Sensors

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E80 Lecture

You’ll Fly Sensors on Your Rockets

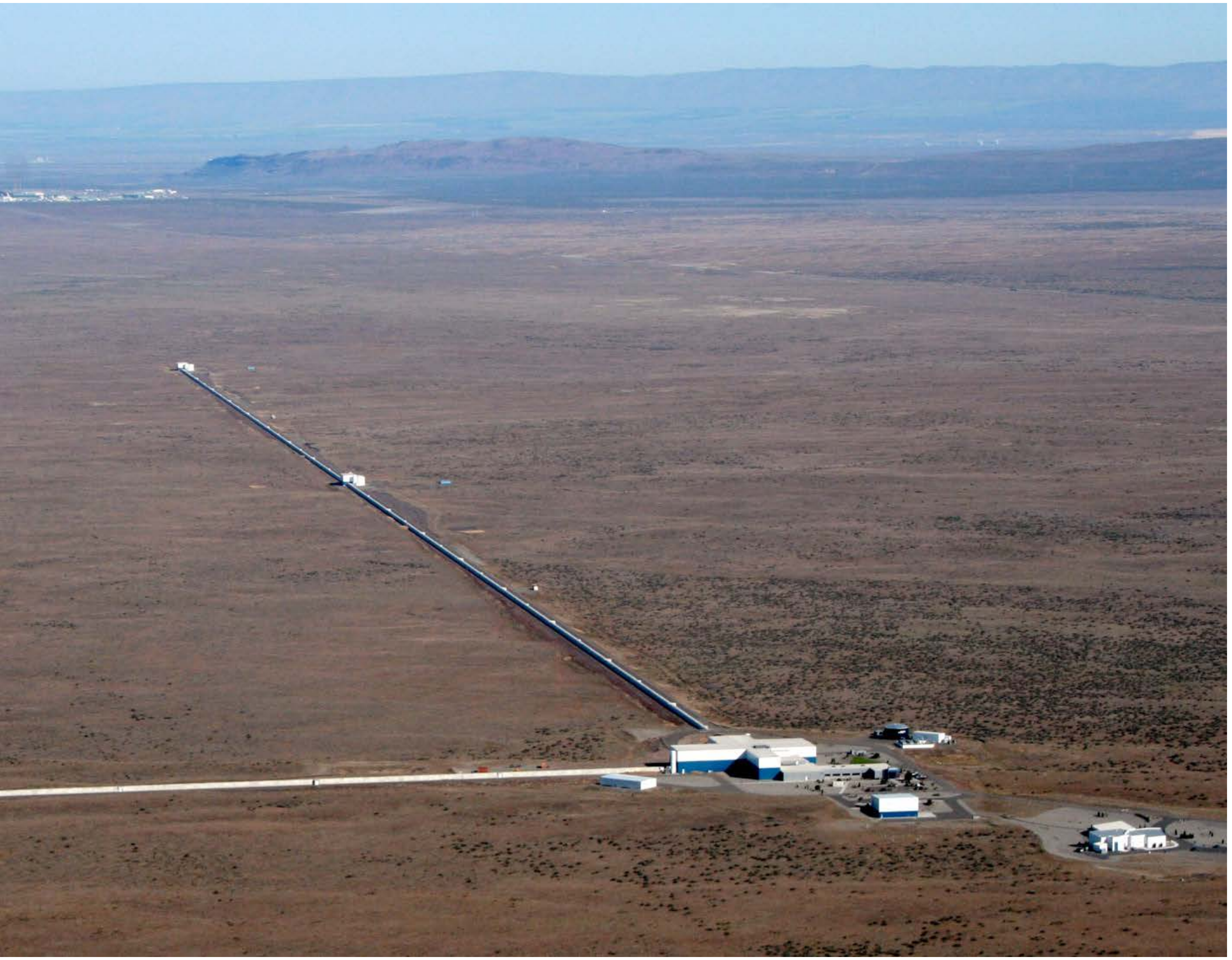
- Also, you need them in your work

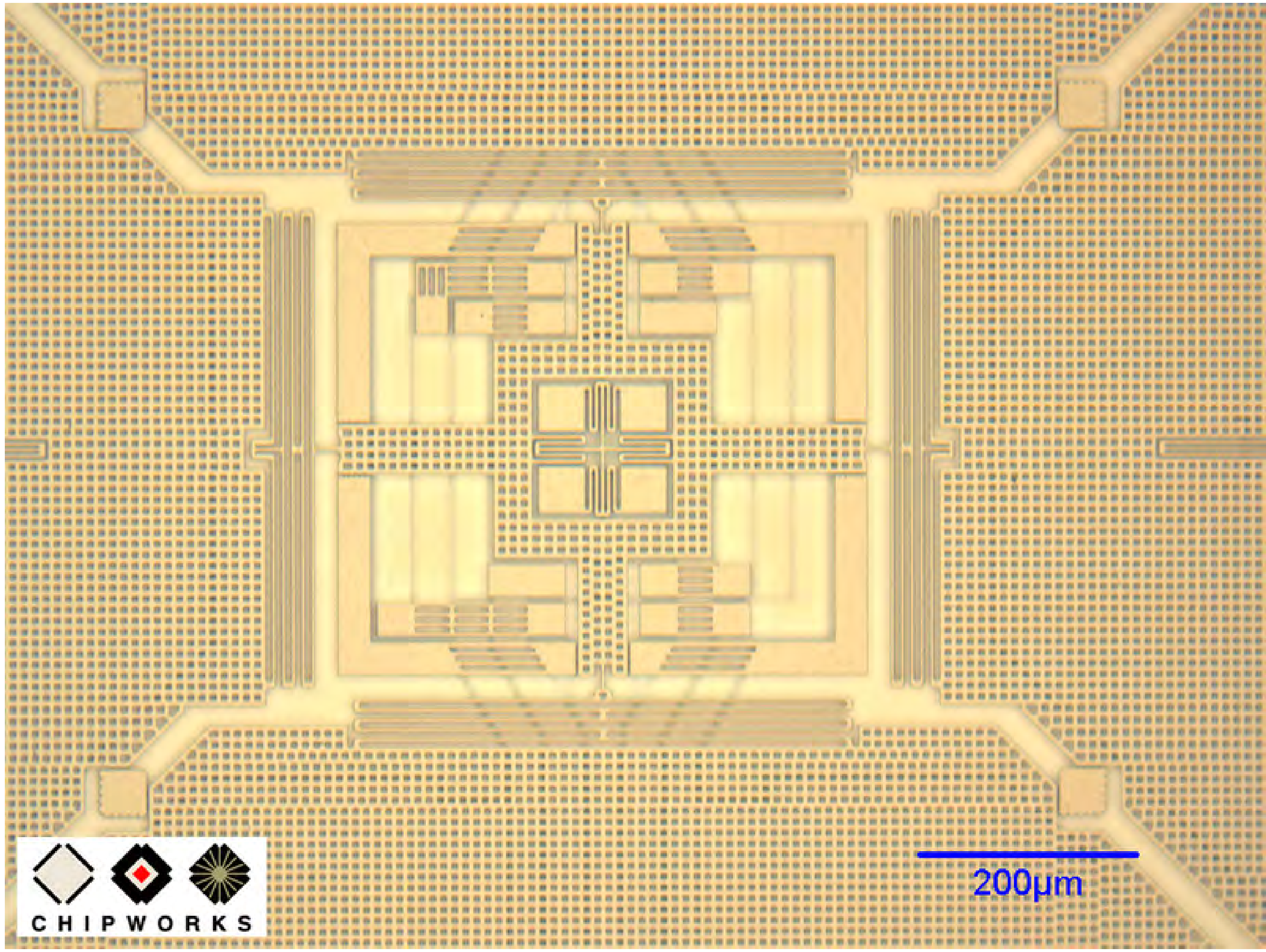
http://thehauntedrocket.tumblr.com/post/135268424227/marsvikings-the-viking-lander-is-a-superbly

Motivating Question

- What kind of altimeters are suitable for our big flight?
- How are we going to answer that question?

Isn’t Sensors a Super Broad Topic?





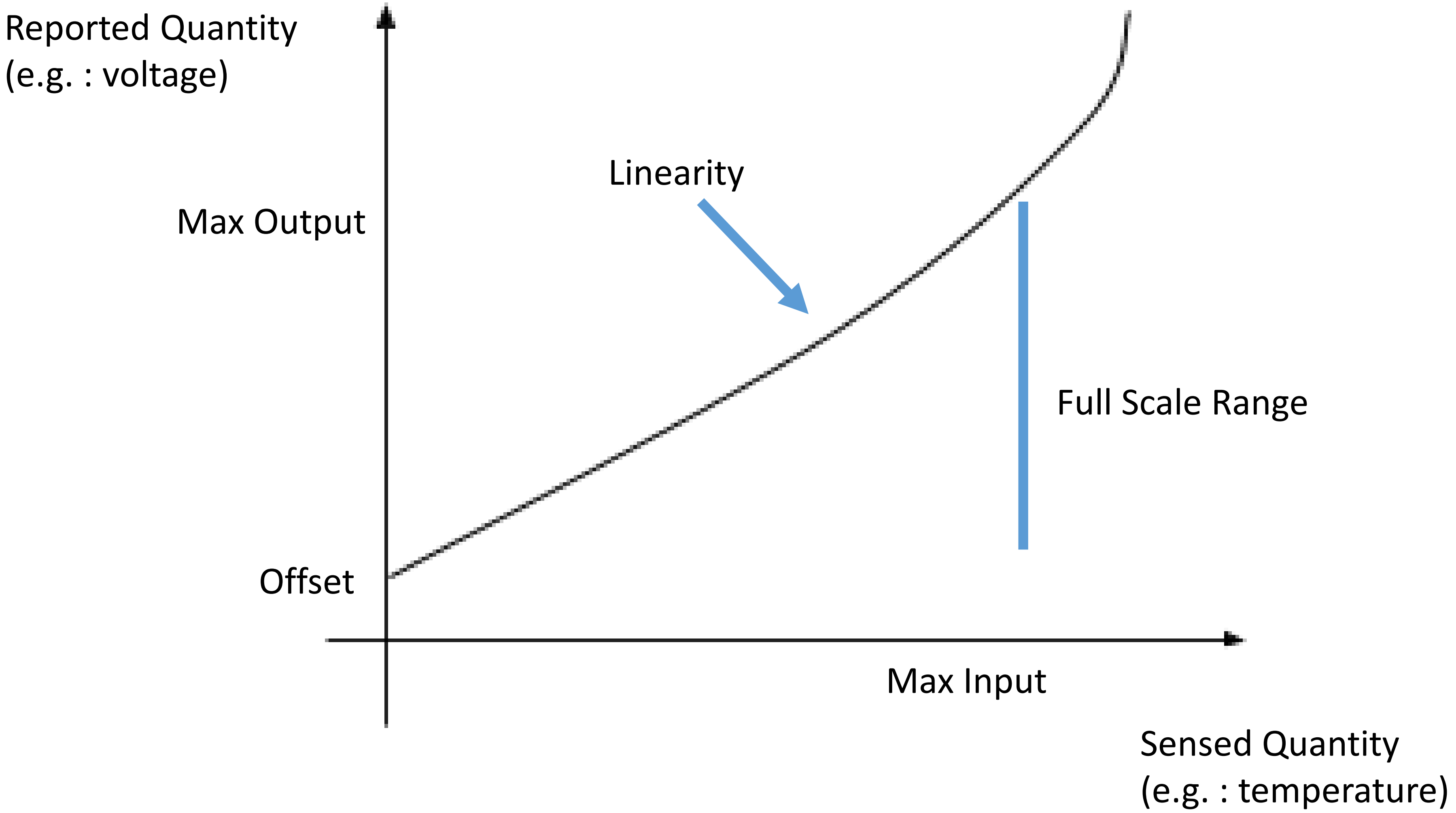
http://www.ligo.org/multimedia/gallery/lho.php

https://www.ifixit.com/Teardown/iPhone+4+Gyroscope+Teardown/3156

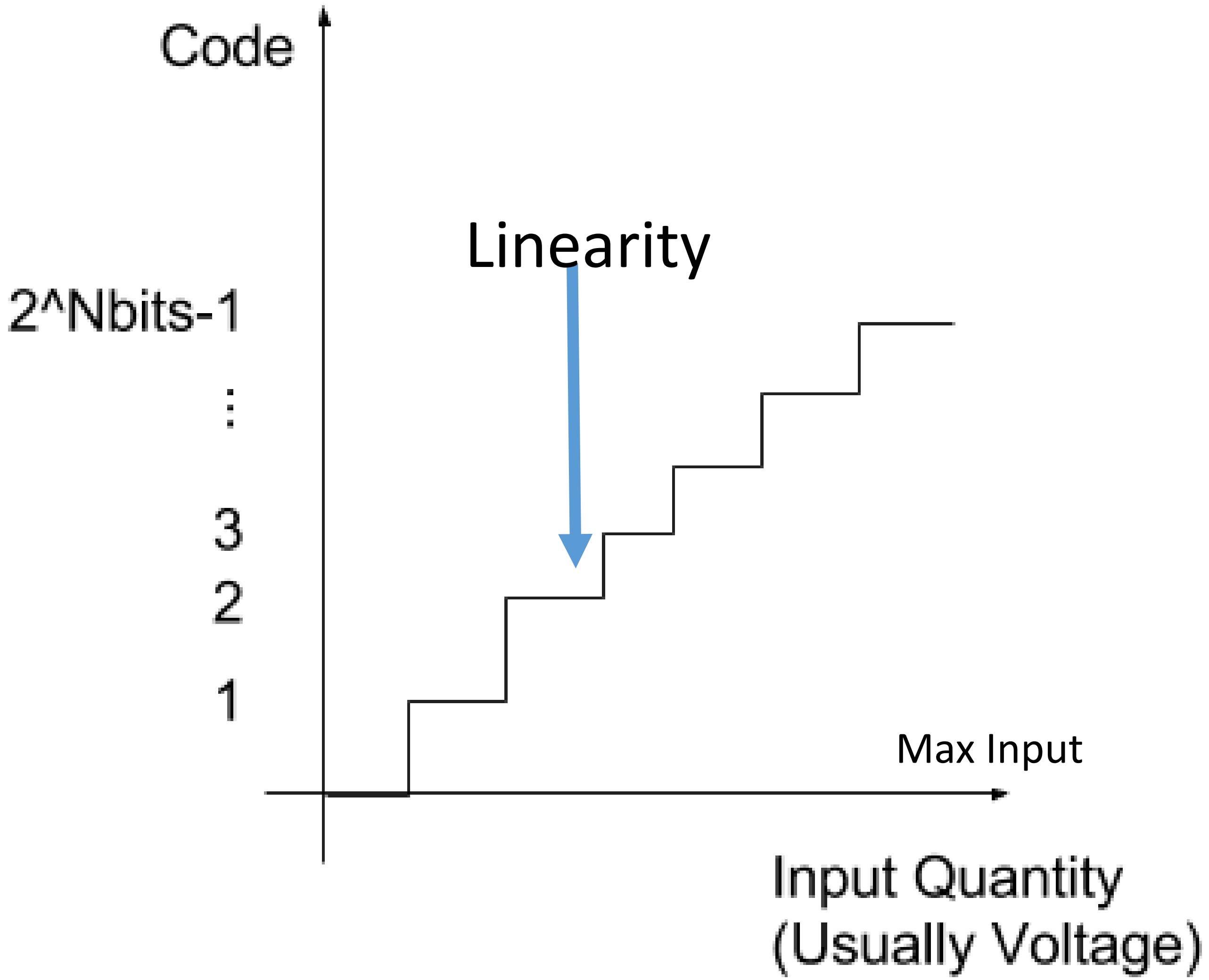
A Disciplined Way to Consider Sensors

- Static Performance
- Dynamic Performance
- Interface and Readout
- Physics Sanity Checks

Static Performance Summarized in a Graph



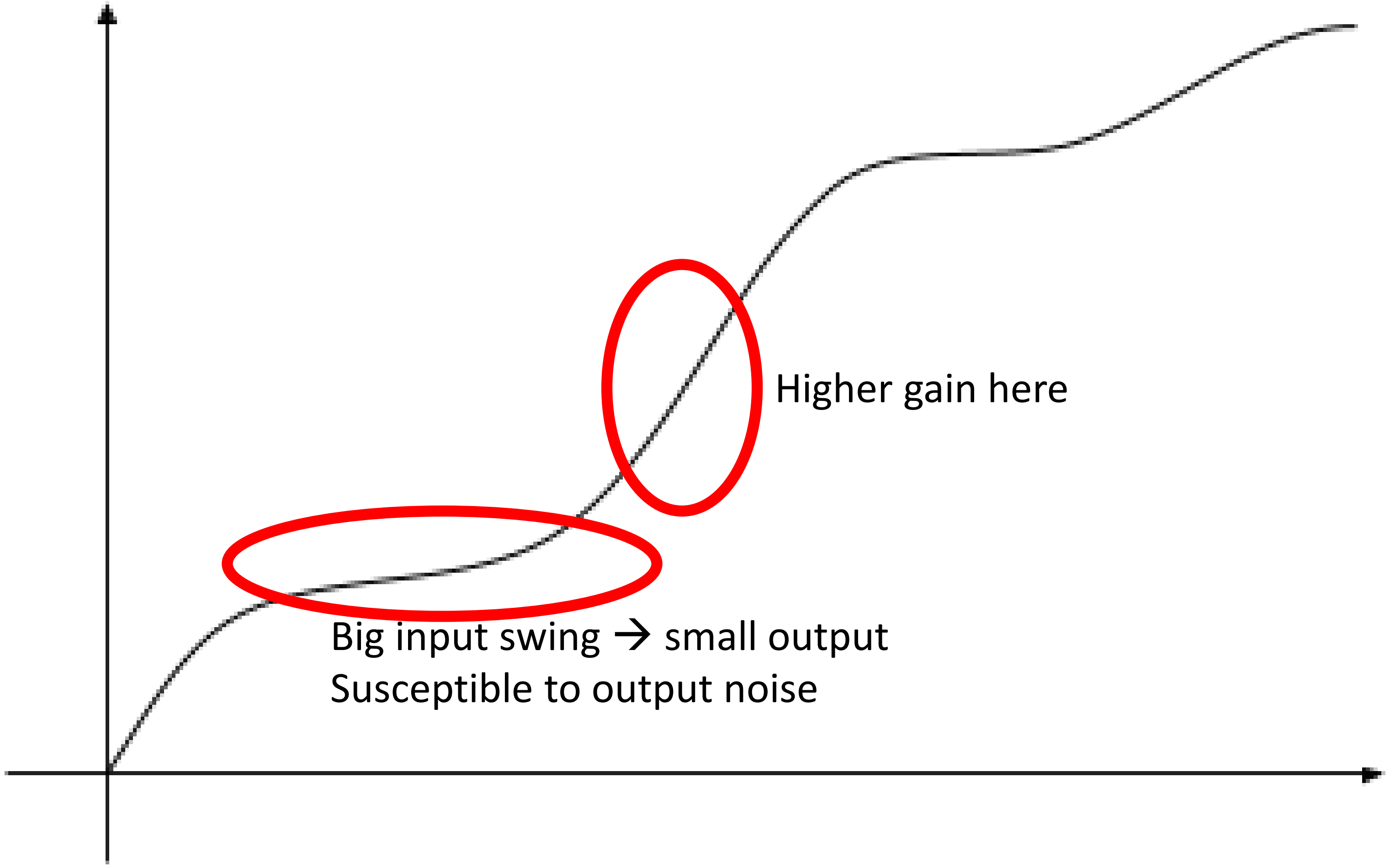
Digitized Sensor Output has Same Properties



Calibration Can Fix Offset and Non-Linearity

- Fixes non-linearity and offset.
- Doesn’t fix noise. Can only fix noise with more power / less loss.
- Difficult to calibrate in production settings: time is money
- Be careful of time-variance. Fancy sensors have online calibration.

Resolution Varies w/ Input if Very Non-linear



Dynamic Performance is Described by E59

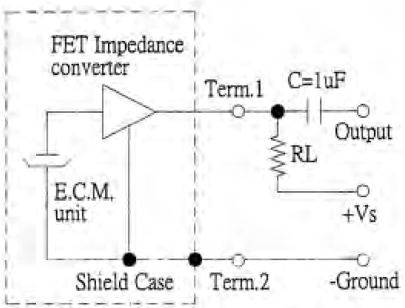
NTC Thermistors, Radial

QUICK REFERENCE DATA	
PARAMETER	**VALUE**
Resistance value at 25 °C	3.3 Ω to 470 kΩ
Tolerance on R_{25} - value	± 2 %; ± 3 %; ± 5 %
$B_{25/85}$ - value	2880K to 4570K
Tolerance on $B_{25/85}$ - value	± 0.5 % to ± 3 %
Maximum dissipation	500 mW
Dissipation factor δ (for information only)	7 mW/K 8.5 mW/K (for R_{25} value ≤ 680 Ω)
Response time (in oil)	≈ 1.2 s
Thermal time constant τ (for information only)	15 s

http://www.vishay.com/sensors/sensors-temperature/ntc/

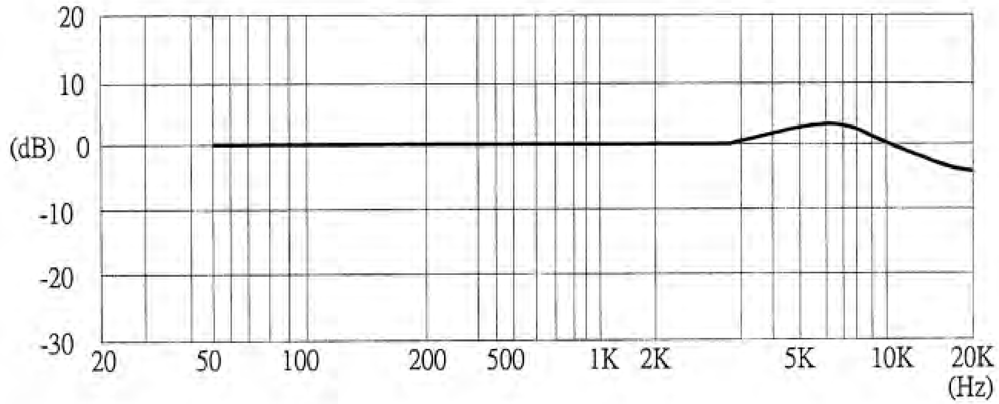
PART NUMBER: CMA-4544PF-W **DESCRIPTION:** electret condenser microphone

MEASUREMENT CIRCUIT



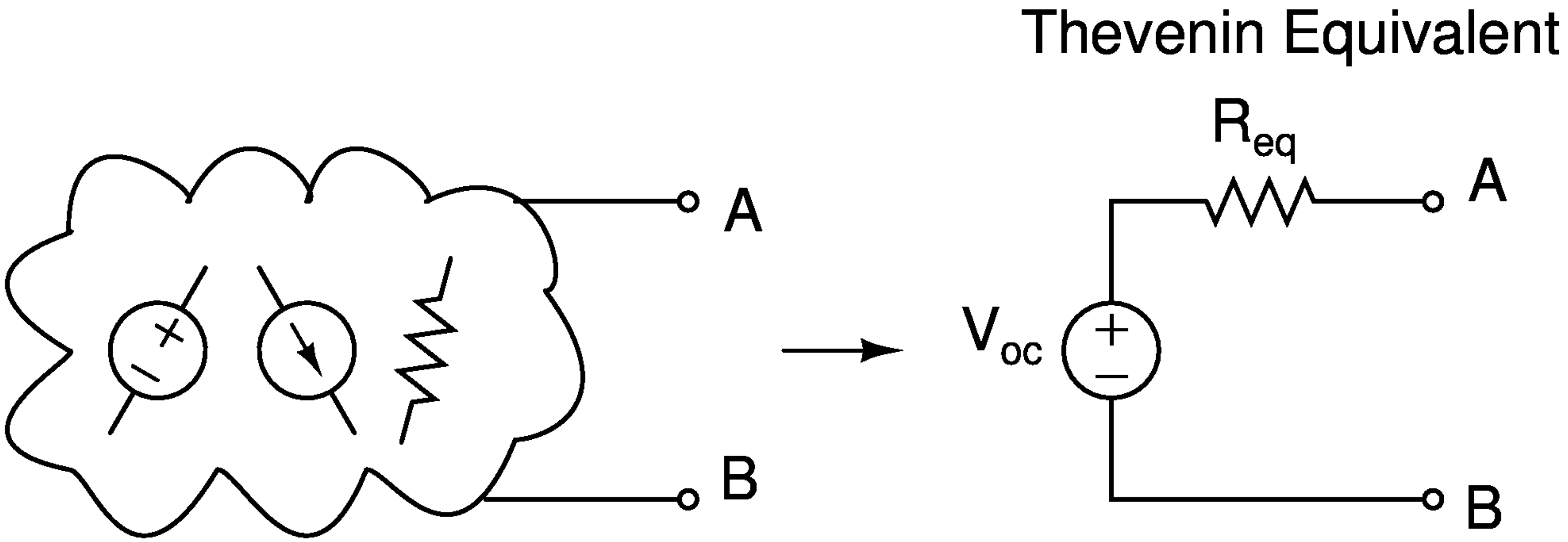
Schematic Diagram RL=2.2KΩ

FREQUENCY RESPONSE CURVE



https://www.adafruit.com/datasheets/CMA-4544PF-W.pdf

Sensor Interfaces – Analog

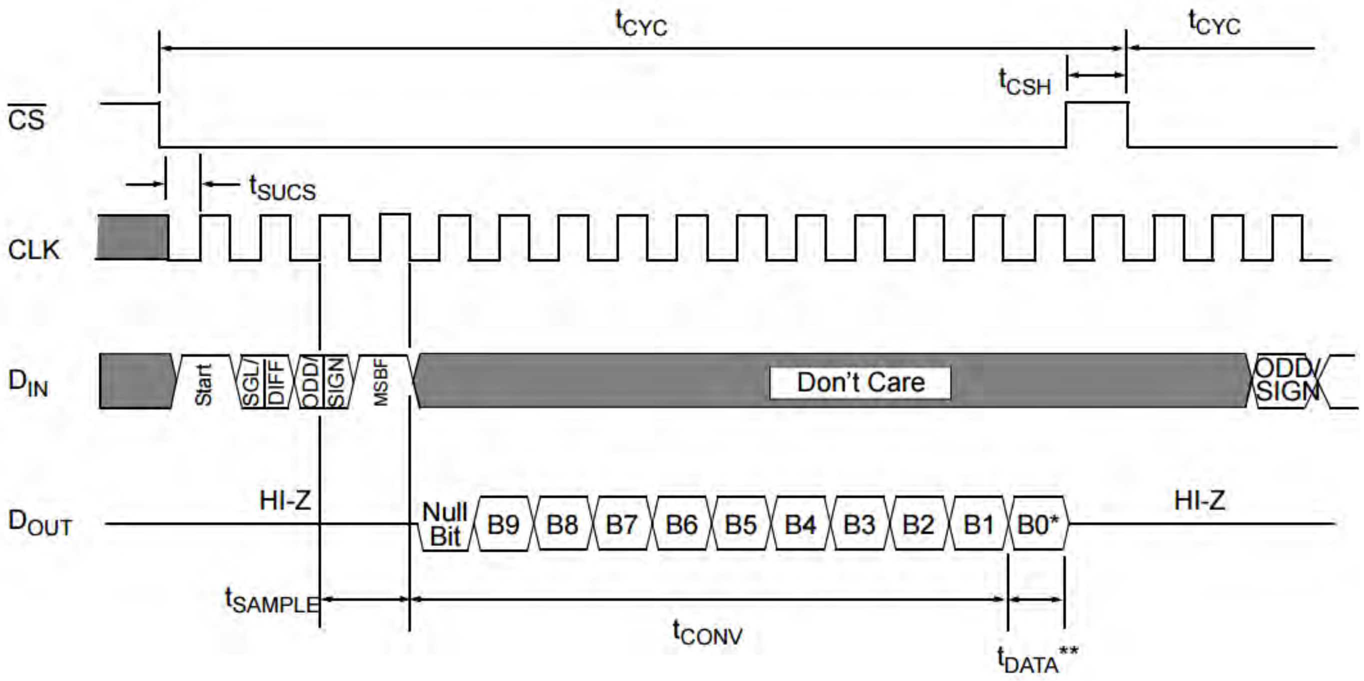


- Use a buffer if Req is big
- Apply gain or offset if Voc is small or centered at an odd voltage
- Probably need to digitize the analog output to record it

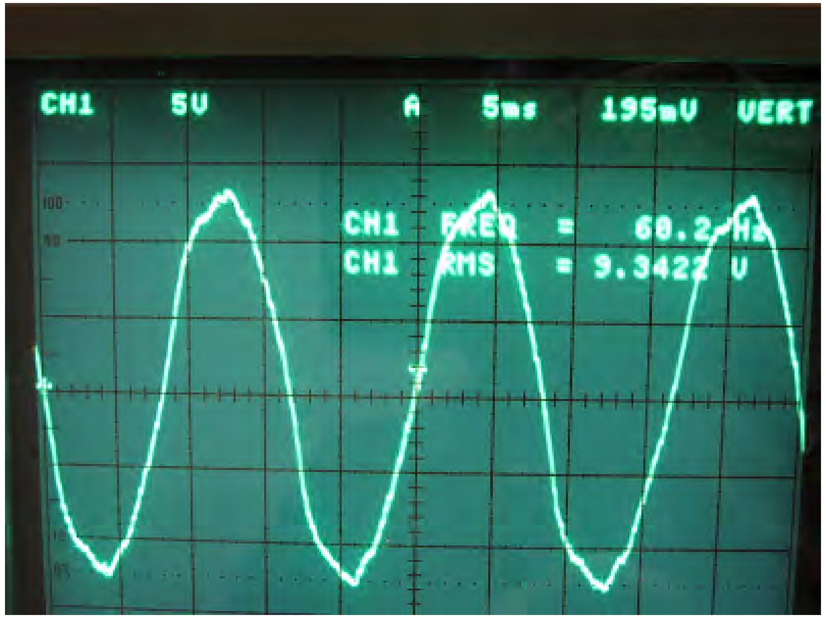
Sensor Interfaces – Digital

- Voltage Levels
- Serial vs. Parallel
- If Serial, what is the protocol?

http://www.microchip.com/wwwproducts/en/MCP3002



Physics Sanity Check



http://www.seeedstudio.com/wiki/images/thumb/3/36/Piezo_Vibration_Sensor_02.jpg/400px-Piezo_Vibration_Sensor_02.jpg
https://prometheusfusionperfection.com/category/oscilloscope/

- Make sure you’re measuring what you think you’re measuring
- Check magnitude and phenomenology

Apply Sensors Checklist to the Theodolite

Apply Sensors Checklist to the Theodolite

- Physics: pendulum points down and user points at rocket.
- Second order system calculation $\omega_0 = \sqrt{\frac{g}{l}} = \sqrt{\frac{9.8}{0.1}} \approx 10\, rad/s$. Flights take 2-3 seconds before apogee.
- ~90 notches: 1/degree. I can't aim to 1 degree.
- Readout is manual / mechanical. Slow, but launches slower

Apply the Sensors Checklist to an Altimeter

MPXA6115AC7U

MPXA6115AC7U
CASE 482C

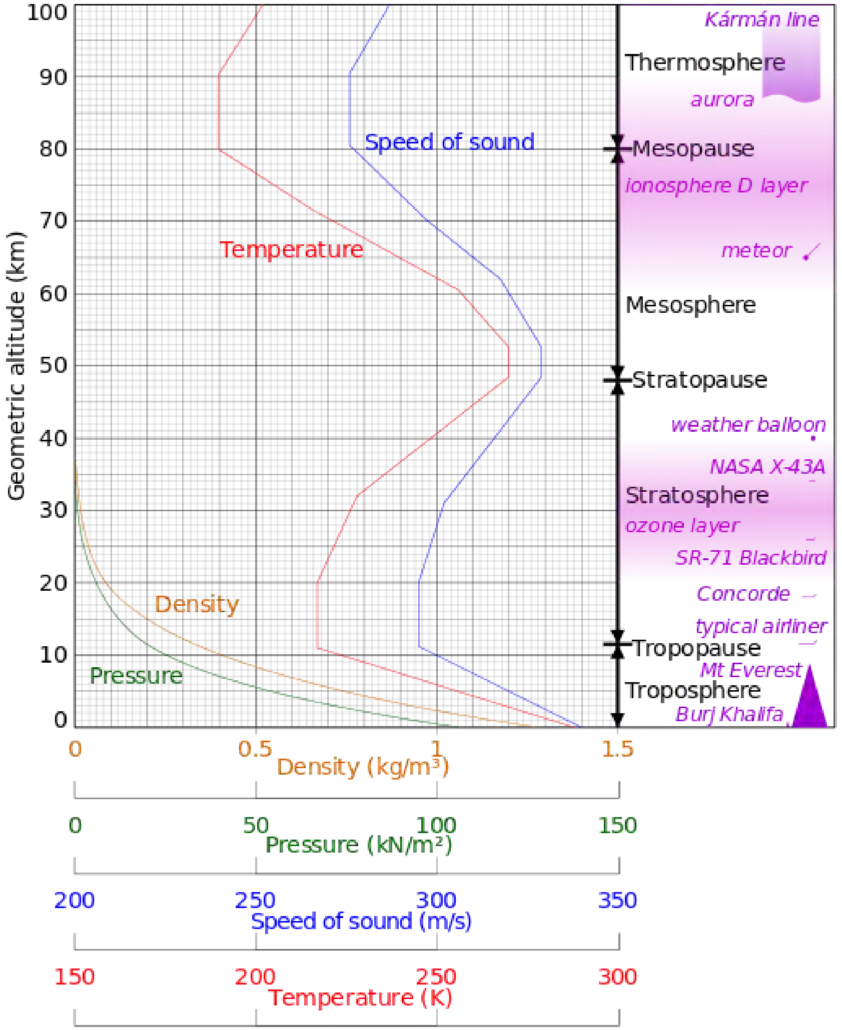
Operating Characteristics

Table 1. Operating Characteristics (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2)

Characteristic	Symbol	Min	Typ	Max	Unit
Pressure Range	P_{OP}	15	—	115	kPa
Supply Voltage(1)	V_S	4.75	5.0	5.25	Vdc
Supply Current	I_o	—	6.0	10	mAdc
Minimum Pressure Offset(2)(0 to 85°C) @ V_S = 5.0 Volts	V_{off}	0.133	0.200	0.268	Vdc
Full Scale Output(3)(0 to 85°C) @ V_S = 5.0 Volts	V_{FSO}	4.633	4.700	4.768	Vdc
Full Scale Span(4)(0 to 85°C) @ V_S = 5.0 Volts	V_{FSS}	4.433	4.500	4.568	Vdc
Accuracy(5)(0 to 85°C)	—	—	—	±1.5	$\%V_{FSS}$
Sensitivity	V/P	—	45.0	—	mV/kPa
Response Time(6)	t_R	—	1.0	—	ms
Warm-Up Time(7)	—	—	20	—	ms
Offset Stability(8)	—	—	±0.25	—	$\%V_{FSS}$

- Information pulled from datasheet
- Asking: “Would this work for the final flight?”

Physics Check: Get Altitude from Air Pressure



- Need a model of air pressure and a model of our flight

Find Model of Troposphere in 2015 Lecture

$$h = \frac{T_0}{-\left(dT/dh\right)} \cdot \left[1 - \left(\frac{P}{P_0}\right)^{\frac{-\left(dT/dh\right) \cdot R}{gM}}\right]$$

(Originally from 1976 Standard Atmosphere Model)

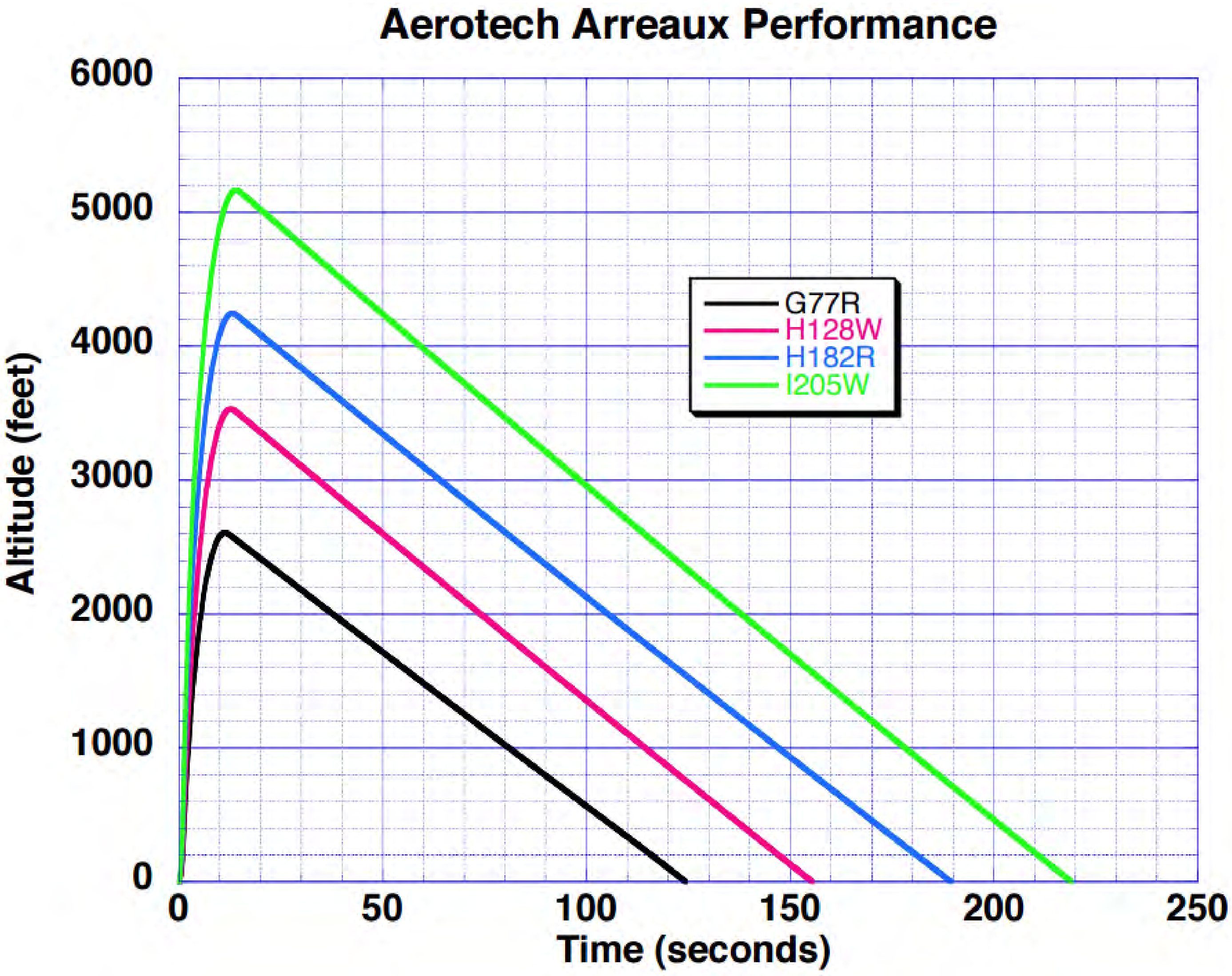
where

- h = geopotential altitude (above sea level) (in meters)
- P_0 = standard atmosphere pressure = 101325Pa
- T_0 = 288.15K (+15°C)
- dT/dh = –0.0065 K/m: thermal gradient or standard temperature lapse rate
- R = 8.31432 Nm/mol K (Current NIST value 8.3144621)
- g = 9.80665 m/s²
- M = 0.0289644 kg/mol

- Be sure to use all resources at your disposal so we can help you!
- Be sure to attribute everything you use. (Thanks, Prof. Spjut!)

Find Arreaux Flight Models

- Apogee is
  - 1 mile AGL
  - At 15s
- Velocity
  - Is ~330 ft/s
  - (~100 m/s)
- Launch at 3000 ft. MSL



Static Properties

- P_launch=90kPa, P_apogee = 74kPa

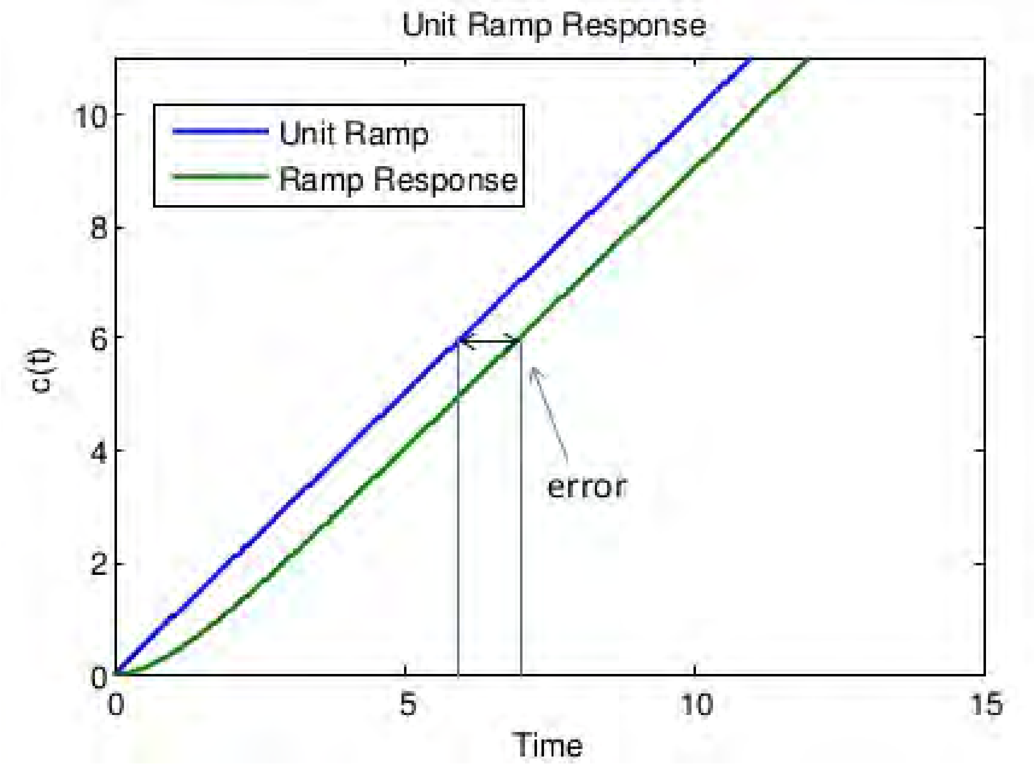
- Add -13% to +7% for Barometric pressure → range is 64kPa – 104kPa

- Accuracy +/- 1.5% Vfs and range is 4.5V representing 100kPa
  - +/- 0.157 kPa, +/- 157m. Resolution OK? Depends on needs.

- Result is non-linear b/c of exponential pressure model. Calibrate.

Dynamics

- Response time (10%-90% rise time) is 1.2ms → tau = 0.46ms
- Velocity is 330 ft/s = 0.33 ft/ms = 10cm/ms



Tau=1 and DC gain = 1 in this example

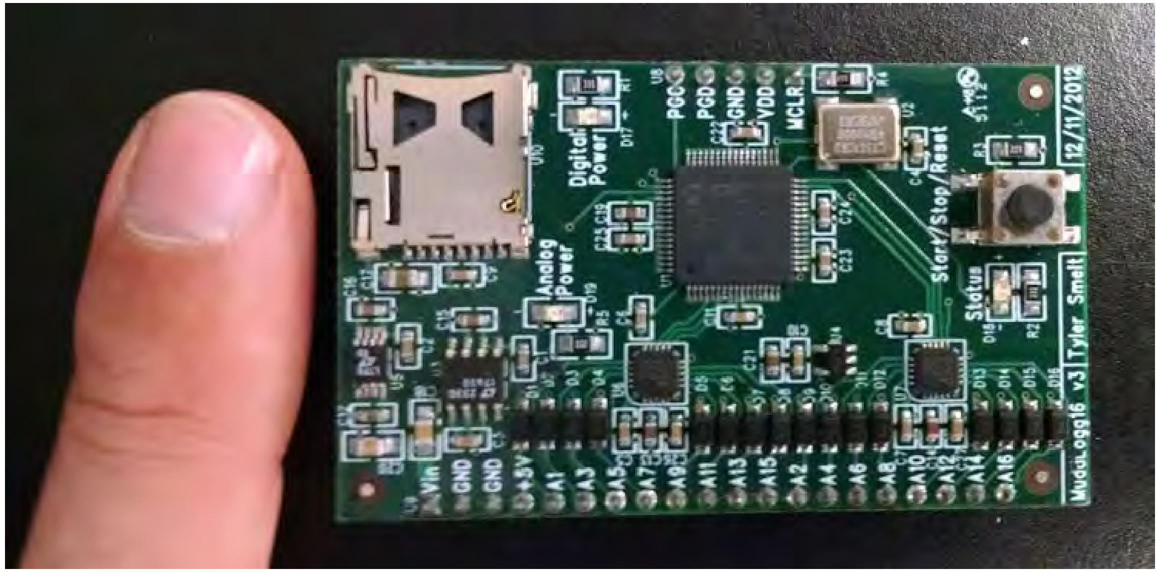
http://www.slideshare.net/SaifUllah32/lecture-13-14timedomainanalysisof1stordersystems

Interface – Analog output

- Need to measure Zout, datasheet says little. (How?)

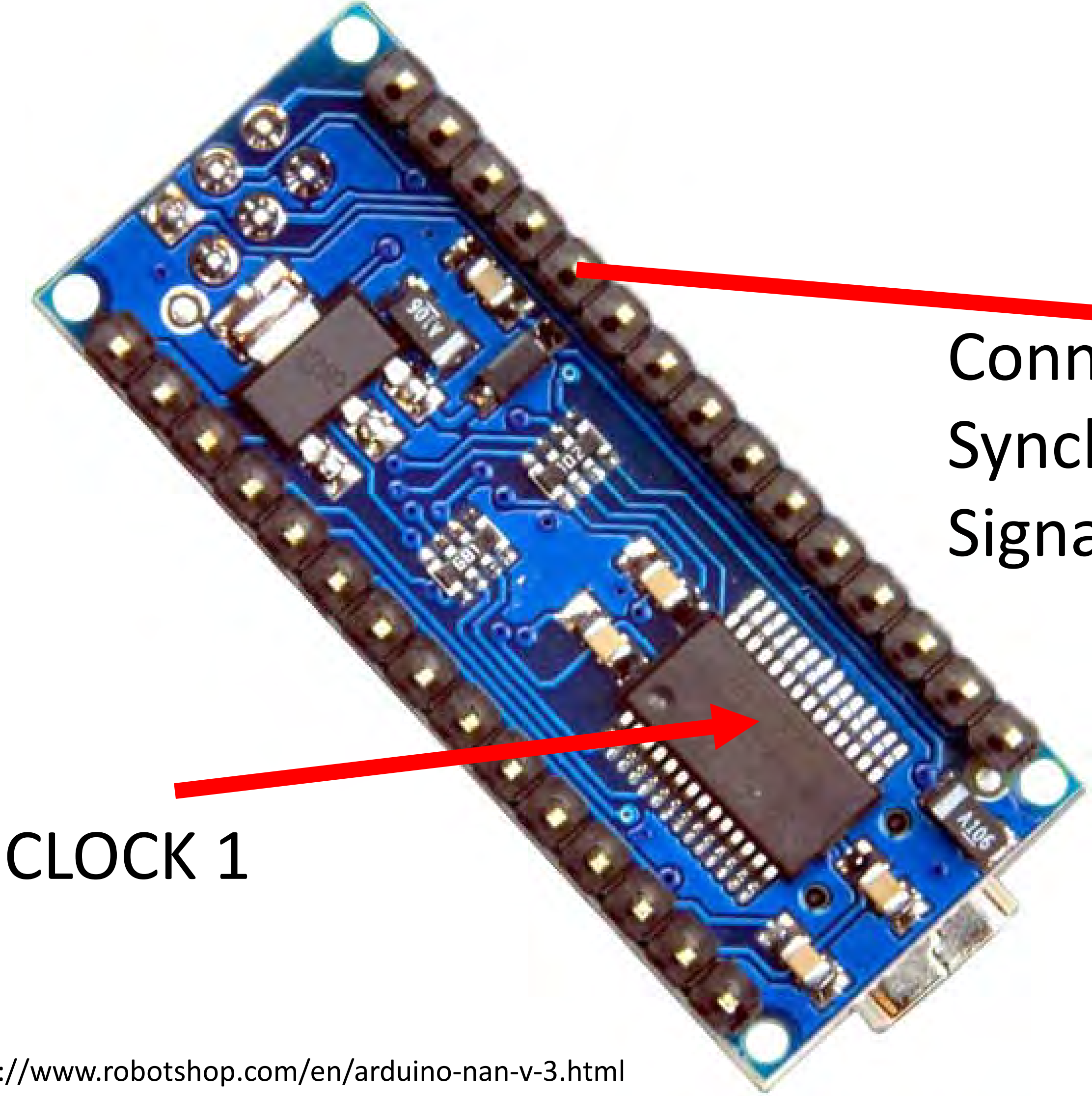
- Expect to get 675 mV of swing on top of 200 mV offset. (Fixable?)

Interface – Digitizing With the Data Logger



- 16 analog channels: 16 bit, 2.2 kOhm Zin, sampled at 12.5 kHz
- 3.3 V supply and full scale input range.
- Saves to on board SD card.

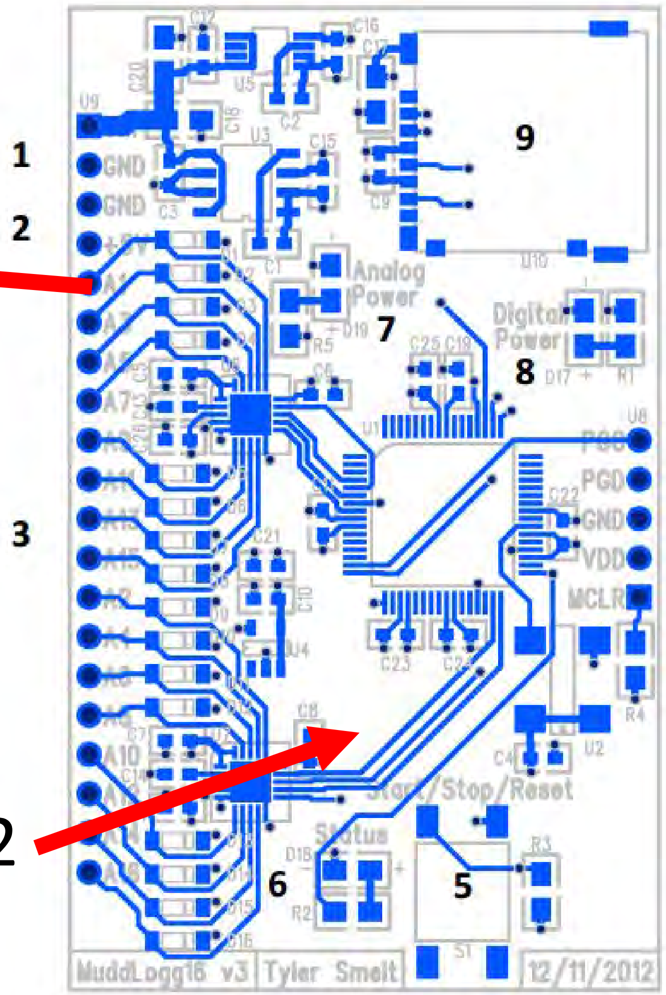
Interface – Data Loggers and Digital Sensors



Connect Synchronizing Signal

CLOCK 1

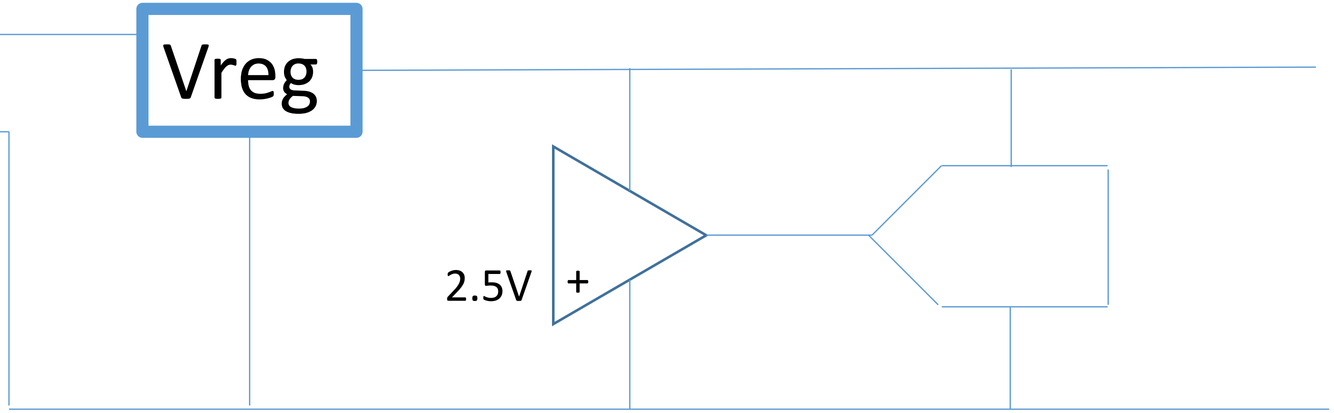
http://www.robotshop.com/en/arduino-nan-v-3.html



CLOCK 2

Figure 1. MuddLogg16 v3 PCB layout.

Interface – Be Careful of Your Power System



Voltages cannot be negative!

Battery has ~250 mA-hrs energy

Separate batteries for high power subsystems

https://upload.wikimedia.org/wikipedia/commons/8/8d/Duracell_9_Volt_0849.jpg

Final Project Ideas

- Science Measurements (measure stuff around the rocket)
  - Atmosphere: Particles, chemicals, flow rate, humidity, material phases, charge
  - Radiation: UV, IR, any optical frequencies, gamma rays, etc.
  - Multimedia: sounds, images, video
- Engineering Measurements (measure stuff about the rocket)
  - Flight: rotation, acceleration, vibration, displacement, orientation, flow rate
  - Electrical: power consumption, voltages, capacitances, inductances
- Don’t forget that you often need a way to get airflow over sensors

Where do I find More Sensors?

- Digikey demonstration

- Last year’s lecture has a deeper dive into a few datasheets.
  - MQ-2 Methane gas sensor (requires heater)
  - GP2Y1010AF Particle sensor (requires pulse signal, could roll your own)
  - A few humidity sensors (capacitive sensors require cool readout circuits!)