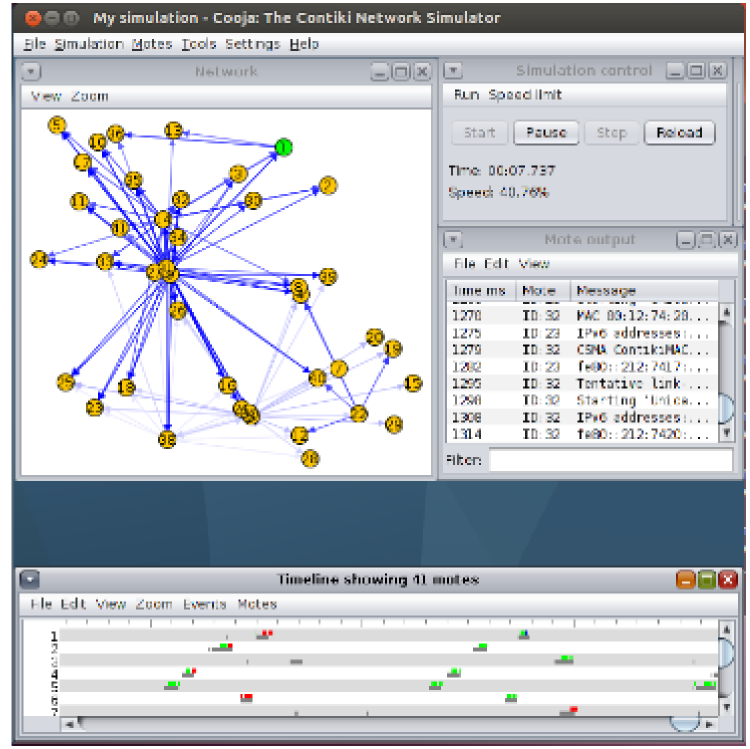
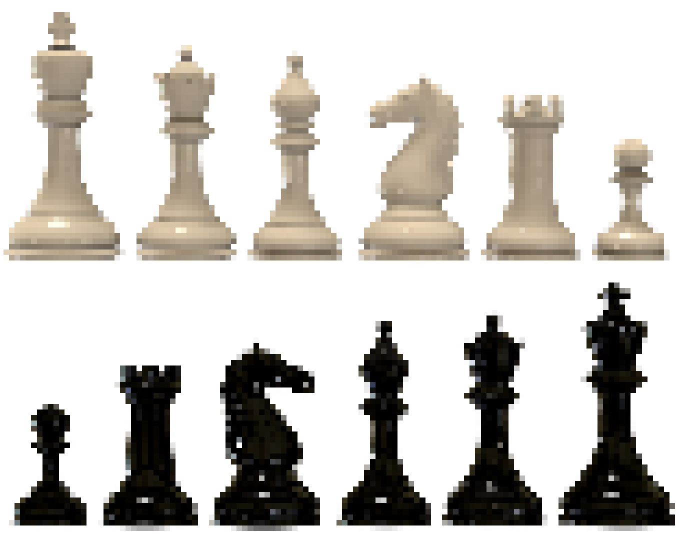
# Chapter 3,4,5
# Transmission Fundamentals



# Electromagnetic Signal

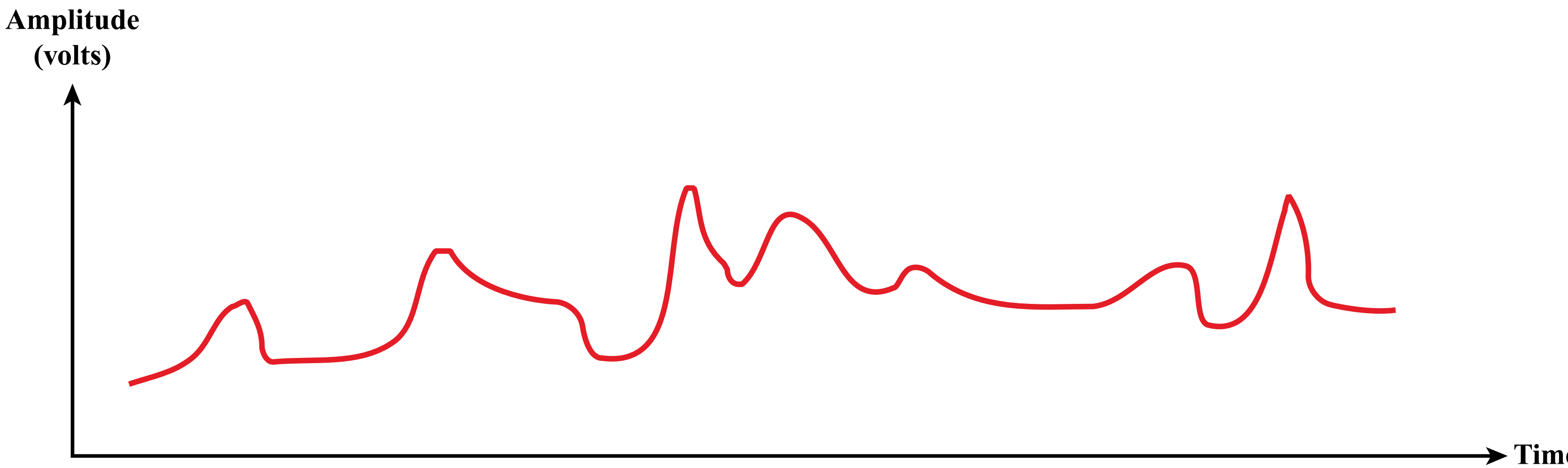
- Function of time
- Can also be expressed as a function of frequency
  - Signal consists of components of different frequencies

# Time-Domain Concepts

- Analog signal - signal intensity varies in a smooth fashion over time
  - No breaks or discontinuities in the signal
- 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 time

$$s(t+T) = s(t) \quad -\infty < t < +\infty$$

  - where $T$ is the period of the signal




(a) Analog


(b) Digital

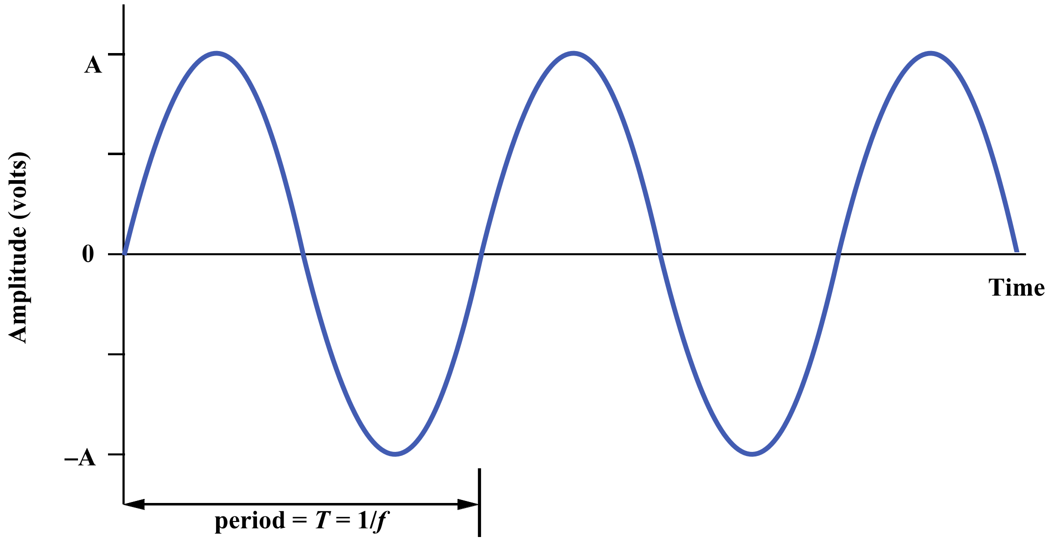
***Analog and Digital Waveforms***

# Time-Domain Concepts

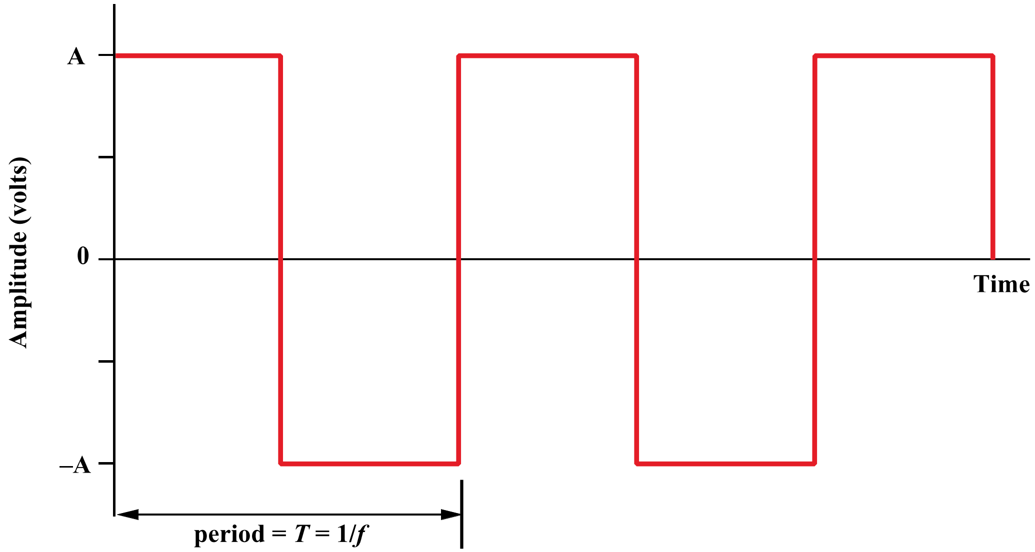
- Aperiodic signal - analog or digital signal pattern that doesn't repeat over time
- Peak amplitude ($A$) - maximum value or strength of the signal over time; typically measured in volts
- Frequency ( $f$ )
  - Rate, in cycles per second, or Hertz (Hz) at which the signal repeats

# Time-Domain Concepts

- Period ($T$) - amount of time it takes for one repetition of the signal
  - $T = 1/f$
- Phase ($\phi$) - measure of the relative position in time within a single period of a signal
- Wavelength ($\lambda$) - distance occupied by a single cycle of the signal
  - Or, the distance between two points of corresponding phase of two consecutive cycles



(a) Sine wave

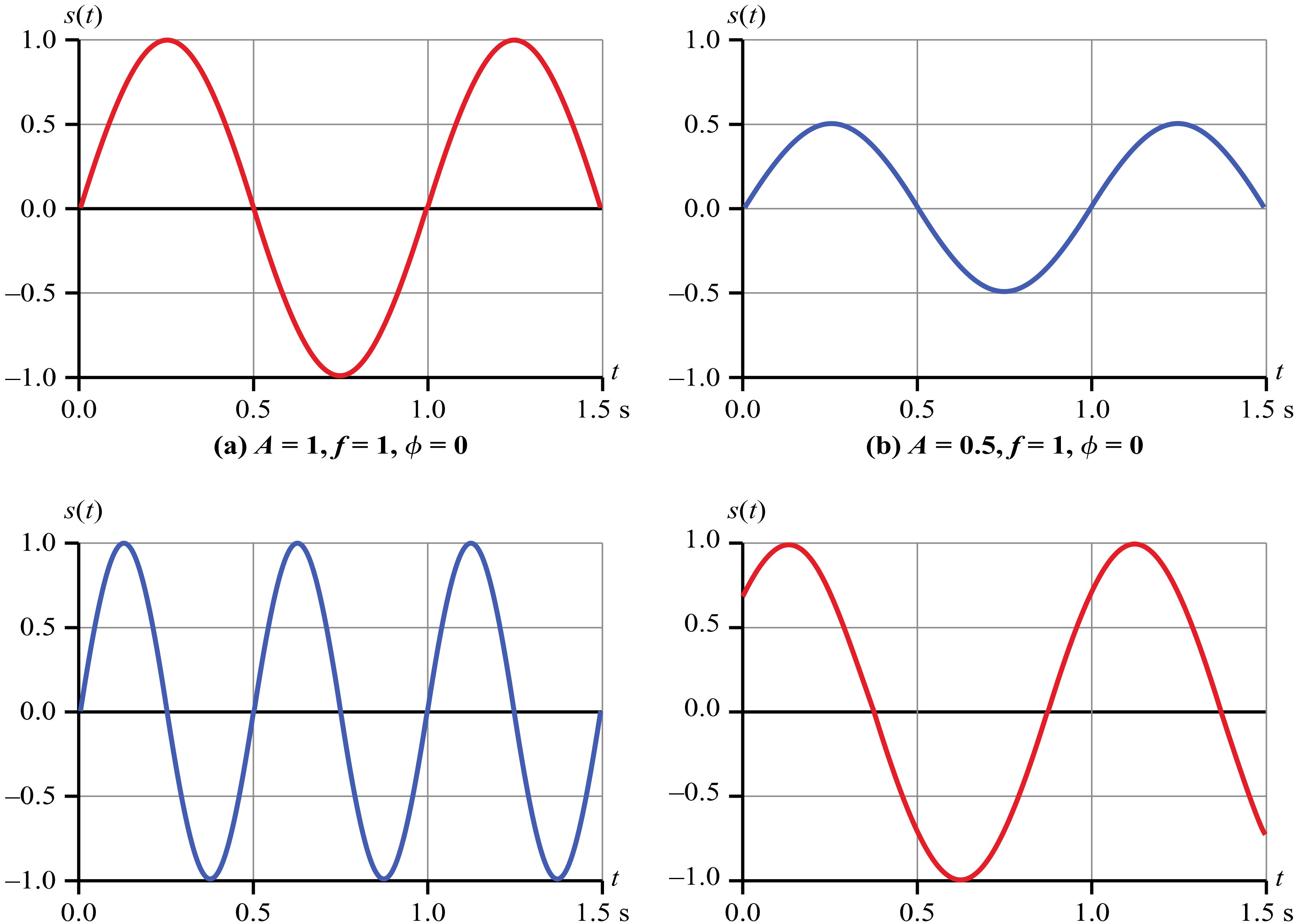


(b) Square wave

# *Examples of Periodic Signals*

# Sine Wave Parameters

- General sine wave
  - $s(t) = A \sin(2\pi f t + \phi)$
- Figure 2.3 shows the effect of varying each of the three parameters
- (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: $2\pi$ radians = 360° = 1 period




(a) $A = 1, f = 1, \phi = 0$

(b) $A = 0.5, f = 1, \phi = 0$

(c) $A = 1, f = 2, \phi = 0$

(d) $A = 1, f = 1, \phi = \pi/4$

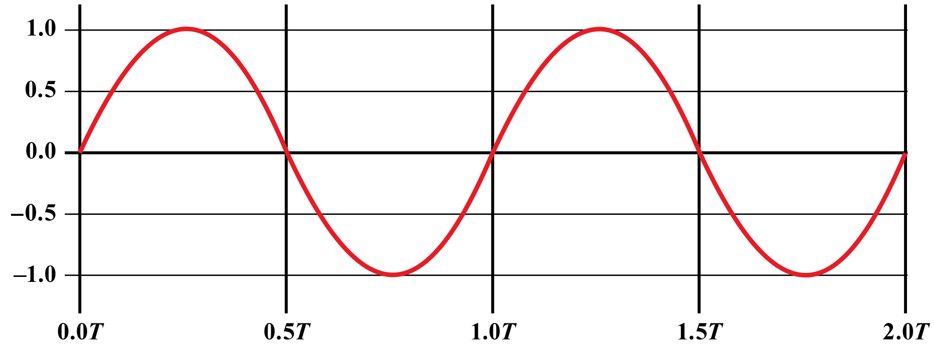
$$s(t) = A \sin (2\pi ft + \phi)$$

# Time vs. Distance

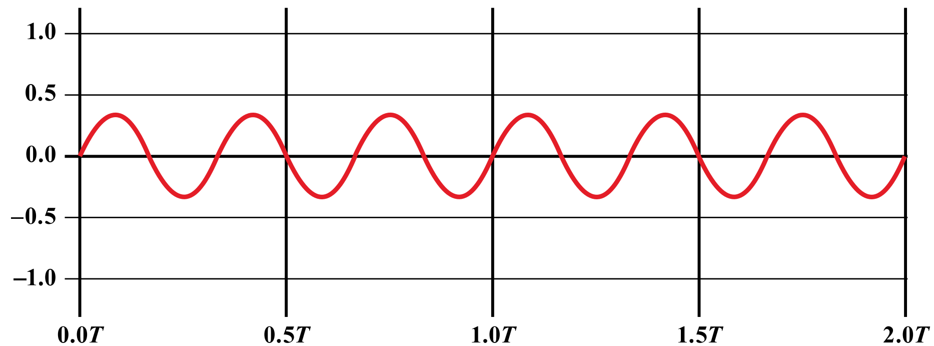
- When the horizontal axis is *time*, as in Figure 2.3, graphs display the value of a signal at a given point in *space* as a function of *time*
- With the horizontal axis in *space*, graphs display the value of a signal at a given point in *time* as a function of *distance*
  - At a particular instant of time, the intensity of the signal varies as a function of distance from the source

# Frequency-Domain Concepts

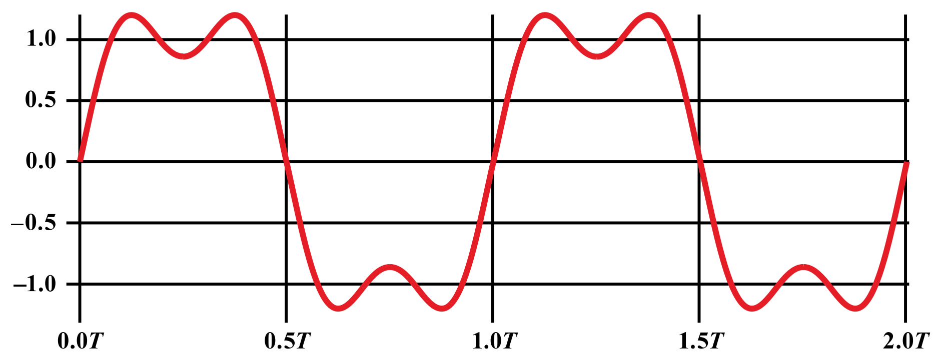
- Fundamental frequency - when all frequency components of a signal are integer multiples of one frequency, it's referred to as the fundamental frequency
- Spectrum - range of frequencies that a signal contains
- Absolute bandwidth - width of the spectrum of a signal
- Effective bandwidth (or just bandwidth) - narrow band of frequencies that most of the signal's energy is contained in $\mathrm{B} = f_{\mathrm{high}} - f_{\mathrm{low}}$




(a) sin ($2\phi ft$)




(b) (1/3) sin ($2\phi(3f)t$)

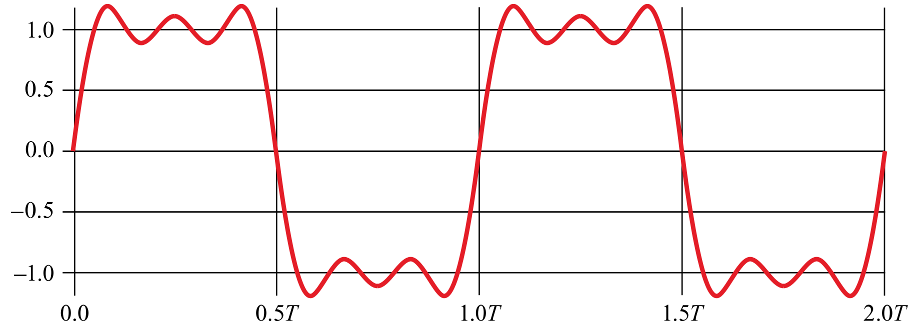



(c) $(4/\phi)$ [sin ($2\phi ft$) + (1/3) sin ($2\phi(3f)t$)]

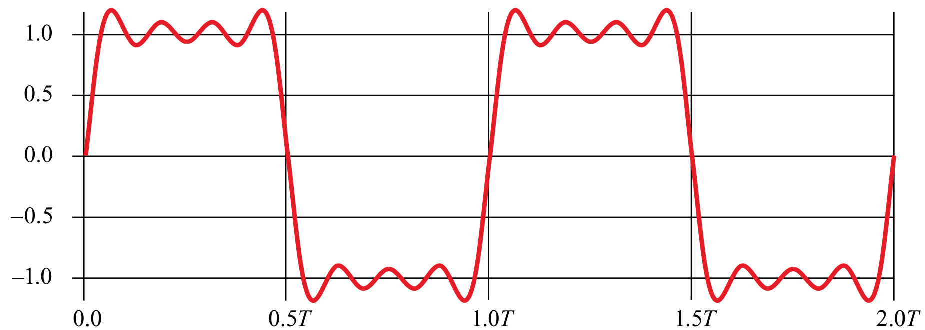
# *Addition of frequency Components(T = 1/f)*

# Frequency-Domain Concepts

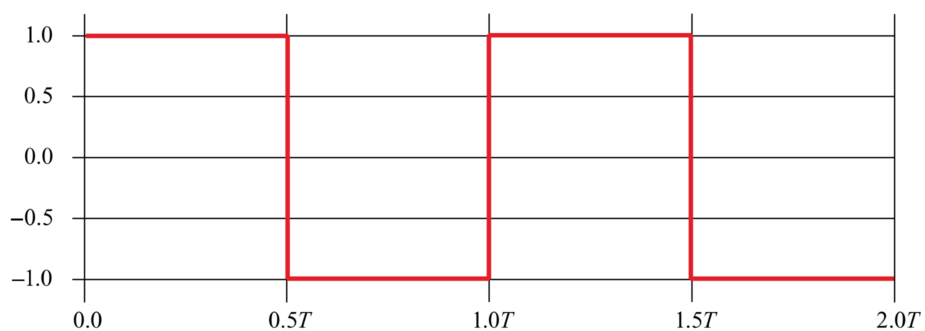
- Any electromagnetic signal can be shown to consist of a collection of periodic analog signals (sine waves) at different amplitudes, frequencies, and phases
- The period of the total signal is equal to the period of the fundamental frequency




**(a) $(4/\phi)\,[\sin(2\phi ft) + (1/3)\sin(2\phi(3f)t) + (1/5)\sin(2\phi(5f)t)]$**




**(b) $(4/\phi)\,[\sin(2\phi ft) + (1/3)\sin(2\phi(3f)t) + (1/5)\sin(2\phi(5f)t) + (1/7)\sin(2\phi(7f)t)]$**

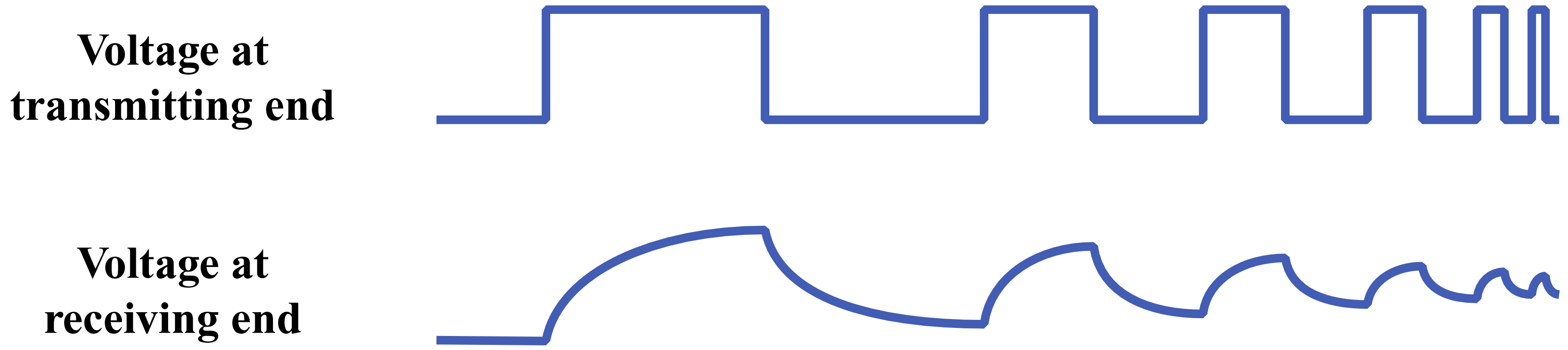



**(c) $(4/\phi)\,\Sigma(1/k)\sin(2\phi(kf)t)$, for $k$ odd**

# *Frequency Components of Square Wave*

# Relationship between Data Rate and Bandwidth

- The greater the bandwidth, the higher the information-carrying capacity
- Conclusions
  - Any digital waveform will have infinite bandwidth
  - BUT the transmission system will limit the bandwidth that can be transmitted
  - AND, for any given medium, the greater the bandwidth transmitted, the greater the cost
  - HOWEVER, limiting the bandwidth creates distortions




*Attenuation of Digital Signals*

# Data Communication Terms

- Data - entities that convey meaning, or information
- Signals - electric or electromagnetic representations of data
- Transmission - communication of data by the propagation and processing of signals

# Examples of Analog and Digital Data

- Analog
  - Video
  - Audio
- Digital
  - Text
  - Integers

# Analog Signals

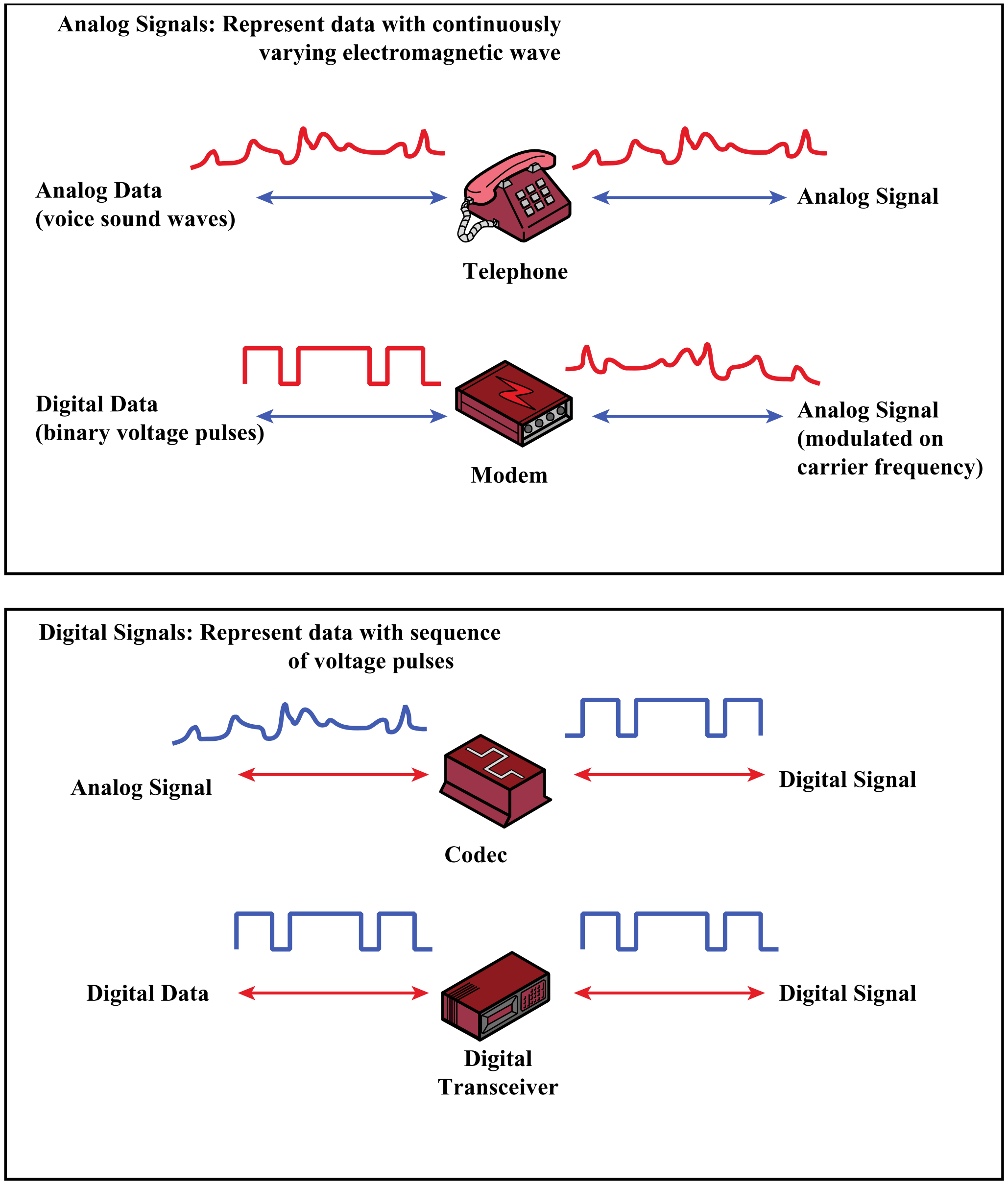
- A continuously varying electromagnetic wave that may be propagated over a variety of media, depending on frequency
- Examples of media:
  - Copper wire media (twisted pair and coaxial cable)
  - Fiber optic cable
  - Atmosphere or space propagation
- Analog signals can propagate analog and digital data

# 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

## 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 and Digital Signaling of Analog and Digital Data***

# Analog Transmission

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

# Digital Transmission

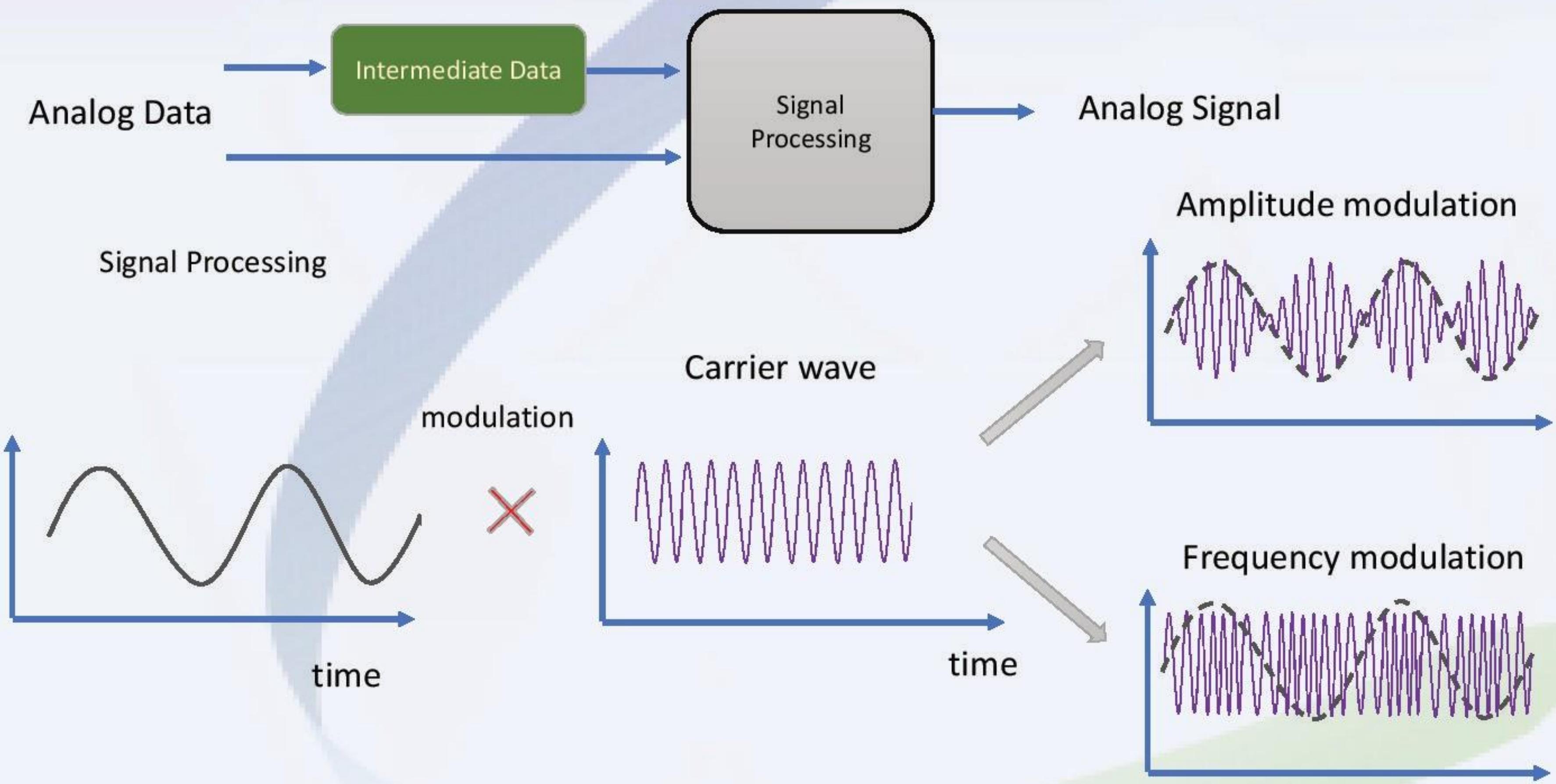
- Concerned with the content of the signal
- Attenuation endangers integrity of data
- Digital Signal
  - Repeaters achieve greater distance
  - Repeaters recover the signal and retransmit
- Analog signal carrying digital data
  - Retransmission device recovers the digital data from analog signal
  -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

# Recall : Analog and Digital Signal

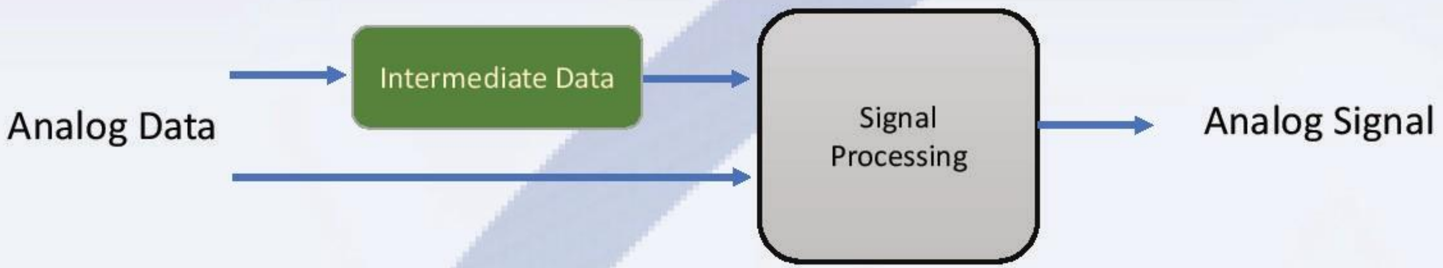
- Electromagnetic wave can only become an analog signals in practice
- Electric voltage or current can be used as analog and digital signals

| | Analog Signal | Digital Signal |
|---|---|---|
| Analog Data | Two alternatives, (1) signal occupies the same spectrum as the analog data (2) analog data are encoded to occupy a different portion of frequency range | Analog data are encoded using a codec to produce a digital bit stream |
| Digital Data | Digital data are encoded using a modem to produce analog signal | Two alternatives, (1) signal consists of two levels values to represent the two binary values (2) Digital data are encoded to produce a digital signal with desired properties |

# Data to Signal : Analog to Analog

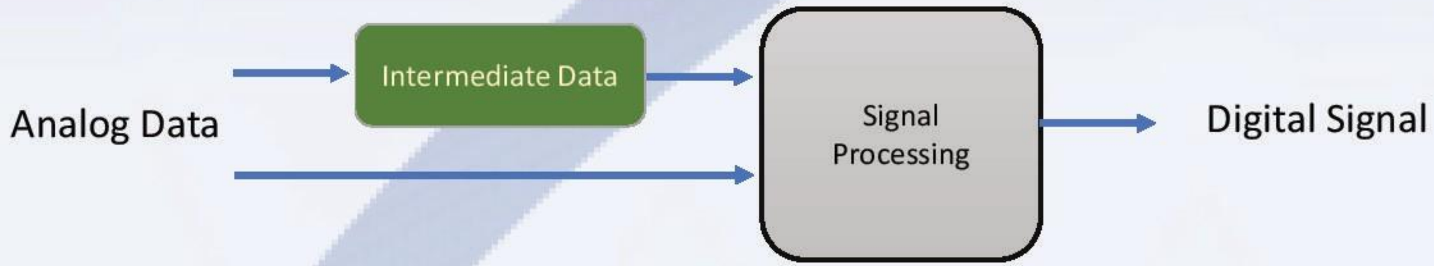


# Data to Signal : Analog to Analog

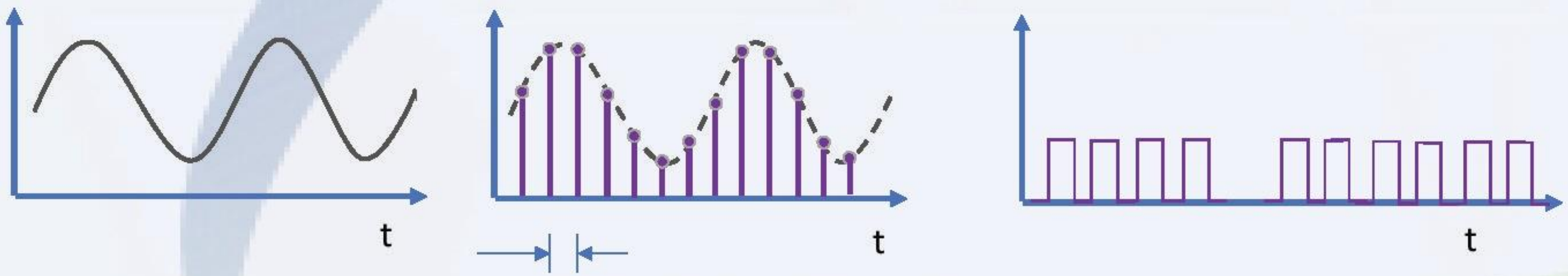



- Why do we need modulation ?
  - To fit channel characteristic
  - To multiplex different context of analog input data that occupies the same bandwidth into different channel
  - In wireless communication case, antenna size is dictated by electromagnetic wave length
    - Lower frequency needs bigger antenna, since wave length also changes.

# Data to Signal : Analog to Digital




Sampled and quantized

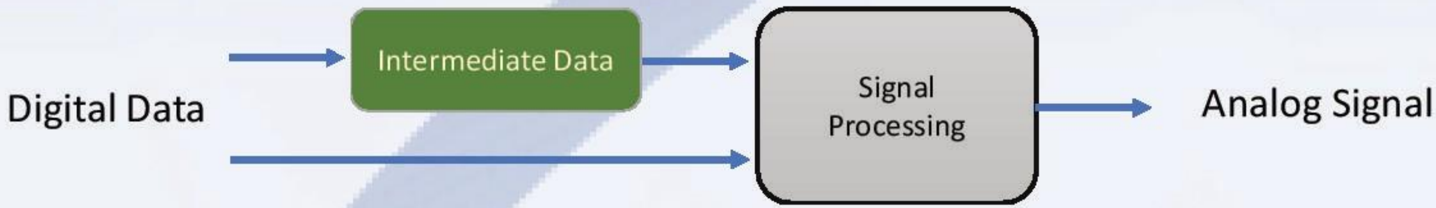


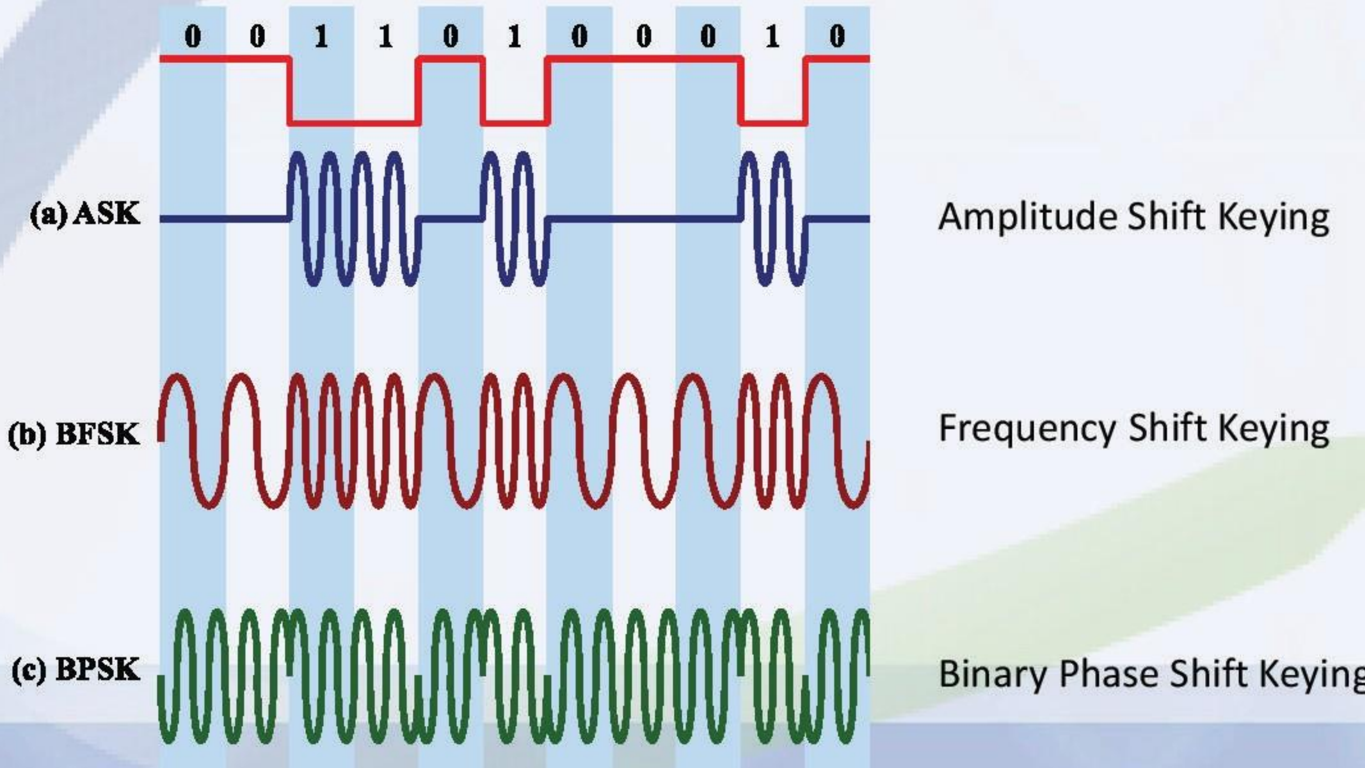

Sampling : $T_S$ : Sampling interval (in second)

$F_S = {}^{1}/_{T_S}$ : Sampling frequency (unit samples/second). Sampling frequency must be at least twice as the highest frequency component in the signal

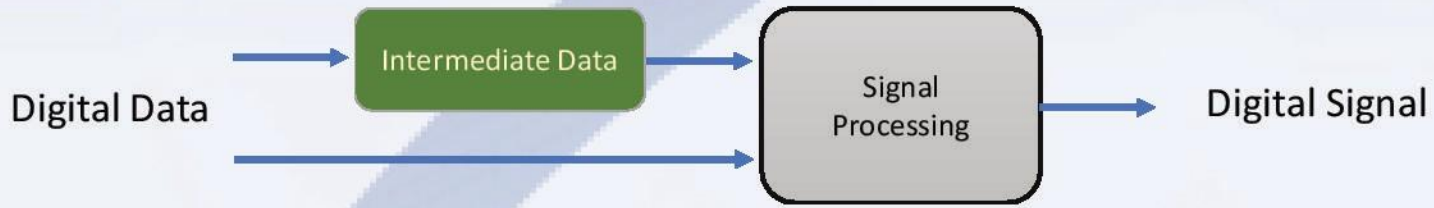
Quantizer : Each sampled signal would be represented by a stream of bits

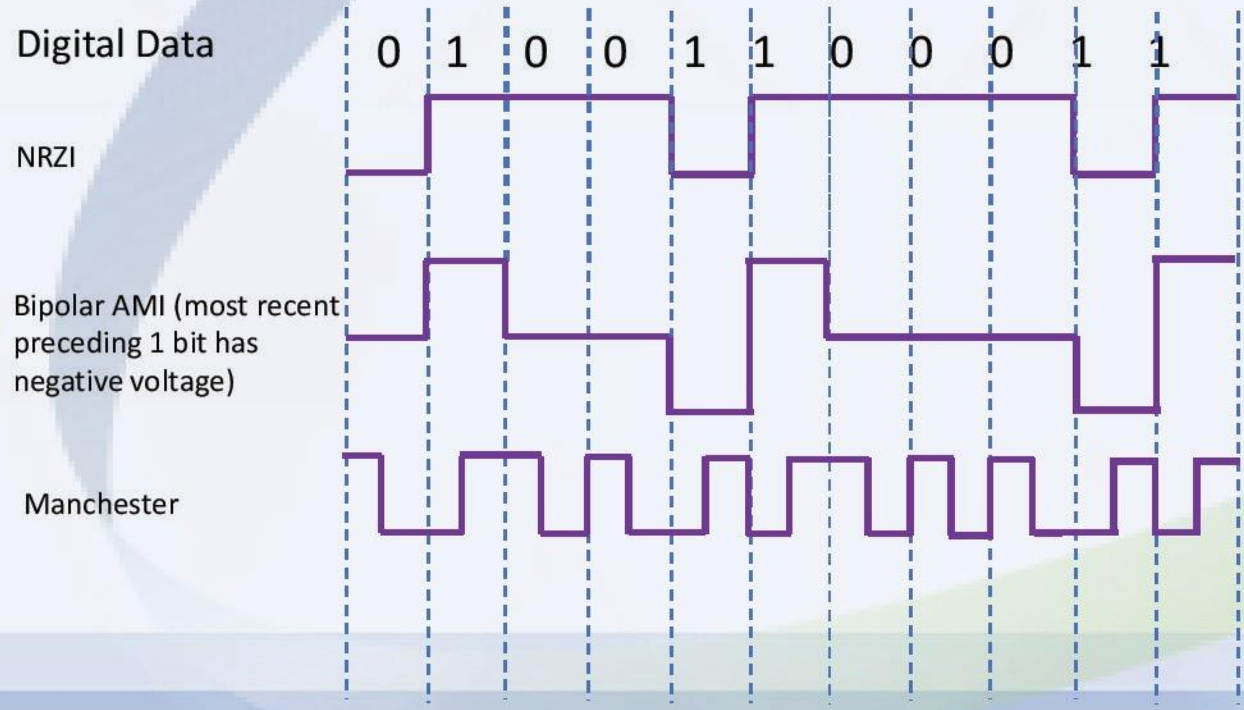
# Data to Signal : Digital to Analaog



# Data to Signal : Digital to Digital



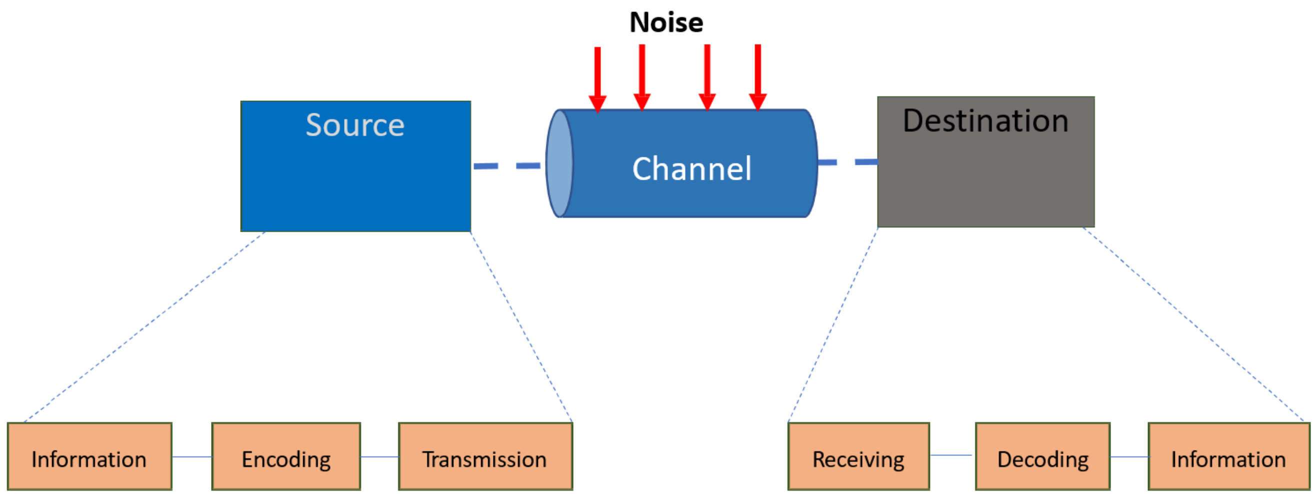
# Signal Transmission

- Analog Transmission
  - Transmit analog signals without regard to content
  - Attenuation limits length of transmission link
  - Cascaded amplifiers boost signal's energy for longer distances but cause distortion
    - Analog data can tolerate distortion
    - Introduces errors in digital data
- Digital Transmission
  - It doesn't always mean transmitting a digital signal
  - Concerned with the content of the signal
    - 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
      - Generates new, clean analog signal

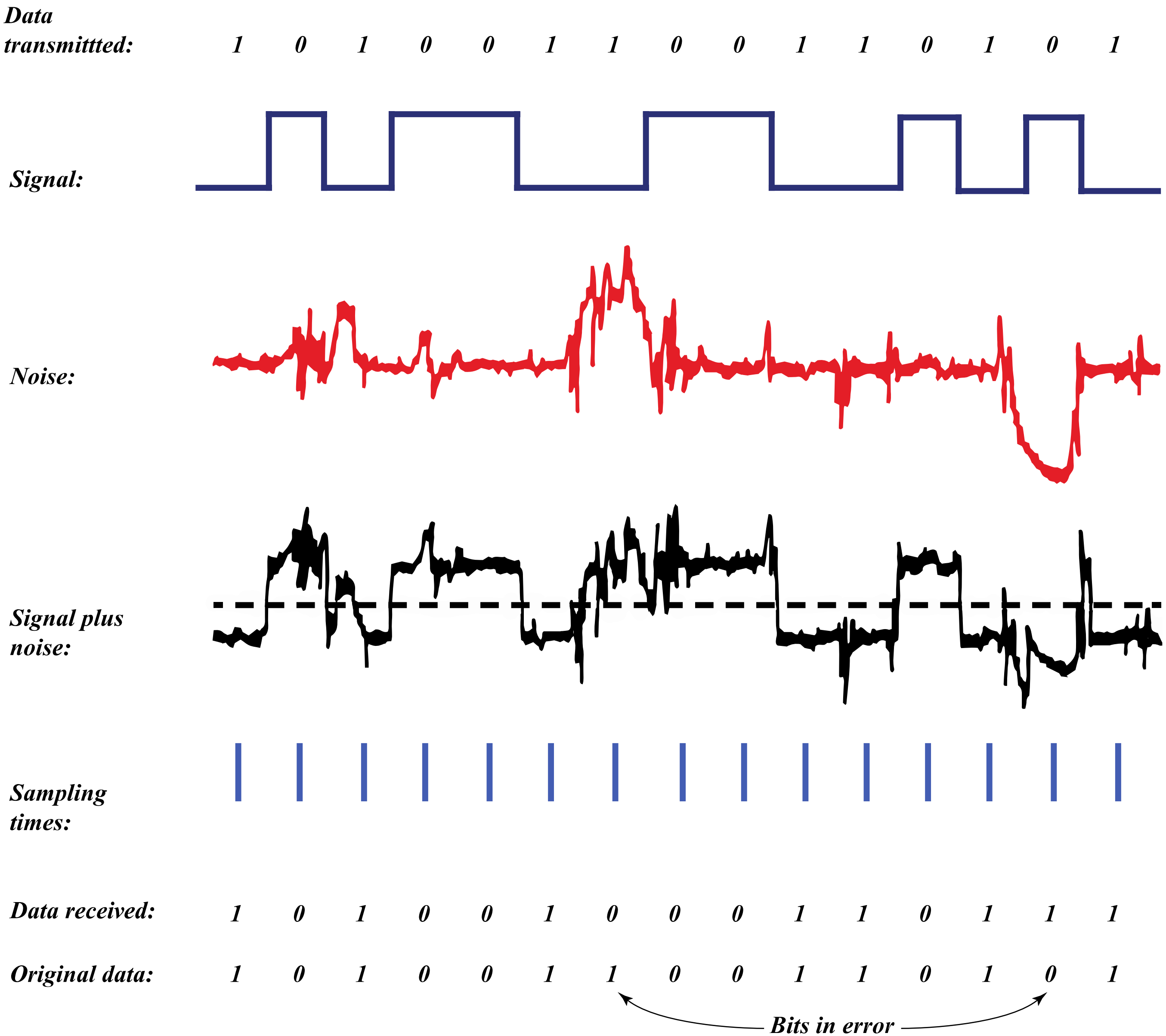
# Signal Transmission

| | Analog Transmission | Digital Transmission |
|---|---|---|
| Analog Signal | Propagated through amplifiers; same treatment whether signal is used to represent analog data or digital data | Assumes that the analog signal represents digital data. Signal is propagated through repeaters; at each repeater, digital data are recovered from inbound signal and used to generate a new analog outbound signal |
| Digital Signal | Not used | Digital signal represents a stream of 1s and 0s, which may represent digital data or may be an encoding of analog data. Signal is propagated through repeaters; at each repeater, stream of 12 and 0s is recovered from inbound signal and used to generate a new digital outbound 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




# Effect of Noise on Digital Signal

# 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: $$C = B\log_2\left(1+\mathrm{SNR}\right)$$
- 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 ; $\text{SNR}_{\text{dB}}$ = 24 dB

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

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

$$\text{SNR} = 251$$

- 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?

$$C = 2B\log_2 M$$

$$8\times10^6 = 2\times\left(10^6\right)\times\log_2 M$$

$$4 = \log_2 M$$

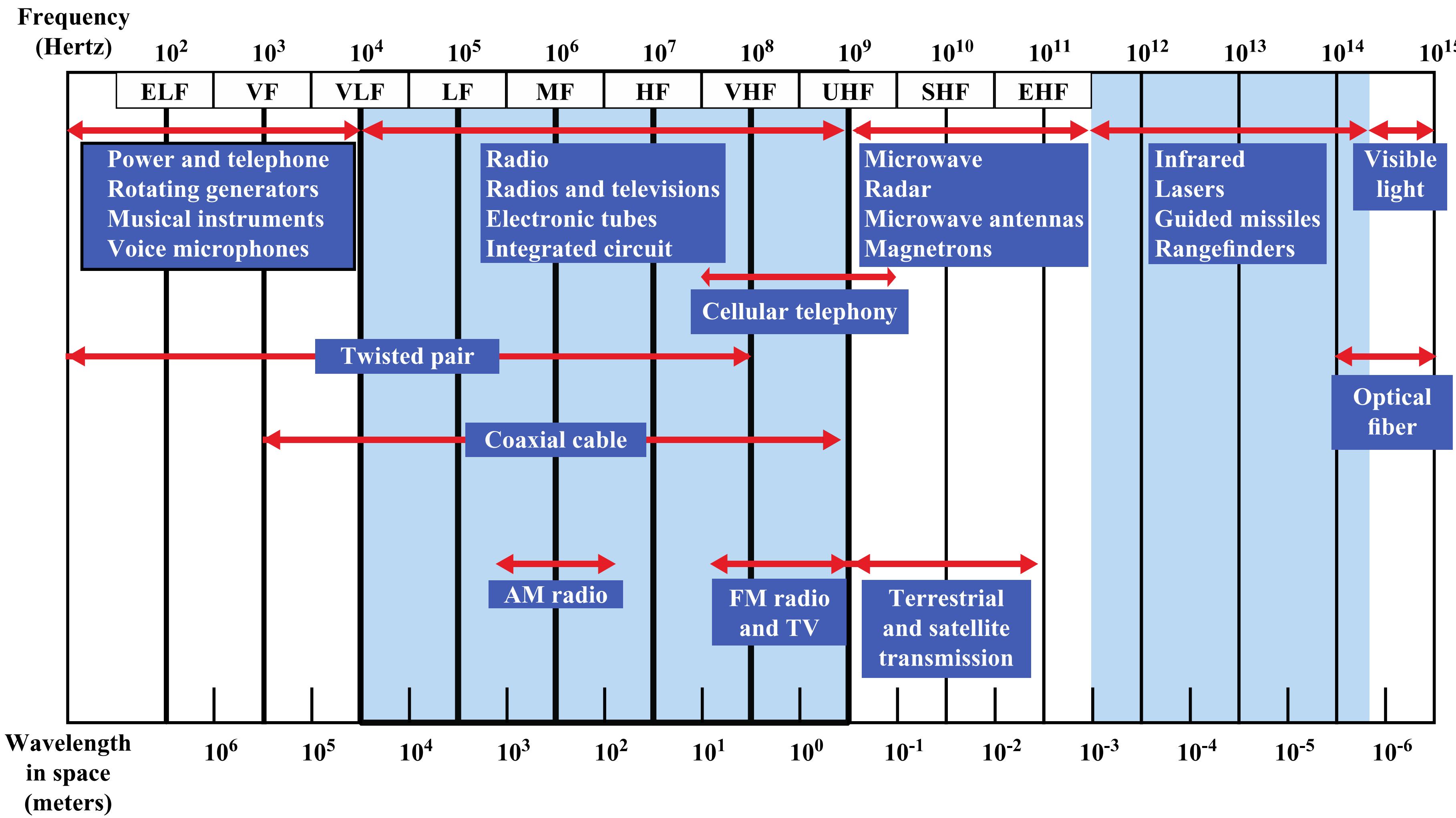
$$M = 16$$

# 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




ELF = Extremely low frequency
VF = Voice frequency
VLF = Very low frequency
LF = Low frequency
MF = Medium frequency
HF = High frequency
VHF = Very high frequency
UHF = Ultrahigh frequency
SHF = Superhigh frequency
EHF = Extremely high frequency

***Electromagnetic spectrum of Telecommunications***

# 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, $3 \times 10^{11}$ to $2 \times 10^{14}$ 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

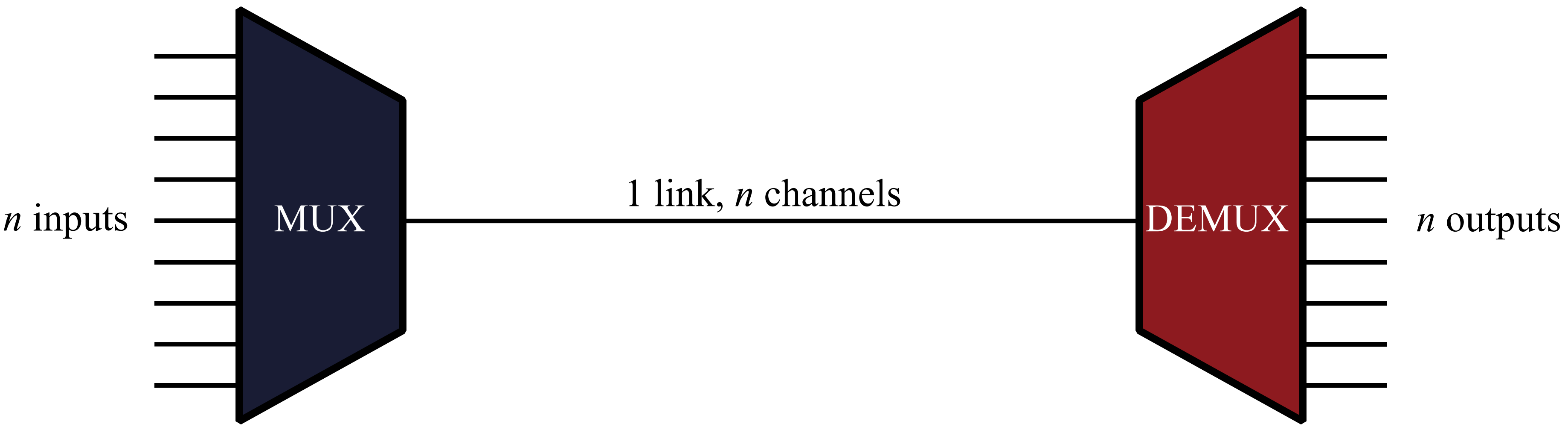
- Description of communication satellite
  - Microwave relay station
  - Used to link two or more ground-based microwave transmitter/receivers
  - Receives transmissions on one frequency band (uplink), amplifies or repeats the signal, and transmits it on another frequency (downlink)
- Applications
 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

# Broadcast Radio

- Description of broadcast radio antennas
  - Omnidirectional
  - Antennas not required to be dish-shaped
  - Antennas need not be rigidly mounted to a precise alignment
- Applications
  - Broadcast radio
    - VHF and part of the UHF band; 30 MHZ to 1GHz
    - Covers FM radio and UHF and VHF television

# 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



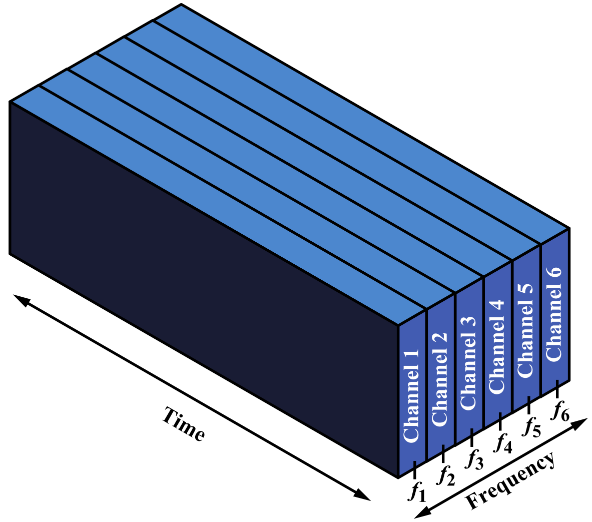

***Multiplexing***

# Reasons for Widespread Use of Multiplexing

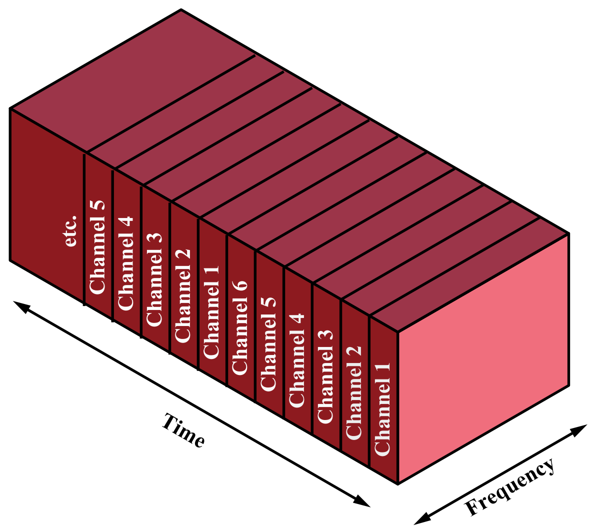
- Cost per kbps of transmission facility declines with an increase in the data rate
- Cost of transmission and receiving equipment declines with increased data rate
- Most individual data communicating devices require relatively modest data rate support

# 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




**(a) Frequency division multiplexing**




**(b) Time division multiplexing**

# FDM and TDM