CNL
Communications & Networking
Laboratory

ECE 462 – Data and Computer Communications

Lecture 3: Data Transmission

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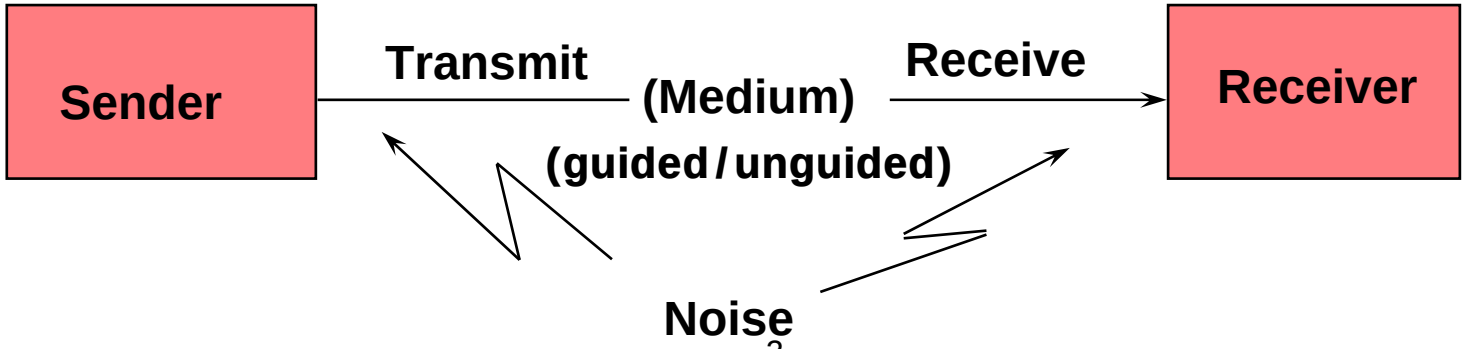
Outline

- Transmission Terminology
- Analog and Digital Data Transmission
- Transmission Impairments
- Bandwidth
- Channel Capacity
- Nyquist Bandwidth

Note: Some material adapted from various textbook. In particular, the sequences of slides have been sorted to match closely that of the textbook Data and Computer Communications by W. Stallings, 8th Edition, Prentice Hall, 2007

Terminology

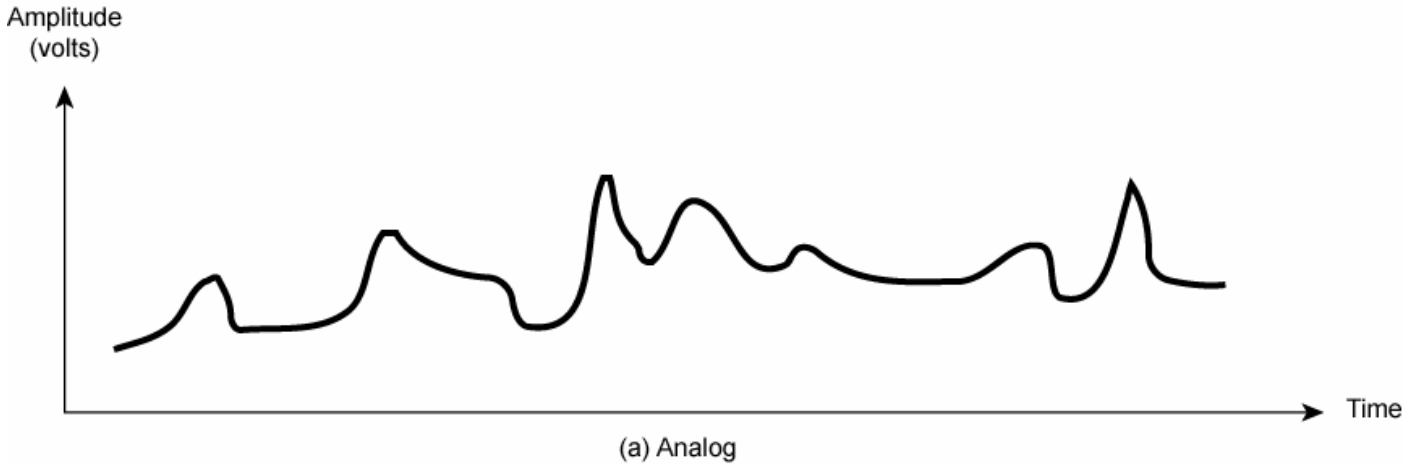
- Transmitter/Receiver and Medium (guided/unguided)
- Types
  - Point-to-point (direct)
  - Multi-point (>2 devices share the medium)
- Mode
  - Simplex, Half duplex, Full duplex



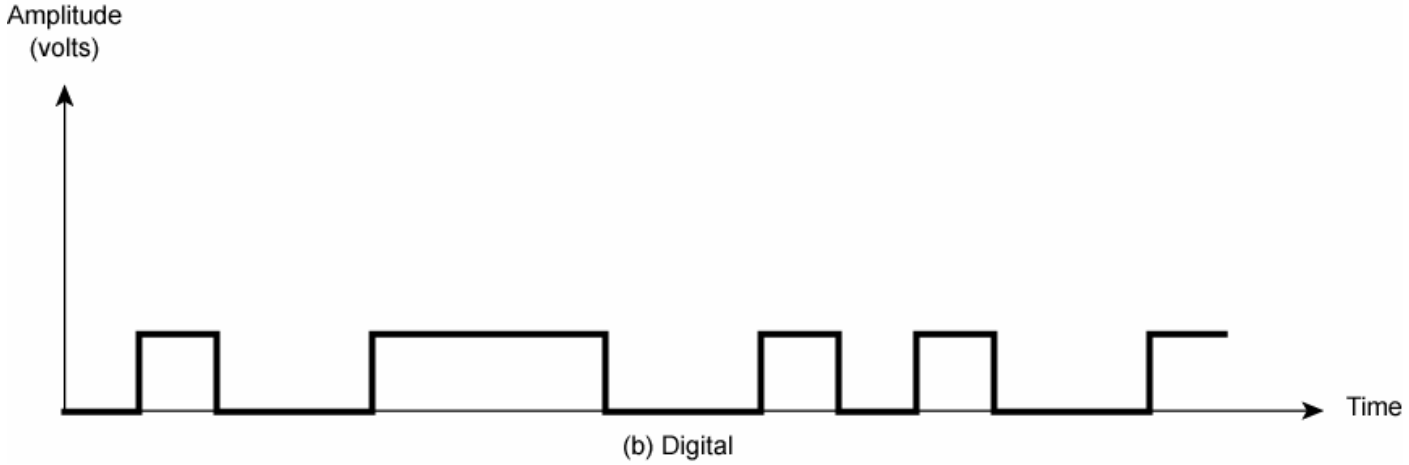
Frequency, Spectrum and Bandwidth

- Time domain concepts
  - Analog signal
    - Various in a smooth way over time
  - Digital signal
    - Maintains a constant level then changes to another constant level
  - Periodic signal
    - Pattern repeated over time
    - $s(t+T)=s(t) \quad -\infty < t < \infty$
  - Aperiodic signal
    - Pattern not repeated over time

Analog and Digital Signals

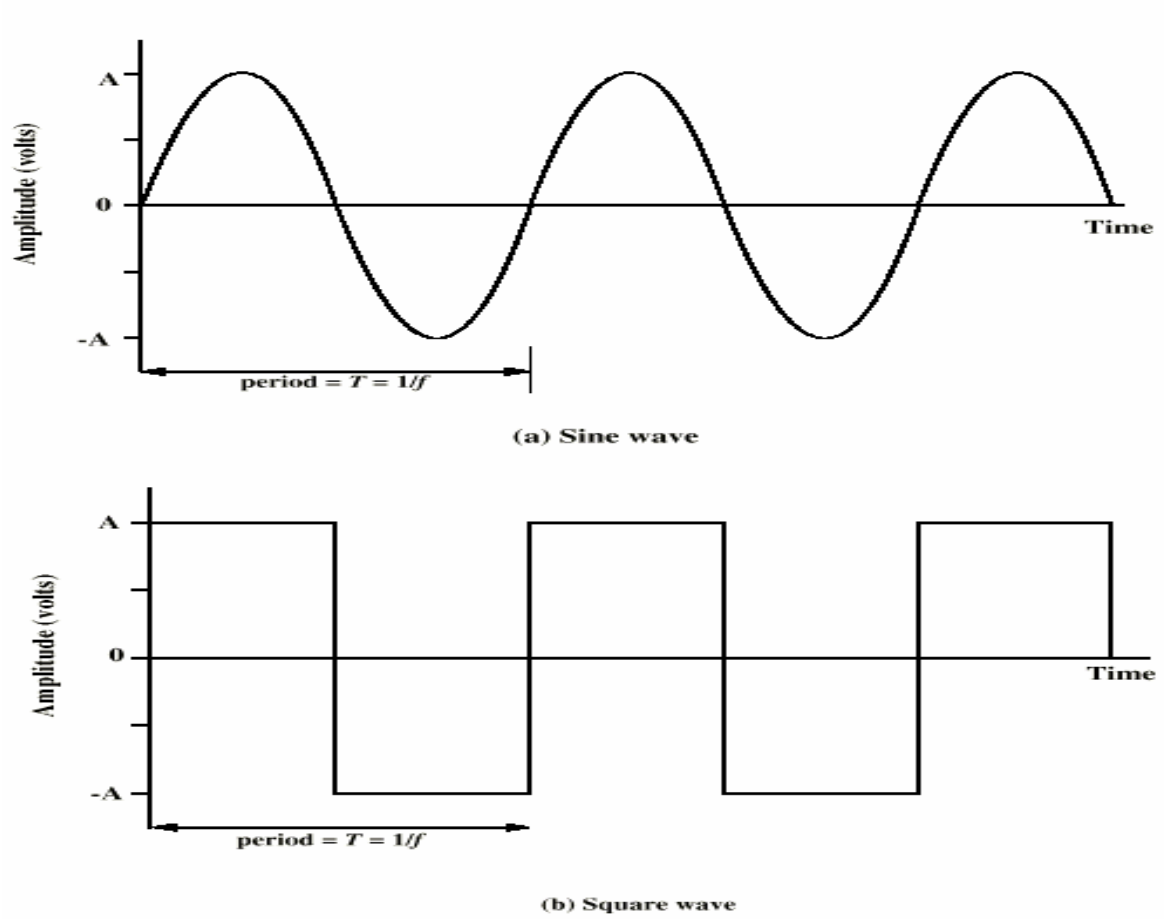


(a) Analog



(b) Digital

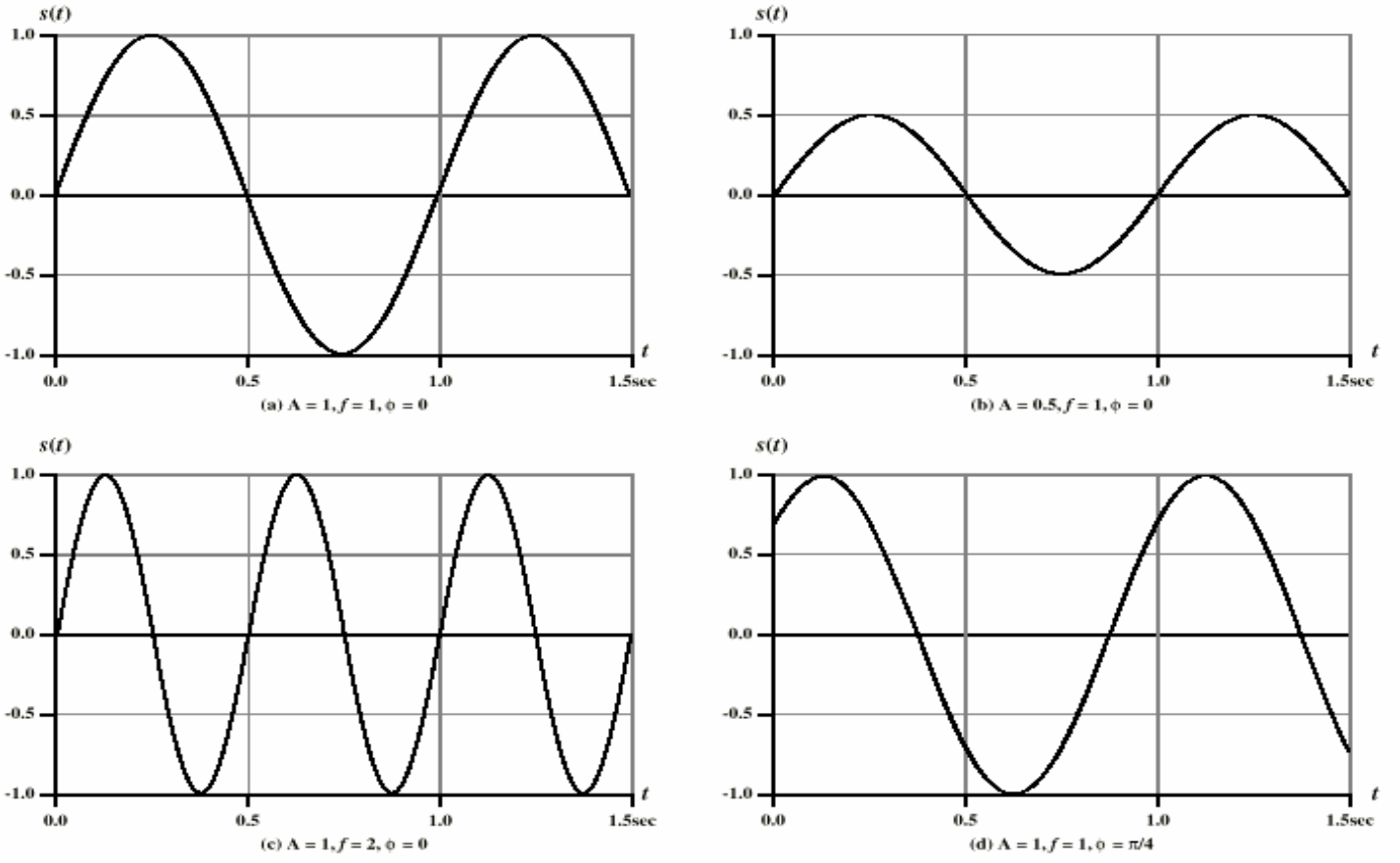
Periodic Signals



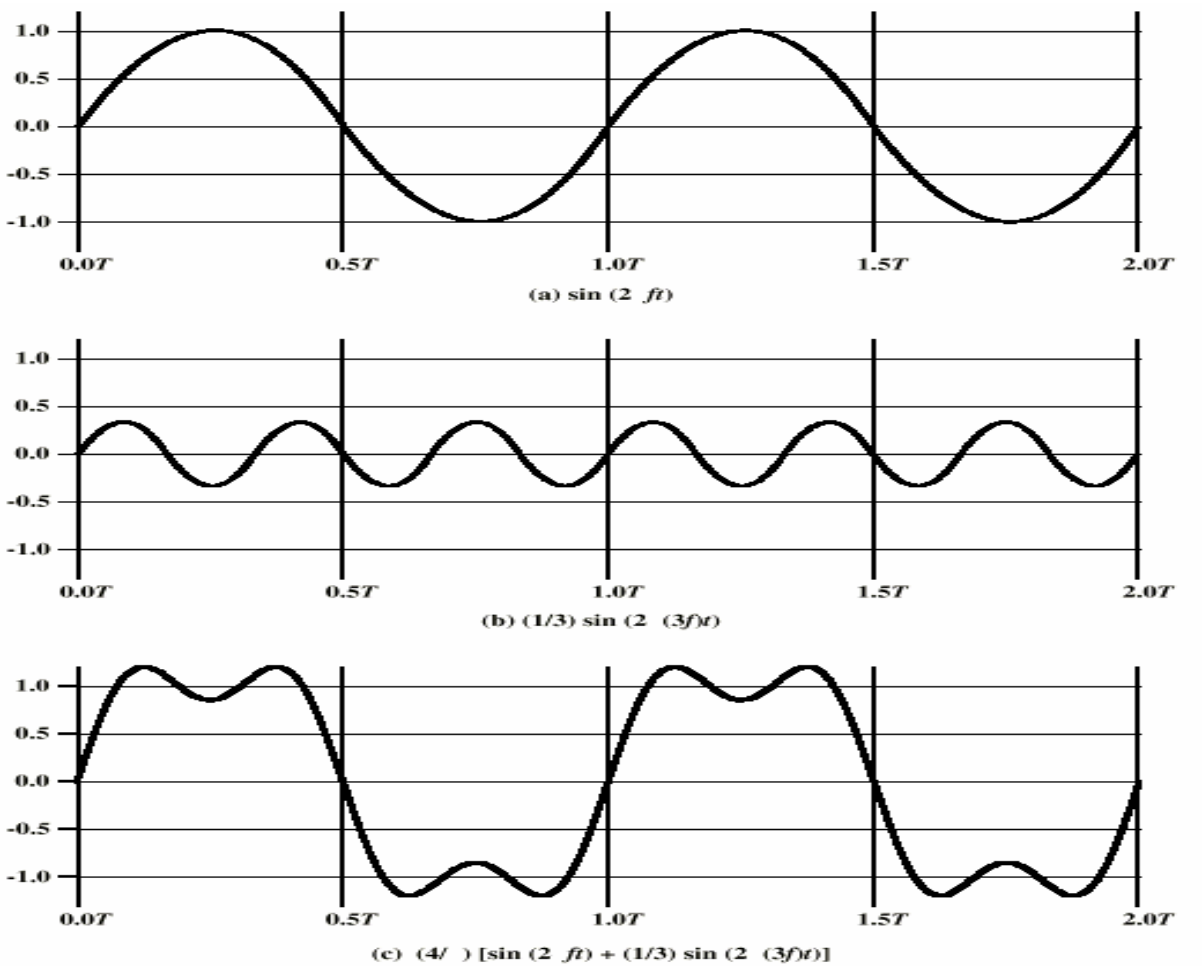
Sine Wave

- Peak Amplitude (A)
  - maximum strength of signal measured in volts
- Frequency (f)
  - Rate of change of signal
  - Hertz (Hz) or cycles per second
  - Period = duration for one repetition =T= 1/f
- Phase (ϕ)
  - Relative position in time

Varying Sine Waves s(t) = A sin(2πft +Φ)



Addition of Frequency Components (T=1/f)



Wavelength

- Wavelegth, λ, is the distance occupied by one cycle
  - Or distance between two points of corresponding phase in two consecutive cycles

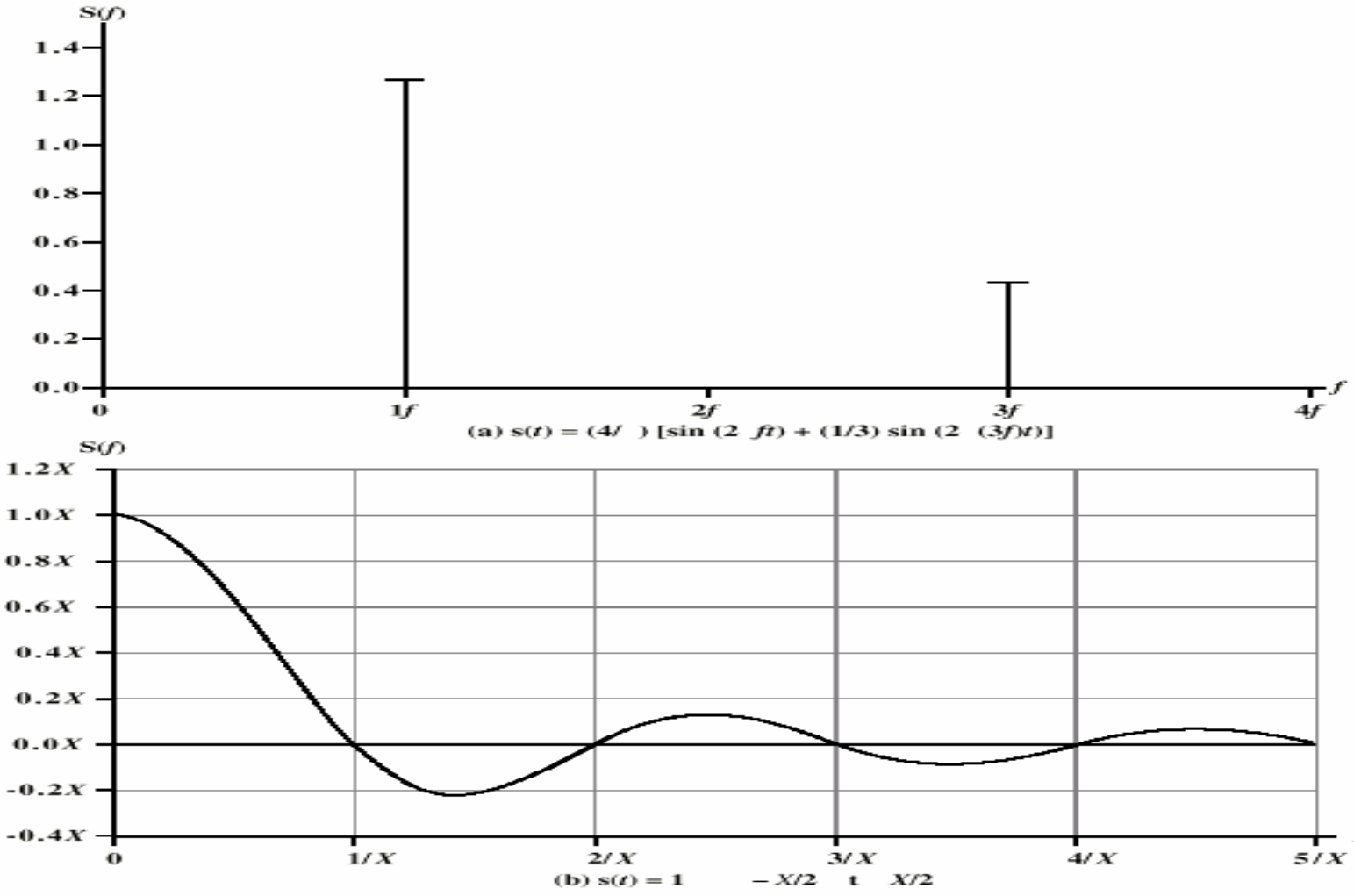
Assuming signal velocity v

- $\lambda = vT$
- $\lambda f = v$
- Note for free space: $v = c = 3 \times 10^8$ ms^{-1} (c=speed of light in free space)

Frequency Domain Concepts

- Signal usually made up of many frequencies
- Can be shown (Fourier analysis) that any signal is made up of sine waves components
- Can plot frequency domain functions

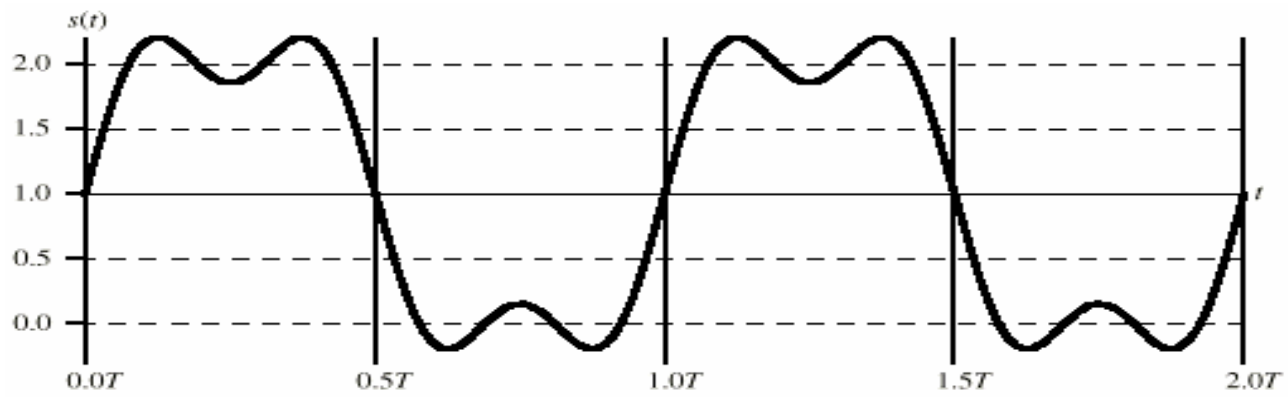
Frequency Domain Representations



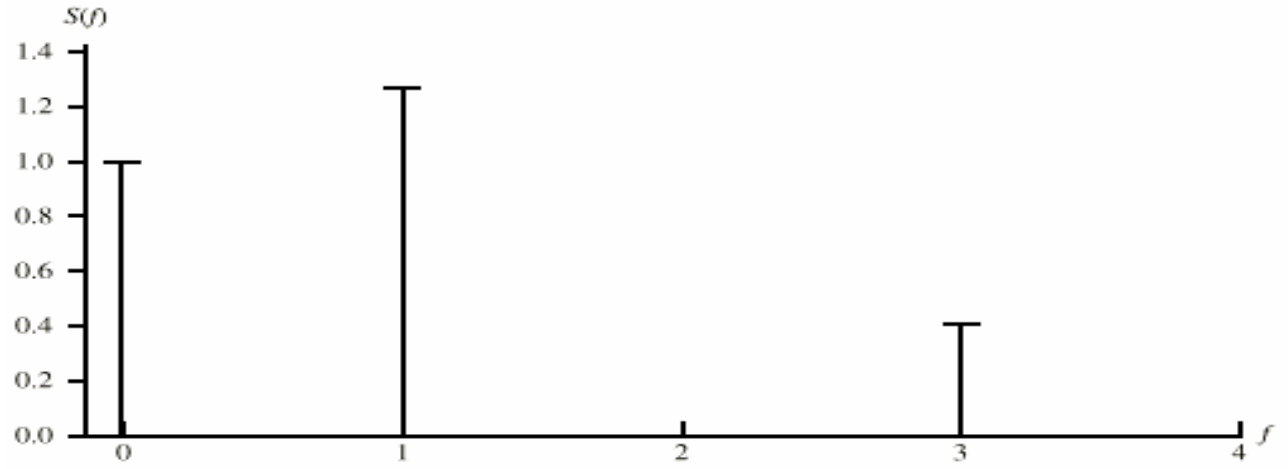
Spectrum and Bandwidth

- 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
- DC Component
  - Component of zero frequency

Signal with DC Component



(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 of frequency bandwidth
- This limits the data rate that can be carried

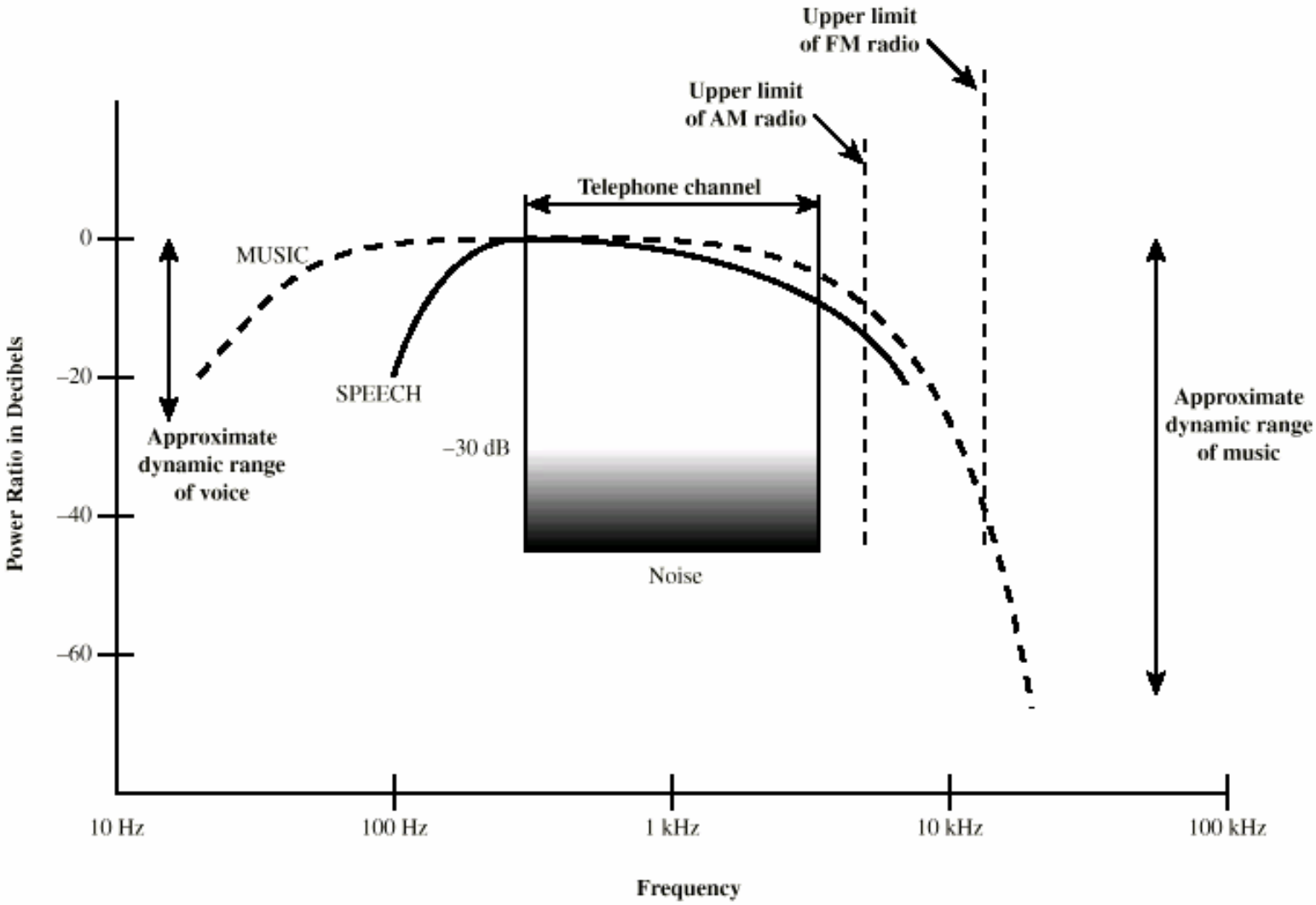
Analog and Digital Data Transmission

- 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)



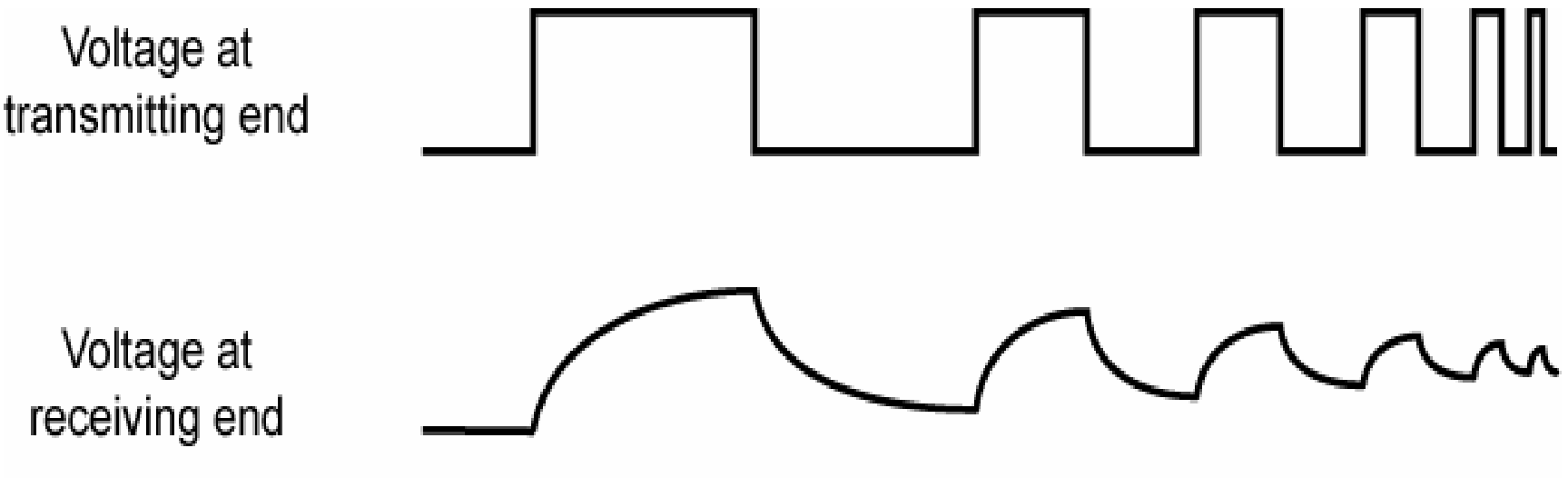
Analog and Digital Signals

- 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
  - Video bandwidth 4MHz
- Digital
  - For example, use two levels

Advantages and 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

Video Components

- 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

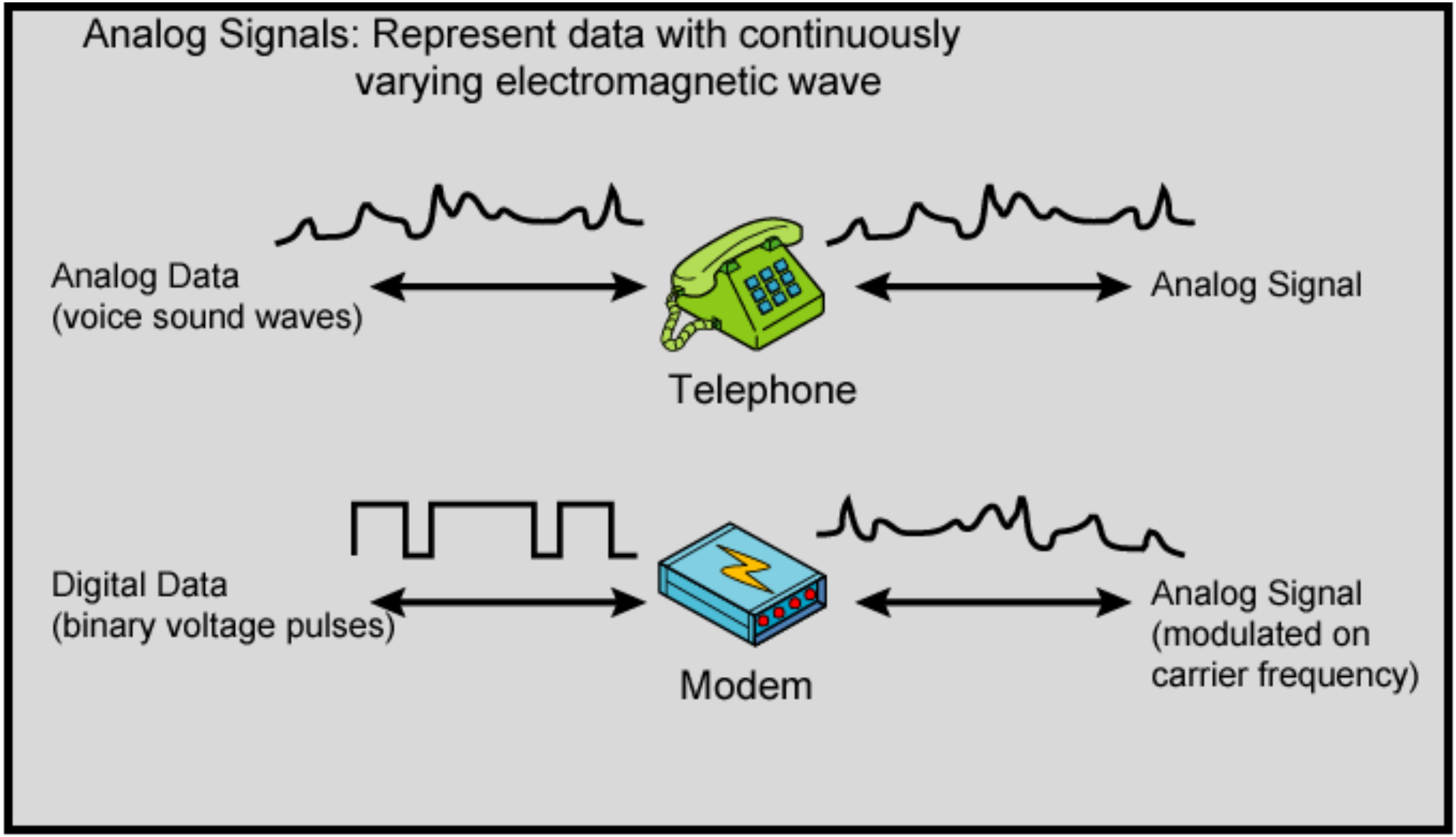
Binary Digital Data

- From computer terminals etc.
- Two dc components
- Bandwidth depends on data rate

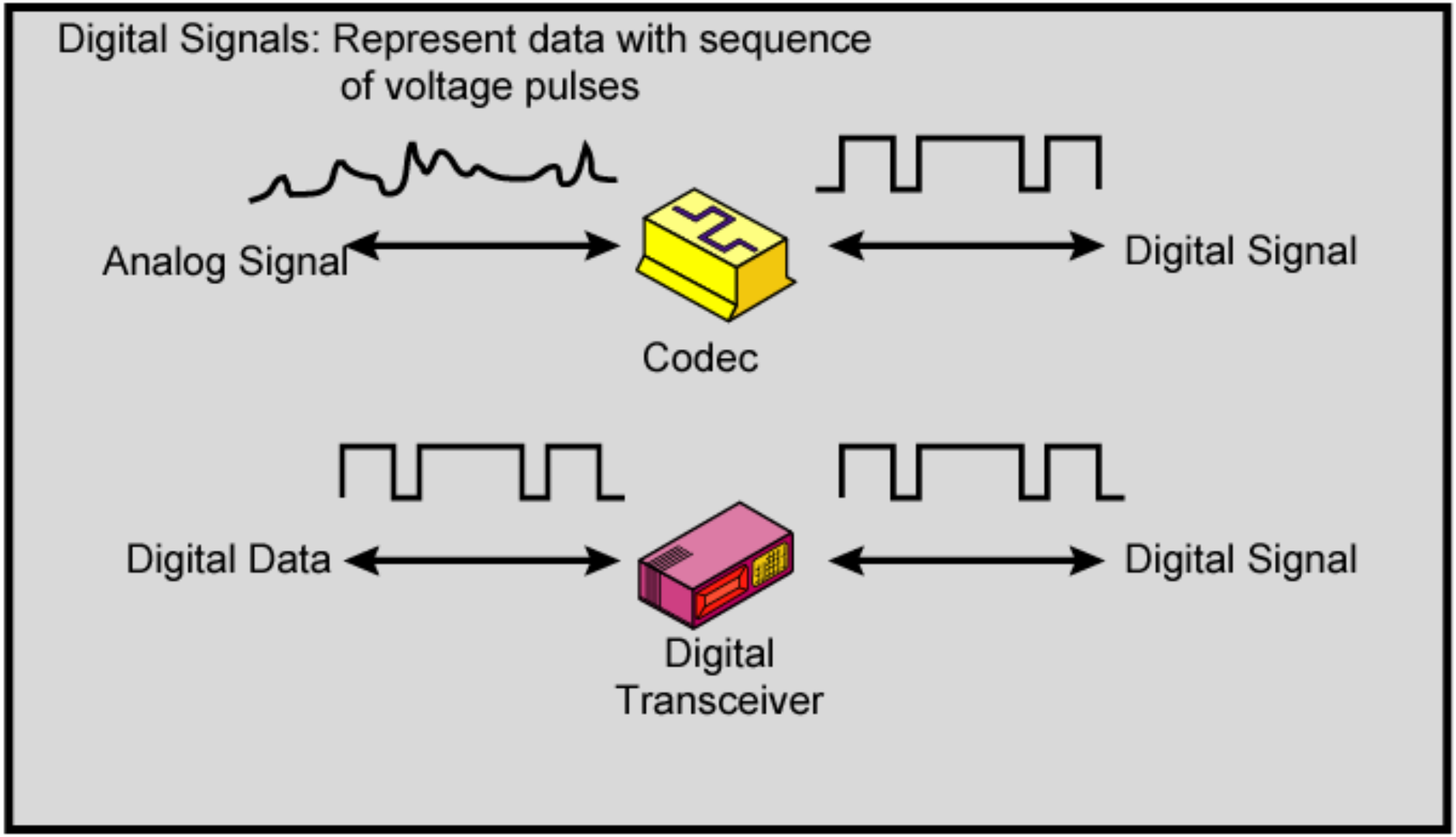
Data and Signals

- 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
  - Compact Disc audio

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
  - Low cost LSI/VLSI technology
- 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

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

- Only in guided media
- Propagation velocity varies with frequency

Noise

- 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 (cont'd)

- 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

Channel Capacity

- Data rate
  - In bits per second
  - Rate at which data can be communicated
- Bandwidth
  - In cycles per second of Hertz
  - Constrained by transmitter and medium

Nyquist Bandwidth

- If rate of signal transmission is 2B then signal with frequencies no greater than B is sufficient to carry signal rate
- Given bandwidth B, highest signal rate is 2B
- Given binary signal, data rate supported by B Hz is 2B bps
- Can be increased by using M signal levels
- $C = 2B \log_2 M$

Example: voice channel B=3.1 KHz, M=8

$C=2x3.1x10^3x \log_2 8=18.6$ Kbps

Shannon Capacity Formula

- Consider data rate, noise and error rate
- Faster data rate shortens each bit so burst of noise affects more bits
  - At given noise level, high data rate means higher error rate
- Signal to noise ratio (in decibels)

$$SNR_{db} = 10 \log_{10} (signal/noise)$$

- Capacity $C = B \log_2(1+S/N)$