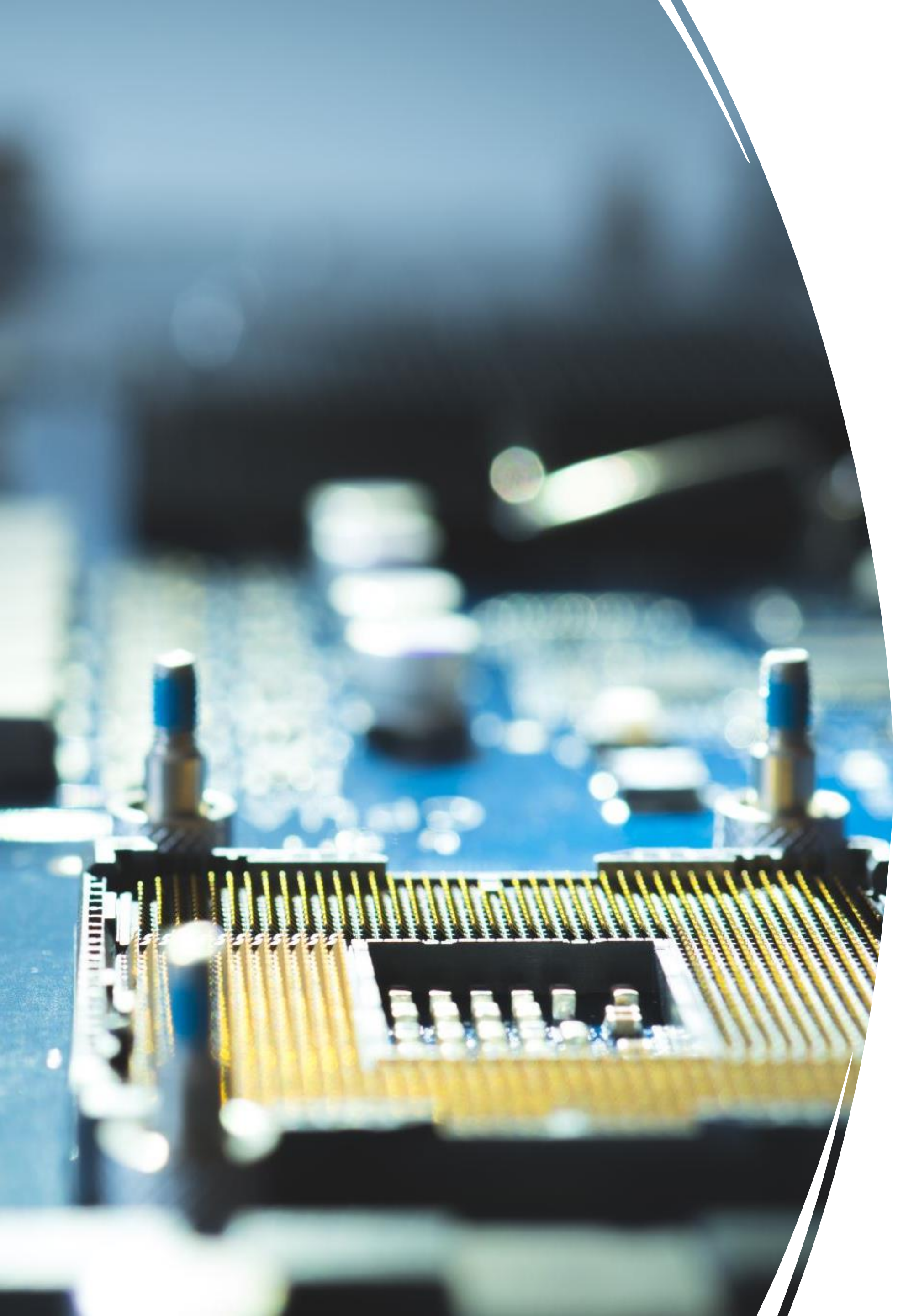
Lecture 3 :

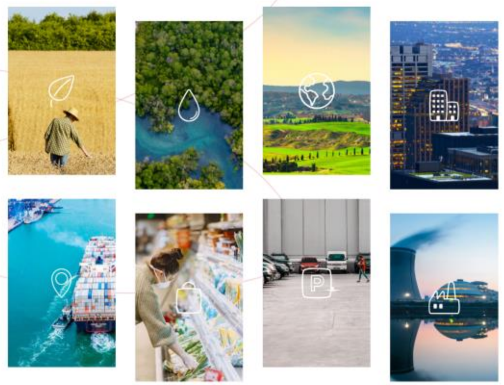
IoT Devices & Hardware Components

ดร.ธนวิชญ์ อนุวงศ์พินิจ

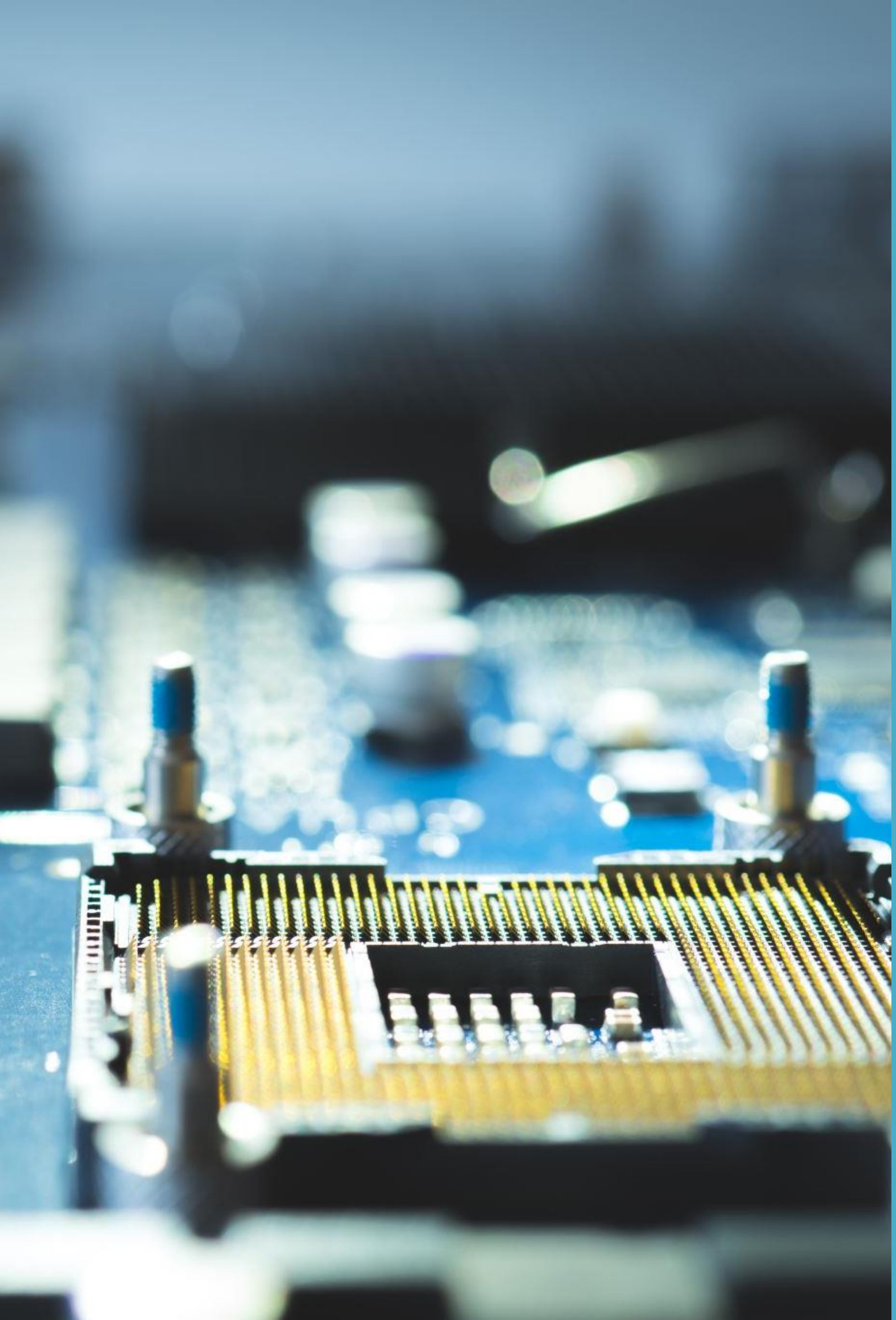
ภาควิชาวิศวกรรมคอมพิวเตอร์ (วิศวกรรมระบบไอโอทีและสารสนเทศ)

คณะวิศวกรรมศาสตร์ สถาบันเทคโนโลยีพระจอมเกล้าเจ้าคุณทหารลาดกระบัง





IoT Devices & Hardware Components



IoT devices

- An IoT device is typically made up of a circuit board with sensors attached that use WiFi to connect to the internet. For example:
  - A pressure sensor on a remote oil pump.
  - Temperature and humidity sensors in an air-conditioning unit.
  - An accelerometer in an elevator.
  - Presence sensors in a room.

How do you build IoT things?

IoT is a synthesis of hardware and software

- Software implementation plus a collection of attached circuits

Not enough to understand Arduino programming

- Good designers know the system they are building on
- Underlying algorithms, protocols, architectures
- External interfaces, APIs, components

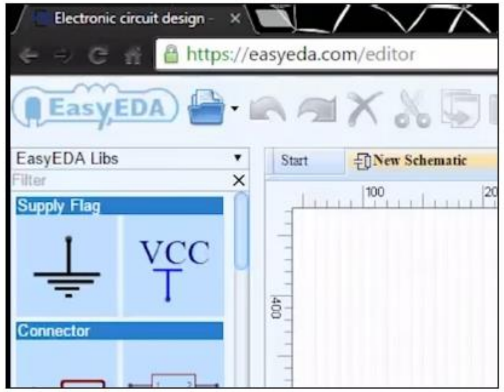
Roadmap : หากเราต้องการสร้างระบบหรืออุปกรณ์ IoT

- **การออกแบบและพัฒนา IoT Hardware**
  - องค์ประกอบของระบบ/อุปกรณ์, sensors/actuators, วงจรหรือ IC ที่จะนำมาใช้
  - ไมโครคอนโทรลเลอร์ (microcontrollers), ที่เก็บข้อมูล (storage), หน่วยความจำ (Memory), บอร์ดทดลอง
- **การศึกษาและประยุกต์ใช้/พัฒนา IoT Platforms**
  - Arduino, Raspberry PI, Amazon (AWS), Microsoft Azure, Google Cloud, Netpie, etc.,
  - การออกแบบ สถาปัตยกรรม (Designs, architectures)
- **การศึกษาการเขียนโปรแกรม (Programming)**
  - Arduino Programming, Other programming Language (C/C++/Python), Development workflow, language, API, coding examples
- **การศึกษากรณีศึกษา Case Studies**
  - Deployment scenarios: Smart Home, Smart buildings, smart retail, Smart Farming, etc.

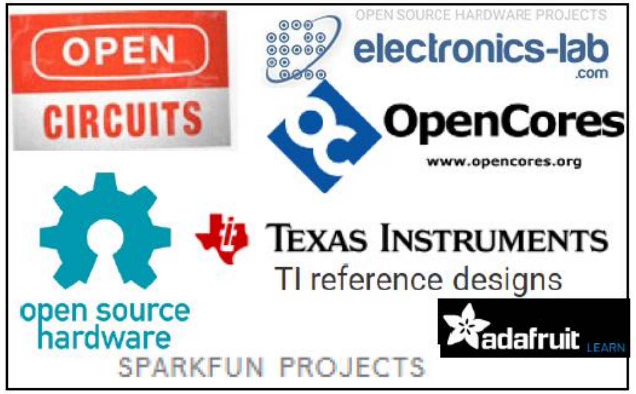
We Are Going through a Hardware Revolution

- Low-cost, componentized hardware enables rapid prototyping without advanced electrical engineering knowledge

Componentized Circuits



Cloud-Based Fabrication

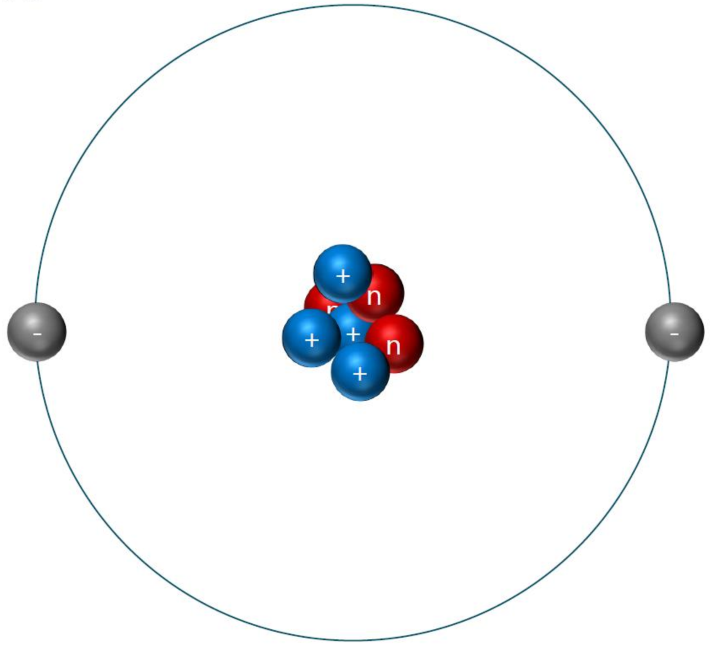


Open-Source Schematics

- This lecture: What You Need to Know to Build IoT Hardware Systems
  - Electricity Fundamentals, basic electronics components, sensors

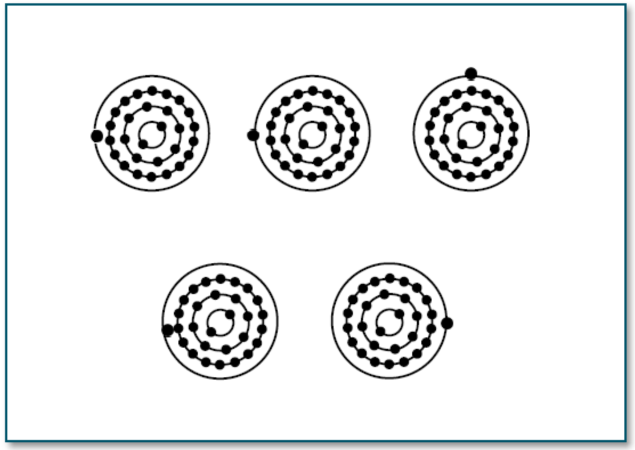
Background: Atoms

- Made of protons, neutrons, and electrons
- In materials, nucleus held in fixed position
- Some electrons are also fixed
- But some electrons may be free to “move”

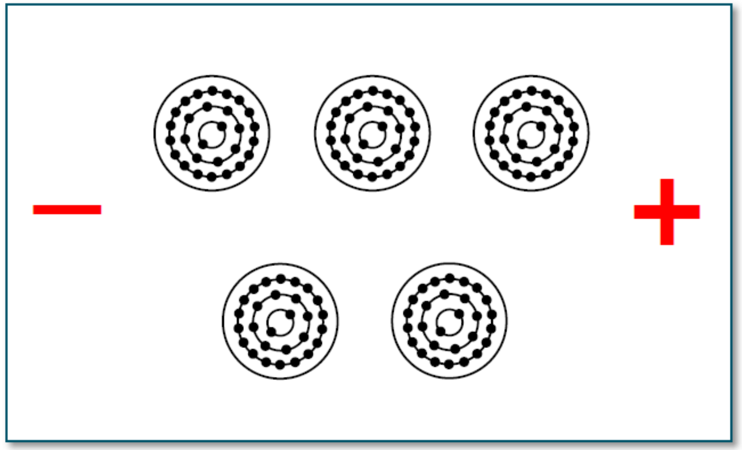


Background: Electrical Current

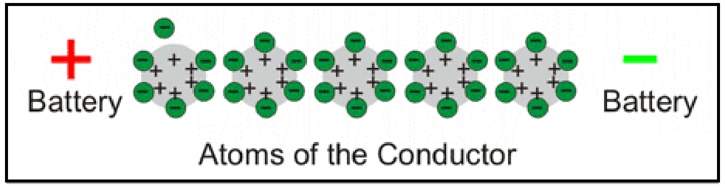
- Usually free electrons hop around randomly
- However, outside forces can encourage them to flow in a particular direction
  - Magnetic field, charge differential →this is called **current**
  - We can vary properties of current to transmit information (via waves, like dominos, as electron **drift velocities** are very slow)



No charge differential

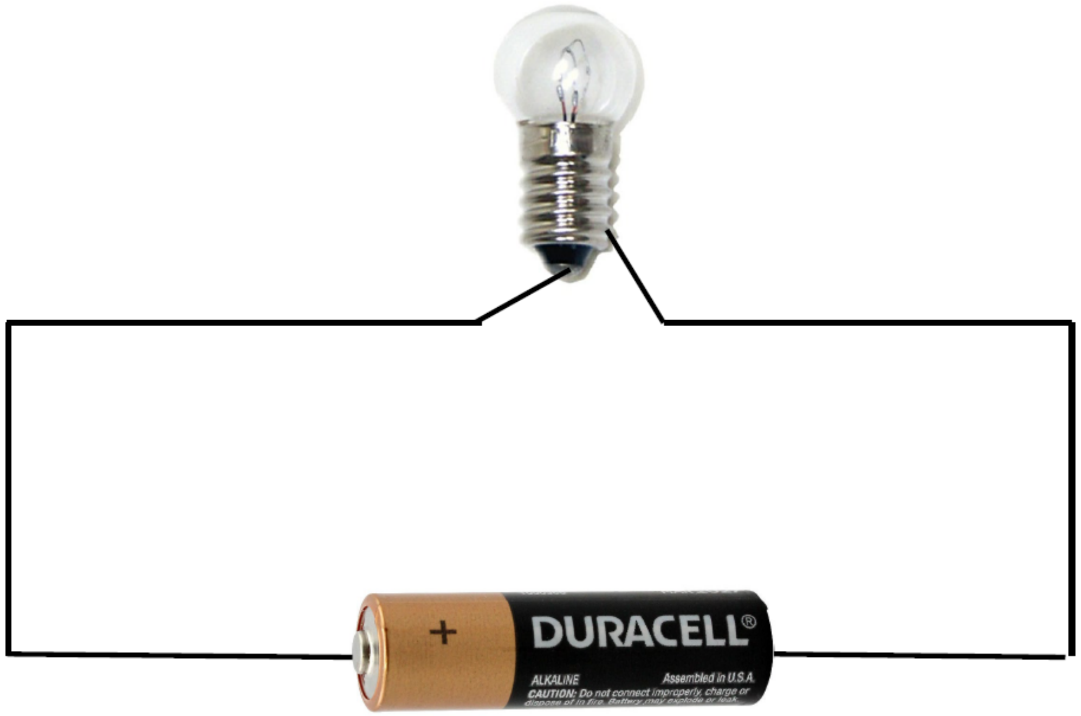


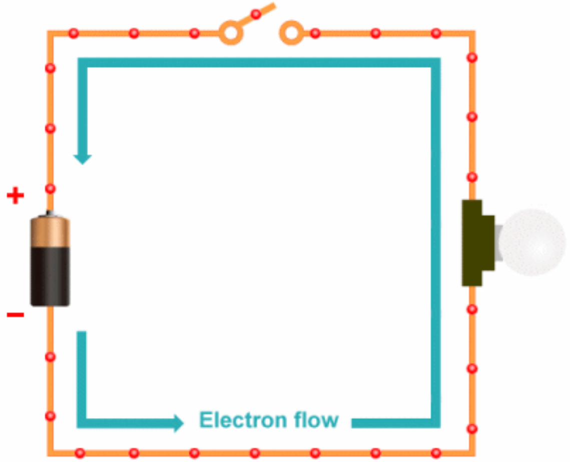
Charge differential



Electricity occurs when electrons in atoms jump from one atom to another.

Making an Electrical "Circuit"





Ohm's Law (V = IR)
One Volt can push a current of one Ampere through a resistance of one Ohm.

Electric current

The flow of electrons jumping between atoms from a negatively charged to a positively charged point is called **electric current** (I). You may think of electric current as like water flowing from a higher to a lower point. Electrical current is measured in **Amperes**. One Ampere represents the flow of one Coulomb of charge per second.

Voltage

ความแตกต่างระหว่างประจุไฟฟ้าระหว่างจุดสองจุดเรียกว่า แรงดันไฟฟ้า voltage (V).

The greater the charge difference (voltage) between two points, the higher the electrical current that will flow. The unit for voltage is the Volt.

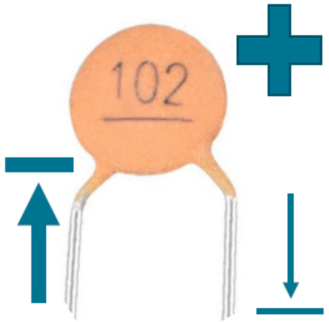
Electrical Current Can Be Manipulated

- It is possible to take current and change it

Example: Resistor

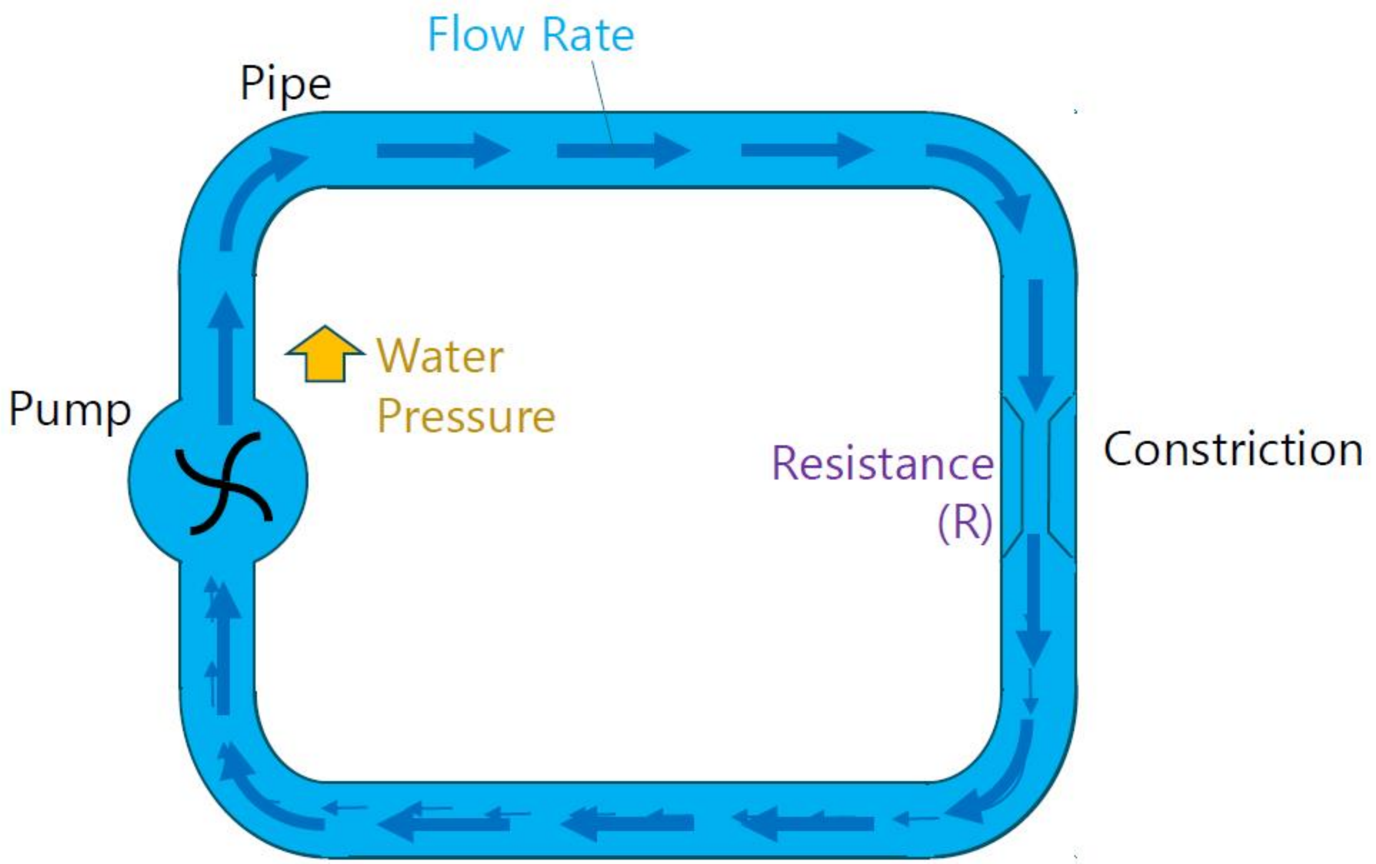
Reduces flow rate of electricity

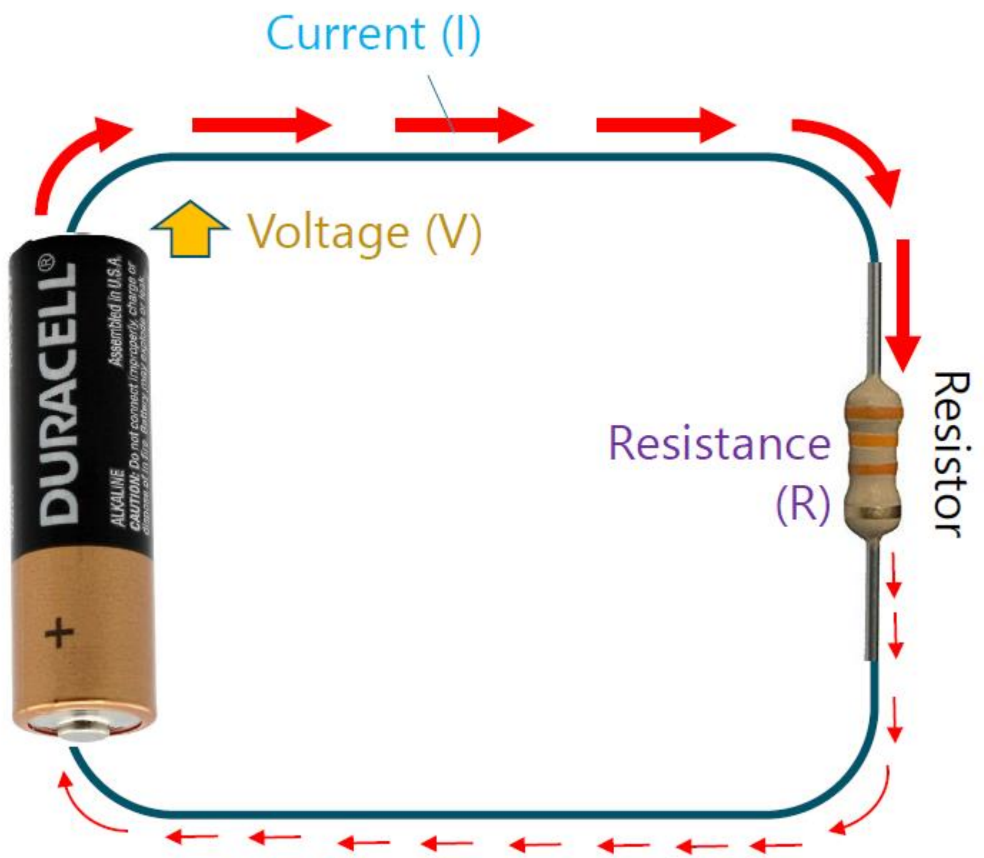
Example: Capacitor



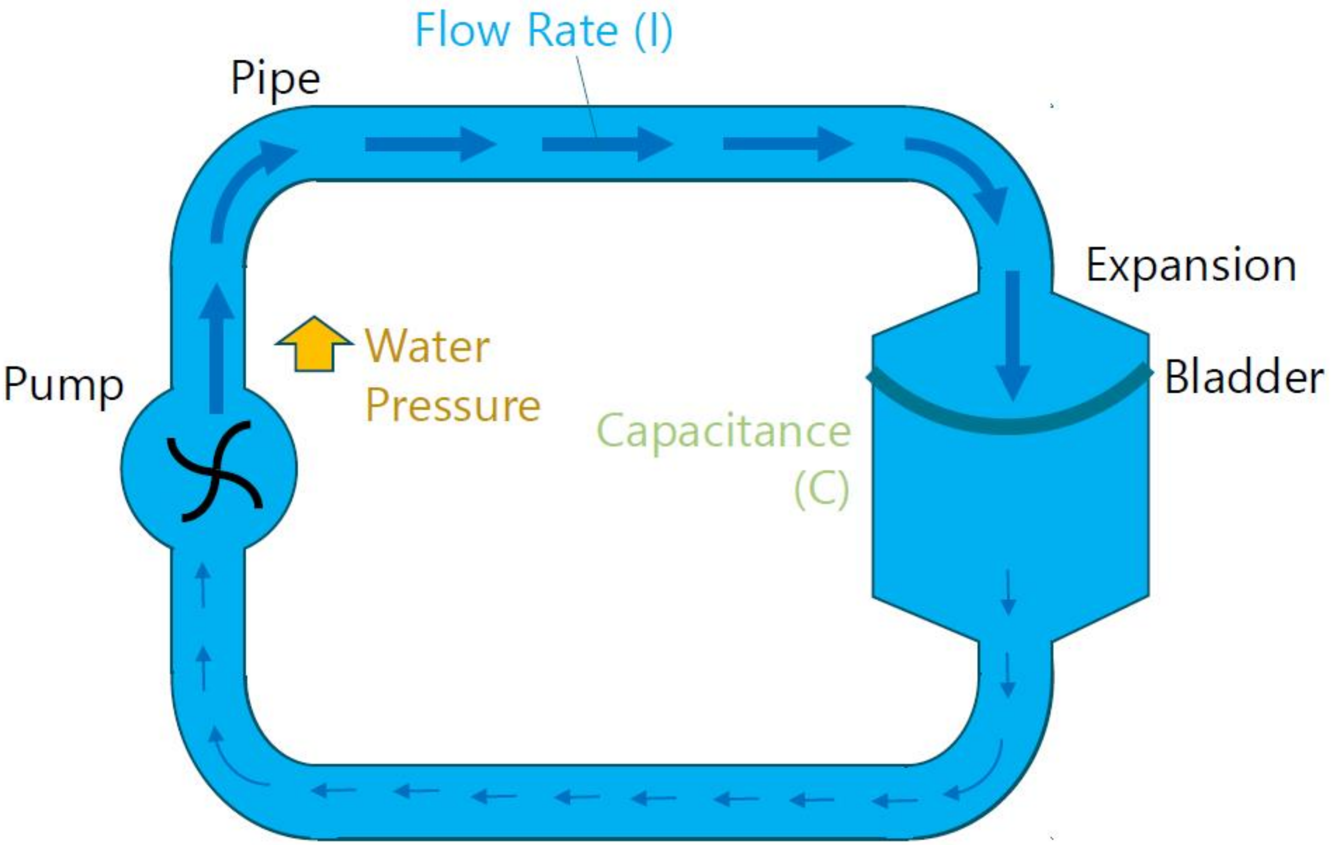
Stores electrical “charge”

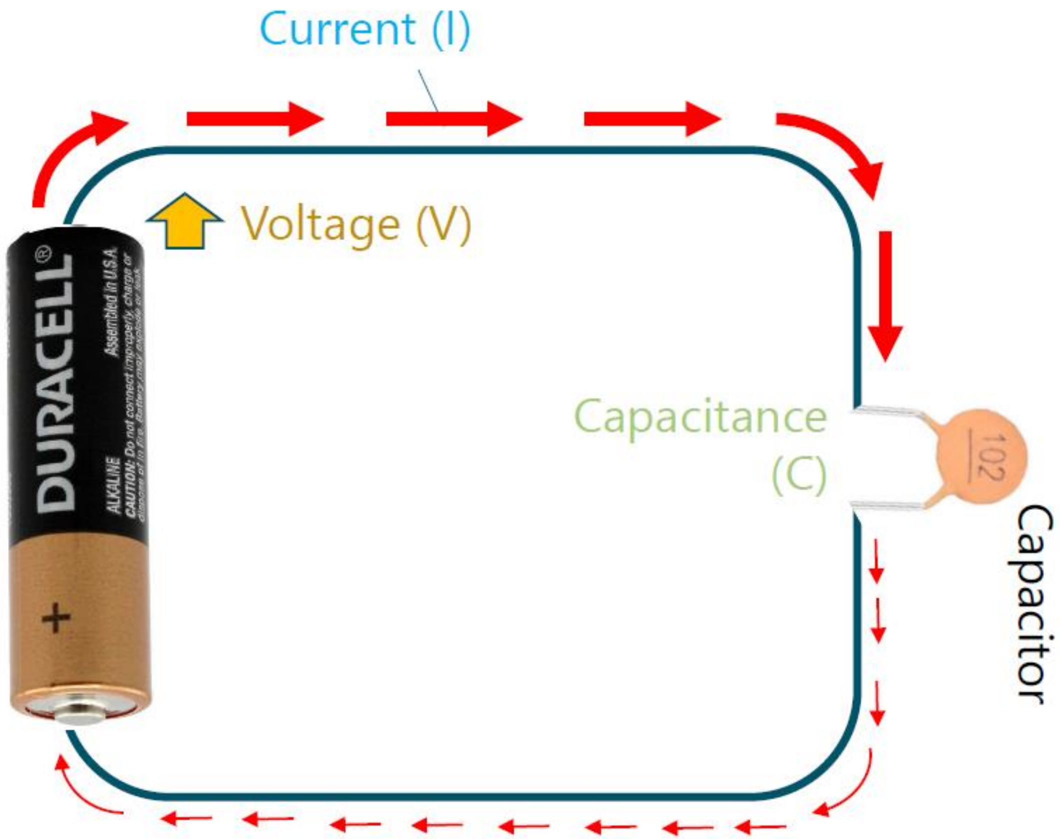
Flowing Electricity Is Like Flowing Water





Water Analogy: Capacitance





Electrical Components


Resistor


Capacitor


Potentiometer

Transistor


Relay


Diode


Photocell


Light-Emitting Diode (LED)


Crystal Oscillator


DC Fan


Speaker


Motor


Piezo Buzzer


7-Segment Display

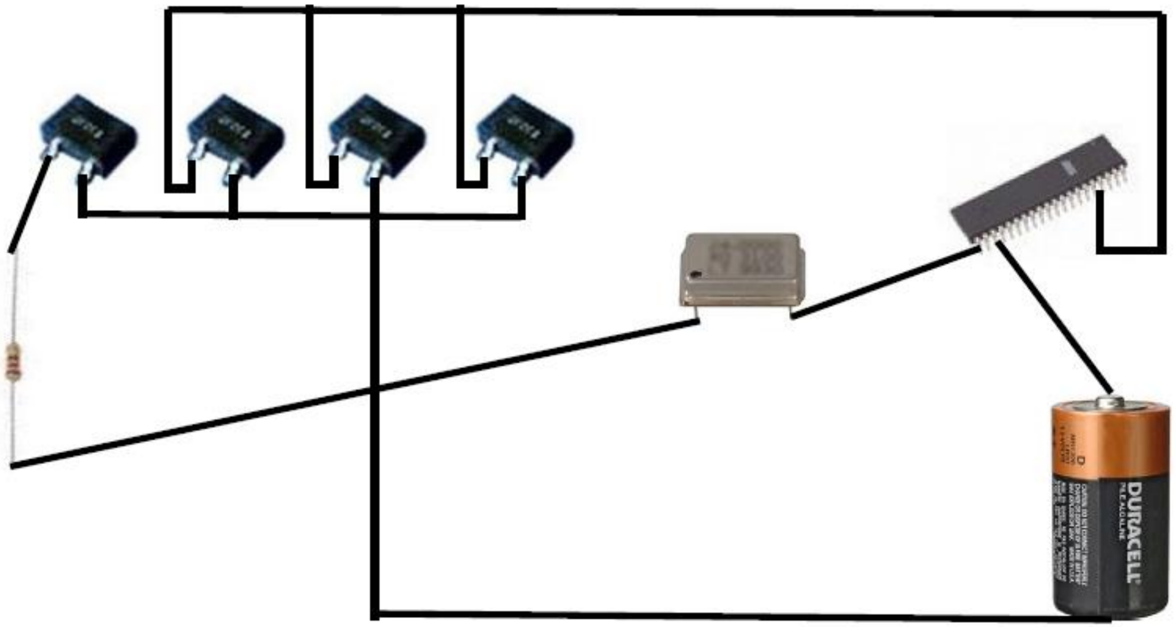

Toggle Switch

AA Battery


Electrical Ground

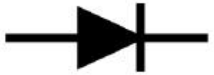
How to draw a circuit?

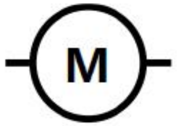
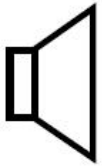
Video : How to read a schematic
https://www.youtube.com/watch?v=_HZ-EQ8Hc8E



- Need to remember our designs, show to others
- Need to clearly describe what each component is, properties of component, which pins are connected, etc.

Electronic Symbols

Name	Picture	Symbol
Resistor		
Capacitor		
Diode		
Transistor		
Oscillator		

Name	Picture	Symbol
Electric Motor		
Speaker		
Voltage Source		
Switch		
Electrical Ground		

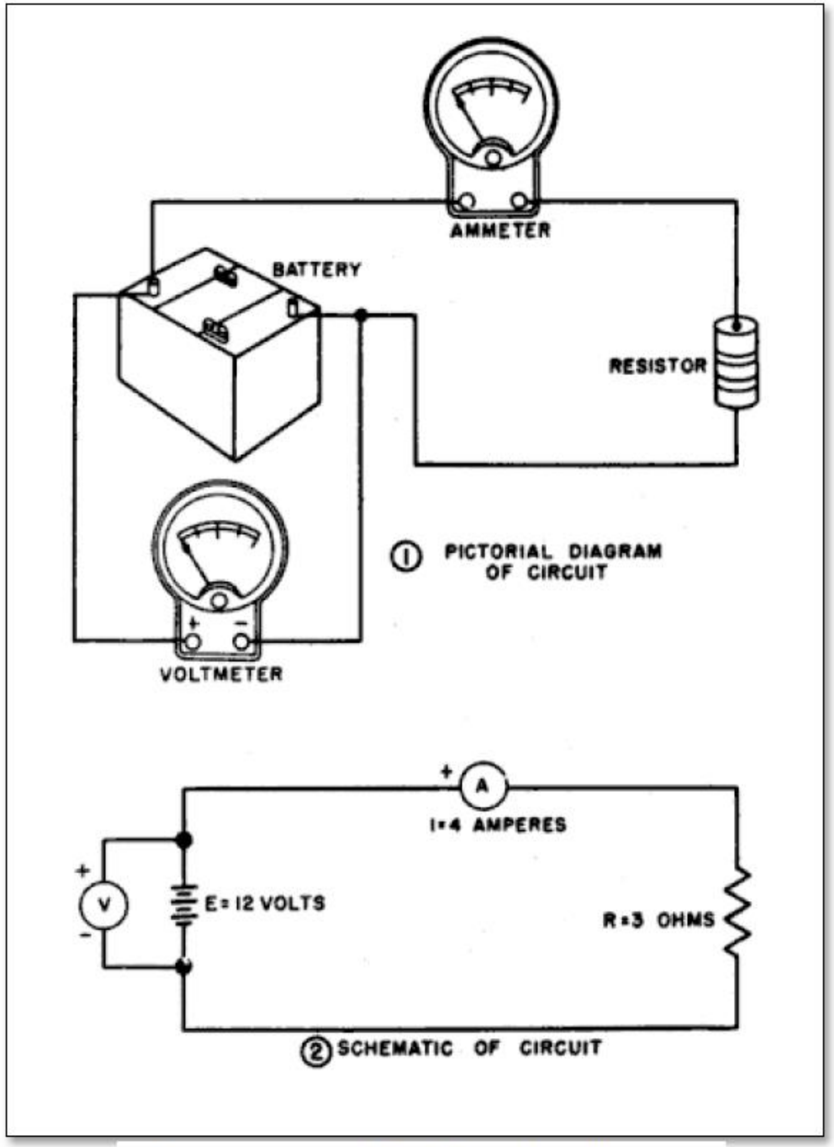
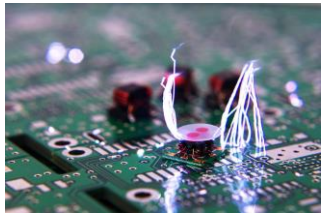


Diagram of a basic Circuit

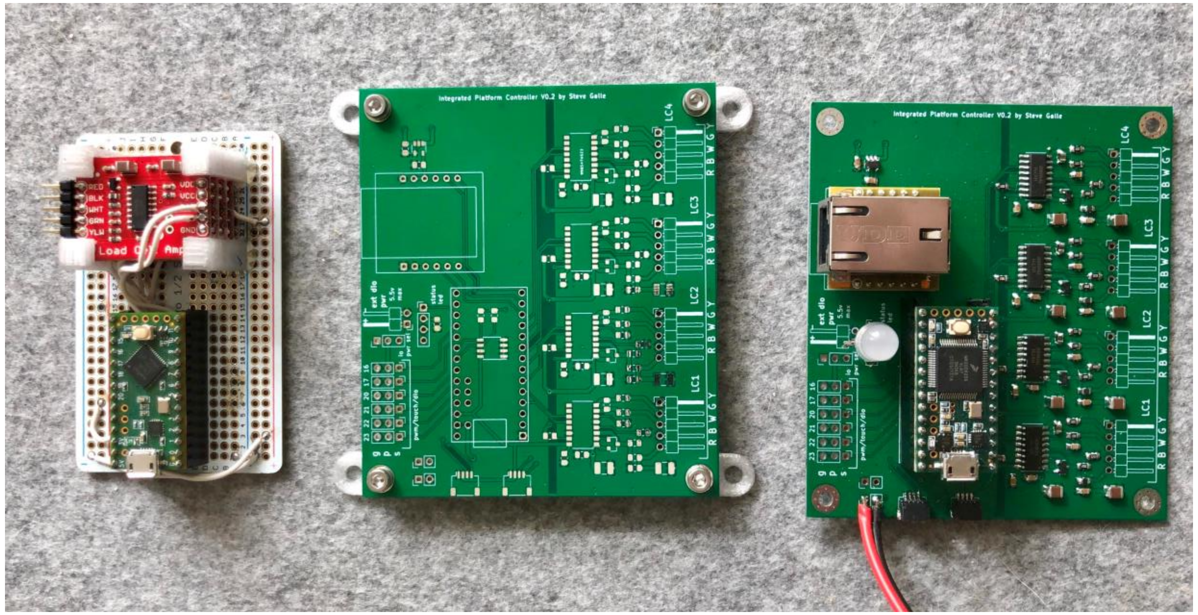
How to decide which components to use?

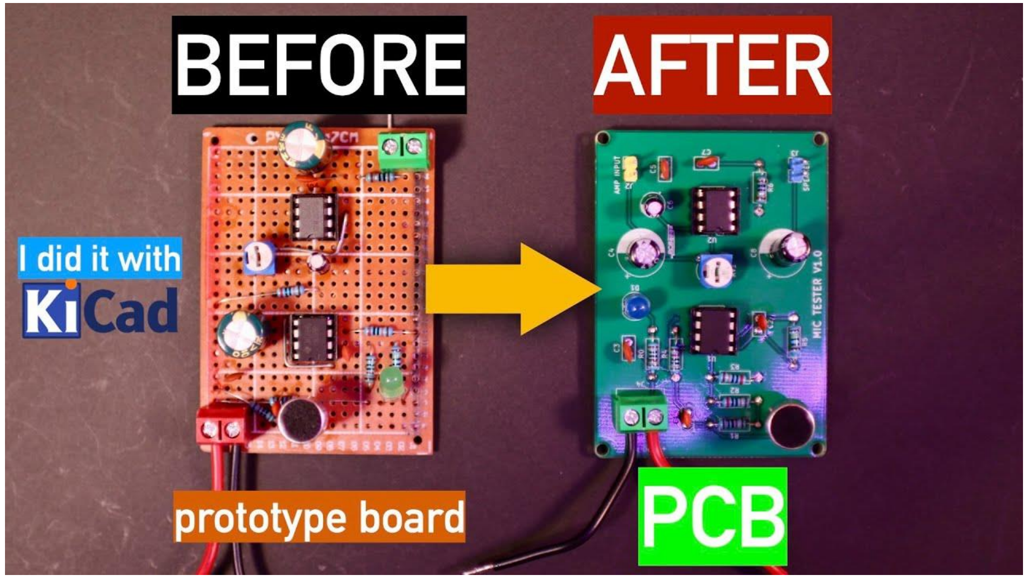
- Think about **what you want to build**
- **Design a circuit** that achieves that **objective**
- **List components** that are required by the circuit and their critical parameters
- **Choose components** with desirable properties
  - Voltage range, tolerance, resistance value, temperature coefficient, wattage, load efficiency, etc.
  - Components that reduce circuit complexity (e.g., built-in ESD protection)
  - Environmental parameters (humidity/pressure/vibration/temperature resilience)



How to decide which components to use?

- Choose components that fit in the circuit well
  - Manufacturer with good documentation/support/tools, long-term availability, lead-time, cost, fall-back options
  - Mechanical parameters (dimensions, weight, etc.)
- Prototype before you start production

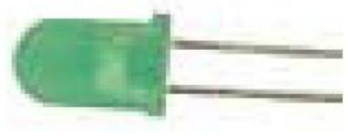




Suppose you want to build…
something that lights up

- Indicator/status signals
- User interfaces and displays
- Illumination sources
- Light effects

Components that make light


LED (green)


TFT Display


Optical Audio Transmitter

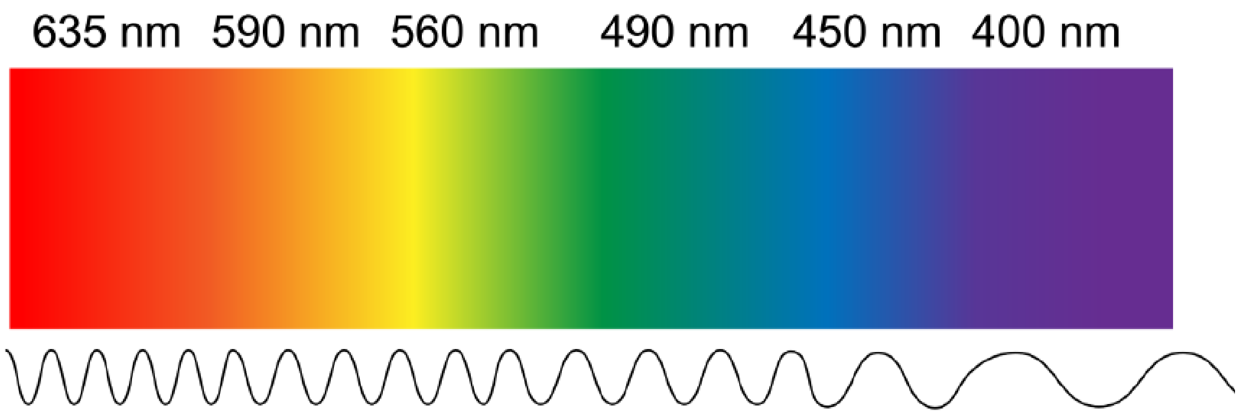
What they do: **Create light**

Key metrics:

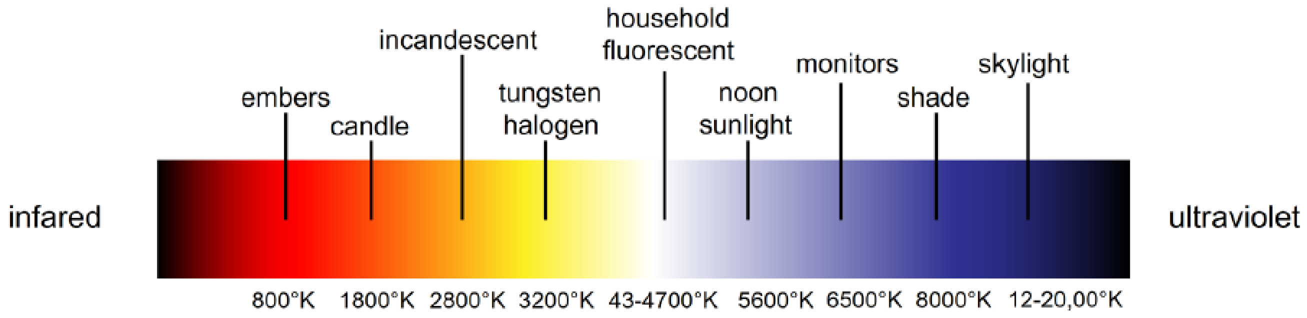
- **Brightness:** how much light is generated (*mcd/nits*)
- **Viewing angle:** over what angle most of the light is visible (*degrees*)
- **Color:** color of emitted light (*nm/kelvin*)
- **Voltage:** voltage needed to “turn on” light (*volts*)
- **Current:** current needed to “turn on” light (*mA*)

How color is measured

- **Option 1: Wavelength**
  - Color of light as function of electromagnetic wavelength/frequency



- **Option 2: Black body radiation**
  - All objects radiate light based on their temperature
  - Color of light as a function of “blackbody” temperature



More components that make light

Colored LEDs


LED (green)


LED (yellow)

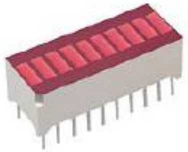

LED (blue)


Red/Green Bi-color LED


Infrared LED


Infrared Phototransistor

Arranged LEDs


Bar Graph Array


7-Segment Display


4-Digit 7-Segment Display

Light Matrices


Flexible RGB LED Matrix


TFT Display


LED Dot Matrix Display

Shaped LEDs


LED (green, flush mount)

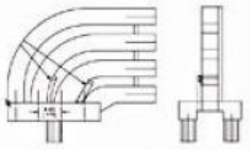

Panel Mount LED

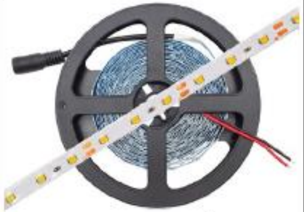

LED Sequin


Backlight Module

Directed Light


Electro-luminescent Wire


Light Pipe


LED Strip

Other Light Tech


Incandescent Bulb


Laser Diode

LCD Display

Light Signaling


Photointerruptor


Optocoupler


Light to Frequency Converter


Optical Audio Transmitter

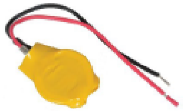
Suppose you want to build…
something that needs electricity

- Operate for long periods of time without management
- Move around without being plugged in
- Collect energy from environment
- Supply electricity to other devices
- Change voltage from one level to another
- Protect against voltage spikes, electronic noise, and static electricity

Electrical power sources

Batteries


Coin cell battery


Coin cell battery
(with leads)


AA battery


AA battery holder


C battery


9V battery snap


9V battery


9V battery holder


USB battery

Plugging in to the Grid

9VDC 2.1mm wall adapter

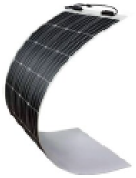

USB to TTL serial cable


2.1mm connector jack

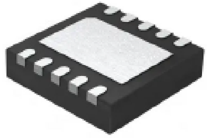

Variable power supply

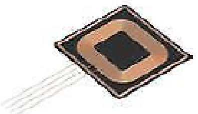
Energy Harvesting


Solar cell [light]

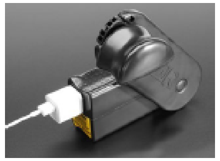

Solar cell [light]
(thin film)


Motor/Generator
[motion]

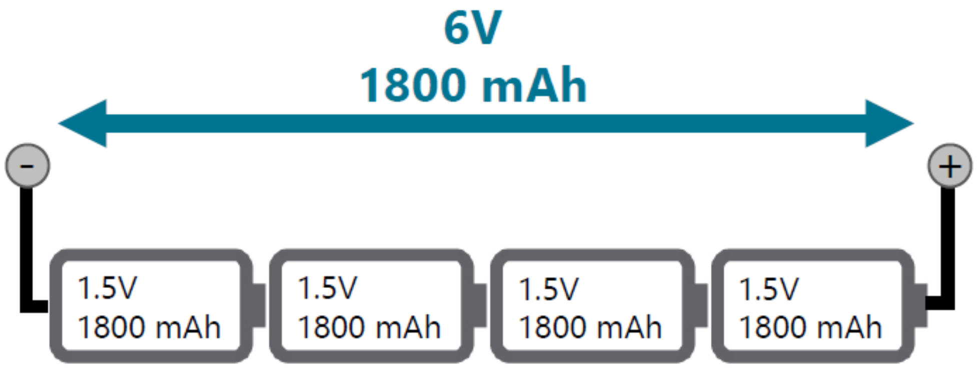

Piezoelectric
generator
[vibration]


Antenna/
Rectenna
[radio waves]

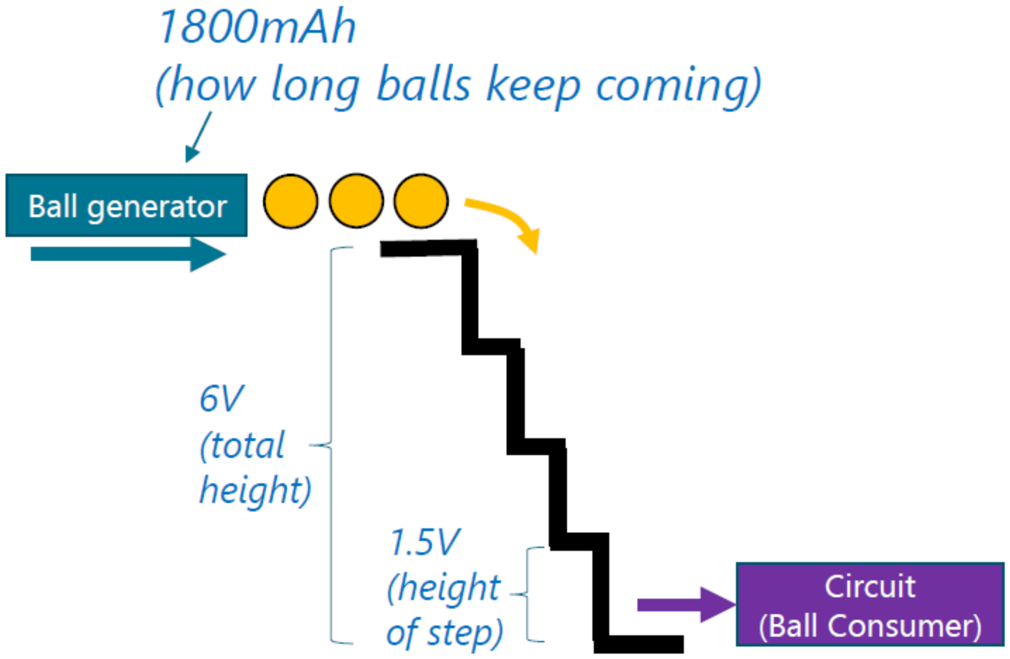

Thermoelectric
generator
[heat]

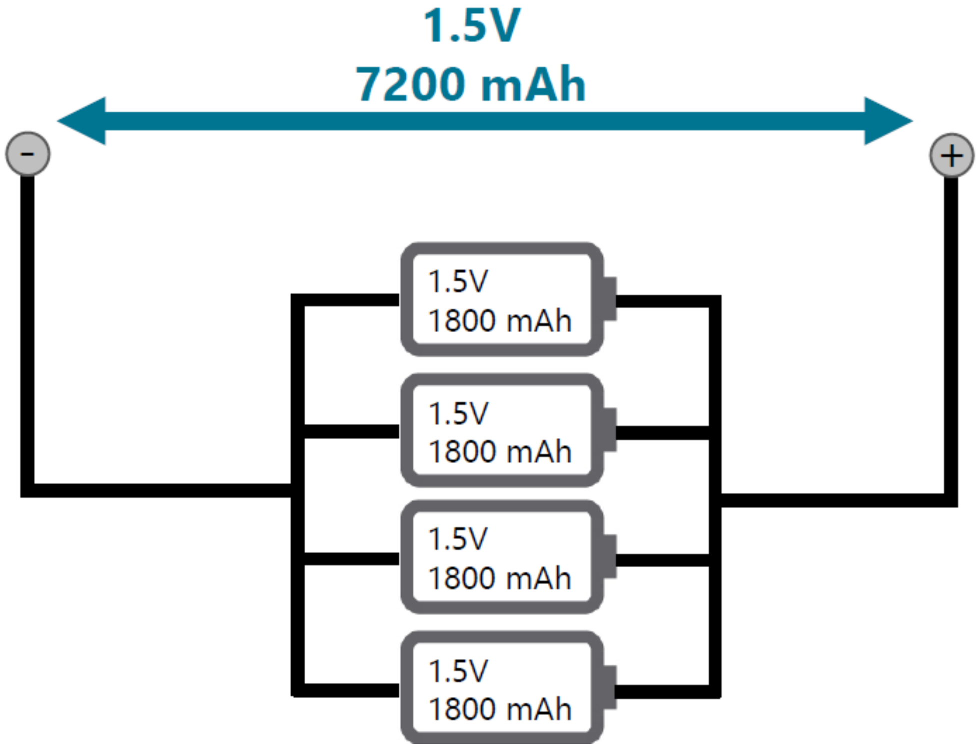

Hand crank

Power: Combining Current Sources

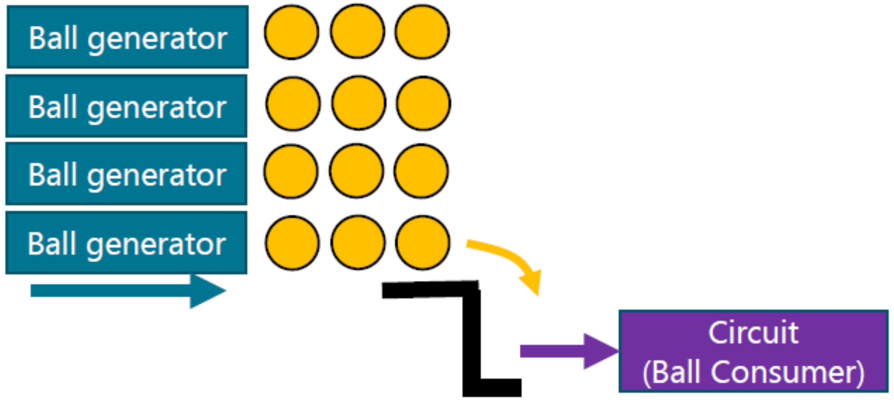


Connected in Series

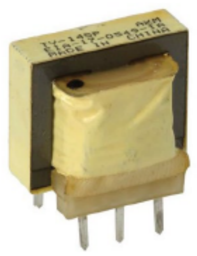




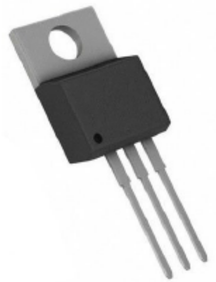
Connected in Parallel



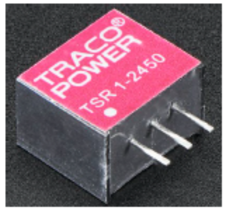
Components that change voltage levels



Transformer
(steps up/down AC voltage)



Voltage regulator
(keeps voltage within range)

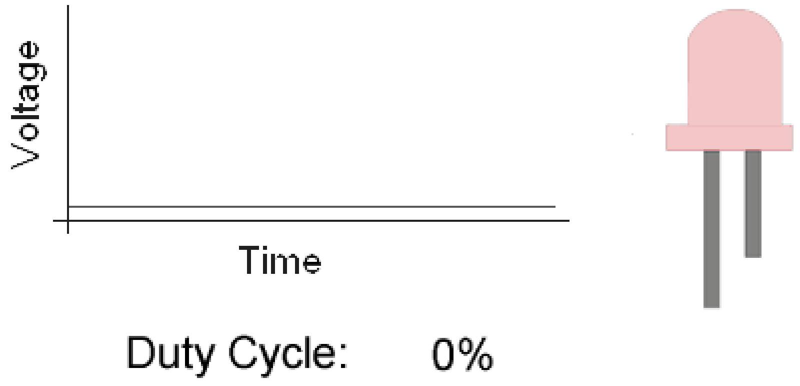


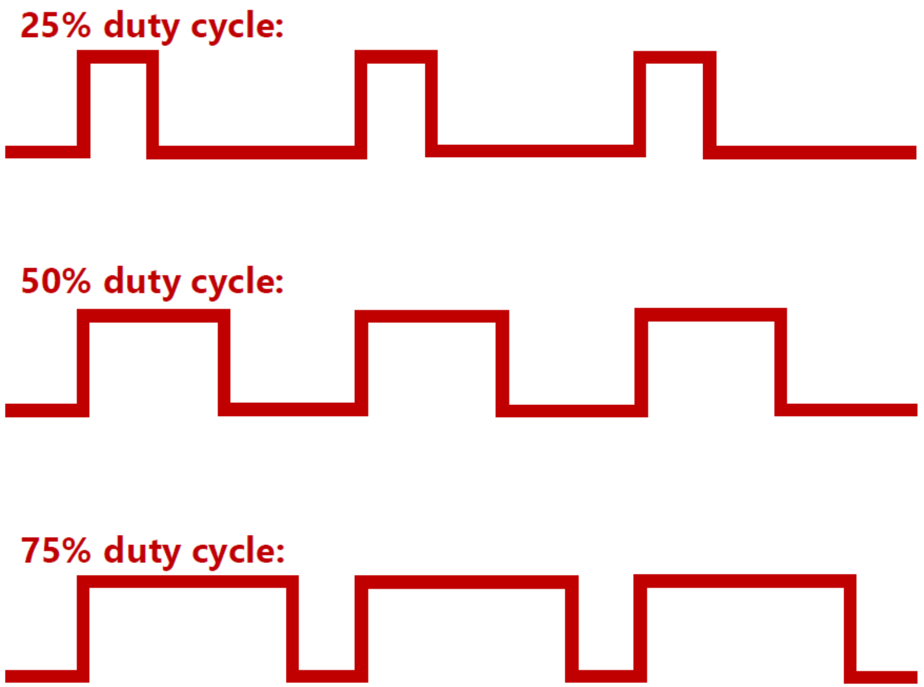
Buck converter
(steps down DC voltage)

Boost converter
(steps up DC voltage)

Power: Pulse-Width Modulation (PWM)

- Suppose you want to increase/ decrease power to a component
  - E.g., vary brightness of LED, speed of motor
- **PWM**: controls power by rapidly turning on/off
  - Cheaper, more efficient electronics than varying voltage



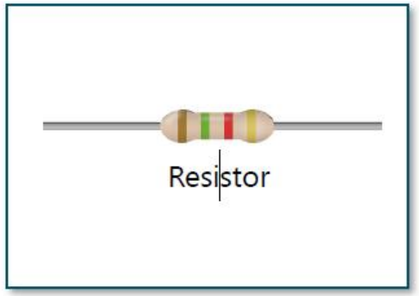


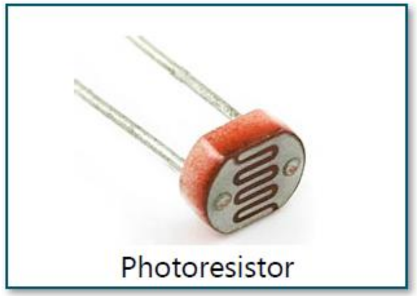
Resistors and Potentiometers

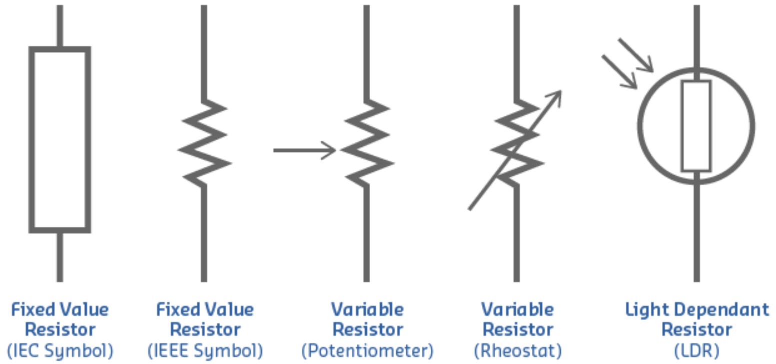
What they do: resist the flow of current

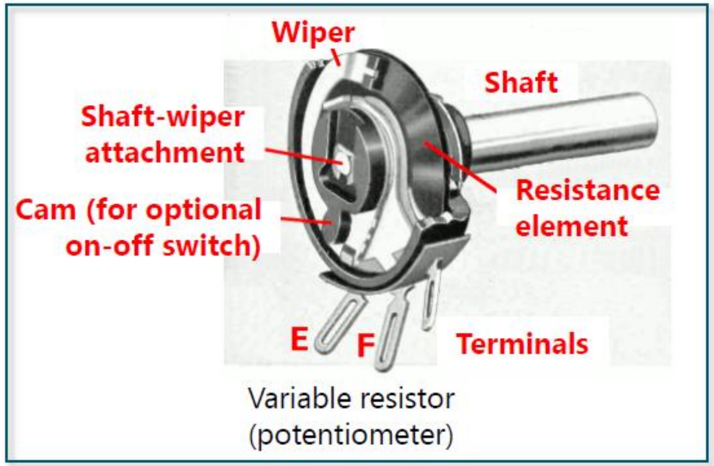
Useful for:

- Protecting components from getting too much current
- Increasing and decreasing voltage
- Measuring things (e.g., light intensity)

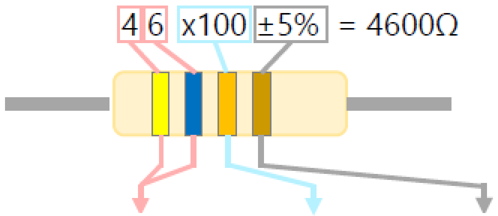








Resistors and Potentiometers



Color	Digit	Multiplier	Tolerance
Black	0	x1	
Brown	1	x10	±1%
Red	2	x100	±2%
Orange	3	x1K	
Yellow	4	x10K	
Green	5	x100K	±0.5%
Blue	6	x1M	±0.25%
Violet	7	x10M	±0.1%
Grey	8	x100M	±0.05%
White	9	x1G	
Gold		x0.1	±5%
Silver		x0.01	±10%

Key metrics:

- **Resistance:** how much they resist current (Ohms)
- **Tolerance:** how accurate their resistance rating is (%)
- **Power rating:** how much current they can handle (Watts)
- **Maximum voltage:** how much voltage difference across their input/output they can handle

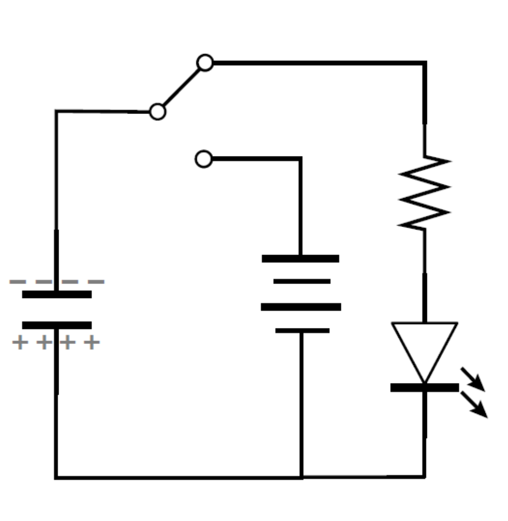
Capacitors

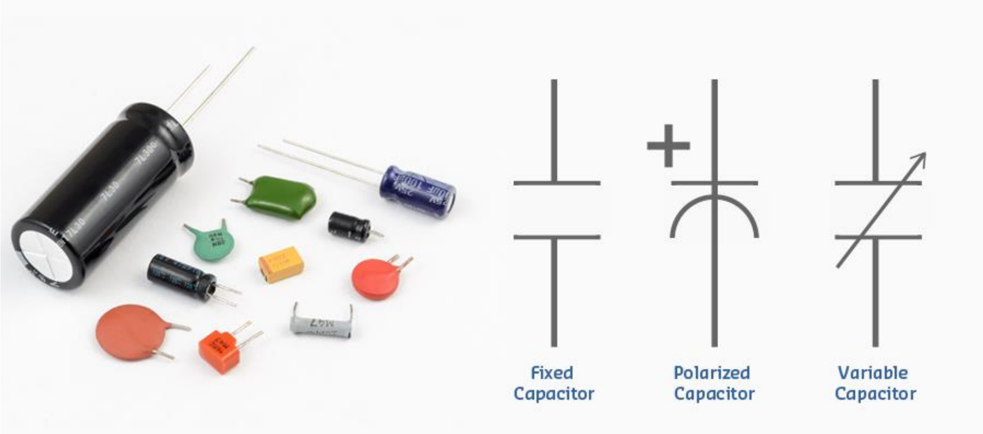
What they do: store charge

Useful for:

- Temporarily holding some charge (like a tiny battery)
- Smoothing out voltage spikes
- Measurement (humidity, pressure, touch sensors)

Capacitor


Example Circuit: Storing Charge in a Capacitor

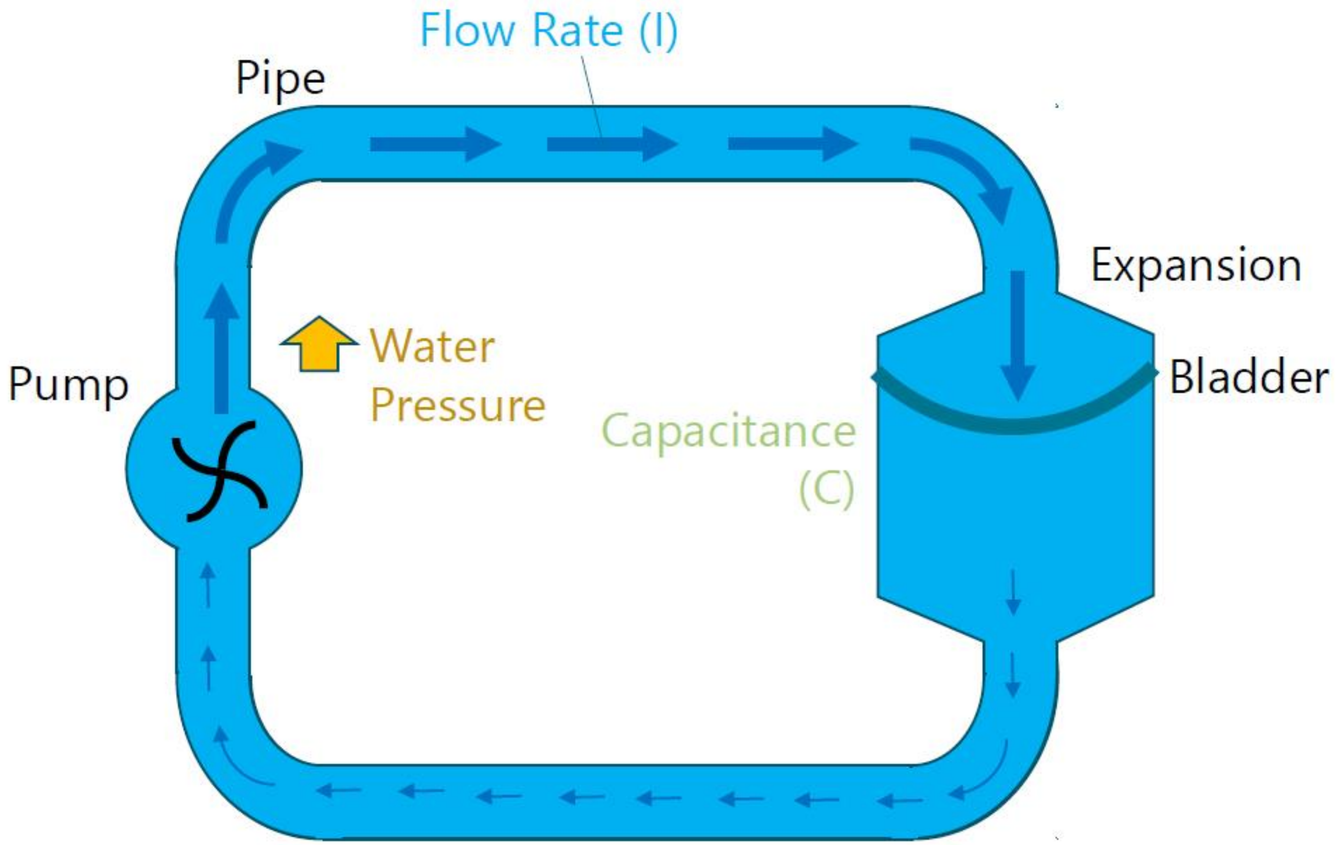


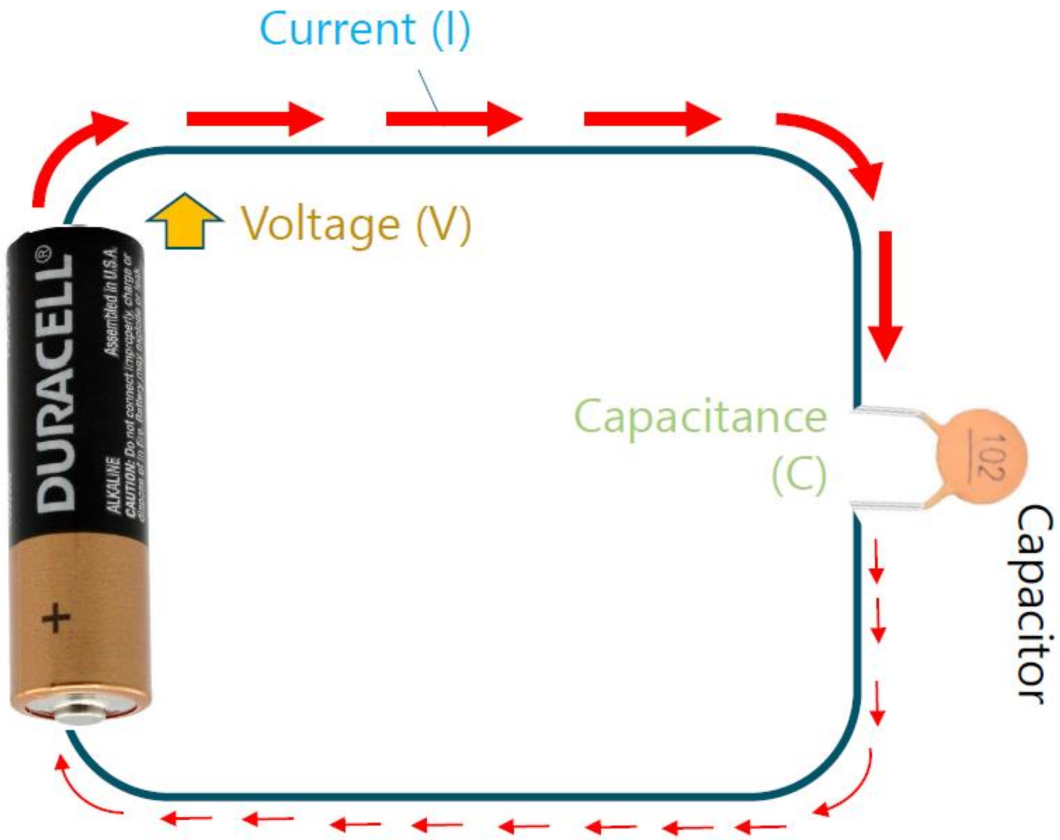
Capacitors – These devices have the ability to **store energy as electric charge**. You may think of capacitors as **tiny batteries** than can be charged and discharged very quickly. Capacitors are useful to **smoothen analogue signals and to decouple power hungry devices from the power supply**.

The **ability to store charge** is called **capacitance**.

The **unit** of capacitance is the **farad**, however one farad is too big and commercial capacitors are measured in micro (10^{-6}) or nano (10^{-9}) farads.

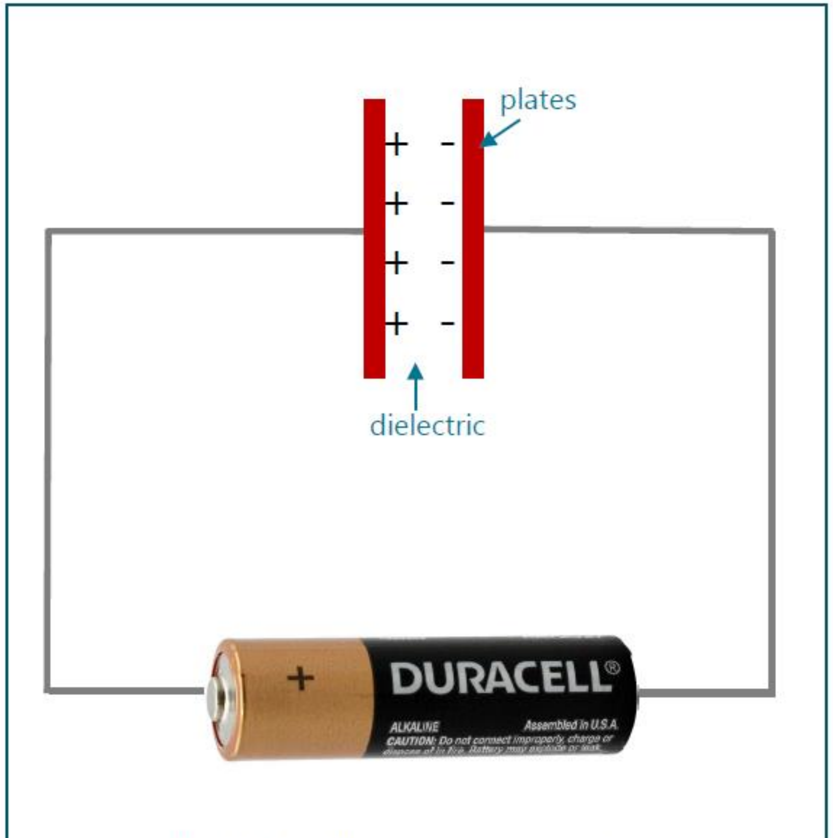
Water Analogy: Capacitance





Capacitors

- **Key metrics:**
- **Capacitance:** how much charge it can store (farads)
- **Tolerance:** how accurate their capacitance rating is (%)
- **Maximum voltage:** how much voltage they can handl (before they short out or burn up)
- **Leakage current:** amount of current that leaks througl dielectric
  - No "current rating" –you can't have a sustained current throu a capacitor aside from leakage
- **Equivalent series resistance (ESR):** capacitors aren't perfect and have tiny amount of resistance (usually les than 0.01Ω)



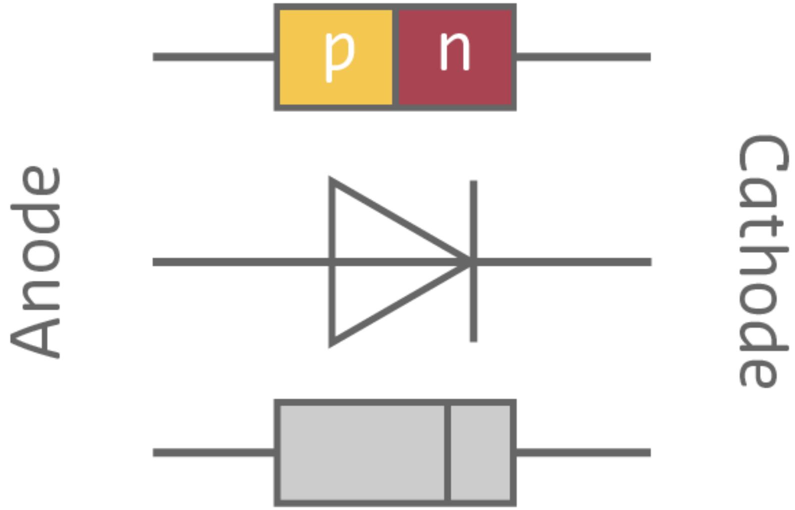
Inducing Charge on a Capacitor

https://www.youtube.com/watch?v=X4EUwTwZ110

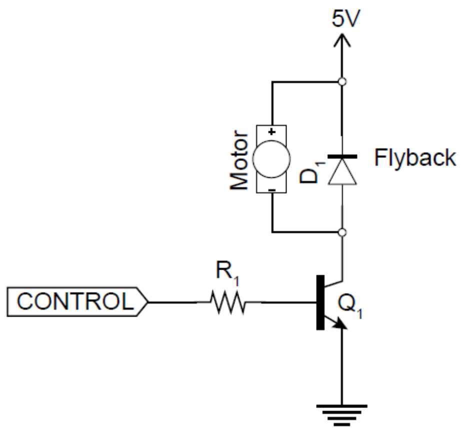
Diode

A **diode** is a 2-terminal device that is very **good at conducting electricity in one direction only.**

- **What it does:** allows current to go in forward direction, but not reverse direction
- **Useful for:**
- Reverse current protection
  - “Rectifying” signals (pulling out positive parts)Converting AC to DC
- Measurement (temperature, radiation)



Diode



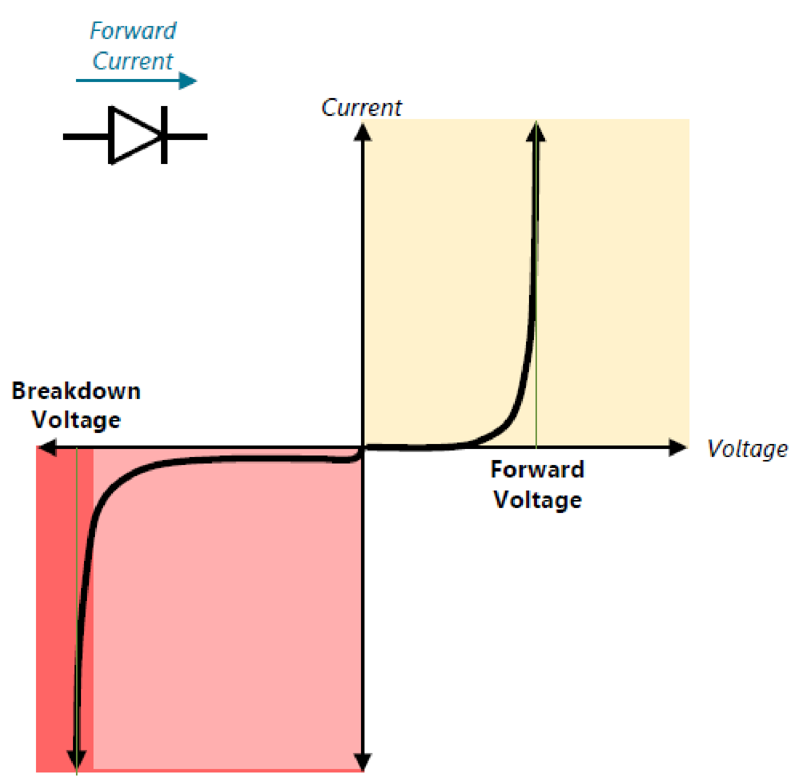
Example Circuit: Preventing Current “Kickback” with a Flyback Diode

How does diode work : https://www.youtube.com/watch?v=JNi6WY7WKAI&feature=emb_title

Diode

Key metrics:

- **Maximum forward current:** how much current can go through in the forward direction (amps)
- **Maximum reverse voltage (breakdown voltage):** how much voltage can be withstood in reverse direction
- **Maximum forward voltage:** voltage difference between input/output when current going through forward direction (ideally should be zero, no resistance to current)



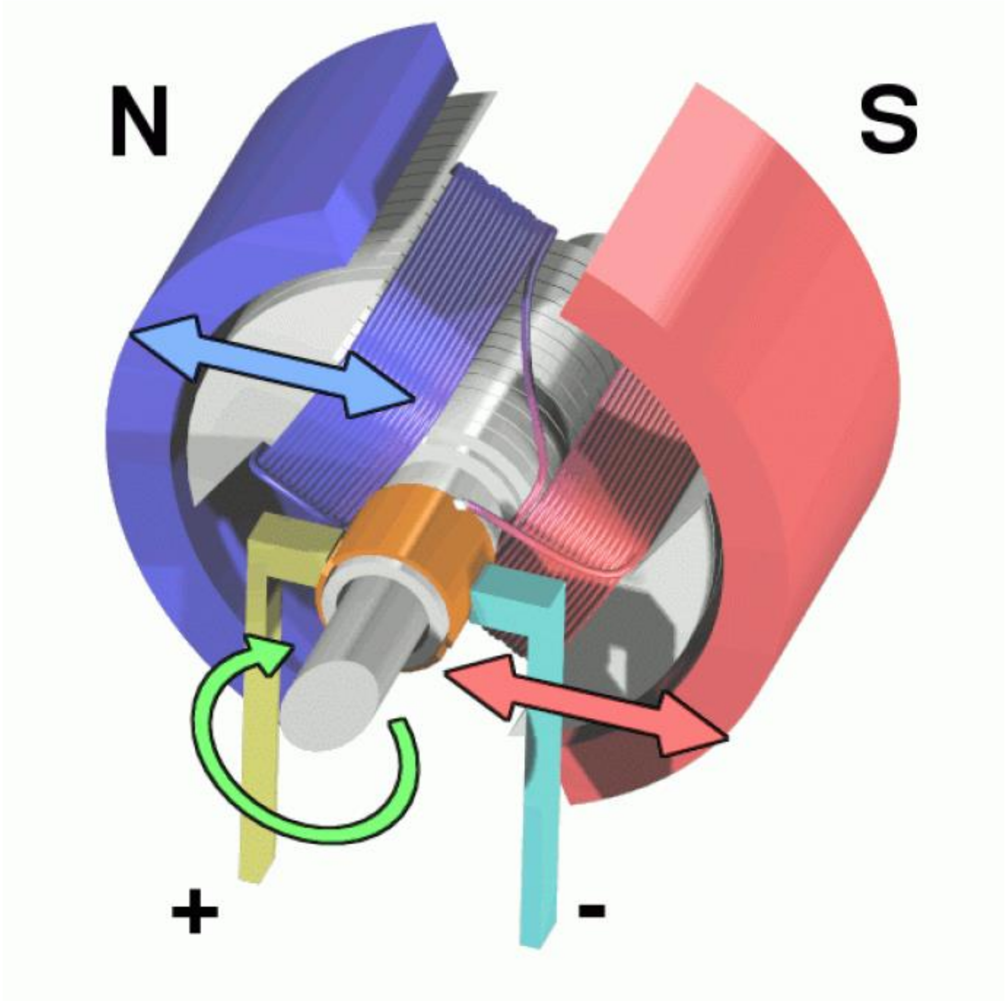
Current-Voltage Relationship of a Diode

Suppose you want to build… *something that moves*

- Position control surfaces, antennas, conveyors, etc.
- Operating grippers, levers, dispensers, belts, cutters, etc.
- With varying speed, preciseness, torque/power, etc.

Electric Motor

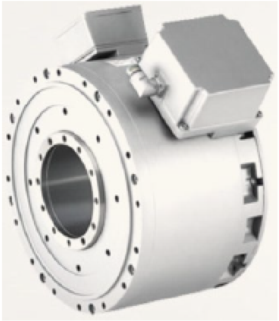
- Converts electricity into motion
- Main idea: Get two big magnets, one north and one south
  - Run electricity through a curved wire
    - Alternatively pushes/pulls against magnets
    - Rotates a mechanical shaft



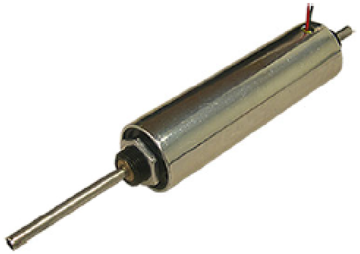
More Types of Electric Motors

Generator
(run brushed motor via external force to generate current)

Servo
(like stepper, but with position feedback mechanism to control position – more expensive, higher torque/speed)



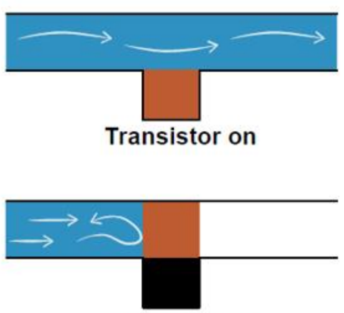
Torque
Can operate indefinitely when stalled, applying constant torque (force feedback games, positioning)



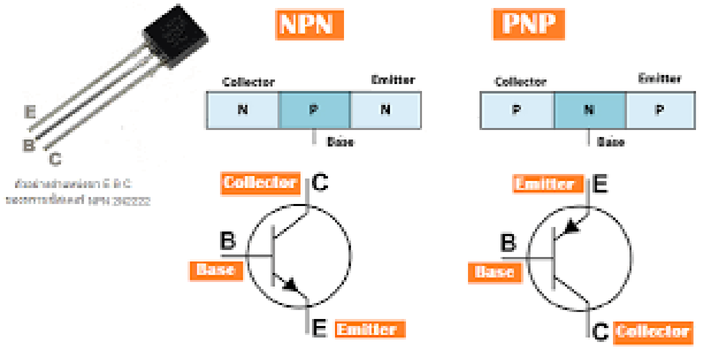
Linear
"Unrolled" motor, produces straight-line torque (maglev trains, pen plotters)

Vibration
Unbalanced weight attached to pole (phones, pagers, toys)

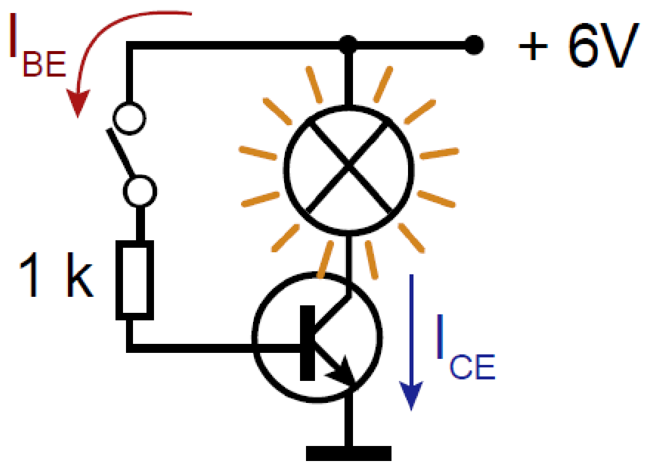
Transistors/Relays



Water Analogy: Transistors/Relays
Stop/Start Flow



Transistor



Example Circuit: Controlling a Light with an NPN Transistor

What it does: acts like a switch; when voltage applied to one wire, forms connection between other two wires

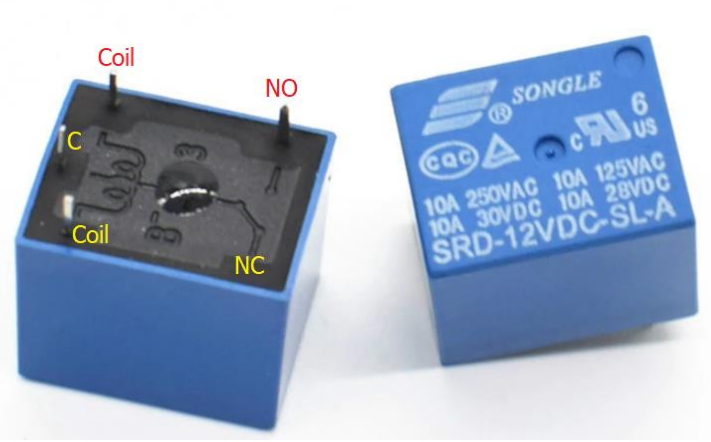
Useful for:

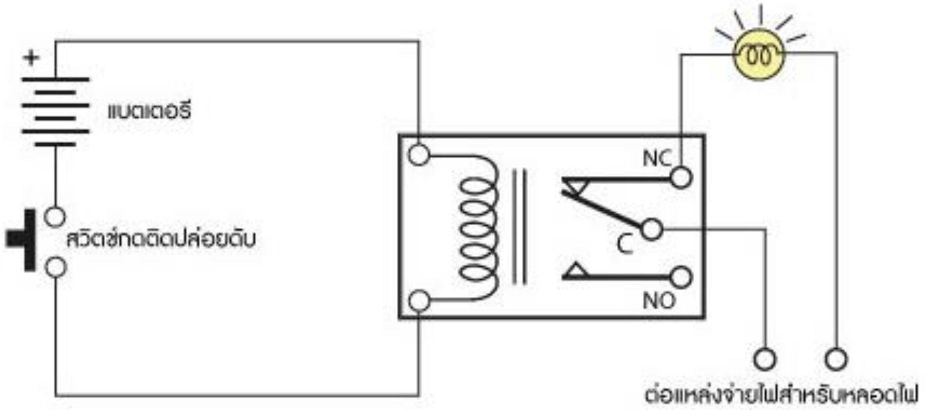
- Acting like a switch
- Amplifying a signal

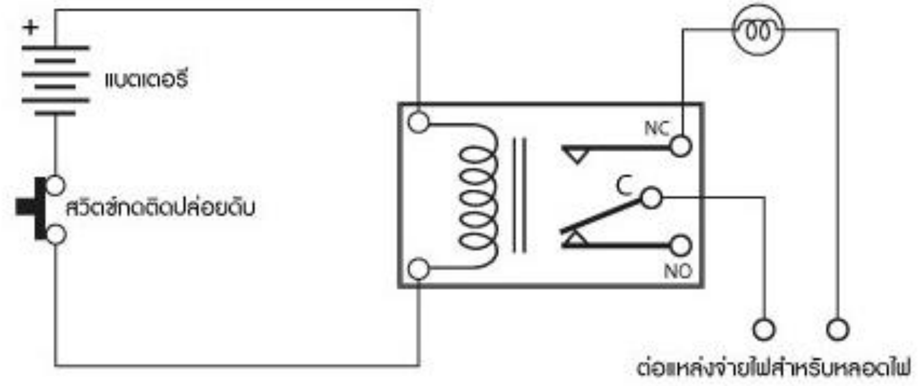
Transistor : How do they work? : https://www.youtube.com/watch?v=7ukDKVHnac4&feature=emb_title

Relays

- Relays are electrically operated switches that open and close the circuits by receiving electrical signals from outside sources.







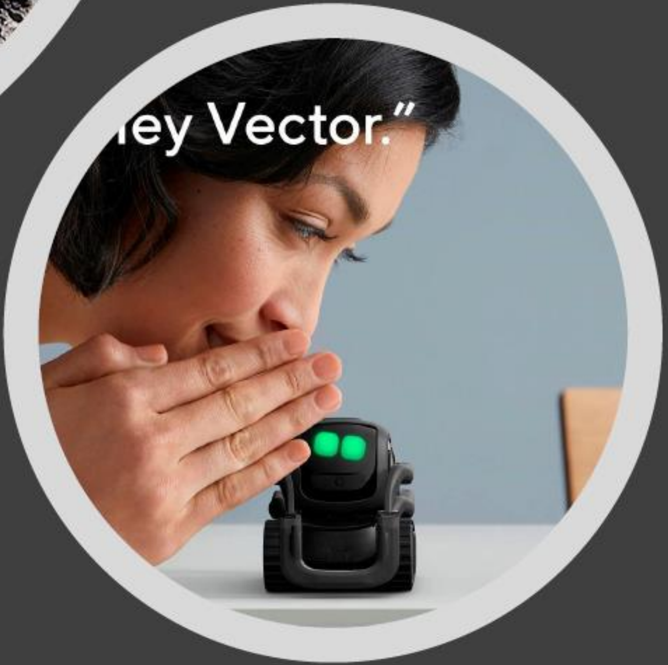
Lecture 4 :

IoT Devices & Hardware Components

ดร.ธนวิชญ์ อนุวงศ์พินิจ

ภาควิชาวิศวกรรมคอมพิวเตอร์ (วิศวกรรมระบบไอโอทีและสารสนเทศ)

คณะวิศวกรรมศาสตร์ สถาบันเทคโนโลยีพระจอมเกล้าเจ้าคุณทหารลาดกระบัง

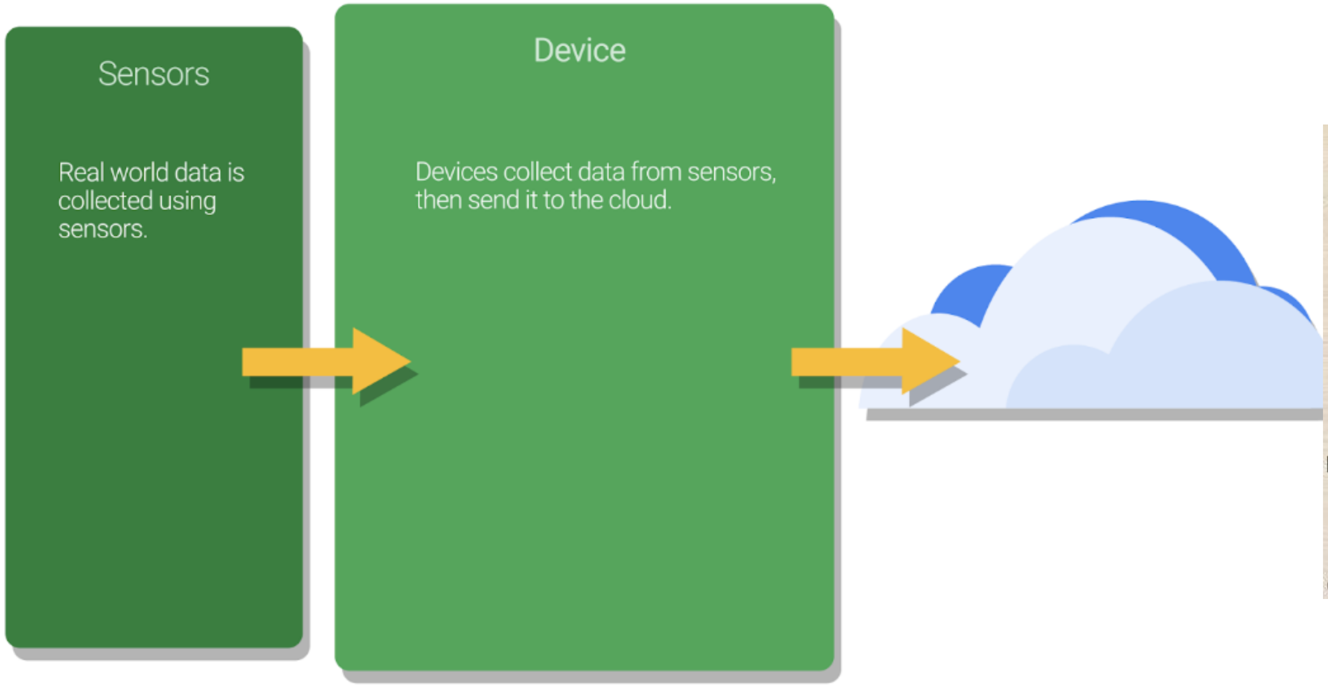


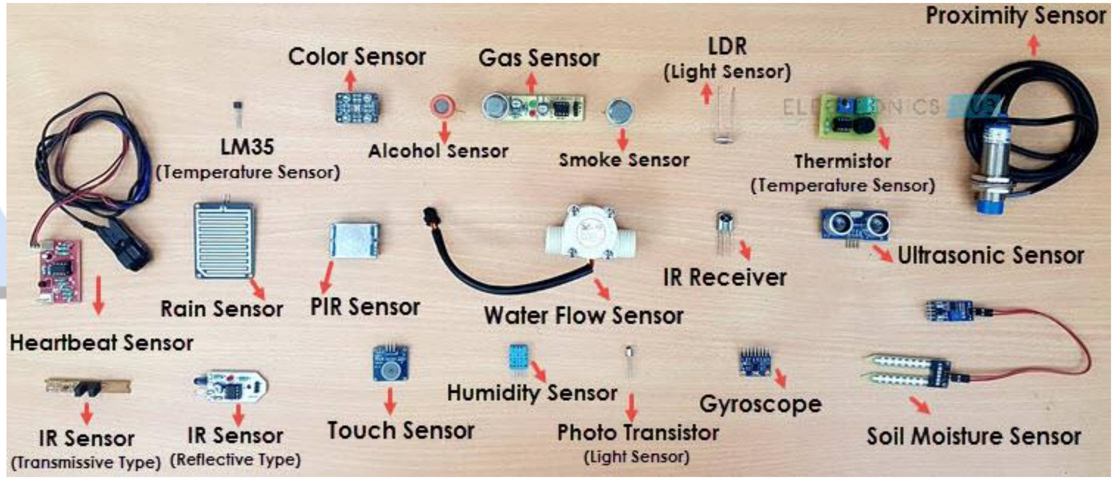
Suppose you want to build...
something that observes

- Listens, sees, measures
- Sound, light, temperature, humidity, magnetic fields, rotation, acceleration, etc.

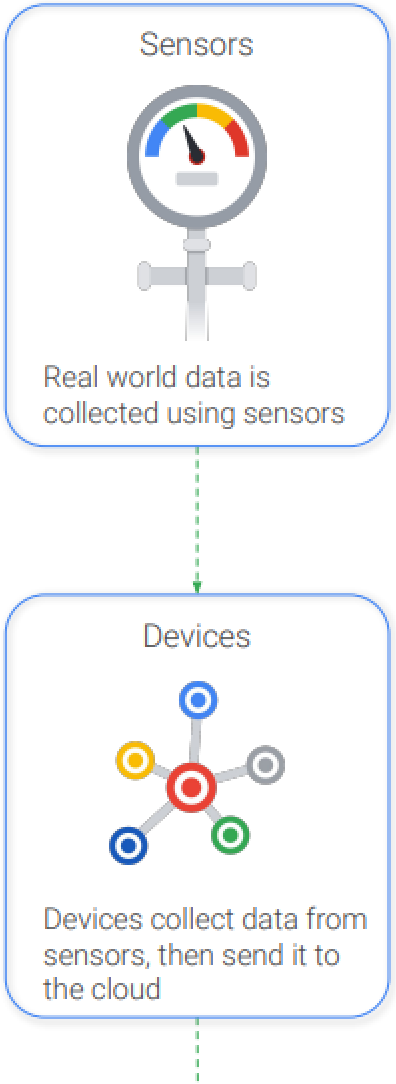
Sensors and Devices Introduction

- A sensor is a device that detects and responds to some type of input from the physical environment.
- The input can be light, heat, motion, moisture, pressure or any number of other environmental phenomena.
- The output is generally a signal that is converted to a human-readable display at the sensor location or transmitted electronically over a network for reading or further





Sensors and Devices Introduction



เซนเซอร์ (Sensor)

- คืออุปกรณ์ตรวจรู้ตัวแรกในระบบการวัด ซึ่งใช้ตรวจจับหรือรับรู้การเปลี่ยนแปลงปริมาณทางกายภาพของตัวแปรต่าง ๆ หรือสภาพแวดล้อม เช่น ความร้อน แสง สีเสียงระยะทางการเคลื่อนที่ ความดัน การไหลเปนต้น แล้วเปลี่ยนให้อยู่ในรูปของสัญญาณทางไฟฟ้า หรือข้อมูลดิจิทัลที่สอดคล้องและเหมาะสมกับส่วนของการกำหนดเงื่อนไขทางการประมวลผลสัญญาณ

ดีไวซ์ (Device)

- ในระบบไอโอที อุปกรณ์หรือดีไวซ์จะรวบรวมข้อมูลจากเซนเซอร์ เพื่อส่งข้อมูลที่ได้ต่อไปยังระบบคลาวด์ โดยอุปกรณ์จะมีขนาดเล็ก ซึ่งหมายถึงมีทรัพยากรต่าง ๆ เช่น การประมวลผล ที่จัดเก็บข้อมูลที่มีขนาดเล็ก เปรียบเสมือนคอมพิวเตอร์จิ๋ว หรืออาจเป็นไมโครคอนโทรลเลอร์ก็ได้

Sensors and Devices Introduction

Further, we can generalise:

1.Environmental condition:

- Usually has limits for temperature/humidity.
- These environmental factors can even have an effect on the readings and need to be factored into the calculations.
- E.g. accelerometers are sensitive to temperature and often have a temperature sensor incorporated into the device.

2. Calibration:

- Essential for most of the measuring devices, as the readings change with time.

3. Sensors can be classified based on **power** or **energy supply requirement/type of signal/ type of measuring device**

Types of Sensors

Sensors can be divided by their external power requirements:

Type	Definition	Example
Passive	Does not require external power to operate. They respond to input from their environment.	A temperature sensor that changes resistance in response to temperature changes
Active	Requires external power to operate.	GPS and radar

Sensors can be divided by the type of signal the sensor produces:

Type	Definition	Example
Analog	Outputs an analog continuous signal	Accelerometers, temperature sensors
Digital	The output is converted to discrete values (digital 1s and 0s) before transmitting to a device	Digital pressure sensor, digital temperature sensor

Sensors can be divided by the type of measuring device:

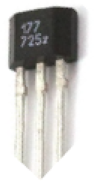
Type	Definition	Example
Chemical	Responds to chemical changes in its environment	Gas sensor
Mechanical	Responds to physical changes in its environment	Microswitch
Electrical	Responds to electrical changes in its environment	Voltage sensor

Choosing sensors for your project requires a clear understanding of what you want to measure and what accuracy is required.

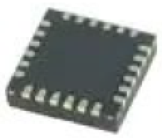
Types of Measuring Device

PHYSICAL PHENOMENON	INPUT DEVICE	OUTPUT DEVICE
Temperature	Thermocouple Thermistor Thermostat Resistive Temperature Detectors (RTDs)	Heater Fan Peltier pumps
Speed	Tacho-generator Reflective/Slotted Opto-coupler Doppler Effect Sensors	AC and DC Motors Stepper Motor Brake
Position	Potentiometer Encoders Reflective/Slotted Opto-switch Linear Variable Differential Transformers (LVDTs)	Motor Solenoid Panel Meters
Sound	Carbon Microphone Piezo-electric Crystal	Bell Buzzer Loudspeaker
Force/Pressure	Strain Gauge Pressure Switch Load Cells	Lifts and Jacks Electromagnet Vibration
Light level	Light Dependant Resistors (LDRs) Photodiode Photo-transistor Solar Cell	Lights and Lamps LEDs and Displays Fibre Optics

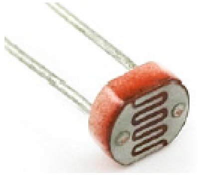
Sensors

Picture	Sensor name	What it detects	Example Applications
	**Color Sensor**	Detects and measures range of visible colors	Test strip reading Sorting by color Ambient light sensing and calibration Color matching
	**Hall Effect Sensor (magnetism)**	Varies output voltage in response to a magnetic field. Can pair with magnet for some applications (e.g, positioning)	Measuring wheel/rotation speed Proximity sensing Positioning/alignment Current sensing
	**Microphone (sound)**	Converts sound into electrical signal	Audio recording Speech recognition/Wake phrase Echolocation
	**Accelerometer**	Measures physical acceleration experienced by an object	Human activities: walking/running/dancing Fall/drop detection, Occupancy detection Detecting which way is down Building/motor health monitoring

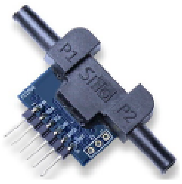
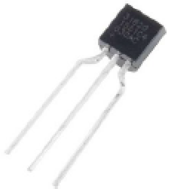
Sensors

Picture	Sensor name	What it detects	Example Applications
	**Gyroscope/ Tilt Sensor**	Measures rotation (pitch/yaw/roll)	Human activities: walking/running/dancing 3D motion control Robotics
	**Gas Sensor**	Detection of gases. Variants measure Carbon Monoxide, Methane, Alcohol/Benzine, Propane, etc.	Safety devices Environmental monitoring
	**Passive Infrared Sensor**	Converts infrared light into electrical signal	Motion detection, entry alarm Remote control/communication Maze navigation, boundary sensing
	**Proximity/ Distance Sensor**	Measures distance to moving or stationary objects. Variants: ultrasonic, laser, infrared.	Parking assistant systems Speed measurement Robotic navigation Interactive displays

Sensors

Picture	Sensor name	What it detects	Example Applications
	**Humidity Sensor (hygrometer)**	Measures humidity/water content	Soil monitoring Weather/microclimate monitoring
	**Touch Sensor**	Detects and measures anything that is conductive or has a dielectric different from air	Touchscreens Fingerprint-based identification
	**Photoresistor**	Light intensity	Sleep mode activation Smart building light controls
	**Load Cell**	Measures force/weight	Presence/arrival detection Weight measurement Impact measurement Mechanical strain detection

Sensors

Picture	Sensor name	What it detects	Example Applications
	**Flow Sensor**	Measure flow rate (and thereby volume) of gas or fluids	Industrial process monitoring Farming (eg. water/pesticide applications) Water/gas meters "Green building" resource usage
	**Anemometer**	Measure wind speed. Can pair with vane to measure wind direction. Also see pitot tube.	Weather/microclimate monitoring Structural safety monitoring (bridge, cranes etc)
	**Temperature Sensor**	Measures temperature	Plant health monitoring Industrial machine health monitoring Circuit overheat protection
	**Camera**	Captures video or pictures. Can be paired with computer vision to recognize objects, faces, track motion, etc.	Customer identification Crop Analysis 3D Object recognition "Go home" function

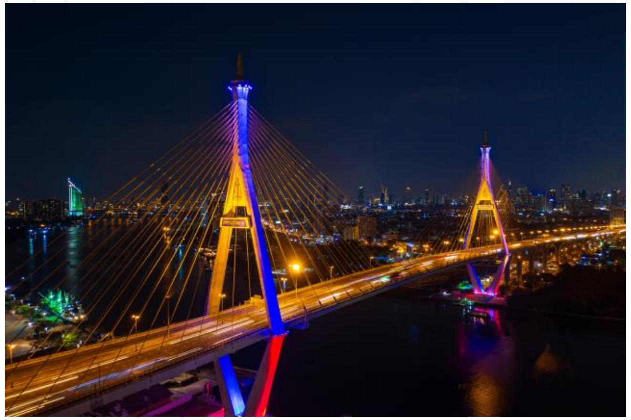
Emerging Sensors
Recently emerging sensor types make IoT more powerful

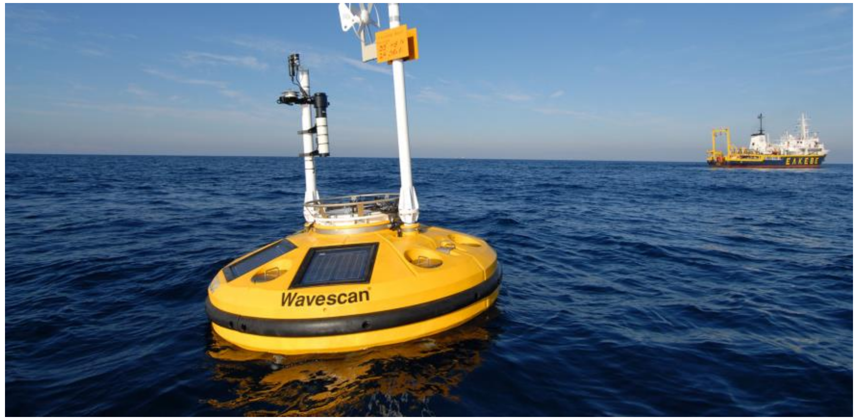
Picture	Sensor name	What it detects	Example Applications
	**Electronic Nose**	Measures chemical concentrations behind scents/smells	Early detection of health problems (eg COPD) Counter-terrorism Computer smell
	**Tactile Sensor**	Determining texture, stiffness, coefficient of friction, thermal conductivity	Robotics Object recognition
	**Blood Gas/Sugar Sensor**	Measures composition of blood, including amount of arterial gases (eg oxygen, carbon dioxide), pH, sugar, etc.	Smart clothes Home health checkup Early asthma detection
	**Brainwave Sensors**	Measures electrical activity of brain. Can pinpoint activity to 3-D location inside brain.	Mental control over objects Diagnose brain faults and mental disorders Understanding user intent Reading innermost thoughts and desires

Phone Sensors

Choosing a Sensor

- ในการศึกษาเรียนรู้นั้น เราอาจจะแค่หยิบมาต่อแล้วแสดงเห็นค่าที่วัดได้
- แต่ในการใช้งานจริงนั้น มีหลายสิ่งที่ต้องพิจารณาเป็นอย่างมาก
- โดยทั่วไป เราอาจจะคาดหวังว่าอุปกรณ์และเซ็นเซอร์ของเราควรจะมีอายุการใช้งานยาวนานโดยมีคนไปยุ่งเกี่ยวตอบสนองด้วยเล็กน้อย
- แต่ถ้าอุปกรณ์เหล่านี้ถูกฝังอยู่ในสถานที่ห่างไกล ไม่สามารถเข้าถึงได้ ?
- ดังนั้น การเปลี่ยนเซ็นเซอร์หรืออุปกรณ์เหล่านี้ อาจมีค่าใช้จ่ายที่สูง หรือในรูปแบบต่าง ๆ ดังนั้นการเลือกพิจารณาใช้งานเซ็นเซอร์จึงเป็นสิ่งสำคัญอย่างมาก

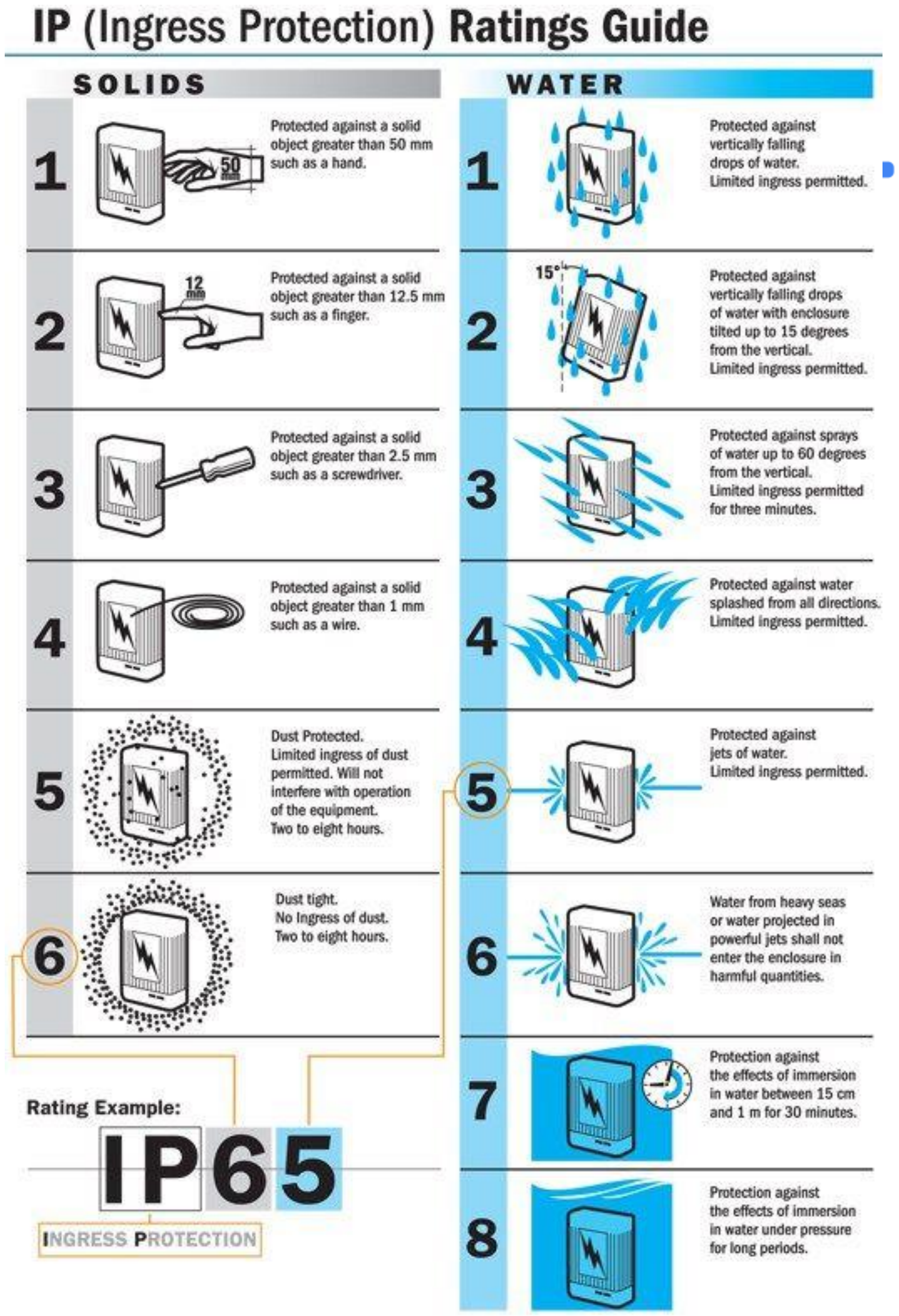




Choosing a Sensor

Durability (ความคงทนในการใช้งาน)

- เป็นการคำนึงถึงความทนทานในการใช้งาน ตามสภาพแวดล้อมที่เหมาะสมกับเซ็นเซอร์ที่เลือกใช้ โดยให้ทำงานตามความจำเป็นในระยะเวลาการทำงานที่เหมาะสม ไม่ต้องสูญเสียค่าใช้จ่ายอื่น ๆ ที่ไม่จำเป็น
- เช่น เซ็นเซอร์วัดสภาพแวดล้อมที่กันน้ำอาจเหมาะสมกับสถานีวัดสภาพอากาศ แต่อาจไม่เหมาะกับการวัดอุณหภูมิในน้ำ (No Waterproof)
- หรือ การเลือกเซ็นเซอร์ที่สภาพแวดล้อมไม่เหมาะสม เช่น ความสามารถวัดได้แค่ 0 – 70 องศาฯ แต่พอไปหน้างานจริงกลับมีอุณหภูมิแปรปรวนตั้งแต่ หน้าหนาว -40 องศาฯ จนไปถึงร้อนจัด เป็นต้น



Choosing a Sensor

Versatility (ความสามารถ,ใช้งานหลากหลาย)

- เซ็นเซอร์จะต้องมีความสามารถทำงานภายใต้สภาพแวดล้อมต่าง ๆ นอกจากความคงทนที่ทนสภาพได้แล้ว จะต้องวัดให้มีประสิทธิภาพอย่างแม่นยำด้วย เช่น หากติดตั้งในที่ว่างเปล่าที่อุณหภูมิทั้งหนาวและร้อนอย่างมาก จะต้องให้วัดได้แม่นยำมากที่สุดในอุณหภูมินั้น ๆ พม่เพียงแต่แค่อุณหภูมิห้องเฉย ๆ
- ตัวอย่างเช่น สร้างสถานีตรวจอากาศระยะไกลสำหรับพื้นที่รกร้างว่างเปล่า จะต้องใช้เซ็นเซอร์ที่สามารถจัดการกับอุณหภูมิในฤดูร้อนและฤดูหนาวสุดขั้วได้
- ไม่มีประโยชน์ที่เซ็นเซอร์ที่ทำงานอย่างแม่นยำที่อุณหภูมิห้องเท่านั้น

Temperature Sensor Performance Graphs

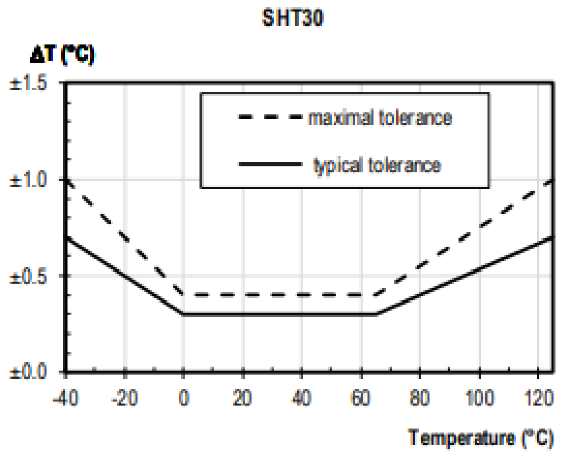


Figure 8 Temperature accuracy of the SHT30 sensor.

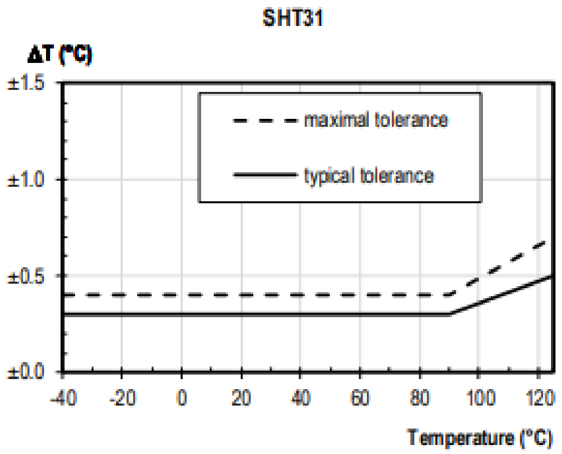


Figure 9 Temperature accuracy of the SHT31 sensor.

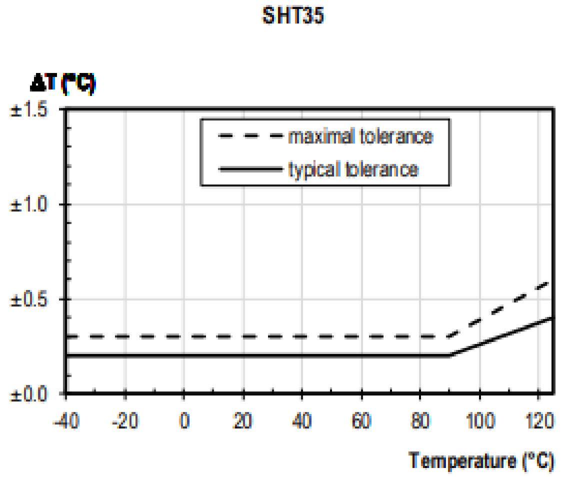
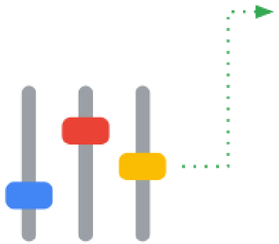


Figure 10 Temperature accuracy of the SHT35 sensor.



Choosing a Sensor

Accuracy ความแม่นยำ

- ความแม่นยำ คือสิ่งสำคัญ แต่ขึ้นอยู่กับลักษณะงานของเราว่าต้องการความแม่นยำแค่ไหน (เป็นการ Safe Cost เพราะว่า Accuracy เยอะ เซ็นเซอร์ก็อาจยิ่งราคาสูง)
- เช่น หากอยากวัดอุณหภูมิห้องทำงานทั่วไปที่ไม่ได้ส่งผลอะไรกับชีวิตมาก อาจใช้เซ็นเซอร์ที่มีความแม่นยำ +/- 2 องศาเซลเซียส
- แต่หากใช้วัดอุณหภูมิที่เกี่ยวข้องกับ “การแพทย์” เช่น วัดอุณหภูมิคนไข้ ควรจะแม่นยำในระดับ +/- 0.2 องศาฯ เลยทีเดียว

Choosing a Sensor

Power Consumption (การบริโภคพลังงาน)

- หากอุปกรณ์ของเราต้องการประหยัดพลังงาน ทำงานในโหมด Low-Power ก็จะขึ้นอยู่กับ Sampling Time (ระยะเวลาที่ต้องการวัด) เช่น อ่านค่าทุก ๆ 5 นาที แล้วก็ทำงานในโหมด Deep-Sleep ต่อเพื่อประหยัดพลังงาน แล้วปลุกขึ้นมา (Wake-up) เมื่อต้องการให้ทำงาน
- เซ็นเซอร์หรืออุปกรณ์ที่ใช้พลังงานจากแบตเตอรี่ที่ชาร์จด้วยพลังงานแสงอาทิตย์อาจต้องใช้เวลาส่วนใหญ่ในโหมดสลีปเพื่อยืดอายุแบตเตอรี่ในช่วงเวลาที่มีแสงน้อย นอกจากนี้ยังอาจต้องทำการปลุกอย่างรวดเร็วเพื่อบันทึกข้อมูลได้อย่างแม่นยำ
- มีหลายปัจจัยที่ผลักดันความต้องการใช้พลังงานต่ำใน IoT เซ็นเซอร์สำหรับ IoT (เช่น สมาร์ทกริด ทางรถไฟ และริมถนน)

Choosing a Sensor

Cost (ค่าใช้จ่าย/ต้นทุน)

- เป็นการพิจารณาในหลาย ๆ ด้าน เพื่อให้ได้ต้นทุนที่เหมาะสมที่สุด ไม่เพียงแค่ราคาของเซ็นเซอร์ที่เหมาะสมกับการใช้งาน แต่ต้องคำนึงถึงต้นทุนในการประกอบ การจัดวางอุปกรณ์ การบำรุงรักษา ความน่าเชื่อถือในการใช้งาน เซ็นเซอร์รุ่นใหม่เปลี่ยนแปลงน้อยมากแค่ไหน จะเลิกผลิตในเร็ววันหรือไม่ ฯลฯ

Supplier (ผู้ผลิต/ผู้จำหน่าย)

- **เป็นการพิจารณาถึงผู้จำหน่าย ว่าน่าเชื่อถือแค่ไหน ? โรงงานผลิตได้มาตรฐานหรือไม่ การจัดส่งตรงเวลา ได้สินค้าที่มีคุณภาพหรือไม่ การรีวิวจากผู้ซื้อคนอื่นเป็นอย่างไร เป็นต้น**

Accessibility (การเข้าถึงอุปกรณ์)

- เป็นการพิจารณาว่าอุปกรณ์ใช้งานเหมาะสมกับโปรเจ็คต์ของเราหรือไม่ เนื่องจากการสั่งซื้อที่เป็น **mass product** คือทีละจำนวนมาก ๆ มีราคาที่ต่ำกว่าซื้อเป็นรายปลีก (อย่างมาก) หรืออุปกรณ์บางอย่างอาจขายเฉพาะในระดับ **mass product** จำนวนมากเท่านั้น การออกแบบ สั่งซื้อ เลือกใช้ จึงควรพิจารณาก่อนจะใช้งานเซ็นเซอร์นั้น ๆ

Choosing a Sensor

Form factor

- เป็นการตรวจสอบว่ามีข้อจำกัดด้านขนาด น้ำหนักของอุปกรณ์หรือไม่ ต้องไปประกอบกับ PCB หรือติดตั้งอย่างไรในแง่ของปัจจัยทางกายภาพอื่น ๆ นอกจากสภาพแวดล้อม

Interface

- การเชื่อมต่อเซ็นเซอร์มีอินเตอร์เฟสที่หลากหลาย เช่น เป็นแบบแอนะล็อก (A2D) เป็นแบบ Digital (one wire/two wire) เป็นแบบ SPI หรือ I2C เป็นต้น อย่างไรก็ตามเราควรพิจารณาสิ่งนี้เป็นลำดับท้าย ๆ เนื่องจากความสามารถของเราในฐานะวิศวกรจะต้องเชื่อมต่อกับอินเตอร์เฟสในทุกแบบได้นั่นเอง !

Choosing Sensor : Datasheet Example : SHT30

- https://www.mouser.com/datasheet/2/682/Sensirion_Humidity_Sensors_SHT3x_Datasheet_digital-971521.pdf

<u>หน้าแรก : ข้อมูลโดยสรุป</u> เช่น ผู้ผลิต ชื่ออุปกรณ์ รหัสอุปกรณ์ คุณสมบัติทางไฟฟ้า การนำไปใช้งาน รายละเอียดอย่างย่อ บล็อคไดอะแกรม สารบัญ หากมีหลายรุ่น ก็จะมีระบุไว้ (ในที่นี้ เช่น SHT3x คือจะมี SHT30 SHT31 SHT32 เป็นต้น

SENSIRION
THE SENSOR COMPANY

Datasheet SHT3x-DIS

Humidity and Temperature Sensor

- Fully calibrated, linearized, and temperature compensated digital output
- Wide supply voltage range, from 2.4 V to 5.5 V
- I2C Interface with communication speeds up to 1 MHz and two user selectable addresses
- Typical accuracy of ± 1.5 %RH and ± 0.2 °C for SHT35
- Very fast start-up and measurement time
- Tiny 8-Pin DFN package

Product Summary

SHT3x-DIS is the next generation of Sensirion's temperature and humidity sensors. It builds on a new CMOSens® sensor chip that is at the heart of Sensirion's new humidity and temperature platform. The SHT3x-DIS has increased intelligence, reliability and improved accuracy specifications compared to its predecessor. Its functionality includes enhanced signal processing, two distinctive and user selectable I2C addresses and communication speeds of up to 1 MHz. The DFN package has a footprint of 2.5 x 2.5 mm² while keeping a height of 0.9 mm. This allows for integration of the SHT3x-DIS into a great variety of applications. Additionally, the wide supply voltage range of 2.4 V to 5.5 V guarantees compatibility with diverse assembly situations. All in all, the SHT3x-DIS incorporates 15 years of knowledge of Sensirion, the leader in the humidity sensor industry.

Benefits of Sensirion's CMOSens® Technology

- High reliability and long-term stability
- Industry-proven technology with a track record of more than 15 years
- Designed for mass production
- High process capability
- High signal-to-noise ratio

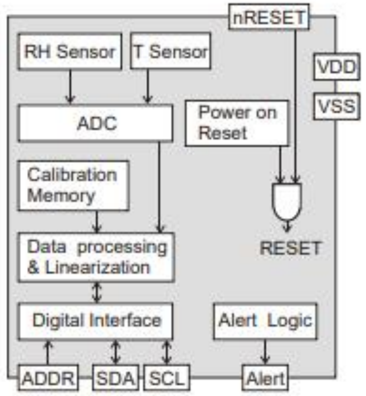


Figure 1 Functional block diagram of the SHT3x-DIS. The sensor signals for humidity and temperature are factory calibrated, linearized and compensated for temperature and supply voltage dependencies.

Content

คุณลักษณะของเซ็นเซอร์ เช่น ค่าความแม่นยำ ความคลาดเคลื่อน ความละเอียด ค่าที่สามารถอ่านได้ เป็นต้น

1 Sensor Performance

Humidity Sensor Specification

Parameter	Condition	Value	Units
SHT30 Accuracy tolerance[1]	Typ.	±3	%RH
	Max.	**Figure 2**	-
SHT31 Accuracy tolerance[1]	Typ.	±2	%RH
	Max.	**Figure 3**	-
SHT35 Accuracy tolerance[1]	Typ.	±1.5	%RH
	Max.	**Figure 4**	-
Repeatability[2]	Low	0.25	%RH
	Medium	0.15	%RH
	High	0.10	%RH
Resolution	Typ.	0.01	%RH
Hysteresis	at 25°C	±0.8	%RH
Specified range[3]	extended[4]	0 to 100	%RH
Response time[5]	$\tau_{63\%}$	8[6]	s
Long-term drift	Typ.[7]	<0.25	%RH/yr

Table 1 Humidity sensor specification.

Temperature Sensor Specification

Parameter	Condition	Value	Units
SHT30 Accuracy tolerance[1]	typ., 0°C to 65°C	±0.3	°C
SHT31 Accuracy tolerance[1]	typ., -40°C to 90°C	±0.3	°C
SHT35 Accuracy tolerance[1]	typ., -40°C to 90°C	±0.2	°C
Repeatability[2]	Low	0.24	°C
	Medium	0.12	°C
	High	0.06	°C
Resolution	Typ.	0.015	°C
Specified Range	-	-40 to 125	°C
Response time [8]	$\tau_{63\%}$	>2	s
Long Term Drift	max	<0.03	°C/yr

Table 2 Temperature sensor specification.

[1] For definition of typical and maximum accuracy tolerance, please refer to the document "Sensirion Humidity Sensor Specification Statement".

[2] The stated repeatability is 3 times the standard deviation (3σ) of multiple consecutive measurements at the stated repeatability and at constant ambient conditions. It is a measure for the noise on the physical sensor output. Different measurement modes allow for high/medium/low repeatability.

[3] Specified range refers to the range for which the humidity or temperature sensor specification is guaranteed.

[4] For details about recommended humidity and temperature operating range, please refer to section 1.1.

[5] Time for achieving 63% of a humidity step function, valid at 25°C and 1m/s airflow. Humidity response time in the application depends on the design-in of the sensor.

[6] With activated ART function (see section 4.7) the response time can be improved by a factor of 2.

[7] Typical value for operation in normal RH/T operating range, see section 1.1. Maximum value is < 0.5 %RH/yr. Higher drift values might occur due to contaminant environments with vaporized solvents, out-gassing tapes, adhesives, packaging materials, etc. For more details please refer to Handling Instructions.

[8] Temperature response times strongly depend on the type of heat exchange, the available sensor surface and the design environment of the sensor in the final application.

คุณลักษณะทางไฟฟ้า : เมื่อรู้แล้วว่าขาไหนมีหน้าที่อะไร แล้วทีนี้เราจะใส่ไฟกี่โวลต์กี่แอมป์เข้าไป หรือไฟจะออกมากี่โวลต์กี่แอมป์ Datasheet ก็บอกเราอีกเช่นเคย ซึ่งจะบอกทั้งค่าที่สามารถทนได้สูงสุด ค่าที่แนะนำให้ใช้ และค่าการทนอุณหภูมิความร้อนต่างๆ

2.2 Timing Specification for the Sensor System

Parameter	Symbol	Conditions	Min.	Typ.	Max.	Units	Comments
Power-up time	t_{PU}	After hard reset, $V_{DD} \geq V_{POR}$	-	0.5	1	ms	Time between V_{DD} reaching V_{POR} and sensor entering idle state
Soft reset time	t_{SR}	After soft reset.	-	0.5	1	ms	Time between ACK of soft reset command and sensor entering idle state
Duration of reset pulse	t_{RESETN}		1	-	-	µs	See section 3.6
Measurement duration	$t_{MEAS,l}$	Low repeatability	-	2.5	4	ms	The three repeatability modes differ with respect to measurement duration, noise level and energy consumption.
	$t_{MEAS,m}$	Medium repeatability	-	4.5	6	ms	
	$t_{MEAS,h}$	High repeatability	-	12.5	15	ms	

Table 4 System timing specification, valid from -40 °C to 125 °C and 2.4 V to 5.5 V.

2.3 Absolute Minimum and Maximum Ratings

Stress levels beyond those listed in Table 5 may cause permanent damage to the device or affect the reliability of the sensor. These are stress ratings only and functional operation of the device at these conditions is not guaranteed.

Parameter	Rating	Units
Supply voltage V_{DD}	-0.3 to 6	V
Max Voltage on pins (pin 1 (SDA); pin 2 (ADDR); pin 3 (ALERT); pin 4 (SCL); pin 6 (nRESET))	-0.3 to VDD+0.3	V
Input current on any pin	±100	mA
Operating temperature range	-40 to 125	°C
Storage temperature range	-40 to 150	°C
ESD HBM (human body model)[9]	4	kV
ESD CDM (charge device model)[10]	750	V

Table 5 Minimum and maximum ratings; voltage values may only be applied for short time periods.

1.1 Recommended Operating Condition

The sensor shows best performance when operated within recommended normal temperature and humidity range of 5 °C – 60 °C and 20 %RH – 80 %RH, respectively. Long-term exposure to conditions outside normal range, especially at high humidity, may temporarily offset the RH signal (e.g. +3%RH after 60h kept at >80%RH). After returning into the normal temperature and humidity range the sensor will slowly come back to calibration state by itself. Prolonged exposure to extreme conditions may accelerate ageing. To ensure stable operation of the humidity sensor, the conditions described in the document "SHTxx Assembly of SMD Packages", section "Storage and Handling Instructions" regarding exposure to volatile organic compounds have to be met. Please note as well that this does apply not only to transportation and manufacturing, but also to operation of the SHT3x-DIS.

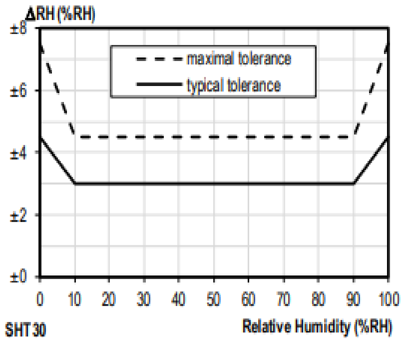
2 Specifications

2.1 Electrical Specifications

Parameter	Symbol	Condition	Min.	Typ.	Max.	Units	Comments
Supply voltage	V_{DD}		2.4	3.3	5.5	V	
Power-up/down level	V_{POR}		2.1	2.3	2.4	V	
Slew rate change of the supply voltage	$V_{DD,slew}$		-	-	20	V/ms	Voltage changes on the VDD line between $V_{DD,min}$ and $V_{DD,max}$ should be slower than the maximum slew rate; faster slew rates may lead to reset;
Supply current	I_{DD}	idle state (single shot mode)	-	0.2	2.0	µA	Current when sensor is not performing a measurement during single shot mode
		idle state (periodic data acquisition mode)	-	45	70	µA	Current when sensor is not performing a measurement during periodic data acquisition mode
		Measuring	-	800	1500	µA	Current consumption while sensor is measuring
		Average	-	2	-	µA	Current consumption (operation with one measurement per second at lowest repeatability, single shot mode)
Alert Output driving strength	IOH		0.8x V_{DD}	1.5x V_{DD}	2.1x V_{DD}	mA	See also section 3.5
Heater power	P_{Heater}	Heater running	4.5	-	33	mW	Depending on the supply voltage

Table 3 Electrical specifications, valid at 25°C.

Humidity Sensor Performance Graphs



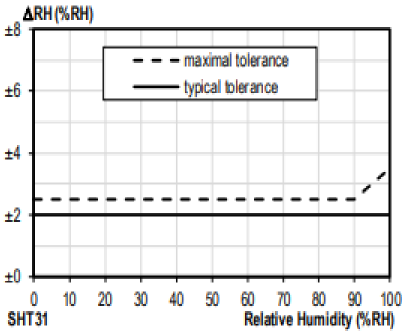


Figure 2 Tolerance of RH at 25°C for SHT30.

Figure 3 Tolerance of RH at 25°C for SHT31.

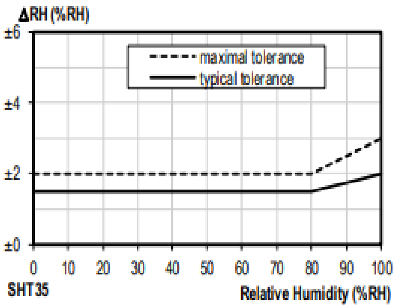


Figure 4 Tolerance of RH at 25°C for SHT35.

Datasheet SHT3x-DIS

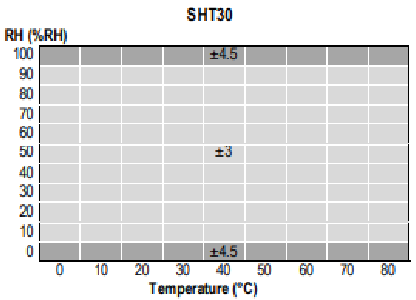


Figure 5 Typical tolerance of RH over T for SHT30.

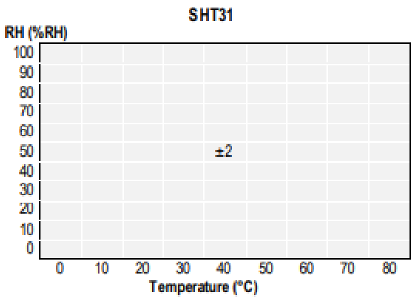


Figure 6 Typical tolerance of RH over T for SHT31.

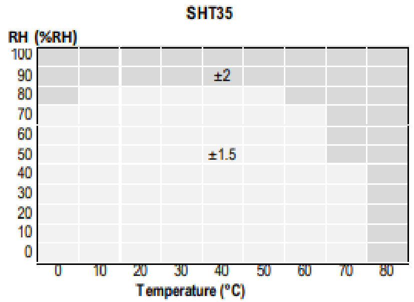


Figure 7 Typical tolerance of RH over T for SHT35.

Temperature Sensor Performance Graphs

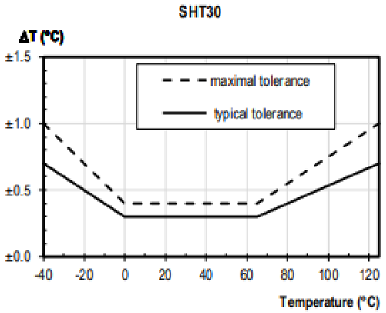


Figure 8 Temperature accuracy of the SHT30 sensor.

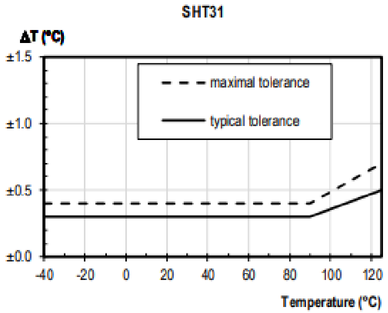


Figure 9 Temperature accuracy of the SHT31 sensor.

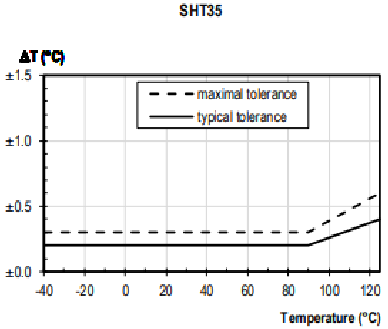


Figure 10 Temperature accuracy of the SHT35 sensor.

<u>กราฟคุณสมบัติทางไฟฟ้าต่างๆ</u> คุณสมบัติทางไฟฟ้าเมื่อจ่ายไฟเข้าไปค่าต่างๆ อุปกรณ์จะทำงานออกมาอย่างไร อุณหภูมิเปลี่ยนไปทำให้การทำงานเปลี่ยนอย่างไร

รายละเอียดการทำงานของ Pin ต่าง ๆ

3 Pin Assignment

The SHT3x-DIS comes in a tiny 8-pin DFN package – see Table 6.

Pin	Name	Comments
1	SDA	Serial data; input / output
2	ADDR	Address pin; input; connect to either logic high or low, do not leave floating
3	ALERT	Indicates alarm condition; output; must be left floating if unused
4	SCL	Serial clock; input / output
5	VDD	Supply voltage; input
6	nRESET	Reset pin active low; input; if not used it is recommend to be left floating
7	R	No electrical function; to be connected to VSS
8	VSS	Ground

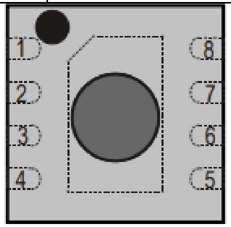


Table 6 SHT3x-DIS pin assignment (transparent top view). Dashed lines are only visible if viewed from below. The die pad is internally connected to VSS.

3.1 Power Pins (VDD, VSS)

The electrical specifications of the SHT3x-DIS are shown in Table 3. The power supply pins must be decoupled with a 100 nF capacitor that shall be placed as close to the sensor as possible – see Figure 11 for a typical application circuit.

3.2 Serial Clock and Serial Data (SCL, SDA)

SCL is used to synchronize the communication between microcontroller and the sensor. The clock frequency can be freely chosen between 0 to 1000 kHz. Commands with clock stretching according to I2C Standard[11] are supported.

The SDA pin is used to transfer data to and from the sensor. Communication with frequencies up to 400 kHz must meet the I2C *Fast Mode*[11] standard. Communication frequencies up to 1 Mhz are supported following the specifications given in **Table 20**.

Both SCL and SDA lines are open-drain I/Os with diodes to VDD and VSS. They should be connected to external pull-up resistors (please refer to Figure 11). A device on the I2C bus must only drive a line to ground. The external pull-up resistors (e.g. R_p=10 kΩ) are required to pull the signal high. For dimensioning resistor sizes please take bus capacity and communication frequency into account (see for example Section 7.1 of NXPs I2C Manual for more details[11]). It should be noted that pull-up resistors may be included in I/O circuits of microcontrollers. It is recommended to wire the sensor according to the application circuit as shown in Figure 11.

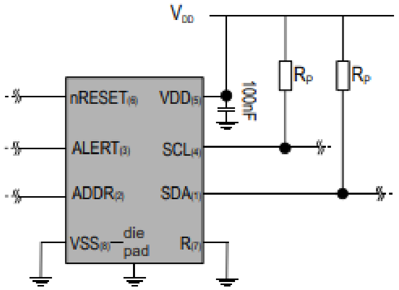


Figure 11 Typical application circuit. Please note that the positioning of the pins does not reflect the position on the real sensor. This is shown in Table 6.

3.3 Die Pad (center pad)

The die pad or center pad is visible from below and located in the center of the package. It is electrically connected to VSS. Hence electrical considerations do not impose constraints on the wiring of the die pad. However, due to mechanical reasons it is recommended to solder the center pad to the PCB. For more information on design-in, please refer to the document "SHTxx Design Guide".

3.4 ADDR Pin

Through the appropriate wiring of the ADDR pin the I2C address can be selected (see Table 7 for the respective addresses). The ADDR pin can either be connected to VDD or VSS, or it can be used as a selector pin. This means that the address of the sensor can be changed dynamically during operation by switching the level on the ADDR pin. The only constraint is that the level has to stay constant starting from the I2C start condition until the communication is finished. This allows to connect more than two SHT3x-DIS onto the same bus. The dynamical switching requires individual ADDR lines to the sensors.

[11] http://www.nxp.com/documents/user_manual/UM10204.pdf

Interfacing

Please note that the I2C address is represented through the 7 MSBs of the I2C read or write header. The LSB switches between read or write header. The wiring for the default address is shown in Table 7 and Figure 11. The ADDR pin must not be left floating. Please note that only the 7 MSBs of the I2C Read/Write header constitute the I2C Address.

SHT3x-DIS	I2C Address in Hex. representation	Condition
I2C address A	0x44 (default)	ADDR (pin 2) connected to VSS
I2C address B	0x45	ADDR (pin 2) connected to VDD

Table 7 I2C device addresses.

3.5 ALERT Pin

The alert pin may be used to connect to the interrupt pin of a microcontroller. The output of the pin depends on the value of the RH/T reading relative to programmable limits. Its function is explained in a separate application note. If not used, this pin must be left floating. The pin switches high, when alert conditions are met. The maximum driving loads are listed in Table 3. Be aware that self-heating might occur, depending on the amount of current that flows. Self-heating can be prevented if the Alert Pin is only used to switch a transistor.

3.6 nRESET Pin

The nReset pin may be used to generate a reset of the sensor. A minimum pulse duration of 1 µs is required to reliably trigger a reset of the sensor. Its function is explained in more detail in section 4. If not used it is recommended to leave the pin floating.

4 Operation and Communication

The SHT3x-DIS supports I2C fast mode (and frequencies up to 1000 kHz). Clock stretching can be enabled and disabled through the appropriate user command. For detailed information on the I2C protocol, refer to NXP I2C-bus specification[12].

All SHT3x-DIS commands and data are mapped to a 16-bit address space. Additionally, data and commands are protected with a CRC checksum. This increases communication reliability. The 16 bits commands to the sensor already include a 3 bit CRC checksum. Data sent from and received by the sensor is always succeeded by an 8 bit CRC.

In write direction it is mandatory to transmit the checksum, since the SHT3x-DIS only accepts data if it is followed by the correct checksum. In read direction it is left to the master to read and process the checksum.

4.1 Power-Up and Communication Start

The sensor starts powering-up after reaching the power-up threshold voltage V_{POR} specified in Table 3. After reaching this threshold voltage the sensor needs the time t_{PU} to enter idle state. Once the idle state is entered it is ready to receive commands from the master (microcontroller).

Each transmission sequence begins with a START condition (S) and ends with a STOP condition (P) as described in the I2C-bus specification. The stop condition is optional. Whenever the sensor is powered up, but not performing a measurement or communicating, it automatically enters idle state for energy saving. This idle state cannot be controlled by the user.

4.2 Starting a Measurement

A measurement communication sequence consists of a START condition, the I2C write header (7-bit I2C device address plus 0 as the write bit) and a 16-bit measurement command. The proper reception of each byte is indicated by the sensor. It pulls the SDA pin low (ACK bit) after the falling edge of the 8th SCL clock to indicate the reception. A complete measurement cycle is depicted in Table 8.

With the acknowledgement of the measurement command, the SHT3x-DIS starts measuring humidity and temperature.

4.3 Measurement Commands for Single Shot Data Acquisition Mode

In this mode one issued measurement command triggers the acquisition of *one data pair*. Each data pair consists of one 16 bit temperature and one 16 bit humidity value (in this order). During transmission each data value is always followed by a CRC checksum, see section 4.4.

In single shot mode different measurement commands can be selected. The 16 bit commands are shown in Table 8. They differ with respect to repeatability (low, medium and high) and clock stretching (enabled or disabled).

The repeatability setting influences the measurement duration and thus the overall energy consumption of the sensor. This is explained in section 2.

[12] http://www.nxp.com/documents/user_manual/UM10204.pdf

<u>คุณสมบัติทางกายภาพ</u> ตรงส่วนนี้จะบอกขนาดของอุปกรณ์ กว้าง ยาว สูง ระยะห่างของขา ขนาดของขา ฯลฯ เพื่อเป็นประโยชน์ในการออกแบบ PCB

รวมถึงการแพ็คออกจากโรงงาน ขนาดถาด ขนาดกล่อง บรรจุกี่ตัวกี่ชิ้นต่อถาดต่อกล่อง

5.2 Package Outline

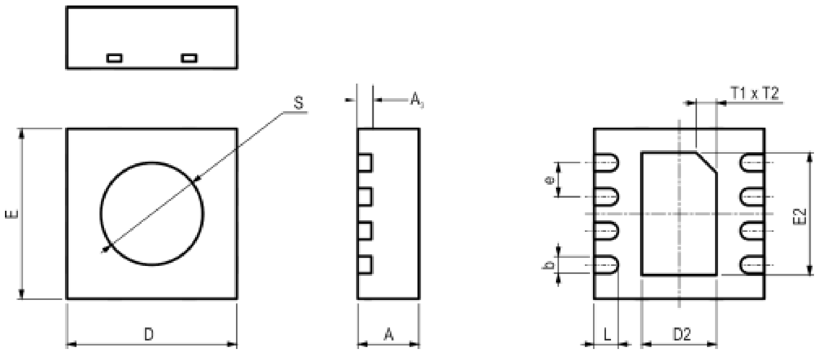


Figure 14 Dimensional drawing of SHT3x-DIS sensor package

Parameter	Symbol	Min	Nom.	Max	Units	Comments
Package height	A	0.8	0.9	1	mm	
Leadframe height	A3	-	0.2	-	mm	
Pad width	b	0.2	0.25	0.3	mm	
Package width	D	2.4	2.5	2.6	mm	
Center pad length	D2	1	1.1	1.2	mm	
Package length	E	2.4	2.5	2.6	mm	
Center pad width	E2	1.7	1.8	1.9	mm	
Pad pitch	e	-	0.5		mm	
Pad length	L	0.3	0.35	0.4	mm	
Max cavity	S	-	-	1.5	mm	Only as guidance. This value includes all tolerances, including displacement tolerances. Typically the opening will be smaller.
Center pad marking	T1xT2	-	0.3x45°	-	mm	indicates the position of pin 1

Table 21 Package outline.

5.3 Land Pattern

Figure 15 shows the land pattern. The land pattern is understood to be the open metal areas on the PCB, onto which the DFN pads are soldered.

The solder mask is understood to be the insulating layer on top of the PCB covering the copper traces. It is recommended to design the solder pads as a Non-Solder Mask Defined (NSMD) type. For NSMD pads, the solder mask opening should provide a 60 μm to 75 μm design clearance between any copper pad and solder mask. As the pad pitch is only 0.5 mm we recommend to have one solder mask opening for all 4 I/O pads on one side.

For solder paste printing it is recommended to use a laser-cut, stainless steel stencil with electro-polished trapezoidal walls and with 0.1 or 0.125 mm stencil thickness. The length of the stencil apertures for the I/O pads should be the same as the PCB pads. However, the position of the stencil apertures should have an offset of 0.1 mm away from the center of the package. The die pad aperture should cover about 70 – 90 % of the die pad area –thus it should have a size of about 0.9 mm x 1.6 mm.

For information on the soldering process and further recommendation on the assembly process please consult the Application Note HT_AN_SHTxx_Assembly_of_SMD_Packages , which can be found on the Sensirion webpage.

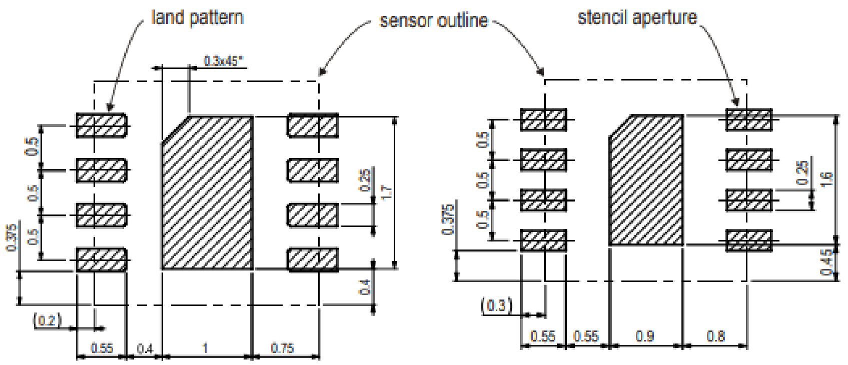


Figure 15 Recommended metal land pattern (left) and stencil apertures (right) for the SHT3x-DIS. The dashed lines represent the outer dimension of the DFN package. The PCB pads (left) and stencil apertures (right) are indicated through the shaded areas.

6 Shipping Package

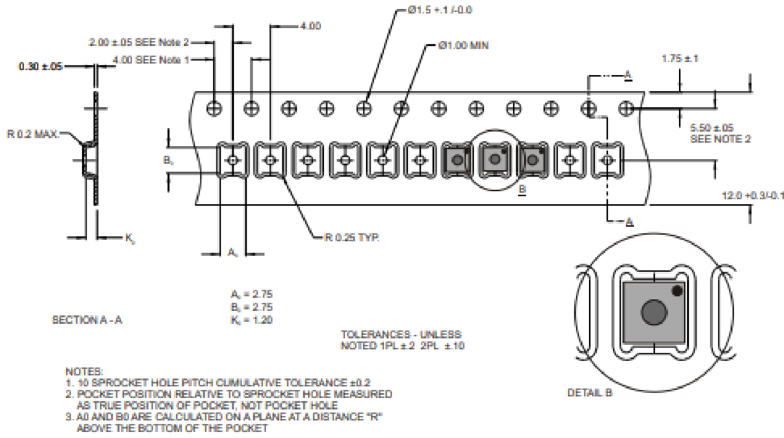


Figure 16 Technical drawing of the packaging tape with sensor orientation in tape. Header tape is to the right and trailer tape to the left on this drawing. Dimensions are given in millimeters.

Where to find datasheet ?

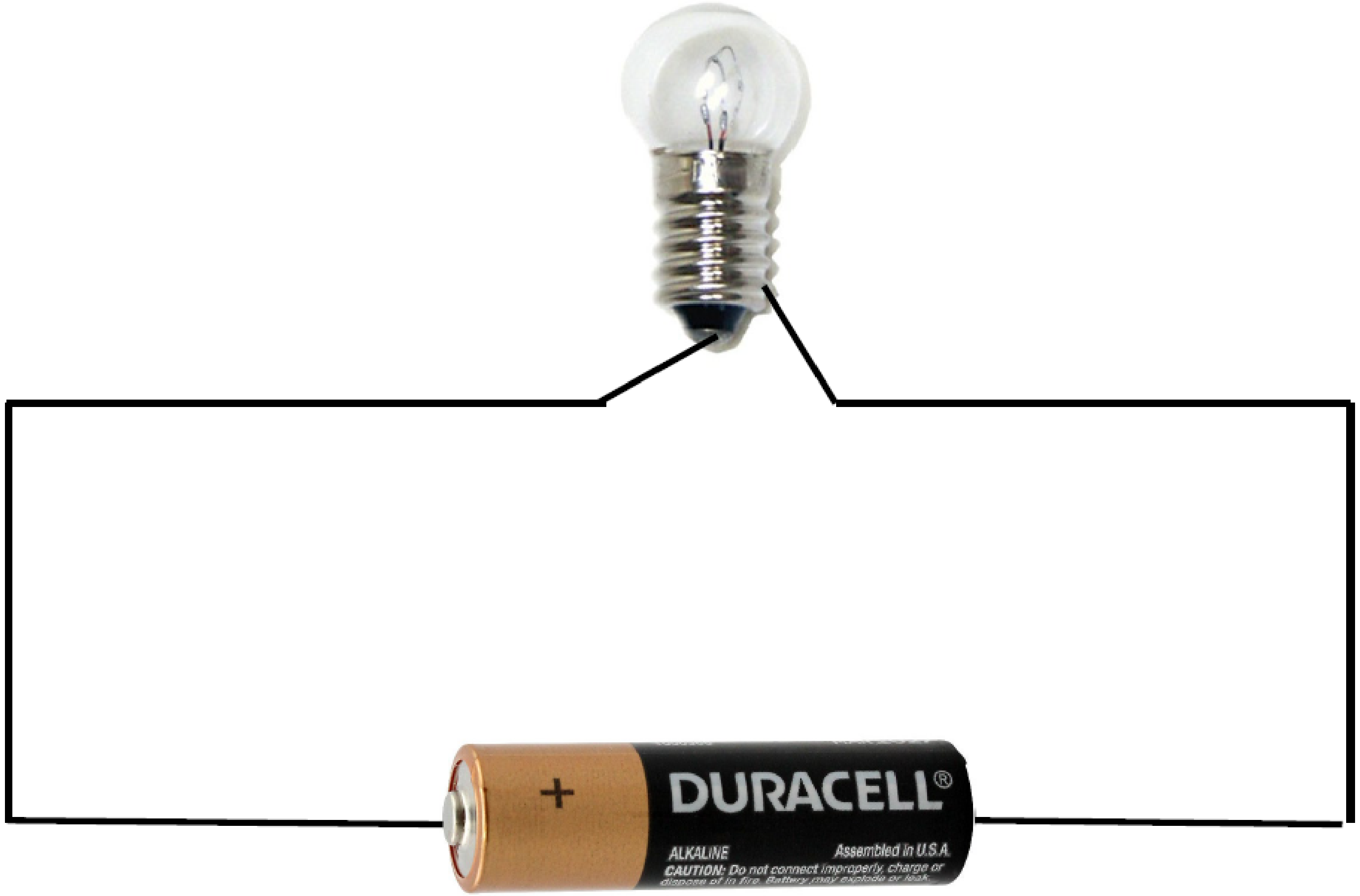
- โดยส่วนใหญ่แล้ว จะมี **Datasheet** ที่มาจากผู้ผลิตโดยตรง
- บางครั้งอาจกระจายไป หาได้จาก **Search Engine** ทั่วไป (ต้องพิจารณาว่าน่าเชื่อถือหรือไม่ ?)
- บางครั้งอาจไม่มี (หายาก/ภาษาอื่น ๆ เช่น ภาษาจีน)

					
Product Name	Gravity: I2C BME280 Environmental Sensor	Gravity: Analog LM35 Temperature Sensor For Arduino	Waterproof DS18B20 Sensor Kit	Gravity: DS18B20 Temperature Sensor	Gravity: Analog High Temperature Sensor
SKU	SEN0226	DFR0023	KIT0021	DFR0024	SEN0198
Operating Voltage	3.3V/5V	3.3V/5V	3.0V~5.5V	3.3V~5V	3.3V~5.5V
Operating Current	2.7μA	<133μA	<3μA	<3μA	2.8μA
Operating Temperature	-40℃~85℃	-40℃~150℃	-55℃~125℃	-55℃~125℃	30℃~350° C
Range of temperature measurement	0℃~65℃	0℃~100℃	-55℃~125℃	-55℃~125℃	-20℃~400° C
Precision of temperature measurement	0.01℃	0.5℃	0.5℃	0.5℃	0.5℃
Temperature deviation	±0.5℃	±0.5℃	±0.5° C	±0.5℃	±2% F.S.
Dimension	30*22(mm)	30*22(mm)	33*22(mm)	22*32(mm)	42*32*18(mm)
Interface	Gravity-IIC	Gravity-analog	Gravity-digital	Gravity-digital	Gravity-analog
Data type	Digit	analog	Digit (unibus)	Digit (unibus)	analog
Price	$8.80	$4.50	$8.00	$4.00	$16.00
Brief introduction	BMP280 Barometer sensor supports Arduino and can measure both temperature and atmospheric pressure. It can be applied to enhance GPS navigation & coordinate with IMU sensor to realize indoor and outdoor navigation. Compared to the last generation BMP180 barometer sensor, it has a lower power consumption, higher resolution and higher sampling frequency. **Application:** Enahnced GPS navigation (e.g time-to-first-fix improvement, dead-reckoning, slope detection) Indoor navigation (floor detection, elevator detection) Outdoor navigation, leisure and sports applications Weather forecast Health care applications (e.g. spirometry) Vertical velocity indication (e.g. rise/sink speed)	A Temperature Sensor can be used to detect ambient air temperature, the output voltage is proportional to temperature. It has good linearity and high sensitivity. **Application:** Medical treatments Personal controls Industrial controls Aeronautics and astronautics.	Waterproof temperature sensor DS18B20 is widely used in many fields, such as soil temperature measurement, hot tank temperature control etc. It supports multipoint measurement. **Application:** Constant temperature control Industrial system Consumer electronics Thermistors Refrigerators Barns Tanks Telecommunication rooms Power communication rooms Cables etc.	A Temperature Sensor can be used to detect ambient air temperature. It can be connect to three-wire in parallel to achieve multipoint temperature measurement. **Application:** Constant temperature control Industrial system Consumer electronics Thermistors Refrigerators Barns Tanks Telecommunication rooms Power communication rooms Cables etc.	It used a PT100 resistance type high temperature probe to measure a temperature range between 30-350° C. **Application:** Especially for high precision of temperature measurements. Medical treatments Motors Industrials Temperature counts Resistance counts

					
Product Name	Gravity: Non-contact IR Temperature Sensor For Arduino	Infrared Thermometer Module	Gravity:SHT1x Humidity and Temperature Sensor	Gravity: DHT11 Temperature Humidity Sensor For Arduino	DHT22 Temperature and Humidity Sensor
SKU	SEN0206	SEN0093	DFR0066	DFR0067	SEN0137
Operating Voltage	3.3V~5V	3V~5V	3.3V~5V	3.3V~5V	+5V
Operating Current	1.2mA	4mA~9mA	2μA	0.5mA~2.5mA	1.5mA
Operating Temperature	-40℃~125 ℃	-10℃~50℃	-40℃~128.8℃	0℃~50℃	-20℃-80℃
Range of temperature measurement	-70.01℃~382.19℃	-33℃~220℃	-40℃~128.8℃	0℃~50℃	-40℃-80℃
Precision of temperature measurement	0.5℃	2℃(full range)	0.5℃	2℃	<0.5℃
Temperature deviation	±0.5℃	±0.6℃	±0.4℃	±1℃	±0.5℃
Dimension	31.5*18(mm)	12*13.7*35(mm)	32*27(mm)	22*32(mm)	38 * 20(mm)
Interface	Gravity-IIC	Digitalx3	Gravity-2-wire digital	Gravity-digital	Gravity-digital
Data type	Digit	Digit	Digit	Digit	Digit (unibus)
Range of humidity measurement			0-100%RH	20-90%RH	0-100%RH
Humidity deviation			±4.5%RH	±5%RH	±2%RH
Price	$16.00	$49.00	$21.05	$5.20	$9.50
Brief introduction	non-contact measurement uses infra-red radiation to measure the temperature and does not require a direct touch. Additionally, this method of measurement can be read quickly and accurately. This module has a FOV of 35° Wave length 5.5um-14um **Application:** Environmental monitor Home automation Automobile electronics Airline industry Military	It is a long distance thermometer specially designed for a high sensitivity, high accuracy, low noise and low power consumption. Wave length:5um-14um This module has a FOV of 26.6° x 2 = 53.2° **Application:** Medical equipment Fire alarm systems telecommunications	It consists of 1 capacitive humidity module and 1 energy gap temperature module, perfect integration of 1 14bit A/D converter and 1 2-wire digital interface. CMOSens technology makes it of advantages such as low power consumption, fast response, strong anti-jamming capacity etc. **Application:** Medical equipment HVAC Meteorology Humidity regulator Dehumidifier Tests and measurements Automobile Automatically control	This sensor includes a resistive element and a sense of wet NTC temperature measuring devices. It has excellent quality, fast response, anti-interference ability and high cost performance advantages. Its signal transmission distance up to 20 meters. These features make it a variety of applications and even the most demanding applications. **Application:** Medical equipment HVAC Meteorology Humidity regulator Dehumidifier Tests and measurements Automobile Automatically control	It contains a resistive element and a sense of wet NTC temperature module. Compared to DHT11, it has smaller humidity deviation, faster response, stronger anti-interference ability and higher cost performance **Application:** Medical equipment HVAC Meteorology Humidity regulator Dehumidifier Tests and measurements Automobile Automatically control

Example of Different Temp Sensor

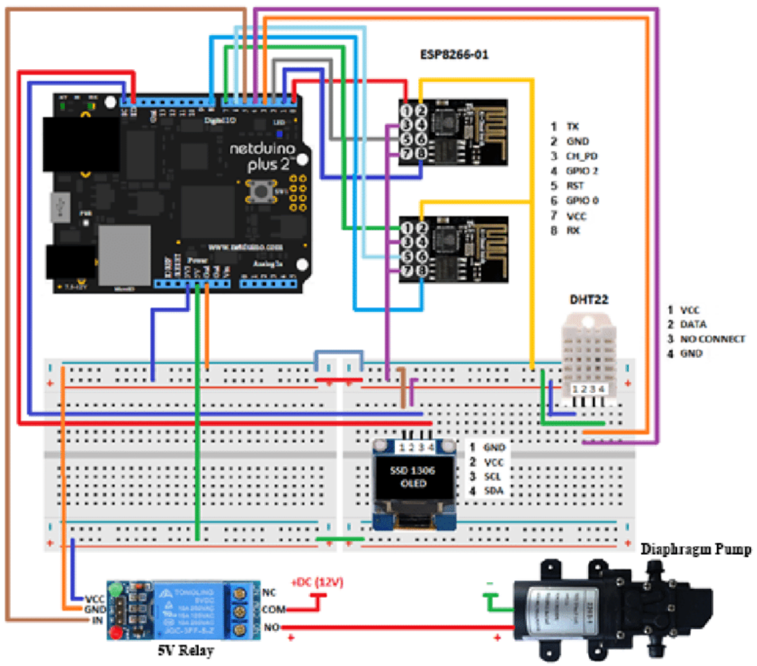
Making a Circuit

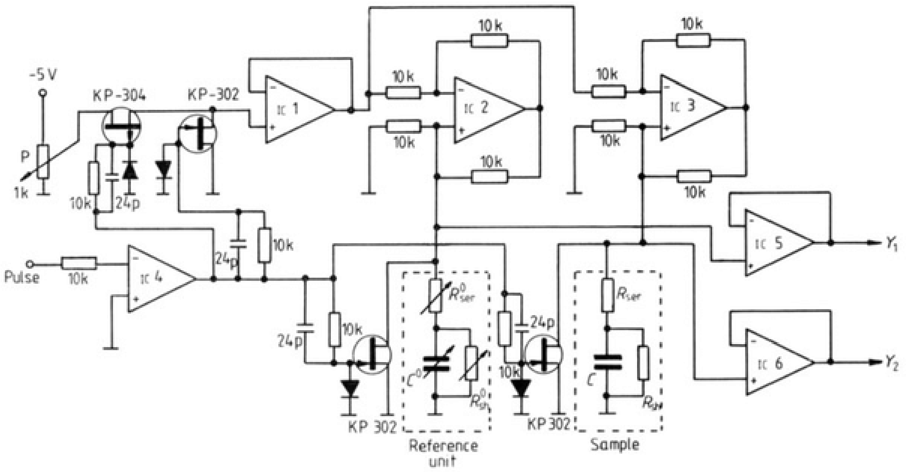


- Can put components together to build circuits that do things

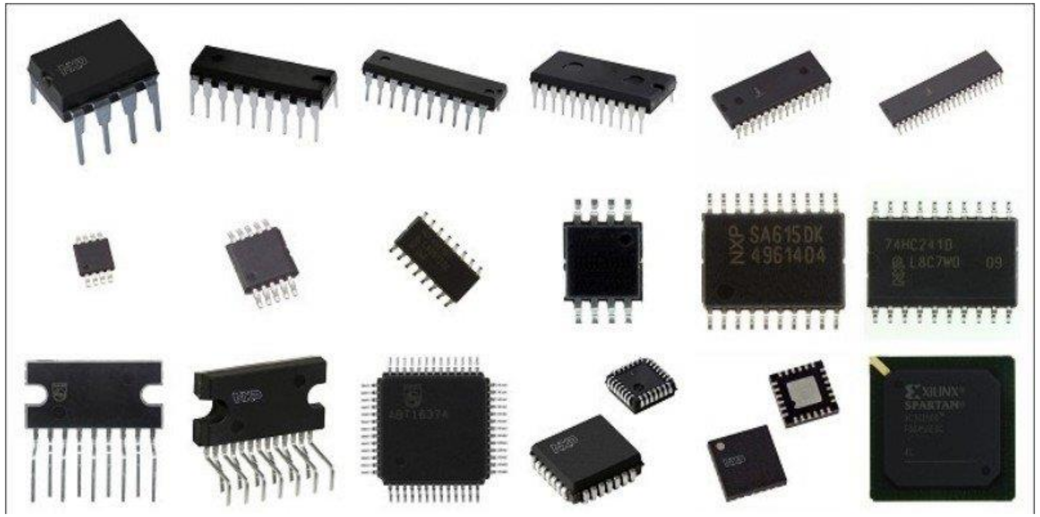
How to Build Circuits

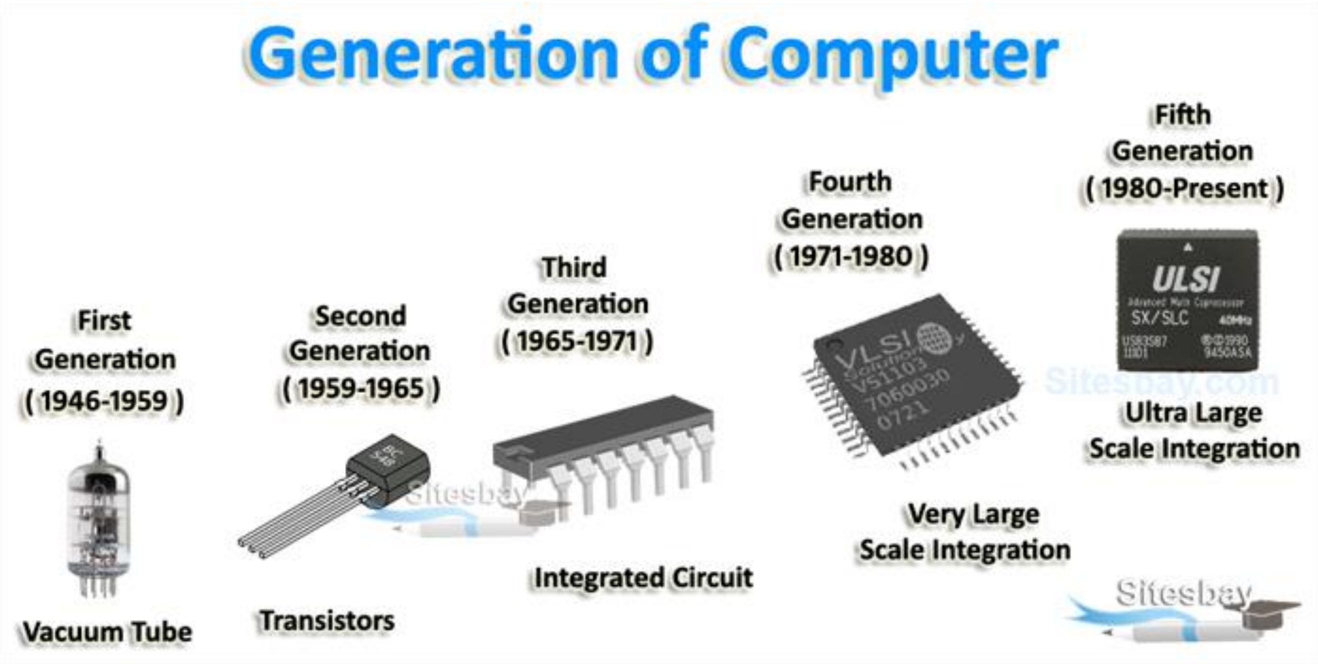
- เปรียบเสมือนการเขียนโปรแกรม การเรียนรู้ทั่ว ๆ ไป ไม่ยาก เราสามารถเรียนรู้พัฒนาเองได้
- เนื่องจากในงานด้าน IoT อาจไม่จำเป็นต้องจำหรือรู้วงจรอิเล็กทรอนิกส์ที่ซับซ้อนมาก ๆ ทั้งหมด
- วงจรซับซ้อนเหล่านั้น จะถูกประกอบเข้ามาด้วยกันอยู่แล้ว
- เราสามารถจัดเตรียมซื้อชิพ อุปกรณ์ PCB ต่าง ๆ ไว้เตรียมใช้งานได้





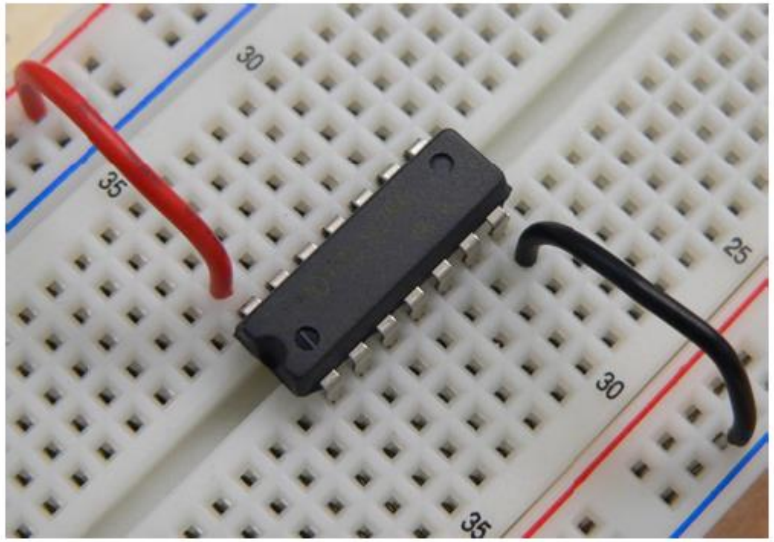
Integrated Circuits



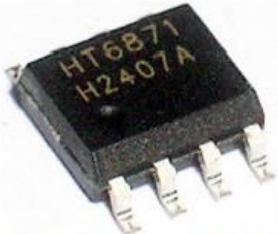


Fabrication of Integrated Circuits Processor Microship : https://www.youtube.com/watch?v=IjVrkYteNwY
Chip Manufacturing - How are Microchips made? : https://www.youtube.com/watch?v=bor0qLifjz4
From Sand to Silicon: the Making of a Chip Intel : https://www.youtube.com/watch?v=Q5paWn7bFg4

Integrated Circuit Packaging



Dual-Inline Package (DIP)



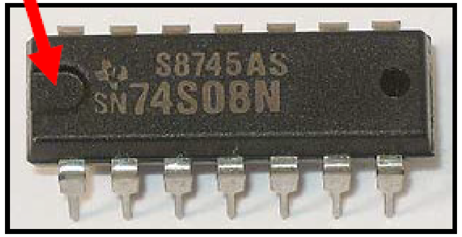
Small-Outline IC (SOIC)

Quad-Flat Package (QFP)

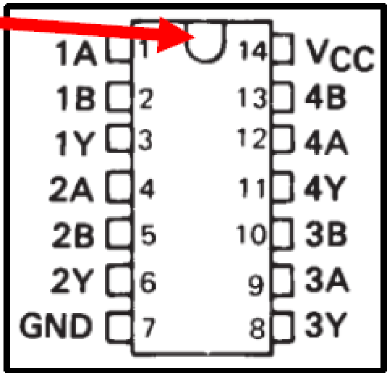
Surface-Mount Device (SMD)

Example IC: Texas Instruments SN74S08N (Quad AND Logic Gates)

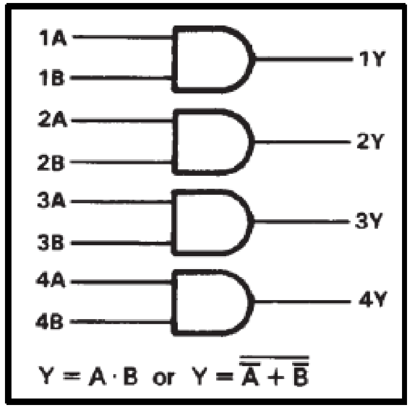
notch



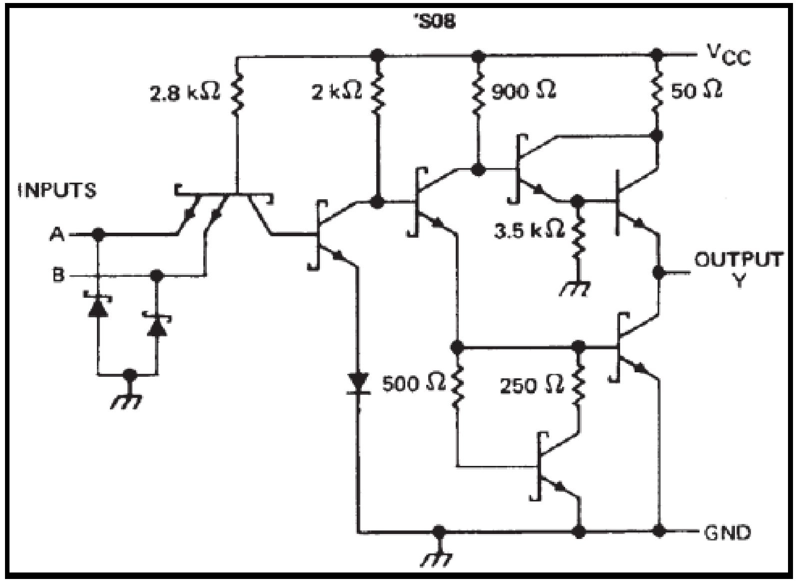
SN74S08N (DIP)



Pinouts



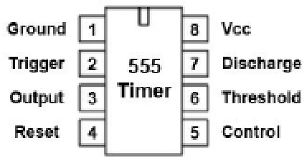
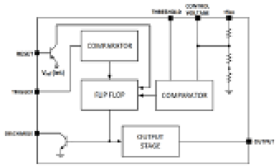
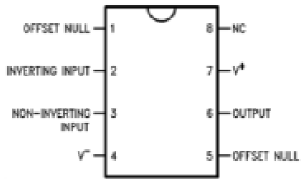
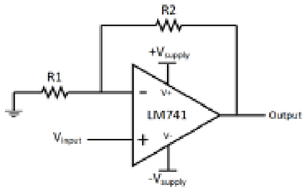
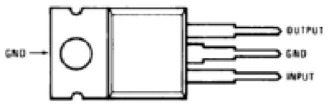
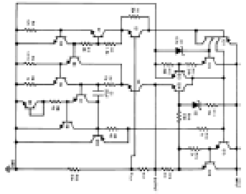
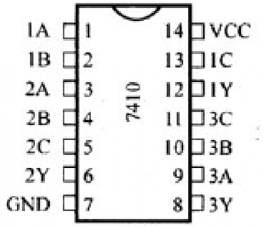
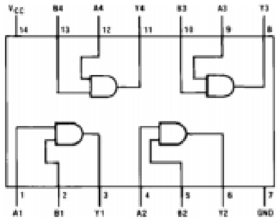
Logic Diagram



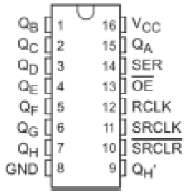
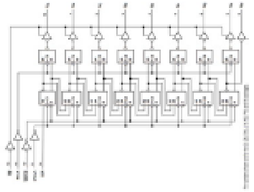
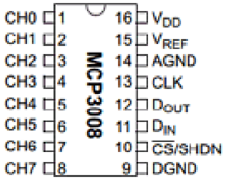
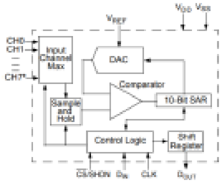
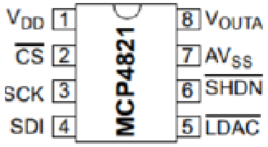
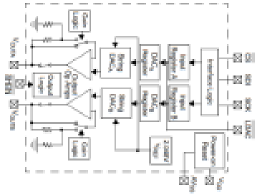
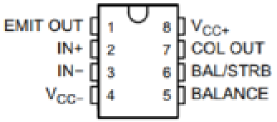
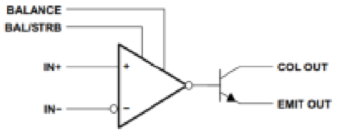
Schematic (each AND gate)

- Datasheet: https://www.ti.com/lit/ds/symlink/sn74ls08.pdf
  - Google "SN74S08N datasheet"

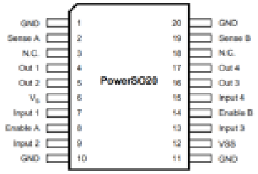
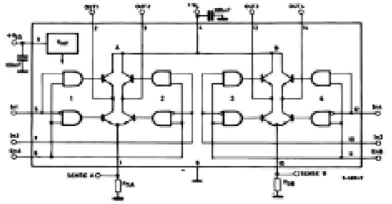
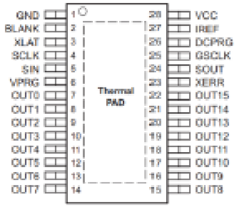
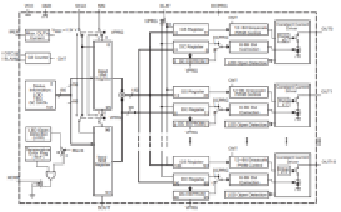
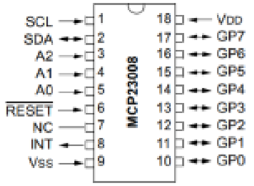
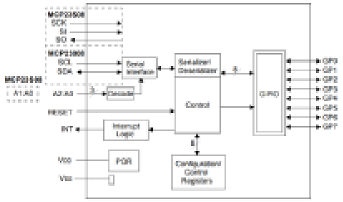
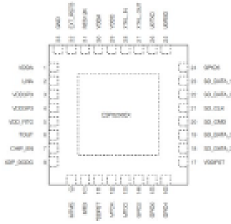
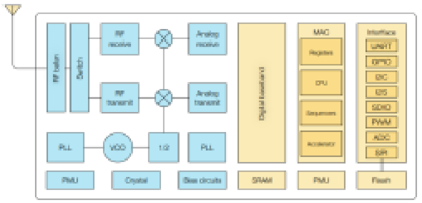
Popular IC Types

IC family	Type	Pinout	Logic diagram	What it does	Alternatives/ Variants
555	Timer			Can configure time and mode. Sends pulse after time period (monostable config) or at regular intervals (astable config). Most popular IC. >1 Billion sold every year.	XR-2206 (also generates sine/sawtooth waves), 8038, CD4046
741	Operational Amplifier (Op-Amp)			Produces output voltage much higher than voltage difference between input terminals	LM324 (has four op-amps in one 14-pin DIP package, doesn't require separate pos/neg power supplies), LM358, TLC272; TL0XX (eg, TL081, TL082, TL084)
78xx	Voltage Regulator			Accepts input voltage within a certain range and produces a constant output voltage. xx represents voltage regulated by chip (e.g., 7805 produces a 5-volt output)	78xxSR, 78xxC, 78xxS, 79xx, LM317, LM2575T-ADJ (output adjustable 1.23V to 37V), MC34063A, XL6009
74xx	Logic Circuits			Digital logic operations. Includes logic gates, flip-flops, counters, buffers, and more.	7408 (AND), 7404 (NOT), 7486 (XOR), 7402 (NOR), 7400 (NAND), 7474 (Flip-flops)

Popular IC Types

IC family	Type	Pinout	Logic diagram	What it does	Alternatives/ Variants
74HC595	Shift Register			Stores an array of bits. Can "shift" bits up, losing (or wrapping) bits off the end. Used to allow many pins to be controlled by 1-2 pins, to multiply by two, etc.	74LS195 (4 bits), 4006 (18 bits), 4014 (8 bit static), 74LS194 (bidirectional 4-bit)
MCP3008	A/D Converter			Converts analog to digital; takes an analog voltage level on one pin, outputs across a set of pins a binary number representing the level of that voltage.	MCP3002. PCF8591,
MCP4822	D/A Converter			Opposite of an A/D converter: takes a binary input across a set of pins, and outputs a voltage corresponding to that number.	MCP4725 (12-bit), MCP4728, MCP4921, AD7390
LM311	Comparator			Compares two input voltages and outputs a digital signal indicating which is larger (output is 1 if V+>V-, 0 otherwise. Can be used to create null detectors (whether input is 0 volts), to generate triangle/square waves (eg car turn signal), etc.	LM312, LM393, LM339

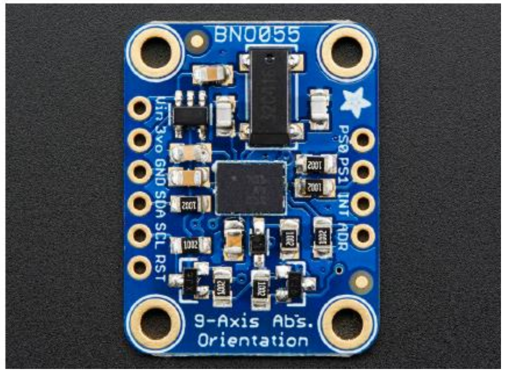
Popular IC Types

IC family	Type	Pinout	Logic diagram	What it does	Alternatives/ Variants
L298D	Motor Driver			Accepts standard TTL logic level voltages, and drives big inductive loads such as electromagnets, stepping motors, valves, pumps, etc.	L298N, L293
TLC5940	LED Driver			16 channels, each has 4096-step PWM brightness control. Brightness controlled by programmable on-chip EEPROM. Reports error information: broken/disconnected LED, overtemperature condition.	TLC5947, LT3741, ADP8861
MCP23008	I/O Expander			Change one serial input to 8 pins of parallel output. Adds 8 pins to your microcontroller.	MCP23017, MCP 23016 (16-bit), SX1509, TCA9535
ESP8266	WiFi module			802.11 b/g/n WiFi with WEP/WPA/WPA2 authentication (or open networks) and full TCP/IP stack. Also contains embedded microprocessor core	ESP8285 (has 1MB built-in flash), ESP32 (successor)

So, can we just make everything an IC?

- ICs are great
  - “Componentize” circuits –don’t need to understand insides so much
  - Reduced cost
- But can’t do everything as an IC
  - High current/voltage –exceeds logic levels
  - Low volume or too new –no ICs exist for it
- Can we componentize non-IC circuits?

Breakout Boards



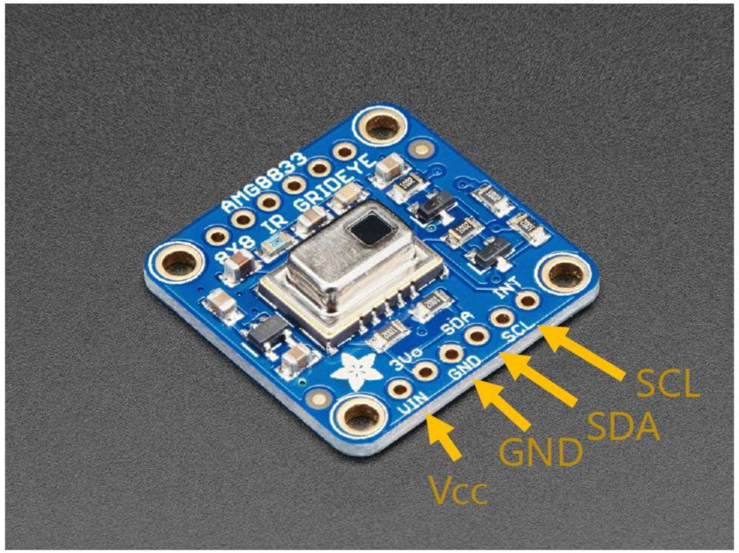
- Standalone board that componentizes a circuit
  - "Breaks out" key pins to simplify prototyping
  - Deals with complicated EE stuff, lets you focus on using the circuit
  - Incorporates collection of components onto a single PC
- Example: Adafruit 9-DOF Absolute Orientation IMU Fusion Breakout –BNO055 (Source: https://www.adafruit.com/product/2472)

Breakout Boards

- Benefits: reduces costs, saves space, improves efficiency/reliability, simplifies reuse, clear pinouts, good documentation
  - Lets you do a lot with less domain knowledge
  - Speeds prototyping
  - Saves you soldering work
- Challenges: may not be interchangeable/compatible (e.g., may target a specific platform like Arduino), may need to solder or install header pins, need to be careful about supply voltage and other inputs

Example: Adafruit AMG8833 IR Thermal Camera Breakout

- 8x8 array of thermal IR sensors
  - Can detect human 23 feet away
  - 10 Hz frame rate
- **Uses:** human detector, thermal camera, intruder alert
- **Incorporates:** Panasonic AMG8833 thermal IR sensor, 3.3V regulator, misc. resistors/capacitors

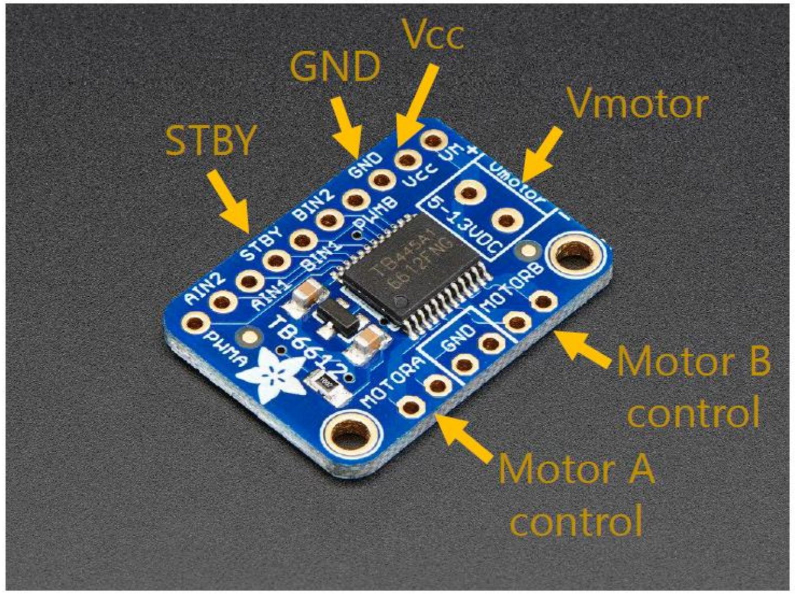


Pinout:

- Input voltage (Vin)
- Output voltage in case you can use it (3Vo)
- Ground (GND)
- Serial clock –output (SCL)
- Serial data –output (SDA)
- Interrupt output –when something changes in vision path (INT)
- (Pins at top for stability, unused)

Example: Adafruit TB6612 1.2A DC/Stepper Motor Driver Breakout Board

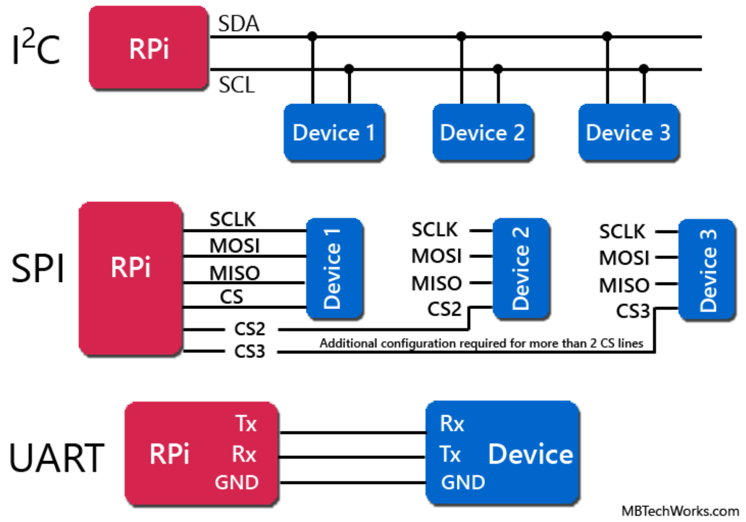
- Driver for stepper motor
  - Can drive 1.2A sustained, 3A peak (20ms)
  - Control direction and speed, stop/brake
  - Motor voltage isolated from logic voltage
- Uses: robot, pan/tilt housing, automotive gauge/dial, toy car
- Incorporates: a Toshiba TB6612 motor driver IC, two H-bridges, polarity protection FET, pullup resistor for inputs, kick-back diodes



Pinout:

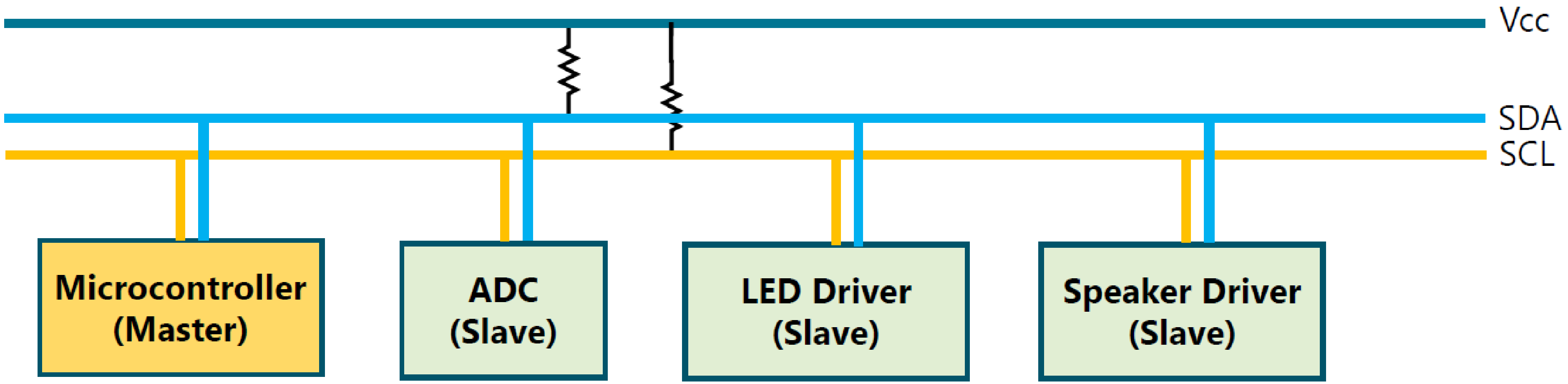
- Input voltage for logic levels (Vcc)
- **Voltage** to drive motor (Vmotor)
- Ground (GND)
- Motor control outputs:
  - INA1, INA2, PWMA: outputs for motor A's H-bridge
  - INB1, INB2, PWMB: outputs for motor B's H-bridge
  - STBY: quickly disable both motors

Example of Sensor Interfacing



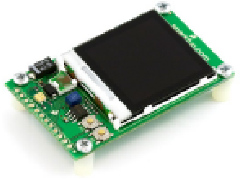
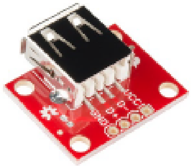
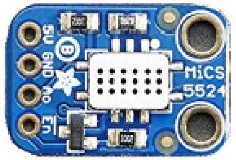
- **Serial Peripheral Interface (SPI)**
  - Max # devices very limited (chip-select for each chip on the bus)
  - Significantly faster than I2C (25Mbps), works over longer cable runs
  - Used for, eg. Connecting microcontroller to SD/microSD card
- **UART**(RS-232/422/485/etc., aka Serial Port)
  - Asynchronous (no shared clock)
  - Parameters: baudRate, parity, stopBits, dataBits (e.g., 115200, none, 1, 8)
  - Max speed 8Mbps
- **GPIO**
  - Not really a protocol –turning pins on and off, defines threshold voltages
  - Used for switches, buttons, motion detectors, LEDs, turning on/off appliances
  - Max speed 1kHz
  - Analog to Digital Convertor (ADC,A2D)

Connecting ICs with the I2C Protocol



- Easy to use, very expandable, serial bus widely used to connect ICs
  - Reduces pinouts, transfers data/commands
- Address-oriented scheme, where addresses are part of packets that you send
  - Handles many devices; each device has an address (can solder jumpers to change address)
  - Message-based communication (unlimited length), 0.1-5Mbps, synchronous
- Multi-master/Multi-slave architecture: master generates clock, initiates communications

Example Breakout Boards

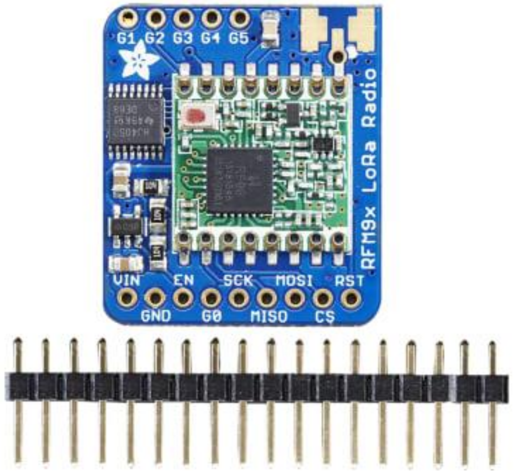
Type	Name	Picture	What it does	Internal Components	Other boards in this category
Actuator	Allegro A4988 Stepper Motor Driver		Takes in logic input and uses that to control a higher-amp input for driving a stepper motor. Includes current limiting, short-circuit/over-current/over-temperature protection. Operates from 8-35V and supports up to 1A without cooling (2A with sufficient additional cooling). Five different resolutions (full, half, quarter, 1/8, 1/16).	A4988 IC	Clock generators, Audio FX sound boards, storage/microSD, NVRAM
Display	SparkFun Color LCD Breakout Board		Uses logic input to write graphics onto and control backlight of color LCD display. Display is 132x132 pixels @12 bit color, same display from cell phones.	Nokia 6100 color LCD, Philips PCF8833 graphics controller, status LEDs, two pushbuttons.	LED matrix backpacks, LED strip controllers, LCD displays, touchscreen controllers
Connector	SparkFun USB Type A Female Breakout		Splits out female USB type A connector's VCC, D-, D+, and GND pins to a standard 0.1"-width header. Good if you need USB but don't want to deal with soldering tiny connectors.	USB Type A female connector	Other types of USB (microB, C, etc), audio connectors, HDMI/DVI coders, USB mouse/keyboard controller Wireless 802.11/LoRA/etc.
Sensor	Adafruit MiCS5524 CO, Alcohol and VOC Gas Sensor Breakout		MEMS sensor breakout to monitor levels of various sorts of gases. Useful for indoor carbon monoxide and natural gas leakage, alcohol breath checker, early fire detection. Sensitive to 1-1000ppm. Can't tell you which gas it has detected.	SGX NICS-5524 gas sensor	Sensors for Oxygen, CO2, methane, PM2.5/PM10, humidity, barometric/altitude, windspeed, temperature, human breath analysis

https://www.adafruit.com/category/35

https://www.seeedstudio.com/sensor-c-788.html

Many .. Many


keyestudio
37 IN 1 SENSOR KIT UPGRADED V3.0


G1 G2 G3 G4 G5
RFM9x LoRa Radio
VIN EN SCK MOSI RST
GND G0 MISO CS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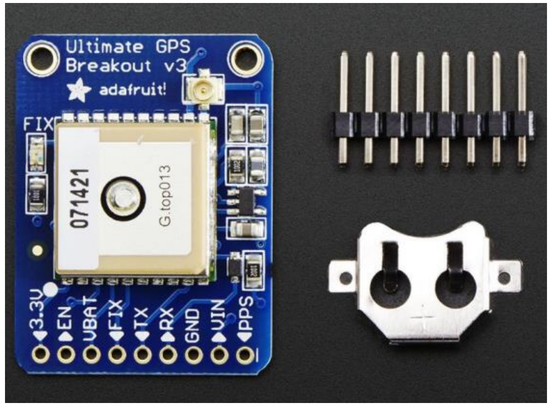
Ultimate GPS
Breakout v3
adafruit!
FIX
3.3V EN VBAT FIX TX RX GND VIN PPS

References

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- IoT Sensors and Devices, CurtinX University
- Sensor Terminology - National Instruments". 2018. Ni.Com. http://www.ni.com/white-paper/14860/en/.

Introduction to Internet of Things