

**William Stallings  
Data and Computer  
Communications  
7<sup>th</sup> Edition**

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**Chapter 3  
Data Transmission**

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**Terminology (1)**

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

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**Terminology (2)**

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- 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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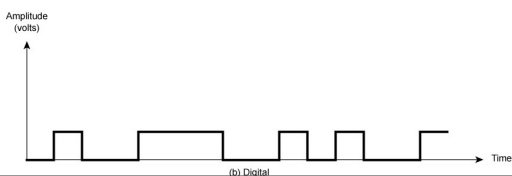
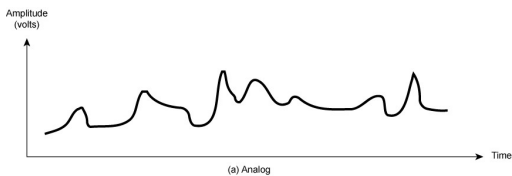
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### Analogue & Digital Signals



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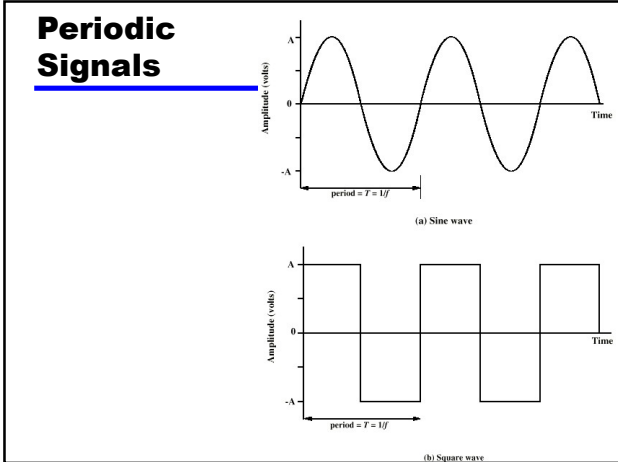
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- ### Sine Wave
- Peak Amplitude (A)
    - maximum strength of signal
    - volts
  - Frequency (f)
    - Rate of change of signal
    - Hertz (Hz) or cycles per second
    - Period = time for one repetition (T)
    - $T = 1/f$
  - Phase ( $\phi$ )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

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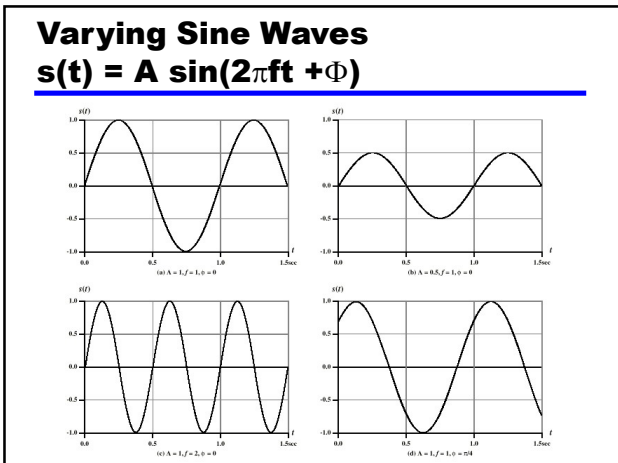
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## Wavelength

- Distance occupied by one cycle
- Distance between two points of corresponding phase in two consecutive cycles
- $\lambda$
- Assuming signal velocity  $v$ 
  - $\lambda = vT$
  - $\lambda f = v$
  - $c = 3 \times 10^8 \text{ ms}^{-1}$  (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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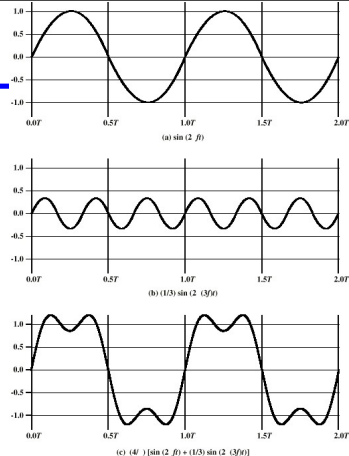
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## Addition of Frequency Components ( $T = 1/f$ )



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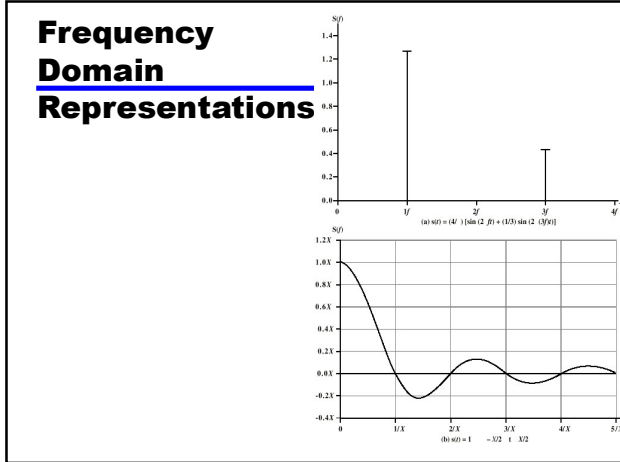
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- ### Spectrum & Bandwidth
- Spectrum
    - range of frequencies contained in signal
  - Absolute bandwidth
    - width of spectrum
  - Effective bandwidth
    - Often just *bandwidth*
    - Narrow band of frequencies containing most of the energy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

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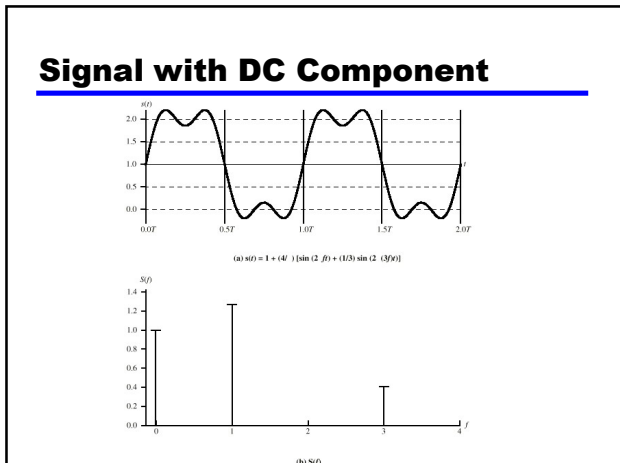
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### **Data Rate and Bandwidth**

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- 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**

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- 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**

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

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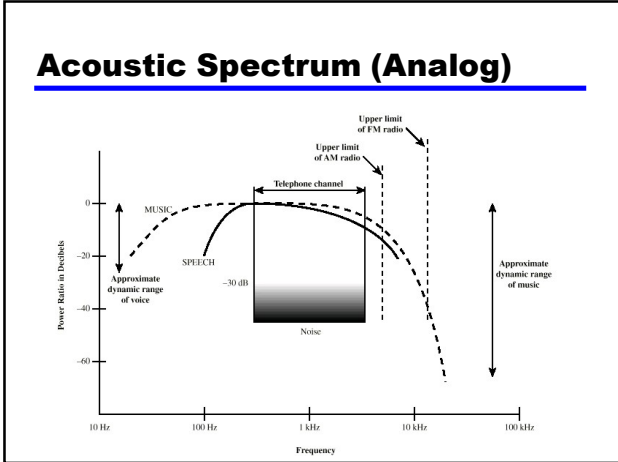
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- ### Analog and Digital Signals
- Means by which data are propagated
  - Analog
    - Continuously variable
    - Various media
      - wire, fiber optic, space
    - Speech bandwidth 100Hz to 7kHz
    - Telephone bandwidth 300Hz to 3400Hz
    - Video 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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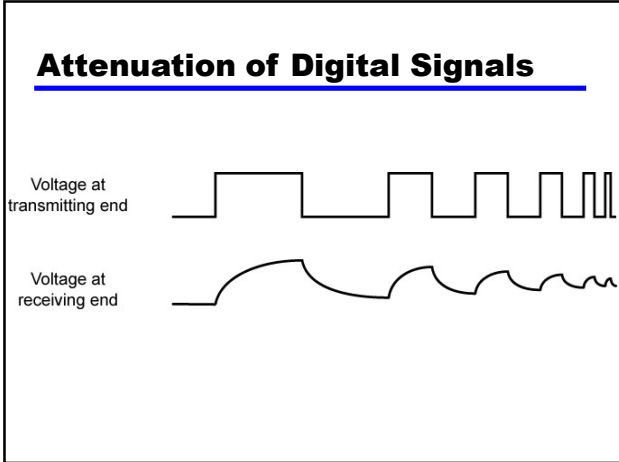
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- ### Components of Speech
- Frequency range (of hearing) 20Hz-20kHz
    - Speech 100Hz-7kHz
  - Easily converted into electromagnetic signal for transmission
  - Sound frequencies with varying volume converted into electromagnetic frequencies with varying voltage
  - Limit frequency range for voice channel
    - 300-3400Hz

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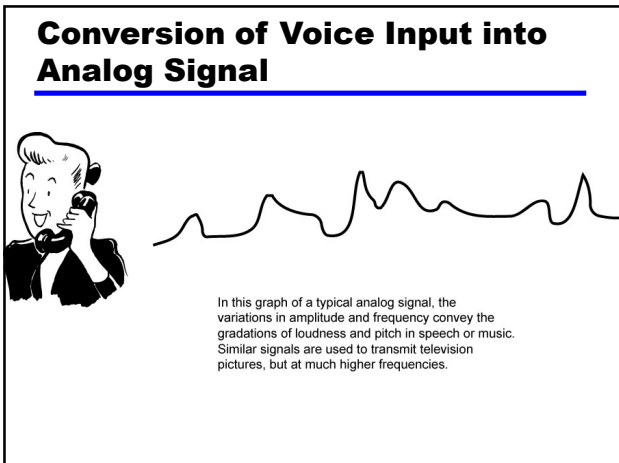
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### Video Components

- 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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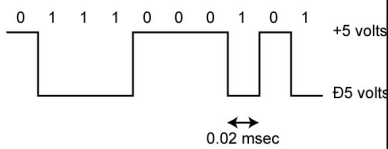
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### Conversion of PC Input to Digital Signal



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 +5 volts and binary zero is represented by 0V. 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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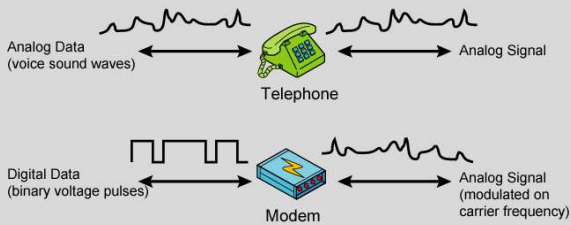
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## Analog Signals Carrying Analog and Digital Data

Analog Signals: Represent data with continuously varying electromagnetic wave



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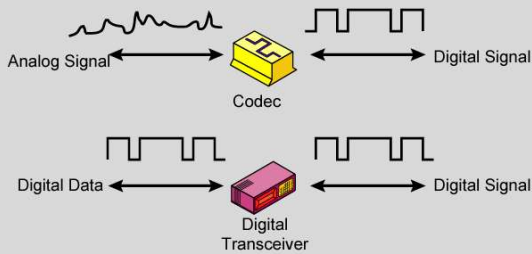
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## Digital Signals Carrying Analog and Digital Data

Digital Signals: Represent data with sequence of voltage pulses



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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)
- $SNR_{db} = 10 \log_{10}(\text{signal/noise})$
- 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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