

Wireless Communication

Lecture 1

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

Time-Domain Concepts

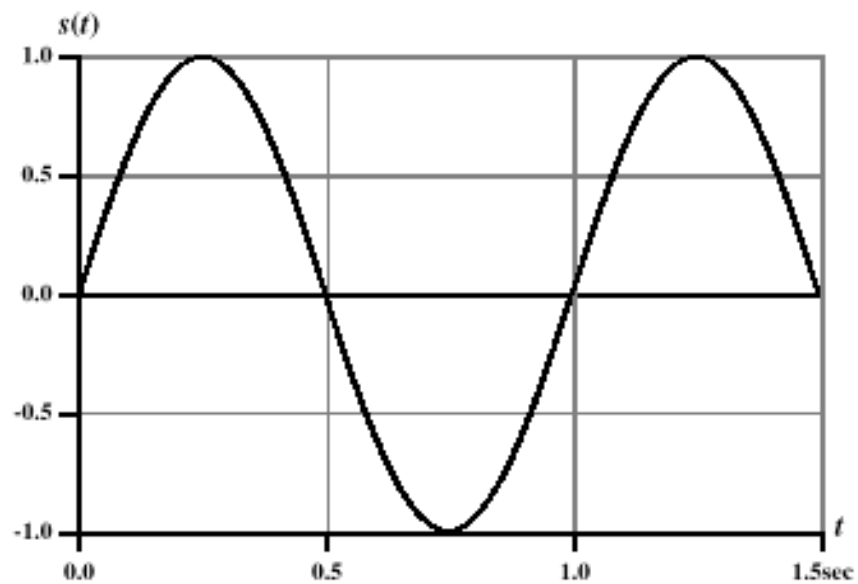
- Aperiodic signal - analog or digital signal pattern that doesn't repeat over time
- Peak amplitude (A) - maximum value or strength of the signal over time; typically measured in volts
- Frequency (f)
 - Rate, in cycles per second, or Hertz (Hz) at which the signal repeats

Time-Domain Concepts

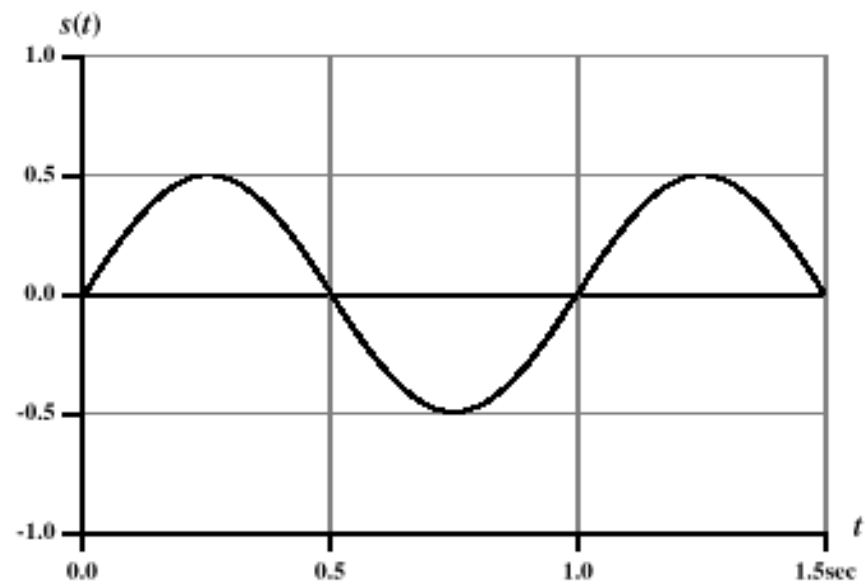
- Period (T) - amount of time it takes for one repetition of the signal
 - $T = 1/f$
- Phase (ϕ) - measure of the relative position in time within a single period of a signal
- Wavelength (λ) - distance occupied by a single cycle of the signal
 - Or, the distance between two points of corresponding phase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

Sine Wave Parameters

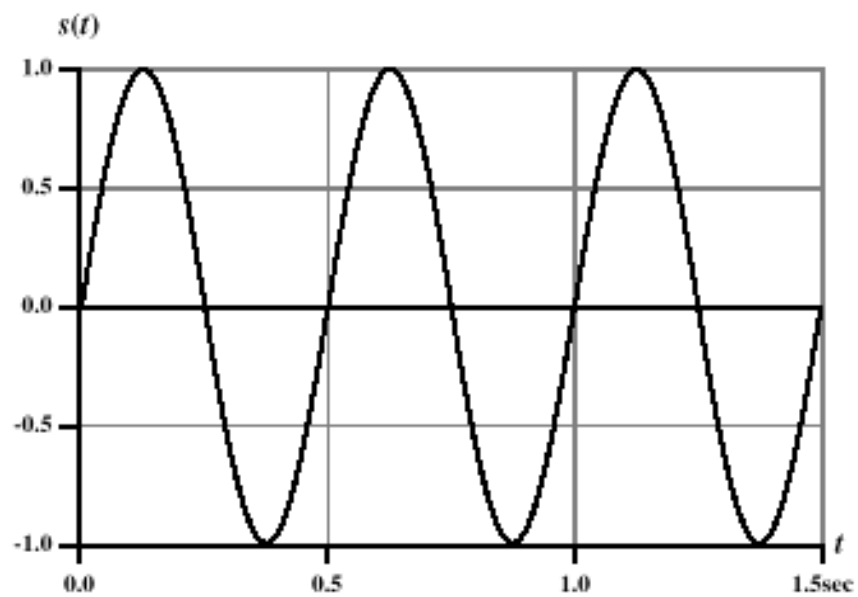
- General sine wave
 - $s(t) = A \sin(2\pi ft + \phi)$
- Figure 2.3 shows the effect of varying each of the three parameters
 - (a) $A = 1, f = 1 \text{ Hz}, \phi = 0$; thus $T = 1\text{s}$
 - (b) Reduced peak amplitude; $A=0.5$
 - (c) Increased frequency; $f = 2$, thus $T = 1/2$
 - (d) Phase shift;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



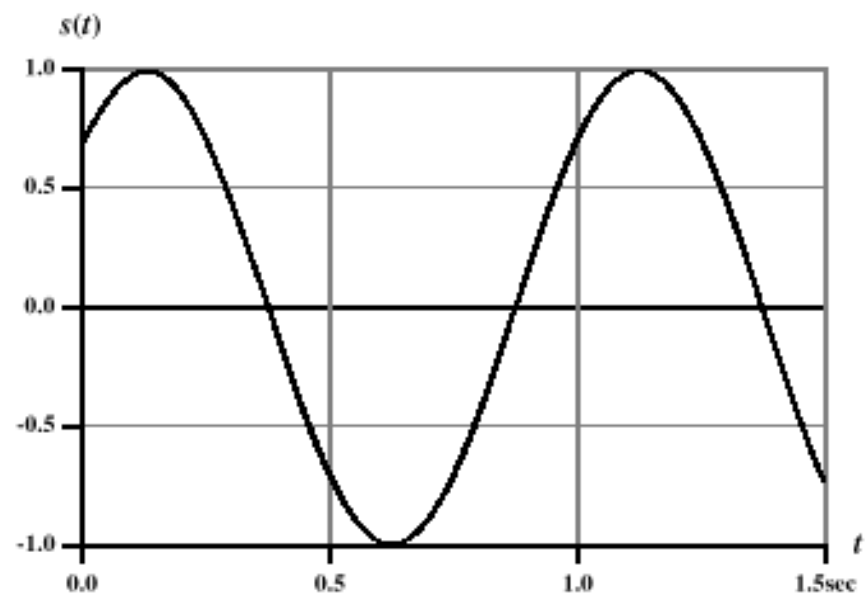
(a) $A = 1, f = 1, \phi = 0$



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



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



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

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

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

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

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

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

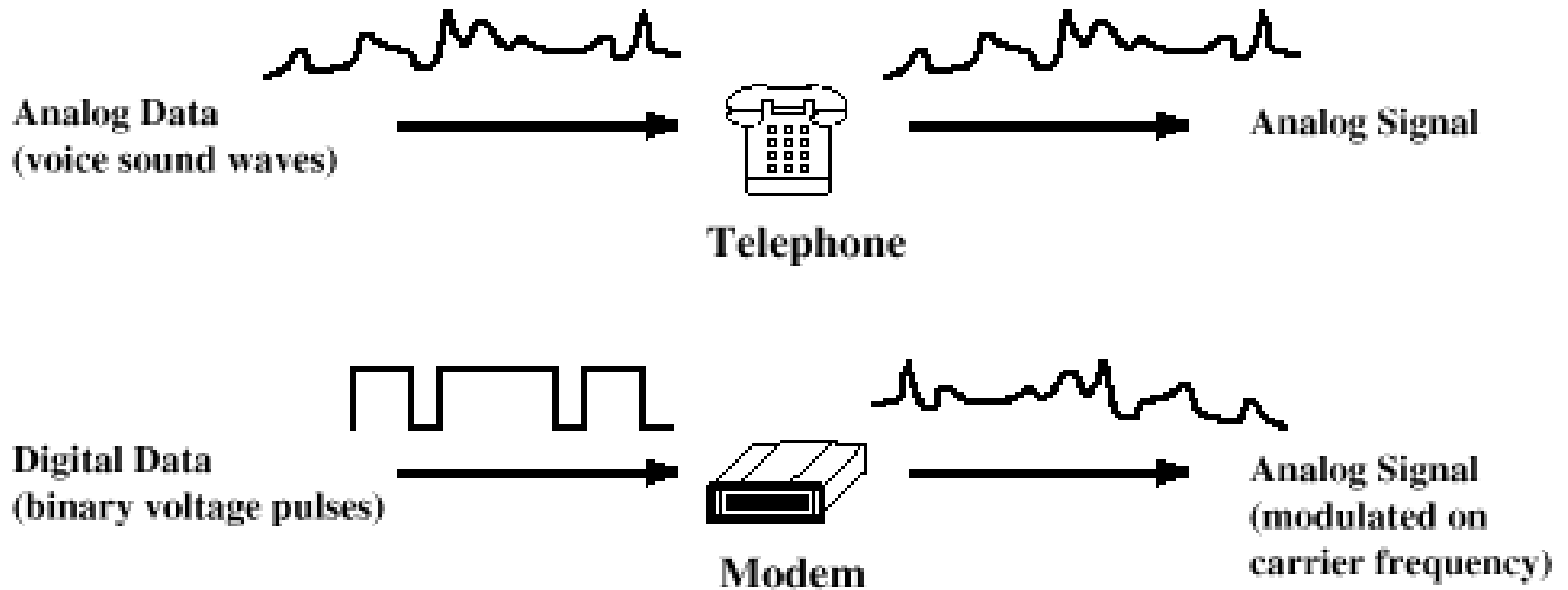
Analog Signals

- 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

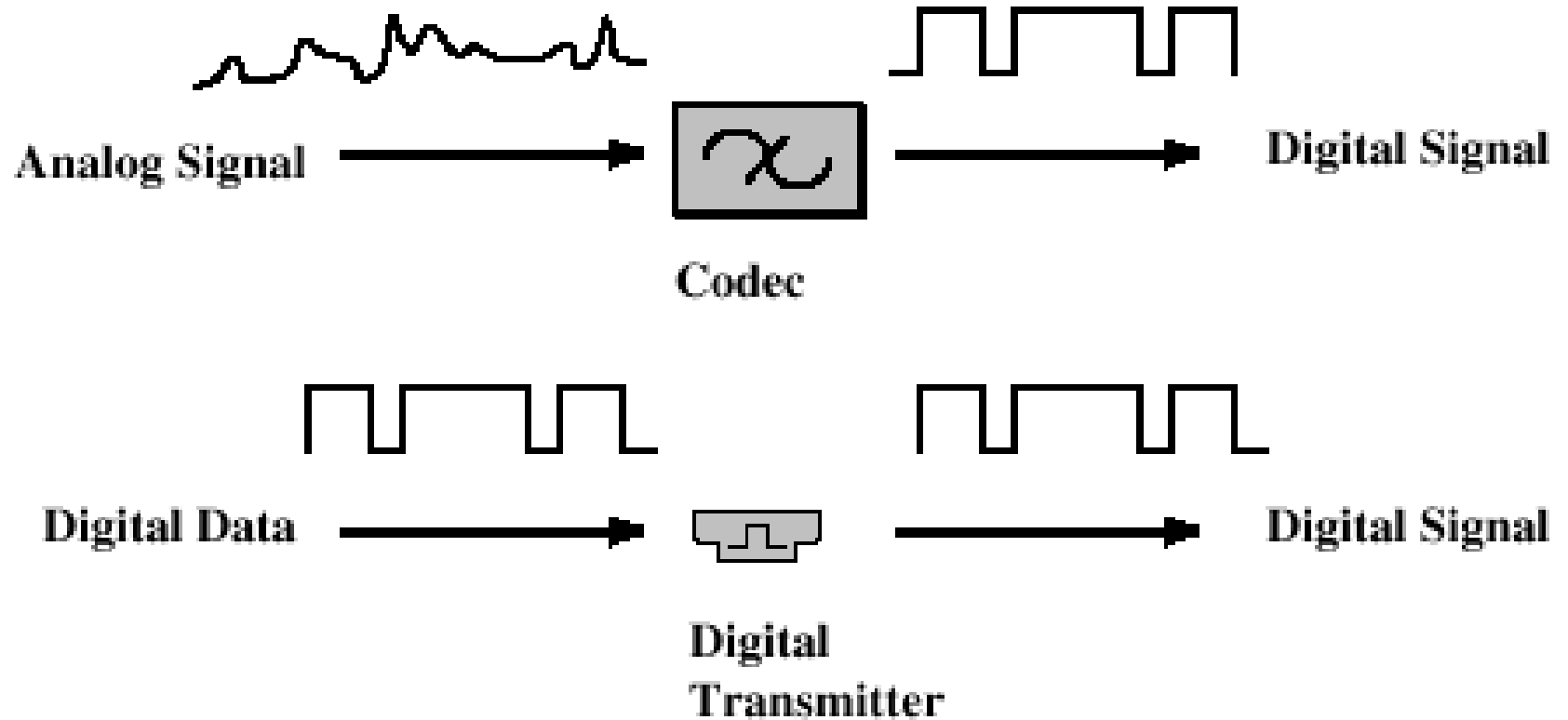
Digital Signals

- 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

Analog Signals: Represent data with continuously varying electromagnetic wave



Digital Signals: Represent data with sequence of voltage pulses



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
- 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

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)

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

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

$$C = 2B \log_2 M$$

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

$$4 = \log_2 M$$

$$M = 16$$

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

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



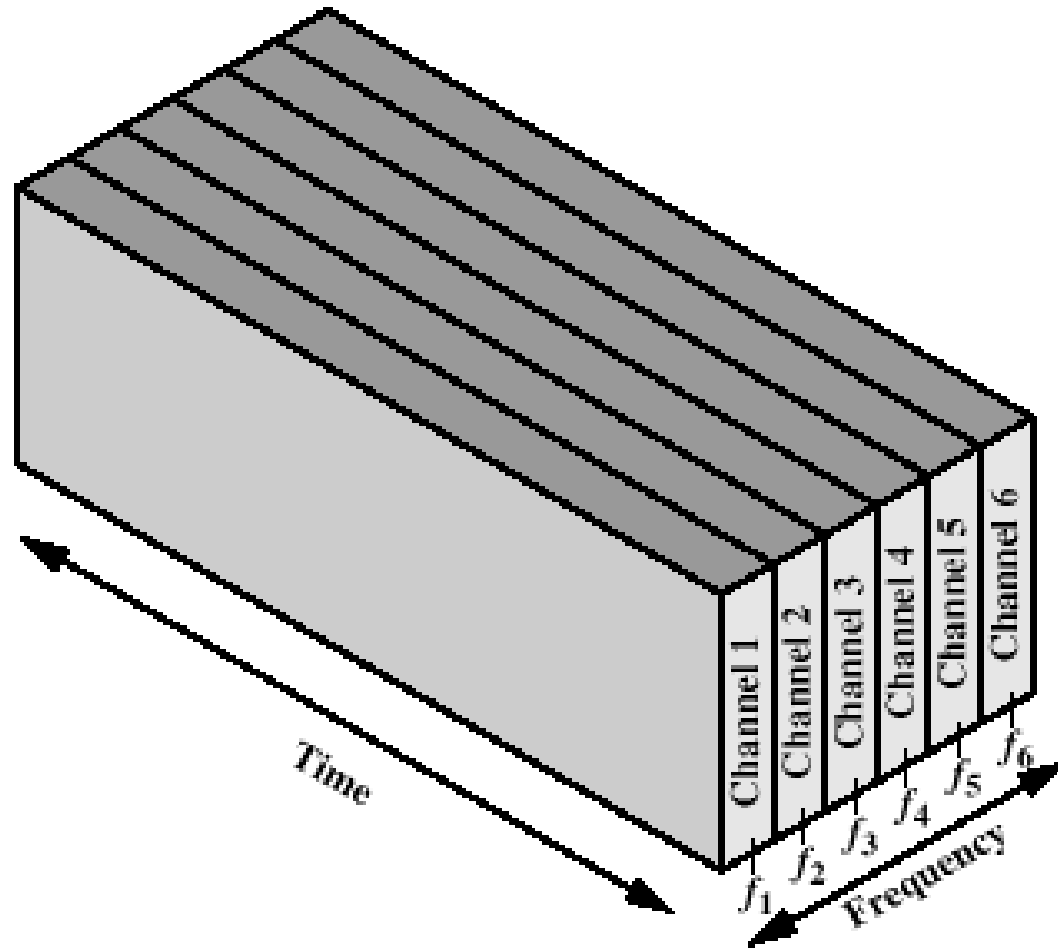
Reasons for Widespread Use of Multiplexing

- 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

Frequency-division Multiplexing



Time-division Multiplexing

