Sensors and Transducers

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E80- Spring 2011
Agenda

- Rocket sensors
- Common sensors/transducers
  - Gas Sensor
  - Humidity Sensor
  - Pressure Sensor
  - Vibration Sensor
- Rocket hardware (next week)
Why sensors on rocket?

You get to choose sensors for your rocket!

http://www.eng.hmc.edu/NewE80/FlightVideos.html

http://www.eng.hmc.edu/NewE80/Muddl11_10_06_800Kbps.mov
Desired Data from Rockets

- Rocket inside/outside environment
  - Temperature
  - Humidity
  - Pressure
- Motion of the rocket
  - Altitude / Apogee time
  - Rate Gyros and Acceleration (translational, rotational)
- Vibration of the rocket
- Vibration of the stand (last year E80)
Common Transducers

- Temperature Sensor (Done)
- Rate Gyro / Accelerometer sensors (Done)
- Gas Sensor
- Humidity Sensor
- Pressure Sensor / Altimeter
- Vibration Sensor
Gas/Chemical Sensors

- Solid State electrolyte
- Metal Oxide
- Catalytic-based sensors
- Electro-Chemical (chemiresistive)

http://www.futurlec.com/Gas_Sensors.shtml (output voltage)

- Sensitivity (ppm, ppb)
- Operation temperature range
- Power consumption
- Size
**Example – CO₂ Gas Sensors**

Cathodic reaction: \[2\text{Li} + + \text{CO}_2 + \frac{1}{2}\text{O}_2 + 2e^- = \text{Li}_2\text{CO}_3\]

Anodic reaction: \[2\text{Na}^+ + \frac{1}{2}\text{O}_2 + 2e^- = \text{Na}_2\text{O}\]

Overall chemical reaction: \[\text{Li}_2\text{CO}_3 + 2\text{Na} + = \text{Na}_2\text{O} + 2\text{Li} + + \text{CO}_2\]

**Nernst’s equation:**

\[
\text{EMF} = \text{Ec} - \frac{(R \times T)}{(2F \ln(P(\text{CO}_2)))}
\]

- \(P(\text{CO}_2)\) — CO₂ partial Pressure
- \(\text{Ec}\) — Constant cell potential under standard conditions
- \(R\) — Gas Constant volume, 8.31 volt-coulomb/(mol-K)
- \(T\) — Absolute Temperature (K)
- \(F\) — Faraday constant, 96500 coulombs/mol

[http://chemistry.about.com/od/electrochemistry/a/nernstequation.htm](http://chemistry.about.com/od/electrochemistry/a/nernstequation.htm)
What is Partial Pressure?
Convert Partial Pressure to ppm or to mass per volume

Ideal gas law:

\[ PV = nRT \]

\( n \): number of moles

Dalton's Law of Partial Pressure:

Partial pressure ratio = mole ratio

ppm \rightarrow \text{decimal fraction} \rightarrow \text{multiply by total pressure to get CO2 partial pressure.}

\[ PV = nRT = (m/M) \cdot RT \]

Mass per volume \( \frac{m}{V} = \frac{P \cdot M}{R \cdot T} \)

\( M \): Molar Mass
What is Partial Pressure?
Convert to ppm or to mass per volume

An example, 1% CO₂, 101.325 kPa atmospheric pressure, 25 °C (298.15 K)

ppm = ?

Partial pressure CO₂ = ?

Mass per volume = P*M/(R*T) = ?
What is Partial Pressure?
Convert to ppm or to mass per volume

An example, 1% CO2, 101.325 kPa atmospheric pressure, 25 °C (298.15 K)

\[ \text{ppm} = \left( \frac{1}{100} \right) \times 10^6 = 10^4 \]

Partial pressure CO2 = 0.01 * 101.325 kPa = 1.01325 kPa = 1013.25 Pa

The gas constant \( R \) is 8.314472 m³ · Pa/(K · mol),
\( M = 44 \) g/mol (for CO2)

Mass per volume = \( \frac{P \times M}{R \times T} \) = 1013.25 Pa * 44 g/mol / (298.15 K * 8.314472 m³ · Pa / (K · mol)) = 18 g/m³
Example Sensor MG811

EMF = Ec - (R x T) / (2F) ln (P(CO2))

http://www.futurlec.com/CO2_Sensor.shtml
Let’s see how other people did it!

Gas Sensor Experiment

Humidity Sensor

What is humidity (relative humidity)?

$$\phi = \frac{e_w}{e^*_w} \times 100\%$$

$e_w$: partial pressure of water vapor

$e^*_w$: saturated vapor pressure of water at a prescribed $T$ maximum water vapor that the air can hold without condensing

$e^*_w = f(T, P)$ empirically correlation

http://en.wikipedia.org/wiki/Relative_humidity
http://en.wikipedia.org/wiki/Hygrometer
Humidity Sensor

Relative humidity measurement (%RH)
- Capacitor based*
- Chemically resistive
- Calibrated vs. voltage output*

Examples:


http://www.sparkfun.com/datasheets/Sensors/Temperature/HH10D.pdf (voltage calibrated)
Humidity Sensor

Capacitive RH sensor:
- Thin layer of water absorbent
- Polymer or inorganic material
- Water’s dielectric constant
- More water → More capacitance?
- How to measure capacitance?
Pressure Sensor

- **What is Pressure?**
  - e.g. 101.325kPa atmospheric pressure at sea level
  - e.g. tire pressure gauge 0 PSI
  - e.g. pressure drop for flow measurement

- **What kind of pressure measurement?**
  - Absolute Pressure Sensor
  - Gauge Pressure Sensor
  - Differential Pressure Sensor
Pressure Sensor Principles

- Force Based–
  - Piezo-resistive Strain Gauge
  - Potentiometric
  - Piezoelectric
  - Capacitive
  - Electromagnetic
  - Optical (gratings)

- Other kinds–
  - Resonance (MEMS)
  - Thermal
  - Ionization (charged gas particles)

http://en.wikipedia.org/wiki/Piezoresistive
Sensor Example: MPXA6115A

Features:
- 1.5% Maximum Error over 0°C to 85°C
- Ideally suited for Microprocessor or Microcontroller-Based Systems
- Temperature Compensated from -40°C to +125°C
- Durable Epoxy Unibody Element or Thermoplastic (PPS) Surface Mount Package

Characteristics of pressure sensor:

- **Pressure range:** 15-115 kPa
- **Sensitivity:** 45.9mV/kPa
- **Supply voltage:** 5V
- **Output analog voltage:**
  - Offset voltage \( (V_{off}) \): output voltage at minimum rated pressure \( \text{Typical} @ 0.204V \)
  - Full scale output \( (V_{fso}) \): output voltage at maximum rated pressure \( \text{Typical} @ 4.794 V \)
- **Pressure units**
  - Pascal \( (Pa) = \text{N/m}^2 \): standard atmosphere
    \( P_0 = 101325 = 101.325 \text{kPa} \)
  - Psi = \( \text{(Force) pound per square inch} \): 1 Psi = 6.89465 KPa
**Pressure Sensor – Altitude Sensing**

\[ P \cdot V = nRT \quad "\text{ideal gas law}" \]

\[
\rho = \frac{\text{Mass}}{nM} = \frac{M \cdot P}{RT} = \frac{nRT}{P} \\
\text{volume} = \frac{nRT}{P}
\]

\[ \Delta P = -\rho g \cdot \Delta h = -\frac{MP}{RT} g \cdot \Delta h \]

\[ P(h) = P_0 \exp\left(-\frac{Mg}{RT} h\right) \]

**Method #1:**

**Method #2:**

- **M:** Molar Mass
- **n:** Number of moles
- **T:** Temperature
- **P:** Pressure
- **h:** Altitude

http://en.wikipedia.org/wiki/Gas_constant
Pressure Sensor – Altitude Sensing

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

where

- \( h \) = altitude (above sea level) (in meters)
- \( P_0 \) = standard atmosphere pressure = 101.325kPa
- \( T_0 \) = 288.15K (+15°C)
- \( dT/\text{dh} = -0.0065 \text{ K/m}: \text{thermal gradient or standard temperature lapse rate} \)
- \( R \) = gas constant (8.31432 N*m/mol*K)
- \( g \) = (9.80665 m/s²)
- \( M \) = molar mass of earth’s air (0.0289644 kg/mol)
Pressure Sensor – Altitude Sensing

Plug in all the constants

Method #3:

\[ h = 4.43 \times 10^4 \times \left( 1 - \left( \frac{101.325 \text{kPa}}{P} \right)^{-0.1902} \right) \]

- \( h \) is measured **in meters**.
- Equation calibrated up to 36,090 feet (11,000m).
- Different values of dT/dh for different layers of the atmosphere
Examples

Suppose, $P = 85$ kPa (from Pressure sensor)

**Method 1:**

$$\Delta h = - \frac{\Delta P}{\rho g} = - \frac{(85 - 101) \text{ kPa}}{(1.2 \text{ kg/m}^3 \times 9.8 \text{ m/s}^2)} = 1.36 \text{ km}$$

**Method 2:**

$$h = - \frac{RT}{M g} \ln\left(\frac{P}{P_0}\right) = - 8440 \ln\left(\frac{85 \text{ kPa}}{101 \text{ kPa}}\right) = 1.46 \text{ km}$$

**Method 3:**

$$h = 4.43 \times 10^4 \times \left(1 - \left(\frac{101.325 \text{ kPa}}{85 \text{ kPa}}\right)^{-0.1902}\right) = 1.43 \text{ km}$$
**Vibration/Impact Sensor**

Mechanical Force/ Deformation → resistance/ voltage output

- Strain gauges
- Piezo electric films


http://en.wikipedia.org/wiki/Strain_%28physics%29


Vibration Sensor

LDT0: Voltage Output vs Tip deflection
(Figure 2)

Vibration Sensor– accelerometers

- [Link](http://www.sparkfun.com/tutorials/167)
- [Link](http://www.sparkfun.com/datasheets/Components/General/MMA7361L.pdf)

- Full-Scale Range
- Number of Axes
- Interface (Analog, Digital, Pulse Output)
- Bandwidth (50–100 Hz)
- Power Consumption (supply voltage)
Now what?

(1) Electronics should fit within rocket
(2) Easy to transmit/store/retrieve data

(3) Telemetry
(4) Video system

http://www.sparkfun.com/products/9228
http://www.sparkfun.com/products/10216

http://www.youtube.com/watch?v=f0Qr1g70aOg&feature=related
http://www.youtube.com/watch?v=2Ax64jfeVCc