Analog & Digital Signals

Course Code: 01078 Course Title: Data Communication

Dept. of Computer Engineering
Faculty of Engineering

Lecture No:	**3**	**Week No:**	**3**	**Semester:**	
Lecturer:					

Lecture Outline

1. Analog and Digital Data
2. Analog and Digital Signals
3. Time and Frequency Domains
4. Composite Signal
5. Bandwidth
6. Transmission Impairment
7. Signal-to-Noise Ratio (SNR)

Analog and Digital Data

Data can be

- **Analog**
- **Digital**

Analog data → information that is continuous

Example: sounds made by a human voice

Digital data → information that has discrete states

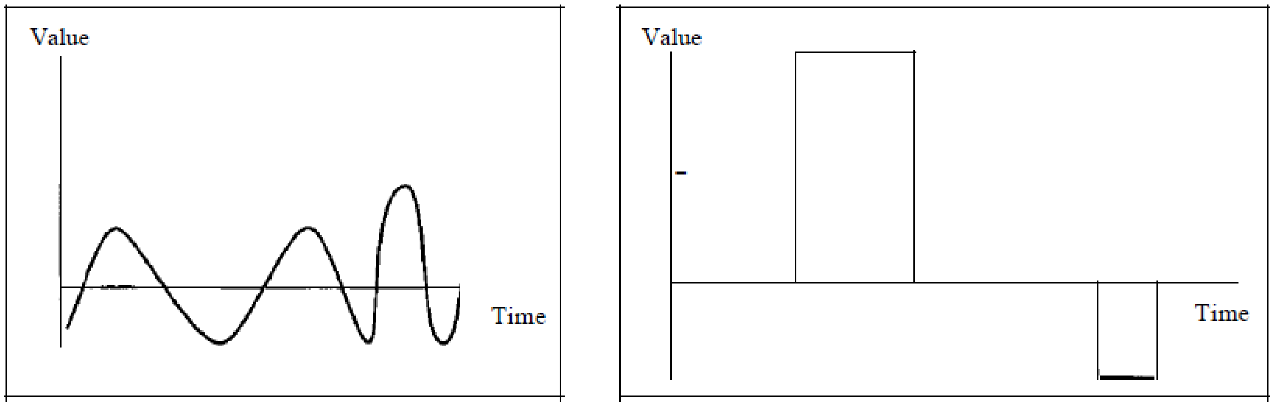
Example: data stored in computer memory (Os and 1s)

Analog and Digital Signals

Like the data they represent, signals can be either

- **Analog**
- **Digital**

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 Nonperiodic 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
- Commonly use: periodic analog signals (need less bandwidth) and nonperiodic digital signals (can represent variation in data)

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

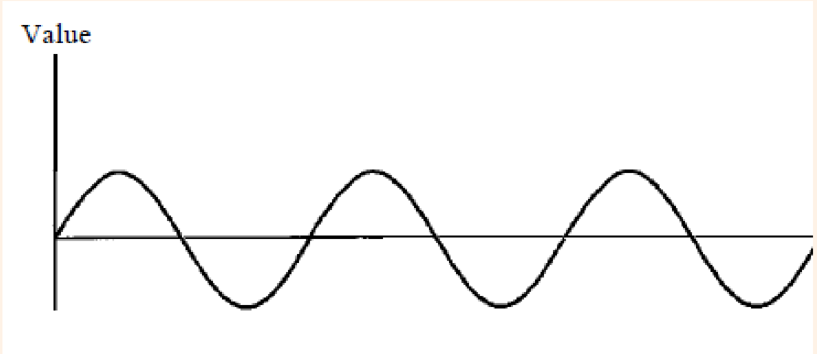


Fig: Simple signal

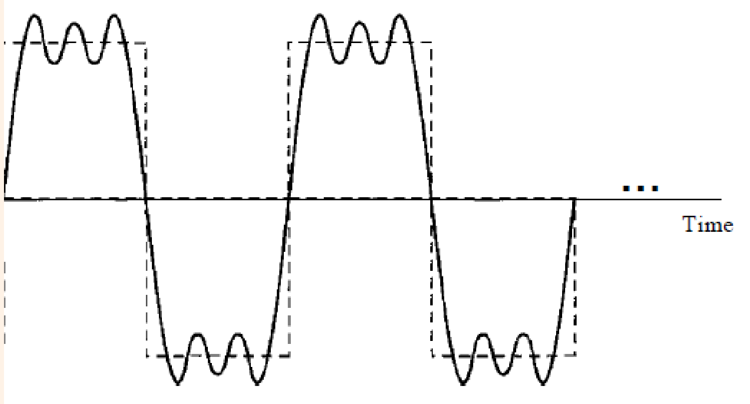


Fig: Composite signal

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*

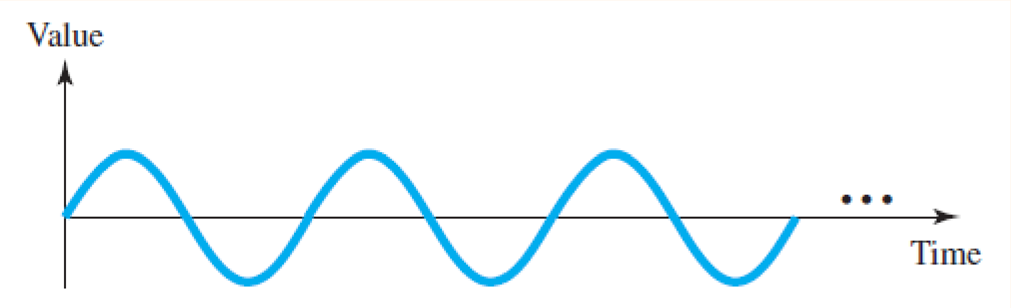


Fig: Sine wave

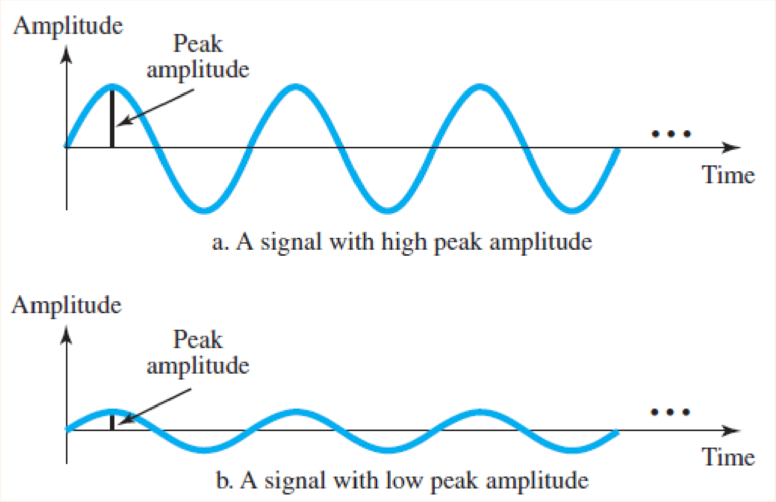
- Peak **Amplitude**
  - is the absolute value of its highest intensity
  - proportional to the energy it carries

- **Frequency** refers to the number of periods in 1 s. 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

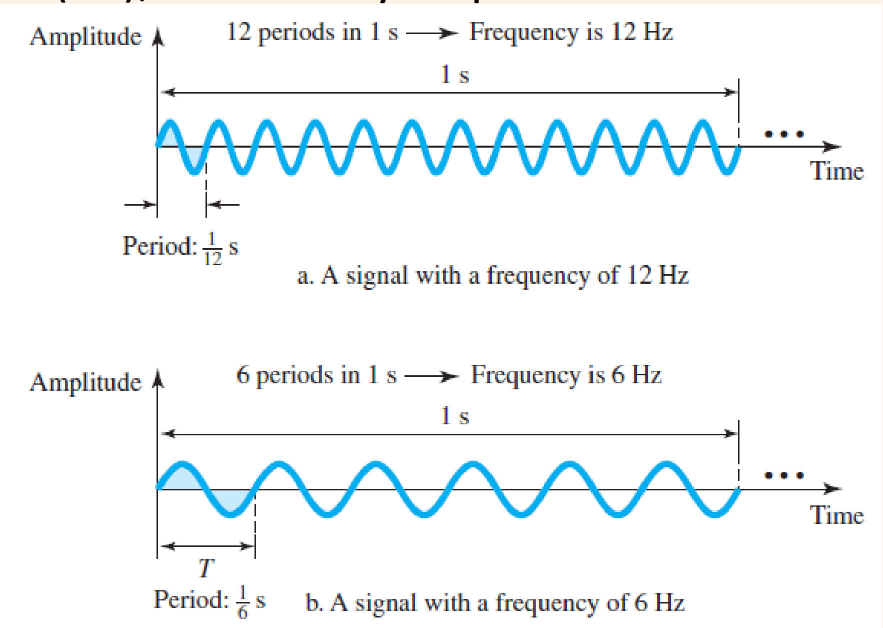
$$f = \frac{1}{T} \quad \text{and} \quad T = \frac{1}{f}$$

- **Frequency** is formally expressed in Hertz (Hz), which is cycle per second.



a. A signal with high peak amplitude

b. A signal with low peak amplitude

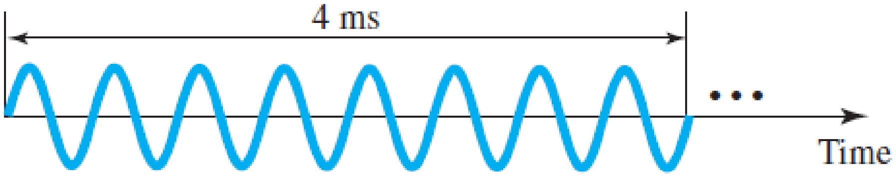


a. A signal with a frequency of 12 Hz

b. A signal with a frequency of 6 Hz

P3-10. What is the frequency of the signal in Figure 3.36?

Figure 3.36 *Problem P3-10*



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

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.

Phase

- Phase describes the position of the waveform relative to time 0
- 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

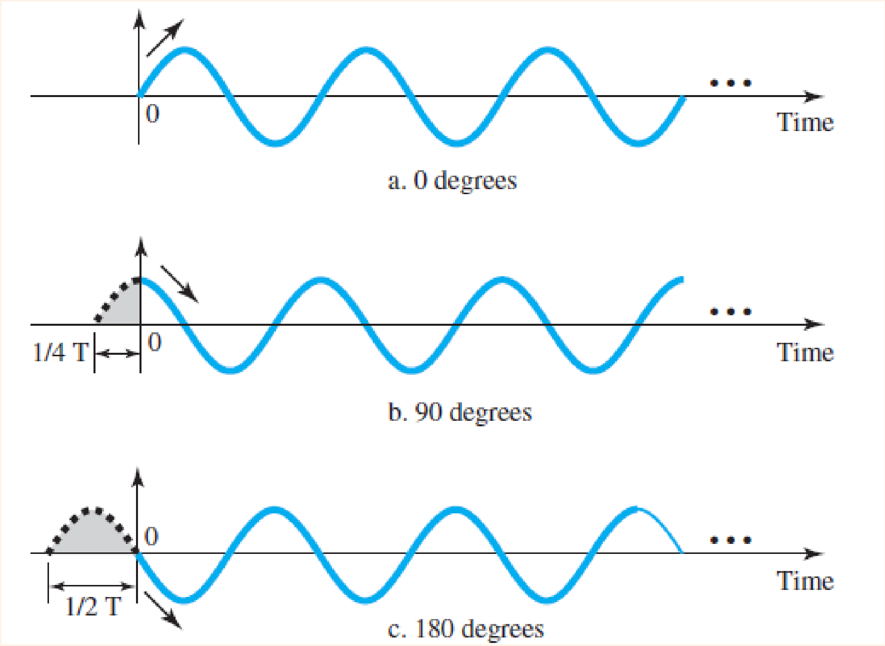
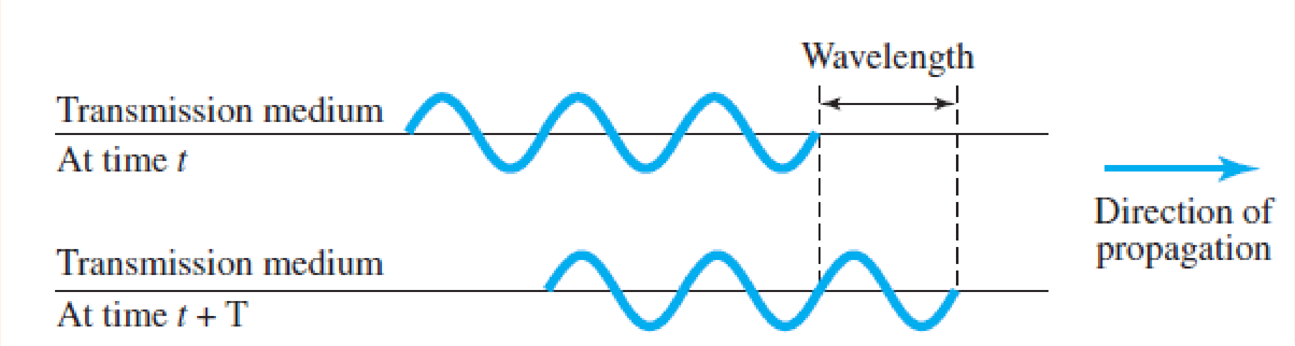


Fig: Three sine waves with the same amplitude and frequency, but different phases

Wavelength

- Wavelength is another characteristic of a signal traveling through a transmission medium
- Wavelength binds the period or the frequency of a simple sine wave to the propagation speed of the medium



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

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

Time and Frequency Domains

- Time-domain plot

  Shows changes in signal amplitude with respect to time → amplitude-versus-time plot

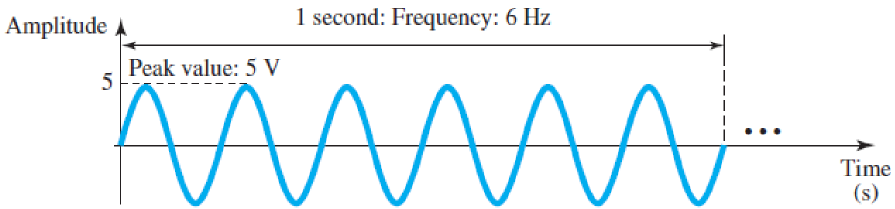
  Phase is not explicitly shown on a time-domain plot

- Frequency-domain plot

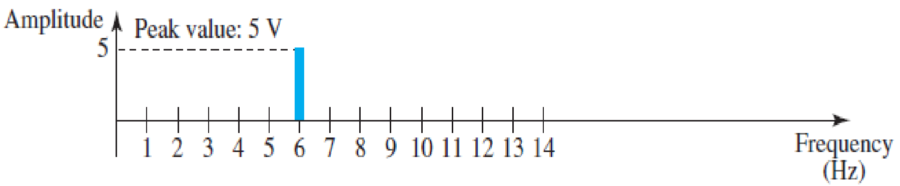
  To show the relationship between amplitude and frequency

  Concerned with only the peak value and the 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)

Composite Signal

- A single-frequency sine wave is not useful in data communications
- Need to send a composite signal → a signal made of many simple sine waves
- 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 nonperiodic, the decomposition gives a combination of sine waves with continuous frequencies

Periodic Composite Signal: can be decomposed into a number of signals with discrete frequencies in the frequency domain

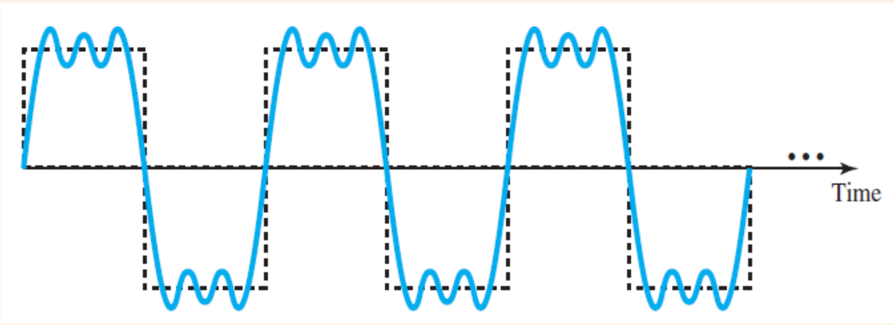


Fig: A composite periodic signal

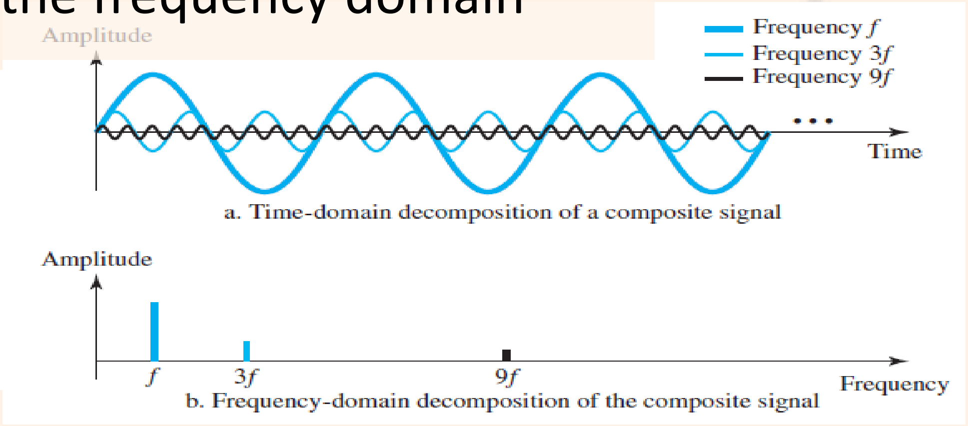
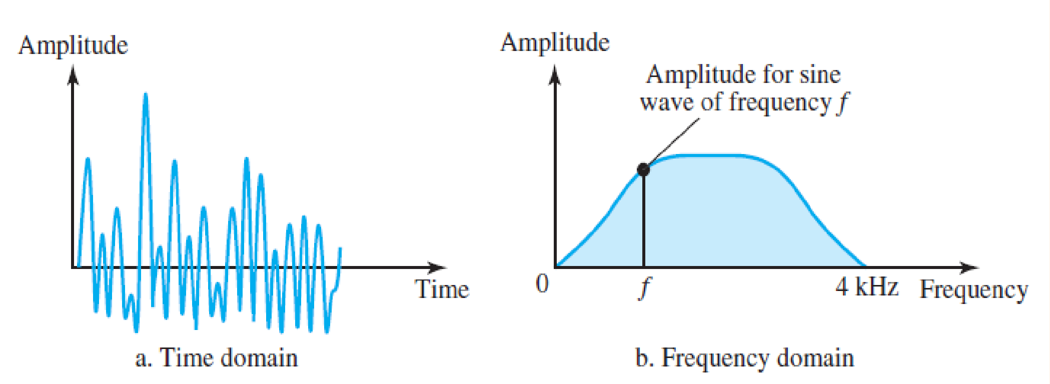


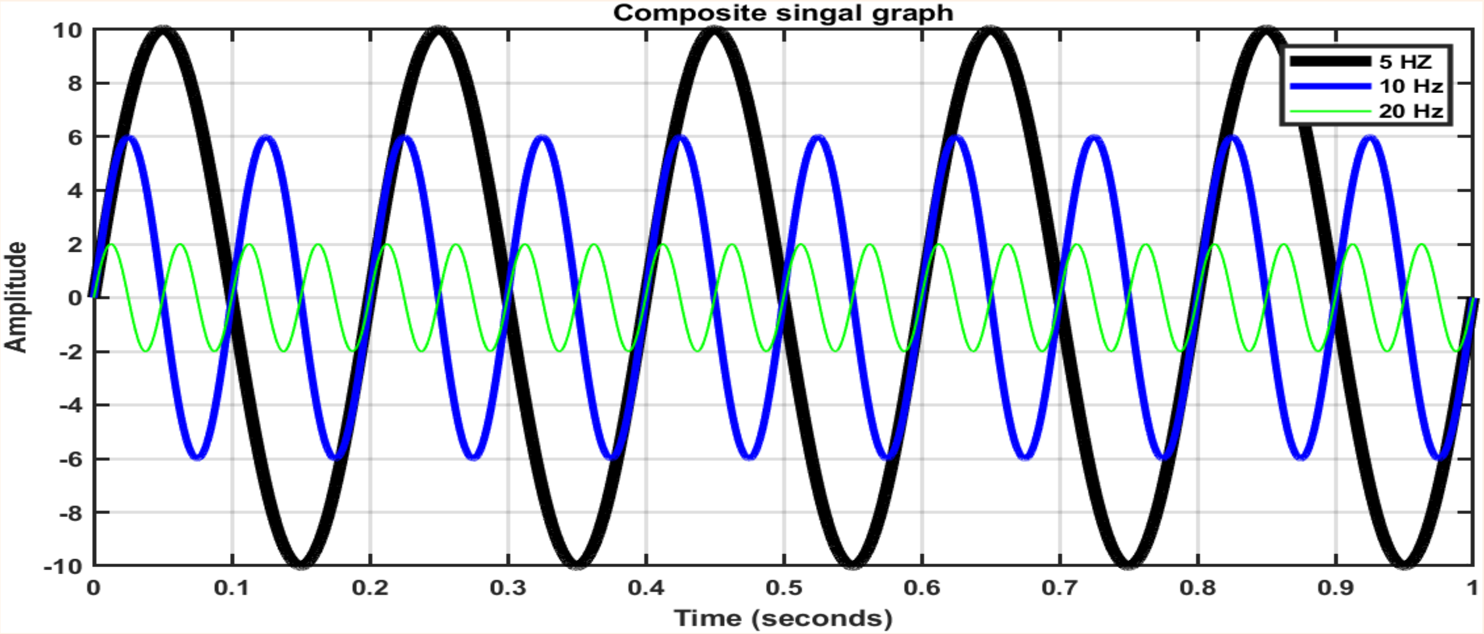
Fig: Decomposition of a composite periodic signal in the time and frequency domains

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

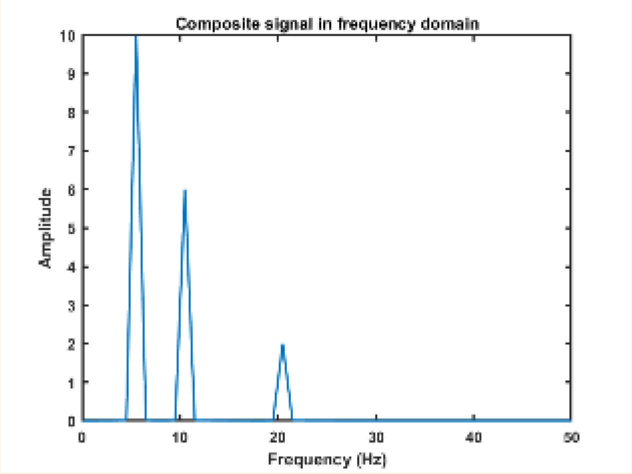


Composite signal in time domain:

$$x(t) = 10\sin(10\pi t) + 6\sin(20\pi t) + 2\sin(40\pi t)$$



Composite signal in frequency domain:



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
- For example, if a composite signal contains frequencies between 1000 and 5000, its bandwidth is 5000 – 1000, or 4000

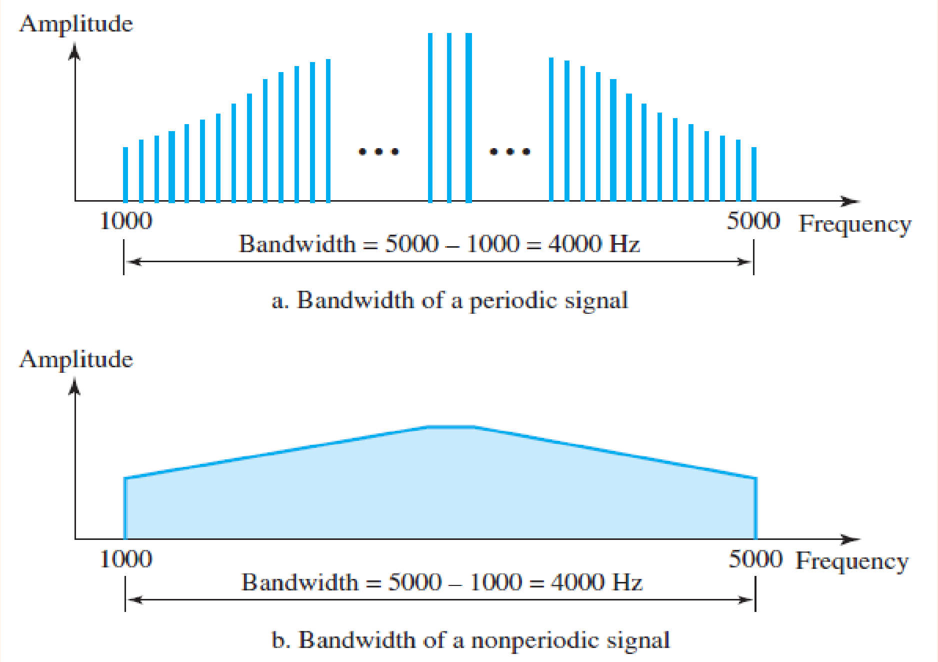
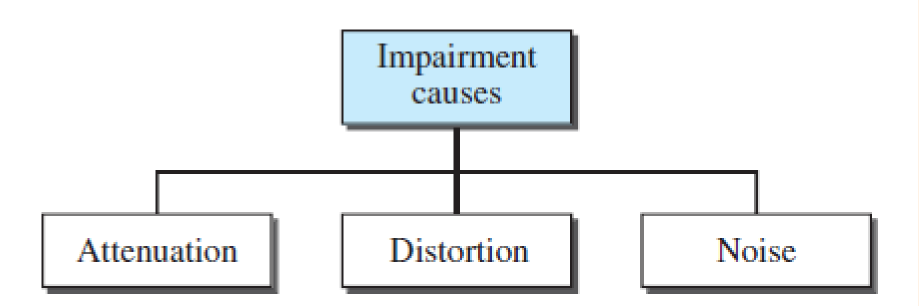


Fig: The bandwidth of periodic and nonperiodic composite signals

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
- Three causes of impairment are-

1. **attenuation,**
2. **distortion, and**
3. **noise**



- **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.

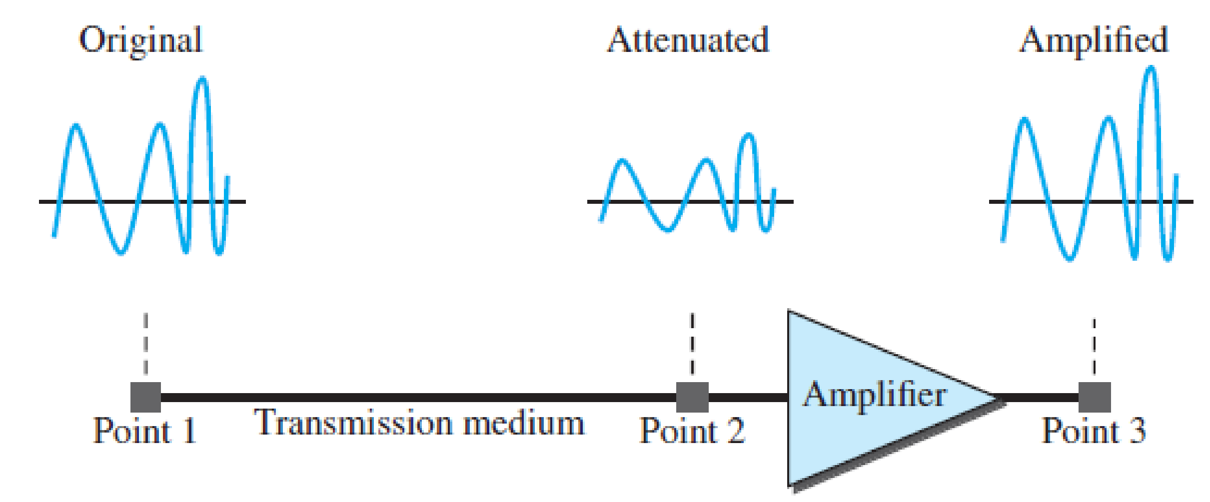


Fig: Attenuation

- 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 $P1$ and $P2$ 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: 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?

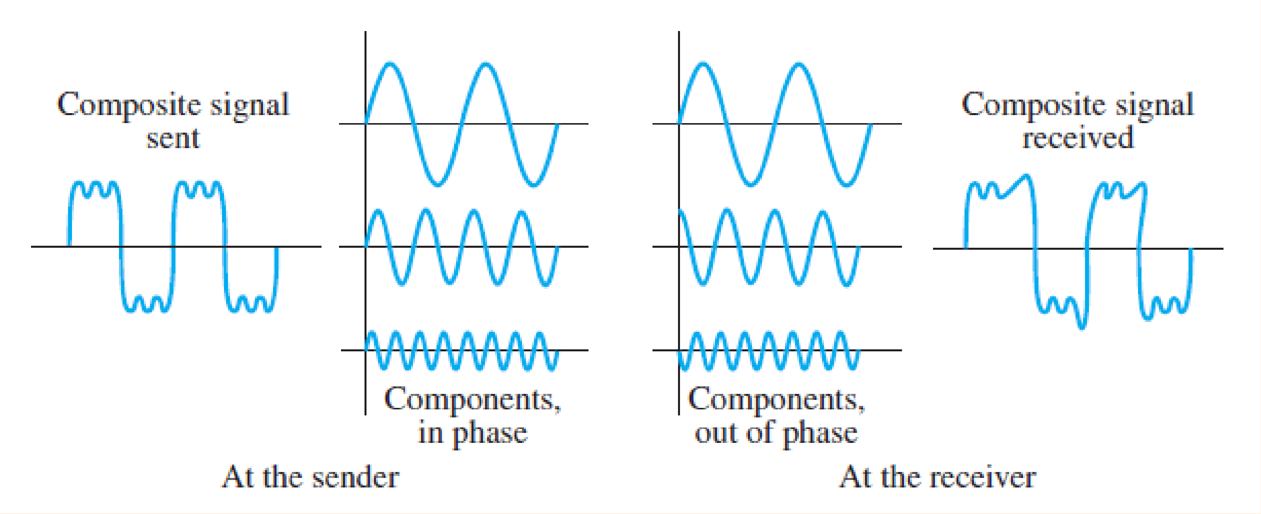
Solution

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

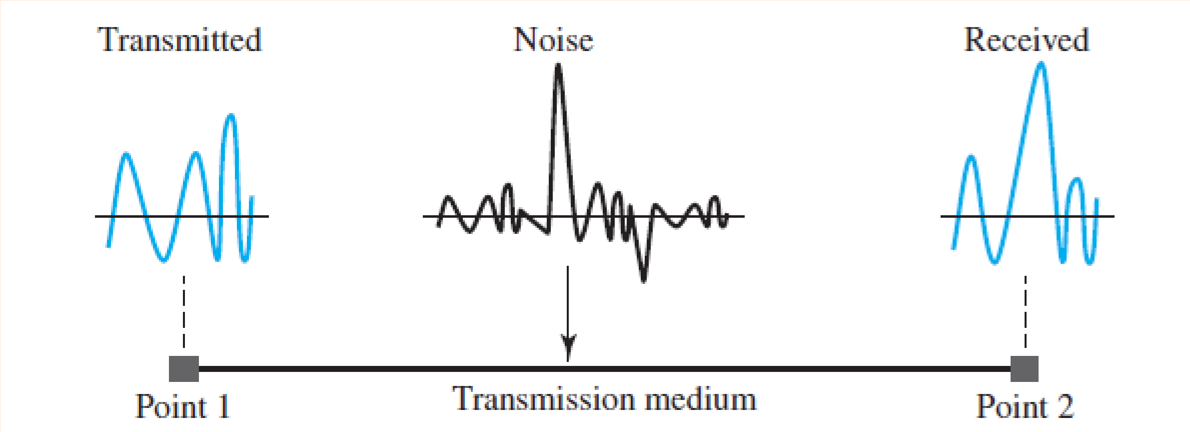
$$\mathrm{dB} = 10 \log_{10} (P_2 / P_1) = -1.5 \quad \longrightarrow \quad (P_2 / P_1) = 10^{-0.15} = 0.71$$

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

- **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.



- **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 → that comes from power lines, lightning, and so on



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

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

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}

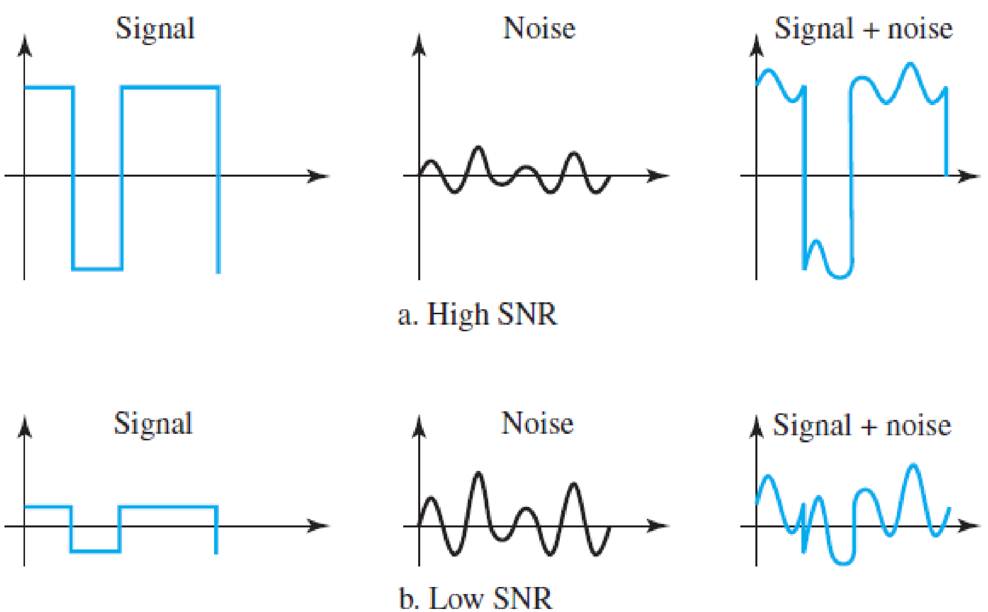
Solution

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

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

Two cases of SNR (Large and Small)

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



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).