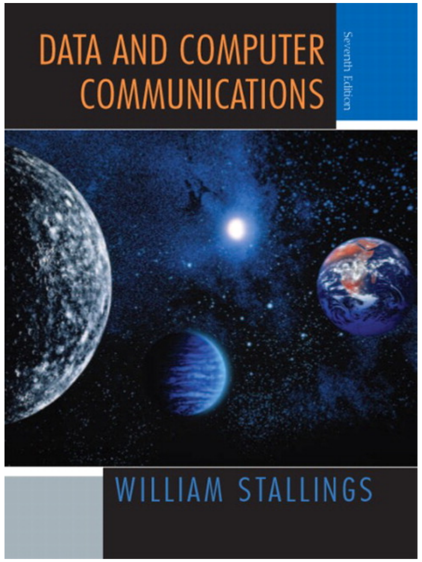
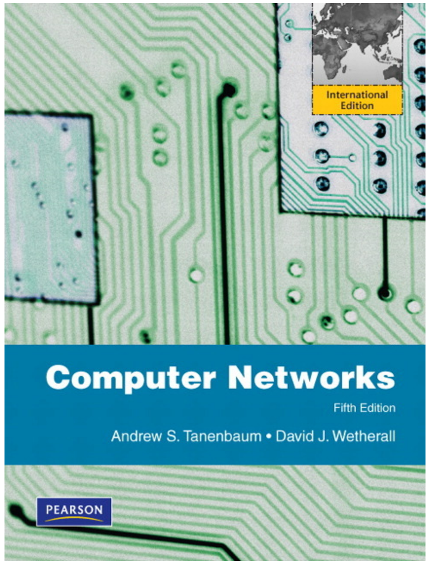
COMP211 Physical Layer



Data and Computer Communications
7th edition
William Stallings
Prentice Hall 2004



Computer Networks
5th edition
Andrew S. Tanenbaum, David J. Wetherall
Pearson 2011

Material adapted from Tanenbaum, Wetherall 2011 and Stallings 2004

Goal for this topic

- Learn some basic communications theory
- Get to know different types of transmission media

Physical Layer

- 7.1 Terminology
- 7.2 Data and Signals
  - analog vs. digital
  - periodic vs. nonperiodic
  - Frequency Domain Concepts
- 7.3 Transmission Impairments
- 7.4 Data Rate Limits
  - Nyquist Bandwidth
  - Shannon's Law
- 7.5 Guided Transmission Media
- 7.6 Wireless Transmission

Terminology (1)

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

Terminology (2)

- Direct link
  - No intermediate devices
- Point-to-point
  - Direct link
  - Only 2 devices share link
- Multi-point
  - More than two devices share the link

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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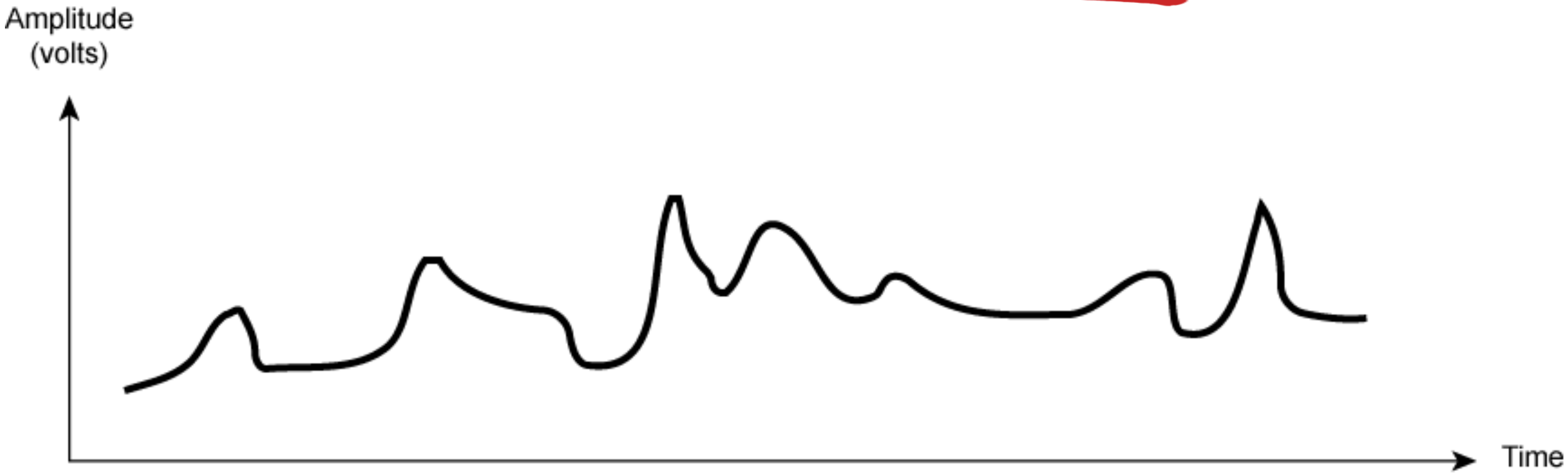
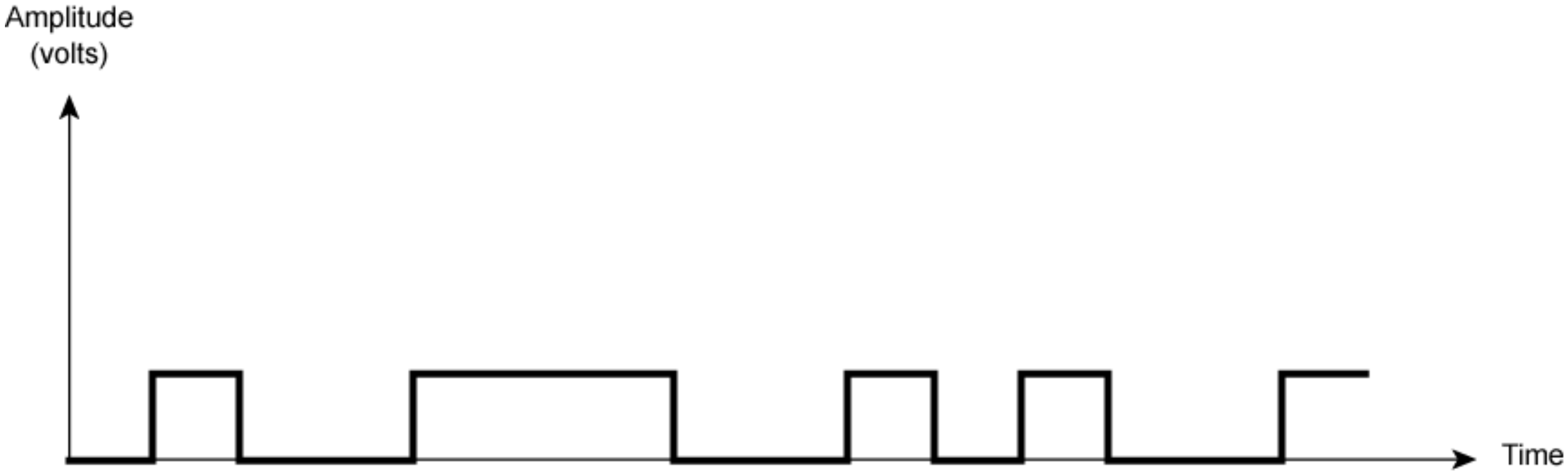
Frequency, Spectrum and Bandwidth

- Time domain concepts
  - Analog signal
    - Varies 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

Analogue & Digital Signals

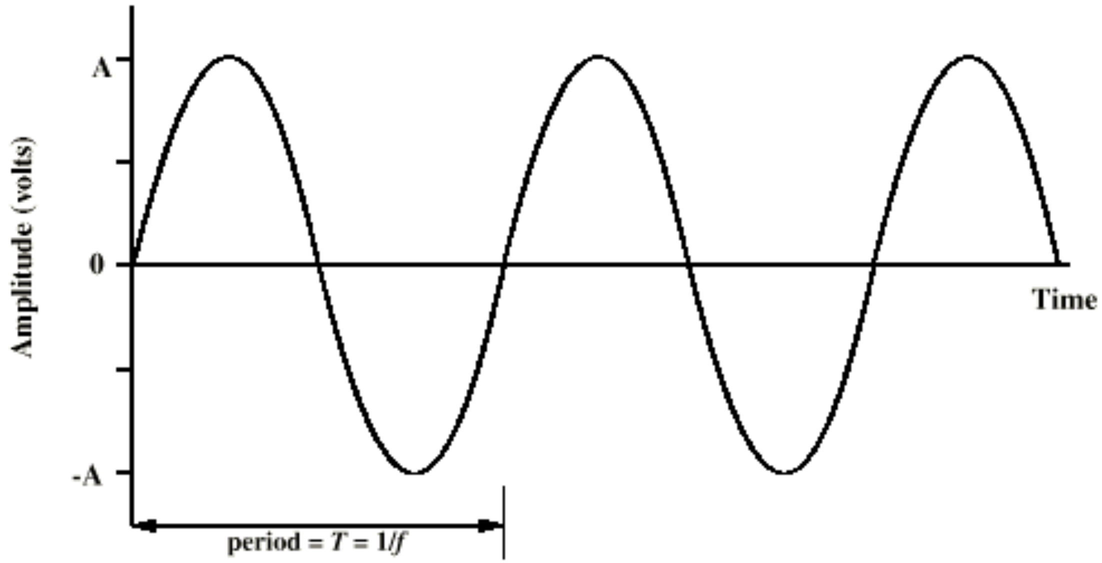


(a) Analog

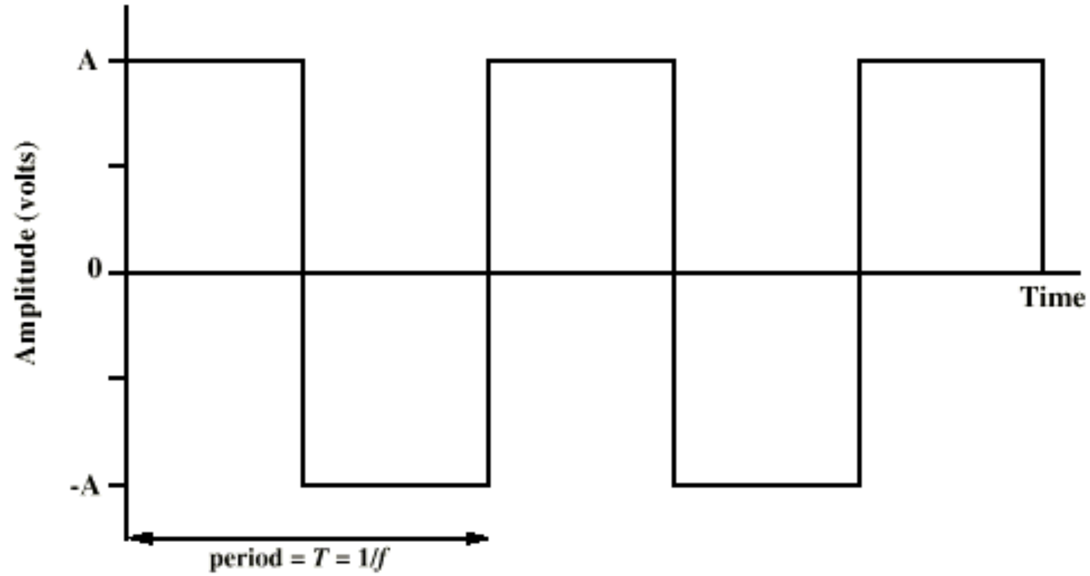


(b) Digital

Periodic Signals



(a) Sine wave



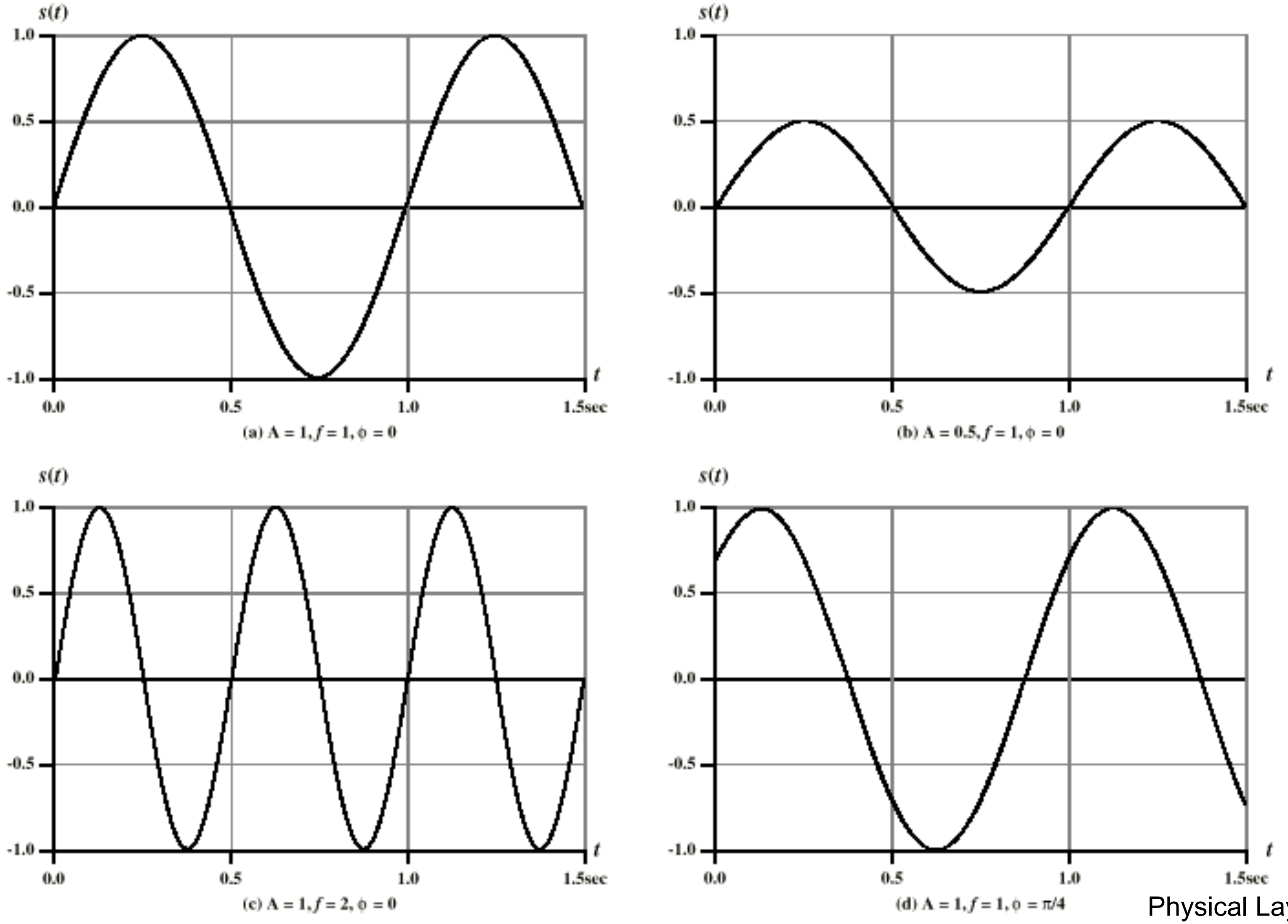
(b) Square wave

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 (ϕ)
  - Relative position in time

Varying Sine Waves

$s(t) = A \sin(2\pi f t + \Phi)$



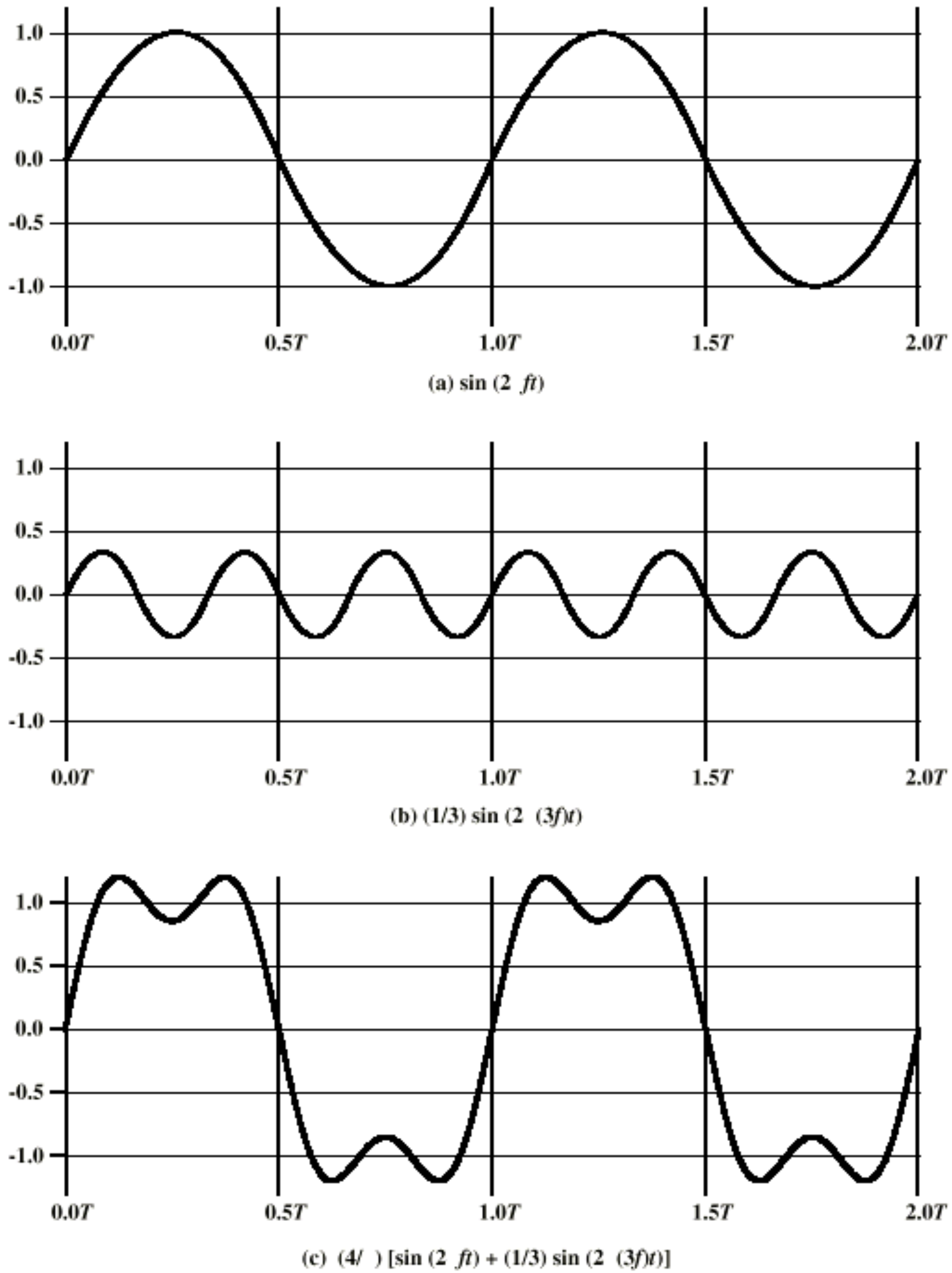
Wavelength

- Distance occupied by one cycle
- Distance between two points of corresponding phase in two consecutive cycles
- λ
- Assuming signal velocity *v*
  - $\lambda = vT$
  - $\lambda f = v$
  - c = $3*10^8$ ms^{-1} (speed of light in free space)

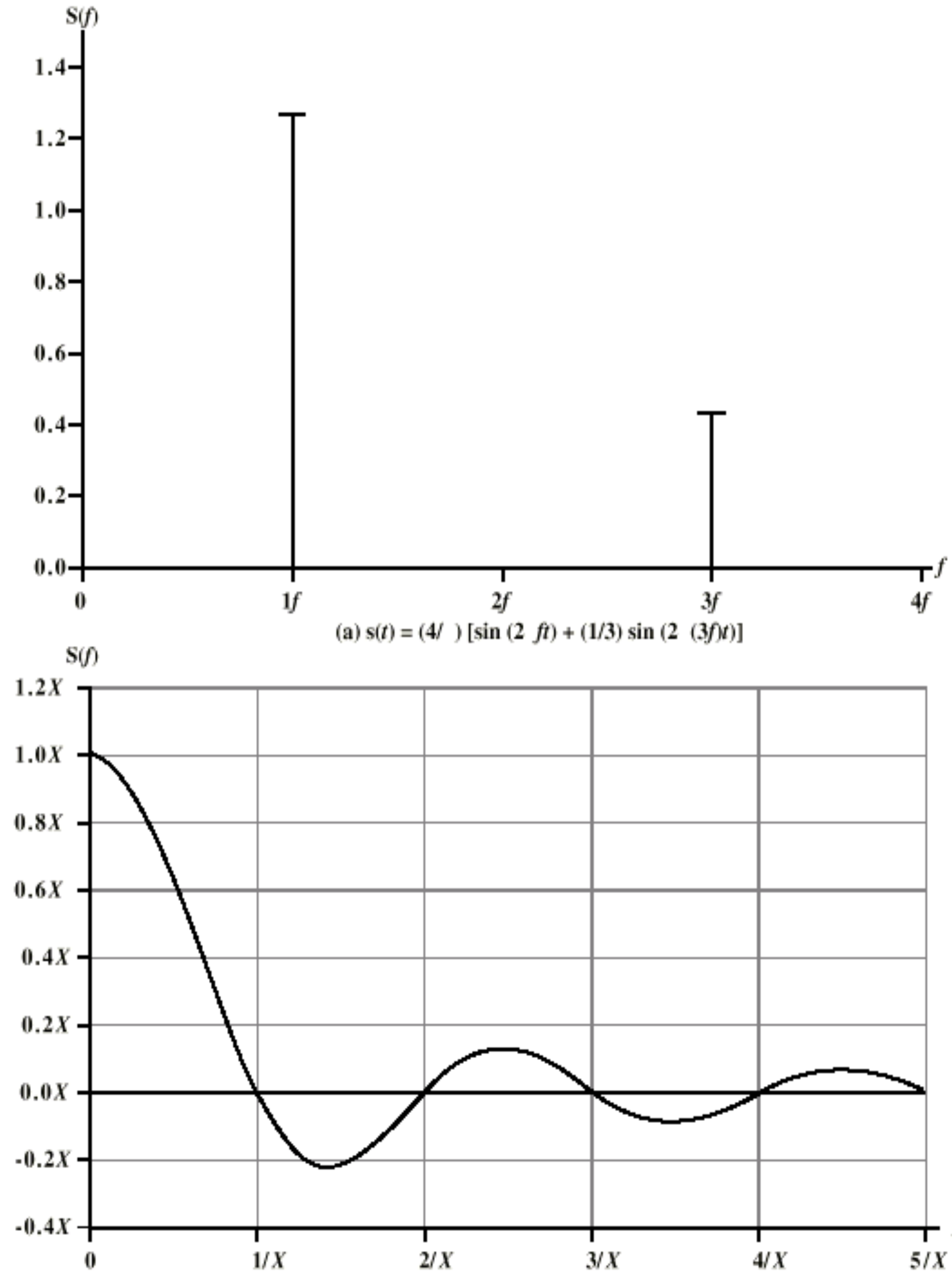
Frequency Domain Concepts

- 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

Addition of Frequency Components (T=1/f)



Frequency Domain Representations



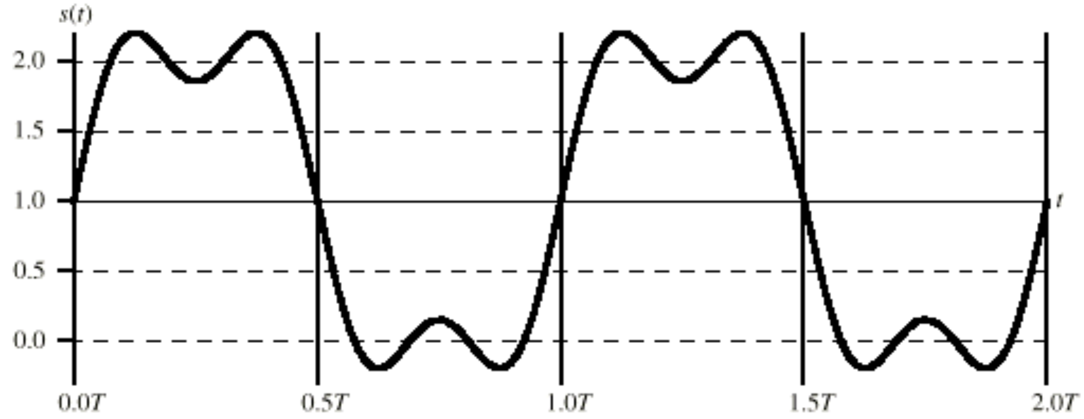
(a) s(t) = (4/) [sin (2 ft) + (1/3) sin (2 (3f)t)]

(b) s(t) = 1 − X/2 t X/2

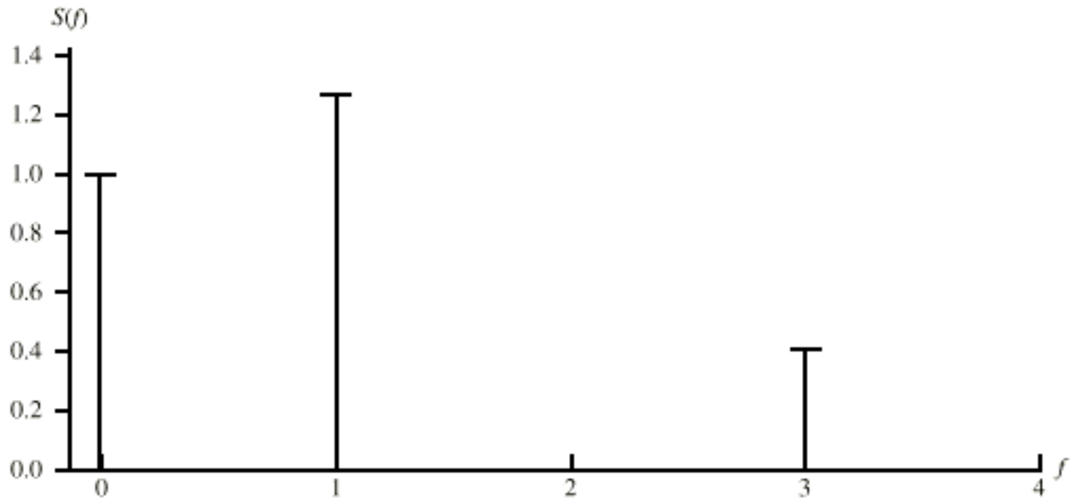
Spectrum & Bandwidth

- 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
- May have component of constant frequency (direct current)

Signals with zero frequency components



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

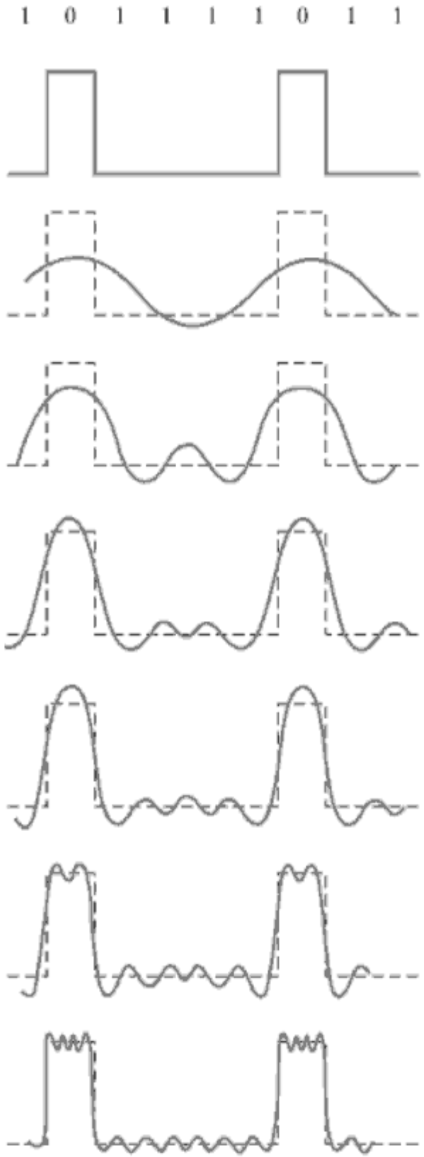


(b) S(f)

Data Rate and Bandwidth

- Any transmission system has a limited band of frequencies
- This limits the data rate that can be carried
- more on this shortly

Effect of Bandwidth on Digital Signal



Bits

Pulses before transmission:
Bit rate 2000 bps

Pulses after transmission:
Bandwidth 500 Hz

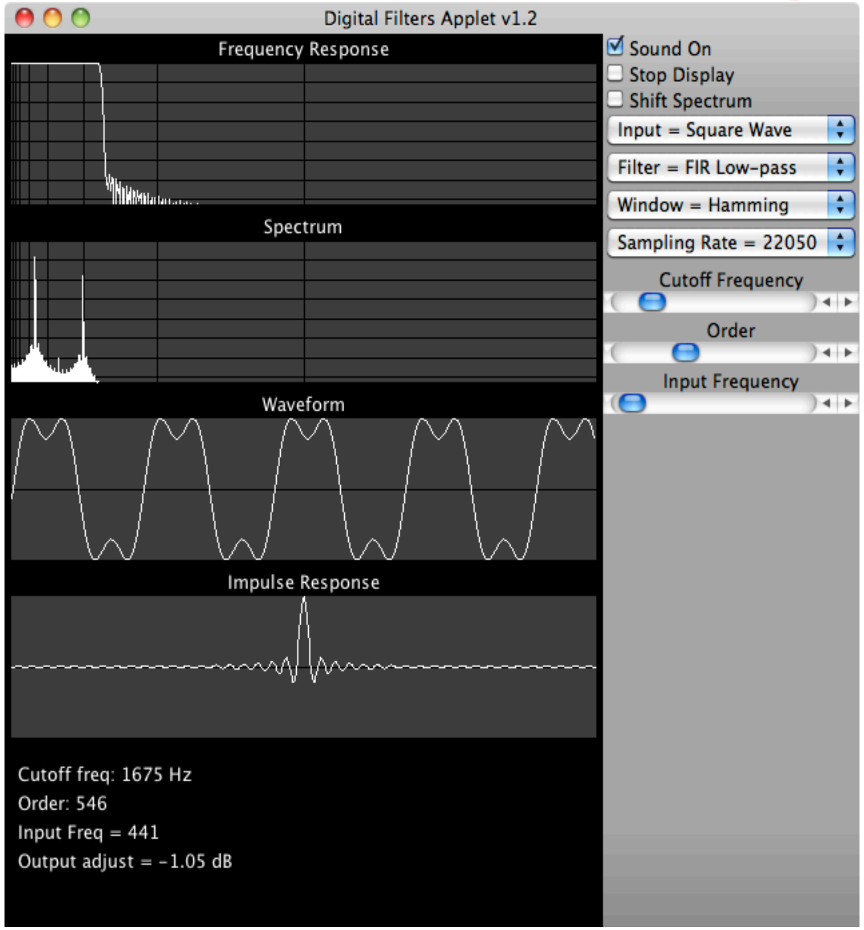
Bandwidth 900 Hz

Bandwidth 1300 Hz

Bandwidth 1700 Hz

Bandwidth 2500 Hz

Bandwidth 4000 Hz



Applet from:
http://www.falstad.com/dfilter/index.html

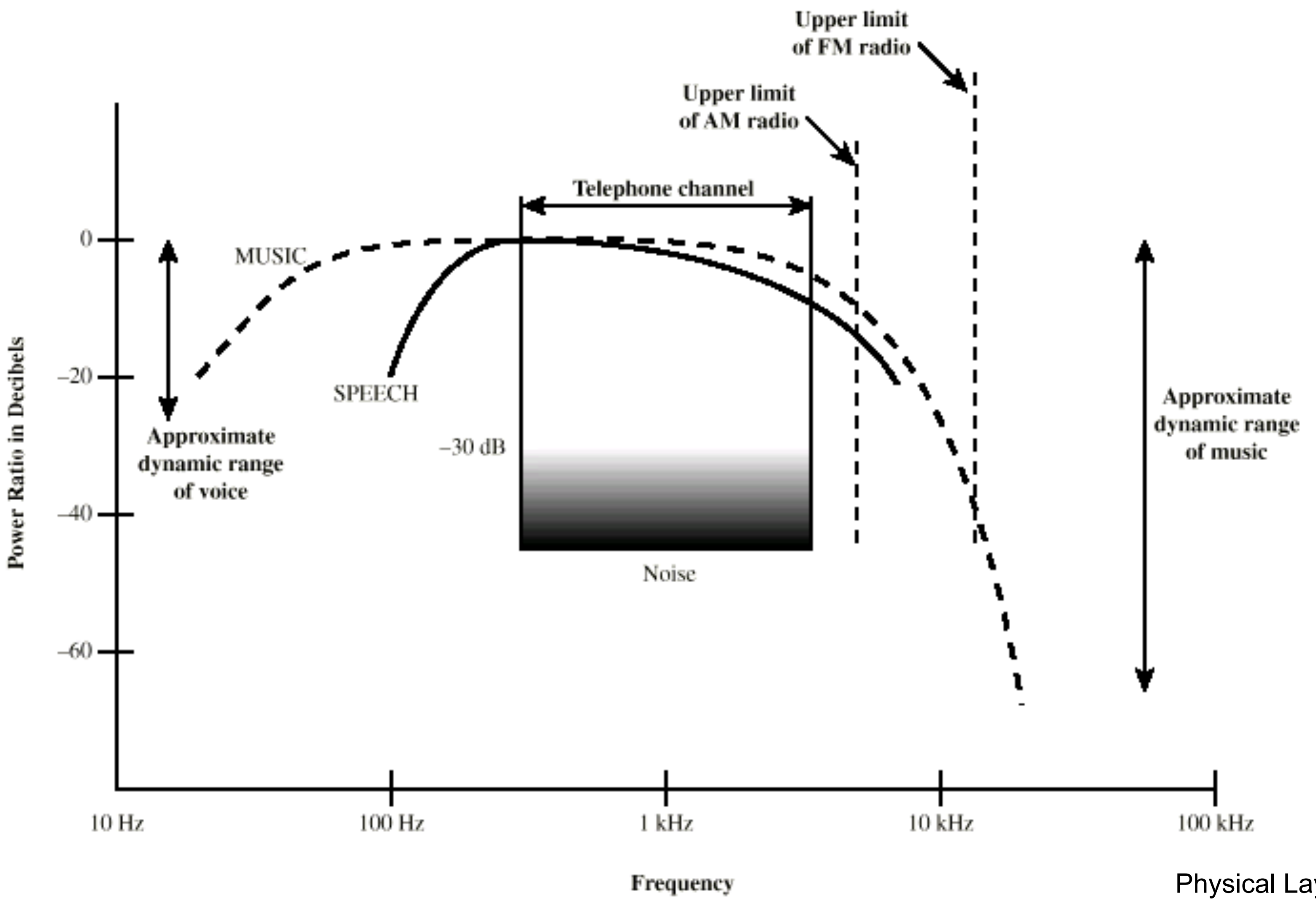
Analog and Digital Data Transmission

- Data
  - Entities that convey meaning
- Signals
  - Electric or electromagnetic representations of data
- Transmission
  - Communication of data by propagation and processing of signals

Analog and Digital Data

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

Acoustic Spectrum (Analog)



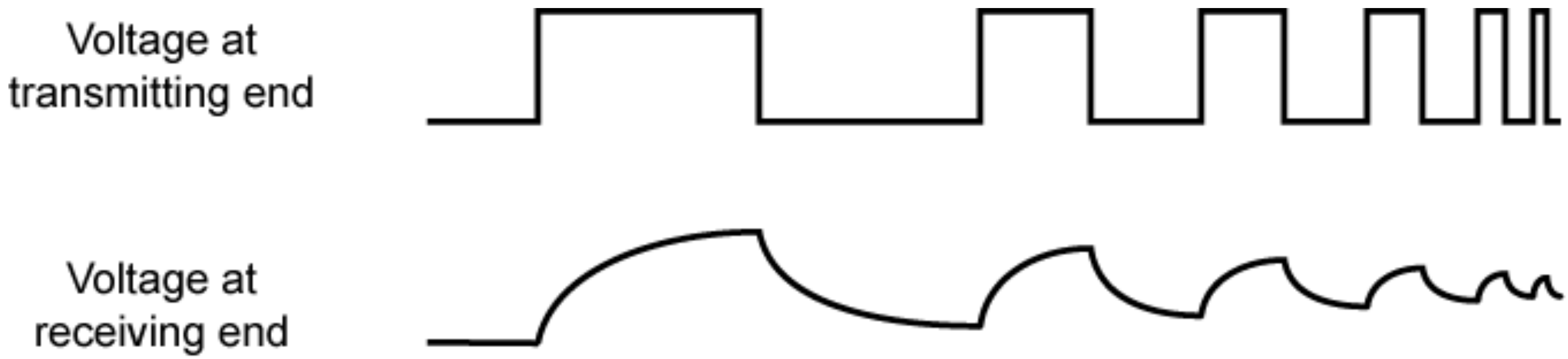
Analog and Digital Signals

- 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
- Digital (binary)
  - Use two constant components
  - To represent 0 and 1

Advantages & Disadvantages of Digital

- Cheaper
- Less susceptible to noise
- Greater attenuation
  - Pulses become rounded and smaller
  - Leads to loss of information

Attenuation of Digital Signals



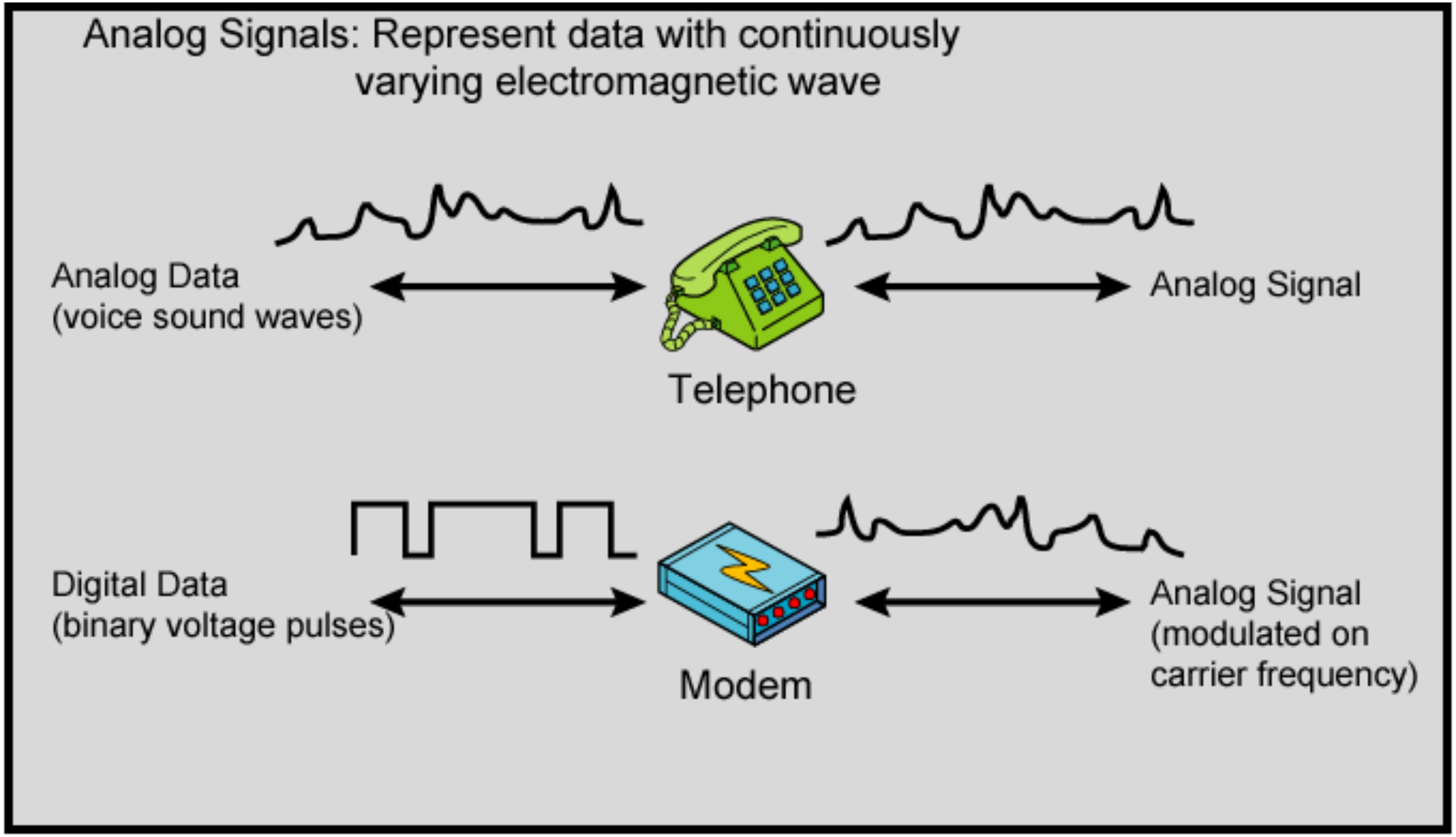
Components of Speech

- 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

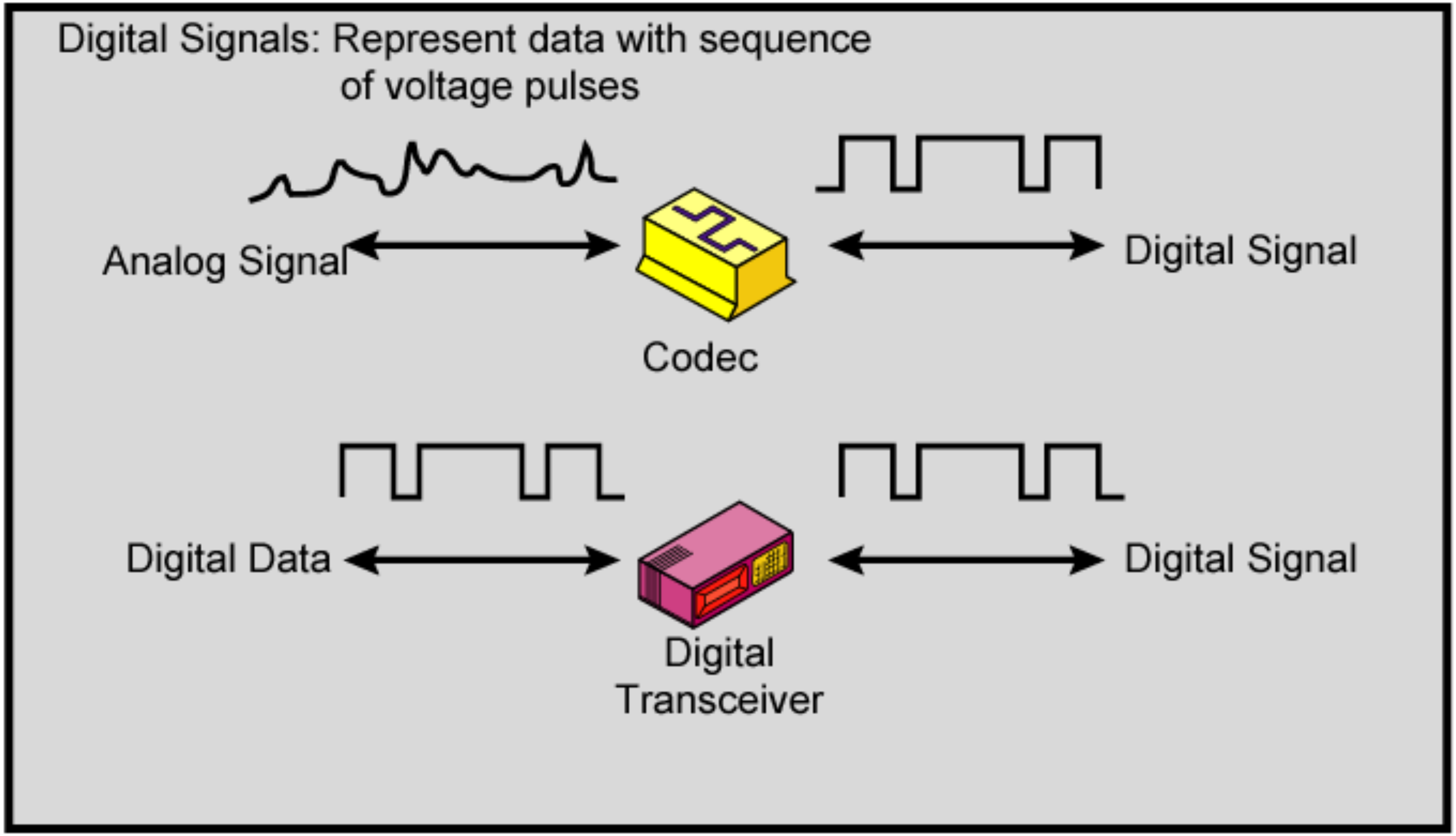
Data and Signals

- 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
  - e.g. audio mp3 codec

Analog Signals Carrying Analog and Digital Data



Digital Signals Carrying Analog and Digital Data



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

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

Advantages of Digital Transmission

- Digital technology lower cost
- 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

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

Delay Distortion

- Occurs because the velocity of propagation of a signal through a guided medium varies with frequency.
  - Only in guided media
  - Propagation velocity varies with frequency
  - Different parts of the spectrum arrive at different times.

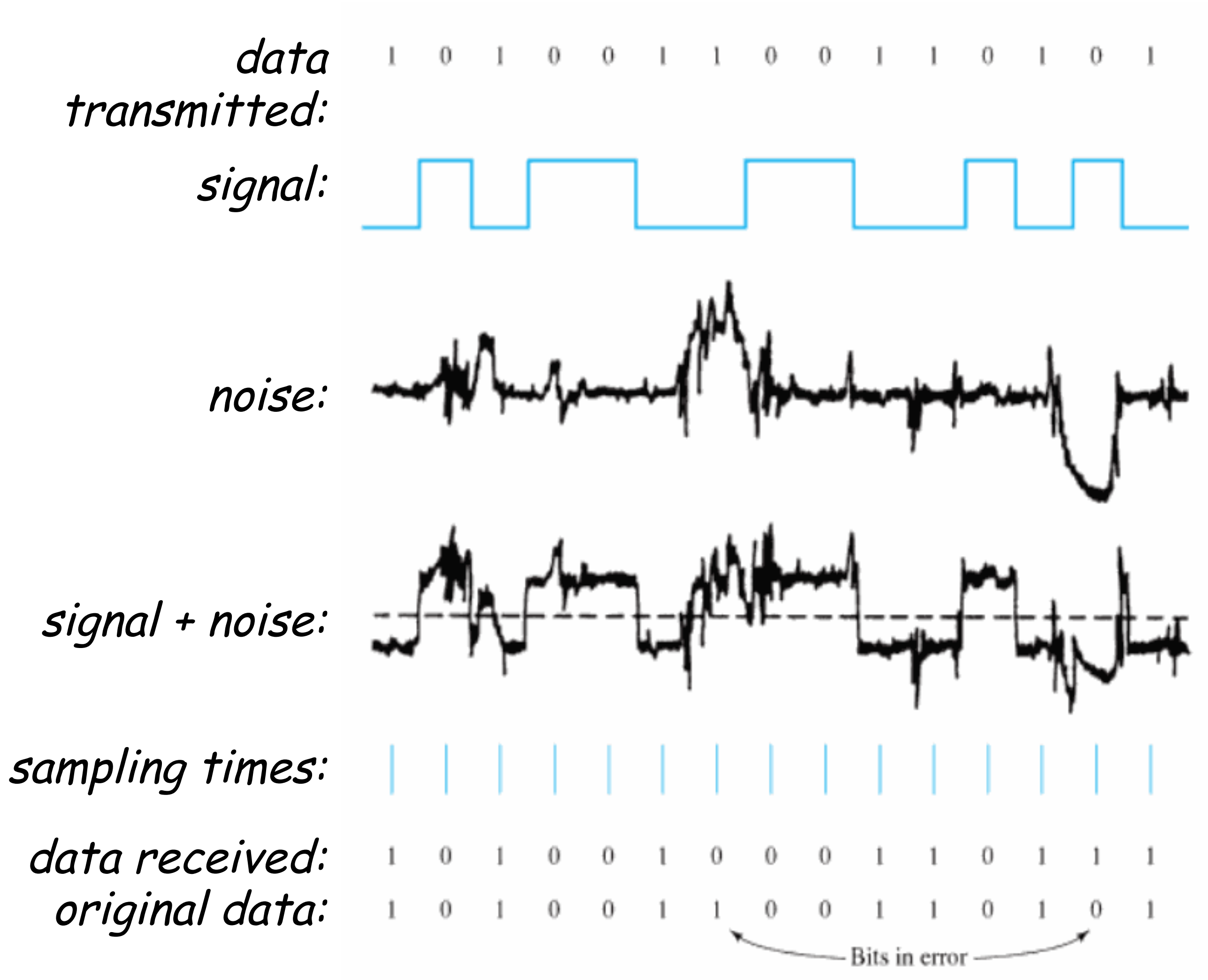
Noise (1)

- 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

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

Noise (3)



data transmitted:
1 0 1 0 0 1 1 0 0 1 1 0 1 0 1
signal:
noise:
signal + noise:
sampling times:
data received:
1 0 1 0 0 1 0 0 0 1 1 0 1 1 1
original data:
1 0 1 0 0 1 1 0 0 1 1 0 1 0 1
Bits in error

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Channel Capacity

- Data rate
  - In bits per second
  - Rate at which data can be communicated
- Bandwidth
  - The frequency width of the transmitted signal
  - In cycles per second or Hertz
  - Constrained by transmitter and medium.

Nyquist Bandwidth

- Nyquist: "If bandwidth is B, then highest signal transmission (baud) rate is 2B."
- For binary signal: data rate supported by B Hz is 2B bps.
- Can be increased by using M signal states.
  - each state encodes multiple bits
  - How many bits can we encode with M signal states ?
- No noise: Max data rate = 2•B•log[base 2](M)
- Example:
  - Suppose a voice channel (B=3100 Hz) is used to transmit digital data via modem which uses 4 different signal states.
  - Then, max data rate = 2•3100•2 bps = 12400 bps.

Shannon's Capacity Formula

- Most communications channels have noise present
  - For example, the motion of molecules in the system create random thermal noise.
- The amount of thermal noise present is measured by the ratio of signal power to noise power
  - This is called the signal-to-noise ratio, S/N.
- Usually the ratio itself is not quoted, but this quantity:
  - 10 log[base 10] (S/N)
    - This is measured in decibels (dB)
  - S/N = 10 → 10 dB
  - S/N = 100 → 20 dB
  - S/N = 1000 → 30 dB
- Fixed analog voice telephone network is typically:
  - 30dB

Shannon's Law

- The maximum data rate of a noisy channel with bandwidth B and signal-to-noise ratio of S/N is
  - Max data rate = B log[base 2] (1 + S/N)
- Example:
  - A typical analog voice telephone channel:
  - The channel has bandwidth of 3100 Hz
  - And Signal-to-noise ratio of 30 dB (ie S/N = 1000)
- Max bits per second:

  = B log[base 2] (1 + S/N)

  = 3100 log[base 2] (1 + 1000)

  = 3100 log[base 2] (1001)

  = 3100 * 9.9658 = 30,894 bps.

Nyquist / Shannon

Recall:
B .. bandwidth
M .. number of signal states
S/N .. signal-to-noise ratio

- Noise free channel (Nyquist)
  - Max data rate = 2•B•log[base 2](M)
- noisy channel (Shannon)
  - Max data rate = B log[base 2] (1 + S/N)
- Exercise:
  - Consider a communication channel with bandwidth B = 3000 Hz.
    - Suppose the channel has a signal-to-noise ratio S/N = 1023. What is the maximum data rate of this channel?
    - What is the minimum number of signal states M needed to achieve a data rate of 24000 bps? How many bits must each signal state encode?

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Guided Transmission Media

- Magnetic Media
- Twisted Pair
- Coaxial Cable
- Fiber Optics

Twisted Pair

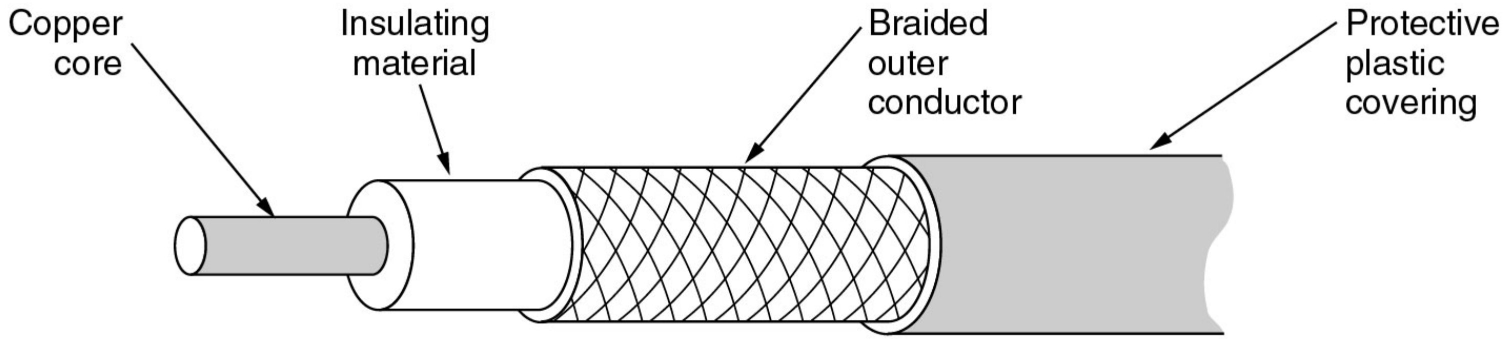
(a)

(b)

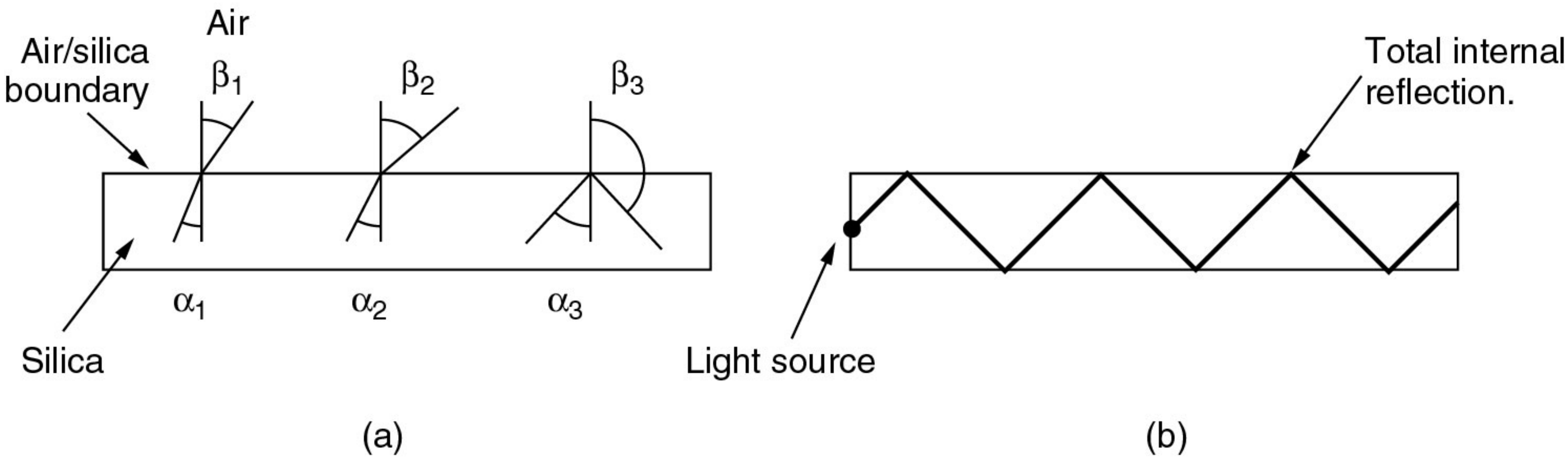
(a) Category 3 UTP (Unshielded Twisted Pair).
(b) Category 5 UTP: less crosstalk, better quality signal.

Coaxial Cable

A coaxial cable.



Fiber Optics

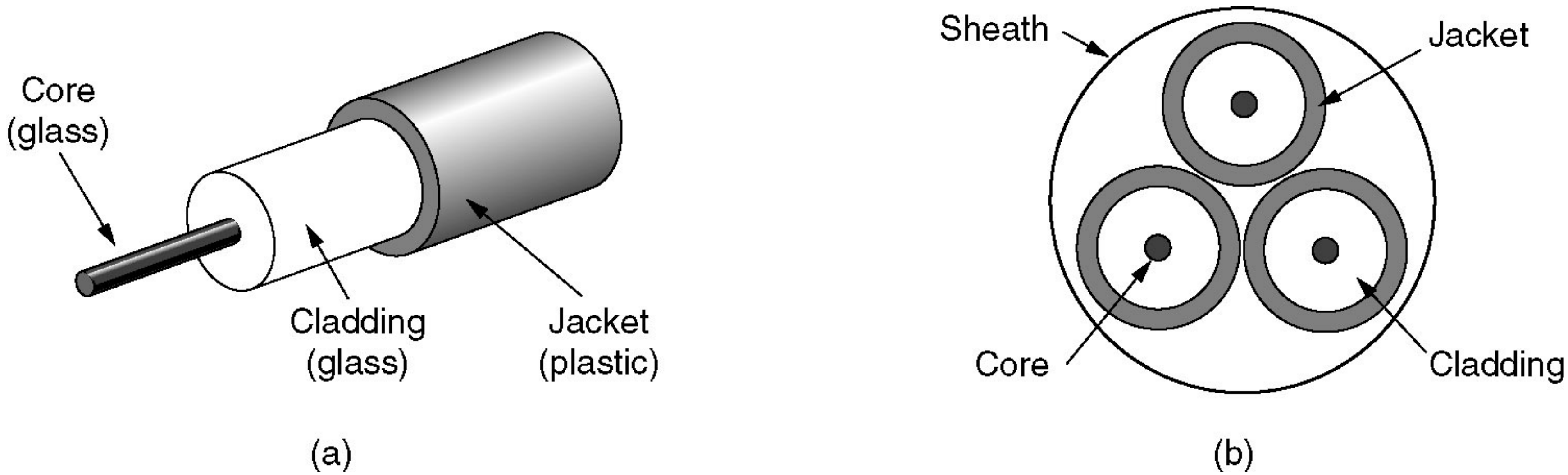


(a) Three examples of a light ray from inside a silica fiber impinging on the air/silica boundary at different angles.

(b) Light trapped by total internal reflection.

Fiber Cables

(a) Side view of a single fiber.
(b) End view of a sheath with three fibers.



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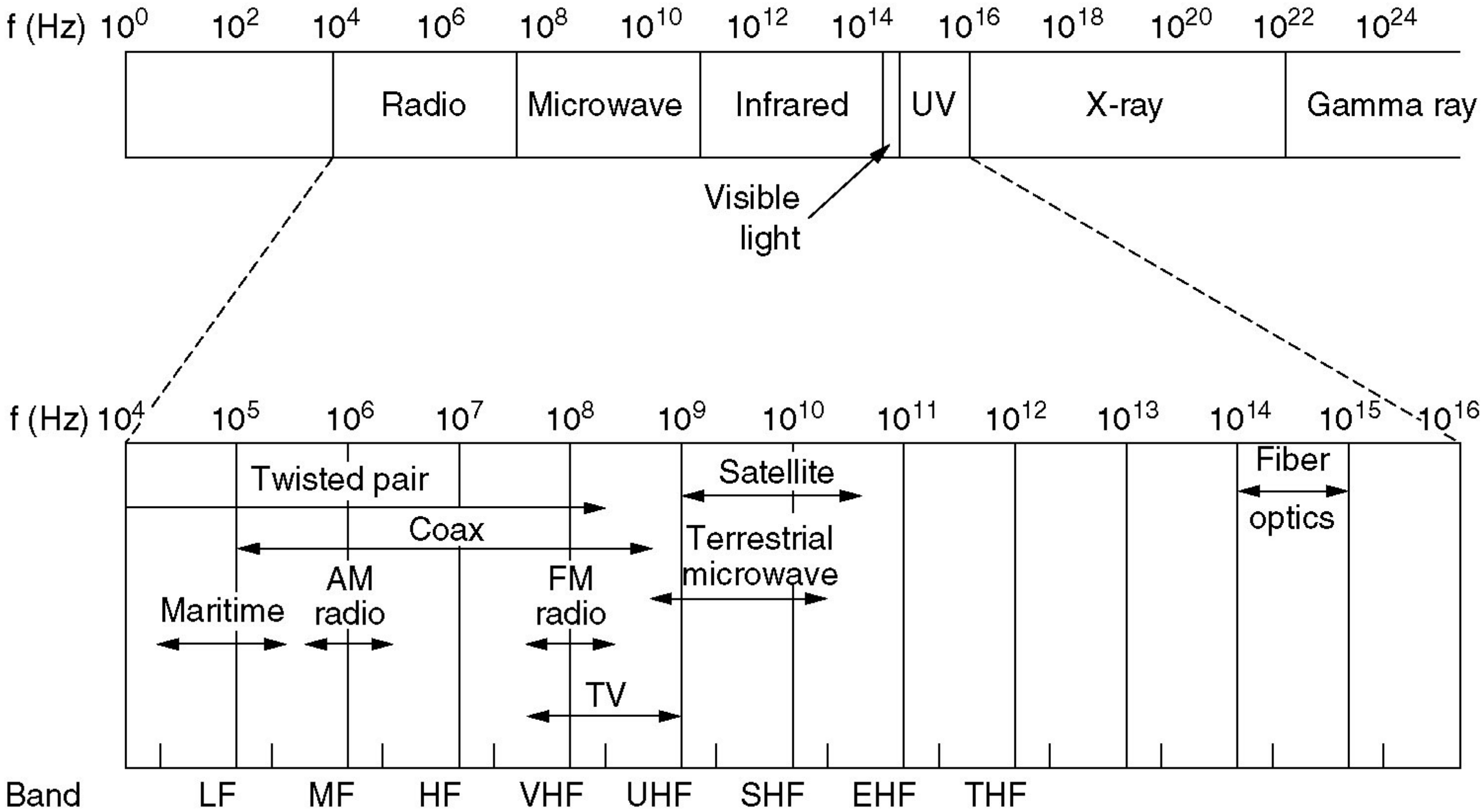
Wireless Transmission

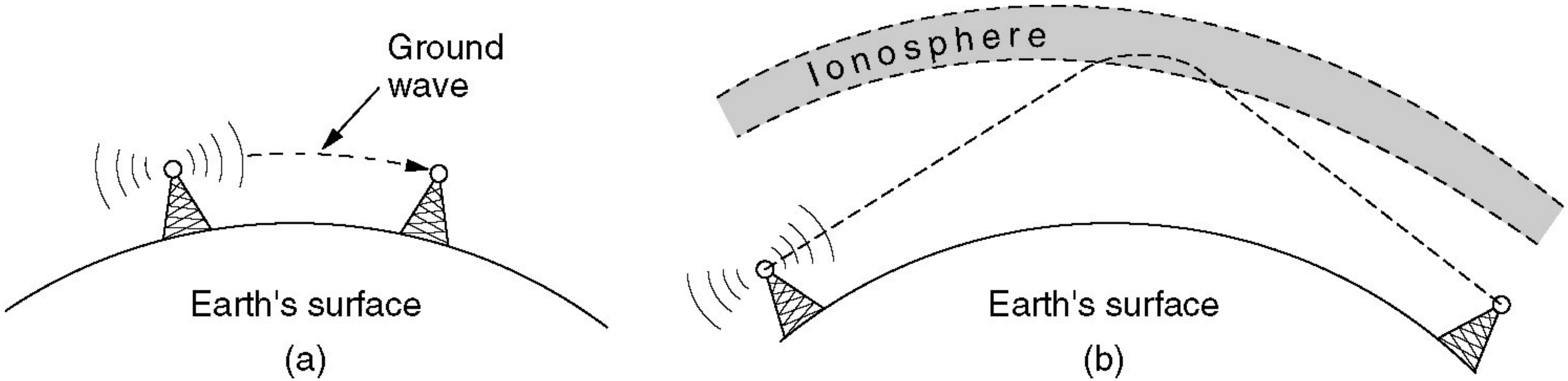
- The Electromagnetic Spectrum
- Radio Transmission
- Microwave Transmission
- Infrared and Millimeter Waves
- Lightwave Transmission

The Electromagnetic Spectrum

The electromagnetic spectrum and its uses for communication.



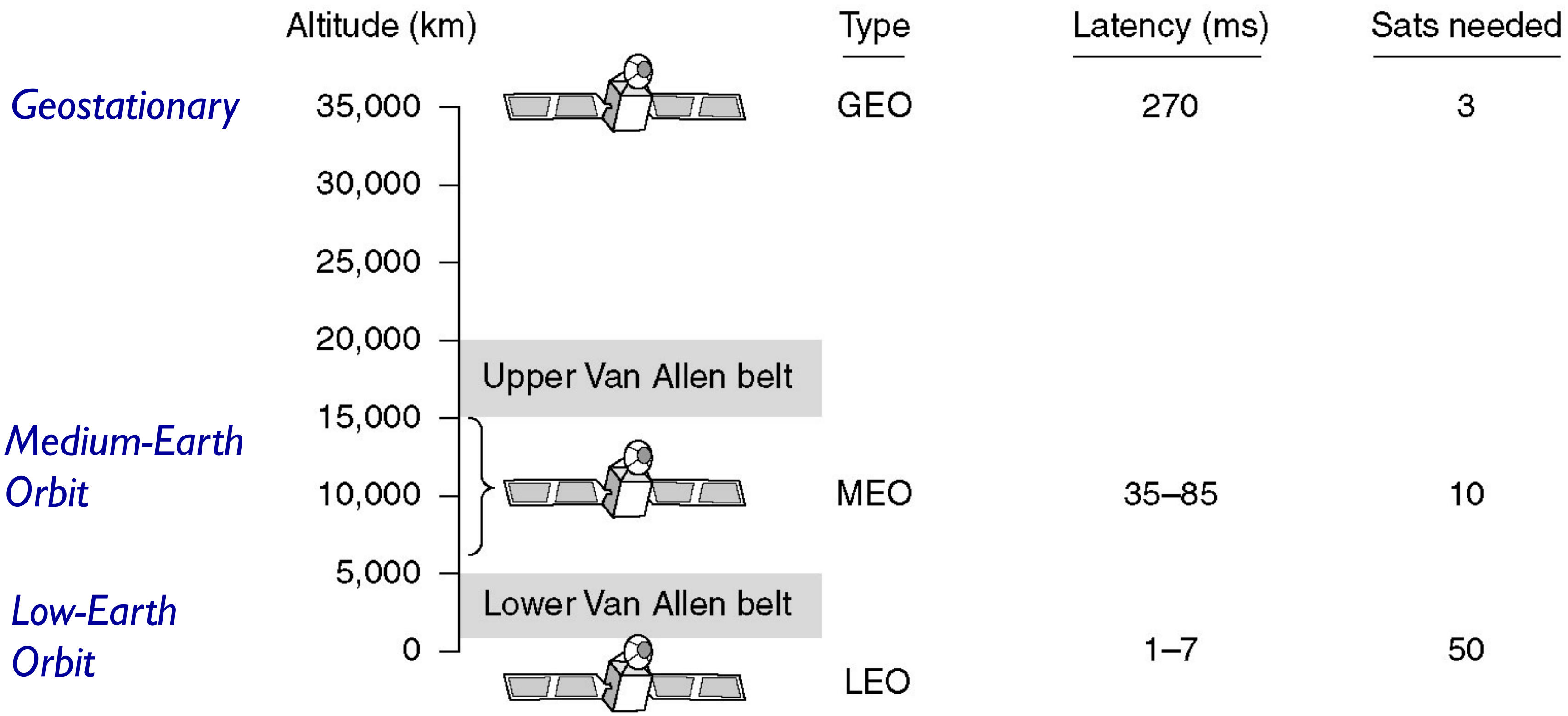
Radio Transmission



(a) In the VLF, LF, and MF bands, radio waves follow the curvature of the earth.

(b) In the HF band, they bounce off the ionosphere.

Communication Satellites



Communication satellites and some of their properties, including altitude above the earth, round-trip delay time and number of satellites needed for global coverage.

Communication Satellites (2)

The principal satellite bands.

Band	Downlink	Uplink	Bandwidth	Problems
L	1.5 GHz	1.6 GHz	15 MHz	Low bandwidth; crowded
S	1.9 GHz	2.2 GHz	70 MHz	Low bandwidth; crowded
C	4.0 GHz	6.0 GHz	500 MHz	Terrestrial interference
Ku	11 GHz	14 GHz	500 MHz	Rain
Ka	20 GHz	30 GHz	3500 MHz	Rain, equipment cost

Summary (Physical Layer)

- some communication theory
  - analog vs digital signals
  - frequency domain representation
    - spectrum
    - effect of bandwidth on signals
  - transmission impairments
    - attenuation, delay distortion, noise
  - channel capacity
    - Nyquist bandwidth, Shannon's Law
- types of transmission media
  - guided media, wireless transmission

Review Questions

1. What data can be transmitted in the Physical Layer?
   What does such data represent? Give examples of such data.
2. What are the advantages and disadvantages of digital transmission?
3. What is the problem of "Delay Distortion"? "Attenuation"?
4. Name and describe four different sources of noise?
5. What is the signal-to-noise ratio corresponding to 20dB?
6. Consider a communication channel with bandwidth B=5000Hz.
   a) Suppose S/N=255. What is the maximum data rate of this channel?
   b) What is the minimum number of signal states M needed to achieve a data rate of 20000 bps? How many bits must each state encode?