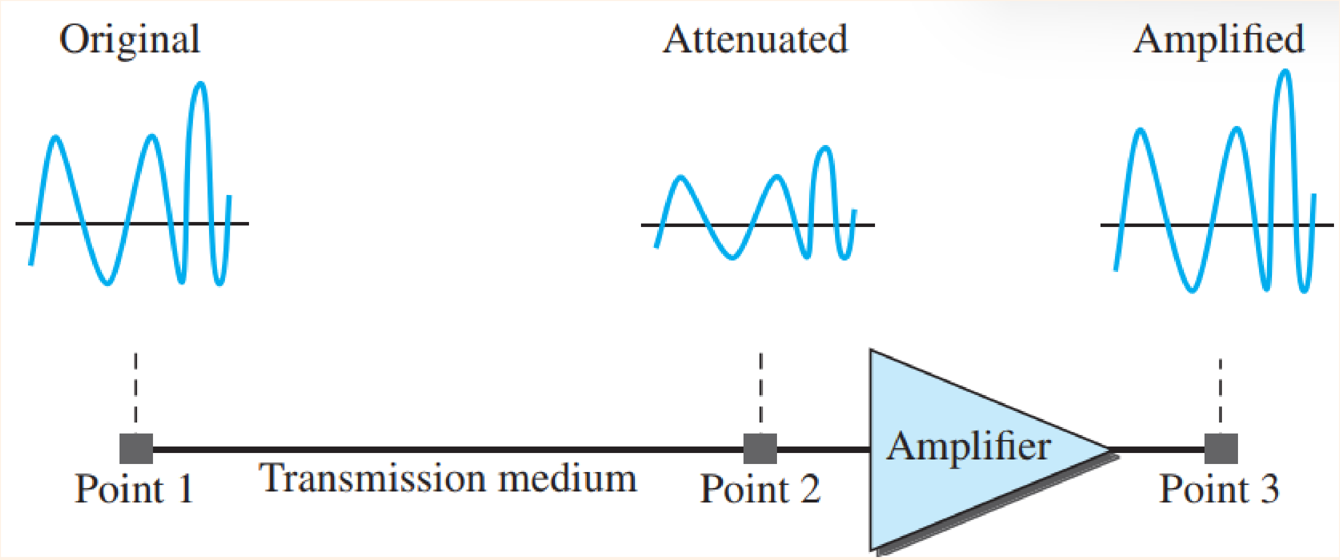


Figure 3.27 Attenuation

Decibel

- To show that a signal has lost or gained strength, engineers use the unit of the decibel.
- The decibel (dB) measures the relative strengths of two signals or one signal at two different points.

$$\mathrm{dB} = 10 \log_{10} \frac{P_2}{P_1}$$

Variables P_1 and P_2 are the powers of a signal at points 1 and 2, respectively.

Note that the decibel is negative if a signal is attenuated and positive if a signal is amplified.

Example 3.26

Suppose a signal travels through a transmission medium and its power is reduced to one-half.

Solution

This means that $P_2 = ½ P_1$. In this case, the attenuation (loss of power) can be calculated as

$$10 \log_{10} \frac{P_2}{P_1} = 10 \log_{10} \frac{0.5P_1}{P_1} = 10 \log_{10} 0.5 = 10(-0.3) = -3 \text{ dB}$$

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?

Solution

The loss in the cable in decibels is 5*(-0.3) = −1.5 dB. We can calculate the power as

$$\text{dB} = 10 \log_{10} (P_2 / P_1) = -1.5 \quad \longrightarrow \quad (P_2 / P_1) = 10^{-0.15} = 0.71$$

$$P_2 = 0.71P_1 = 0.7 \times 2 \text{ mW} = 1.4 \text{ mW}$$

Distortion

- **Distortion** means that the signal changes its form or shape and can occur in a composite signal.
- Each signal component has its own propagation speed through a medium and, therefore, its own delay in arriving at the final destination
- Differences in delay may create a difference in phase if the delay is not exactly the same as the period duration.

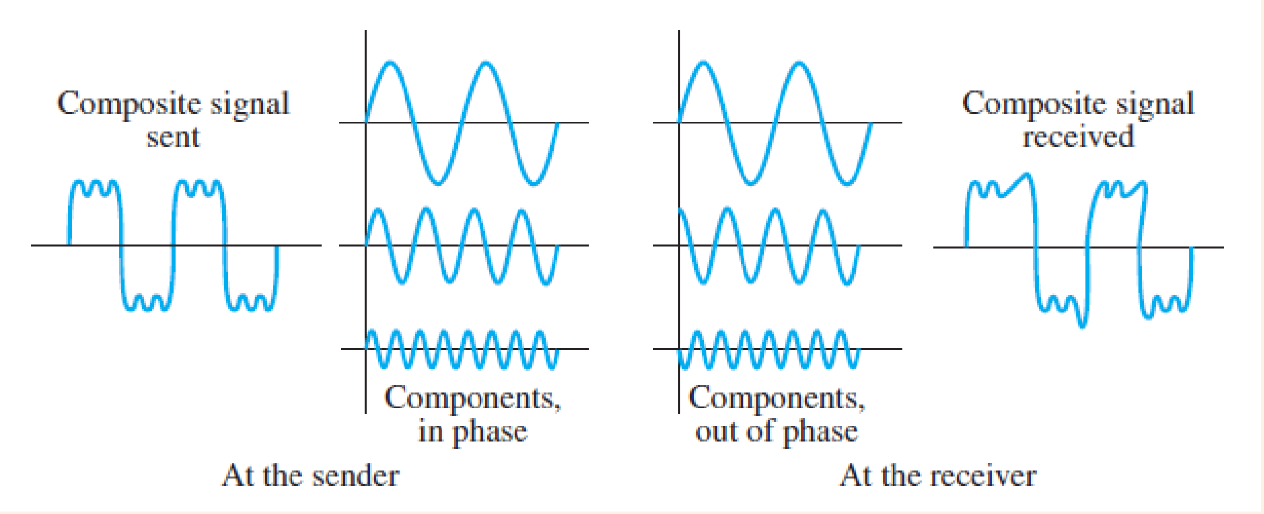


Figure 3.27 Distortion

Noise

- **Noise** is another cause of impairment.
- Several types of noise,
  - Thermal noise: random motion of electrons in a wire, which creates an extra signal not originally sent by the transmitter
  - Induced noise: comes from sources such as motors and appliances
  - Impulse noise: comes from power lines, lightning, and so on

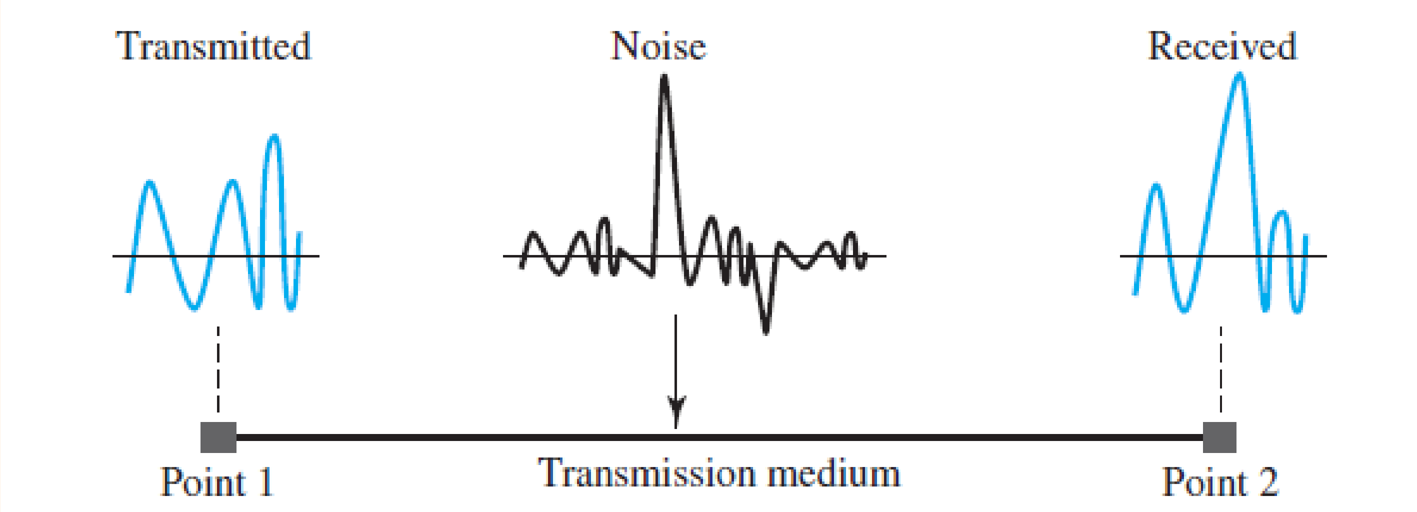


Figure 3.27 Noise

Signal-to-Noise Ratio (SNR)

To find the theoretical bit rate limit, we need to know the ratio of the signal power to the noise power. The **signal-to-noise ratio** is defined as

$$\text{SNR} = \frac{\text{average signal power}}{\text{average noise power}}$$

SNR is actually the ratio of what is wanted (signal) to what is not wanted (noise).

SNR is the ratio of two powers, it is often described in decibel units, SNR_{dB}, defined as

$$\text{SNR}_{dB} = 10 \log_{10} \text{SNR}$$

SNR (contd.)

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

Solution

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

$$SNR = (10{,}000\ \mu w) / (1\ \mu w) = 10{,}000 \qquad SNR_{dB} = 10 \log_{10} 10{,}000 = 10 \log_{10} 10^4 = 40$$

Books

1. Forouzan, B. A. "Data Communication and Networking. Tata McGraw." (2005).

References

1. Prakash C. Gupta, “Data communications”, Prentice Hall India Pvt.
2. William Stallings, "Data and Computer Communications”, Pearson
3. Forouzan, B. A. "Data Communication and Networking. Tata McGraw." (2005).