無線網路概論
Intro. to Wireless Internet

Lecture 02 - Signals

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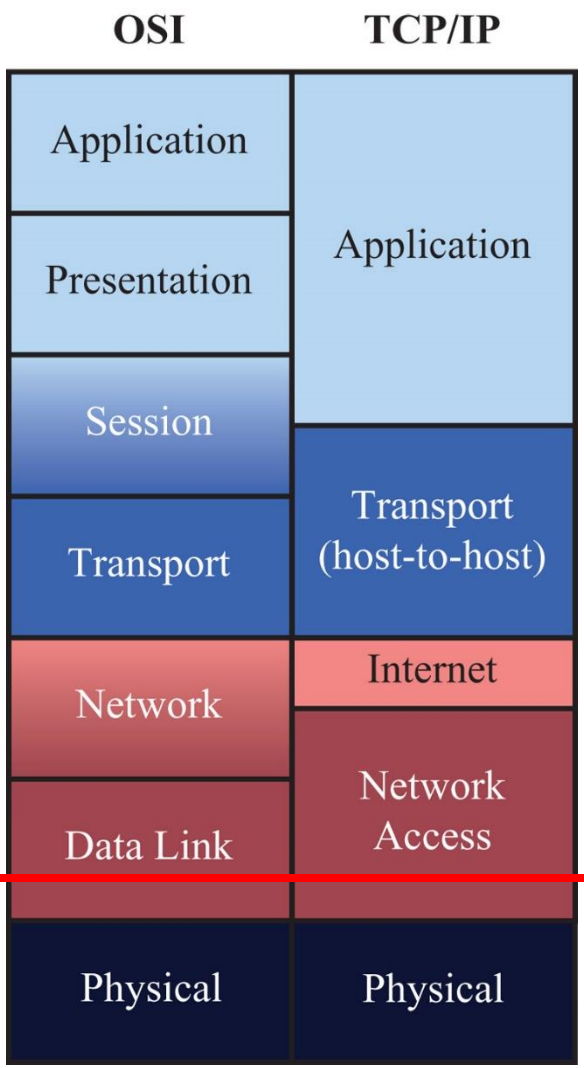
YZU CSE

Lecture Material

- “Wireless Communication Networks and Systems”, Corry Beard and William Stallings, 2016.
  - Ch 2. Transmission fundamentals



Application

Provides access to the OSI environment for users and also provides distributed information services.

Presentation

Provides independence to the application processes from differences in data representation (syntax).

Session

Provides the control structure for communication between applications; establishes, manages, and terminates connections (sessions) between cooperating applications.

Transport

Provides reliable, transparent transfer of data between end points; provides end-to-end error recovery and flow control.

Network

Provides upper layers with independence from the data transmission and switching technologies used to connect systems; responsible for establishing, maintaining, and terminating connections.

Data Link

Provides for the reliable transfer of information across the physical link; sends blocks (frames) with the necessary synchronization, error control, and flow control.

Physical

Concerned with transmission of unstructured bit stream over physical medium; deals with the mechanical, electrical, functional, and procedural characteristics to access the physical medium.

Outline

- Signals?
- Signal types
- Analog & digital data transmission
- Channel capacity
- Transmission media
- Multiplexing

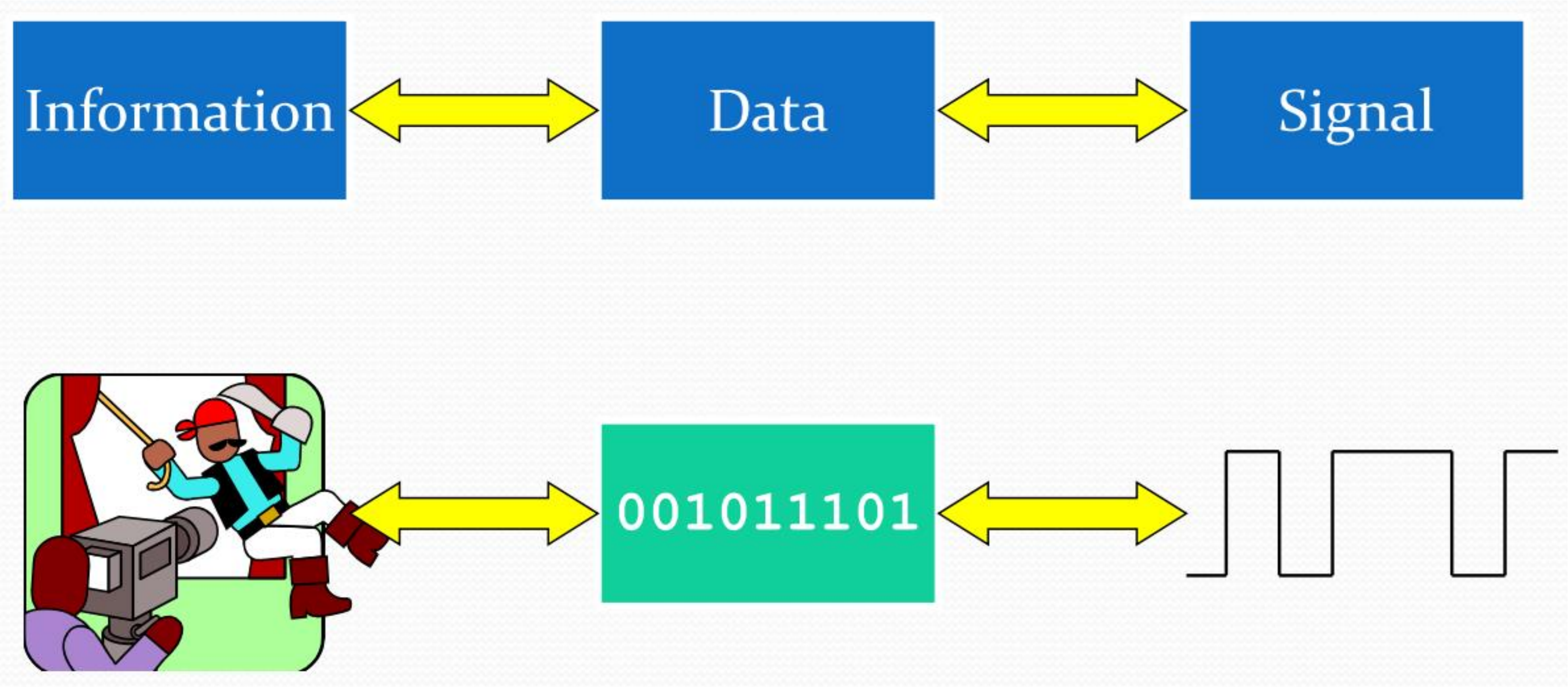
Signals in the Real World (1/2)

Signals in the Real World (2/2)

Signal in Computer?

- Data
  - A representation of facts, concepts, or instructions in a formalized manner suitable for communication, interpretation, and processing by human beings or by automatic means.
- Information
  - The meaning that is currently assigned to data by means of the conventions applied to those data.

Data & Info. vs. Signal



Signal in Computer?

- Computers use signals for communication.
- Computers transmit data using digital signals, which are sequences of specified voltage levels.
- Computers sometimes communicate over telephone line using analog signals, which are formed by continuously varying voltage levels.

Outline

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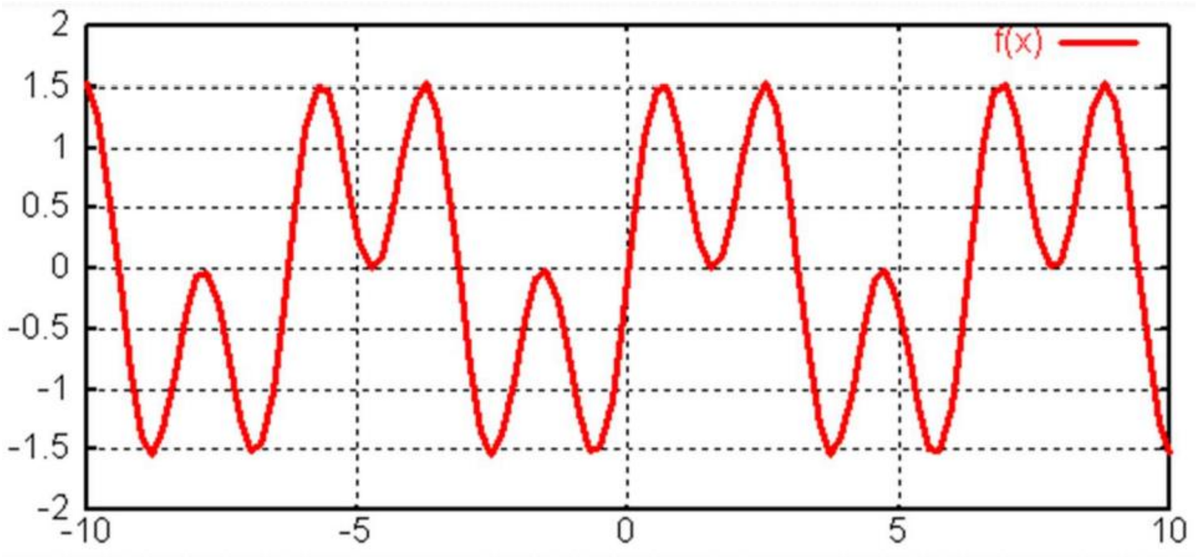
Electromagnetic Signal

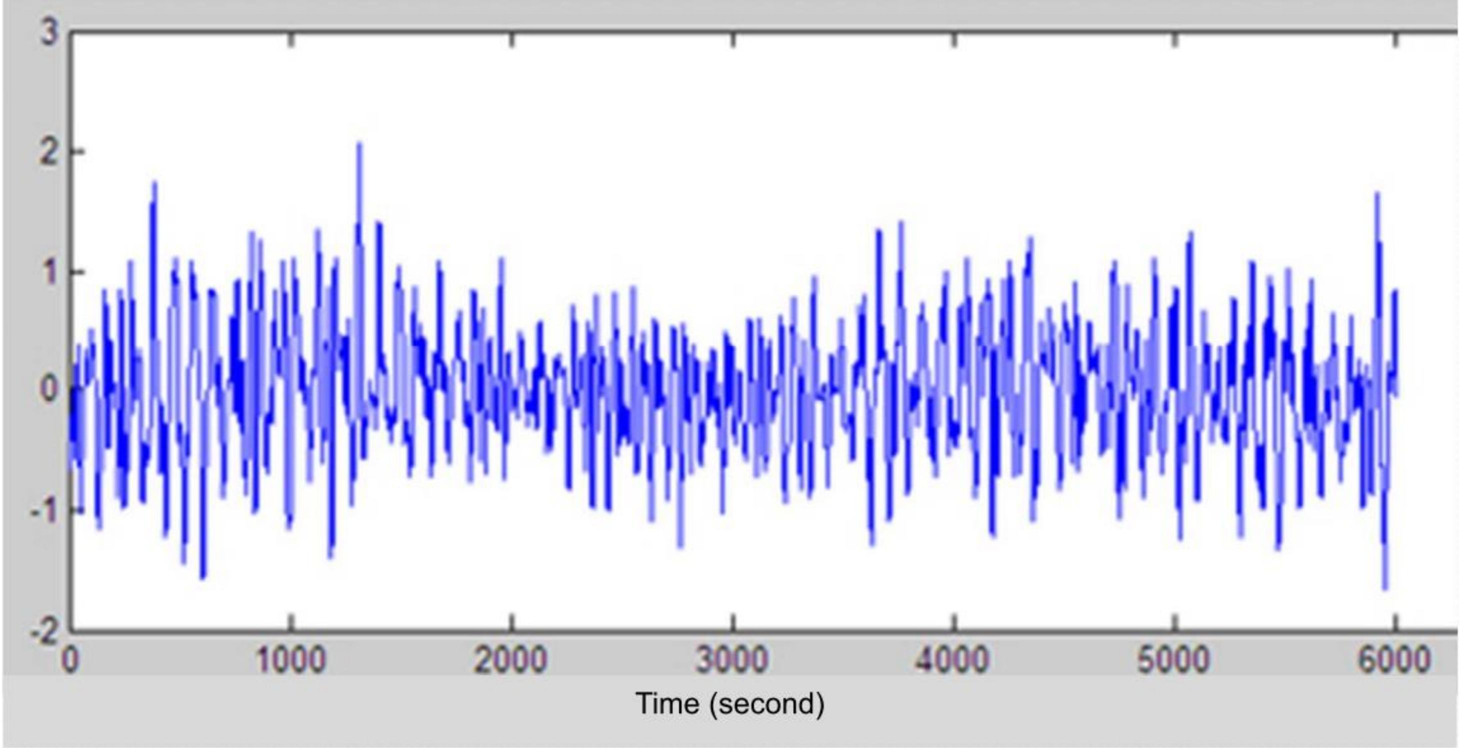
- A signal is a function of time.



- Can also be expressed as a function of frequency.
  - Signal consists of components of different frequencies

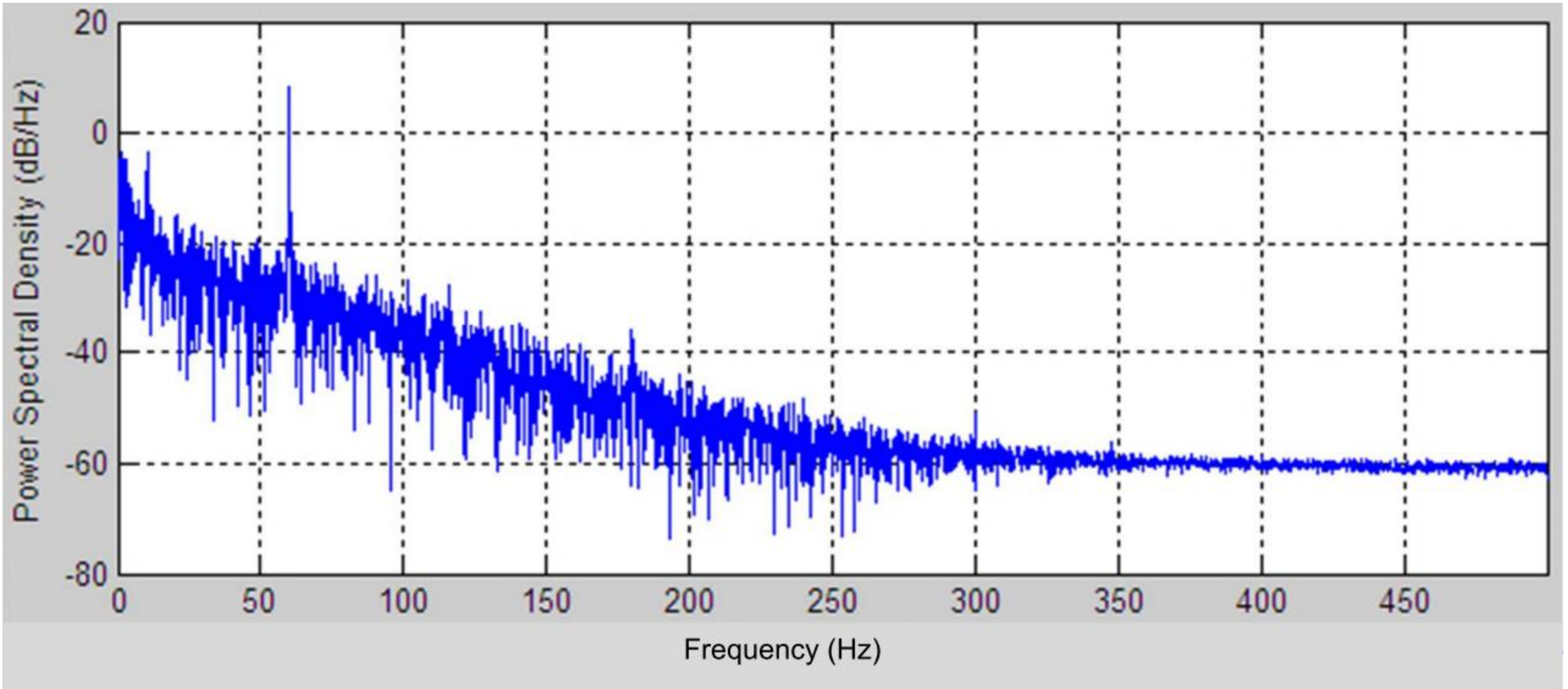
Signals (1/2)

- Represent a signal by a function of time.



Signals (2/2)

- Represent a signal by a function of frequency.

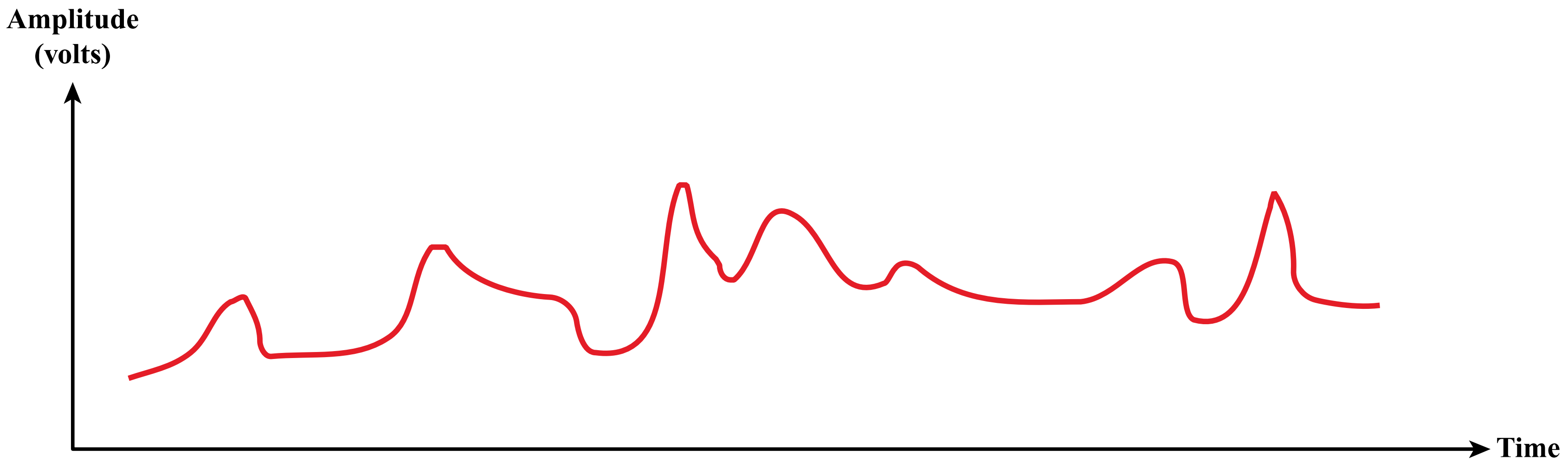


Time-Domain Concepts

- Analog signal
- Digital signal
- Periodic signal
- Aperiodic signal

Analog Signal

- Signal intensity varies in a smooth fashion over time.
- No breaks or discontinuities in the signal
- Analog signals are common in the nature.
  - Ex: light, voice, …



(a) Analog

Digital Signal

- Signal intensity maintains a constant level for some period of time and then changes to another constant level.
- Digital signals are usually artificial.
  - Ex: Audios in your smartphone.

(b) Digital

Periodic Signal

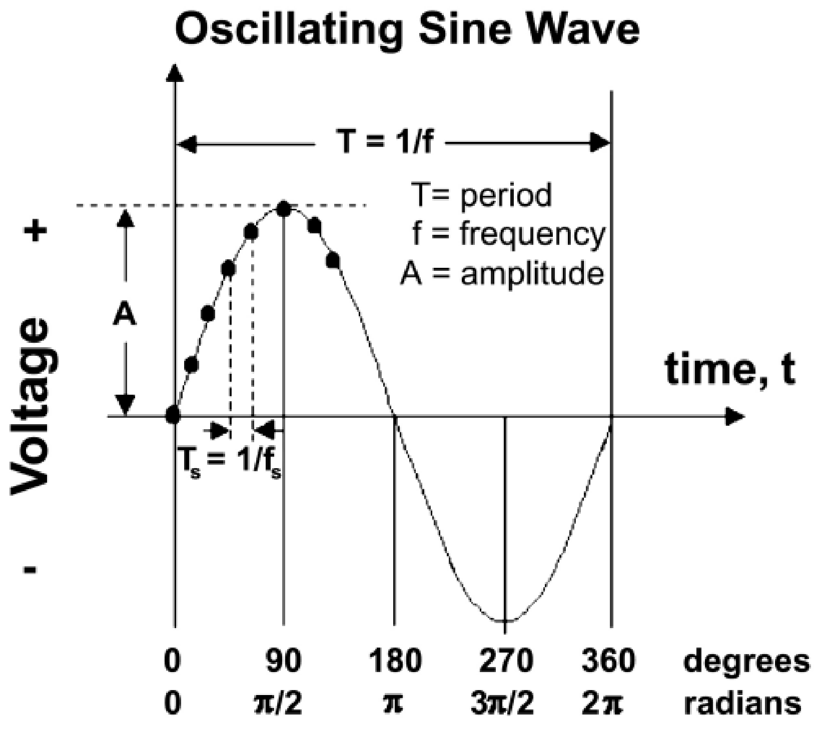
- Analog or digital signal pattern that repeats over time.
- $s(t + T) = s(t)$, $-\infty < t < +\infty$, where T is the period of the signal.
- Ex: Heart beat

Aperiodic Signal

- Analog or digital signal pattern that doesn't repeat over time.
- In communication system, we are interested in periodic signal.

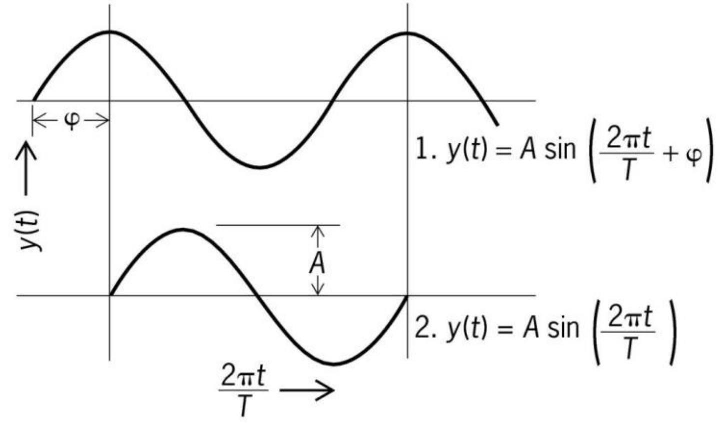
Periodic Signal Representation (1/3)

- A general periodic wave can be represented by five parameters.
- Peak amplitude (*A*)
  - Maximum value or strength of the signal over time.
  - Typically measured in volts.
- Frequency (*f*)
  - Rate, in cycles per second, or Hertz (Hz) at which the signal repeats
- Period (*T*)
  - Amount of time it takes for one repetition of the signal
  - $T = 1/f$

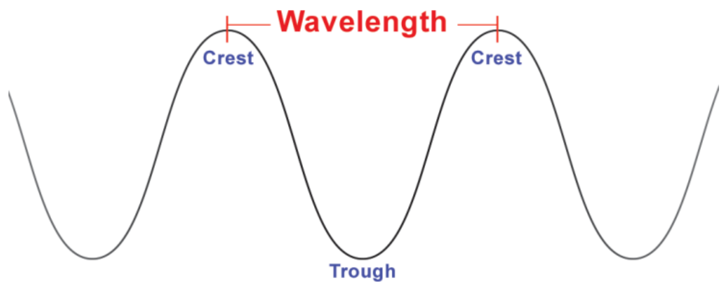


Periodic Signal Representation (2/3)

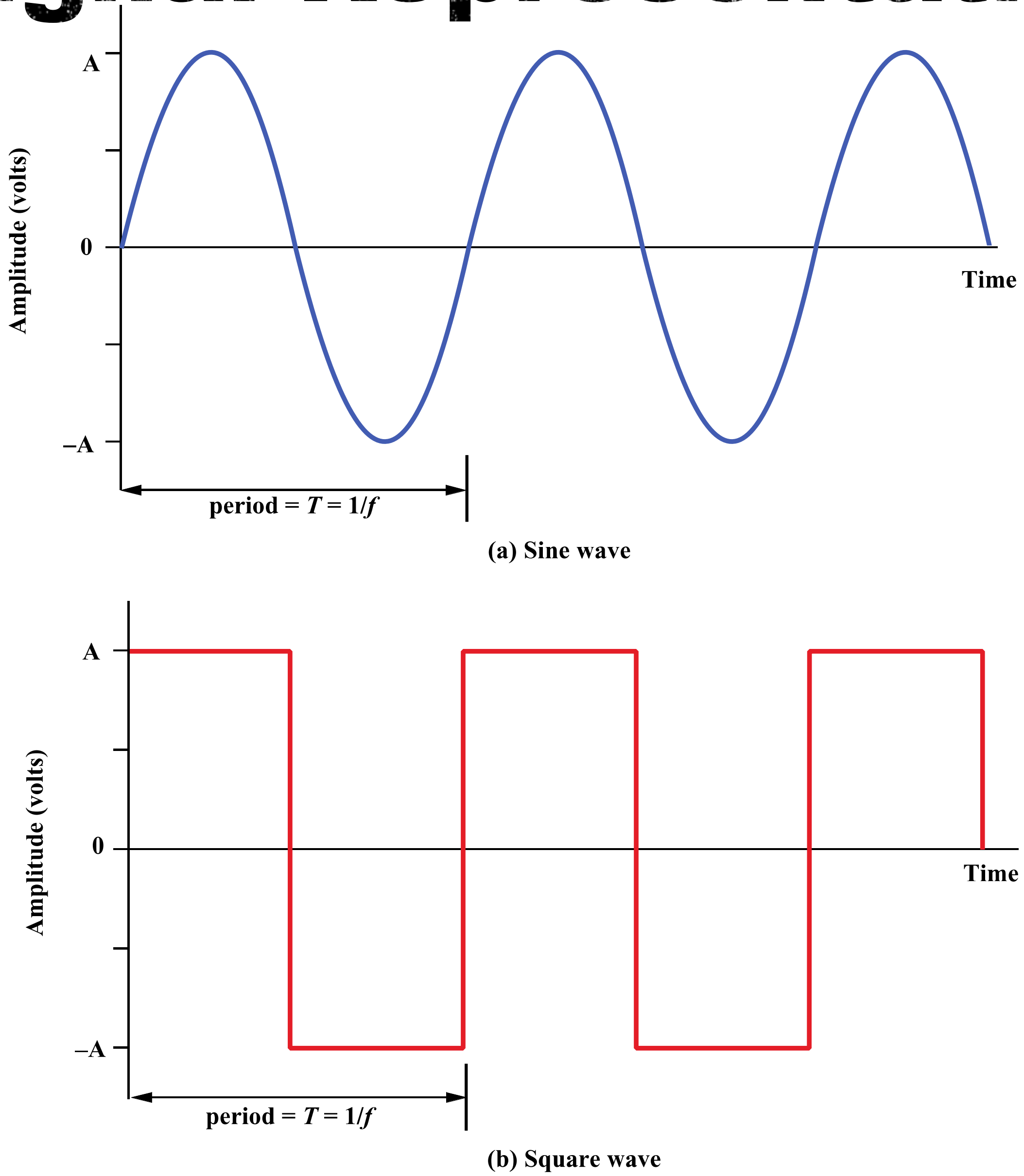
- Phase (ϕ)
  - Measure of the relative position in time within a single period of a signal



- Wavelength (λ)
  - Distance occupied by a single cycle of the signal.
  - Or, the distance between two points of corresponding phase of two consecutive cycles.



Periodic Signal Representation (3/3)

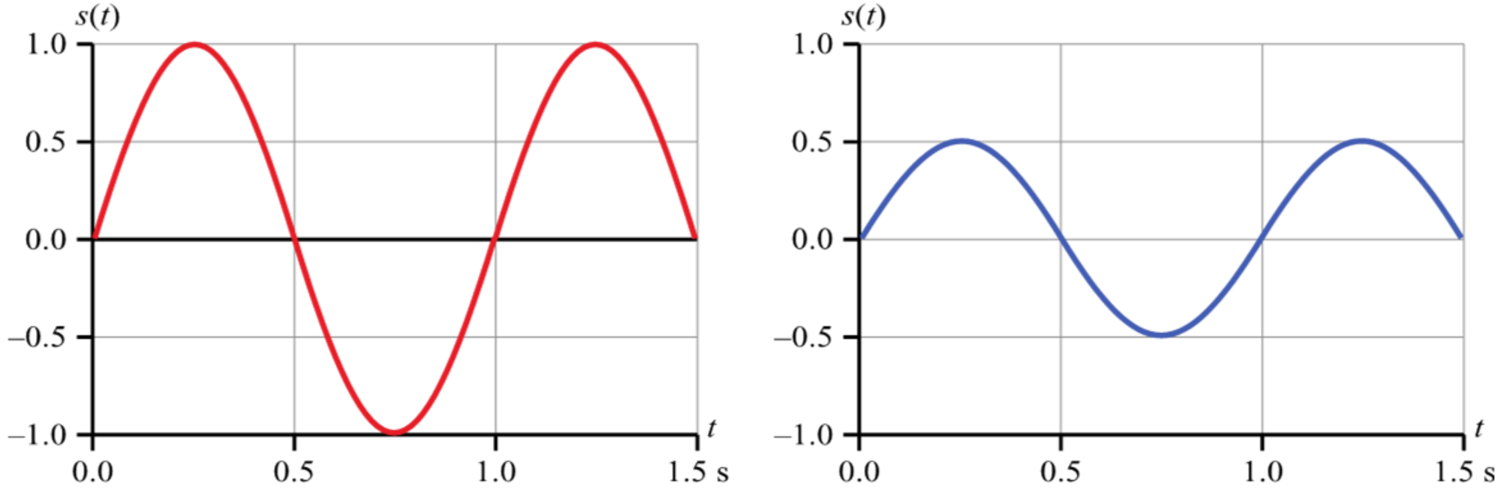


Units

Unit	*Equivalent*	*Unit*	*Equivalent*
Seconds (s)	1 s	Hertz (Hz)	1 Hz
Milliseconds (ms)	10^{-3} s	Kilohertz (kHz)	10^{3} Hz
Microseconds (μs)	10^{-6} s	Megahertz (MHz)	10^{6} Hz
Nanoseconds (ns)	10^{-9} s	Gigahertz (GHz)	10^{9} Hz
Picoseconds (ps)	10^{-12} s	Terahertz (THz)	10^{12} Hz

Sine Wave Parameters (1/2)

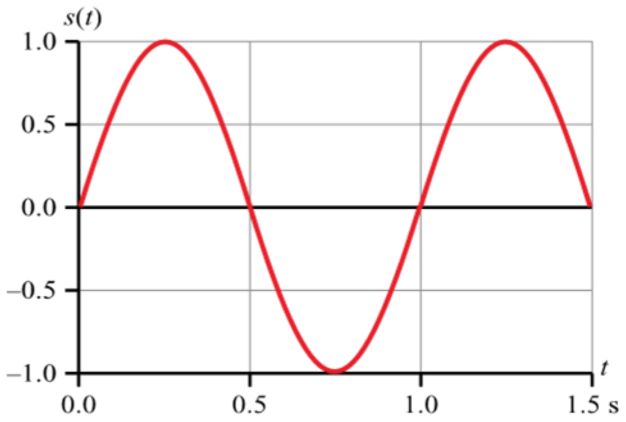
- General sine wave
  - $s(t) = A \sin(2\pi f t + \phi)$
  - 2π radians = 360° = 1 period
- The effect of varying each of the three parameters
  - (a) $A = 1$, $f = 1$ Hz, $\phi = 0$; thus $T = 1$ s



(a) $A = 1, f = 1, \phi = 0$ **(b) $A = 0.5, f = 1, \phi = 0$**

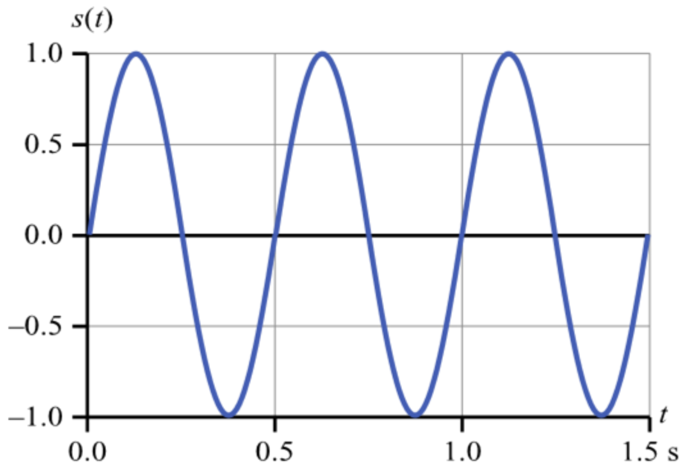
  - (b) Reduced peak amplitude; A=0.5

Sine Wave Parameters (2/2)

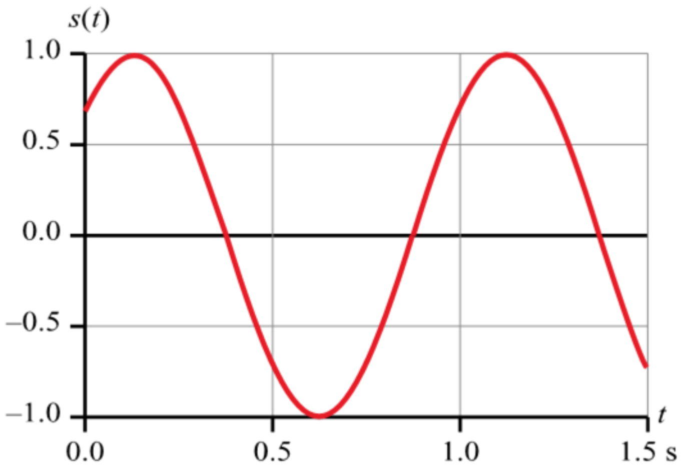


(a) $A = 1, f = 1, \phi = 0$

- (c) Increased frequency; f = 2, thus T = ½
- (d) Phase shift; ϕ = π/4 radians (45 degrees)



(c) $A = 1, f = 2, \phi = 0$



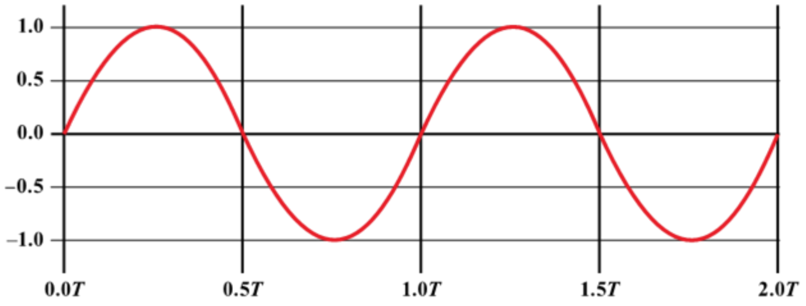
(d) $A = 1, f = 1, \phi = \pi/4$

Time vs. Distance

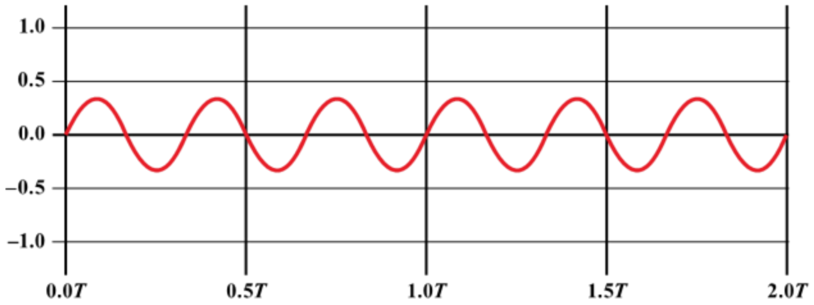
- When the horizontal axis is *time*, graphs display the value of a signal at a given point in *space* as a function of *time*
- With the horizontal axis in *space*, graphs display the value of a signal at a given point in *time* as a function of *distance*
  - At a particular instant of time, the intensity of the signal varies as a function of distance from the source

Frequency-Domain Concepts (1/4)

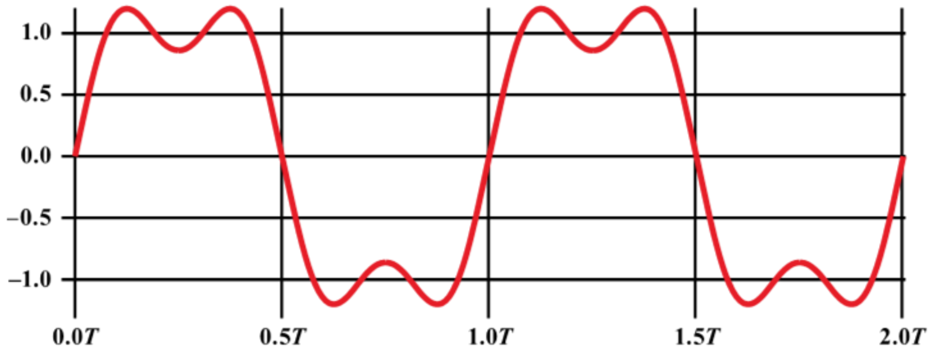
- A signal can be made up of various frequencies.
  - Ex: we have two frequency components f and 3f.



$\sin 2\pi f t$



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



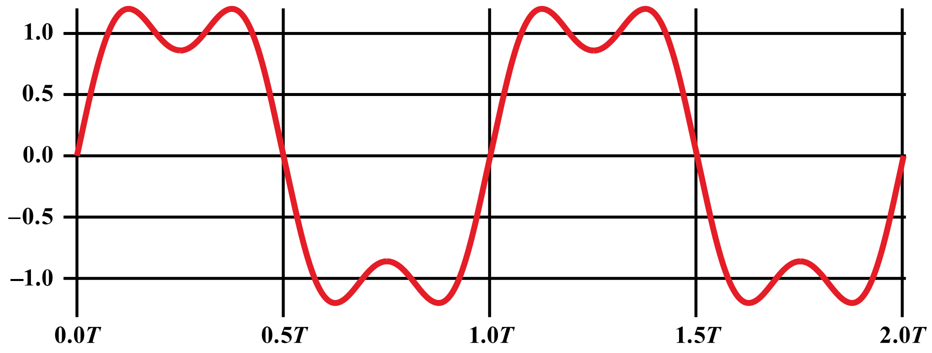
$$\frac{4}{\pi}\left(\sin 2\pi f t + \frac{\sin 2\pi 3 f t}{3}\right)$$

Frequency-Domain Concepts (2/4)

- Any electromagnetic signal can be shown to consist of a collection of periodic analog signals (sine waves) at different amplitudes, frequencies, and phases.
- The period of the total signal is equal to the period of the fundamental frequency.

Frequency-Domain Concepts (3/4)

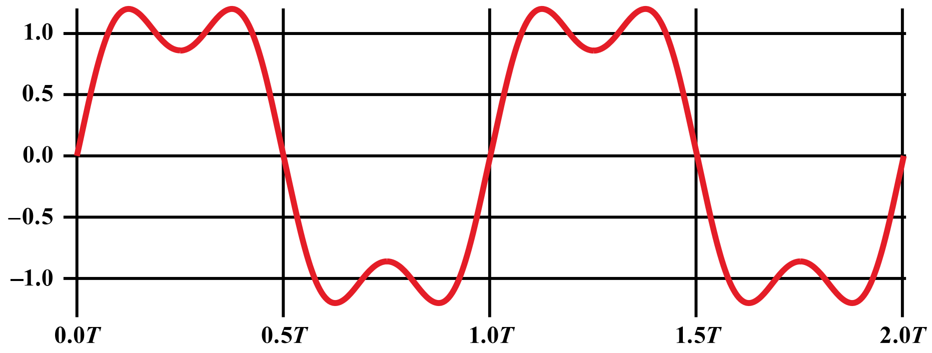
- Fundamental frequency
  - when all frequency components of a signal are integer multiples of one frequency, it's referred to as the fundamental frequency
- Spectrum
  - Range of frequencies that a signal contains
  - Ex: the spectrum extends from *f* to *3f*.



$$\frac{4}{\pi}(\sin 2\pi f t + \frac{\sin 2\pi 3 f t}{3})$$

Frequency-Domain Concepts (4/4)

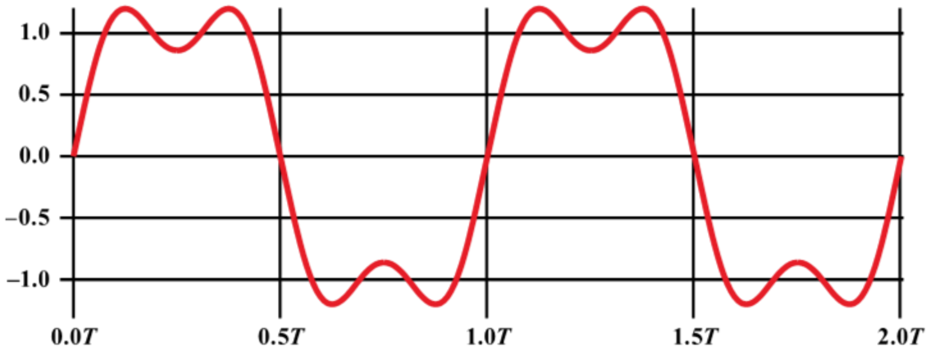
- Absolute bandwidth
  - Width of the spectrum of a signal
  - Ex: the absolute bandwidth is $3f - f = 2f$.
- Effective bandwidth (or just bandwidth)
  - Narrow band of frequencies that most of the signal's energy is contained in.



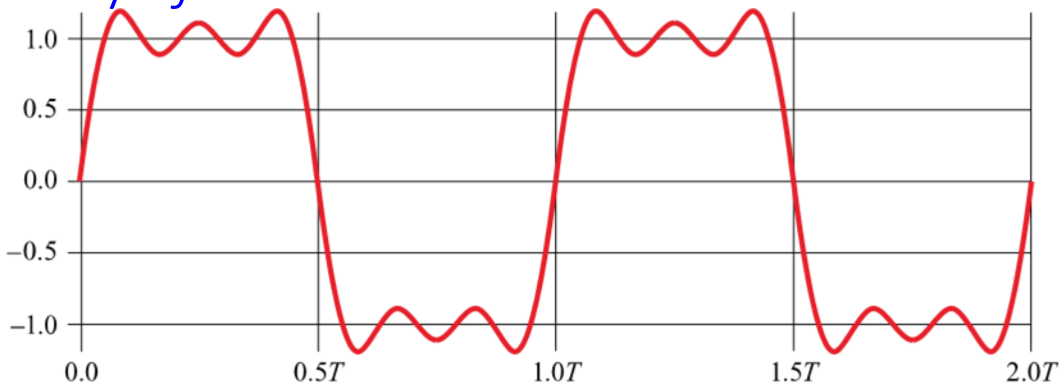
$$\frac{4}{\pi}\left(\sin 2\pi f t + \frac{\sin 2\pi 3 f t}{3}\right)$$

Square-wave Signal (1/2)

- How to obtain a square-wave signal.
  - Recall that any signal can be made up of different sine waves.



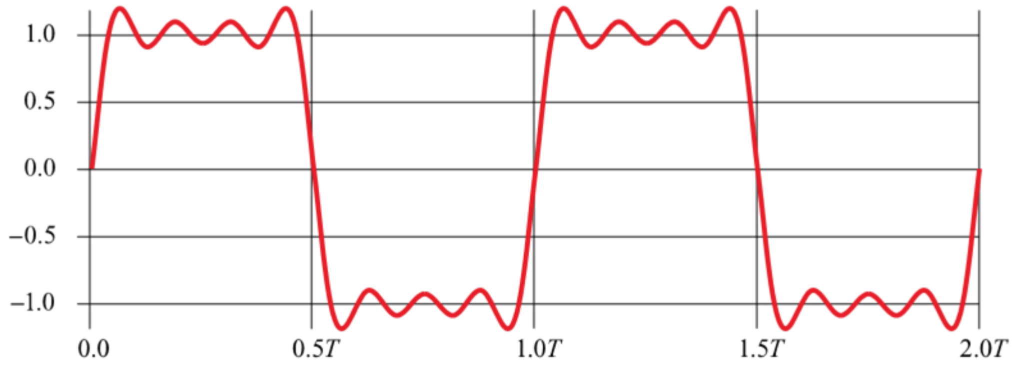
  - Add a signal with frequency *5f*.



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

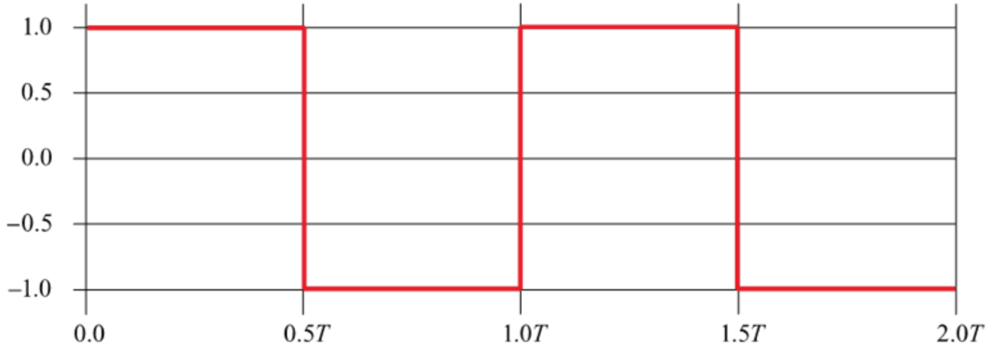
Square-wave Signal (2/2)

- Add a signal with frequency *7f*.



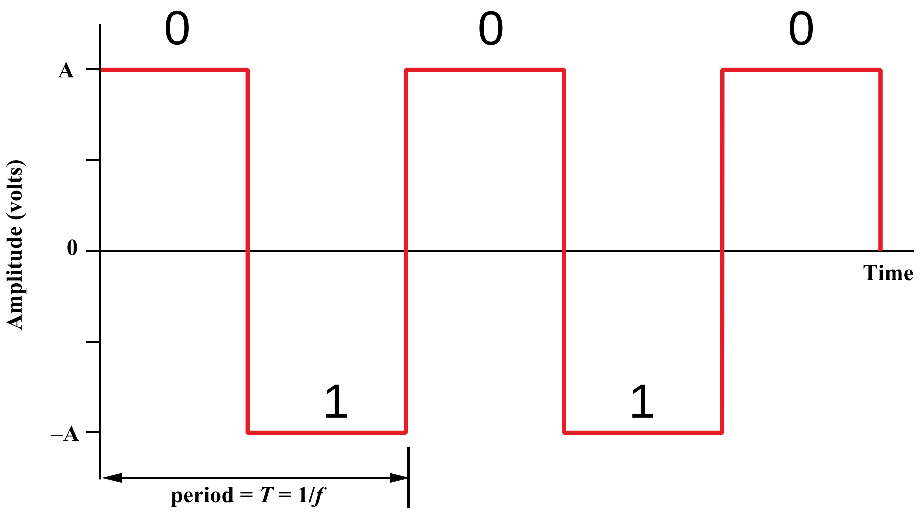
$$4/\pi[\sin 2\pi f t + (1/3)\sin 2\pi(3f)t + (1/5)\sin 2\pi(5f)t + (1/7)\sin 2\pi(7f)t]$$

- If we add infinite frequency components (i.e., *9f*, *11f*, …), we can finally obtain a square-wave signal.



Relationship between Data Rate and Bandwidth

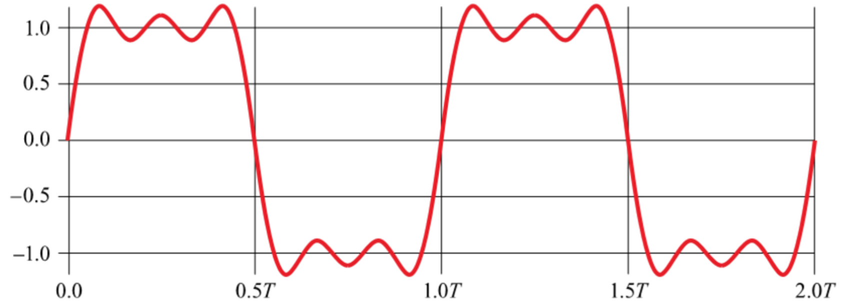
- Consider the square wave
  - Binary 0: positive pulse
  - Binary 1: negative pulse
  - The duration of each pulse is 1/(2*f*).
  - Data rate: 2*f* bits per second (bps)



$$s(t) = A \times 4/\pi \times \sum_{k\ odd, k=1}^{\infty} \frac{\sin(2\pi k f t)}{k}$$

- Infinite frequency components -> infinite bandwidth
- Peak amplitude of the *k*th component is only 1/*k*.
- Most energy is in the first few components.

Data Rate (1/2)

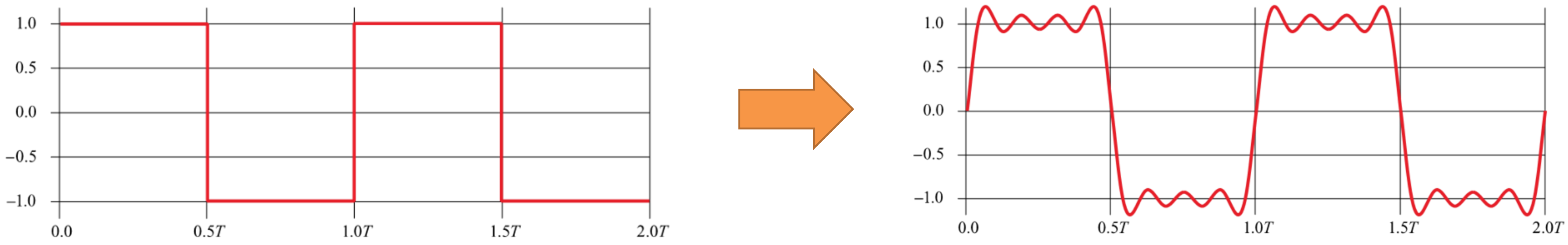


$4/\pi[\sin 2\pi f t + (1/3)\sin 2\pi(3f)t + (1/5)\sin 2\pi(5f)t]$

- Ex 1:
  - f = 10^6 cycles/sec = 1 MHz
  - Absolute bandwidth: 5f – f = 4f = 4MHz
  - Data rate = 2Mbps (1 bit per 0.5us)
- Ex 2:
  - f = 2 x 10^6 cycles/sec = 2 MHz
  - Absolute bandwidth: 10M – 2M = 8MHz
  - Data rate = 4Mbps (1 bit per 0.25us)

Data Rate (2/2)

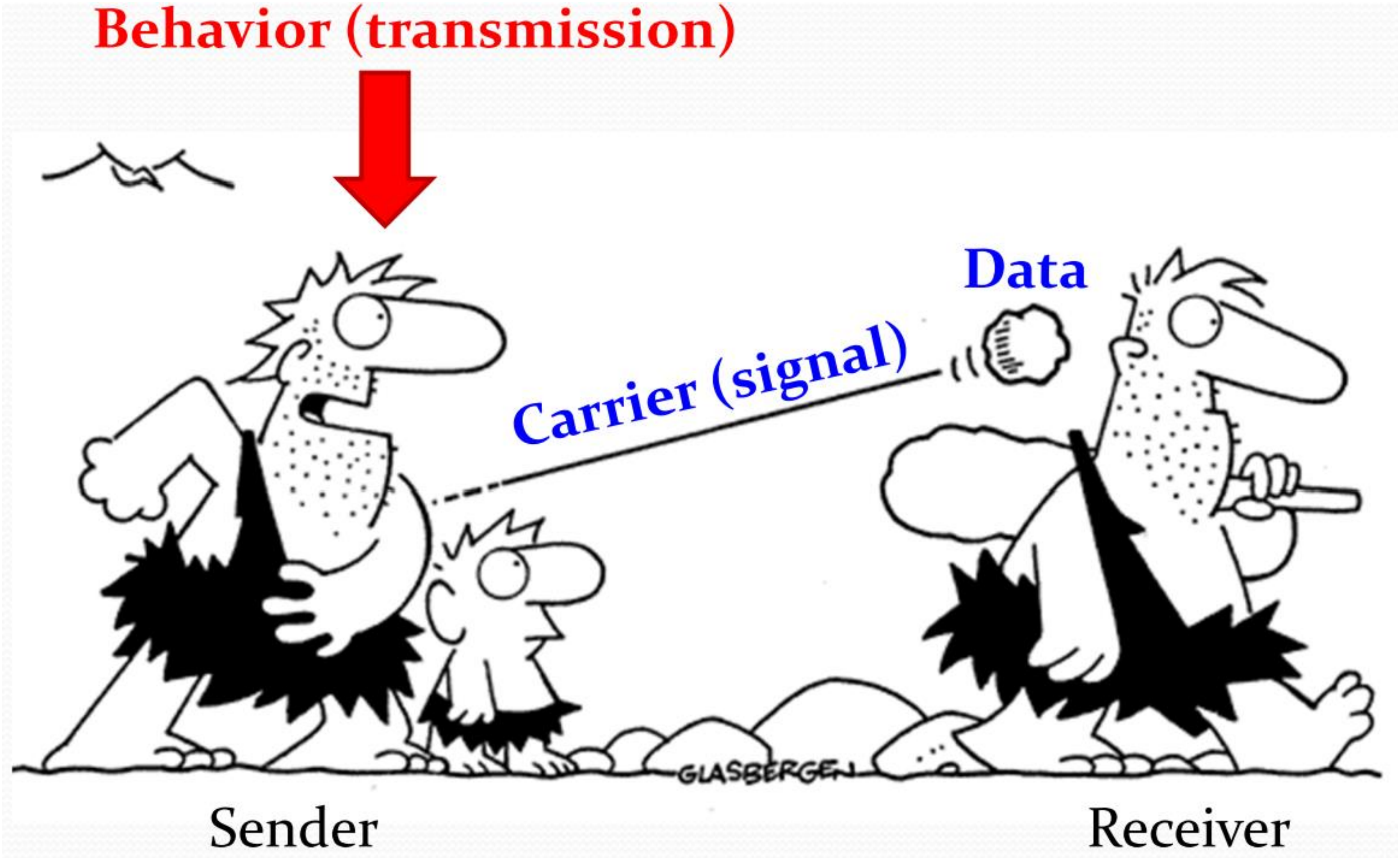
- The greater the bandwidth, the higher the information-carrying capacity.
- Remark
  - Any digital waveform will have infinite (absolute) bandwidth.
  - BUT the transmission system will limit the bandwidth that can be transmitted.
  - AND, for any given medium, the greater the bandwidth transmitted, the greater the cost.
  - HOWEVER, limiting the bandwidth creates distortions.



Outline

- Signals?
- Signal types
- Analog & digital data transmission
- Channel capacity
- Transmission media
- Multiplexing

Communication



Data Communication Terms

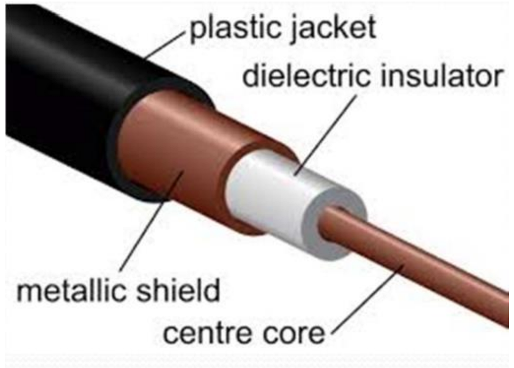
- Data
  - Entities that convey meaning, or information.
- Signals
  - Electric or electromagnetic representations of data.
- Transmission
  - Communication of data by the propagation and processing of signals.
- Each term has analog and digital types.

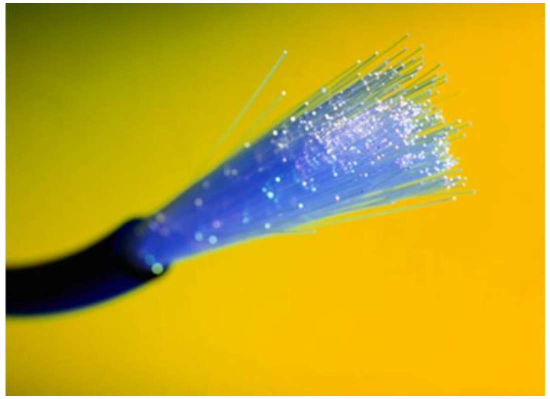
Analog and Digital Data

- Analog data
  - Continuous values in some interval
  - Ex: video, audio, etc.
- Digital data
  - Discrete values
  - Ex: text, integers, etc.

Analog Signals

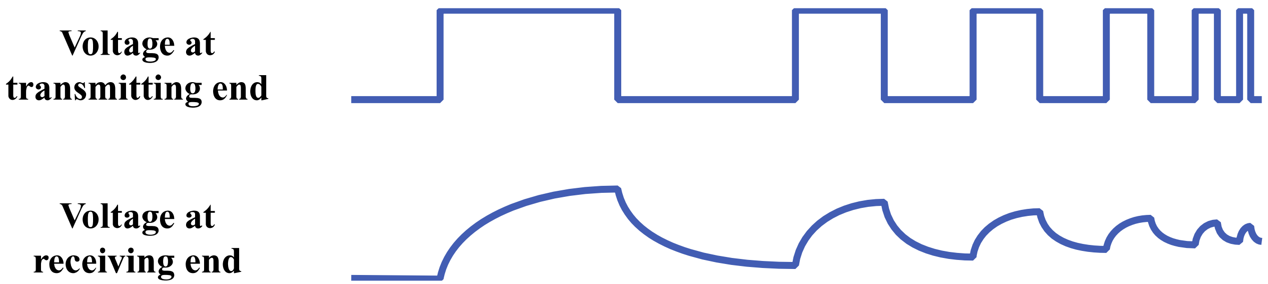
- A continuously varying electromagnetic wave that may be propagated over a variety of media, depending on frequency.
- Examples of media:
  - Copper wire media (twisted pair and coaxial cable)
  - Fiber optic cable
  - Atmosphere or space propagation
- Analog signals can propagate analog and digital data





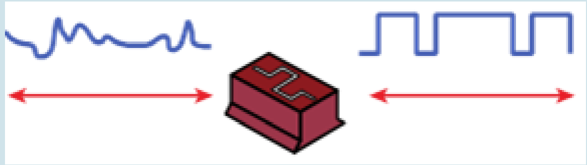
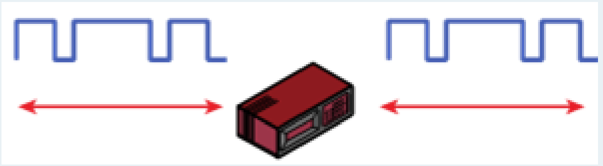
Digital Signals

- A sequence of voltage pulses that may be transmitted over a copper wire medium
- Generally cheaper than analog signaling
- Less susceptible to noise interference
- Suffer more from attenuation.
- Digital signals can propagate analog and digital data.



Analog and Digital Signaling

- Both analog and digital data can be represented, and hence propagated, by either analog or digital signals.

	Analog signal	Digital signal
Analog data	Telephone: Voice sound waves are carried by an analog signal 	Codec: Translate video/audio data to binary information. 
Digital data	Modem: Send binary data through a telephone line. 	Digital transceiver: Binary data are sent through a digital signal. 

Choices

- Digital data, digital signal
  - Equipment for encoding is less expensive than digital-to-analog equipment
- Analog data, digital signal
  - Conversion permits use of modern digital transmission and switching equipment
- Digital data, analog signal
  - Some transmission media will only propagate analog signals
  - Examples include optical fiber and satellite
- Analog data, analog signal
  - Analog data easily converted to analog signal

Analog Transmission

- Transmit analog signals without regard to content.
- May be analog or digital data (through a modem).
- Attenuation limits length of transmission link.
- Cascaded amplifiers boost signal’s energy for longer distances but cause distortion.
  - The noise components are also boosted.
  - Analog data can tolerate distortion.
  - Introduces errors in digital data.

Digital Transmission

- Concerned with the content of the signal.
- Attenuation endangers integrity of data.
- Digital Signal
  - Repeaters achieve greater distance.
  - Repeaters recover the signal and retransmit.
- Analog signal carrying digital data
  - Retransmission device recovers the digital data from analog signal.
  - Generates new, clean analog signal.

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About Channel Capacity

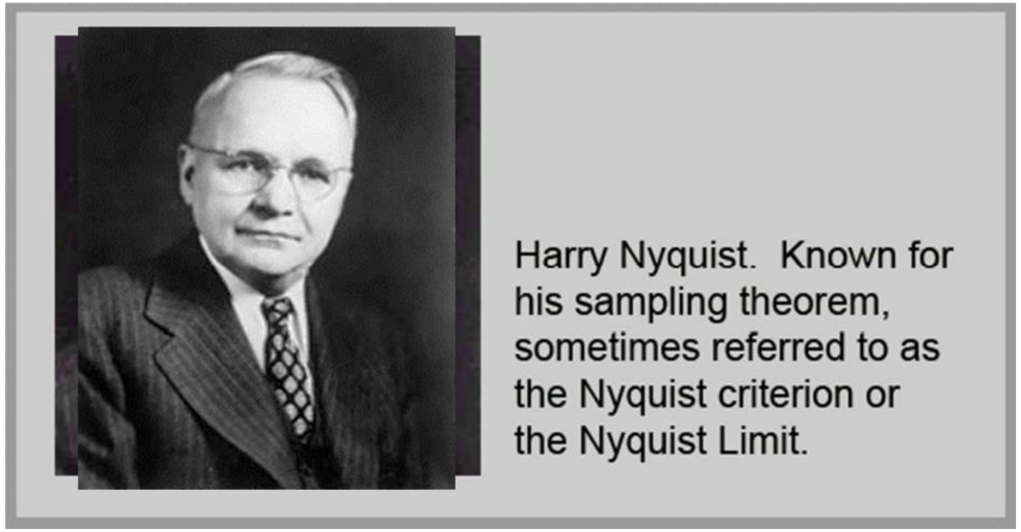
- Impairments, such as noise, limit data rate that can be achieved.
- For digital data, to what extent do impairments limit data rate?
- Channel Capacity
  - The maximum rate at which data can be transmitted over a given communication path, or channel, under given conditions.

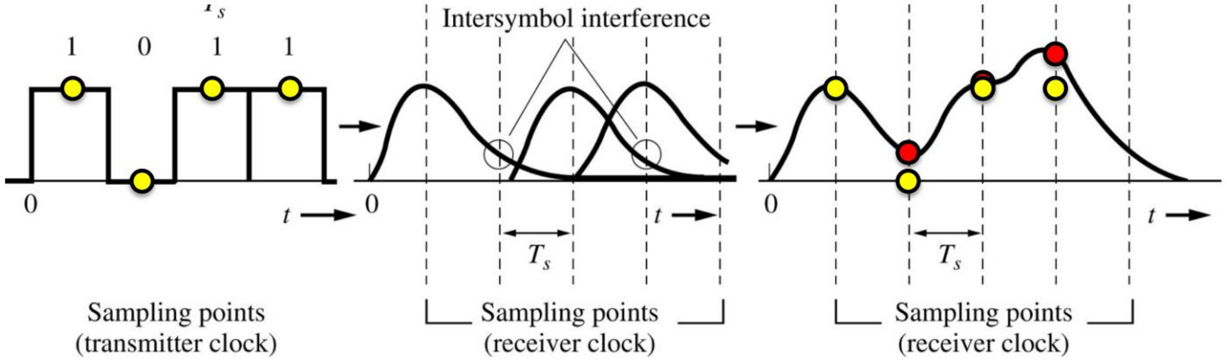
Concepts

- Data rate (bits per second, bps)
  - Rate at which data can be communicated.
- Bandwidth (Hertz, Hz)
  - The bandwidth of the transmitted signal as constrained by the transmitter and the nature of the transmission medium.
- Noise
  - Average level of noise over the communications path.
- Error rate
  - Rate at which errors occur.
  - Error = transmit 1 and receive 0; transmit 0 and receive 1

Nyquist Bandwidth

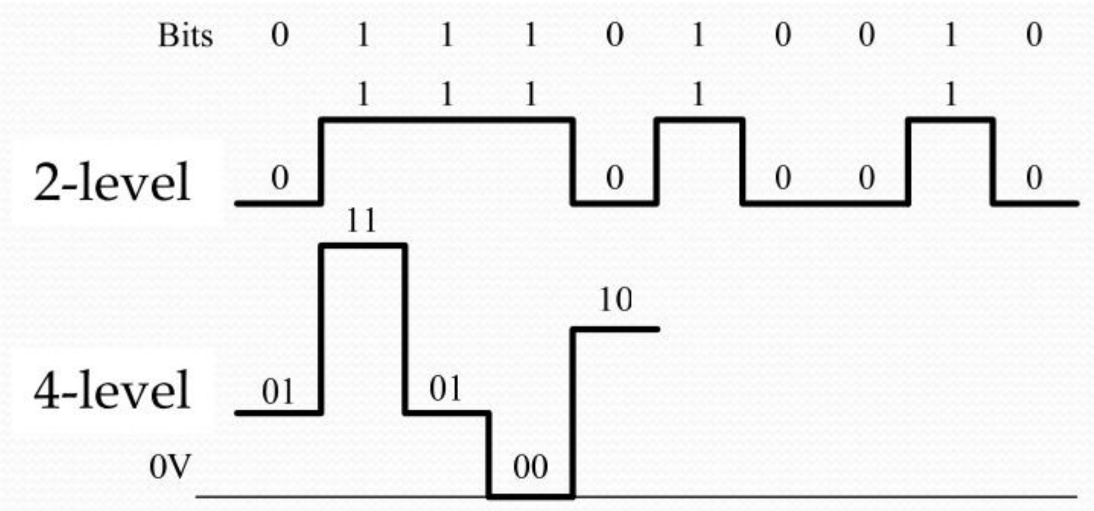
- For binary signals (two voltage levels), given a bandwidth B, the maximum transmission rate (C) is 2B.
  - $C = 2B$
  - Ex: B = 3,100Hz; C = 6,200bps.



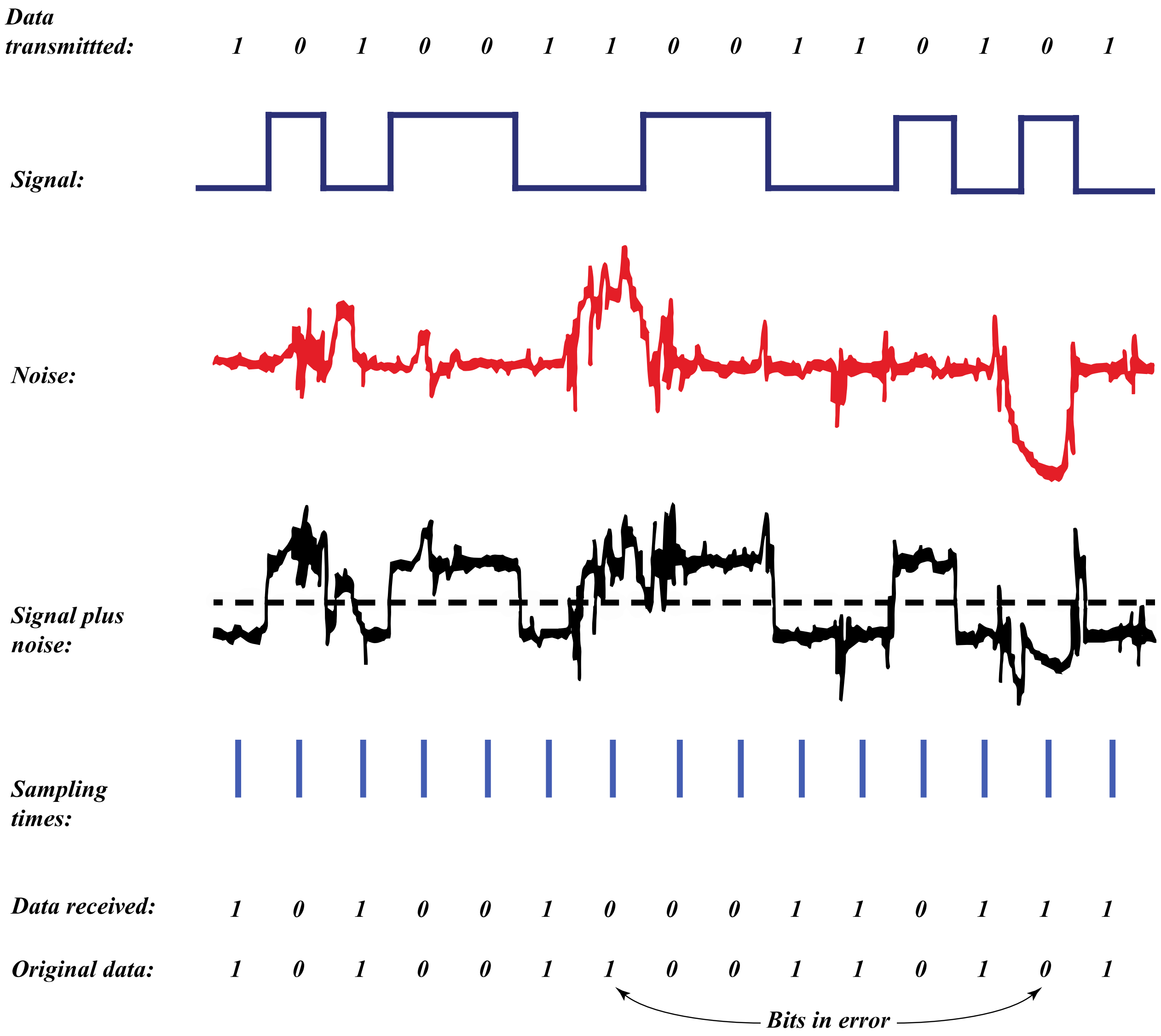


Nyquist Bandwidth

- For multilevel signaling, we have $C = 2B \log_2 M$, where M is the number of discrete signal or voltage levels.
- Ex: If M = 8 is used, a bandwidth of B = 3,100Hz yields a capacity of C = 18,600bps.



Effect of Noise on Digital Signal



Signal-to-Noise Ratio

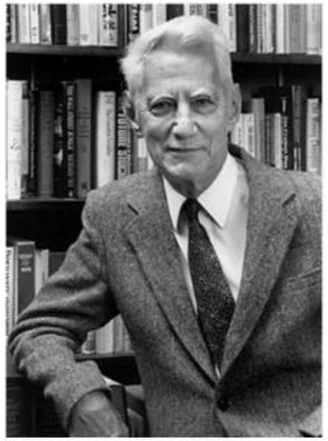
- Ratio of the power in a signal to the power contained in the noise that is present at a particular point in the transmission.
  - Typically measured at a receiver
- Signal-to-noise ratio (SNR, or S/N)

$$(SNR)_{\text{dB}} = 10 \log_{10} \frac{\text{signal power}}{\text{noise power}}$$

- A high SNR means a high-quality signal, low number of required intermediate repeaters.
- SNR sets upper bound on achievable data rate.

Shannon Capacity Formula

- Equation: $$C = B\log_2(1 + \mathrm{SNR})$$
- Represents theoretical maximum that can be achieved
- In practice, only much lower rates achieved
  - Formula assumes white noise (thermal noise).
  - The formula does not account for impulse noise, attenuation distortion, and delay distortion.



Claude Shannon

Example (1/3)

- For human voice, the frequency band is between 300Hz and 3,400Hz. Thus, in telecomm. systems, each voice channel has a bandwidth of 4kHz.
- Q1: Supposing that SNR of a voice channel is 24dB, what is the maximum transmission rate? ($10^{2.4}$=251)
- Answer:

$$SNR_{dB} = 24dB = 10 \times \log_{10} SNR \ \Rightarrow \ SNR = 251$$

According to Shannon's formula,

$$C = B \times \log_2(1 + SNR) = 4kHz \times \log_2(1 + 251)$$

$$\approx 4kHz \times 8 = 32kbps$$

Example (2/3)

- Q2: To achieve such a transmission rate, how many voltage levels will you need to represent a signal?
- Answer:
  - According to Shannon's and Nyquist's equations

$$C = B \times \log_2(1 + SNR) = 2 \times B \times \log_2 M$$
$$4kHz \times \log_2(1 + 251) = 2 \times 4kHz \times \log_2 M$$
$$\Rightarrow \log_2(252) = 2 \times \log_2 M \Rightarrow M \approx 16$$

Example (3/3)

- Q3: What is the bandwidth of a channel whose SNR is 24dB and transmission rate is 8Mbps?
- Answer:

$$C = 8Mbps = B \times \log_2(1 + 251) \;\Rightarrow B = 1.003MHz$$

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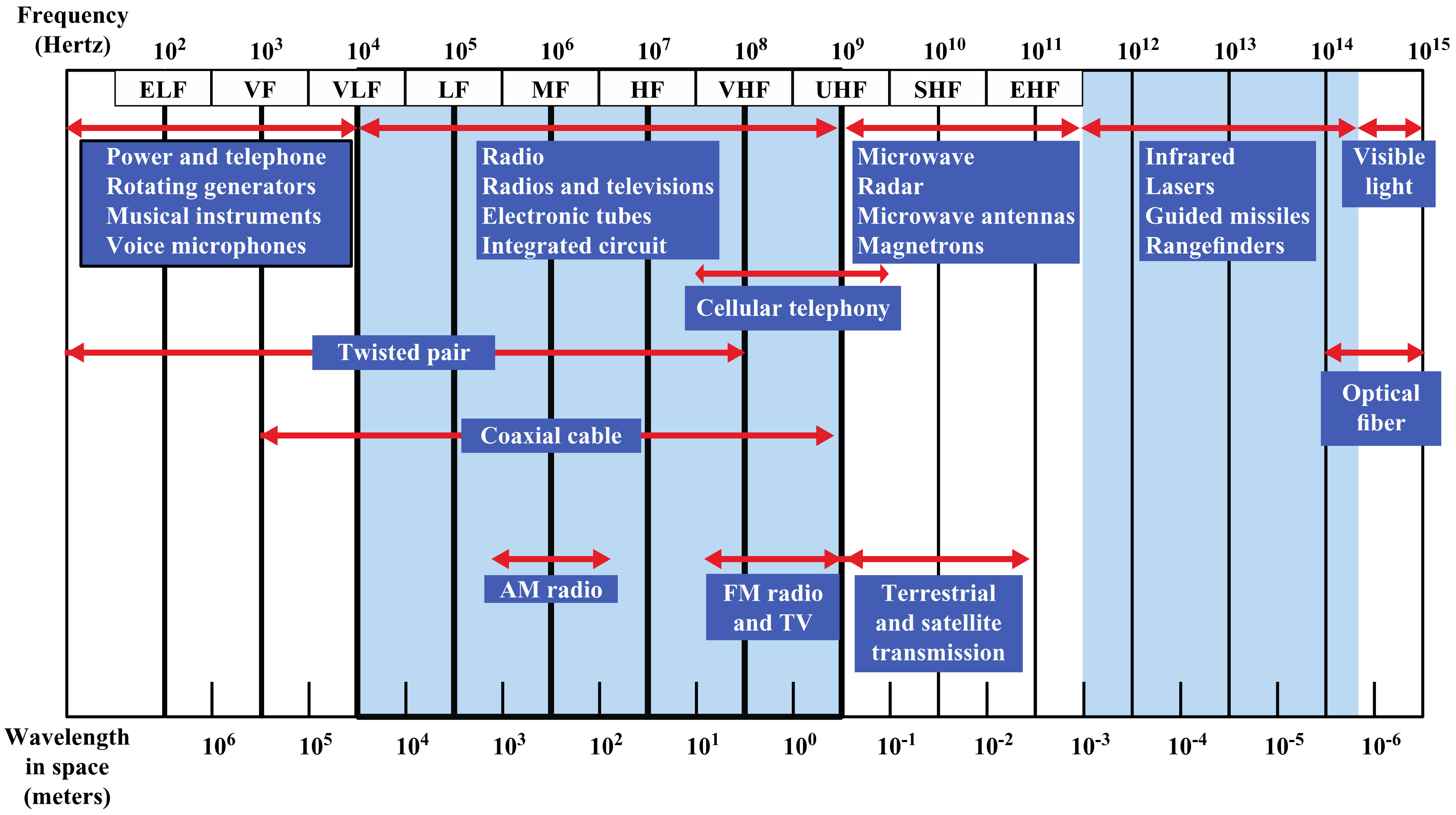
Classifications

- Transmission Medium
  - Physical path between transmitter and receiver
- Guided Media
  - Waves are guided along a solid medium.
  - E.g., copper twisted pair, copper coaxial cable, optical fiber
- Unguided Media
  - Provides a means of transmitting electromagnetic signals but does not guide them.
  - Usually referred to as wireless transmission
  - E.g., atmosphere, outer space

Unguided Media

- Transmission and reception are achieved by means of an antenna
- Configurations for wireless transmission
  - Directional
  - Omnidirectional

Electromagnetic spectrum of Telecommunications



ELF = Extremely low frequency
VF = Voice frequency
VLF = Very low frequency
LF = Low frequency
MF = Medium frequency
HF = High frequency
VHF = Very high frequency
UHF = Ultrahigh frequency
SHF = Superhigh frequency
EHF = Extremely high frequency

General Frequency Ranges

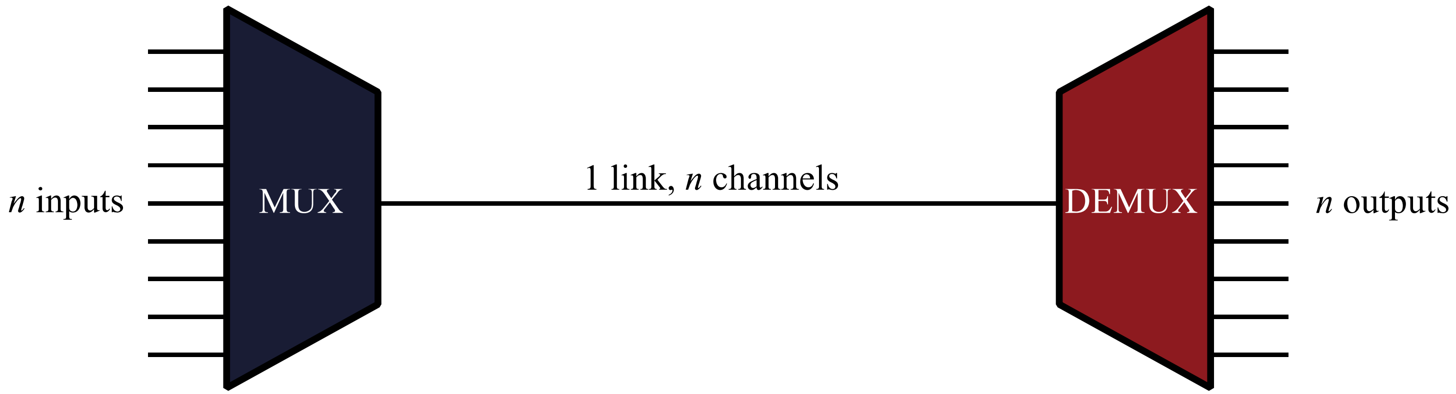
- Microwave frequency range
  - 1 GHz to 40 GHz
  - Directional beams possible
  - Suitable for point-to-point transmission
  - Used for satellite communications
- Radio frequency range
  - 30 MHz to 1 GHz
  - Suitable for omnidirectional applications
- Infrared frequency range
  - Roughly, 3×10^{11} to 2×10^{14} Hz
  - Useful in local point-to-point multipoint applications within confined areas

Outline

- Signals?
- Signal types
- Analog & digital data transmission
- Channel capacity
- Transmission media
- Multiplexing

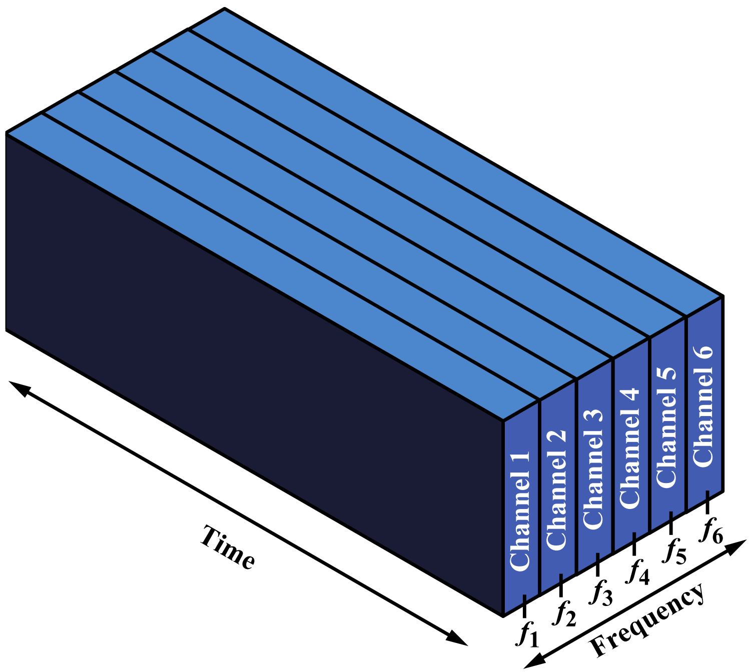
Multiplexing

- Capacity of transmission medium usually exceeds capacity required for transmission of a single signal.
- Multiplexing
  - Carrying multiple signals on a single medium
  - More efficient use of transmission medium



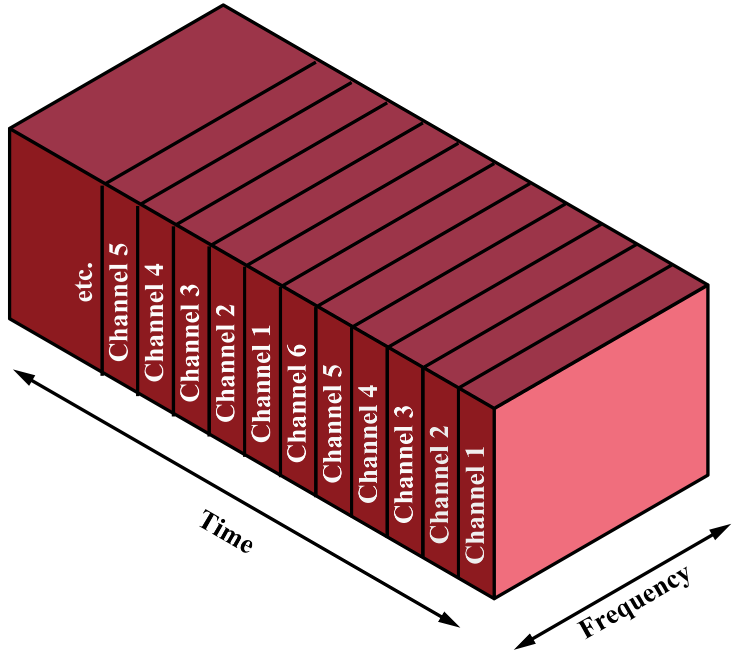
Multiplexing Techniques

- Frequency-division multiplexing (FDM)
  - Each signal is modulated onto a different carrier frequency.
  - These carrier frequencies are sufficiently separated so that the "channel" of any two signals do not overlap.



Multiplexing Techniques

- Time-division multiplexing (TDM)
  - Multiple digital signals can be carried on a single transmission path by interleaving portions of each signal in time.
    - Can be realized in the bit level, blocks of bytes, or larger quantities.



Summary

- Computers usually use signals for communication purpose.
- A signal is a time-varying or spatial-varying quantity.
- Any signals can be made up of different sine waves with different amplitudes, frequencies, and phases.
- Data, signal, and transmission can have analog and digital types.
- Nyquist's bandwidth equation and Shannon's capacity formula are useful to measure bandwidth.
- FDM and TDM are two popular multiplexing schemes.