William Stallings
Data and Computer Communications
7th Edition

**Chapter 3
Data Transmission**

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Terminology (1)

- Transmitter
- Receiver
- Medium
  - Guided medium
    - e.g. twisted pair, optical fiber
  - Unguided medium
    - e.g. air, water, vacuum

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Terminology (2)

- Direct link
  - No intermediate devices
- Point-to-point
  - Direct link
  - Only 2 devices share link
- Multi-point
  - More than two devices share the link

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Terminology (3)

- Simplex
  - —One direction
    - e.g. Television
- Half duplex
  - —Either direction, but only one way at a time
    - e.g. police radio
- Full duplex
  - —Both directions at the same time
   - e.g. telephone
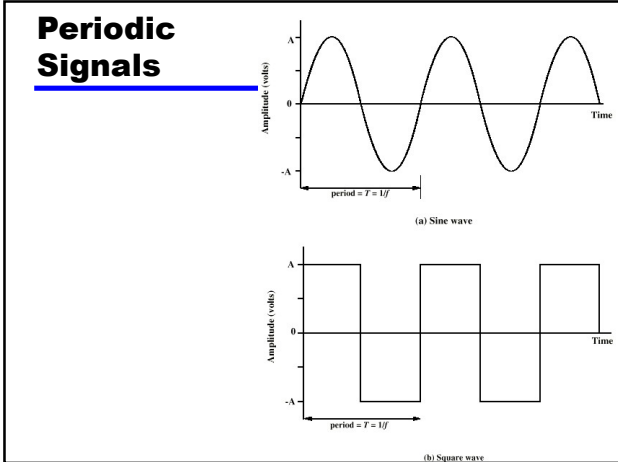
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Frequency, Spectrum and Bandwidth

- Time domain concepts
  - —Analog signal
    - Various in a smooth way over time
  - —Digital signal
    - Maintains a constant level then changes to another constant level
  - —Periodic signal
    - Pattern repeated over time
  - —Aperiodic signal
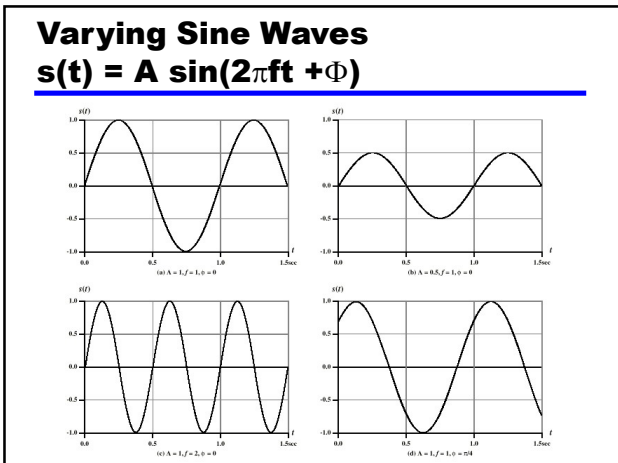   - Pattern not repeated over time

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Analogue & Digital Signals

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Periodic Signals

(a) Sine wave

(b) Square wave
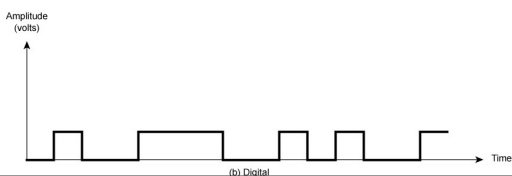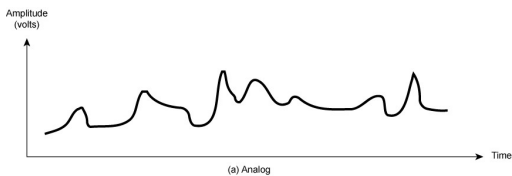
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Sine Wave

- Peak Amplitude (A)
  —maximum strength of signal
  —volts
- Frequency (f)
  —Rate of change of signal
  —Hertz (Hz) or cycles per second
  —Period = time for one repetition (T)
  —T = 1/f
- Phase (ϕ)
  —Relative position in time

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Varying Sine Waves
$s(t) = A \sin(2\pi ft + \Phi)$

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Wavelength

- Distance occupied by one cycle
- Distance between two points of corresponding phase in two consecutive cycles
- λ
- Assuming signal velocity v
  - $\lambda = vT$
  - $\lambda f = v$
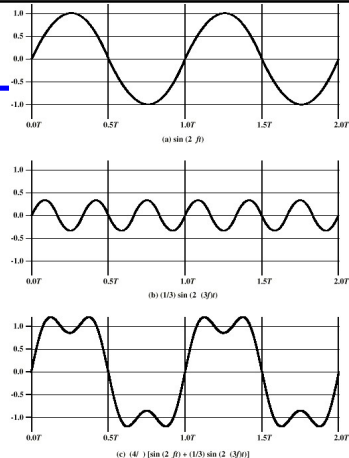 - $c = 3*10^8$ ms^{-1} (speed of light in free space)
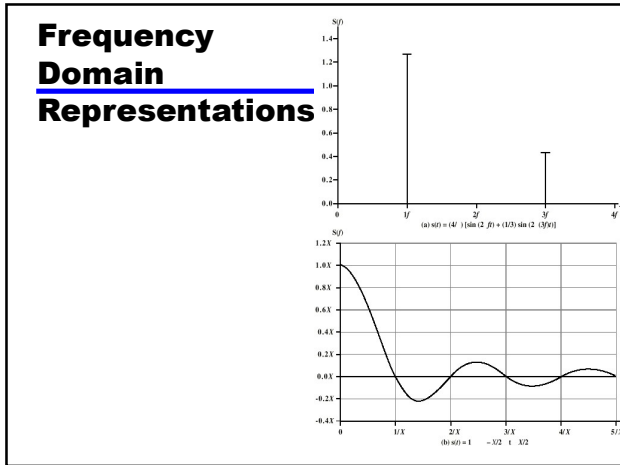
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Frequency Domain Concepts

- Signal usually made up of many frequencies
- Components are sine waves
- Can be shown (Fourier analysis) that any signal is made up of component sine waves
- Can plot frequency domain functions

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Addition of Frequency Components (T=1/f)

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Frequency Domain Representations

(a) s(t) = (4/π) [sin (2πft) + (1/3) sin (2π(3f)t)]

(b) s(t) = 1   −X/2 ≤ t ≤ X/2
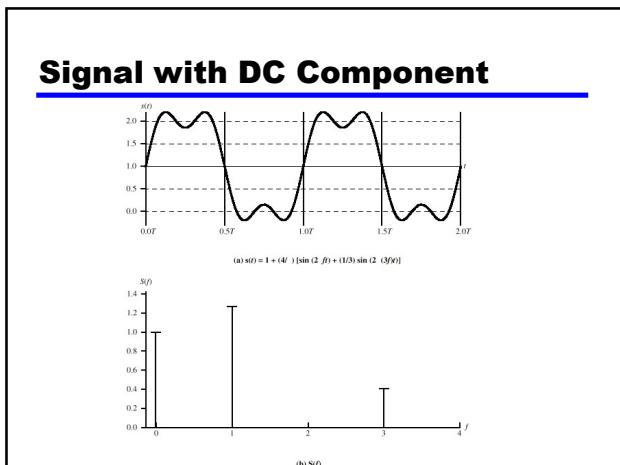
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Spectrum & Bandwidth

- Spectrum
  - —range of frequencies contained in signal
- Absolute bandwidth
  - —width of spectrum
- Effective bandwidth
  - —Often just *bandwidth*
  - —Narrow band of frequencies containing most of the energy
- DC Component
  - —Component of zero frequency

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Signal with DC Component

(a) s(t) = 1 + (4/π) [sin (2πft) + (1/3) sin (2π(3f)t)]

(b) S(f)

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Data Rate and Bandwidth

- Any transmission system has a limited band of frequencies
- This limits the data rate that can be carried

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Analog and Digital Data Transmission

- Data
  - Entities that convey meaning
- Signals
  - Electric or electromagnetic representations of data
- Transmission
  - Communication of data by propagation and processing of signals

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Analog and Digital Data

- Analog
  - Continuous values within some interval
  - e.g. sound, video
- Digital
  - Discrete values
  - e.g. text, integers

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Acoustic Spectrum (Analog)
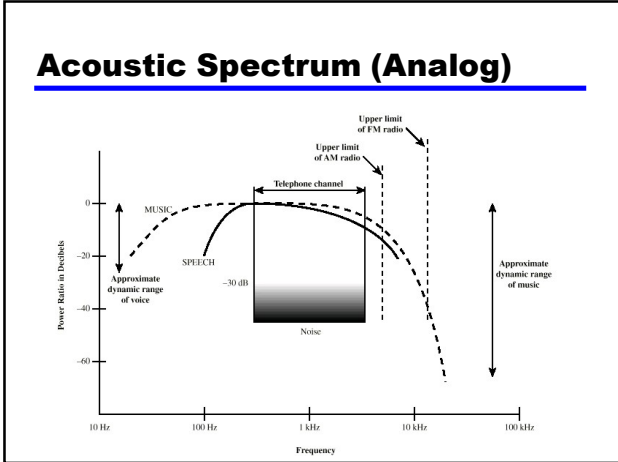
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Analog and Digital Signals

- Means by which data are propagated
- Analog
  —Continuously variable
  —Various media
    • wire, fiber optic, space
  —Speech bandwidth 100Hz to 7kHz
  —Telephone bandwidth 300Hz to 3400Hz
  —Video bandwidth 4MHz
- Digital
  —Use two DC components

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Advantages & Disadvantages of Digital

- Cheaper
- Less susceptible to noise
- Greater attenuation
  —Pulses become rounded and smaller
  —Leads to loss of information

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Attenuation of Digital Signals

Voltage at transmitting end
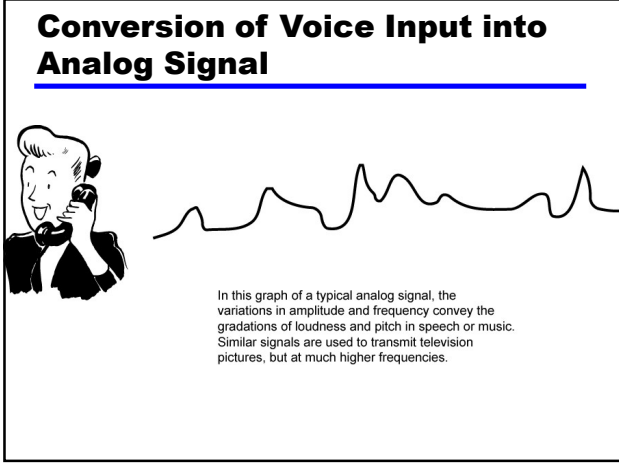
Voltage at receiving end
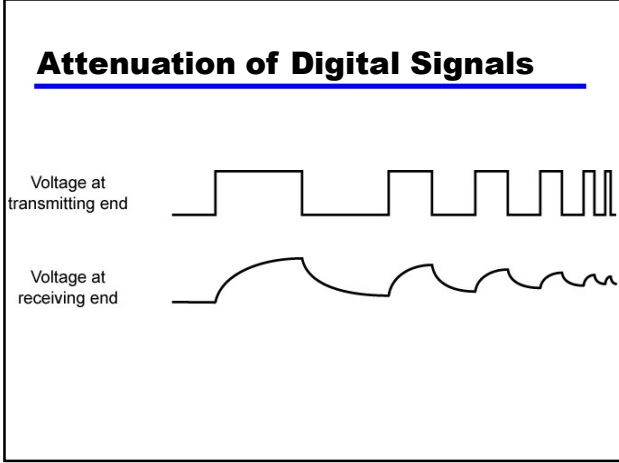
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Components of Speech

- Frequency range (of hearing) 20Hz-20kHz
  —Speech 100Hz-7kHz
- Easily converted into electromagnetic signal for transmission
- Sound frequencies with varying volume converted into electromagnetic frequencies with varying voltage
- Limit frequency range for voice channel
  —300-3400Hz

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Conversion of Voice Input into Analog Signal

In this graph of a typical analog signal, the variations in amplitude and frequency convey the gradations of loudness and pitch in speech or music. Similar signals are used to transmit television pictures, but at much higher frequencies.

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Video Components

- USA - 483 lines scanned per frame at 30 frames per second
  - — 525 lines but 42 lost during vertical retrace
- So 525 lines x 30 scans = 15750 lines per second
  - — 63.5μs per line
  - — 11μs for retrace, so 52.5 μs per video line
- Max frequency if line alternates black and white
- Horizontal resolution is about 450 lines giving 225 cycles of wave in 52.5 μs
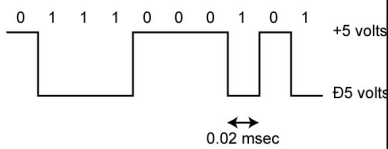- Max frequency of 4.2MHz

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Binary Digital Data

- From computer terminals etc.
- Two dc components
- Bandwidth depends on data rate

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Conversion of PC Input to Digital Signal

0 1 1 1 0 0 0 1 0 1

+5 volts

Ð5 volts

0.02 msec

User input at a PC is converted into a stream of binary digits (1s and 0s). In this graph of a typical digital signal, binary one is represented by Ð5 volts and binary zero is represented by +5 volts. The signal for each bit has a duration of 0.02 msec, giving a data rate of 50,000 bits per second (50 kbps).
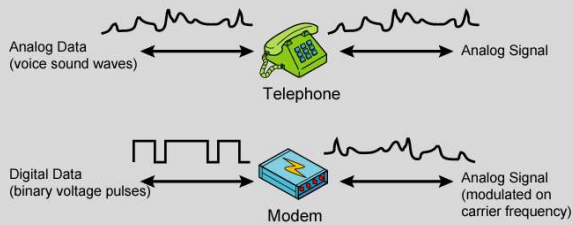
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Data and Signals

- Usually use digital signals for digital data and analog signals for analog data
- Can use analog signal to carry digital data
  —Modem
- Can use digital signal to carry analog data
  —Compact Disc audio

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Analog Signals Carrying Analog and Digital Data

Analog Signals: Represent data with continuously varying electromagnetic wave

Analog Data
(voice sound waves) ↔ Telephone ↔ Analog Signal

Digital Data
(binary voltage pulses) ↔ Modem ↔ Analog Signal
(modulated on carrier frequency)

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Digital Signals Carrying Analog and Digital Data

Digital Signals: Represent data with sequence of voltage pulses

Analog Signal ↔ Codec ↔ Digital Signal

Digital Data ↔ Digital Transceiver ↔ Digital Signal
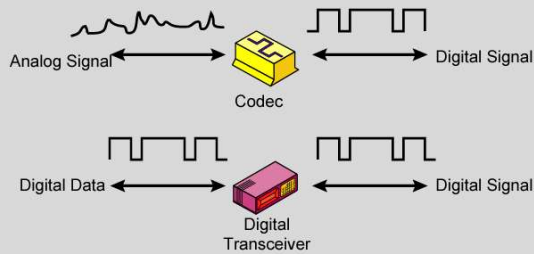
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Analog Transmission

- Analog signal transmitted without regard to content
- May be analog or digital data
- Attenuated over distance
- Use amplifiers to boost signal
- Also amplifies noise

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Digital Transmission

- Concerned with content
- Integrity endangered by noise, attenuation etc.
- Repeaters used
- Repeater receives signal
- Extracts bit pattern
- Retransmits
- Attenuation is overcome
- Noise is not amplified

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Advantages of Digital Transmission

- Digital technology
  - Low cost LSI/VLSI technology
- Data integrity
  - Longer distances over lower quality lines
- Capacity utilization
  - High bandwidth links economical
  - High degree of multiplexing easier with digital techniques
- Security & Privacy
  - Encryption
- Integration
  - Can treat analog and digital data similarly

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Transmission Impairments

- Signal received may differ from signal transmitted
- Analog - degradation of signal quality
- Digital - bit errors
- Caused by
  - Attenuation and attenuation distortion
  - Delay distortion
  - Noise

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Attenuation

- Signal strength falls off with distance
- Depends on medium
- Received signal strength:
  - must be enough to be detected
  - must be sufficiently higher than noise to be received without error
- Attenuation is an increasing function of frequency

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Delay Distortion

- Only in guided media
- Propagation velocity varies with frequency

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Noise (1)

- Additional signals inserted between transmitter and receiver
- Thermal
  - Due to thermal agitation of electrons
  - Uniformly distributed
  - White noise
- Intermodulation
  - Signals that are the sum and difference of original frequencies sharing a medium

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Noise (2)

- Crosstalk
  - A signal from one line is picked up by another
- Impulse
  - Irregular pulses or spikes
  - e.g. External electromagnetic interference
  - Short duration
  - High amplitude

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Channel Capacity

- Data rate
  - In bits per second
  - Rate at which data can be communicated
- Bandwidth
  - In cycles per second of Hertz
  - Constrained by transmitter and medium

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Nyquist Bandwidth

- If rate of signal transmission is 2B then signal with frequencies no greater than B is sufficient to carry signal rate
- Given bandwidth B, highest signal rate is 2B
- Given binary signal, data rate supported by B Hz is 2B bps
- Can be increased by using M signal levels
- $C = 2B \log_2 M$

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Shannon Capacity Formula

- Consider data rate, noise and error rate
- Faster data rate shortens each bit so burst of noise affects more bits
  - At given noise level, high data rate means higher error rate
- Signal to noise ration (in decibels)
- $SNR_{db} = 10 \log_{10} (signal/noise)$
- Capacity $C = B \log_2(1+SNR)$
- This is error free capacity

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Required Reading

- Stallings chapter 3

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