Chapter 2: Physical Layer

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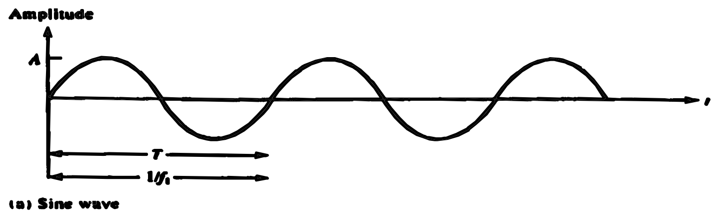
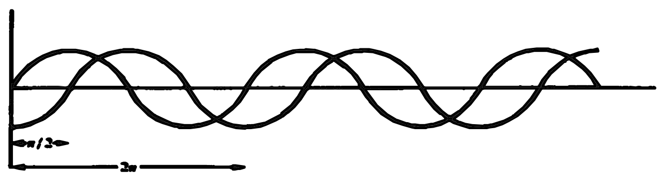
- Frequency domain vs time domain
- Bandwidth of a channel
- Transmission Media
  - UTP, Coax, Fiber
  - Wireless: Radio, Microwave, Satellite

Frequency, Period, and Phase

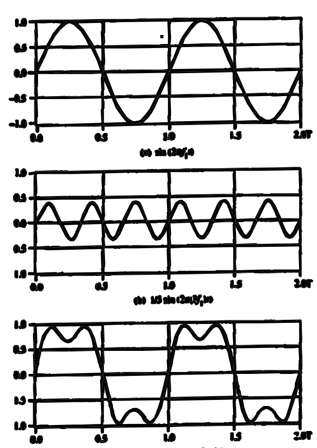
- A Sin(2πft+ θ)



- A Sin(2πft) and A Sin(2πft+ π/2)



Time Domain vs Frequency Domain

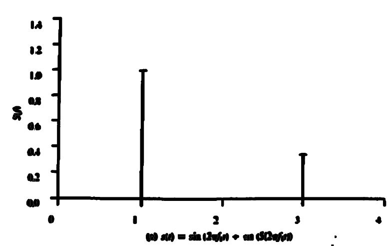


f

3f

f + 3f

f 3f



Fourier Analysis

- Information can be transmitted on wires by varying voltage or current
- Any reasonable periodic function g(t) with period T can be constructed as
- $g(t) = 1/2\, c + \Sigma\, (a_n \sin(2\pi nft)) + \Sigma\, b_n \cos(2\pi nft)$
- Where, f = 1/T is the fundamental frequency
- a_n and b_n amplitudes can be computed from g(t) by integration

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Bandwidth-Limited Signals

- Suppose we want to transmit the ASCII character "b"
- This translates to the bit pattern 01100010
- Fourier analysis gives
  $a_n = 1 / \pi n\, [\cos(\pi n/4) - \cos(3 \pi n/4) + \cos(6 \pi n/4) - \cos(7 \pi n/4)]$ and
  $b_n = 1 / \pi n\, [\sin(3 \pi n/4) - \sin(\pi n/4) + \sin(7 \pi n/4) - \sin(6 \pi n/4)]$
  with c = 3/8
- Root mean square = RMS = ✔$(a_n^2 + b_n^2)$
  $RMS^2 \propto$ Energy transmitted at nth frequency

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Time vs Frequency Domain

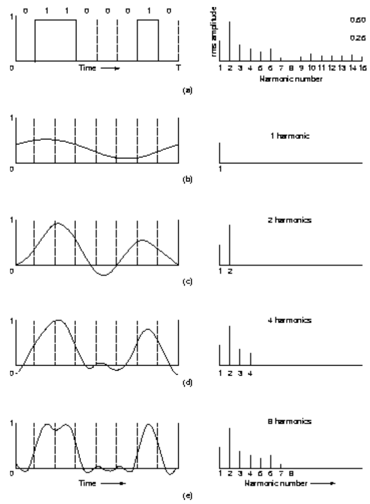

Fig 2.1

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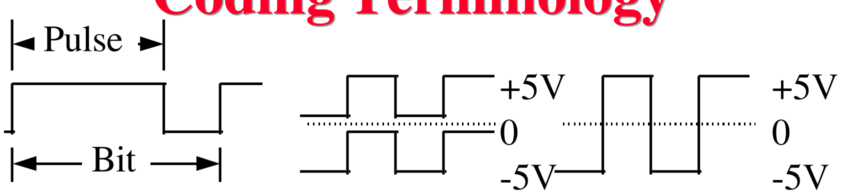
Coding Terminology



- Signal element: Pulse
- Modulation Rate: 1/Duration of the smallest element
  =Baud rate
- Data Rate: Bits per second
- Data Rate = Fn(Bandwidth, signal/noise ratio, encoding)

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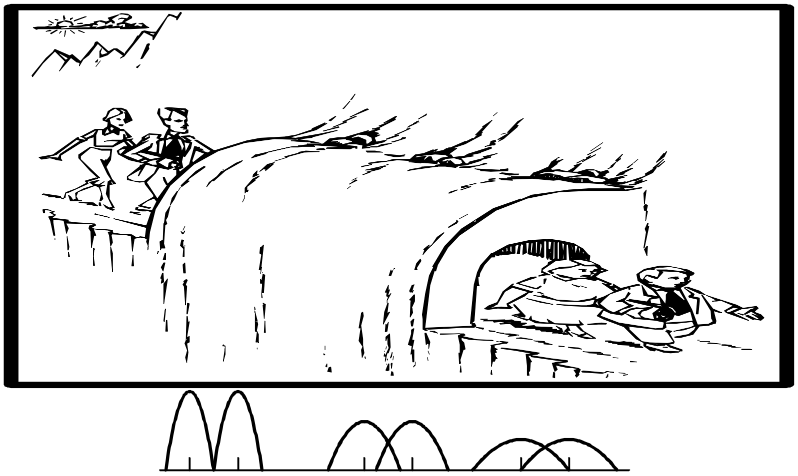
Attenuation and Dispersion



Distance →

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Decibels

- Attenuation $= \text{Log}_{10} \dfrac{\text{Pin}}{\text{Pout}}$ Bel
- Attenuation $= 10\ \text{Log}_{10} \dfrac{\text{Pin}}{\text{Pout}}$ deciBel
- Attenuation $= 20\ \text{Log}_{10} \dfrac{\text{Vin}}{\text{Vout}}$ 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

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Signal Distortion

- All transmission facilities diminish different Fourier components by different amounts, introducing distortion
- Frequencies above a certain cutoff frequency f_c (measured in cycle/second or Hertz) are strongly attenuated ⇒ Bandwidth of the medium

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Maximum Data Rate of a Channel

- Nyquist's Theorem: No noise
- Shannon's Theorem: Noise
- Thermal noise is measured by the signal-to-noise ratio (S/N).
- Usually $10 \log_{10}$ S/N is given (in decibels or dB)

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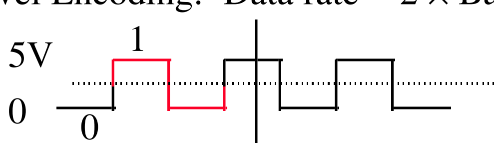
Nyquist's Theorem

- If a signal passes through a low-pass filter of bandwidth H, and the signal consists of V discrete levels, then
- Maximum Date Rate = 2 H $\log_2$ V bits/sec
- This means that signal can be completely reconstructed by making only 2 H samples per second
- Example: A noiseless 3 kHz channel cannot transmit binary signals at a rate exceeding 6000 bps

Nyquist's Theorem (Cont)

- **Nyquist Theorem**: Bandwidth = H
  Data rate $\leq$ 2 H $\log_2$V
- Bilevel Encoding: Data rate = 2 $\times$ Bandwidth



- Multilevel Encoding: Data rate = 2$\times$Bandwidth $\times\log_2$ V

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

Shannon's Theorem

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

$$S/N = 30 \text{ dB}$$
$$10 \text{ Log}_{10} S/N = 30$$
$$\text{Log}_{10} S/N = 3$$
$$S/N = 10^3 = 1000$$
$$\text{Capacity} = 3100 \log_2 (1+1000)$$
$$= 30{,}894 \text{ bps}$$

Transmission Media

- Magnetic Media: Physically transfer data stored on a magnetic tape or floppy disk
- Guided Media: UTP, STP, Coax, Fiber

Twisted Pair

- Unshielded Twisted Pair (UTP)
  - Category 3 (Cat 3): Voice Grade. Telephone wire. Twisted to reduce interferece
  - Category 4 (Cat 4)
  - Category 5 (Cat 5): Data Grade. Better quality. More twists per centimeter and Teflon insulation

  100 Mbps over 50 m possible

- Shielded Twisted Pair (STP)

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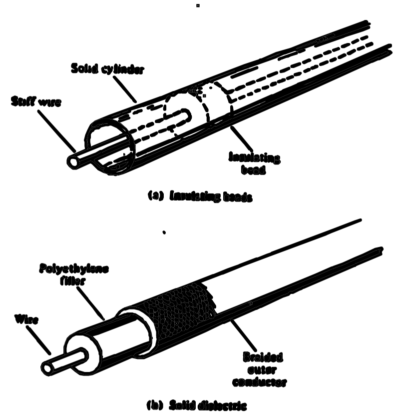
Coaxial Cable



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Baseband Coaxial Cable

- Better sheilding
  $\Rightarrow$ longer distances and higher speeds
- 50-ohm cable used for digital transmission
- Construction and shielding
  $\Rightarrow$ high bandwidth and noise immunity
- For 1 km cables, 1-2 Gbps is feasible
- Longer cable $\Rightarrow$ Lower rate

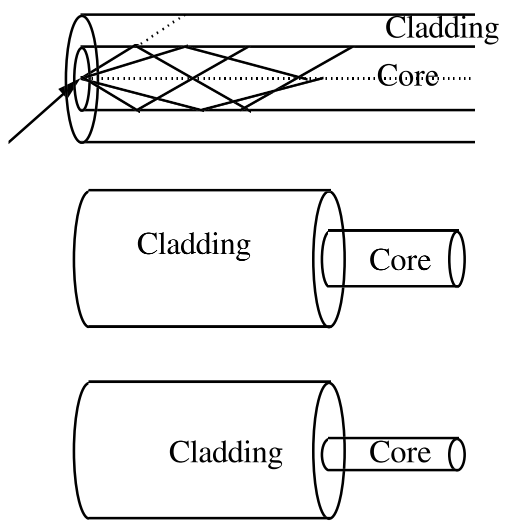
Broadband Coaxial Cable (Cont)

- 75-ohm cable used for analog transmission (standard cable TV)
- Cables go up to 450 MHz and run to 100 km because they carry analog signals
- System is divided up into multiple channels, each of which can be used for TV, audio or converted digital bitstream
- Need analog amplifiers to periodically strengthen signal

- Dual cable systems have 2 identical cables and a head-end at the root of the cable tree
- Other systems allocate different frequency bands for inbound and outbound communication, e.g. subsplit systems, midsplit systems

Optical Fiber

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



Fiber Optics

- With current fiber technology, the achievable bandwidth is more than 50,000 Gbps
- 1 Gbps is used because of conversion from electrical to optical signals
- Error rates are negligible
- Optical transmission system consists of light source, transmission medium and detector

- Pulse of light indicates a 1-bit and absence 0-bit
- Detector generates electrical pulse when light falls on it
- Refraction traps light inside the fiber
- Fibers can terminate in connectors, be spliced mechanically, or be fused to form a solid connection
- LEDs and semiconductor lasers can be used as sources
- Tapping fiber is complex $\Rightarrow$ topologies such as rings or passive stars are used

Wavelength Bands

- 3 wavelngth bands are used

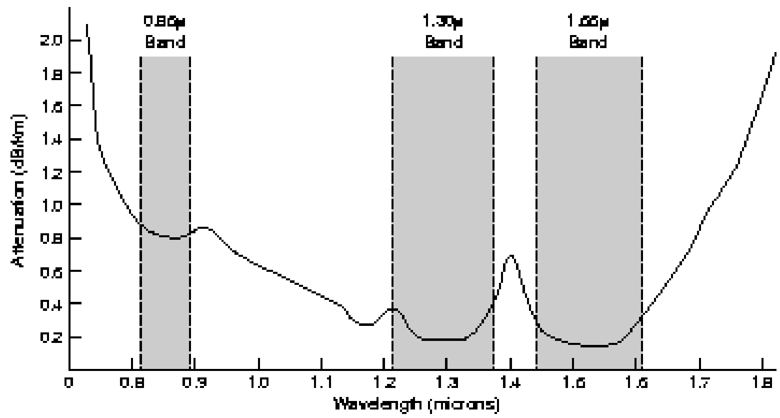


Fig 2-6

Wireless Transmission

- The Electromagnetic Spectrum
- Radio Transmission
- Microwave Transmission
- Infrared and Millimeter Waves
- Lightwave Transmission
- Satellite Transmission

Electromagnetic Spectrum

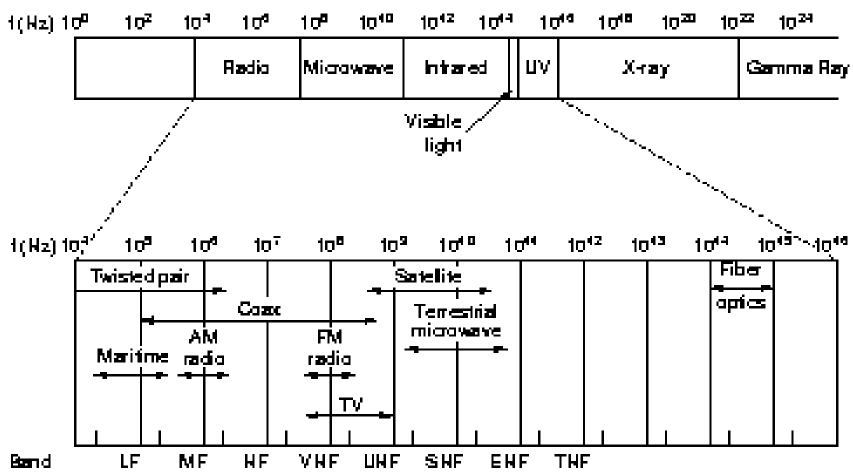


Fig 2-11

The Electromagnetic Spectrum

- Electromagnetic waves oscillate at a certain frequency f
- The distance between 2 consecutive maxima is the wavelength λ
- An antenna can broadcast electromagnetic waves
- Electromagnetic waves travel at the speed of light, c, in vacuum

$$\lambda f = c$$

- Radio, microwave, infrared and visible light portions of the electromagnetic spectrum can be used to transmit information
- Given wavelength, we can compute data rate

$$df / d\lambda = -c / \lambda^2$$

$$\Delta f = c \Delta\lambda / \lambda^2$$

- In USA, FCC allocates spectrum

Radio Transmission

- Easy to generate, travel long distances in all directions and easily penetrate buildings
- At low frequency, radio wave power falls off sharply with distance from the source
- At high frequencies, radio waves travel in straight lines, bounce off obstacles and are absorbed by rain
- Interference is a problem at all frequencies
- Bandwidth is relatively low

Microwave Transmission

- Above 100 MHz waves travel in straight lines
- S/N is high, but antennas must be accurately aligned
- Repeaters are needed periodically
- Signals do not easily pass through buildings
- Multipath fading
  $\Rightarrow$ waves do not arrive at the same time
- Easier to install than fiber
  $\Rightarrow$ widely used and inexpensive
- ISM bands

Infrared and Millimeter Waves

- Widely used for short-range communications
- Directional, cheap and easy to build, but do not pass through solid objects
- Secure $\Rightarrow$ no licensing is needed
- Used indoors and for LANs

Lightwave Transmission

- High bandwidth, cheap, easy to install and no licensing needed
- Laser beams cannot penetrate rain or thick fog

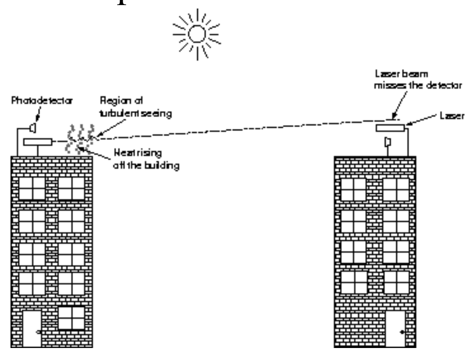


Fig 2-13

Communication Satellites

- Communication satellites can be used as microwave repeaters
- Each satellite contains several transponders, one for amplifying each portion of the spectrum

Geosynchronous Satellites

- Geosynchronous satellites are placed at high altitudes to be "fixed" in the sky
  - C band: 4/6 GHz
  - Ku band: 11/14 GHz
  - Ka band: 20/30 GHz
- Spot beams are small and highly focused
- Large delay (typically 270 ms) causes problems
- Satellites are inherently broadcast media
  ⇒ security risks
- Cost is independent of distance, and error rates are low

VSATs

- Very Small Aperture Terminals: Very low-cost microstations, but a special station, called hub is needed to relay traffic to VSATs

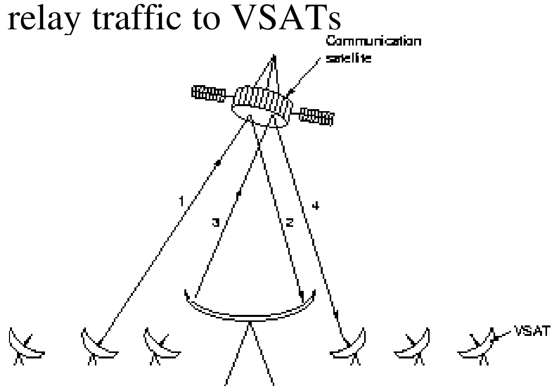


Fig 2-56

Low-Orbit Satellites

- As soon as a satellite goes out of view, another replaces it

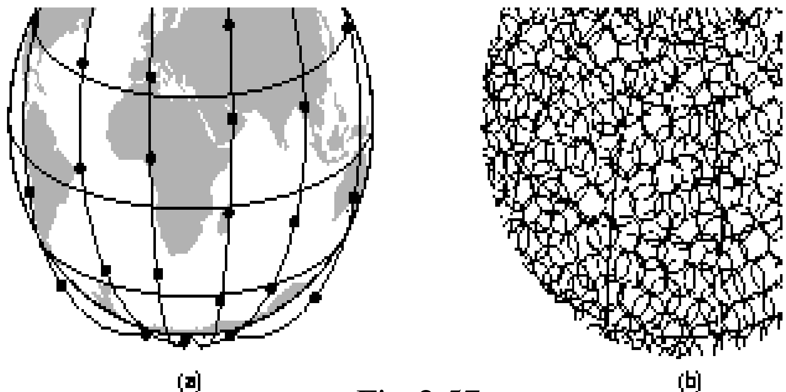


Fig 2.57

Summary

- Frequency domain and time domain
- Bit, Baud, Hertz
- Nyquist theorem and Shannon's Theorem
- UTP, Coax, Fiber, Radio, Microwave, Satellite
- Attenuation and Dispersion

Homework

- Problems 4, 8, 11
- Read sections 2.1, 2.2, 2.3, and 2.8