Chapter 2
Transmission Fundamentals

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Electromagnetic Signal

- **Function of time**
- **Can also be expressed as a function of frequency**
  - Signal consists of components of different frequencies.

Time-Domain Concepts

- **Analog signal:** signal intensity varies in a smooth fashion over time
  - No breaks or discontinuities
- **Digital signal:** signal intensity maintains a constant level for some period of time and then changes to another constant level.
- **Periodic Signal:** analog or digital signal pattern that repeats over the time.

$$s(t+T) = s(t) \quad -\text{¥} < t < +\text{¥}$$

- where T is the period of the signal

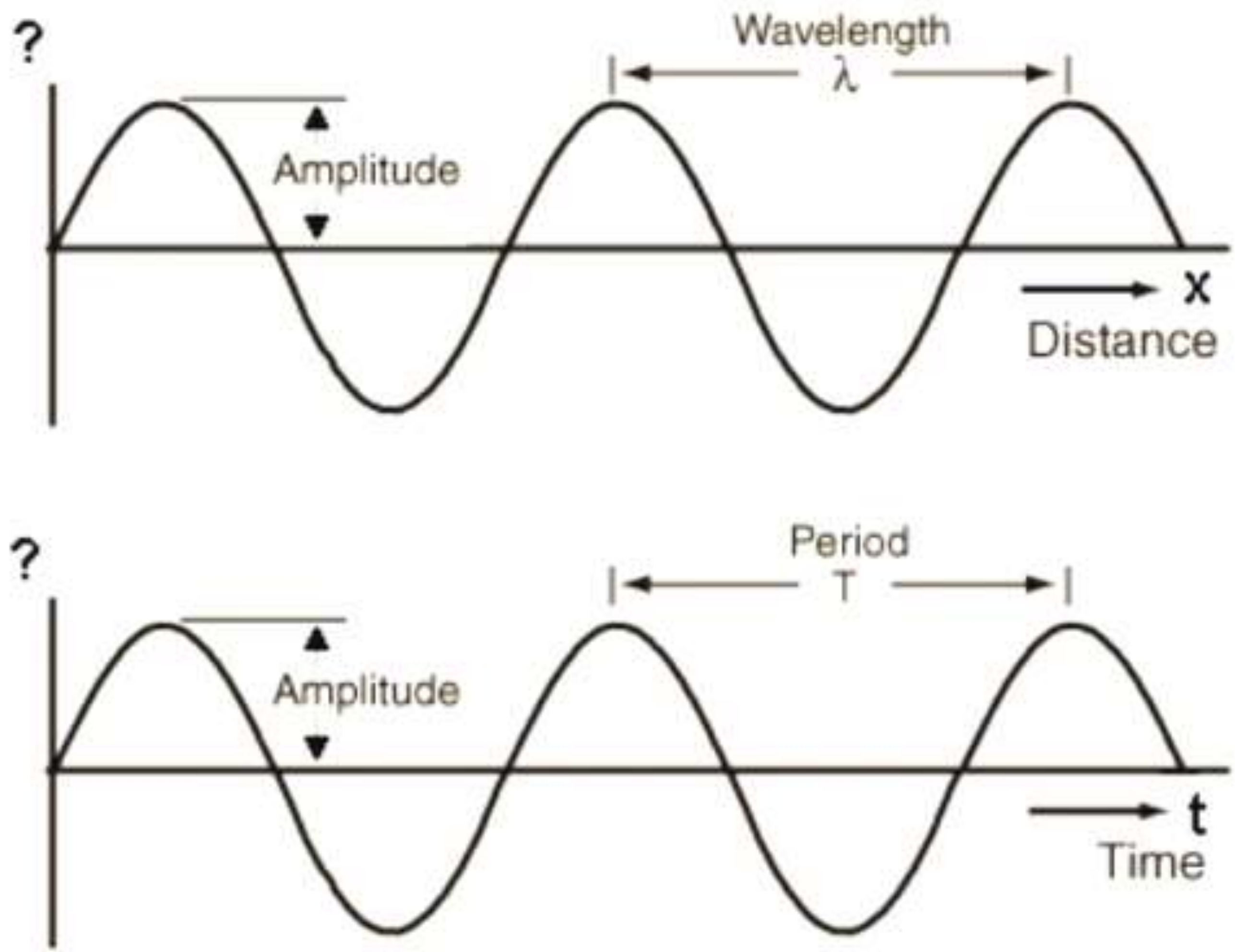
Time-Domain Concepts

- **Aperiodic Signal:** analog or digital signal pattern that does not repeat over the time
- **Peak amplitude (*A*):** a maximum value or strength of the signal over time, typically measured in volts.
- **Frequency(*F*):** Rate, in cycles per second, or Hertz(Hz) at which the signal repeats.

Time-Domain Concepts

- **Period (T):** amount of time it takes for one repetition of the signal T=1/F
- **Phase**(ϕ) –measure of the relative position in time within a single period of a signal.
- **Wavelength**(λ) – distance occupied by a single cycle of the signal.
  - Or, the distance between two points of corresponding phase of two consecutive cycles.

Periodic Signal Example



Sine Wave Parameters

- General Sine Wave

  $s(t) = A \sin(2\pi f t + \phi)$

- The next figure shows the effect of varying each of the three parameters (amplitude, frequency, phase):

  (a) $A = 1$, $f = 1$ Hz, $\phi = 0$; thus $T = 1$s

  (b) Reduced peak amplitude; A=0.5

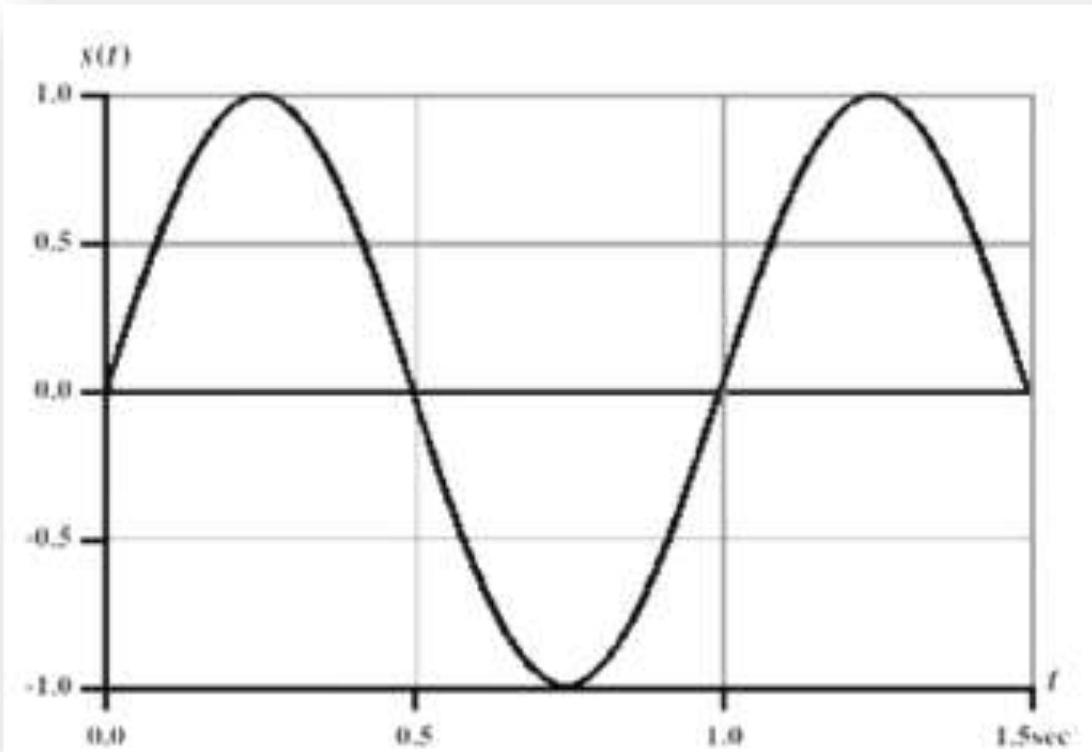
  (c) Increased frequency; $f = 2$, thus $T = ½$

  (d) Phase shift; $\phi = \pi/4$ radians (45 degrees)

- **Note**:

  2π radians = 360° = 1 period

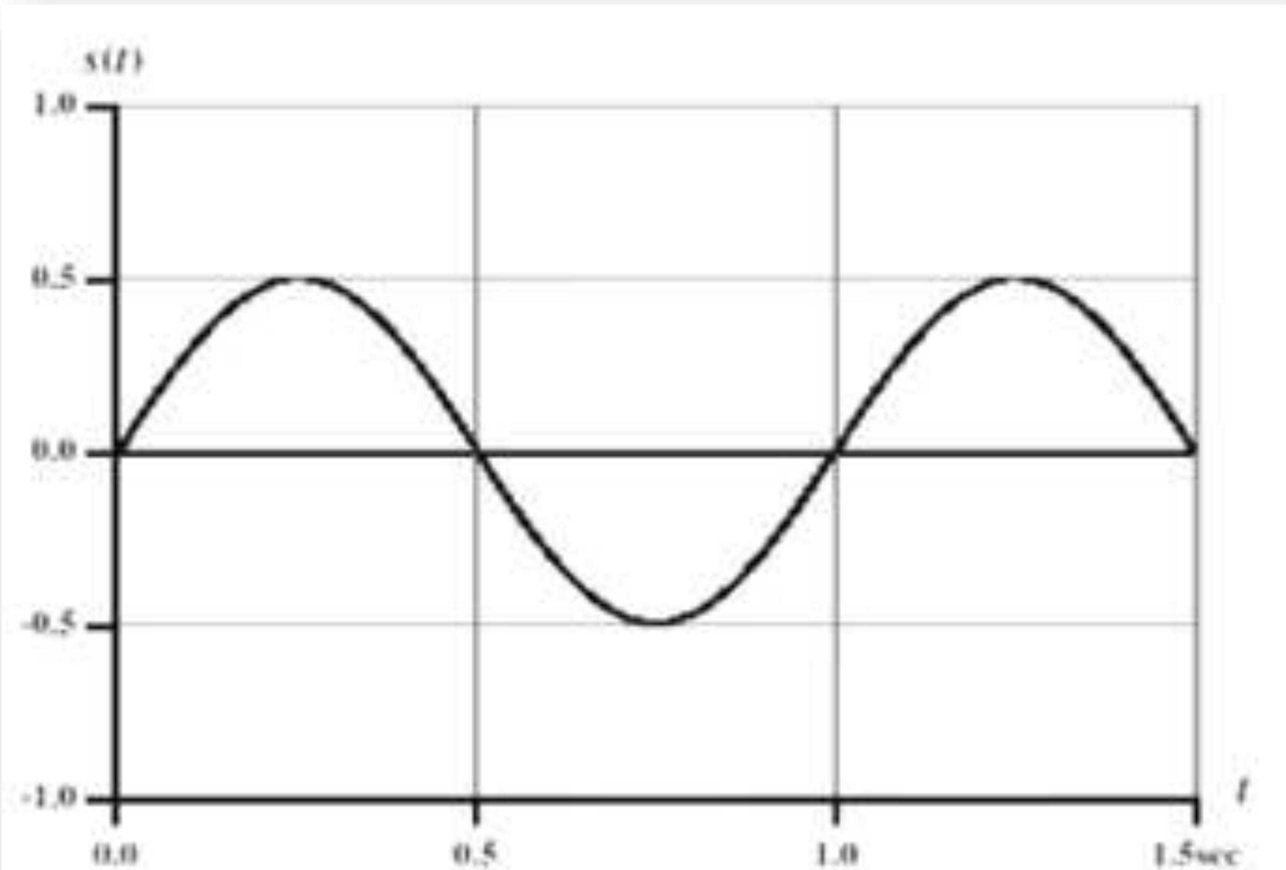
Case 1



- **<u>Parameters</u>**: Amplitude =1, Frequency=1, phase=0

$$s(t) = A \sin (2 \ ft + \phi)$$

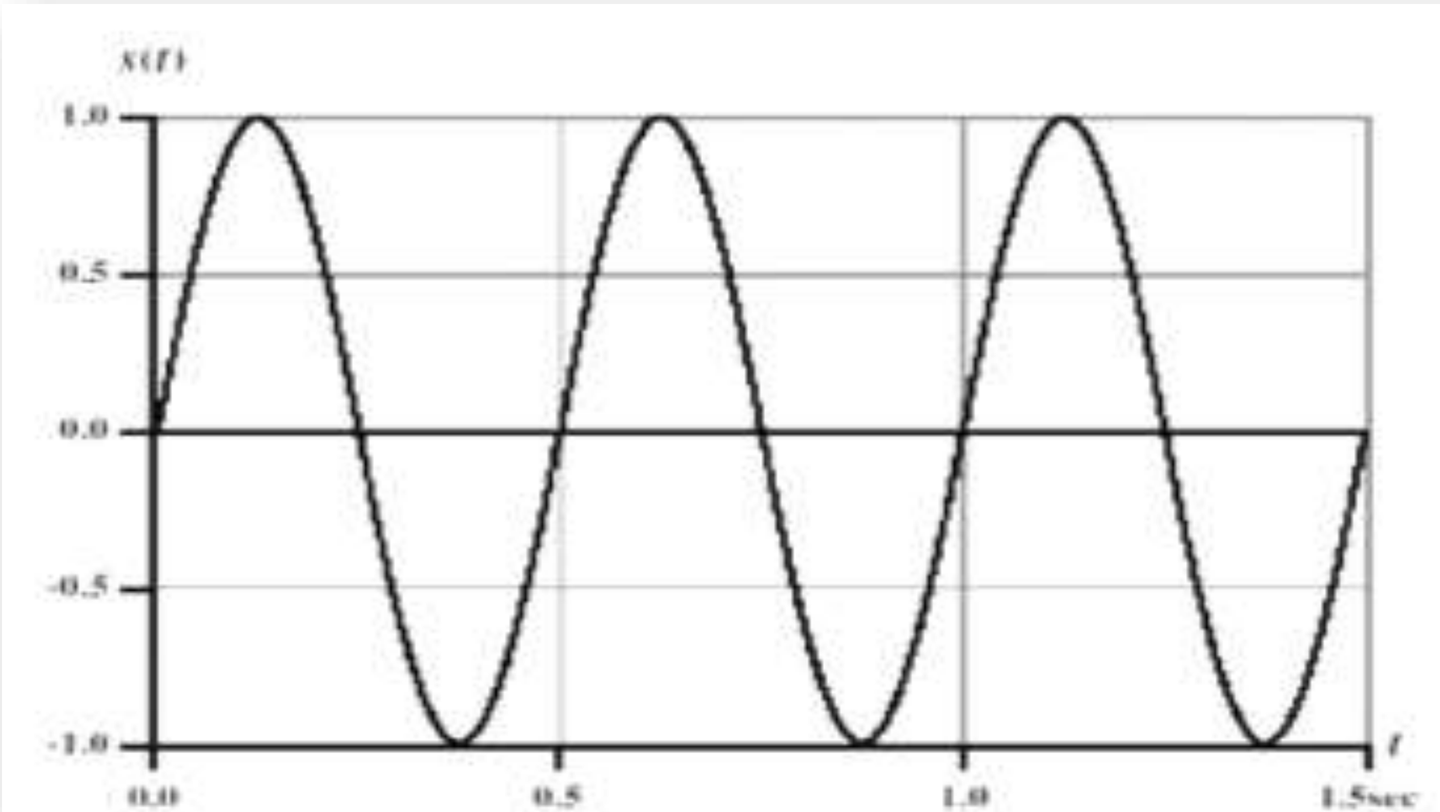
Case 2



- **Parameters**: Amplitude =0.5, Frequency=1, phase=0

$$s(t) = A \sin(2 \;\, ft + \phi)$$

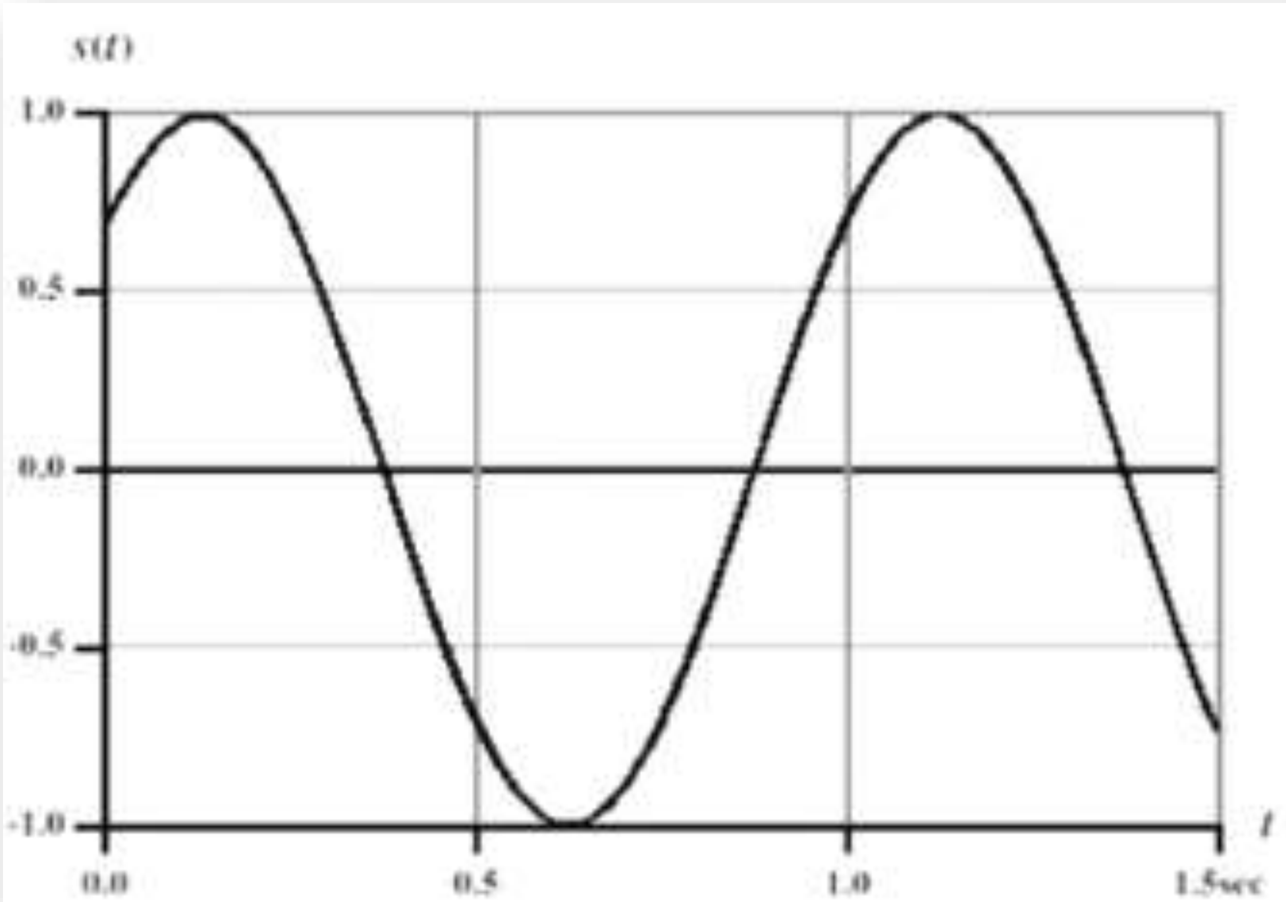
Case 3



- **<u>Parameters</u>**: Amplitude =1, Frequency=2, phase=0

$$s(t) = A \sin (2 \ ft + \phi)$$

Case 4



- **<u>Parameters</u>**: Amplitude =1, Frequency=2, phase=0

$$s(t) = A \sin(2\ ft + \phi)$$

Time VS. Distance

- When the horizontal axis is **time**, as shown in the pervious figure, the graph displays the value of a signal at a given point in space as a function of time.
- With horizontal axis in **space**, graph displays the value of a signal at a given point in time as function of distance
  - At a particular instant of time, the intensity of the signal varies as a function of distance from the source.

Frequency-Domain Concepts

- **Fundamental frequency** – when all frequency components of a signal are integer multiples of one frequency, it's refereed to as the fundamental frequency
- **Spectrum** – range of frequencies that a signal contains
- **Absolute bandwidth-** width of the spectrum of signal
- **Effective bandwidth** (or just bandwidth) – narrow band of frequencies that most of signal's energy is contained in.

Frequency-Domain Concepts

- Any electromagnetic signal can be shown to consists of a collection of periodic analog signals (sine waves) at different amplitudes, frequencies, and phases

- The period of the total signal is equal to the period of the fundamental frequency.

Data Communication Terms

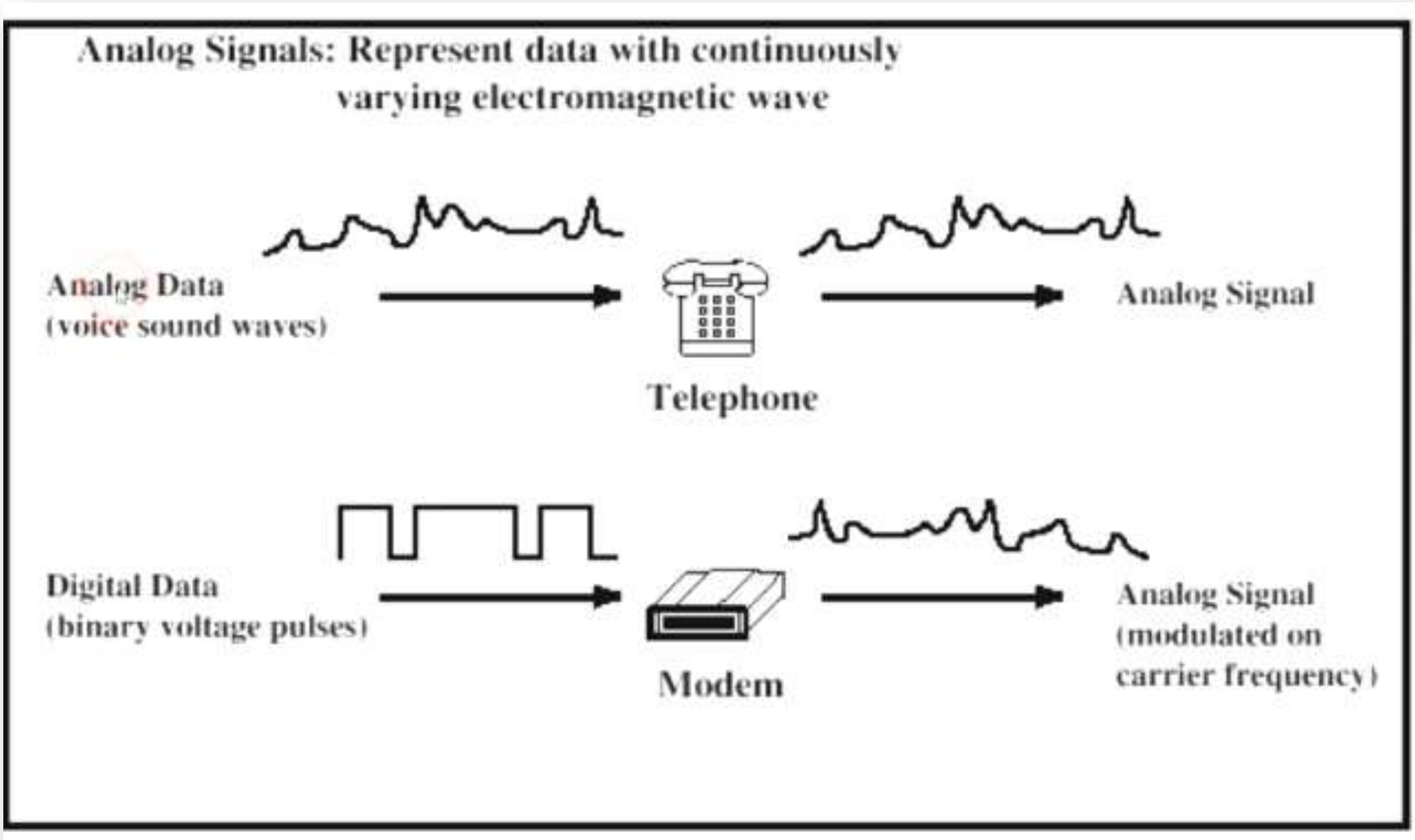
- **Data** – entities that convey meaning, or information
- **Signals** – electric or electromagnetic representations of data., Signals can be analog or digital.
  - **Examples of analog data**: video and audio
  - **Examples of digital data** : text
- **Transmission** – communication of data by the propagation and processing of signals

Analog signals

- A continuously varying electromagnetic wave that may be propagated over a variety of media, depending on the frequency.

- Analog signals can propagate analog and digital data

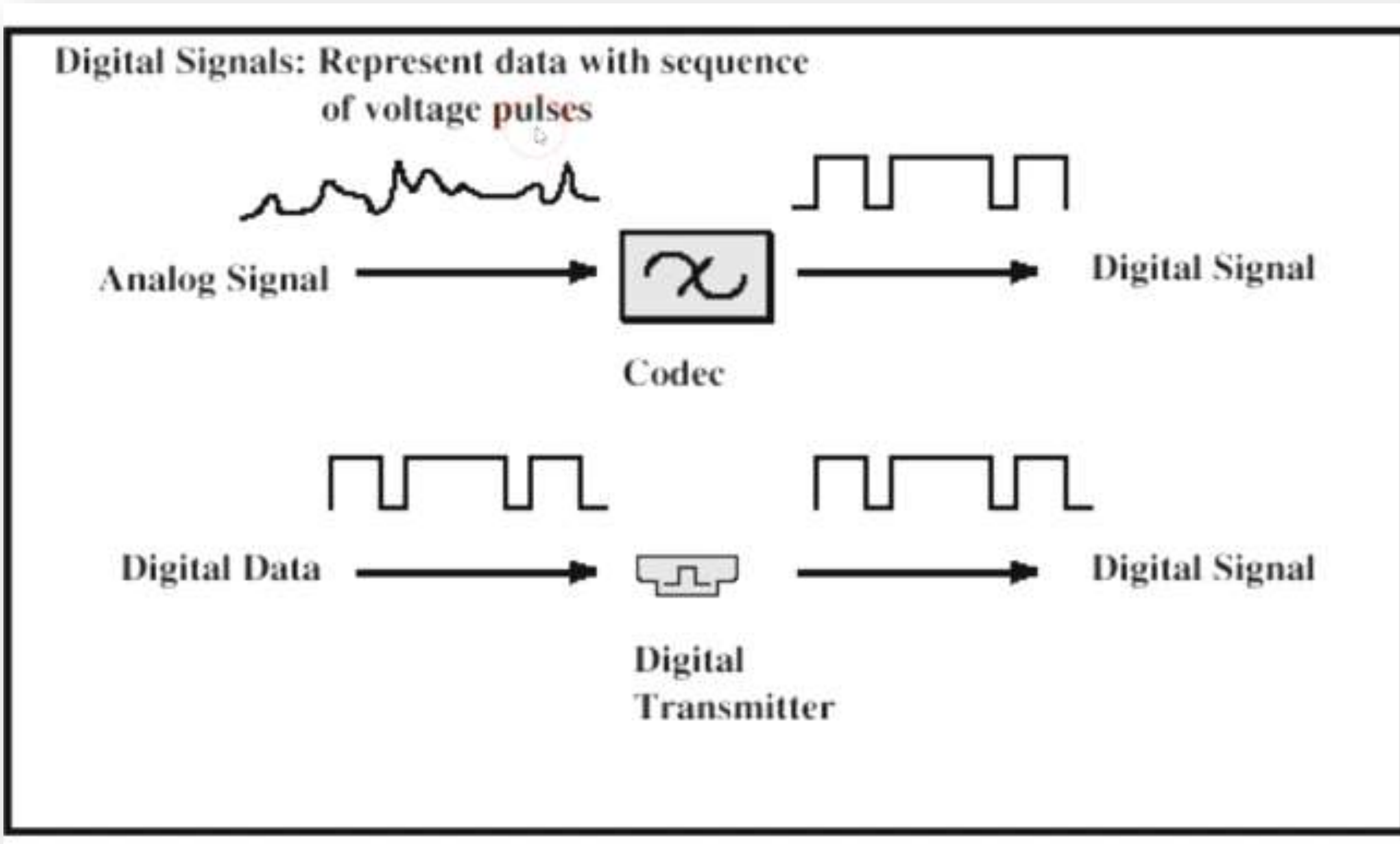
Analog signals



Digital signals

- A sequence of voltage pulses that may be transmitted over a copper wire medium
- Generally cheaper than analog signaling
- Less susceptible to noise interference
- Suffer more from attenuation
- Digital signals can propagate analog and digital data.

Digital signals



Reasons for Choosing Data and Signal Combinations

- **Digital data, digital signal**
  - Equipment for encoding is less expensive than digital-to-analog equipment
- **Analog data, digital signal**
  - Conversion permits use of modern digital transmission and switching equipment
- **Digital data, analog signal**
  - Some transmission media will only propagate analog signals
  - Examples include optical fiber and satellite
- **Analog data, analog signal**
  - Analog data easily converted to analog signal

Analog Transmission

- Transmit analog signals without regard to content
- Attenuation limits length of transmission link
- Cascade amplifiers boost signal’s energy for longer distances but cause distortion
  - Analog data can tolerate distortion
  - Introduces errors in digital data.

Digital Transmission

- Concerned with the content of the signal
- Attenuation endangers integrity of data
- Digital Signal
  - Repeaters achieve greater distance
  - Repeaters recover the signal and retransmit
- Analog signal carrying digital data
  - Retransmission device recovers the digital data from analog signal
  - Generate new, clean analog signal.

About Channel Capacity

- Impairments, such as noise, limit data rate that can be achieved
- For digital data, to what extent do impairments limit data rate?
- Channel Capacity – the maximum rate at which data can be transmitted over a given communication path, or channel, under given conditions

Concepts Related to Channel Capacity

- Data rate - rate at which data can be communicated (bps)
- Bandwidth - the bandwidth of the transmitted signal as constrained by the transmitter and the nature of the transmission medium (Hertz)
- Noise - average level of noise over the communications path
- Error rate - rate at which errors occur
  - Error = transmit 1 and receive 0; transmit 0 and receive 1

Nyquist Bandwidth

- For binary signals (two voltage levels)
  - $C = 2B$
- With multilevel signaling
  - $C = 2B \log_2 M$
    - M = number of discrete signal or voltage levels

Signal-to-Noise Ratio

- Ratio of the power in a signal to the power contained in the noise that's present at a particular point in the transmission
- Typically measured at a receiver
- Signal-to-noise ratio (SNR, or S/N)

$$(SNR)_{\mathrm{dB}} = 10\log_{10} \frac{\text{signal power}}{\text{noise power}}$$

- A high SNR means a high-quality signal, low number of required intermediate repeaters
- SNR sets upper bound on achievable data rate

Shannon Capacity Formula

- Equation:

$$C = B\log_2\left(1+\text{SNR}\right)$$

- Represents theoretical maximum that can be achieved
- In practice, only much lower rates achieved
  - Formula assumes white noise (thermal noise)
  - Impulse noise is not accounted for
  - Attenuation distortion or delay distortion not accounted for

Example of Nyquist and Shannon Formulations

- Spectrum of a channel between 3 MHz and 4 MHz ; $SNR_{dB} = 24$ dB

$$B = 4\text{ MHz} - 3\text{ MHz} = 1\text{ MHz}$$

$$SNR_{dB} = 24\text{ dB} = 10\log_{10}(SNR)$$

$$SNR = 251$$

- Using Shannon's formula

$$C = 10^6 \times \log_2(1+251) \approx 10^6 \times 8 = 8\text{Mbps}$$

Example of Nyquist and Shannon Formulations

- How many signaling levels are required?

$$
\begin{aligned}
C &= 2B\log_2 M \\
8\times10^6 &= 2\times\left(10^6\right)\times\log_2 M \\
4 &= \log_2 M \\
M &= 16
\end{aligned}
$$

Classifications of Transmission Media

- Transmission Medium
  - Physical path between transmitter and receiver
- Guided Media
  - Waves are guided along a solid medium
  - E.g., copper twisted pair, copper coaxial cable, optical fiber
- Unguided Media
  - Provides means of transmission but does not guide electromagnetic signals
  - Usually referred to as wireless transmission
  - E.g., atmosphere, outer space

Unguided Media

- Transmission and reception are achieved by means of an antenna
- Configurations for wireless transmission
  - Directional
  - Omnidirectional

General Frequency Ranges

- Microwave frequency range
  - 1 GHz to 40 GHz
  - Directional beams possible
  - Suitable for point-to-point transmission
  - Used for satellite communications
- Radio frequency range
  - 30 MHz to 1 GHz
  - Suitable for omnidirectional applications
- Infrared frequency range
  - Roughly, 3×10^{11} to 2×10^{14} Hz
  - Useful in local point-to-point multipoint applications within confined areas

Terrestrial Microwave

- Description of common microwave antenna
  - Parabolic "dish", 3 m in diameter
  - Fixed rigidly and focuses a narrow beam
  - Achieves line-of-sight transmission to receiving antenna
  - Located at substantial heights above ground level
- Applications
  - Long haul telecommunications service
  - Short point-to-point links between buildings

Satellite Microwave

- Description of communication satellite
  - Microwave relay station
  - Used to link two or more ground-based microwave transmitter/receivers
  - Receives transmissions on one frequency band (uplink), amplifies or repeats the signal, and transmits it on another frequency (downlink)
- Applications
  - Television distribution
  - Long-distance telephone transmission
  - Private business networks

Multiplexing

- Capacity of transmission medium usually exceeds capacity required for transmission of a single signal
- Multiplexing - carrying multiple signals on a single medium
  - More efficient use of transmission medium

Multiplexing

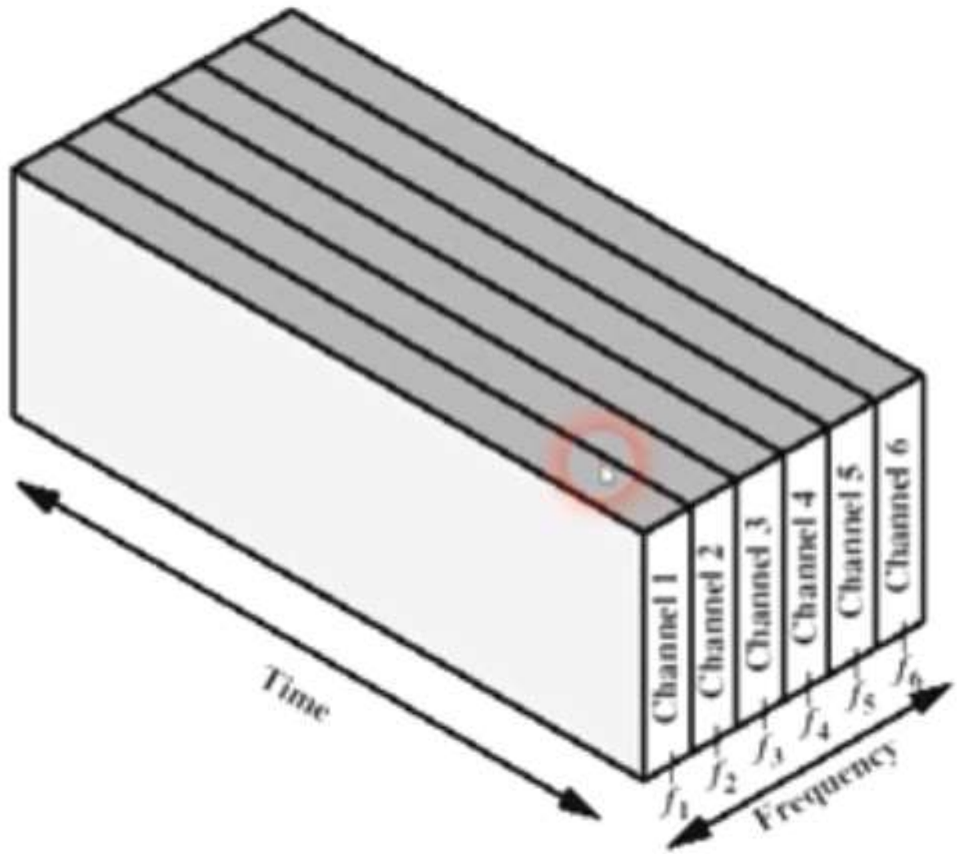
Reasons for Widespread Use of Multiplexing

- Cost per kbps of transmission facility declines with an increase in the data rate
- Cost of transmission and receiving equipment declines with increased data rate
- Most individual data communicating devices require relatively modest data rate support

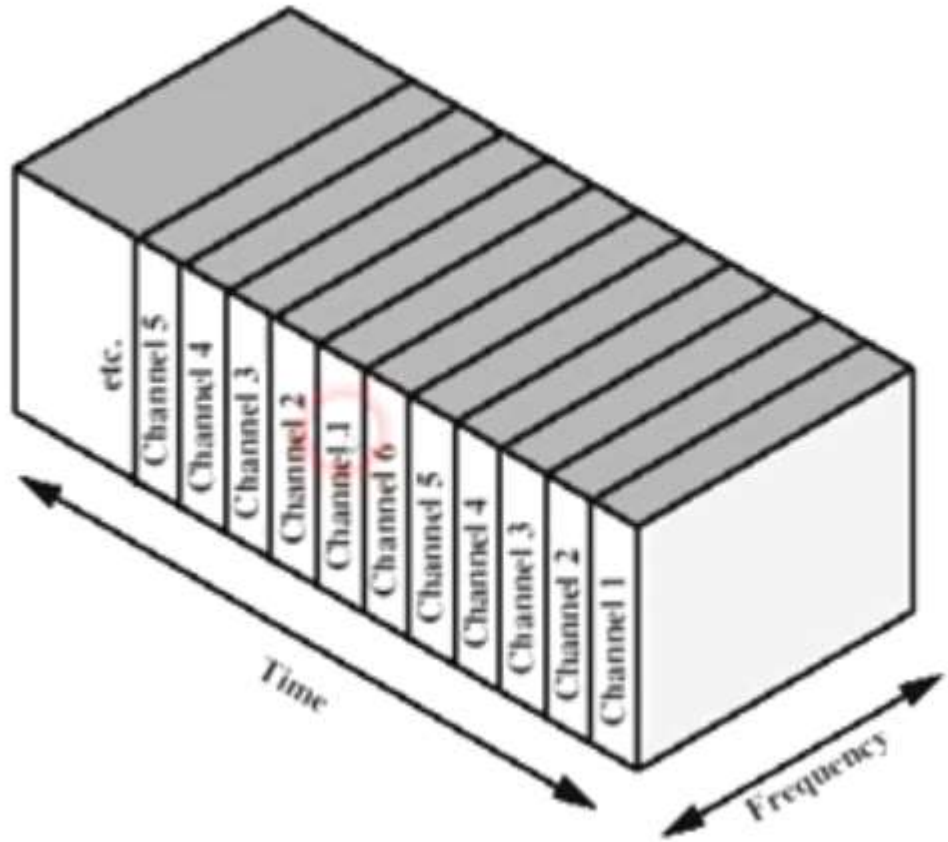
Multiplexing Techniques

- Frequency-division multiplexing (FDM)
  - Takes advantage of the fact that the useful bandwidth of the medium exceeds the required bandwidth of a given signal
- Time-division multiplexing (TDM)
  - Takes advantage of the fact that the achievable bit rate of the medium exceeds the required data rate of a digital signal

Frequency-division Multiplexing



Time-division Multiplexing



Questions

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