# Data Transmission

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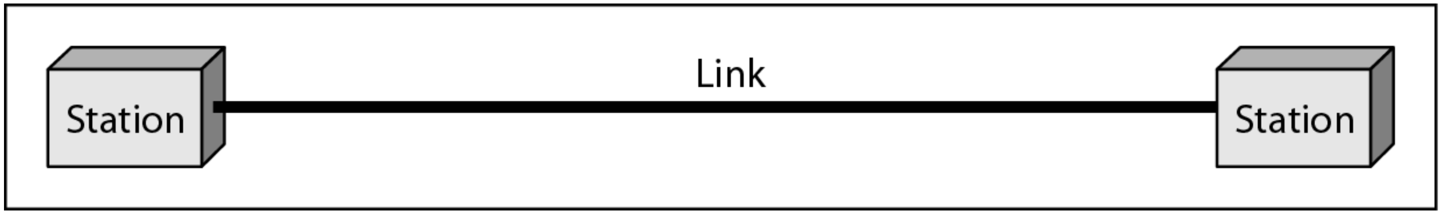
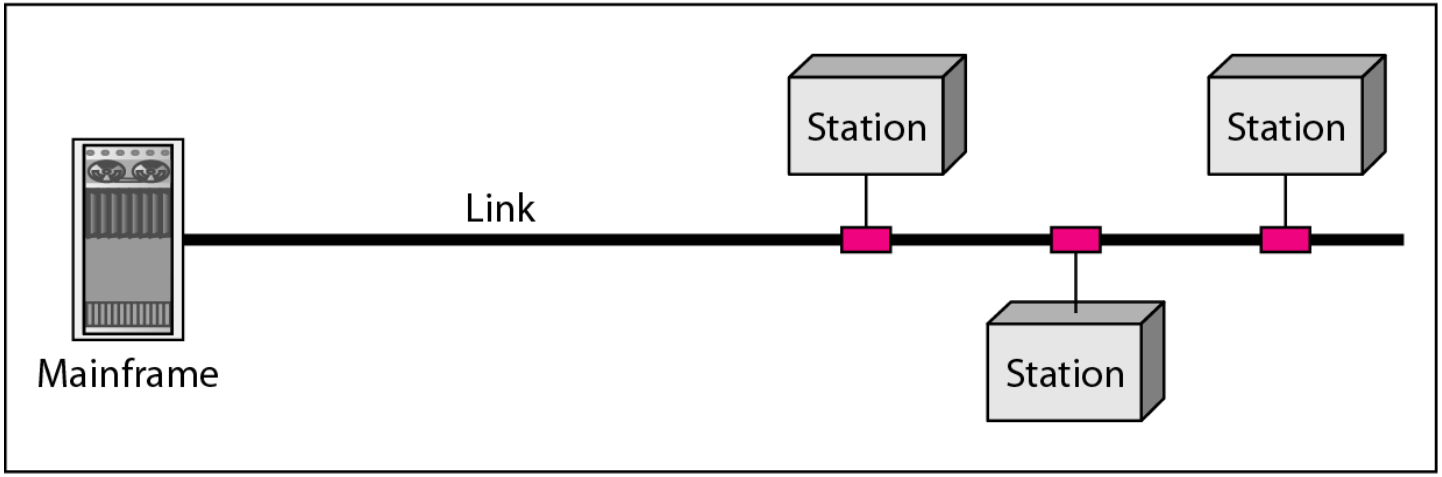
# Transmission Terminology

- Data transmission occurs between a *transmitter* and *receiver* via some medium
- Communication is in form of *electromagnetic waves*
- The medium may be:
  - *Guided medium*, e.g. twisted pair, coaxial cable, optical fiber
  - *Unguided / wireless medium*, e.g. air, water, vacuum
- The configuration may be:
  - *Point-to-point*: only 2 devices share medium
  - *Multipoint*: more than 2 devices share medium
- Direction of communications may be:
  - *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

# Transmission Configuration

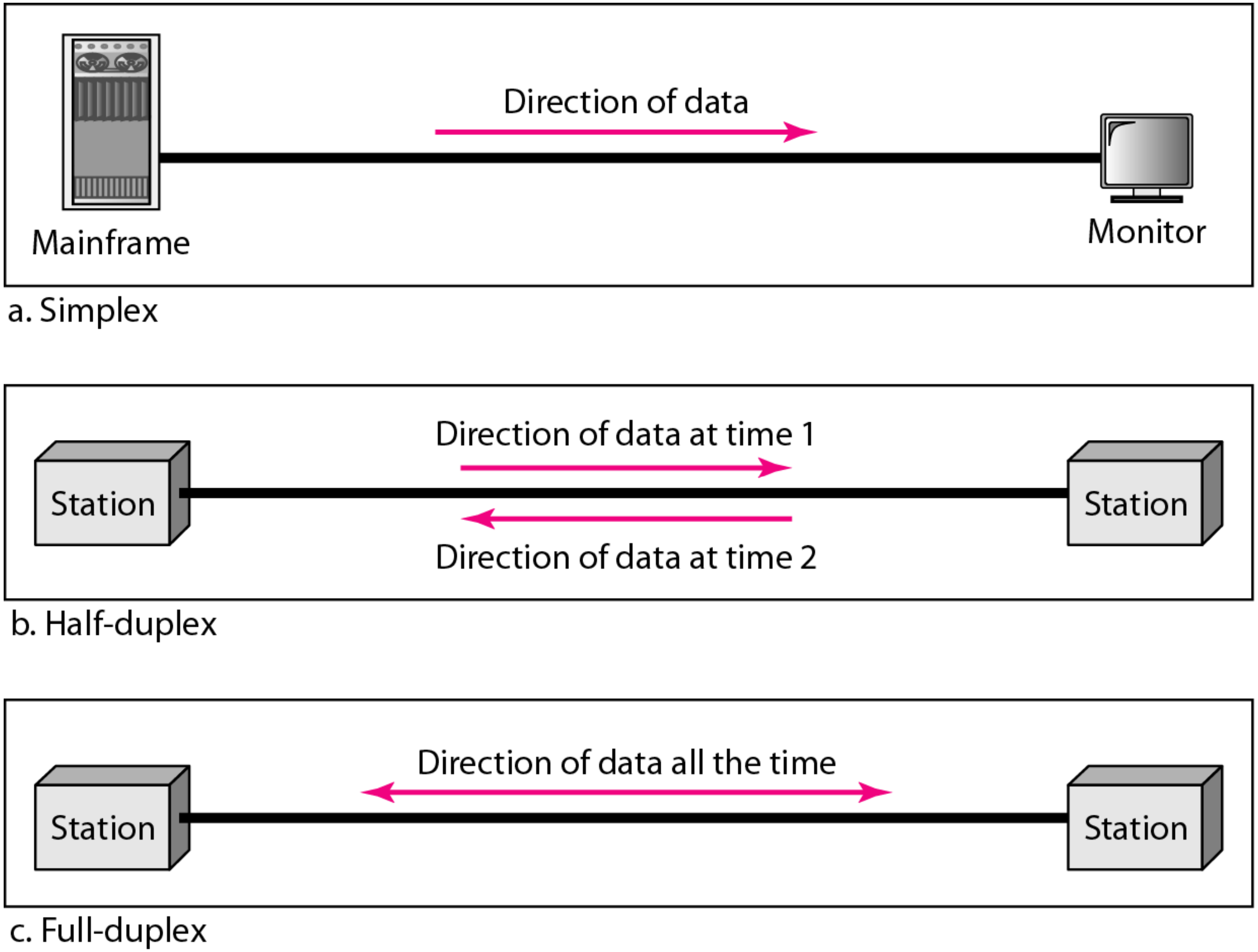



a. Point-to-point




b. Multipoint

# Directions of Communication

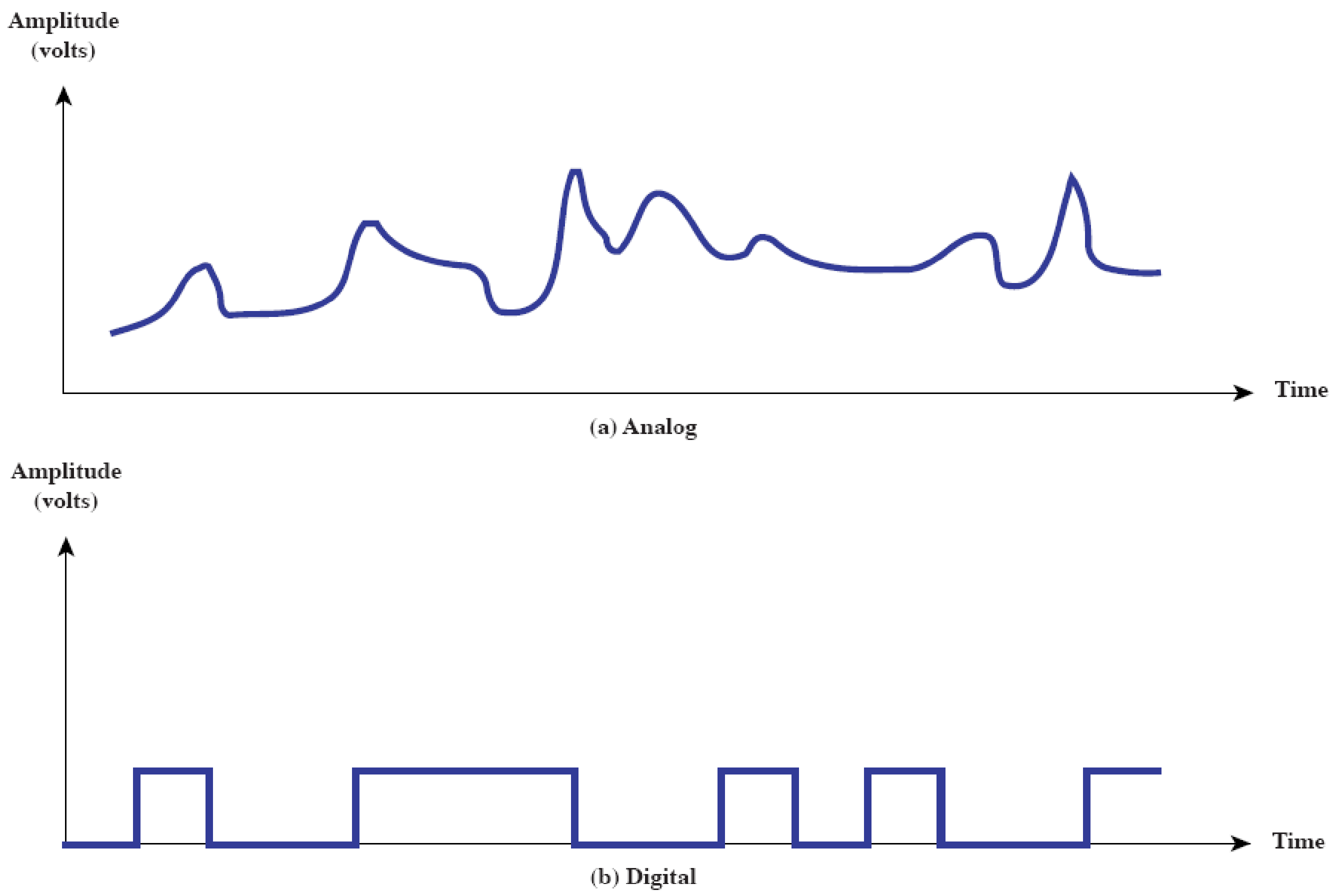


# Frequency, Spectrum and Bandwidth

- Electromagnetic signal (wave) can be viewed in:
  - Time domain
  - Frequency domain
- 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
  - Aperiodic signal
    - pattern not repeated over time

# Time Domain Concepts

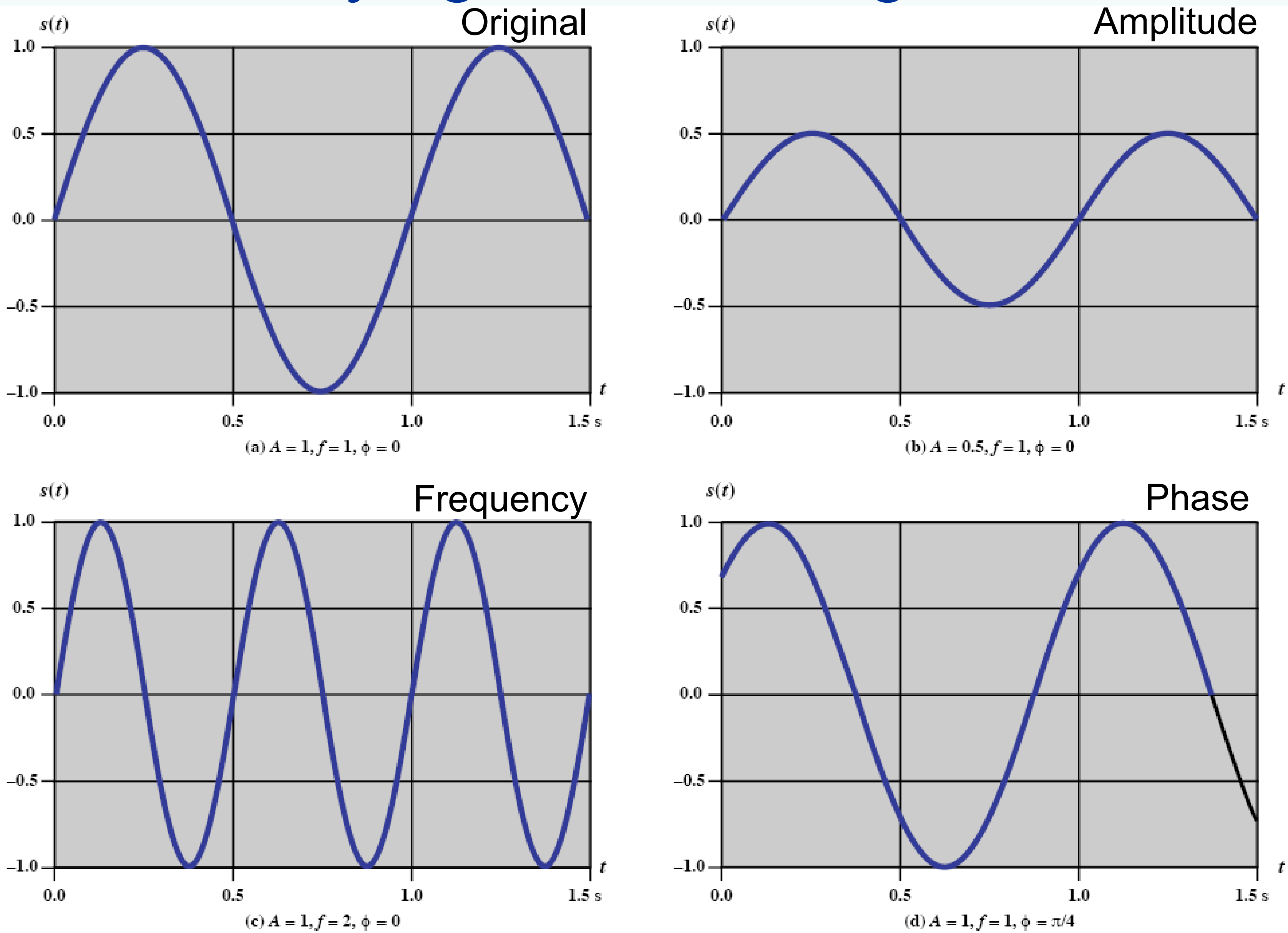
- Signal is a function of time
  - Example of analog and digital signals versus time



# Sinusoid Signals

- Communication signals are made up of sinusoid signals
- General sine wave function:
  - $s(t) = A \sin(2\pi f t + \phi)$
    - A: peak amplitude – maximum strength of signal over time [volts]
    - f: frequency – rate at which signal repeats [cycles per second or Hertz]
    - T: period – T = 1/f [seconds]
    - Φ: phase – relative position signal has advanced (or shifted) to some origin (usually 0) [radians]
- Following plots show signal at single point in space, as a function of time
  - Can also show signal at a single point in time, as a function of space (e.g. distance from transmitter)
    - Also a sinusoid
  - Relationship between space and time: Wavelength ($\lambda$)
    - Distance occupied by single cycle
    - $\lambda = vT = v/f$
    - $v$ is velocity; normally speed of light, $c = 3*10^8\ ms^{-1}$

# Varying Sinusoid Signals

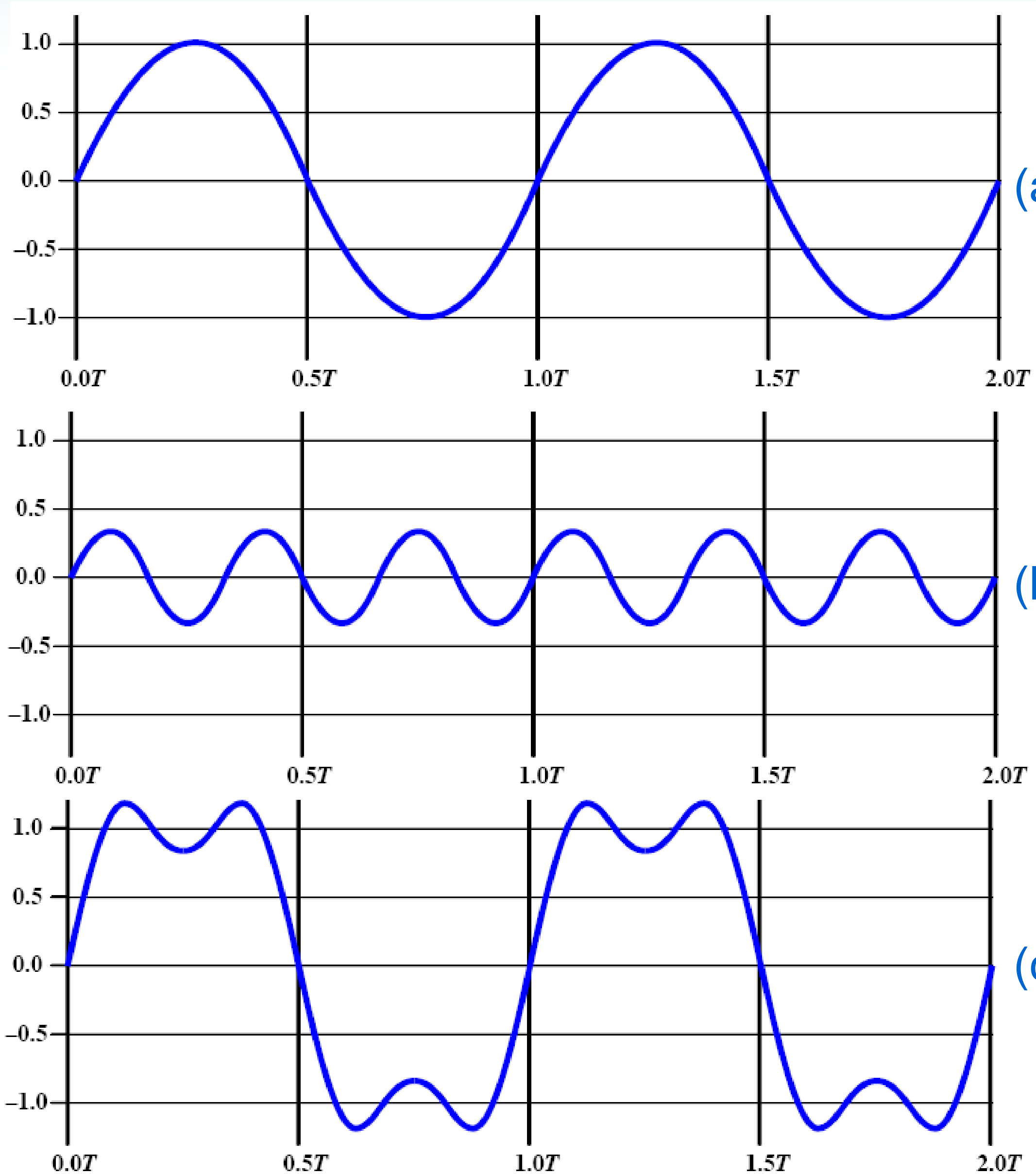


# Frequency Domain Concepts

- A signal can also be viewed in the frequency domain
  - Any signal can be made up of component signals at different frequencies, where each component is a sinusoid
    - Fourier Analysis (not covered in this course)
    - When all frequency components of a signal are integer multiples of one frequency, the latter is called *fundamental frequency*
    - Period of total signal is equal to period of fundamental frequency
  - Time Domain: s(t) specifies the amplitude of signal at each instant in time
  - Frequency Domain: S(f) specifies the peak amplitude of constituent frequencies of signal

# Example Constituent Frequencies

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




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

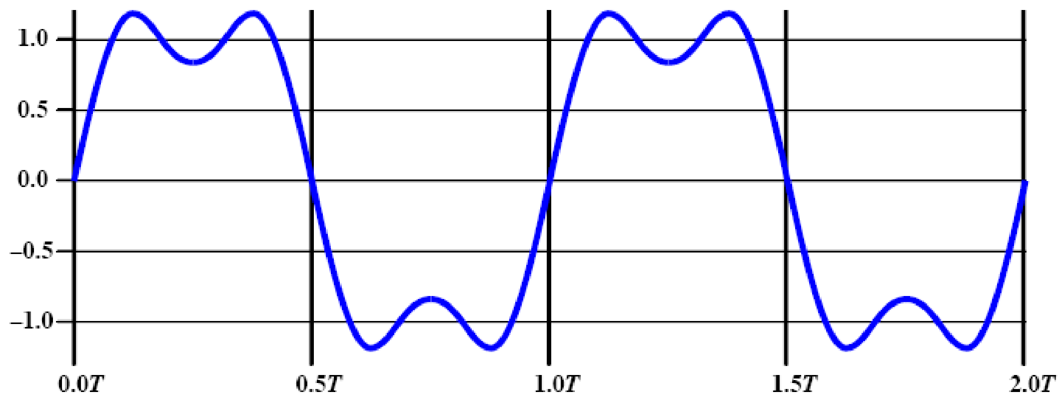
(b): $(1/3)\sin(2\pi(3f)t)$

(c): (a) + (b)

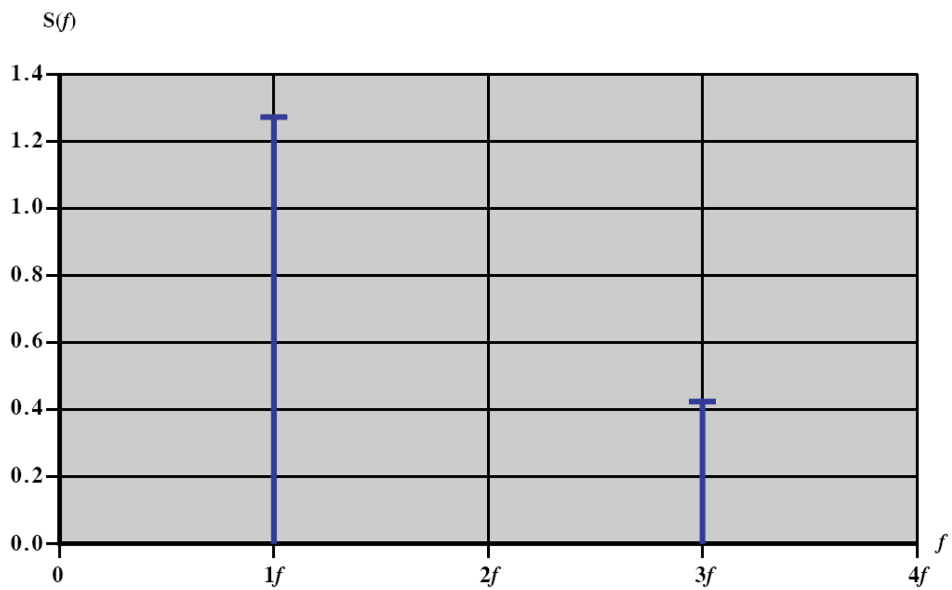
# Example Frequency Domain

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

Time domain

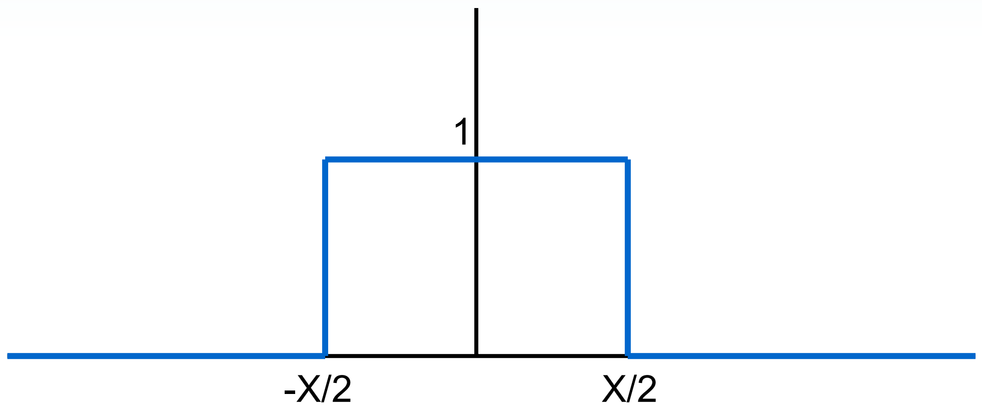



Frequency domain

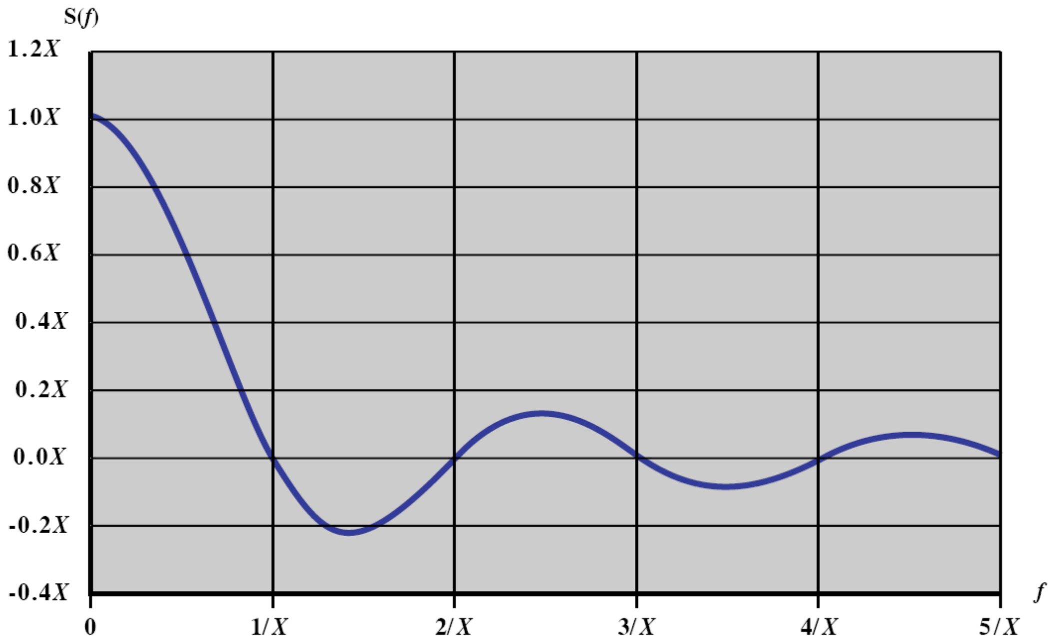


# Example Frequency Domain

Time domain




Frequency domain

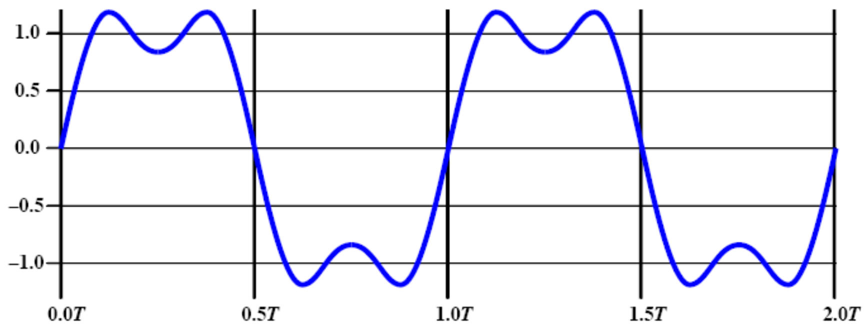



(b) $s(t) = 1 \quad -X/2 \le t \le X/2$

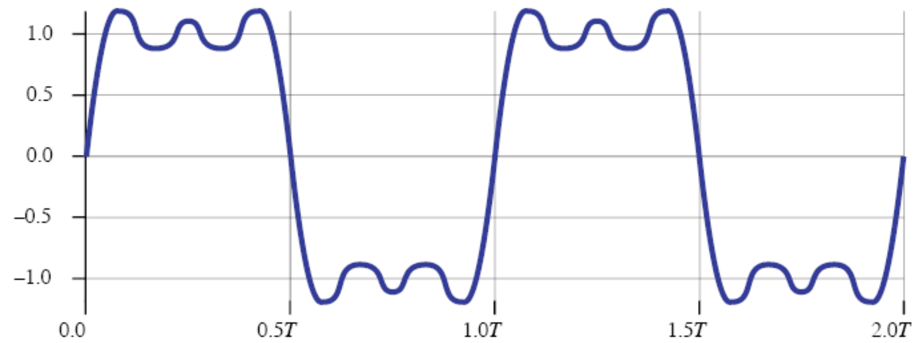
# Spectrum, Bandwidth and Data Rates

- Spectrum of a signal is range of frequencies it contains
  - E.g. 1f to 3f
- Absolute bandwidth is width of spectrum
  - E.g. 2f
  - However, many signals have infinite absolute bandwidth
  - But most of the signal energy is contained in narrow band of frequencies – called Effective Bandwidth or just Bandwidth
- Bandwidth
  - No formal definition of which frequencies are in effective bandwidth
  - But all practical systems can only support limited band of frequencies (and hence, this determines bandwidth)
- Data Rates
  - Bandwidth limit of system determines data rate

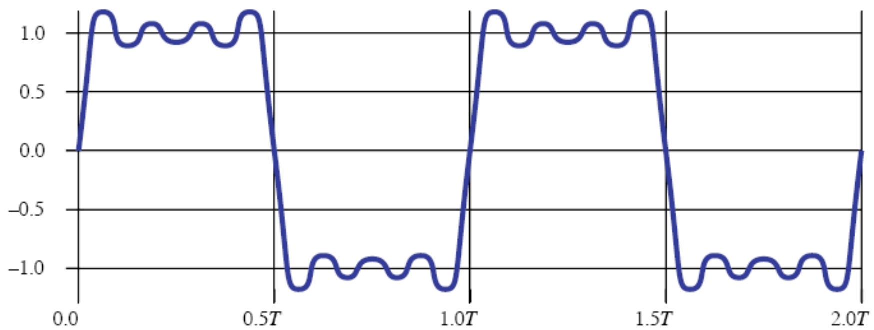
# Example: Square Wave



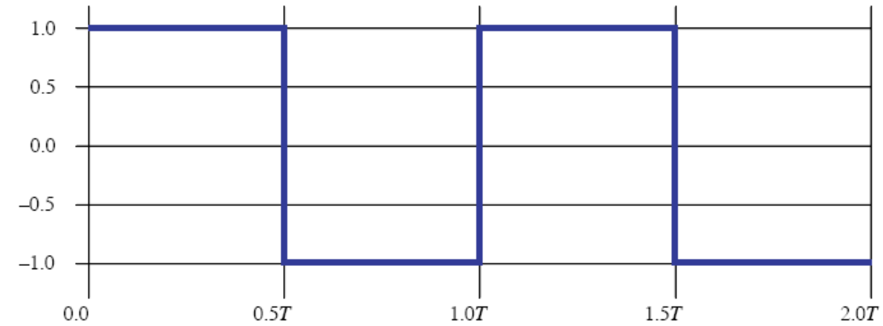

$s(t)=[(4/\pi) \times (\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t)]$




$s(t)=(4/\pi)\ [\ (\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t) + (1/5)\sin(2\pi(5f)t)]$



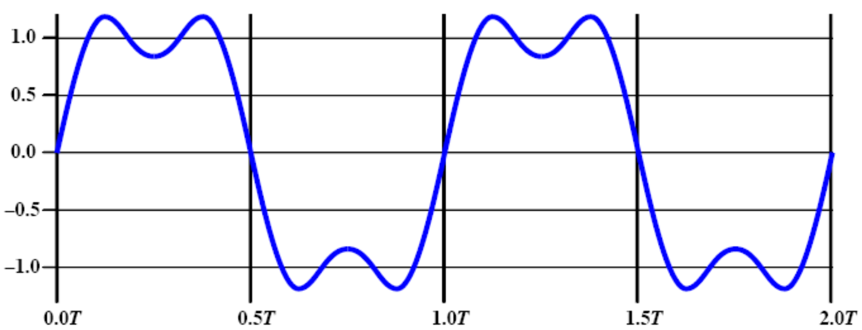

$s(t)=(4/\pi)\ [\ (\sin(2\pi ft) + (1/3)\sin(2\pi(3f)t) + (1/5)\sin(2\pi(5f)t) + (1/7)\sin(2\pi(7f)t)]$



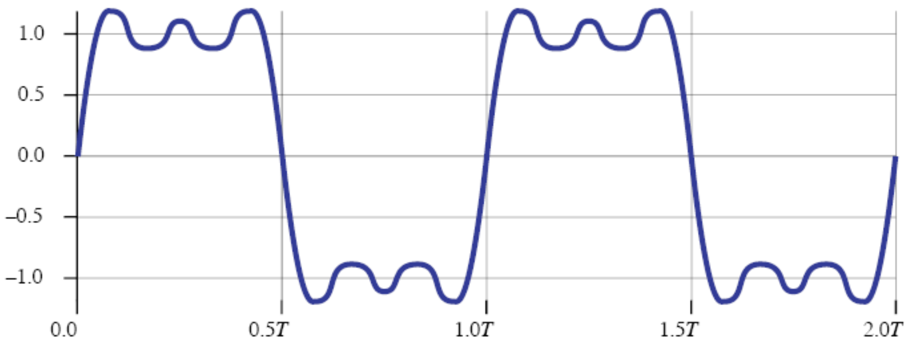

$s(t)=(4/\pi) \sum (1/k)\sin(2\pi(kf)t)$ , for k odd

# Example: Square Wave

Lets assume our system can transmit 4MHz signals




If f=2MHz, BW=4MHz
T=0.5μs
1 bit per 0.25μs
Data Rate = 4Mb/s




If f=1MHz, BW=4MHz
T=1μs
1 bit per 0.5μs
Data Rate = 2Mb/s

If f=2MHz, BW=8MHz
T=0.5μs
1 bit per 0.25μs
Data Rate = 4Mb/s

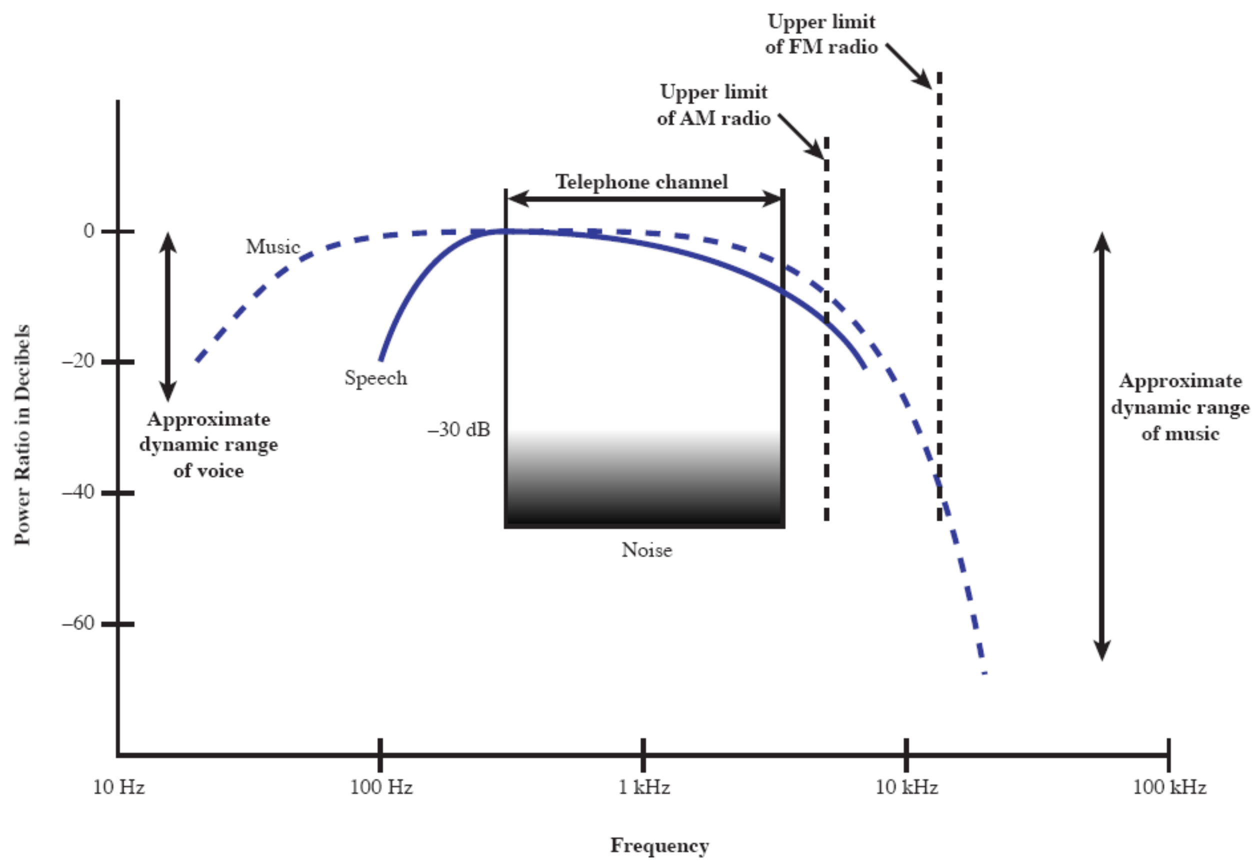
- Greater bandwidth transmitted, greater the cost
- Doubling the bandwidth, doubles the data rate
- Using a smaller bandwidth signal is more efficient
- But smaller bandwidth, more chance of errors

# Analog versus Digital

- Analog roughly corresponds to *continuous* and digital to *discrete*
- Analog and Digital are used in different contexts:
  - Data: the information we want to send, e.g. audio, video, text
  - Signals: the electromagnetic signals sent over medium
  - Transmission: the way in which signals are sent

# Analog and Digital Data

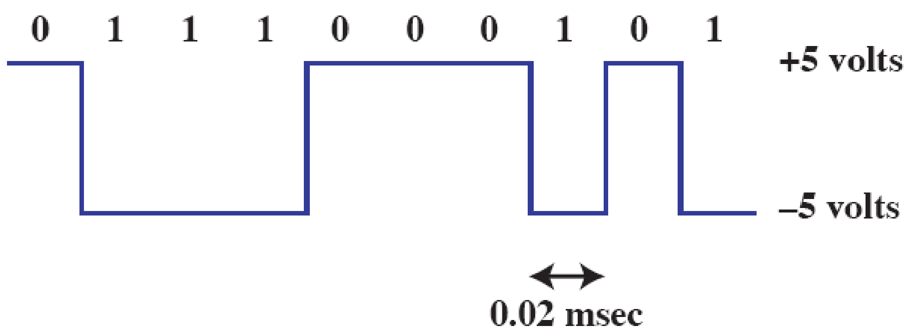
- Analog Data
  - Audio
  - Video

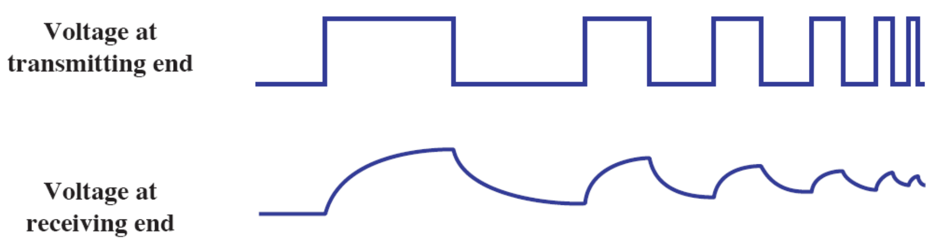



- Digital Data
  - Text
    - Use ASCII or International Reference Alphabet (IRA) to map characters (e.g. letters) to 7-bits

# Analog and Digital Signals

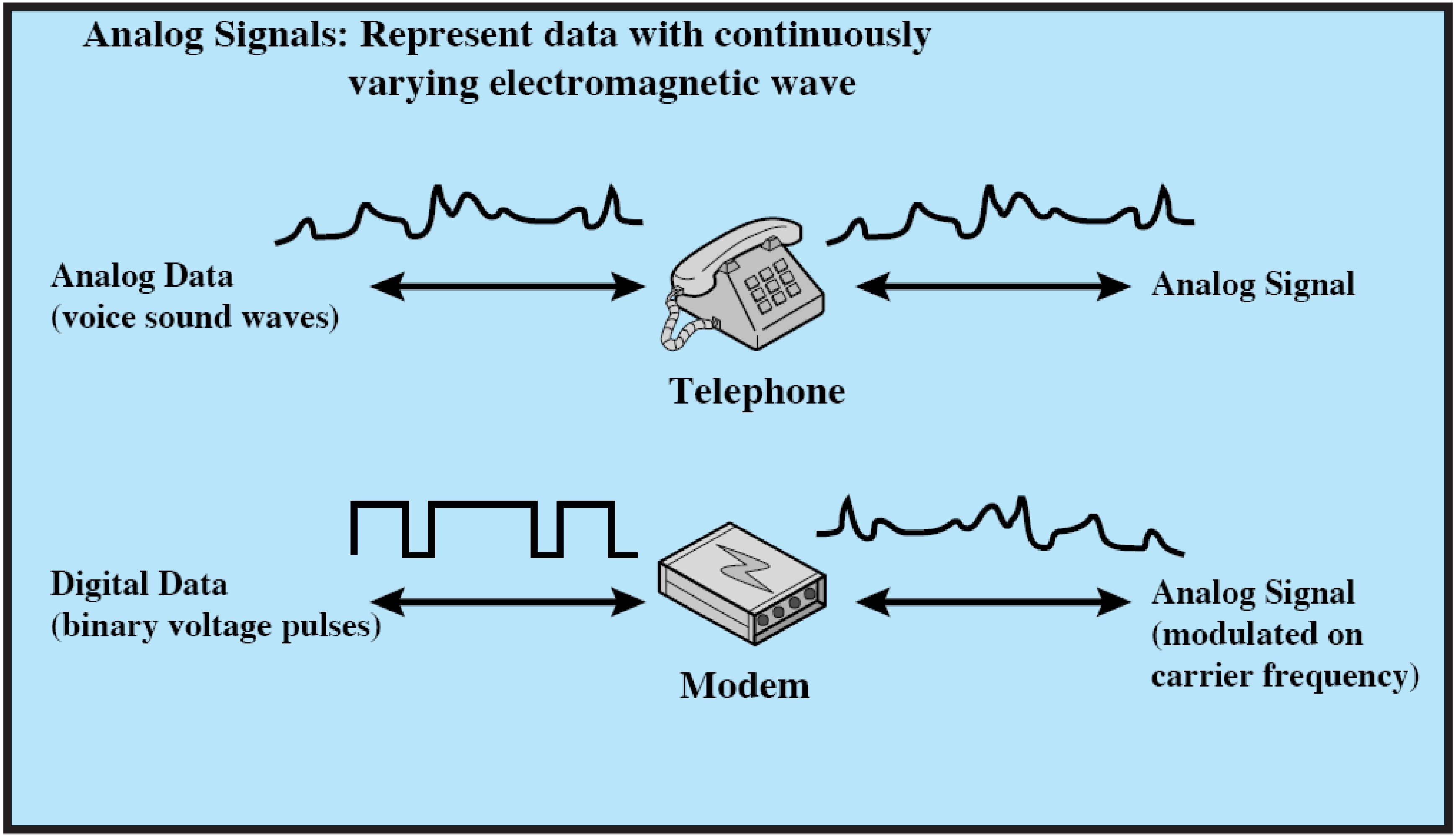
- Analog signals
  - Audio: sound waves converted to electromagnetic signals, e.g. amplitude of sound wave is proportional to amplitude of voltage signals
- Digital signals
  - Use voltage to represent 0's and 1's (e.g. +5 volts, -5 volts)



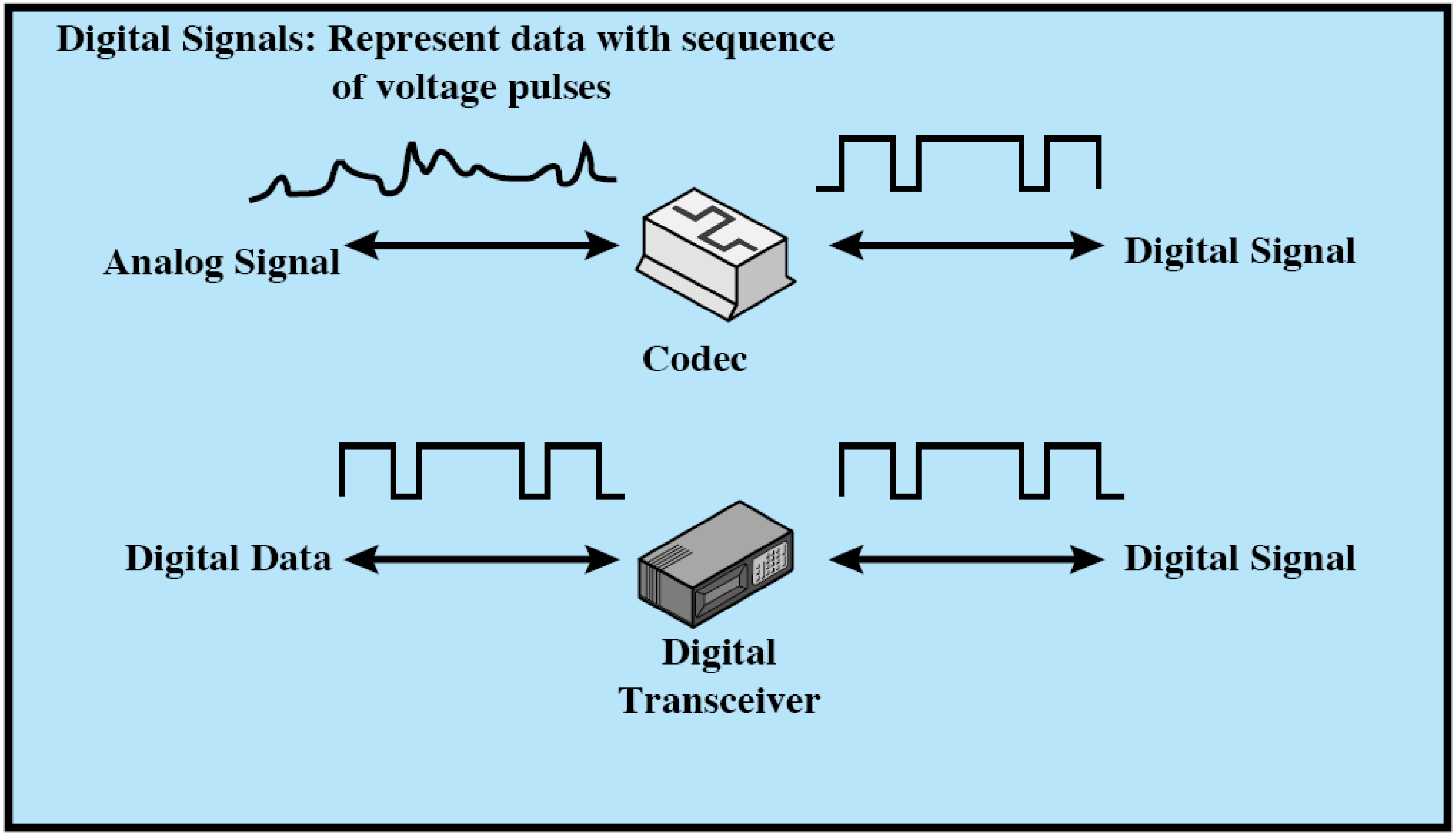




With attenuation and higher frequencies, it is harder to tell whether receiver signal is 0 or 1

# Analog Signals



# Digital Signals



# Analog and Digital Transmission

- Analog Transmission
  - Transmit analog signals: content of signals may be analog (e.g. voice) or digital (e.g. text)
  - Analog transmitted signals attenuate over distance
    - Need amplifiers to boost energy
      - But amplifiers also boost noise, so over long distances signal can be distorted (leads to errors)
- Digital Transmission
  - Transmit digital signals
  - Digital transmitted signals are susceptible to errors over long distances
    - Need repeaters to repeat the signal; the errors are not accumulated

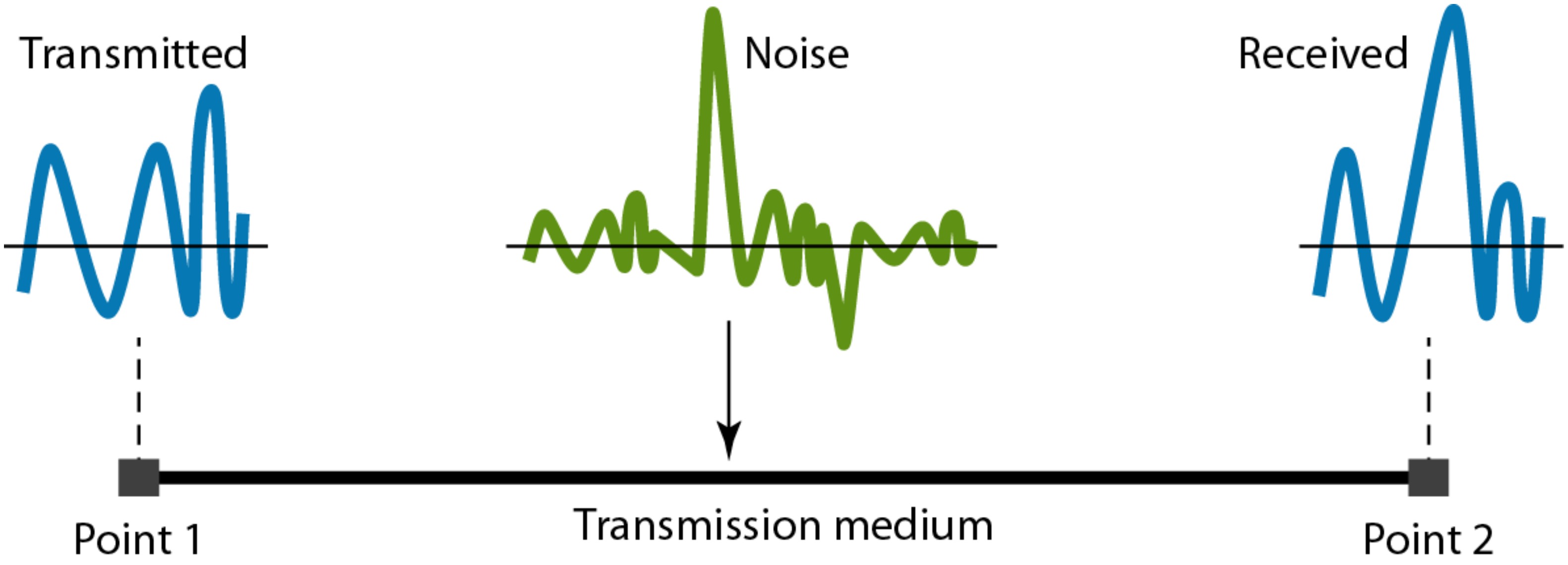
# Analog versus Digital

- Telecommunications industry prefers digital transmission (and signals) over analog
- Especially for long-haul telecommunications and intra-building services
- Why?
  - Cost of digital circuits reduced rapidly (whereas analog circuits did not)
  - Digital repeaters do not cumulate errors (whereas analog amplifiers do) – less likely for errors
  - Easier and cheaper to multiplex many digital signals onto one large-capacity transmission system
  - Encryption techniques can be applied easily to digital signals
  - Easier to integrate analog and digital data onto a digital transmission system

# Transmission Impairments

- Signal received may differ from signal transmitted causing:
  - Analog – degradation of signal quality
  - Digital – bit errors
- Most significant impairments are:
  - Attenuation and attenuation distortion
    - Signal degrades with distance (usually exponentially)
  - Delay distortion
    - Different frequency components of signal received with different delays
    - Received signal is distorted, leading to inter-symbol interference in digital data
  - Noise
    - Thermal noise: always present; function of temperature
    - Inter-modulation noise: different frequencies interfere with each other
    - Crosstalk: multiple signals interfere with each other
    - Impulse noise: spikes, e.g. lightning, power faults

# Impact of Noise



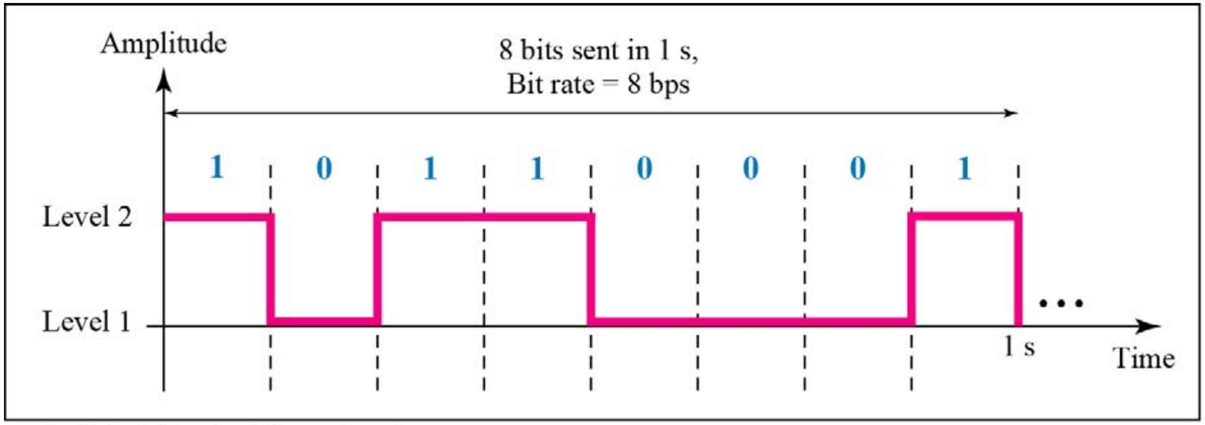
# Successfully Receiving Data

- A signal is transmitted with some strength or amplitude
  - Transmitted signal strength (Tx) is often measured in Volts or Watts (or dBW)
  - Decibels:
    - Gain (measured in dB): $G_{db} = 10 \log_{10} (P_{out}/P_{in})$
    - Power (measured in dBW): $P_{dBW} = 10 \log_{10} (Power_W/1W) = 10 \log_{10} (Power_W)$
- The signal is attenuated over the transmission medium
  - E.g. Path loss, L, measured in dB or Watts
- Noise (N) may be introduced into the system (between transmitter and receiver)
- For digital circuits to be able to successfully received and process the data, the received signal must be:
  - Significantly greater than the noise:
    - $(Tx-L)/N = SNR > SNRThreshold$
    - where SNR is Signal-to-Noise Ratio
  - Most devices specify a Receive threshold (or sensitivity) that is the minimum Signal strength that can be received such that we are above the SNRThreshold (or a given Noise value)

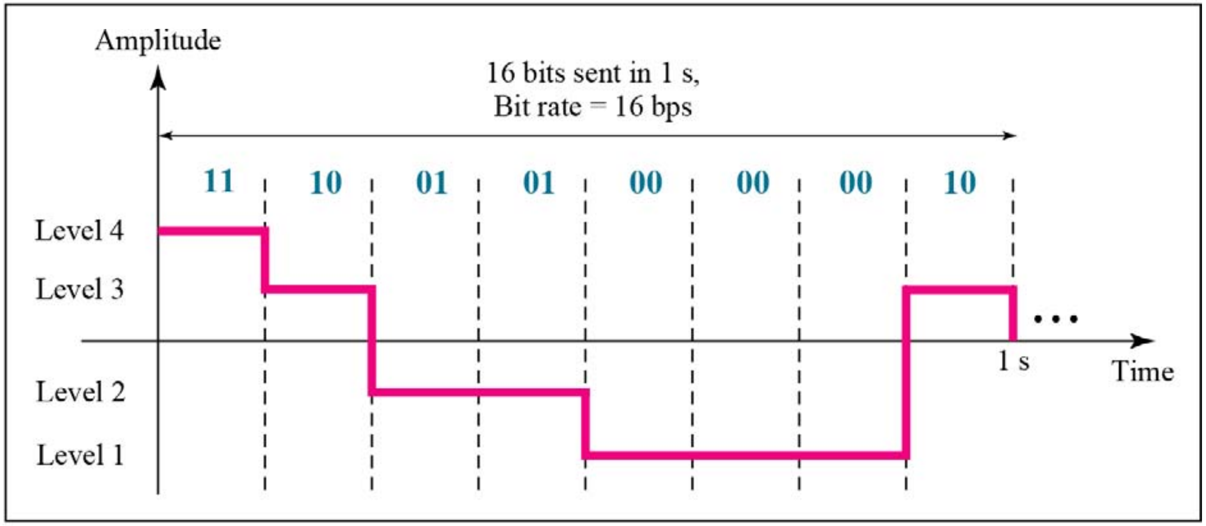
# Channel Capacity

- What is the maximum rate at which data can be sent over a communication medium?
- Concepts of interest:
  - Data Rate; Bandwidth; Noise; Error Rate
- Nyquist Bandwidth
  - Assume the channel is noise free
  - $C = 2 B \log_2 M$
  - C: capacity [bits per second]
  - B: bandwidth [Hertz] – practically limited due to cost
  - M: voltage levels used
    - If transmit binary (+5V, -5V), M=2
    - But could transmit 4 levels (+5=11, +2=10, -2=01, -5V=00): M=4
    - Practically limited due to noise and other impairments

# Multiple Level Signals




a. A digital signal with two levels




b. A digital signal with four levels

# Channel Capacity

- Shannon Capacity
  - Nyquist says: double bandwidth, doubles the capacity (but doesn't consider noise)
  - With noise, some bits may be corrupted
    - Higher date rate leads to more bits being corrupted
      - E.g. of noise spike lasts for 1us, then at 1Mb/s data rate, 1 bit is corrupted; but with 2Mb/s data rate, 2 bits are corrupted
  - With a higher powered signal we can overcome noise:
    - Signal-to-Noise Ratio, SNR = 10 $\log_{10}$ (signal power / noise power)
  - Shannon Capacity:
    - $C = B \log_2 (1 + SNR)$
  - This is a theoretical limit – in practice, cannot achieve Shannon capacity