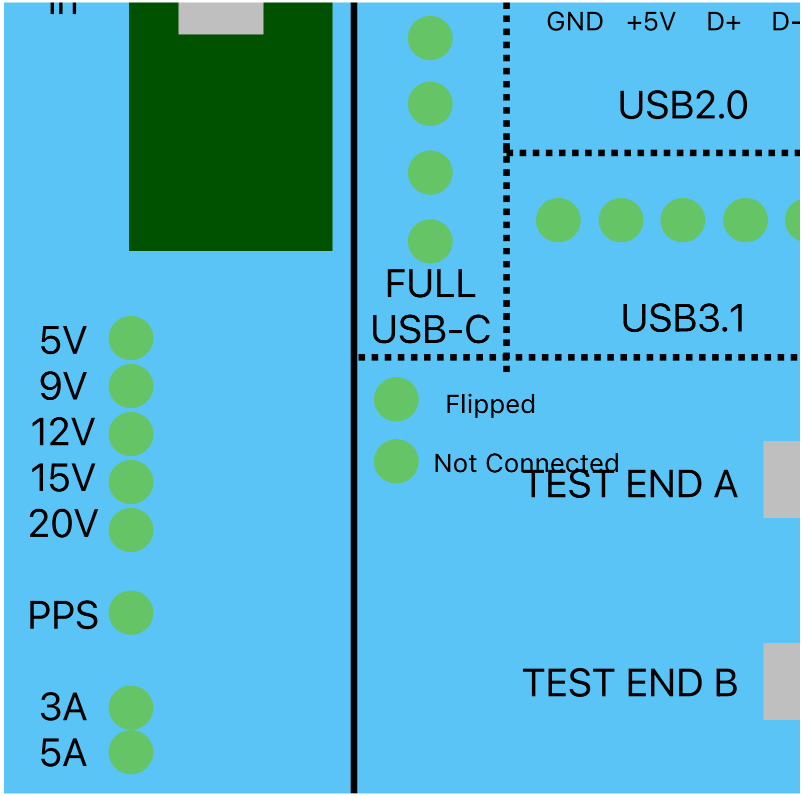
USB C Tester

- Why?
  - USB C cables come in many different types
    - USB 2.0 Data only, Power Only, USB 3.0, USB 3.1, Sideband use, 60 Watt capable, 100 Watt capable, 240 Watt capable
  - USB C PD Power supplies come in many different types
    - Supporting wattages from 10W to 240W, Voltages from 5V to 20V, Currents up to 3A or up to 5A, some support arbitrary voltages while others only support a few specific voltages.
  - And, of course, cables can fail, or be miswired, as we’ve all dealt with in this class

USB C Tester

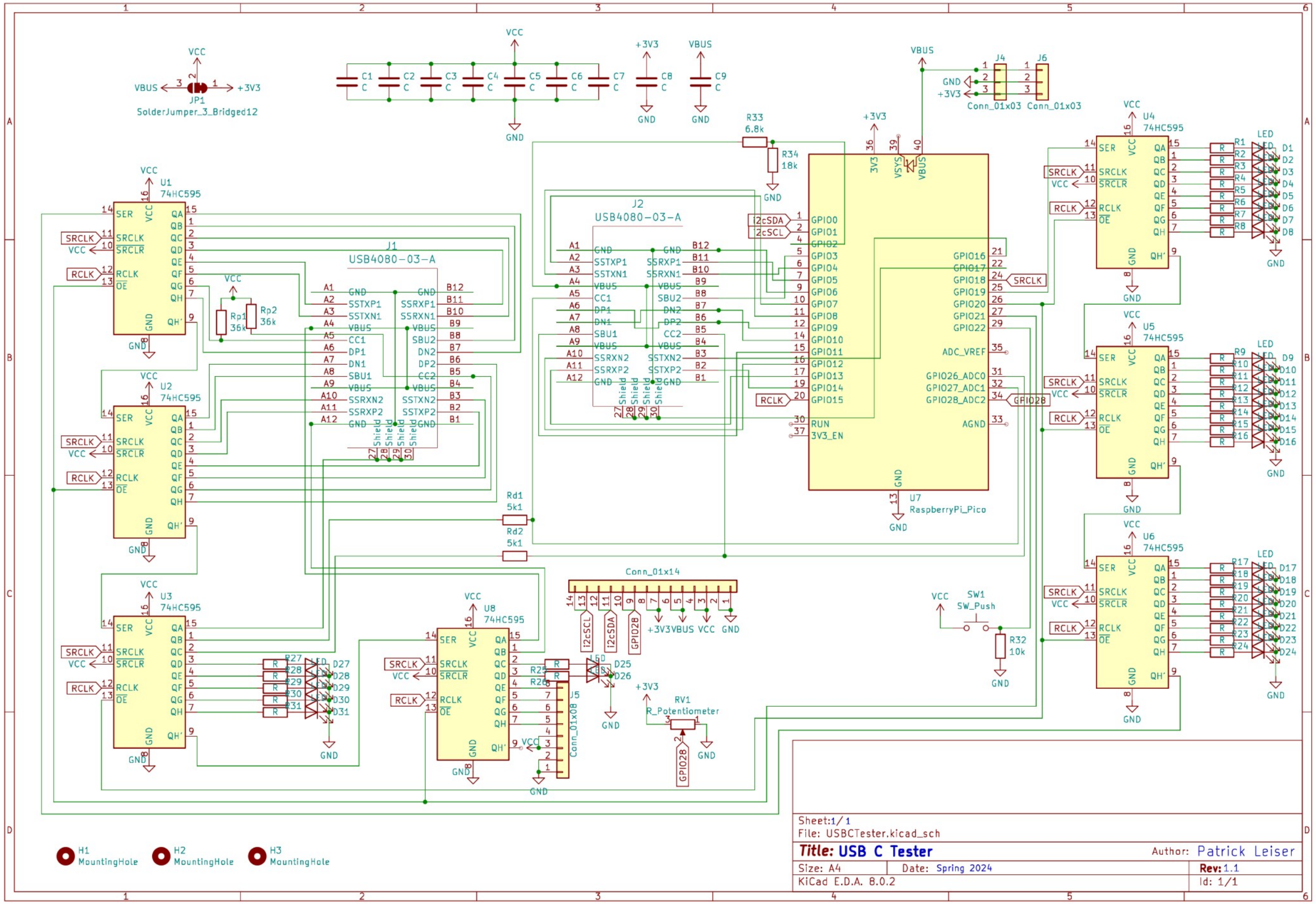
- How?
  - My design has 2 main approaches:
    - It negotiates power delivery from a power supply to determine supported voltages and currents
    - It tests every signal pin in another cable, and indicates which are connected properly



An early concept diagram, showing the basic interface of the device, with 3 USB ports for testing, and lots of indicator LEDs

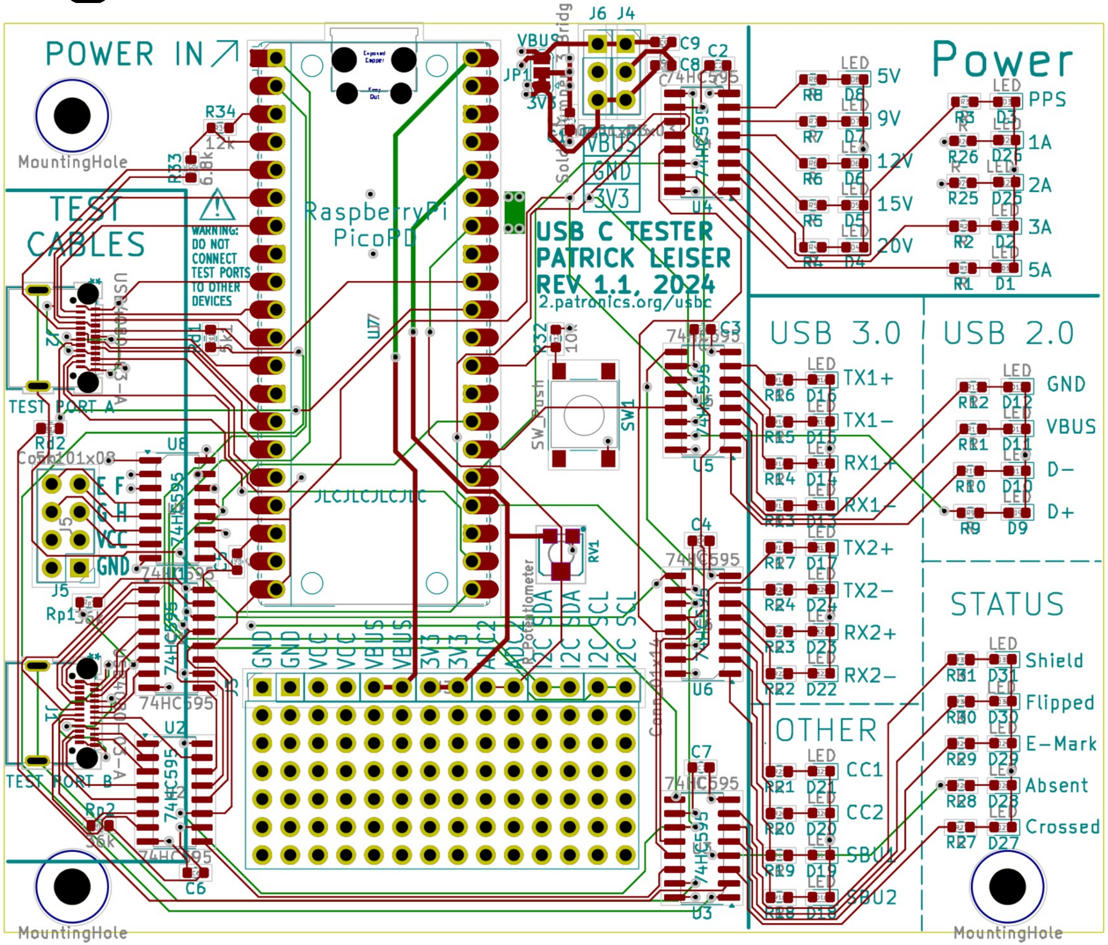
Designing

- I designed the circuit in KiCad, using a variant of the Raspberry Pi Pico as the controller, and 6-7 shift registers for controlling all the needed output signals
- See handout for more details on the hardware I chose and why I chose it



Designing - Part 2

- As I adjusted the schematic, I also designed the physical circuit board.
- I wanted to push myself to gain more experience with smaller surface-mount components, so used 0603 size (0.06 by 0.03 inch) components when possible

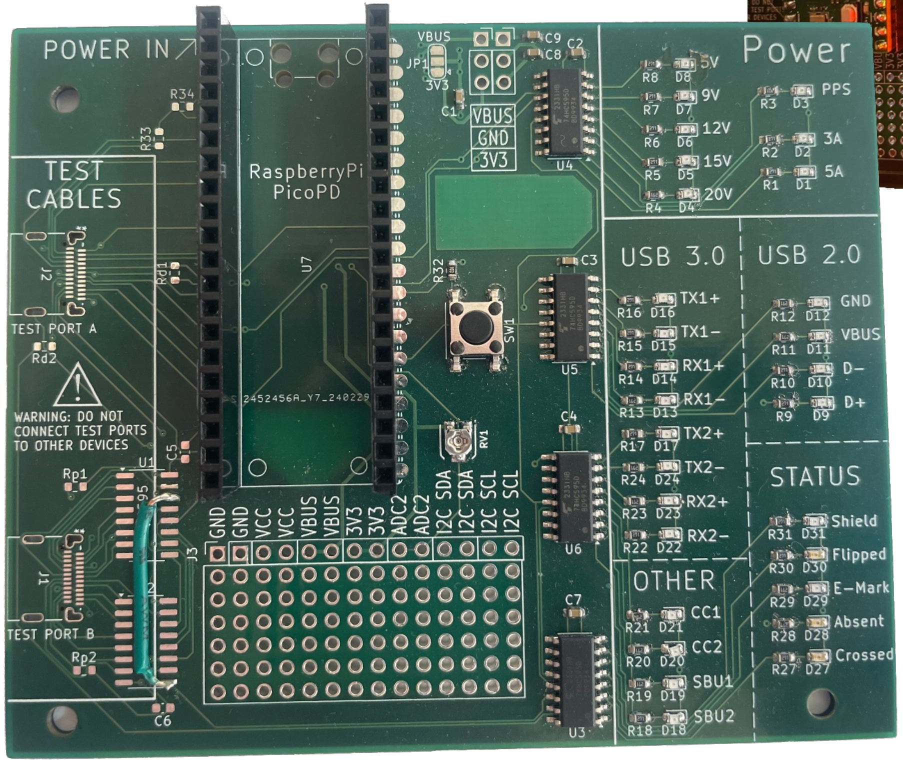


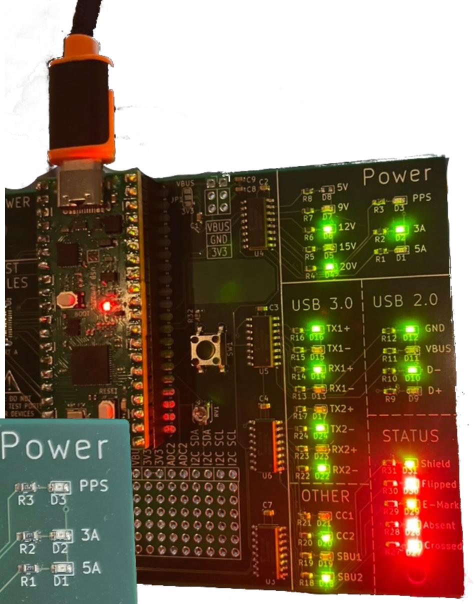
Cooking the circuit boards

- This project gave me the perfect excuse to finally finish a project I'd had on hold for a while, making my own reflow oven out of a toaster oven, removing my dependence on the one in the makerspace

Board 1

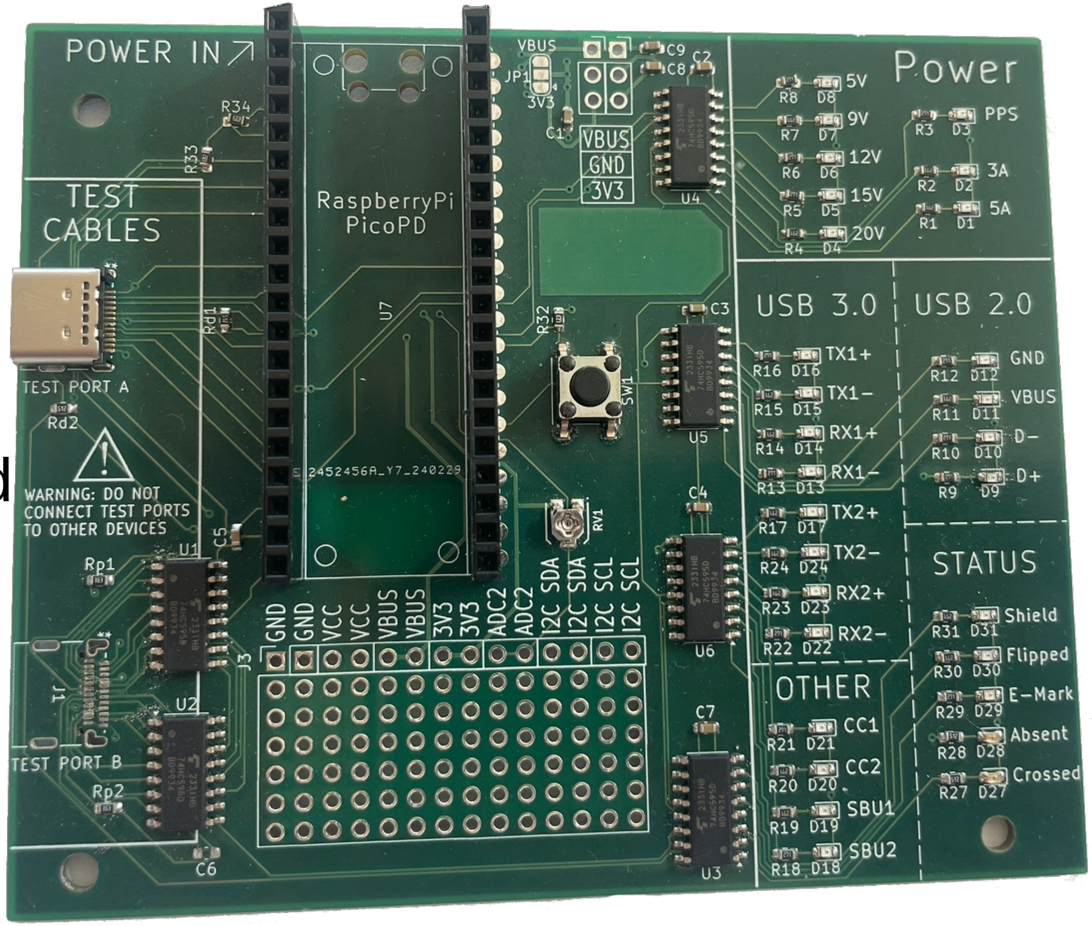
- LEDs worked great
- Decided not to add USB C ports to first test device
- “Green-wiring” required to workaround missing USB C port chips
- Minor printing flaws too





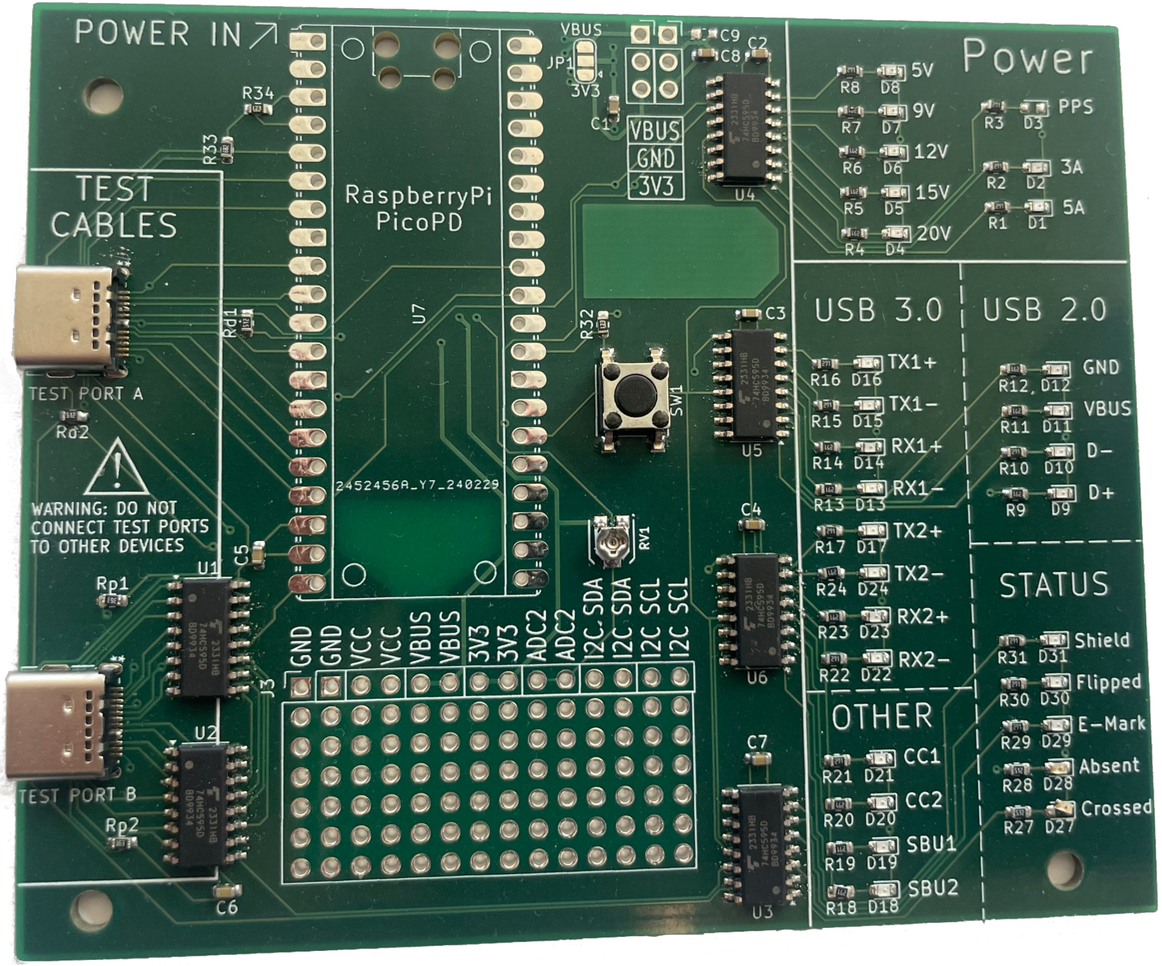
Board 2

- Same design, second soldering attempt
- Tried to solder USB C ports too
- Some pins shorted
- Port broke off
- Turns out Soldering 24 pin USB C ports is hard!



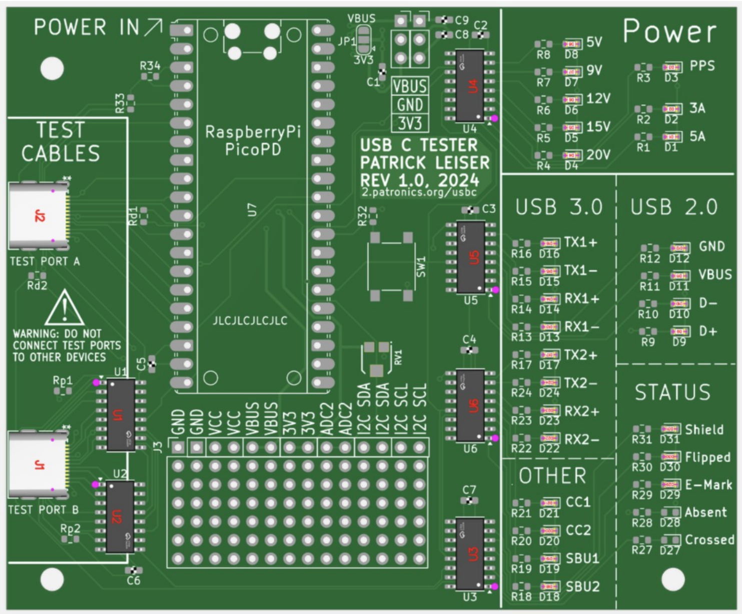
Board 3

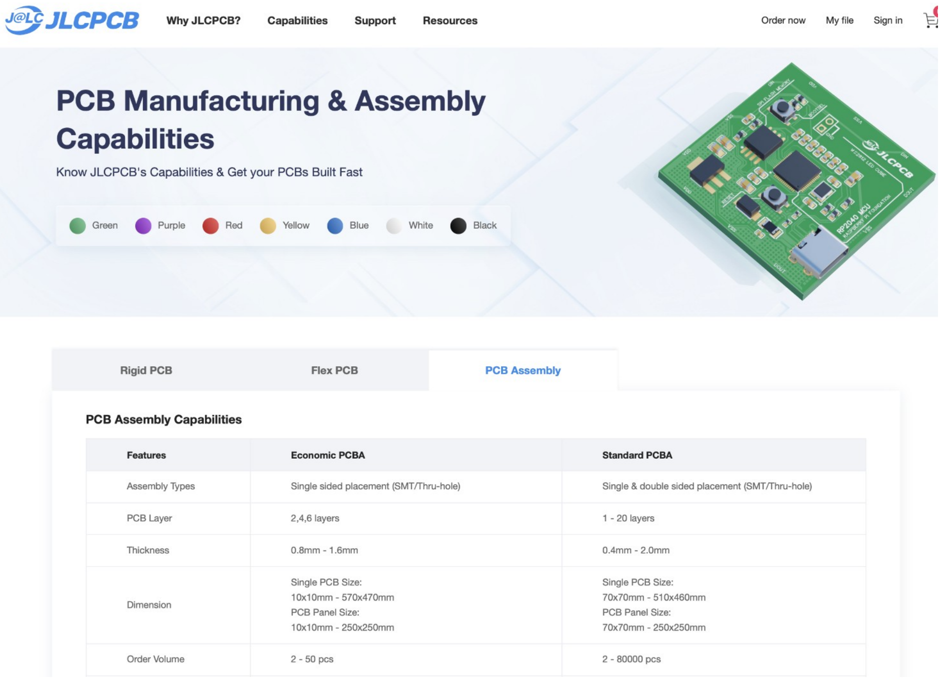
- Again, the small USB C Port connections had shorts between pins and wasn’t usable
- Clearly a different approach was needed...



Solution: Pay JLCPCB to make them for me!

Part Detail	Top Designator	Qty	Source	Ext. Price
TYPE-C 24P QT Extended C2681555	J1,J2	20	JLCPCB	$7.6800
XL-1608SYGC-06 Extended C965805	D1,D10,D11,D12,D13,D14,D15,D			
74HC595A Extended C110383				
GRM188R72A104KA35J Extended C3011705				

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PCB Manufacturing & Assembly Capabilities

Know JLCPCB's Capabilities & Get your PCBs Built Fast

Green   Purple   Red   Yellow   Blue   White   Black

Rigid PCB   Flex PCB   PCB Assembly

PCB Assembly Capabilities

Features	Economic PCBA	Standard PCBA
Assembly Types	Single sided placement (SMT/Thru-hole)	Single & double sided placement (SMT/Thru-hole)
PCB Layer	2,4,6 layers	1 - 20 layers
Thickness	0.8mm - 1.6mm	0.4mm - 2.0mm
Dimension	Single PCB Size: 10x10mm - 570x470mm PCB Panel Size: 10x10mm - 250x250mm	Single PCB Size: 70x70mm - 510x460mm PCB Panel Size: 70x70mm - 250x250mm
Order Volume	2 - 50 pcs	2 - 80000 pcs

Board 4/5: New Problems

- Boards with presoldered components arrived
- These presoldered components were chosen from LCSC’s parts catalog, so may not be identical but should be equivalent to the parts in the first set of prototypes
- But there’s a new problem
- LEDs don’t work! Neither do the new ports!
  - Why??

Time to do lots of testing, and dig into the datasheets

- All signals to the shift registers seemed to be transmitted fine
- But the shift registers we never outputting a high signal to the LEDs or other outputs?
- The datasheet indicated some features were missing (NC pins on next slide) on this shift-register variant, but those missing features could be worked around, that wasn't the issue
- Datasheets also weren't exactly the most legible...

深圳市富满电子集团股份有限公司
SHENZHEN FINE MAD ELECTRONICS GROUP CO., LTD.

74HC595A(文件编号：S&CIC1485) 显示屏驱动 IC

概述

74HC595A 是一款高速 CMOS 8 位串行移位寄存器，带有存储寄存器和低电平及高阻输出。移位寄存器和存储寄存器分别采用单独的时钟。在 SCK 的上升沿，数据发生移位，而在 RCK 的高电平时间内，数据从每个寄存器中传送到存储寄存器。

移位寄存器带有一个串行输入（SER）端和一个串行标准输出（Q7’）端，用于级联。74HC595A 存储寄存器带有 8 个总线驱动输出，数据输出方式为低电平及高阻态。

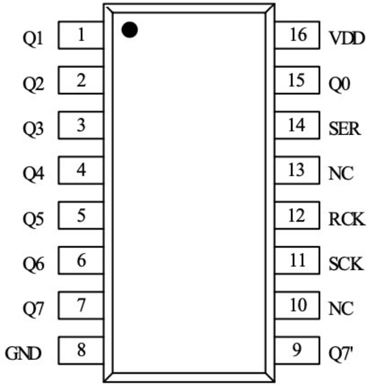
特点

- 采用 CMOS 工艺。
- 工作电压范围：3.0-5.0V。
- 高速移位时钟频率 Fmax＞25MHz。
- 串行输出可用于多个设备的级联。
- 封装形式：SOP-16。

产品应用

- LED 单色显示屏。

管脚定义及说明



SOP-16

管脚号	管脚名称	管脚说明
15，1-7	Q0-Q7	并行数据输出端
8	GND	逻辑地
9	Q7’	串行数据输出端
11	SCK	移位寄存器时钟，上升沿移位
12	RCK	锁存寄存器时钟，高电平存储
14	SER	串行数据输入端
16	VDD	逻辑电源
10，13	NC	悬空脚

- Unfortunately, I can’t read Chinese, and the website made it difficult to download a PDF to autotranslate. We’ll come back to this

- Finally, a breakthrough discovery:
  - When the shift register outputs were commanded low, the voltage measured between the output pins and ground was 0v (as expected), and the voltage between the output pin and the +3.3V supply was 3.3V, also as expected. However, measuring when the outputs were commanded high revealed that the voltage between BOTH ground to the output pin and +3.3V to the output pin were reporting as 0V!
  - Thinking about this unexpected result revealed the likely cause, which examining the translated manual confirmed

Translation of the datasheet’s summary

- 74HC595A (file number: S&CIC1485) Overview 74HC595A is a high-speed CMOS 8-bit serial shift register with storage registers and low-level and high-impedance output. The shift register and the storage register use separate clocks. At the rising edge of SCK, the data shifts, and in the high-level time of RCK, the data is transmitted from each register to the storage register. The shift register has a serial input (SER) end and a serial standard output (Q7') end for cascading. The 74HC595A storage register has 8 bus drive outputs, and the data output mode is low level and high resistance. The characteristics of the display drive IC adopt the CMOS process. Operating voltage range: 3.0-5. OV. High-speed shift clock frequency Fmax>25MHz. Serial output can be used for cascade of multiple devices. Encapsulation form: SOP-16. The product applies LED monochrome display.
- Can you see the problem?

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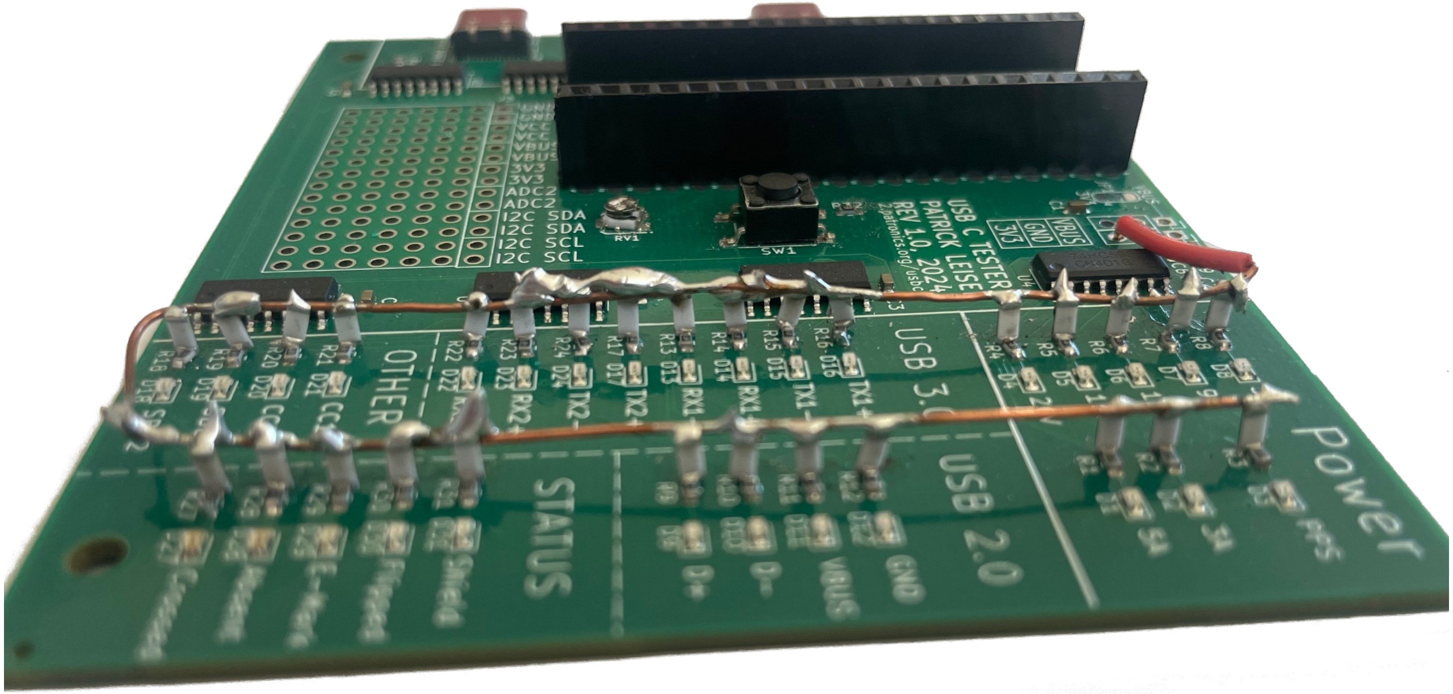
- Can you see the problem?
  - The output is either *Low level* or *High Resistance*
  - We generally call this “High Impedance” rather than High Resistance.
  - It’s open drain, no ability to pull the output high!

A hacky workaround

- Not content to give up on these boards yet (this was already the second $100+ batch), I brainstormed potential solutions
  - If I could pull up the output signals externally from the shift registers, it should still work
  - How to do that, within the existing constraints of the board design?

A hacky workaround

- How to do that, within the existing constraints of the design?



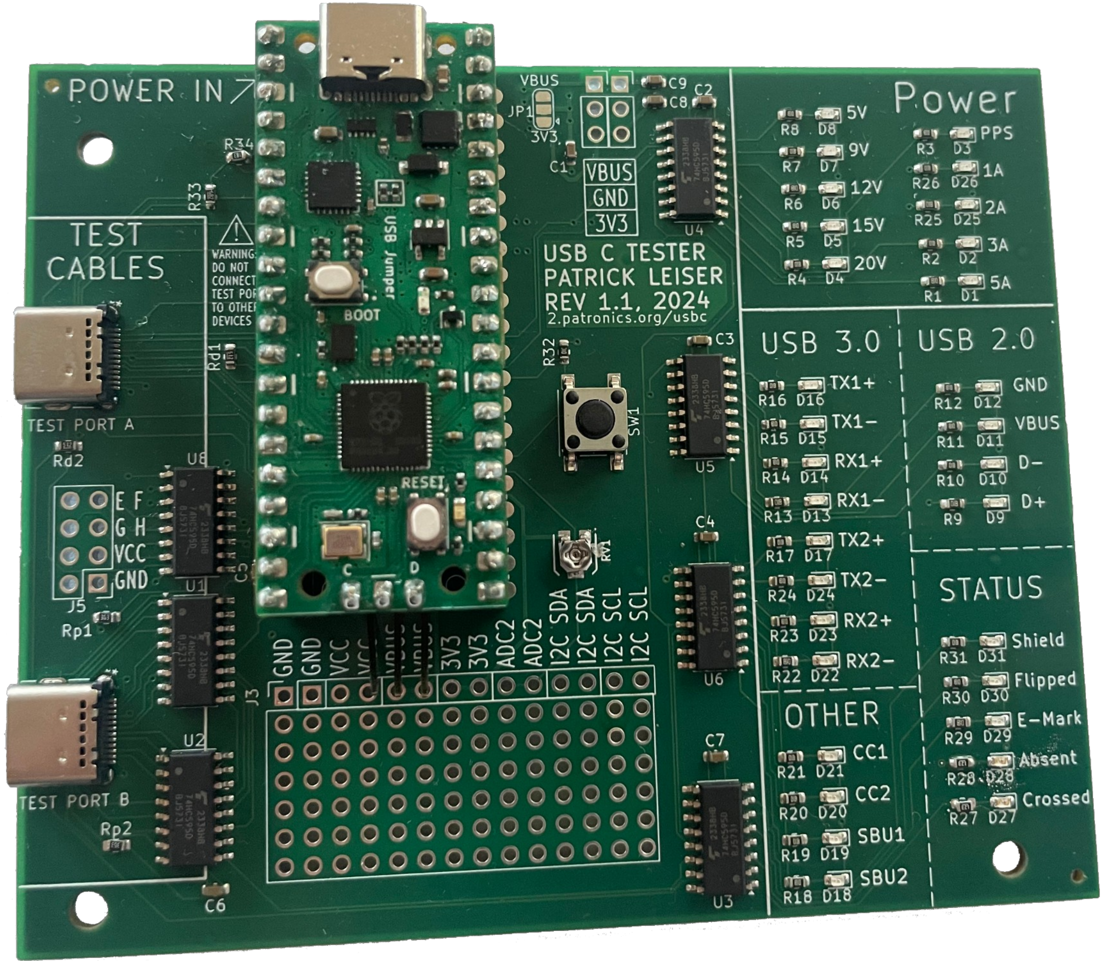
- Inspired by overhead power lines, I used leftover large surface-mount resistors from a previous project as pull-up resistors for the LEDs. This worked surprisingly well!

Revision 1.1 (The third batch)

- Unfortunately, the power-line inspired approach worked for the LEDs but not for the small connections for the USB C port, so another board revision was still required, this time with the exact same shift registers as the first generation board used (costing a whole $0.15 more per chip)
- I was able to do some basic testing with the 2nd batch despite the limitations, and found a few tweaks needed for the third board revision.
- These tweaks needed an additional shift register to drive a few more outputs, so the third batch of boards have that addition as well, with a few extra pins exposed for future use.

Revision 1.1 (The third batch)

- Works great!
- Just had to write the code to actually do the test of each pin

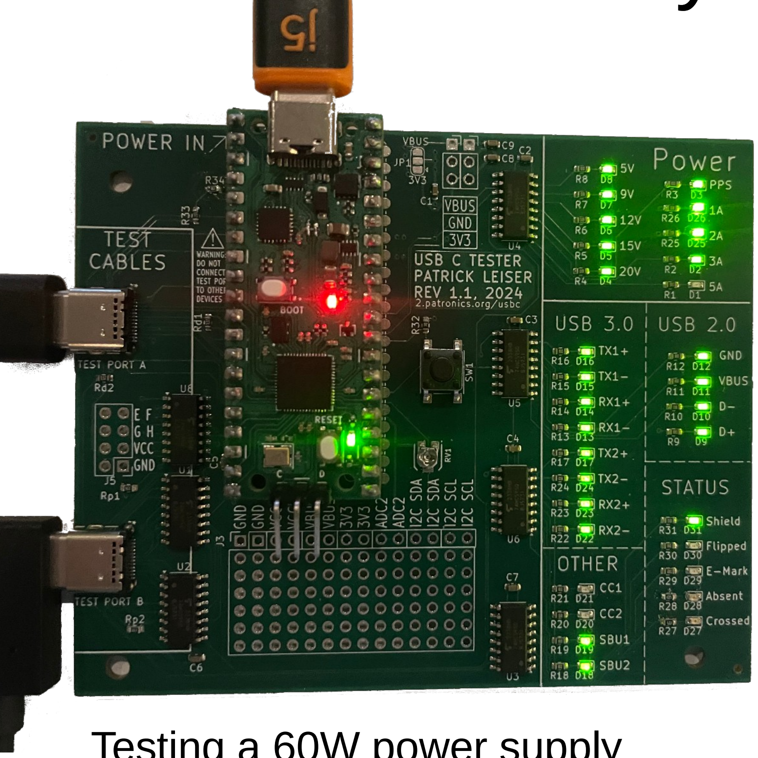


The Code

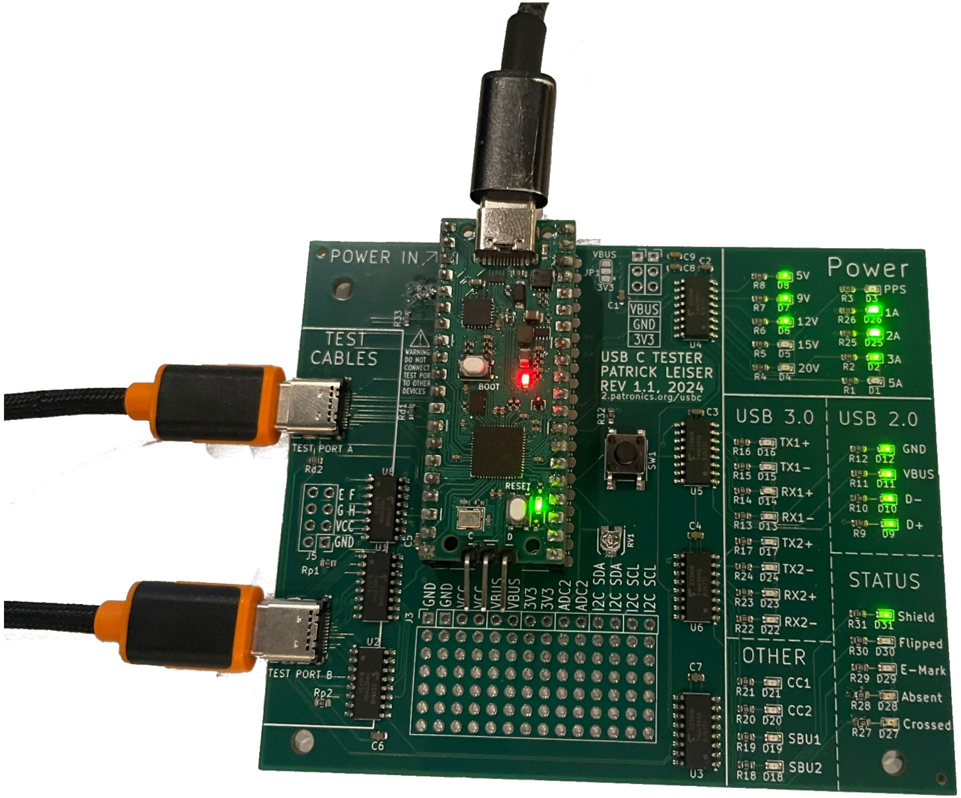
- The final version of the code turned out to be around 590 lines long, much too long to reproduce here.
- You can access it, along with the hardware design files (and this presentation) on my Github, at github.com/Patronics/USBC-Tester

Results

- It works really well!



Testing a 60W power supply and full-featured USB-C cable



Testing a 20W power supply and a USB-C cable that only supports USB2.0

In the interest of time I’m not going to cover these additional challenges and details in depth, but any questions are welcome :)

- High – impedance output mode for the good shift registers
  - The two “Zones” I used for that, and how that split was essential for testing the USB Ground and Shield pins
- Timing and voltage drop challenges
  - One particular cable seemed to indicate power was disconnected in my tests, when that cable clearly worked with other devices, I needed to increase time delays and substitute a pull-down resistor to fix this
- Adding features to the upstream Power Delivery library to add the ability to test current limits at each voltage level
- “Soft-Bricking” my Pi Pico, and designing my own PicoProbe boards to enable easier debugging of this and similar issues in the future
  - And etching the first one of these PicoProbe boards on my CNC machine

In the interest of time I’m not going to cover these additional challenges and details in depth, but any questions are welcome :)

- Daisy-chaining the shift registers
- Programmatically converting the hardware order of pins to more friendly software-order
- Focusing on abstraction and overloading to simplify code
- Protecting against common misuse of connecting to wrong USB port with voltage dividers
- Designing with future projects in mind
  - button and potentiometer included for use as a configurable USB PD power supply
- Prototyping board space at the bottom, and with breaking out available I/O and power pins
- Displaying software version information at boot to disambiguate between boards

Other boards I designed to help with the project

- PicoProbe Debugging Board
- USB C Breakout