# Data Transmission
## (Module – 1)

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# References


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# Outline

## Data and Signals

- Analog and Digital
- Analog-to-Analog Conversion
- Digital Signals
- Transmission Impairment
- Data-rate Limits
- Performance

# Terminology

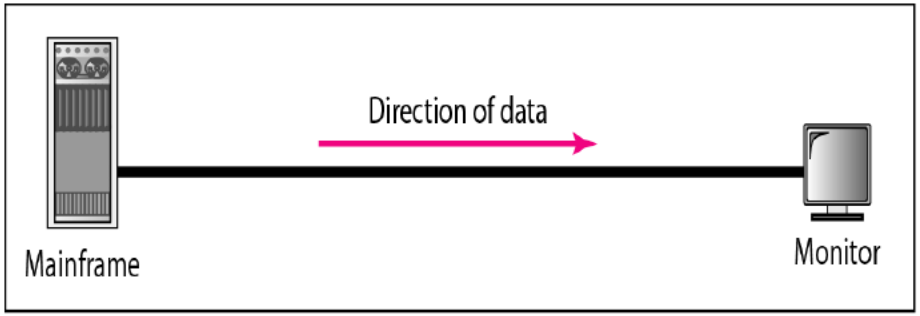
- Transmitter
- Receiver
- Medium
  - —Guided medium
    - e.g. twisted pair, optical fiber
  - —Unguided medium
    - e.g. air, water, vacuum

# Terminology

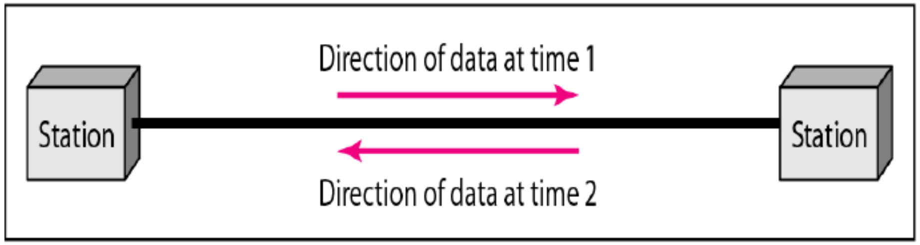
- Direct link
  - No intermediate devices
- Point-to-point
  - Direct link
  - Only 2 devices share link
- Multi-point
  - More than two devices share the link

# Terminology

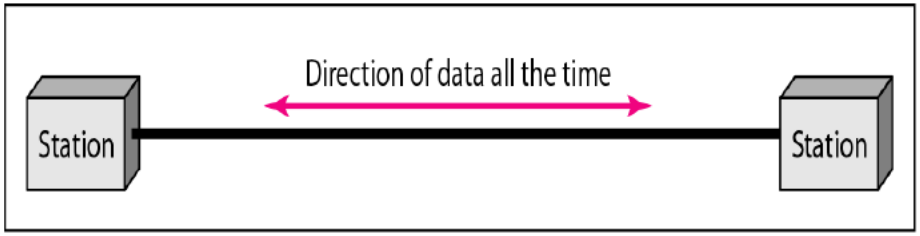
- Simplex
  - — One direction
    - e.g., Television
- Half duplex
  - — Either direction, but only one way at a time
    - e.g., police radio
- Full duplex
  - — Both directions at the same time
    - e.g., telephone



a. Simplex



b. Half-duplex



c. Full-duplex

# Analog Data and Digital Data

Data can be analog or digital

- Analog data refers to information that is continuous
- Analog data take on continuous values
  - e.g., analog clock
- Digital data refers to information that has discrete states
- Digital data take on discrete values
  - e.g., digital clock

# Analog Signal and Digital Signal

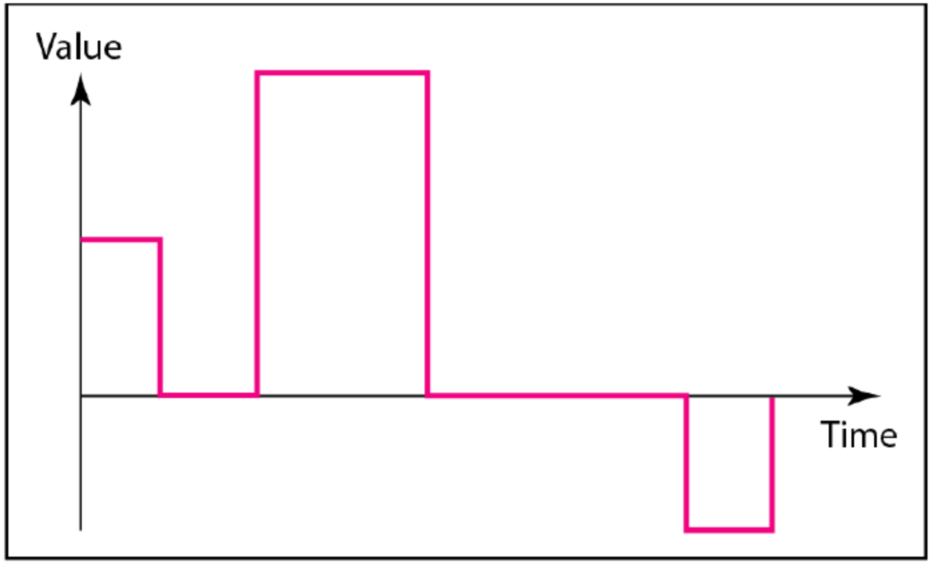
Like the data they represent, signals can be either analog or digital

- Analog signals can have an infinite number of values in a range
- Digital signals can have only a limited number of values

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

# Comparison of Analog and Digital Signals

a. Analog signal



b. Digital signal

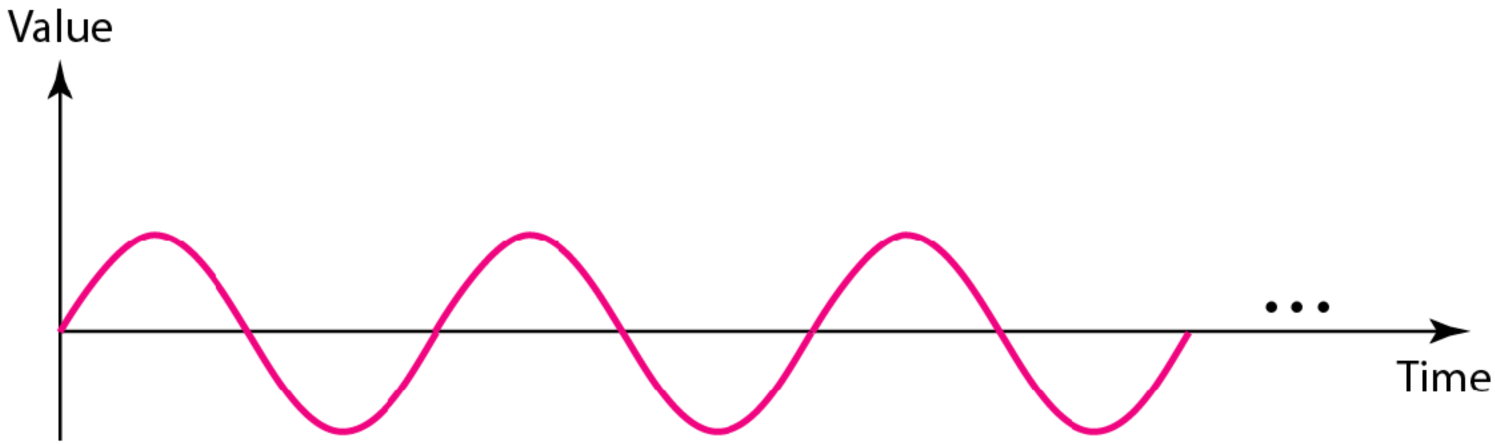
# Periodic and Nonperiodic

- 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 nonperiodic signal changes without exhibiting a pattern or cycle that repeats over time

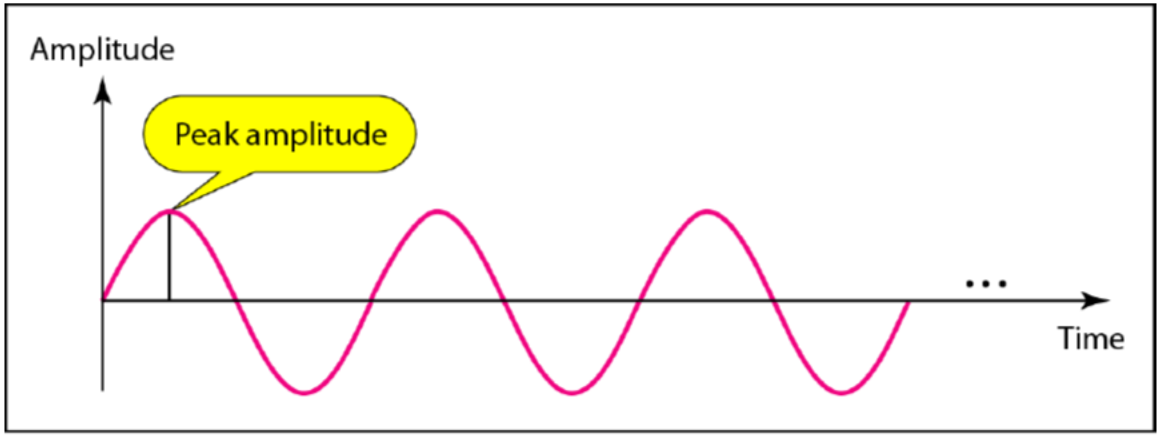
# PERIODIC ANALOG SIGNALS

*Periodic analog signals can be classified as simple or composite.*

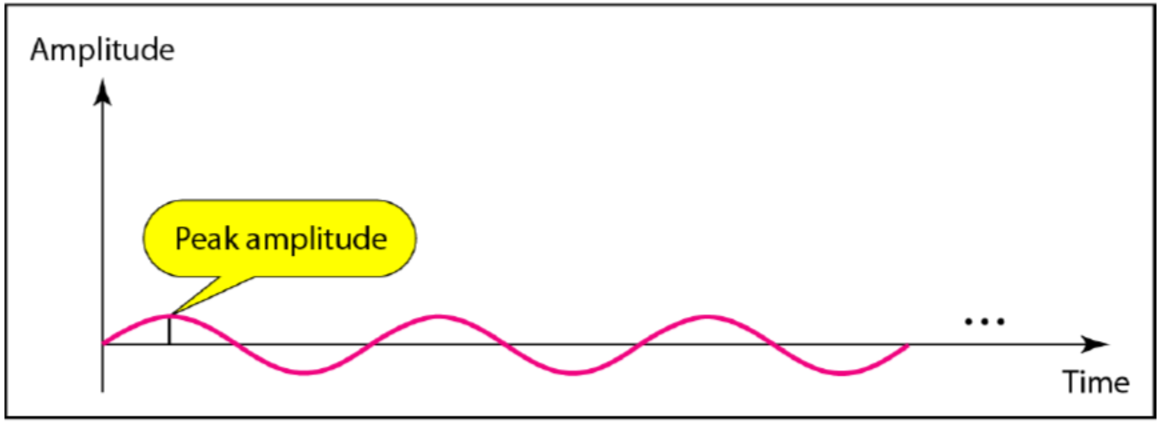
- A simple periodic analog signal, a sine wave, cannot be decomposed into simpler signals.
- A composite periodic analog signal is composed of multiple sine waves.



# Signal Amplitude




a. A signal with high peak amplitude




b. A signal with low peak amplitude

# Frequency

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.

# Frequency and Period

Frequency and period are the inverse of each other.

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

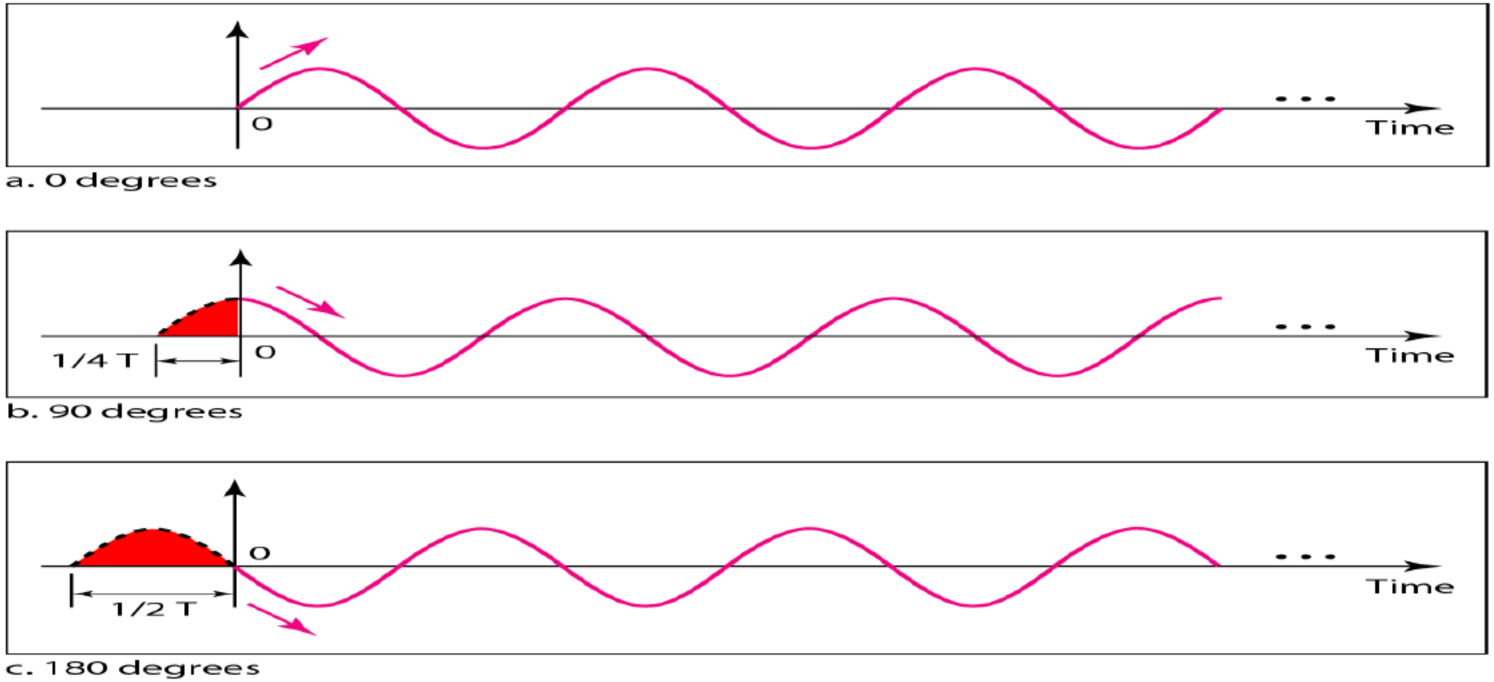
*Units of period and frequency*

| *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 |

# Phase

Phase describes the position of the waveform relative to time 0

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



# Example

*A sine wave is offset 1/6 cycle with respect to time 0. What is its phase in degrees and radians?*

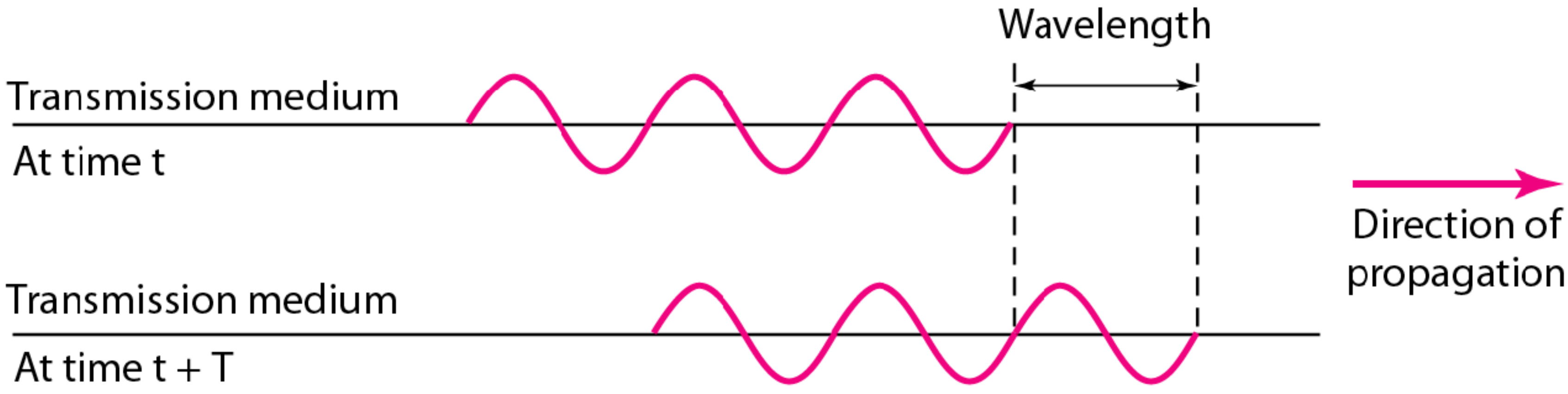
## Solution

*We know that 1 complete cycle is 360°. Therefore, 1/6 cycle is*

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

# Wavelength and Period

Wavelength = Propagation speed x Period
= Propagation speed / Frequency

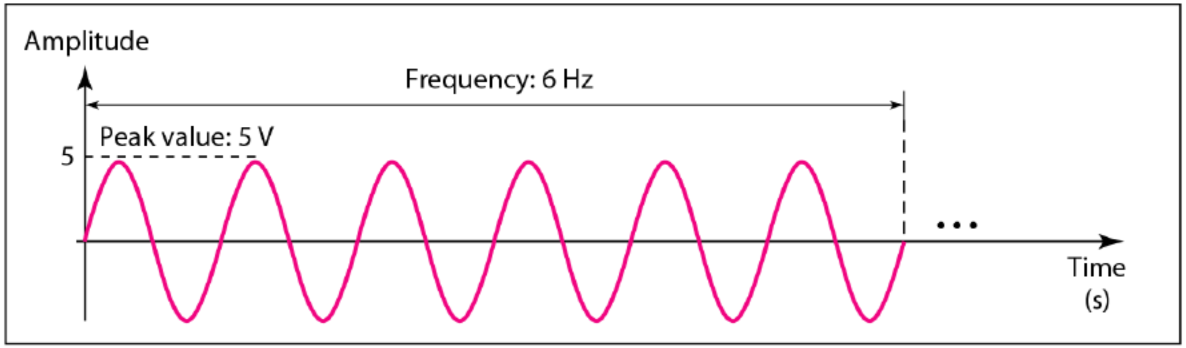


# Time and Frequency Domains

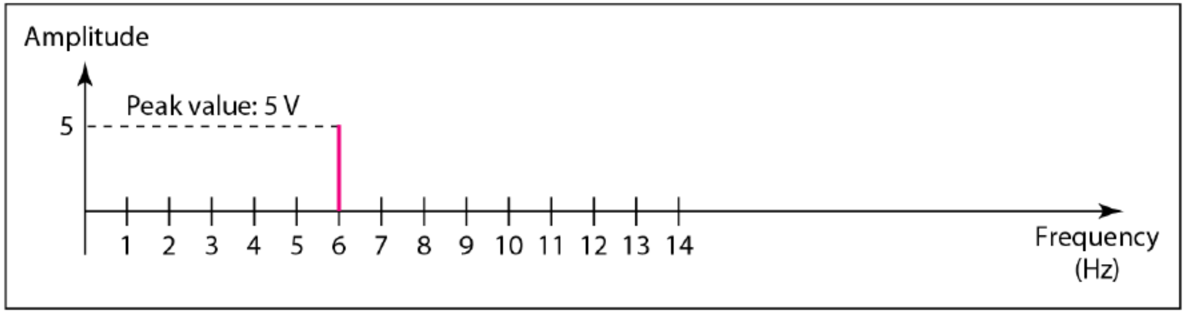
- A sine wave is comprehensively defined by its amplitude, frequency, and phase.
- We have been showing a sine wave by using what is called a time domain plot. The time-domain plot shows changes in signal amplitude with respect to time (it is an amplitude-versus-time plot).
- Phase is not explicitly shown on a time-domain plot.

# Time-domain and frequency-domain plots of a sine wave

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

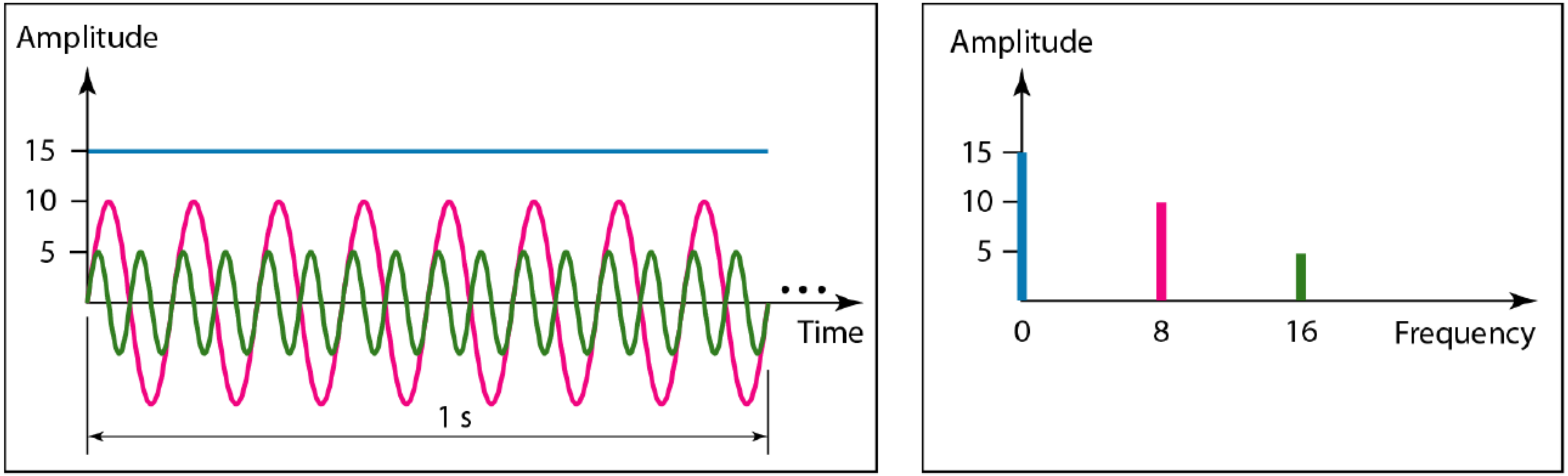



a. A sine wave in the time domain (peak value: 5 V, frequency: 6 Hz)




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

# 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

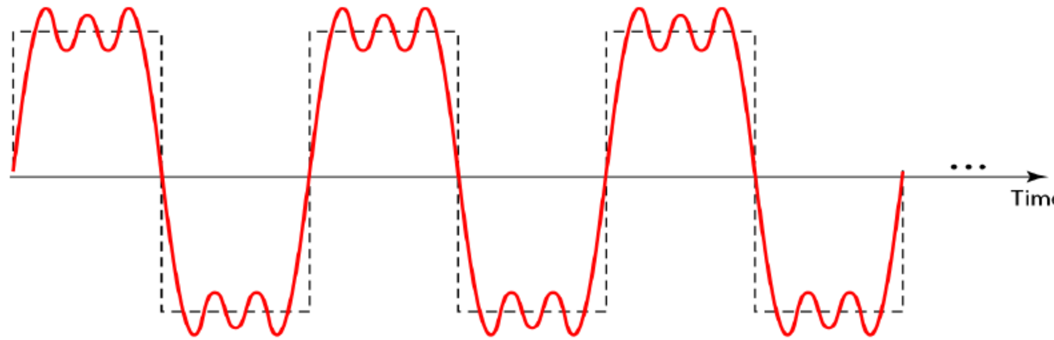
- The frequency domain is more compact and useful when we are dealing with more than one sine wave.
- A single-frequency sine wave is not useful in data communication We need to send a composite signal, a signal made of many simple sine waves.

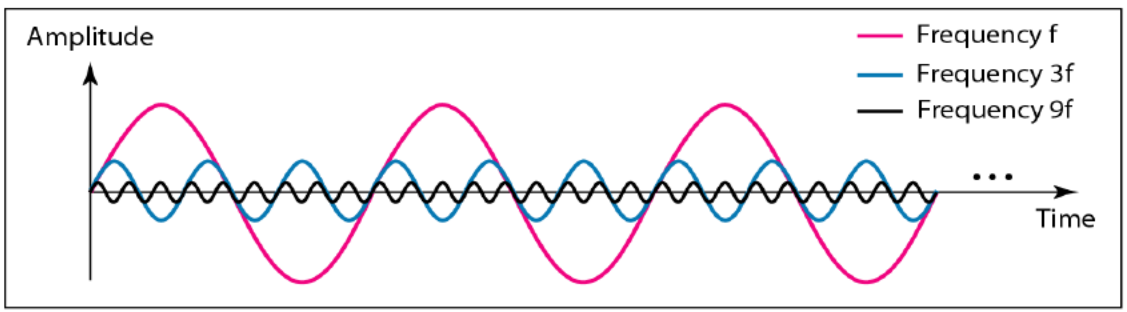
# Fourier analysis

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

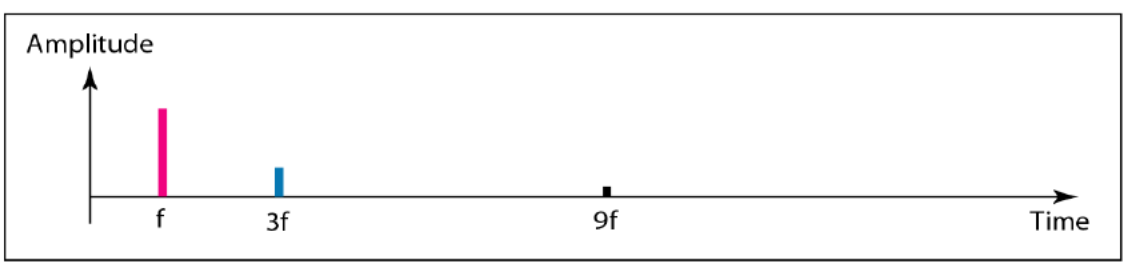
- If the composite signal is periodic, the decomposition gives a *series of signals with discrete frequencies*.
- If the composite signal is nonperiodic, the decomposition gives a *combination of sine waves with continuous frequencies*.

# A composite periodic signal




a. Time-domain decomposition of a composite signal




b. Frequency-domain decomposition of the composite signal

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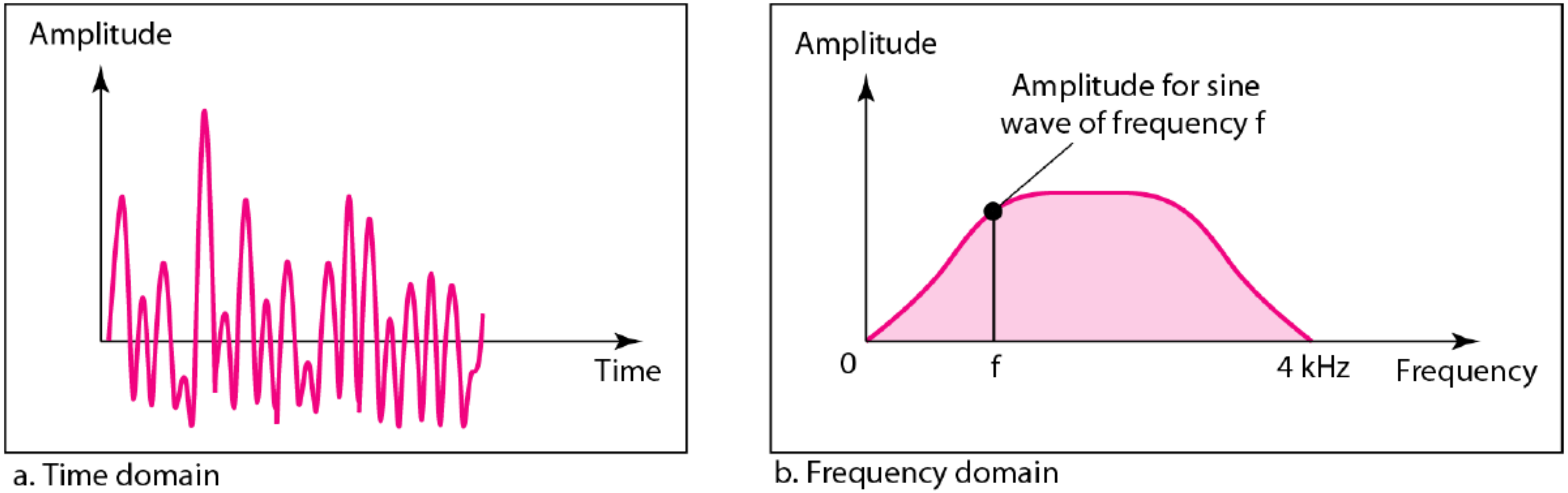
# Time and frequency domains of a nonperiodic signal

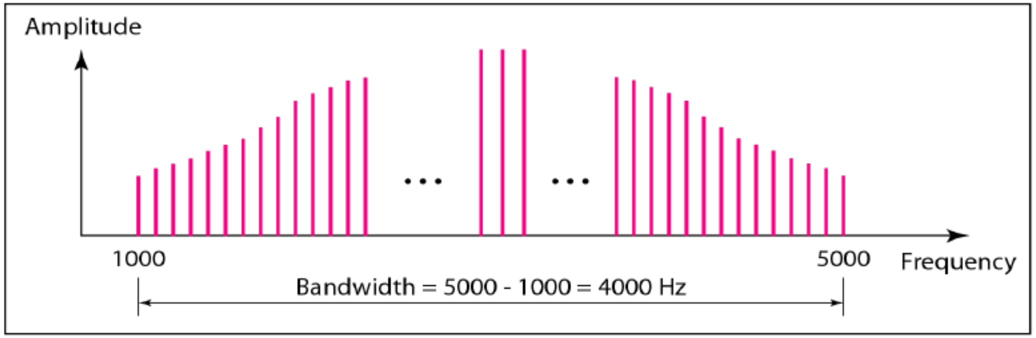
## A nonperiodic composite signal

- It can be a 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.

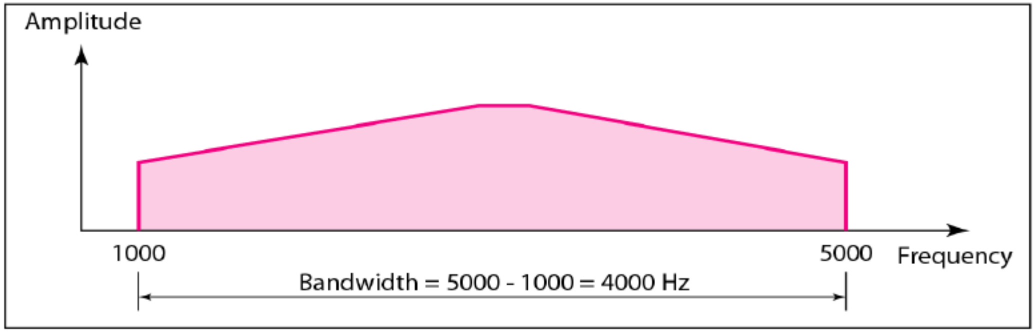


# Bandwidth

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




a. Bandwidth of a periodic signal

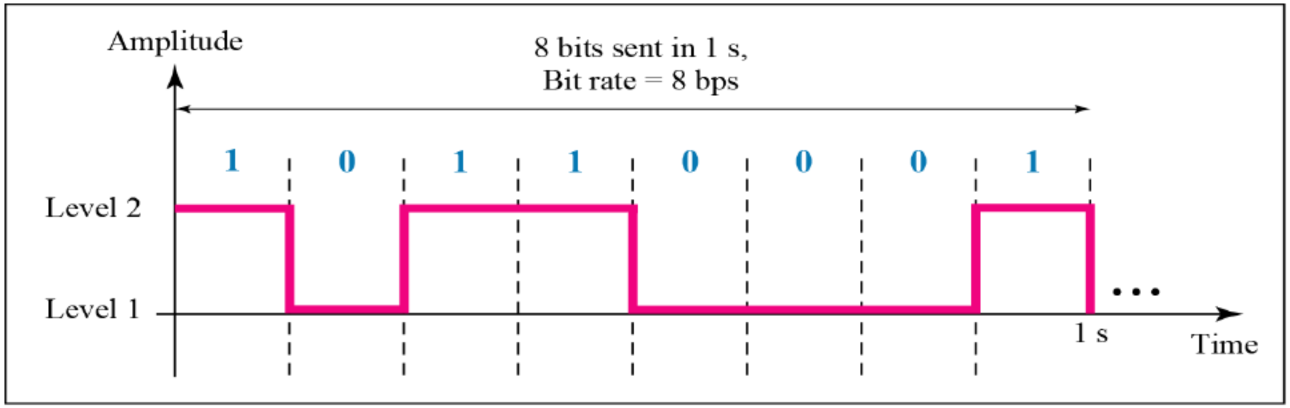



b. Bandwidth of a nonperiodic signal

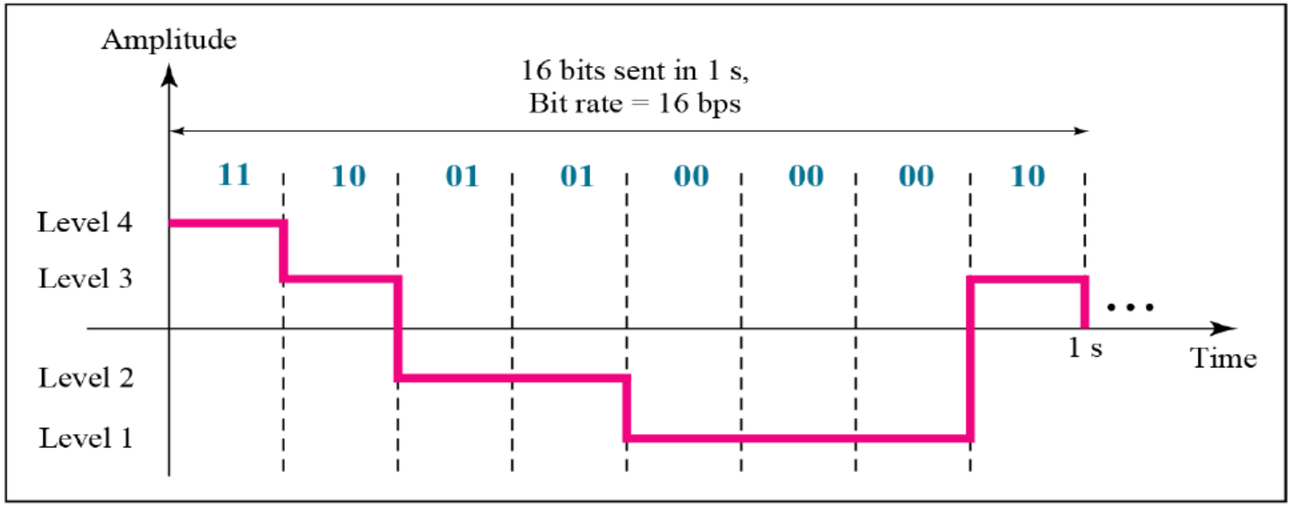
# DIGITAL SIGNALS

- 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

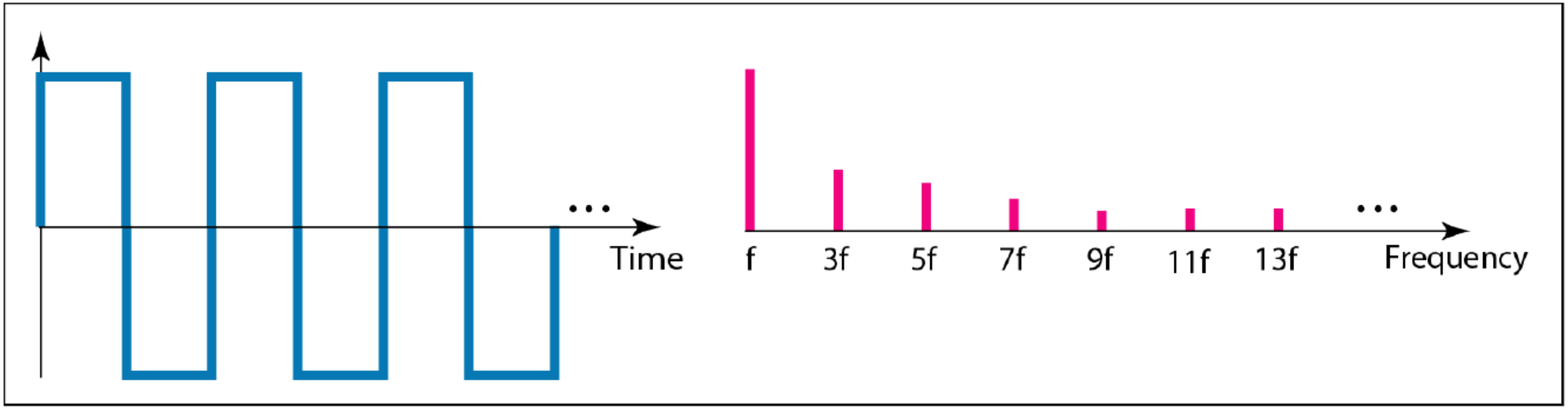



a. A digital signal with two levels

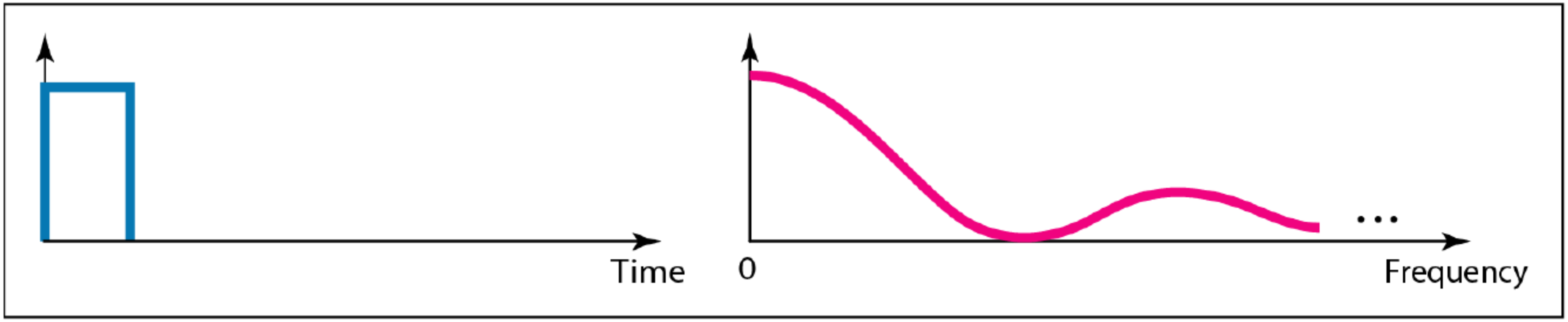



b. A digital signal with four levels

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



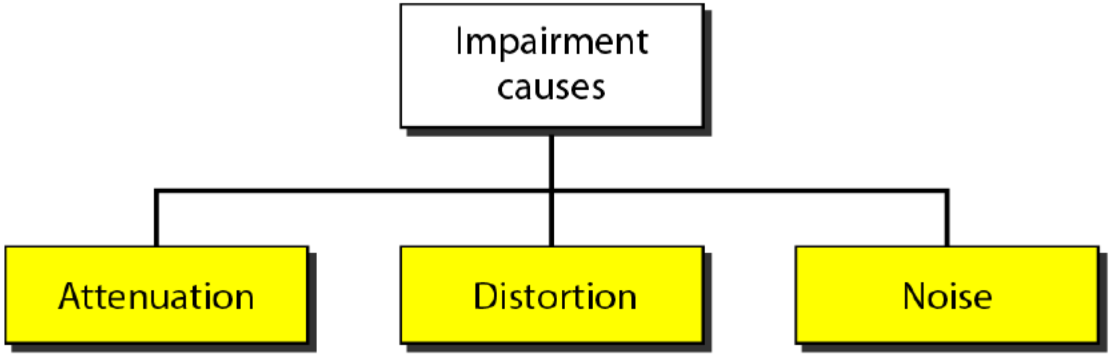

a. Time and frequency domains of periodic digital signal



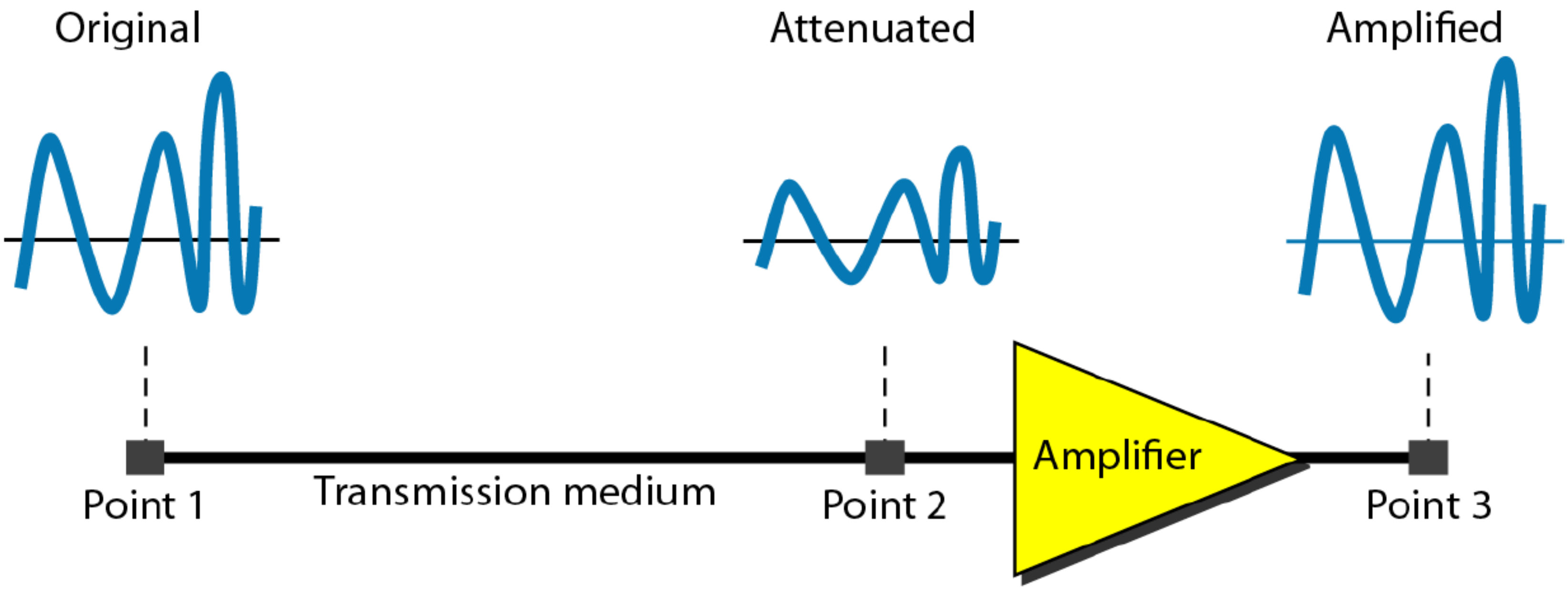

b. Time and frequency domains of nonperiodic digital signal

# 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 ( i.e., What is sent is not what is received).
- Three causes of impairment are attenuation, distortion, and noise.



# Attenuation



# Attenuation

- Attenuation can be considered as the loss of energy
- When a signal travels through a medium it loses energy overcoming the resistance of the medium. That is why a wire carrying electric signals gets warm, if not hot, after a while. Some of the electrical energy in the signal is converted to heat.
- It decides how far the signal can go without amplification
- Amplifiers are used to compensate for this loss of energy by amplifying the signal.

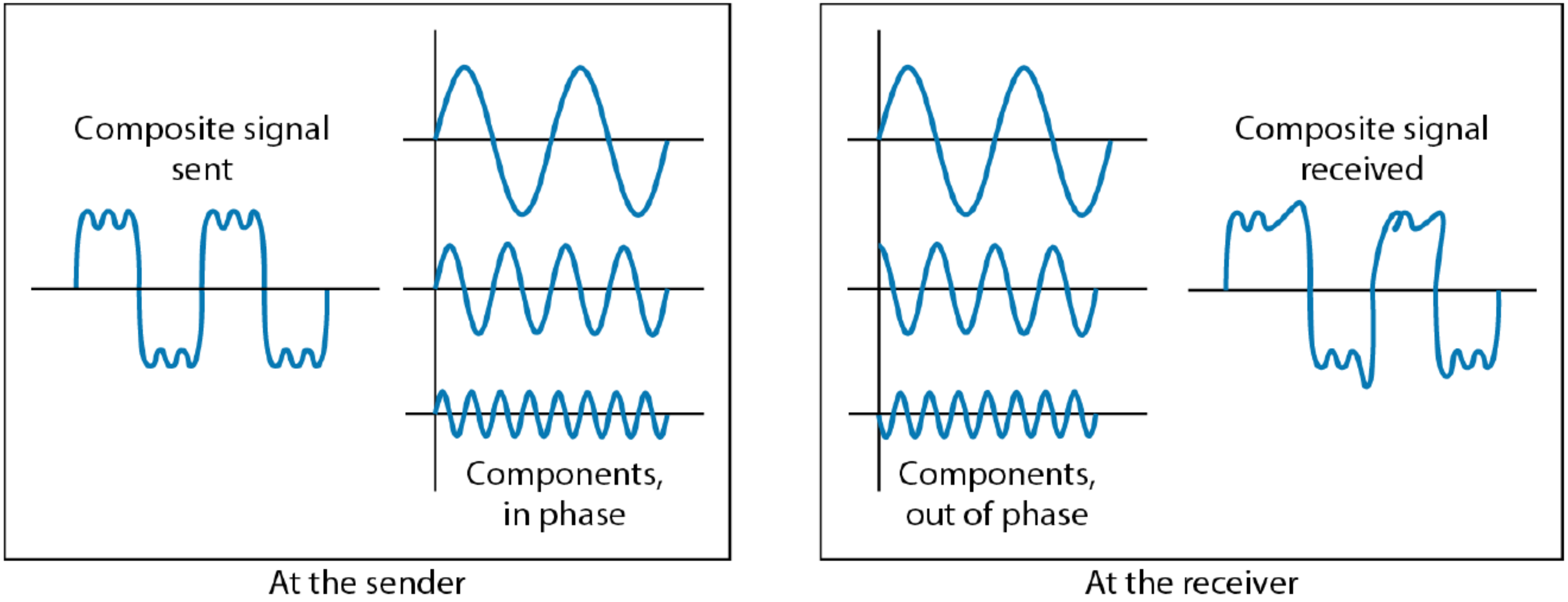
# Decibel

- To show that a signal has lost or gained strength, we use the unit of the decibel.
- 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.

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

- PI and P2 are the powers of a signal at points 1 and 2, respectively

# Distortion

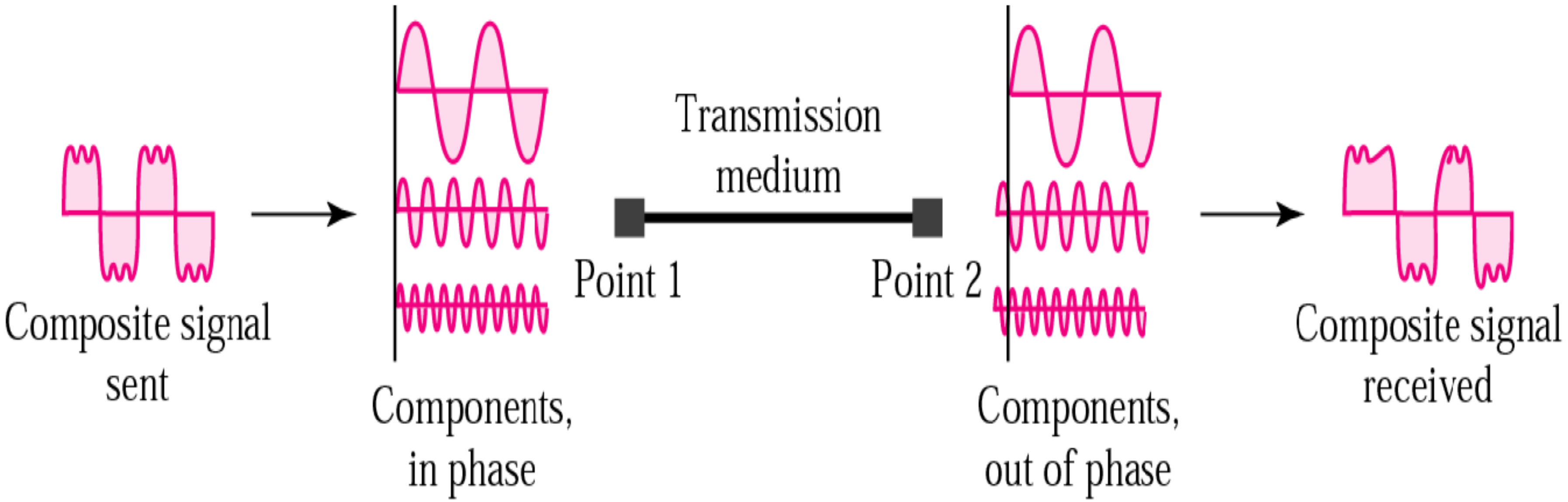


Composite signal
sent
Components,
in phase
At the sender
Composite signal
received
Components,
out of phase
At the receiver

# Distortion

- Means that the signal changes its form or shape
- Distortion occurs in composite signals
- Each frequency 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 did at the source.

- Distortion means that the signal changes its form or shape.
- Distortion can occur in a composite signal made of different frequencies.
    - 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.
    - In other words, signal components at the receiver have phases different from what they had at the sender.
    - The shape of the composite signal is therefore not the same.

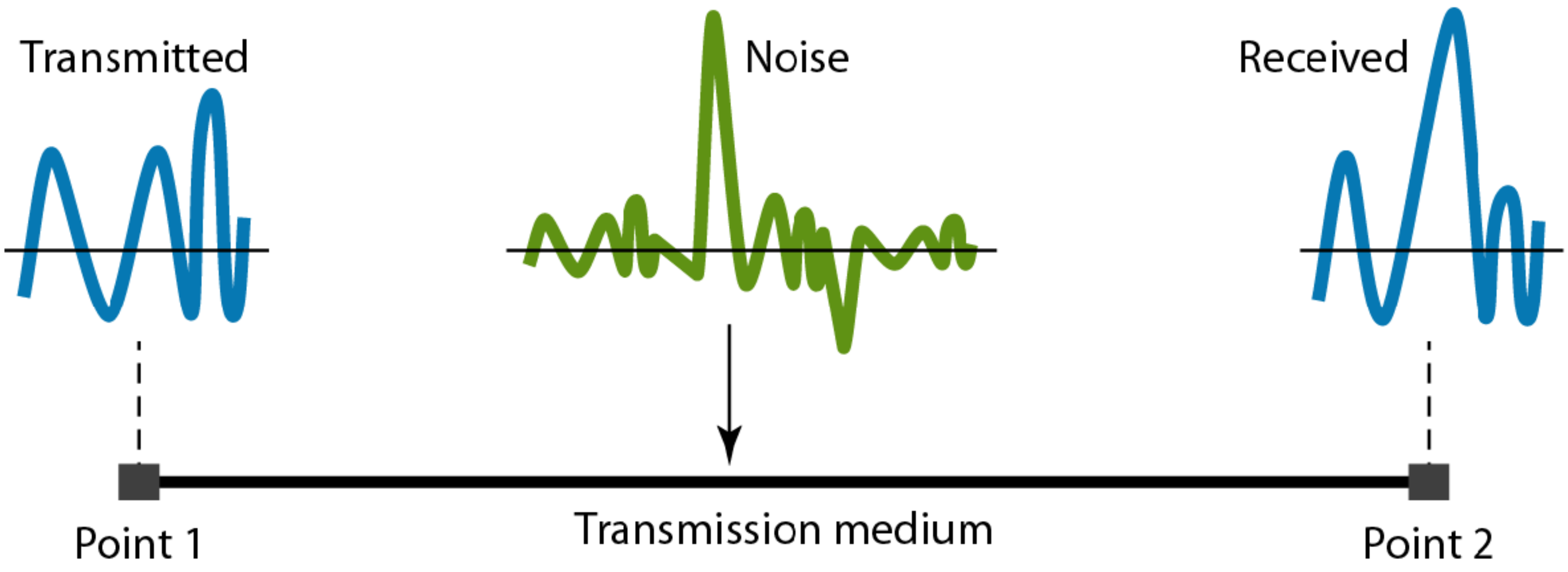



Effect Of Distortion On A Composite Signal.

# Delay distortion

- Delay distortion arises particularly in a guided media but not in air
- Delay distortion arises because velocity of propagation varies with frequency.
- That means this signal components that we are sending will have different velocities for different frequency components as it passes through a guided media, and this leads to delay distortion

# Noise


Transmitted
Noise
Received
Point 1
Transmission medium
Point 2

# Noise

- Thermal noise is the 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.
  - These devices act as a sending antenna, and the transmission medium acts as the receiving antenna.
- Cross-talk 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 is a spike (a signal with high energy in a very short time) 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:

  SNR = average signal power / average noise power

- We need to consider the average signal power and the average noise power because these may change with time.

# Idea of SNR

- The values of SNR and SNRdB for a noiseless channel are

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

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

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

# Signal-to-Noise Ratio (SNR)

- SNR is actually 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, $SNR_{dB}$ defined as:

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

# 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:
  - By Nyquist: For a noiseless channel
  - By Shannon: For a noisy channel.

# Thank You