IoT Product Design and Coding Bootcamp

Brian Rashap, Ph.D.

24-Feb-2020

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IoT Fun


I THINK MY NEST SMOKE ALARM IS GOING OFF. GOOGLE ADWORDS JUST PITCHED ME A FIRE EXTINGUISHER AND AN OFFER FOR TEMPORARY HOUSING.
TOM FISH BURNE

Brian Rashap, Ph.D.

- Proud husband of Krista and father of Shelby (21) and Ethan (18)
- Electrical Engineer with 25 years industrial experience
- High School track coach
- Hobbies: running, cycling, reading, spending time with family

Introductions

INTRODUCTIONS

Class Rules

- Respect Each Other, Help Each Other
- Ask Questions
- Be On Time (let's us know via Slack if you won't be here)
- Keep Your Workspace and the Classroom Neat and Tidy
- If you are struggling, let myself, Susan, or Esteban know. We are here to HELP!

Grading

1. In class assignments - 30
2. Individual smart device – 20
3. Capstone – 40
4. Assessments – 10

More information later today on how assignments are turned in

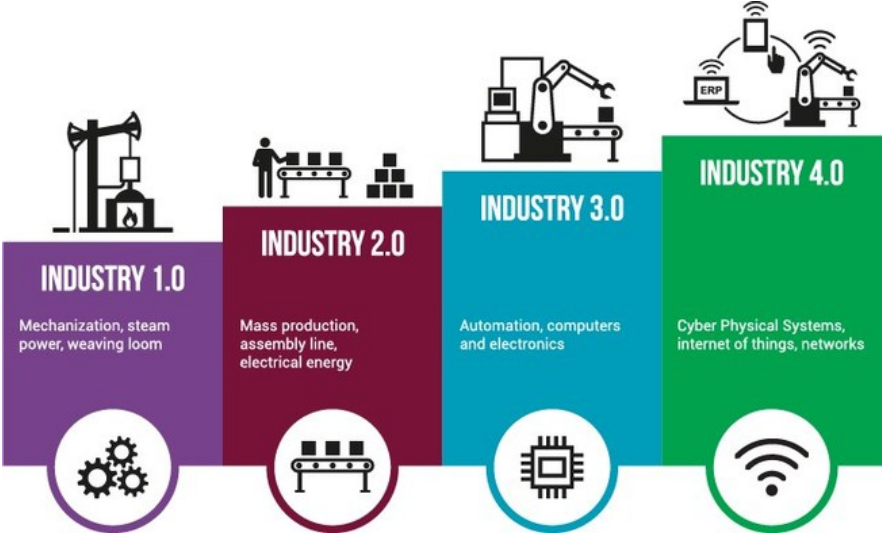
GITHUB Simplified

```
// In Powershell go to ./Documents/<yourname>
// Get a repository that already exists and pull
   it into your local machine
  git clone <URL of repository>

// From the repository directory, get updates
  git pull

// Send your changes up to the repository
  git add .
  git commit -m "<comment>"
  git push

// You may get asked to enter your GIT username
git config --global user.email "you@example.com"
```

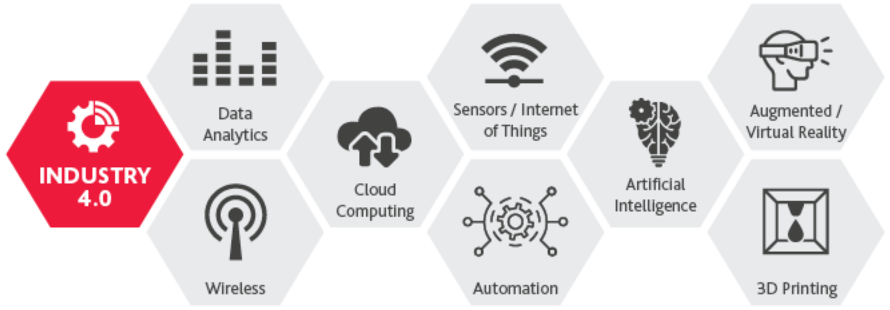
Powershell Commands Simplified

```
mkdir <directory name>  //make a directory
rmdir <directory name> //remove directory
ls //list contents of current directory
pwd //print path of current directory
cd <directory name> // change directory
cd .. //change directory to the directory above
new-item <file name> //create a file
cp <file name> <new file name> //copy file
mv <file name> <directory> //move file to new dir
rm <file name> //delete file
cat <file name> //display contents of file
```

Evolution of Industry

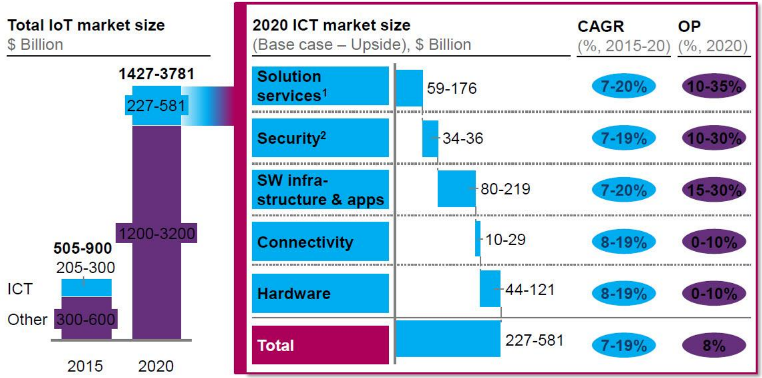


Components of Industry 4.0



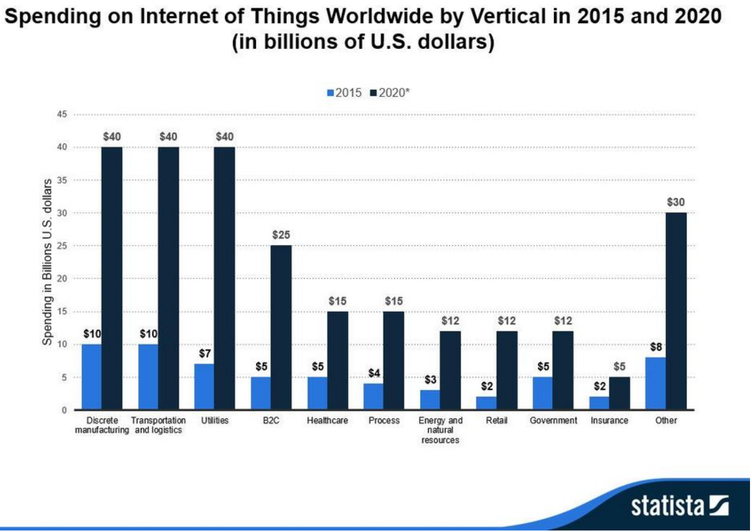
IoT Market Size

Resulting in a large IoT market size, of which a significant component is ICT

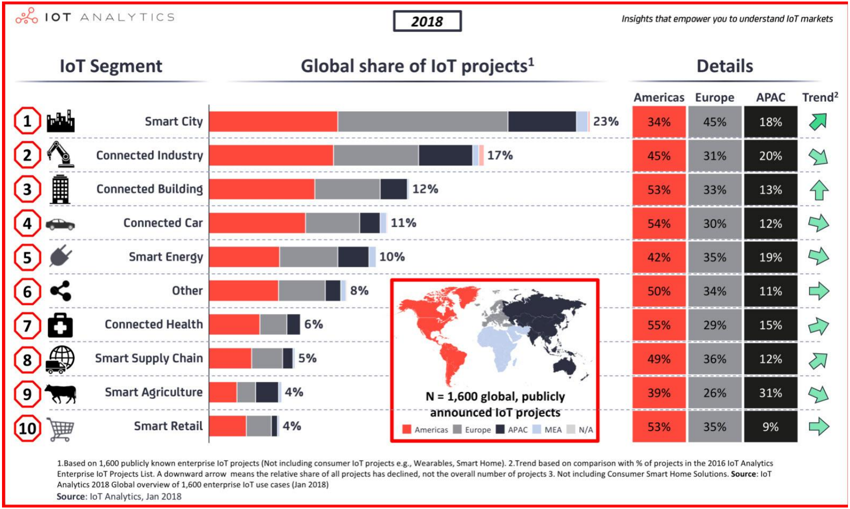


1 Solution services not considered technical products
2 $3-$6B is IoT security and $25-$35B is for mobile security

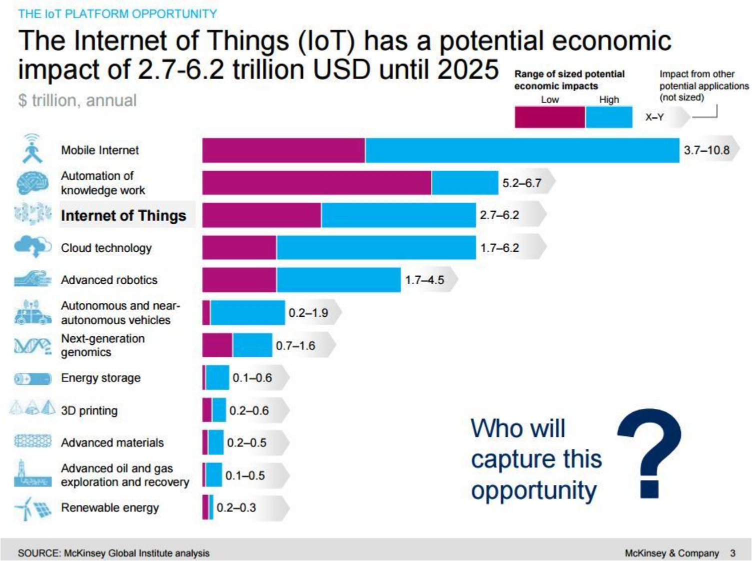
Spending by IoT Vertical



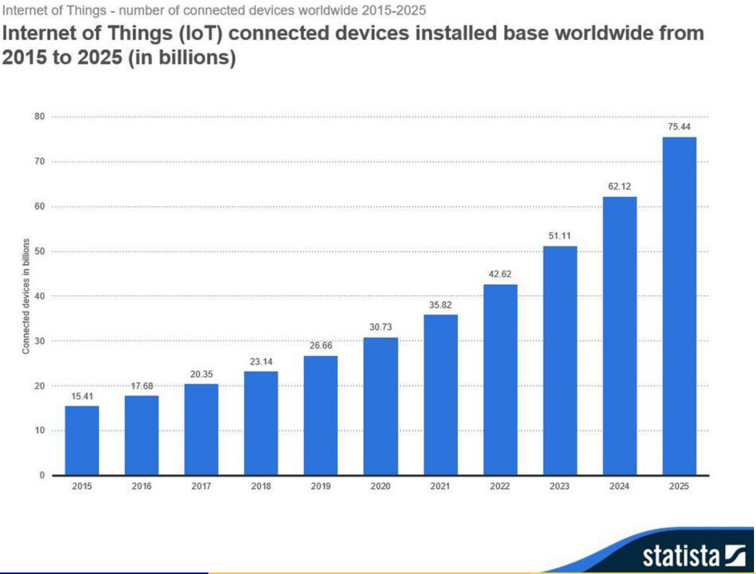
IoT Segments



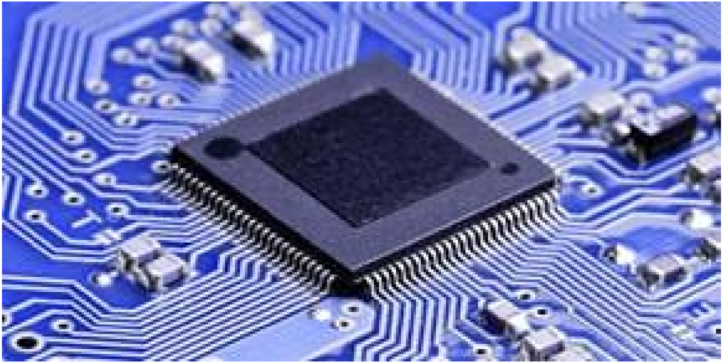
IoT Potential Economic Impact



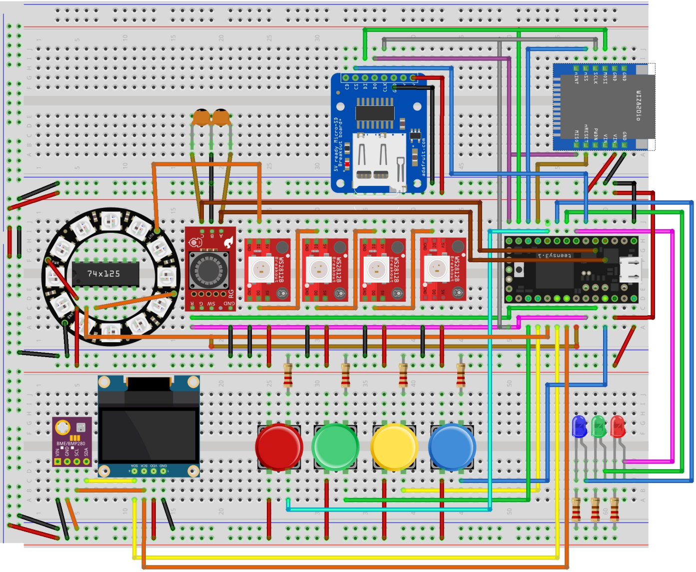
IoT Growth


Internet of Things - number of connected devices worldwide 2015-2025
Internet of Things (IoT) connected devices installed base worldwide from 2015 to 2025 (in billions)
Connected devices in billions
0
10
20
30
40
50
60
70
80
15.41
17.68
20.35
23.14
26.66
30.73
35.82
42.62
51.11
62.12
75.44
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
statista

Our First Microcontroller

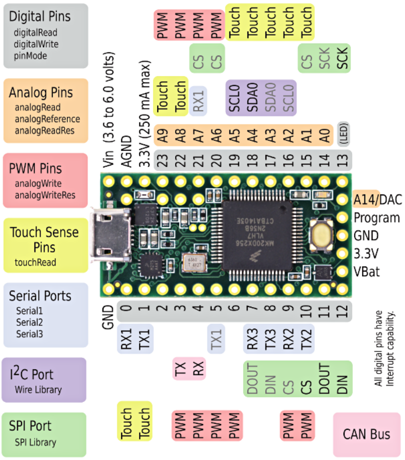


Smart Room Controller



Teensy 3.2

- Cortex-M4 72MHz (overclocked to 96 MHz)
- 34 GPIO pins
- 3.3V and 5.0V operating voltages
- 500mA of available power with USB



Arduino IDE for Teensy

We are going to start off using the Arduino IDE[1]. The Arduino IDE is programmed essentailly using C++ code, but make the compiling and loading onto the microcontroller simplier.

We begin by installing the Arduino IDE:
https://www.arduino.cc/en/main/software

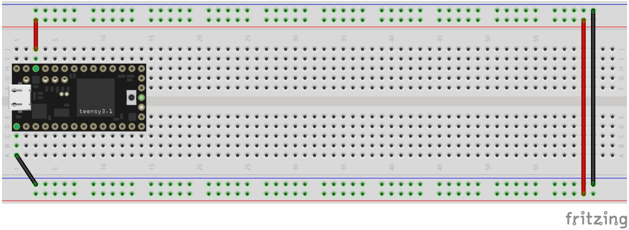
Then, we install the Teensyduino add-on:
https://www.pjrc.com/teensy/td_download.html

[1] An IDE, or Integrated Development Environment, enables programmers to consolidate the different aspects of writing a computer program.

Other Software

- Fritzing
- Fusion 360
- Drawio

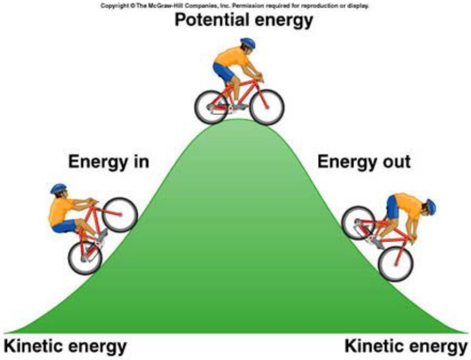
Teensy on Breadboard



Basic Structure of Arduino Sketch

```
// the "header" is used for GLOBALS
#include <library.h> // library files
int class_size;      // declare global variables
Adafruit_BME280 bme; // name object in class

void setup() {
  oled.init();                // initialize objects
  bme.begin(0x76)             // begin processes
  arraySize = sizeof(array)4; // set variables
}

void loop() {
  // functionality of your code
  // this loops indefinately
}
```

Energy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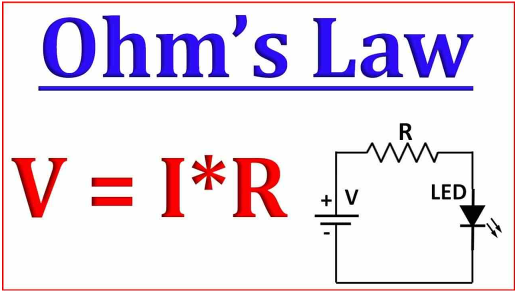
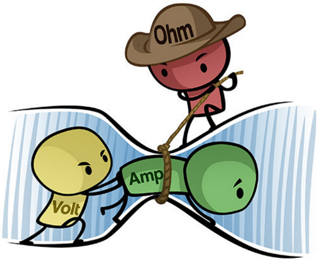
Potential energy
Energy in
Energy out
Kinetic energy
Kinetic energy

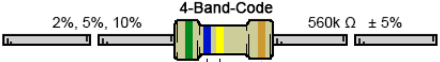
Ohm's Law

Georg Ohm (16 March 1789 – 6 July 1854) was a German physicist and mathematician. As a school teacher, Ohm began his research with the new electrochemical cell, invented by Italian scientist Alessandro Volta. Ohm found that there is a direct proportionality between the potential difference (voltage) applied across a conductor and the resultant electric current. This relationship is known as Ohm's law:



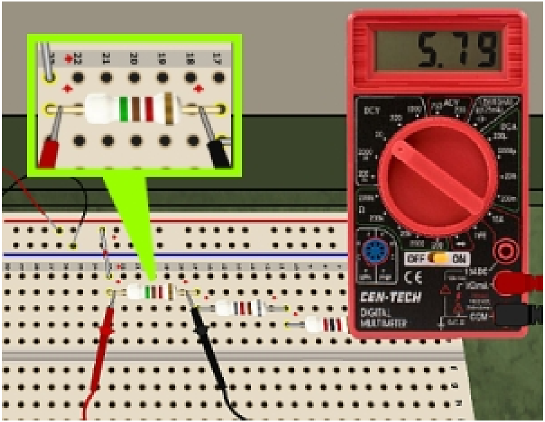


Resistor Color Bands

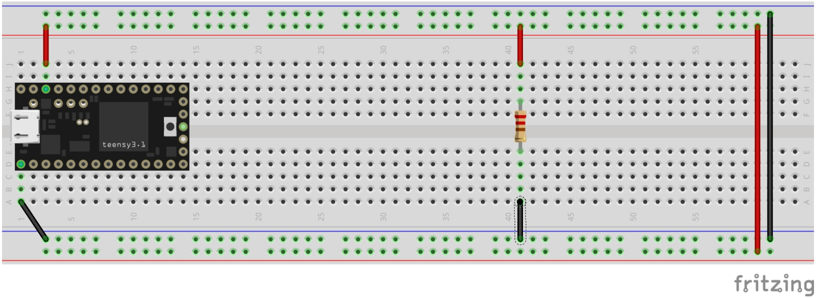


COLOR	1ST BAND	2ND BAND	3RD BAND	MULTIPLIER	TOLERANCE
Black	0	0	0	1Ω	
Brown	1	1	1	10Ω	± 1% (F)
Red	2	2	2	100Ω	± 2% (G)
Orange	3	3	3	1KΩ	
Yellow	4	4	4	10KΩ	
Green	5	5	5	100KΩ	± 0.5% (D)
Blue	6	6	6	1MΩ	± 0.25% (C)
Violet	7	7	7	10MΩ	± 0.10% (B)
Grey	8	8	8	100MΩ	± 0.05%
White	9	9	9	1GΩ	
Gold				0.1Ω	± 5% (J)
Silver				0.01Ω	± 10% (K)

Measuring Voltage, Current, and Resistance



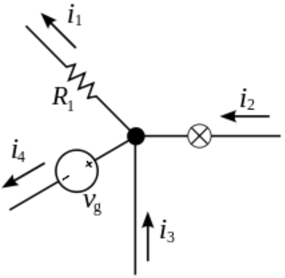
One Resistor



Kirchhoff's First Law

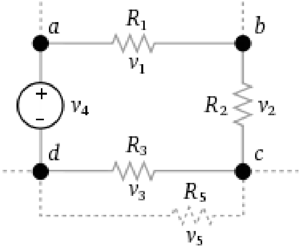
Gustav Robert Kirchhoff (12 March 1824 – 17 October 1887) was a German physicist who contributed to the fundamental understanding of electrical circuits. His first law:

> In an electrical circuit, the sum of currents flowing into that node is equal to the sum of currents flowing out of that node

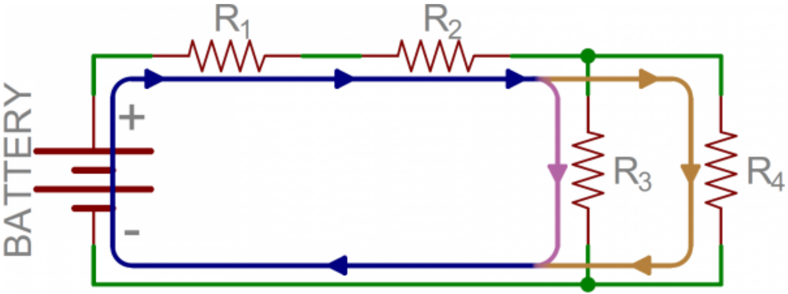


Kirchhoff's Second Law

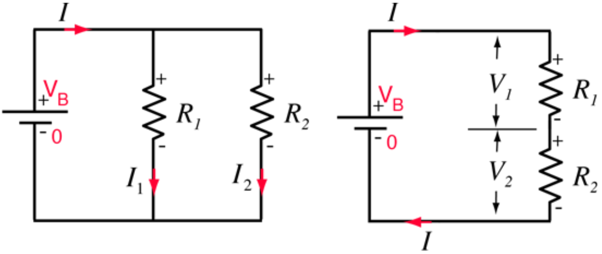
The directed sum of the potential differences (voltages) around any closed loop is zero.



Resistors in Series and Parallel



Resistors in Series and Parallel



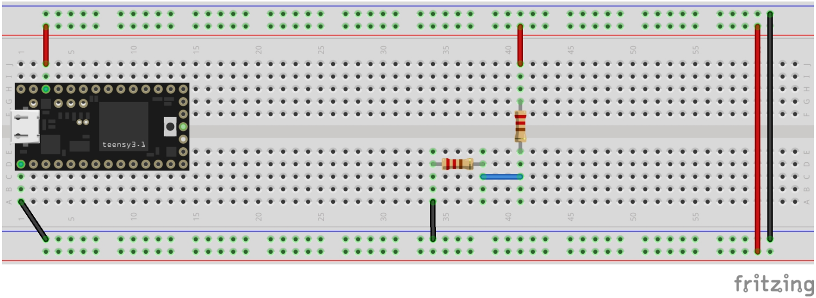
Parallel resistors

$$\frac{1}{R_{equivalent}} = \frac{1}{R_1} + \frac{1}{R_2}$$

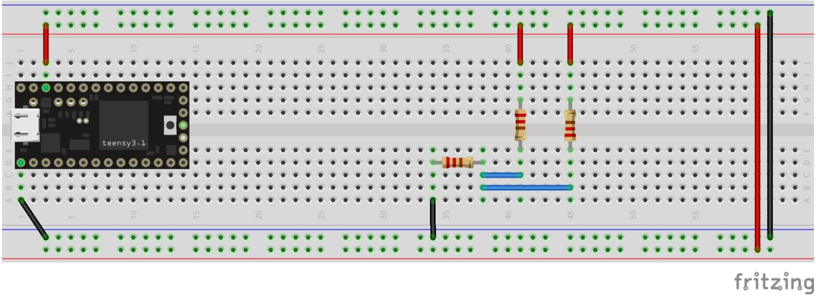
Series resistors

$$R_{equivalent} = R_1 + R_2$$

Resistors in Series



Resistors in Series and Parallel



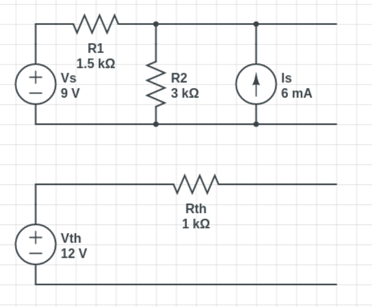
Thevenin Equivalent Circuits

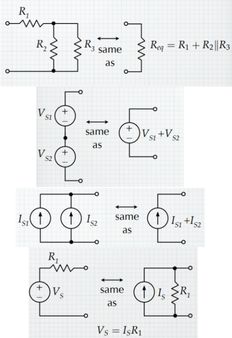
Léon Charles Thévenin (30 March 1857 – 21 September 1926) was a French telegraph engineer who extended Ohm's law to complex circuits.

Any combination of batteries and resistances with two terminals can be replaced by a single voltage source V_{th} and a single series resistor R_{th}.

Useful relationships

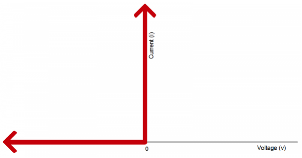
Equivalent Circuit

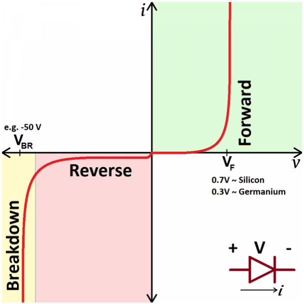




Diodes

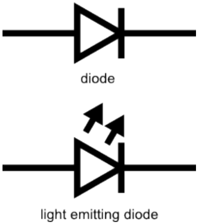
The key function of an diode is to control the direction of current-flow. Current passing through a diode can only go in one direction, called the forward direction. Current trying to flow the reverse direction is blocked.





Light Emitting Diodes

LEDs (that's "ell-ee-dees") are a particular type of diode that convert electrical energy into light.

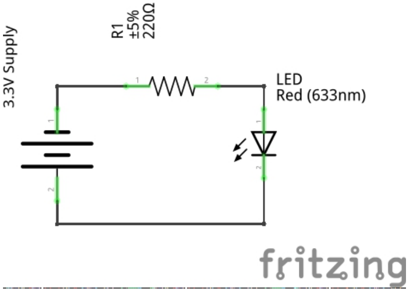


Current Limiting Resistors

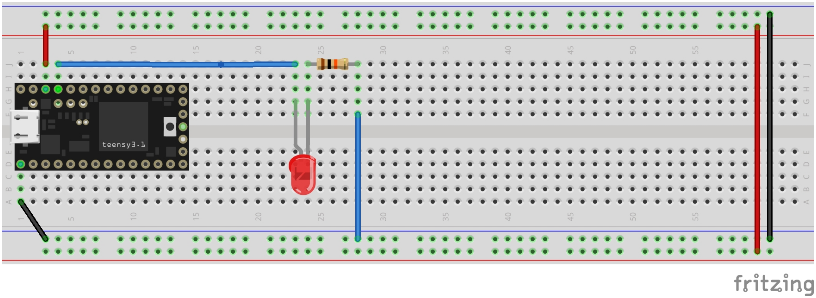
As a LED has very little resistance, when it is connected directly to a power supply, the current draw will exceed its specs and it will burn out.

$$V_{pp} - V_{LED} = IR \implies R >= \frac{V_{pp} - V_{LED}}{I_{max}}$$

For a 3.3V power supply, a 0.43V across the LED, and a max current of 100mA, the resistor needs to be greater than 29Ω.



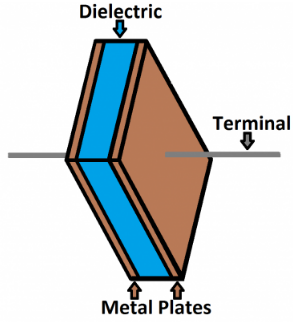
Hello LED



Capacitors

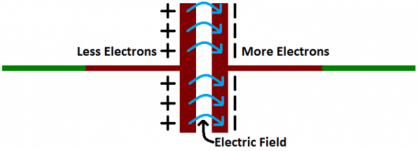
A capacitor is created out of two metal plates and an insulating material called a dielectric. The metal plates are placed very close to each other, in parallel, but the dielectric sits between them to make sure they don't touch.

- The dielectric can be made out of all sorts of insulating materials: paper, glass, rubber, ceramic, plastic, or anything that will impede the flow of current.
- The plates are made of a conductive material: aluminum, tantalum, silver, or other metals.



Capacitors

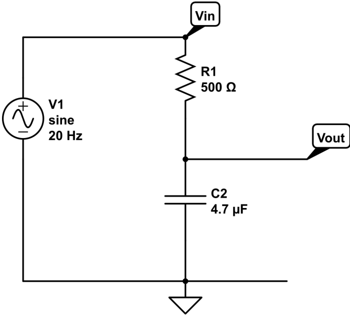
When current flows into a capacitor, the charges get "stuck" on the plates because it can not get past the insulating dielectric. Electrons build up on one of the plates, and it becomes overall negatively charged. The large amount of negative charges pushes away like charges on the other plate, making it positively charged.



The stationary charges on these plates create an electric field, which influence electric potential energy and voltage. When charges group together on a capacitor like this, the cap is storing electric energy just as a battery might store chemical energy.

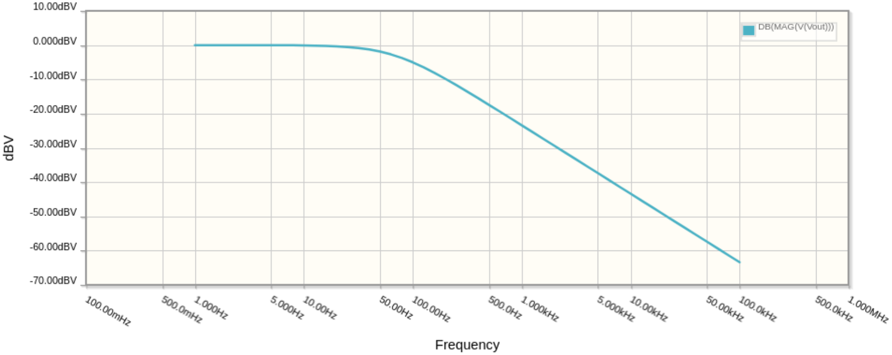
Low Pass Filter - cutoff frequency f_c

- At low frequencies, there is plenty of time for the capacitor to charge up to practically the same voltage as the input voltage.
- At high frequencies, the capacitor only has time to charge up a small amount before the input switches direction. The output goes up and down only a small fraction of the amount the input goes up and down. At double the frequency, there's only time for it to charge up half the amount.



$$f_c = \frac{1}{2\pi\tau} = \frac{1}{2\pi RC}$$

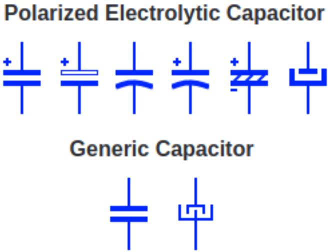
Low Pass Filter Response



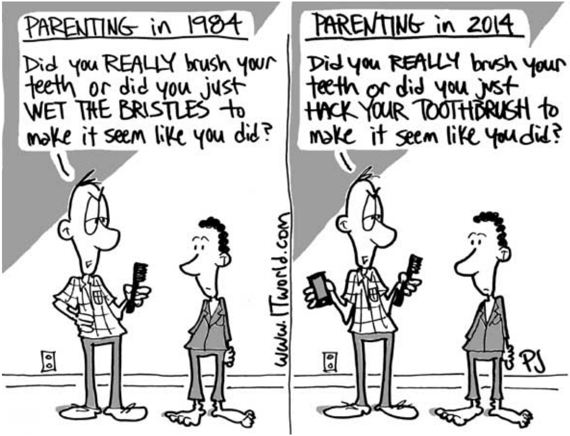
$$f_c = \frac{1}{2\pi RC} = \frac{1}{2\pi(500)(4.7x10^{-6})} = 67.5678Hz$$

Capacitors - does it matter how they are placed

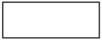
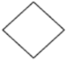
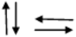
- Some types of capacitors (electrolytic and tantalum) are polarized (the have + and - terminals). This is due to how the dielectric film has been deposited, the reverse polarity leads to degradation of the dielectric.
- Other capacitors (ceramic and film) do not have a polarity and can be installed in either direction.



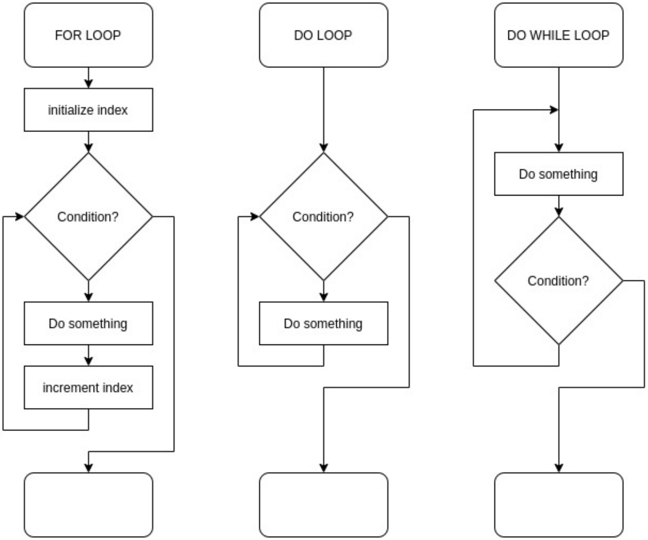
IoT Fun


PARENTING in 1984
Did you REALLY brush your teeth or did you just WET THE BRISTLES to make it seem like you did?
www.ITworld.com
PARENTING in 2014
Did you REALLY brush your teeth or did you just HACK YOUR TOOTHBRUSH to make it seem like you did?
PJ

Flowcharts

Symbol	Name	Function
	Process	Indicates any type of internal operation inside the Processor or Memory
	input/output	Used for any Input / Output (I/O) operation. Indicates that the computer is to obtain data or output results
	Decision	Used to ask a question that can be answered in a binary format (Yes/No, True/False)
	Connector	Allows the flowchart to be drawn without intersecting lines or without a reverse flow.
	Predefined Process	Used to invoke a subroutine or an Interrupt program.
	Terminal	Indicates the starting or ending of the program, process, or interrupt program
	Flow Lines	Shows direction of flow.

Loops


FOR LOOP
initialize index
Condition?
Do something
increment index
DO LOOP
Condition?
Do something
DO WHILE LOOP
Do something
Condition?

FOR Loop syntax

```
// FOR loop syntax
for (initialization; condition; increment) {
  // statement(s);
}

// EXAMPLE
for (j=0; j <= 255, j++) {
  analogWrite(ledPin, j);
  }
```

WHILE loop syntax

```
// WHILE loop syntax
while (condition) {
  // statement(s)
}


// EXAMPLE
while (button == HIGH) {
  digitalWrite(ledPin, HIGH);
} //continue this loop until button is released
```

For vs While Loops

For vs While Loop

Comparison Chart

For Loop	While Loop
The for loop is used for definite loops when the number of iterations is known.	The while loop is used when the number of iterations is not known.
For loops can have their counter variables declared in the declaration itself.	There is no built-in loop control variable with a while loop.
This is preferable when we know exactly how many times the loop will be repeated.	The while loop will continue to run infinite number of times until the condition is met.
The loop iterates infinite number of times if the condition is not specified.	If the condition is not specified, it shows a compilation error.

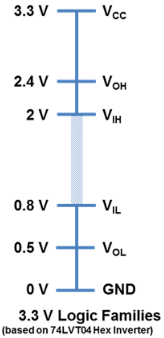
DifferenceBetween.net

Serial Monitor

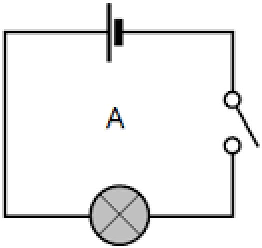
```
void setup() {

// Enable Serial Monitor
  Serial.begin (9600);
  while (!Serial);  // wait for Serial monitor
  Serial.println ("Ready to Go");
}

void loop() {
  for (i=0; i <=13; i++)
  Serial.print(i);
  delay(ledDelay);
}
```

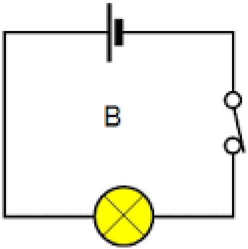
Digital Output

Digital electronics rely on binary logic to store, process, and transmit data or information. Binary Logic refers to one of two states – ON or OFF. This is commonly translated as a binary 1 or binary 0. A binary 1 is also referred to as a HIGH signal and a binary 0 is referred to as a LOW signal.

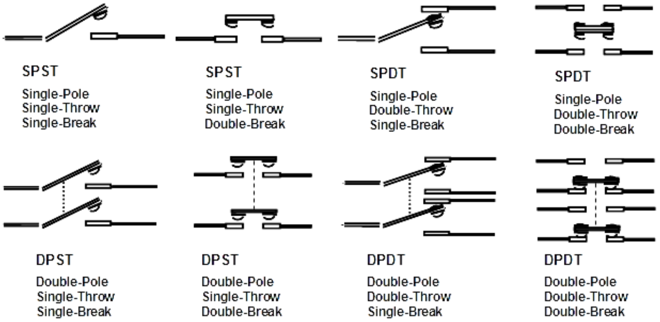


Switches

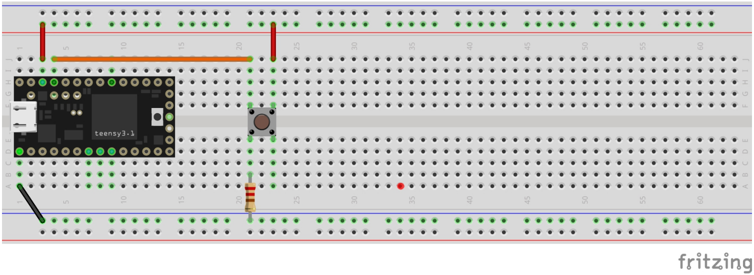




Types of Switches



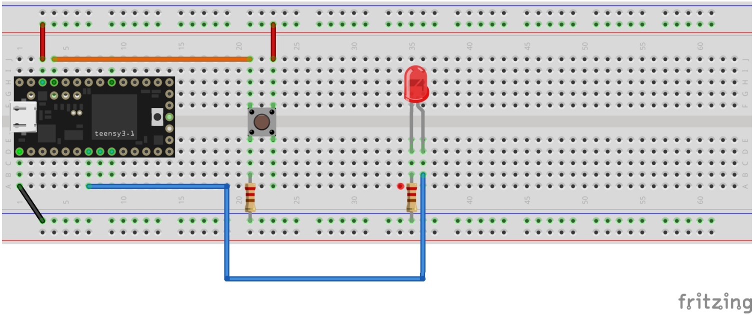
Our First Button



IF Statements

```
// IF statement SYNTAX
if (condition) {
  //statement(s)
}

// EXAMPLE
if (button == HIGH) {
  digitalWrite(ledPin, HIGH);
  }
```

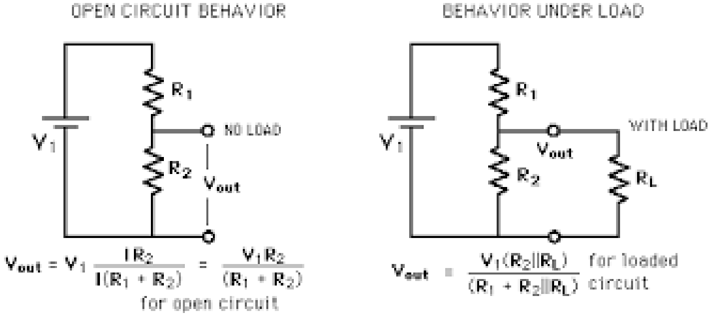
Button and LED



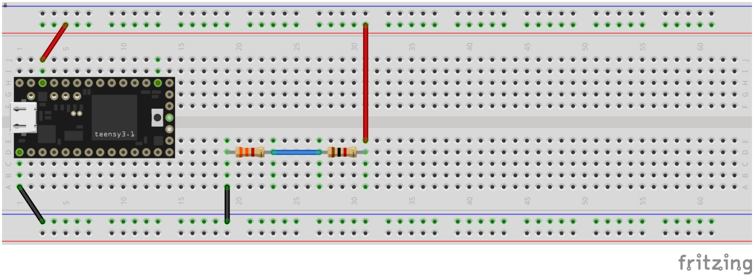
IoT Humor

"I remember when you could only lose a chess game to a supercomputer."

Voltage Divider

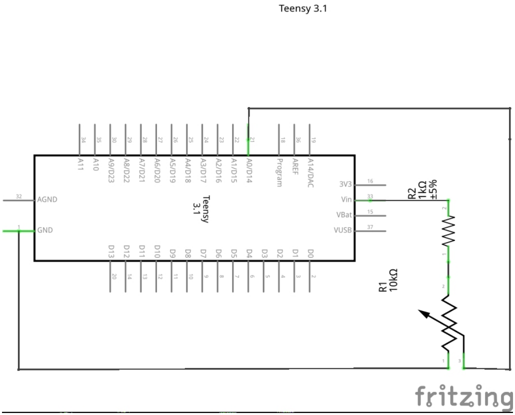


Voltage Dividing



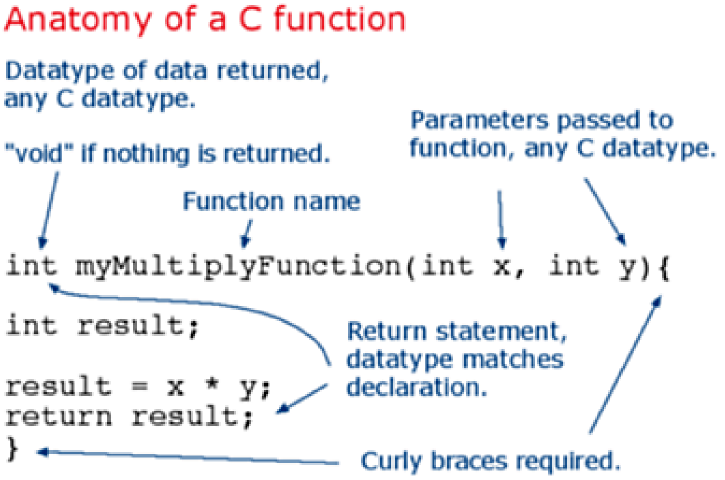
We are just using the Teensy to provide Power and GND.
The right resistor should be 1kΩ
The left resistor between 2.2kΩ and 6.8kΩ

Analog Input Schematic

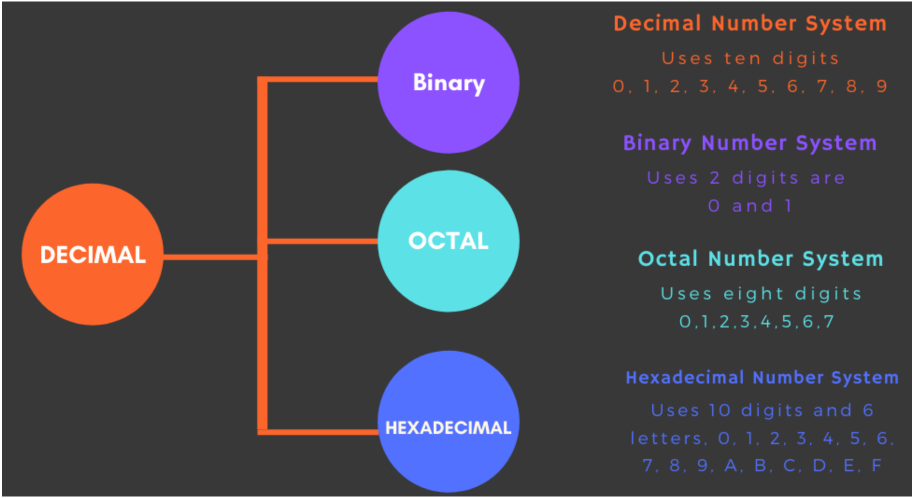


Feel free to use any PIN you would like to measure the voltage.

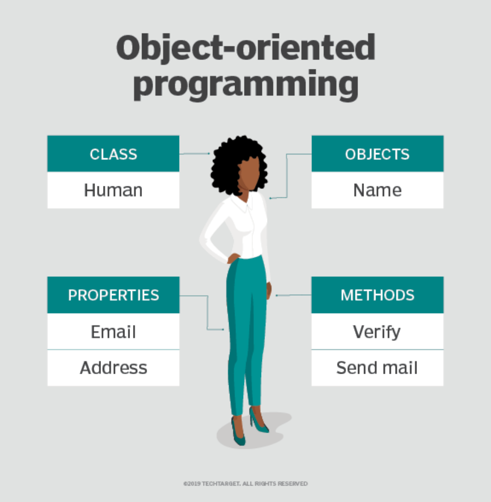
Anatomy of a Function



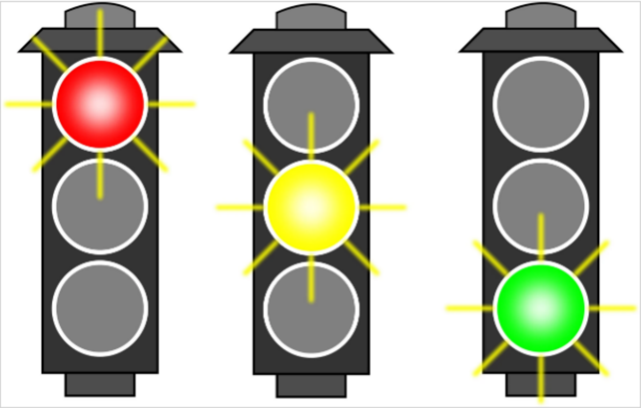
Number Systems



Objects

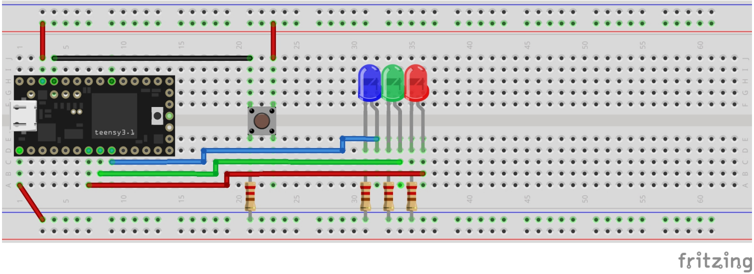

Object-oriented programming
CLASS
Human
OBJECTS
Name
PROPERTIES
Email
Address
METHODS
Verify
Send mail
©2019 TECHTARGET. ALL RIGHTS RESERVED

Traffic Light

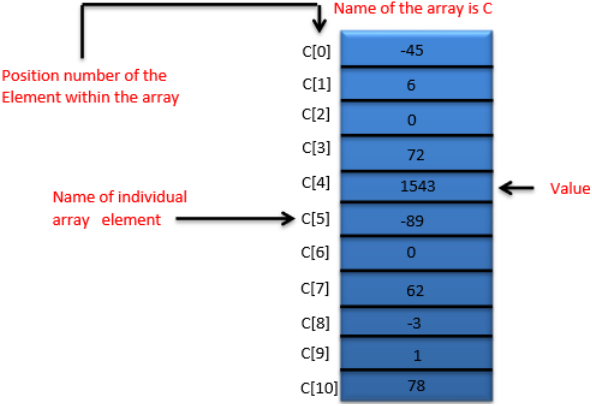


Let's use the traffic light to build our own Objects

oneButton LED



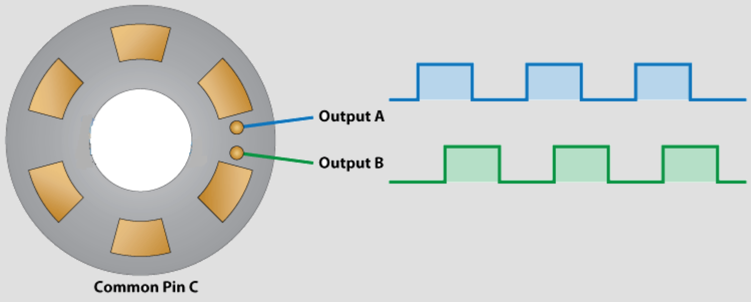
Arrays


Name of the array is C
Position number of the
Element within the array
Name of individual
array element
Value
C[0]
-45
C[1]
6
C[2]
0
C[3]
72
C[4]
1543
C[5]
-89
C[6]
0
C[7]
62
C[8]
-3
C[9]
1
C[10]
78

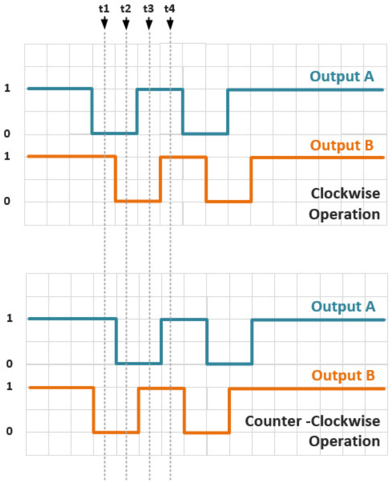
IoT Humor


"WE HAVE TO GO OUT FOR DINNER. THE REFRIGERATOR ISN'T SPEAKING TO THE STOVE."

Encoders



Encoders



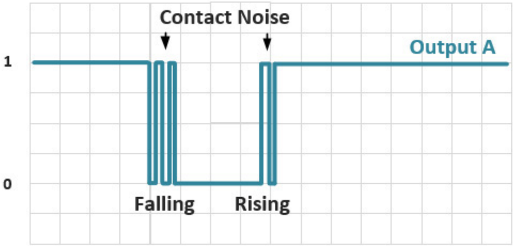
Clockwise
Sequence

	A	B
t1	0	1
t2	0	0
t3	1	0
t4	1	1

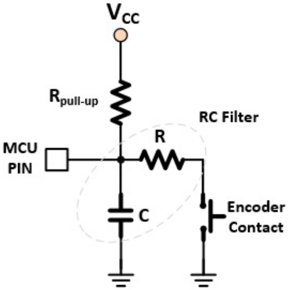
Counter-Clockwise
Sequence

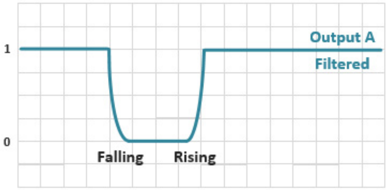
	A	B
t1	1	0
t2	0	0
t3	0	1
t4	1	1

Encoders

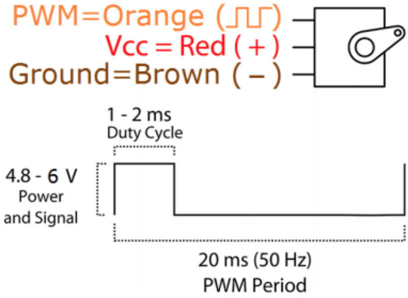


Encoders


Vcc
Rpull-up
RC Filter
R
MCU
PIN
C
Encoder
Contact

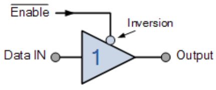

1
0
Output A
Filtered
Falling
Rising

Servo Motors



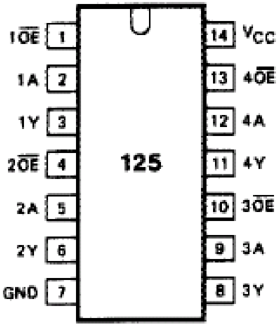
TriState Buffer

Symbol	Truth Table		
	Enable	IN	OUT
	0	0	0
	0	1	1
	1	0	Hi-Z
	1	1	Hi-Z



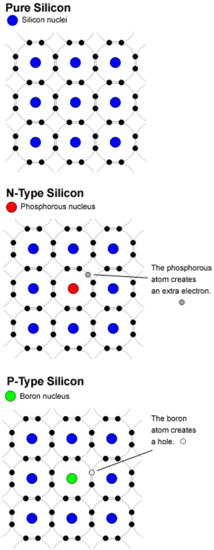
Tri-state Buffer

Read as Output = Input if Enable is **NOT** equal to “1”



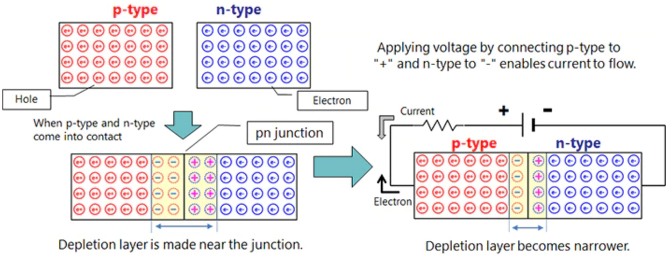
Semiconductor

- A silicon atom has four electrons in its outer shell and bonds tightly with four surrounding silicon atoms creating a crystal matrix with eight electrons in the outer shells. The tight bonds make pure silicon non-conducting.
- Phosphorus has five electrons, and when combined, the fifth electron becomes a "free" electron that moves easily within the crystal when a voltage is applied.
- Boron has only three electrons in its outer shell and can bond with only three of surrounding silicon atoms. Thus one silicon atom has a vacant location in its outer shell, called a "hole," that readily accepts an electron.



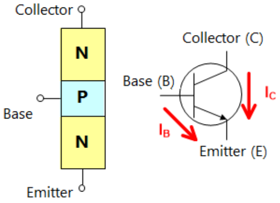
pn junction diode

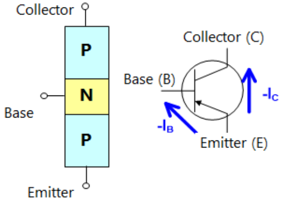
- When p-type and n-type semiconductors are bonded, holes and free electrons are attracted, combine, and disappear near the boundary. Since there are no carriers in this area, it is called a depletion layer and it is an insulator.
- A positive voltage applied to the p-type region causes electrons to flow sequentially from the n-type. The electrons will first disappear by combining with holes, but excess electrons move to the positive pole and current will flow.



Bipolar Junction Transistor

The transistor has three regions, namely base, emitter and collector. The emitter is a heavily doped terminal and emits electrons into the base. Base terminal is lightly doped and passes the emitter-injected electrons on to the collector. The collector terminal is intermediately doped and collects electrons from base. This collector is large as compared with other two regions so it dissipates more heat.

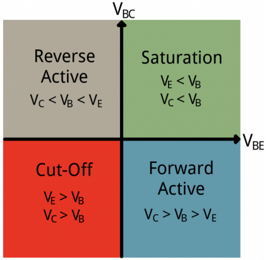




Bipolar Junction Transistor - Modes of Operation

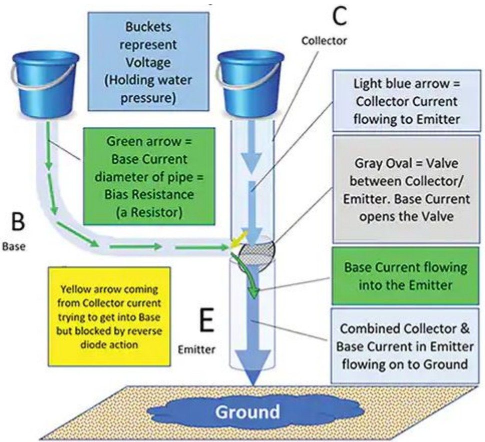
- **Saturation:** Current freely flows from collector to emitter. (ON Switch)
- **Cut-off:** No current flows from collector to emitter. (OFF Switch)
- **Active:** The current from collector to emitter is proportional to the current flowing into the base. (Amplifier)
- **Reverse-Active:** Like active mode, the current is proportional to the base current, but it flows reverse from emitter to collector (not the purpose transistors were designed for).

NPN Modes



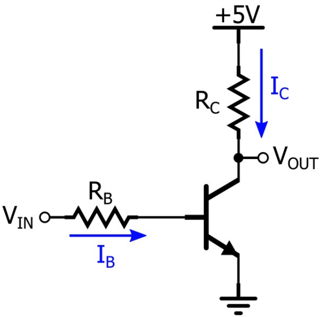
Voltage relations	NPN Mode	PNP Mode
$V_E < V_B < V_C$	Active	Reverse
$V_E < V_B > V_C$	Saturation	Cutoff
$V_E > V_B < V_C$	Cutoff	Saturation
$V_E > V_B > V_C$	Reverse	Active

Water Analogy



Active Mode NPN Transistor Circuit

If you apply a voltage V_{IN} that is high enough to forward-bias the base-to-emitter junction, current (I_B) will flow from the input terminal, through R_B, through the BE junction, to ground. Current (I_C) will also flow through R_C and the collector-to-emitter portion of the transistor.

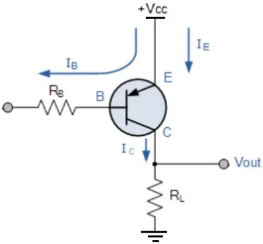


NOTE: V_{OUT} is an amplified but inverted signal of V_{IN}.
This simple circuit will step-up an 0 - 3.3V output from the microcontroller to 0 - 5.0V (inverted). The low impedance of the output will also provide sufficient current to drive a higher current device (e.g., a relay).

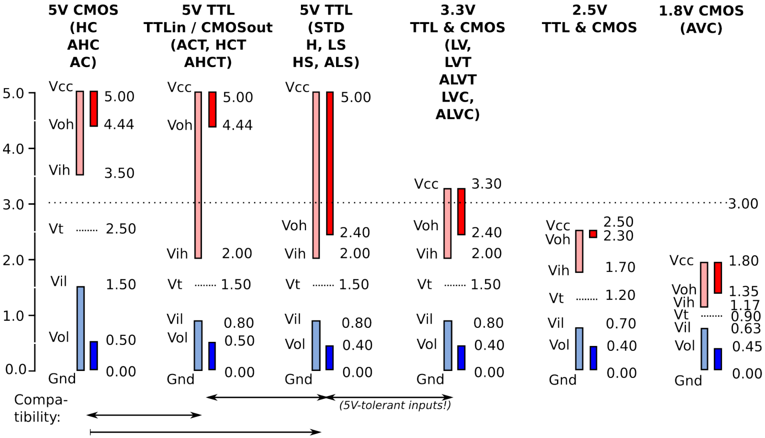
PNP Transistor

NPN Transistors are more common than PNP for a number of reasons:

- The voltage and current behavior of an NPN transistor is significantly more intuitive.
- When a switch or driver circuit is required, NPNs provide a more straightforward interface to digital output signals (such as a control signal generated by a microcontroller).
- NPNs are higher performance (faster switching speeds) due to higher mobility of electrons vs holes.



Logic Voltage Level Standards

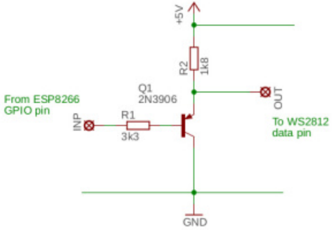


Data source: EETimes, A brief recap of popular logic standards (Mark Pearson, Maxim).

Or, what is wrong with the NeoPixels.

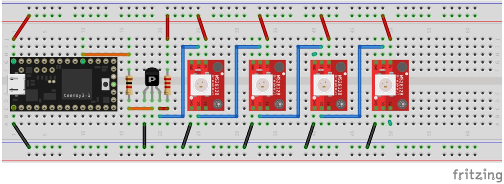
Emitter Follower

- NeoPixels are designed around 5V CMOS transistors
  - $V_{IH} > 3.5V$
  - 3.3V Microcontroller $V_{OH} = 3.3V$
- An Emitter Followers (i.e., a PNP transistor wired backwards) is a current amplifier, but will also produce a $V_{OUT} = 3.9V$.
- Alternatively, the first NeoPixel could be sacrificed by reducing its V_{cc} to 4.3V with a diode.

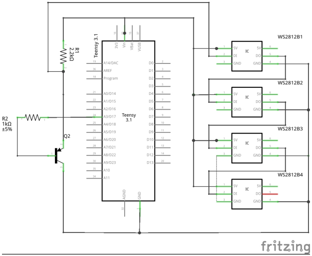


Emitter Follower Layout

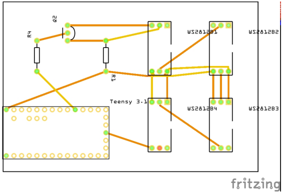
Fritzing



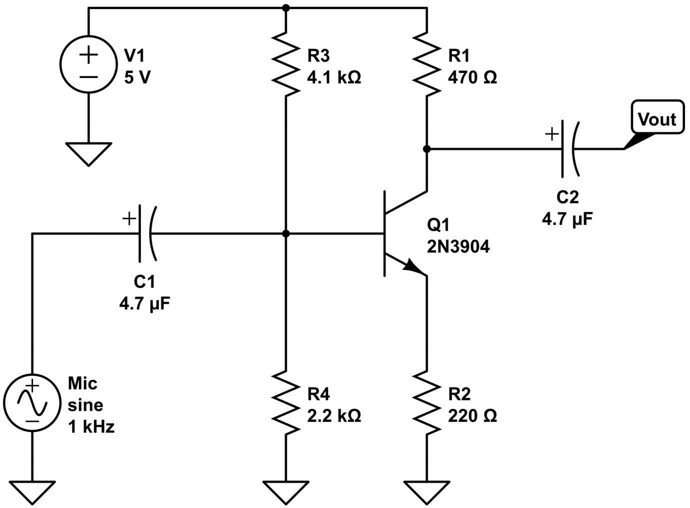
Schematic



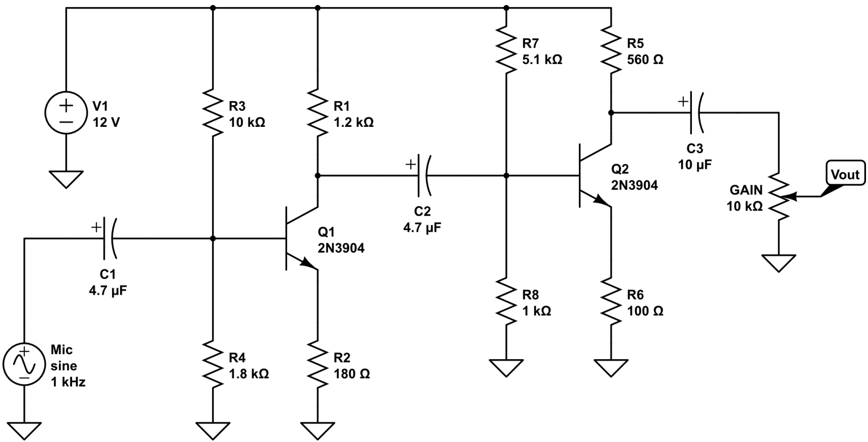
PCB Layout



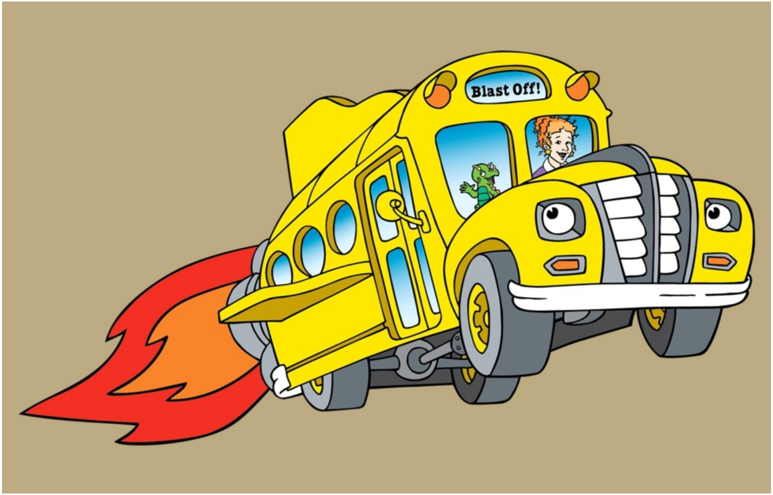
NPN Pre-Amplifier Circuit



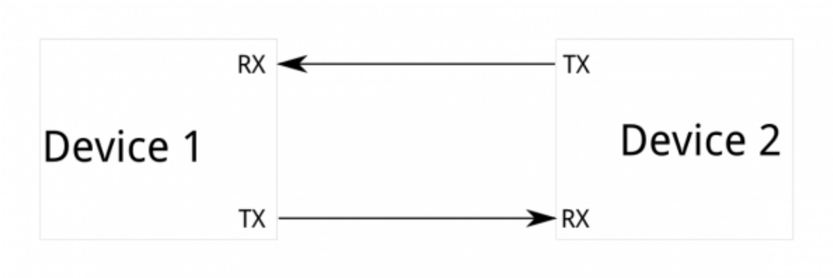
Two Stage Amplifier



Buses and Interfaces

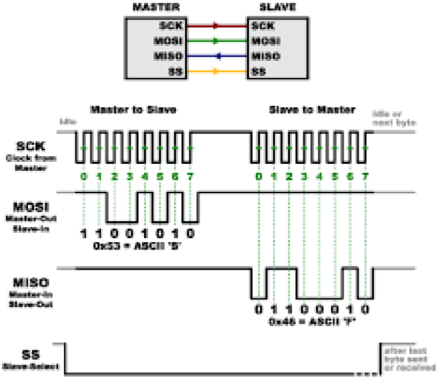


UART

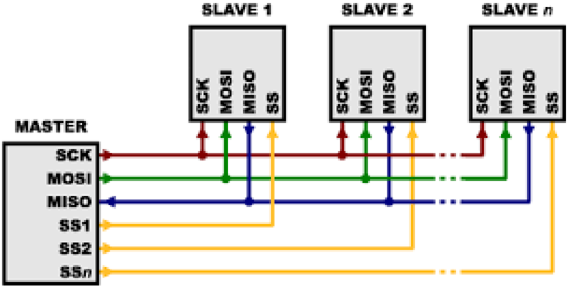


Universal Asynchronous Receiver/Transmitter

Serial Peripheral Interface

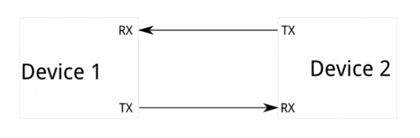


Serial Peripheral Interface

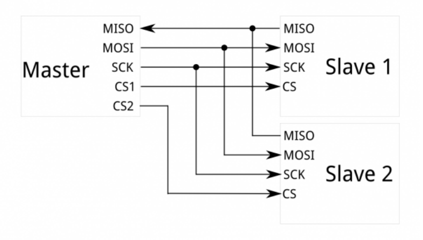


Serial +/−

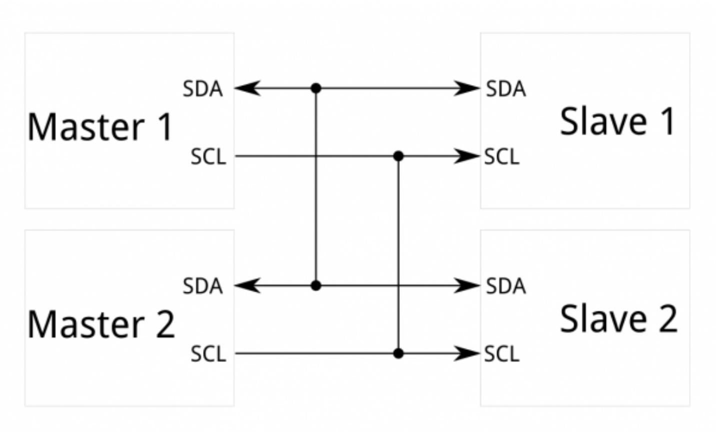
UART



SPI



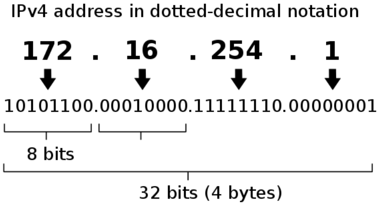
Inter-integrated Circuit (I^2C)



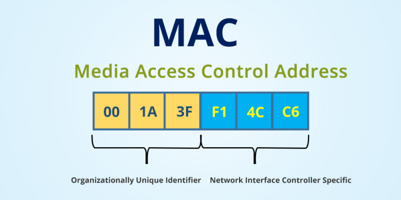
The Internet

IP Addresses

- When a device joins the network it is given an internet address.
  - static or dynamic
- IPv4 (32-bit) - 4.2 billion
- IPv6 (128-bit) - 340 quadrilliard
- In Powershell, try: *ipconfig/all*
- In Terminal (MAC), try: ipconfig getifaddr en0



MAC Address

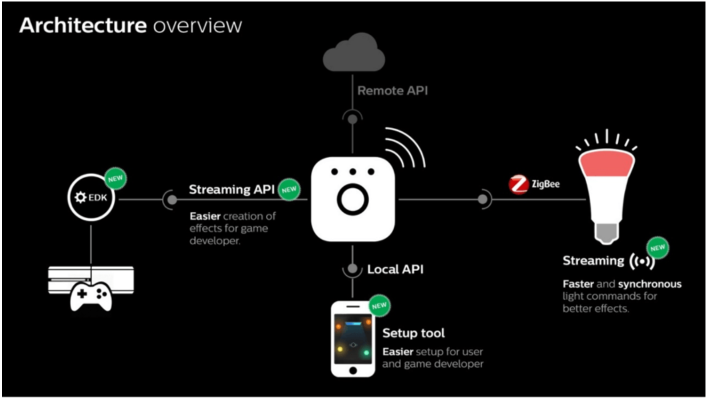


A MAC Address is a unique 6-byte (48-bit) address that is usually permanently burned into a network interface card (NIC) and uniquely identifies the device on an Ethernet-based network. The uniqueness of MAC addresses is ensured by IEEE.

If you are creating your own MAC address, the 2's place bit of the first byte, the "locally administered bit" should be set. The 1's place bit, the "globally administered" bit must be off.

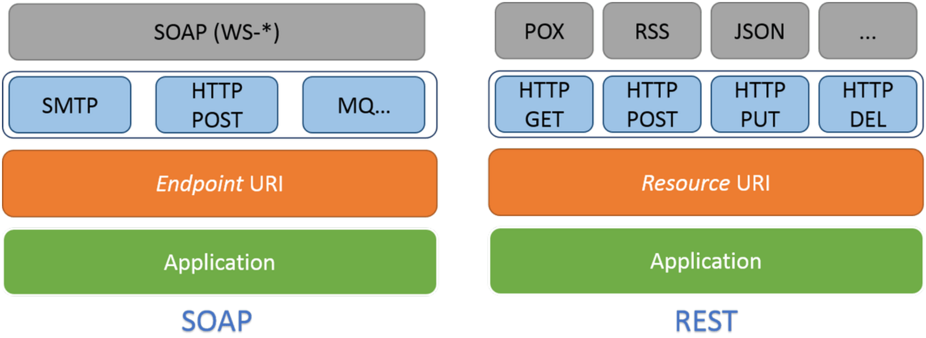
Therefore, xA-xx-xx-xx-xx-xx is valid, while x7-xx-xx-xx-xx-xx is not.

Phillips Hue API



Application Programming Interface: a set of functions and procedures allowing the creation of applications that access the features or data of an operating system, application, or other service.

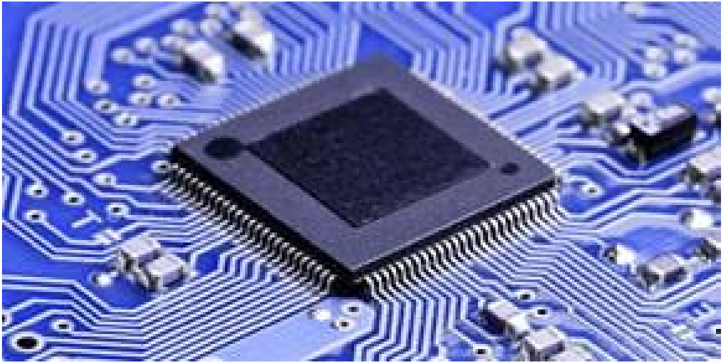
SOAP vs REST


SOAP (WS-*)
SMTP
HTTP POST
MQ...
Endpoint URI
Application
SOAP
POX
RSS
JSON
...
HTTP GET
HTTP POST
HTTP PUT
HTTP DEL
Resource URI
Application
REST

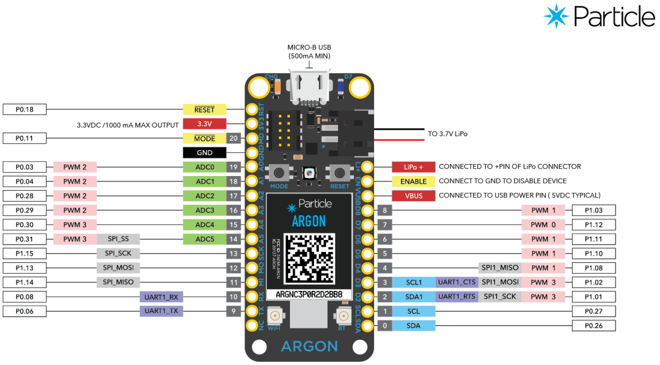
GITHUB Simplified

```
// In Powershell go to ./Documents/<yourname>
// Get a repository that already exists and pull
   it into your local machine
  git clone <URL of repository>

// From the repository directory, get updates
  git pull

// Send your changes up to the repository
  git add .
  git commit -m "<comment>"
  git push

// You may get asked to enter your GIT username
git config --global user.email "you@example.com"
```

Our Second Microcontroller



Particle Argon Pin Layout



PWM 0	GROUP 0 PWM PINS	ADC	ANALOG TO DIGITAL INPUT PINS	UART1	SERIAL COMMUNICATION PINS (SERIAL1)
PWM 1	GROUP 1 PWM PINS	SDA/SCL	I2C COMMUNICATION PINS (WIRE)	SDA1/SCL1	I2C COMMUNICATION PINS (WIRE1)
PWM 2	GROUP 2 PWM PINS	SPI	SPI COMMUNICATION PINS (SPI)	SPI1	SPI COMMUNICATION PINS (SPI1)
PWM 3	GROUP 3 PWM PINS	PX.XX	nRF52840 PIN NAMES		

v1.0