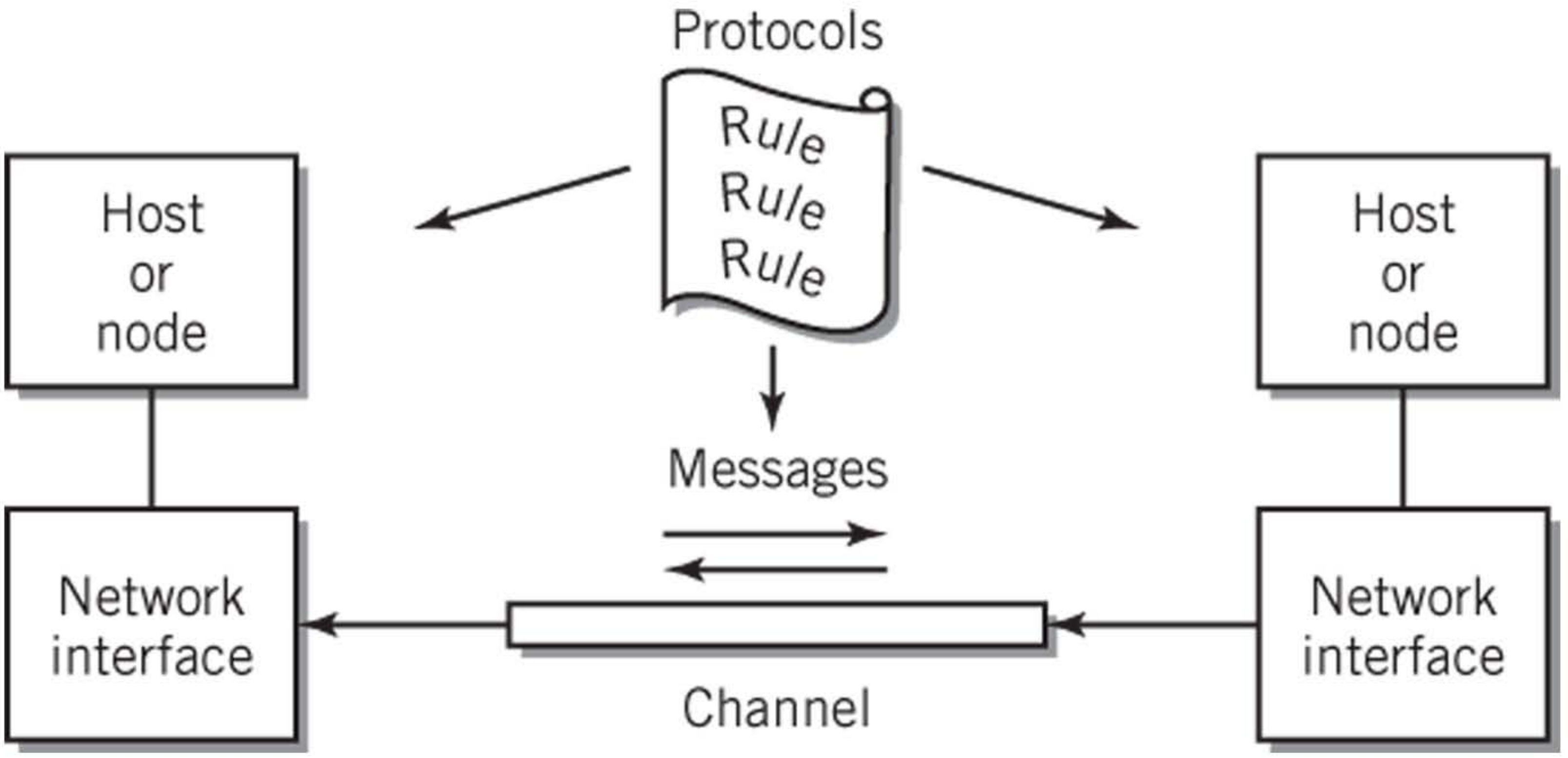
CHAPTER 14: Communication Channel Technology

The Architecture of Computer Hardware, Systems Software & Networking:
An Information Technology Approach

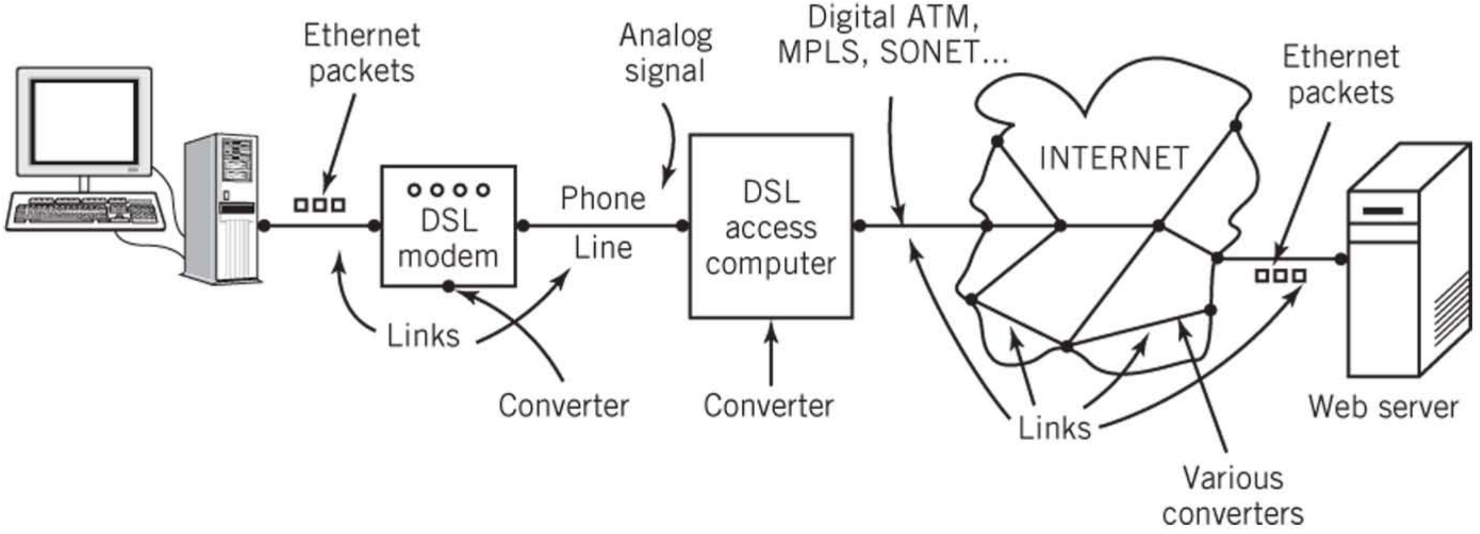
4th Edition, Irv Englander

Communication Channel



Communication Channels: Many Ways to Implement

- Signal: specific data transmitted
- Diagram shows a multi-link channel connecting a client (home computer) with a web server
  - Physically: signal passes through different channel forms including audio, digital, light, radio
  - Converters between separate channel links



Communication Channel

- Characterized by
  - Signaling transmission method
  - Bandwidth: amount of data transmitted in a fixed amount of time
  - Direction(s) in which signal can flow
  - Noise, attenuation, and distortion characteristics
  - Time delay and time jitter
  - Medium used

Channel Organization

- Point to point channels
  - Simplex: channel passes data in one direction only (TV and radio broadcast)
  - Half-duplex: transmits data one direction at a time (walkie-talkie)
  - Full-duplex: transmits data in both directions simultaneously (telephone)
- Multipoint: broadcasts messages to all connected receivers

Multiplexing

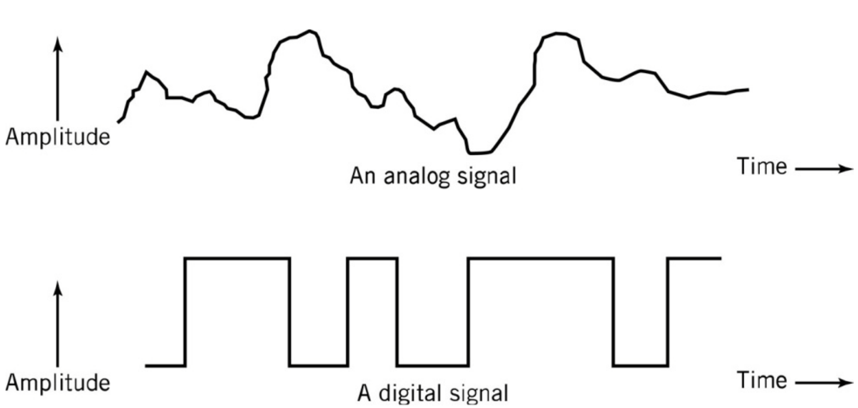
- Carrying multiple messages over a channel simultaneously
  - TDM (time division multiplexing)
    - Example: packet switching on the Internet
    - Use: digital channels
  - FDM (frequency division multiplexing)
    - Example: Cable TV
    - Analog channels
- Synchronized switches or filters separate different data signals at receiving end

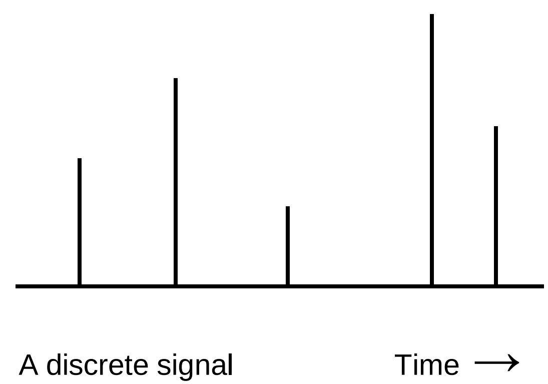
Signaling Transmission Method

Signals are the means used to communicate data

Choice depends on medium and signal characteristics

- Analog
  - Signal takes on a continuous range of values
- Discrete
  - Signal takes on only finite, countable set of values
- Digital
  - Binary discrete signal
  - Frequently preferred because less susceptible to noise and interference





Waveform – a representation of a signal shown as a function of time

Signaling Technology

- Signal carriers
  - Electrical voltage
  - Electromagnetic radio wave
  - Switched light
- Data represented by changes in the signal as a function of time

Transformation between Digital and Analog

- Ideally conversion should be reversible
- Limitations
  - Noise: interference from sources like radio waves, electrical wires, and bad connections that alter the data
  - Attenuation: normal reduction in signal strength during transmission caused by the transmission medium
  - Distortion: alteration in the data signal caused by the communication channel
- Compensation – error correction techniques
- Digital → Analog → Digital
  - Ability to perfectly represent digital data in analog form
  - Possible to recover the original digital data exactly
- Analog → Digital → Analog
  - Small information loss results from converting analog to digital

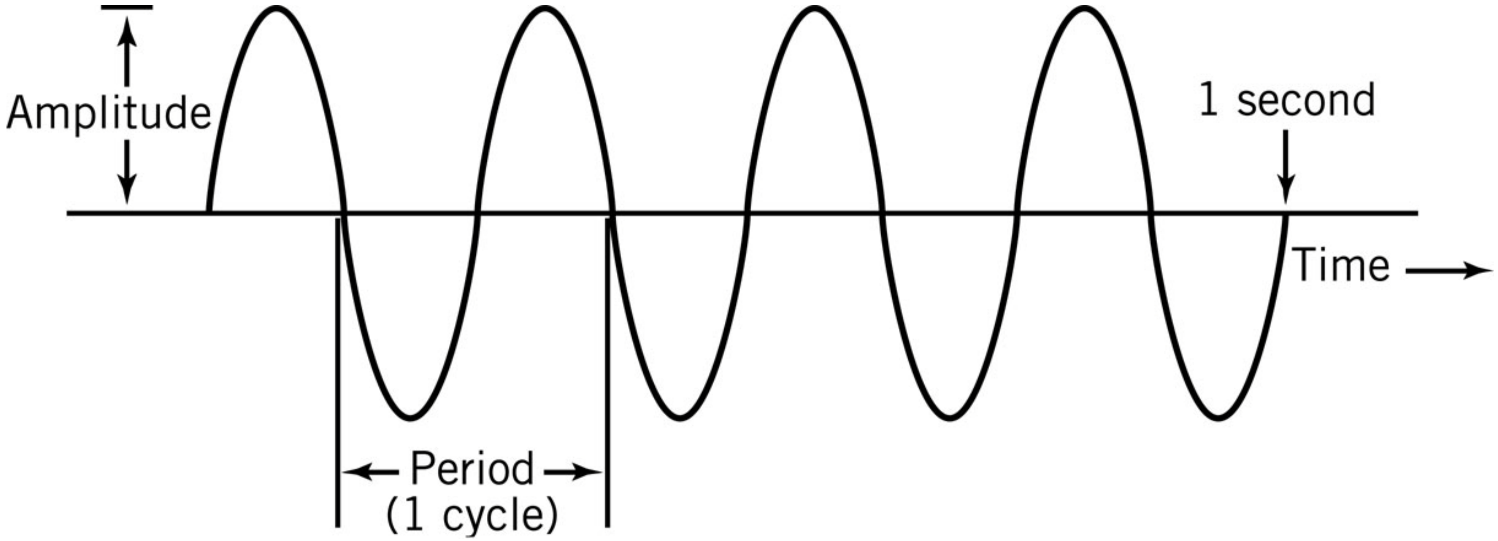
Analog Signals

- Wireless networking
- Most telephones
- Satellites
- Microwave communications
- Radio and sound
  - Radio waves can be converted to electrical signals for use with wire media for mixed digital and analog data
    - Example: Cable TV with digital Internet feed

Sine Waves

- Occur naturally throughout nature
  - Sound, radio waves, light
- Basic unit of analog transmission
- Properties
  - Amplitude: wave height or power
  - Period: amount of time to trace one complete cycle of the wave
  - Wavelength : distance spanned by a sine wave in space
  - Frequency: cycles per second, i.e., number of times sine wave repeated per second
    - 1 Hertz = 1 cycle/sec
    - Unit of bandwidth for analog device
  - Phase
    - The difference in position of a sine wave with respect to a reference sine wave

Sine Wave



f = 1/T   *f* is the frequency of the sine wave, where T is the period measured in seconds

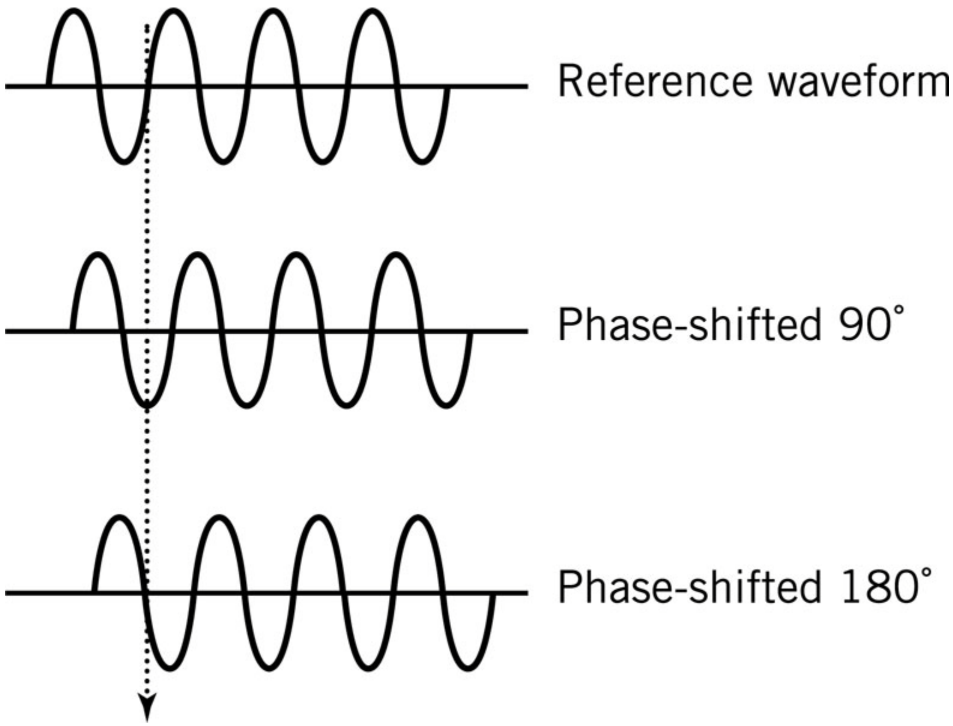
If *f*=4Hz then T=1/*f*=1/4=0.25s

T is a reciprocal of *f*

λ = c/*f*   λ is the wavelength of the sine wave and c is the speed of light

Phase-Shifted Sine Waves

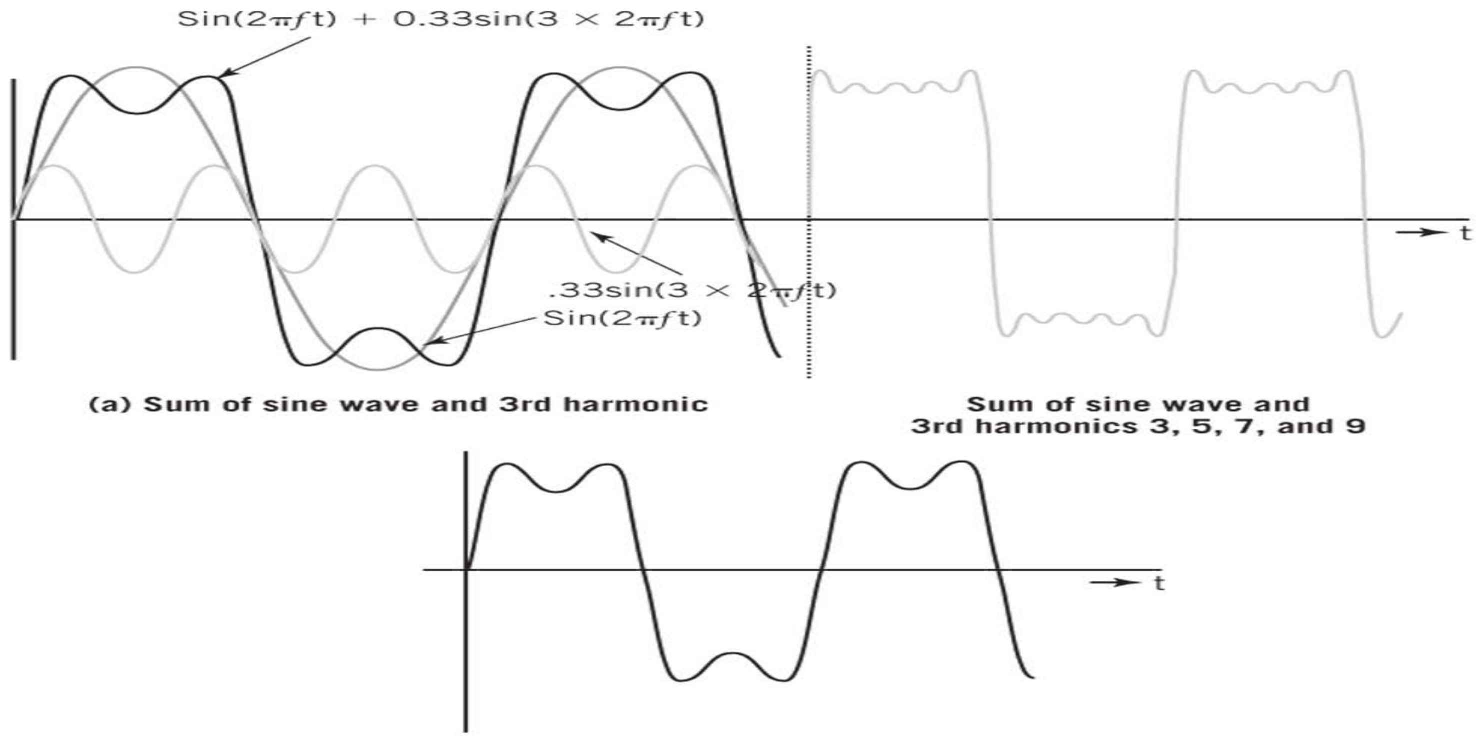
- The difference in position of a sine wave with respect to a reference sine wave
- Measured in degrees, from 0º to 360º
  - 90º – jumping forward one-quarter of the cycle
  - 180º – jumping forward one-half of the cycle



Creating a Square Wave from Sine Waves

All waveforms can be represented as the sum of sine waves of different frequencies, phases, and amplitudes

- A digital waveform is a composition of analog sine waves



(a) Sum of sine wave and 3rd harmonic

(b) Everything above 3rd harmonic blocked

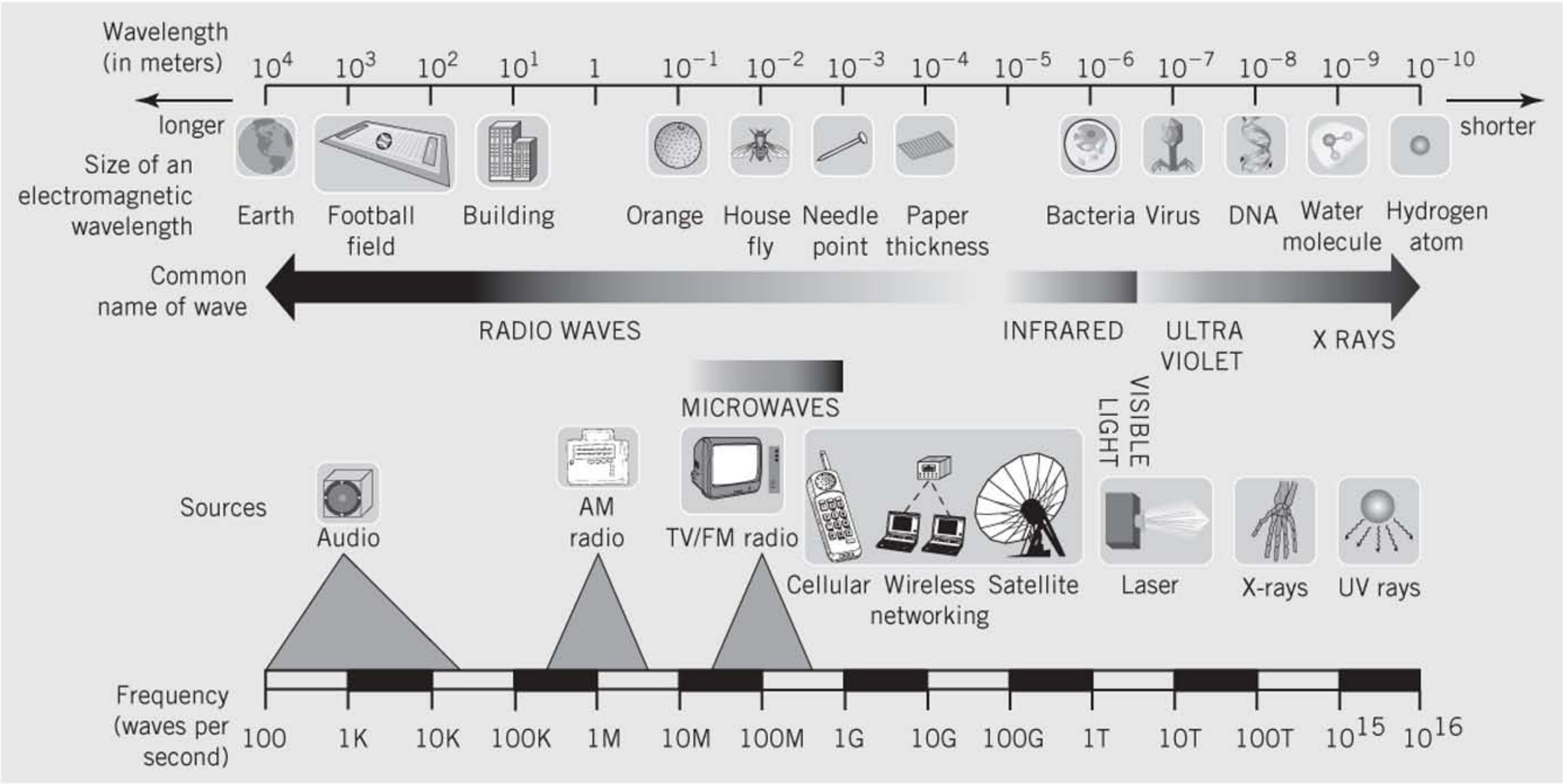
Properties of Signals/Waveforms

- Spectrum, bandwidth, filtering
- Spectrum: frequencies that make up a signal
  - Range of frequencies that a signal spans from minimum to maximum
  - Average voice has a frequency range of roughly 300 Hz to 3400 Hz
  - The spectrum would thus be 300 - 3400 Hz
- Bandwidth: range of frequencies passed by the channel with a small amount of attenuation
  - The absolute value of the difference between the lowest and highest frequencies of a signal
  - The bandwidth would be 3100 Hz calculated as |3400Hz – 300 Hz|
  - effective bandwidth < bandwidth because noise degrades original signals
- Filtering: controlling the channel bandwidth to prevent interference from other signals

Signal Frequencies

- The bandwidth required for different types of signals depends on the application
- Sound waves: approximately 20 Hz to 20 KHz
  - Stereo systems: 20-20,000 Hz for high fidelity
  - Phones: 0-4000 Hz for voice but limits speed
- Electromagnetic radio waves: 60 Hz to 300 GHz
  - AM radio: 550 KHz to 1.6 MHz
    - 20 KHz bandwidth centered around dial frequency of the station
    - Guard bands prevent stations/signals from interfering
  - FM radio: 88 MHz to 108 MHz
    - 100 KHz bandwidth per station
  - TV: 54 MHz to 700 MHz
    - >4.5 MHz bandwidth per channel
  - Cell phones, Wi-Fi wireless networks: 800 MHz to 5.2GHz

Signal Frequencies

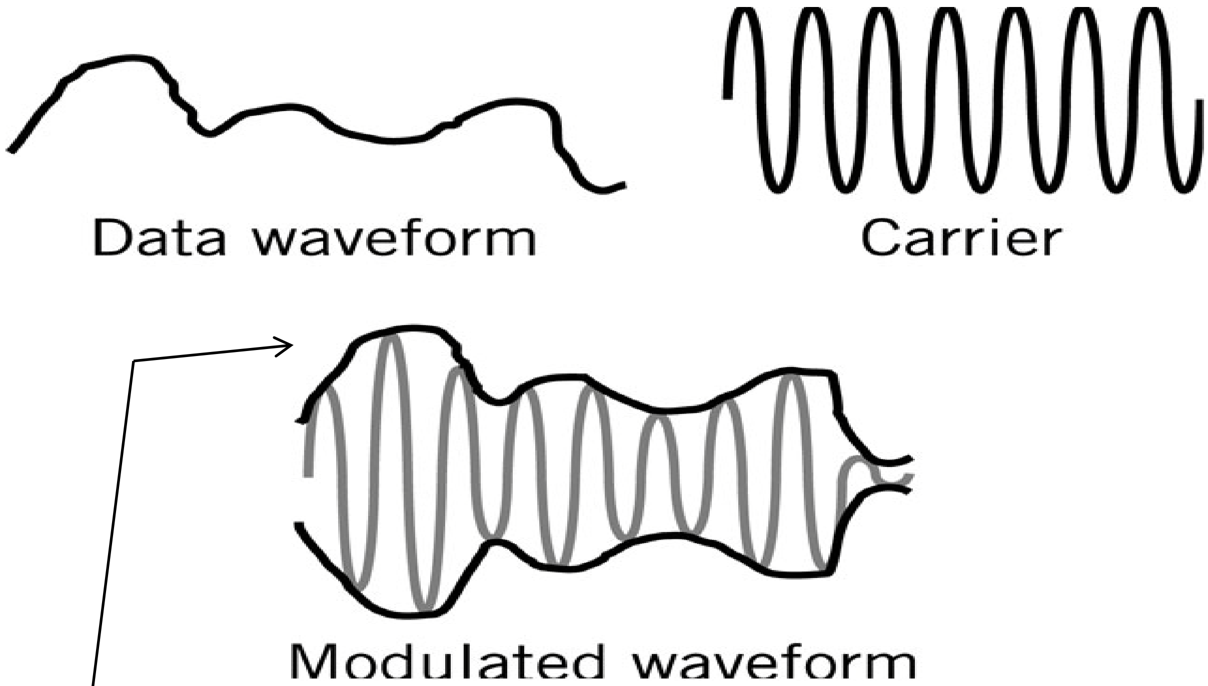


A general map of the useful frequency spectrums

Sine Waves as Carriers

- A sound made up of a sine wave produces a single, pure tone
  - A 440 Hz sine wave produces the tone called *A*
  - A 1650 Hz sine wave used by the modem is the carrier frequency and it alone does not carry any information
- To represent the signal modulate one of the three characteristics – amplitude, frequency, phase
  - An AM radio station at 1100 KHz modulates amplitude of the 1100 KHz sine wave carrier to correspond to the sound of music
- Demodulator or detector restores original waveform

Amplitude Modulations

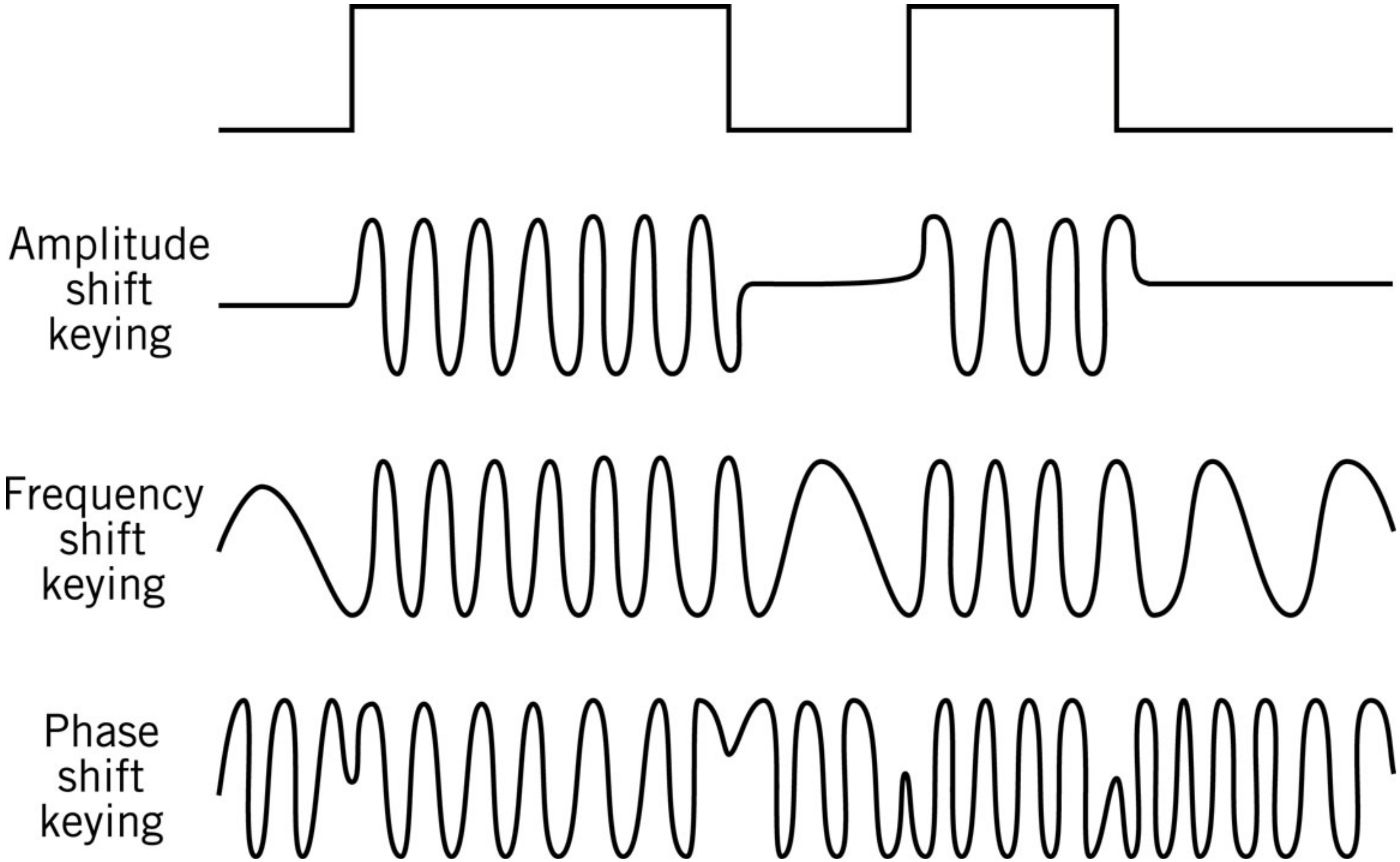


Analog data can be transmitting with analog carrier signals. The data waveform and carrier are essentially added together to produce modulated waveform. The modulated waveform <u>follows the same outline</u> as the data waveform.

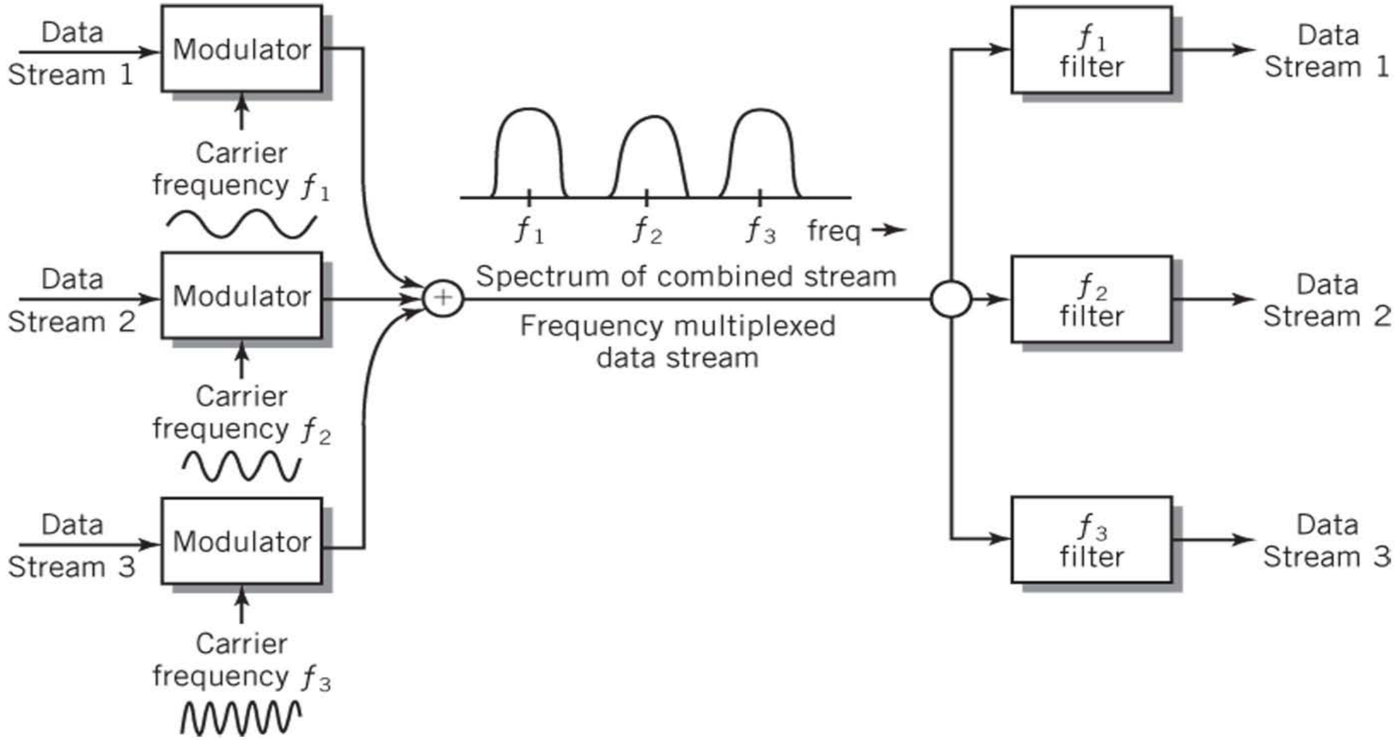
Modulating Digital Signals

- Analog data can be transmitted with digital carrier signals
- The carrier signal is modulated with only two possible values: 0 and 1
- 3 techniques
  - ASK: amplitude shift keying
    - Represents data by holding the frequency constant while varying the amplitude
  - FSK: frequency shift keying
    - Represents data by holding the amplitude constant while varying the frequency
  - PSK: phase shift keying
    - Represents data by an instantaneous shift in the phase or a switching between two signals of different phases

Modulating Digital Signals



Frequency Division Multiplexing



Optical form of frequency division multiplexing (FDM) is known as wavelength division multiplexing (WDM). Light of different colors have different wavelengths (frequencies). Data signals can be modulated with different carrier wavelengths to carry these data signals simultaneously over the same fiber-optic cable.

Noise

- Unwanted electrical or electromagnetic energy that degrades the quality of signals and data
- Can appear in analog data modulated with analog signals, and analog data modulated with digital signals

Figure 2-1
A simple example of an analog waveform

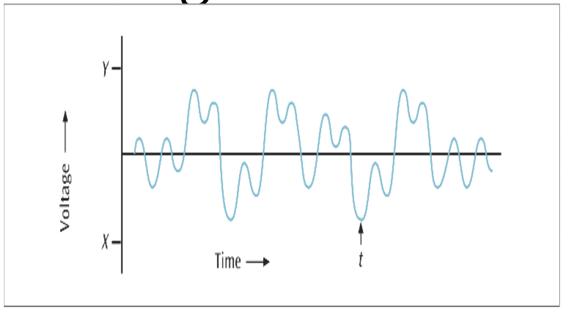


Figure 2-2
The waveform of a symphonic overture with noise

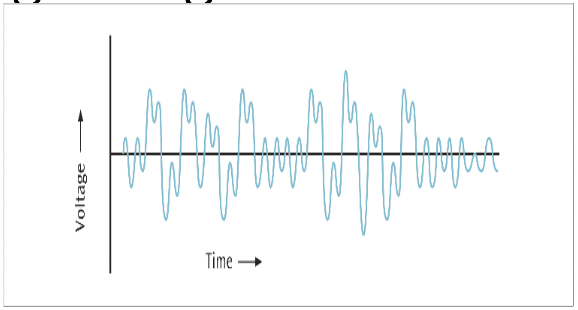


Figure 2-4
A digital signal with some noise introduced

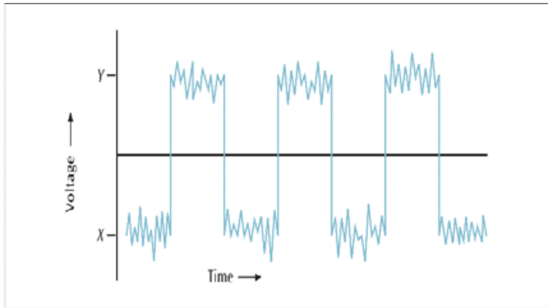
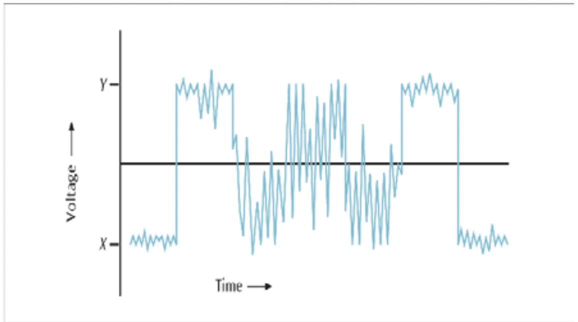


Figure 2-5
A digital waveform with noise so great that you can no longer recognize the original waveform



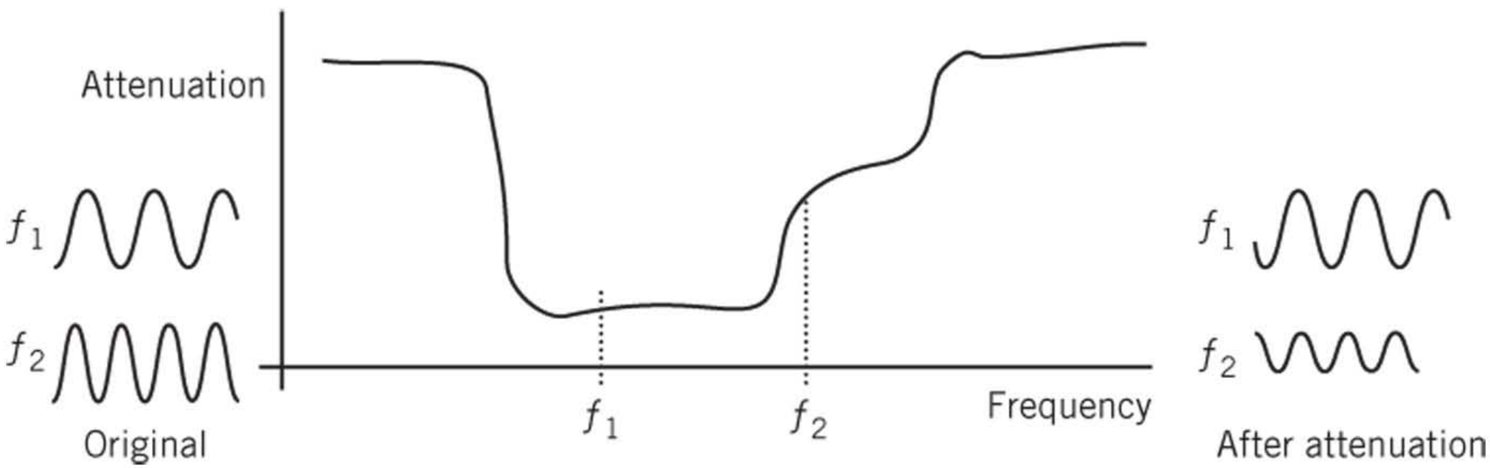
Attenuation – Signal Loss

- Reduction of a signal that occurs in a medium as a function of the physical length of the channel
- More difficult to separate the signal from noise at higher transmission speeds
- Signal-to-noise ratio should be high
- Amplifiers: restore original strength of the signal (but also amplifies noise)
- Signal loss/gain is measured in decibels [dB]
  - Loss or Gain [dB] = 10 $\log_{10}$ (P2/P1)
  - P2 and P1 are the ending and beginning power levels, respectively, expressed in watts
  - What is the decibel ***loss*** of a signal that starts at point A with a strength of 2000 watts and ends at point B with the strength of 400 watts?

    Loss [dB] = 10 $\log_{10}$ (P2 / P1) = 10 $\log_{10}$ (400 / 2000) = 10 $\log_{10}$ (.2) = 10 (-0.699) ≈ -7 dB

Effects of Attenuation

- Loss of amplitude and phase shifts vary with the frequency of the signal
  - Example: If the signal consists of sine waves of frequencies f_1 and f_2 from different parts of the spectrum, the output of the channel will be distorted



Digital Signaling

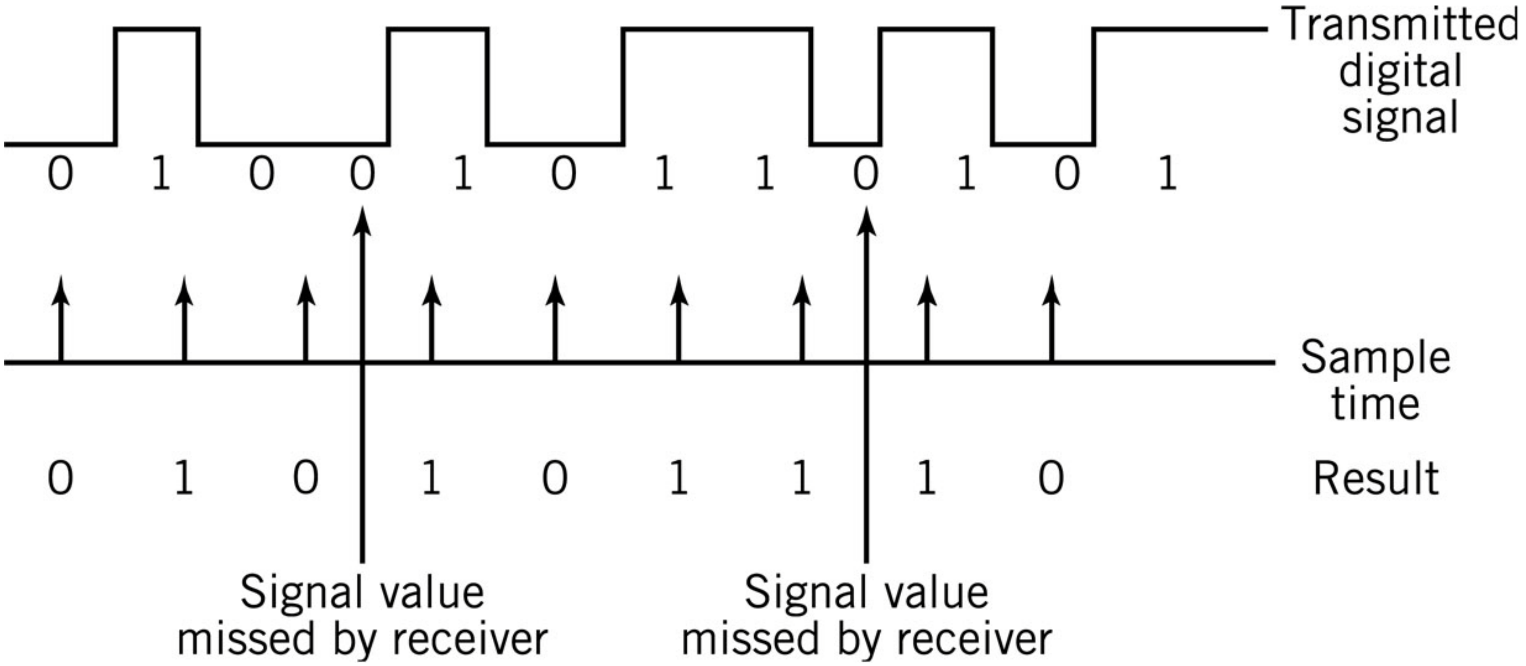
- Digital data transmitted with digital signals
  - Data is already in the correct format
  - So everything seems to be easy
    - A 1 or 0 could be transmitted as a positive voltage or zero voltage, respectively
    - But
      - How do you transmit a series of 10 consecutive 0s?
      - How do you distinguish between a 0 signal and no signal?
      - How do you group bits into bytes on the receiving end?

Synchronizing Digital Signals

- Synchronizing digital signals difficult
- Asynchronous transmission
  - Clear start and stop signals
  - Small number of bits, usually one byte
  - Use: low-speed modems, Ethernet frames
- Synchronous transmission
  - Continuous digital signal
  - Use: high-speed modems and point-to-point methods

Reception Errors

- Timing mismatch between sending and receiving computers
- Inability to distinguish groups of 1's or 0's



Block and Manchester Encoding

Block Encoding

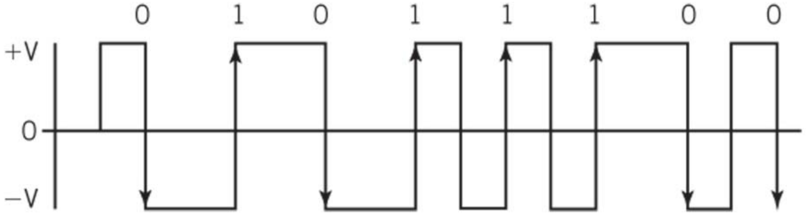
4-bit data sequence	5-bit code	4-bit data sequence	5-bit code
0000	11110	1000	10010
0001	01001	1001	10011
0010	10100	1010	10110
0011	10101	1011	10111
0100	01010	1100	11010
0101	01011	1101	11011
0110	01110	1110	11100
0111	01111	1111	11101

a. 4B/5B encoding table

Input data	0101	1100
Transmitted code	01011	11010

b. An example of 4B/5B encoding

Manchester Encoding

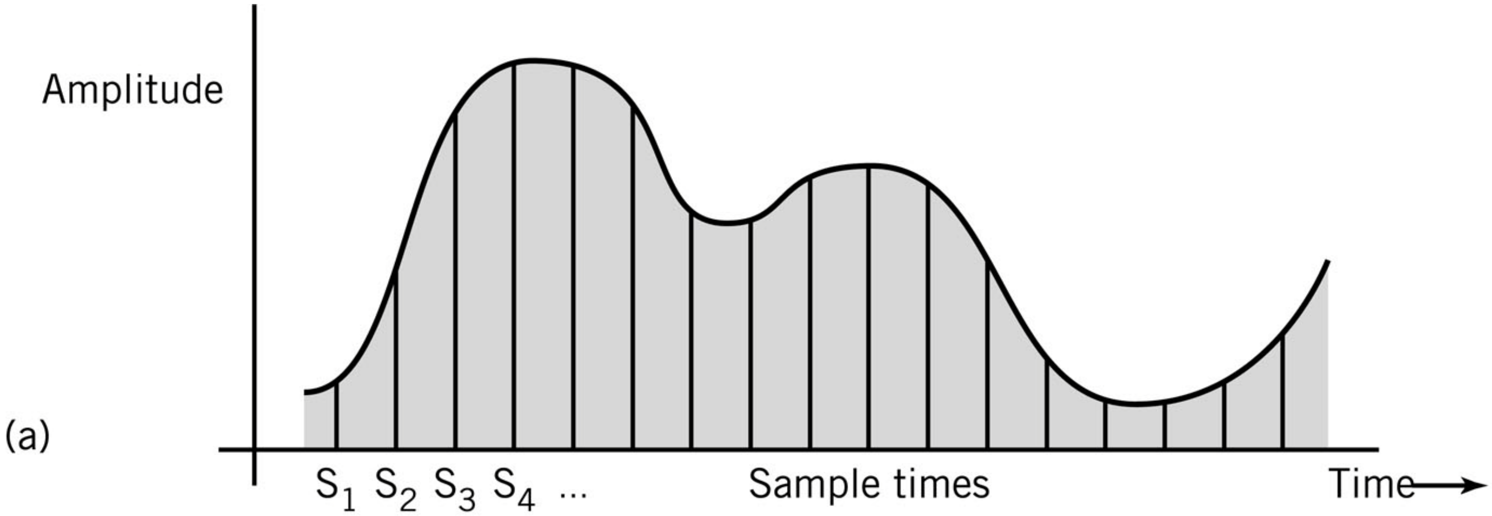


A-to-D Conversion

- Digital signals used to represent analog waveforms
- Examples:
  - CDs, DVDs
  - Direct satellite TV,
  - VOIP
  - Telephone voice mail
  - Streaming video
- A-to-D Pulse Code Modulation

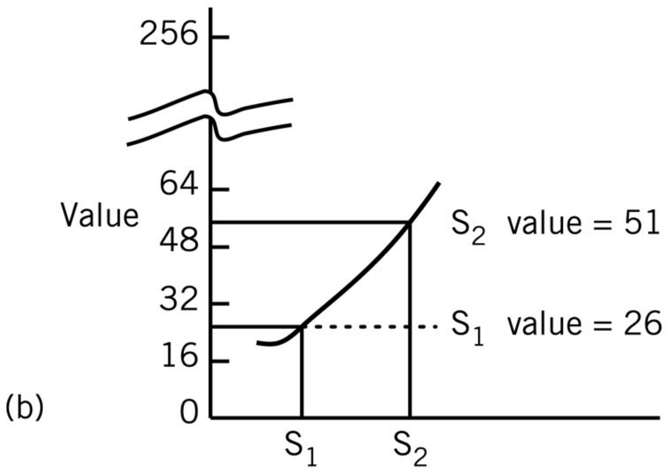
A-to-D: Pulse Code Modulation

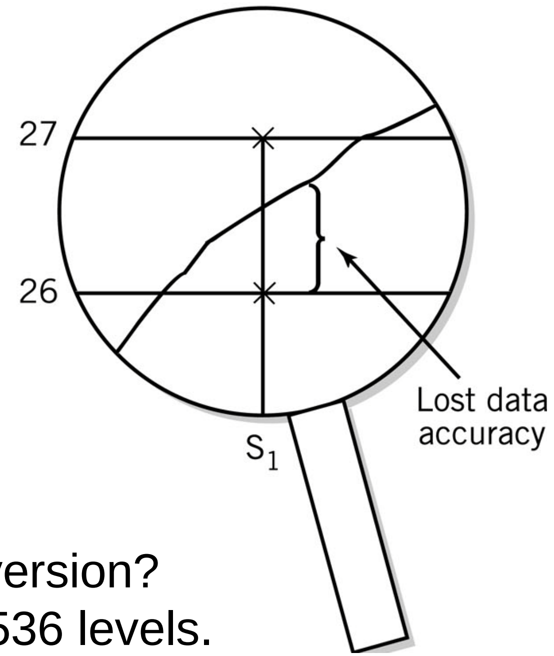
1. Analog waveform sampled at regular time intervals
   - Maximum amplitude divided into intervals
     - Example: 256 levels requires 8 bits/sample



A-to-D: Pulse Code Modulation

2. Sample values converted into corresponding number value
   - Information lost in conversion

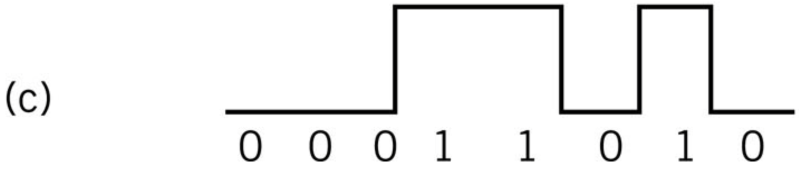




How to increase the accuracy of conversion?
Use 16 bits/sample. You will have 65536 levels.

A-to-D: Pulse Code Modulation

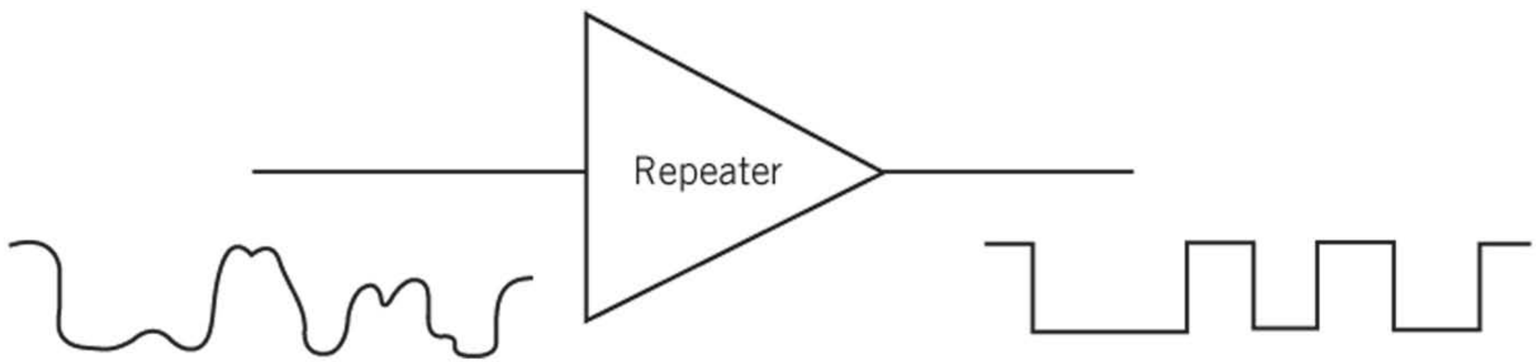
3. Number reduced to binary equivalent



26 represented as a stream of 8 bits: 00011010
26 represented as a stream of 16 bits:
00000000 00011010

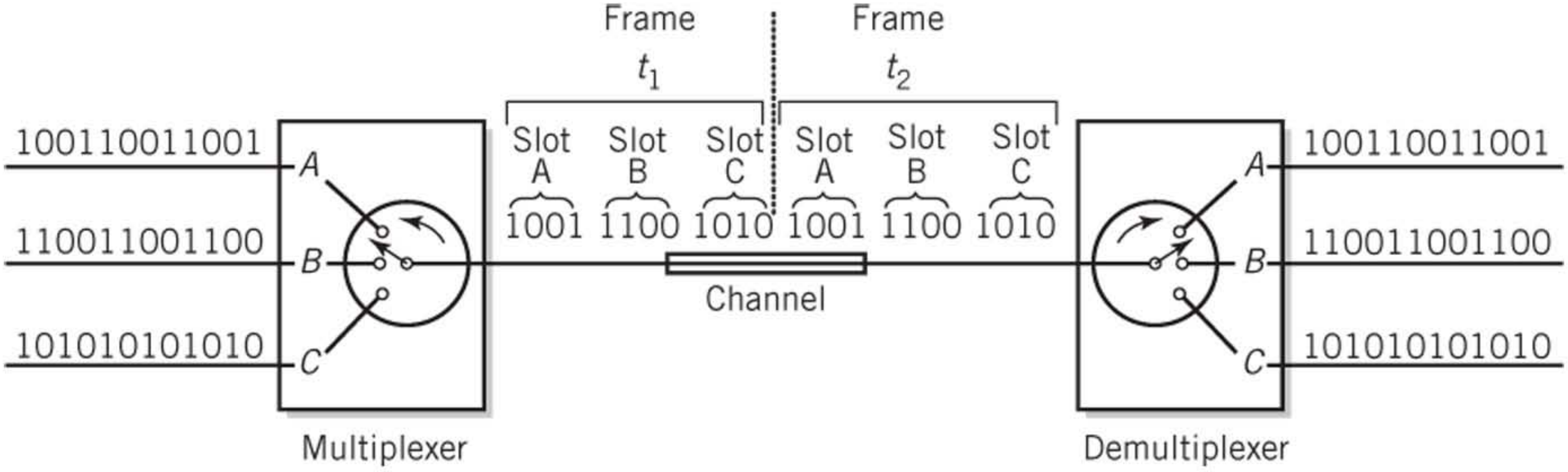
Digital Signal Quality

- Subject to noise, attenuation, distortion like analog
- Signal quality less affected because only necessary to distinguish 2 levels
- Repeaters
  - Recreate signals at intervals
  - Use: transmit signals over long distances
- Error correction techniques available



Time Division Multiplexing

- TDM - multiple signals share channel



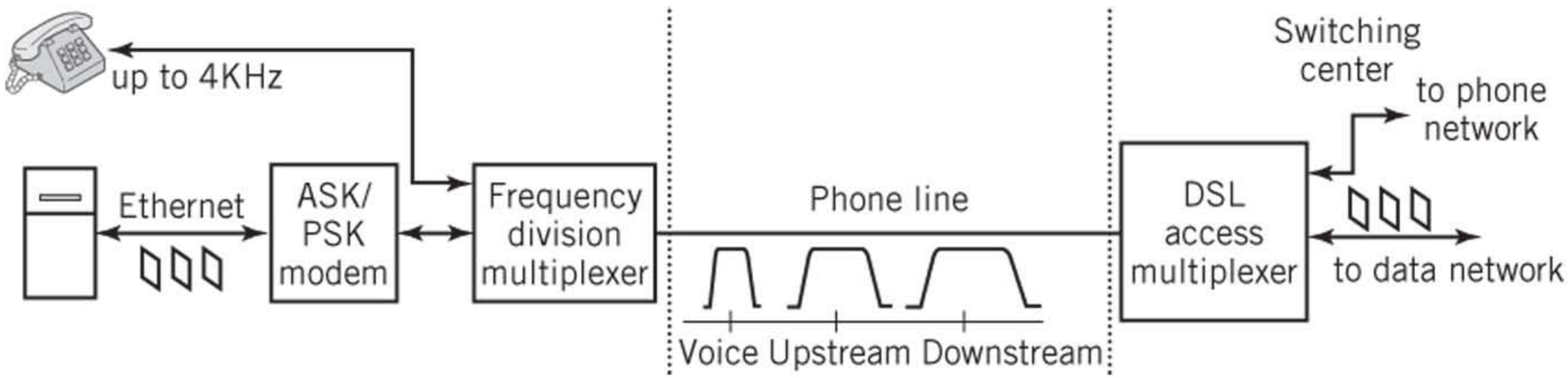
Bandwidth

- Digital signals: sum of sine waves of different frequencies
- Higher frequencies: higher data rates
- Channel with wider bandwidth has higher data rates
- Data rates usually measured in bits per second

Modems

- Modem (modulator/demodulator)
  - Convert digital signals to analog and back
  - Use: home to service provider via phone line or cable
  - Speed: baud rate or bits per second (bps)

DSL



Transmission Media

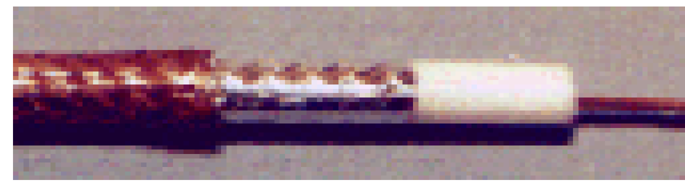
- Means used to carry signal
- Characterized by
  - Physical properties
  - Signaling method(s)
  - Bandwidth
  - Sensitivity to noise
- Guided media: confine signal physically to some kind of cable
- Unguided media: broadcast openly
- Signal-to-noise ratio
  - Higher ratio for given bandwidth increases data capacity of the channel

Electrical Media

- Require complete circuit
  - 2 wires: one to carry the signal, second as a return to complete the circuit
- Wired media or just wire
  - Inexpensive and easy to use
- Signals carried as changing electrical voltage or current

Types of Cable: Copper

- Coaxial cable
  - Wire surrounded by insulation
  - Copper shield around insulation
    - Acts as signal return
    - Shields from external noise



  - High bandwidth: 100 Mbps
    - Example: analog cable TV with FDM for dozens of channels at 6 MHz
- Twisted pair
  - Most local area networks; phone lines in buildings
  - More susceptible to noise than coaxial cable
  - Used for shorter distances and slower signals

Types of Cable: Fiber Optic

- Fiber optic cable
  - Consists of glass fiber thinner than human hair
  - Uses light to carry signals
  - Laser or light-emitting diode produces signal
  - Cladding: plastic sheath to protect fibers
- Advantages
  - Light waves: high frequency means high bandwidth
  - Less susceptible to interference and tampering
  - Lighter than copper cable
- Disadvantages
  - Difficult to use, especially for multipoint connections

Figure 3-6
A person holding a plain fiber-optic cable and a fiber-optic cable in an insulated jacket

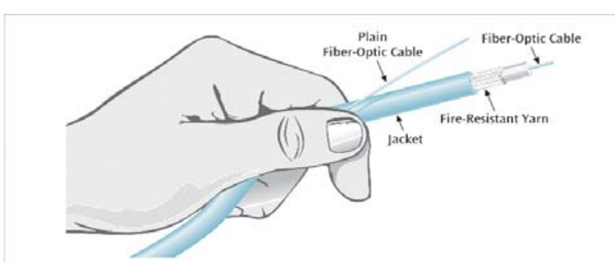


Figure 3-7
A fiber-optic cable with multiple strands of fiber

Electromagnetic Waves

- Microwaves
  - Frequencies below light but above 1 GHz
- Unguided medium
  - Tightly focused for point-to-point use
  - Highly susceptible to interference
- Applications
  - Large-scale Internet backbone channels
  - Direct satellite-to-home TV
  - IEEE 802.11 Wi-Fi

Wireless Networking

- Wi-Fi (wireless Ethernet)
  - Short-range, local area networking
- WiMAX, cellular telephone technology
  - Competing versions of longer range wireless networking
- Bluetooth
  - Personal level networking

Wi-Fi

- Access point
  - Hub for wireless devices
  - Router between wireless and wired devices
  - Forwards packet to destination station
- CSMA-CA
  - Collision avoidance, not collision detection!

Wi-Fi Network Configuration