Data Transmission

Raj Jain
Professor of CSE
Washington University in Saint Louis
Saint Louis, MO 63130
Jain@cse.wustl.edu

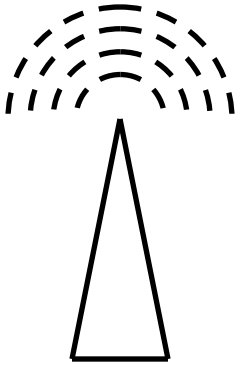
These slides are available on-line at:
http://www.cse.wustl.edu/~jain/cse473-05/

Overview

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

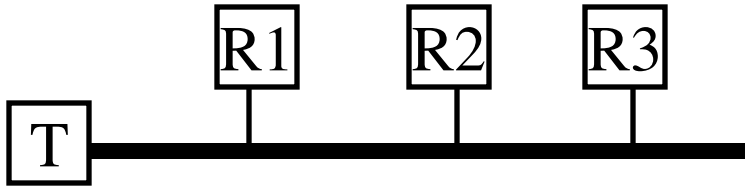
Transmission Terminology

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



- **Direct Link**

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



Line Duplexity

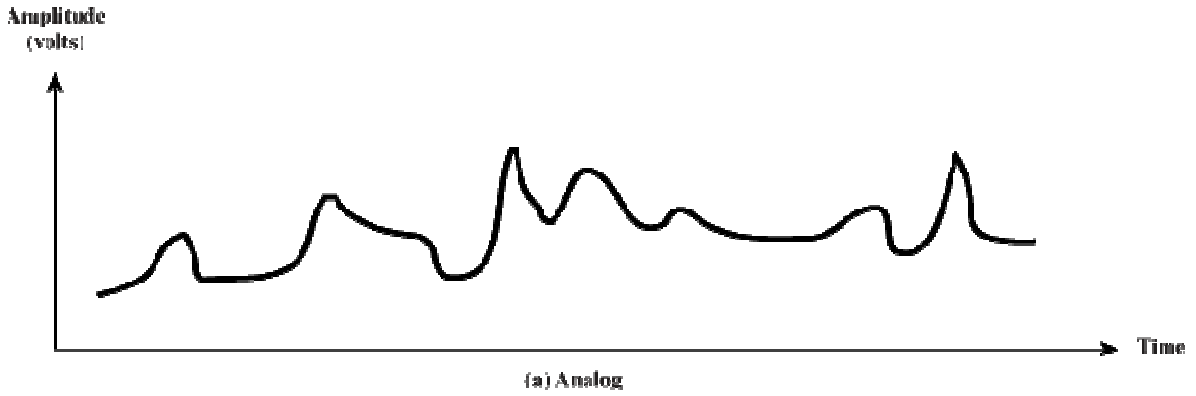
- Simplex: Transmit or receive,
  e.g., Television

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

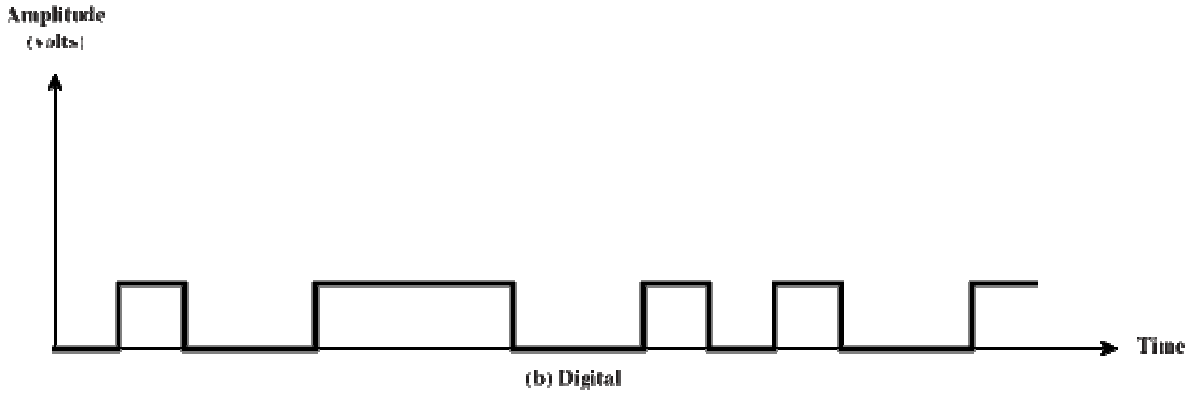
- Half-Duplex: Transmit and receive alternately,
  e.g., Police Radio

Analog vs Digital Signals

- **Analog:**

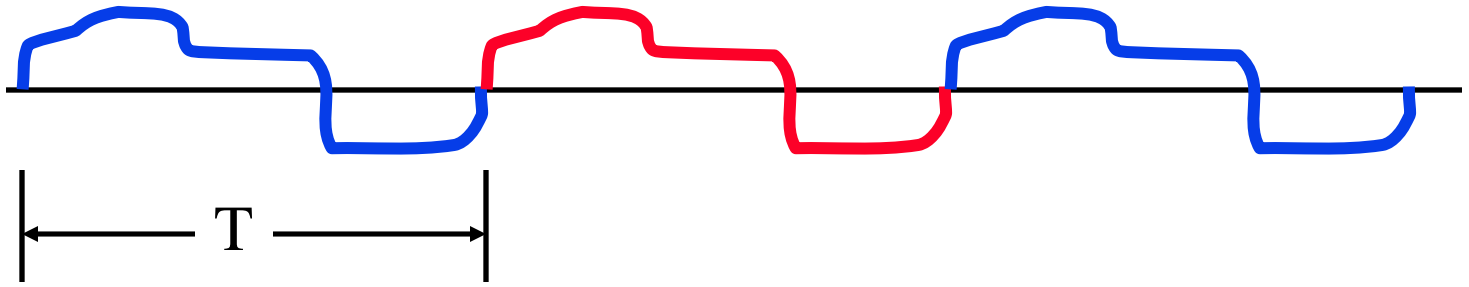


- **Digital:**



Periodic vs Aperiodic

- Periodic: Signal pattern repeats over time



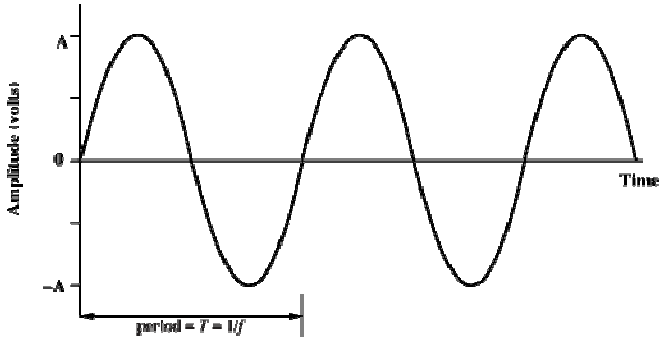
$$S(t+T) = s(t) \text{ for all t}$$

Period = T

- Aperiodic: Not periodic

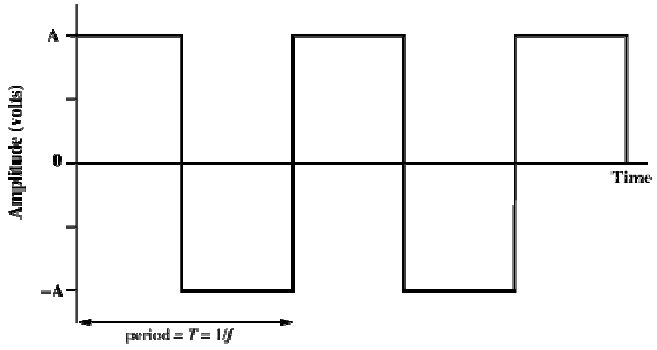
Examples of Periodic Signals

- **Sine Wave**:



(a) Sine wave

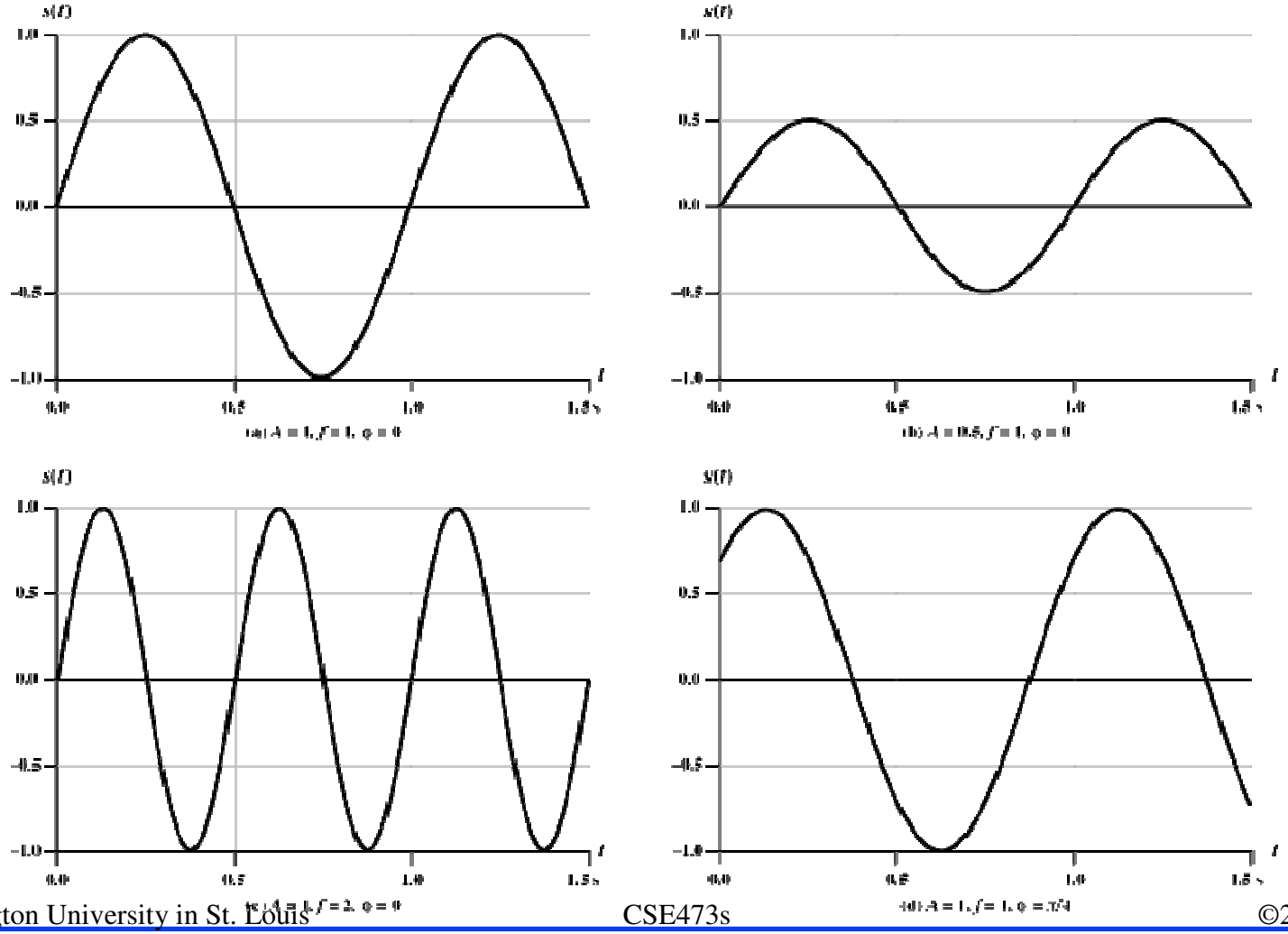
- **Square Wave**:



(b) Square wave

Frequency, Period, and Phase

- A Sin(2πft + θ), Period T=1/f, Frequency in **Hertz**



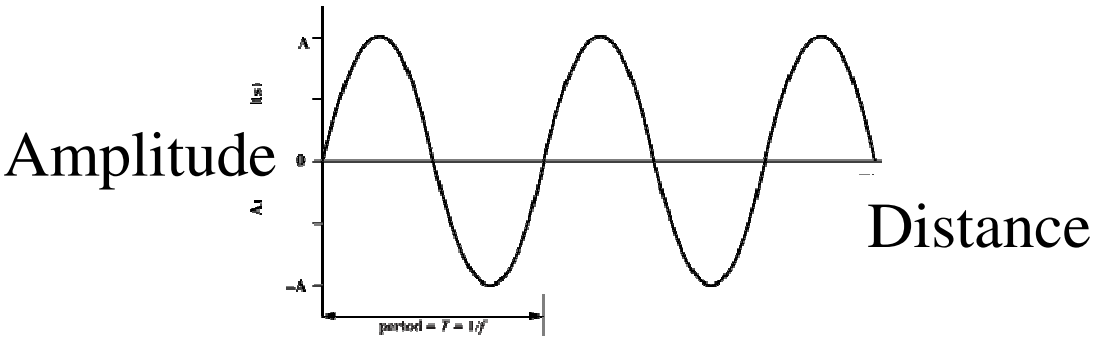
Sine Wave

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

$$T = 1/f$$

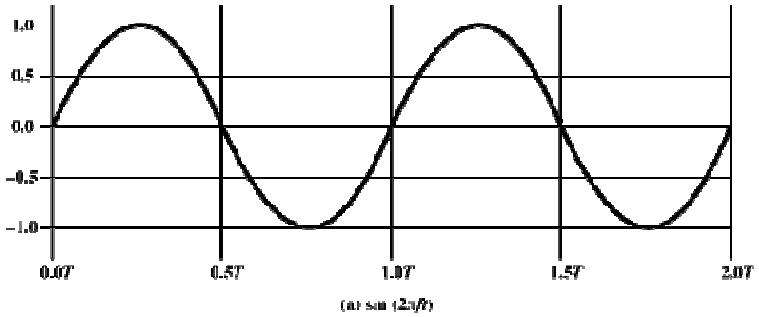
- **Phase** (ϕ): Relative position in time

Wavelength

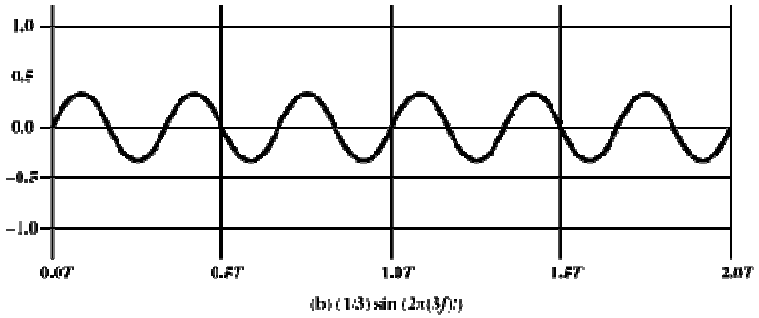


- Distance occupied by one cycle
- Distance between two points of corresponding phase in two consecutive cycles
- Wavelength = λ
- Assuming signal velocity v
  - $\lambda = vT$
  - $\lambda f = v$
  - c = $3*10^8$ m/s (speed of light in free space) = 300 m/μs

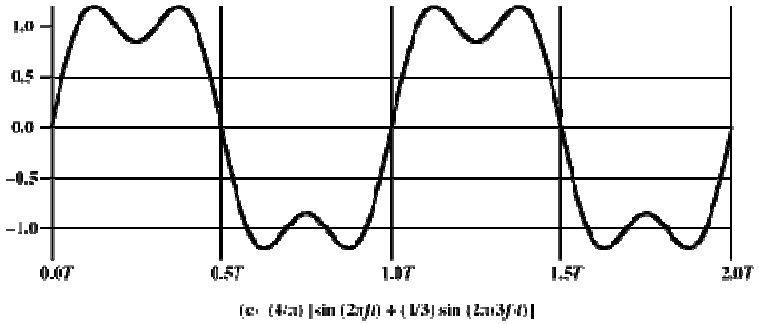
Time and Frequency Domains



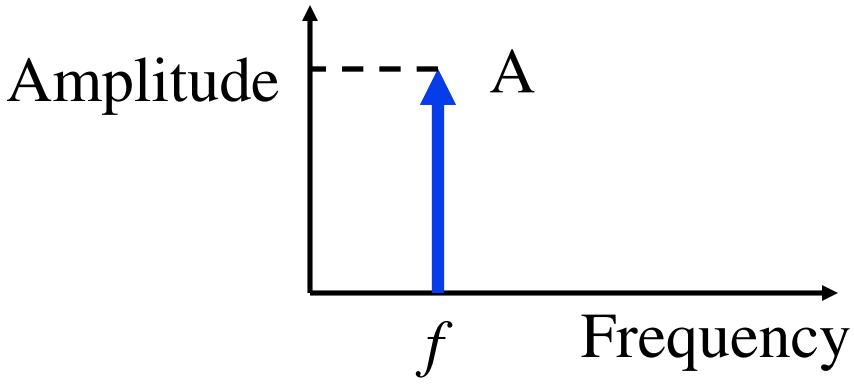
(a) $\sin(2\pi ft)$

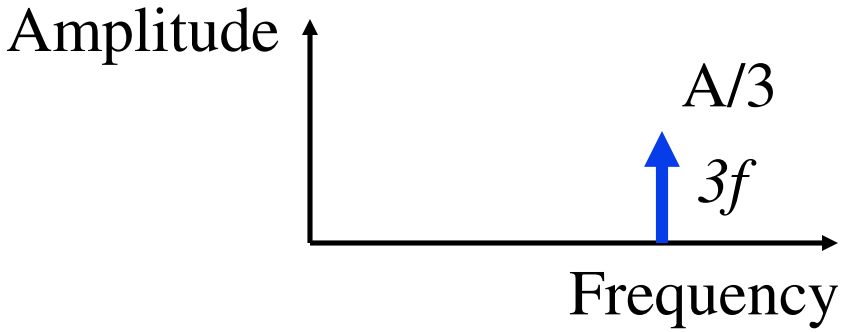


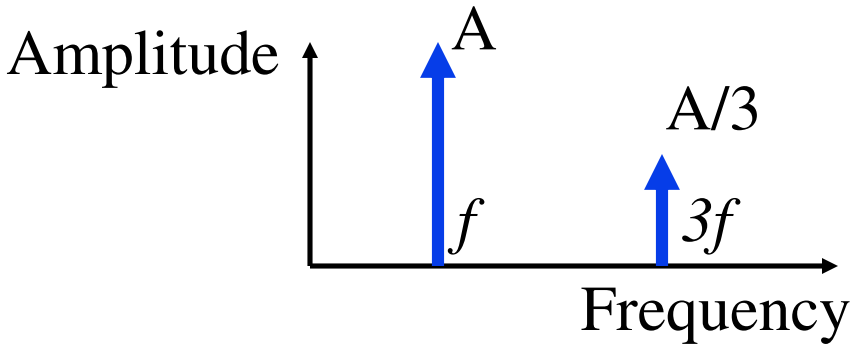
(b) $(1/3)\sin(2\pi(3f)t)$



(c) $(4/\pi)[\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t)]$







Frequency Domain Concepts

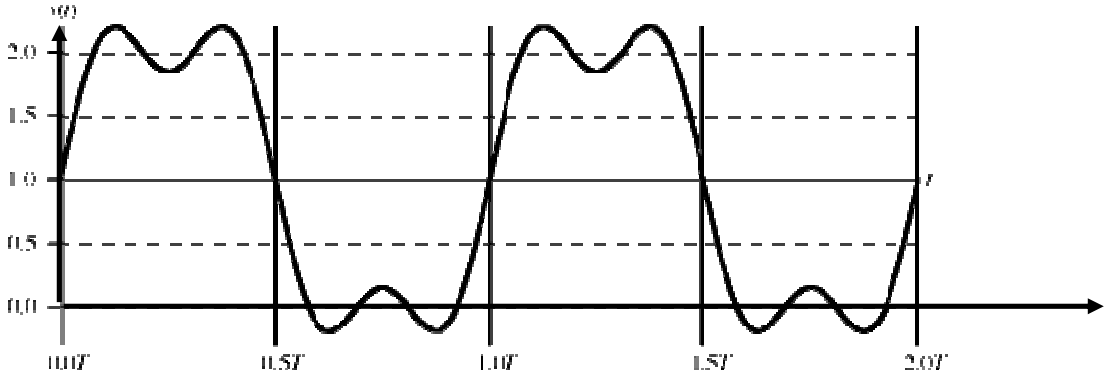
- **Fundamental Frequency**: All other frequency components are multiple of fundamental frequency f
- **Period** = 1/f
- **Spectrum**: Range of frequencies
- **Absolute Bandwidth**: Width of the spectrum

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

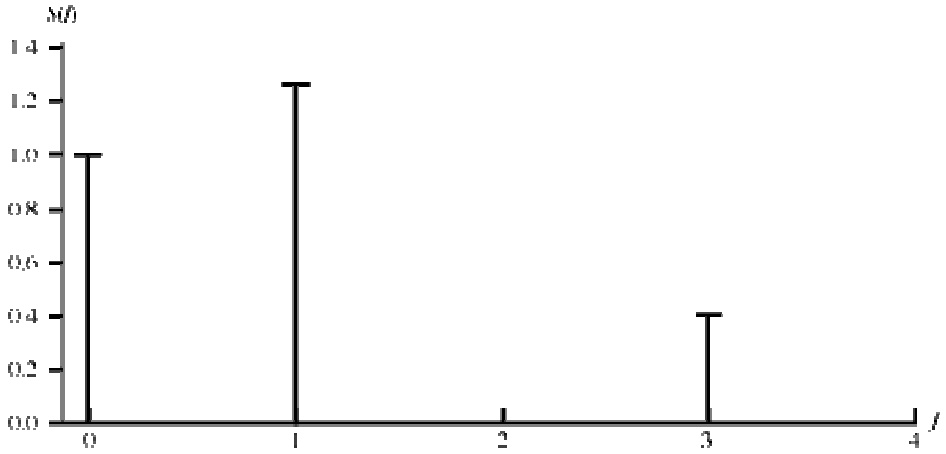
- **Effective Bandwidth:** Narrow band of frequencies containing most of the energy
- **DC Component**: Constant or zero frequency

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

Signal with DC Component

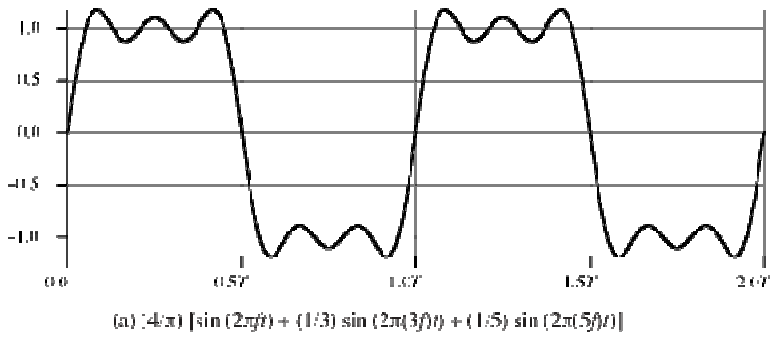


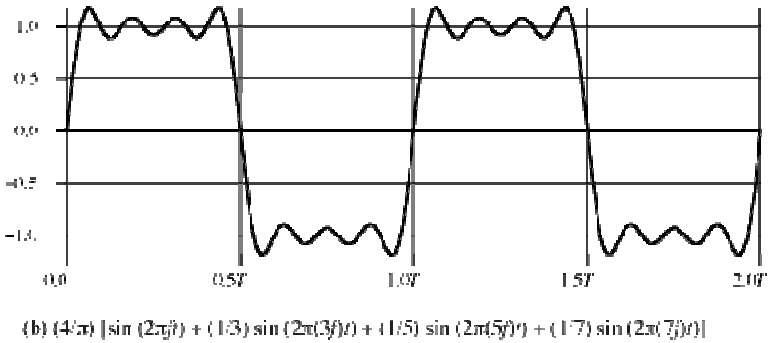
(a) $s(t) = 1 + (4/\pi)[\sin(2\pi f t) + (1/3)\sin(2\pi(3f)t)]$

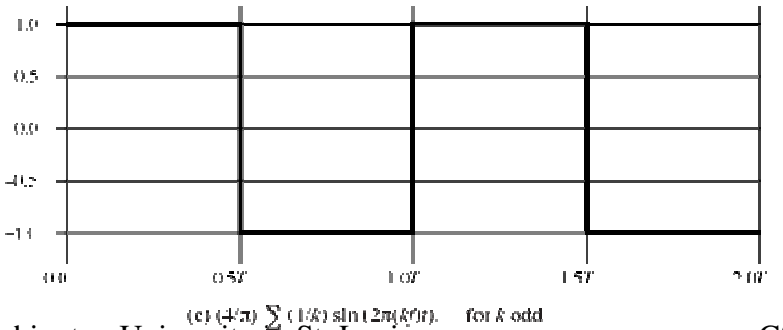


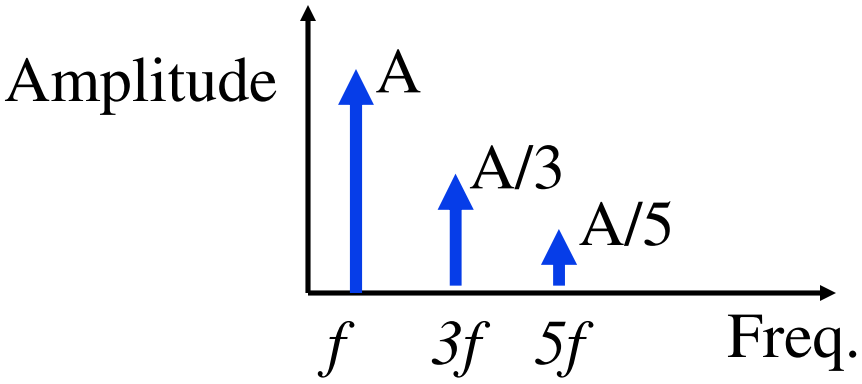
(b) $S(f)$

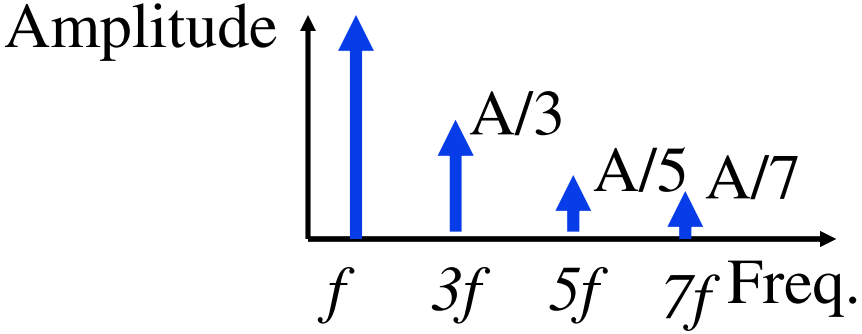
Frequency Components of Square Wave







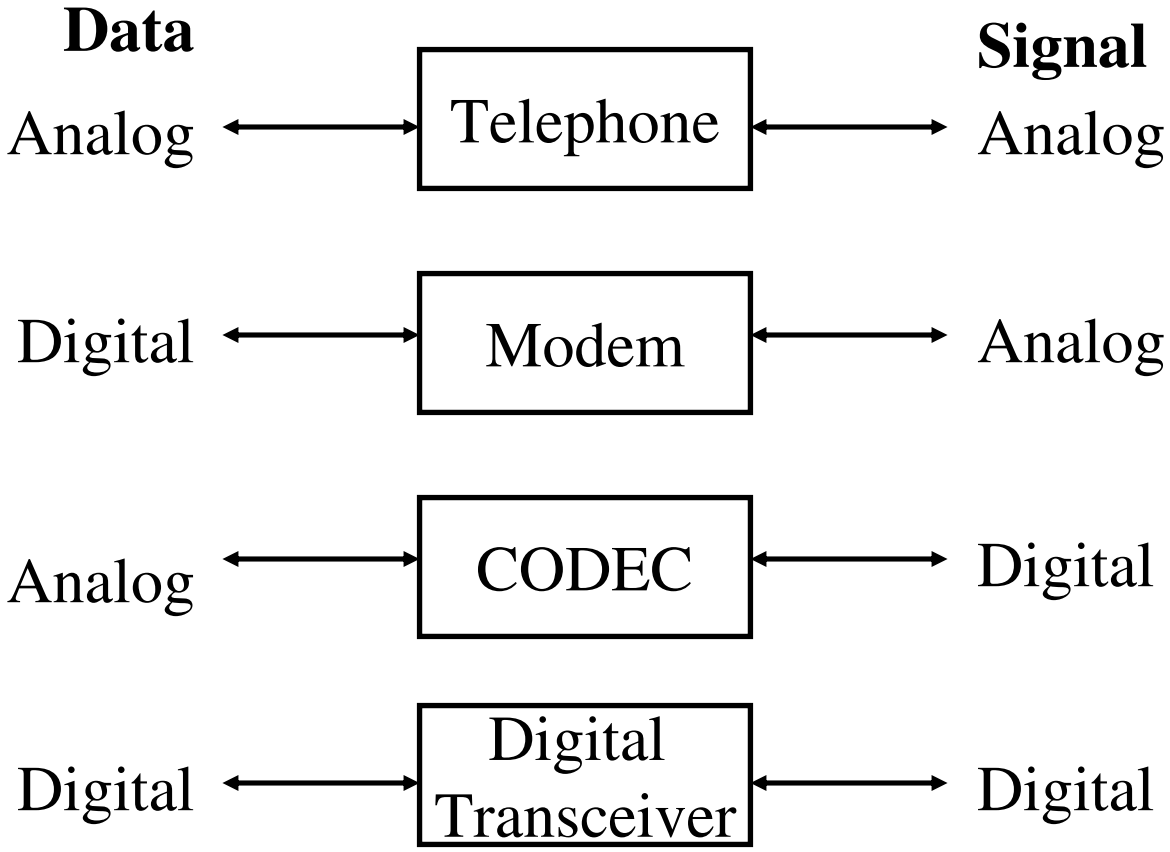




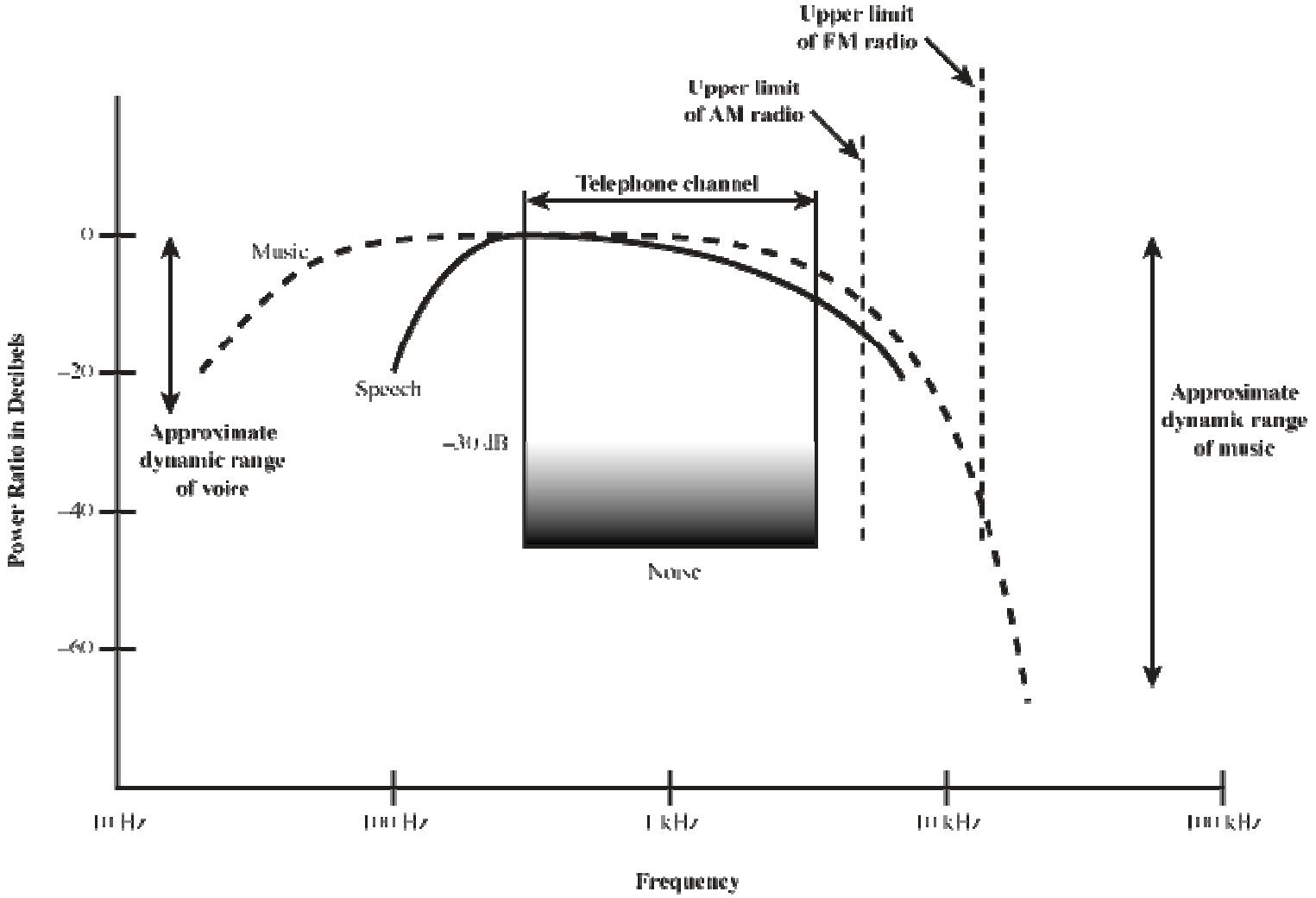
$$\Sigma_{k=1,3,5,} \quad A/k \sin(2\pi kft)$$

Frequency

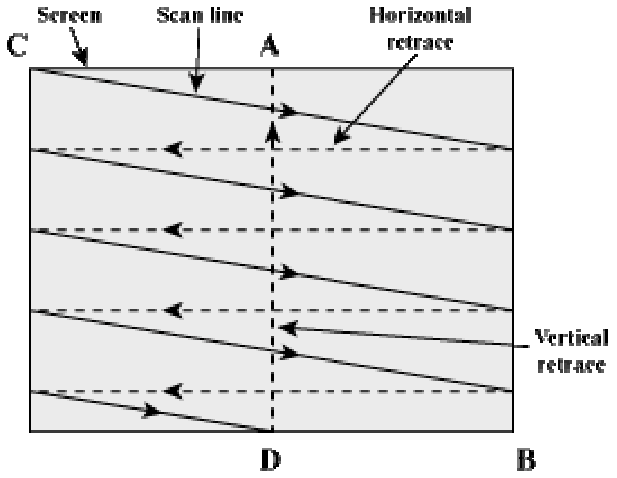
Data vs Signal



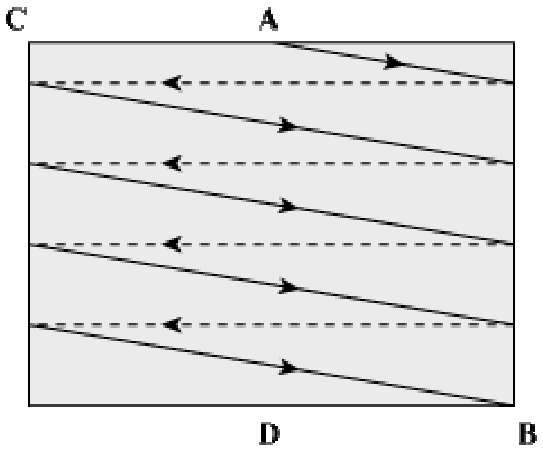
Analog Data Example: Speech and Music



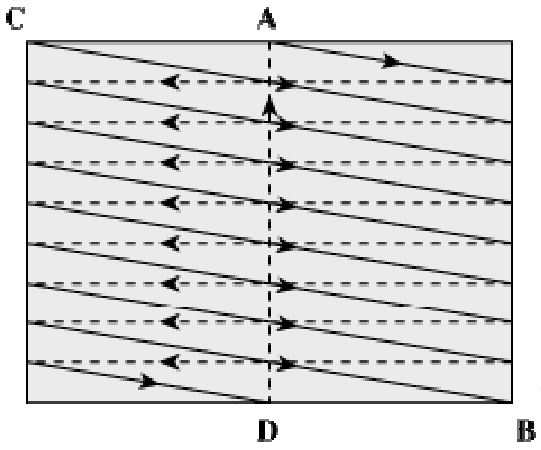
Analog Data Example 2: Television



(a) Even field only



(b) Odd field only



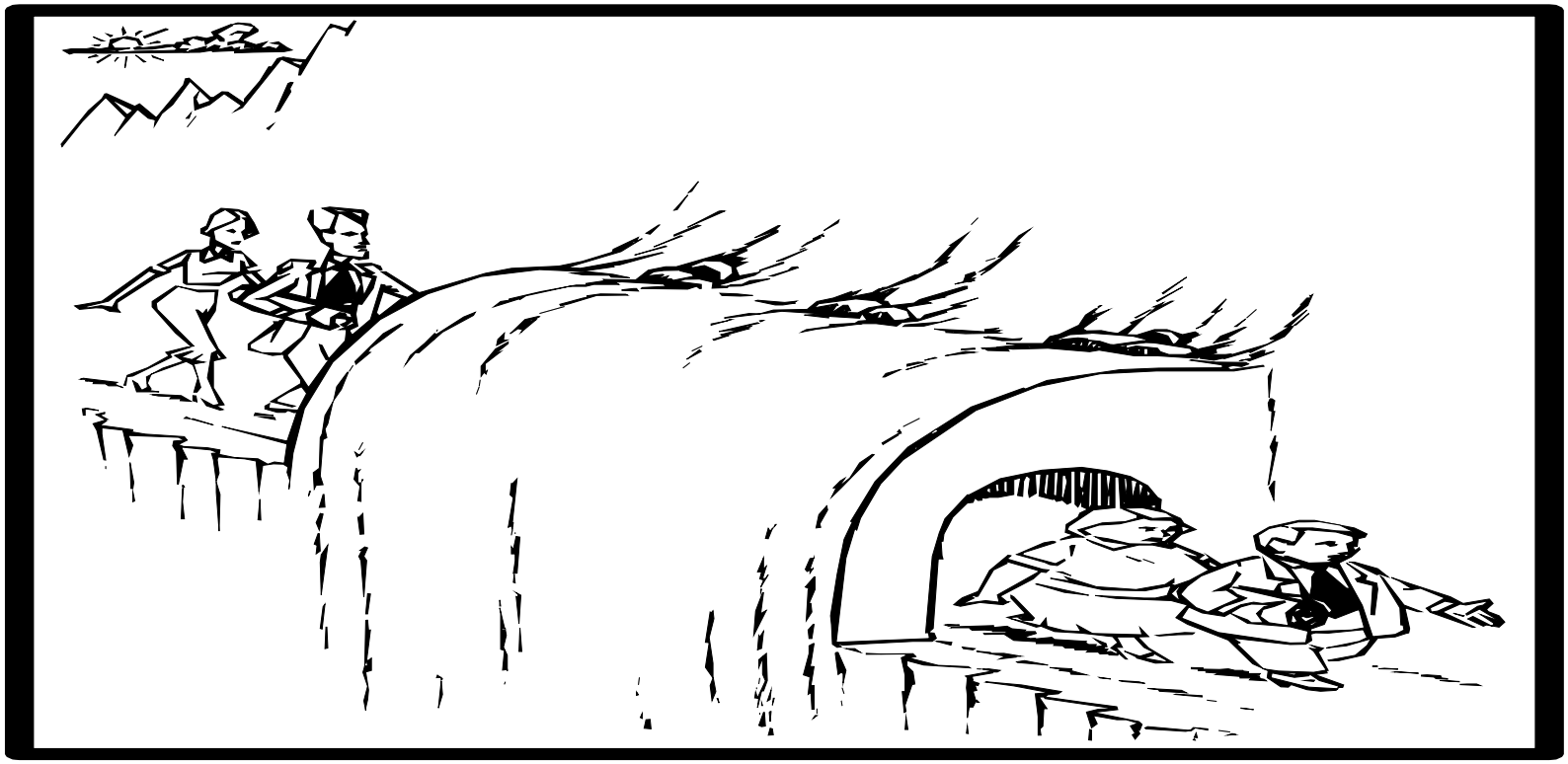
(c) Odd and even fields

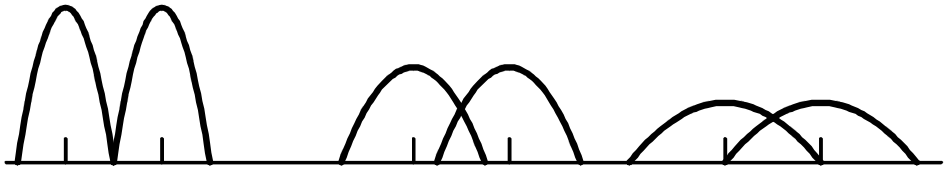
30 Screens/sec
Interlacing: Odd lines every 1/60 s
and even lines every 1/60 s
483 lines/screen

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
  - 63.5µs 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

Attenuation and Dispersion (Delay Distortion)





Distance →

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

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
- **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

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

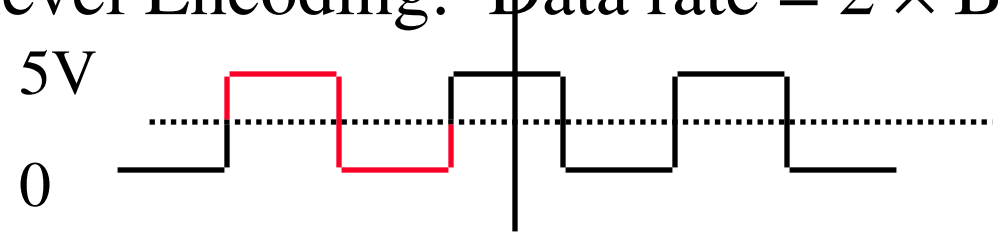
Noise (Cont)

- **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 ≤ 2 B
- Bi-level Encoding: Data rate = 2 × Bandwidth



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

Example: M=4, Capacity = 4 × 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

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

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

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

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

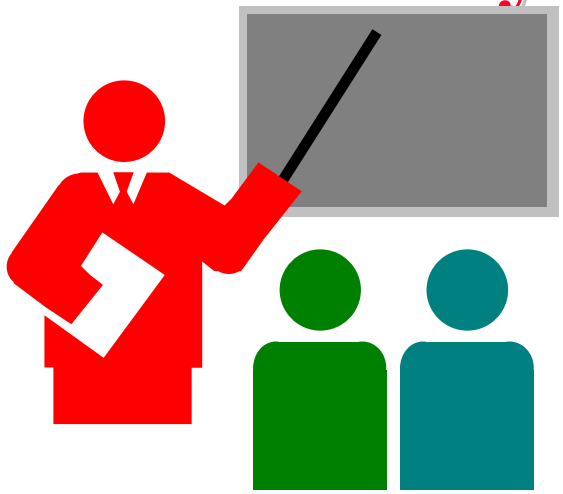
$$\text{Capacity} = 3100 \log_2 (1+1000)$$

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

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 21ºC
  - 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 = $10 \log_{10} N$
    $= 10\log_{10}(1.38 \times 10^{-23)} + 10\log_{10}(294.15) + 10 \log_{10} (10^{7})$
    $= -228.6 + 24.7 + 70 = -133.9$ 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.