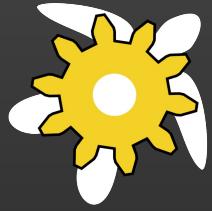


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Electronics and Soldering

TURTLE Hatchling



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Electronics

American Wire Gauge



Logarithmic Scale ranging from 0000 to 40

We have AWG 12 (9.3 Amps), 18 (2.3 Amps), 22 (0.92 Amps)



Wire Traits -

- Max Current - Increases as gauge gets smaller
- Conductive Diameter - Increases as gauge gets smaller
- Cross-sectional Area - Increases as gauge gets smaller
- Resistance - Decreases as gauge gets smaller
- Max Frequency - Decreases as gauge gets smaller



Wire Core

Solid Core

- Cheaper
- Higher Current Capacity
- Effectively male pins



Stranded Core

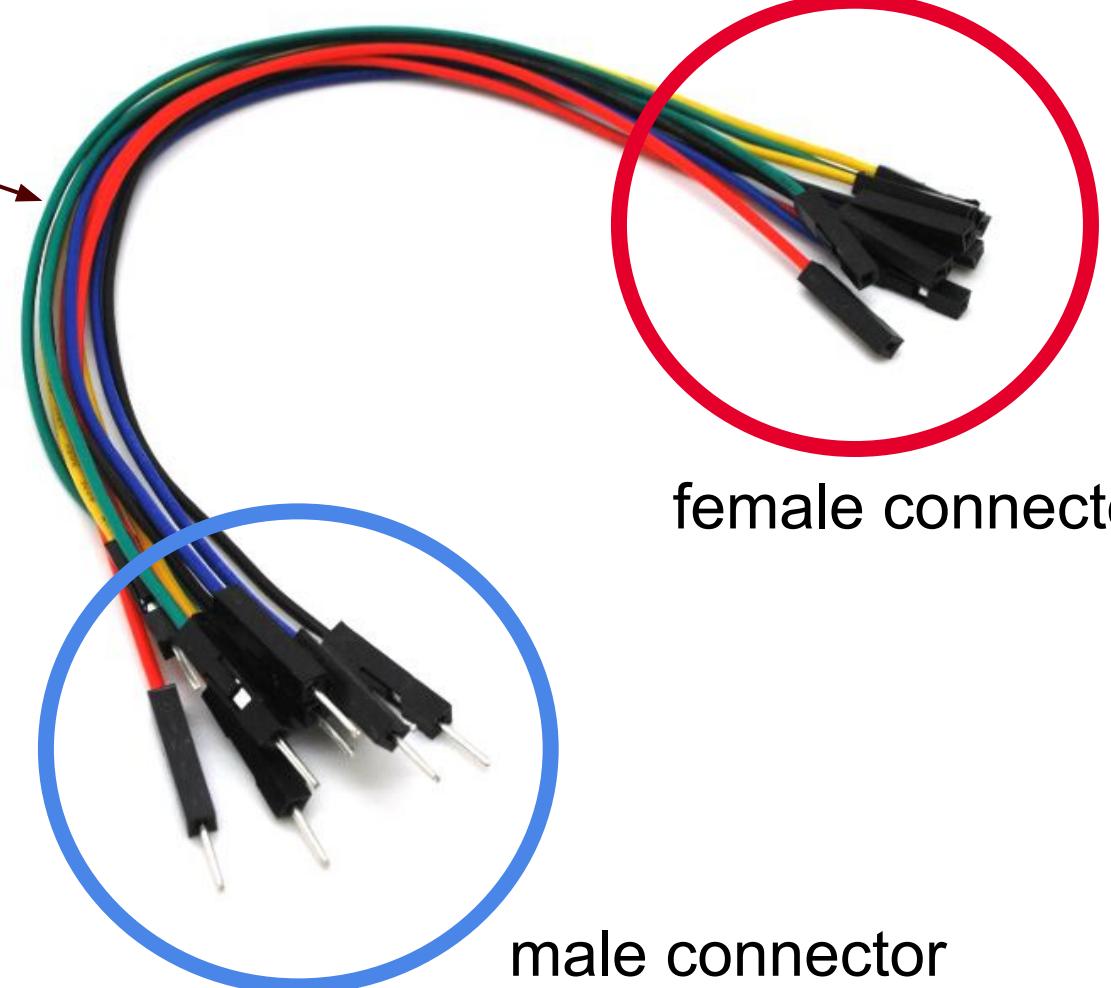
- More resistant to vibrations
- More flexible



Other Notes



- Jumper Wires
 - Male = protruding pin
 - Female = hole for pin



Typical Wire Color Coding

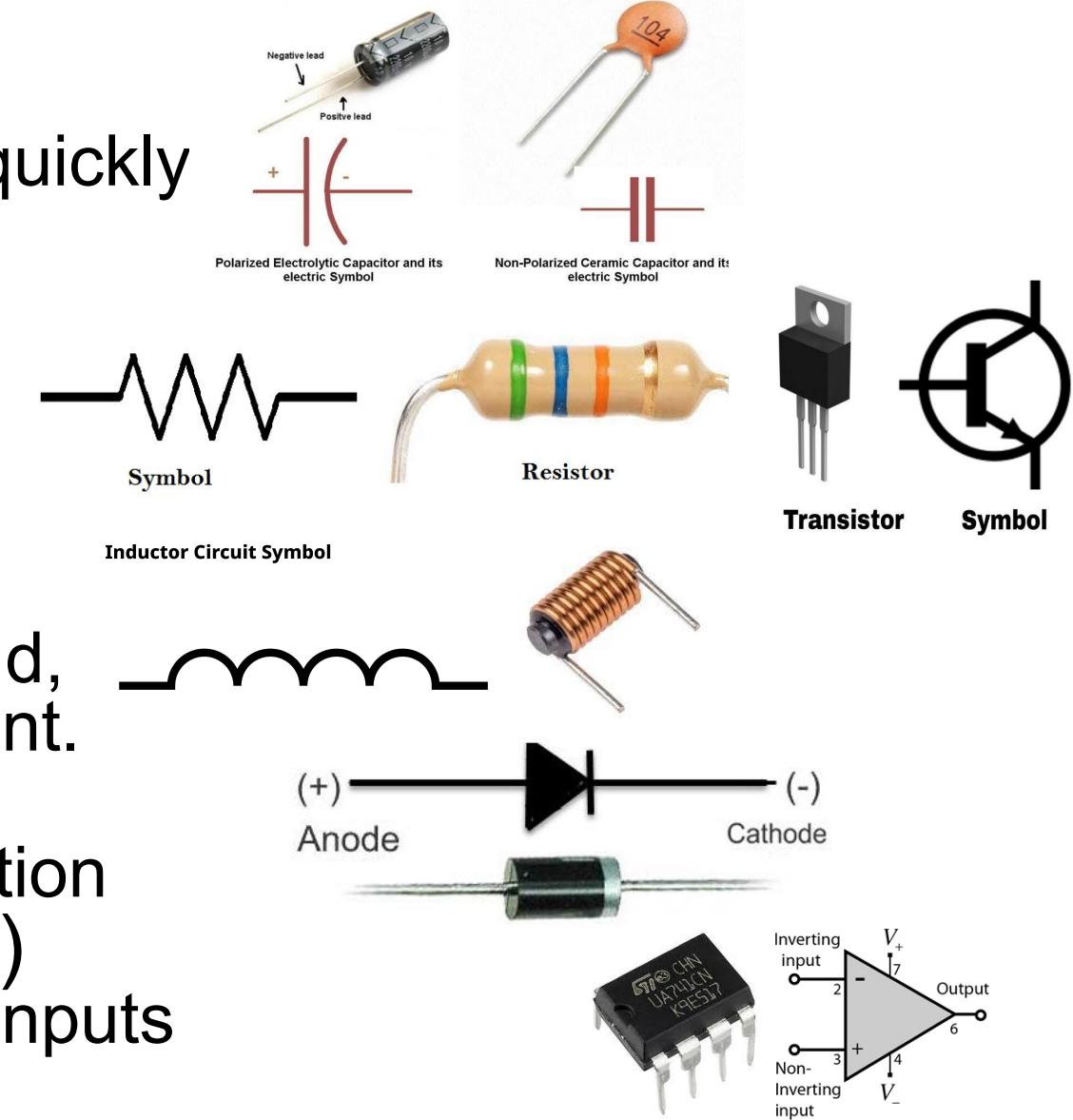
- Black/Brown is GND
- Red is PWR

Always check the items documentation about color coding

Common Electronic Components



- Capacitors
 - Stores and discharges charge quickly
 - Can be extremely dangerous
- Resistors
 - Impedes the flow of current
- Transistors and MOSFET
 - Amplify signals/digital switch
- Inductor
 - Stores energy in a magnetic field, opposes rapid changes in current.
- Diode
 - Allows current in only one direction
- Operational Amplifier (op-amp)
 - Amplifies voltage between two inputs

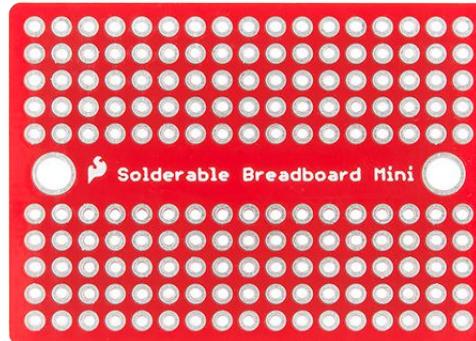


Ways to build circuits

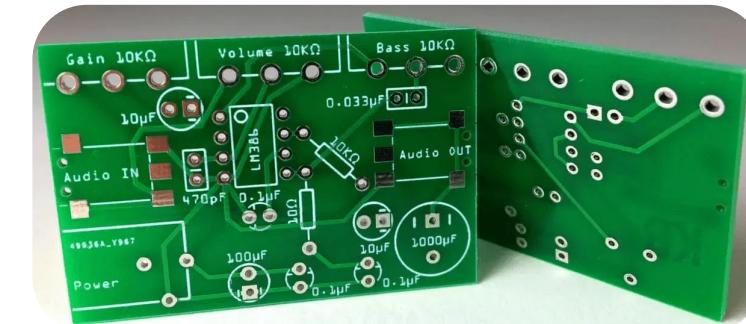
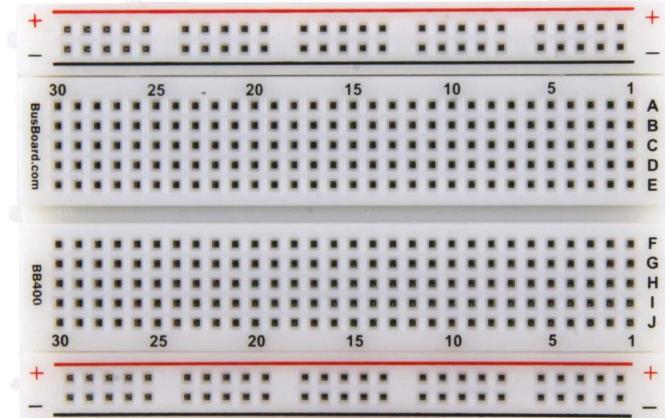


- Solderless breadboard
 - Commonly used for prototyping
 - Inexpensive and easy to change
- Solderable breadboard
 - More permanent than a solderless breadboard
 - Easy to transfer components from a solderless breadboard
- PCBs (printed circuit boards)
 - Permanent connections that are more reliable
 - Expensive

Note: When creating a PCB, it is advisable to test the circuit on both solderless and soldered breadboards before investing in the final PCB.



Made of fiberglass with plated through holes



Made of plastic with metal strips or spring terminals

Two main types:
Surface mount PCB (SMT) - components soldered directly onto the board
Through hole PCB (THT) - components inserted into holes and then soldered

Battery Cells



Stores and generates DC current through a chemical reaction

Many types, but most common are:

- Lead-Acid
 - Cheap, High peak current, Heavy, Large form factor
- Lithium Polymer (LiPo) Note: Only use dedicated LiPo chargers and do NOT use if damaged
 - Highest discharge rate, High care requirements
- Lithium Ion (Li-ion) Note: Typically 18650 or 21700 cells
 - Highest energy density, Long cycle life
- Nickel Metal Hydride (NiMH)
 - Robust, Compared to lithium: Cheaper, lower energy density



Battery Pack Notes



- Convention is #S#P → Cell count = #S(eries) * #P(arallel)



- Cells in series add voltage, parallel adds capacity

- #C * capacity is the maximum continuous current draw

Parallel

- Capacity is sustained current for one hour of charge

Series

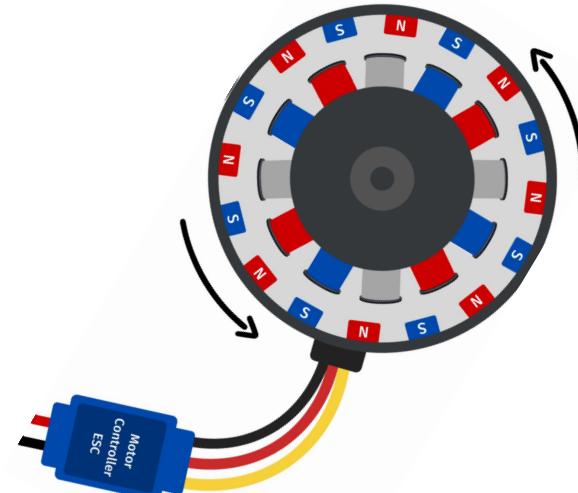
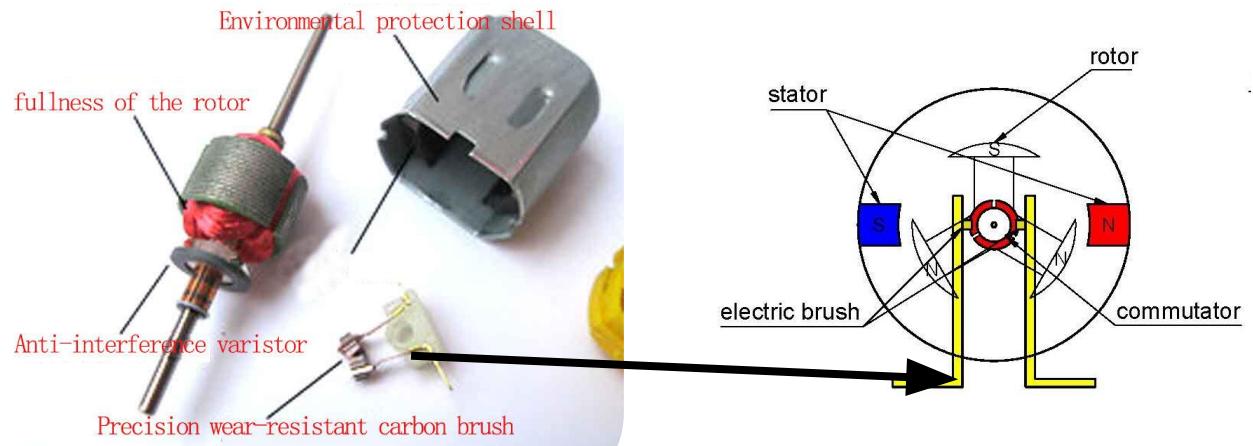
- To determine the required capacity, add power not current



DC Motors- Brushed vs Brushless



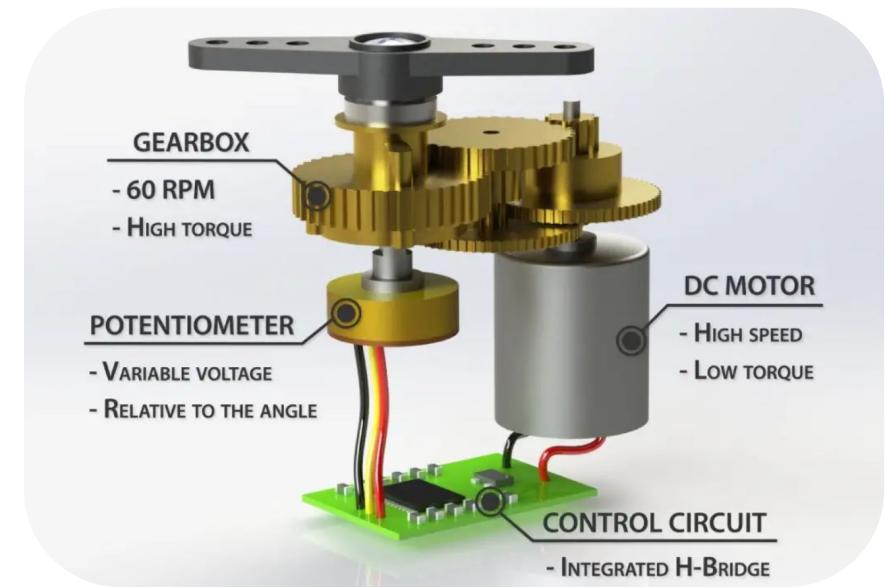
- **Brushed**
 - Spins when power is supplied
 - High starting torque
 - Cheaper
- **Brushless**
 - Requires specific timing of stator coils to spin
 - Continuously changes the internal magnetic field
 - Consistent torque
 - Higher efficiency %
 - Longer life cycle



DC Motors - Servos



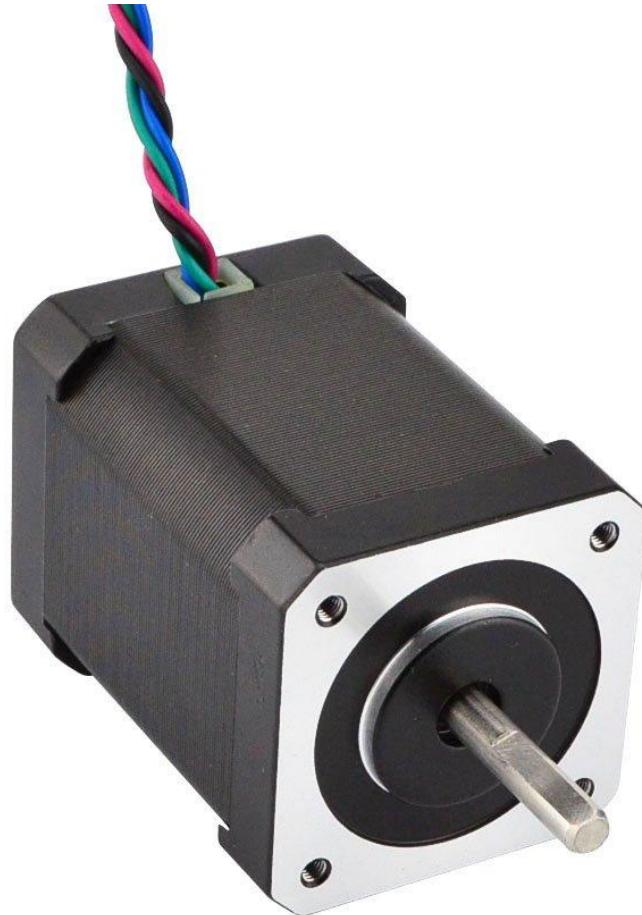
- Servos are DC motors with a gearbox meant for torque.
- Servos typically have limited motion (0 to 180 degrees), this is due to their built in potentiometer.
- Servos have a brushed DC motor and integrated H-bridge. H-bridge controlled by signal wire.
- {Signal,PWR,GND} Wiring
 - The order prevents bad things if a TJC8 connector is plugged in backwards.



DC Motor - Stepper Motors



- A type of motor that rotates in a series of precise steps via changing the internal magnetic field sequentially
 - A step is typically 1.8 degrees
- High precision and repeatability
 - Lower speed
- Higher low speed torque
 - Draws full current at all times (Even at rest)

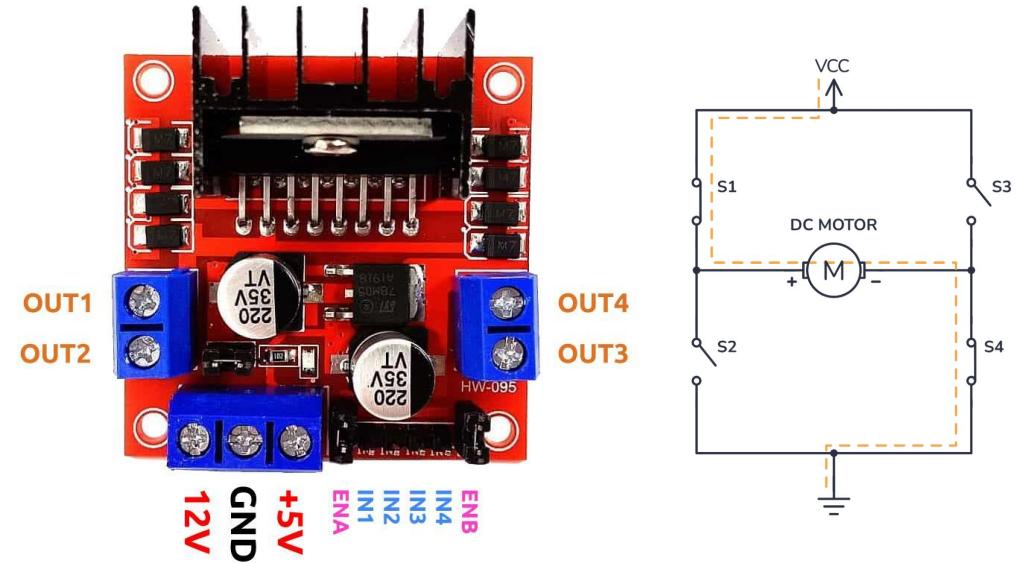


Motor drivers



Brushed Motor Driver

- Controls via an H-Bridge
 - Four switches that control current direction
- Requires external power supply
 - Large heatsink due to inefficiency



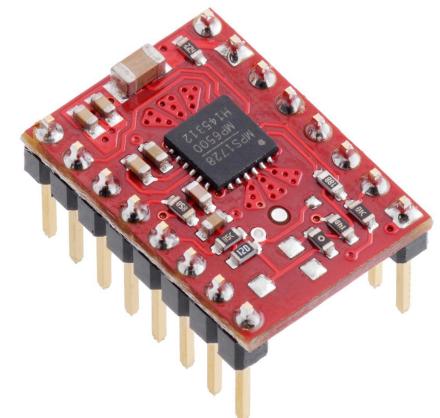
Electronic Speed Controllers (ESCs)

- Regulates the timing of stator coils in Brushless DC motors



Stepper Motor Driver

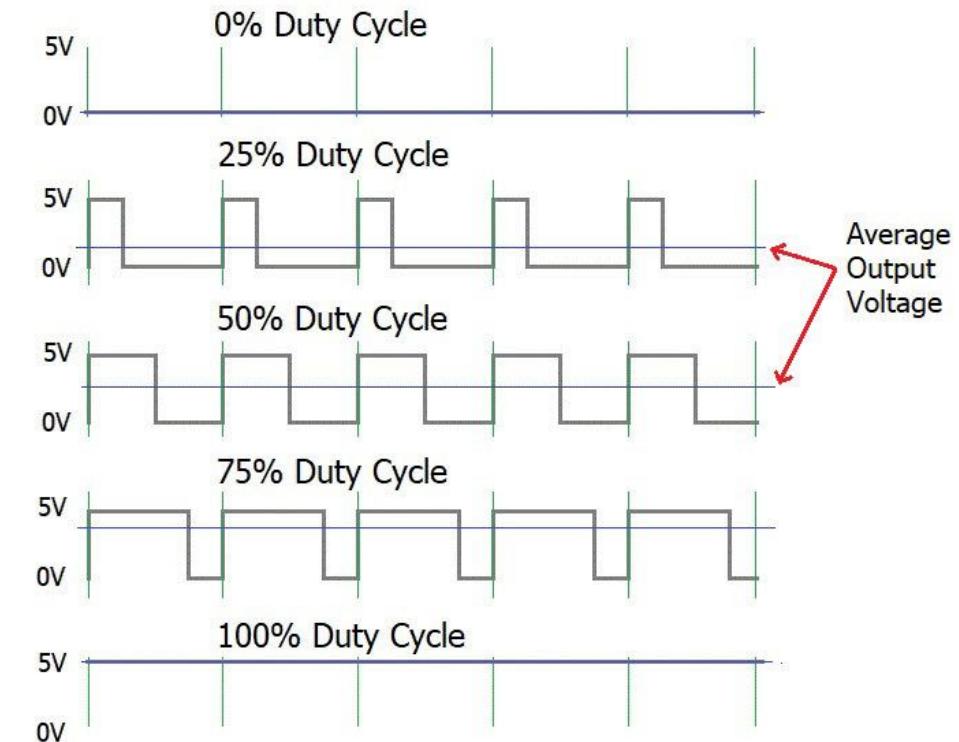
- Regulates the timing of stator coils in stepper motors
 - Most capable of microstepping



PWM (Pulse Width Modulation)



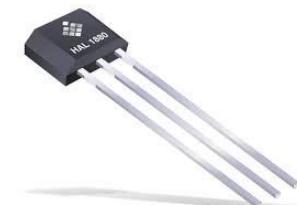
- The default way of controlling signals
 - Includes motors, servos, LEDs
- Tri-state Logic [H(igh)-L(ow)-Z(erо)] changing the duty cycle to regulate average voltage
 - Duty Cycle is typically 1 to 2 ms
- Exploits the ability of transistors to operate as fast switches



Common Sensors (Not all)



- Accelerometer
 - measures acceleration
- Gyroscope
 - Measures the change in rotation angle per unit of time
- IMU - Inertial Measurement Units
 - Combines various sensors into one unit
- Ultrasonic Distance
 - Measures distance through ultrasonic waves
- Rotary Encoders
 - Digital device used to measure the rotation of a shaft
- Hall Effect
 - transduce magnetic fields to electrical signals
- Torque Sensor
 - Measures torque on a rotating system



Microcontroller (MCU) vs Single-Board Controller (SBC)



Micro Controller

- None or Real Time OS
- Lower power consumption
 - Limited processing
 - Limited memory
- GPIO Peripheral
- Low level languages
 - Single program always running
- Examples:
 - Arduino
 - ESP32/ESP8266
 - STM32



Single-Board Controller

- Full OS (Typically Linux)
- Higher computation ability
- Peripherals
 - GPIO, USB, HDMI, etc
- Higher-level languages
 - Can run multiple programs
- Examples:
 - Raspberry Pi
 - BeagleBoard
 - NVIDIA Jetson Nano



Common Board Pins



#V# - Power output of #.# Volts

GND- Ground

GPIO# - General Purpose Input/Output

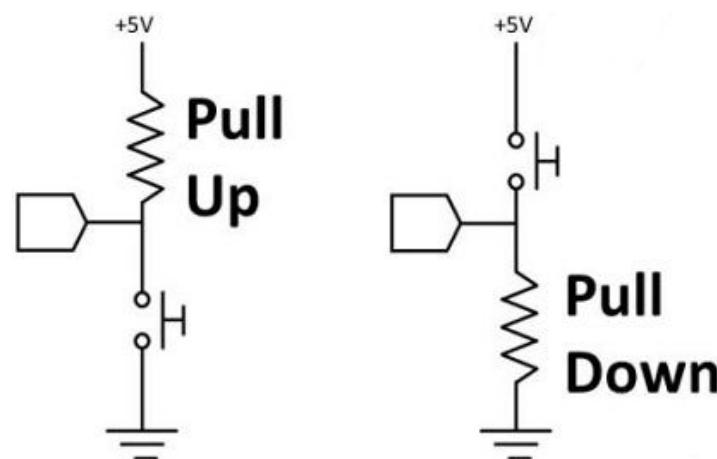
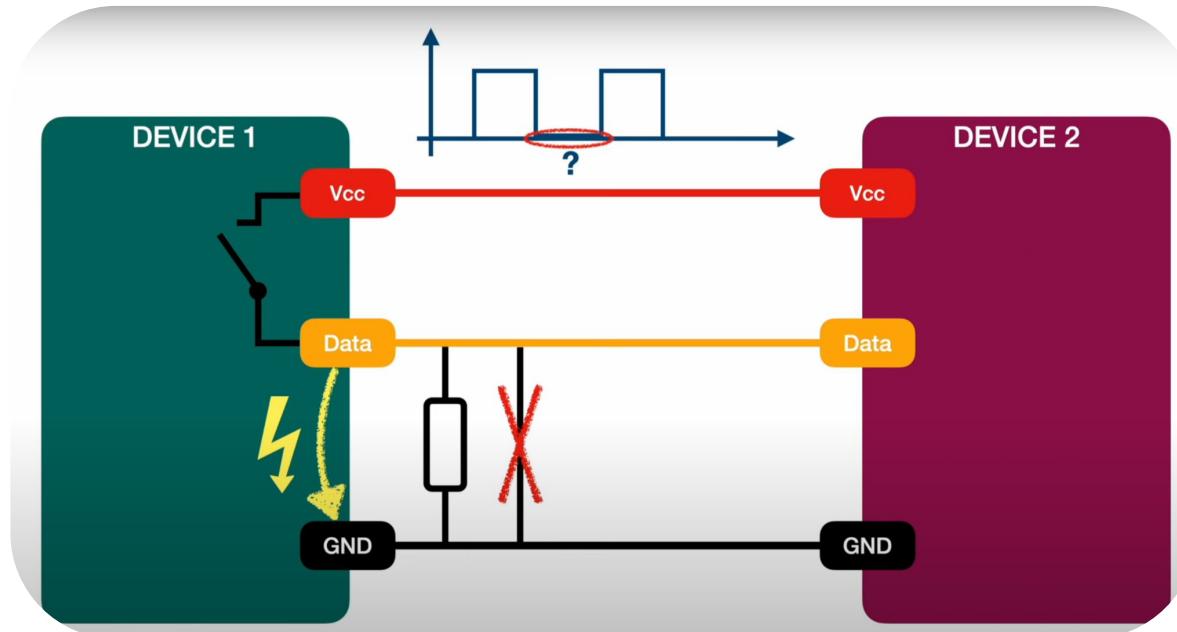
I2C/UART/SPI - Communication Protocols

PWM/PCM - Pulse Width/Code Modulation

PCM is an audio transmission protocol

3V3 Power	1	2	5V Power
GPIO2 SDA1 I2C	3	4	5V Power
GPIO3 SCL1 I2C	5	6	Ground
GPIO4	7	8	GPIO14 UART0_TXD
Ground	9	10	GPIO15 UART0_RXD
GPIO17	11	12	GPIO18 PCM_CLK
GPIO27	13	14	Ground
GPIO22	15	16	GPIO23
3V3 Power	17	18	GPIO24
GPIO10 SPI0_MOSI	19	20	Ground
GPIO9 SPI0_MISO	21	22	GPIO25
GPIO11 SPI0_SCLK	23	24	GPIO08 SPI0_CE0_N
Ground	25	26	GPIO07 SPI0_CE1_N
ID_SD I2C ID EEPROM	27	28	ID_SC I2C ID EEPROM
GPIO5	29	30	Ground
GPIO6	31	32	GPIO12
GPIO13	33	34	Ground
GPIO19	35	36	GPIO16
GPIO26	37	38	GPIO20
Ground	39	40	GPIO21

Pull up / Pull Down Resistors

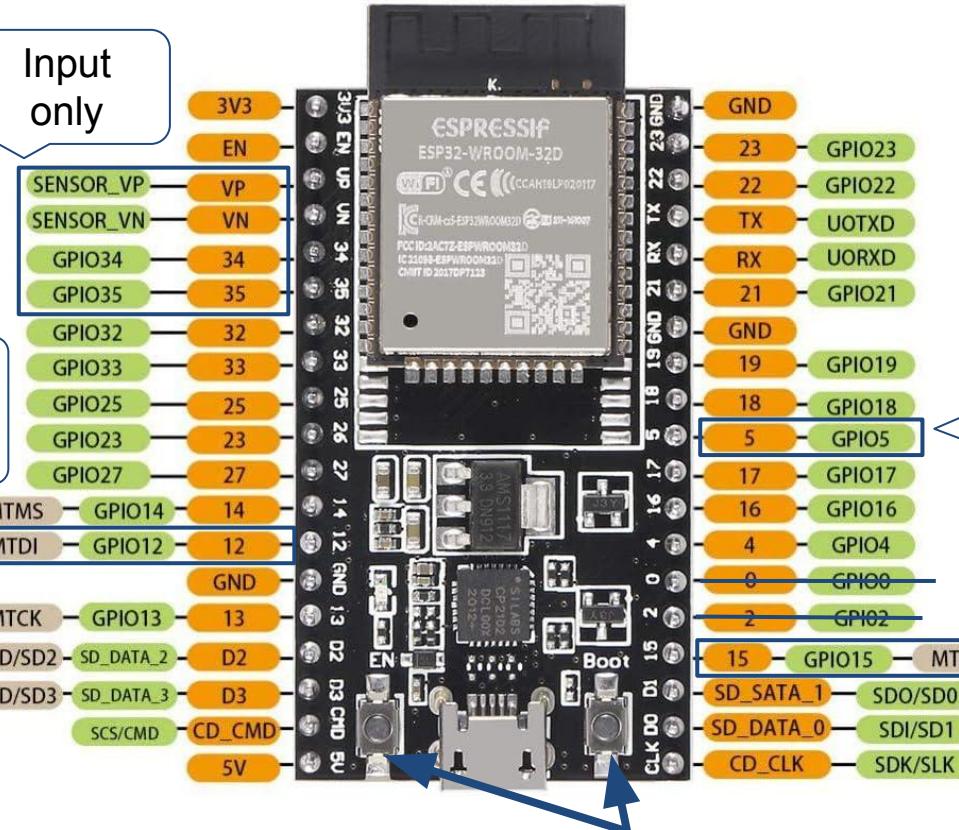


Use:

- Device 1 will change the switch depending on the bit it wants to send
- Without resistor
 - Short
 - Pin would float
 - When it does not ground properly giving the pin unreliable readings

Note: Most chips have embedded pull up and down resistors

ESP32-DevkitC Development Board



- MCU ESP32 Chips have built in Wi-Fi and Bluetooth low energy (BLE) meant for IOT
- Operates on 3.3V logic

Note: Do **NOT** power **ANY** board by the **GPIO** and **USB Port** at the same time

“EN” Button: Press to soft reset

“Boot” Button: Hold on code upload if failing

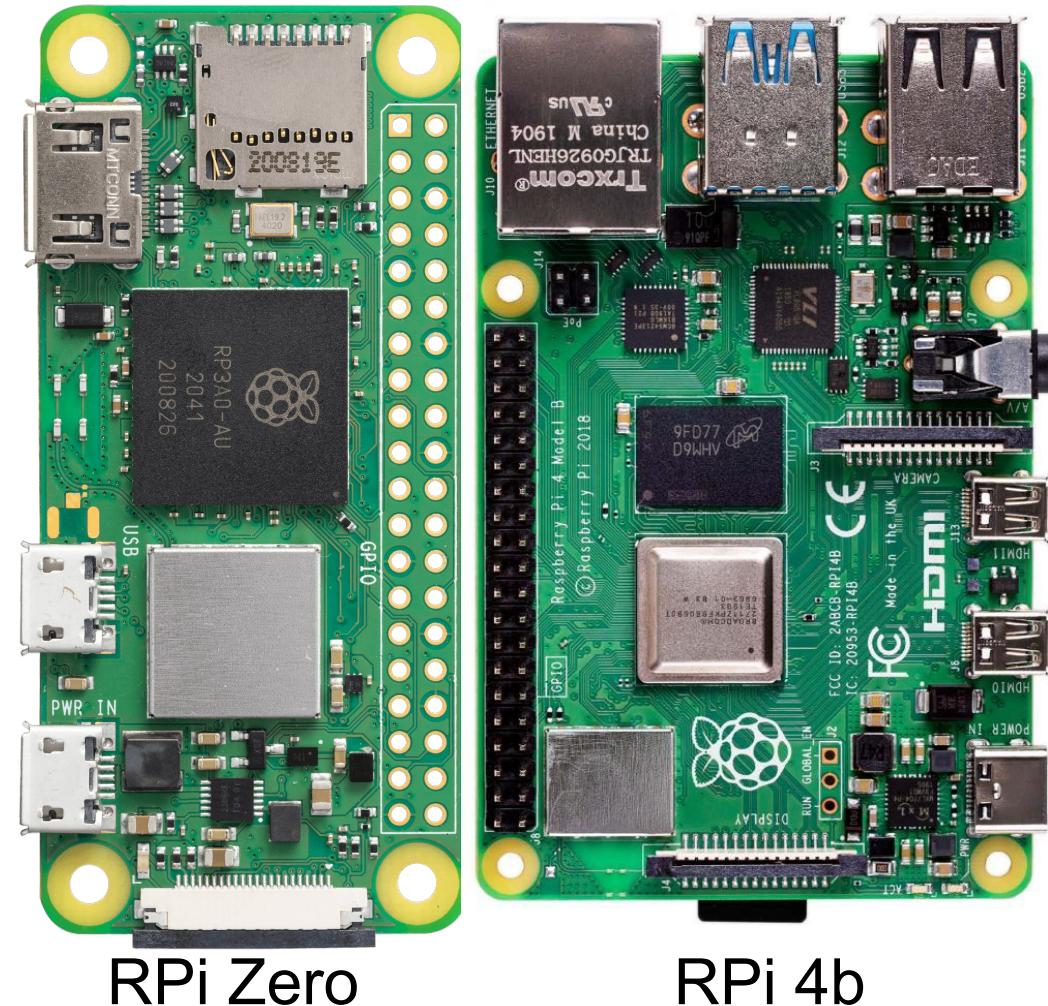
Raspberry Pi



Small form factor, low cost computer (SBC) used for digital/hardware projects

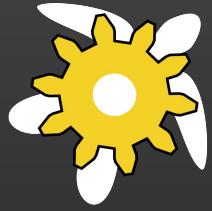
Features:

- Operates on 3.3V logic
- Bluetooth, WIFI, and *Ethernet
- HDMI, GPIO, and USB
- Can run High-level languages like Python
- Requires micro-SD card to boot OS



RPi Zero

RPi 4b



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Very Brief Linux

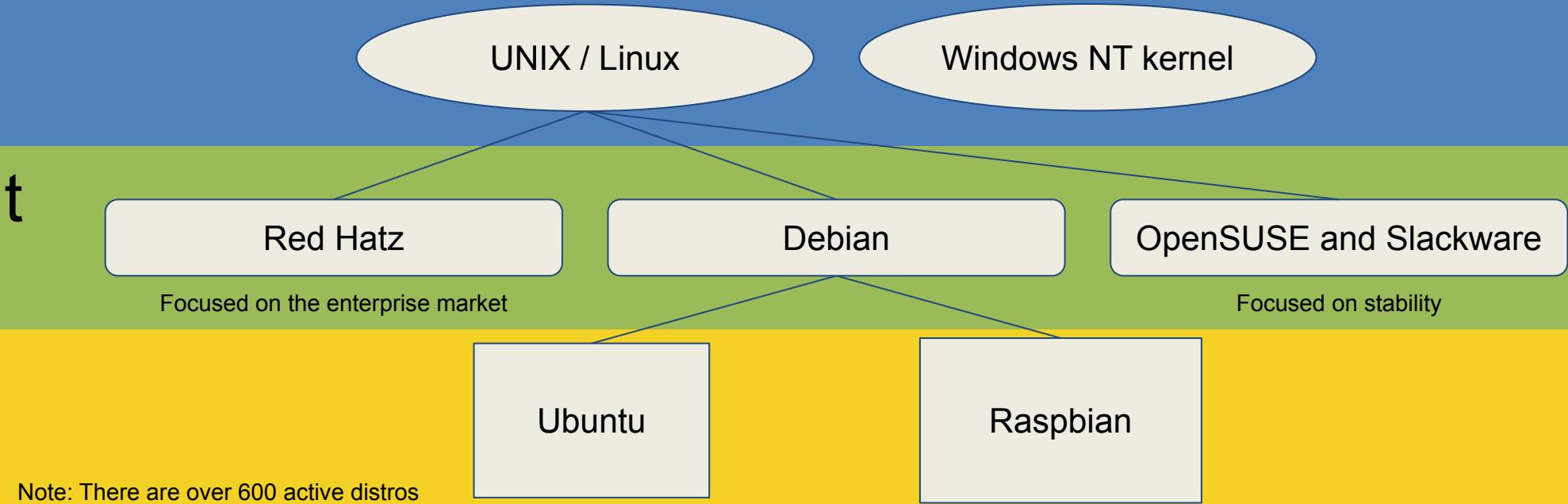
Simplified OS Tree



Kernel

Independent
Distros

Derived
Distros



Kernel - Program bridging the hardware and software

Distros - Full OS, short for distribution

Shells - Command Line Interpreter

Common Shells

- Bash (Bourne Again Shell) - Default for Linux
- Zsh (Z-Shell) - Default for Mac
- Fish (Friendly interactive shell) - Uses different syntax

Common Bash and Zsh Commands



```
ping 192.168.8.1
ssh 192.168.8.1
echo $0
uname -a
zsh or bash; exit
chsh -s /bin/zsh
pwd
ls -lah
mkdir foo
cd foo; cd ..
touch bar
echo 'hello' > bar
echo 'world' >> bar
man echo ;(space);q
cat bar
less bar ;(space);q
head bar ; tail bar
(up arrow);(down arrow)
history
hist (tab)
rm bar
rmdir foo
```

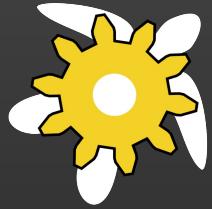
measure speed of connection to machine with IP number 192.168.8.1
securely open a shell on 192.168.8.1
show what kind of shell you are currently in
show info about processor architecture, system hostname, and kernel version
spawn & enter a new zsh or bash shell (inside current shell); exit this shell
change your default shell to zsh (recommended, if it isn't already)
print the name of the current working directory
list all files in current directory, including ownership, privileges, and size
make a new directory named foo
change directory to foo; change back to parent directory
create a new file named bar (or, just update its timestamp)
create (or, erase and create) the file bar, and write "hello" to this file
append "world" to the file bar (or, create and write to this file)
display detailed manual page (alternative to Google) for the command echo
show contents of the file bar (all at once)
show contents of the file bar (pausing after each screenfull)
show the 10 lines at the head (or, the tail) of the file bar
scroll up to recently executed commands; scroll down
show a list of recently executed commands
complete (as far as possible) name of command(s) starting with "hist"
remove (warning: permanently!) the file named bar
remove directory foo, but only if it is empty

```
rm -rf foo
cp foo/bar* foo1/.
cp -r foo foo1
mv bar foo/bar1
chmod 644 bar
chown foo1:foo bar
sudo rm bar
su;exit
df -h
du -sh foo
grep psfrag *.tex
top
ps -ef
ps -ef | grep kernel
file bar
find bar
tar cvfz fb.tgz fb
scp fb.tgz bar:.
tar xvf fb.tgz
alias l='ls -lah'
env
vim; nano
~/.bashrc
make foo
```

remove recursively the directory foo and all files contained in it (**danger!!!**)
copy all files starting with the letters bar in foo into the directory foo1
copy recursively everything in foo to the directory foo1
move and rename the file bar as bar1 inside the directory foo
change mode (\$2.2.3.2) of bar to read/write for owner, read for group & world
change ownership of file bar to user foo1 and group foo
do the command rm bar as superuser (**danger!**)
enter superuser mode for subsequent commands (**danger!!!**); exit su mode
report disk free space on the available filesystems
report significant disk use within directory foo
search files ending in .tex (in current directory) for the string "psfrag"
periodically report a list of all running threads, sorted by top CPU usage
report all running processes (once)
pipe output of ps to grep, to extract the lines with "kernel" in them
test bar to determine what type of file it is
scan current directory and all its children for filenames containing bar
compress all contents of fb into a (compact) gzipped tarball fb.tgz
securely copy fb.tgz to machine with name bar on local network
extract contents of fb.tgz, retaining its original directory structure
use "l" as a shorthand alias for the command "ls -lah" in this shell
list all aliases and other environmental variables defined in this shell
command-line text editors (see §2.4.1.2) available in all linux distros
initial run commands executed when a bash or zsh shell is spawned
run commands in Makefile (see §2.2.3.3) to make an executable boo

Commands follow:
<command> -<options> <arguments>

Note: Commands are often shortened versions of words/phrases



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Communication Protocols

Edge vs Cloud Compute



Edge

- Performing calculations locally on robot / devices.
- Real-time
- Lower computation ability
- Decentralized

Cloud

- Performing calculations remotely on computer clusters (servers)
- Latency delayed
- Higher computation ability
- Centralized

*Hybrid approaches exists, but all real-time safety decisions are made on edge devices.

SSH - Secure Shell



Secure remote access and communication protocol. Allows you to work on the RPi from your laptop.

How to do it via command line:

1. Connect RPi and computer to same network
 - a. Make sure RPi has SSH enabled in settings or `sudo raspi-config`
2. Find RPi IP address with `hostname -I`
3. On computer, type `ssh <RPi username>@<ip address>`
 - a. Type your RPi password when prompted

Duplex



Think of it like roads

- Full (Two way road)
 - Data can be sent and received at the same time
- Half (Single wide road)
 - Data can be sent and received but **NOT** at the same time
- Simplex (One way road)
 - Data can be sent or received but **NOT** both



Short-Range Wired Communication Protocols



SPI - Serial Peripheral Interface (~Max of 10 meters)

- A Master-Slave architecture using wires to identify between slaves
- Full-duplex

I2C/I3C - Integrated Circuit (~Max of 5 meters)

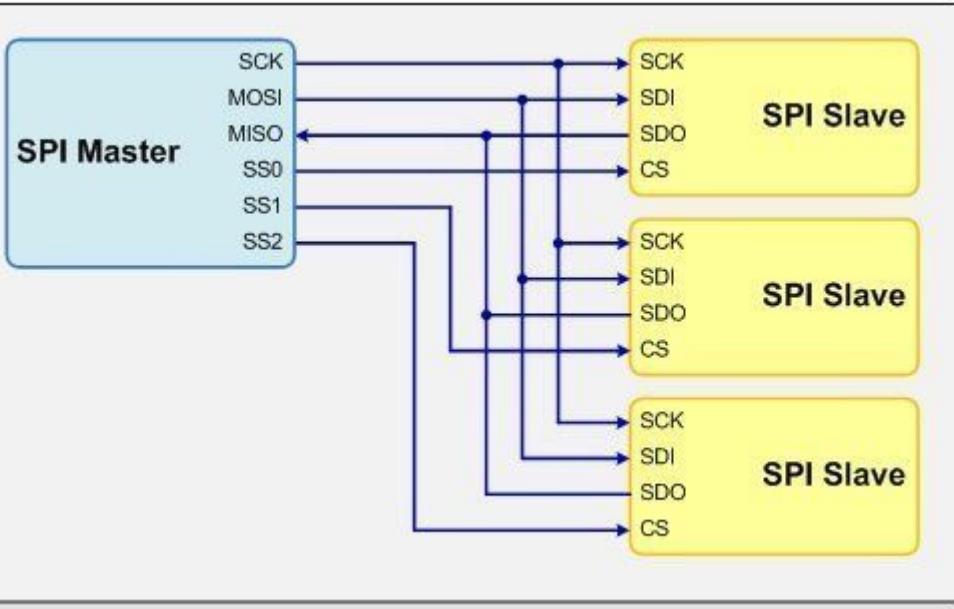
- A Master-Slave architecture using unique addresses on a shared-bus
- Half-duplex

UART - Universal Asynchronous Receiver Transmitter (~Max of 15 meters)

- A point-to-point architecture where both devices can initiate transmissions
- Simplex/Half/Full-duplex

Note: Master-Slave convention is becoming outdated.
Typically renamed Master-<Peripheral>

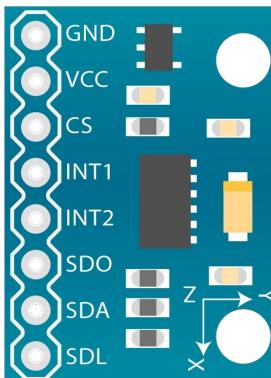
SPI Serial Peripheral Interface



Four Wires Full Duplex:

- SCLK: Clock that controls bit upload speed
- MOSI: Data from Master to Slave
- MISO: Data from Slave to Master
- CS: Selects which Slave it is communicating to

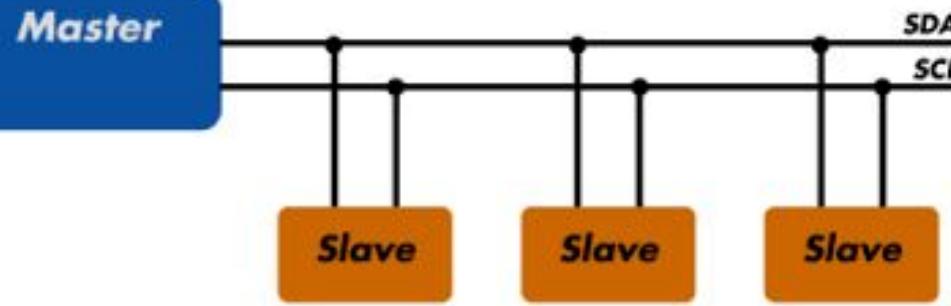
ADIY ADXL345 Triple Axis Accelerometer Module



Connecting Using SPI Accelerometer:

- Find GPIO compatible with SPI (able to do I/O and Clk)
- MISO(SDA) & MOSI(SDO): Most GPIO Pins will do as long as it isn't reserved for other comm. protocols.
- SCLK(SDL): Look for SCLK compatibility
- SS(CS): Most GPIO will work

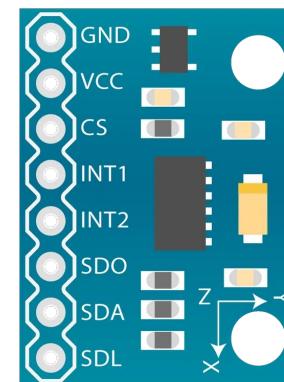
I2C Integrated Circuit



Two Wires Half Duplex:

- SCL: Clock that controls bit upload speed
- SDA: Line for data
- Note: No need for chip select b/c address is sent to active Slave before data transmission

ADIY ADXL345 Triple Axis Accelerometer Module

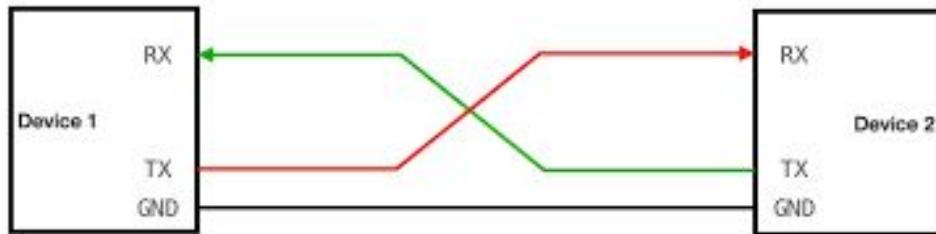


Connecting Using I2C Accelerometer:

- Find GPIO compatible with I2C (able to do I/O and Clk)
- SDA (SDA): Most GPIO Pins will do as long as it isn't reserved for other comm. protocols.
- SCL(SDL): Look for SCL compatibility
- Note: Some parts are compatible with multiple protocols



Two Wires Full Duplex:



- Tx: Transmits data
- Rx: Receives data
- Note: No need for Clk b/c it has a set baud rate which is the speed it will transfer data



- Connecting Using UART IMU (NOT COMMON WITH IMU):
- Find GPIO compatible with UART (UART has dedicated Tx and Rx pins most of the time)
 - Note: This is the protocol used for uploading code into arduino boards

Long-Range Wired Communication Protocols



RS485/Modbus RTU (~Max of 1200 meters)

- A Master-Slave architecture using hardware addresses
- Half-duplex

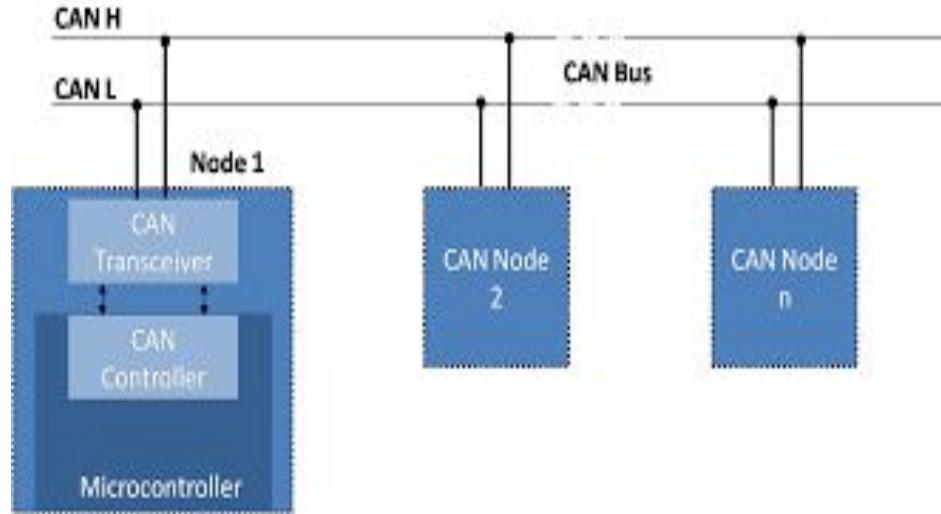
CAN - Controller Area Network (~Max of 40 meters)

- A real-time multimaster architecture using message frames
- Half-duplex

Ethernet/EtherCAT (~Max of 100 meters)

- A real time Master-Slave architecture using message frames
- Full-duplex

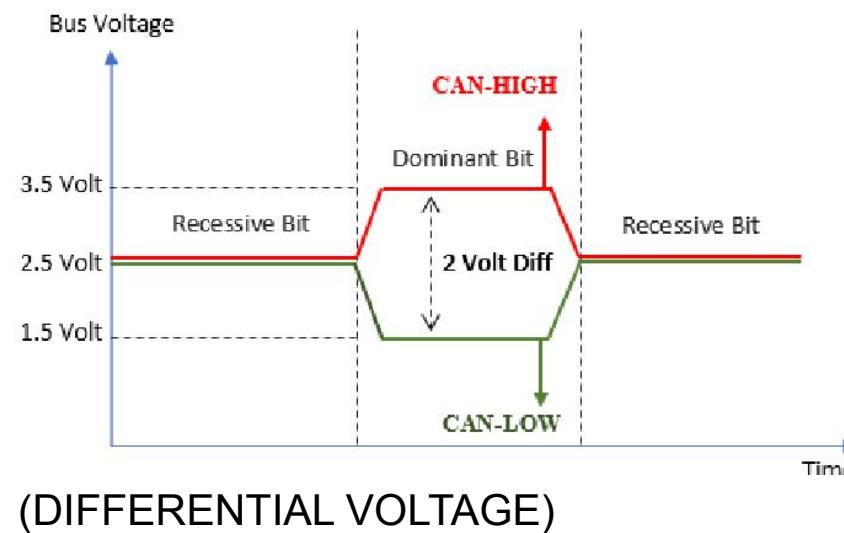
Note: Ethernet is peer-to-peer
and not real time



Reliant and fault tolerant:

- CAN_H & CAN_L: Data transmission
- Bits are transmitted using differential voltage
- Uses IDs (11bit) for each node which also denotes the nodes “importance” in the network
 - If node 1&100 wants to signal node 1 takes priority (non-destructive arbitration)
- Uses baud rate like UART

- Shared bus should terminate with a 120Ω resistor and use twisted pair cables for maximum signal integrity
 - Resistor blocks the signal from being reflected (cable impedance matching)
 - Twisted pair cables minimize electromagnetic interference



Wireless Communication Protocols



RFID - Radio-Frequency IDentification (Distance Varies)

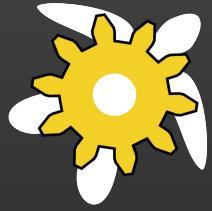
- Reader emits radio waves, activating a tag to return its stored data
- Half-duplex

WIFI - Wireless Fidelity (Distance Varies)

- Router transmits information packets through radio waves (2.4, 5, 6 GHz)
- Half-duplex

Bluetooth/BLE (Distance Varies)

- A 2.4 GHz Master-Slave architecture using packets
- Half-duplex



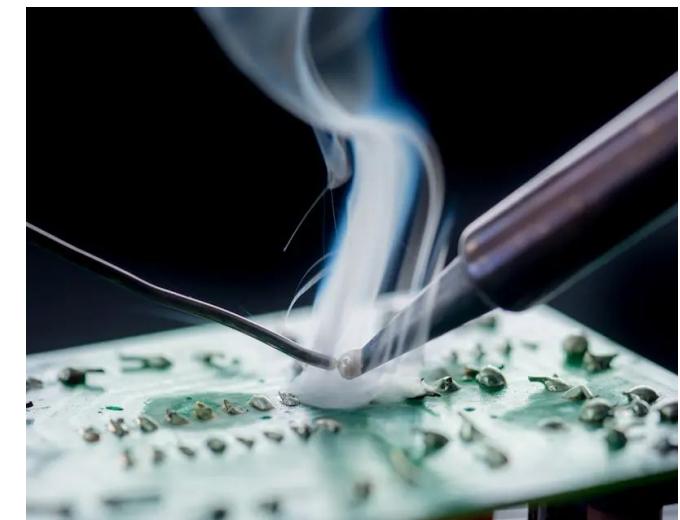
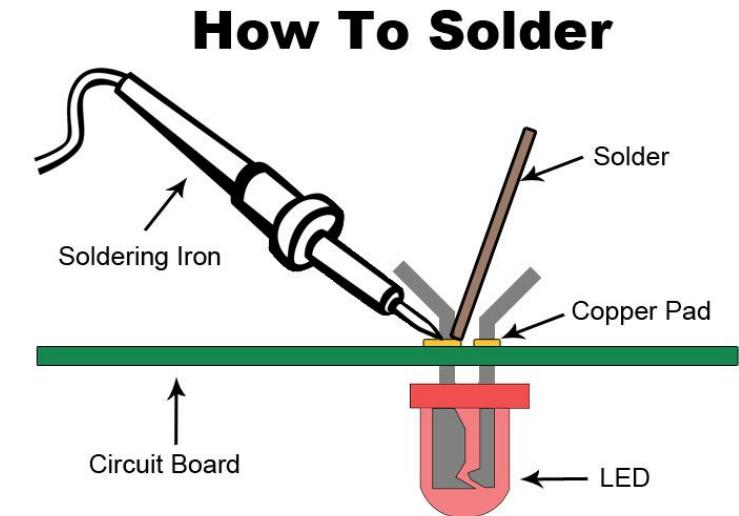
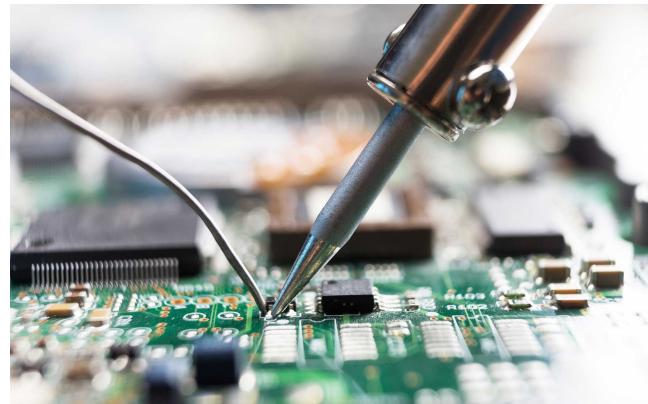
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Soldering

What is soldering?



- Process of joining two or more metal pieces together by melting a filler metal alloy, called solder, into the joint
- Heat is applied to the pieces, causing the solder to melt and flow into the spaces between them, creating a strong, conductive bond upon cooling



Soldering Tools



Soldering Iron



Easy to transport

Soldering Station



Allows for more precise temperature control and may have additional features

Soldering Tools



Soldering Iron Tips

- The tip at the end of most soldering irons are interchangeable.
- Each tip has a specific purpose. The most common ones are:
 - Conical Tip – Used in precision electronics soldering because of the fine tip.
 - Chisel Tip – Well-suited to soldering wires or other larger components because of its broad flat tip.



Soldering Tools



Sponge

- Using a sponge will help to keep the soldering iron tip clean by removing the oxidation that forms
- Tips with oxidation will tend to turn black and not accept solder as it did when it was new.



Copper
Sponge



Solder

- Solder comes in a different diameters
 - Thicker diameter solder is good for soldering larger joints quickly
 - Thinner solder is useful for precision projects



Tinning the tip



- This process will help improve the heat transfer from the iron to your project as well as helping to protect the tip and reduce wear. You should tin the tip of your iron **before and after each soldering session.**

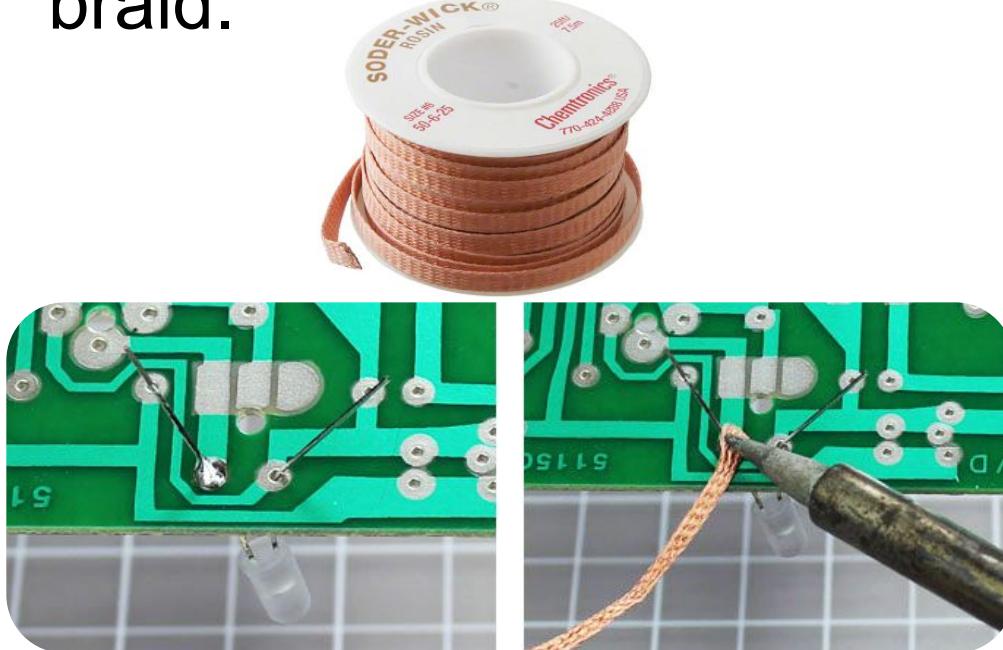
1. Make sure the tip is attached to the iron and screwed tightly in place.
2. Turn on your soldering iron and let it heat up. Set it to 400°C
3. Wipe the tip of the soldering iron on a damp wet sponge to clean it. Wait a few seconds to let the tip heat up again before proceeding to step 4.
4. Hold the soldering iron in one hand and solder in the other. Touch the solder to the tip of the iron and make sure the solder flows evenly around the tip.



Desoldering



1. Place a piece of desoldering braid on top of the joint/solder
2. Heat your soldering iron and touch the tip to the top of the braid.



1. Press the plunger down at the end of the solder pump
2. Heat the joint with your soldering iron and place the tip of the solder pump over the hot solder
3. Press the release button to suck up the liquid solder
4. Press down on the plunger to empty the solder pump



Example



Tips

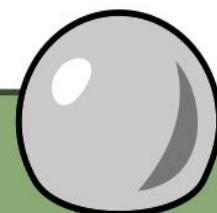


- Ensure your iron is set to the correct temperature
 - Solder sticking to the tip? Too hot
 - Solder is not free flowing? Too cold
 - Typically 600°- 650°F (316°- 343°C) for lead-based solder and 650°- 700°F (343°- 371°C) for lead-free solder
- Plan the order you will solder components
- Hold your iron to the contact point for a few seconds before applying solder
- Tin your iron every time
- Use flux
- Trim components after soldering
- Use the least amount of solder possible

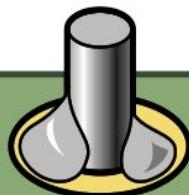
Examples



Perfect!



**Too
Much
Solder**



**Not
Enough
Solder**



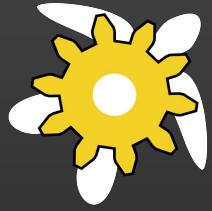
**Cold
Joint**



**Too
Much
Heat**



Short

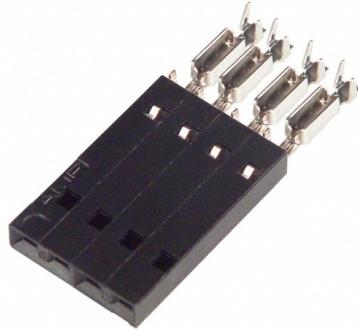


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Wire Crimping

Common Wire Connector Types

Note: Pin count may vary



Dupont
GPIO



JST
Consumer electronics

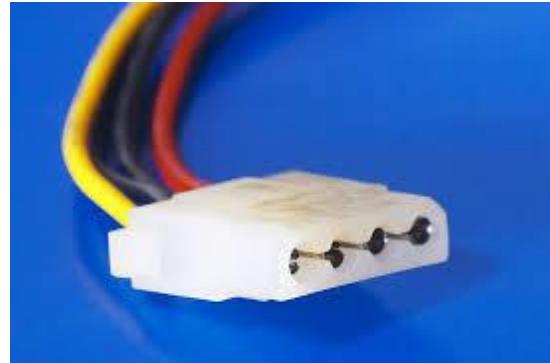


Dean/T-Plug
RC power connections

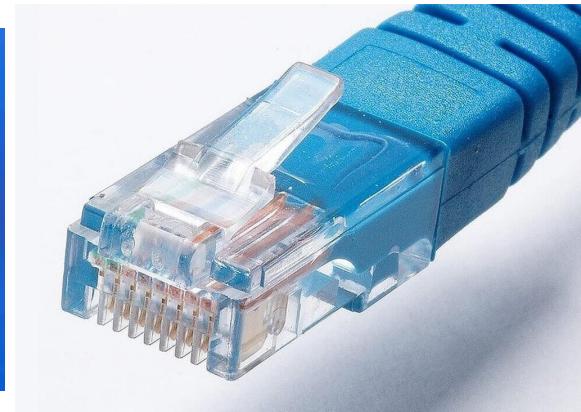


Soldered

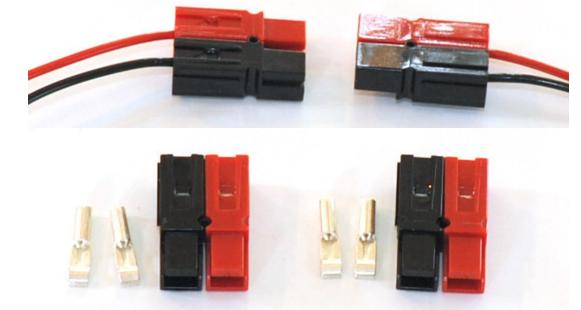
XT Family
High-current power
connections



Molex
Power and Signal



RJ Family
Telecommunications



Anderson Powerpole
High-current DC power
connections

Crimping



Depends on the type of connector

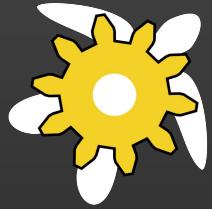
Generally:

1. Strip wire
2. Grab metallic connection in grove
3. Insert stripped wire
4. Fully clamp crimping tool on wire arms
5. Fully clamp crimping tool on insulation arms
6. Push metallic connection into the connector housing



Example





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Documentation Navigation

How to Read



Aa Bb Cc Dd Ee Ff Gg

/eɪ/ /bi:/ /si:/ /di:/ /i:/ /ef/ /dʒi:/

Hh Ii Jj Kk Ll Mm Nn

/eɪtʃ/ /aɪ/ /dʒeɪ/ /keɪ/ /el/ /em/ /en/

Oo Pp Qq Rr Ss Tt Uu

/oʊ/ /pi:/ /kju:/ /a:r/ /es/ /ti:/ /ju:/

Vv Ww Xx Yy Zz

/vi:/ /'dʌb.əl.ju:/ /eks/ /waɪ/ /zi:/

Technical Documentation aka Datasheets



Understanding technical documentation is an important skill

Most datasheets contain the same information in a similar format. These sheets convey important information such as:

- Physical dimensions and possible manufacturing tolerances
- Pin configurations
- Absolute maximum ratings and recommended operating conditions
- Truth tables and timing diagrams



T200 Thruster Specifications

Performance

Full Throttle FWD/REV Thrust @ 12 V	3.71 / 2.92 kg f	8.2 / 6.4 lb f
Full Throttle FWD/REV Thrust @ Nominal (16 V)	5.25 / 4.1 kg f	11.6 / 9.0 lb f
Full Throttle FWD/REV Thrust @ Maximum (20 V)	6.7 / 5.05 kg f	14.8 / 11.1 lb f
Minimum Thrust	0.02 kg f*	0.05 lb f*

Electrical

Operating Voltage	7-20 volts
Full Throttle Current (Power) @ 12 V	17 Amps (205 Watts)
Full Throttle Current (Power) @ Nominal (16 V)	24 Amps (390 Watts)
Full Throttle Current (Power) @ Maximum (20 V)	32 Amps (645 Watts)



- With most PCB having the pinout of the GPIO's will give you most of the information you need
- With other electrical components (Special motors, sensors, etc)
- Looking at the data sheet will be useful to understanding the communication protocols and the voltage/current needed for each input/output (**IMPORTANT AS TO NOT DAMAGE HARDWARE AND BEWARE OF UNITS**).

Important Things to Check



- Ensure that the part numbers the document covers matches your part
- Keep an eye on the units
- Make sure that you are supplying the correct voltage and current
 - Avoid damaging hardware

...Kahoot Time!



ESP32 Documentation



Datasheet

Hatchling Competition Announcement



A Team will be Crowned

Lab
opens at
10 AM

Saturday

April 25th

12:00 PM

**Wisenbaker Lobby
(WEB)**





Networking is very important for your career. The people you've met this semester could be the ones who get you a future job.

LinkedIn is the professional network platform.

Add your teammates. Add us!



Advanced Project List on Website



turtlerobotics.org

Reminders From Week 1



- Our capacity for Hatchling is 120 people
 - Priority goes to new members
 - Do **NOT** expect spots to be available for repeating members next semester
- Advanced Projects are not guaranteed for Hatchling graduates
 - Every Advanced Project lead determines their own team
 - Selection is based on the needs of the project
 - Most will look for the Hatchling project on your resume
 - Do NOT lie about Hatchling
 - A lot will check if you finished a Hatchling robot
 - If you are interested in a certain project, contact the project lead and learn more about what skills they are looking for



That's all for our lectures

Let's build robots

*All future meetings will be in your home organizations

lab*



Let's work

Lab typically opens at ~10am on weekdays. Feel free to come work on your robot anytime an officer is present.

There are a few rules:

- 1) Clean up after yourself. Leave the lab nicer than you found it
- 2) Be respectful of Advanced Project meetings. APs are working hard to prepare for project showcase. Please listen to requests by the project lead.
- 3) 3D printing priority goes to APs during their meeting time. If your print will overlap any AP meeting times, please ask the project lead if the printer is available.

Next Milestone



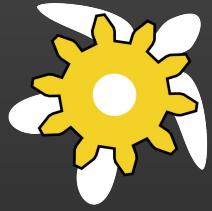
Milestone: Prototype Review

Date: Week 9 - Prototype (1 week from today)

Expectation: Have a CAD assembly of a drive system. Have a finished electronics wiring diagram.

Exceed Expectation: Have a CAD of the entire robot and started prototyping. Began programming the robot.

Impact: We will review design viability and suggest improvements. Potential to prototype your mechanism.



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Prototype Week

Next Week



**“Why can’t I ever invent something that does
what it’s supposed to do?”**

~ Dr. Doofenshmirtz



Hatchling

