Signal and Distortion

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Signal and System

- Signals are variables that carry information
- **System** is an assemblage of entities/objects, real or abstract, comprising a whole with each every component/element interacting or related to another one.

  Systems process input signals to produce output signals

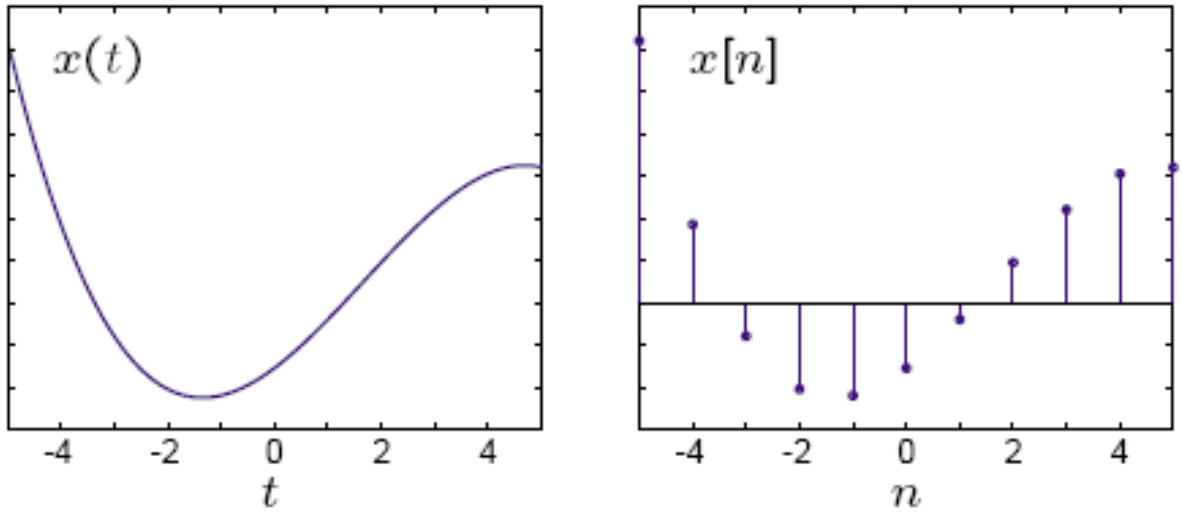
- Examples
  i. Motion, sound, picture, video, traffic light…
  ii. Natural system (ecosystem), human-made system (machines, computer storage system), abstract system (traffic, computer programs), descriptive system (plans)

Signal Basics

- **Continuous time (CT) and discrete time (DT) signals**

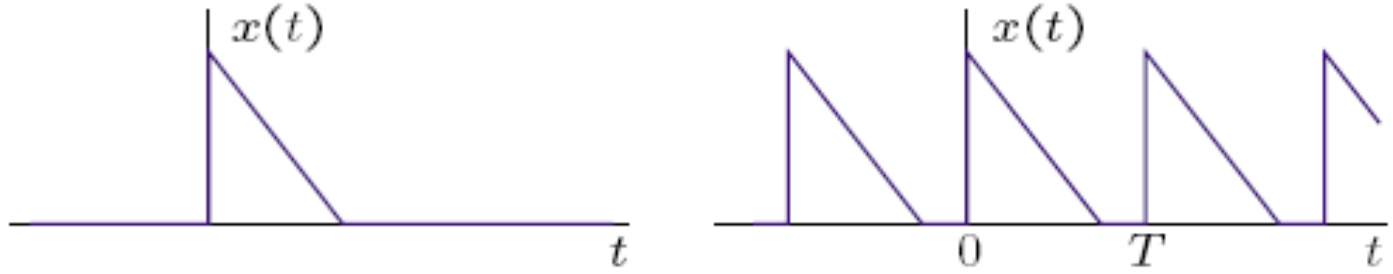
  CT signals take on real or complex values as a function of an independent variable that ranges over the real numbers and are denoted as $x(t)$.

  DT signals take on real or complex values as a function of an independent variable that ranges over the integers and are denoted as $x[n]$.



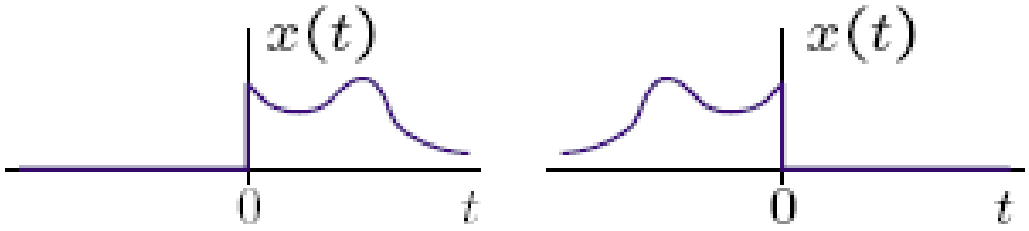
Periodic vs. Aperiodic Signals

- Periodic signals have the property that $x(t + T) = x(t)$ for all t.
- The smallest value of T that satisfies the definition is called the *period*.
- Shown below are an aperiodic signal (left) and a periodic signal (right).



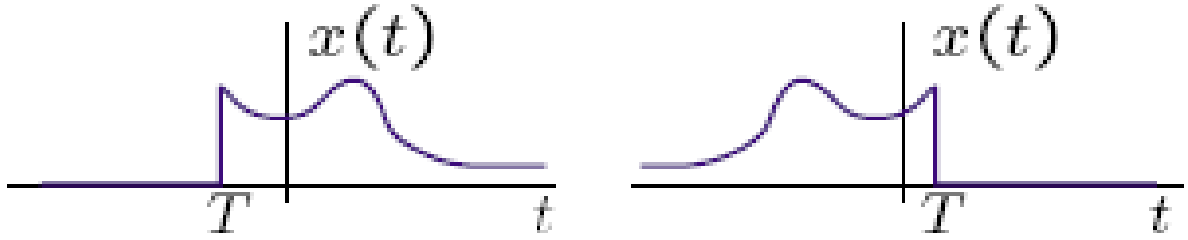
Causal vs. Non-causal

- A **causal** signal is zero for $t < 0$ and an **non-causal** signal is zero for $t > 0$



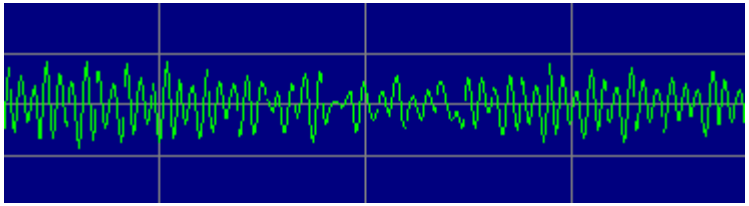
- **Right- and left-sided signals**

  A right-sided signal is zero for $t < T$ and a left-sided signal is zero for $t > T$ where T can be positive or negative.



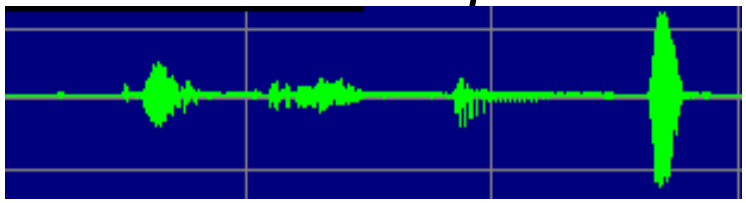
Analog Signals

- A set of voice tones:



  - Several tones superimposed (added)
  - Tones can not be separated from the time domain representation
  - **Frequency components** can be separated from frequency domain representation

- "*This is some speech*"

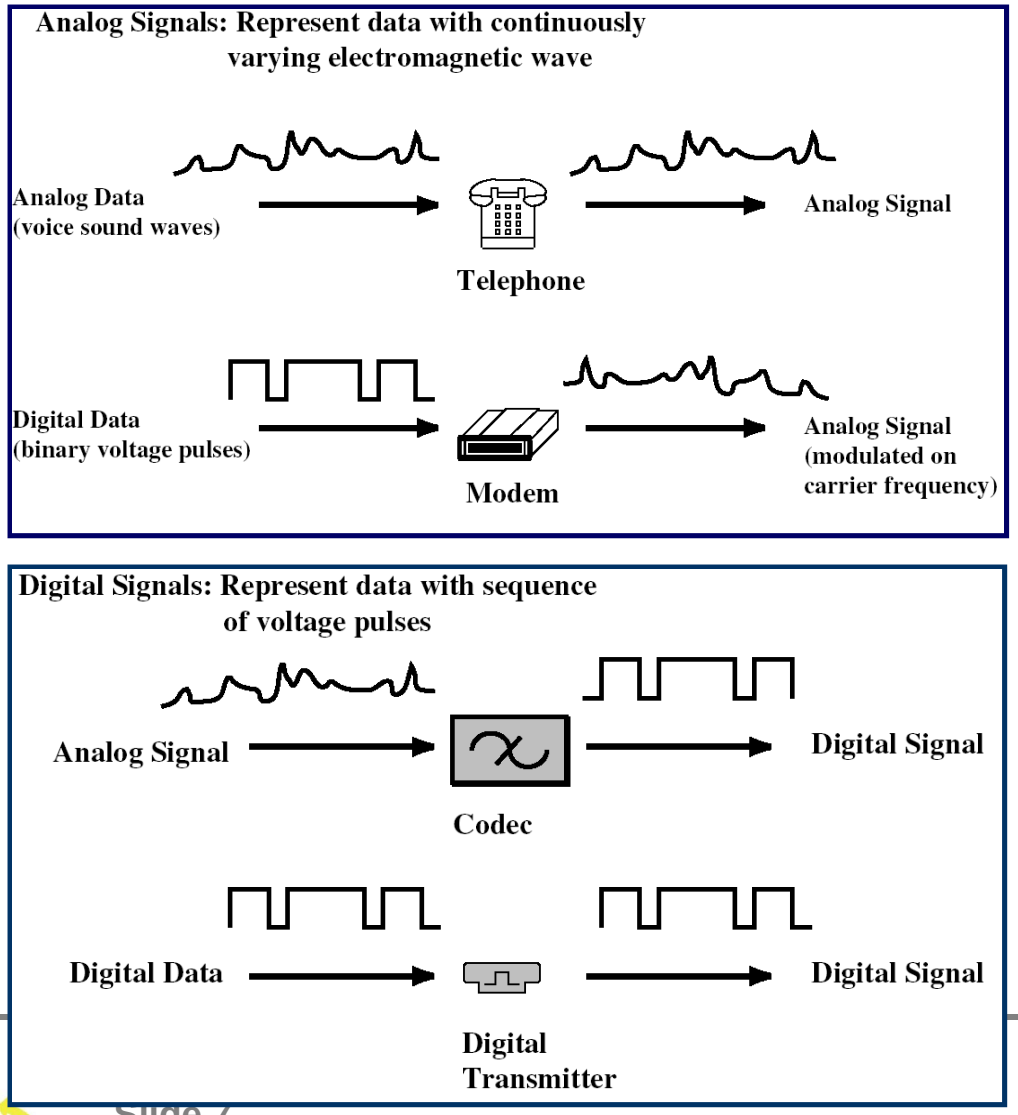


Bursts

  - Amplitude varies
  - Frequency (phase) varies
  - Many other practical sources are bursty as
    - video signals
    - Ethernet data packets

- Often analog sources are digitized for transmission that carries several benefits as
  - error correction & detection
  - easy multiplexing
  - easy adaptivity

Analog and Digital Signals



Why the signals in the figure are analog or digital?

Bit Rate of Digitized Signal

- Bandwidth W_s Hertz: how fast the signal changes
  - Higher bandwidth → more frequent samples
  - Minimum sampling rate = 2 x W_s

- Representation accuracy: range of approximation error
  - Higher accuracy

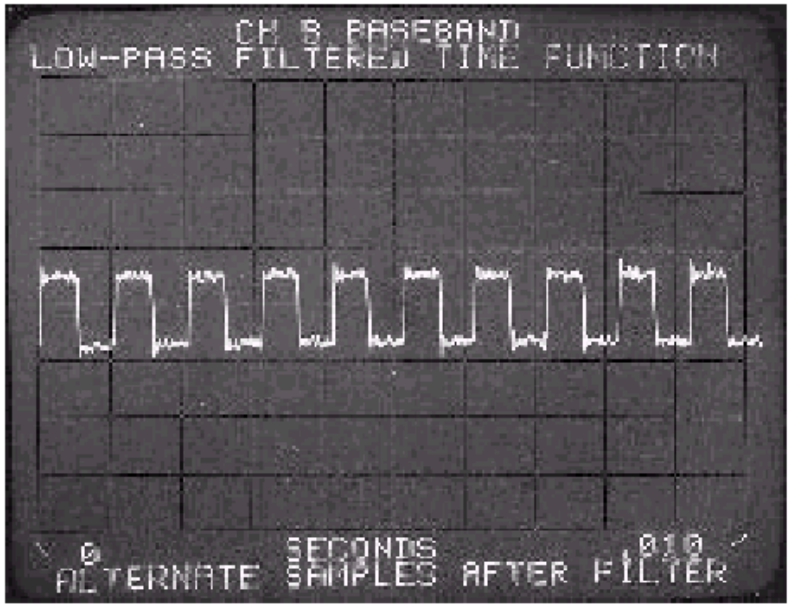
  → smaller spacing between approximation values

  → more bits per sample

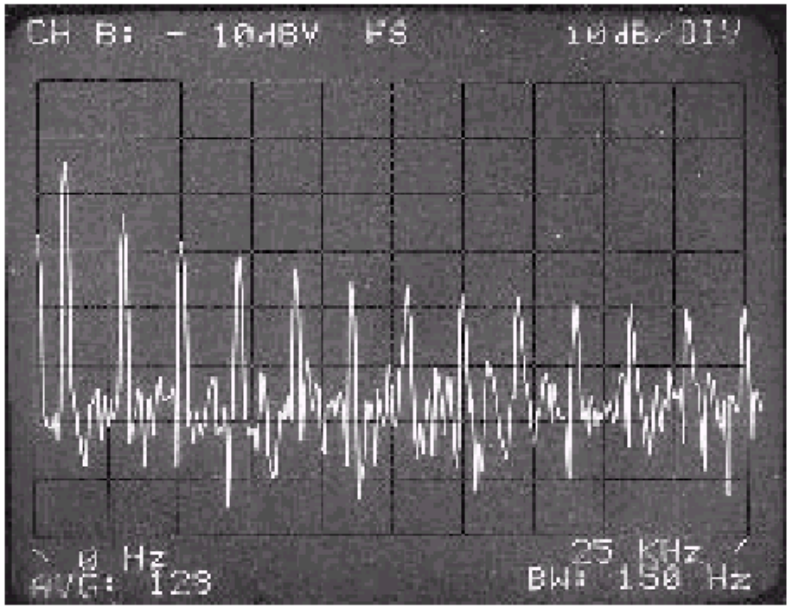
Noise and Interference

- In practical communication systems signals are blurred by noise and interference:

Time domain



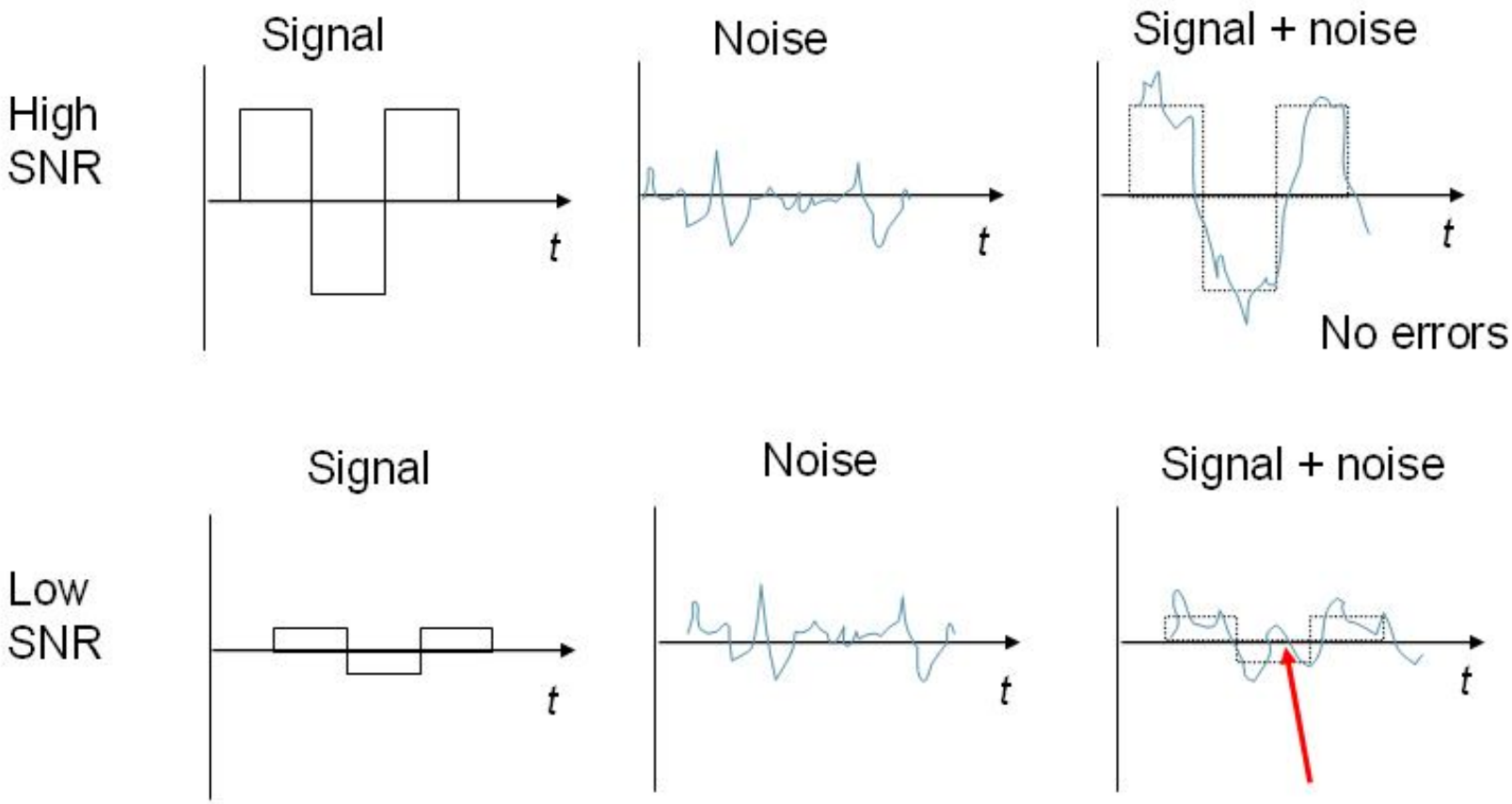
Frequency domain



Noise & Reliable Communications

- All physical systems have noise
  - Electrons always vibrate (at non-zero temperature)
  - Motion of electrons induces noise
- Presence of noise limits accuracy of measurement of received signal amplitude
- Errors occur if signal separation is comparable to noise level
- Bit Error Rate (BER) increases with decreasing signal-to-noise ratio
- Noise places a limit on how many amplitude levels can be used for pulse transmission

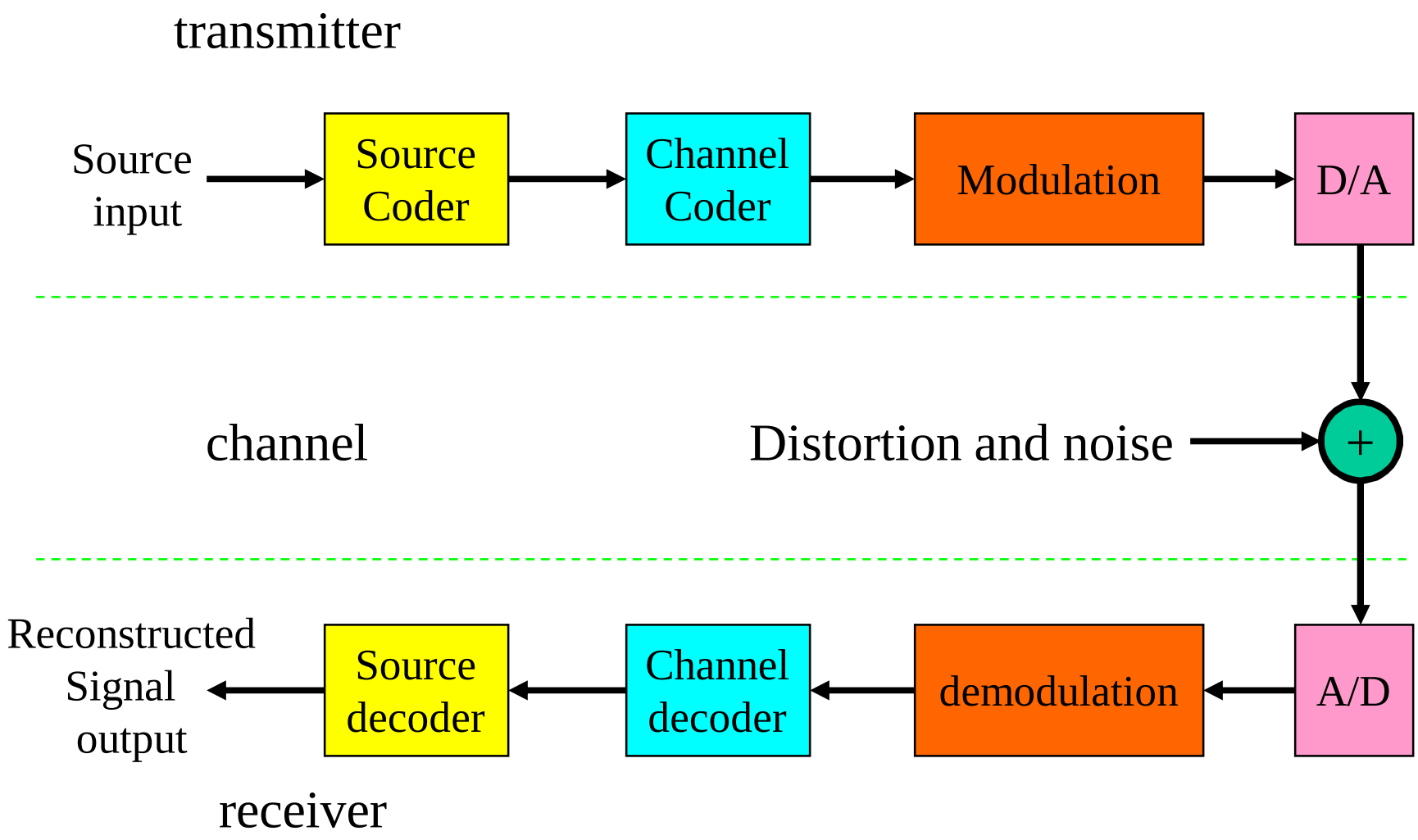
Signal-to-Noise Ratio



$$\text{SNR} = \frac{\text{Average signal power}}{\text{Average noise power}}$$

$$\text{SNR (dB)} = 10 \log_{10} \text{SNR}$$

Communication System



Questions of Interest

- How long will it take to transmit a message?
  - How many bits are in the message (text, image)?
  - How fast does the network/system transfer information?
- Can a network/system handle a voice (video) call?
  - How many bits/second does voice/video require? At what quality?
- How long will it take to transmit a message without errors?
  - How are errors introduced?
  - How are errors detected and corrected?
- What transmission speed is possible over radio, copper cables, fiber, infrared, …?

Distortion and Noise

- Channel responses to different frequency and different time
  - Satellite: almost flat over frequency, change slightly over time
  - Cable or line: response very different over frequency, change slightly over time.
  - Fiber: perfect
  - Wireless: worst. Multipath reflection causes fluctuation in frequency response. Doppler shift causes fluctuation over time
- Noise and interference
  - AWGN: Additive White Gaussian noise
  - Interferences: power line, microwave, other users (CDMA phone)

Multipath and Fading

- Multipath causes frequency response fluctuation
- Propagation loss
- Slow fading (shadowing)
  - FM radio on the highway.
- Fast fading
- Doppler shifting cause time variance, frequency and phase changes

Questions?