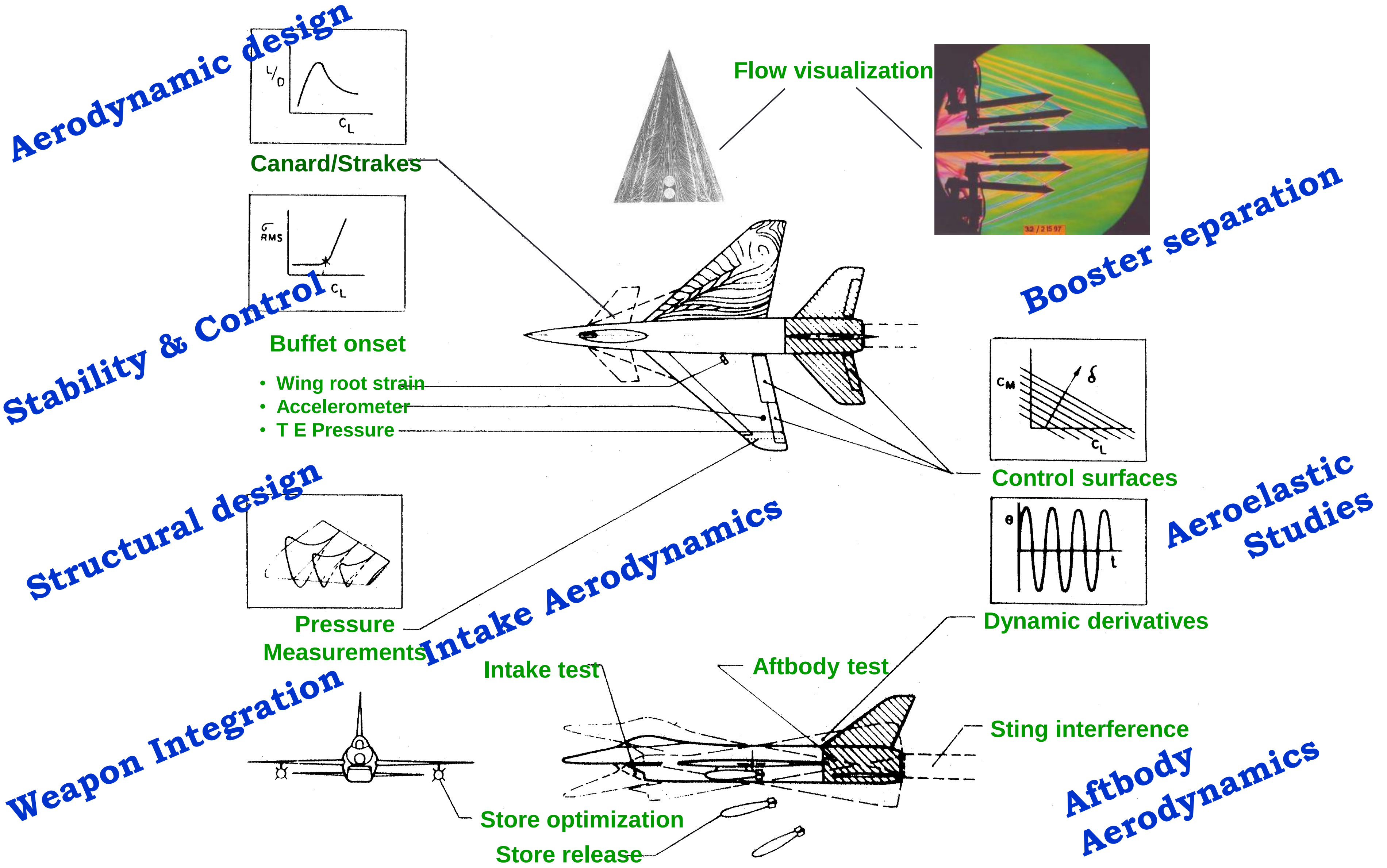
TESTS ON A FLIGHT VEHICLE MODEL



Aerodynamic design

Canard/Strakes

Stability & Control

Buffet onset

- Wing root strain
- Accelerometer
- T E Pressure

Structural design

Pressure Measurements

Intake Aerodynamics

Intake test

Weapon Integration

Store optimization

Store release

Flow visualization

Booster separation

Control surfaces

Aeroelastic Studies

Dynamic derivatives

Aftbody test

Sting interference

Aftbody Aerodynamics

Planning Experiments & Measurements

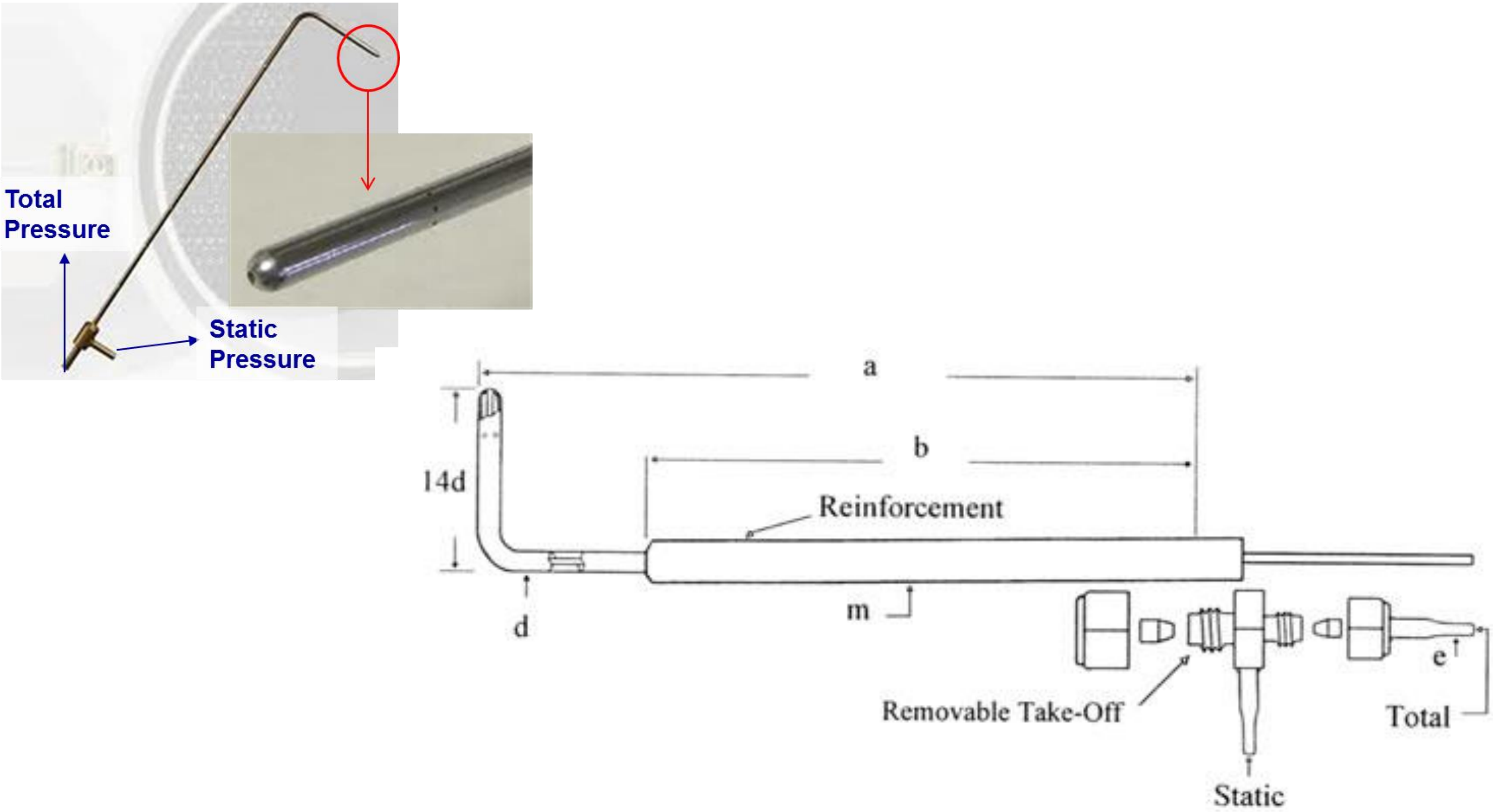
- Plan before doing/buying/measuring anything
  - First and most critical step
- Define the problem
  - Ask questions
  - Lots of questions

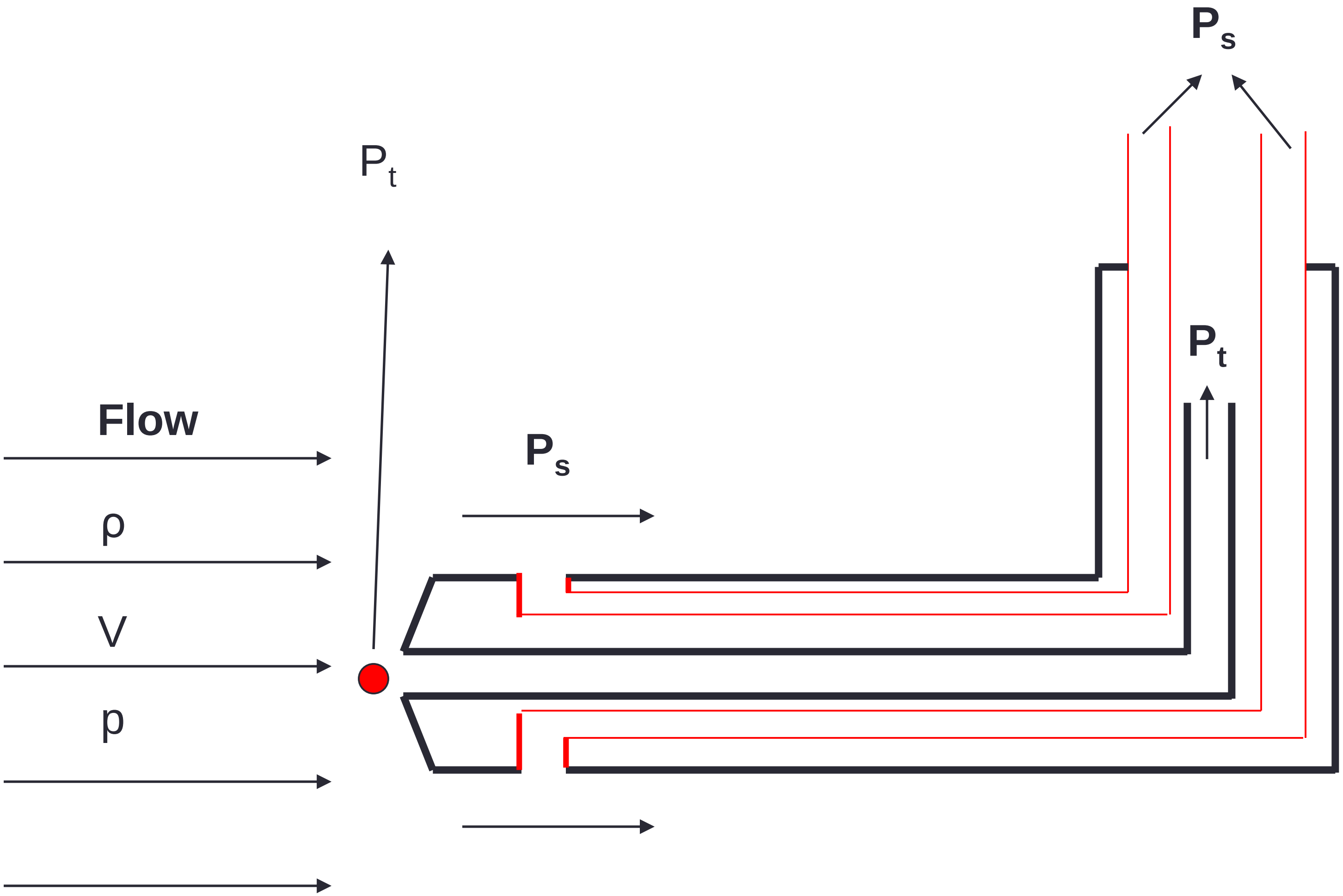
- Unless you define the problem, you cannot find the solution(s)
  - At least not the best solution(s)

Some Questions

- **What is the problem?**
- **What physical laws are involved?**
- **What experiment(s) may provide the answer? (most efficiently)**
- **What (physical) quantities must be measured?**
  - **What is their range?**
- **How accurately do you need to measure them?**
  - **Precision**
- **What parameters/variables can be/need to be controlled?**
  - **How well?**
- **What Instrumentation & Hardware should be used?**
  - **Sensors (thermocouples, pressure sensors, accelerometers, cameras, …)**
  - **Signal conditioning & processing (filters, amplifiers, …)**
  - **Data acquisition systems → Data rate, number of points, …**
- **How to analyze the data → Numerical & analytical approach, modeling, …**
- **How to *best present* or *summarize* the data**

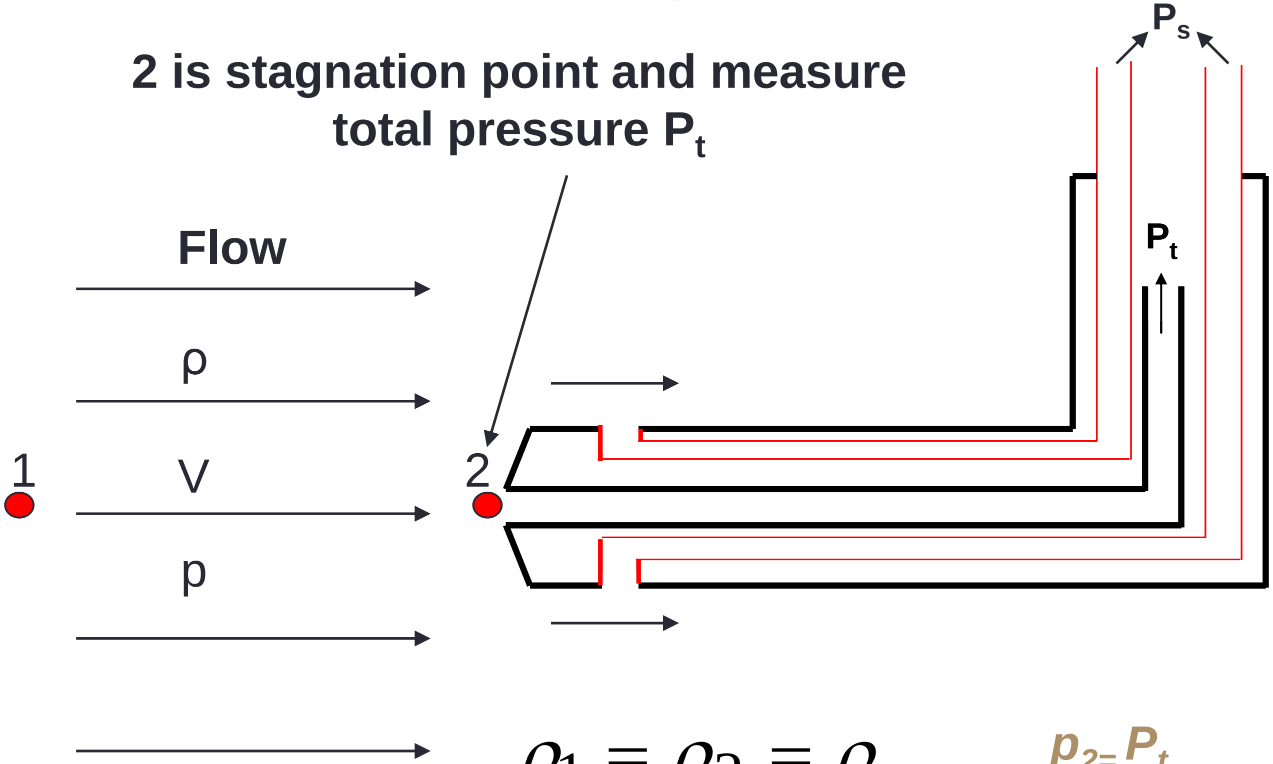
Pressure Measurements (Pitot Static Tube)





Pitot- Static tube measure static (P_s) and total pressure (P_t)

Velocity measurement using pitot-static tube



2 is stagnation point and measure total pressure P_t

$$\rho_1=\rho_2=\rho$$

$p_2 = P_t$

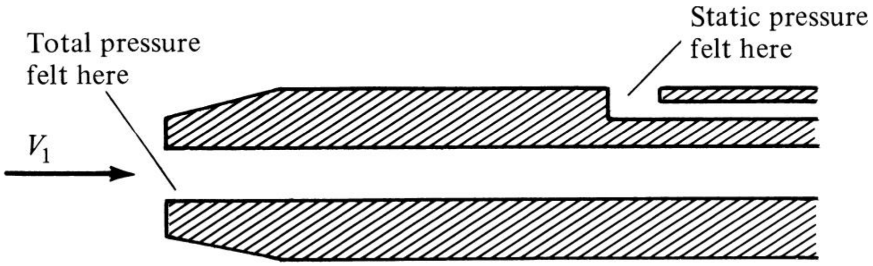
$p_1 = P_s$

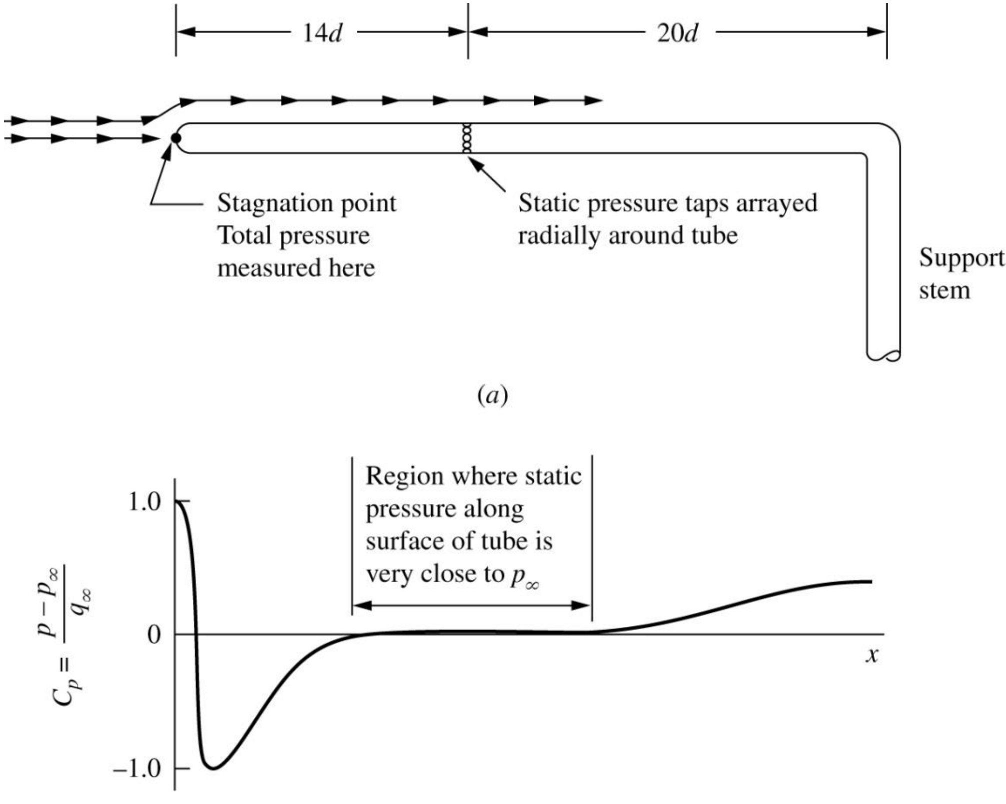
Bernoulli's Equation

$$\frac{\overset{P_s}{p_1}}{\rho_1}+\frac{V_1^{\,2}}{2}+\cancel{z_1}=\frac{\overset{P_t}{p_2}}{\rho_2}+\cancel{\frac{V_2^{\,2}}{2}}+\cancel{z_2}$$

$$V_1=\sqrt{2\left(\frac{p_2-p_1}{\rho}\right)}\Rightarrow\underline{\underline{\sqrt{2\left(\frac{p_t-p_s}{\rho}\right)}}}$$

Pitot Static Tube





(a)

(b)

Picking the Right 'Stuff'

Remember to *ask questions* and *plan*

1. Transducers: Measure a physical parameter or variable and convert it into an electrical signal which is related to (usually proportional to) the value of the parameter

- E.g., 1) Microphone: fluctuating pressure to voltage
  2) Pressure transducer: pressure to voltage
  3) Thermocouple: temperature to voltage
  4) Camera sensors: CCD arrays: photons to voltage

Picking the Right ‘Stuff’

2. Input Circuitry: E.g. wheatstone bridge

    - Signal conditioning: To improve the quality of the signal: usually consists of filters and amplifiers
    - Removes noise, improves signal-to-noise ratio (SNR)

3. Transmission: Shielded cables

    - E.g., scopes, voltmeters, analog-to-digital converters (A/D)
    - Each process has specific types of hardware and with each type, certain precautions need to be taken

- Also, each type has an error associated with it

Digital Data Acquisition

- Output of most measuring instruments is ANALOG, i.e., continuous

- However, most recording devices are DIGITAL, e.g., DVD player

- Analog Recording / Display devices
  1. Strip chart recorder
  2. Analog scope
  3. Most modern devices use a (digital) computer to record and store and display the signal
     - This is done through the use of *Analog-to-Digital Converters* (A/Ds), which is a piece of hardware – usually a card

Choosing the Right A/D or DAQ System

- When sampling an analog signal, it is important that we sample fast enough to accurately measure the analog signal
- Sampling frequency, f_s must be $\geq$ 2 times the signal frequency
  - Otherwise, aliasing will occur
- In a real signal, $f_s \geq 2f_c$

  where f_c = the highest frequency present, determined by *filter cutoff* frequency
- Most measurement and control devices are analog
- Encoders are an exception (in that they provide a digital output)

Analog-to-Digital Converters (A/D)

A/Ds are a critical part of Data Acquisition (DAQ) systems

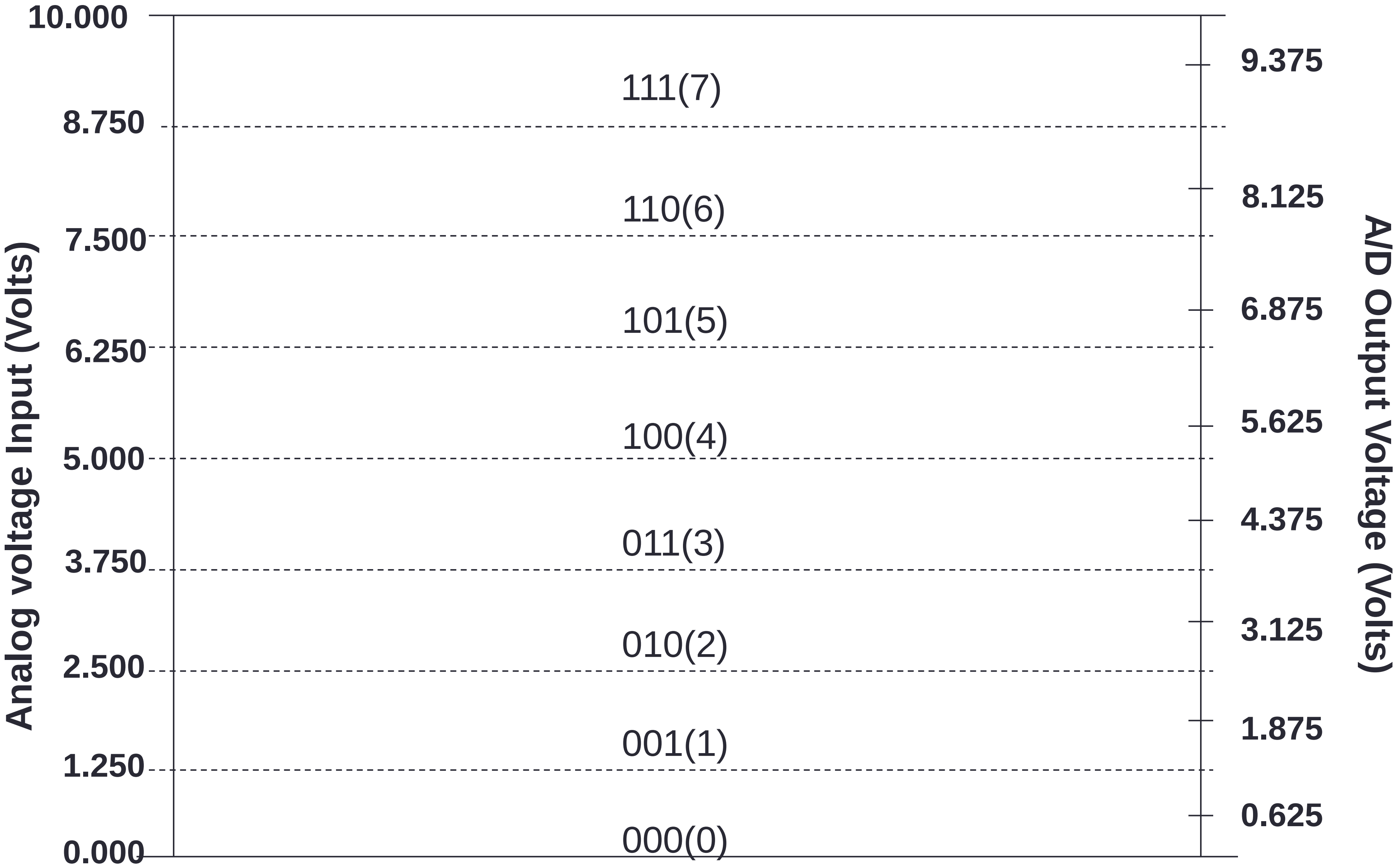
- The outside world is analog while computers are digital
- A/D and D/A converters serve as translators, enabling computers to communicate with the outside world.
  - E.g., A/D – Sample output from pressure probes, thermocouples, hotwires, etc., and store those outputs in digital form

- D/A – Take the output from the computer to control an analog device.
  - E.g., Controlling a heater (current), Controlling the position of a motor.

Important Parameters of A/D Converters

1. Input Voltage Range: Usually ± Volts and ± mV. Sometimes only + V or + mV
   - This determines how much the input signal needs to be amplified to use the maximum input range
   - More of a choice, input resolution is usually more expensive

2. A/D Resolution (Digitization Resolution)
   - Number of bits N which make up the digital resolution (binary)
   - The larger the number of bits, the greater the resolution
   - The number of bins = 2^N for an N-bit A/D,
     i.e., a 3-bit A/D has $2^3 = 8$ bins
   - Resolution = $(V_{max} – V_{min}) / 2^N$



Input voltage range = 0 – 10 V

3 bit A/D converter → 10 V / 8 bins = 1.25 V/div (Resolution)

Digitization error = ± 0.5 $(V_{max} – V_{min}) / 2^N$ = ± 0.625 V

Important Parameters of A/D Converters

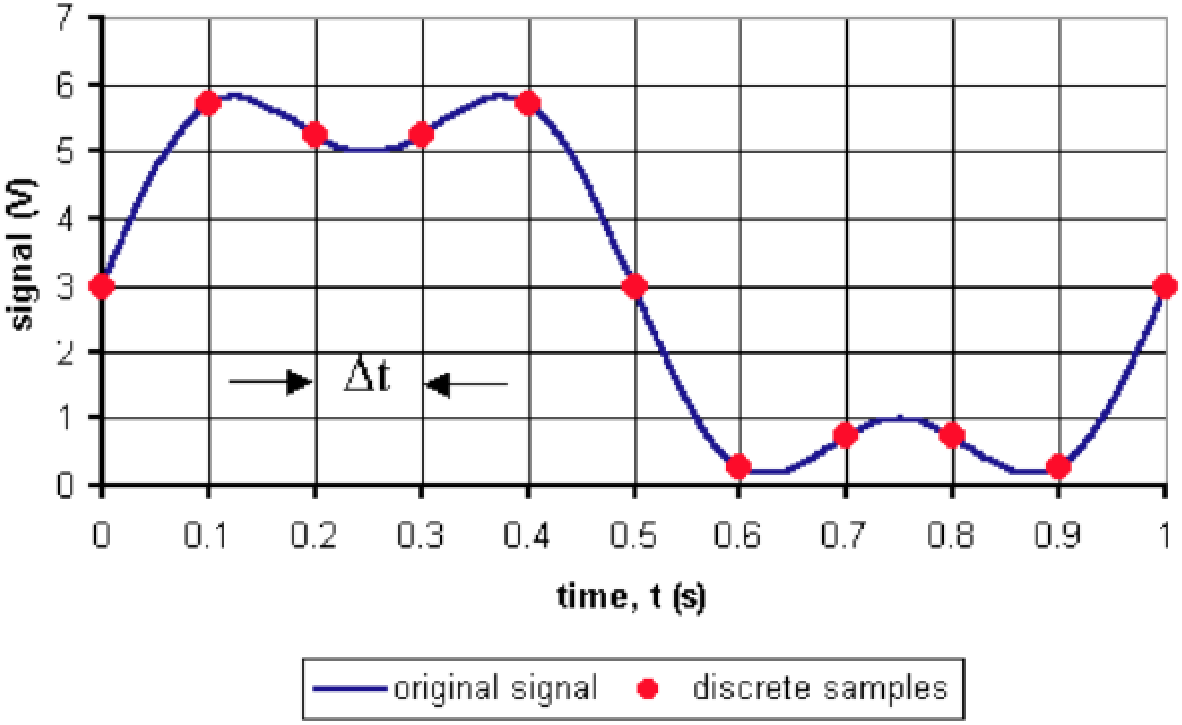
- Usually, input range should encompass the transducer output range closely (be careful of *clipping*)
- Most common cards are 8-bit and 12-bit, although 16-bit cards are also available

3. Sampling Rate

- How quickly can the analog signal be digitized or converted (also called the conversion rate)
- Can range from a few kHz up to a few MHz
- What determines the sampling rate?
  - The frequency content of the measured parameter(s)
- According to the ***Nyquist*** criterion, the sampling frequency (rate) must be at least 2 times the highest frequency present in the input signal to avoid aliasing

Sampling Rate & Aliasing

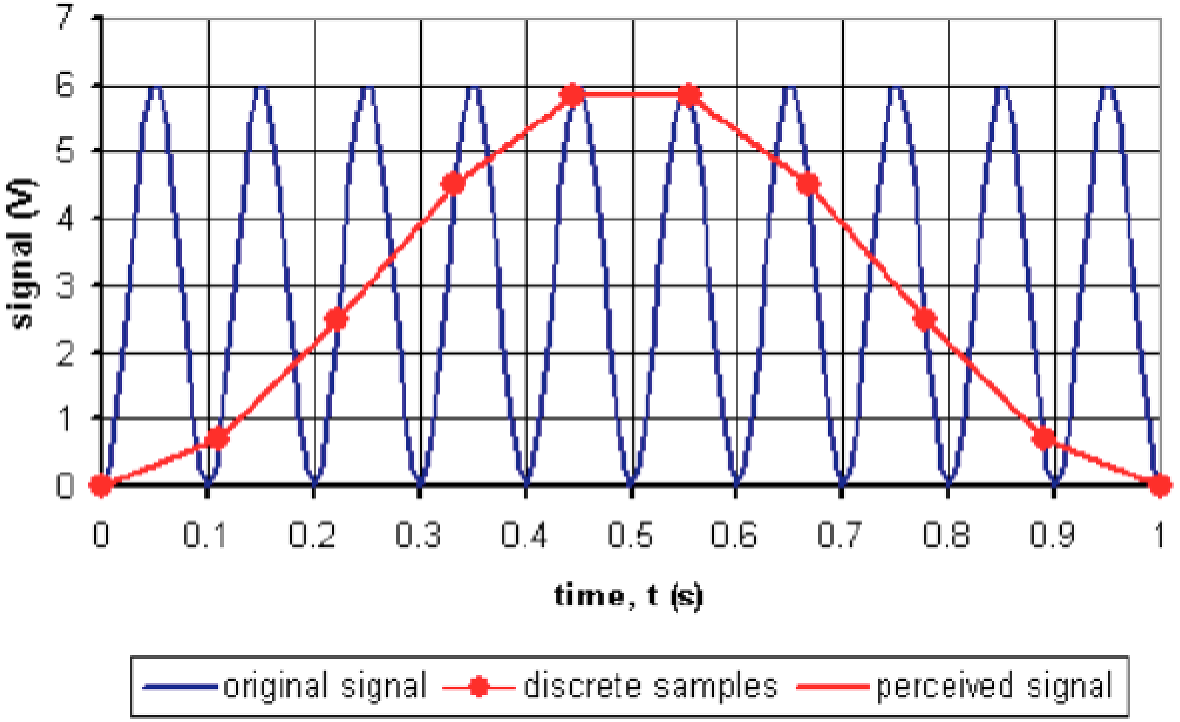
- Digital systems sample signals *at discrete times only*, not continuously
- In a digital DAQ system, no information is recorded at times *in between* these discrete sampling times



$\Delta t = 1 / f_s$

Sampling Rate & Aliasing

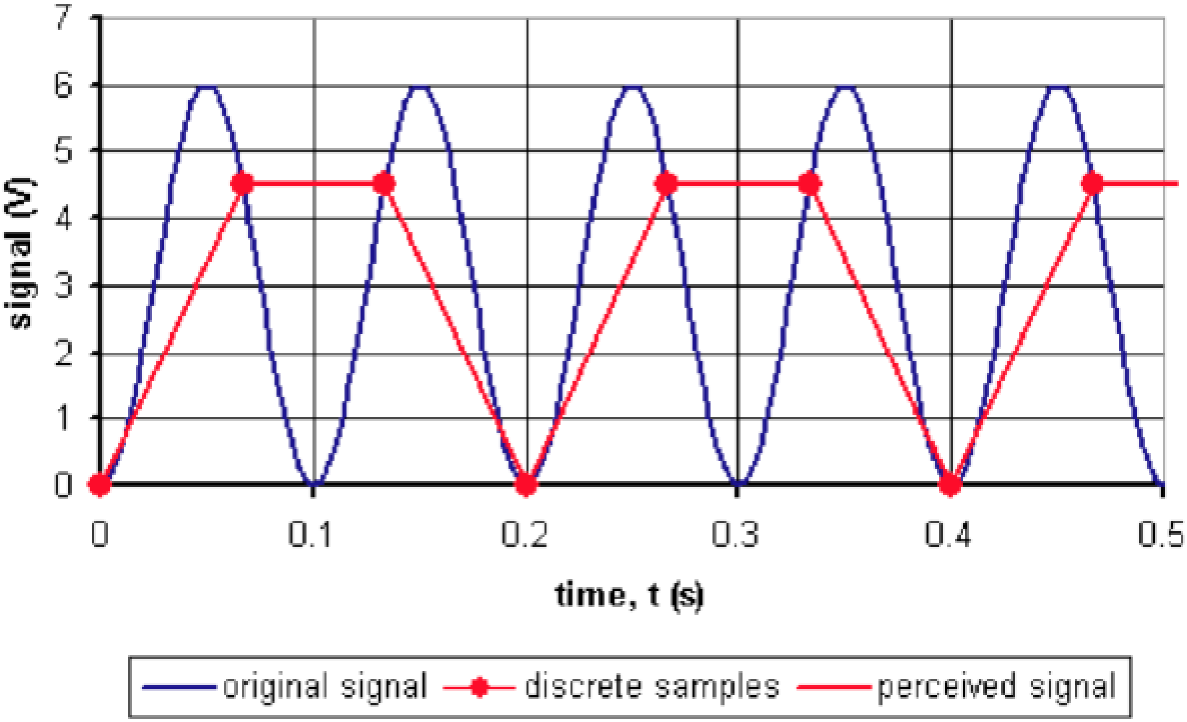
- Same signal, $signal = 3 + 3\sin\left(2\pi 10t - \frac{\pi}{2}\right)$ sampled at 11 Hz



To avoid aliasing, the sampling frequency must be greater than twice the highest frequency component of the analog signal.

Sampling Rate & Aliasing

- If the sampling frequency f_s is too low, one can actually measure an *incorrect* frequency! This is called ***aliasing***
- $signal = 3 + 3\sin\left(2\pi 10t - \frac{\pi}{2}\right)$ sampled at f_s = 15 Hz.



Important Parameters of A/D Converters

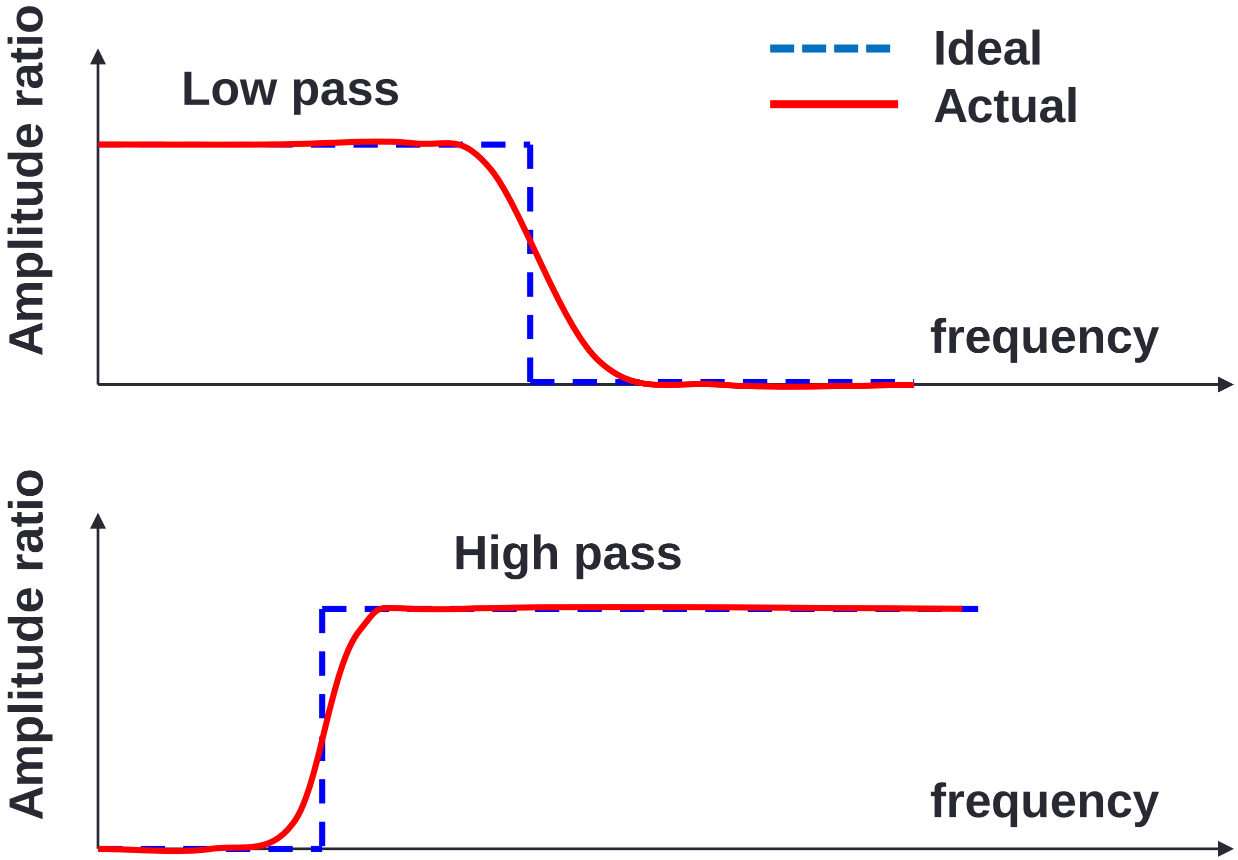
4. Number of Channels
5. Memory

- How does one control the frequency content of a signal?

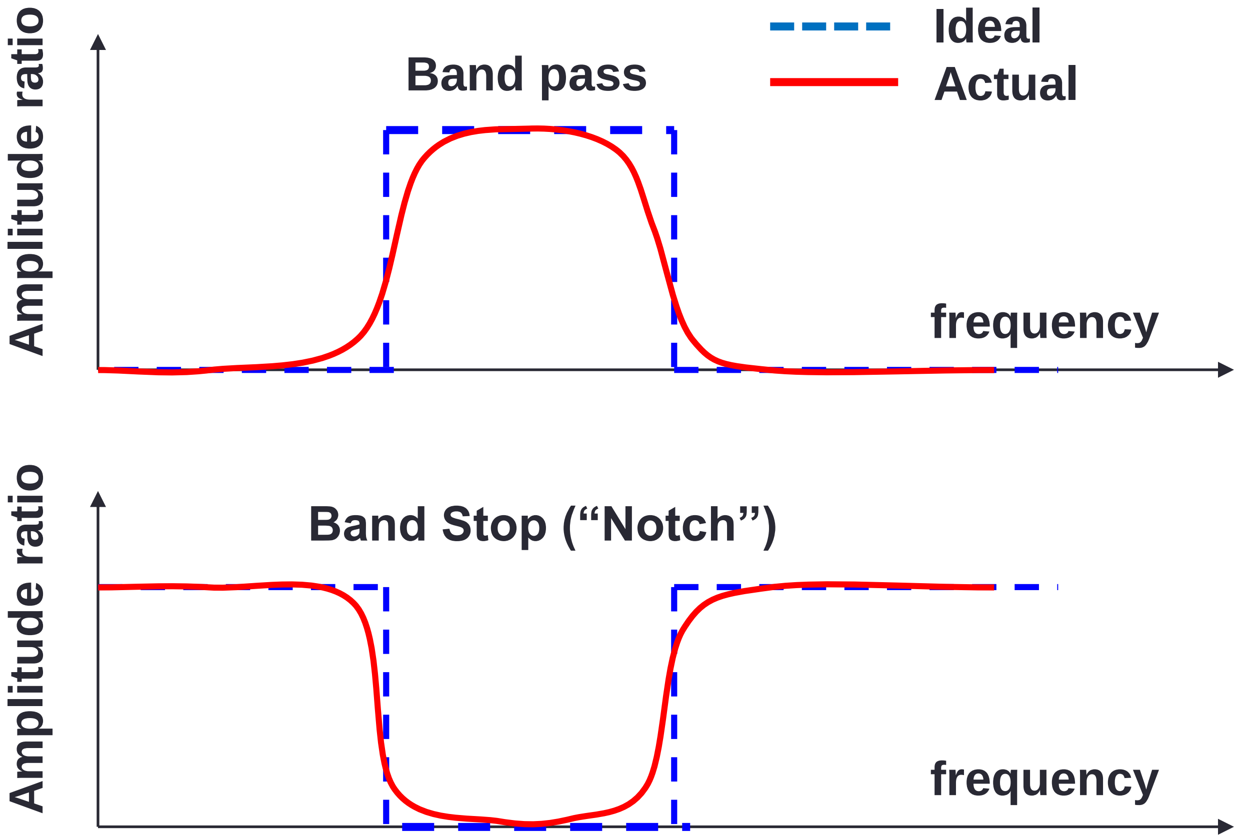
- Filtering
  - High Pass
  - Low Pass
  - Band Pass
  - Band Stop or “Notch”

- Note that real filters will never have the sharp functions of an ideal filter

Filters


Low pass
Ideal
Actual
Amplitude ratio
frequency
High pass
Amplitude ratio
frequency

Filters


Band pass
Ideal
Actual
Amplitude ratio
frequency
Band Stop (“Notch”)
Amplitude ratio
frequency

Decibel Scale (dB)

- dB is just another way of comparing relative amplitudes between 2 signals
- Value in dB is a ratio of the output / the input in log scale:
  $\text{dB} = 20 \log_{10}(\text{output}/\text{input})$
- E.g., 20 dB implies what amplitude ratio?
- $20\ \text{dB} = 20 \log_{10}(\text{output}/\text{input})$
- $\text{Log}_{10}(\text{output}/\text{input}) = 1$
- Output/input = 10
- Similarly, 40 dB implies output/input = 100

Amplifiers

- Amplify the signal to minimize noise and increase Signal-to-Noise ratio (SNR) and match the input voltage range of the A/D
- Amplification usually given in dB’s (also called gain)
- Usually filters and amplifiers are packed in one unit

Examples

- Transducers:
  - Omega
  - Kulite
  - Endevco
  - Bruel & Kjaer
- Amplifiers:
  - Omega
  - National Instruments
  - In-house
- Filters:
  - Stanford Research Systems
- DAQ:
  - National Instruments