Elior Bilow
2025-11-09
ECEN 5730 – PCB Design
CU Boulder
Board 3 Report

Project Overview:

POR:

1. Rough Schematic / Block Diagram

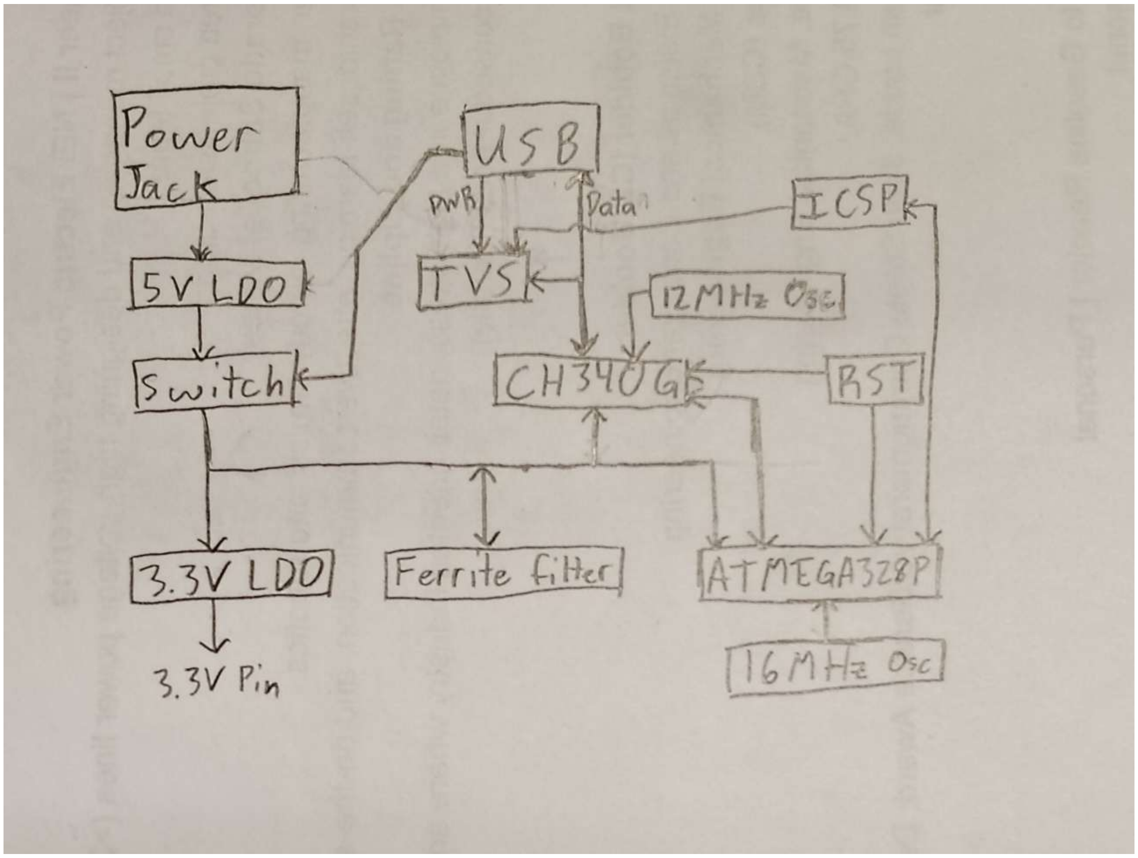


Figure 1: Block Diagram

2. Significant Parts
    a. 3.3V LDO (AMS1117-3.3. SOT-223 package)
    b. ATMEGA328P
    c. CH340g
    d. 16MHz and 12MHz Oscillators
    e. TVS Chip
    f. USB Connector
3. Definition of "Working"
    a. The board can communicate with Arduino IDE
    b. The board can execute the "blink" example.
    c. The board protects against overvoltage and reverse polarity.
    d. The board can accommodate a typical Arduino shield

   e. Ability to bootload the ATMEGA328P without removing the chip
   f. Board noise is reduced by 20%-50% as compared to the commercial VELLEMAN Arduino Uno
4. Schedule
   a. 2025-10-16 – POR
   b. 2025-10-20 – CDR
   c. 2025-11-05 – Assembly and test
   d. 2025-10-10 – Report
5. Test plan
   a. Test fit-up
      i. See if the provided power board shield fits on the new board
   b. Power-on
      i. Plug in 5V, ensure it lights the power on LED
      ii. Plug in the USB, ensure it lights the power on LED
   c. SPI and bootloading
      i. Perform Lab 10, utilizing the ICSP port
   d. Communicate with Arduino IDE, load "blink"
      i. Connect to a computer with USB, flash "blink"
   e. Test board noise
      i. Probe "blink" pin on the board and on a commercial Arduino. Compare overshoot and settle time.
      ii. Probe power rail when "blink" is running. Analyze power rail collapse and ground bounce.
6. Power budget and supply
   a. Power brick can supply 5V @ 0.2A
   b. Power brick can supply 9V @ 1A
   c. USB 2.0 can supply 5V @ 0.5A
   d. USB C can supply 5V @ 0.6A
   e. The power draw of a traditional Arduino is less than 0.4A if all pins are powered and drawing their maximum current. In these conditions, the power brick may fail to deliver enough power, but the USB ports should be able to cover it.
7. Potential risk sites
   a. Incorrect clock configuration
   b. Incorrect serial configuration (namely flipping TX and RX)
   c. Incorrect placement of pins such that the custom board is not compatible with traditional Arduino Uno shield modules

Altium Schematic:

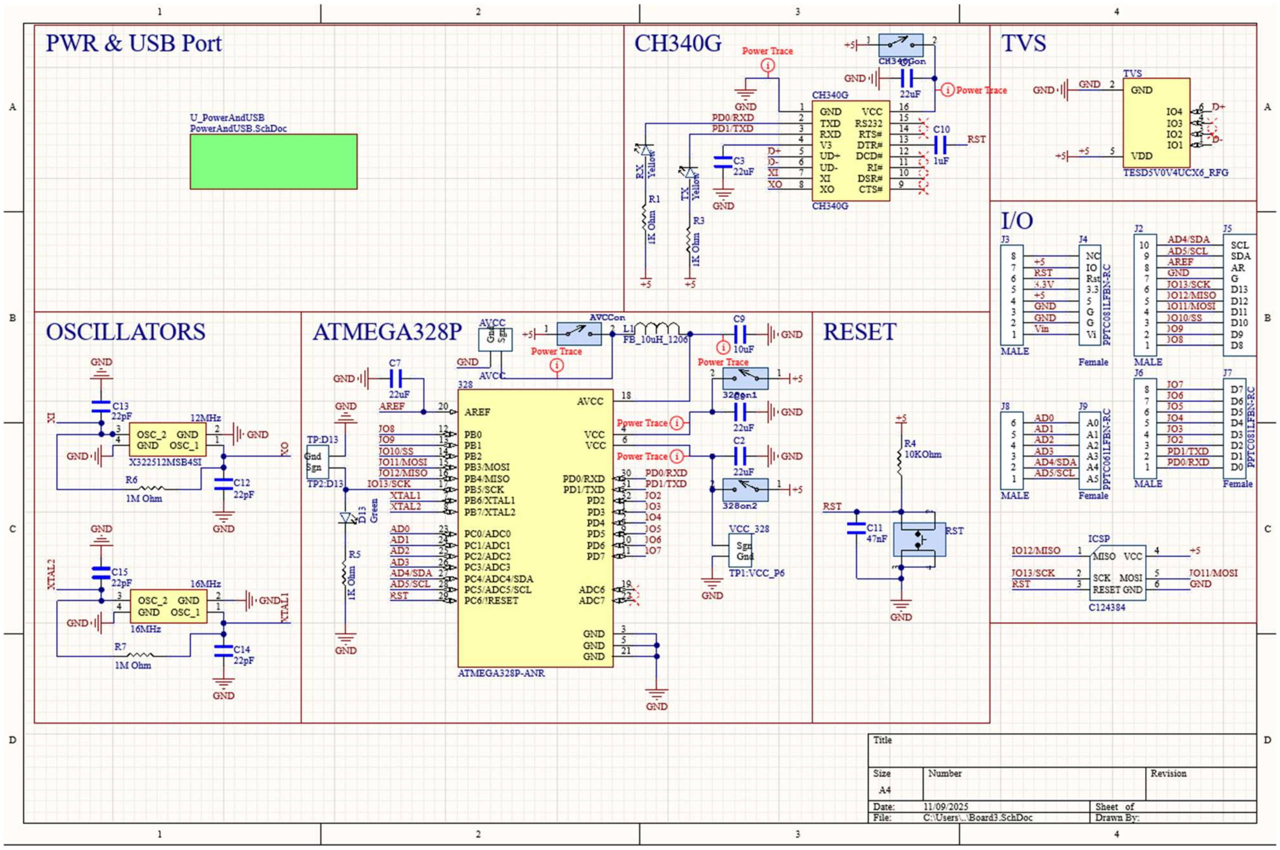


Figure 2 Main schematic

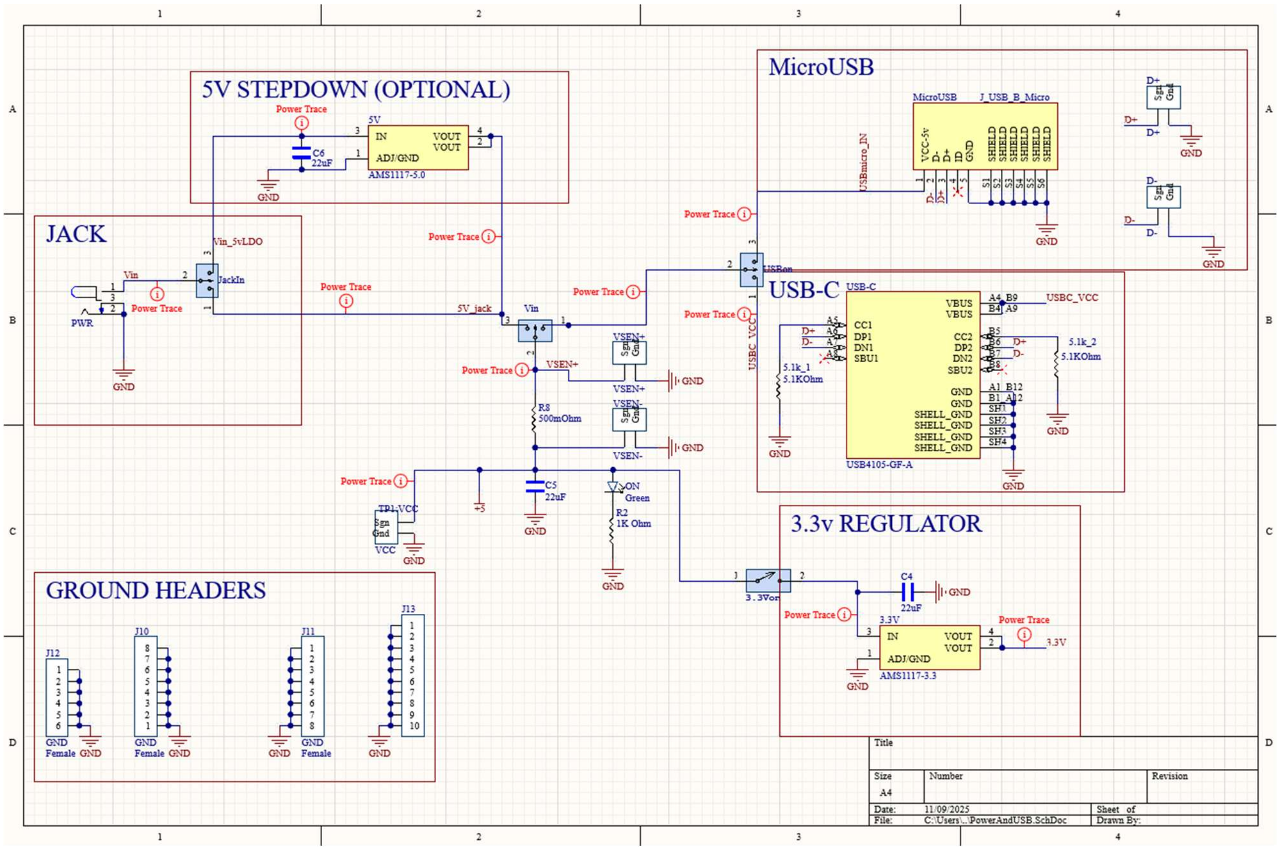


Figure 3: Power and USB schematic.

Board Layout:

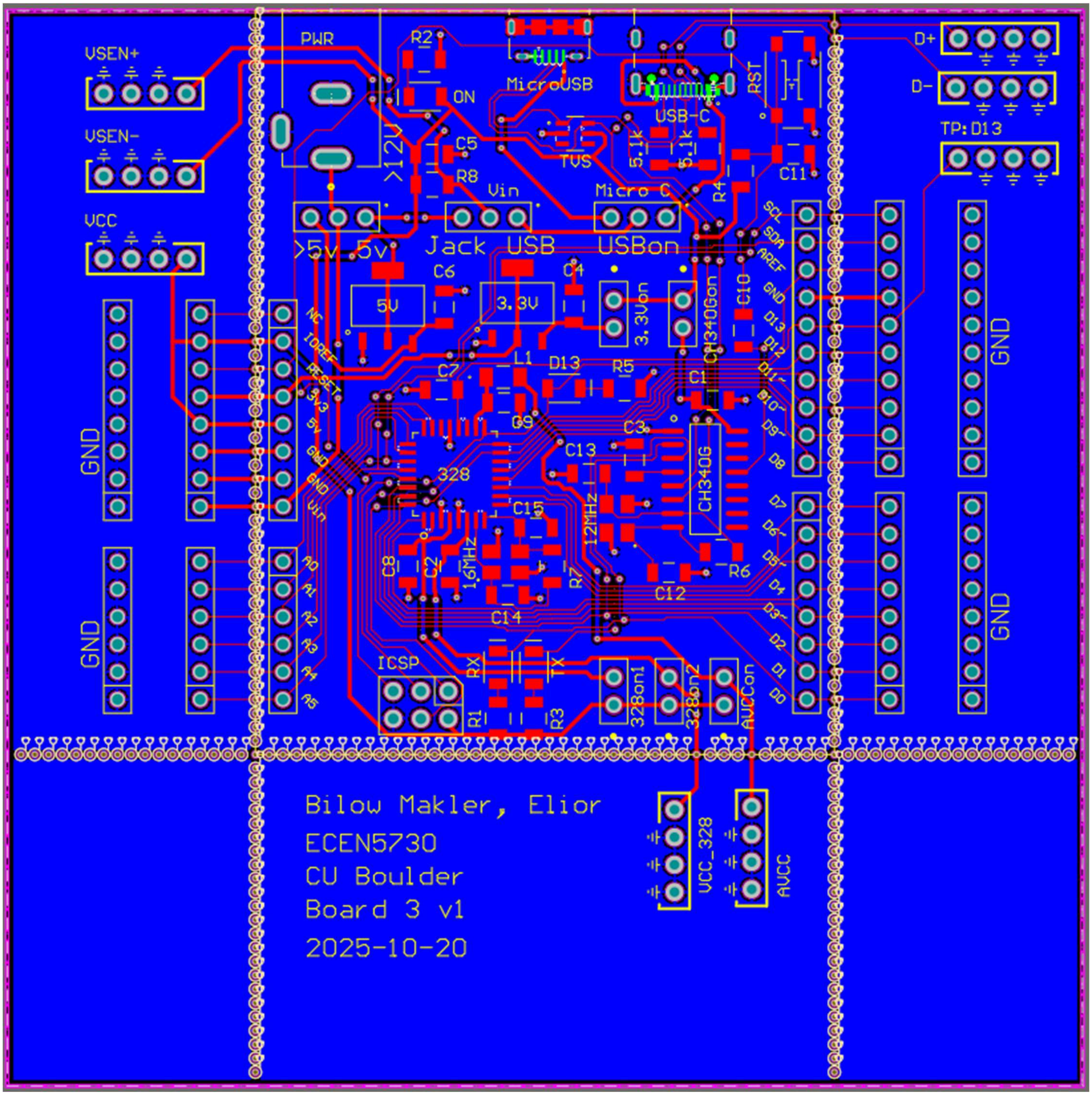


Figure 4: Board Layout

Picture of Bare Board:

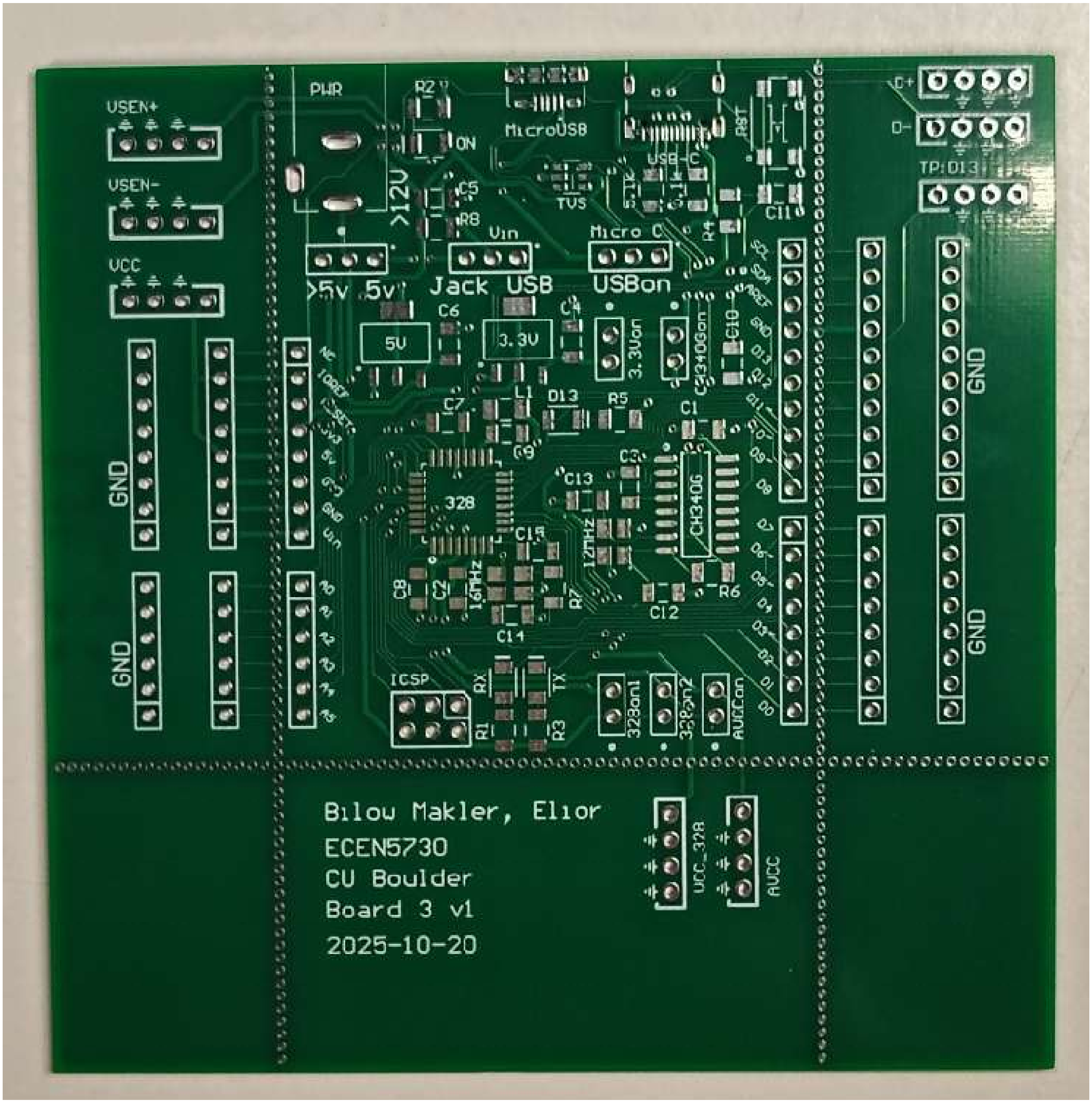


Figure 5: Bare PCB received from the board manufacturer.

Picture of Assembled Board:

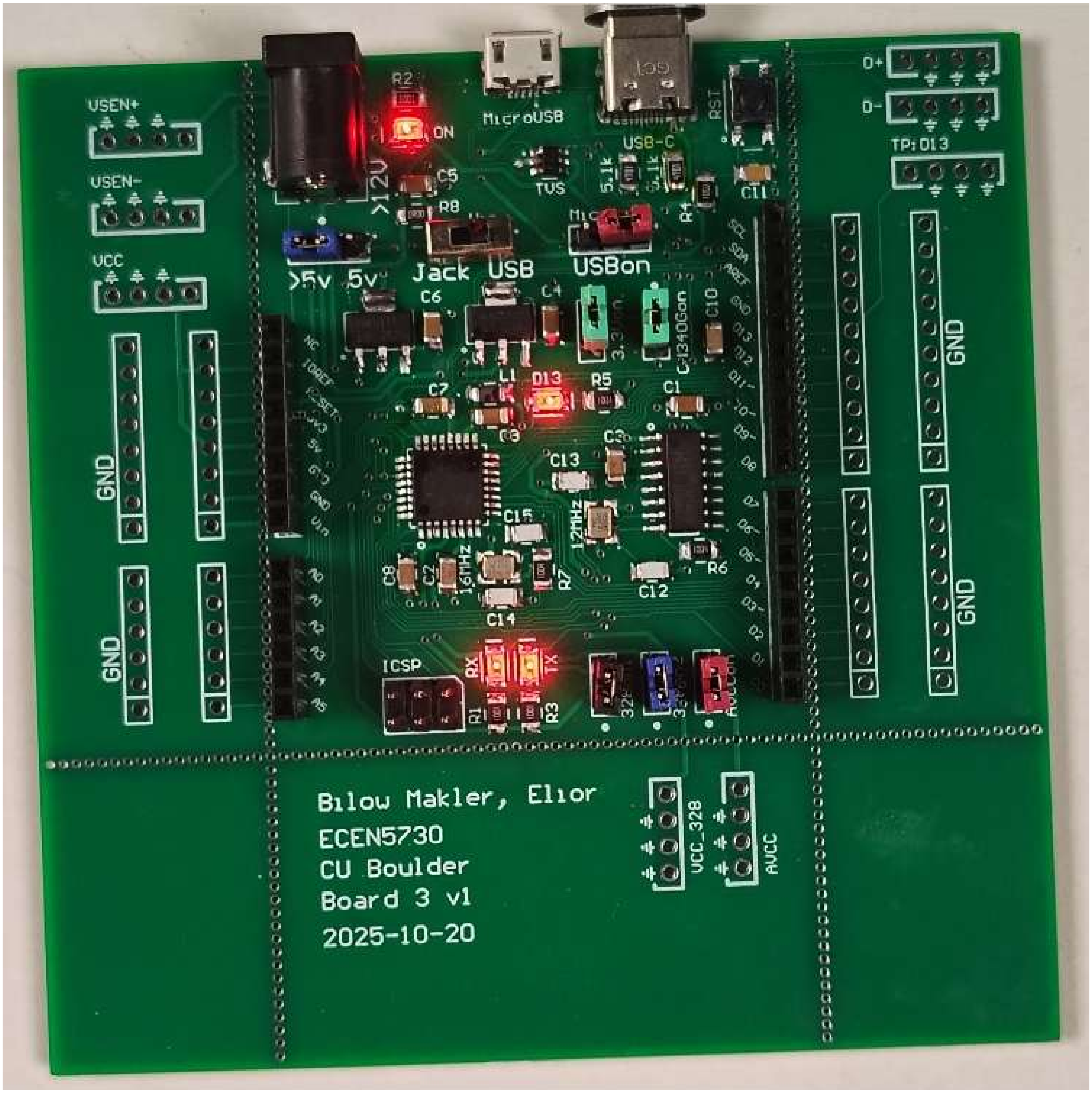


Figure 6: Assembled board powered on

Testing and Validation (What Worked):

There was very little debugging to perform in order to get the board running. Initially, I didn't install SMD resistors for the USB-C port and was unable to connect or power on the board while using a USB-C to USB-C cable. I soldered on some temporary jumper wires to put in 4.7kΩ through-hole resistors because we had SMD resistors of that size to test if it made the USB-C port work. With the temporary resistors, the USB-C to USB-C cable worked, so I removed the temporary jumper wires and added two 4.7kΩ SMD resistors (which is close to the spec of 5.1kΩ resistors), the board functioned with the USB-C to USB-C cable perfectly.

After soldering the board, I was able to bootload it using the ICSP pins without a problem. I was then able to upload the "blink" sketch to the board from Arduino IDE on my computer and it ran flawlessly using both the USB-C and micro-USB ports.

Overvoltage testing was performed by connecting to the 9V power supply directly (as opposed to through the LDO). Under these conditions, the TVS got hot, but otherwise the board performed as normal. This suggests that the TVS functions as intended. Static discharge testing was not performed.

Comparison with commercial board:

Various parameters of the board were tested against a commercially available Arduino board with the use of a cross-talk circuit and a slammer circuit. The board that was compared to was the ELEGOO UNO R3. Results for these tests are summarized in table 1, with pictures of the tests apparatus and discussion provided on the following pages. Note that all measurements were averages across 32 samples unless otherwise noted.

Test	Measurement	units	Commercial	Golden	performance boost (%)
Switching (rising edge)	Switch rise	ns	5.243	5.686	-8.4
	Switch Pk-Pk	V	4.66	4.78	-2.6
	Q_Low Pk-Pk	mV	340	320	5.9
	Q_High Pk-Pk	mV	560	410	26.8
	5V rail noise	mV	70	40	42.9
Switching (falling edge)	Switch fall	ns	6.697	5.551	17.1
	Switch Pk-Pk	V	5.16	5.01	2.9
	Q_Low Pk-Pk	mV	1470	1180	19.7
	Q_High Pk-Pk	mV	620	670	-8.1
	5V rail noise	mV	210	100	52.4
Slammer	Switch rise	ns	21.036	25.39	-20.7
	Switch Pk-Pk	V	3.62	3.89	-7.5
	Q_Low Pk-Pk	mV	23	160	-595.7
	Q_High Pk-Pk	mV	42	270	-542.9
	5V rail noise	mV	650	1460	-124.6
RF	Switch rise	ns	22.114	25.12	-13.6
	Switch Pk-Pk	V	3.68	3.89	-5.7
	RF (below)	mV	70	12	82.9
	RF (above)	mV	21	20	4.8
	5V rail noise	mV	700	1520	-117.1

Table 1: Commercial vs "Golden" Arduino test results

Switching noise:

In the switching noise (crosstalk) test on the leading edge, the "Golden" Arduino only performed slightly better in most cases. While the rise time was slightly longer (8.4%), the quiet low and quiet high noise were reduced by 5.9% and 26.8% respectively, suggesting that the ground plane aided in decoupling. The effect of decoupling capacitors is also seen as a reduction in power rail noise by 42.9%. Results were similar for the falling edge, though the fall time was shorter for the "Golden" Aduino by 17.1%.

Figure 7: Switching noise test setup, "Golden" Arduino

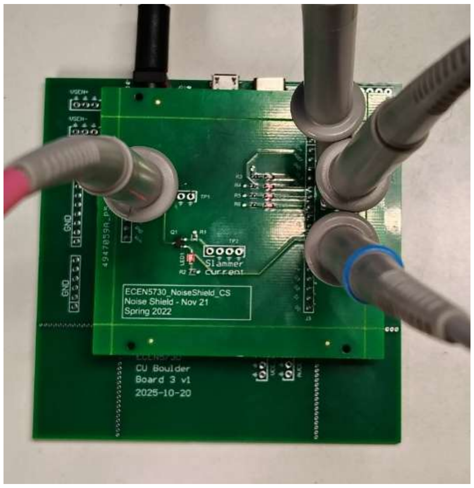


Figure 8: Switching noise test setup, commercial Arduino

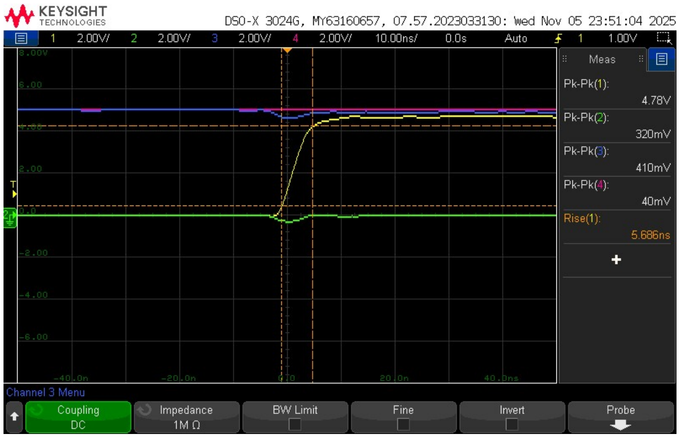


Figure 9: Switching noise, "Golden" Arduino, rising edge (yellow: D13, blue: quiet high, green: quiet low, pink: 5V rail)

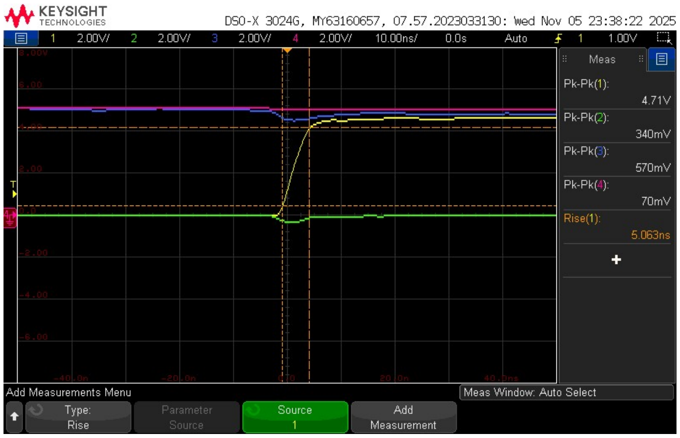
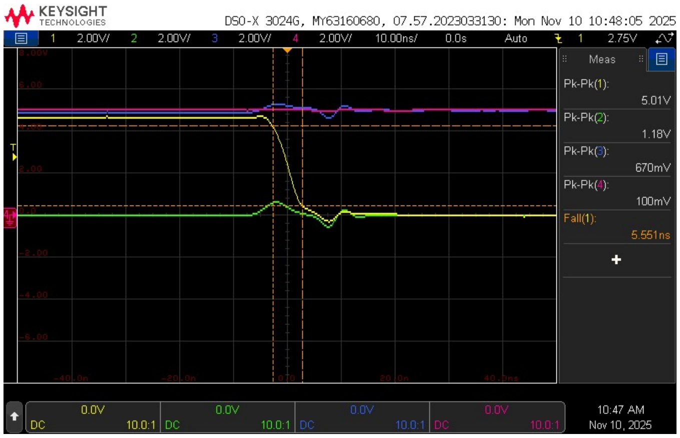


Figure 10: Switching noise, commercial Arduino, rising edge (yellow: D13, blue: quiet high, green: quiet low, pink: 5V rail)



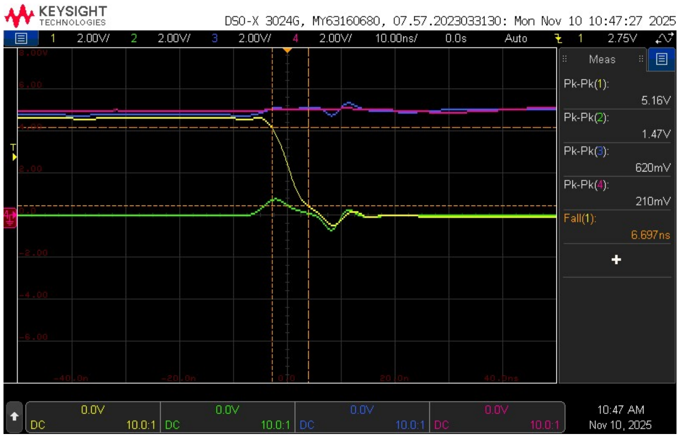


Figure 11: Switching noise, "Golden" Arduino, falling edge (yellow: D13, blue: quiet high, green: quiet low, pink: 5V rail)

Figure 12: Switching noise, commercial Arduino, falling edge (yellow: D13, blue: quiet high, green: quiet low, pink: 5V rail)

Slammer circuit and 5V rail collapse:

However, the commercial board performed much better with the slammer circuit under every metric. This is likely because the decoupling capacitor for the 5V rail was far away from the 5V pin and its measuring point, whereas on the commercial board there were many capacitors near the 5V pin. When the slammer circuit was turned on, noise was similar between the 5V rail test point and the die since they were measuring near the same point, but the collapse was significantly smaller (89.4%) at the test point for the 5V rail at the ATMEGA328P Vcc pin, likely due to the decoupling capacitor at that location and showcasing their effectiveness.

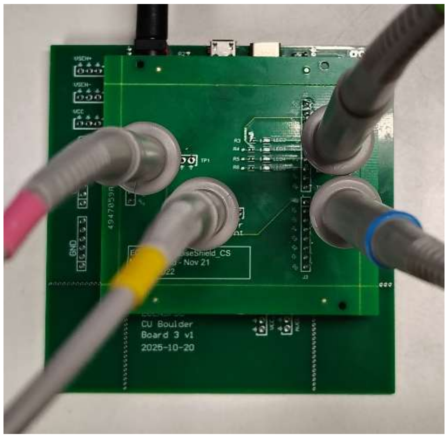


Figure 13: Slammer circuit test setup, "Golden" Arduino

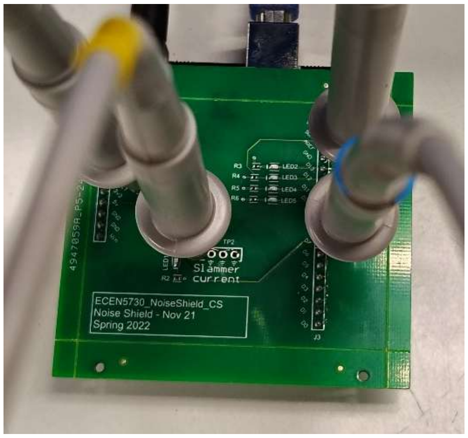
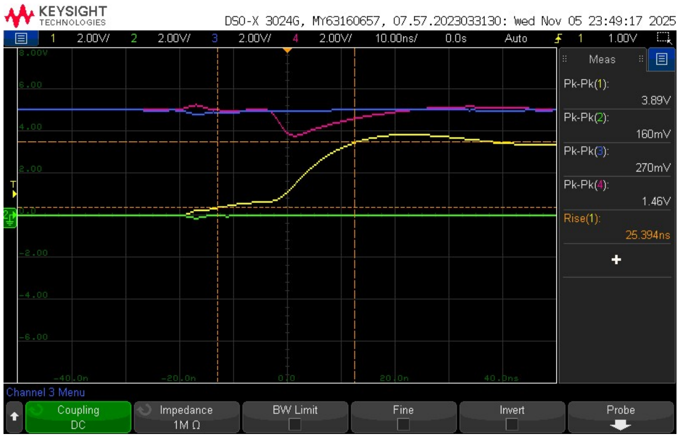


Figure 14: Slammer circuit test setup, commercial Arduino

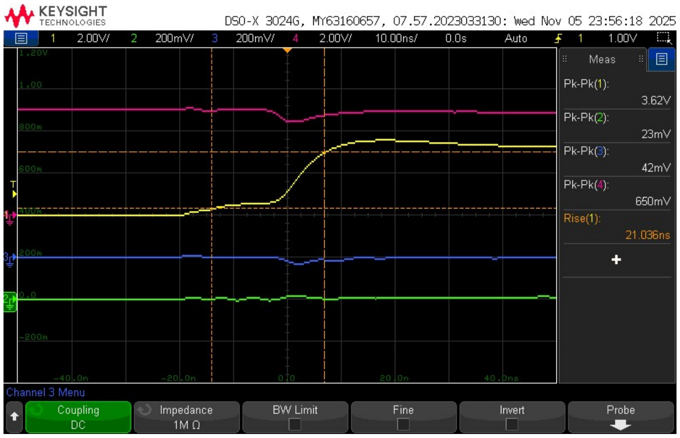


DSO-X 3024G, MY63160657, 07.57.2023033130: Wed Nov 05 23:49:17 2025

1 2.00V/ 2 2.00V/ 3 2.00V/ 4 2.00V/ 10.00ns/ 0.0s Auto 1 1.00V

Meas
Pk-Pk(1): 3.89V
Pk-Pk(2): 160mV
Pk-Pk(3): 270mV
Pk-Pk(4): 1.46V
Rise(1): 25.394ns

Figure 15: 5V rail collapse, "Golden" Arduino (yellow: slammer output, blue: quiet high, green: quiet low, pink: 5V rail @ die)



DSO-X 3024G, MY63160657, 07.57.2023033130: Wed Nov 05 23:56:18 2025

1 2.00V/ 2 200mV/ 3 200mV/ 4 2.00V/ 10.00ns/ 0.0s Auto 1 1.00V

Meas
Pk-Pk(1): 3.62V
Pk-Pk(2): 23mV
Pk-Pk(3): 42mV
Pk-Pk(4): 650mV
Rise(1): 21.036ns

Figure 16: 5V rail collapse, commercial Arduino (yellow: slammer output, blue: quiet high, green: quiet low, pink: 5V rail @ die)

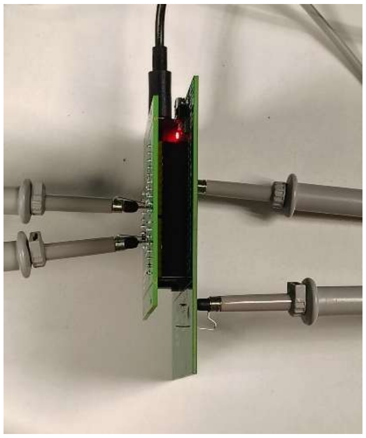
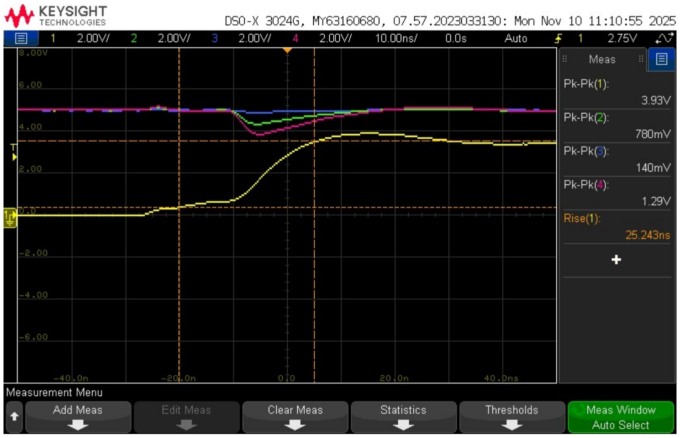


Figure 17: 5V rail collapse, "Golden" Arduino, die vs. board, test setup (yellow: D13, blue: quiet high, green: quiet low, pink: 5V rail)



DSO-X 3024G, MY63160680, 07.57.2023033130: Mon Nov 10 11:10:55 2025

1 2.00V/ 2 2.00V/ 3 2.00V/ 4 2.00V/ 10.00ns/ 0.0s Auto 1 2.75V

Meas
Pk-Pk(1): 3.93V
Pk-Pk(2): 780mV
Pk-Pk(3): 140mV
Pk-Pk(4): 1.29V
Rise(1): 25.243ns

Figure 18: 5V rail collapse, "Golden" Arduino, die vs. board, measurements (yellow: slammer output, blue: Vcc@328, green: Vcc@5V pin, pink: Vcc@die)

Near-field emissions:

In the near-field emissions test, the poor placement of the 5V rail decoupling capacitor is seen again in the worse 5V rail noise parameter, but the near field emissions were reduced, especially when measured directly below the board by about 82.9%.

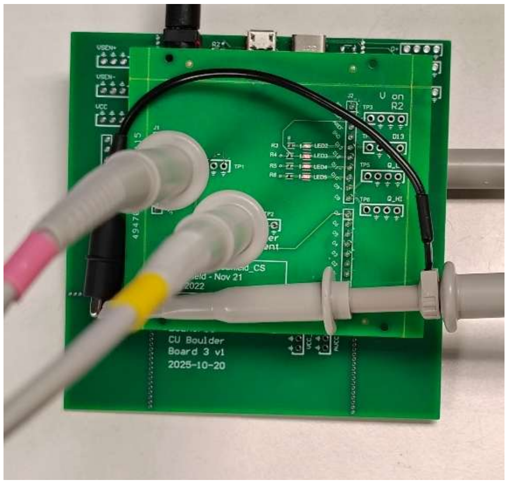


Figure 19: Near field emissions test setup, "Golden" Arduino

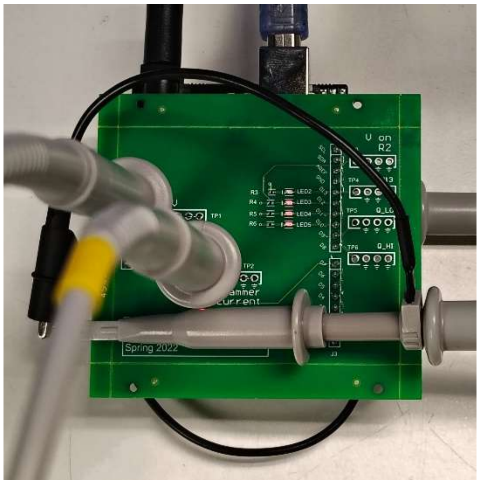
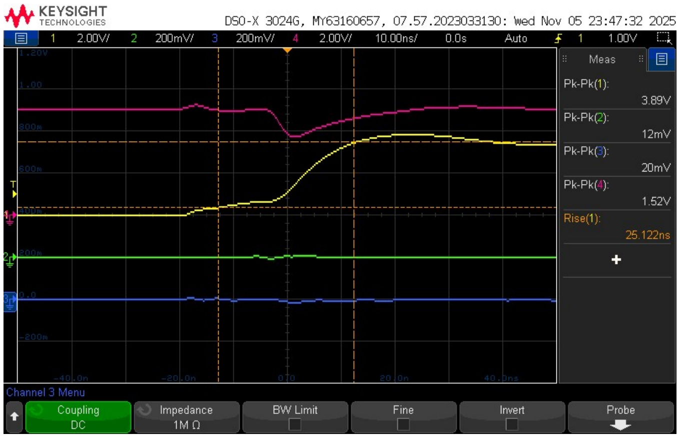
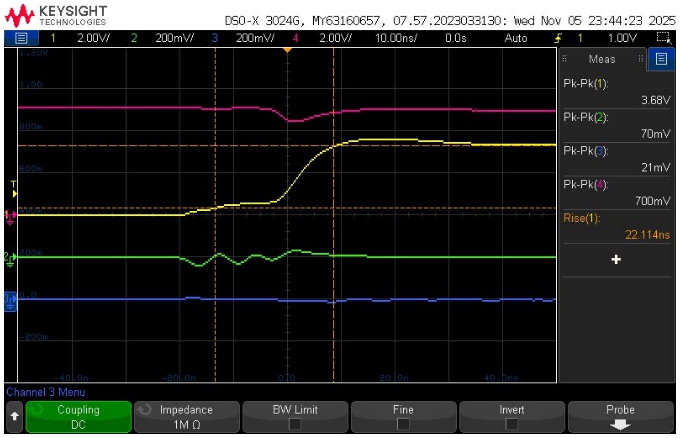


Figure 20: Near field emissions test setup, commercial Arduino



```
DSO-X 3024G, MY63160657, 07.57.2023033130: Wed Nov 05 23:47:32 2025
1  2.00V/  2  200mV/  3  200mV/  4  2.00V/  10.00ns/  0.0s  Auto  1  1.00V
Pk-Pk(1): 3.89V
Pk-Pk(2): 12mV
Pk-Pk(3): 20mV
Pk-Pk(4): 1.52V
Rise(1): 25.122ns
Channel 3 Menu
Coupling DC  Impedance 1M Ω
```

Figure 21: Near field emissions results, "Golden" Arduino (yellow: slammer output, blue: quiet high, green: quiet low, pink: 5V rail @ die)



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DSO-X 3024G, MY63160657, 07.57.2023033130: Wed Nov 05 23:44:23 2025
1  2.00V/  2  200mV/  3  200mV/  4  2.00V/  10.00ns/  0.0s  Auto  1  1.00V
Pk-Pk(1): 3.68V
Pk-Pk(2): 70mV
Pk-Pk(3): 21mV
Pk-Pk(4): 700mV
Rise(1): 22.114ns
Channel 3 Menu
Coupling DC  Impedance 1M Ω
```

Figure 22: Near field emissions results, commercial Arduino (yellow: slammer output, blue: quiet high, green: quiet low, pink: 5V rail @ die)

Thevenin resistance:

When testing the slammer circuit while powered with a 9V adapter through the barrel jack, 339.1mA were flowing through the 5V rail. At steady-state, the voltage of the 5V rail was 5.060V with a current draw of 35.9mA. Under a the load of the slammer (339.1mA), the voltage dropped to 4.706V. This suggests that the 5V rail of the “Golden” Arduino has a Thevenin resistance of 1.168Ω when powered via the 5V LDO.

$$R_{th} = \frac{v_{o,1} - v_{o,2}}{i_{o,2} - i_{o,1}}$$

Equation 1: Thevenin resistance calculation

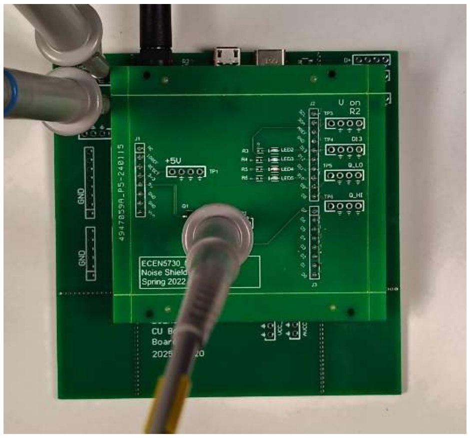
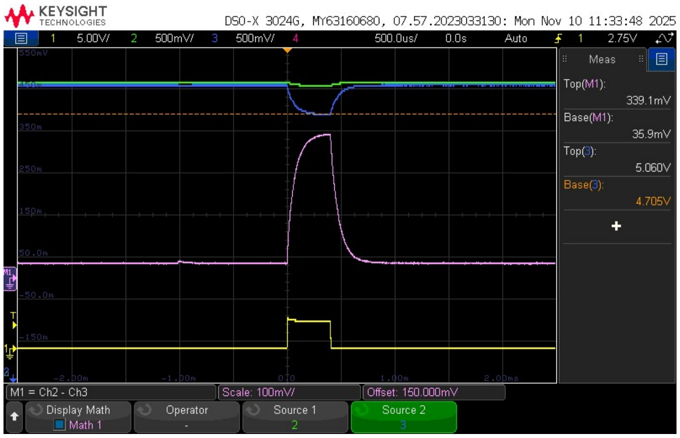


Figure 23: Thevenin resistance test setup


DSO-X 3024G, MY63160680, 07.57.2023033130: Mon Nov 10 11:33:48 2025

Top(M1): 339.1mV
Base(M1): 35.9mV
Top(3): 5.060V
Base(3): 4.705V

M1 = Ch2 - Ch3
Scale: 100mV/
Offset: 150.000mV

Figure 24: Thevenin resistance scope shots. R_{sen}=1Ω. (yellow: slammer output, blue: VSEN-, green: VSEN+, purple: VSEN+ minus VSEN-)

Thevenin resistance:

These measurements were not averaged over 32 samples like all of the other measurements in this lab.

The maximum inrush current was 4.3438A. This was measured by capturing the voltage across a 1Ω sense resistor right after the board was plugged in. The sense resistor is after the 5V LDO, so it does not account for any inrush current upstream of that component. However, I would expect the same inrush current if I were using a 5V power supply and bypassing the 5V LDO.

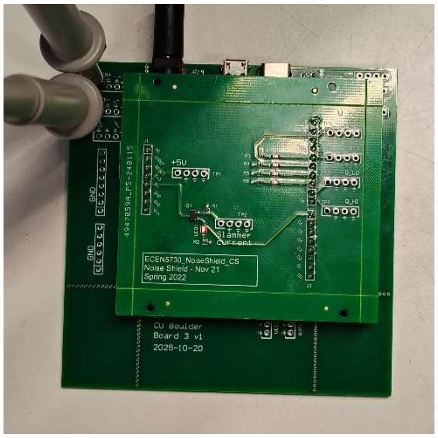
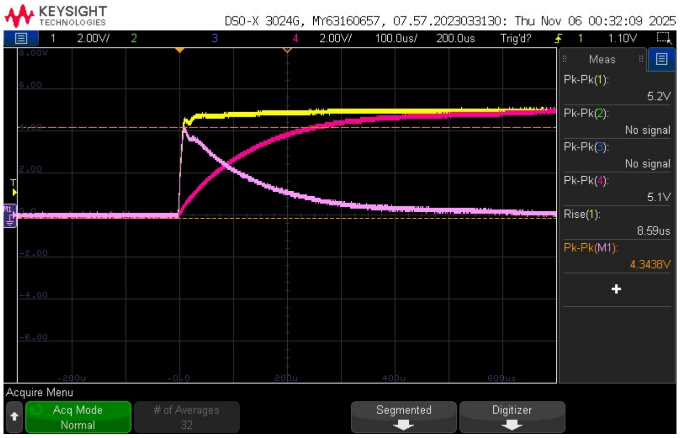


Figure 25: Thevenin resistance test setup


DSO-X 3024G, MY63160657, 07.57.2023033130: Thu Nov 06 00:32:09 2025

Pk-Pk(1): 5.2V
Pk-Pk(2): No signal
Pk-Pk(3): No signal
Pk-Pk(4): 5.1V
Rise(1): 8.59us
Pk-Pk(M1): 4.3438V

Acq Mode: Normal
\# of Averages: 32

Figure 26: Thevenin resistance scope shots. R_{sen}=1Ω. (yellow: VSEN+, pink: VSEN-, purple: VSEN+ minus VSEN-)

Analysis and Conclusions:

The design, bring up, and testing was largely a success. No modifications had to be made to the board to get it to meet the board requirements.

The “Golden” board performed better than the commercial board in some areas (such as switching, cross-talk, and RF), and worse in other areas (such as power rail stability when using the 5V pin as a power source). To improve the board, I would move the generic 5V rail decoupling capacitor to a spot closer to the 5V pin. The commercial board had a decoupling capacitor close to the 5V pin and two large 47uF electrolytic capacitors near the power barrel, so it had much more capacitance in close proximity to the 5V pin.

The proximity of the decoupling capacitors to the ATMEGA328P worked well since the voltage collapse on its input was approximately 90% lower than on the commercial board.

I was surprised by the difference in near field emissions between the top and bottom of the board. The bottom of the board experienced much lower near field emissions even though it was closer to the Arduino itself, suggesting that the ground plane acts as a very strong EMF shield.

Something else that I would change on future boards is to increase the size of the holes around the area with the functional microcontroller components so I could snap off the test points and have a standalone, compact board. With the size of holes that I used, I cannot snap off the test points by hand.

I liked having test points for each pin available to me even though I didn’t use them for these tests because it would have given me more options for test points if I did want to investigate anything.