Sensors and Transducers

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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)

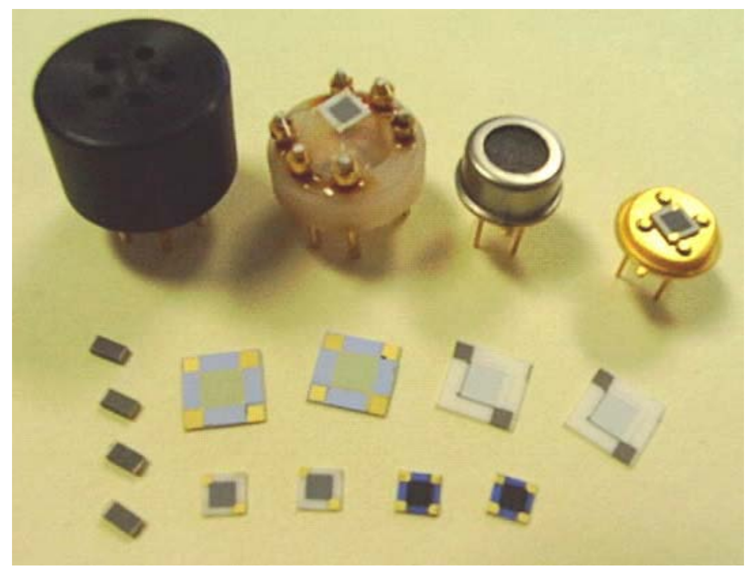
Common Transducers

- 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)
http://www.ipm.fraunhofer.de/fhg/Images/metallsensor-eng_tcm180-16346.pdf (output resistance)
http://www.synkera.com/chemical-sensing-analysis/solid-state-gas-sensors.html (output resistance)
http://www.boulder.nist.gov/div853/Publication%20files/NIST_BCC_Nano_Hooker_2002.pdf



- Sensitivity (ppm, ppb)
- Operation temperature range
- Power consumption
- Size

Example– CO_2 Gas Sensors

Cathodic reaction: 2Li + + CO2 + 1/2O2 + 2e – = Li2CO3
Anodic reaction: 2Na+ + 1/2O2 + 2e– = Na2O
Overall chemical reaction: Li2CO3 + 2Na + = Na2O + 2Li + + CO2

Nernst's equation:

EMF = Ec – (R x T) / (2F) ln (P(CO2))

P(CO2)—CO2--- partial Pressure
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://answers.yahoo.com/question/index?qid=20080928213959AAgI0u6

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→ decimal fraction→ multiply by total pressure to get CO_2 partial pressure.

$PV=nRT=(m/M)*RT$ → Mass per volume $m/V = P*M/(R*T)$

M: Molar Mass

What is Partial Pressure?

Convert to ppm or to mass per volume

An example, 1% CO_2, 101.325 kPa atmospheric pressure, 25 °C (298.15 K)

ppm=?

Partial pressure CO_2 =?

Mass per volume = P*M/(R*T)=?

What is Partial Pressure?

Convert to ppm or to mass per volume

An example, 1% CO_2, 101.325 kPa atmospheric pressure, 25 ℃ (298.15 K)

ppm=(1/100)*10^6=10^4

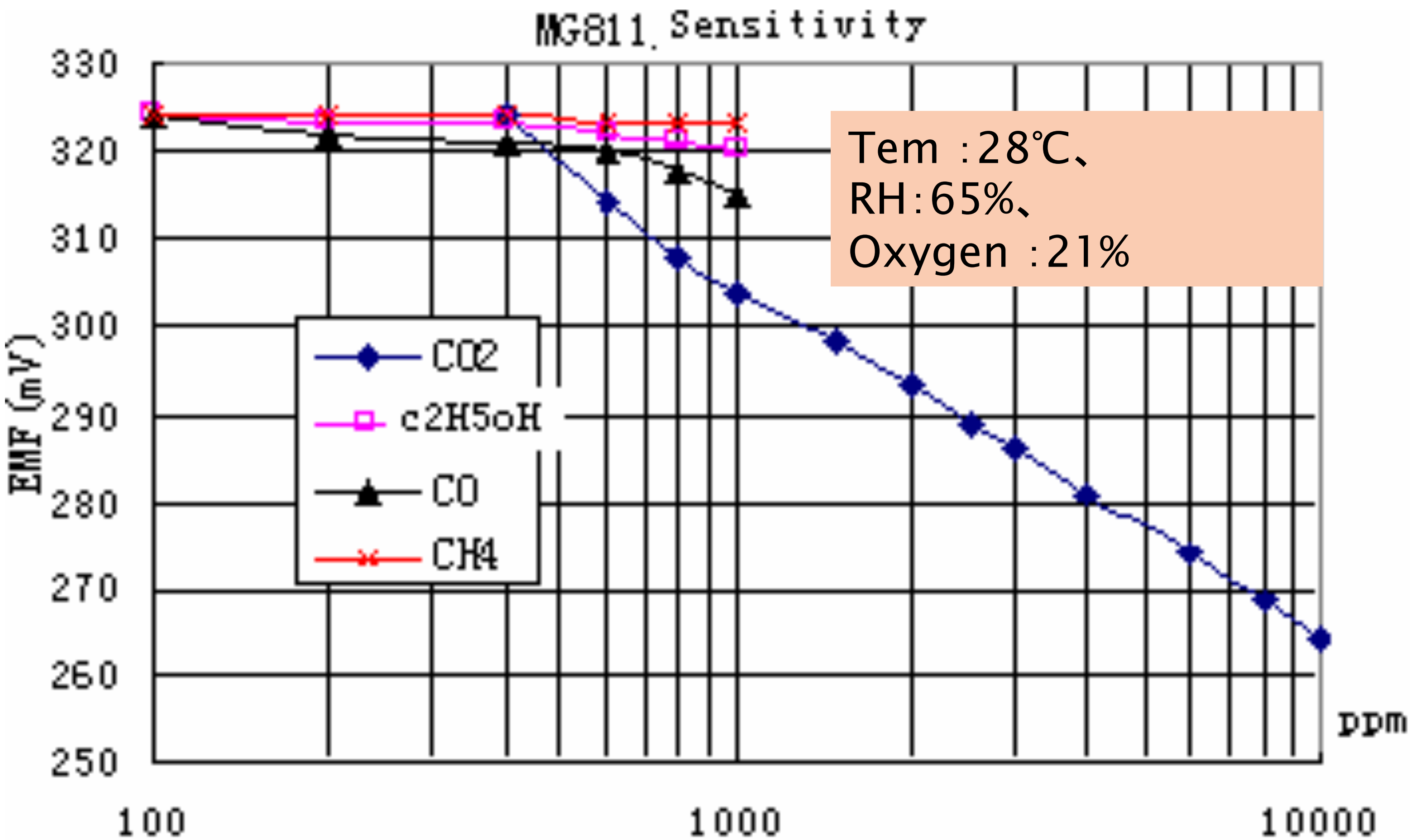
Partial pressure CO_2 = 0.01*101.325 kPa = 1.01325 kPa =1013.25 Pa

The gas constant R is 8.314472 $m^3 \cdot Pa/(K \cdot mol)$, M= 44 g/mol (for CO_2)

Mass per volume =P*M/(R*T) =1013.25 Pa * 44 g/mol / (298.15 K * 8.314472 $m^3 \cdot Pa/(K \cdot mol)$) = 18 g/m^3

Example Sensor MG811

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



http://www.futurlec.com/CO2_Sensor.shtml http://www.synkera.com/chemical-sensing-analysis/solid-state-gas-sensors.html

Let's see how other people did it!

Gas Sensor Experiment

http://spacegrant.colorado.edu/COSGC_Projects/RockSat-C%202011/2010Pres/CDR/CDR_Puerto%20Rico_2010.pdf

Humidity Sensor

What is humidity (relative humidity)?

$$\phi = \frac{e_{\mathrm{w}}}{e^{*}_{\mathrm{w}}} \times 100\%$$

e_{W} : partial pressure of water vapor

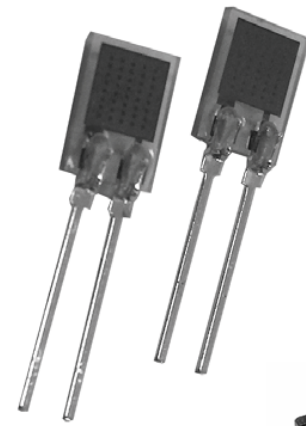
e^{*}_{W} : saturated vapor pressure of water at a prescribed T

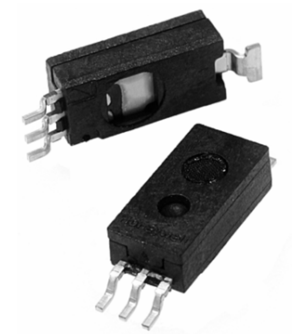
maximum water vapor that the air can hold without condensing

$e^{*}_{\mathrm{W}} = f(T, P)$ 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://media.digikey.com/pdf/Data%20Sheets/Honeywell%20Sensing%20&%20Control%20PDFs/HCH-1000%20Series.pdf

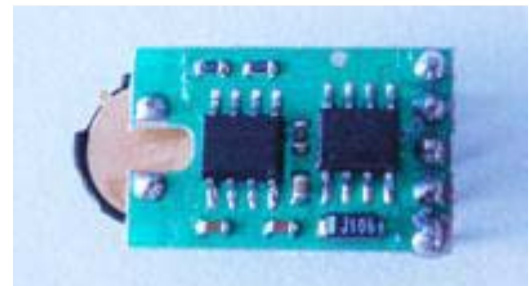
http://www.sparkfun.com/datasheets/Sensors/Weather/SEN-09569-HIH-4030-datasheet.pdf

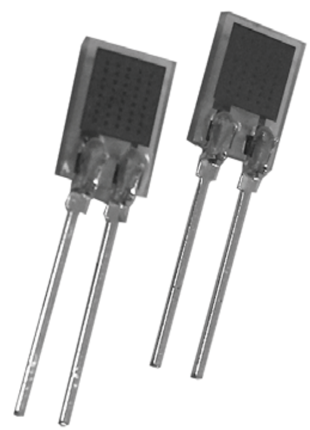
http://www.sparkfun.com/datasheets/Sensors/Temperature/HH10D.pdf (voltage calibrated)

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-
  - Pieozo-resistive Strain Gauge
  - Potentiometric
  - Piezoelectric
  - Capacitive
  - Electromagnetic
  - Optical (gratings)

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

http://en.wikipedia.org/wiki/Piezoresistive
http://www.maxim-ic.com/app-notes/index.mvp/id/871

Sensor Example: MPXA6115A

SMALL OUTLINE PACKAGE

MPXA4115A6U
CASE 482

MPXA4115AC6U
CASE 482A

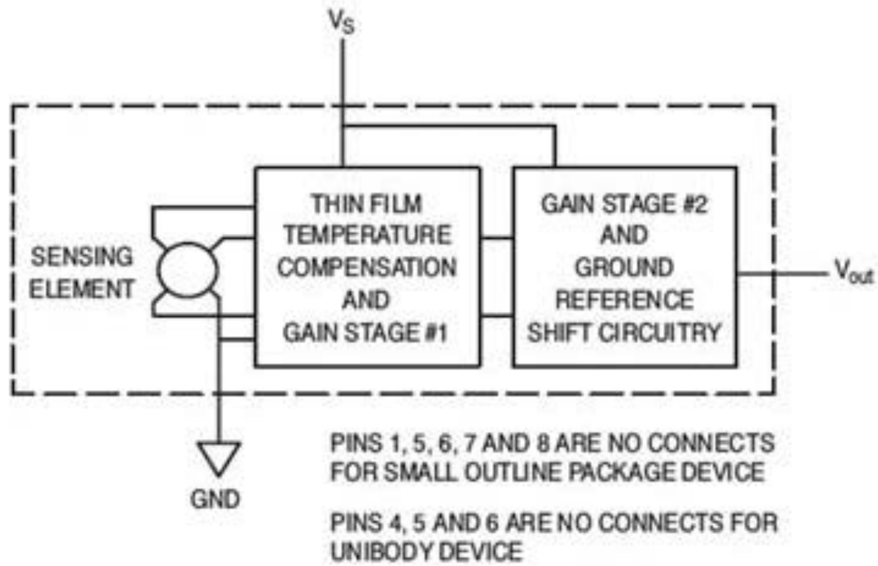


Figure 1. Fully Integrated Pressure Sensor Schematic

Features

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

http://shops.eccn.com/freescale/PDFDoc/MPXH6115A6U.pdf

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 (Typical@ 0.204V)
  - Full scale output (Vfso): output voltage at maximum rated pressure (Typical@ 4.794 V)
- **Pressure units**
  - Pascal (Pa)=N/m^2: standard atmosphere P_0=101325=101.325kPa
  - Psi= (Force) pound per square inch: 1 Psi=6.89465 KPa

Pressure Sensor – Altitude Sensing

$$P \cdot V = nRT \qquad \text{"ideal gas law"}$$

$$\rho = \frac{\text{Mass} = nM}{\text{volume} = \dfrac{nRT}{P}} = \frac{M \cdot P}{R \cdot T}$$

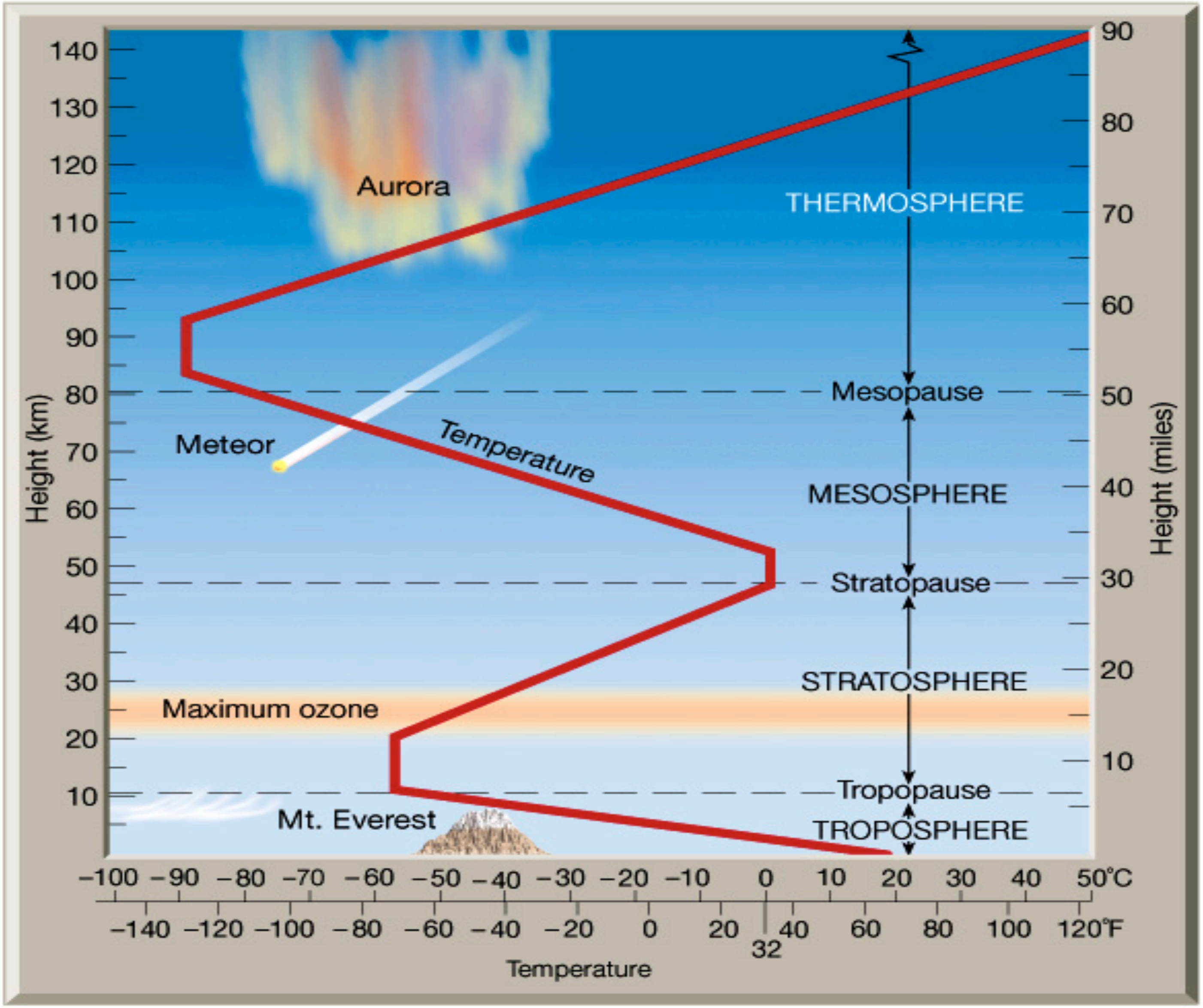
Method #1: $$\Delta P = -\rho g \cdot \Delta h = -\frac{MP}{RT} g \cdot \Delta h$$

Method #2: $$P(h) = P_0 \exp\left(-\frac{Mg}{RT} h\right)$$

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

http://en.wikipedia.org/wiki/Gas_constant

Pressure Sensor – Altitude Sensing



Pressure Sensor – Altitude Sensing

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

where

- h = altitude (above sea level) **(in meters)**
- P_0 = standard atmosphere pressure= 101.325kPa
- T_0 = 288.15K (+15°C)
- dT/dh= - 0.0065 K/m: 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).
- Reference: http://en.wikipedia.org/wiki/Atmospheric_pressure
- Different values of dT/dh for different layers of the atmosphere

Examples

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

Method 1:

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

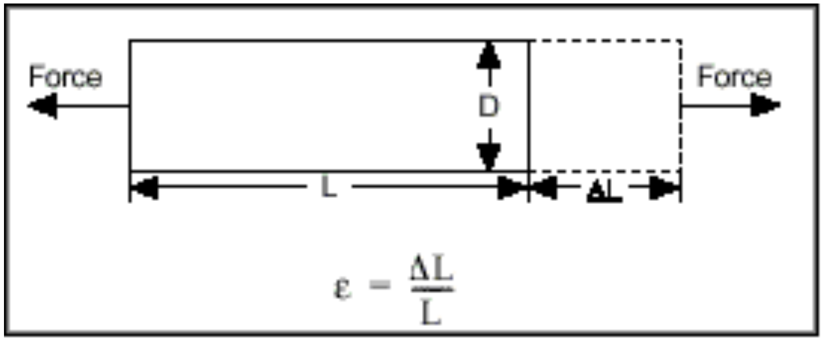
Method 2:

$$h = -\frac{RT}{Mg}\ln(\frac{P}{P_0}) = -8440\ln(\frac{85kPa}{101kPa}) = 1.46km$$

Method 3:

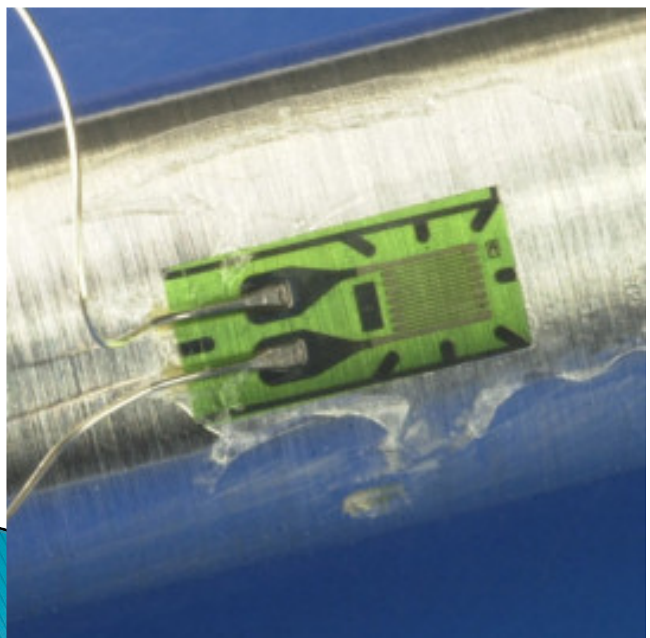
$$h = 4.43\times 10^4 \times \left(1-\left(\frac{101.325kPa}{85kPa}\right)^{-0.1902}\right) = 1.43\,km$$

Vibration/Impact Sensor



Mechanical Force/ Deformation
→ resistance/ voltage output

- Strain gauges
- Piezo electric films



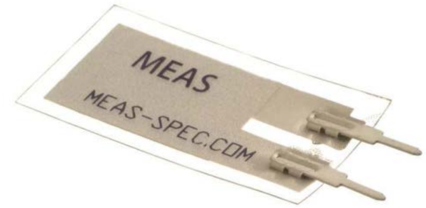
http://www.digikey.com/Scripts/US/DKSUS.dll?Detail&name=MSP1006-ND

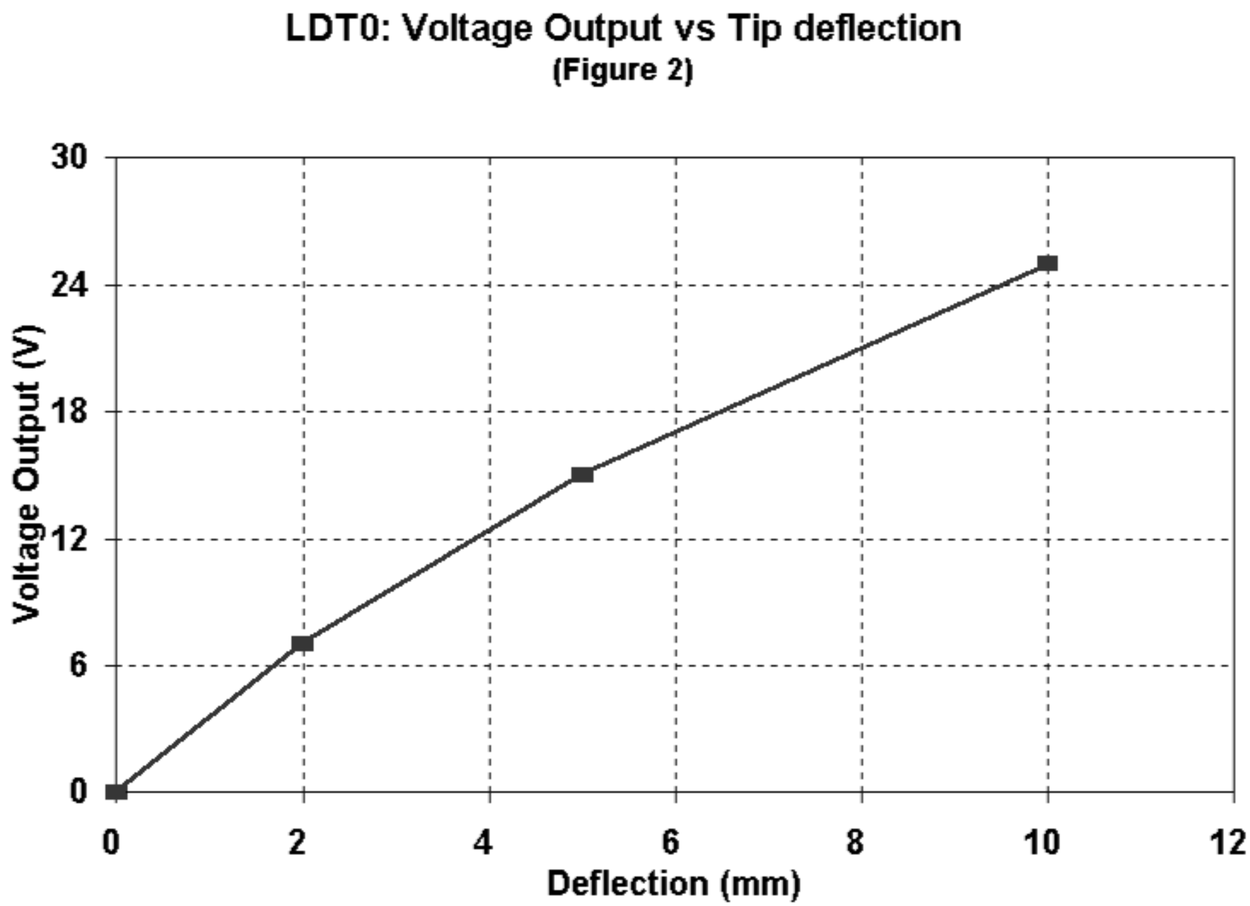
http://en.wikipedia.org/wiki/Strain_%28physics%29

http://www.vishaypg.com/micro-measurements/transducer-class-strain-gages/

http://www.sparkfun.com/datasheets/Sensors/Flex/MSI-techman.pdf

Vibration Sensor





http://www.meas-spec.com/downloads/LDT_Series.pdf

Vibration Sensor– accelerometers

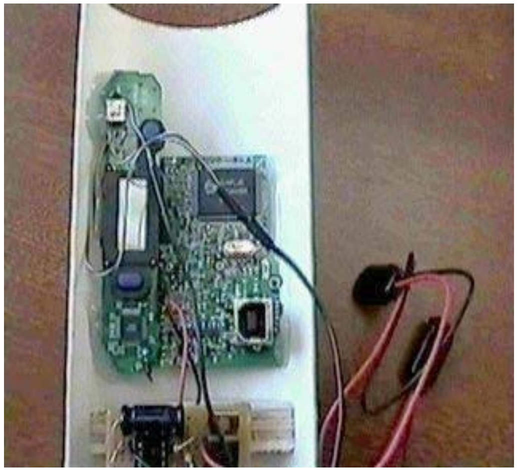
- http://www.sparkfun.com/tutorials/167
- http://www.sparkfun.com/datasheets/Components/General/MMA7361L.p

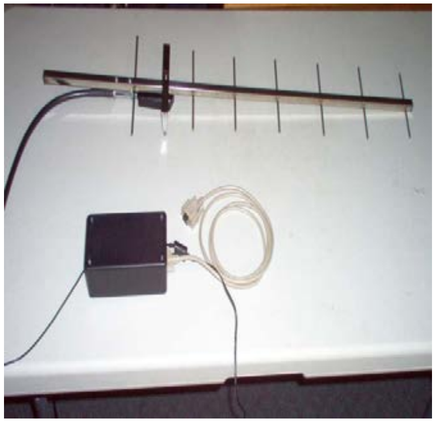
- Full-Scale Range
- Number of Axes
- Interface (Analog, Digital, Pulse Output)
- Bandwidth (50-100 Hz)
- Power Consumption (supply voltage)

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