What Motors Will You Fly?

- Motor Lottery/Draft at 9:35 AM on Tuesday, 10 MAR 2015.
- List on [http://www.eng.hmc.edu/NewE80/RocketLaunchLab.html#Motors](http://www.eng.hmc.edu/NewE80/RocketLaunchLab.html#Motors)
- Those with * require an extra-long motor mount and MUST be reinforced with a layer of fiberglass.

Scientific & Engineering Measurements

- **Scientific Measurements**
  - What you measure *with* a rocket.
  - What are examples?
- **Engineering Measurements**
  - What you measure *about* a rocket.
  - What are examples?
## Experimental Measurements

- Mass
- Force
- Acceleration
- Velocity
- Position
- Displacement
- Orientation
- Vibration
- EM Intensity
  - Radio
  - Microwave
  - IR
  - Visible
  - UV
  - X-ray
  - Gamma

## Experimental Measurements II

- Temperature
- Pressure
- Flow Rate
- Composition
  - Partial Pressure
  - Humidity
  - Mass fraction
  - Mole fraction
- pH
- Phases
  - Aerosols
  - Suspensions
  - Microstructure
- Sound
- Images
- Video

## Experimental Measurements III

- Electrical
  - Voltage
  - Charge
  - Current
  - Resistance
  - Inductance
  - Capacitance
  - Power
- Time
- Frequency
- Phase
- Angular
  - Position
  - Velocity
  - Acceleration
Digikey’s List of Sensors

- Accelerometers (1069 items)
- Accessories (3933 items)
- Amplifiers (312 items)
- Capacitive Touch Sensors, Proximity Sensor ICs (569 items)
- Color Sensors (126 items)
- Current Transducers (1555 items)
- Dust Sensors (17 items)
- Encoders (4286 items)
- Flex Sensors (3 items)
- Float, Level Sensors (533 items)
- Flow Sensors (177 items)
- Force Sensors (76 items)
- Gas Sensors (69 items)
- Gyroscopes (246 items)
- Image Sensors, Camera (354 items)
- Inclinometers (44 items)
- IrDA Transceiver Modules (294 items)
- LVDT Transducers (Linear Variable Differential Transformer) (153 items)
- Magnetic Sensors - Compass, Magnetic Field (Modules) (23 items)
- Magnetic Sensors - Hall Effect, Digital Switch, Linear, Compass (ICs) (3023 items)
- Magnetic Sensors - Position, Proximity, Speed (Modules) (3641 items)
- Magnets (101 items)
- Moisture Sensors, Humidity (354 items)
- Moistion Sensors, Detectors (282 items)
- Multifunction (80 items)
- Optical Sensors - Ambient Light, IR, UV Sensors (639 items)
- Optical Sensors - Distance Measuring (45 items)
- Optical Sensors - Mouse (117 items)
- Optical Sensors - Photo Detectors - Logic Output (131 items)
- Optical Sensors - Photo Detectors - Remote Receiver (1139 items)
- Optical Sensors - Photodiodes (990 items)
- Optical Sensors - Photoelectric, Industrial (11099 items)
- Optical Sensors - Photointerrupters - Slot Type - Logic Output (1078 items)
- Optical Sensors - Photointerrupters - Slot Type - Transistor Output (1164 items)
- Optical Sensors - Phototransistors (781 items)
- Opitical Sensors - Reflective Analog Output (325 items)
- Opitical Sensors - Reflective Logic Output (130 items)
- Position Sensors - Angle, Linear Position Measuring (1213 items)
- Pressure Sensors, Transducers (26694 items)
- Proximity Sensors (3759 items)
- Proximity/Occupancy Sensors - Finished Units (236 items)
- RTD (Resistance Temperature Detector) (60 items)
- Shock Sensors (18 items)
- Solar Cells (85 items)
- Specialized Sensors (359 items)
- Strain Gages (21 items)
- Temperature Regulators (3803 items)
- Temperature Sensors, Transducers (1031 items)
- Temperature Switches (719 items)
- Thermistors - NTC (4972 items)
- Thermistors - PTC (1253 items)
- Thermocouple, Temperature Probe (399 items)
- Tilt Sensors (54 items)
- Ultrasonic Receivers, Transmitters (77 items)
- Vibration Sensors (35 items)

What Spec’s Do We Care About?

- Quantity Measured
- Range or Span
- Accuracy
- Precision
- Noise
- Linearity
- Speed of Response
- Voltage Requirements
- Current Requirements
- Output Impedance
- Mounting Requirements

Example – Altimeter

- Measure Absolute Pressure and Calculate Altitude
  – What range of pressures do we need?
  – What accuracy do we expect?
Calculate Altitude from Pressure

For the Troposphere

\[ h = T_0 \left[ \frac{dP}{dh} + 1 \right] \left[ \frac{P}{P_0} \right]^{-\frac{dT}{dh}} \left[ \frac{\gamma}{R} \right] \]

where
- \( h \) = geopotential altitude (above sea level) (in meters)
- \( P_0 \) = standard atmosphere pressure = 101325 Pa
- \( T_0 = 288.15 \text{K} \) (+15°C)
- \( dP/dh = -0.0065 \text{ Pa/m} \) = thermal gradient or standard temperature lapse rate
- \( \gamma = 8.314462 \text{ J/mol K} \) (Current NIST value 8.3144621)
- \( M = 0.0289644 \text{ kg/mol} \)
- \( g = 9.80665 \text{ m/s}^2 \)

From 1976 US Standard Atmosphere

How Does Pressure Vary With Height?

<table>
<thead>
<tr>
<th>Alt. (m)</th>
<th>Alt. (ft)</th>
<th>Alt. (mi)</th>
<th>P (Pa)</th>
<th>dP/dh (Pa/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0.000</td>
<td>101325</td>
<td>-12.01</td>
</tr>
<tr>
<td>200</td>
<td>656</td>
<td>0.065</td>
<td>98945</td>
<td>-11.78</td>
</tr>
<tr>
<td>400</td>
<td>1312</td>
<td>0.124</td>
<td>96610</td>
<td>-11.56</td>
</tr>
<tr>
<td>600</td>
<td>1969</td>
<td>0.183</td>
<td>94321</td>
<td>-11.34</td>
</tr>
<tr>
<td>800</td>
<td>2625</td>
<td>0.242</td>
<td>92076</td>
<td>-11.12</td>
</tr>
<tr>
<td>1000</td>
<td>3281</td>
<td>0.301</td>
<td>89841</td>
<td>-10.90</td>
</tr>
<tr>
<td>1200</td>
<td>3937</td>
<td>0.361</td>
<td>87616</td>
<td>-10.69</td>
</tr>
<tr>
<td>1400</td>
<td>4593</td>
<td>0.420</td>
<td>85598</td>
<td>-10.48</td>
</tr>
<tr>
<td>1600</td>
<td>5249</td>
<td>0.479</td>
<td>83582</td>
<td>-10.27</td>
</tr>
<tr>
<td>1800</td>
<td>5906</td>
<td>0.538</td>
<td>81488</td>
<td>-10.07</td>
</tr>
<tr>
<td>2000</td>
<td>6562</td>
<td>0.597</td>
<td>79449</td>
<td>-9.87</td>
</tr>
<tr>
<td>2200</td>
<td>7218</td>
<td>0.656</td>
<td>77446</td>
<td>-9.67</td>
</tr>
<tr>
<td>2400</td>
<td>7874</td>
<td>0.715</td>
<td>75524</td>
<td>-9.48</td>
</tr>
<tr>
<td>2600</td>
<td>8530</td>
<td>0.774</td>
<td>73691</td>
<td>-9.29</td>
</tr>
</tbody>
</table>
Calculate Flight Height

Assume 1 Mile AGL Max Alt

- Lucerne Valley at 3000 ft MSL, Claremont 1200 ft
- $P_{\text{ground}} = 90$ kPa
- $P_{\text{apogee}} = 74$ kPa
- Span $= \Delta P = 16$ kPa
- Need to allow for Barometric Pressure Changes
  $+7\%$ to $-13\%$
- $P_{\text{max}} = \text{MAX}(104 \text{ kPa}, 97 \text{ kPa})$
- $P_{\text{min}} = 64$ kPa

MPXA6115AC7U

Operating Characteristics

From Freescale Data Sheet
Nominal Values

- $V_{P_{\min}} = 0.200 \text{ V} + (64 \text{ kPa} - 15 \text{ kPa}) \times 0.045 \text{ V/kPa} = 2.41 \text{ V}$
- $V_{P_{\max}} = 0.200 + (104 \text{ kPa} - 15 \text{ kPa}) \times 0.045 \text{ V/kPa} = 4.21 \text{ V}$
- Accuracy (Uncalibrated) $\pm 1.5\%$ $V_{FS} = \pm 1.5\% \times 4.7 \text{ V}$
  $= \pm 0.071 \text{ V} = \pm 1.57 \text{ kPa} = \pm 157 \text{ m}$
- $t_{R10\%-90\%} = 1.0 \text{ ms}, \tau = t_{R10\%-90\%}/\ln(9) = 0.46 \text{ ms}$

Output Impedance

- Can drive circuit with 0.5 mA at 4.7 V
- Impedance of driven circuit $= V/I = 4.7 \text{ V} / 0.0005 \text{ A} = 9400 \Omega$
- Actual output impedance determined empirically. How?

Choices on Conditioning

- Data Logger
  - 0 V to 3.3 V
  - Input Impedance ~2200 Ω
  - 16 bit, 1 LSB = 3.3 V/2^16 = 50 µV
1. Change gain so $V_{\max} = 3.3 \text{ V}$
  - 1 LSB = 50 µV = 0.16 m = 6 in
2. Change gain and offset so $V_{\min} = 0 \text{ V}$ & $V_{\max} = 3.3 \text{ V}$
  - 1 LSB = 50 µV = 0.06 m = 2.4 in
Signal Conditioning

- Does it need a buffer amp? How would you know?
- How do you change the gain?
- How do you change the gain and offset?
- What about aliasing?

Single-Sided Circuits

(Will visit again under Flight Hardware)

- Data logger expects 0 V to 3.3 V signals
- Classical op-amp circuit power ±15 V
- Low-voltage op-amp circuit power
  - ±1.4 V to ±3 V
  - 0-to-2.8 V to 0-to-6 V
- Signal offset
- Reference offset
- Virtual ground

Inverting Amps

\[ V_{out} = -\left( \frac{R_f}{R_i} \right) V_{in} \]

\[ V_{out} = -\left( \frac{R_f}{R_i} \right) V_{in} + 2.5 \left( 1 + \frac{R_f}{R_i} \right) \]
Non-Inverting Amps

\[ V_{\text{out}} = \left(1 + \frac{R_f}{R_{\text{in}}} \right) V_{\text{in}} \]

\[ V_{\text{out}} = \left(1 + \frac{R_f}{R_{\text{in}}} \right) V_{\text{in}} - 2.5 \left( \frac{R_f}{R_{\text{in}}} \right) \]

Can You do Single Sided for:

- Differential Amplifier?
- Integrator?
- Transimpedance Amplifier?
- Sallen-Key Filter?
- Bipolar sensor like piezoelectric vibration?

Example – Gas Sensor

- MQ-2 CH₄ Gas Sensor (Digikey, Parallax, or Pololu)
Other Specs

### Sensitivity

#### Specifications

<table>
<thead>
<tr>
<th>Condition</th>
<th>Sensitivity</th>
<th>Remarks</th>
</tr>
</thead>
</table>
| 0% RH | 100 ppm | Low concentration
| 50% RH | 50 ppm | Medium concentration
| 100% RH | 10 ppm | High concentration

#### Power Calculations

- 5 V @ 800 mW = 160 mA.
- 5 V @ 33 Ω = 150 mA.
- Standard 9 V battery is ~250 mAh
  - Would last about 1 ½ hours
  - Separate battery for sensor and system.
Signal Conditioning

- Must get air to sensor.
- Resistance changes with gas concentration.
- Designed to work in voltage divider.
- Need R in range of approx. 3 kΩ to 30 kΩ.
- Need buffer amp.
- What is time constant?
  for more info

Example – Particle Sensor

Driving & Reading Circuits
Output & Caution

![Fig. 3 Output Voltage vs. Dust Density](image1)

10 Vibration influence: The sensor may change its value under mechanical oscillation. Before usage, please make sure that the device works normally in the application.

Driving Circuit

![ICM7555](image2)

The three samples are connected as shown in Figure 29. In this circuit, the frequency is

\[ f = \frac{1}{4 \cdot R_x \cdot C_c} \]

The duty cycle is controlled by the values of \( R_x \) and \( C_c \) by the equation

\[ D = \frac{R_x}{R_x + R_c} \]

D must be ≥ 0.5


Reading Circuit

- Pulse Width 0.32 ms
- Minimum 1 point
- Best 10 points
- Sample rate = 10/0.32 ms = 31.25 kSPS
Could You Do Better?

- IRED and Driver
- Photodiode & Reading Circuit
- Mechanical & Optical Chamber
- Start at [http://en.wikipedia.org/wiki/Particle_counter](http://en.wikipedia.org/wiki/Particle_counter) for more information

Example – Humidity Sensor

  - Digital, I²C – 18 s response time
  - Capacitive – 15 s, 5 s response time
  - Linear Voltage – 5 s response time

Digital, I²C

- Need microcontroller, e.g., Arduino Pro Mini 328 - 3.3V/8MHz <Sparkfun>
- Power separately from data logger
- Must synchronize
- Must program
Capacitive

- How do you measure capacitance?
  - Put in a timer circuit
  - Put in an integrator
  - Put in a voltage divider

In a Timer Circuit

\[ f = \frac{1}{RC} \quad \text{(EQ. 1)} \]

HS1101LF (Capacitive)

**ELECTRICAL CHARACTERISTICS OF HUMIDITY SENSOR**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humidity Measuring Range RH</td>
<td></td>
<td></td>
<td></td>
<td>±1%RH</td>
</tr>
<tr>
<td>Supply Voltage Vs</td>
<td>10 V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nominal capacitance @55%RH</td>
<td>177 pF</td>
<td>180 pF</td>
<td>183 pF</td>
<td>pF</td>
</tr>
<tr>
<td>Temperature coefficient Tcc</td>
<td>-0.01 pF/°C</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Sensitivity from 33% to 75%RH</td>
<td>0.31 pF/%RH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leakage Current (Vcc=5V) I</td>
<td>1 nA</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recovery time after 150 hours of condensation tR</td>
<td>10 s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humidity Hysteresis</td>
<td>±1%RH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long term stability T</td>
<td>±0.5%RH/yr</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Constant (at 63% of signal, still air) 33%RH to 80%RH tA</td>
<td>3 s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deviation to typical response curve (10% RH to 90%RH)</td>
<td>±2%RH</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**HS1101LF – Relative Humidity Sensor**

**ELECTRICAL CHARACTERISTICS OF HUMIDITY SENSOR**

(Ta=25° C, measurement frequency @10kHz / 1V unless otherwise noted)

**POLYNOMIAL RESPONSE OF HS1101LF**

\[ C(pF) = C@55\% \times (3.903 \times 10^{-8} \times RH^3 - 8.294 \times 10^{-6} \times RH^2 + 2.188 \times 10^{-3} \times RH + 0.898) \]

**TYPICAL RESPONSE LOOK-UP TABLE (POLYNOMIAL REFERENCE CURVE) @ 10KHZ / 1V**

<table>
<thead>
<tr>
<th>RH (%)</th>
<th>Cp (pF)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>161.6</td>
</tr>
<tr>
<td>5</td>
<td>163.6</td>
</tr>
<tr>
<td>10</td>
<td>165.4</td>
</tr>
<tr>
<td>15</td>
<td>167.2</td>
</tr>
<tr>
<td>20</td>
<td>169.0</td>
</tr>
<tr>
<td>25</td>
<td>170.7</td>
</tr>
<tr>
<td>30</td>
<td>172.3</td>
</tr>
<tr>
<td>35</td>
<td>173.9</td>
</tr>
<tr>
<td>40</td>
<td>175.5</td>
</tr>
<tr>
<td>45</td>
<td>177.0</td>
</tr>
<tr>
<td>50</td>
<td>178.5</td>
</tr>
<tr>
<td>55</td>
<td>180.0</td>
</tr>
<tr>
<td>60</td>
<td>181.4</td>
</tr>
<tr>
<td>65</td>
<td>182.9</td>
</tr>
<tr>
<td>70</td>
<td>184.3</td>
</tr>
<tr>
<td>75</td>
<td>185.7</td>
</tr>
<tr>
<td>80</td>
<td>187.2</td>
</tr>
<tr>
<td>85</td>
<td>188.6</td>
</tr>
<tr>
<td>90</td>
<td>190.1</td>
</tr>
<tr>
<td>95</td>
<td>191.6</td>
</tr>
<tr>
<td>100</td>
<td>193.1</td>
</tr>
</tbody>
</table>

**REVERSE POLYNOMIAL RESPONSE OF HS1101LF**

\[ RH(\%) = -3.4656 \times 10^{+3}\times X^3 + 1.0732 \times 10^{+4}\times X^2 - 1.0457 \times 10^{+4}\times X + 3.2459 \times 10^{+3}\]

With \( X = \frac{C\text{read}}{C@55\%RH} \)

**MEASUREMENT FREQUENCY INFLUENCE**

In this data sheet, all capacitance measurements are done at 10 kHz / 1V. However, the sensor can operate without restriction from 5 kHz to 300 kHz.

**Characteristics**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Humidity Measuring Range RH</td>
<td>1</td>
<td>99% RH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Supply Voltage Vs</td>
<td>10 V</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nominal capacitance @55%RH</td>
<td>177</td>
<td>pF</td>
<td>180</td>
<td>pF</td>
</tr>
<tr>
<td>Temperature coefficient Tcc</td>
<td>-0.01</td>
<td>pF/°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average Sensitivity from 33% to 75%RH</td>
<td>∆C/%RH</td>
<td>0.31</td>
<td>pF/%RH</td>
<td></td>
</tr>
<tr>
<td>Leakage Current (Vcc=5V)</td>
<td>I</td>
<td>1 nA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recovery time after 150 hours of condensation tr</td>
<td></td>
<td>1 0 s</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Humidity Hysteresis</td>
<td></td>
<td>+/−1% RH</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long term stability T</td>
<td></td>
<td>+/−0.5%RH/yr</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Constant (at 63% of signal, still air) 33%RH to 80%RH ta</td>
<td>3 5 s</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Deviation to typical response curve (10% RH to 90%RH)</td>
<td></td>
<td>+/−2%RH</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**Timer Calc’s**

<table>
<thead>
<tr>
<th>f</th>
<th>5.291 kHz</th>
<th>f@VMin</th>
<th>5878 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>fn</td>
<td>5.291 kHz</td>
<td>f@VMax</td>
<td>4939 Hz</td>
</tr>
<tr>
<td>Cnom</td>
<td>180 pF</td>
<td>55%RH</td>
<td>-9.8 Hz/%RH</td>
</tr>
<tr>
<td>R</td>
<td>1.8E-10 F</td>
<td>Mite Frame</td>
<td>0.1044 s</td>
</tr>
<tr>
<td></td>
<td>750 kΩ</td>
<td>Mite SR</td>
<td>11755 SPS</td>
</tr>
<tr>
<td></td>
<td>750 kΩ</td>
<td>SR</td>
<td>58777 SPS</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>58.7 BPS</td>
</tr>
</tbody>
</table>

The sample rate will need to be twice the frequency and preferably 10X. The frame size needs to be the reciprocal of the frequency resolution.

---

**Integrator**

\[ V_{out}(t_1) = V_{out}(t_0) - \frac{1}{RC_1} \int_{t_0}^{t_1} V_{in}(t) \, dt \]
Issues

- Easiest input is constant voltage
  - Output is then a ramp
  - Calculate $C$ from ramp slope or time to $V_{set}$
  - Ramp up or down? Single-sided supply?
- How control reset switch?
  - Solid state switch
  - Signal generator
  - Comparator
- Are you just making an oscillator?

Voltage Divider

- Need sinusoidal input

\[
\begin{align*}
\frac{V_{out}}{V_{in}} &= \frac{1}{1 + jRC\omega} \\
\frac{V_{out}}{V_{in}} &= \frac{1}{j\omega C_1} + \frac{1}{j\omega C_2} = \frac{1}{1 + C_2/C_1} \\
\end{align*}
\]

Voltage Divider Performance
How Do You Generate a Sine Wave?

- [http://www.valvewizard.co.uk/signalgenerator.pdf](http://www.valvewizard.co.uk/signalgenerator.pdf)

Linear Voltage

Honeywell

HIH-5030/5031 Series
Low Voltage Humidity Sensors
The challenges are how and where to connect it, how and where to mount it, and how to get airflow over it.
Where to look for sensors

- Digikey: http://www.digikey.com
- Mouser: http://www.mouser.com
- Arrow: http://www.arrow.com
- Sparkfun: https://www.sparkfun.com
- Pololu: https://www.pololu.com
- Parallax: http://www.parallax.com
- SGX Sensortech: http://sgx.cdistore.com