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# Transmission Fundamentals

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## Chapter 2



# Electromagnetic Signal

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- 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



# Time-Domain Concepts

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- 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



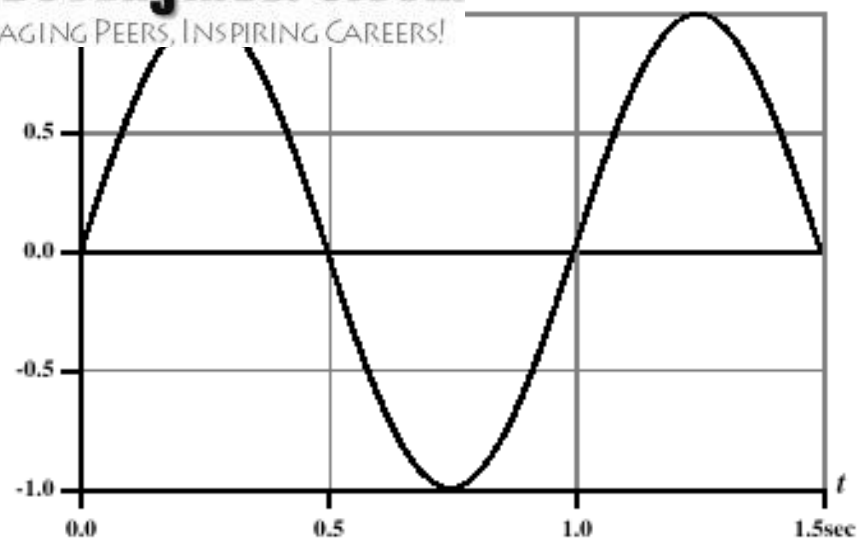
# Time-Domain Concepts

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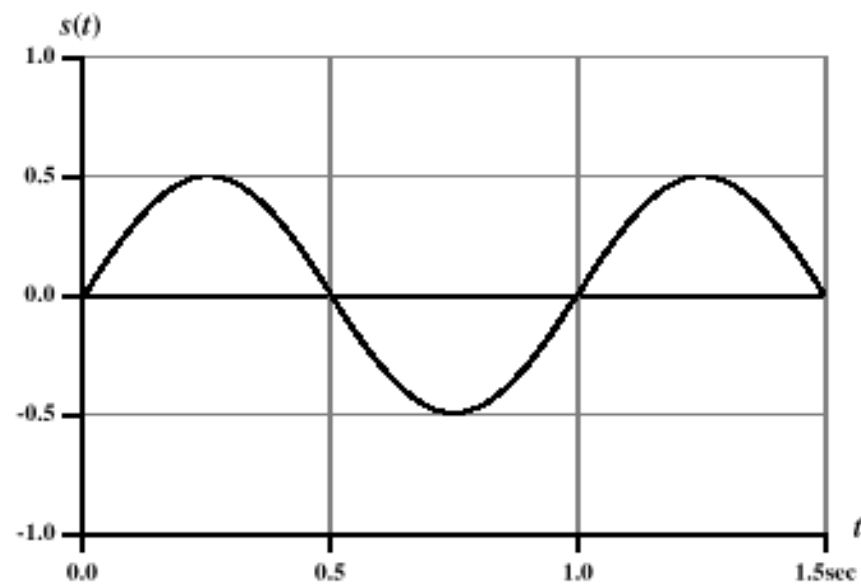
- Period ( $T$ ) - amount of time it takes for one repetition of the signal
  - $T = 1/f$
- Phase ( $\phi$ ) - measure of the relative position in time within a single period of a signal
- Wavelength ( $\lambda$ ) - distance occupied by a single cycle of the signal
  - Or, the distance between two points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

# Sine Wave Parameters

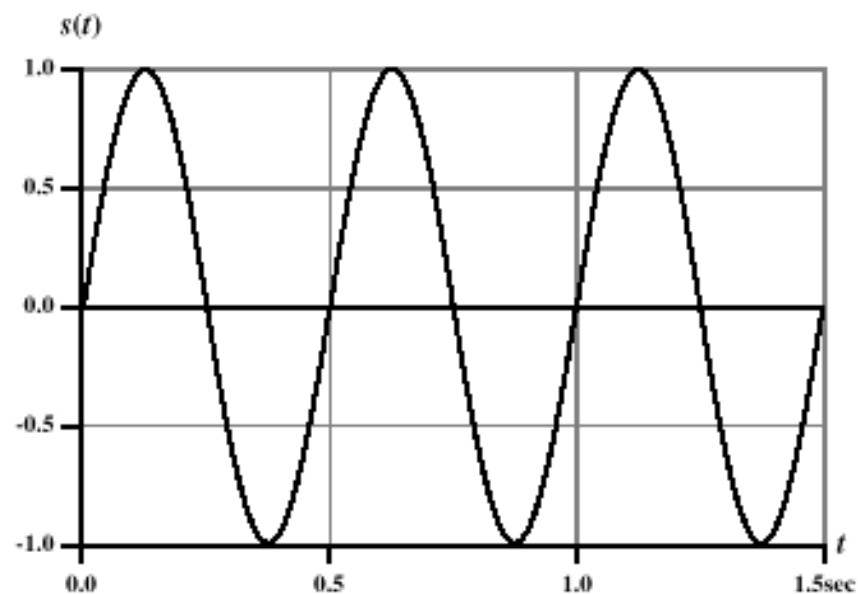
- General sine wave
  - $s(t) = A \sin(2\pi ft + \phi)$
- Figure 2.3 shows the effect of varying each of the three parameters
  - (a)  $A = 1, f = 1 \text{ Hz}, \phi = 0$ ; thus  $T = 1 \text{ s}$
  - (b) Reduced peak amplitude;  $A = 0.5$
  - (c) Increased frequency;  $f = 2$ , thus  $T = 1/2$
  - (d) Phase shift;  $\phi = \pi/4$  radians (45 degrees)
- note:  $2\pi \text{ radians} = 360^\circ = 1 \text{ period}$



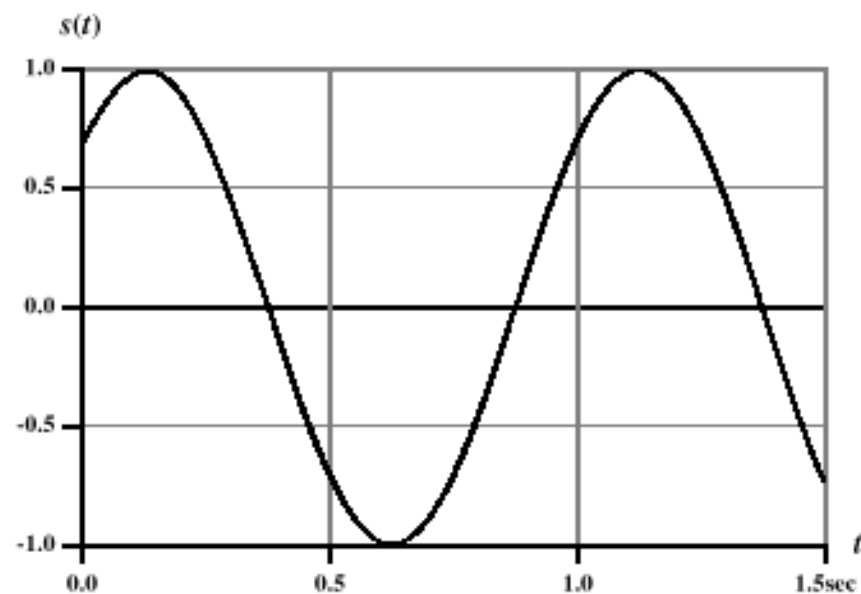
(a)  $A = 1, f = 1, \phi = 0$



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



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



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

**Figure 2.3**  $s(t) = A \sin (2 ft + \phi)$





# Time vs. Distance

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- 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

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- 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



# Frequency-Domain Concepts

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- 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

# Relationship between Data Rate and Bandwidth

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- 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



# Data Communication Terms

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- 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

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- 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



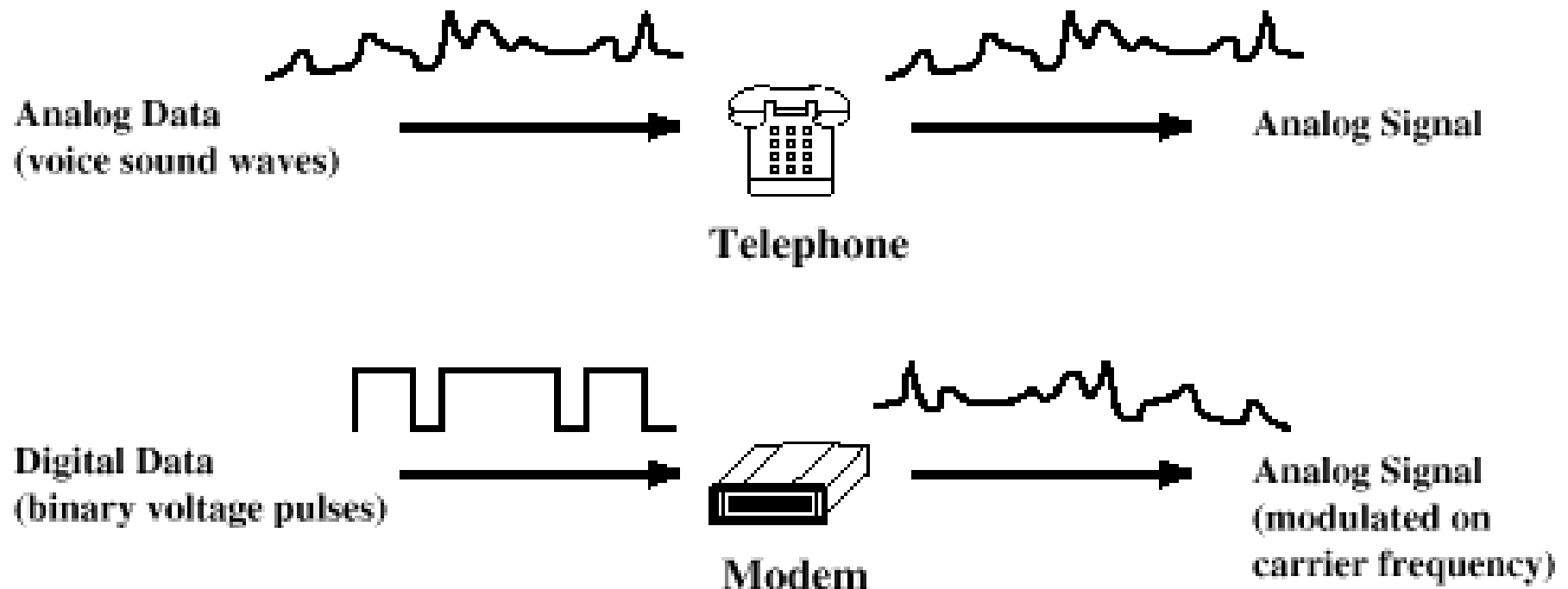
# Digital Signals

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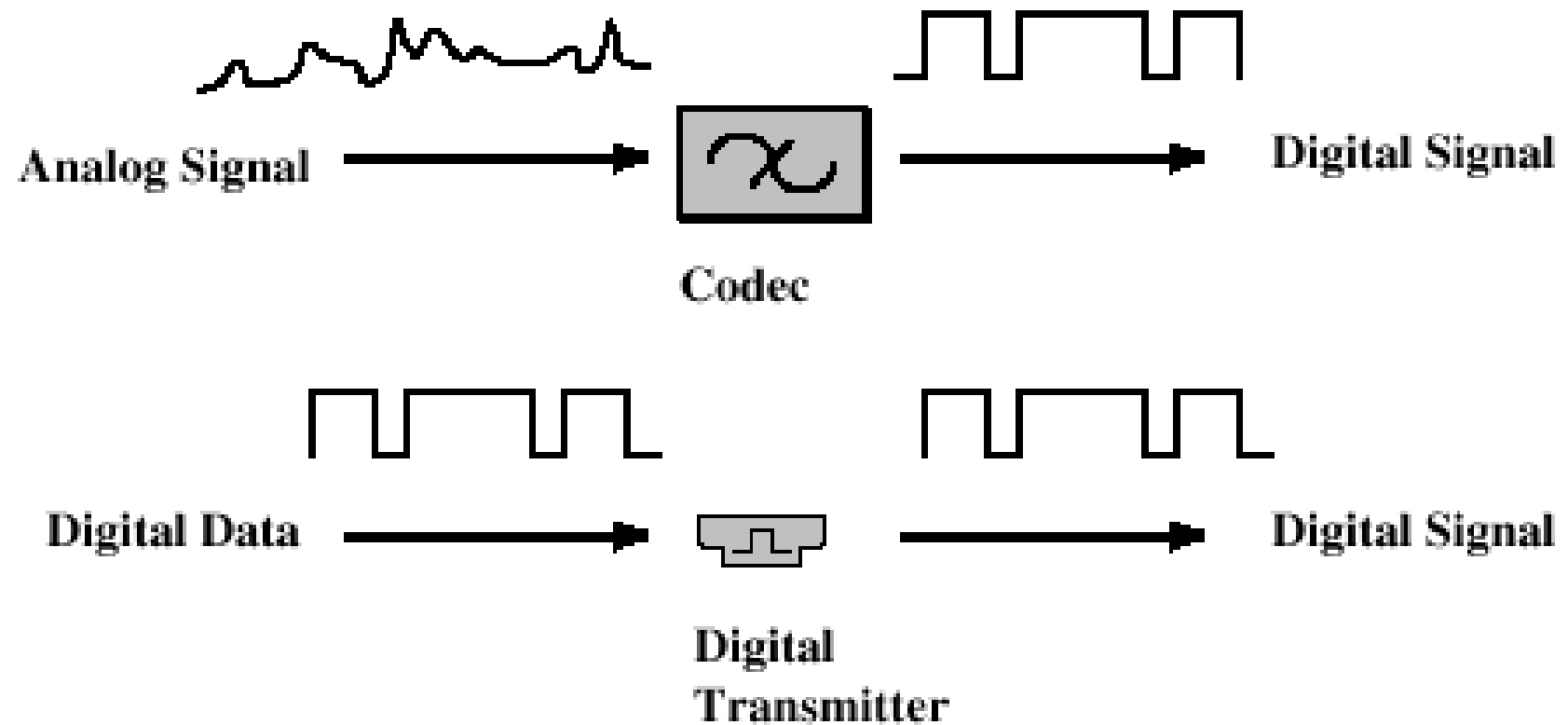
- A sequence of voltage pulses that may be transmitted over a copper wire medium
- Generally cheaper than analog signaling
- Less susceptible to noise interference
- Suffer more from attenuation
- Digital signals can propagate analog and digital data



## Analog Signals: Represent data with continuously varying electromagnetic wave



**Digital Signals: Represent data with sequence of voltage pulses**



# ns 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

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- 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

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- 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



# About Channel Capacity

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- 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

# Factors 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

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- 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

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- 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)

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

- 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

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- Equation:

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

- 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 ;  $\text{SNR}_{\text{dB}} = 24 \text{ dB}$

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

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

$$\text{SNR} = 251$$

- 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?

$$C = 2B \log_2 M$$

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

$$4 = \log_2 M$$

$$M = 16$$



## Media

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- 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

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



# General Frequency Ranges

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- 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

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- 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

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- 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

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- 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

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- 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



# ns for Widespread Use of Multiplexing

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- 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

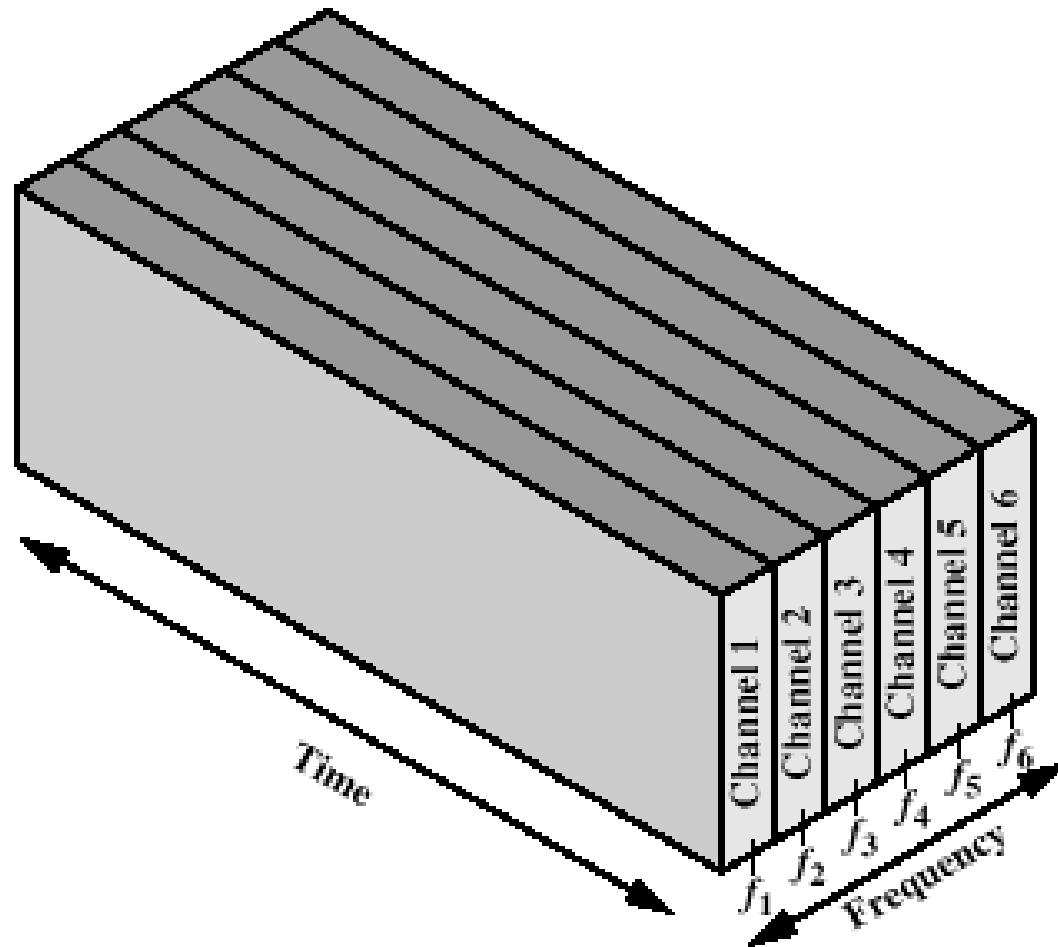


# Multiplexing Techniques

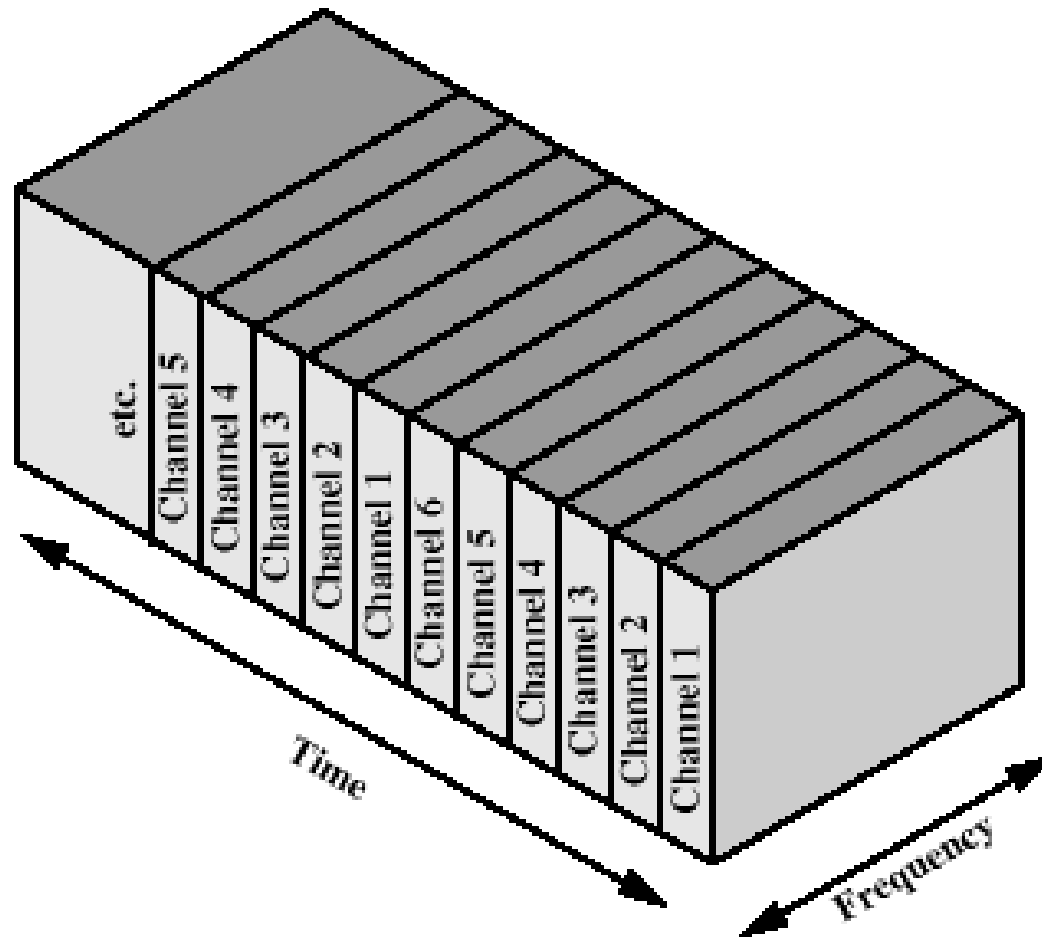
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- Frequency-division multiplexing (FDM)
  - Takes advantage of the fact that the useful bandwidth of the medium exceeds the required bandwidth of a given signal
- Time-division multiplexing (TDM)
  - Takes advantage of the fact that the achievable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

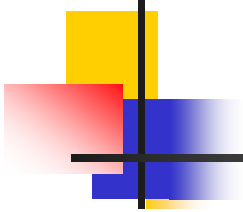
# Frequency-division Multiplexing



# Time-division Multiplexing







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