FUNDAMENTAL : Communication Transmission

Week 2 day 1

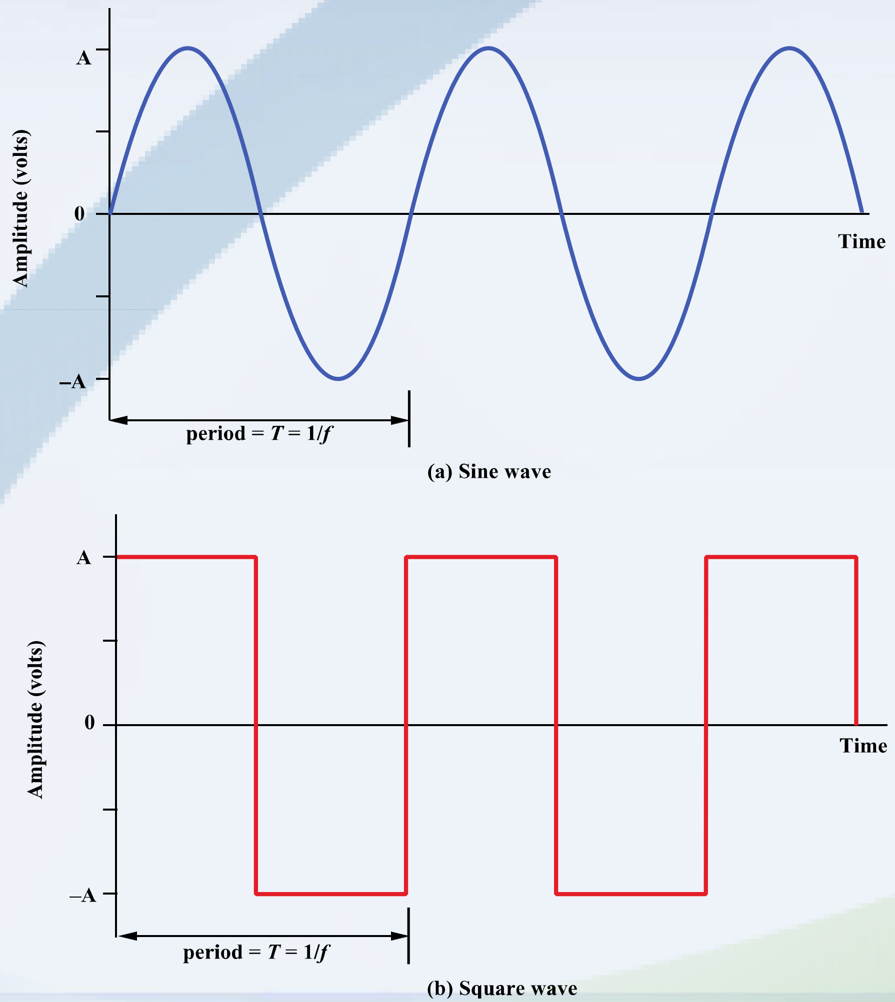
Signal Representation : Time domain

- Can be expressed as function of time
- Periodic signal - analog or digital signal pattern that repeats over time

$$s(t + T) = s(t) \quad -\infty < t < +\infty$$

    - S() is the intensity or magnitude of the signal.
  - Period (*T*) - amount of time it takes for one repetition of the signal
  - Rate or frequency, f, in cycles per second, or Hertz (Hz) at which the signal repeats
    - $T = 1/f$
- Aperiodic signal - analog or digital signal pattern that doesn't repeat over time

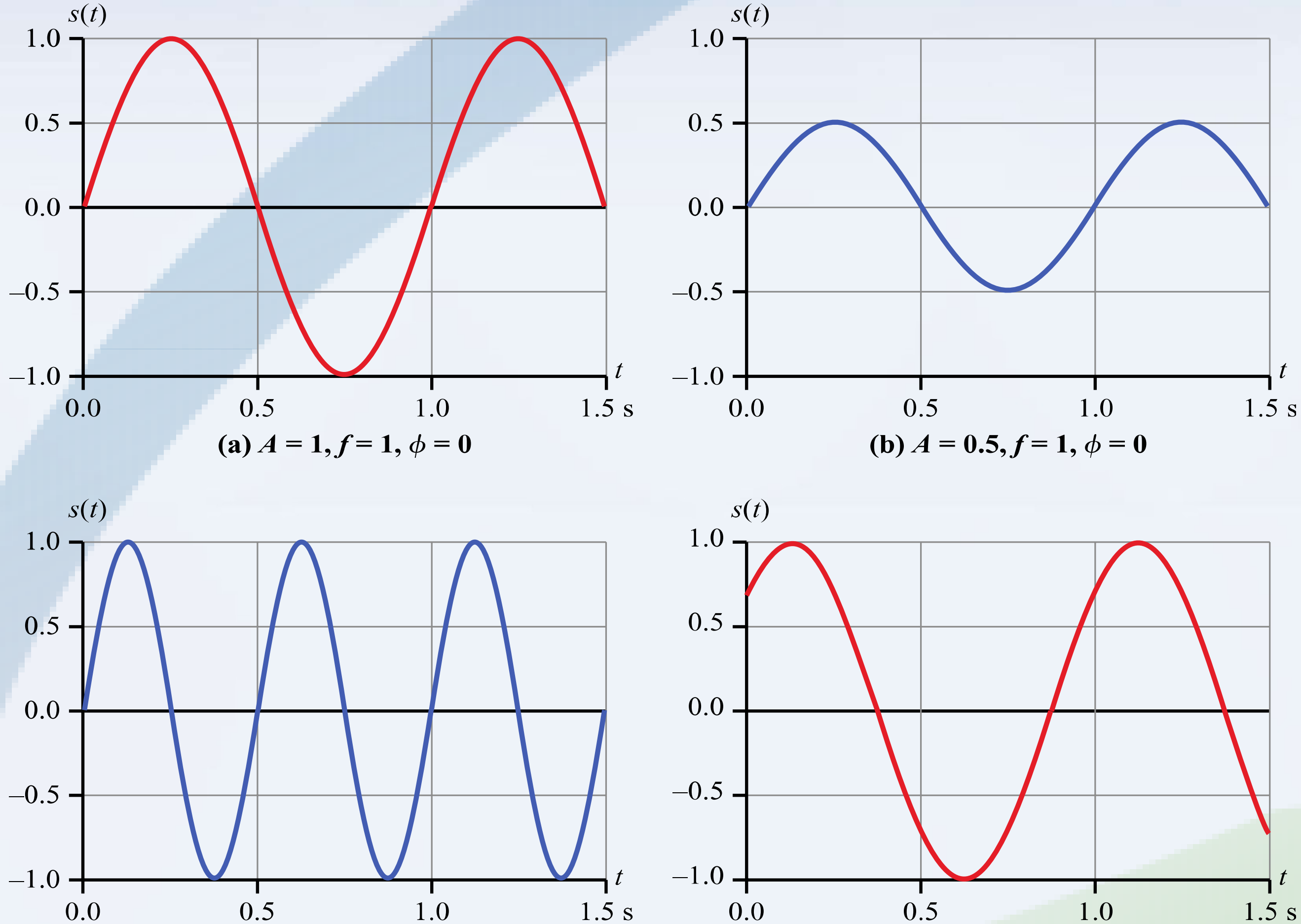
Example of Periodic Signal :



Periodic Signal : Sine wave signal

- General sine wave
  - $s(\theta) = A \sin(\theta)$ (or sometime is also expressed in cosine)
    - θ denotes angle in radian, and A is the amplitude of sine wave
    - Angle : 2π radians = 360°
    - Sinewave is periodic every 2π radians
- If angle varies with time, then
  - $s(t) = A \sin(\omega t + \phi)$; where ω= 2πf
    - ω= 2πf ➔ denotes angular velocity, f is frequency
    - t denotes time, and ϕ denotes phase
- The figures in following slide show the effect of varying each of those three parameters
  - (a) $A = 1$, $f = 1$ Hz, $\phi = 0$; thus $T = 1$ s
  - (b) Reduced peak amplitude; A=0.5
  - (c) Increased frequency; $f = 2$, thus $T = ½$
  - (d) Phase shift; $\phi = \pi/4$ radians (45 degrees)

Sinewave



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

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

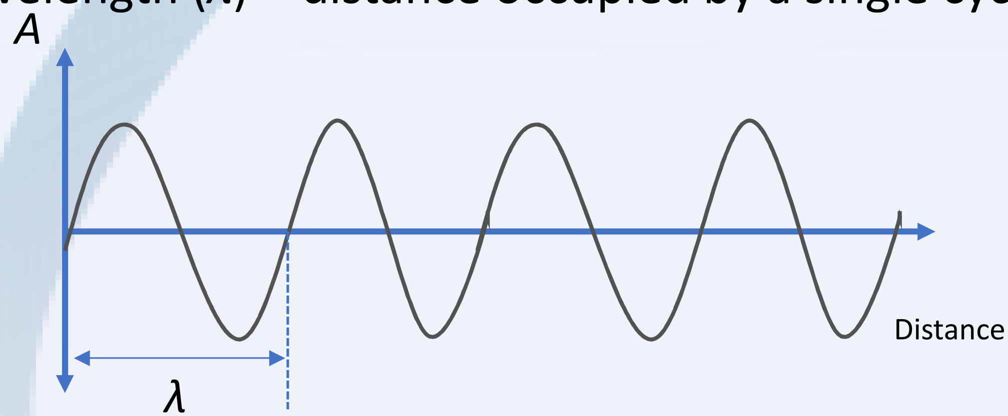
(c) $A = 1, f = 2, \phi = 0$

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

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

Propagation of Periodic Signal

- In this class context, signal also propagates in space
  - 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
  - Wavelength (λ) - distance occupied by a single cycle of the signal



  - The time duration for a signal to traverse as far as λ also imposes the period of signal T=1/ f. Hence:
  - $v = f.\lambda$, where v is signal propagation speed. For electromagnetic wave, v equals to the speed of light in empty space: 3×10^8 m/s

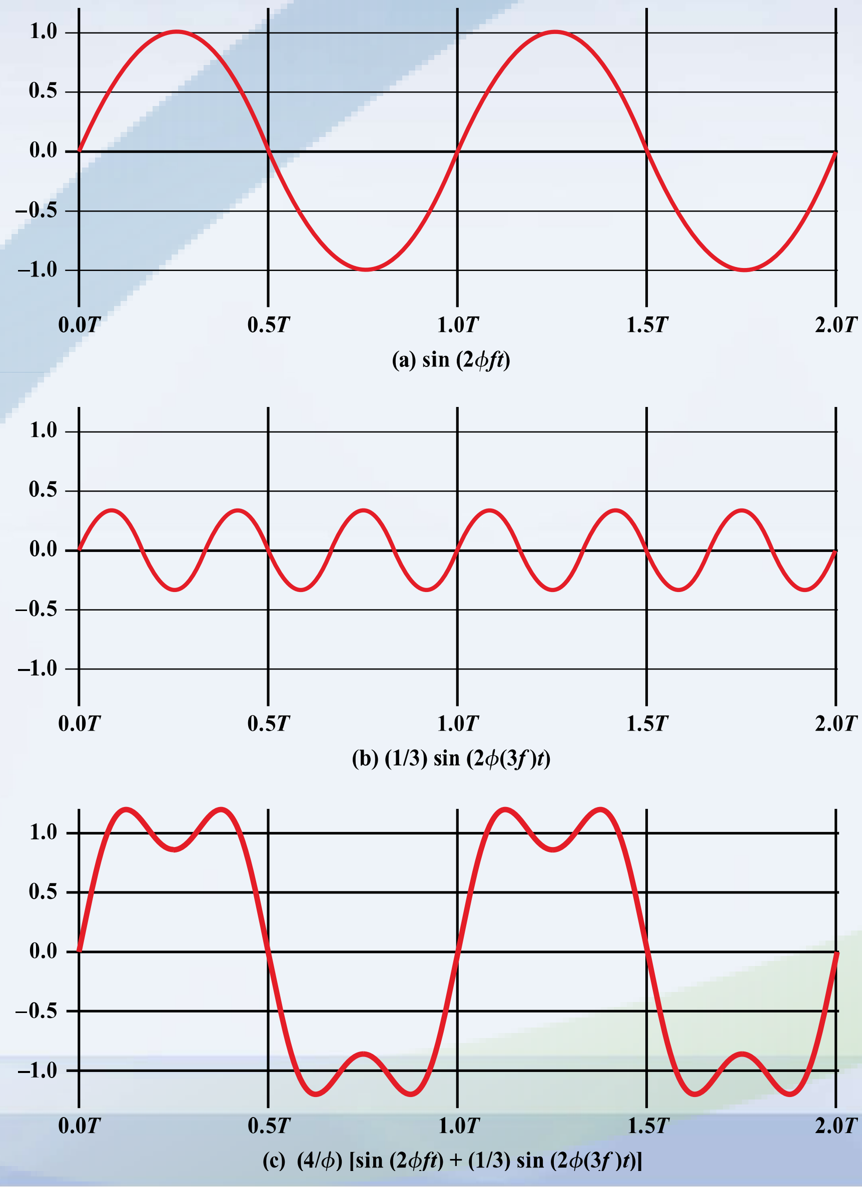
Signal : Frequency Domain

- Effective bandwidth (or just bandwidth) - narrow band of frequencies that most of the signal's energy is contained in
  - If *B* denotes bandwidth, then it can be expressed as follows

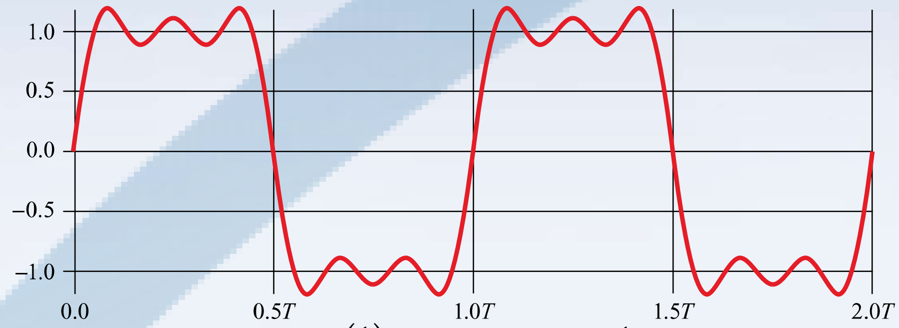
$$B = f_{high} - f_{low}$$

- Any form of periodic signal can be constructed by using a collection of sine waves at different amplitudes, frequencies, and phases
  - Fundamental frequency - when all frequency components of a signal are integer multiples of one frequency, it's referred to as the fundamental frequency
  - Mathematically, a Fourier series can be used to decompose any periodic signal using set of sine waves.
- The period of the total signal is equal to the period of the fundamental frequency

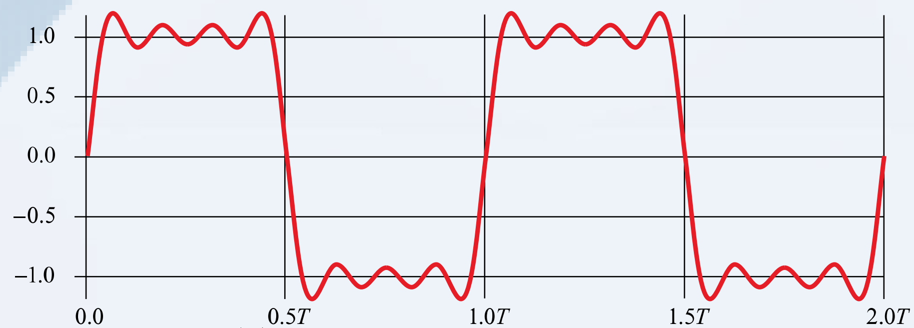
Sum of sine waves : Square Wave Signal



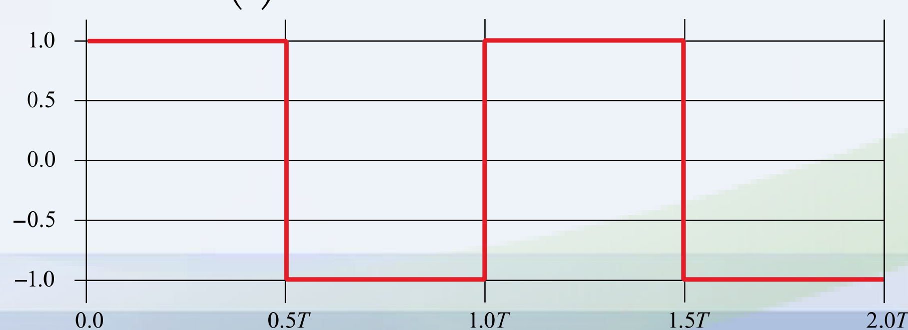
Sum of sine waves : Square Wave Signal



$$4/\pi[\sin(2\pi \mathrm{ft}) + \left(\frac{1}{3}\right)\sin(2\pi(3f)t) + \frac{1}{5}\sin(2\pi(5f)t)]$$



$$4/\pi[\sin(2\pi \mathrm{ft}) + \left(\frac{1}{3}\right)\sin(2\pi(3f)t) + \frac{1}{5}\sin(2\pi(5f)t) + \frac{1}{7}\sin(2\pi(7f)t)]$$



(c) $(4/\phi)\ \Sigma(1/k)\ \sin(2\phi(kf)t)$, for k odd

Signal : Square Wave

- For square wave with amplitudes of A and –A

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

  Where f is the fundamental frequency in Hz

- Example : A square wave with $f = \frac{10^6 cycles}{s} = 1\ MHz = 10^6$Hz. If the signal in figure 2.5a is sufficient to represent square wave, then bandwidth of signal is:

$$(5 \times 10^6 - 10^6) = 4 \times 10^6 \text{ Hz} = 4 \text{ MHz}$$

  If square wave with this period is used to represent string of bit 1s and 0s, which means one bit occurs every 0.5us, then data rate, R, would be 2×10^6 bit per second or 2 Mbps

Signal : Square Wave

- If the same shape of signal is expected, but with higher data rate, R= 4 Mbps

  Duration of one bit = 1/R = second

  Fundamental frequency f = Hz

  3^{rd} frequency f = Hz

  Bandwidth = Hz

- If the signal bandwidth is 4 MHz, transmitting data rate of 4 Mbps is still possible,
  - It results in higher signal distortion.
  - Vulnerable to signal impairment due to noise.

Data Rate and Bandwidth

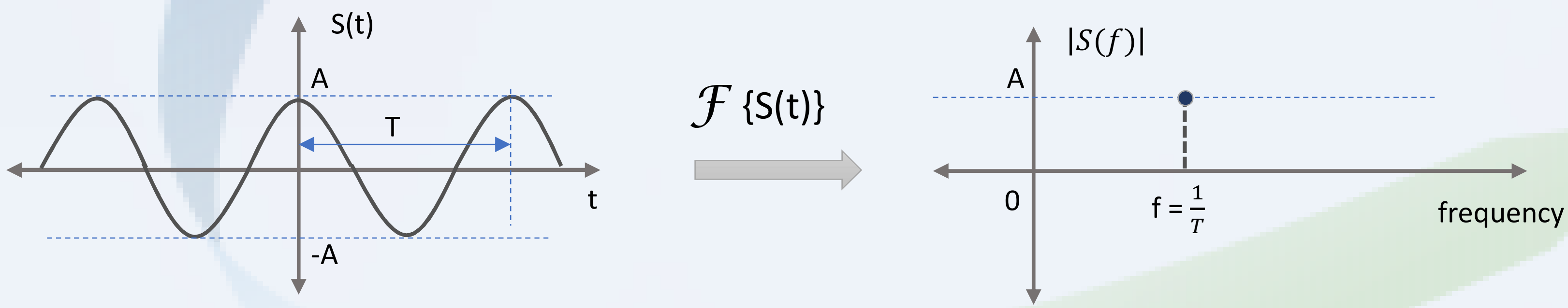
- The greater the bandwidth, the higher the information-carrying capacity
- Conclusions
  - Any digital waveform will have infinite bandwidth
  - BUT the transmission system will limit the bandwidth that can be transmitted
  - AND, for any given medium, the greater the bandwidth transmitted, the greater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

Intermezzo : What Image is it?

- A face of a man or a woman walking over a pond of water?
- As matter of fact, we are looking at the same thing : the image

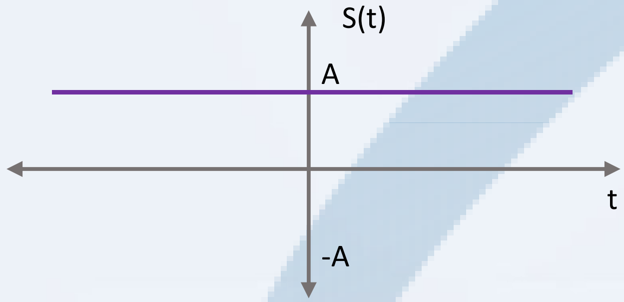
Domain of Signal Analysis : Time or Frequency

- A signal can be analyzed from two different perspectives: time domain and frequency domain
  - Signal(t) ←→ Signal(f)
  - Sometime it is easier to do analysis in frequency domain than time domain
  - Mathematically, a Fourier Transform is used in order to transform signal representation in time into signal representation in frequency

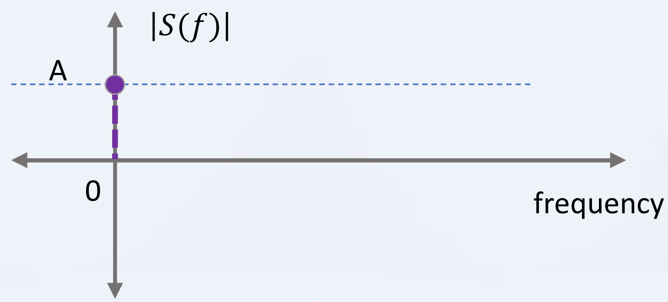


Signal Analysis : Time or Frequency

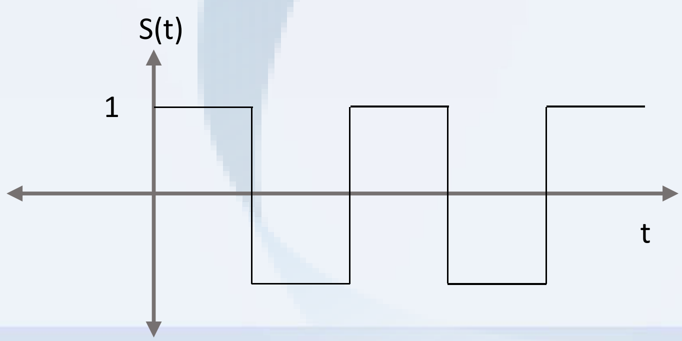
- Fourier transform of a DC or constant level signal



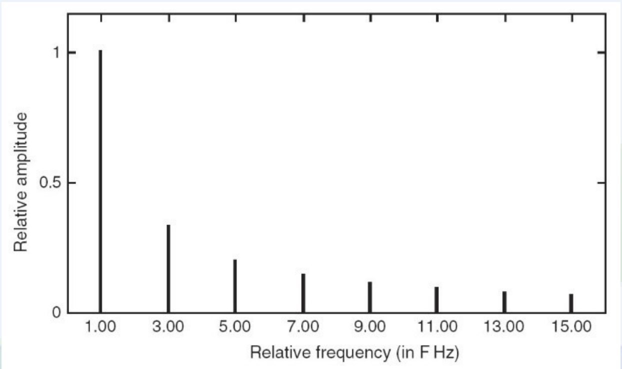
$\mathcal{F}$ {S(t)}



- Fourier transform of square wave



$\mathcal{F}$ {S(t)}



Fourier Transform in Real World

- Spectrum Analyzer
  - http://www.rigol.eu/products/spectrum-analyzers/

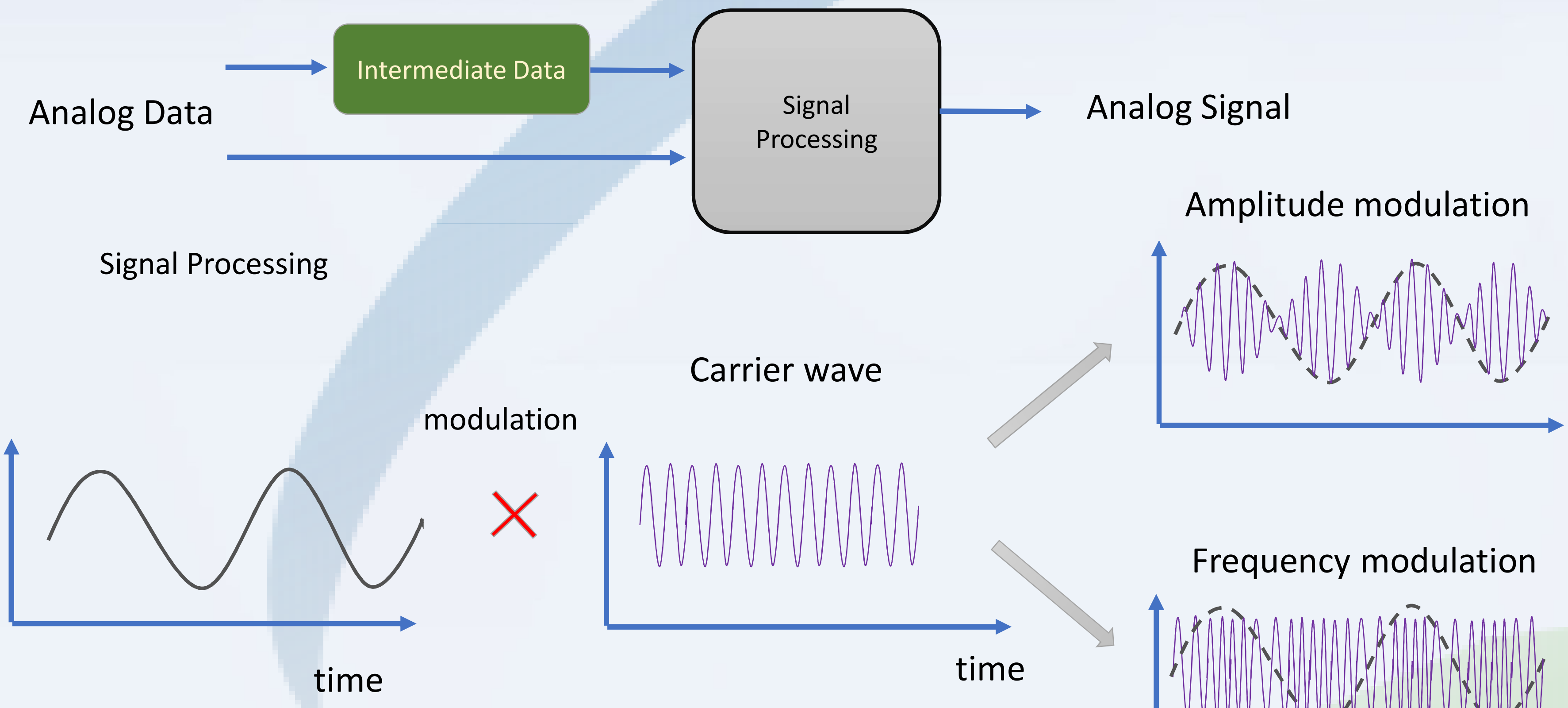
- Audio Equalizer
  - http://ww

Recall : Analog and Digital Signal

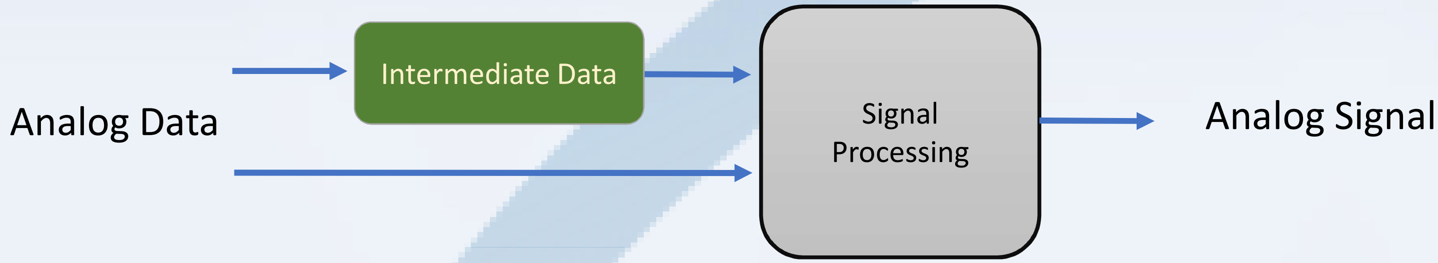
- Electromagnetic wave can only become an analog signals in practice
- Electric voltage or current can be used as analog and digital signals

	Analog Signal	Digital Signal
Analog Data	Two alternatives, (1) signal occupies the same spectrum as the analog data (2) analog data are encoded to occupy a different portion of frequency range	Analog data are encoded using a codec to produce a digital bit stream
Digital Data	Digital data are encoded using a modem to produce analog signal	Two alternatives, (1) signal consists of two levels values to represent the two binary values (2) Digital data are encoded to produce a digital signal with desired properties

Data to Signal : Analog to Analog

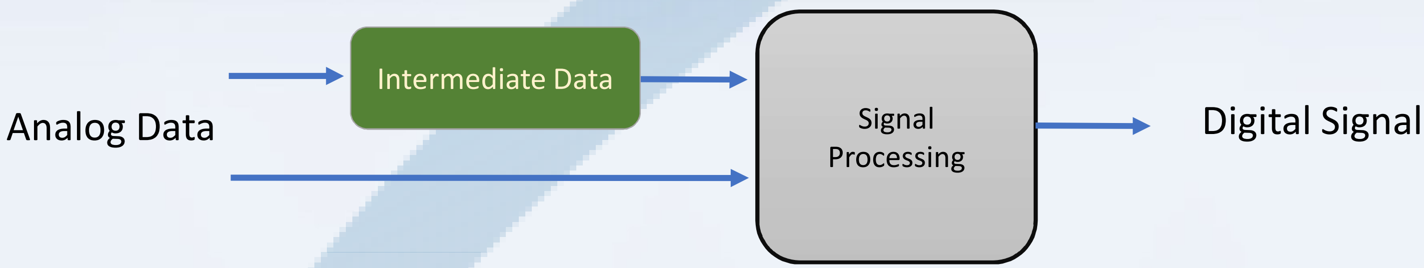


Data to Signal : Analog to Analog

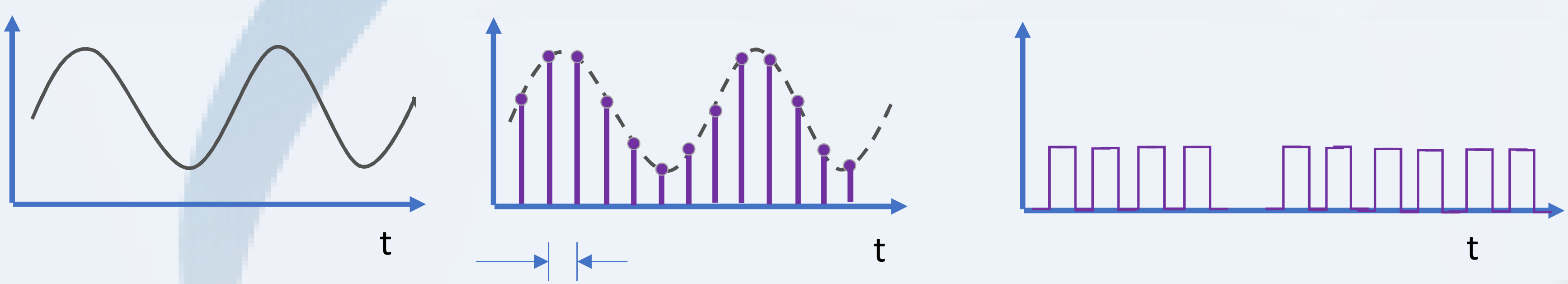


- Why do we need modulation ?
  - To fit channel characteristic
  - To multiplex different context of analog input data that occupies the same bandwidth into different channel
  - In wireless communication case, antenna size is dictated by electromagnetic wave length
    - Lower frequency needs bigger antenna, since wave length also changes.

Data to Signal : Analog to Digital



Sampled and quantized

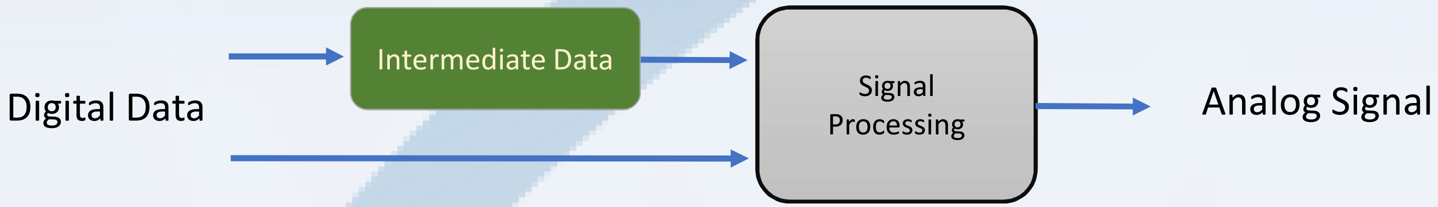


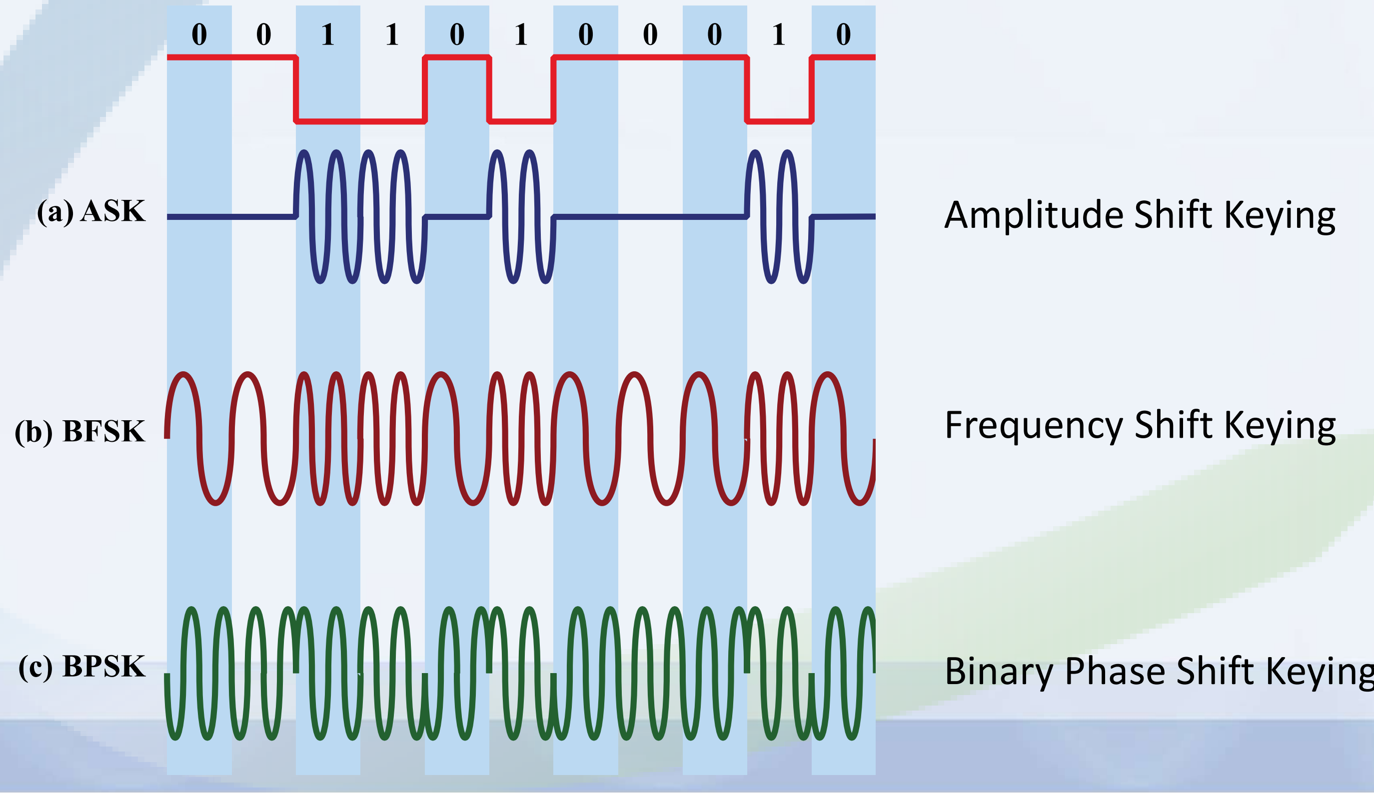
Sampling : T_S : Sampling interval (in second)

$F_S = {}^{1}/_{T_S}$: Sampling frequency (unit samples/second). Sampling frequency must be at least twice as the highest frequency component in the signal

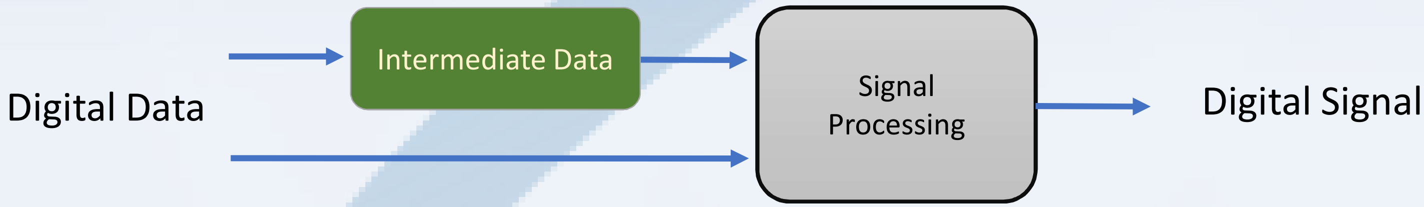
Quantizer : Each sampled signal would be represented by a stream of bits

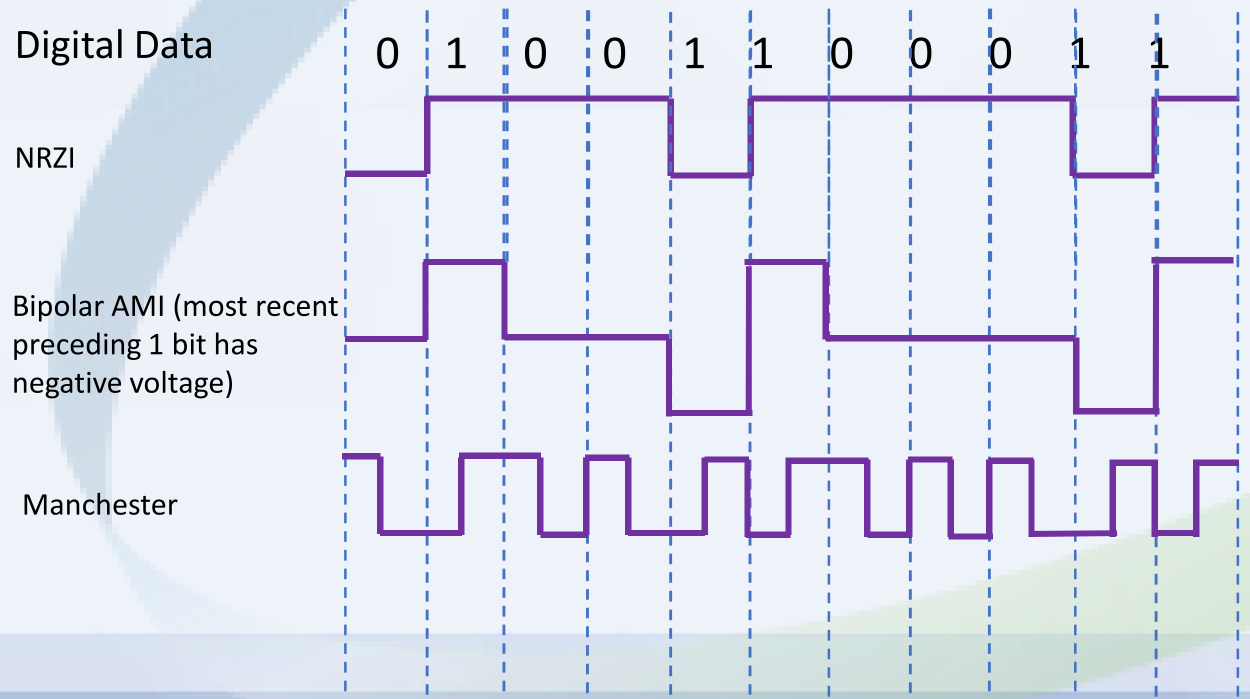
Data to Signal : Digital to Analaog





Data to Signal : Digital to Digital





Signal Transmission

- Analog Transmission
  - Transmit analog signals without regard to content
  - Attenuation limits length of transmission link
  - Cascaded amplifiers boost signal's energy for longer distances but cause distortion
    - Analog data can tolerate distortion
    - Introduces errors in digital data
- Digital Transmission
  - It doesn't always mean transmitting a digital signal
  - Concerned with the content of the signal
    - 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

Signal Transmission

	Analog Transmission	Digital Transmission
Analog Signal	Propagated through amplifiers; same treatment whether signal is used to represent analog data or digital data	Assumes that the analog signal represents digital data. Signal is propagated through repeaters; at each repeater, digital data are recovered from inbound signal and used to generate a new analog outbound signal
Digital Signal	Not used	Digital signal represents a stream of 1s and 0s, which may represent digital data or may be an encoding of analog data. Signal is propagated through repeaters; at each repeater, stream of 12 and 0s is recovered from inbound signal and used to generate a new digital outbound signal