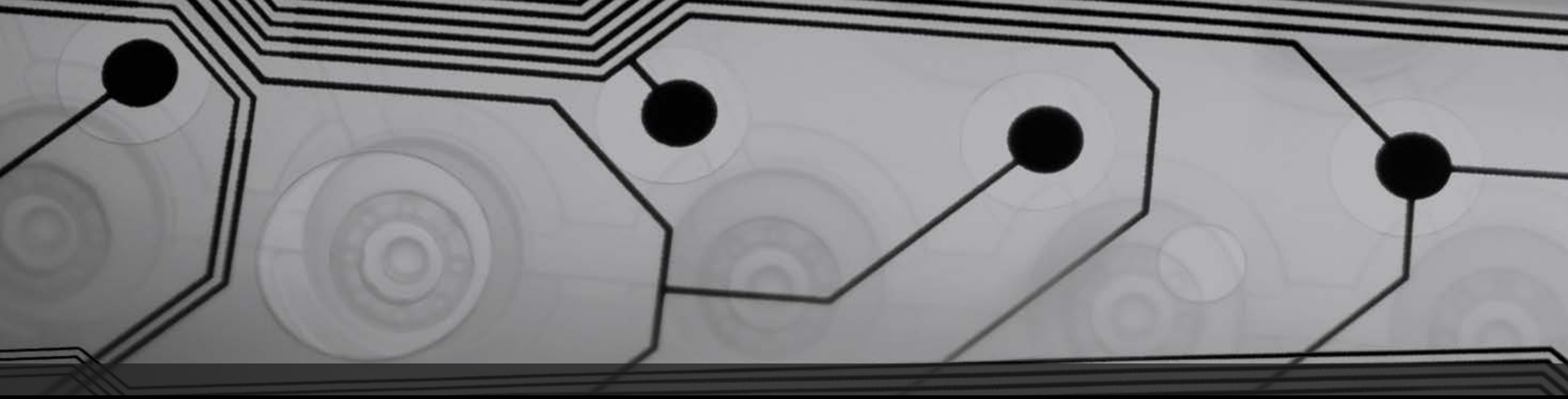


Badge My IoT Life - Part I

Paul Pagel

Badge My IoT Life – Part I

Sign in at the table to receive your hardware kit and handout materials

- Create your nameplate (print big, first name only.)
- You'll receive a red cup if you're a paid ticket holder.
- You'll receive a blue cup if you're a free ticket holder.
- Free ticket holders will need to pair up with other free ticket holders to share a badge.
- **Please do NOT turn on soldering irons or begin assembly yet.**

If you have not already done so:

- Download the pre-requisites instructions and complete all downloads and installations: http://prereqs.codemash.org/

Slide Decks and Labs (PDF):
https://github.com/DigiTorus86/ESP32Badge/tree/master/documents

About Paul Pagel

- 20+ years of developing software professionally and managing software teams
- Manufacturing Systems Architect at First Solar, Inc.
- Martial arts instructor, former infantry reserve officer
- Particular area of electronic/hardware interest = Audio & Video

- Email: pjpagel86@gmail.com


FANUC R-2000

Prizes!

Schedule for the Day

Morning: Hardware - “Conformity”

LUNCH!

Afternoon: Software - “Creativity”

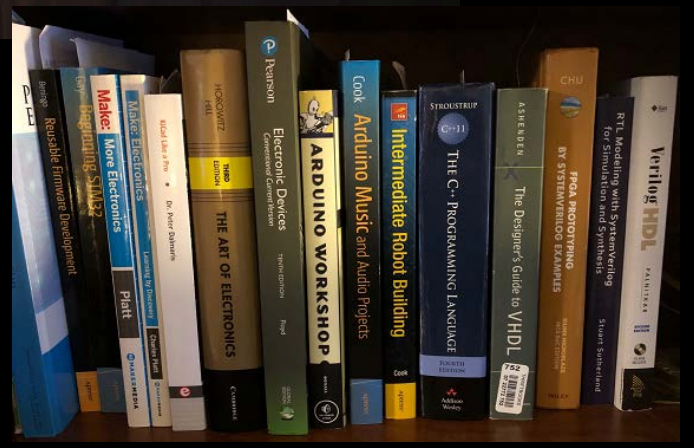
Session Objectives

Learn/review the basics of working with electronics and microcontrollers

- Terminology
- Schematics and pinouts
- Soldering and assembly techniques
- Testing and troubleshooting hardware

Build and test a working wireless-enabled conference badge!

How I Got Here



Session Guidelines

- This is an interactive workshop. Be an active participant.
- If I ask a question to the group, go ahead and call out the answer.
- If you have a question, raise you hand… the sooner the better.
- Acronyms and abbreviations - now in nested varieties…
- Work with the session assistants and participants around you during the assembly and testing process. Leverage the wisdom of teams.
- Be respectful of your fellow attendees and keep side conversations to a minimum during the lecture portions.
- Set phones on vibrate and step out to take calls.
- **Have fun!**

The Badge

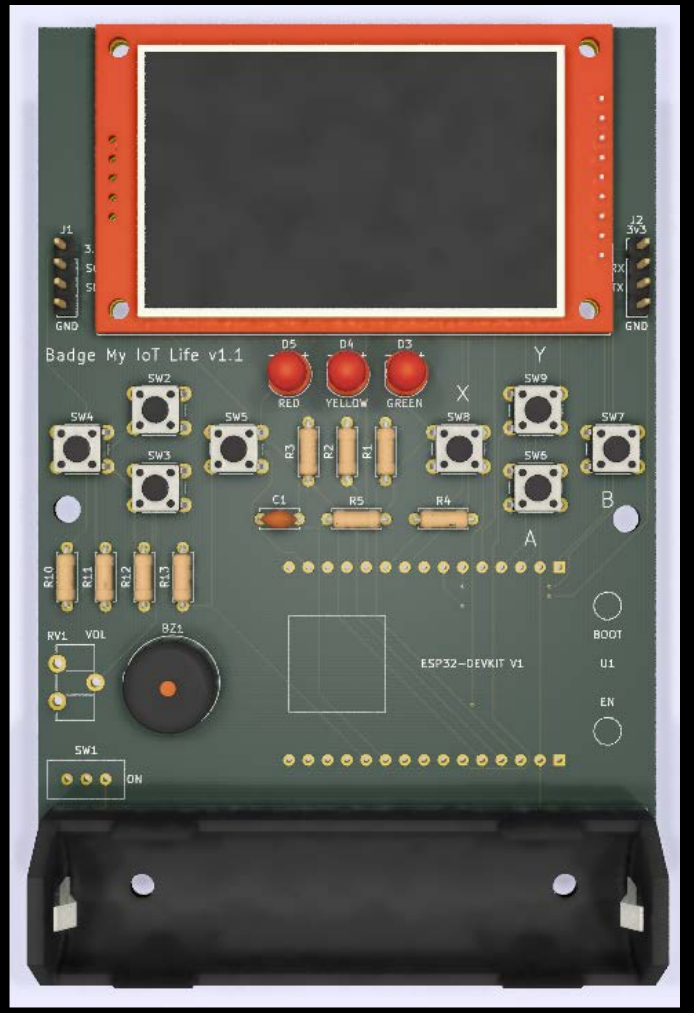
Begin with the End in Mind

The Badge

- Think hackable internet-enabled Game Boy with options to add your own sensors and accessories.
- Can expect 6 to 8 hours of operation with a fresh, fully-charged battery.
- Layout facilitates easy soldering.
- Designed so that key components can be removed and reused in other projects.

The Badge – Capabilities

- Relatively large 262K color display
- WiFi and Bluetooth/BLE (Bluetooth Low Energy) connectivity
- Lots of buttons for user input
- Can be powered from battery or USB
- Battery level detection circuit
- Digital audio/WAV file output to speaker
- Jumpers for Inter Integrated Circuits (I2C) bus and Universal Asynchronous Receive Transmit (UART)



The Badge – Limitations

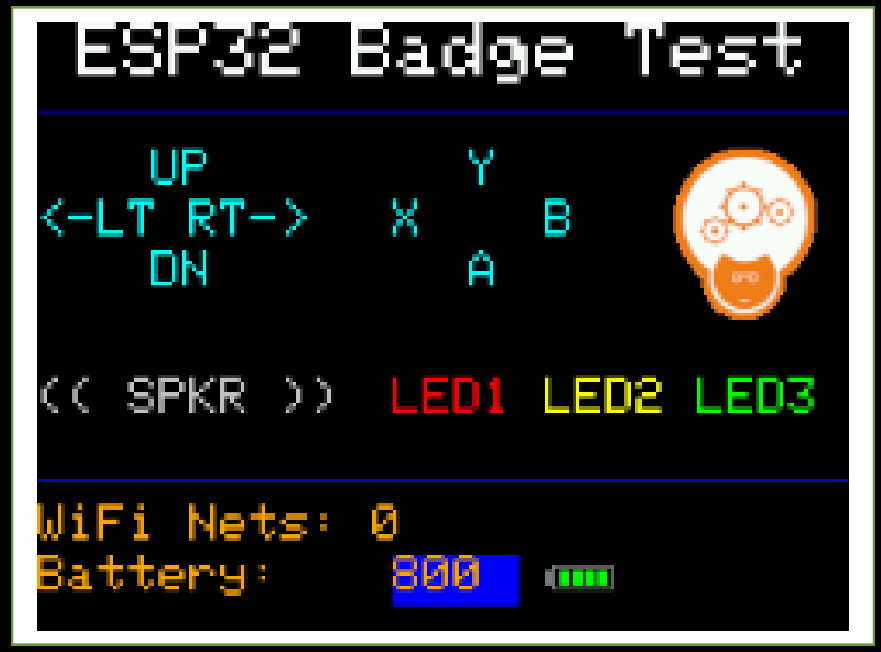
- Rather bulky compared to coin cell powered badges with e-Ink displays.
- Don’t expect 60 Hz display refresh (closer to 1 Hz for full screen)
- Fairly quiet, low-fidelity sound from the button speaker/transducer.

The Badge Tester App

Allows you to easily exercise all the buttons and peripherals on the badge and detect any problems.

Comes pre-loaded onto the microcontroller included in the kits.

This should be the first thing you see when you power on your completed badge.



Microcontrollers

A Quick Overview

Microcontrollers

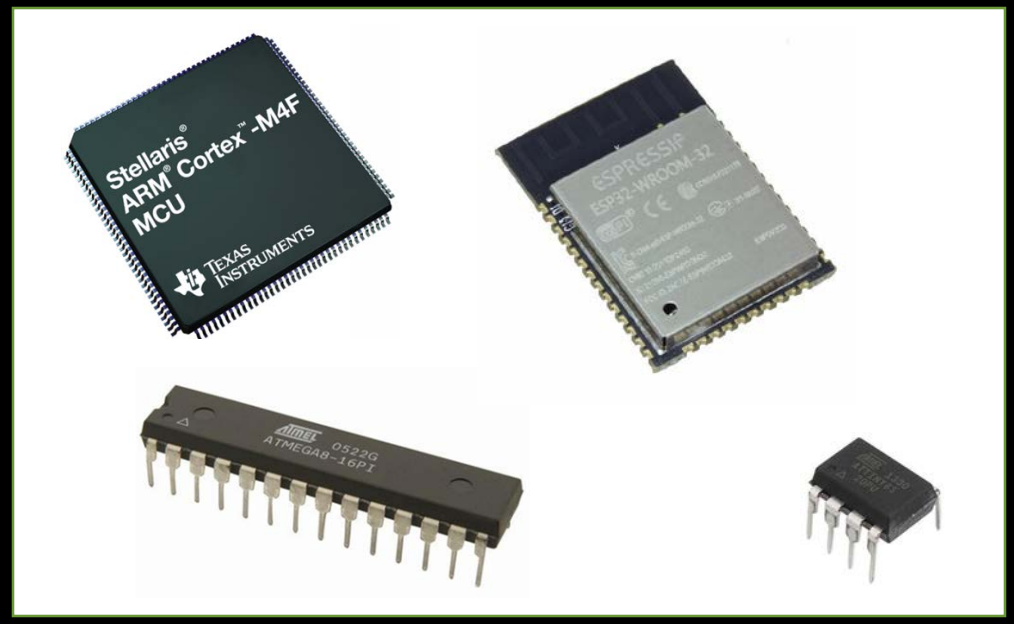
Microcontroller: A small computer on a single integrated circuit often used in embedded applications. Also referred to as a Micro Control Unit or MCU.

A few common examples:

- Atmel AVR
- ARM Cortex M-series
- ESP8266 / ESP32-Wroom-32

Come in a number of form factors

- Dual Inline Package (DIP)
- Surface Mount Devices (SMD)

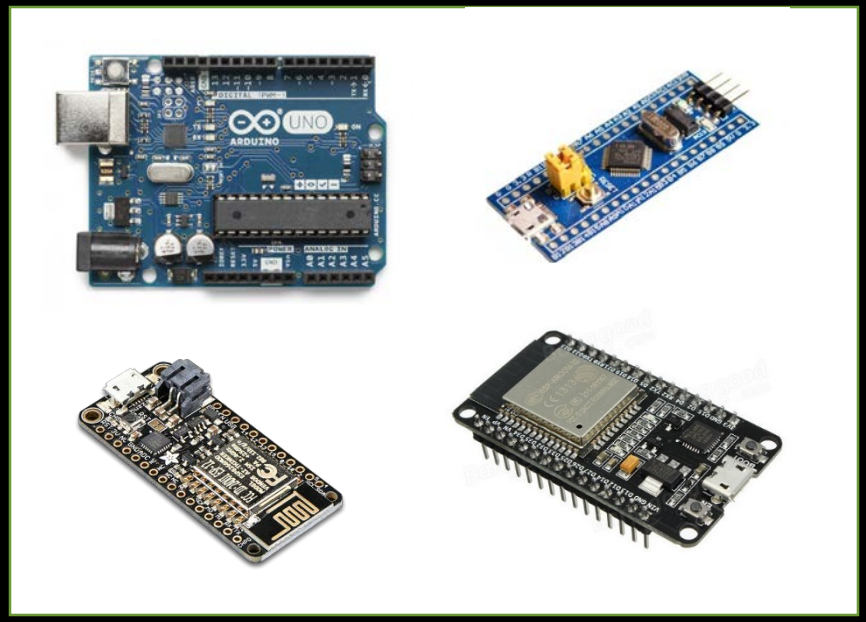


Development Boards

Dev boards are designed to make the MCU easier to evaluate and to use in small scale custom designs.

Common examples:

- Arduino Uno
- Adafruit Feather
- STM32F103 “Blue Pill”
- ESP32 Dev Kit



Meet the ESP32 DevkitC/NodeMCU-32S

Processing power and memory

- Espressif ESP WROOM-32D MCU
- Dual-core 32-bit Tensilica Extensa LX6 processor @ 160 or 240 MHz
- 448KB ROM, 520KB SRAM, 4MB Flash

In Kit:

- 1 – ESP32 DevKitC w/38 pins

Meet the ESP32 DevkitC/NodeMCU-32S

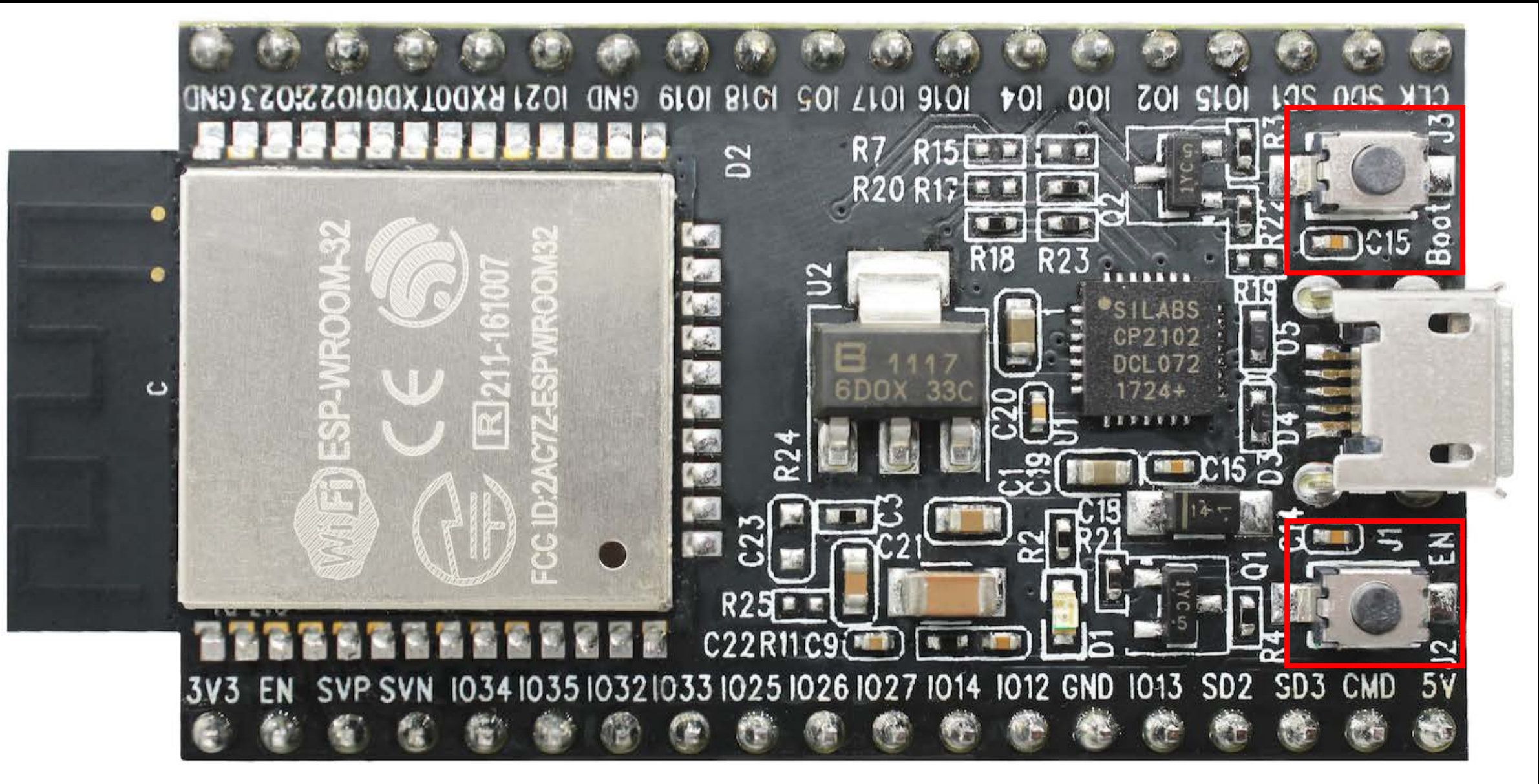
Excellent connectivity capabilities

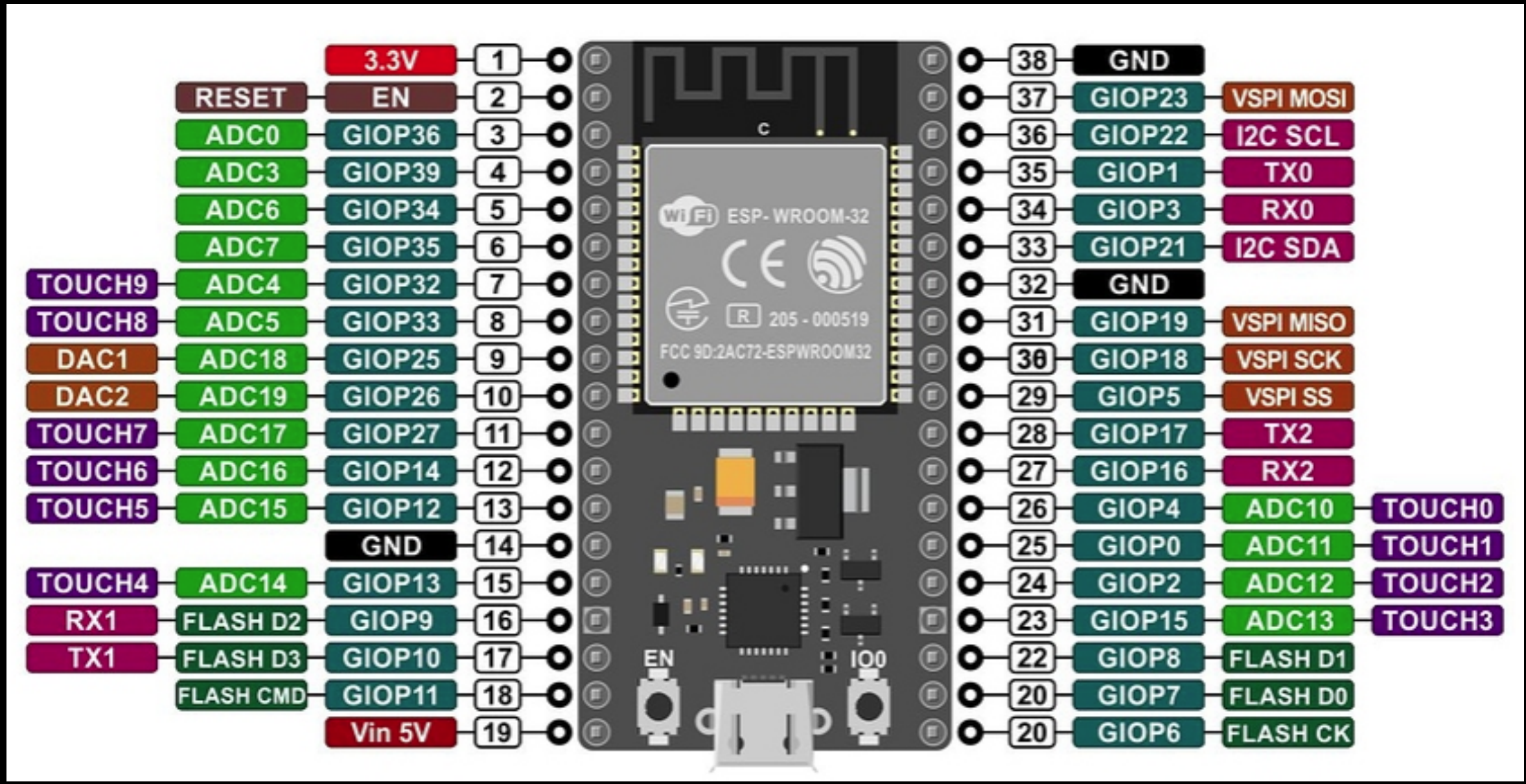
- 2.4GHz dual-mode WiFi + Bluetooth 4.2 + BLE
- Support for security and encryption

Meet the ESP32 DevkitC/NodeMCU-32S

Many built-in peripherals

- Integrated UART, SPI, I2C, I2S, CAN, PWM
- 18-channel 12-bit Analog-to-Digital Converter (ADC)
- 2-channel 8-bit Digital-to-Analog Converter (DAC)
- 30+ General Purpose Input Output pins (GPIO)


3V3 EN SVP SVN I034 I035 I032 I033 I025 I026 I027 I014 I012 GND I013 SD2 SD3 CMD 5V
CLK SD0 SD1 I015 I02 I00 I04 I016 I017 I05 I018 I019 GND I021 RXD0 TXD0 I022 I023 GND
ESP-WROOM-32
211-161007
FCC ID:2AC7Z-ESPWROOM32
SILABS
CP2102
DCL072
1724+
1117
6DOX 33C
Boot
EN
C15
R7
R15
R20
R17
R18
R23
R24
R25
C22
R11
C9
C23
C21
C20
C19
C1
R21
Q1
D1
D2
D3
D4
U1
U2
U3
U5
J1
J2


3.3V 1
RESET EN 2
ADC0 GIOP36 3
ADC3 GIOP39 4
ADC6 GIOP34 5
ADC7 GIOP35 6
TOUCH9 ADC4 GIOP32 7
TOUCH8 ADC5 GIOP33 8
DAC1 ADC18 GIOP25 9
DAC2 ADC19 GIOP26 10
TOUCH7 ADC17 GIOP27 11
TOUCH6 ADC16 GIOP14 12
TOUCH5 ADC15 GIOP12 13
GND 14
TOUCH4 ADC14 GIOP13 15
RX1 FLASH D2 GIOP9 16
TX1 FLASH D3 GIOP10 17
FLASH CMD GIOP11 18
Vin 5V 19
38 GND
37 GIOP23 VSPI MOSI
36 GIOP22 I2C SCL
35 GIOP1 TX0
34 GIOP3 RX0
33 GIOP21 I2C SDA
32 GND
31 GIOP19 VSPI MISO
30 GIOP18 VSPI SCK
29 GIOP5 VSPI SS
28 GIOP17 TX2
27 GIOP16 RX2
26 GIOP4 ADC10 TOUCH0
25 GIOP0 ADC11 TOUCH1
24 GIOP2 ADC12 TOUCH2
23 GIOP15 ADC13 TOUCH3
22 GIOP8 FLASH D1
20 GIOP7 FLASH D0
20 GIOP6 FLASH CK
WiFi ESP-WROOM-32
205 - 000519
FCC 9D:2AC72-ESPWROOM32
EN
IO0

Electronic Components

What’s in the Kit and What It Does

Printed Circuit Board (PCB)

- Contains attachment points / through-holes for components and the wiring traces to connect them.
- Silk screen identifies the location and orientation for components to be soldered.
- Allows for quicker assembly, fewer mistakes, and smaller footprint compared to proto or strip board.

In Kit:

- 1 – custom PCB (v1.2)

PCB Structures

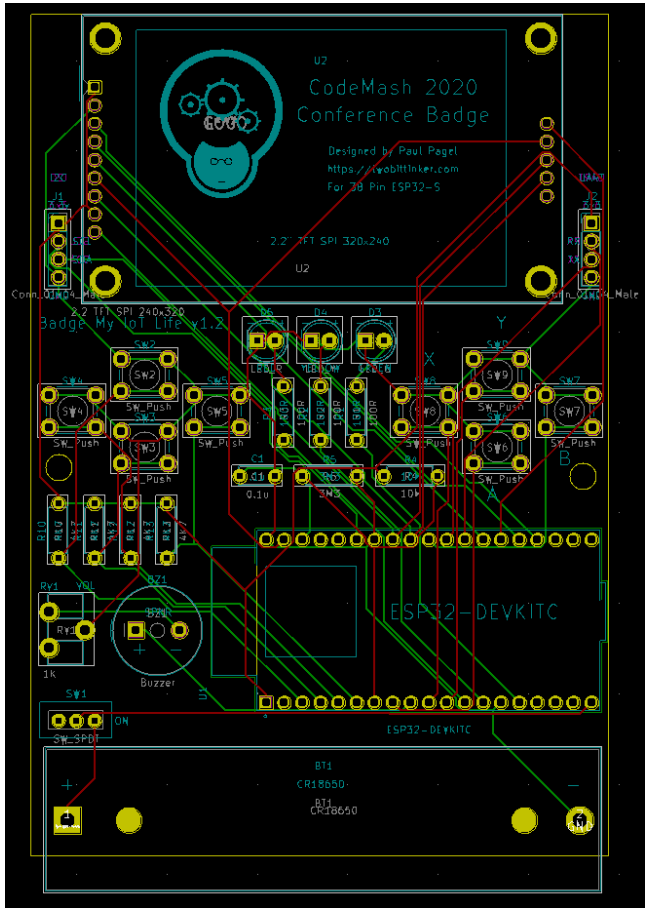
Solder Mask

- Top layer that repels solder and protects the traces
- Often contains lead, so don’t lick it

PCB Structures

Traces

- Copper wires that connect the solder pads/rings
- The badge board has 2 layers of traces (front & back)
- Traces can be damaged

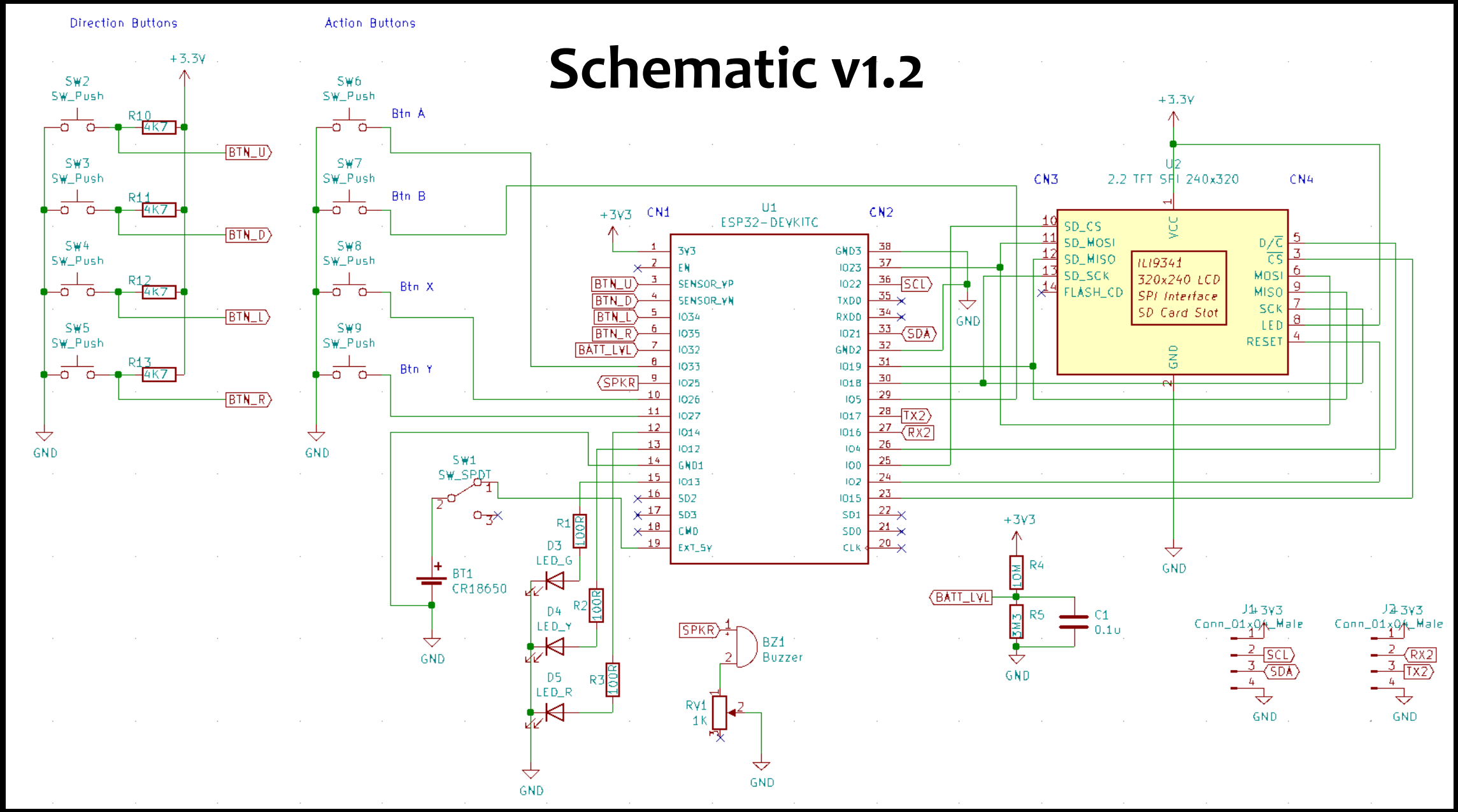


PCB Structures

Through Holes

- **Mounting holes:** large, may or may not have metallic annular rings. Used to connect cases, peripherals, etc.
- **Component holes:** sized to accommodate component wires (~22 gauge) and always have an annular ring for soldering.
- **Vias:** smaller holes that allow the traces to carry current from one layer to another. Not for soldering!

Schematic v1.2



Matching the Schematic to the PCB

- The schematic can help identify the role of each component on the PCB
- Component identifiers on the schematic match up to those on the PCB and BOM (Bill of Materials)

  SW1 = Switch1, R1 = Resistor1, C1 = Capacitor1, etc.

- Schematic circuit is easier to follow than the traces on the PCB and is useful for diagnosing problems or determining if a substitute component can be used
- The physical pin layout on the PCB may be different from the logical pin layout on the schematic

TFT LCD Screen

Thin Film Transistor (TFT)
Liquid Crystal Display (LCD)

- Usually have a specific control chip, i.e. ILI9341
- Often include an SD card reader on the back
- May or may not have touch capability (T_ pins)
- Often use Serial Peripheral Interface (SPI) protocol for communication with the MCU
- Frame rate vs low resource utilization tradeoffs

In Kit:

- 1 – TFT LCD, 2.2” 320x240 w/integrated ILI9341 SPI controller, 3.3v, 262K colors [U2]

18650 Lithium Battery

3.7 v lithium rechargeable battery

- 18650 indicates 18mm diameter x 65mm height
- Voltage output range is 4.2v – 2.5v, which pairs nicely with 3.3v MCUs
- Capacity is measured in mAh (milliamp hours) and maximum continuous discharge in Amperes.
- These are inversely related. Generally favor capacity for MCUs.

In Kit:

- 1 – 18650 3.7v rechargeable battery

Battery Holder

Holds battery in place and provides electrical connection between battery and circuit board

Polarized – pay attention to **+** / **-**

In Kit:

- 1 – 18650 battery holder [BT1]

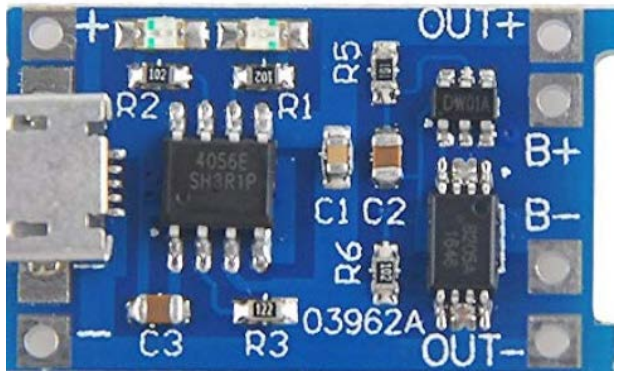
TP4056 Battery Charger

5v 1A micro USB board for recharging CR18650 batteries

- Allows you to charge the battery without having to remove it from the badge
- Optional – not required

In Kit:

- 1 – TP4056 charging module
- 2 - hookup wires (+ / -)



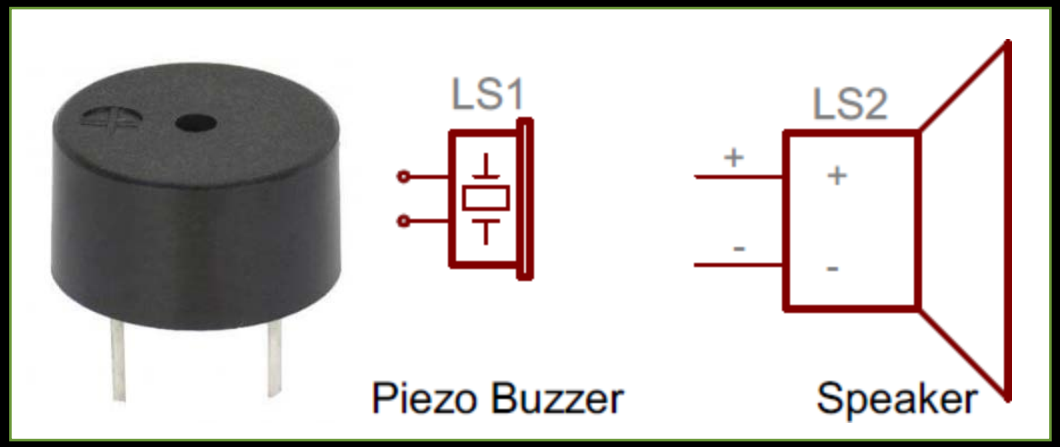
Piezo Buzzer/ Electrodynamic Speaker

Generates tones or other sounds

Two general types

- Active – generates tones based on DC voltage
- Passive – requires oscillating input to convert to sound

Polarized – positive leg marked with a (+) on top or bottom



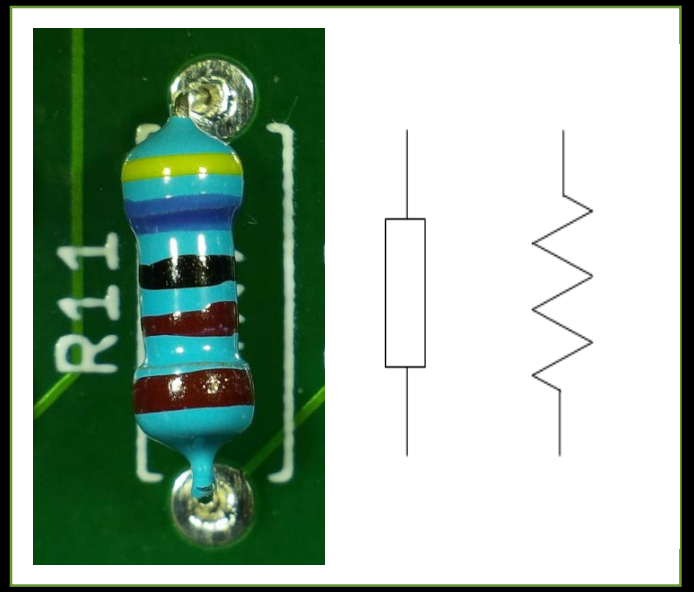
In Kit:

- 1 passive speaker (polarized) [BZ1]

Resistors

Passive device used reduce current or divide voltages

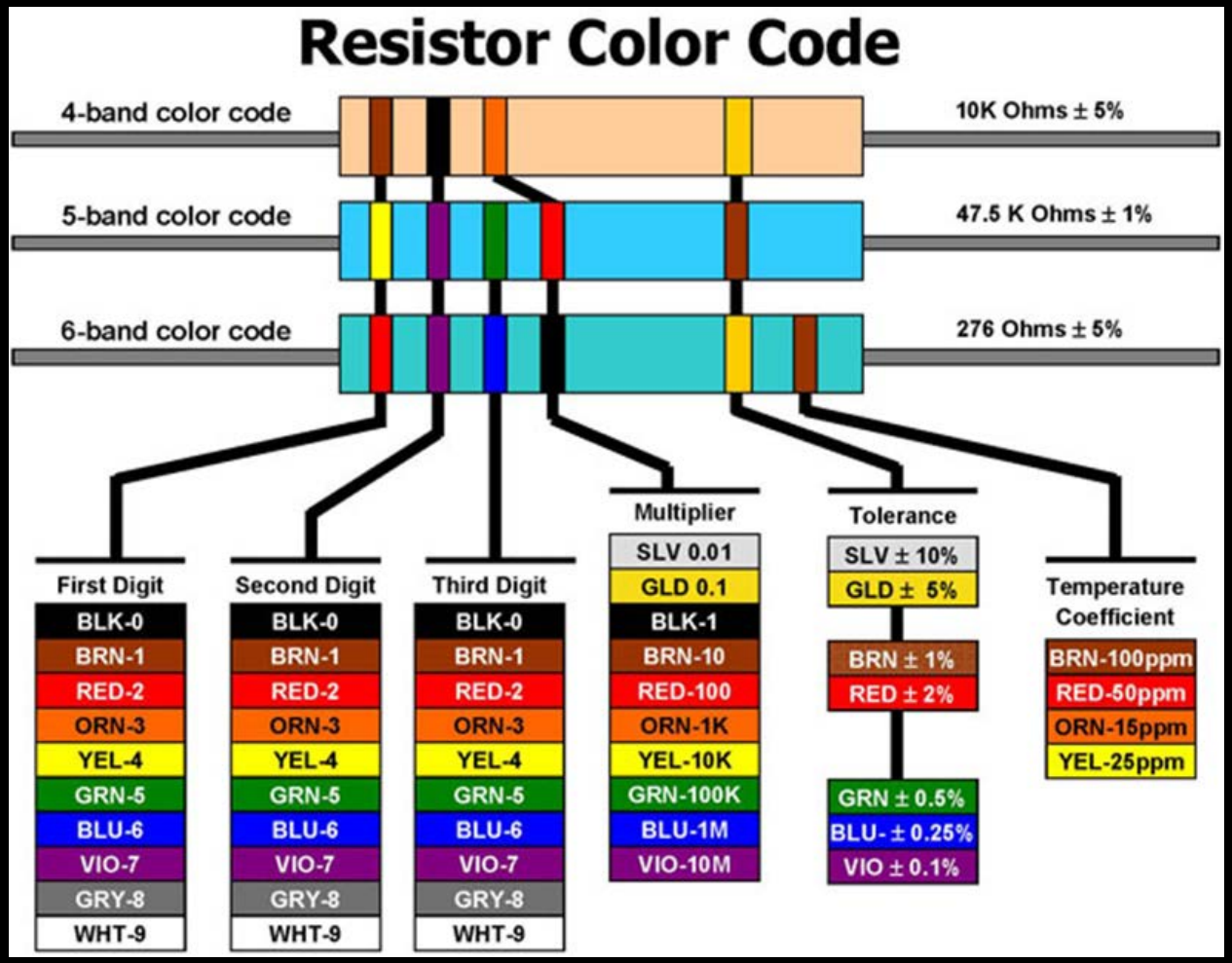
- Non-polarized (no right or wrong orientation)
- Measured in Ohms
  - 100R indicates 100 Ohms
  - 4K7 indicates 4,700 Ohms
  - 3M3 indicates 3,300,000 Ohms
- R10 – 13 can be 2k – 8k Ohm
- R1-3 can be 100 – 330 Ohm



In Kit:

- 4 – 4k7 [R10-13] Ye-Vi-Bk-Br
- 3 – 100R [R1-3] Br-Bk-Bk-Bk
- 1 – 3M3 [R5] Or-Or-Bk-Ye
- 1 – 10M [R4] Br-Bk-Bk-Gr

Breaking the Code



Many mnemonics available. One example:

Bright **B**oys **R**ave **O**ver **Y**oung **G**irls **B**ut **V**eto **G**etting **W**ed

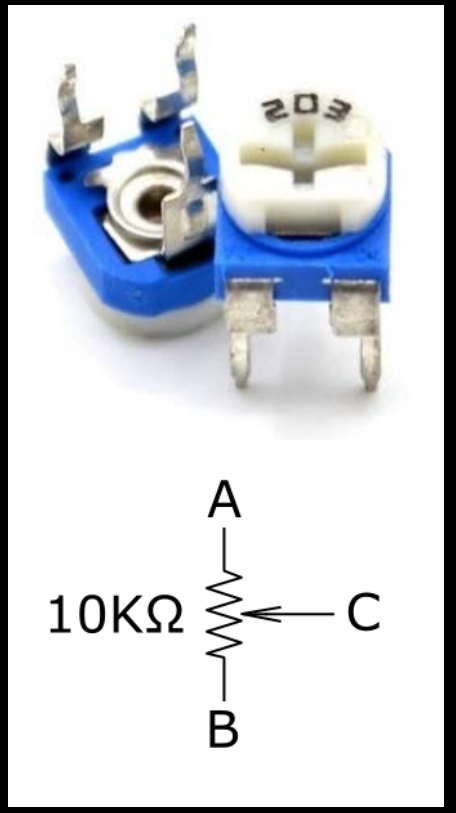
When in doubt, measure with a multimeter.

Potentiometers

Variable resistors

- Can be rotary (dial) or linear (slide)
- Middle leg is connected to the wiper (C)
- Markings indicate maximum resistance
  - First 2 digits x 10^3rd digit
  - 501 = 50 x 10^1 = 500 Ohm
  - 102 = 10 x 10^2 = 1k Ohm

For the badge, any value from 500 to 2000 Ohm will work.



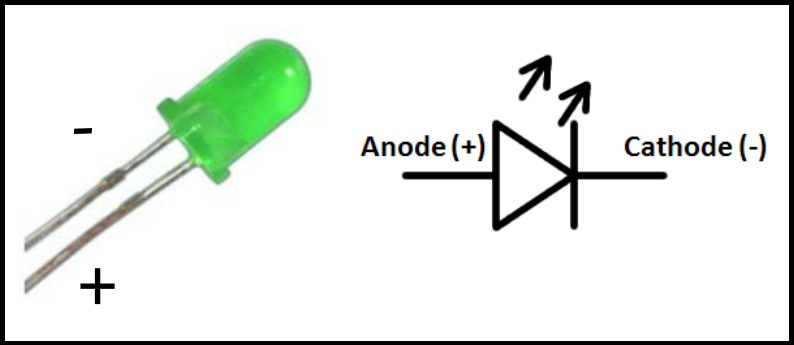
In Kit:

- 1 – 1K pot [RV1]

LEDs

Light Emitting Diodes

- Polarized - orientation is critical
  - Longer leg = positive
  - Flat side = negative (may not be present)
- Popular sizes are 3mm, 5mm, and 10mm
- Usually require a current-limiting resistor



In Kit:

- 1 – Red [D5]
- 1 – Yellow [D4]
- 1 – Green [D3]

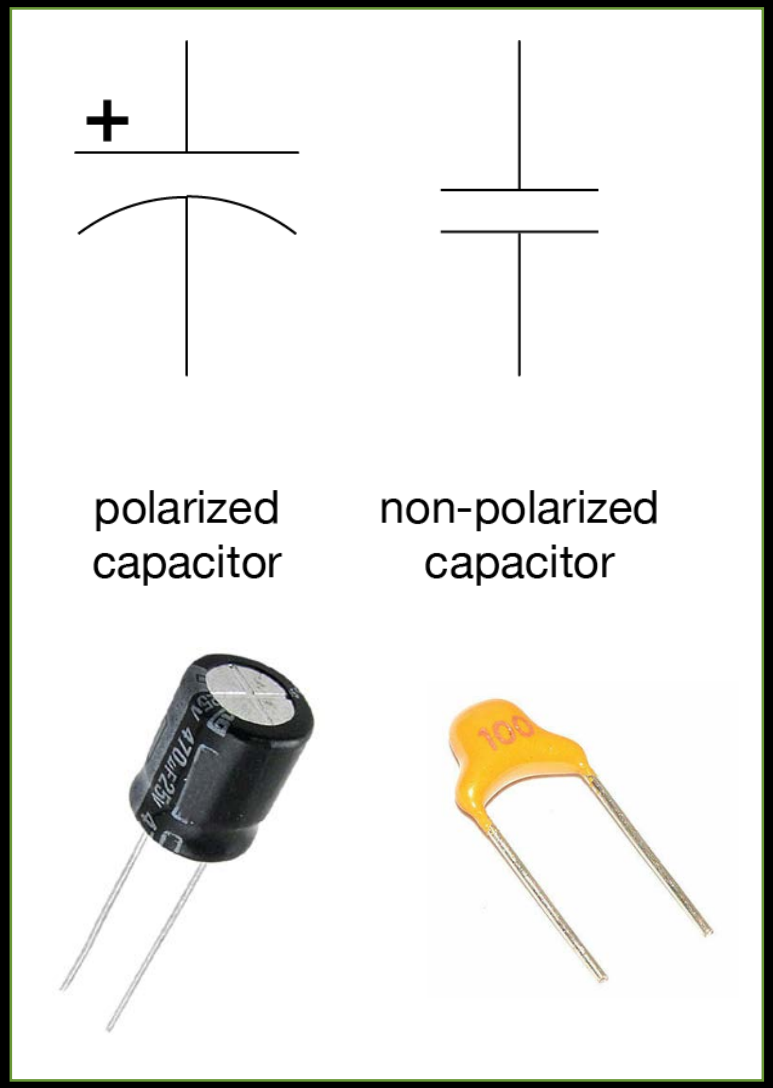
Capacitors

Passive devices that store electrical energy

- Some types are polarized, others are not
  - Ceramic = non-polarized
  - Electrolytic = polarized
- Measured in Farads
  - nF = nano Farads (1 billionth)
  - uF = micro Farads (1 millionth)

In Kit:

- 1 – 100nF / 0.1uF ceramic capacitor [C1] (usually marked with a "104")



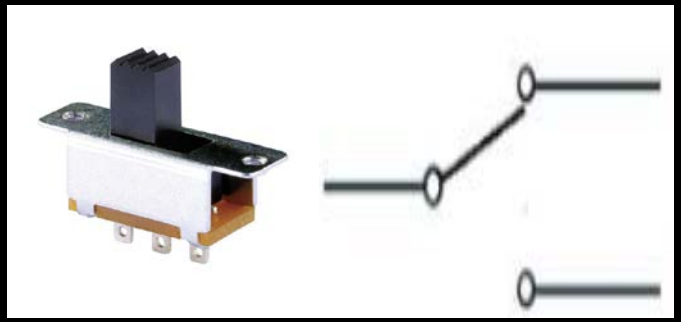
Buttons and Switches

Mechanical devices for opening and closing a circuit

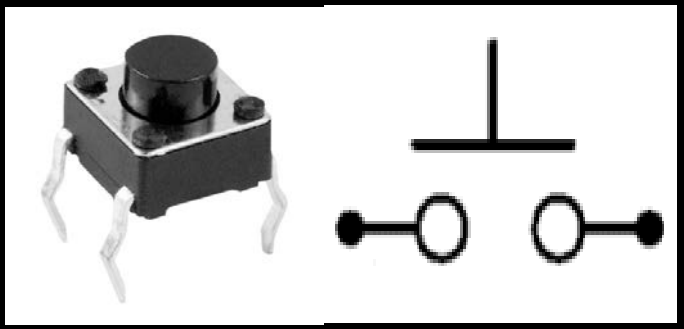
- Momentary vs. Latching
- Normally Open (NO) vs. Normally Closed (NC)
- Poles = number of circuits connected
- Throw = number of positions (on/off is single)

In Kit:

- 1 – SPDT slide switch (power) [SW1]
- 8 – momentary NO buttons [SW2 - 9]



SPDT slide switch
(Single Pole Double Throw)



Tactile momentary
NO button
(Normally Open)

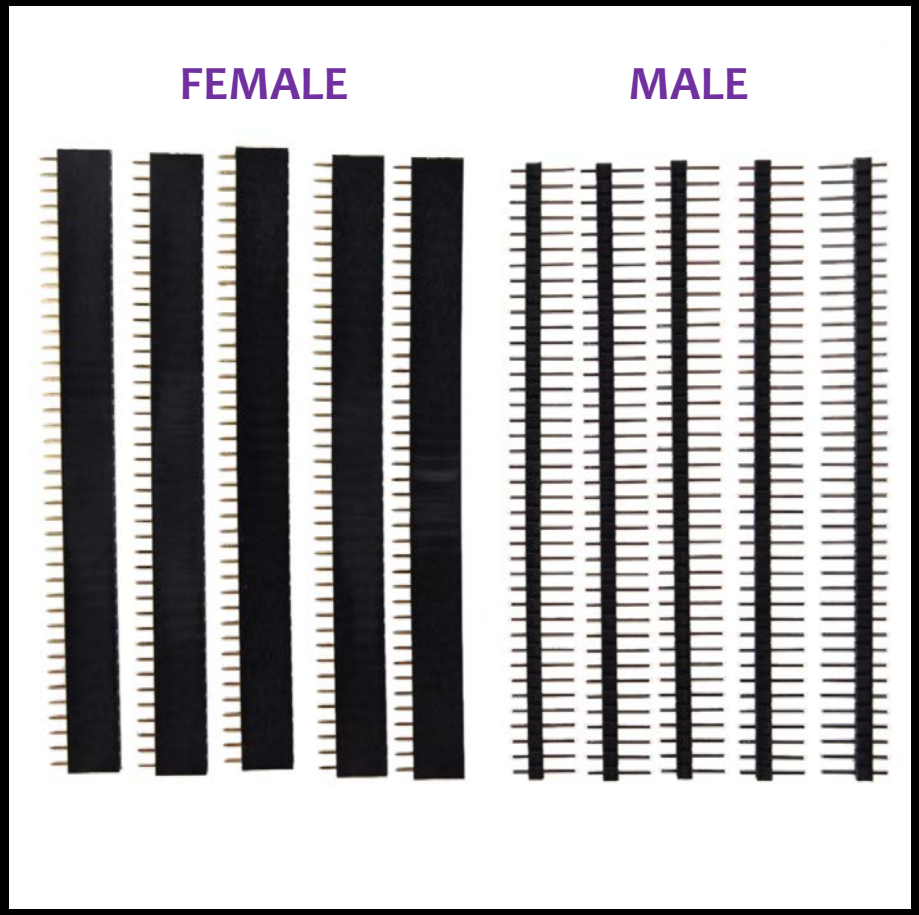
Header Pins

Connect controllers, breakout boards, major components, and jumpers

- Come in male and female varieties.
- The short end goes into the PCB

In Kit:

- Female header pins
- Male header pins



Soldering

Bringing the Heat Without Getting Burned

Soldering Iron

- Tip needs to heat up to about 700F / 370C before use.
- Keep the tip lightly tinned (shiny) but not gobbed with solder.
- Use the scouring pad to remove excess solder from the tip.

Soldering Iron

Safety

- Only pick up by the handle.
- Practice good tip control at all times - no balancing, waving, or gesturing with the iron. It's not a wand.
- Keep cords clear of obstacles.
- Don't set down on table – always use the provided stand.
- Don't hand it to another person. Let them pick it up.
- Turn the iron off/unplug before leaving your station.

Solder

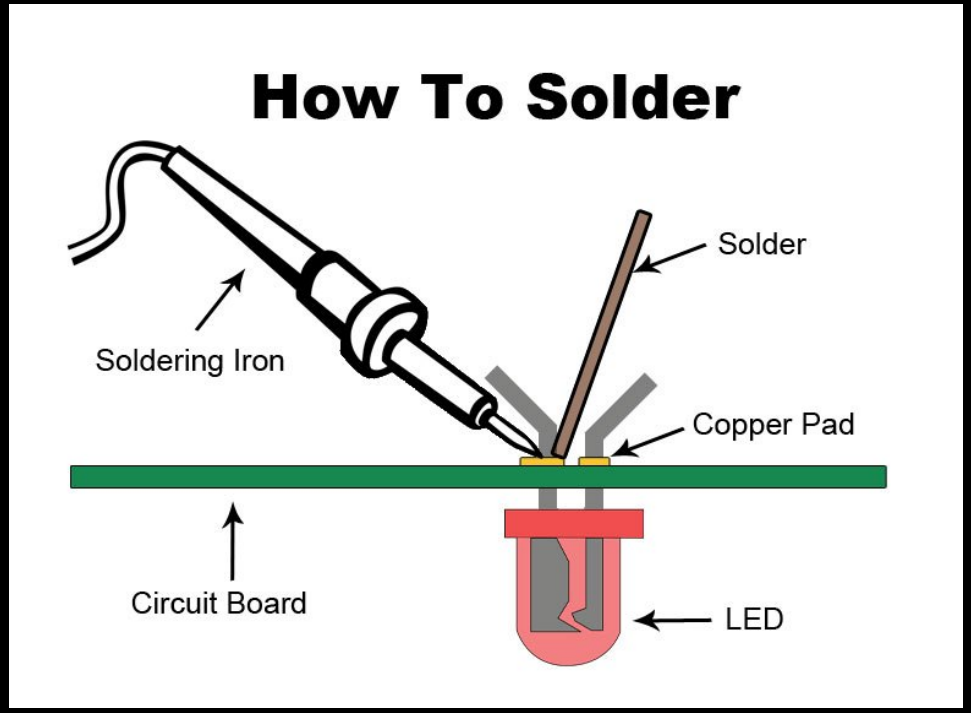
- Most common solder for hand-soldering is a mix of tin (~60%) and lead (~40%)
- Rosin core allows the melted solder to flow smoothly onto the pads and wires
- Rosin has the downside of producing smoke that is a lung irritant – avoid inhaling.
- Lead-free wire is available, but requires a higher melting temperature and is more difficult to work with.

Soldering Technique

- Heat both of the elements that you are soldering (i.e. the solder pad and the component wire) for a few seconds, then apply the solder.

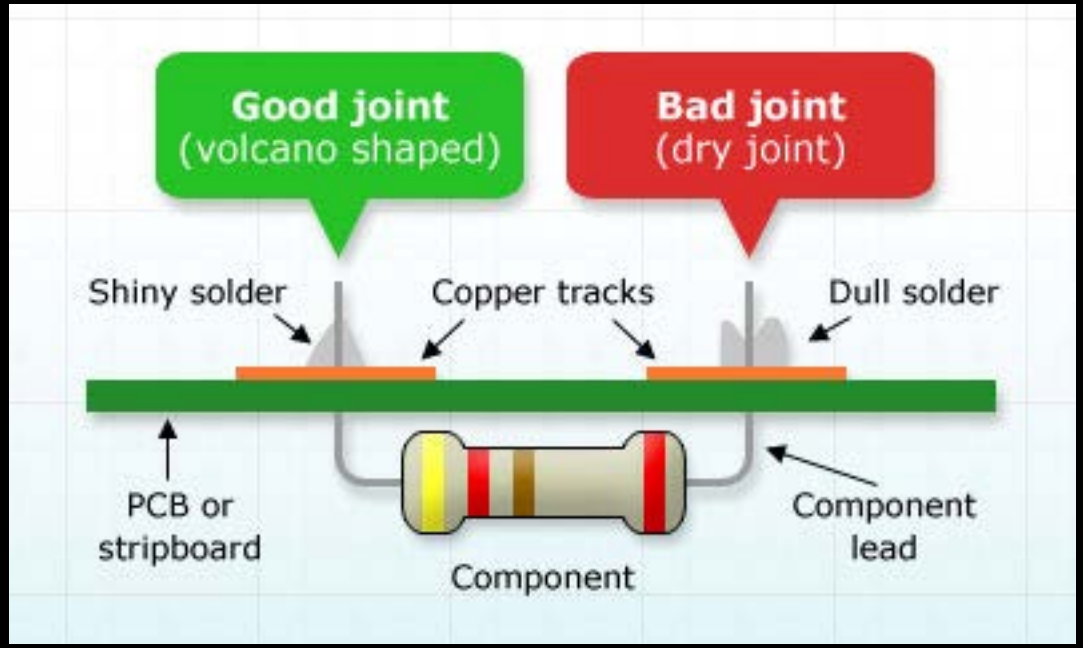
  Solder flows *towards* heat!

- Don't keep applying heat to components for more that a few seconds or you may damage them.

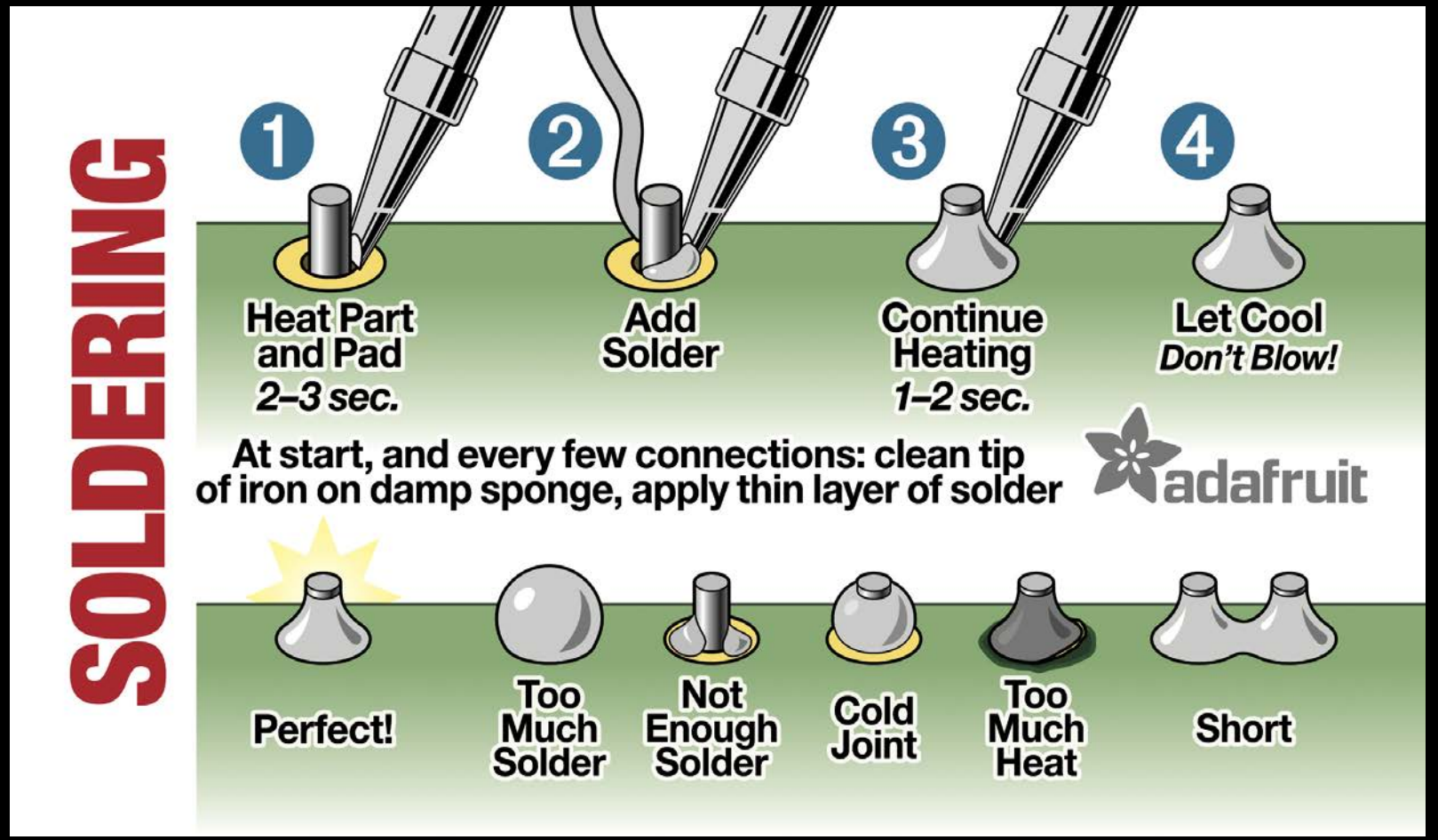


Soldering Technique

- Ensure you have a smooth, shiny, volcano-shaped join and that all the gaps are filled in.
- Watch out for solder bridges/shorts to other pads or components.



Soldering Technique



Flush Cut Pliers

Trim component lead wires after soldering

- Leads and pins often separate at high speeds and go flying, so cup them with your hand and don't point them at your eyes while using.
- Keep wire cuttings and waste in your plastic cup – not scattered around on your table.

Desoldering

Dealing With “Oops!”

Desoldering Pen (aka Solder Sucker)

Used to suck away solder when removing soldered components.

- Use the plunger to prime the pen, and the button to perform the suction operation.
- Requires a bit of precision and timing as nozzle needs to be pretty close to the liquefied solder and triggered before the solder starts to solidify.
- Often requires multiple attempts to get most of the solder.

Desoldering Braid/Wick

Used to pull away solder when removing soldered components.

- Use a section of the braid without solder on it.
- Heat the solder through the braid to get the solder to melt and flow onto the braid and then pull it away from the area.

Remember, solder flows *towards* heat.

Desoldering

1. Reheat the joint and get as much solder away from it as you can using a desoldering pump.
2. Alternatively, heat joint through a soldering wick/braid to get the solder to stick to the wick.
3. Use a pliers to gently pull the component wires from the board.
4. Reheat and remove any excess solder that is still left using solder braid.
5. Insert and solder the replacement component.

For a More Pleasant Experience…

- Take your time. This isn't a race. No points awarded for finishing first.
- Help others around you. No soldier or (solderer) gets left behind.
- Cup up = working on badge
- Cup down = done and good to go
  Please put your trimmings/waste in the garbage can first!

Assembling the Board

Putting It All Together

General Assembly Guidelines

- Keep parts segregated to avoid confusion (especially resistors)
- Start with the smaller/shorter passive components and work towards the larger ones
- Bend resistor leads to a 90 degree angle as close to the body as possible
- If you're not sure about a resistor's value, use a multimeter to test it.
- Pay close attention to polarity! (LEDs, speaker, battery)
- Even though orientation doesn't matter for non-polarized components (like resistors) it's easier to identify them on the board if you orient them consistently.
- Check twice, solder once – always on the back of the board. Desoldering is a bit of a pain.
- Don't trim leads until after you've soldered and inspected them
- Use magnification to check for breaks, shorts, solder bridges, splashes, etc.

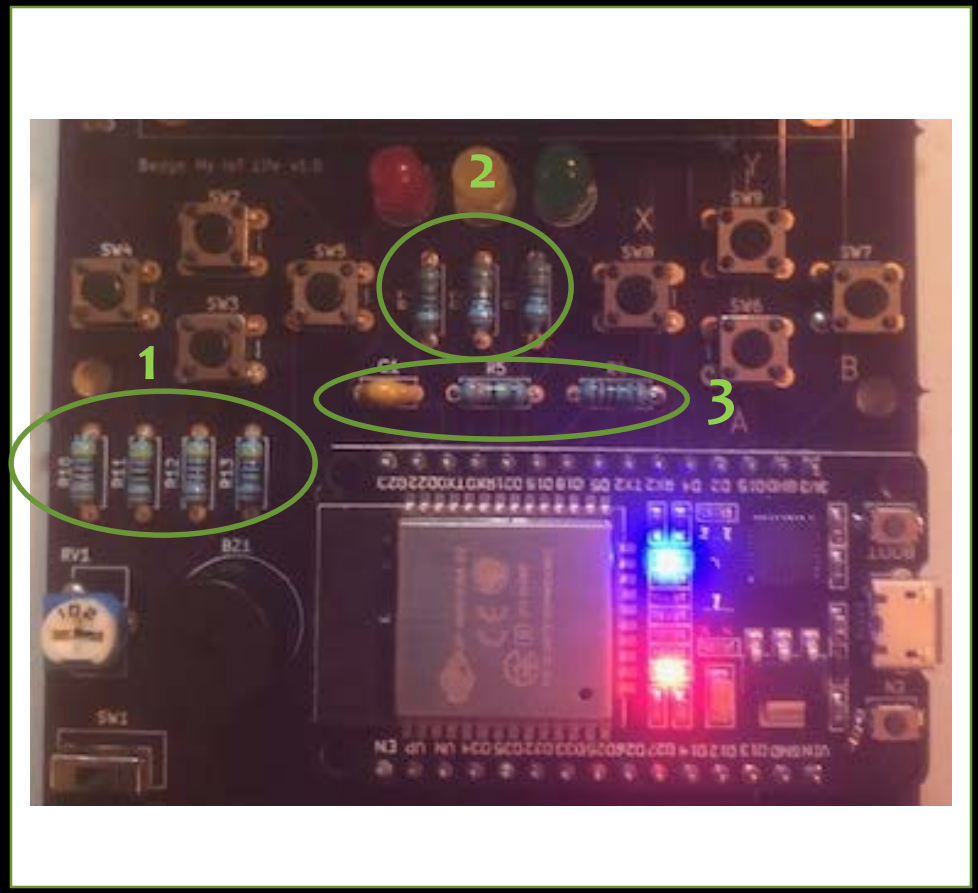
Detailed Assembly Instructions - 1

1. Identify the (4) 4.7K Ohm button pull-up resistors (yellow, violet, black, brown) . Place them in the board, bend the ends out slightly, and solder in place.

2. Next the (3) 100 Ohm current-limiting resistors (brown, black, black, black) for the LEDs

3. Then the 3M3 (orange, orange, black, yellow) and 10M resistors (brown, black, black, green) and the .1 uF ceramic capacitor for the battery level voltage divider

4. Solder, inspect, and trim leads.



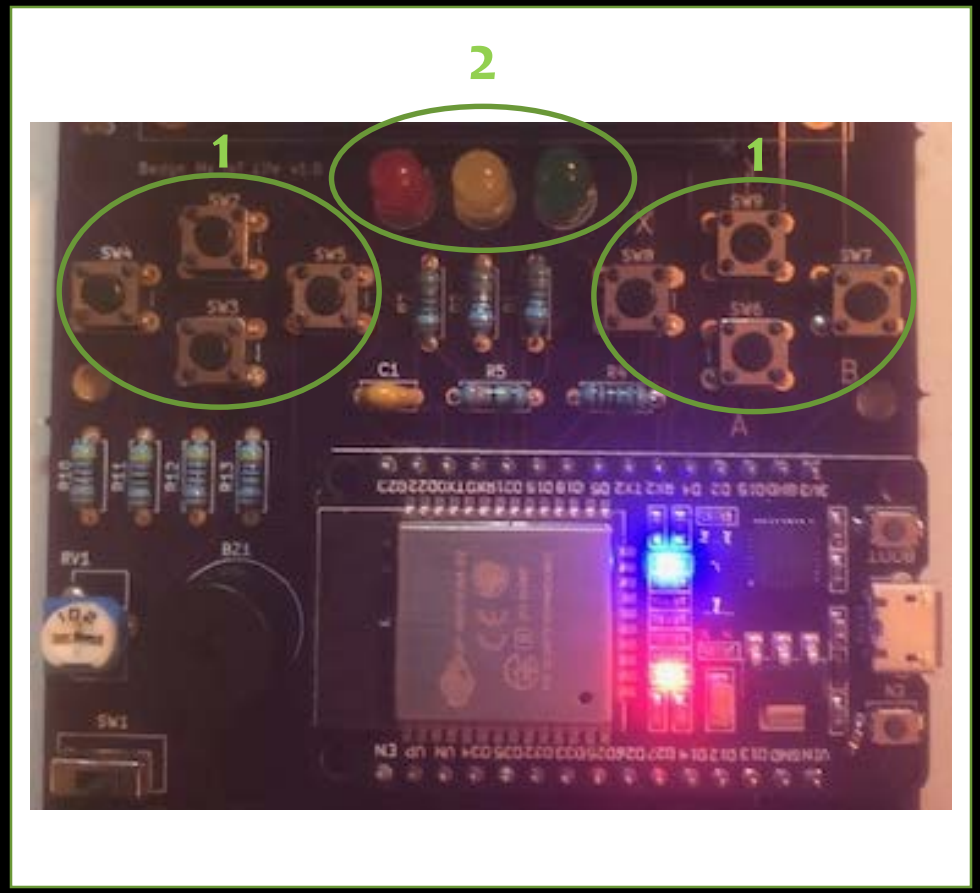
Detailed Assembly Instructions - 2

5. Place the 4 direction and 4 action buttons. The buttons will only fit with the legs oriented left/right.

6. Insert the 3 LEDs as shown. Make sure the longer leg goes to the hole on the right (marked +)

   LEDs can be destroyed by too much heat, so don't keep the soldering iron touching the led leads for more than a few seconds at a time.

7. Solder, inspect, and trim leads.

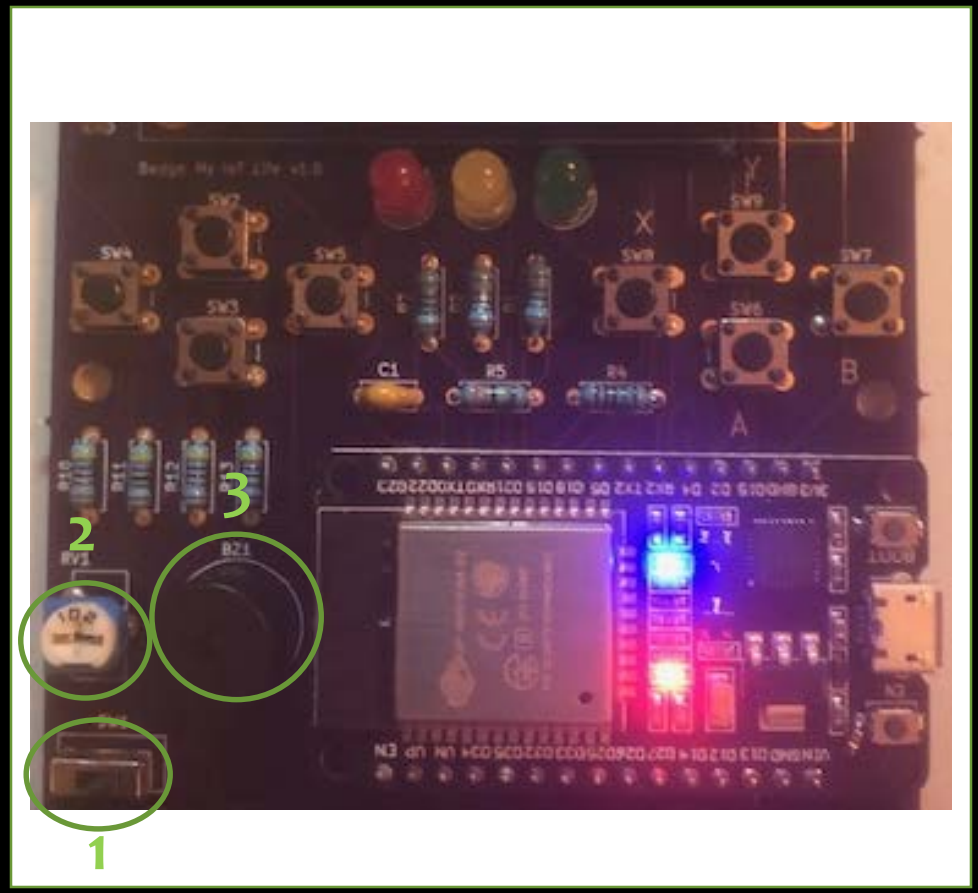


Detailed Assembly Instructions - 3

8. Add the on/off SPDT switch. Don't worry about polarity.
9. Insert the 1k Ohm trim pot (102)
10. Add the speaker. Pay attention to the polarity (+ lead to + hole)

    You may want to cover the speaker hole with a piece of cellophane tape to increase volume.

11. Solder, inspect, and trim leads.



Detailed Assembly Instructions - 4

12. Insert one row of pins on the ESP32 into the female header pins as shown. Trim to header to proper length (19 pins for v1.2)
13. Repeat for other row of pins on the ESP32.
14. With the female header pins attached to the ESP32, insert them into the board with the USB port to the right. Painter's tape is useful to hold the ESP32 in place as you solder the header pins.

Detailed Assembly Instructions – 5

15. Cut male and female header pins for the TFT display.

16. Insert the male pins into the female pins, then place the TFT over the short ends of the male pins and solder them to the TFT.

    It will help to have the ends of the female pins inserted into the board as you solder the TFT.

17. Flip the board over and solder the female pins to the board. Painter's tape may help to hold everything in place.

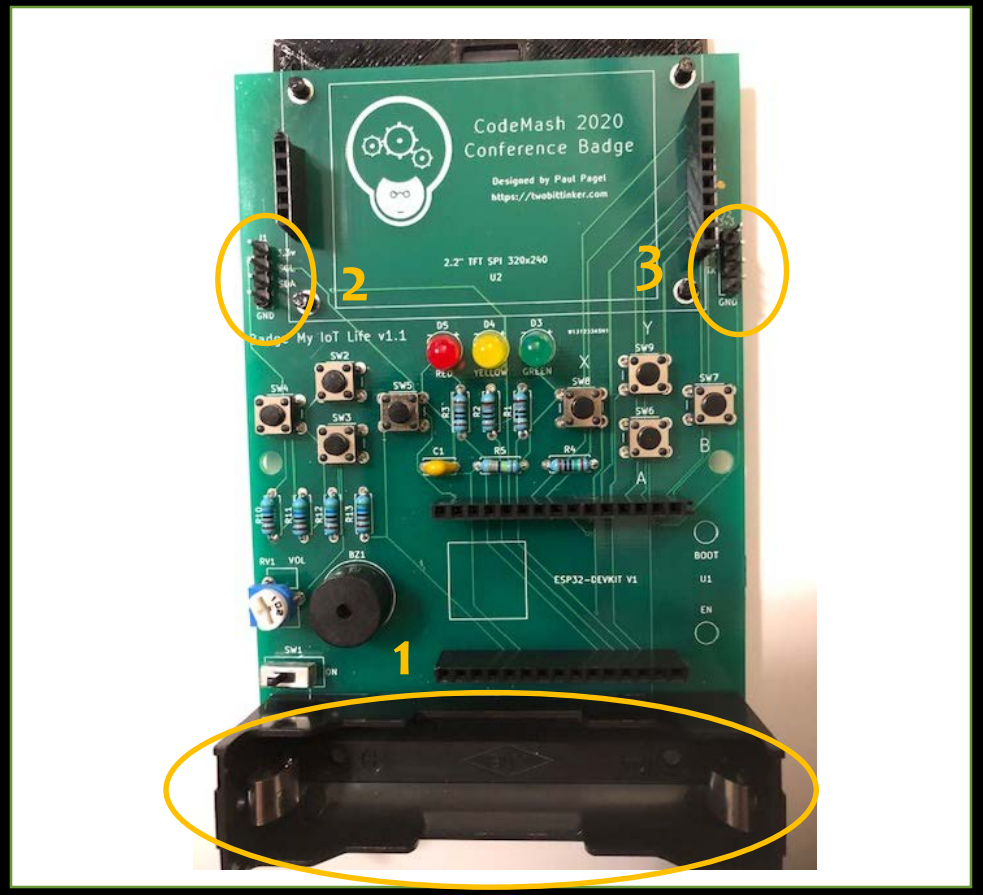
Detailed Assembly Instructions - 6

18. Solder the battery holder to the board. Mind the polarity (+ to the left) Suggest marking polarity with metallic marker.

    Go fairly heavy with the solder as this part will be subject to mechanical stress.

19. Take a 4 pin male header for the I2C bus and solder to the left of the TFT.

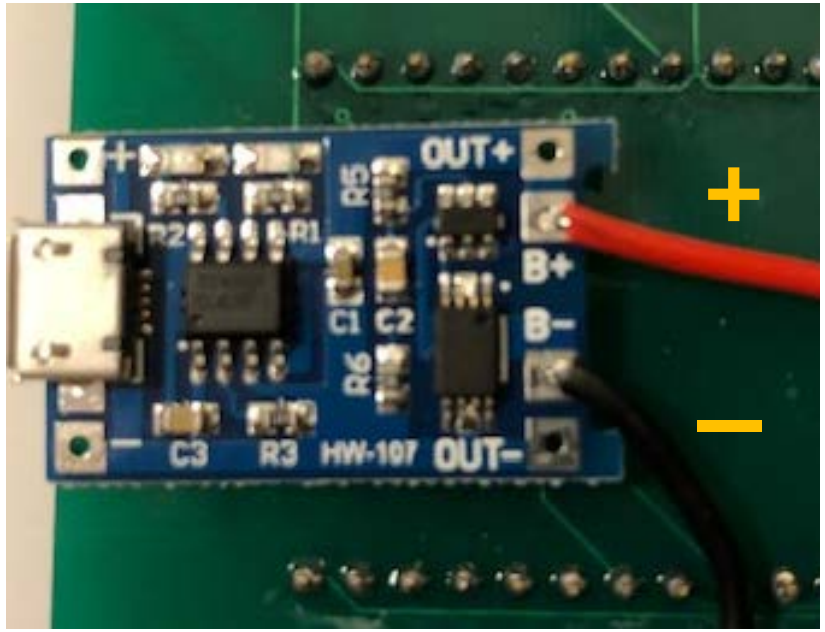
20. Take another 4 pin male header for for the RX/TX header on the right and solder in place.



Detailed Assembly Instructions - 7

OPTIONAL – Battery Charger

21. Solder the positive lead wire to the B+ pad on the TP4056 module, and the negative lead to the B- pad.
22. Stick the TP4056 to the back of the badge using double-sided tape.
23. Solder the wires to the corresponding battery holder terminal. Note that positive is on the right when looking at the back.



Final Check

Before energizing your badge, double-check:

- ESP32 orientation (USB port to outside of board)
- Battery holder and charger polarity are correct and clearly marked
- All wires and pins have been soldered
- No solder bridges are present

Have one of the session assistants or an experienced neighbor perform a final check on your board.

Testing

Keep Your Fingers Crossed

Booting the Assembled Board

1. Hook up the ESP32 controller to your laptop or 5v / 1A DC power source using the Micro USB cable.
2. The badge test app should boot up after a few seconds.
3. If not, try pressing and releasing the EN button below the micro USB port.

Testing the Assembled Board

1. Network count will be 0 initially. Battery level should be around 800 or higher and stable. Zero or a wildly fluctuating value indicates a problem.
2. Press all the buttons and verify that the corresponding element is highlighted on the screen while the button is pressed.
3. The following buttons have additional actions that should be triggered:
   - X: Red LED
   - Y: Yellow LED
   - A: Green LED
   - B: Tone should play through the speaker
4. You may need to adjust the trimpot to get the desired volume. Counterclockwise = Louder (Be gentle – don't force it!)

Louder

Softer

Testing Battery Operation

1. Disconnect the USB cord from the ESP32.
2. Ensure the power switch is in the “Off” position (all the way to the left)
3. Place the loop of ribbon across the battery holder perpendicularly. (Not required if you have exceptionally strong fingers or enjoy the challenge of battery extraction.)
4. Take a charged CR18650 battery and insert it with the positive end pointed towards the left side of the board and firmly seat in place.
5. Move the switch to the “On” position.
6. Repeat the previous button test.
7. Verify that the battery level indicator is lower than what was shown in the previous test. Usually it will be under 1000.

Troubleshooting – Dead Board

If you get no response from the badge at all:

- Remove the ESP32 from the badge and see if the power light comes on when hooked up to your laptop via the USB cable
- Ensure you have the ESP32 oriented on the board correctly with the USB port to the right
- Swap your ESP32 with a different one
- Swap out your TFT display
- Swap out your USB cable
- Connect the USB to a 5v 1A transformer (i.e. iPhone charger) instead of your laptop

Change only 1 element/test parameter at a time.

Troubleshooting Components

If the badge works, but one or more particular components are non-functional:

- Re-examine the solder joints, looking for shorts/solder bridges (preferably under magnification)
- Scrub the back of the board lightly with a brush to remove an fine solder splashes/shorts.
- Ensure you have the polarity correct (battery, LEDs)
- Re-heat/re-flow the solder for the non-functional component
- Verify the component using a multimeter
- Look for discolorations that indicate an LED is burned out
- Test LEDs using a regulated power source.
- Swap out the component with a verified operational one

Use the schematic to help identify the components that may be involved in the failure!

Charging Your Battery

1. Connect a micro USB cable to the charger and a 5v DC power source.
2. LED on the charger will show red when charging.
3. The blue LED will come on when the battery is fully-charged.

The charger has built-in overcharge protection, but should *not* be used to drive loads while charging (which would negate this feature).

Charging

Charged

Finishing Touches

- Snap in the black plastic badge hanger to the top 4 holes on the back of the badge.
- Clean up your area and put your trimmings/waste in the garbage.

Interface Protocols

A Small Byte of Serial

Common Interface Protocols

Standardized methods and wire layouts for communicating with other systems, peripherals, and sensor breakouts

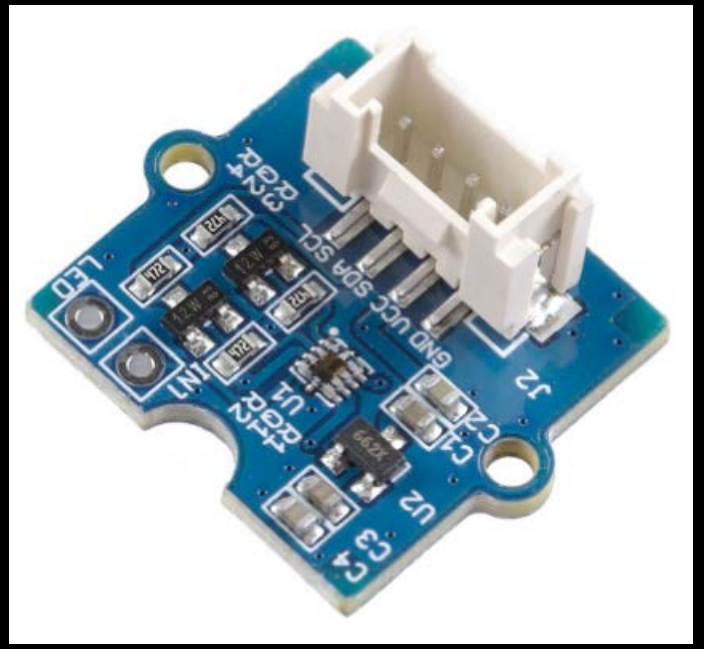
Common examples:

- UART
- SPI
- I2C
- I2S
- CAN
- USB
- USART
- 1-Wire

Common Interface Protocols

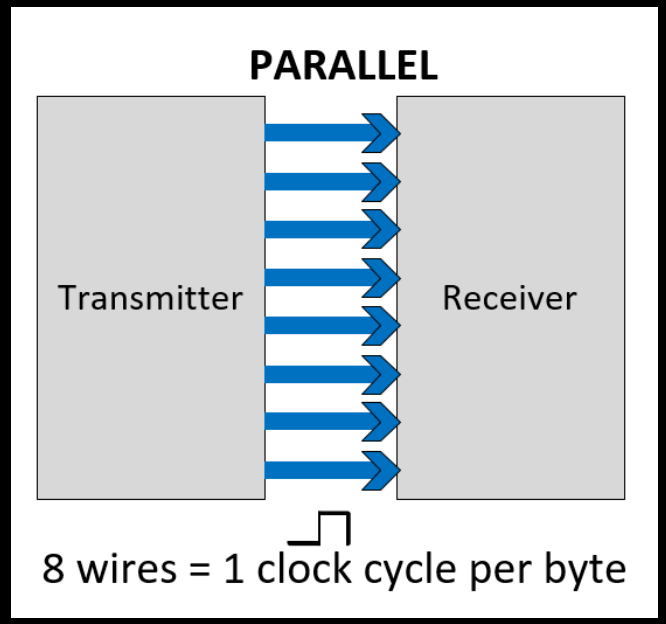
Do not confuse connector standards with the underlying protocols.

- Grove
- Qwiic
- Gravity
- MikroBUS
- JST

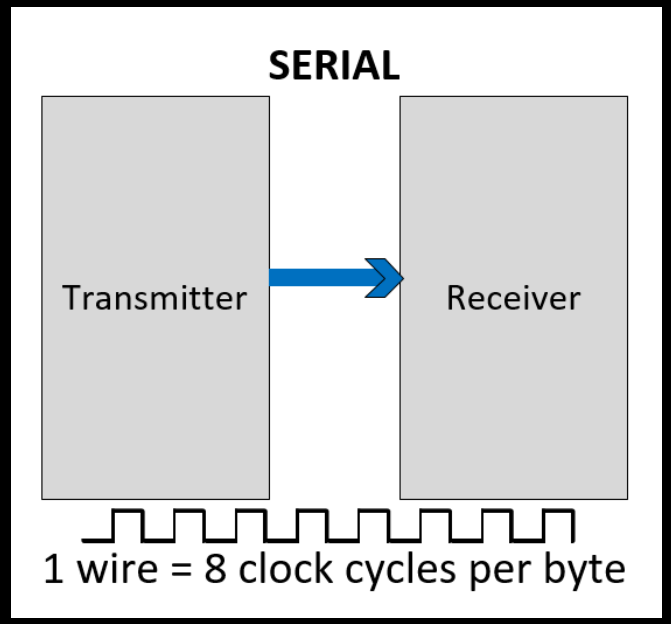


Parallel vs Serial

Parallel requires a pin/wire for every bit

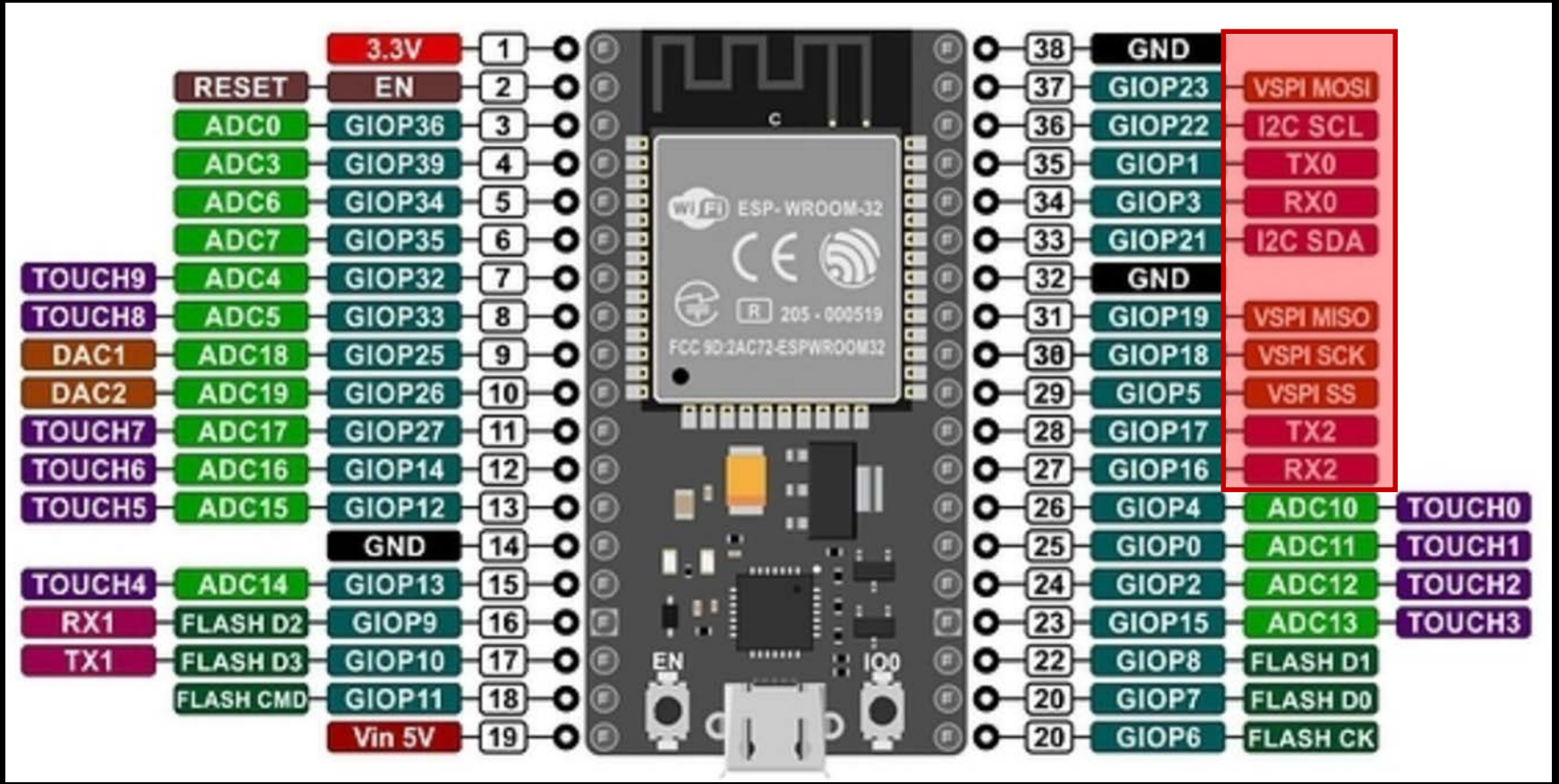


Serial sends data for a channel over the same pin/wire



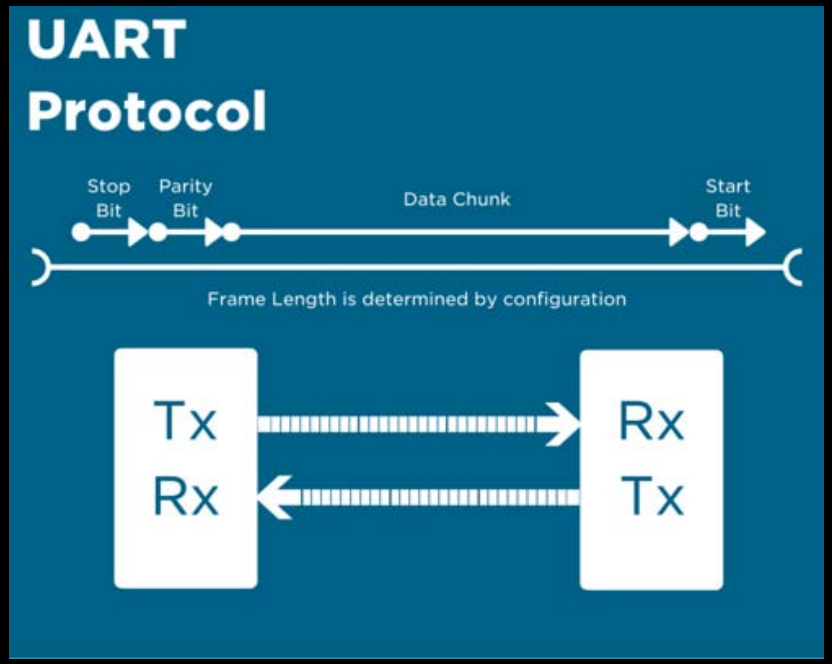
Serial protocols tend to be much more common with microcontrollers.

Serial Protocol Hardware Pins



Universal Asynchronous Receive Transmit (UART)

- Takes bytes and serially shifts them to the receiver, which then assembles them back into bytes.
- May be simplex (one direction only), half-duplex (one direction at a time), or full-duplex (both directions at the same time)
- Most microcontrollers use full-duplex with separate RX/TX lines
- Must configure both sender and receiver with the correct baud rate.
- May also have options for different data bits, bit parity, stop bits, and handshakes.



https://core-electronics.com.au/tutorials/serial-communications-arduino-uno.html

UART – Usage Considerations

- Ubiquitous and easy to use
- Often used for debugging and simple data transmissions between devices
- Other common peripherals include RFID readers, fingerprint scanners, MIDI ports, and BLE adapters.
- Serial UART output can be monitored with a number of standard tools: Arduino Serial Monitor, VS Code terminal, TeraTerm, etc.
- USB to TTL (Transistor Transistor Logic) level UART cables used to program and debug many microcontrollers.

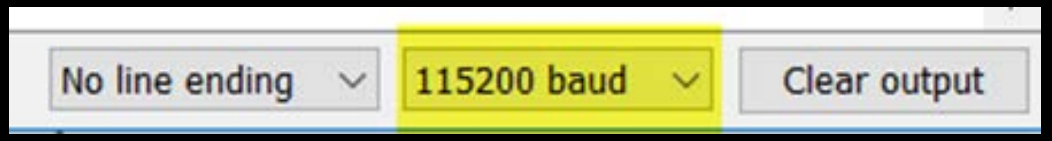
UART on ESP32

- ESP32 devkit board has 2 UART peripherals broken out (UART 0, UART 2)
- In Arduino environment, initialized with:

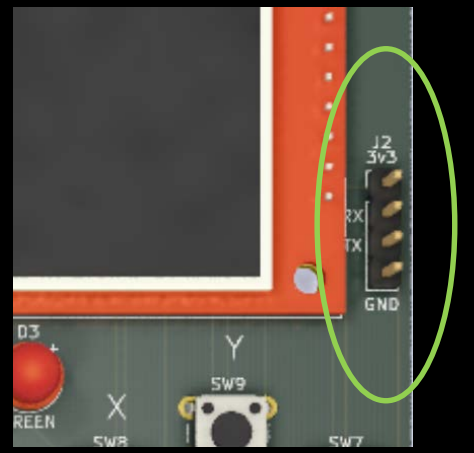
```
Serial.begin(baud_rate);
Serial2.begin(baud_rate);
```

- Unmatched baud rates = garbage data received

  Pay attention to your serial console/monitor settings:



- On the badge, Serial is accessed through USB and Serial2 via jumper to the right of the TFT

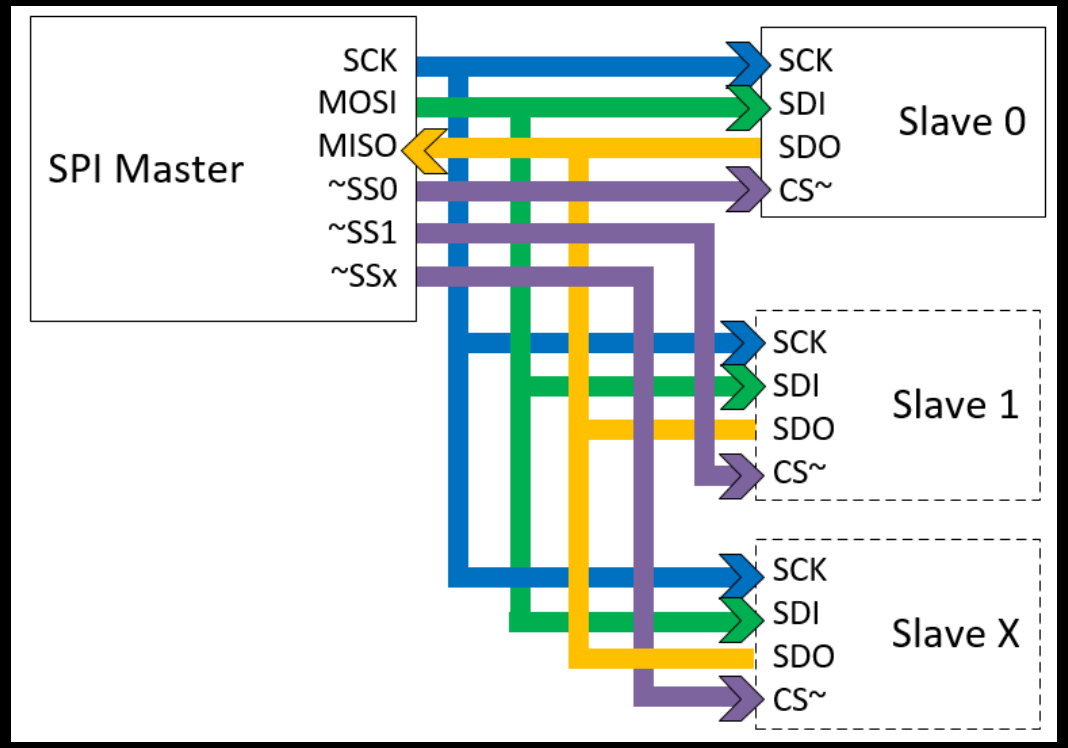


Serial Peripheral Interface (SPI)

SPI Pins:

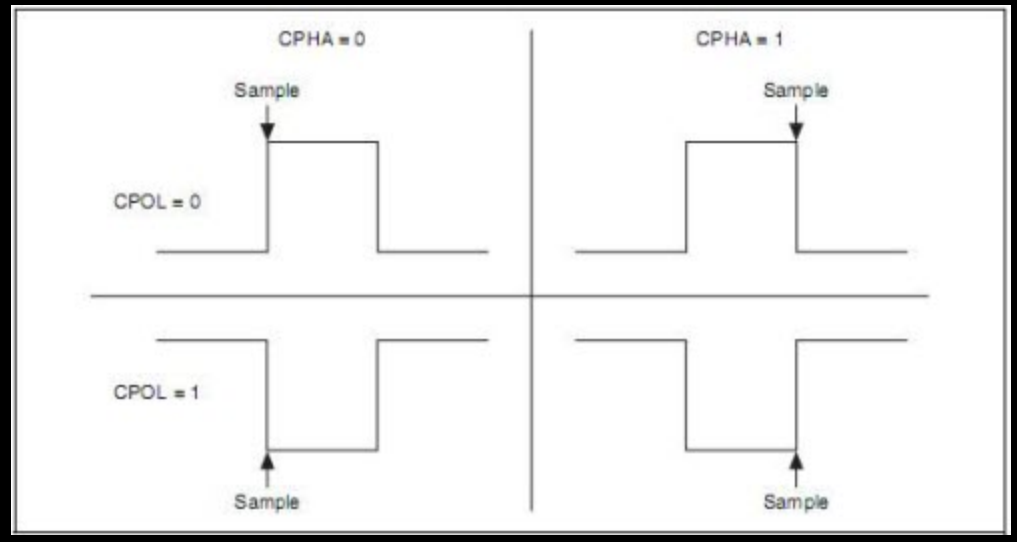
- SCK: Serial Clock (hi/low pulse)
- MOSI: Master Out Slave In
  SDI = Slave Data In
- MISO: Master In, Slave Out
  SDO = Slave Data Out
- SS: Slave Select or CS=Chip Select
  ~, n, or bar indicates active low
- Vcc and GND are always assumed
- May have an INT (interrupt) pin

SPI devices can share the same GPIO pins - except for SS



SPI - Usage Considerations

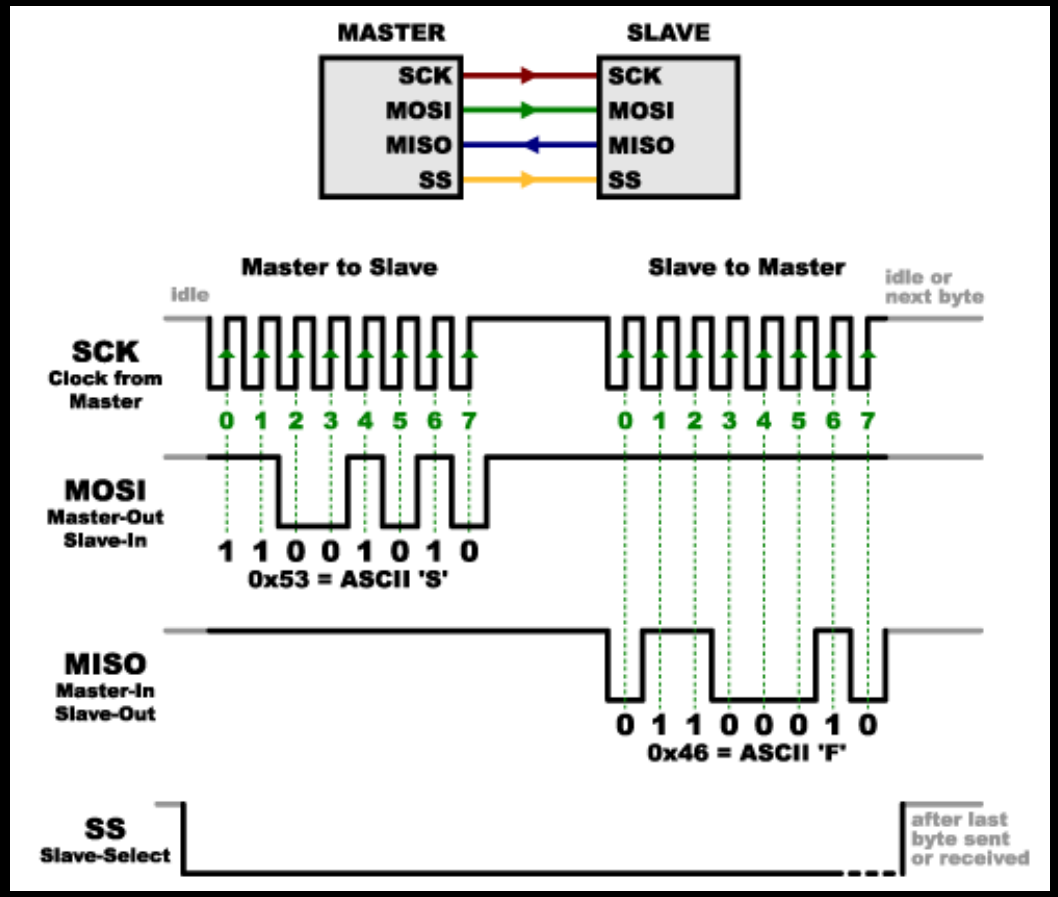
- Commonly used for displays (TFT, OLED, e-Ink, etc.), storage/SD, lower-end audio applications
- Is full-duplex, so can send and receive data at the same time
- Is synchronous and can use a range of clock frequencies
- Comes in 4 different “flavors” depending on clock phase and polarity



SPI on ESP32

Arduino environment uses SPI.h library

- ESP32 has 4 SPI peripherals
  - SPI0 & SPI1 used internally
  - SPI2 = HSPI, SPI3=VSPI
- Badge uses VSPI
- SS can be any digital GPIO pin
- Most common devices have existing libraries that take the SPI pin assignments as a constructor



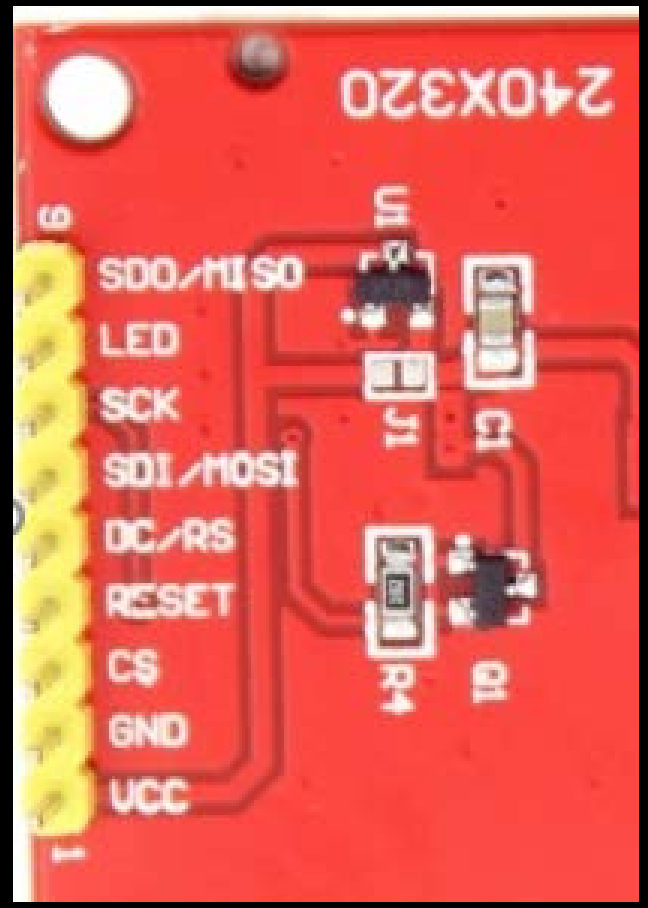
https://learn.sparkfun.com/tutorials/serial-peripheral-interface-spi/

SPI on Screen

The ILI9341 display adds a couple extra pins to the SPI interface:

- **LED:** power/brightness for the screen backlight LED
- **DC/RS:** Data Command/Register Select – tells the TFT the nature of the bits coming across MOSI wire
  Low = Command
  High = Data / Command Parameter
- **Reset:** Resets the display when low

There are also SPI pins for the SD card (SD_xx) and optional SRAM chip (F_CS)

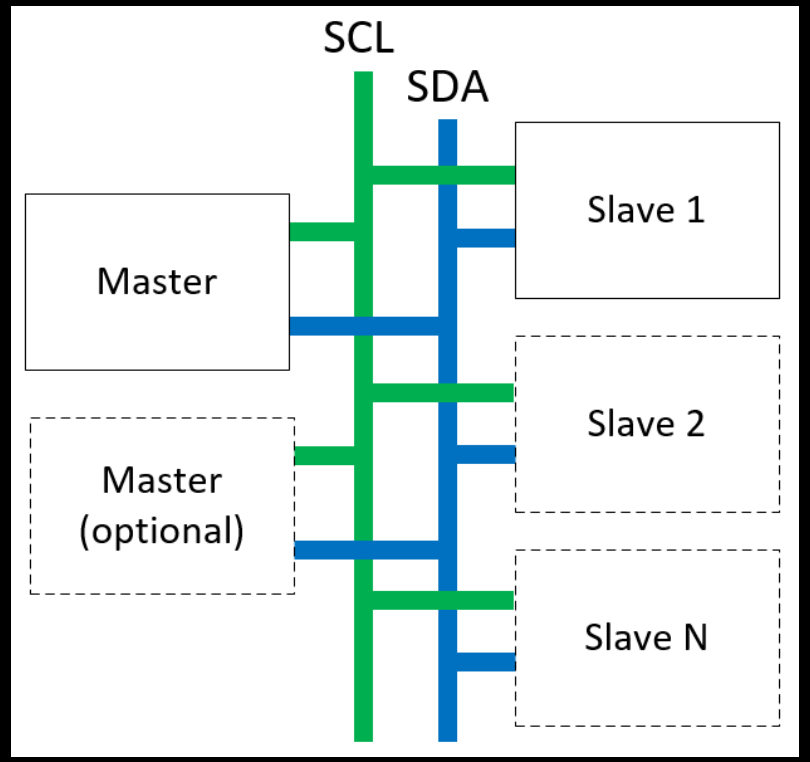


http://www.lcdwiki.com/2.2inch_SPI_Module_ILI9341_SKU:MSP2202

Inter Integrated Circuits (I2C)

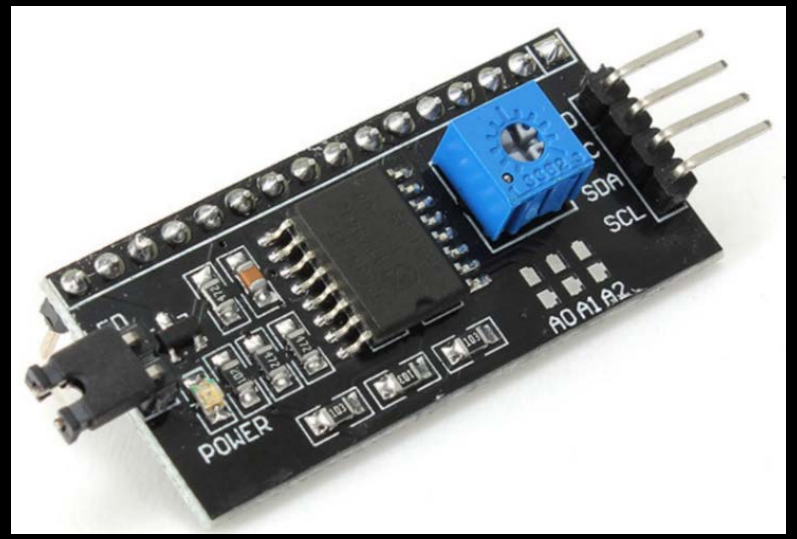
Half-duplex "two-wire" serial protocol

- Master always initiates communication
- Pins
  - SCL = Serial CLock
  - SDA = Serial DAta
- Multiple devices (100+) can exist on the same I2C bus without any additional pins
- Each slave device must have a unique 7-bit address



I2C – Usage Considerations

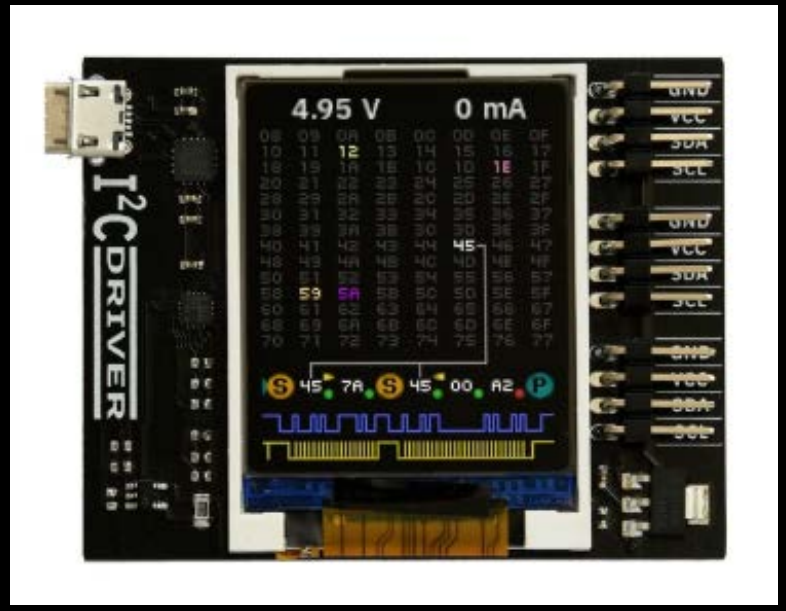
- Good for pin-constrained situations (only uses 2 wires) or when you need to control a lot of devices
- Easy to add digital IO expander and ADC chips
- Supports multiple masters with arbitration
- Often used for audio/video/camera control interfaces, but not for the data itself
- A bit more complicated under the hood than SPI

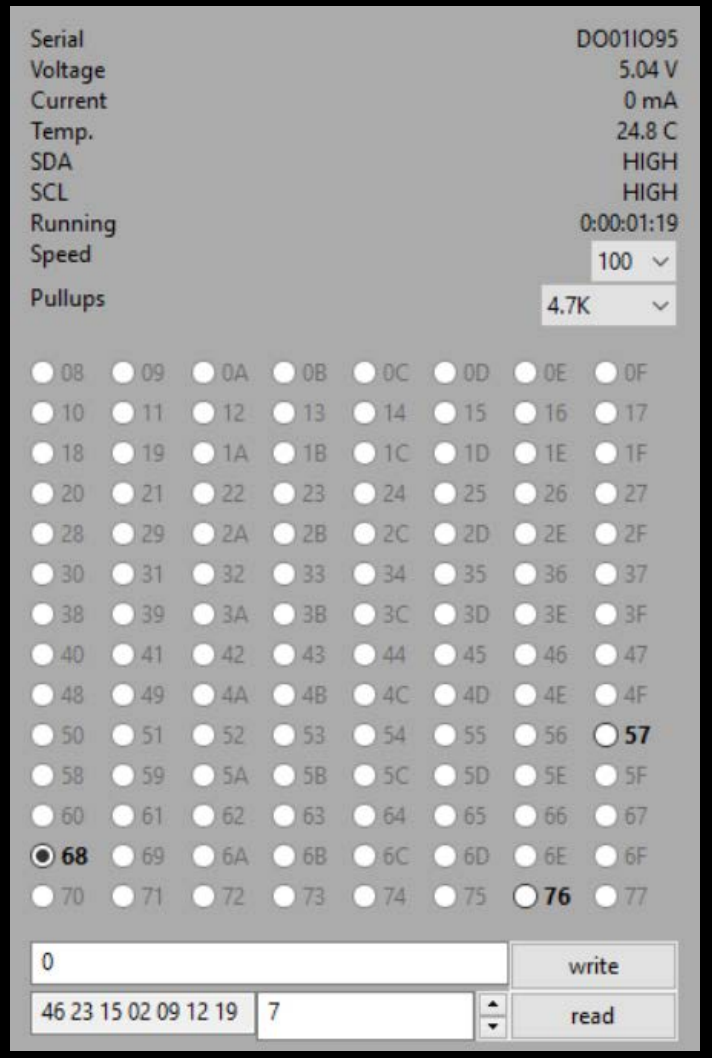


I2C Driver

Open source hardware tool for controlling I2C devices

- Includes a TFT display of current status/activity
- GUI running on your computer is used to select addresses and read/write data





I2C – Badge Implementation

Arduino environment uses the Wire.h library for I2C

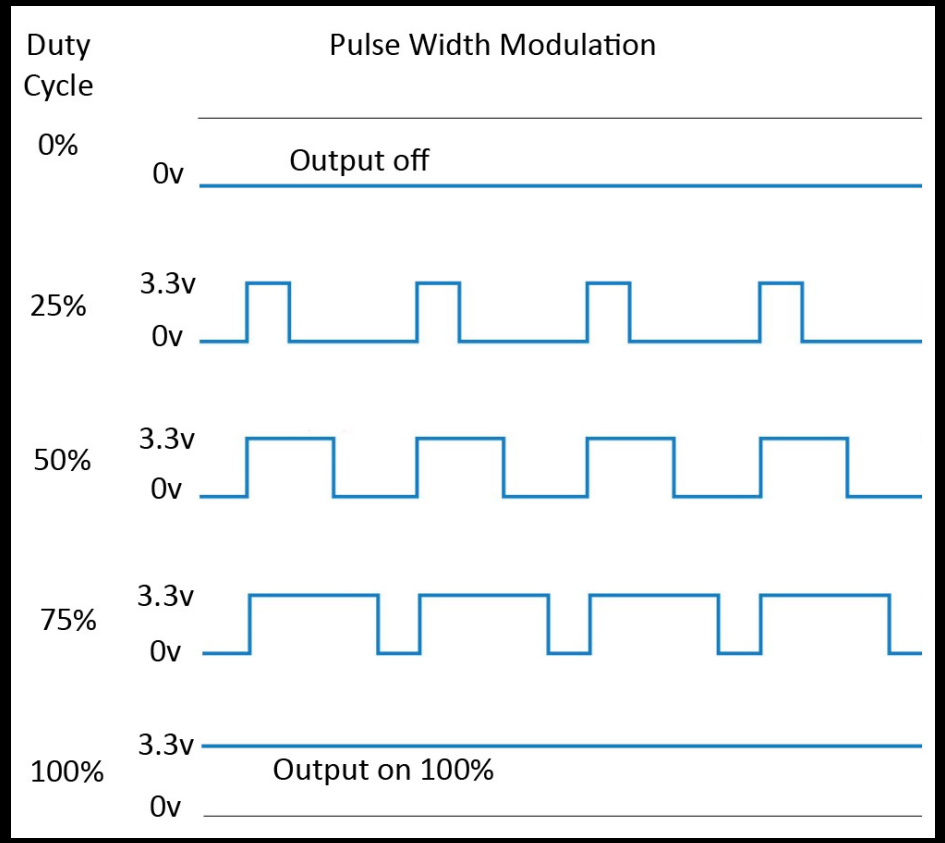
- Normal high-level process:

```
Wire.begin();
Wire.beginTransmission(I2C_ADDRESS);
... read and write data to/from different registers...
Wire.endTransmission();
```

- Refer to the device datasheet for the registers and commands to read/write.
- On the badge, the I2C jumper pins are to the left of the TFT

Pulse Width Modulation (PWM)

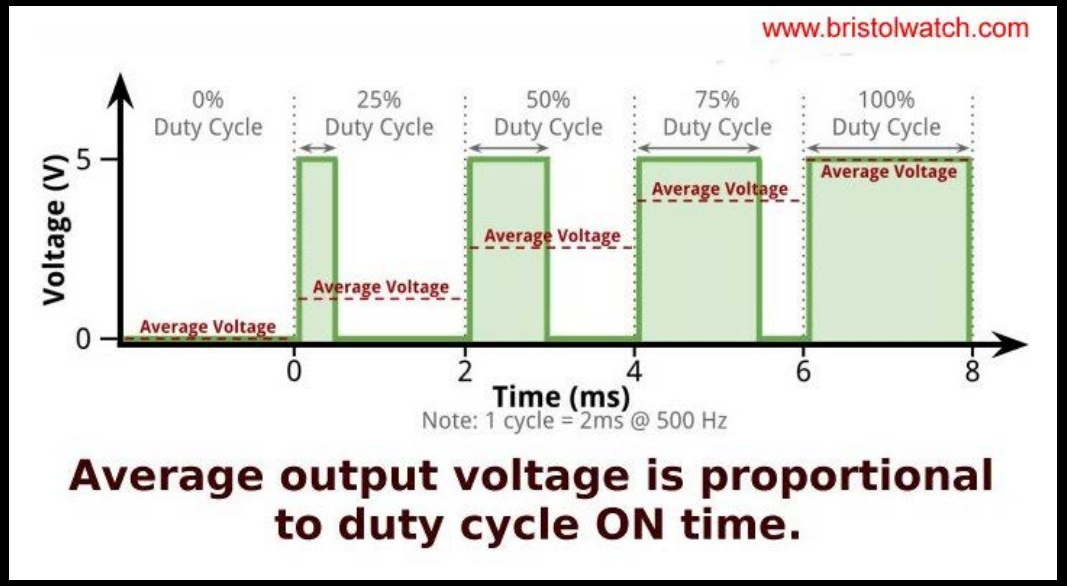
- Technique used to encode a value on a digital pin based on the percentage of time the value is high vs. low.
- The percentage of high vs. low is known as the duty cycle
- PWM is commonly used to dim LEDs, control servos, or drive an audio signal.
- Different applications require different frequencies (how often the voltage changes)
  - LED dimming: 100 - 500 Hz (cycles/second)
  - Motor driver: 200 – 5,000 Hz
  - Audio: 44 KHz+



Pulse Width Modulation (PWM)

ESP32 uses the LEDC (LED Control) library

- https://github.com/espressif/arduino-esp32/blob/master/cores/esp32/esp32-hal-ledc.h
- Set up an LEDC channel with a frequency and a timer
- Attach the channel to one or more output pins for the PWM signal
- Write the duty cycle to the channel



See the Badge Marquee sketch for an example of using PWM to dim LEDs

Next Steps

Where do we go from here?

Finishing Touches

- Take a picture of your completed badge for posterity (selfies will come in the next session when we load and customize the other badge apps) #codemash2020.
- Prepare for the afternoon session:
  - Ensure Arduino IDE or VS Code w/PlatformIO is installed on you laptop
  - Make sure you have some image and audio editing software installed
  - Check that your laptop recognizes the ESP32 when connected via USB
  - Make sure you mobile phone is charged and has a QR code app loaded
  - Full prerequisite instructions: http://prereqs.codemash.org/Files/Badge%20My%20IoT%20Life%20-%20Prework.pdf

Hardware Considerations

- Recommend turning switch to OFF position when the ESP32 is connected to laptop of other power source, as well as when charging the battery via the TP4056.
- The I2C and UART pin headers on the badge support a wide variety of 3v3 peripheral devices. If you have any, you may want to consider connecting them to the badge with female DuPont connectors or soldering hookup wire to female header pins to create a custom connector.

Resources

- Greg Huber's instructional videos on assembling the badge
  Part 1: https://youtu.be/l8pbRDcyUmc
  Part 2: https://www.youtube.com/watch?v=5SnY-SC2Caw

- Adafruit Guide to Excellent Soldering
  https://learn.adafruit.com/adafruit-guide-excellent-soldering/tools

- Instructables Ultimate Guide to Desoldering
  https://www.instructables.com/id/The-Ultimate-Guide-to-Desoldering/

- Espressif ESP32 WROOM-32D Documentation
  https://docs.espressif.com/projects/esp-idf/en/latest/hw-reference/modules-and-boards.html

Acronyms

- ADC: Analog to Digital Conversion
- BLE: Bluetooth Low Energy
- DAC: Digital to Analog Conversion
- GND: Ground
- GPIO: General Purpose Input Output (pins)
- I2C: Inter-Integrated Circuit pronounced "I squared C" (serial bus with 2 pins: SCL, SDA)
- I2S: Inter-IC Sound (serial audio protocol with 3 pins: SCK/BCLK, WS/LRCLK, SD/SDATA)
- MCU: Micro Control Unit
- MISO: Master In - Slave Out (SPI pin) sometimes referred to as SDI on a master
- MOSI: Master Out - Slave In (SPI pin) sometimes referred to as SDO on a master
- PCM: Pulse Coded Modulation (WAV files)
- PWM: Pulse Width Modulation
- RXD: Receive Data (UART pin)
- SCK: Serial Clock (SPI pin)
- SCL: Serial Clock (I2C pin)
- SDA: Serial Data (I2C pin)
- SPI: Serial Peripheral Interface (4 pins: SCK, MOSI, MISO, SS)
- SRAM: Static Random Access Memory
- SS: Slave Select (SPI pin)
- TFT: Thin Film Transistor (Liquid Crystal Display)
- TTL: Transistor Transistor Logic (0v/LOW & Vcc/HIGH)
- TXD: Transmit Data (UART pin)
- UART: Universal Asynchronous Receiver/Transmitter (2 pin interface using RXD and TXD pins)
- USB: Universal Serial Bus
- V+ / Vbus / Vcc - Voltage positive signal (USB header pin)
- V_{REF}: ADC reference voltage, usually 1/2 the ADC voltage range, i.e. 1.65v for 3.3v logic