# Lecture 6: Working with registers MPU5060 Demo

Vikram Iyer

Adapted from material by Blake Hannaford, and Jon Froehlich

# Administrative

- Lab 1
  - Due next week
  - Pick up a speaker in the Lab 1 in the EE store, same place as the lab kits
- Assignment 2 posted

# Last time

- Hardware architecture- what's inside a processor?
  - Registers
  - Data bus and signaling
  - How a processor works
  - Example of code execution

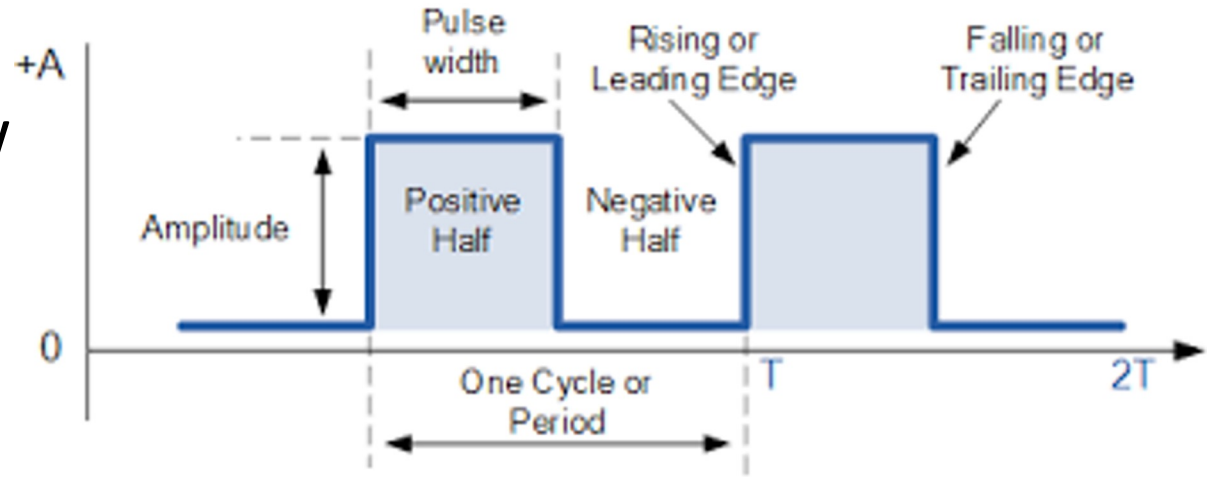
- Getting started with Arduino

# Plan for today

- Lab 1 background
  - Frequency
  - Timing functions
  - Brief intro to circuits
- Working with registers: MPU6050 demo
  - What is an IMU and how does it work?
  - Reading datasheets
  - Demo of reading and writing registers to control sensor

# Lab 1 hints: Frequency and period

- Frequency = 1/Period
- Similarly, Period = 1/Frequency
  - Example: a 440 Hz frequency wave has a period of 1/440 seconds = 2.27 ms period.
- Period for square wave: high-low



# Lab 1 hints: Handy Arduino functions

- Do NOT use `tone()`: hard to manage 2 different frequencies simultaneously, can cause issues
- `delay(1)`: Pause the program by 1 millisecond
  - If called for every loop, pauses 1 ms after execution
  - ATMega2560 clock speed = 16MHz, 1 ms is slow comparatively

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  - What does '`millis() % 1000`' do when called every loop?
  - Return type: `unsigned long`
    - What is the maximum value we can get?

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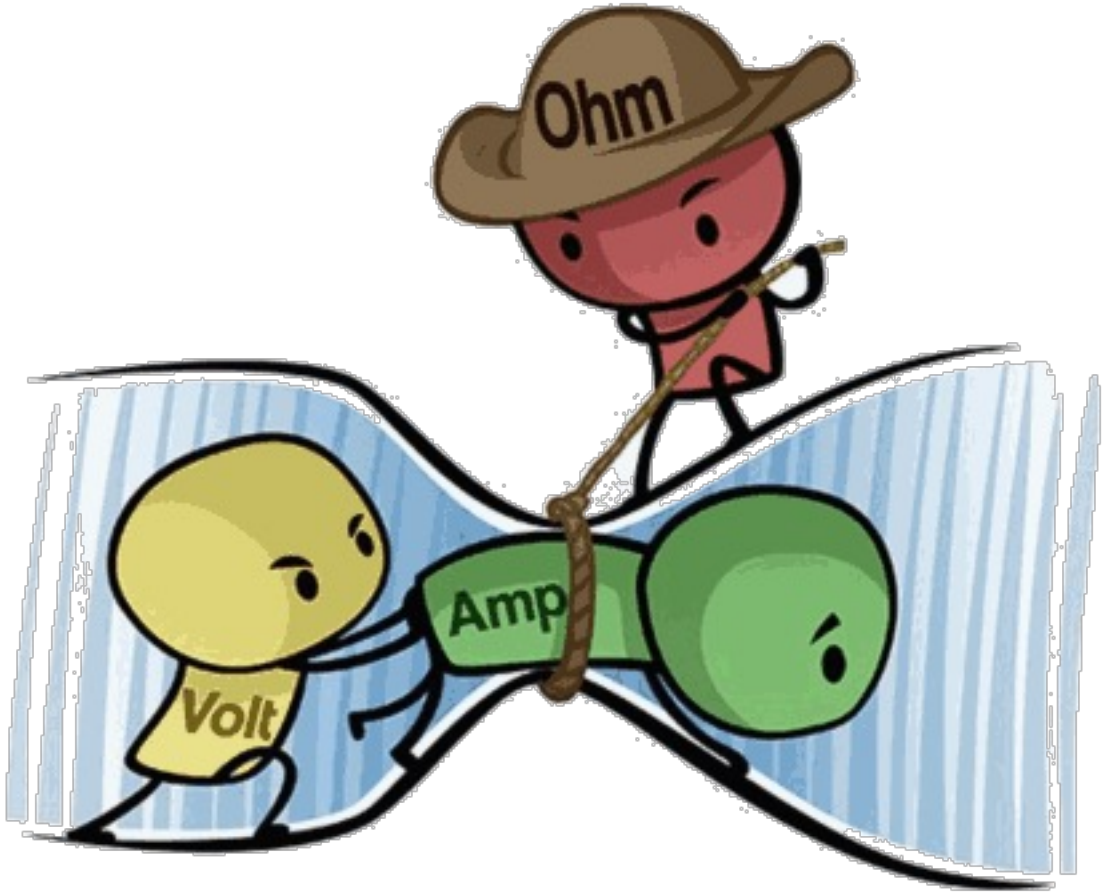
- `millis()`: returns the current time in milliseconds - relative to the system
  - What does '`millis() % 1000`' do when called every loop?
  - Return type: `unsigned long`
    - What is the maximum value we can get?
    - (2^32 – 1) = 4,294,967,295 ms = around 49.7 days

# A very brief circuits review/overview




Adapted from material Jon Froehlich

# A very brief circuits review/overview

| Quantity | Symbol | Unit | Abbreviation |
|---|---|---|---|
| Current | *I* | Ampere (Amp) | A |
| Voltage | *V* | Volt | V |
| Resistance | *R* | Ohm | Ω |

**Ohm's Law:**

$V=I*R$

Adapted from material Jon Froehlich

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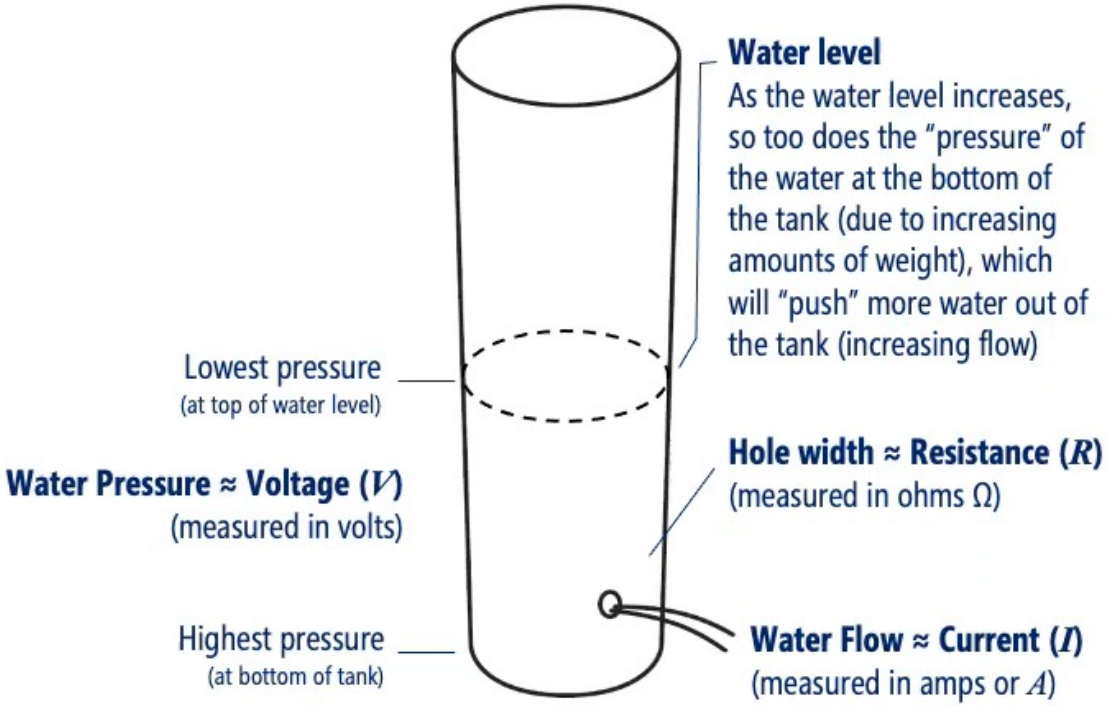
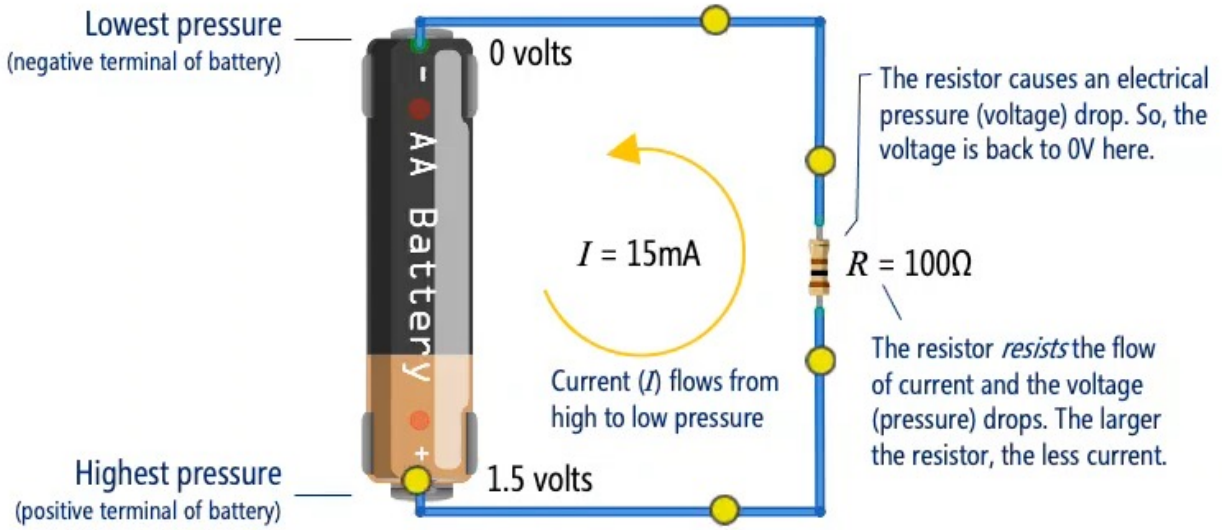
## Water flow (hydraulic) analogy

| | Electric | Hydraulic |
|---|---|---|
| Flow rate | Current, *amps (coloumbs/sec)* | Flow rate, *GPM (gallons/minute)* |
| Potential | Voltage, *volts* | Pressure, *psi (pound per square inch)* |
| Resistance | Resistance, *ohm (volts/amp)* | Resistance, *psi/gpm* |

Adapted from material Jon Froehlich

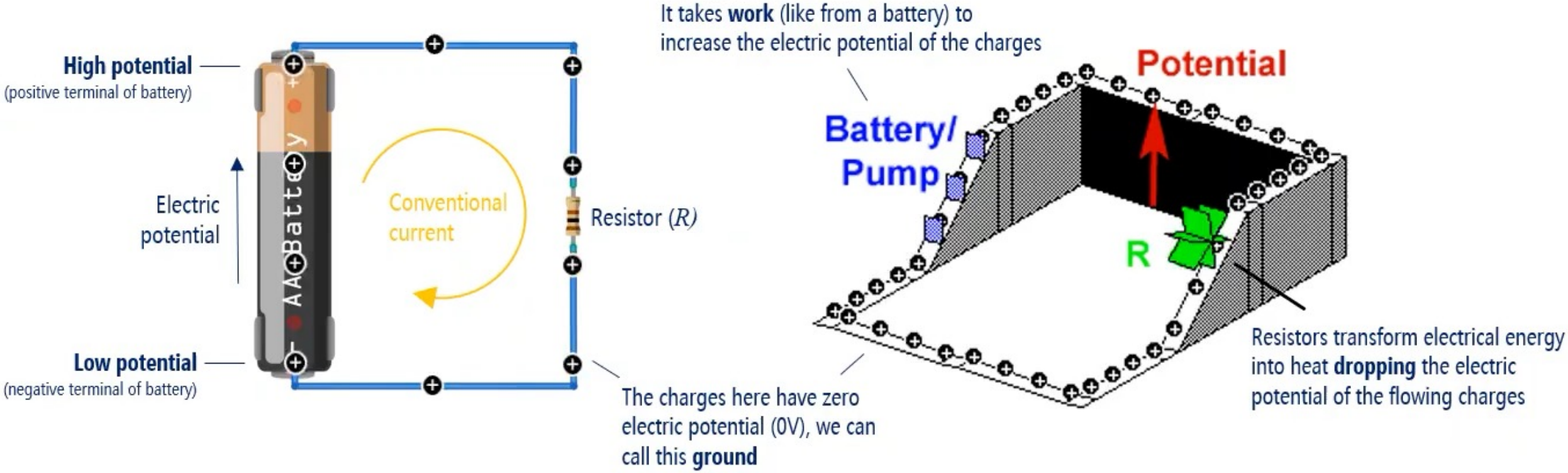
# HYDRAULIC–ELECTRIC ANALOGY




*Animation credit: Jon Froehlich*

# 1 V= 1 joule (of work) / 1 coulomb (of charge)

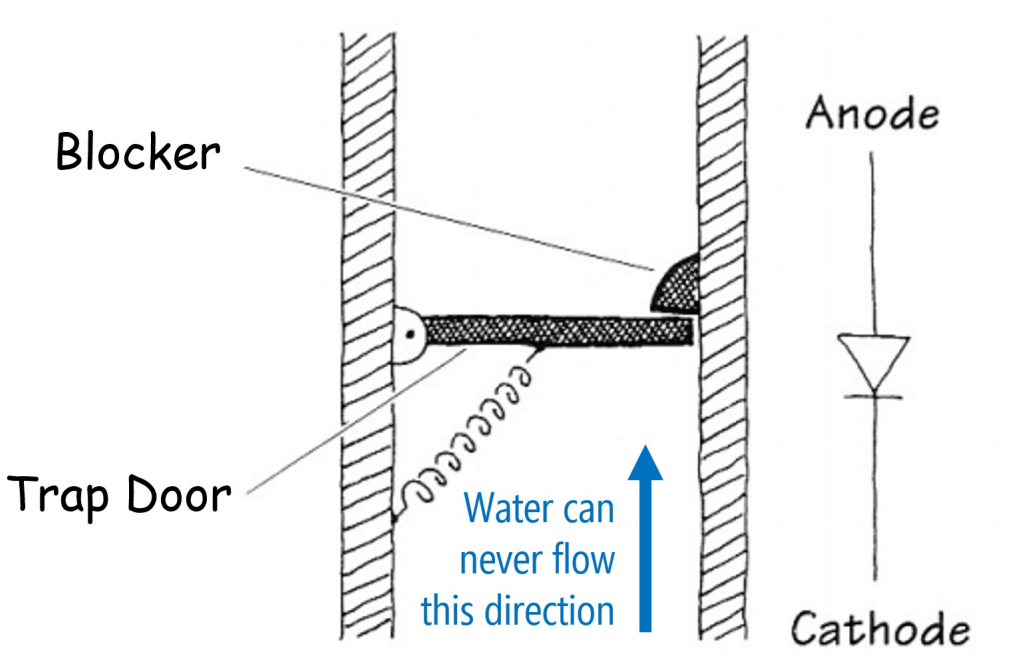



Power = work / time, 1 W = 1 joule / second

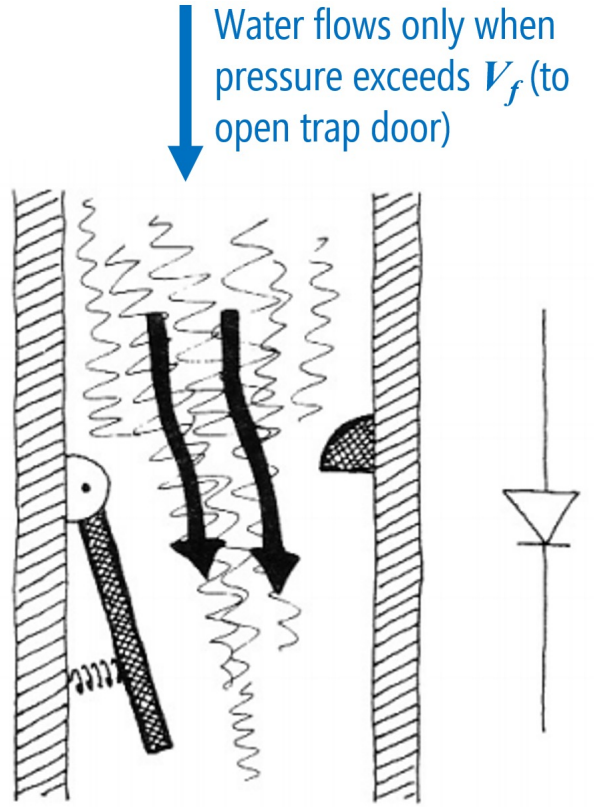
Watts = **Voltage** (joules / coulomb) x **Current** (coulombs / second)

*Animation credit: Jon Froehlich*

# Diodes

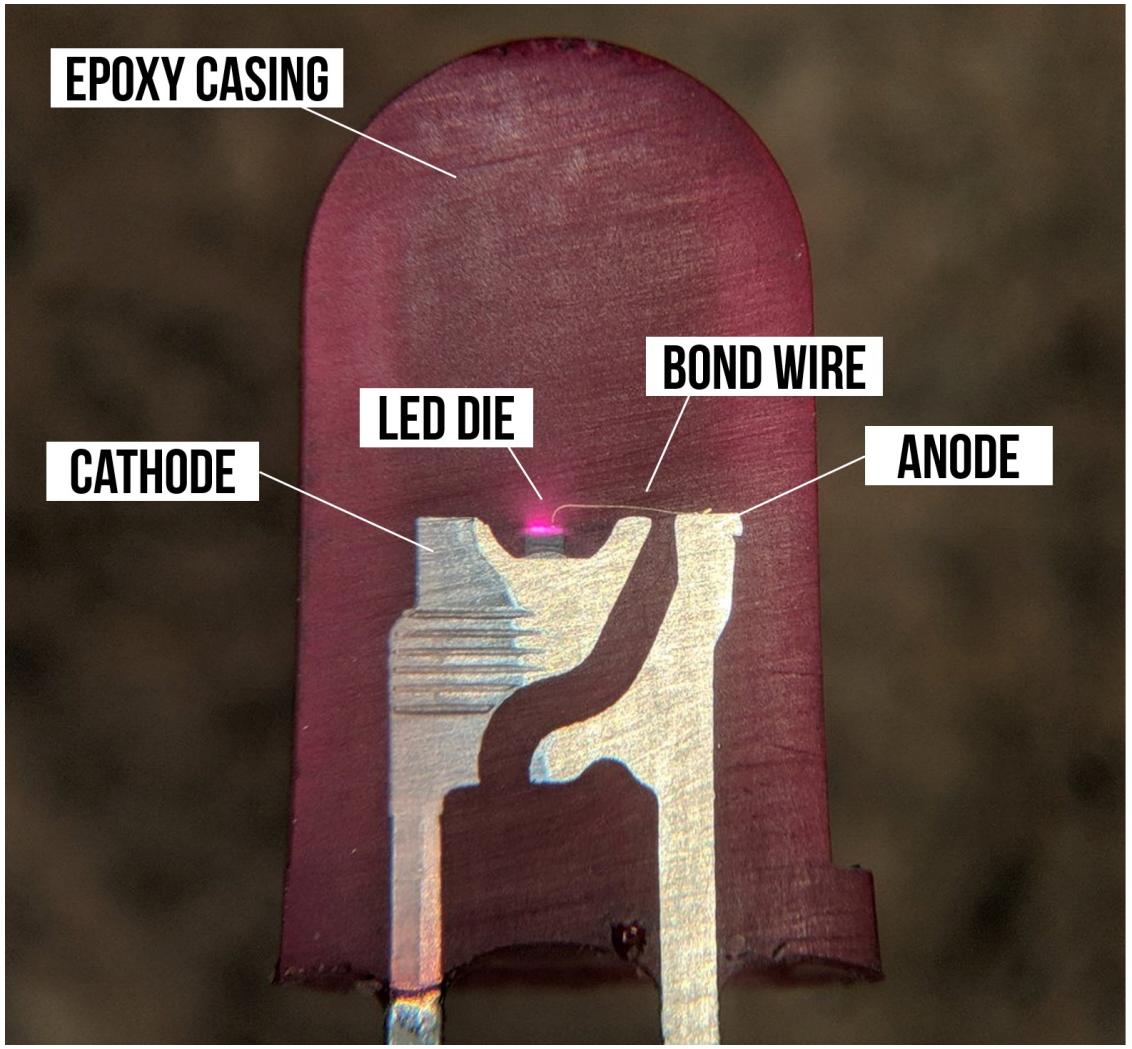


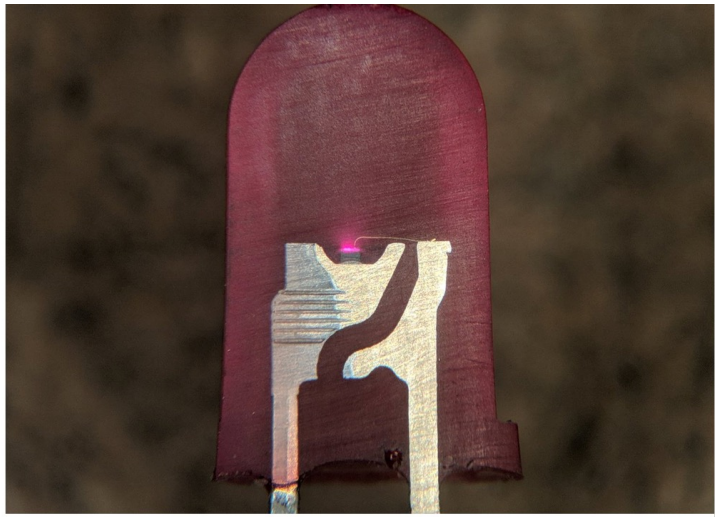

Imagine this trap door won't open unless a certain water pressure threshold is met (this is the forward voltage $V_f$, which is sometimes called the "on" voltage $V_{on}$).

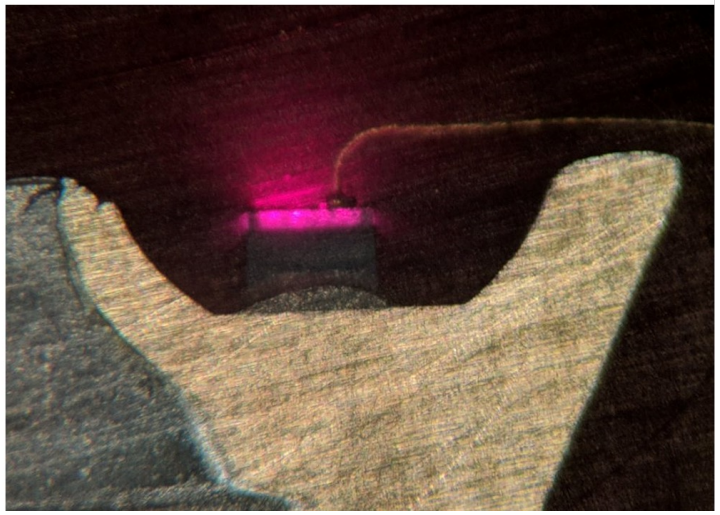



Once the $V_f$ threshold is met, the trap door opens and water (current) passes through.

# Light Emitting Diodes (LEDs)

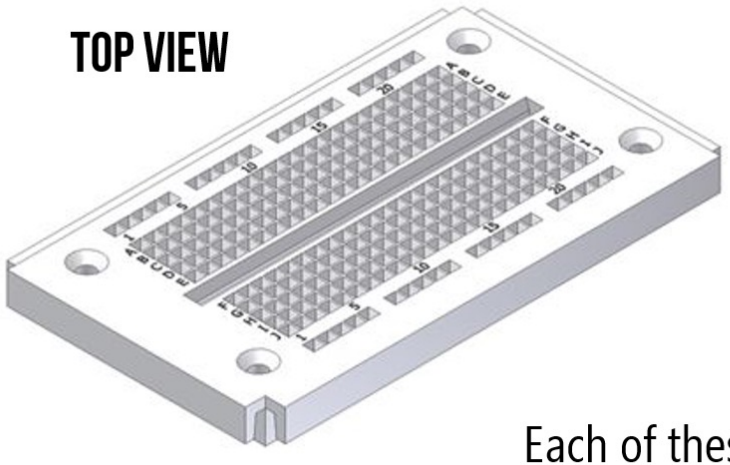


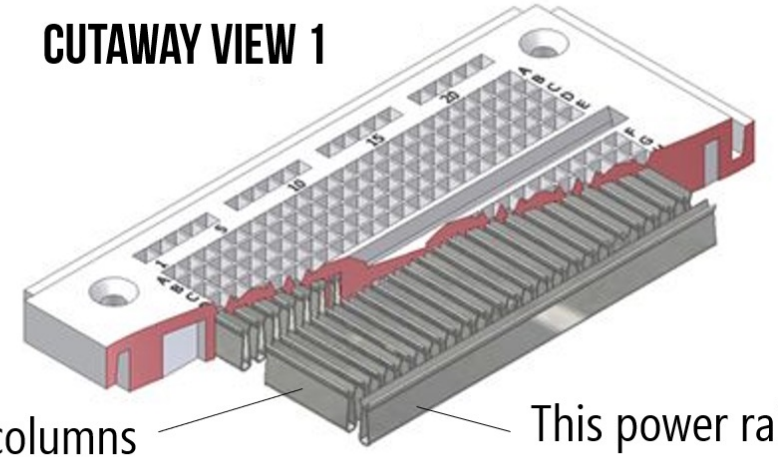


# Prototyping with breadboards

TOP VIEW



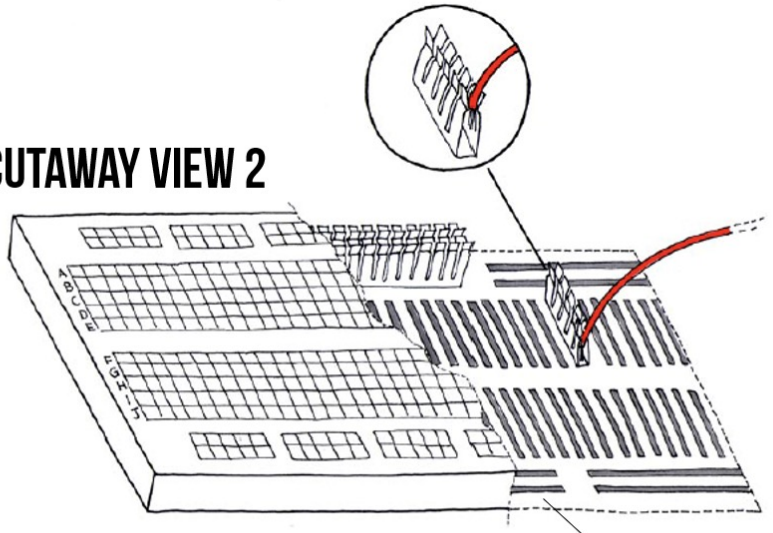
CUTAWAY VIEW 1



Each of these columns are independent **nodes**

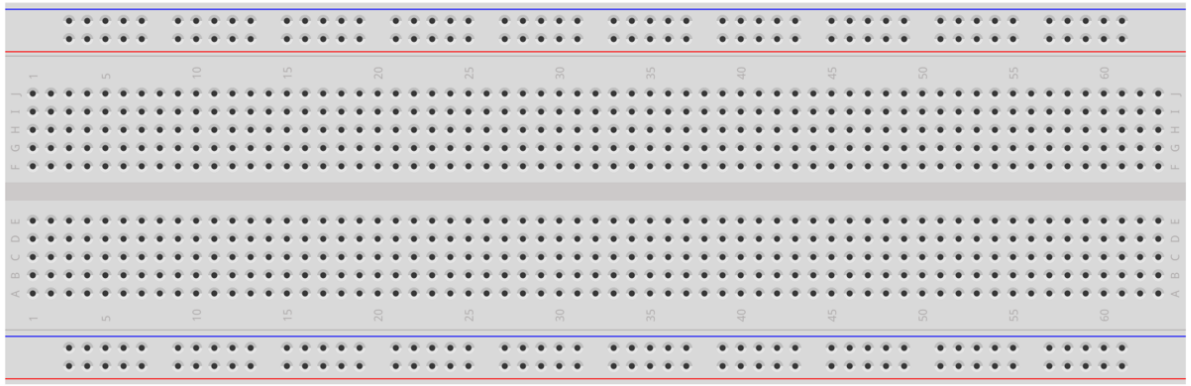
This power rail is one giant wire (or **node**)

CUTAWAY VIEW 2

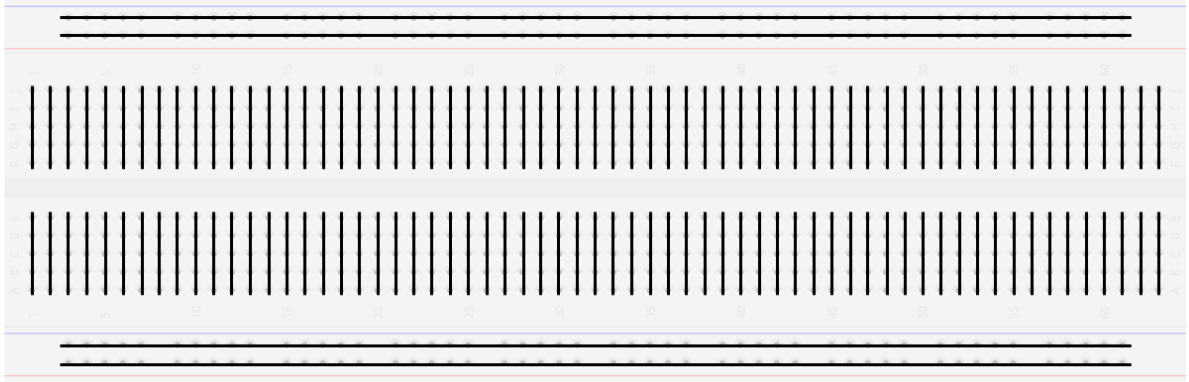


This breadboard has **two power rails** on each side

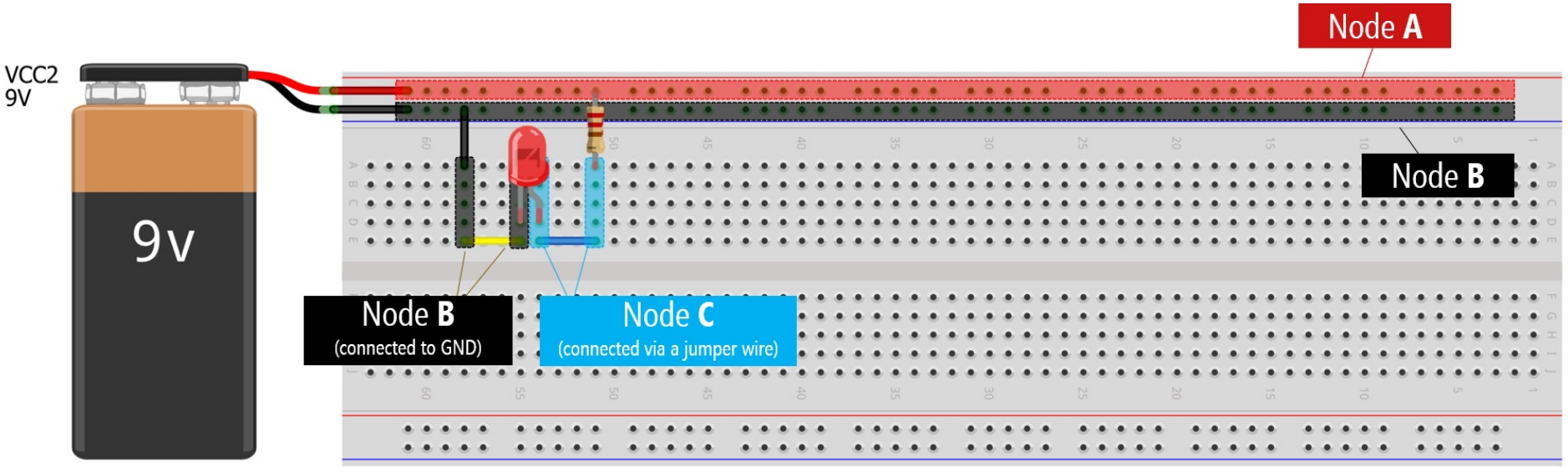
# Prototyping with breadboards

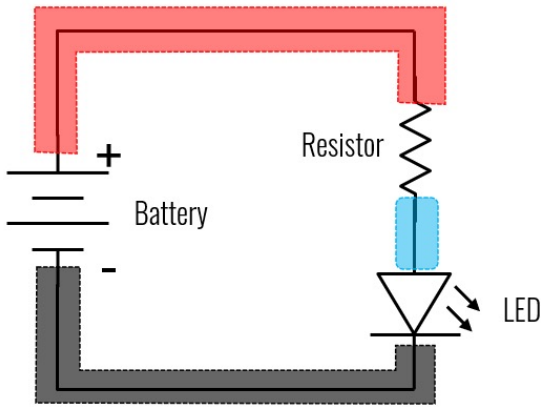


## Internal connections



# Prototyping with breadboards



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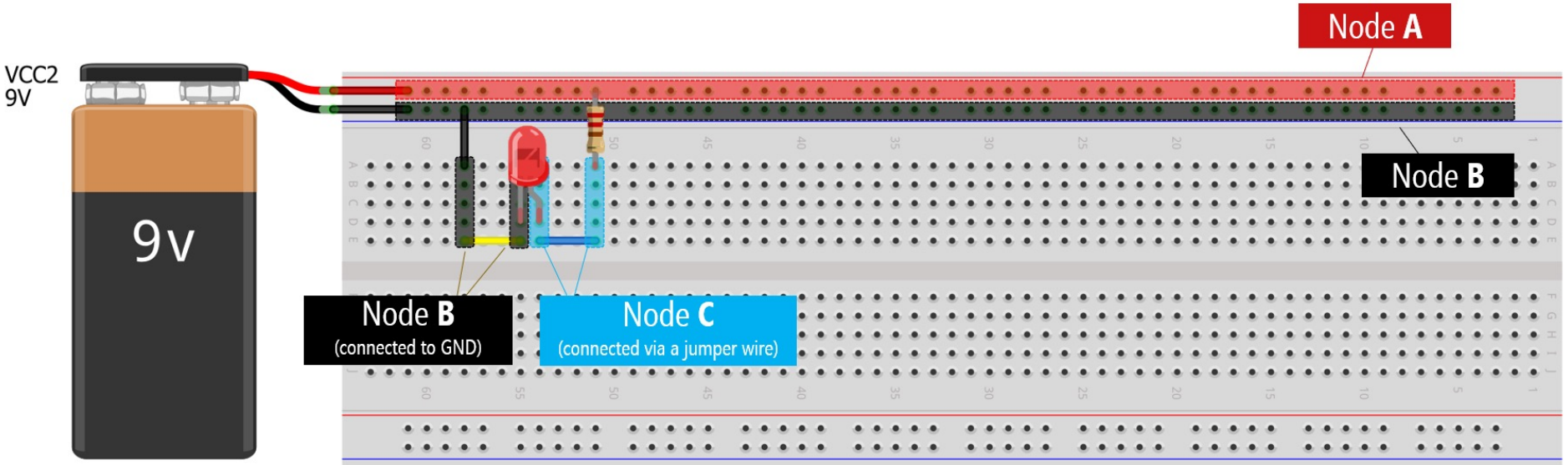
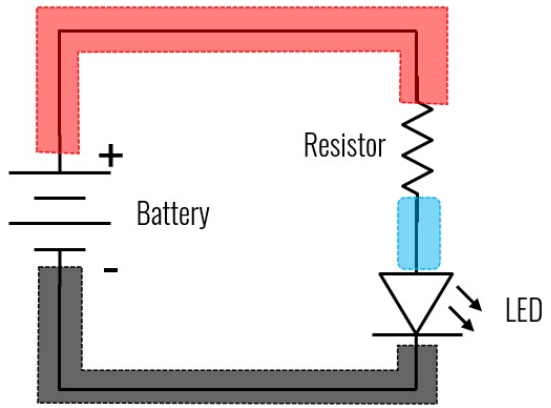
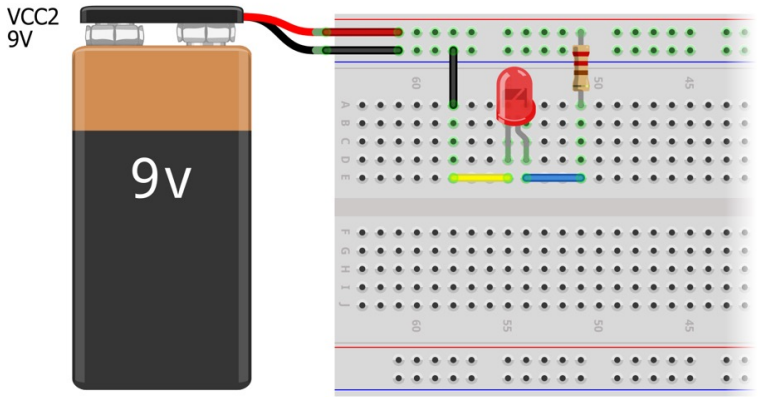
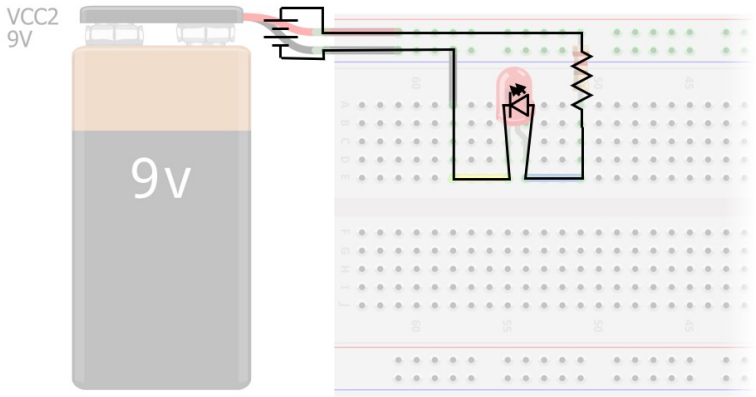


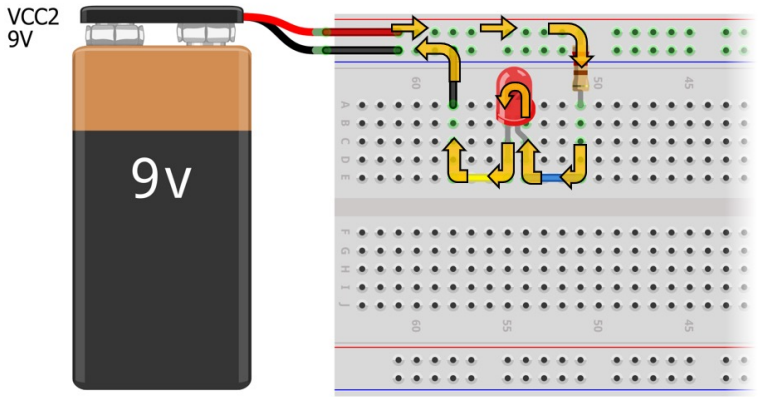

## SIMPLE BREADBOARDED LED CIRCUIT




## UNDERLYING CIRCUIT AND CONNECTIONS



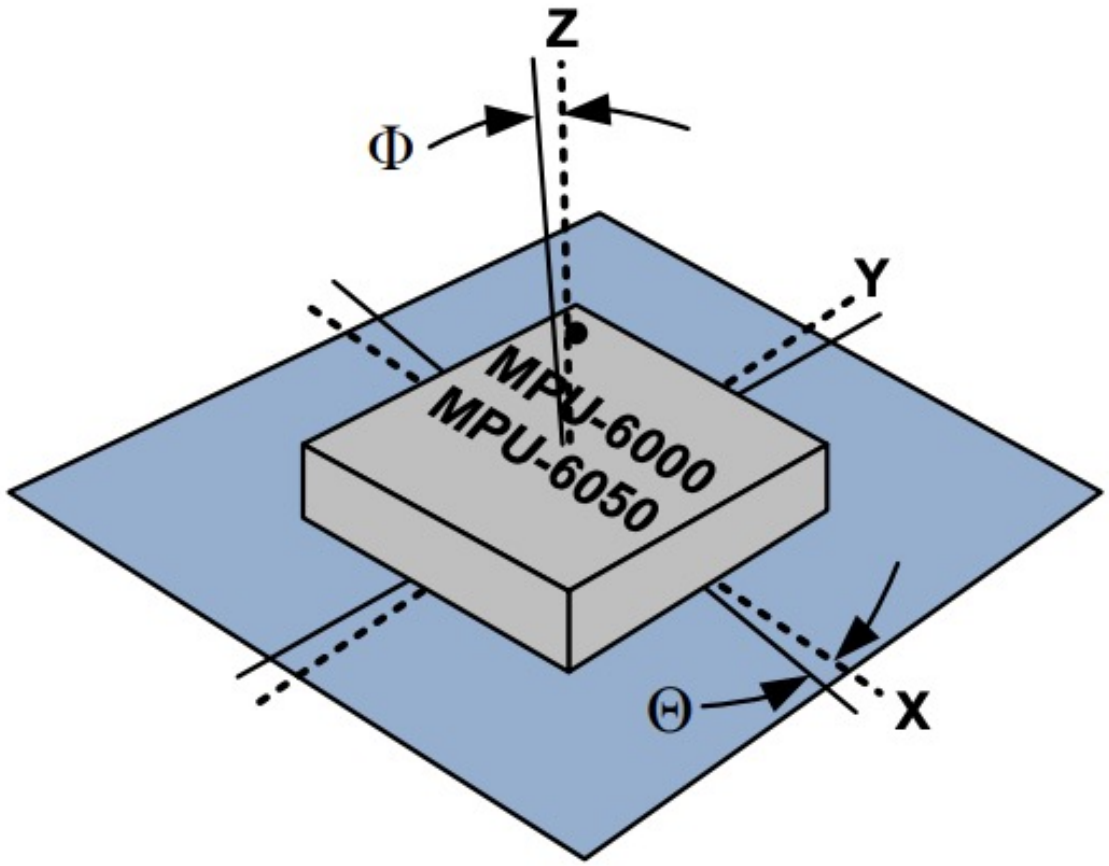

## CURRENT FLOW THROUGH BREADBOARD



# MPU6050: Inertial measurement unit (IMU)

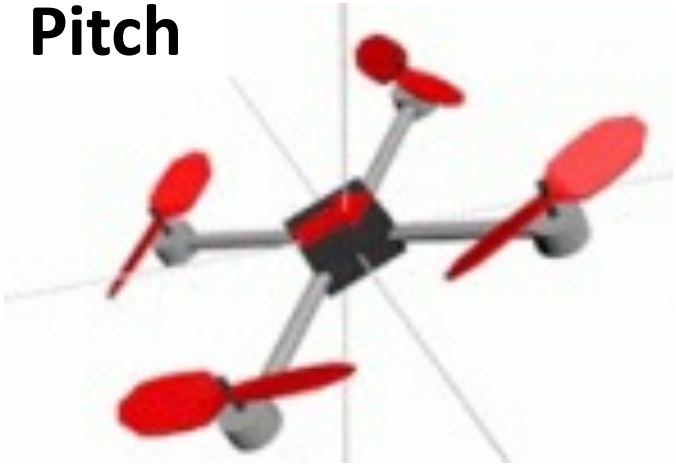
Includes:

- 3 axis Accelerometer- sensor that measures acceleration
- 3 axis Gyroscope- sensor that measures angular acceleration
- Temperature sensor

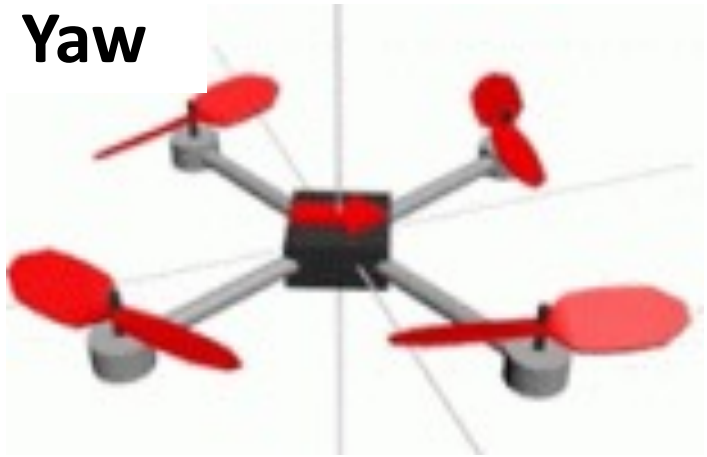


# IMU use case 1: Drones and flying robots

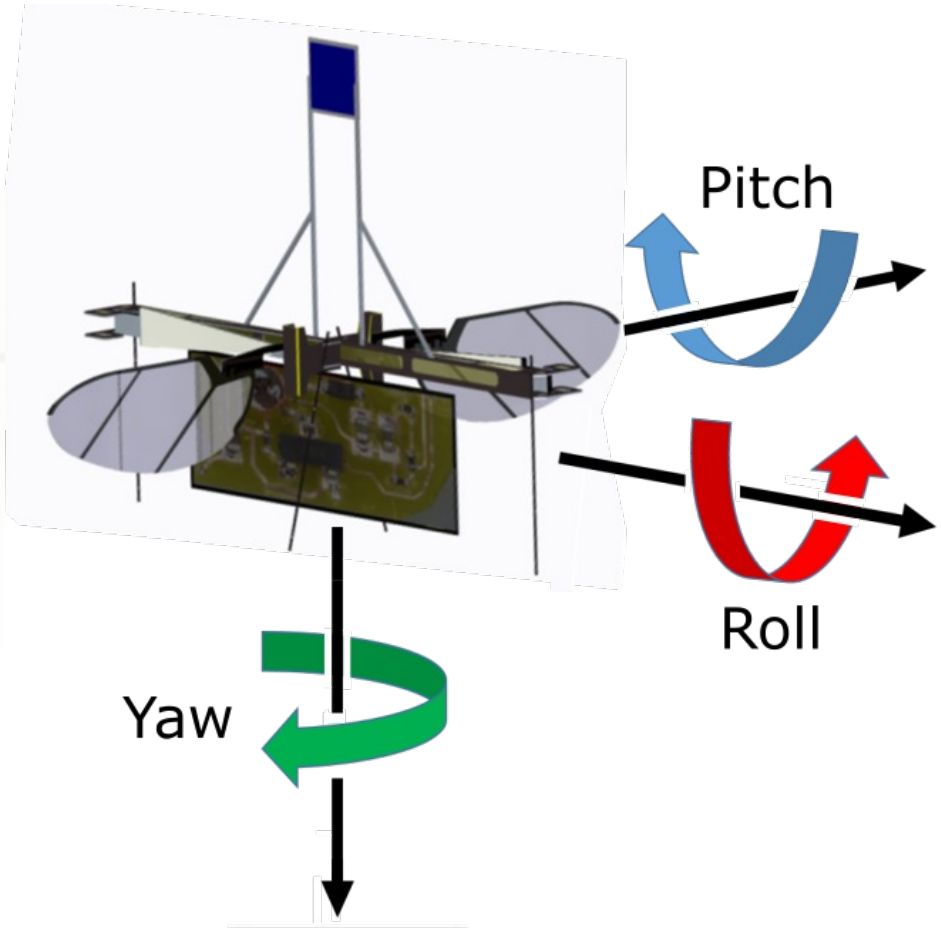
Pitch



Yaw



Roll



# IMU use case 2: Tracking hummingbirds

DEPARTMENT OF BIOLOGY

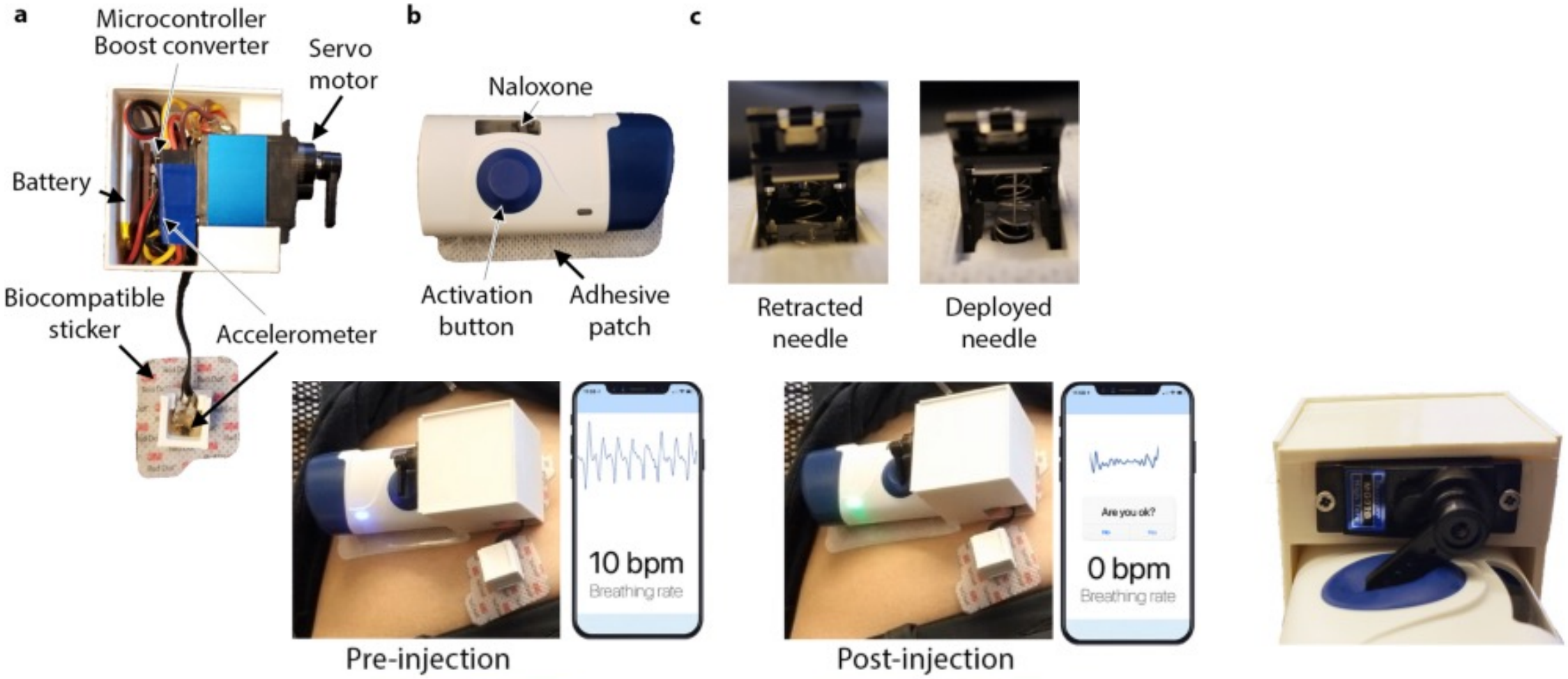
Alejo Rico-Guevera


Alyssa Sargent

Yash Talwekar

Video credit: Alyssa Sargent

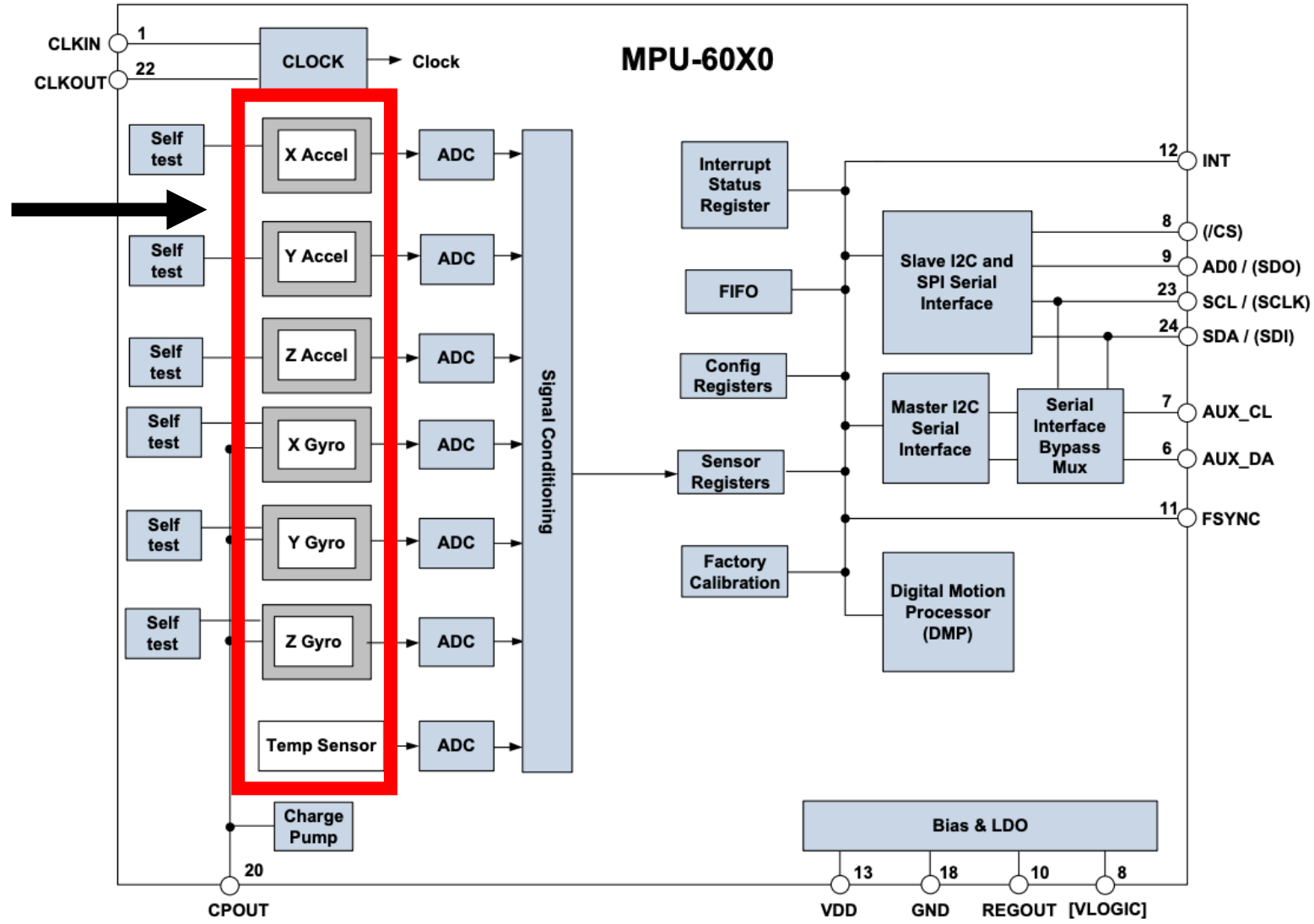
# IMU use case 3: Measuring breathing




J. Chan, V. Iyer, A. Lyness, P. Kooner, J. Sunshine, S. Gollakota. **Closed-loop wearable naloxone injector system**

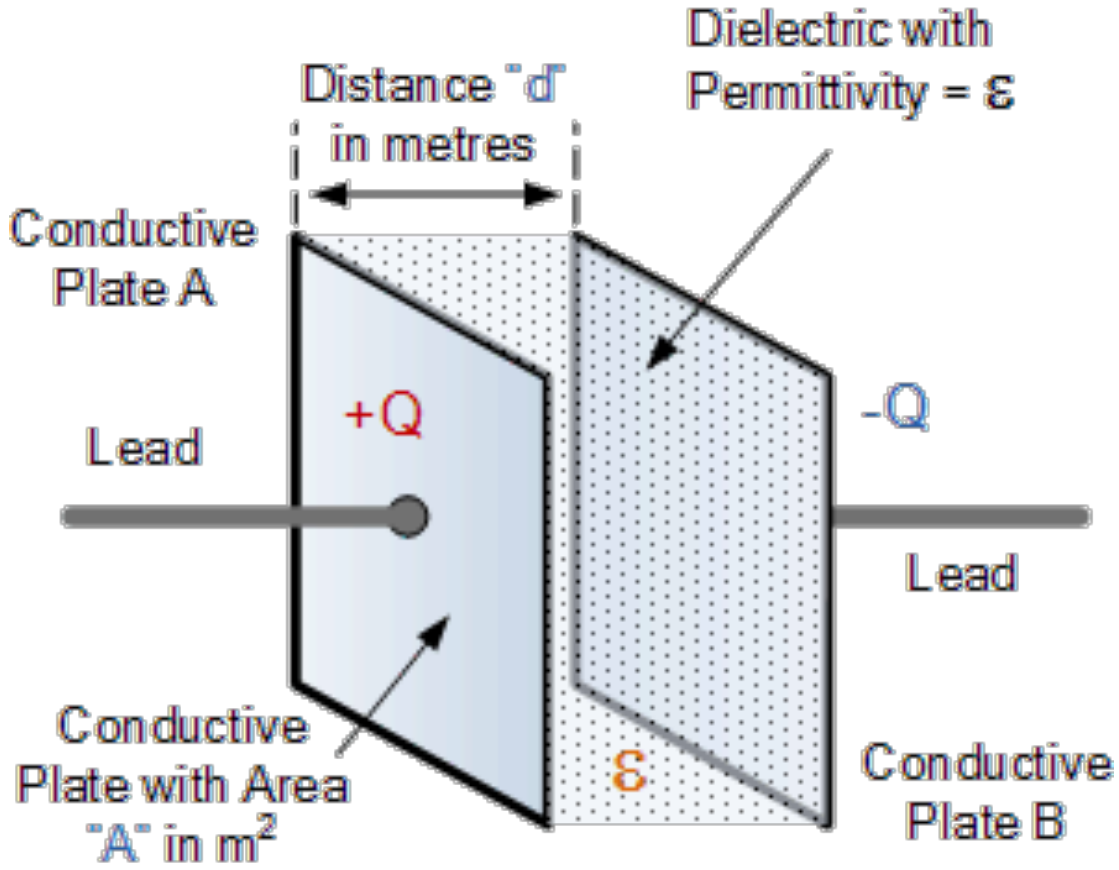
# What's inside the chip?

**Physical sensors**

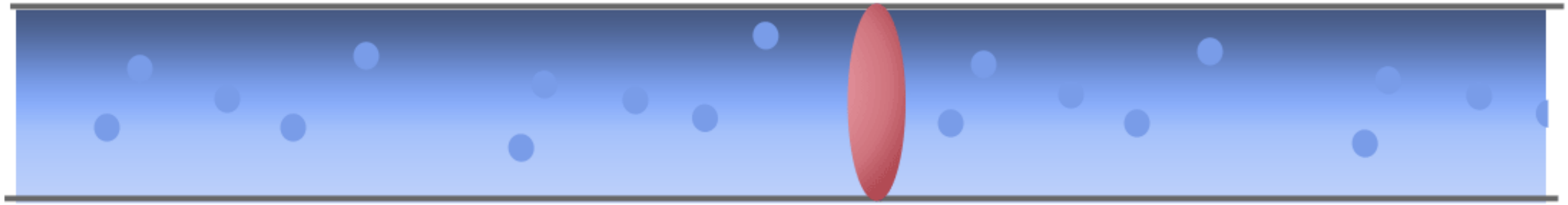


# Capacitors

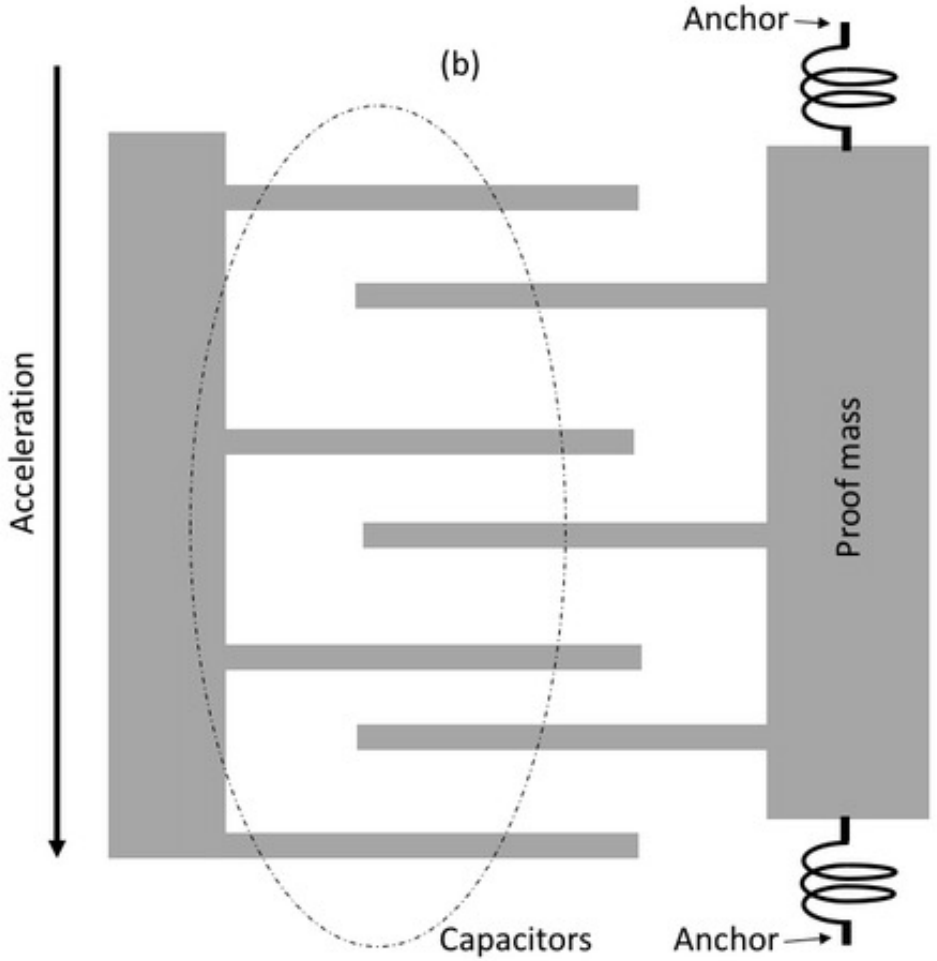
$$C = \frac{\varepsilon A}{d}$$

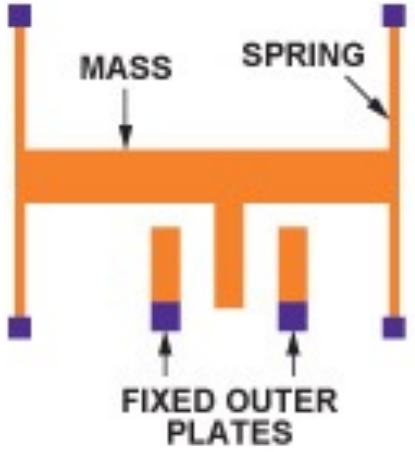


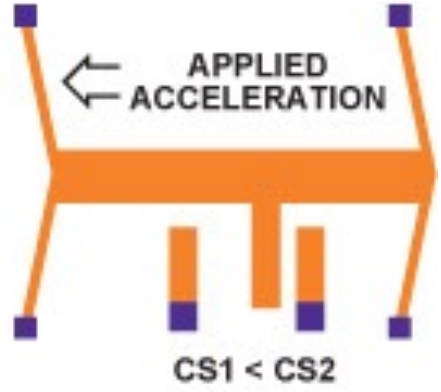

## Analogy: rubber membrane

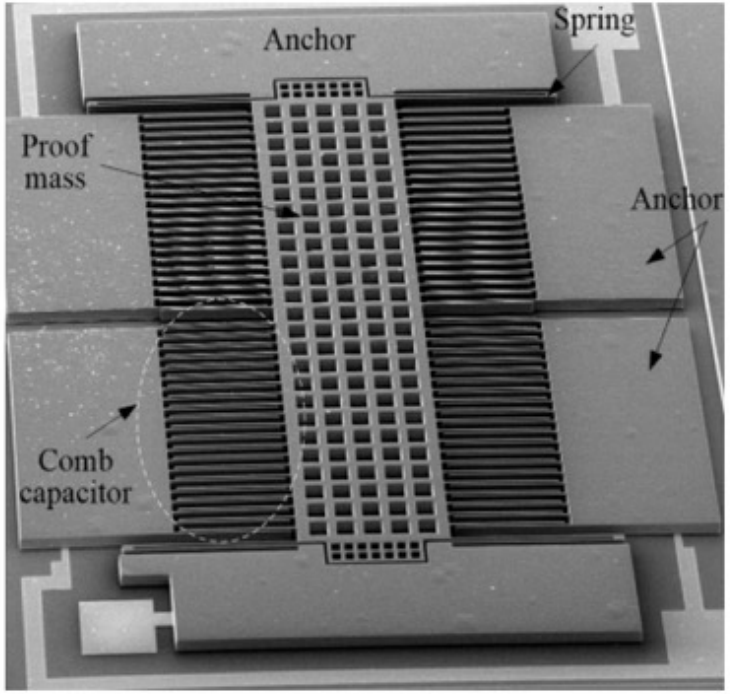


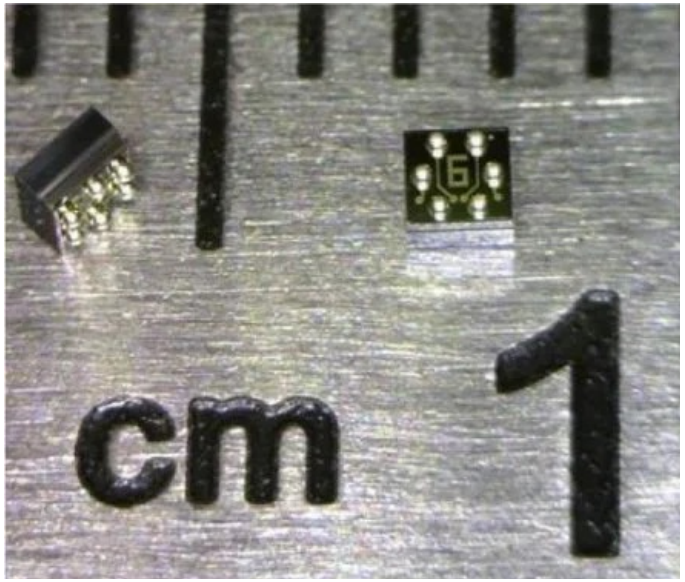
# MEMS Accelerometer



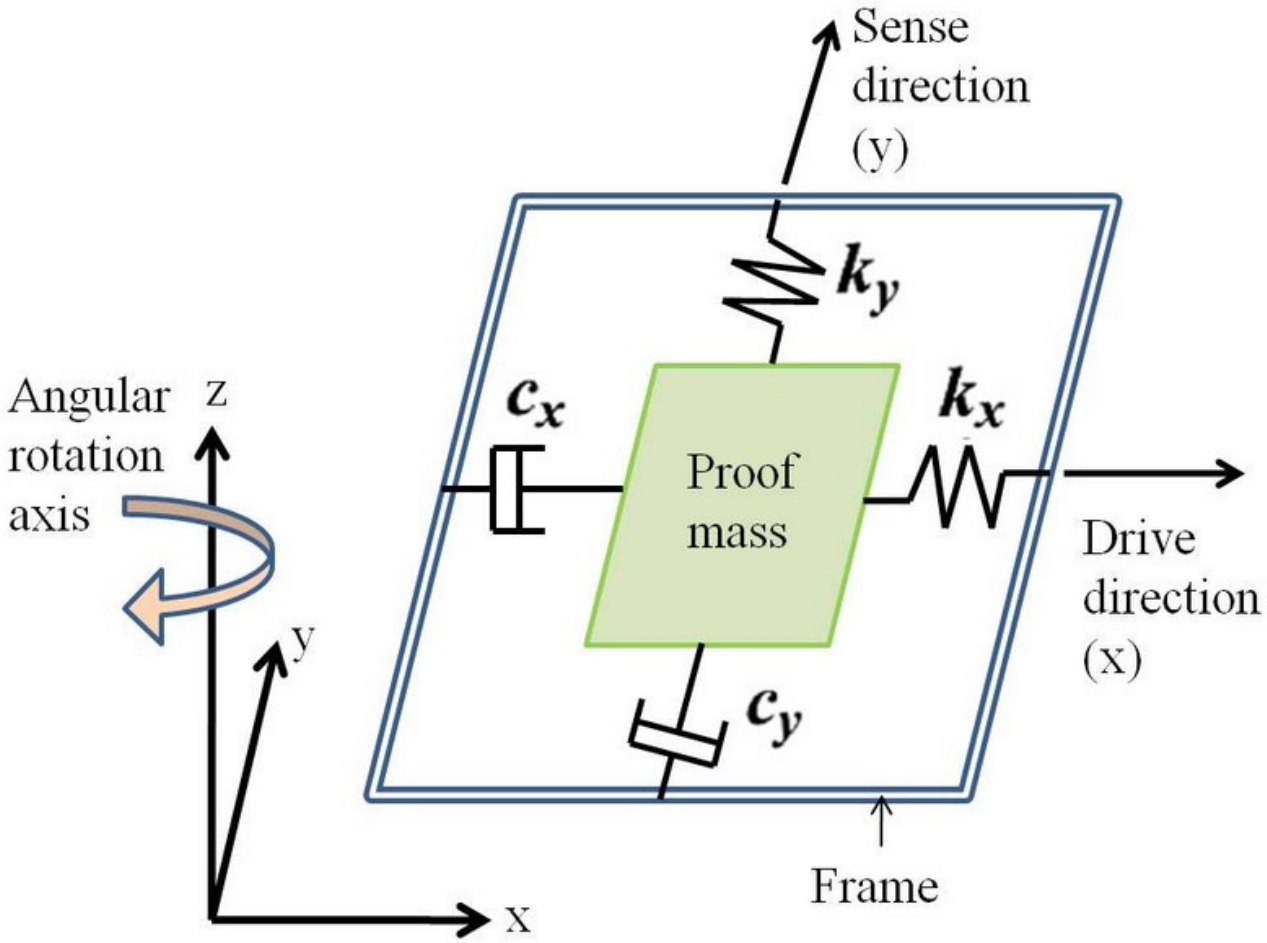



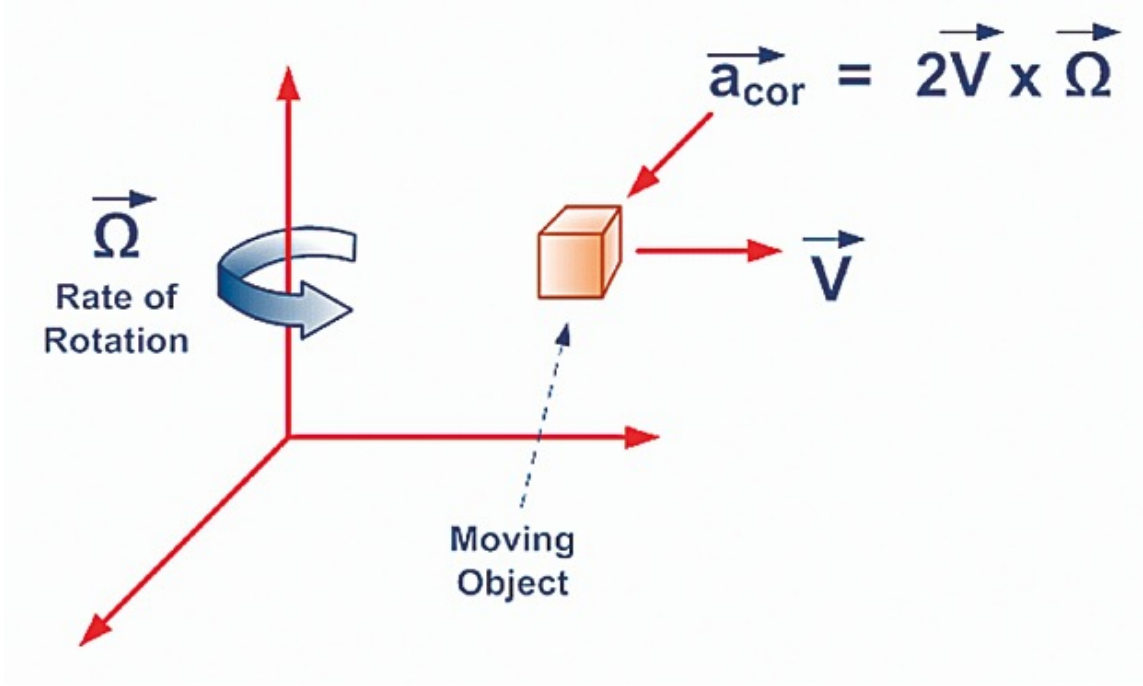



# MEMS Gyroscope




# What's inside the chip?

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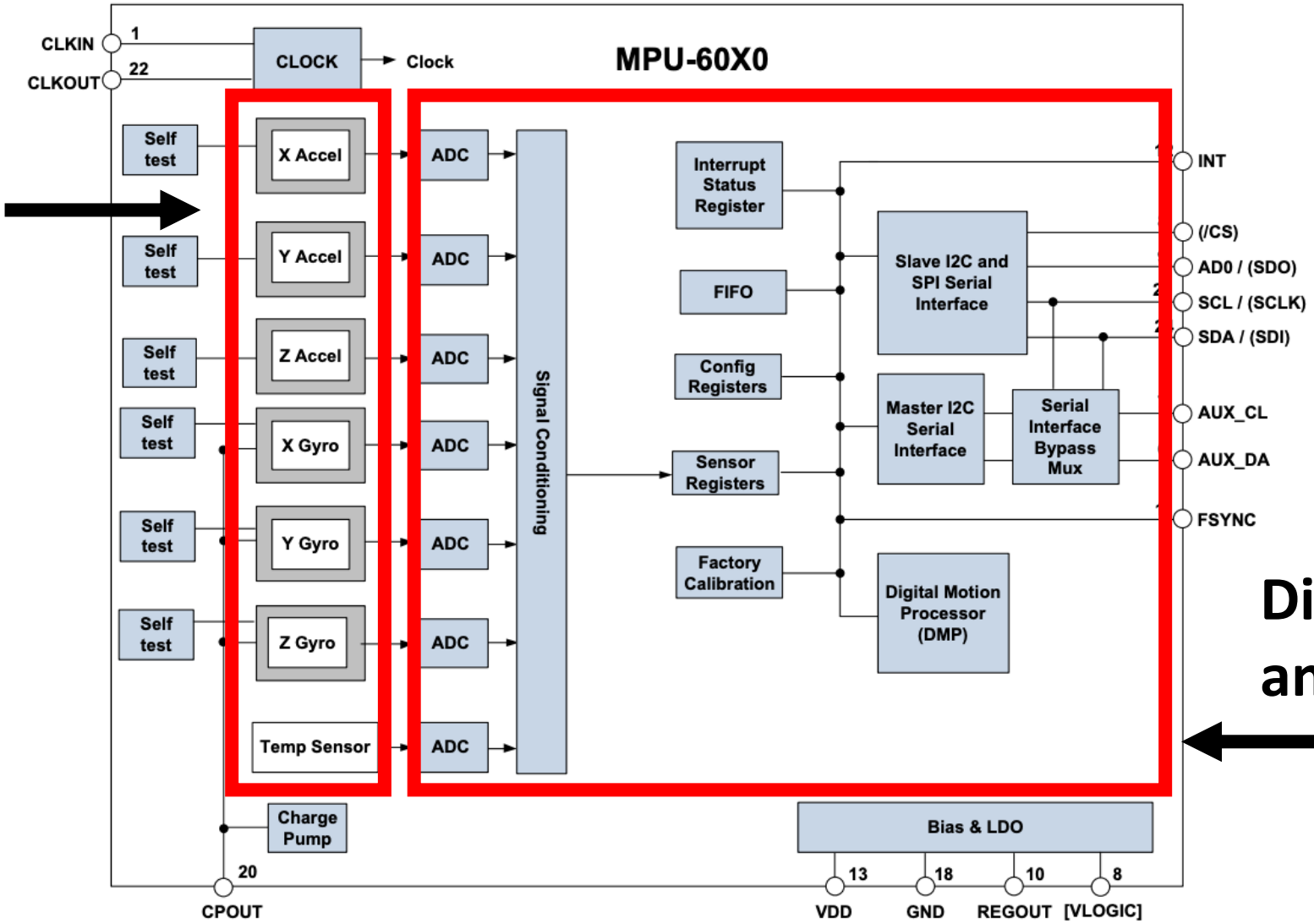


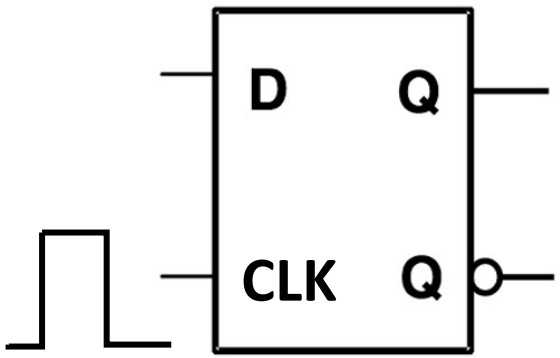

Digital readout and interface

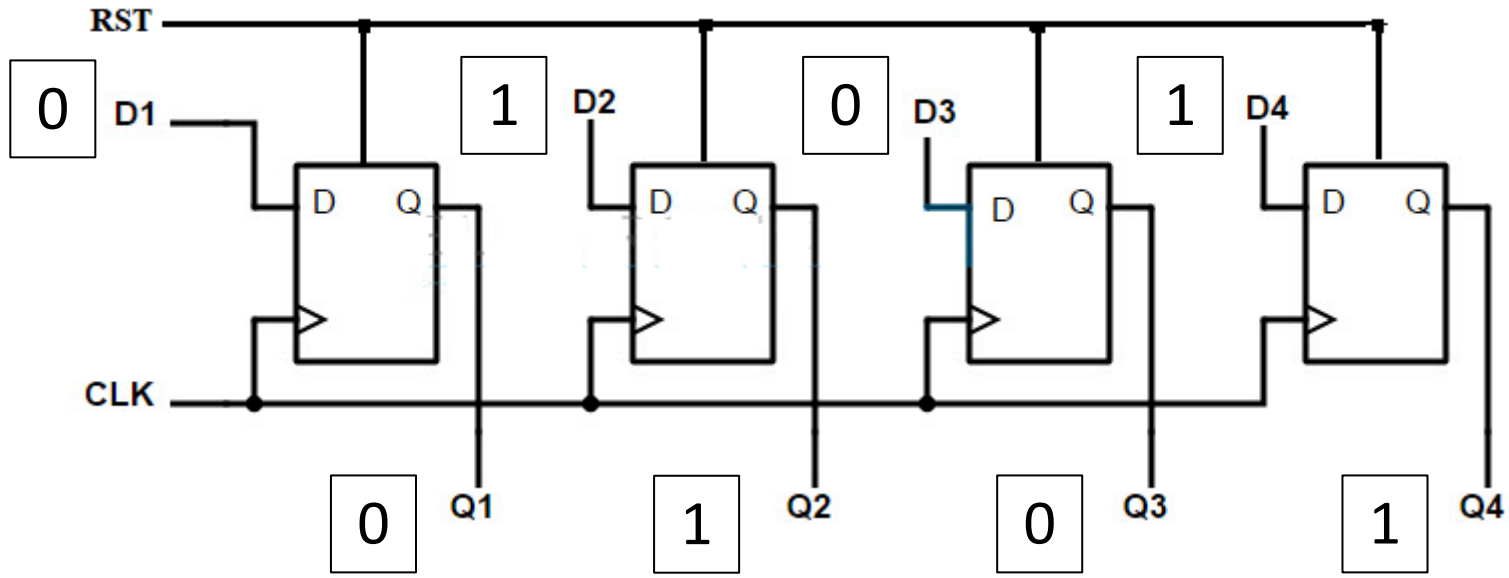
# Registers

Register- an array of D flip-flops which can store a collection of bits

An *n* bit register has *n* inputs, *n* outputs, and one clock line

Flip flop: Memory element that stores 1 bit



# Hardware control registers

ON

OFF

# Hardware control registers

ON

OFF


| Fcn 7 | Fcn 6 | Fcn 5 | Fcn 4 | Fcn 3 | Fcn 2 | Fcn 1 | Fcn 0 |
|---|---|---|---|---|---|---|---|
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |

# Hardware control registers

ON

OFF


| Fcn 7 | Fcn 6 | Fcn 5 | Fcn 4 | Fcn 3 | Fcn 2 | Fcn 1 | Fcn 0 |
|---|---|---|---|---|---|---|---|
| | | | | | | | |

# MPU6050 Register table

| Addr (Hex) | Addr (Dec.) | Register Name | Serial I/F | Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 67 | 103 | I2C_MST_DELAY_CTRL | R/W | DELAY_ES_SHADOW | - | - | I2C_SLV4_DLY_EN | I2C_SLV3_DLY_EN | I2C_SLV2_DLY_EN | I2C_SLV1_DLY_EN | I2C_SLV0_DLY_EN |
| 68 | 104 | SIGNAL_PATH_RESET | R/W | - | - | - | - | - | GYRO_RESET | ACCEL_RESET | TEMP_RESET |
| 6A | 106 | USER_CTRL | R/W | - | FIFO_EN | I2C_MST_EN | I2C_IF_DIS | - | FIFO_RESET | I2C_MST_RESET | SIG_COND_RESET |
| 6B | 107 | PWR_MGMT_1 | R/W | DEVICE_RESET | SLEEP | CYCLE | - | TEMP_DIS | CLKSEL[2:0] | | |
| 6C | 108 | PWR_MGMT_2 | R/W | LP_WAKE_CTRL[1:0] | | STBY_XA | STBY_YA | STBY_ZA | STBY_XG | STBY_YG | STBY_ZG |
| 72 | 114 | FIFO_COUNTH | R/W | FIFO_COUNT[15:8] | | | | | | | |
| 73 | 115 | FIFO_COUNTL | R/W | FIFO_COUNT[7:0] | | | | | | | |
| 74 | 116 | FIFO_R_W | R/W | FIFO_DATA[7:0] | | | | | | | |
| 75 | 117 | WHO_AM_I | R | - | WHO_AM_I[6:1] | | | | | | - |

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| Addr (Hex) | Addr (Dec.) | Register Name | Serial I/F | Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 67 | 103 | I2C_MST_DELAY_CTRL | R/W | DELAY_ES_SHADOW | - | - | I2C_SLV4_DLY_EN | I2C_SLV3_DLY_EN | I2C_SLV2_DLY_EN | I2C_SLV1_DLY_EN | I2C_SLV0_DLY_EN |
| 68 | 104 | SIGNAL_PATH_RESET | R/W | - | - | - | - | - | GYRO_RESET | ACCEL_RESET | TEMP_RESET |
| 6A | 106 | USER_CTRL | R/W | - | FIFO_EN | I2C_MST_EN | I2C_IF_DIS | - | FIFO_RESET | I2C_MST_RESET | SIG_COND_RESET |
| 6B | 107 | PWR_MGMT_1 | R/W | DEVICE_RESET | SLEEP | CYCLE | - | TEMP_DIS | CLKSEL[2:0] | | |
| 6C | 108 | PWR_MGMT_2 | R/W | LP_WAKE_CTRL[1:0] | | STBY_XA | STBY_YA | STBY_ZA | STBY_XG | STBY_YG | STBY_ZG |
| 72 | 114 | FIFO_COUNTH | R/W | FIFO_COUNT[15:8] | | | | | | | |
| 73 | 115 | FIFO_COUNTL | R/W | FIFO_COUNT[7:0] | | | | | | | |
| 74 | 116 | FIFO_R_W | R/W | FIFO_DATA[7:0] | | | | | | | |
| 75 | 117 | WHO_AM_I | R | - | WHO_AM_I[6:1] | | | | | | - |

# 4.28 Register 107 – Power Management 1 PWR_MGMT_1

## Type: Read/Write

| Register (Hex) | Register (Decimal) | Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
|---|---|---|---|---|---|---|---|---|---|
| 6B | 107 | DEVICE_RESET | SLEEP | CYCLE | - | TEMP_DIS | CLKSEL[2:0] | | |

## Description:

This register allows the user to configure the power mode and clock source. It also provides a bit for resetting the entire device, and a bit for disabling the temperature sensor.

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# PWR_MGMT_1

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| 6B | 107 | DEVICE_RESET | SLEEP | CYCLE | - | TEMP_DIS | CLKSEL[2:0] | | |

## Parameters:

*DEVICE_RESET* When set to 1, this bit resets all internal registers to their default values.

The bit automatically clears to 0 once the reset is done.

The default values for each register can be found in Section 3.

*SLEEP* When set to 1, this bit puts the MPU-60X0 into sleep mode.

*CYCLE* When this bit is set to 1 and *SLEEP* is disabled, the MPU-60X0 will cycle between sleep mode and waking up to take a single sample of data from active sensors at a rate determined by *LP_WAKE_CTRL* (register 108).

*TEMP_DIS* When set to 1, this bit disables the temperature sensor.

*CLKSEL* 3-bit unsigned value. Specifies the clock source of the device.

# 4.18 Registers 65 and 66 – Temperature Measurement TEMP_OUT_H and TEMP_OUT_L

**Type: Read Only**

| Register (Hex) | Register (Decimal) | Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 |
|---|---|---|---|---|---|---|---|---|---|
| 41 | 65 | TEMP_OUT[15:8] | | | | | | | |
| 42 | 66 | TEMP_OUT[7:0] | | | | | | | |

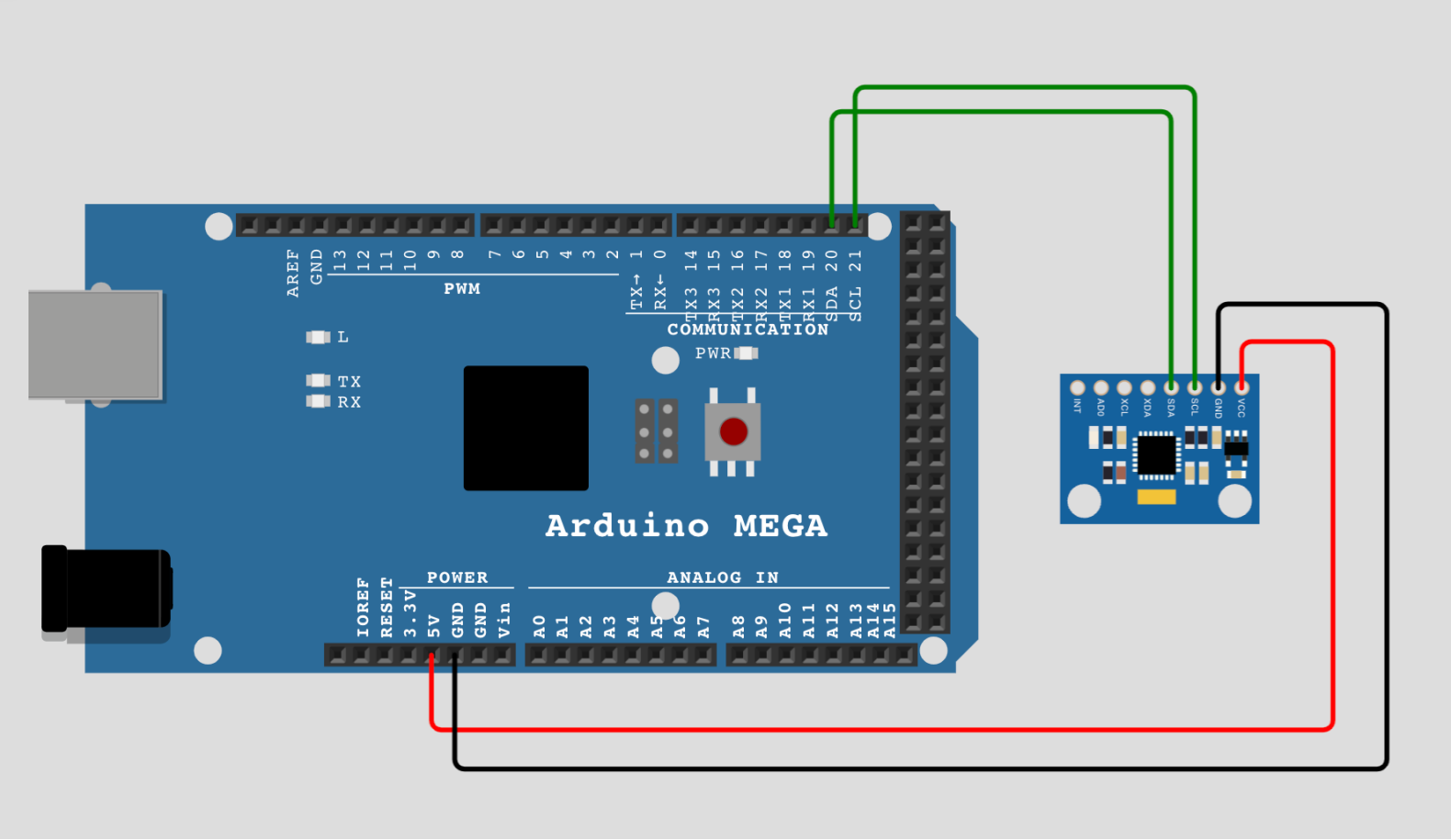
**Description:**

These registers store the most recent temperature sensor measurement.

The temperature in degrees C for a given register value may be computed as:

Temperature in degrees C = (TEMP_OUT Register Value as a signed quantity)/340 + 36.53

# Wiring the MPU6050 to the Arduino




Note: I2C connections typically require pull up resistors but those are omitted here for simplicity (we have confirmed this setup will work). We'll discuss what t