Build Your Own Portable Gaming System

Paul Pagel

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

- Create your nameplate (print big, first name only)
- Take a blue cup if you're pretty new to PCBs and soldering (or it's been a while)
- Take a red cup if you're experienced with PCBs and soldering
- Try to sit next to someone with a different colored cup than your own
- **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 deck download (PDF):
https://github.com/DigiTorus86/Teensy-R4ge-Pro/tree/master/documents

About Me

- 20+ years of developing software professionally and managing software teams
- Application Architect for Domino's Technology team
- Long-time CodeMash attendee
- Particular area of electronic/hardware interest = Audio & Video

- Email: pjpagel86@gmail.com
- Blog: twobittinker.com

Schedule for the Day

Morning: Hardware

LUNCH!

Afternoon: Software

Session Objectives

Learn/review the basics of setting up and working with electronics and microcontrollers

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

Build and test a working portable game system!

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...
- Don’t suffer in silence.
- 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.
- **Have fun!**

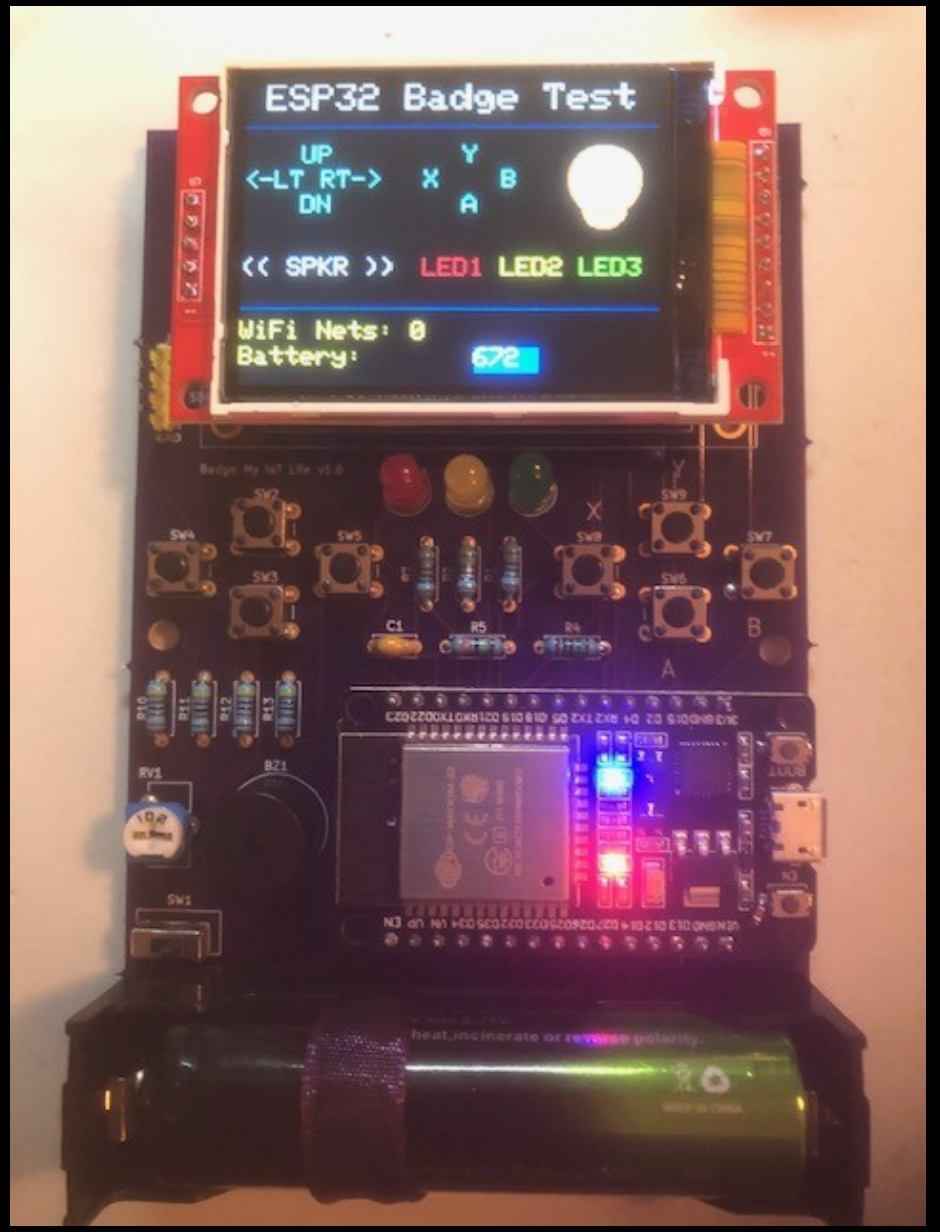
The R4ge Pro System

Begin with the End in Mind

Remember Me?

CodeMash 2020 badge

Based on ESP32



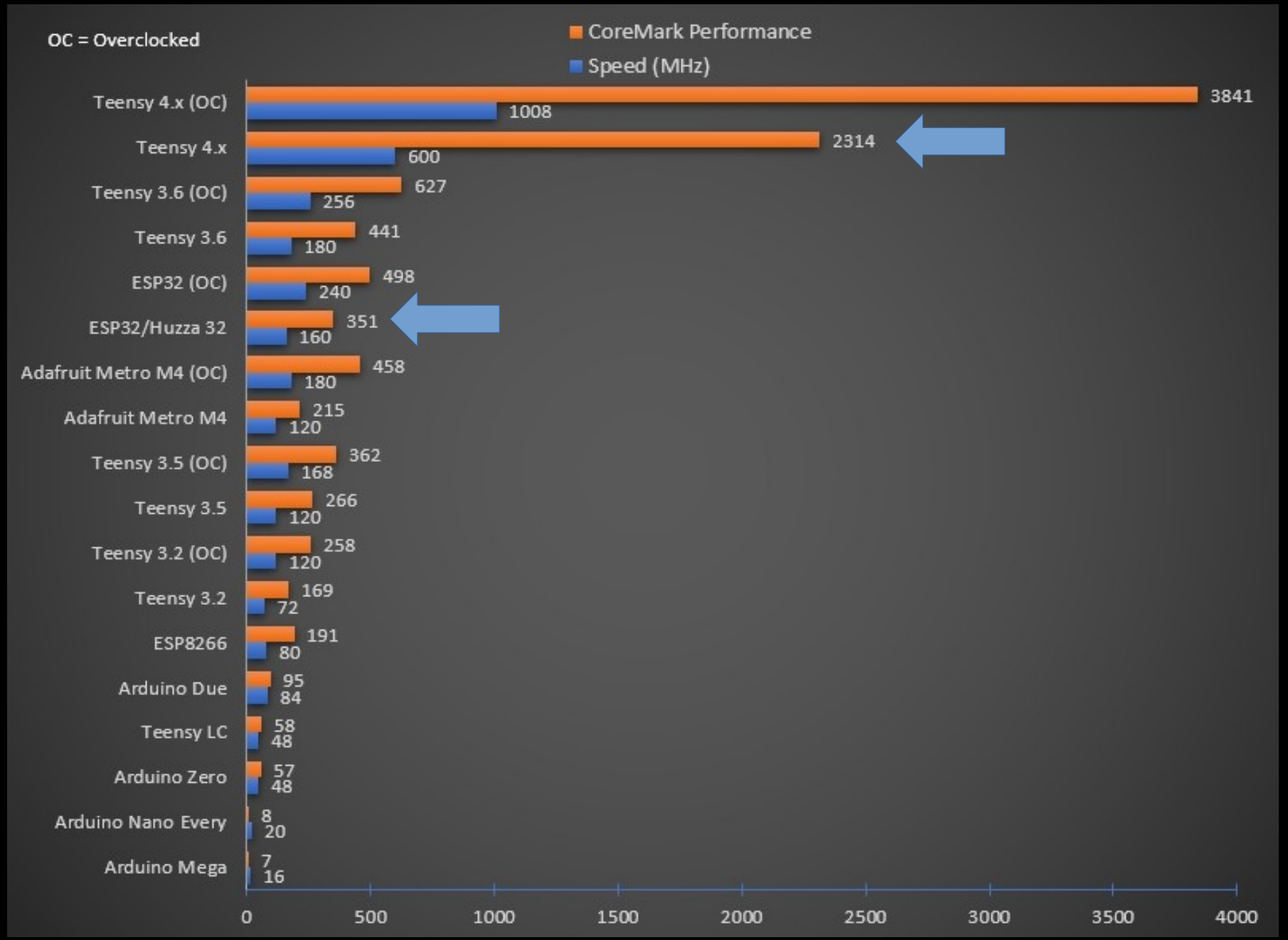
Teensy R4ge Pro

+ Bigger screen
+ Faster controller
+ More controls
+ Way better audio

- No WiFi or BLE
- Less battery life

Features and Capabilities

- Teensy 4.1 microcontroller board
- 2.8” TFT Touchscreen
- CD quality stereo input and output audio
- Joystick, button, and rotary encoder inputs
- Micro SD card slot
- Runs from USB or battery power
- On-board battery charger



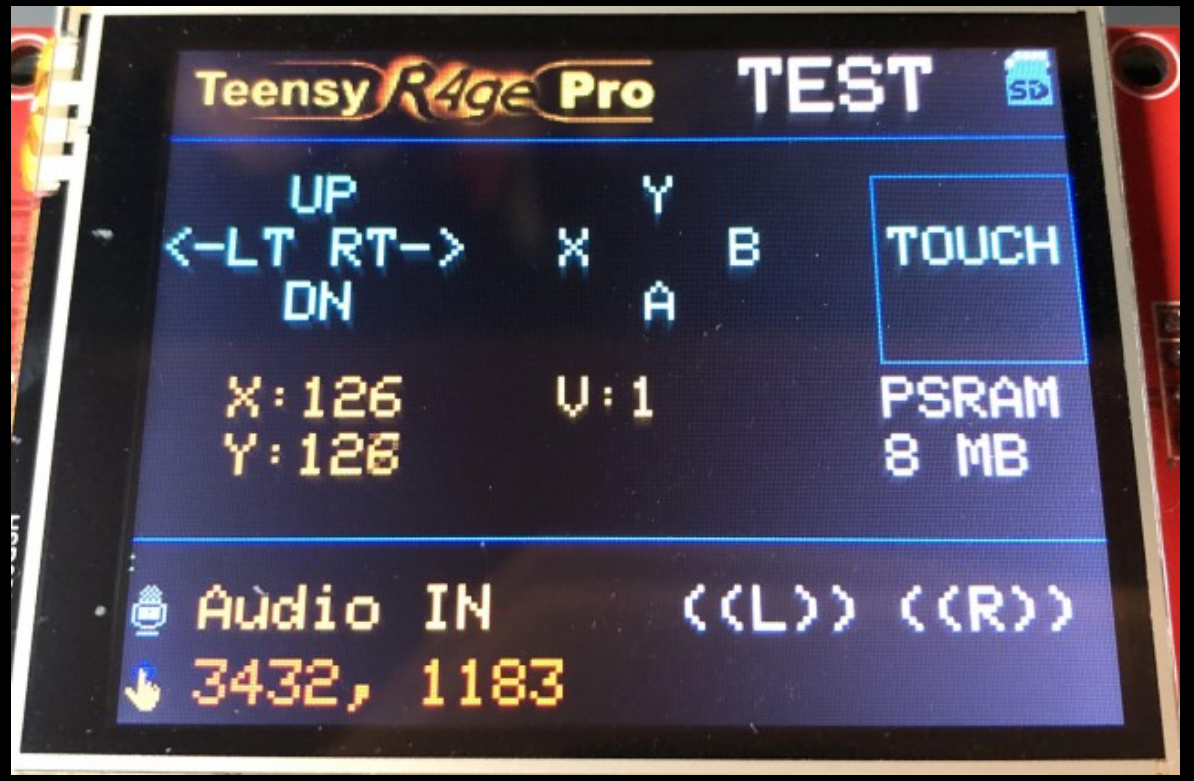
Source: https://protosupplies.com/product/teensy-4-1/?add-to-cart=7010

The Tester App

Allows you to easily exercise all the button and peripherals on the board and detect any problems.

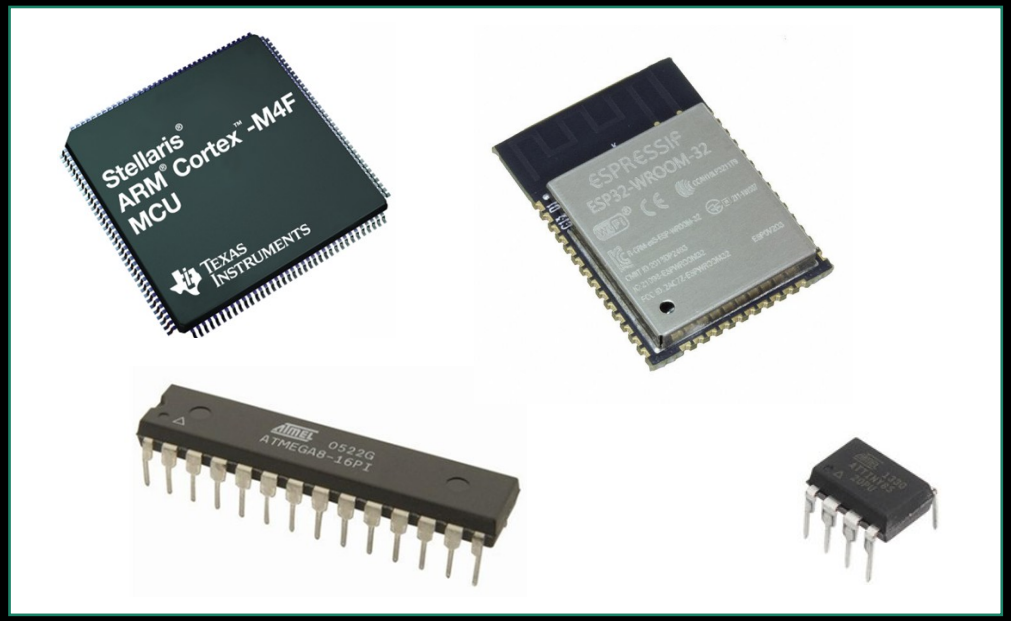
Comes pre-loaded onto the microcontroller included in the kits.

Should be the first thing you see on powering up.



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)

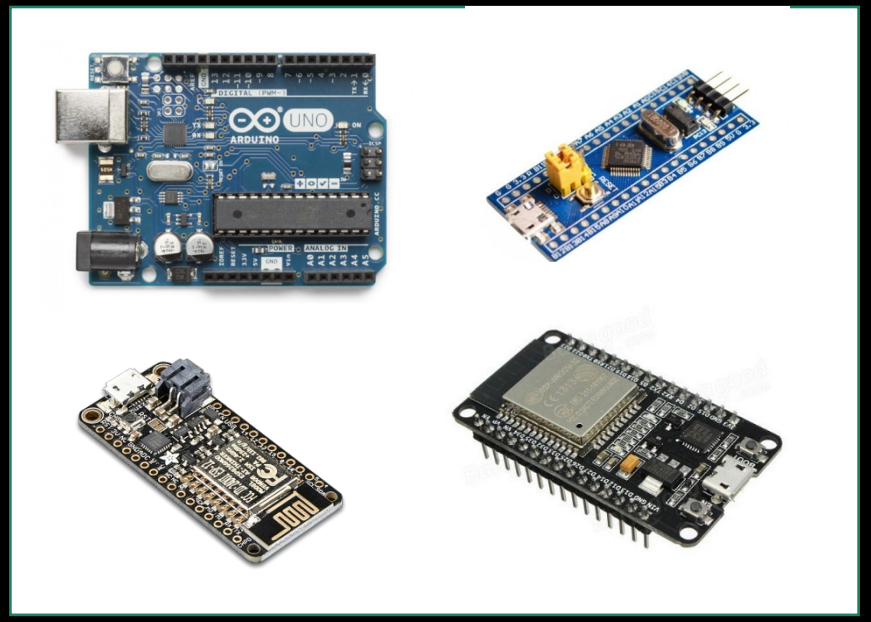


Development Boards

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

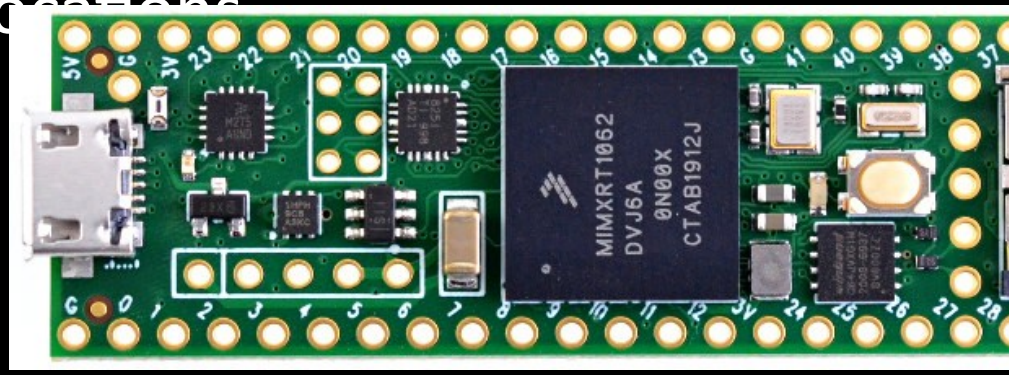
Common examples:

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

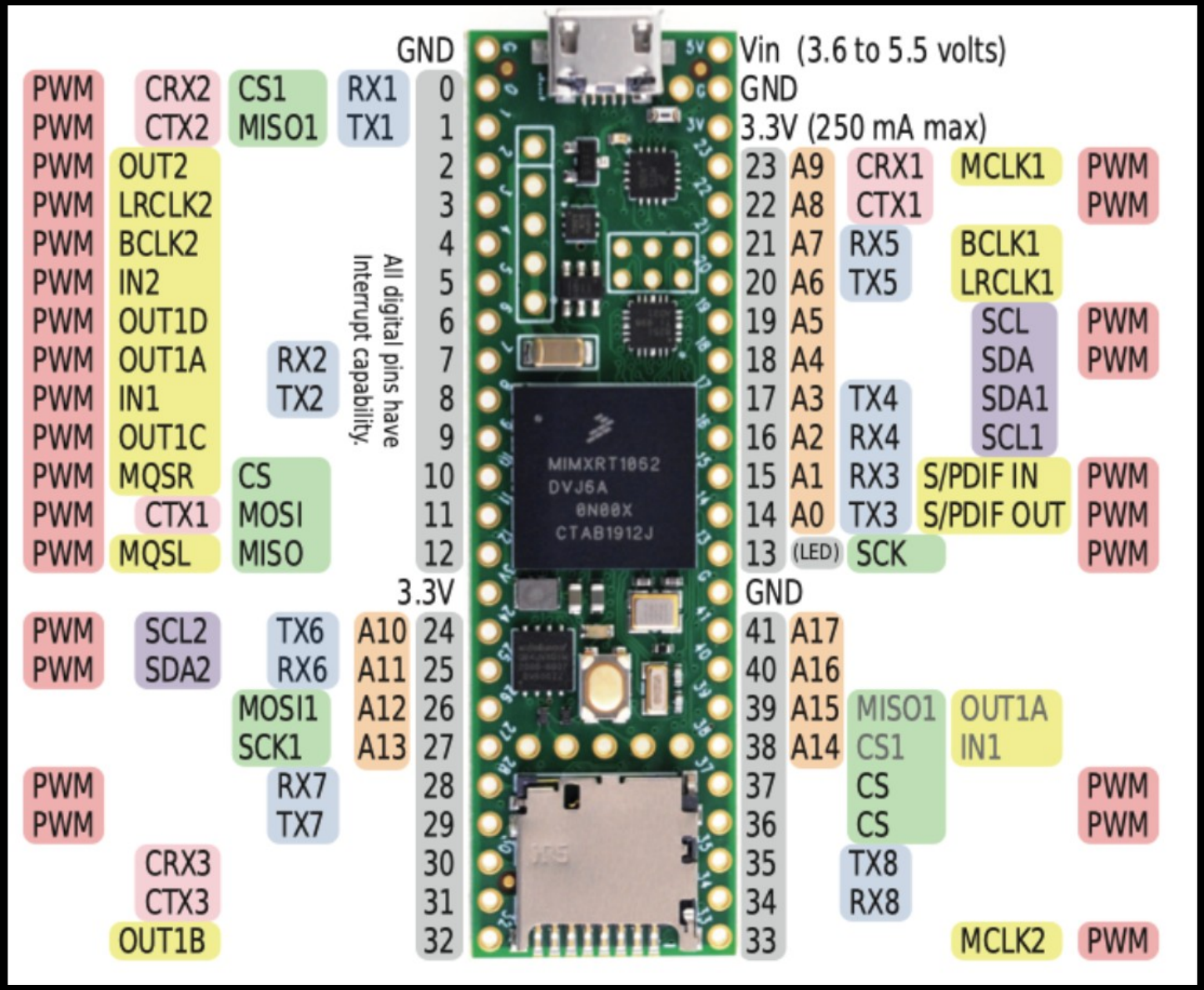


Meet the Teensy 4.1

- NXP ARM Cortex M7 running @ 600 MHz
- 8 MB Flash, 1 MB RAM + 2 expansion locations
- Micro SD card port
- 55 digital input/output pins
- USB device and USB host
- https://www.pjrc.com/store/teensy41.html



Teensy 4.1 Pinout



Electronic Components

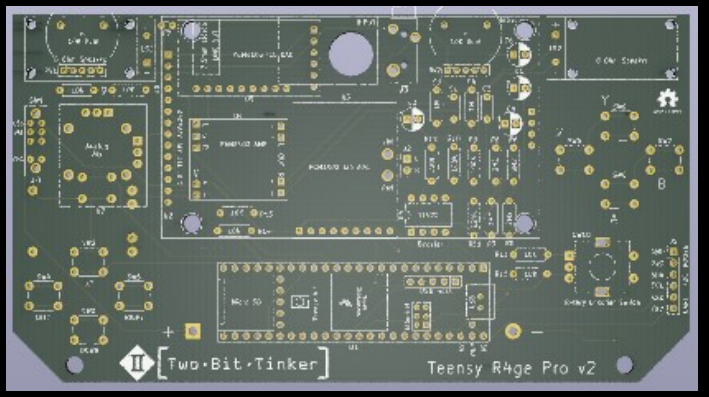
What’s in the Kit and What It Does

Printed Circuit Board (PCB)

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

In Kit:

- 1 custom PCB (v2)



PCB Structures

Solder Mask

- Top layer that repels solder and protects the traces

Traces

- Copper wires that connect the solder pads and rings
- The PCB has 2 layers of traces (front and back)
- Traces can be damaged

PCB Structures

Through Holes

- Mounting holes: various sizes, may or may not have metallic annular rings. Used to connect cases, standoffs, 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!

PCB Structures

Surface Mount

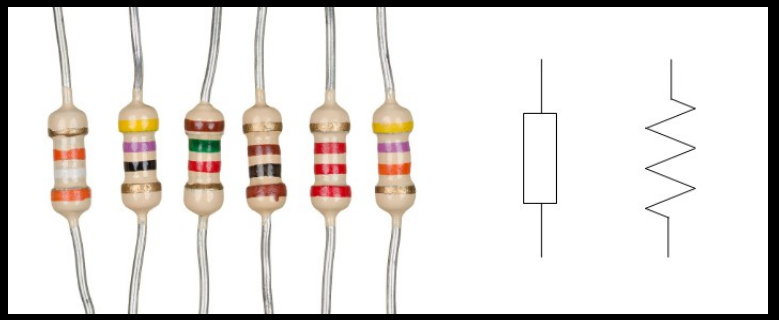
- Solder pads: used to connect the leads and pads on surface mount device (SMD) components to the PCB

- Solder bridge: two small squarish pads close to each other designed to be connected by a single blob of solder, wire, or 0R resistor. Operates like a semi-permanent dip switch.

Resistors

Passive device used reduce current or divide voltages

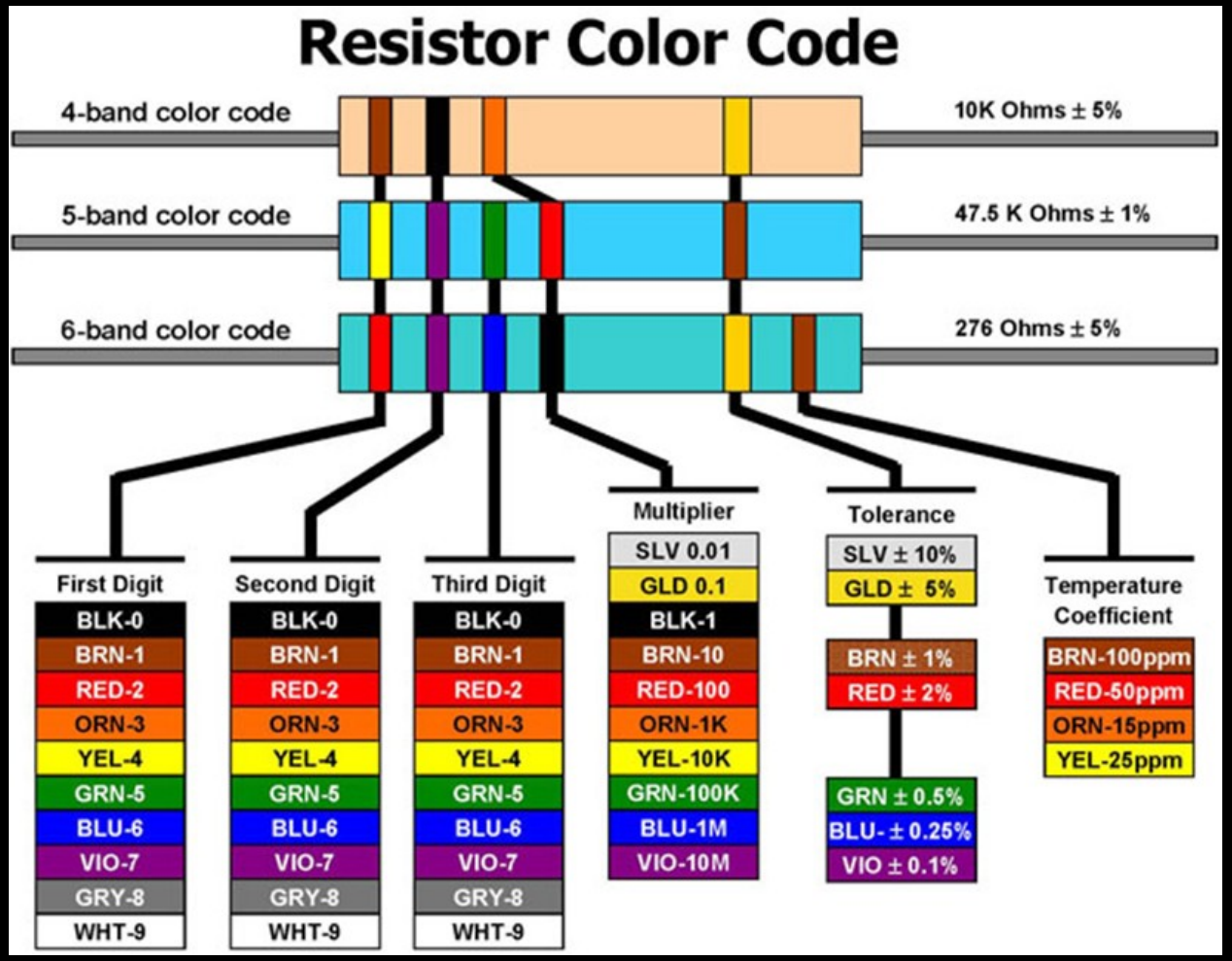
- Non-polarized (no right or wrong orientation)
- Rated by % tolerance to named value and power capacity
  - Example: 10% tolerance and ¼ watt
- Measured in Ohms
  - 220R indicates 220 Ohms
  - 4K7 indicates 4,700 Ohms
  - 3M3 indicates 3,300,000



In Kit:

- 4 – 4k7 [R10-13]
- 3 – 220R [R1-3]
- 1 – 3M3 [R5]
- 1 – 10M [R4]

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.

Capacitors

Passive devices that store electrical energy

Some types are polarized, others are not

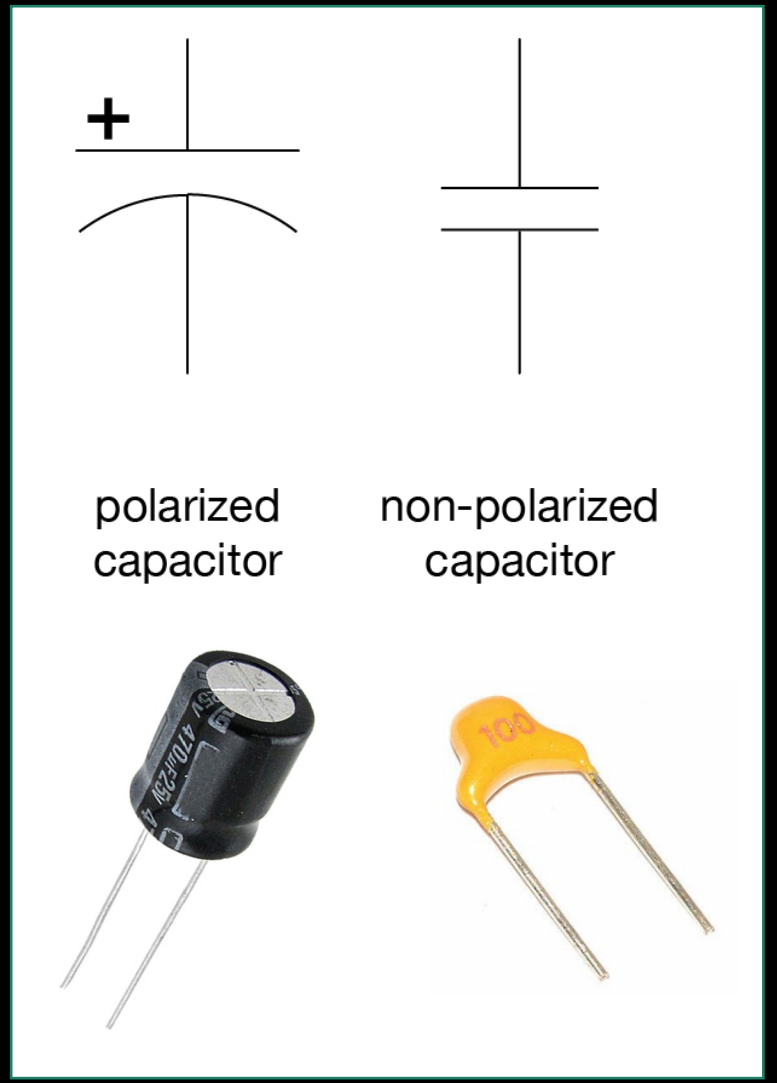
- Ceramic = non-polarized
- Electrolytic = polarized

Measured in Farads

- pF = pico Farads (1 trillionth)
- nF = nano Farads (1 billionth)
- uF = micro Farads (1 millionth)

In Kit:

- 2 – 100nF ceramic [C1, C2]
- 4 – 10uF electrolytic [C3-C6]
- 1 – 22pF ceramic [C7]

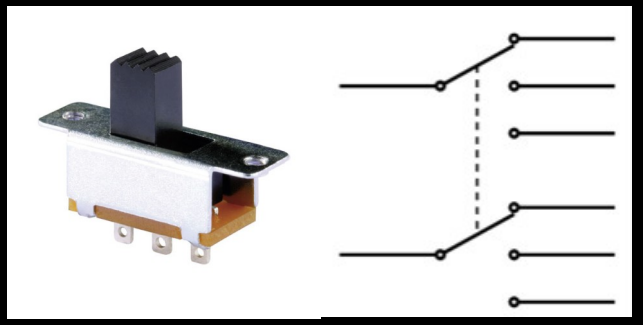


Buttons and Switches

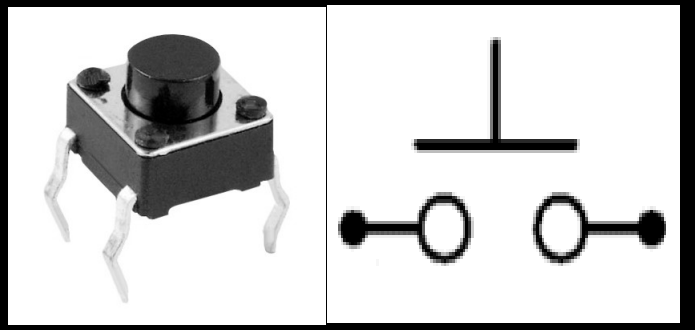
- Mechanical devices for opening and closing a circuit
- Momentary vs. Latching
- Normally Open (NO) vs. Normally Closed (NC)
- Poles = number of circuits connected
- Throw = number of positions (on/off is single)

In Kit:

- 1 – Dual Pole 3-Throw [SW1]
- 8 – momentary NO buttons [SW2 - 9]



DP3T – Double Throw
Triple Pole



Tactile momentary
NO button
(Normally Open)

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, 2.8” 320x240 w/integrated ILI9341 SPI controller, 3.3v, 262K colors [U2]

18650 Lithium Battery

3.7 v lithium rechargeable battery, commonly used in flashlights and vaping gear

- 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.
- Safety: don’t puncture or short!

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 close attention to + / -

Battery fit may be a bit tight. Recommend looping some ribbon or tape around battery to ease extraction.

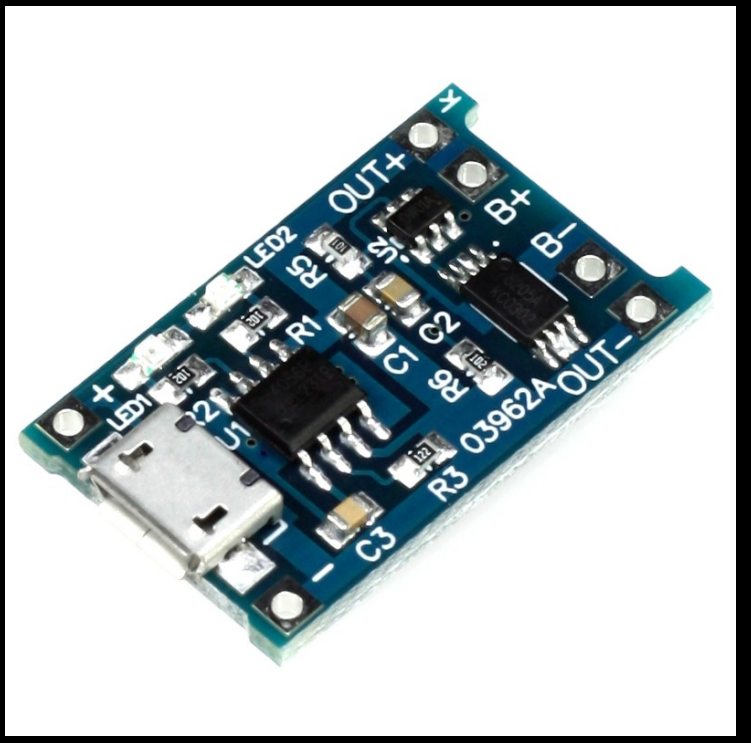
In Kit:

- 1 – 18650 battery holder [BT1]

Battery Charger

5V 1A micro USB board for charging CR18650 batteries

- Allows charging without having to remove the battery from the board.
- Red LED indicates charging.
- Blue LED indicates charged or powering board directly.



In Kit:

- 1 – TP4056 battery charger [U9]

Digital to Analog Converter

Takes digital audio data and converts it to analog waveform output

- Uses the Inter IC Sound (I2S) protocol.
- Support multiple sampling rates and bit depths.
- No built-in amplification or volume control.

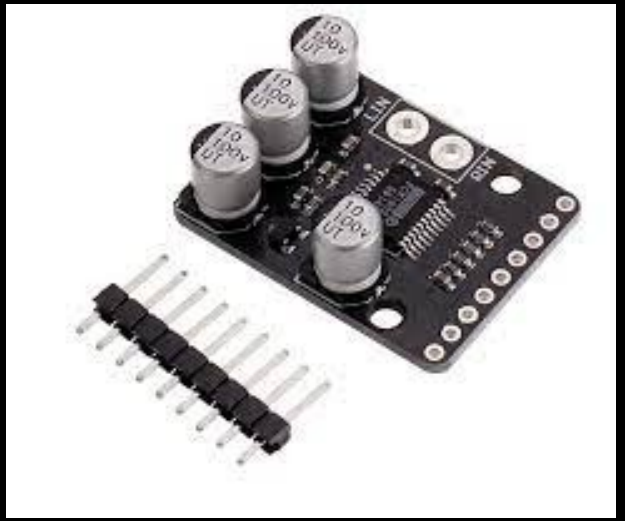
In Kit:

- 1 – PCM5102A DAC breakout board

Analog to Digital Converter

Takes analog input and converts it to digital data

- Uses the Inter IC Sound (I2S) protocol.
- Support multiple sampling rates and bit depths.
- Most breakouts of this model have a board error where the configuration solder bridge is not connected to power.



In Kit:

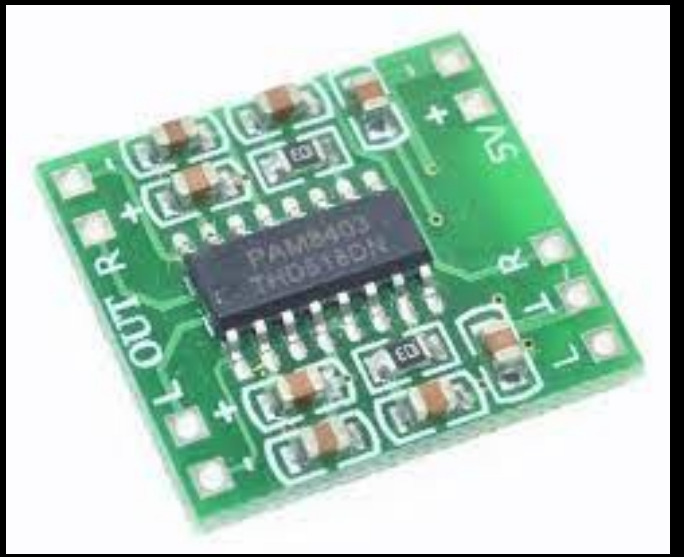
- 1 – PCM1802 ADC breakout board

Audio Amplifier

Takes low-voltage analog output and amplifies it

Amplification is limited by the power rating (watts)

Can be mono or stereo



In Kit:

- 1 – PAM8403 2x3W class D amplifier breakout board

Potentiometers

Variable resistors

- Can be rotary (dial/thumbwheel) or linear (slide)
- Can be single or multi-channel
- Can have linear or logarithmic resistance tapers

In Kit:

- 2 – 10K stereo potentiometers

Analog Joystick

Provides 2-axis control with variable output

- Consists of two potentiometers, one for the X-axis and one for the Y-axis.
- Must be read using an Analog to Digital Converter (ADC)
- Often incorporates a button that is activated by pushing down on the joystick
- Commonly used in game console controllers

In Kit:

- 1 – Analog joystick

Rotary Encoder

Knob that can be rotated indefinitely to provide numerical values

- Contains 2 pins that are used to determine what direction the knob is turned.
- Unlike a potentiometer, has no intrinsic state or value.
- Often incorporates a button that is activated by pushing down on the knob.
- May or may not click when turned.

In Kit:

- 1 – Rotary encoder

Audio Jack

Standard TRS stereo audio connector

- **T**ip: Left channel
- **R**ing: Right channel
- **S**leeve: Ground

- Also come in TS (mono) varieties
- May or may not be switched
- Usually 3.5mm (1/8”) or 1/4” sizes

In Kit:

- 1 – Stereo jack

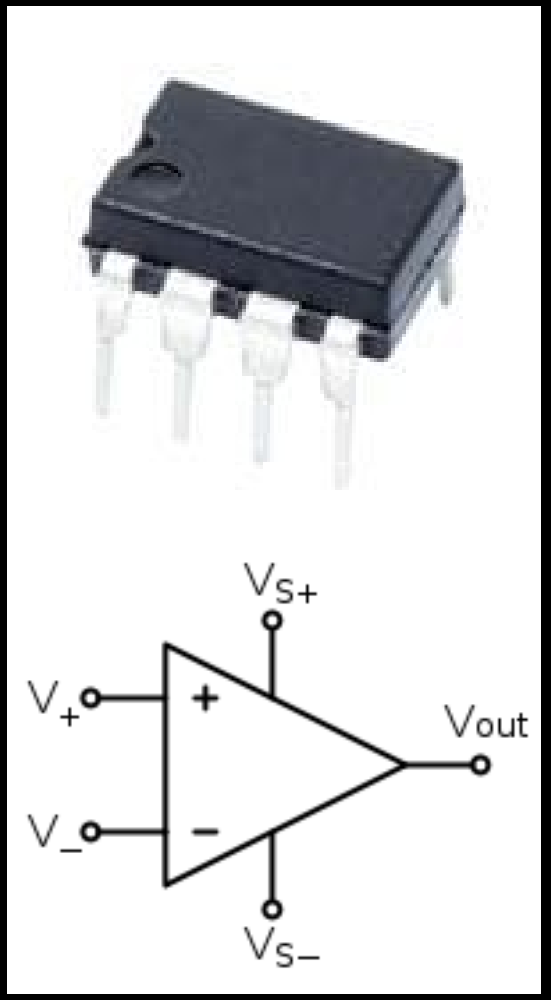
Operational Amplifier

Multipurpose voltage amplifier integrated circuit (IC)

- Used in a huge variety of applications
- Always consists of
  - Inverting input (in-)
  - Non-inverting input (in+)
  - Output (Vout)
- Pip on top indicates pin #1
- Pins are sharp and bend easily

In Kit:

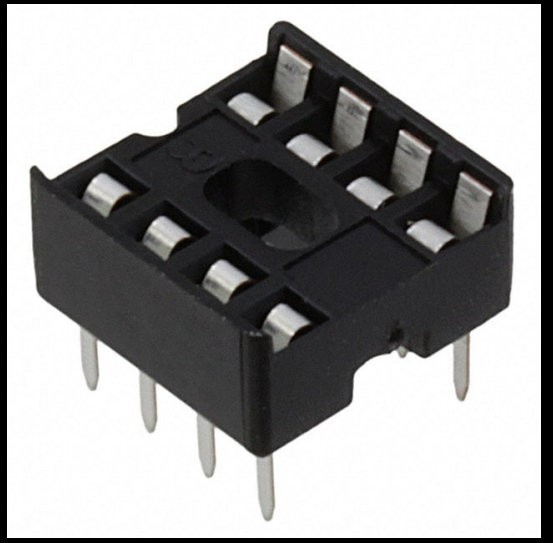
- 1 – TL072 OpAmp



IC Sockets

Allow ICs to be removed without soldering

- One end will always have a notch indicating the end for Pin #1
- Inserting the IC takes a little finesse
- Optional, but strongly recommended



In Kit:

- 1 – 8 pin socket for TL072 OpAmp

Speakers

Convert analog AC signals to audio

- Rated by impedance (Ohms) and power (Watts)
- Smaller speakers produce higher frequencies
- Bigger speakers produce lower frequencies

In Kit:

- 2 – 8 ohm 1W speakers

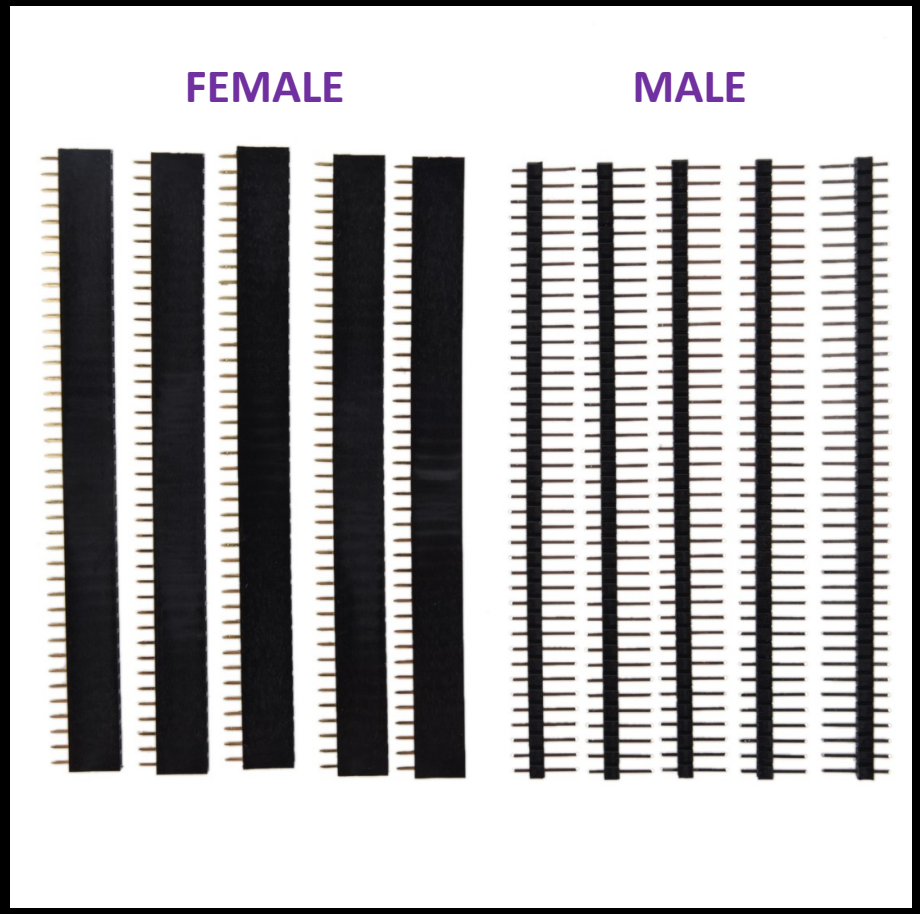
Header Pins

Connect controllers, breakout boards, major components, and jumpers

- Come in male and female varieties.
- Additional common characteristics
  - normal height or extended (stacking) height
  - straight or right-angled
  - single row or double row

In Kit:

- Female header pins
- Male header pins



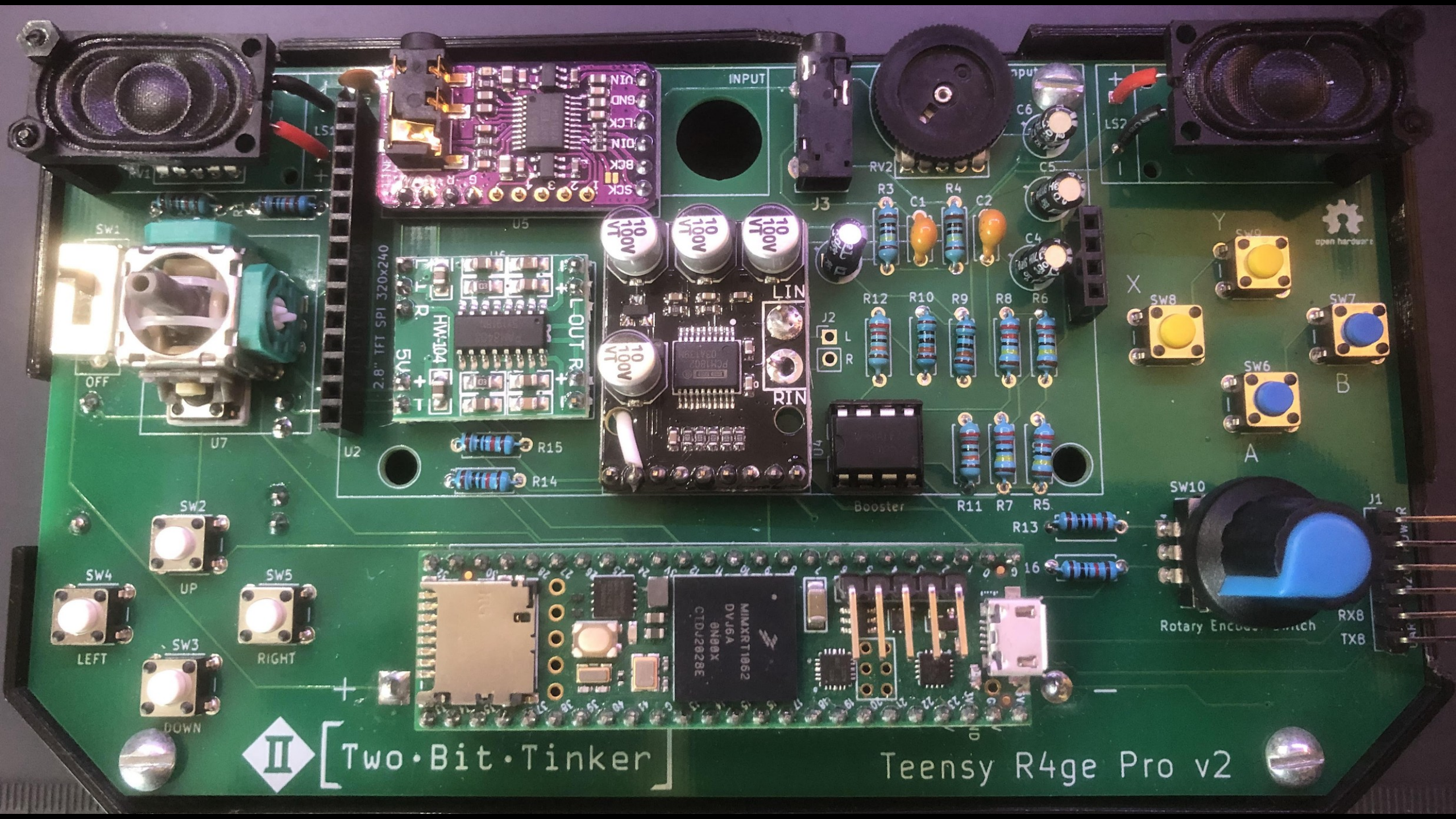
Standoffs

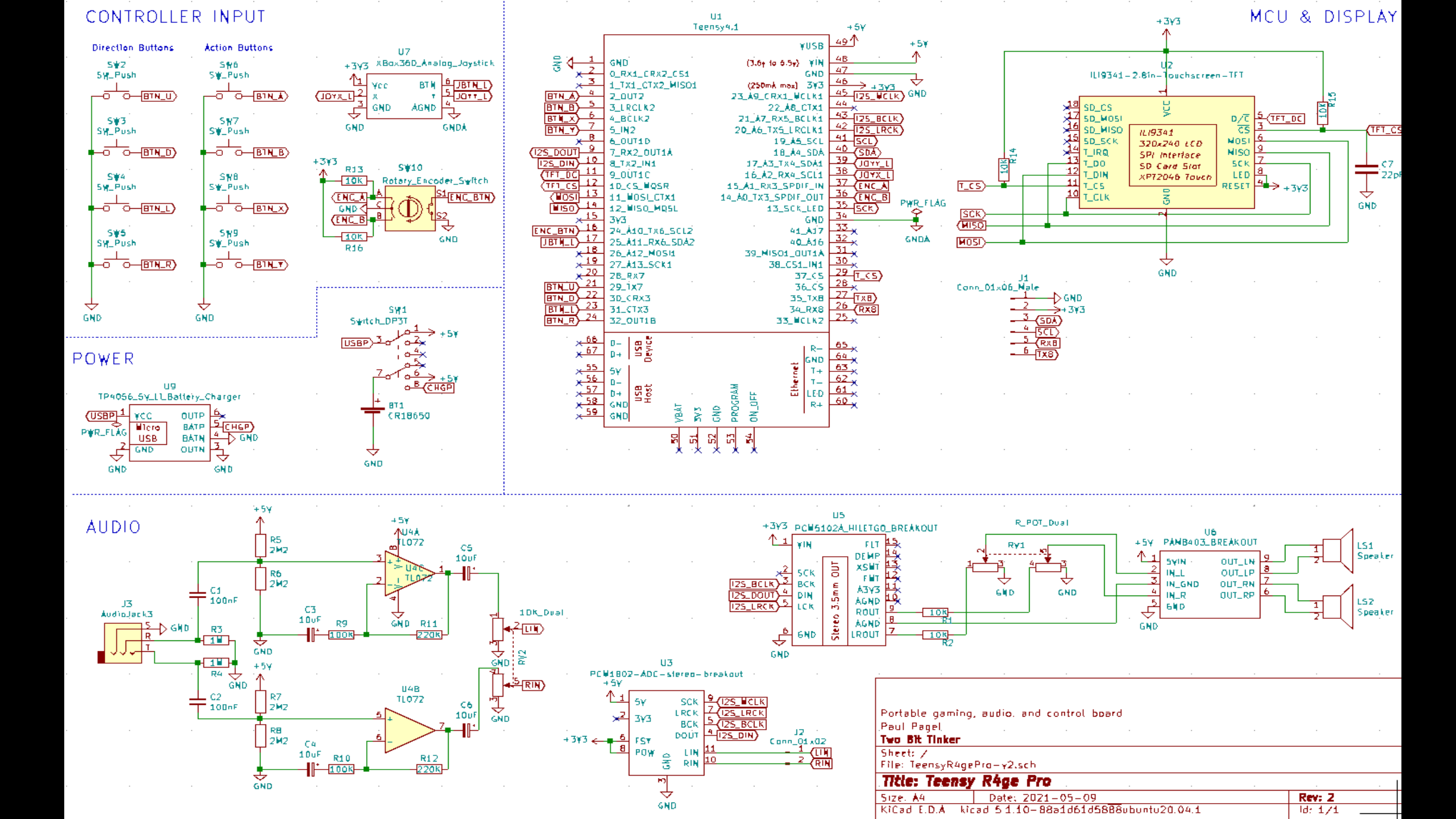
Connect components, PCBs, and cases

- Come in various lengths and thicknesses
- Usually hexagonal
- May be plastic/nylon or brass

In Kit:

- 4 – nylon M2 standoffs, screws, and nuts


INPUT
SW1
OFF
U7
U5
U6
U2
2.8" TFT SPI 320x240
HW-104
LIN
RIN
L OUT R
J3
J2
L
R
RV1
RV2
LS1
LS2
C6
C5
C4
C1
C2
R3
R4
R12
R10
R9
R8
R6
R15
R14
U4
Booster
R11
R7
R5
R13
R16
SW2
UP
SW4
LEFT
SW5
RIGHT
SW3
DOWN
SW10
Rotary Encoder Switch
RX8
TX8
J1
X
Y
SW9
SW8
SW7
SW6
A
B
open hardware
MIMXRT1062
DVJ6A
Two·Bit·Tinker
Teensy R4ge Pro v2


CONTROLLER INPUT
Direction Buttons
Action Buttons
SW2 SW_Push BTN_U
SW3 SW_Push BTN_D
SW4 SW_Push BTN_L
SW5 SW_Push BTN_R
SW6 SW_Push BTN_A
SW7 SW_Push BTN_B
SW8 SW_Push BTN_X
SW9 SW_Push BTN_Y
GND
U7 XBox360_Analog_Joystick
+3V3
JOYX_L
JOYY_L
JBTN_L
GNDA
R13 10K
SW10 Rotary_Encoder_Switch
ENC_A
ENC_B
ENC_BTN
R16 10K
SW1 Switch_DP3T
USBP
CHGP
+5V
BT1 CR18650
POWER
U9 TP4056_5V_LiBattery_Charger
PWR_FLAG
U1 Teensy4.1
+5V
GND
BTN_A
BTN_B
BTN_X
BTN_Y
I2S_DOUT
I2S_DIN
TFT_DC
TFT_CS
MOSI
MISO
ENC_BTN
JBTN_L
BTN_U
BTN_D
BTN_L
BTN_R
USB Device
USB Host
Ethernet
VBAT
3V3
PROGRAM
ON_OFF
PWR_FLAG
MCU & DISPLAY
U2 ILI9341-2.8in-Touchscreen-TFT
ILI9341 320x240 LCD SPI Interface SD Card Slot XPT2046 Touch
SD_CS
SD_MOSI
SD_MISO
SD_SCK
T_IRQ
T_DO
T_DIN
T_CS
T_CLK
D/C
CS
MOSI
MISO
SCK
LED
RESET
R14 10K
R15 10K
C7 22pF
J1 Conn_01x06_Male
SDA
SCL
RX8
TX8
AUDIO
U4A TL072
U4B TL072
C1 100nF
C2 100nF
C3 10uF
C4 10uF
C5 10uF
C6 10uF
R5 2M2
R6 2M2
R7 2M2
R8 2M2
R9 100K
R10 100K
R11 220K
R12 220K
R3 1M
R4 1M
J3 AudioJack3
10K_Dual
RV2
LIN
RIN
U5 PCM5102A_HILETGO_BREAKOUT
Stereo 3.5mm OUT
R_POT_Dual
RV1
R1 10K
R2 10K
U6 PAM8403_BREAKOUT
LS1 Speaker
LS2 Speaker
U3 PCM1802-ADC-stereo-breakout
J2 Conn_01x02
Portable gaming, audio, and control board
Paul Pagel
Two Bit Tinker
Sheet: /
File: TeensyR4gePro-v2.sch
Title: Teensy R4ge Pro
Size: A4
Date: 2021-05-09
Rev: 2
KiCad E.D.A. kicad 5.1.10-88a1d61d58~88ubuntu20.04.1
Id: 1/1

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

https://github.com/DigiTorus86/Teensy-R4ge-Pro (documents folder)

Soldering

Bringing the Heat Without Getting Burned

Ummm...No

Soldering Iron

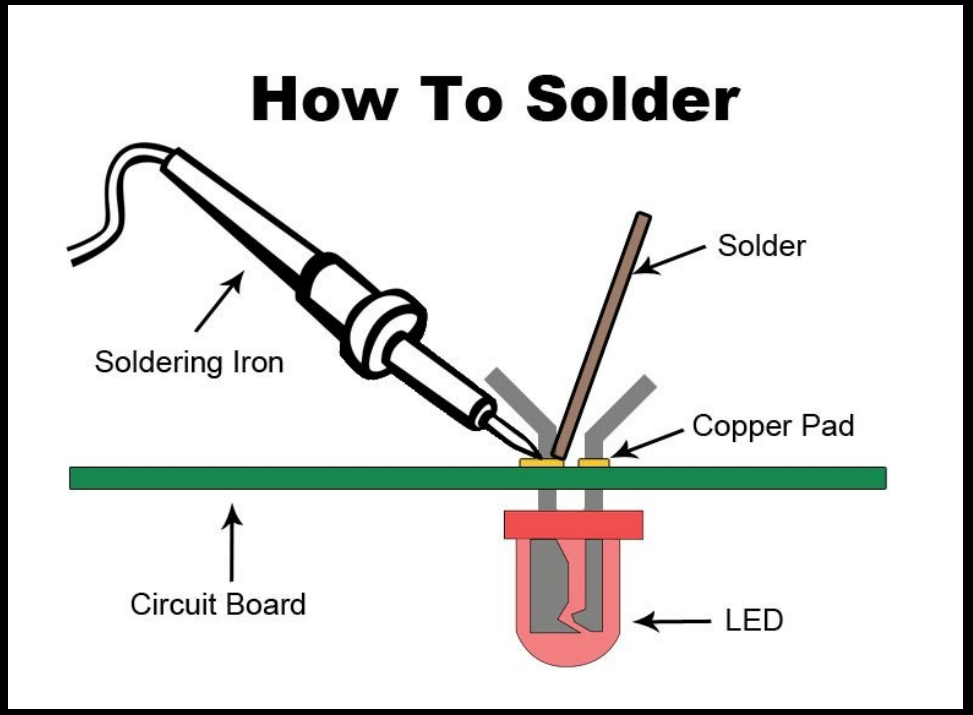
- Tip needs to heat up to about 700F / 370C before use.
- Keep the tip lightly tinned (shiny) but not gobbed with solder.
- Use the scouring pad to remove excess solder from the tip.
- **Safety:**
  - Only pick up by the handle
  - Practice good tip control at all times - no balancing, waving, or gesturing 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

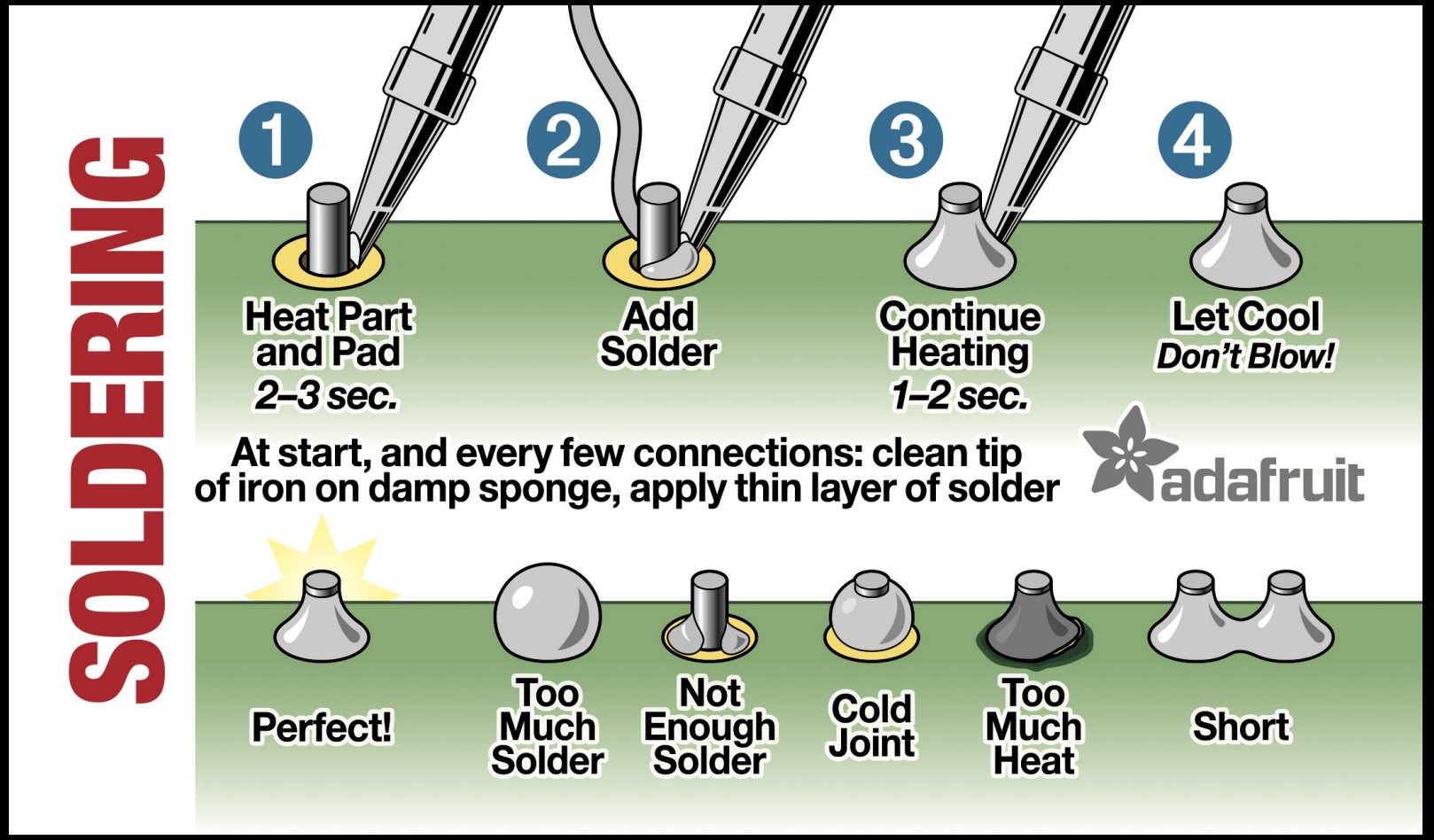
- Most common solder for hand-soldering is a mix of tin (~60%) and lead (~40%)
- Rosin core allows the melted solder to flow smoothly onto the pads and wires.
- Rosin has the downside of producing smoke that is a lung irritant – avoid inhaling.
- Lead-free wire is available, but requires a higher melting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

- Used to trim component lead wires after soldering.
- Good for cutting header pins to length.
- 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.
- Solder flows *towards* heat.

Desoldering

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

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

Assembling the Board

Putting It All Together

Safety

- Components and pins can be somewhat sharp so handle carefully.
- If you need to clip or shorten a wire, do it angled downward – not towards anyone.
- If a component doesn't fit, reposition and wiggle it instead of forcing it.
- Soldering irons are hot. Only touch the handle.
- Flux contains acid, which is a skin and lung irritant. Keep away from skin and don't breathe the fumes.
- Lead is a component of solder wire, so wash hands before eating and avoid rubbing eyes.
- Keep your work area clear, especially of open liquid containers.
- Some components can be damaged by static shock, so grounding yourself after walking around is generally a good idea
- If you're not sure if something would be safe or OK, please stop and ask.
- **If you see something that looks unsafe, call a stop immediately so it can be evaluated and addressed.**

General Assembly Guidelines

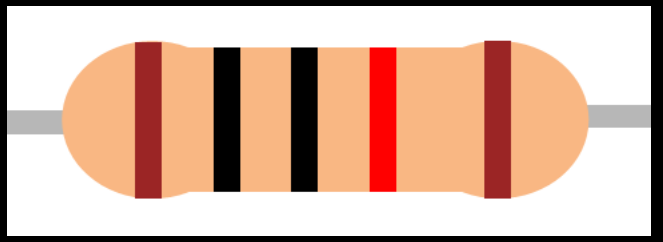
- Keep parts segregated to avoid confusion (especially resistors)
- Start with the smaller/shorter passive components and work towards the larger ones
- Bend resistor leads to a 90 degree angle as close to the body as possible
- If you're not sure about a resistor's value, use a multimeter to test it.
- Pay close attention to polarity! (electrolytic capacitors, 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 – usually 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.

For a More Pleasant Experience

- Print your name using a metallic marker somewhere on the board.
- 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!

Detailed Assembly Instructions: 1

- Start with all the resistors on the board. These will be marked R1 through R15.
- Bend them to 90 angles close to the ceramic body, insert into the board, bend the ends out slightly, and solder on back of board.
  - 10K (brown-black-black-red)
  - 100K (brown-black-black-orange)
  - 220K (red-red-black-orange)
  - 1M (brown-black-black-yellow)
  - 2M2 (red-red-black-yellow)



- Inspect and trim leads using flush cut trimmer.

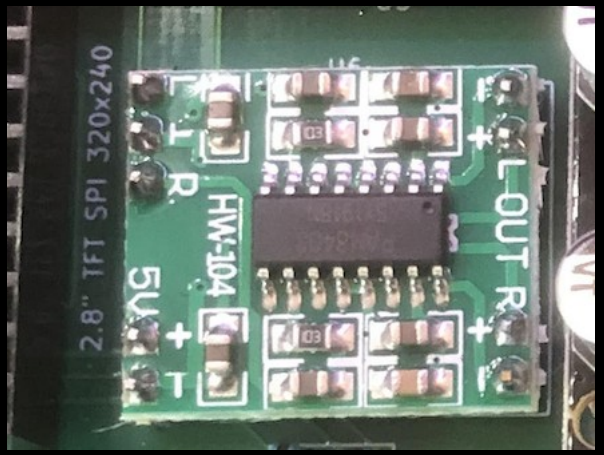
https://circuitdigest.com/calculators/5-band-resistor-color-code-calculator

Detailed Assembly Instructions: 2

- Place the 4 directional and 4 action buttons (SW2-SW9). The buttons will only fit with the legs oriented left/right.
- Insert the two 10K thumbwheel pots (RV1, RV2)
- Insert the ceramic capacitors
  - 100nF – marked “104” (C1, C2)
  - 22pF – marked “22” (C7)
- Solder and inspect the leads.

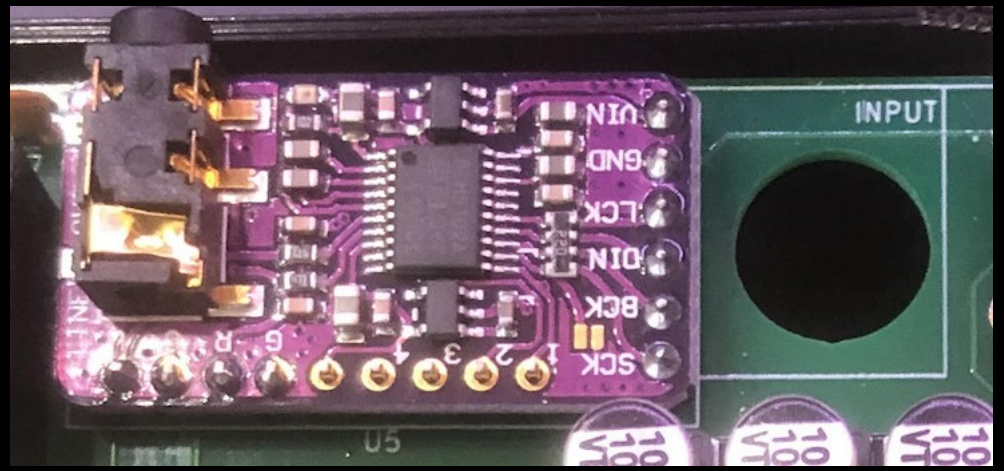
Detailed Assembly Instructions: 3

- Snip male pin headers for the PAM8403 amplifier board (1) 3-pin and (3) 2-pin.
- Put the long end of the pins into the R4ge board and set the amplifier board (U6) on the short ends of the pins.
- Solder the pins to the amplifier board.
- Flip the board over and solder the pins to the R4ge board.
- Inspect and trim the pins. These pins are thicker and can fly at high velocity when trimmed.
  Be careful!



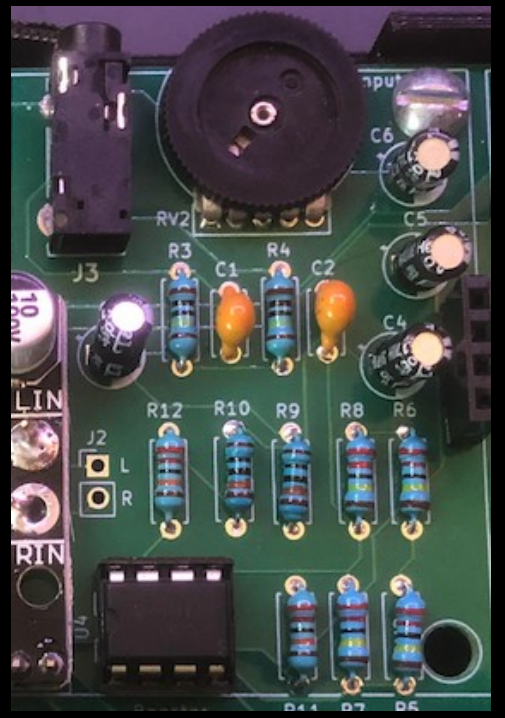
Detailed Assembly Instructions: 4

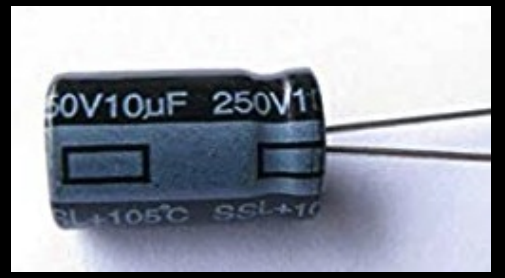
- Snip male pin headers for the PCM5102a I2S DAC board (1) 9-pin and (1) 6-pin.
- Put the long end of the pins into the R4ge board and set the DAC board (U5) on the short ends of the pins.
- Solder the pins to the DAC board.
- Flip the board over and solder the pins to the R4ge board.
- Inspect and trim the pins.
  Again, be careful!



Detailed Assembly Instructions: 5

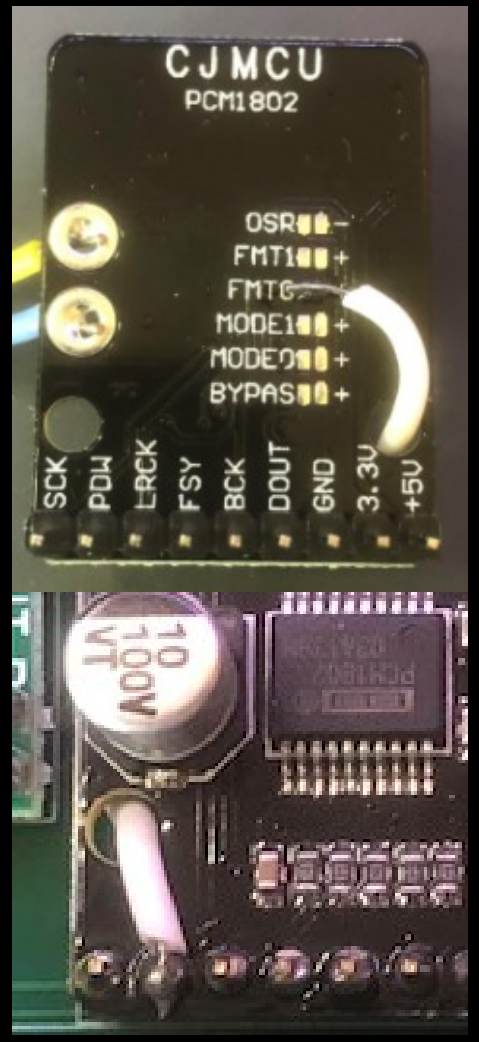
- Insert the 1/8” TRS audio jack (J3)
- Insert the 10uF electrolytic capacitors (C3 – C6).
  - The white half of the footprint indicates the NEGATIVE lead.
  - The white stripe on the capacitor is negative.
- Insert the 8-pin IC socket for the TL072 (U4) with the notch to the left.





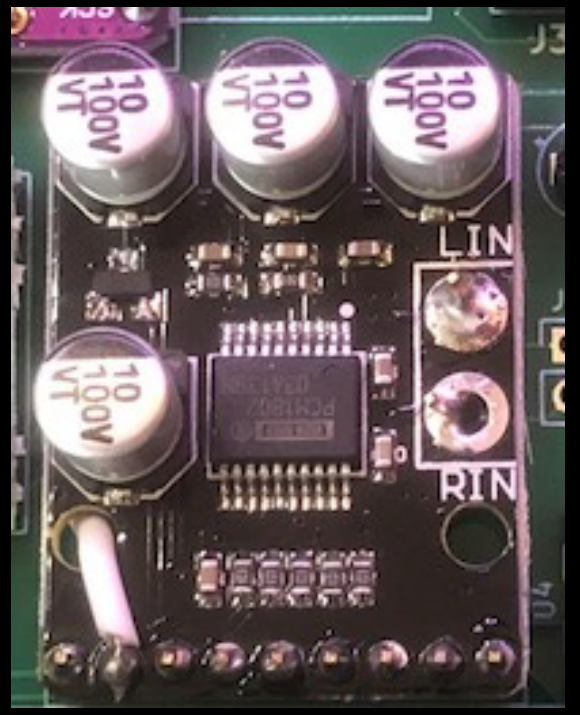
Detailed Assembly Instructions: 6

- Snip a 1” wire and strip about 1/8” from one end.
- Solder it to the FMT0 solder bridge on the back of the PCM1802 ADC board (U3) so that both pads are connected.
- Run the other end through the hole on the ADC.
- Strip the wire to the length shown.



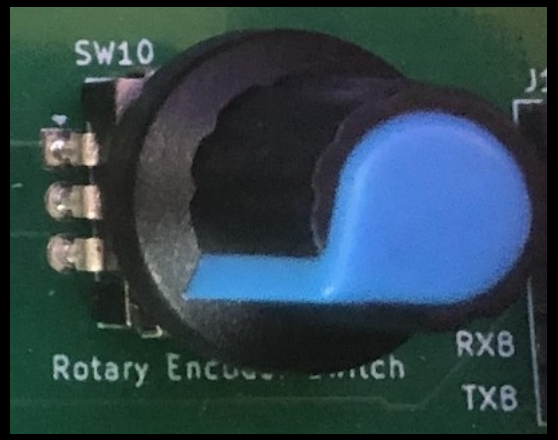
Detailed Assembly Instructions: 7

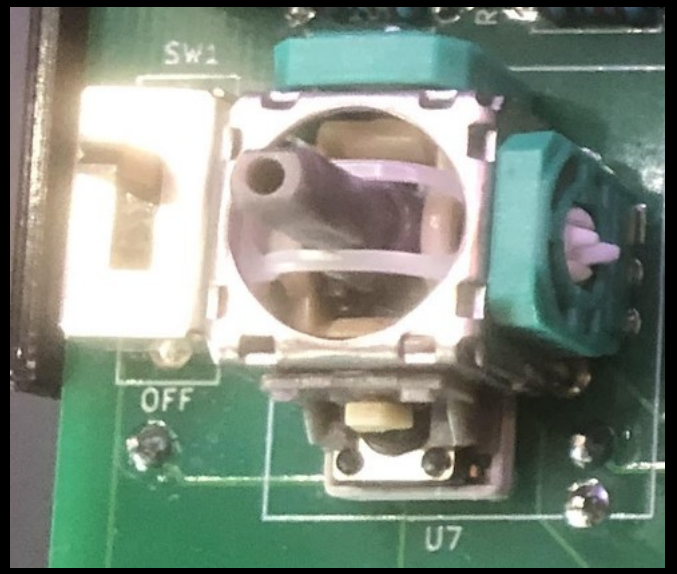
- Snip a 9-pin male header for the PCM1802a I2S ADC board, and (2) 1-pin headers for LIN and RIN.
- Put the long end of the pins into the R4ge board and set the ADC board (U5) on the short ends of the pins.
- Solder the pins to the DAC board.
- Solder the wire to the 3v3 pin (2nd from left)
- Flip the board over and solder the pins to the R4ge board.
- Inspect and trim the pins.
  Again, be careful!



Detailed Assembly Instructions: 8

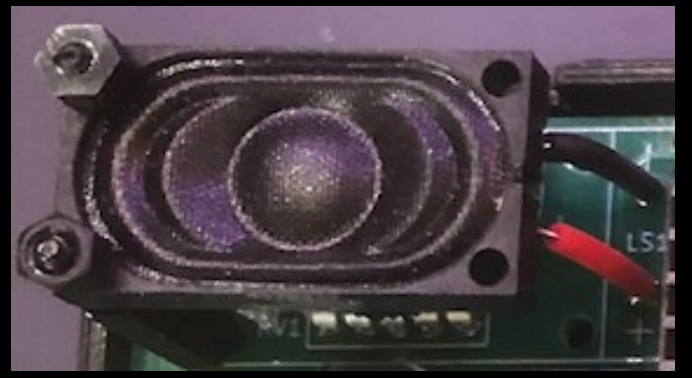
- Insert the rotary encoder (SW10)
- Insert the joystick (U7)
  - This has a lot of pins, so may take some finesse to get them all seated.
  - A pen or small screwdriver can be helpful to push the pins.
- Insert the power switch (SW1)
- Flip over, solder, and inspect.





Detailed Assembly Instructions: 9

- Cut (4) 1” sections of wire for the speakers.
- Strip 1/8” from one end.
- Strip all but 1/4” from the rest.
- Solder the 1/8” ends to the pads on the back of the speakers.
- Attach the (4) M3 standoffs to the holes by the speakers using M3 screws from the back of the board.
- Don’t over-tighten.



Detailed Assembly Instructions: 10

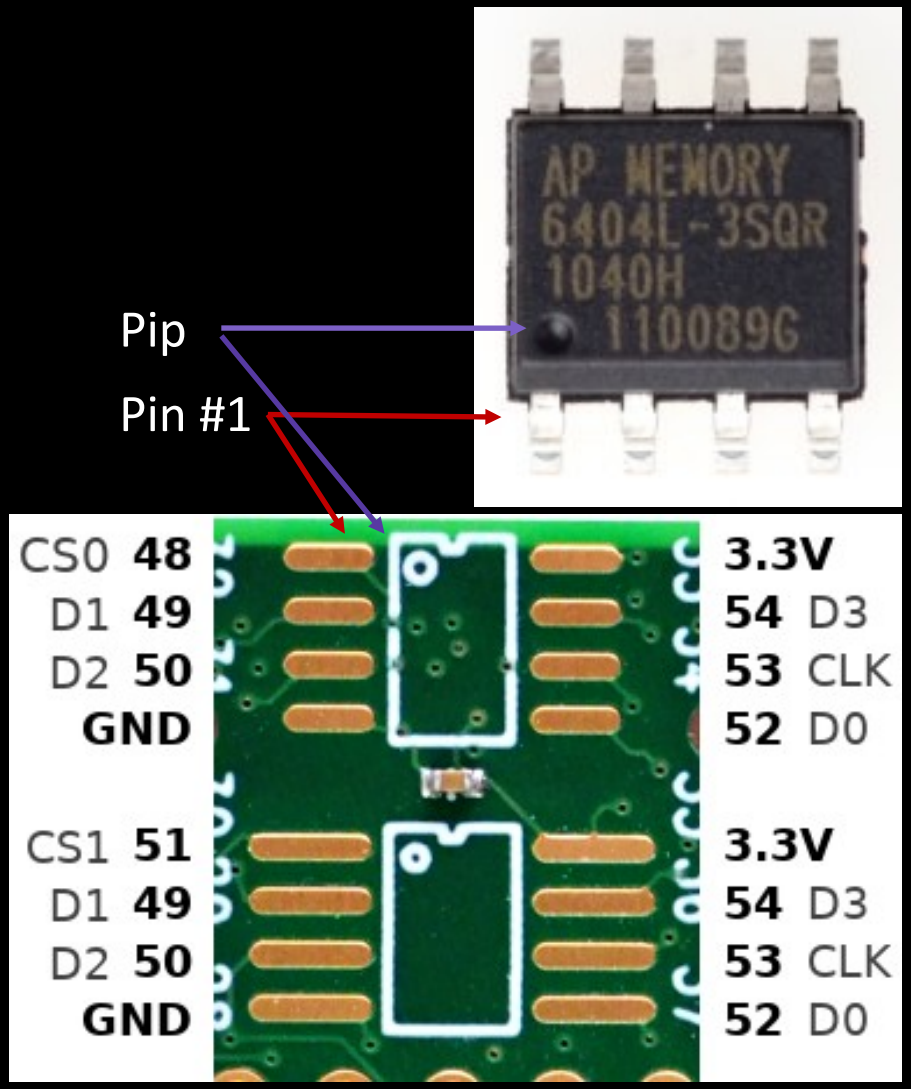
- GENTLY bend the speaker wires to 90.
- Insert the free end of the speaker wires into the PCB.
- Ensure that the holes on the speaker fit over the standoff threads and the speaker is parallel to the PCB (or angled slightly inward)
- May need to strip off a bit more insulation if too long.
- Attach speakers to standoffs using the small M3 nuts.
- Solder the speaker wires to the back of the board.

Intermission

If you haven’t already done so,
take a short brain and bio break at this point.

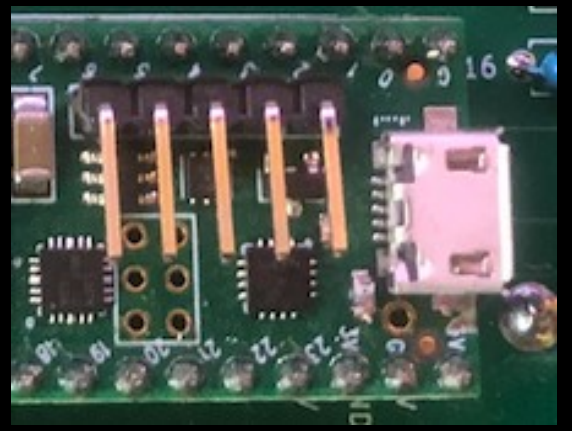
Detailed Assembly Instructions: 11

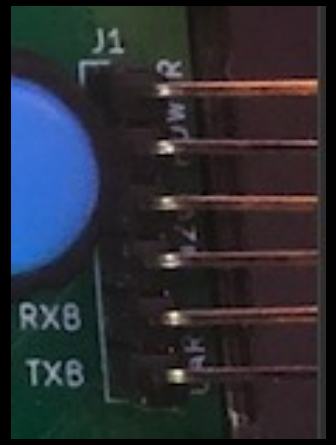
- Flip the Teensy 4.1 over and locate the pads for the memory chip.
- Place a small dab of solder on pad 48.
- Take the QSPI memory chip and place it on the footprint **closest to the end of the board** (pads 48 – 52) aligning the pip on the chip with the circle on the footprint.
- Holding the chip down with a tweezers or pencil, keep it aligned with the other pads as you melt the corner solder.
- Solder the other 7 leads to the pads.
- Inspect closely!



Detailed Assembly Instructions: 12

- Optional: take a 5-pin male angled header and solder to Teensy as shown. This is can allow the Teensy to act as a USB host device.
- Optional: take a 6-pin male angled header (J1) and attach to R4ge PCB as shown.



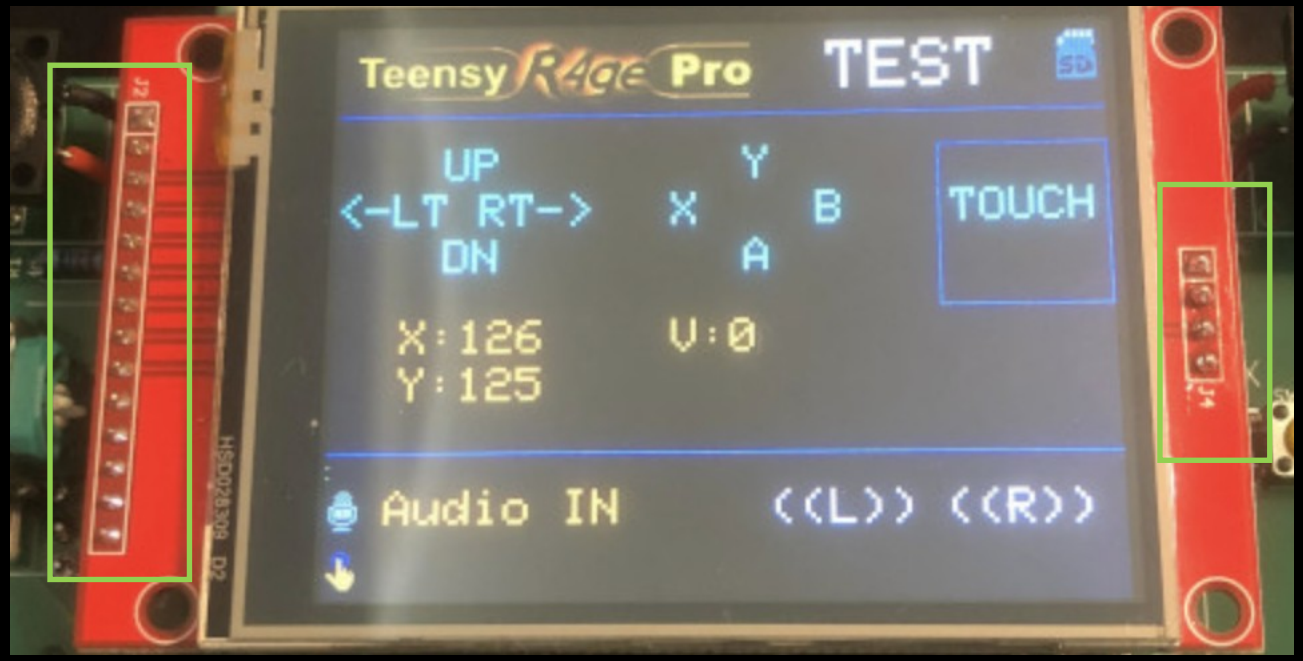


Detailed Assembly Instructions: 13

- Snip (2) each 24-pin male and female pin headers to fit the Teensy.
- Put the female headers in the R4ge PCB.
- Place the long ends of the male headers into the female headers.
- Place the Teensy over the short ends of the male headers and push down gently until all pins are seated flush.
- Solder the male pins to the Teensy. Flip over and solder to R4ge PCB.

Detailed Assembly Instructions: 14

- Snip (1) each 4-pin male and female pin headers to fit the TFT display, and (1) 14-pin female header.
- Put the female headers in the R4ge PCB.
- Place the long ends of the male headers into the female headers.
- Place the TFT over the short ends of the male headers and push down gently until all pins are seated flush.
- Solder the male pins to the TFT. Flip over and solder to R4ge PCB.



Initial Test

1. Hook up the Teensy to your laptop using the Micro USB cable.
2. The test app should boot up. If not, disconnect cable and see the Troubleshooting slides in the Testing section.
3. SD icon should be shown in upper right corner with a red line through it.
4. Press all the buttons, move the joystick, and rotate the encoder. Verify that the corresponding element value is displayed or highlighted on the screen.
5. In addition, the following buttons have additional actions that should be triggered:
   - Left: audio from left speaker
   - Right: audio from right speaker
   - Up: Sample audio in (green bars indicate left and right channel signal strength)
   - Down: stop sampling audio in
6. You may need to adjust the volume (under the left speaker) to get audio output. Clockwise = Louder

Detailed Assembly Instructions: 15

- Snip (6) 1-pin male and female pin headers for the TP4056 charger.
- Flip the R4ge board over and place the long ends of the pins into the R4ge PCB and place the charger on the short end of the pins.
- Solder the pins to the charger.
- Flip over to the front of the R4ge board and solder the pins there.
- Inspect and trim the pins.

Detailed Assembly Instructions: 16

- Insert the battery holder on the back of the board.
- Pay attention to the polarity (negative to the left)
- Flip over and solder on the front. Don’t be stingy here!

CONGRATULATIONS – ASSEMBLY IS COMPLETE!!!

Time for the final test…

Testing

Keep Your Fingers Crossed

Testing the Assembled Board

1. Insert the SD card.
2. Hook up the Teensy to your laptop using the Micro USB cable.
3. The test app should boot up.
4. SD icon should be shown in upper right corner.
5. Press all the buttons, move the joystick, and rotate the encoder. Verify that the corresponding element value is displayed or highlighted on the screen.
6. In addition, the following buttons have additional actions that should be triggered:
   - Left: audio from left speaker
   - Right: audio from right speaker
   - Up: Sample audio in (green bars indicate left and right channel signal strength)
   - Down: stop sampling audio in
7. You may need to adjust the volume (under the left speaker) to get audio output. Clockwise = Louder

Testing Battery Operation

1. Disconnect the USB cord from the Teensy.
2. Ensure the power switch is in the “CHG” position (all the way to the bottom)
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 CR18650 battery and insert it with the positive end pointed towards the right side of the board and firmly seat in place.
5. Attach the USB cable to the battery charger.
6. Lights on the charger should be red, indicate the battery is charging.
7. Move the switch up to the USB position. Test app should boot up.
8. Repeat the previous button test.
9. Move switch back to CHG position to allow battery to fully charge (charger light will turn blue when done)

Troubleshooting – Dead Board

- If you get no response from the board at all:
  - Remove the Teensy from the board and see if the power light comes on when hooked up to your laptop via the USB cable
  - Ensure you have the Teensy oriented on the board correctly with the USB port to the right
  - Swap your Teensy 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. DON'T THRASH!

Troubleshooting Components

- If the board works, but one or more particular subsystems or 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 any fine solder splashes/shorts.
  - Ensure you have the polarity/orientation correct (battery, electrolytic capacitors, ICs)
  - Re-heat/re-flow the solder for the non-functional component
  - Verify the component using a multimeter
  - Look for discolorations or deformities that indicate capacitor is burned out
  - Swap out the component with a verified operational one
- Use the schematic to help identify the components that may be involved in the failure

Finishing Touches

- Ensure you've put your name on the board somewhere (they all look alike)
- Take a picture of your completed board for posterity #codemash2022
- Prepare for the afternoon session:
  - Ensure VS Code withPlatformIO or Arduino IDE is installed on you laptop
  - Check that your laptop recognizes the Teensy when connected via USB
  - Full prerequisite instructions: http://todo/

Acronyms and Abbreviations

- ADC: Analog to Digital Conversion
- 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