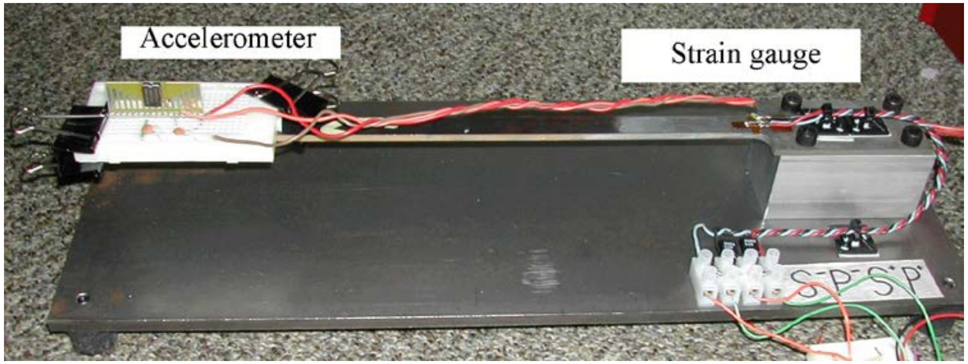


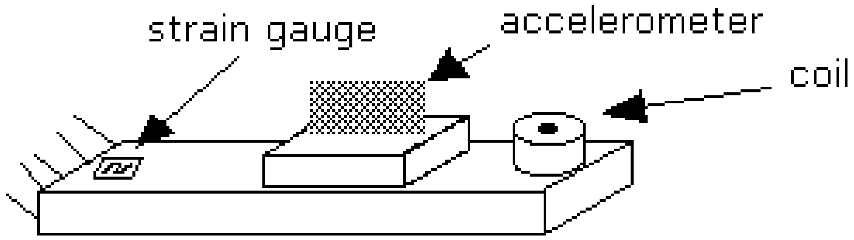
Electronic Instrumentation

Project 2

Velocity Measurement

Cantilever Beam Sensors

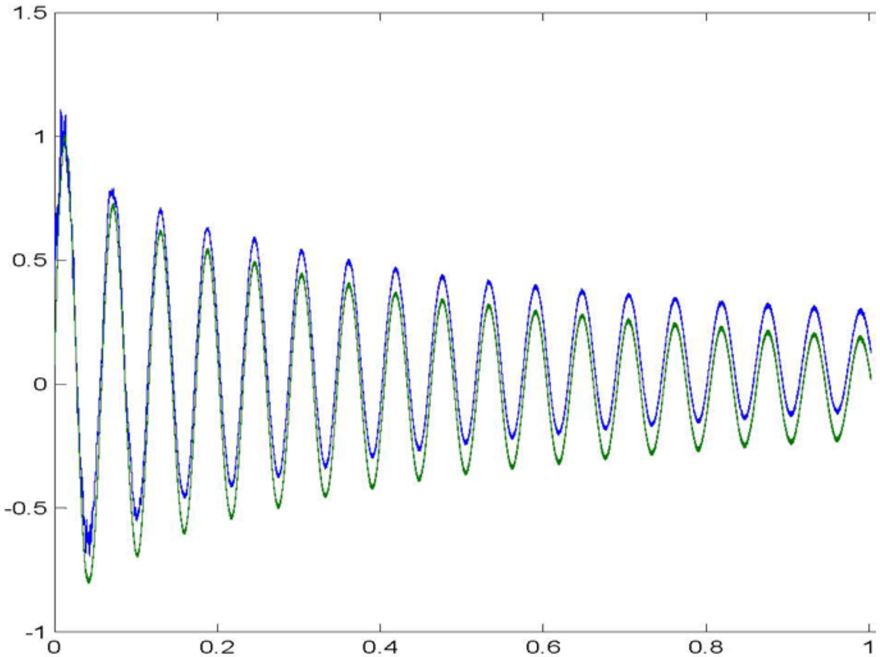
- Position Measurement – obtained from the strain gauge
- Velocity Measurement – previously obtained from the magnetic pickup coil (not available since Fall of 2006)
- Acceleration Measurement – obtained from the Analog Devices accelerometer



Sensor Signals

- The 2 signals
  - Position

$$x = x_o e^{-t/\tau} \cos \omega t$$



  - Acceleration

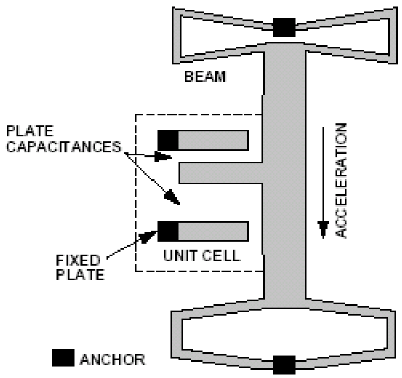
$$a = \frac{d^2 x}{dt^2}$$

Basic Steps for Project

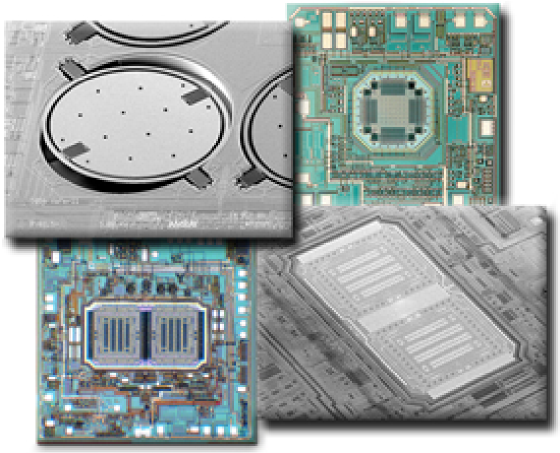
- Mount an accelerometer close to the end of the beam
  - Wire +2.5V, -2.5V, and signal between IOBoard and Circuit (Note that this cannot be done directly. Follow the circuit diagram in the Project write-up and in slide 7 of this presentation.)
  - Record acceleration signal
- Reconnect strain gauge circuit
  - Calibrate the stain gauge
  - Record position signal
- Compare accelerometer and strain gauge signals
- Build an integrator circuit to get velocity from the accelerometer sensor
- Build a differentiator circuit to get velocity from the strain gauge sensor
- Include all calibration and gain constants and compare measurements of velocity

Building the Accelerometer Circuit

The Analog Device Accelerometer

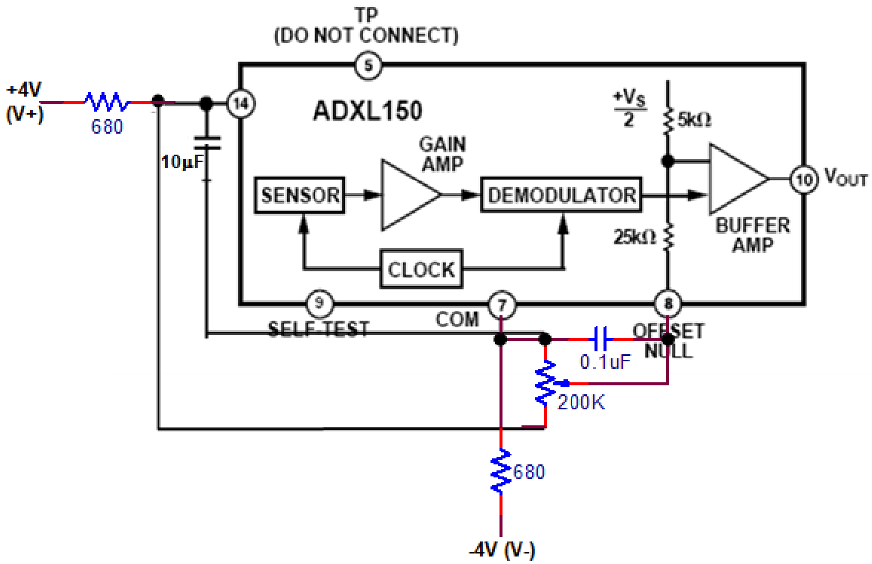


Simplified View of Sensor Under Acceleration



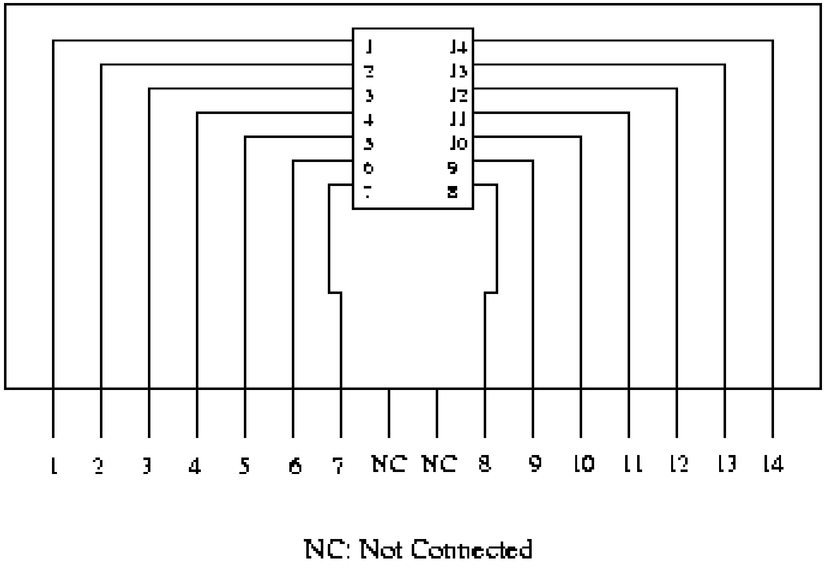
- The AD Accelerometer is an excellent example of a MEMS device in which a large number of very, very small cantilever beams are used to measure acceleration. A simplified view of a beam is shown here.

Accelerometer Circuit



- The Analog Device chip produces a very accurate signal proportional to acceleration
- Voltage between pins 7 and 14 must be about 5V
- Only 3 wires need to be connected, +4V, -4V and the signal v_{out}. Once you have the circuit connected correctly, measure the voltages on pins 7 and 14 to be sure they are -2.5V and +2.5V, respectively

Accelerometer Circuit



- The ADXL150 is surface mounted, so we must use a surfboard to connect it to a protoboard

Caution

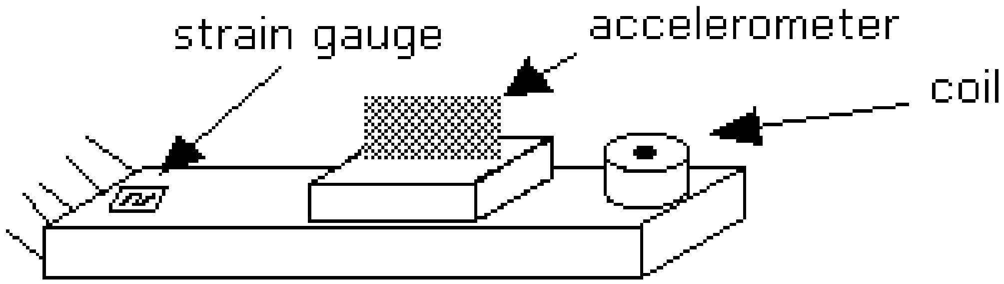
- Please be very careful with the accelerometers. While they can stand quite large g forces, they are electrically fragile. If you apply the wrong voltages to them, they will be ruined. AD is generous with these devices (you can obtain samples too), but we receive a limited number each year.
- Note: this model is obsolete, so you can't get this one. Others are available.

Extra Protoboard

- You will be given a small protoboard on which you will insert your accelerometer circuit.
- Keep your circuit intact until you complete the project.
- We have enough accelerometer surfboards that you can keep it until the end of project 2.

Mounting the Accelerometer

Mount the Accelerometer Near the End of the Beam



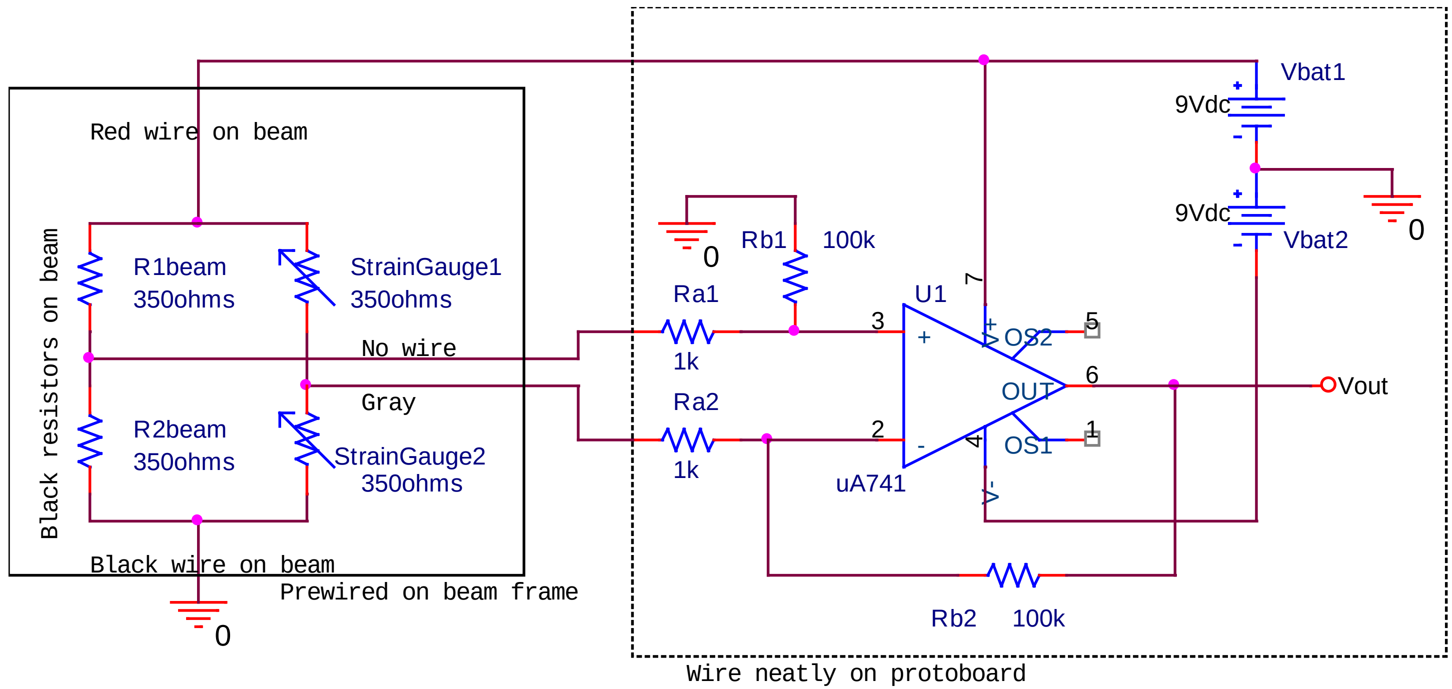
- Place the small protoboard as close to the end as practical
- The axis of the accelerometer needs to be vertical

Accelerometer Signal

- The output from the accelerometer circuit is 38mV per *g*, where *g* is the acceleration of gravity.
- The equation below includes the units in brackets

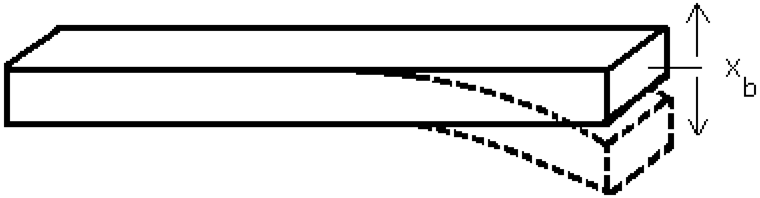
$$a(t)[m/s^2] = \frac{V_a(t)[mV]}{\dfrac{38[mV]}{9.8[m/s^2]}} \rightarrow \quad a(t)[m/s^2] = -\frac{9.8[m/s^2] \cdot V_a(t)[V]}{0.038[V]}$$

Amplified Strain Gauge Circuit



$$V_{out} = \left(\frac{R_b}{R_a} \right) \left(V_{left} - V_{right} \right)$$

Position Measurement Using the Strain Gauge



$$x_b(t) = C_{sg} V_{sg}(t) = {V_{sg}(t)} / {k1}$$

- Set up the amplified strain gauge circuit
- Place a ruler near the end of the beam
- Make several measurements of bridge output voltage and beam position
- Find a simple linear relationship between voltage and beam position (k1) in V/m.

Comparing the accelerometer measurements with the strain gauge measurements

$$x(t) = Ce^{-\alpha t} \sin \omega t$$

$$v = \frac{\partial x}{\partial t} \cong C\omega e^{-\alpha t} \cos \omega t \quad \text{for } \alpha \text{ small compared to } \omega$$

$$a = \frac{\partial v}{\partial t} \cong -C\omega^2 e^{-\alpha t} \sin \omega t = -\omega^2 x(t)$$

- The position, *x*, is calculated from the strain gauge signal.
- The acceleration is calculated from the accelerometer signal.
- The two signals can be compared, approximately, by measuring ω.

Velocity

- The velocity is the desired quantity, in this case.
- One option – integrate the acceleration signal
  - Build a Miller integrator circuit - exp. 4
  - Need a corner frequency below the beam oscillation frequency
  - Avoid saturation of the op-amp – gain isn't too big
  - Good strong signal – gain isn't too small
- Another option – differentiate the strain gauge signal.
  - Build an op-amp differentiator – exp. 4
  - Corner frequency higher than the beam oscillation frequency
  - Avoid saturation but keep the signal strong.

Velocity

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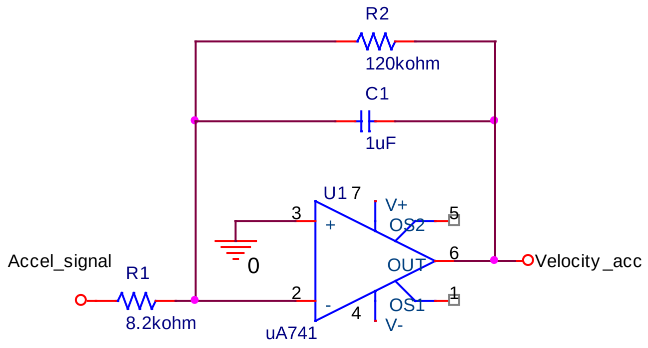

Velocity

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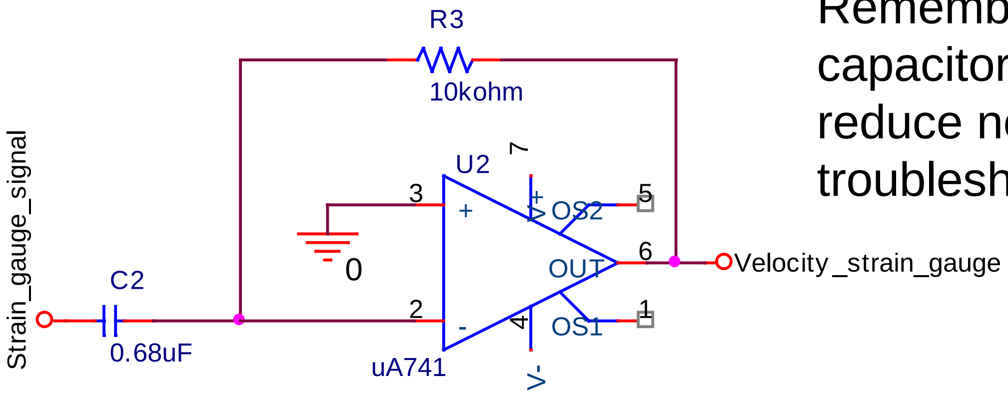


Remember that a feedback capacitor is probably necessary to reduce noise on the signal. See troubleshooting guide.

Velocity

- Be careful to include all gain constants when calculating the velocity.
  - For the accelerometer
    - Constant of sensor (.038V/g) [g = 9.8m/s^2]
    - Constant for the op-amp integrator (-1/RC)
  - For the strain gauge
    - The strain gauge sensitivity constant, k1
    - Constant for the op-amp differentiator (-RC)

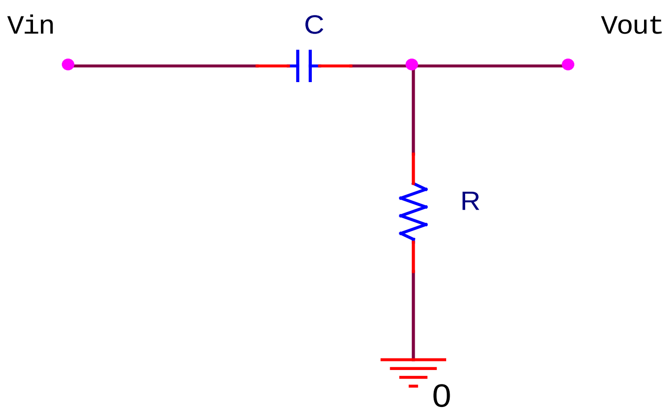
MATLAB

- Save the data to a file
  - Open the file with MATLAB
    - faster
    - Handles 65,000 points better than Excel
  - Basic instructions are in the project write up

Some Questions

- How would you use some of the accelerometer signals in your car to enhance your driving experience?
- If there are so many accelerometers in present day cars, why is acceleration not displayed for the driver? (If you find a car with one, let us know.)
- If you had a portable accelerometer, what would you do with it?

Passive Differentiator

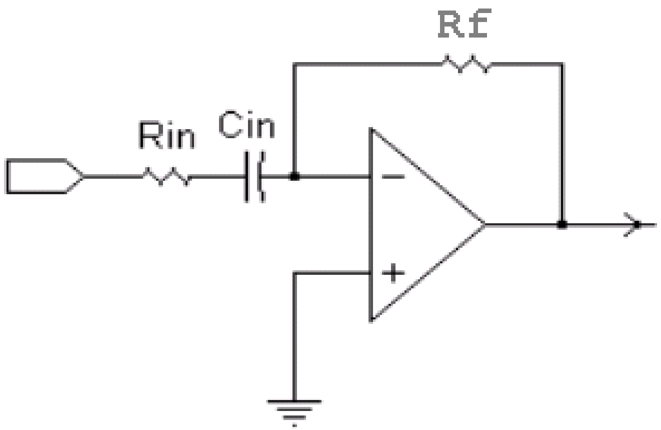


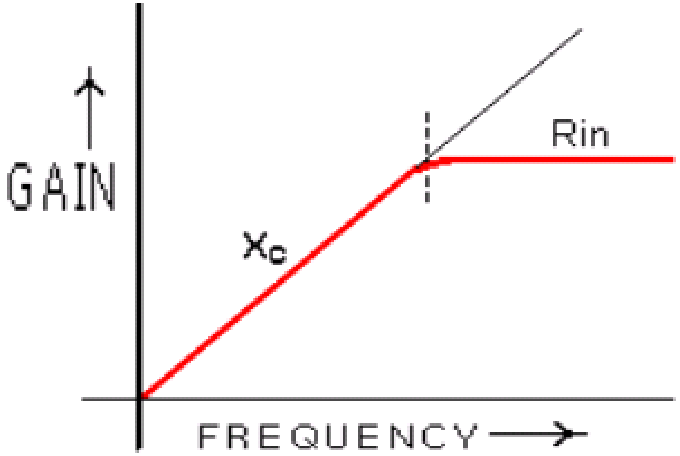
$$H(j\omega) = \frac{j\omega RC}{1 + j\omega RC}$$

$$H_{LO}(j\omega) = j\omega RC$$

$$V_{out} = V_R = RC\frac{dV_C}{dt} \approx RC\frac{dV_{in}}{dt} \quad \textit{at low frequencies}$$

Active Differentiator





$$H(j\omega) = -j\omega R_f C_{in}$$

$$V_{out} = -R_f C_{in} \frac{dV_{in}}{dt}$$

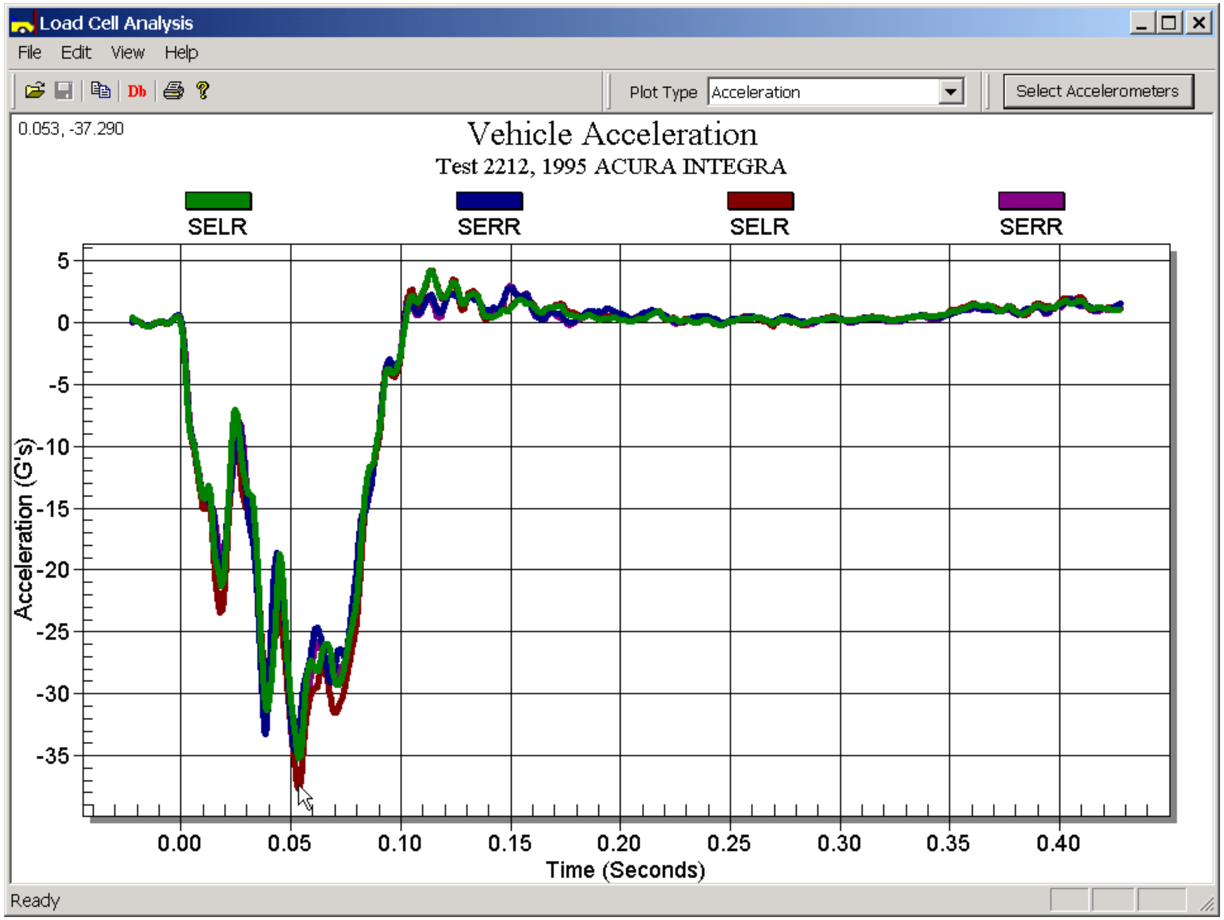
$$f << \frac{1}{2\pi R_{in} C_{in}}$$

Typical Acceleration

- Compare your results with typical acceleration values you can experience.

Elevator (fast service)	0.3 g
Automobile (take off)	0.1-0.5g
Automobile (brake or corner)	0.6-1 g
Automobile (racing)	1-2.5 g
aircraft take off	0.5 g
Earth (free-fall)	1 g
Space Shuttle (take off)	3 g
parachute landing	3.5 g
Plop down in chair	10 g
30 mph car crash w airbag	60 g
football tackle	40 g
seat ejection (jet)	100 g
jumping flea	200 g
high speed car crash	700 g

Crash Test Data



Ballpark Calc:

56.6mph = 25.3m/s

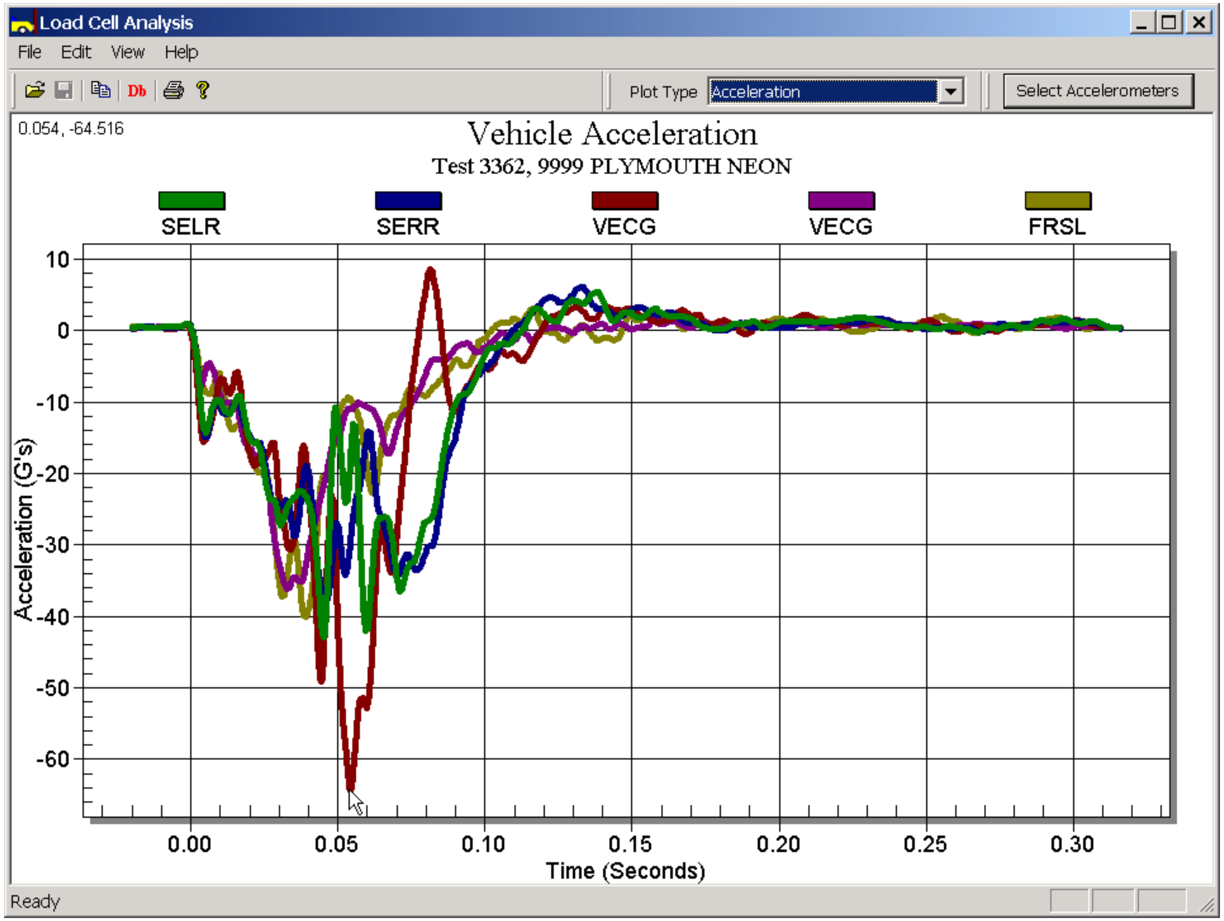
Stopping in 0.1 s

Acceleration is about

$-253\ m/s^2 = -25.8\ g$

- Head on crash at 56.6 mph

Crash Test Data



Ballpark Calc:

112.1mph = 50.1 m/s

Stopping in 0.1 s

Acceleration is about

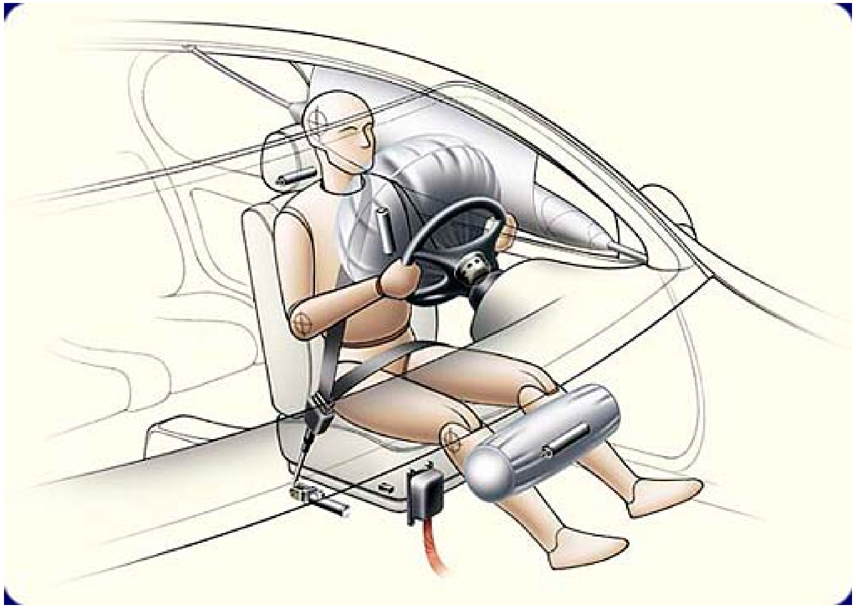
-501 m/s^2 = -51.1 g

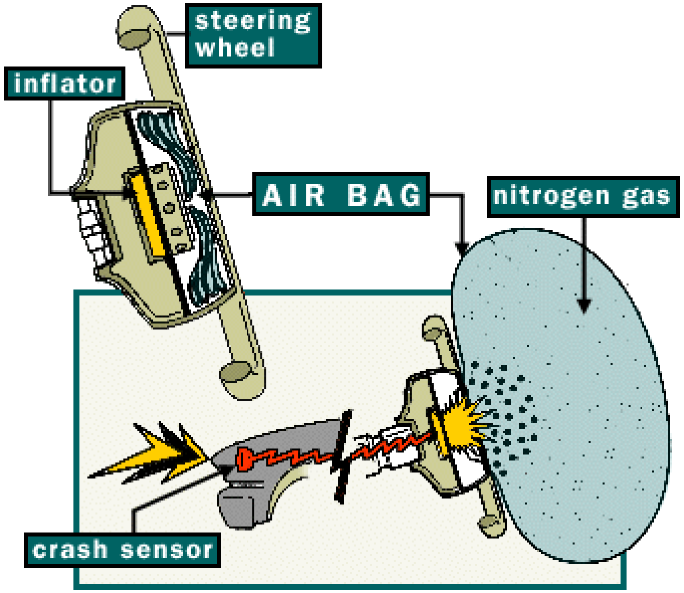
- Head on crash at 112.1 mph

Crash Test Analysis Software

- Software can be downloaded from NHTSA website
- http://www.nhtsa.gov/

Airbags





- Several types of accelerometers are used & at least 2 must sense excessive acceleration to trigger the airbag.