# Lab 7

# Microsystems & Motion Sensing



# Introduction

In this lab you will investigate an on-chip acceleration sensor, which is designed to detect motion, vibration, and tilt angle.

- You will study its sensitivity to motion.
- You will build a circuit which uses the motion sensing chip to control a motor, which will then be used to build a self-leveling platform.

Before we can do these experiments, we need to understand:

- What are microsystems.
- Where are microsystems used.
- How the motion sensing chip works.

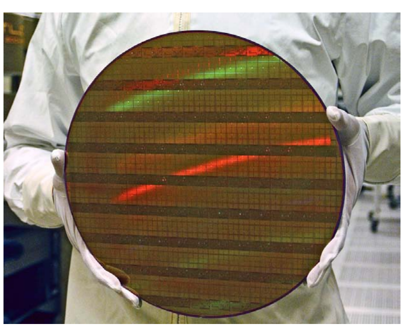
# Microsystem Technologies



# Microelectronics

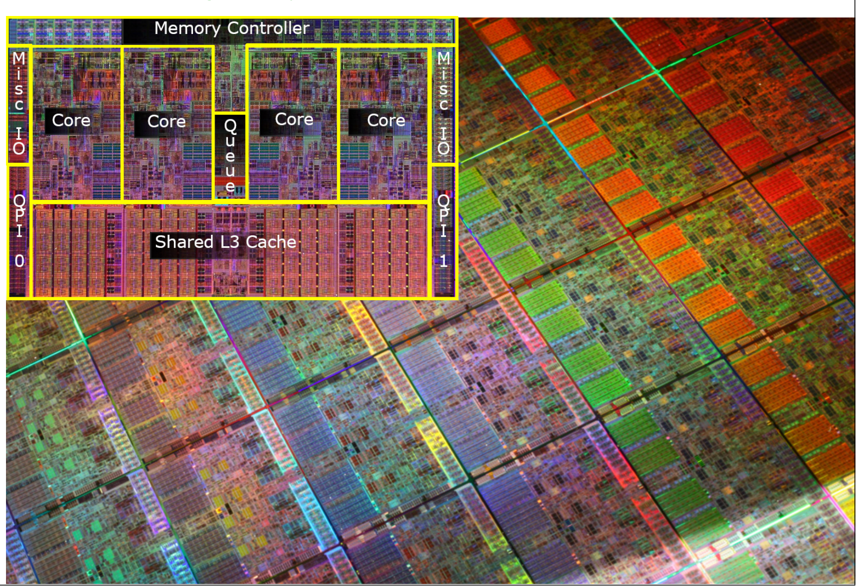
Many electrical and computer engineers specialize in the design and fabrication of microelectronics and computer architecture.

Most microprocessors are made on silicon wafers.



*Intel*

On each silicon wafer, 100's of chips are made. Making many at once reduces individual cost.

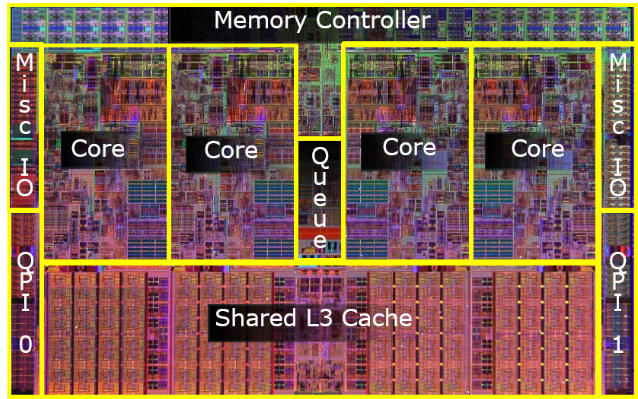



Intel i7 processors. Each chip is 263 mm$^2$, has 4 processing cores, and 731 million transistors.

# Architecture of Advanced Processors

The Intel i7 processor has many specialized sub-systems.

- 4 computation cores, each capable of 2 concurrent computations, called Threads.
- High speed Cache memory, which stores often used information.
- Data input/output circuitry.
- Queuing circuitry to manage the flow of data.



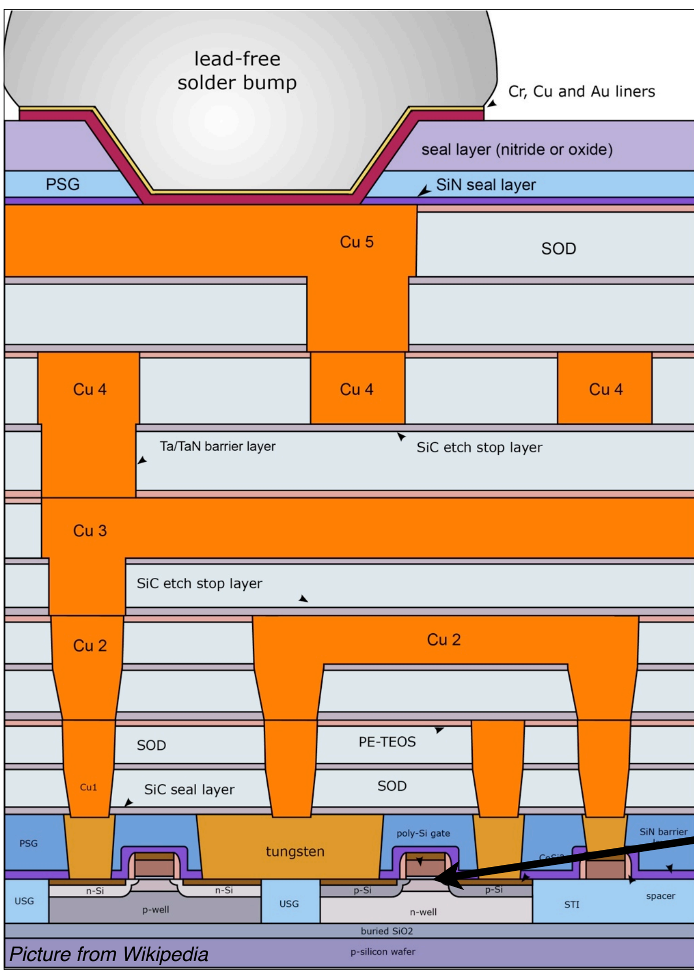

*Intel*

Computer architecture design is one of the many specialities of computer engineering.

- Computer architecture design involves many concepts, such as instruction set architecture, computation methodology, circuit design, and system design of all the other hardware connected to the central processing unit (CPU).



# CPU Cross-Section




*Picture from Wikipedia*

The skills of both electrical and computer engineers are required to design the complex structure of a CPU.

Multiple wiring layers above silicon surface to interconnect the millions of transistors.

- Silicon (Si) n-Si p-Si
- Polysilicon (Poly-Si)
- Undoped silicon glass (USG, $SiO_2$)
- Silicon dioxide (TEOS oxide, $SiO_2$)
- Cobalt disilicide ($CoSi_2$)
- Spin-on dielectric (SOD)
- Phosphor-silicate glass (PSG)
- Tungsten (W)
- Copper (Cu)
- Silicon nitride (SiN)
- Silicon nitride (SiN)
- Silicon carbide (SiC)

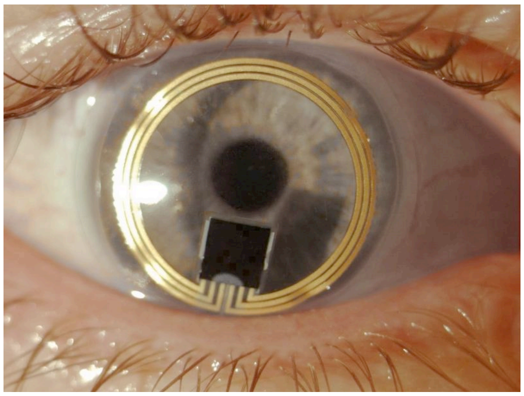
Transistor dielectric layers on the silicon surface are only 10’s of atoms thick.

Transistors built within silicon wafer.

# Microsystems and Nanotechnologies

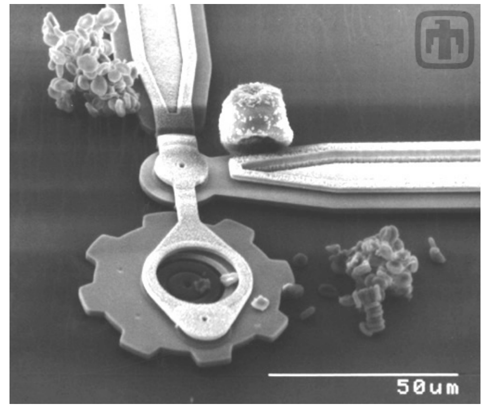
In addition to microelectronics, electrical and computer engineers also make many other types of microsystems.

Contact lens that measures intra-ocular pressure for glaucoma patients. It also has a wireless transmitter to send data.



*Sensimed*

Micro-gear with a grain of pollen and red blood cells to demonstrate scale.



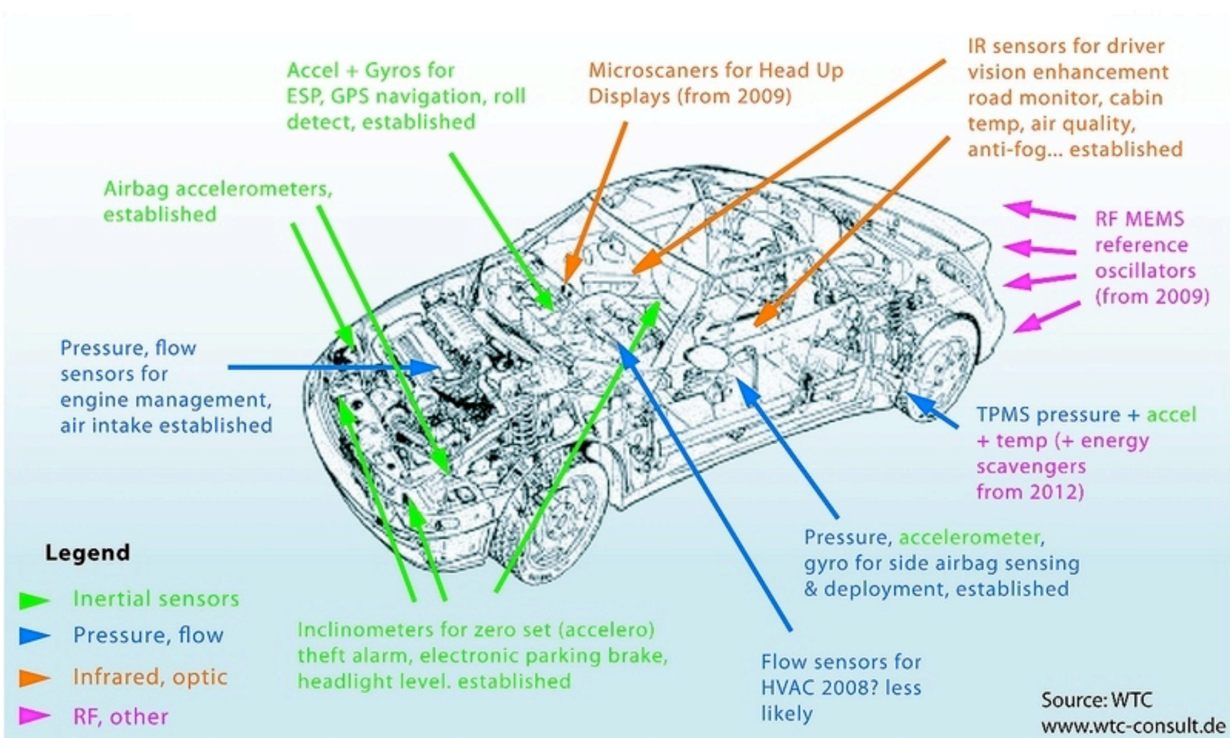

*Sandia National Laboratories*

These microsystems are often called MEMS (micro-electro-mechanical systems), since they combine multiple technologies in their operation.



# Microsystems in Automobiles

The automobile industry is one of the biggest users of microsystems.



# MEMS Inertial Sensors

Motion sensors are one of the most commonly used microsystems. They are used in many applications.

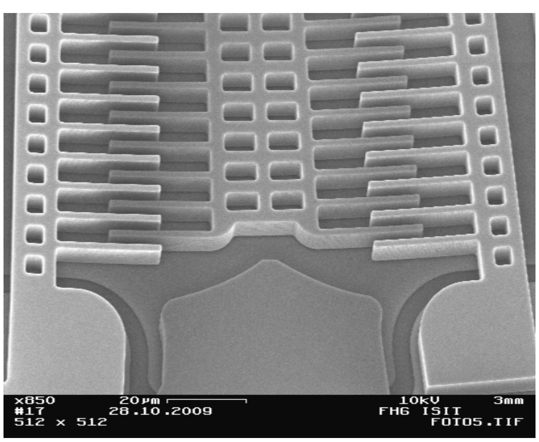
- PDA's and cell phones which respond to natural movements
- Handheld PC and gaming peripherals
- Hard drive shock "park disk" protection
- Camcorder image stabilization
- Aircraft or spacecraft guidance systems
- Monitoring motions in buildings or bridges
- Sports equipment
- Washing machines
- Automobile stability control systems and rollover detection

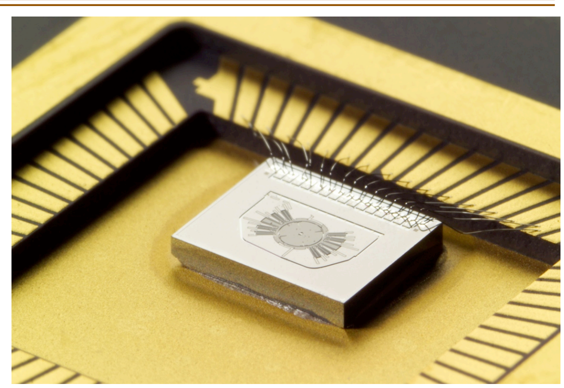
How do these devices work?



# On-Chip Gyroscope

This on-chip gyroscope uses variable capacitors to measure motion.



Sensor Dynamics

Tiny conductors, that are suspended above the chip surface, form an interlocked "*comb*" structure.

The conductors are held up by tiny springs.

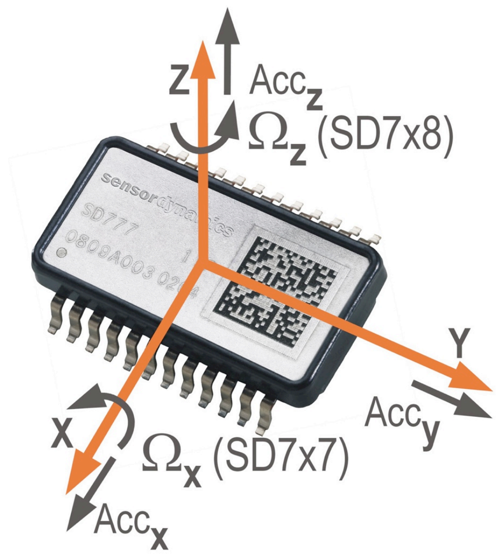
- Movement causes the overlap distance of the comb teeth to change, which changes the capacitance between them.
- An electric circuit monitors the capacitance changes, and so measures motion.

# Specific Axis Sensitivity

MEMS inertial sensors generally can give data on motions or rotations specific to different axis of motions.

- Knowledge of axial specific motion is very useful in many engineering applications.

Two axis gyroscope, and 3 axis accelerometer chip.

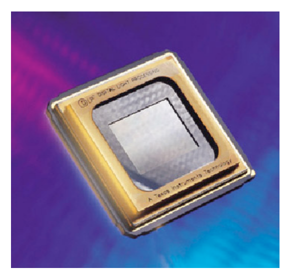


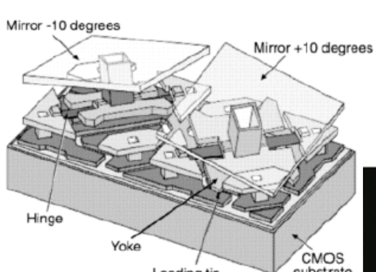


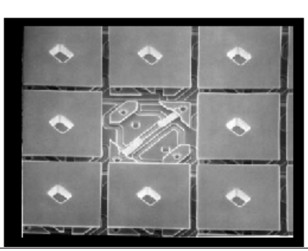

# Digital Light Processor (DLP)

This chip built by Texas Instruments has 100,000's of tiny tilting micro-mirrors in it.

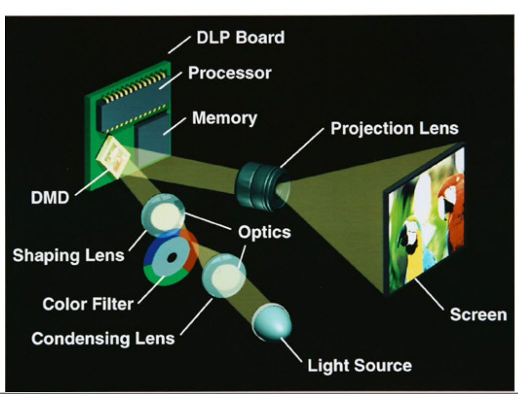
- Each mirror measures the about width of ~ 2 red blood cells.
- They are used in some data projectors, projection screen televisions, and movie theatres.





When voltage is applied to an electrode under one (or the other) side of the mirror, the mirror tilts.




- Each mirror reflects light to a specific point on the screen.
- They flip back and forth faster than your eye can see, creating the moving picture on the screen.

# Hard Disk Drives

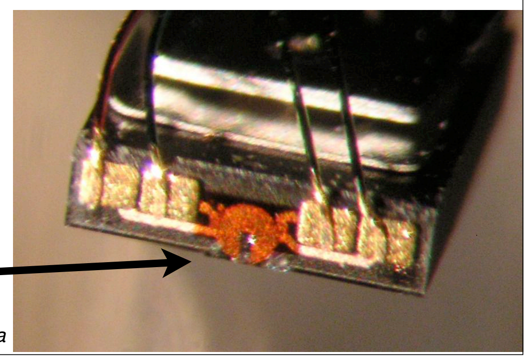
Picture from Wikipedia

Hard disk drives record data by magnetizing the surface of spinning magnetic disks.

- The spinning disks (called platters) are coated with a thin layer (10 - 20 nm thick) of magnetic material.
- Read/write heads magnetize tiny regions, 10's of nanometers in size, with a north or south polarity, to represent a 0 or 1 binary digit.
- The read/write heads can be as close as a few nanometers above the spinning platter.

There are different technologies used to make the read/write heads.

- In this picture, a tiny copper coil is used, which measures ~ 0.2 mm in diameter.



Picture from Wikipedia



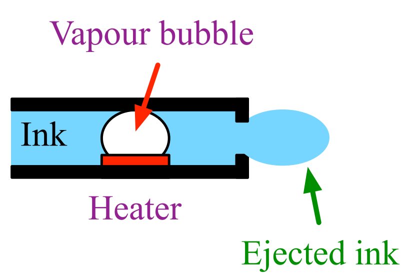
# Inkjet Printers

Inkjet printers work by propelling tiny drops of ink onto a page.

- Ink cartridges can have hundreds of tiny nozzles which eject picolitre ($10^{-12}$ litre) sized drops of ink.
- These nozzles fire billions of individually placed drops of ink onto a page to draw a full page colour picture.

Thermal inkjet (bubble jet) printers have tiny electrically heated chambers in the print cartridge. Ink in the chambers is vaporized to form a bubble, which propels a droplet of ink onto the paper.

- Lexmark, Canon, and HP inkjet printers use this technology.




Piezoelectric inkjet printers use a vibrating piezoelectric material to propel ink out of the chamber.

- Epson inkjet printers use this technology.

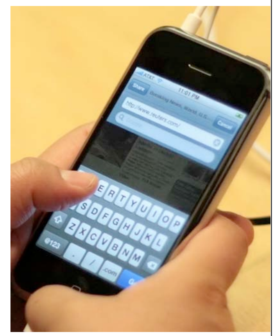
# Touchscreen Technology

There are many ways of making touchscreens.  Two common technologies are resistive sensing and capacitive sensing.

Picture from Wikipedia

This device’s touchscreen operates by electrical resistance.

This device’s touchscreen operates by electrical capacitance.



Picture from Wikipedia

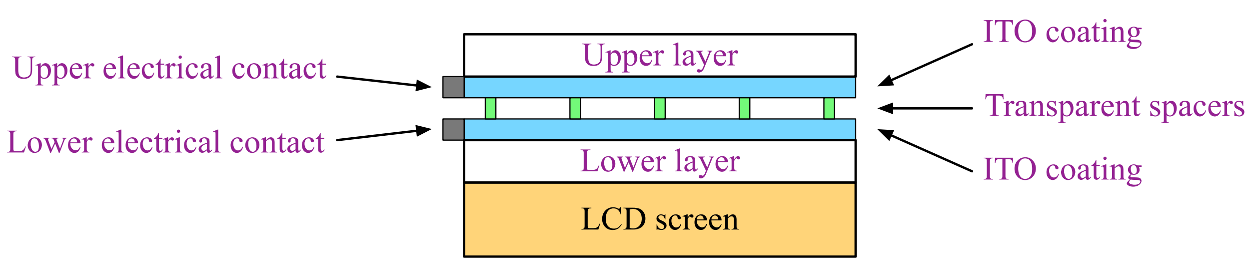


# Touchscreen Technology - Resistive

Picture from Wikipedia

Resistive touchscreens have two layers of transparent material placed over the screen, which are separated by transparent electrically insulating spacers.

- Each layer is coated with a transparent electrically resistive material, called indium tin oxide (ITO).

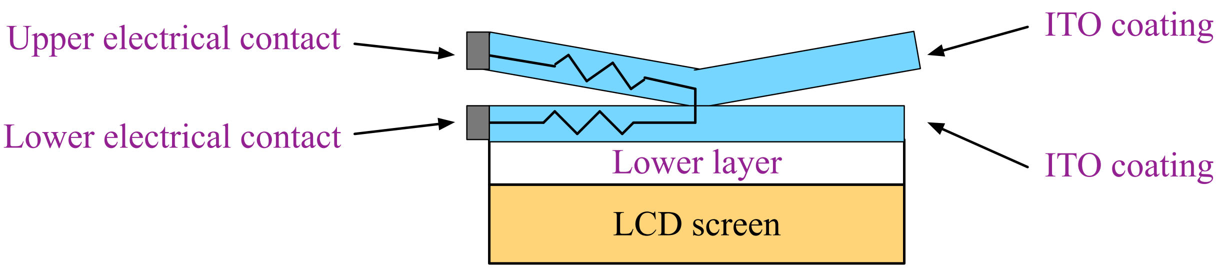



How do they work?

# Resistive Touchscreen Operation

Pushing on the upper layer causes it to touch the lower layer. This completes the circuit between the electrical contacts attached to the upper and lower layers at the edge of the screen.

- The resistance between these electrical contacts circuit depends on the location touched.

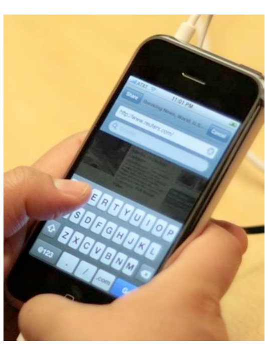





# Touchscreen Technology - Capacitive

Capacitive touchscreens have arrays of wires and electrodes under the screen, which are made of transparent indium tin oxide (ITO) material.

- Electronic circuitry measures the capacitance between adjacent electrodes.
- Touching the screen with your finger causes the capacitance between nearby electrodes to change, which is detected by the electronics.



*Picture from Wikipedia*

Capacitive touch screens need to be touched by an object that has a high dielectric constant ($\varepsilon_r$), otherwise they won't detect the object.

- Your finger works, because it has lots of water in it ($\varepsilon_r$ of water is ~ 80 at room temperature).
- Objects like metal, wood, paper, or plastic won't work. If you wear gloves they also won't work (unless your gloves are wet).

Capacitive touchscreens are more transparent than resistive touchscreens, and less sensitive to temperature and scratches. But they have problems when wet.

# Today's Lab:

# Motion Sensing Circuit
# &
# Self-Leveling Platform

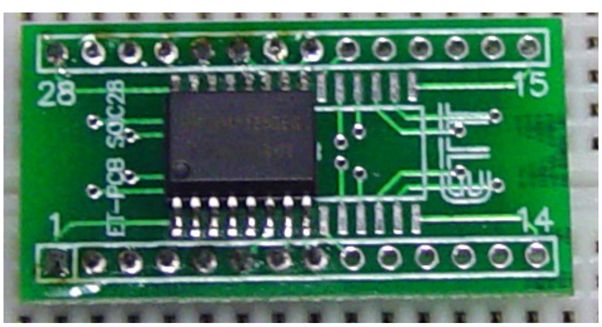


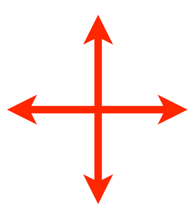
# Motion Sensor Chip

In today's lab you will investigate the MMA1260EG acceleration sensor.  It is a 1-axis low G micromachined accelerometer.

- It can measure ± 1.5 g motions in the Z axis (up and down).  This enables it to measure Z axis motion, vibration, and tilt angle.

Motion measurement is specific to the Z axis, and so motions in the X and Y axis will give no reading.



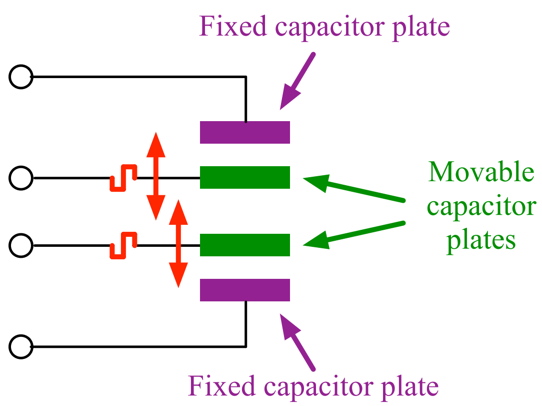



No reading for side to side or back and forth motions.

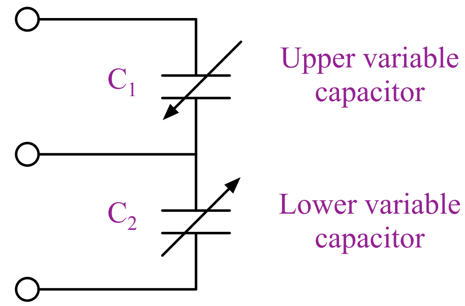
# Operation of this Motion Sensor

This chip has two tiny capacitors inside it ($C_1$ and $C_2$).

- One plate of each capacitor is held up by tiny silicon springs and is free to move. Therefore, when the chip moves, the capacitances $C_1$ and $C_2$ change, since the spacing between the two plates forming the capacitors changes.
- Electronics in this chip monitor how the capacitances change, and interpret the changes as motion.




Mechanical Structure



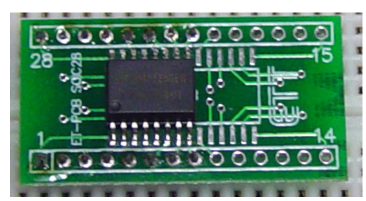

Electric Circuit



# Sensor Output & Motor Control

The output of motion sensors can be an analog or a digital signal, depending on the sensor.

- The MMA1260EG acceleration sensor that you are using will give you an analog voltage output.
- The voltage output will vary as the sensor is tilted or shaken.



You will use this output signal to control a small DC motor.

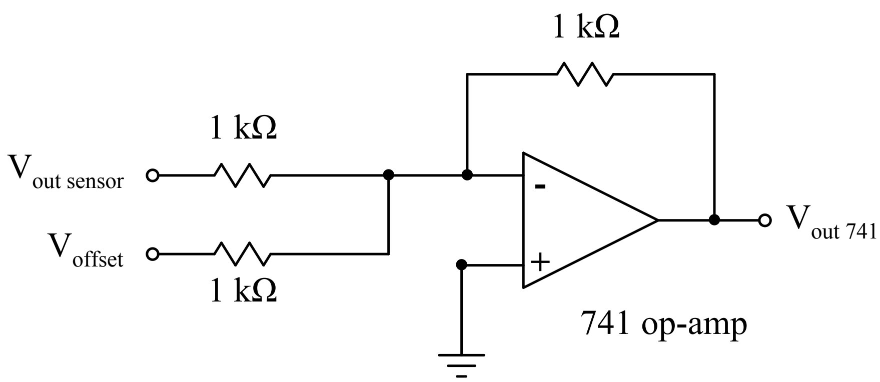
- You will build a circuit that will enable you to turn the DC motor clockwise or counterclockwise, depending on the tilt angle of the motor.
- Your circuit will also allow you to control the motor speed, depending on the tilt angle of the motor.

Similar motion sensing concepts are used in an iPod Touch or Nintendo Wii game controller.

# Control Circuit

The sensor's output varies depending on the tilt angle on either side of 90° tilt.

- At 90° tilt, the sensor output is ~ 2.5 V.
- You will use an op-amp to add $V_{offset}$ = -2.5 V to the sensor output, to negate the 90° normal sensor output.
- The output of this control circuit, $V_{out\ 741}$, is then a non-zero value only when the sensor is tilted on either side of 90°.





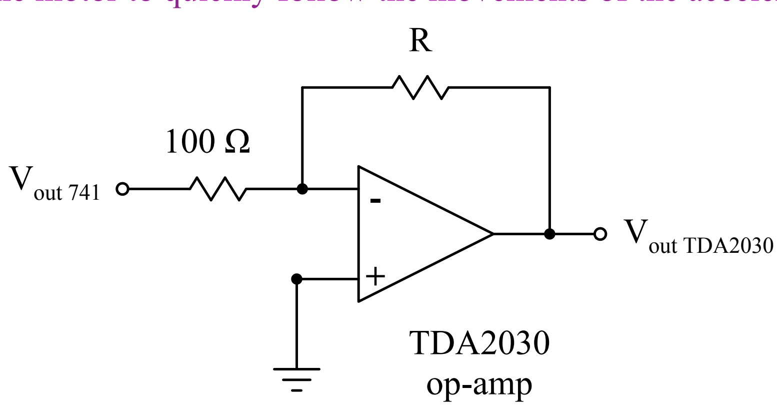

# Motor Current Needs

The DC motor requires a current of around 50 mA to move.

- This current is too high for the sensor chip or your control circuit to provide.

Therefore, you will connect a high power op-amp to your control circuit.

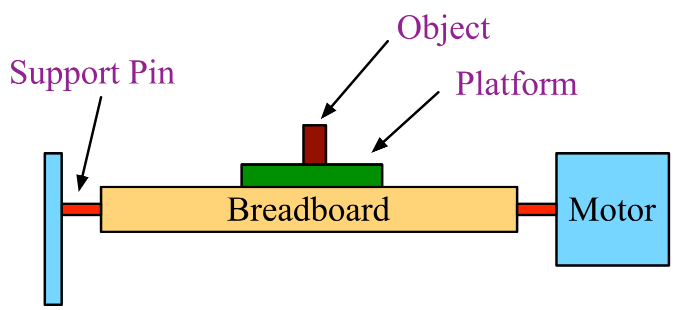
- This op-amp will read the voltage of the control circuit, and act as a current buffer to power the motor.
- Select the feedback resistor R appropriately, so that the gain is enough to enable the motor to quickly follow the movements of the accelerometer chip.



# Self-Leveling Platform

Attach the breadboard with the accelerometer chip to the motor wheel, and construct a small platform on the breadboard.

- The motor should rotate to keep the platform level as you rotate the structure.
- You will need to support the opposite end of the breadboard, in order to to balance the weight load on the motor shaft.






# Gain of Control Circuit

Adjust the gain of the motor control circuit as needed, so that an object on the platform does not fall off when you rotate the structure.

- The gain should be appropriate in order for the motor to rotate rapidly enough (but not too fast) to follow the movements of the platform.