# Data Transmission

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- Time Domain and Frequency Domain
- Bit, Hertz
- Decibels
- Data vs Signal
- Attenuation, Delay Distortion, Noise, Capacity
- Physical Media: Twisted pair, coaxial cable, optical fiber, radio, microwave, satellite,

# Analog vs Digital

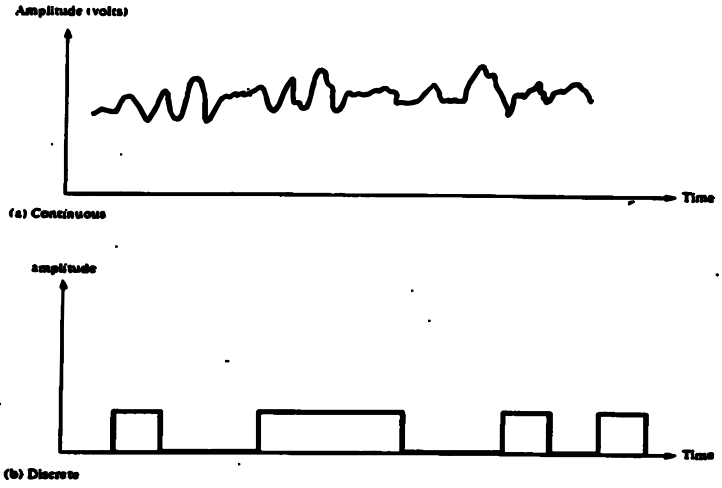
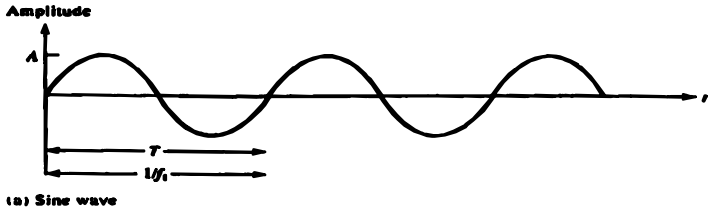



Fig 2.2



# Frequency, Period, and Phase

- A Sin(2πft+ θ)




- A Sin(2πft) and A Sin(2πft+ π/2)

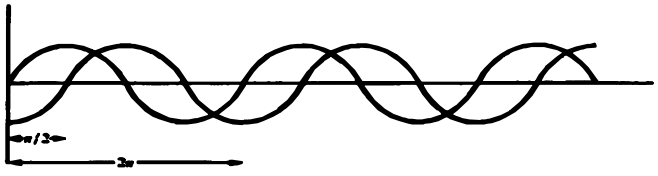
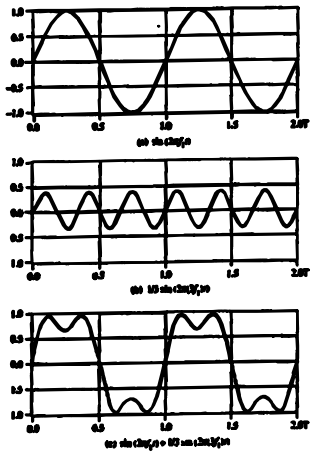



Fig 2.3a+2.4

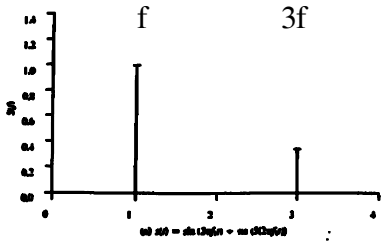
# Time Domain vs Frequency Domain



f

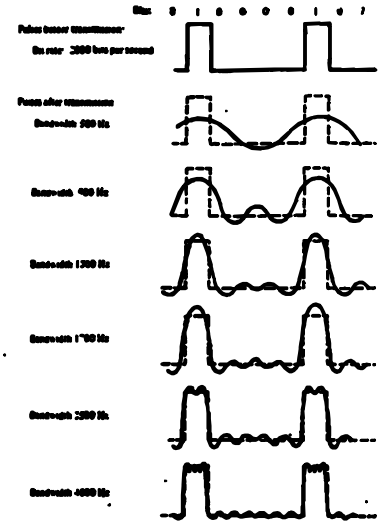
3f.

f + 3f

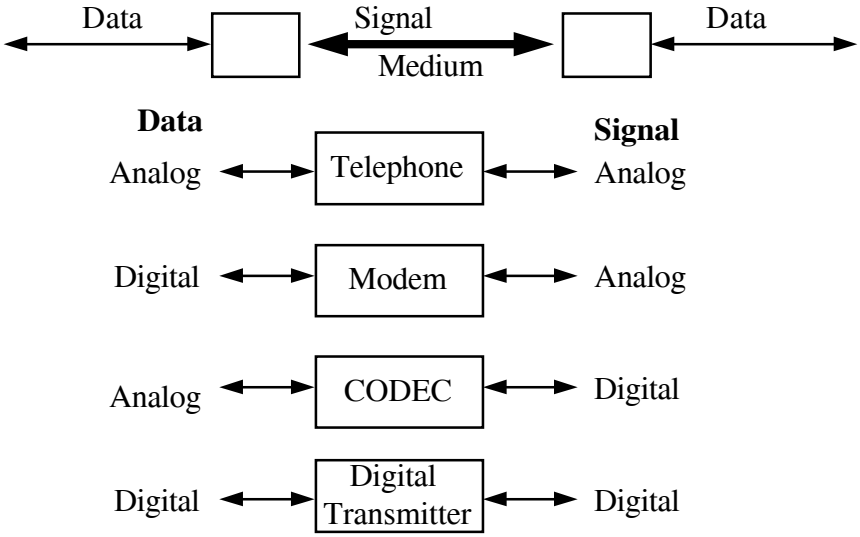





# Effect of Bandwidth

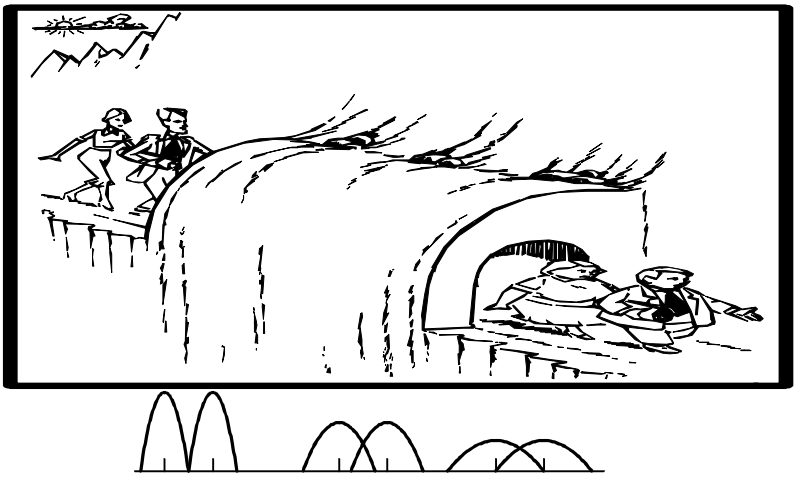


# Data vs Signal






# Attenuation and Dispersion (Delay Distortion)



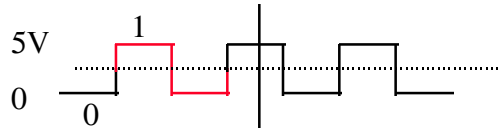
# Decibels

- Attenuation = $\text{Log}_{10} \frac{\text{Pin}}{\text{Pout}}$ Bel
- Attenuation = $10\ \text{Log}_{10} \frac{\text{Pin}}{\text{Pout}}$ deciBel
- Attenuation = $20\ \text{Log}_{10} \frac{\text{Vin}}{\text{Vout}}$ deciBel Since $P=V^2/R$
- **Example 1**: Pin = 10 mW, Pout=5 mW
  Attenuation = $10 \log_{10} (10/5) = 10 \log_{10} 2 = 3$ dB
- **Example 2**: Pin = 100mW, Pout=1 mW
  Attenuation = $10 \log_{10} (100/1) = 10 \log_{10} 100 = 20$ dB

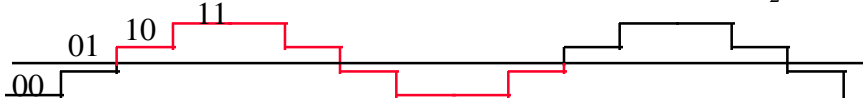


# Channel Capacity

- Capacity = Maximum data rate for a channel
- **Nyquist Theorem**: Bandwidth = W
  Data rate $\leq 2$ W
- Bilevel Encoding: Data rate = 2 × Bandwidth




- Multilevel Encoding: Data rate = 2 × Bandwidth × $\log_2$ M




**Example**: M=4, Capacity = 4 × Bandwidth

# Noise

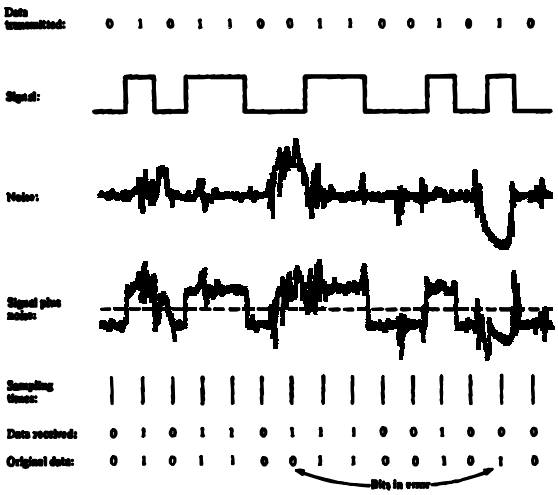


Fig 2.15



# Shannon's Theorem

- Capacity = Bandwidth × $\log_2$ (1+ signal/noise)
- Example: Phone wire bandwidth = 3100 Hz

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

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

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

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

$$\text{Capacity} = 3100 \log_2 (1+1000)$$

$$= 30{,}894 \text{ bps}$$

# Thermal Noise

- Due to thermal agitation of electrons in the media and devices
- Uniformly distributed across the frequency spectrum
- It cannot be eliminated ⇒ Upper bound on capacity
- Thermal noise = kTW watts
  - k = Boltzman's constant =$1.3803 \times 10^{-23}$ Joules/ ° K
  - T = Temperature in ° K
  - W = Bandwidth
- Noise density $N_0$ = Noise per Hertz = kT



# Bit Error Rate

- Energy/bit $E_b = ST_b$, where $T_b$ = bit time
- For each code, $E_b/N_0$ and bit error rates are related
- **Example**: For a particular coding, $10^{-4}$ BER is achieved if $E_b/N_0$ is 8.4 dB. How much signal is required for 2400 bps at 290°K?

$T_b$ = bit time = 1/2400 second ⇒ $E_b$=S/2400

$N_0 = kT$

$E_b/N_0 = S/(2400kT)$

in dB: $10\text{Log}(S/2400kT) = 8.4$

$10 \text{ Log } S = 8.4 + 10 \text{ Log } 2400 + 10 \text{ Log } k + 10 \text{ log } T$

$= -161.8$ dBW

# Transmission Media

- Twisted pair
- coaxial cable
- Optical Fiber
- Radio
- Terestrial Microwave
- Satellite Microwave



# Twisted Pair

- Unshielded Twisted Pair (UTP)
  - Category 3 (Cat 3): Voice Grade. Telephone wire.
  - Category 4 (Cat 4)
  - Category 5 (Cat 5): Data Grade. Better quality.

  100 Mbps over 50 m possible
- Shielded Twisted Pair (STP)

# Coaxial Cable

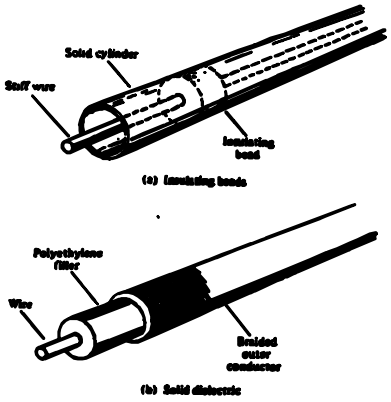
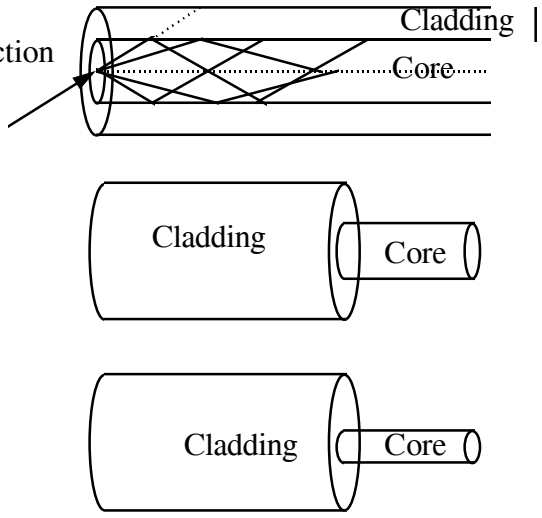



Fig 2.20



# Optical Fiber

- Modes
  Index=Index of referection
  =Speed in Vacuum/
  Speed in medium
- Multimode
- Single Mode

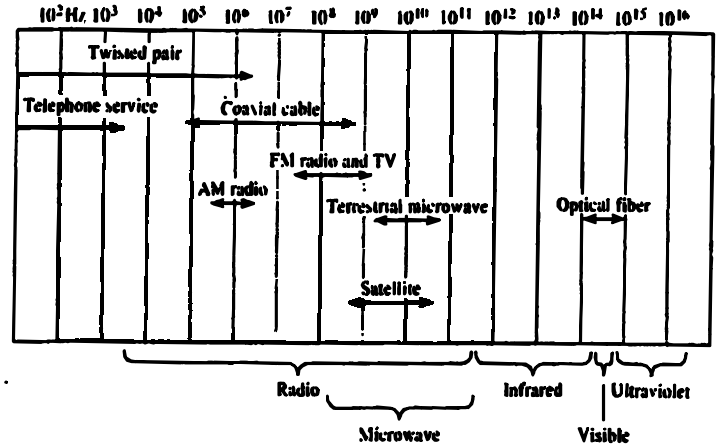


# Radio

- Omnidirectional
- 30 MHz to 1 GHz ⇒ FM, UHF, VHF
- Short distance and low data rates
- Maximum distance slightly more than 7.14 $(Kh)^{1/2}$
- Attenuation = 10 log $(4\pi d/\lambda)^2$
  d=distance, λ=wavelength, λf=c
- Less attenuation since λ is large
- Multipath interference
- Used in Aloha system:
  407.35 MHz for transmicsion from users and
  413.35 MHz to users
  100 kHz bandwidth, 9600 bps, 30 km



# Electromagnetic Spectrum



# Terrestrial Microwave

- Above 100 MHz, Line of sight communication
- Parabolic dish antenna 10 ft diameter
- Maximum distance d = 7.14 $(Kh)^{1/2}$ km
  K= adjustment factor =4/3, h=height in m
  Example: h=100 m d=7.14 $(133)^{1/2}$ =82 km
- Typical data rates:

| Band | Bandwidth | Data Rate |
|---|---|---|
| GHz | MHz | Mbps |
| 2 | 7 | 12 |
| 6 | 30 | 90 |
| 11 | 40 | 90 |
| 18 | 220 | 274 |

- Attenuation L = 10 log $(4\pi d/\lambda)^2$ dB; d=distance, $\lambda$=wavelength



# Satellite Microwave

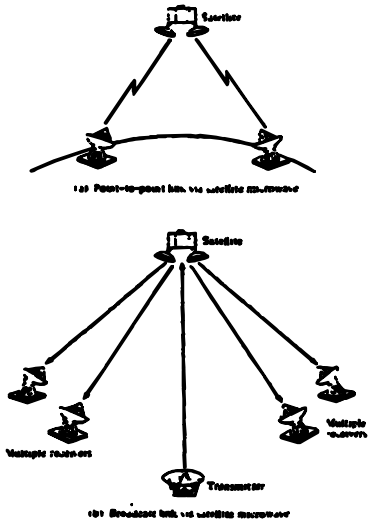


Fig 2.23

# Summary

- Time domain vs frequency domain
- Data rate vs Bandwidth
- Data vs Signal, Analog vs Digital
- Attenuation, Dispersion (delay distortion), noise
- Media: Twisted pair, coaxial, fiber, microwave, radio



# Homework

- Exercises 2.7, 2.17, 2.20