

Data Transmission

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These slides are available on-line at:
<http://www.cse.wustl.edu/~jain/cse473-05/>



- Time Domain and Frequency Domain
- Decibels
- Data vs Signal
- Attenuation, Delay Distortion, Noise, Capacity

Transmission Terminology

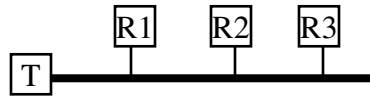
- **Guided Media:** Wire, Fiber, coax
- **Unguided Media:** Air, Vacuum, sea water



- **Direct Link**



- **Point to Point vs Point to Multipoint**



Line Duplexity

- **Simplex:** Transmit or receive, e.g., Television



- **Full Duplex:** Transmit and receive simultaneously, e.g., Telephone

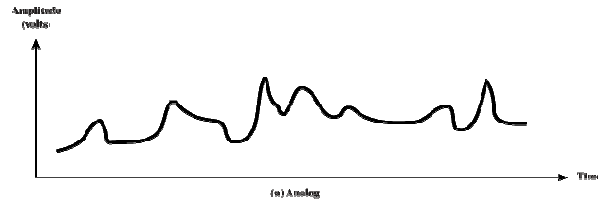


- **Half-Duplex:** Transmit and receive alternately, e.g., Police Radio

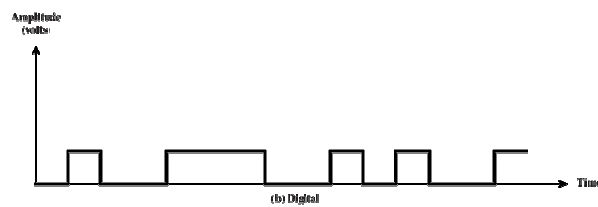


Analog vs Digital Signals

□ Analog:

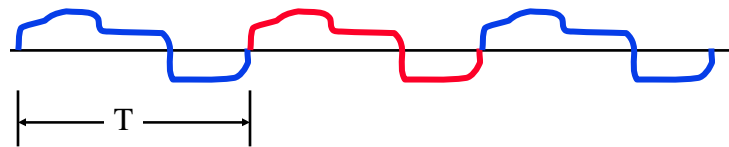


□ Digital:



Periodic vs Aperiodic

□ Periodic: Signal pattern repeats over time



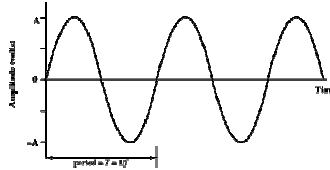
$$S(t+T) = s(t) \text{ for all } t$$

Period = T

□ Aperiodic: Not periodic

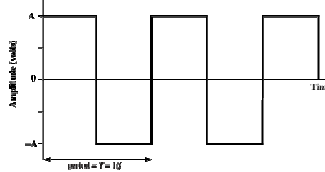
Examples of Periodic Signals

□ Sine Wave:



(a) Sine wave

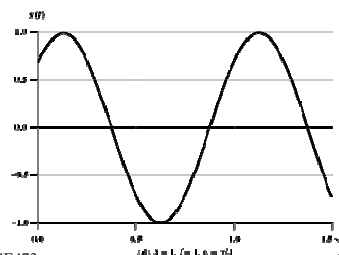
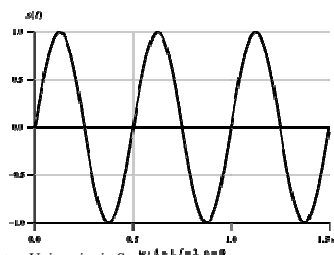
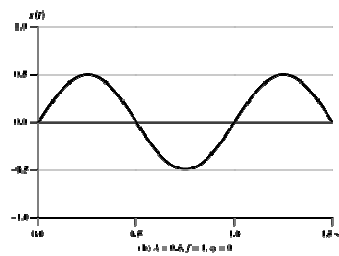
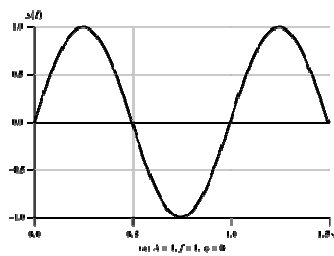
□ Square Wave:



(b) Square wave

Frequency, Period, and Phase

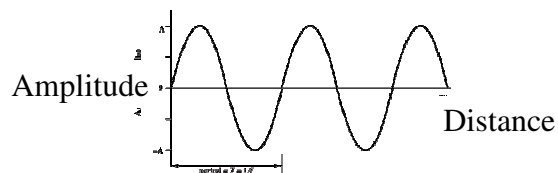
□ A Sin($2\pi ft + \theta$), Period $T=1/f$, Frequency in **Hertz**



Sine Wave

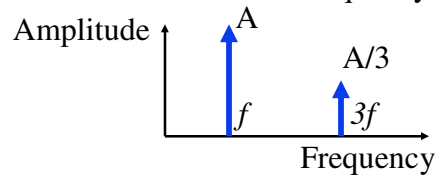
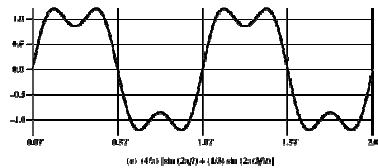
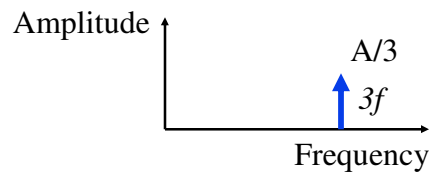
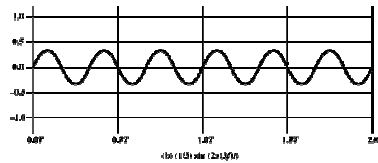
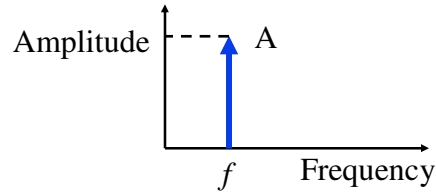
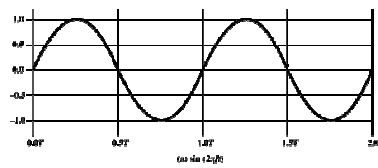
- **Peak Amplitude (A)**: Maximum strength of signal in volts
- **Frequency (f)**: Hertz (Hz) or cycles per second
- **Period** = time for one repetition (T)
$$T = 1/f$$
- **Phase (ϕ)**: Relative position in time

Wavelength



- Distance occupied by one cycle
- Distance between two points of corresponding phase in two consecutive cycles
- Wavelength = λ
- Assuming signal velocity v
 - $\lambda = vT$
 - $\lambda f = v$
 - $c = 3 \cdot 10^8$ m/s (speed of light in free space) = 300 m/ μ s

Time and Frequency Domains



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Frequency Domain Concepts

- ❑ **Fundamental Frequency:** All other frequency components are multiple of fundamental frequency f
- ❑ **Period** = $1/f$
- ❑ **Spectrum:** Range of frequencies
- ❑ **Absolute Bandwidth:** Width of the spectrum

$$\text{Absolute Bandwidth} = 3f - f = 2f$$

- ❑ **Effective Bandwidth:** Narrow band of frequencies containing most of the energy

- ❑ **DC Component:** Constant or zero frequency

$$A + B \sin(2\pi ft + \theta)$$

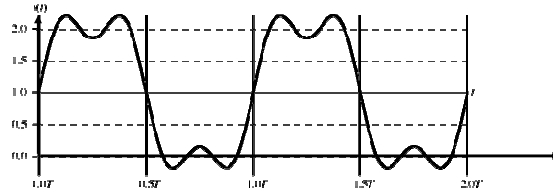
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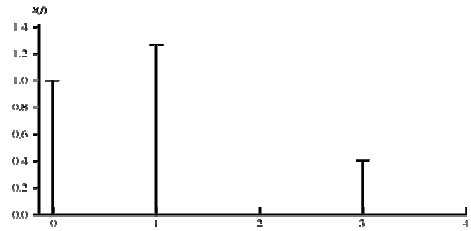
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Signal with DC Component

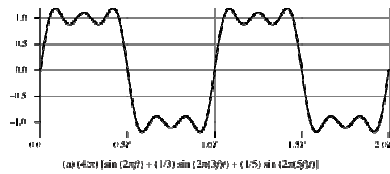


$$(a) x(t) = 1 + (4/\pi) \sum_{k=1,3,5} \sin(2\pi kt) + (1/5) \sin(2\pi 5t)$$

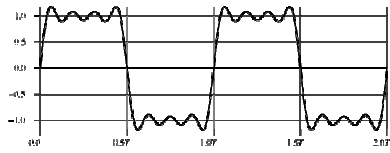


(b) $S(f)$

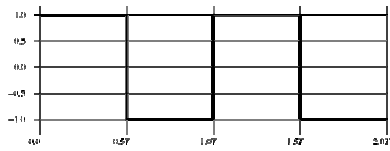
Frequency Components of Square Wave



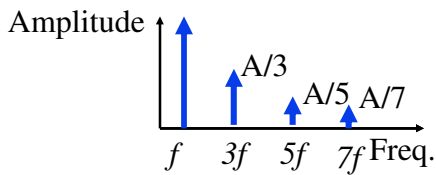
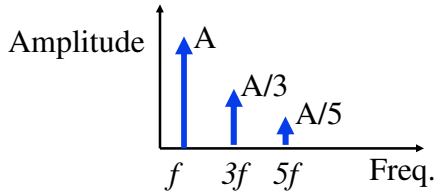
$$(a) x(t) = \sum_{k=1,3,5} \sin(2\pi kt) + (1/3) \sin(2\pi 3t) + (1/5) \sin(2\pi 5t)$$



$$(b) x(t) = \sum_{k=2,4,6} \sin(2\pi kt) + (1/2) \sin(2\pi 2t) + (1/4) \sin(2\pi 4t) + (1/6) \sin(2\pi 6t)$$



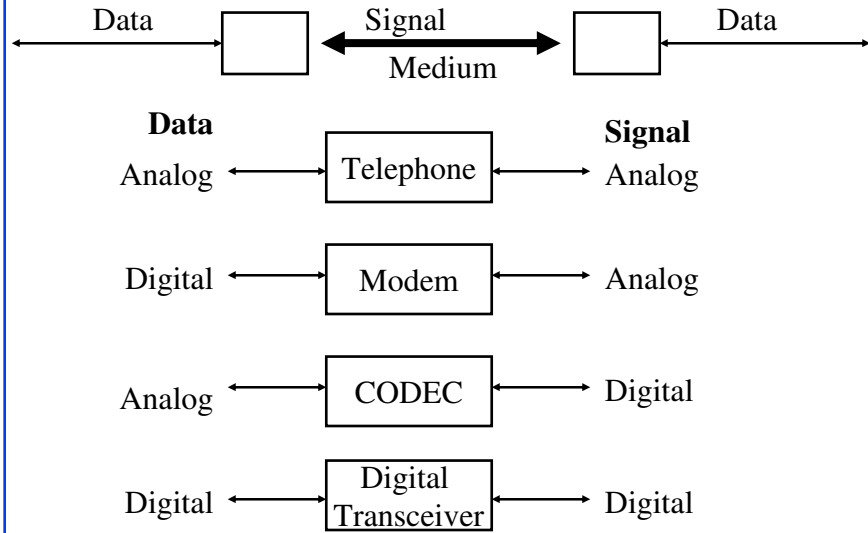
$$(c) x(t) = \sum_{k=1,3,5} \sin(2\pi kt) \quad \text{for } k \text{ odd}$$



$$\sum_{k=1,3,5} A/k \sin(2\pi kft)$$

Frequency

Data vs Signal



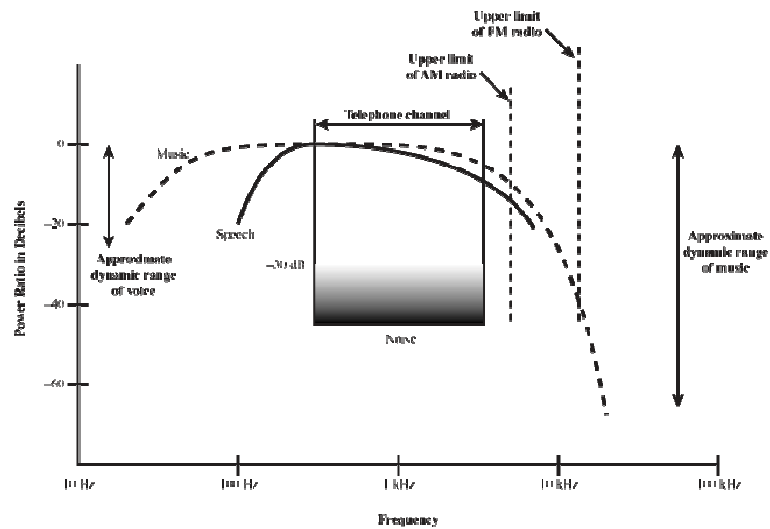
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Analog Data Example: Speech and Music



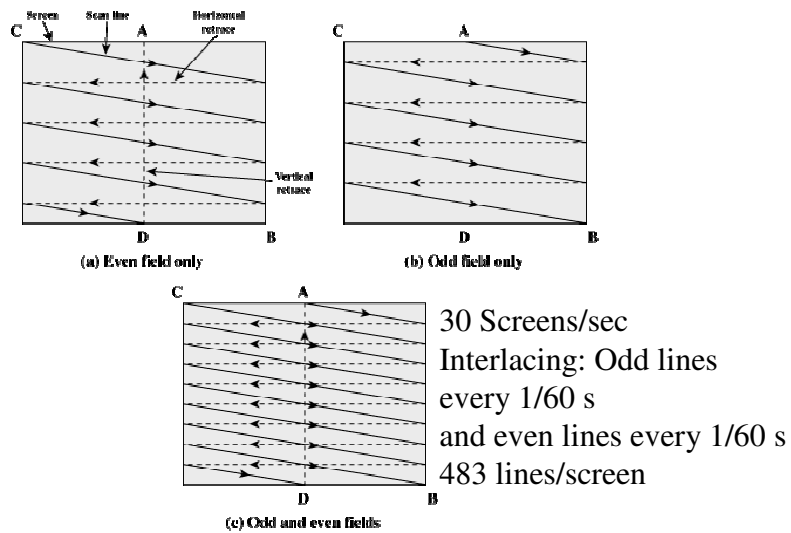
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Analog Data Example 2: Television



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Video Signal

- 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
 - 63.5 μ s per line
 - 11 μ s for retrace, so 52.5 μ s 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 μ s
- Max frequency of 4.2MHz

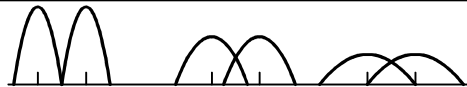
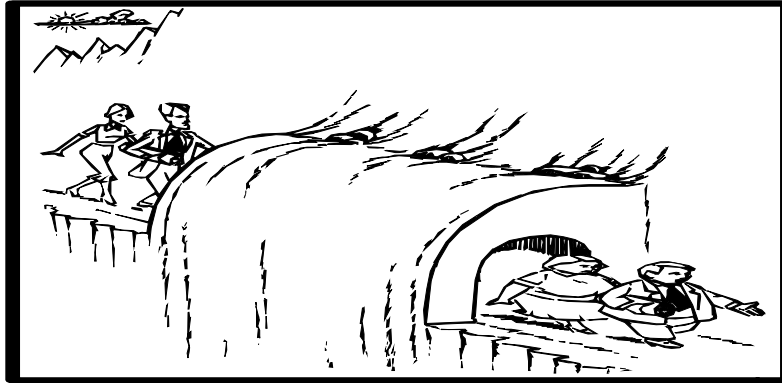
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Attenuation and Dispersion (Delay Distortion)



Distance →

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Digital Transmission

- ❑ Repeaters are used to regenerate digital signal
- ❑ Signal attenuation is overcome
- ❑ Noise is not amplified
- ❑ Low cost LSI/VLSI technology
- ❑ Longer distances over lower quality lines
- ❑ Capacity utilization
 - ❑ High bandwidth links economical
 - ❑ High degree of multiplexing easier with digital techniques
- ❑ Security & Privacy: Encryption

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Decibels

- Attenuation = $\text{Log}_{10} \frac{P_{in}}{P_{out}}$ Bel
- Attenuation = $10 \text{Log}_{10} \frac{P_{in}}{P_{out}}$ decibel
- Attenuation = $20 \text{Log}_{10} \frac{V_{in}}{V_{out}}$ decibel
- **Example 1:** $P_{in} = 10 \text{ mW}$, $P_{out} = 5 \text{ mW}$
Attenuation = $10 \log_{10} (10/5) = 10 \log_{10} 2 = 3 \text{ dB}$
- **Example 2:** $P_{in} = 100 \text{ mW}$, $P_{out} = 1 \text{ mW}$
Attenuation = $10 \log_{10} (100/1) = 10 \log_{10} 100 = 20 \text{ dB}$

Noise

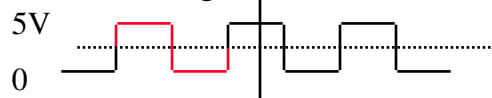
- Additional signals inserted between transmitter and receiver
- **Thermal Noise:**
 - Due to thermal agitation of electrons
 - Uniformly distributed
 - White noise
- **Intermodulation Noise:**
 - Signals that are the sum and difference of original frequencies sharing a medium

Noise (Cont)

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

Channel Capacity

- ❑ Capacity = Maximum data rate for a channel
- ❑ **Nyquist Theorem:** Bandwidth = B
Data rate $\leq 2 B$
- ❑ **Bi-level Encoding:** Data rate = $2 \times$ Bandwidth



- ❑ **Multilevel:** Data rate = $2 \times$ Bandwidth $\times \log_2 M$



Example: $M=4$, Capacity = $4 \times$ Bandwidth

Shannon's Theorem

- Bandwidth = B Hz
Signal-to-noise ratio = S/N
- Maximum number of bits/sec = $B \log_2 (1+S/N)$
- Example: Phone wire bandwidth = 3100 Hz

$$S/N = 30 \text{ dB}$$

$$10 \text{ Log}_{10} S/N = 30$$

$$\text{Log}_{10} S/N = 3$$

$$S/N = 10^3 = 1000$$

$$\begin{aligned} \text{Capacity} &= 3100 \log_2 (1+1000) \\ &= 30,894 \text{ bps} \end{aligned}$$

Thermal Noise

- Thermal Noise per Hertz = kT W/Hz
- k = Boltzman's constant = 1.38×10^{-23} Joules/Kelvin
- T = Absolute Temperature (in Kelvins)
- **Example:** 10MHz receiver at 21°C
 - Thermal Noise per Hertz = $1.38 \times 10^{-23} \times (21+273.15)$
 - Thermal Noise N = $1.38 \times 10^{-23} \times (294.15) \times 10 \times 10^6$
 - Thermal Noise in dBW = $10 \log_{10} N$
 $= 10 \log_{10}(1.38 \times 10^{-23}) + 10 \log_{10}(294.15) + 10 \log_{10}(10^7)$
 $= -228.6 + 24.7 + 70 = -133.9 \text{ dBW}$

Summary



- Guided Media vs unguided media
- Analog vs digital signal
- 3 Important characteristics of sinusoidal signal
- Relationship between Wavelength and Frequency
- Attenuation vs delay distortion
- Key factors affecting channel capacity

Reading Assignment

- Read Chapter 3 and Appendix 3A of Stallings 7th edition.

Homework

- Submit answer to exercises 3.15 (Teleprinter channel) and 3.16 (digital signaling system) of 7th edition by Stallings.