Accelerometers and How they Work

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  - Definition of Acceleration
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  - Terminology
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  - Summary

Acceleration Fundamentals

- **What is Acceleration?**
  - Definition: the time rate of change of velocity
  - A.K.A.: the time rate of change of the time rate of change of distance

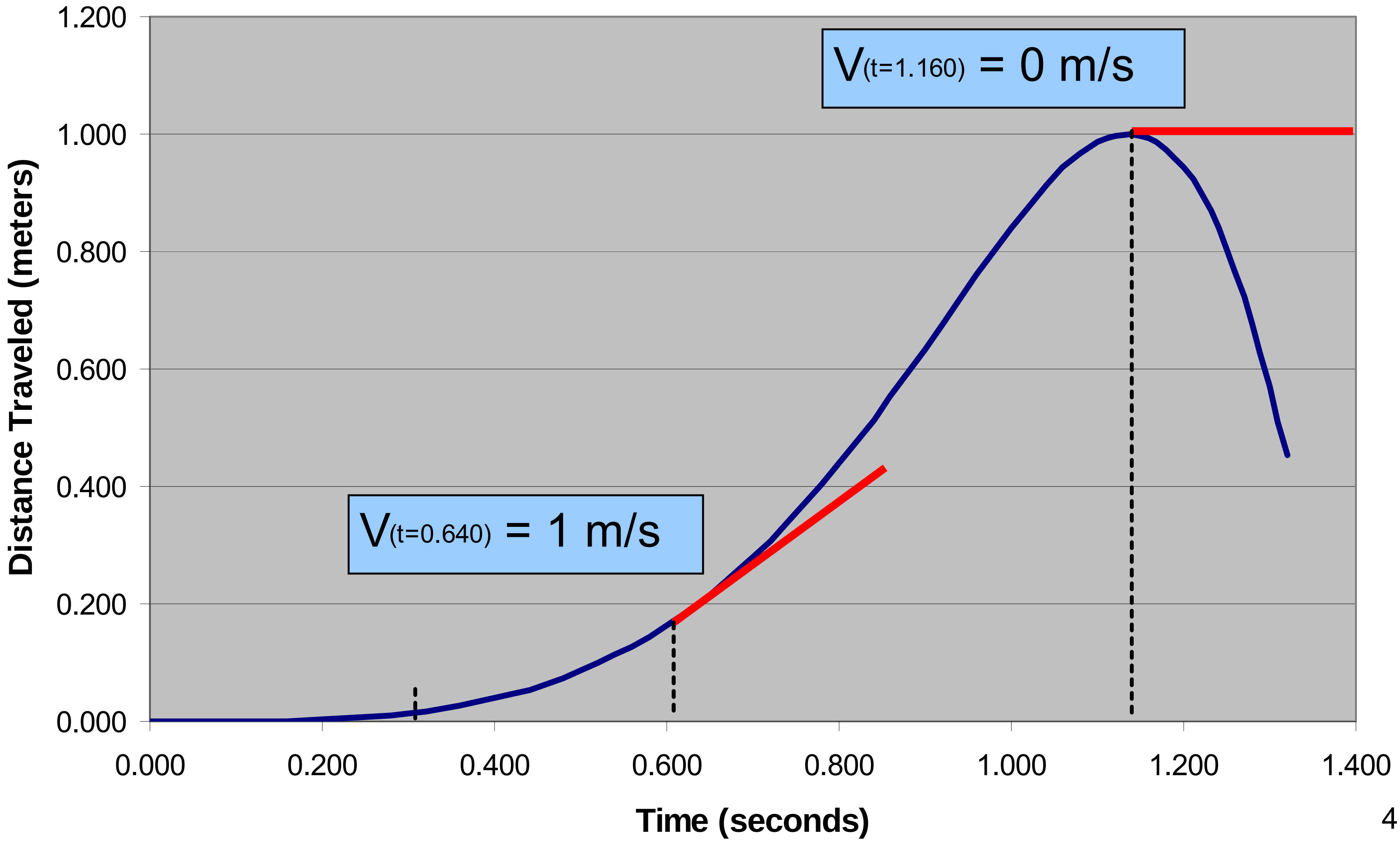
$$a = \frac{\partial v}{\partial t} = \frac{\partial^2 x}{\partial t^2}$$

- **What are the units?**
  - Acceleration is measured in (ft/s)/s or (m/s)/s
- **What is a "g"?**
  - A "g" is a unit of acceleration equal to Earth's gravity at sea level
    - 32.2 ft/s^2 or 9.81 m/s^2

More Notes on Acceleration

- **What is the time rate of change of velocity?**
  - When plotted on a graph, velocity is the **slope** of distance versus time
  - Acceleration is the **slope** of velocity versus time

How to find velocity from distance traveled



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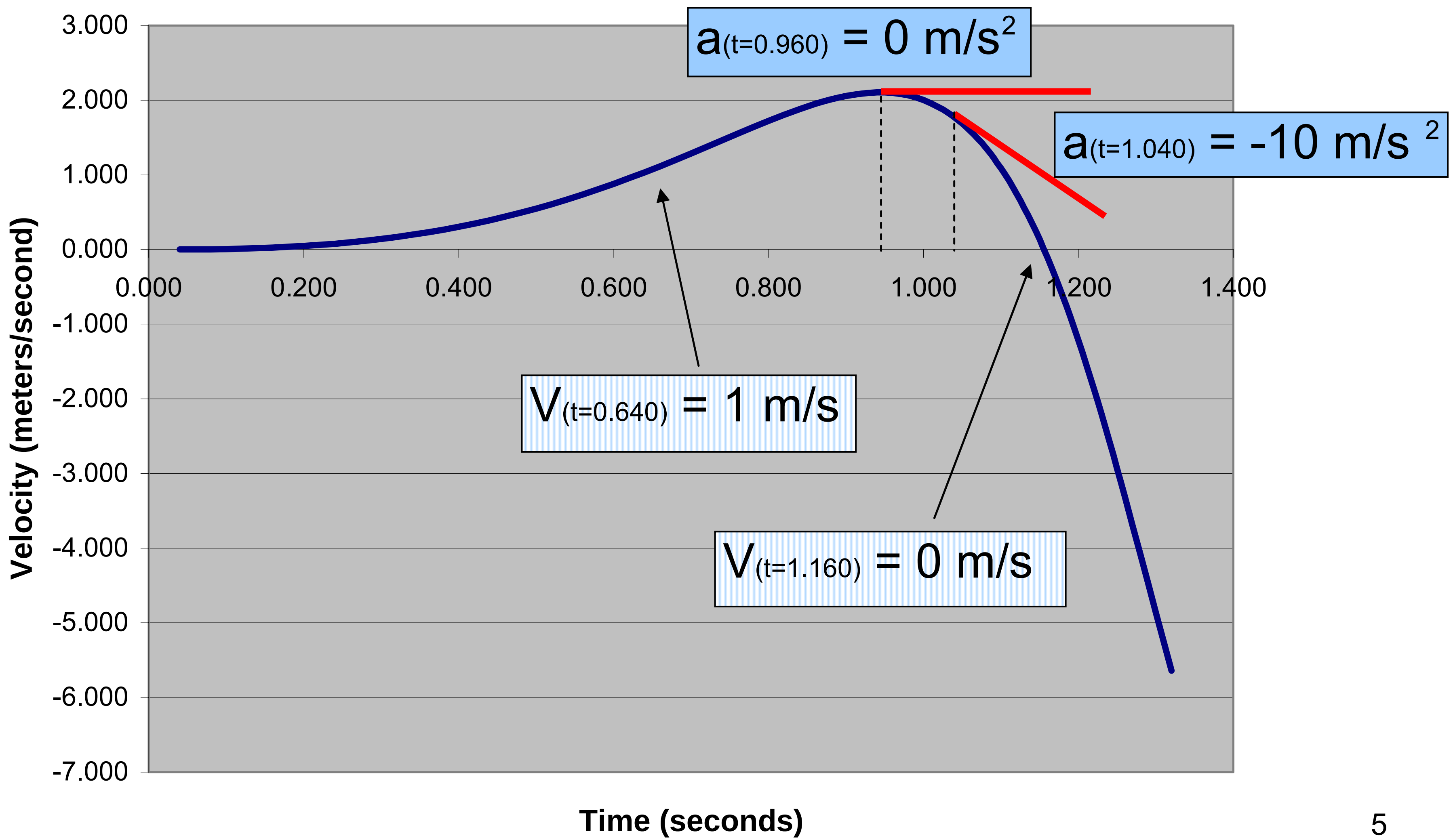
How to find acceleration from velocity



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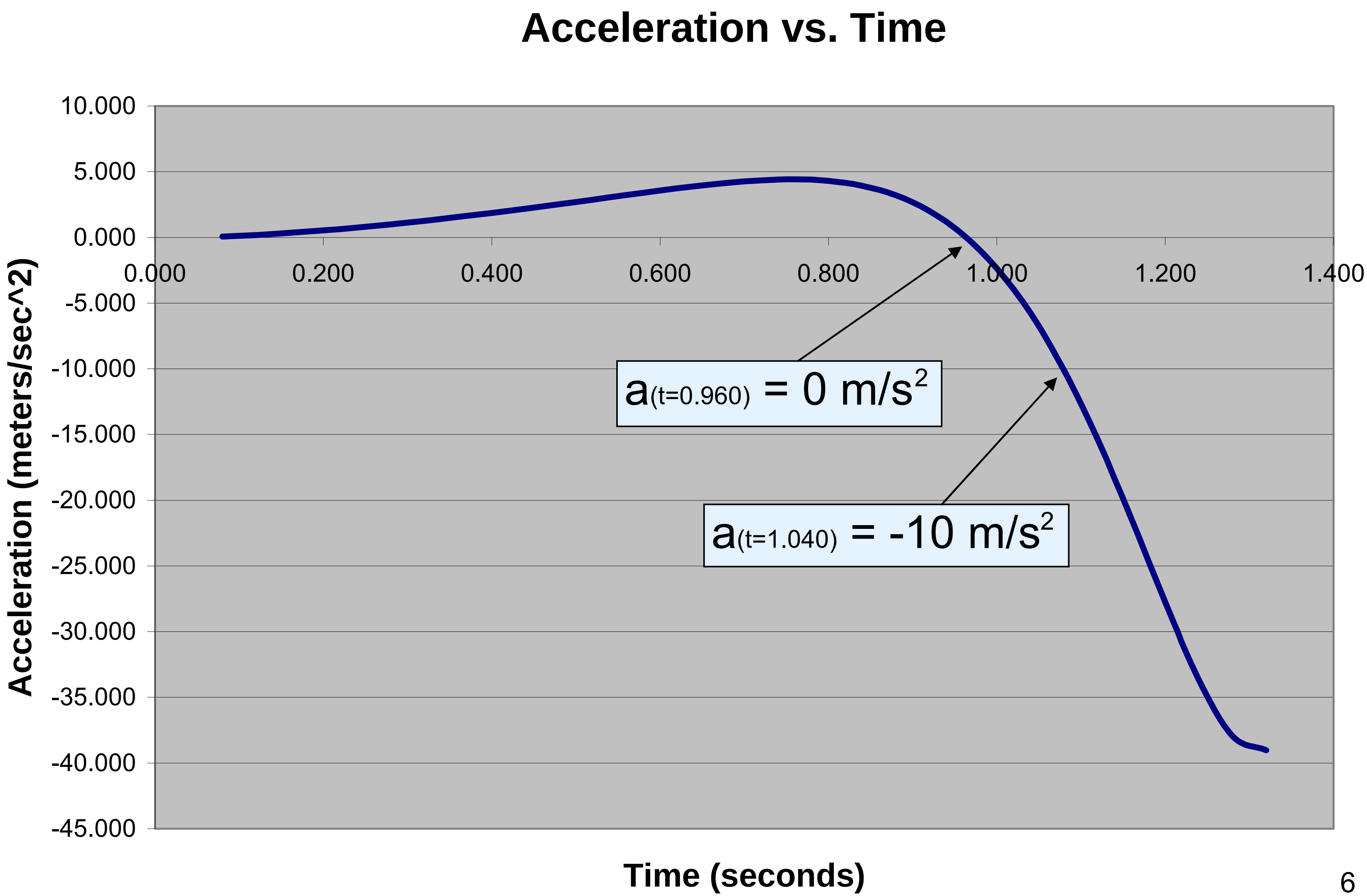
Acceleration vs. Time
10.000
5.000
0.000
-5.000
-10.000
-15.000
-20.000
-25.000
-30.000
-35.000
-40.000
-45.000
0.000
0.200
0.400
0.600
0.800
1.000
1.200
1.400
Acceleration (meters/sec^2)
Time (seconds)
a(t=0.960) = 0 m/s2
a(t=1.040) = -10 m/s2

Acceleration in Human Terms

- **What are some "g" reference points?**

Description	"g" level
Earth's gravity	1g
Passenger car in corner	2g
Bumps in road	2g
Indy car driver in corner	3g
Bobsled rider in corner	5g
Human unconsciousness	7g
Space shuttle	10g

What's the point?

- **Why measure acceleration?**
  - Acceleration is a physical characteristic of a system.
  - The measurement of acceleration is used as an input into some types of control systems.
  - The control systems use the measured acceleration to correct for changing dynamic conditions

Common Types of Accelerometers

Sensor Category	Key Technologies
• **Capacitive**	-Metal beam or micromachined feature produces capacitance; change in capacitance related to acceleration
• **Piezoelectric**	-Piezoelectric crystal mounted to mass – voltage output converted to acceleration
• **Piezoresistive**	-Beam or micromachined feature whose resistance changes with acceleration
• **Hall Effect**	-Motion converted to electrical signal by sensing of changing magnetic fields
• **Magnetoresistive**	-Material resistivity changes in presence of magnetic field
• **Heat Transfer**	-Location of heated mass tracked during acceleration by sensing temperature

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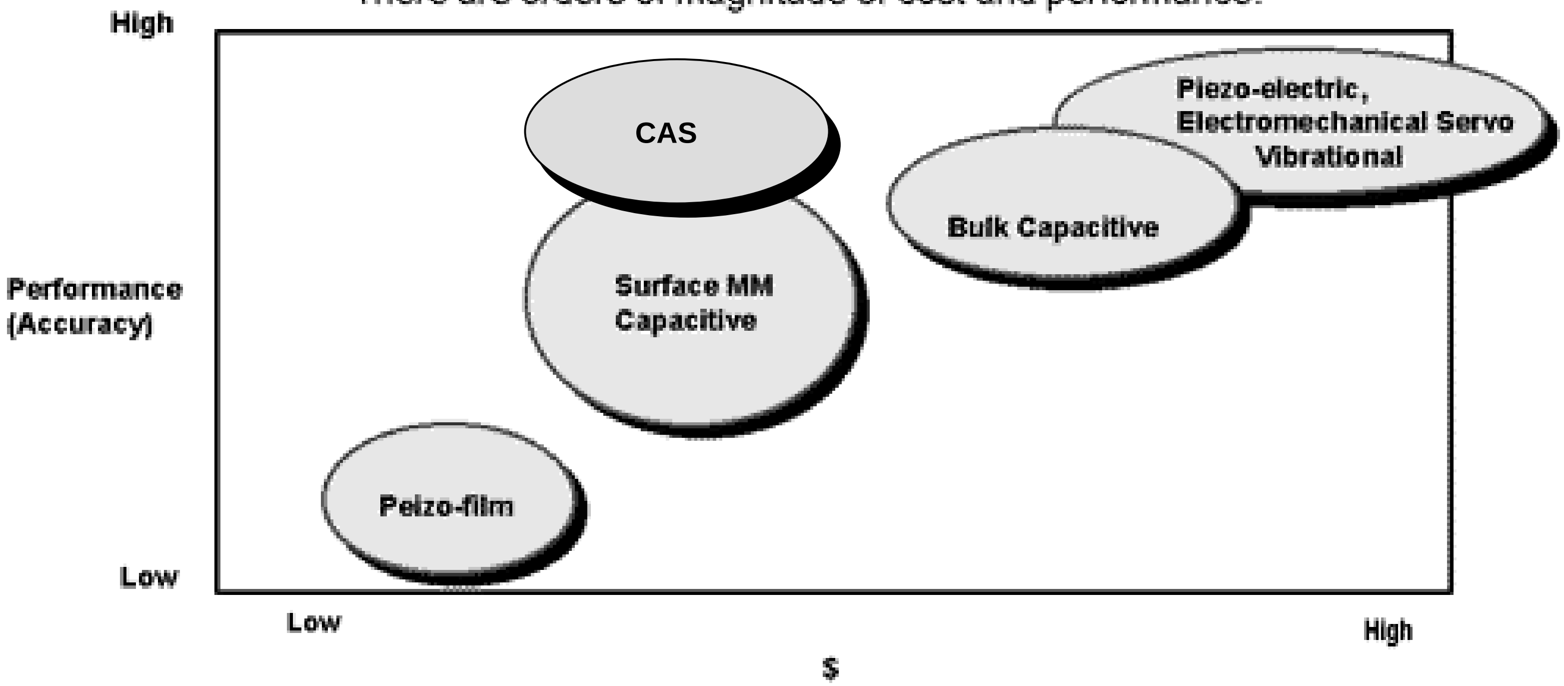
What Type of Acceleration Sensor Does TI Produce and why?

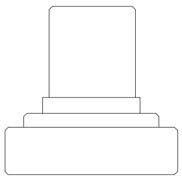
- **Capacitive Acceleration Sensor**
  - **“CAS”**

There are orders of magnitude of cost and performance!

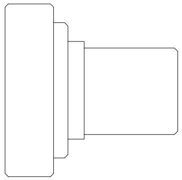


Acceleration Sensor Terminology

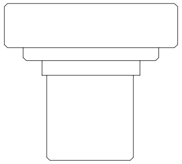
(TI Convention)



- **+1g:** Output of the sensor with the base connector pointed up



- **0g:** Output of the sensor with the base connector horizontal



- **-1g:** Output of the sensor with the base connector pointed down

- **Linearity:** The maximum deviation of the calibration curve from a straight line.

$$Linearity = V_{out,0g} - \frac{1}{2}\left(V_{out,+1g} + V_{out,-1g}\right)$$

Acceleration Sensor Terminology

- **Sensitivity:** A measure of how much the output of a sensor changes as the input acceleration changes. Measured in Volts/g

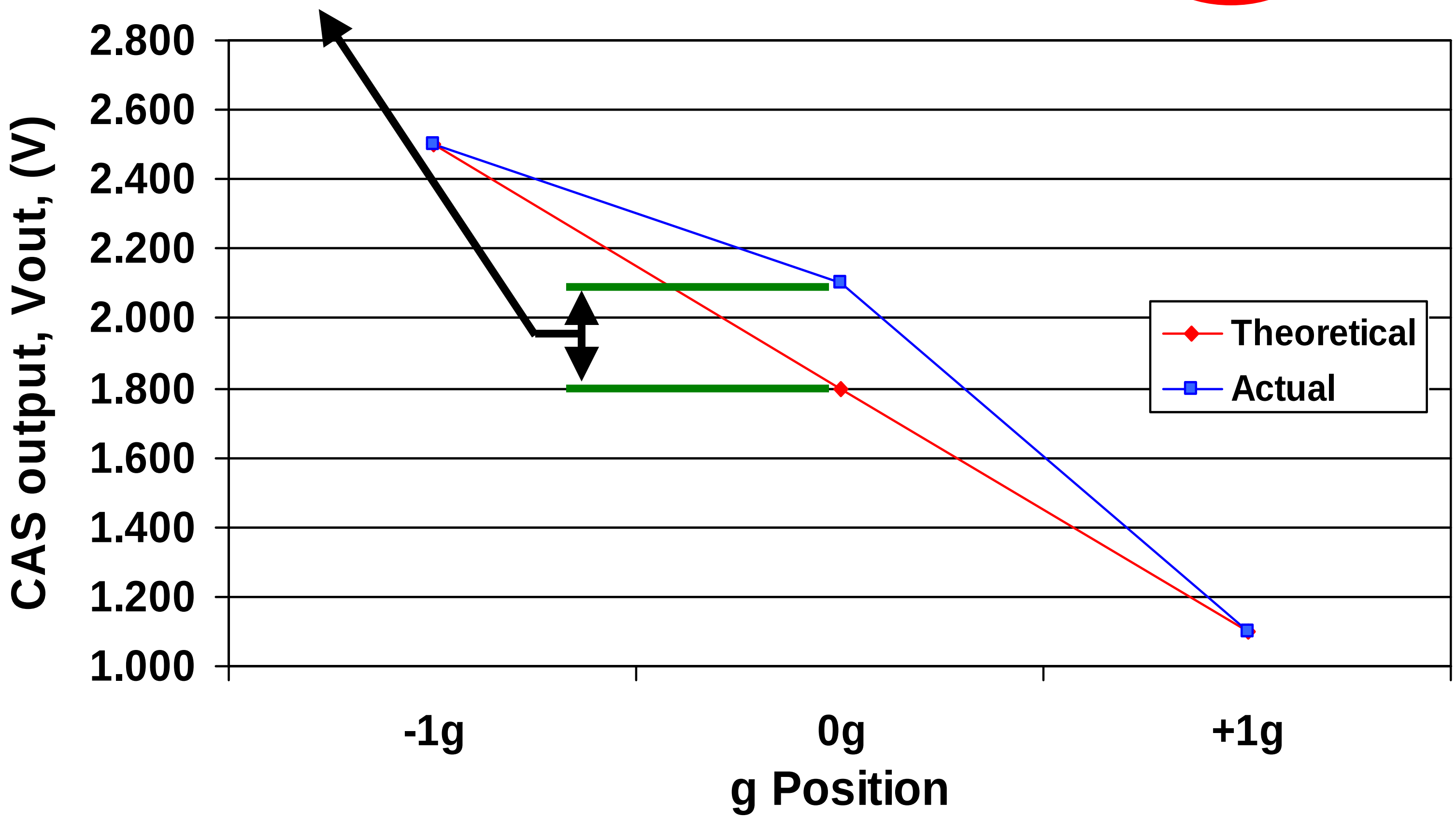
$$Sensitivity = \frac{\Delta V_{out}}{\Delta g} = \frac{V_{out,+1g} - V_{out,-1g}}{2g}$$

- **Vcc:** The voltage supplied to the input of the sensor
  - 5.000 ± 0.005V for CAS device
- **%Vcc:** Readings are often represented as a % of the supply voltage. This allows for correction due to supply voltage variances between readings.

Example: Sensitivity & Linearity

$$Sensitivity = \frac{\Delta V_{out}}{\Delta g} = \frac{V_{out,+1g} - V_{out,-1g}}{2g} = \frac{1.1V - 2.5V}{2g} = \frac{1.1V - 2.5V}{2g} = -0.7\frac{Volts}{g}$$

$$Linearity = V_{out,0g} - \frac{1}{2}\left(V_{out,+1g} + V_{out,-1g}\right) = 2.1 - \frac{1}{2}(1.1 + 2.5) = 0.3Volts$$



Acceleration Sensor Terminology

- **Ratiometric:** The output of the sensor changes with a change in the input voltage.
  - Example

    At Vcc = 5.000V, Vout at 0g = 1.800V

    In terms of %Vcc, this is 1.800Vout/5.000Vcc *100% = 36%Vcc

    Now suppose the input voltage changes: Vcc = 5.010V.

    At 0g, the ratiometric device output is still 36% Vcc.

    In terms of the output voltage, 36%Vcc * 5.010Vcc = 1.804Vout

  - So a 0.010V change in Vcc will cause a 0.004V error in the 0g output if you do not evaluate the output as %Vcc

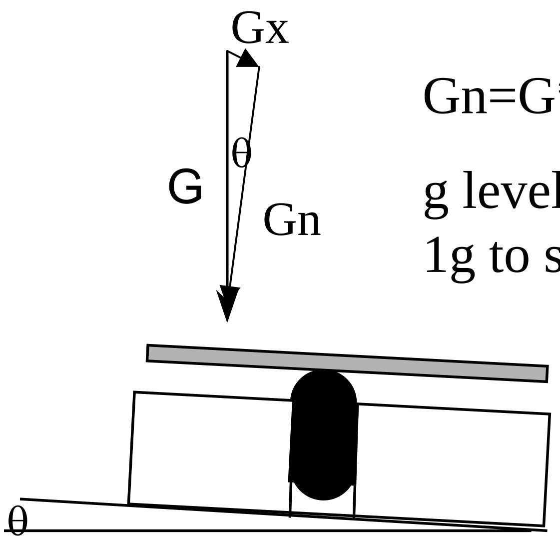
Important Setup Requirements for your CAS Device

- **Rigid Mounting**
  - Bees Wax
  - Double Sided tape
  - Bolt(s)
- **No Loose Wires**
  - Loose wires can create false signals
  - Secure wires firmly to mounting body
- **Weight of Sensor**
  - Should be approximately an order of magnitude less than object being measured
    - Example: CAS = 47g; accelerating object should be more than 470g
- **Don't drop the sensor!**
  - Extreme jarring accelerations can cause permanent errors in device output

Effect of Tilt

- **DC response sensors measure tilt. Mounting errors are therefore significant**
- **a 1^{o} tilt in the 0g position creates an output error equivalent to a 10^{o} tilt in the +1g or -1g positions**
- **0g is the most sensitive to mounting errors**

Why is device sensitive to tilt in the 0g orientation?



$Gn=G*Cos(\theta)$

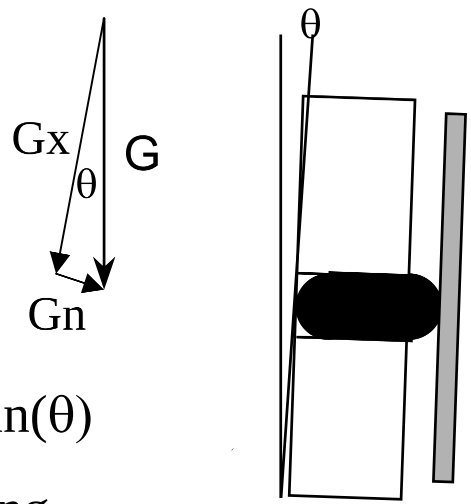
g level going from 1g to some % of 1g

+1g Position

(-1g Position uses same equation)

$\theta = 1° \rightarrow$

$Gn = 0.9998*G$



$Gn = G*Sin(\theta)$

g level going from 0g to some value

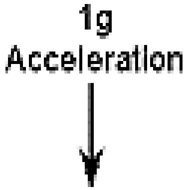
0g Orientation

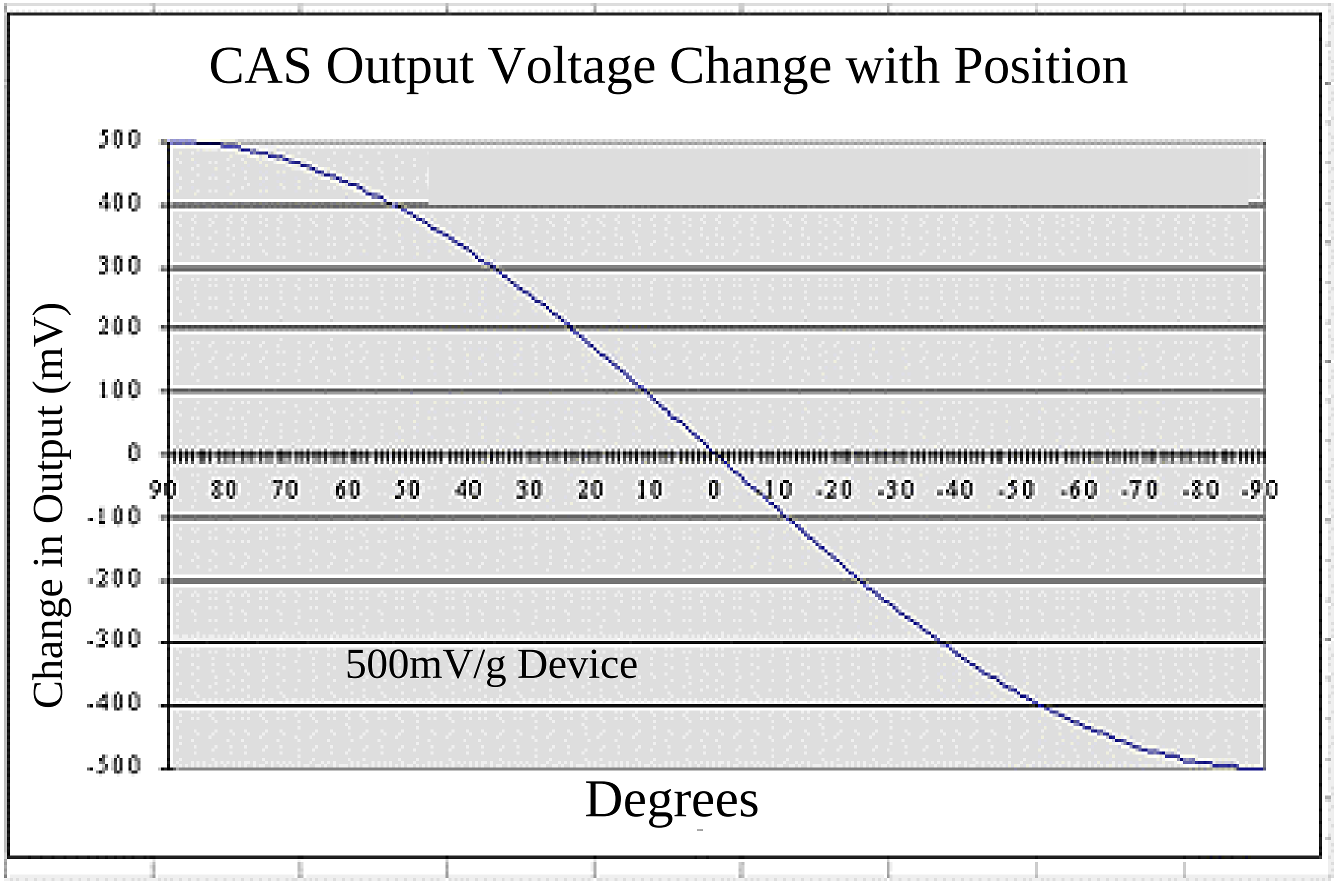
$\theta = 1° \rightarrow$

$Gn = 1.7x10^{-2}*G$

Conclusion: at 0g orientation, change in 1° tilt causes 57x bigger change in sensor output versus -1g or +1g orientation

Effect of Tilt on DC Accelerometer





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Typical Accelerometer Applications

- **Tilt / Roll**
- **Vibration / “Rough-road” detection**
  - Can be used to isolate vibration of mechanical system from outside sources
- **Vehicle skid detection**
  - Often used with systems that deploy “smart” braking to regain control of vehicle
- **Impact detection**
  - To determine the severity of impact, or to log when an impact has occurred
- **Input / feedback for active suspension control systems**
  - Keeps vehicle level

Summary

- **Acceleration is a measure of how fast the speed of something is changing**
- **It is used as an input to control systems**
- **Sensor voltage output should be determined as a percentage of voltage input for consistency**
- **The device is sensitive to tilt in the 0g position**
  - 1^{o} tilt in 0g = 10^{o} of tilt in the +1g and -1g positions