University of Colorado Boulder

Electrical and Computer Engineering

ECEN3730 Practical PCB Design Manufacture

LABORATORY REPORT

Board 3 Report

Student Name: Mathias Labuszewski

Submission Date : 11/11/2023

1 Introduction

Board 3 was our first big circuit board. This lab will incorporate all of our best practices learned so far and will put it to the test. Board 3 is a custom version of an Arduino Uno. We will use a Atmega microcontroller and add supporting circuity to be able to flash the board via usb, and proper power conditioning. Then, we can compare our PCB and a commercial PCB and see what gives better performance.

2 Objectives

This section delves deeper into the specific outcomes of Board 3. The focus is on:

1. Demonstrating the influence of layout decisions on switching noise: The main objective is to show that good design practices lead to lower noise levels compared to poor design practices.
2. Implementing best design practices on one circuit and bad practices on another: Board 3 has lots of important elements that need low noise to function correctly.

3 Plan of Record

Board 3's design process. The design plan involves several key steps:

1. Creating a schematic and defining parts
   - 1206 size SMD parts
2. Determining power requirements
   - 5 V AC to DC converter to power board, aswell as usb.
3. Selecting components such as the CH340, LEDs, and resistors
   - Use red LEDs and 1k ohm resistors as the indicators
4. Planning signal routing and the layout
   - Copper poured return plane and single return path.
   - Place signal lines far from each other.
5. Designing an isolation switch for the circuit
   - Switches at each of the key signal nodes. 5v, CH340, Atmega.
6. Incorporating test points for measurements
   - Test points for each of the inverters to measure noise. 5v, 3.3v, Tx, Rx
7. Implementing usb communication
   - Wire up the CH340 properly
   - Add a TVS diode to protect usb lines.
8. Engineering the layout to best fit all components
   - Clock signals close to IC's
   - Decoupling capacitors close to IC's
9. Making sure board 3 acts like an Arduino Uno
   - Upload code from Arduino IDE.
   - Be able to use microcontroller.

4 What it means to work

- Power Rail Stability: The board must deliver a stable power rail voltage of approximately 3.3 V, and the 5 V rail should be close to 5 V.
- Clock Functionality: The clocks for the Arduino and CH340 should be operating at 16Mhz and 12Mhz.
- Arduino Performance: The board should have low noise.
- Usb Functionality: The Arduino should be able to take in code from the usb via the CH340
- Measurement Accuracy: All measurements taken during the experiment should align with expectations based on design specifications.

5 Board Design, Assembly, Bring-Up Testing

5.1 Initial Block Diagram:

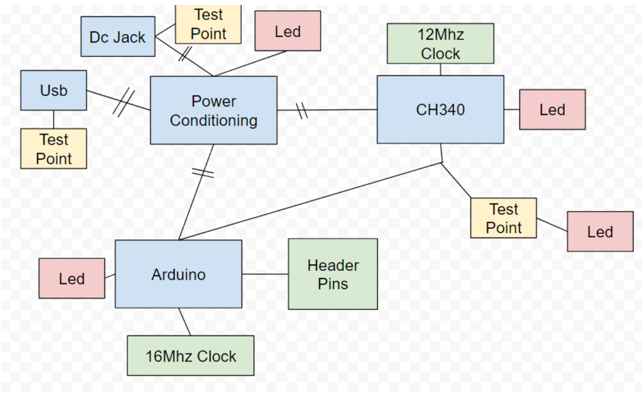

Figure 1: Block Diagram for Board 3

5.2 Schematic of board

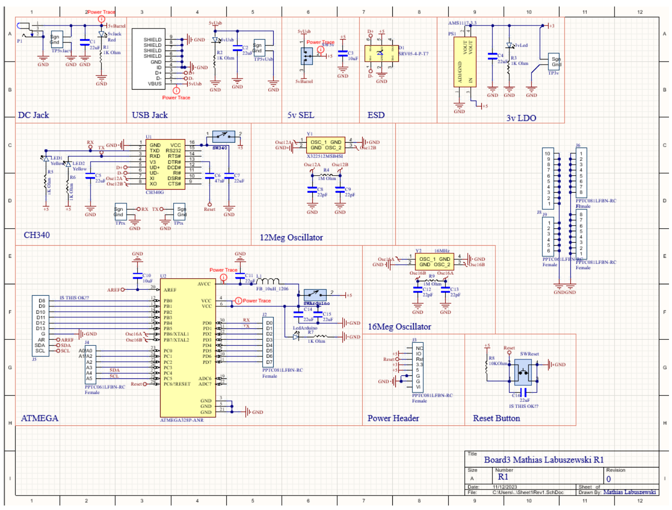

Figure 2: Schematic for Board 3

5.3 Altium designer board layout

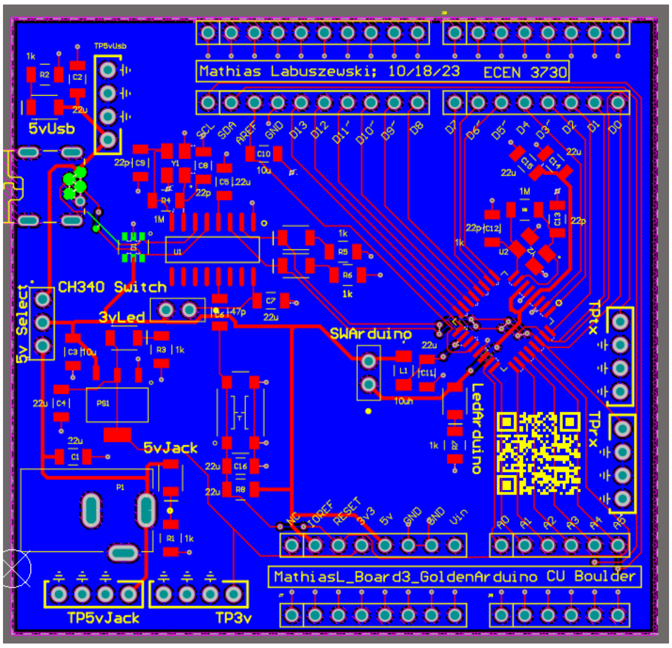

Figure 3: Board layout

5.4 Altium designer 3d view

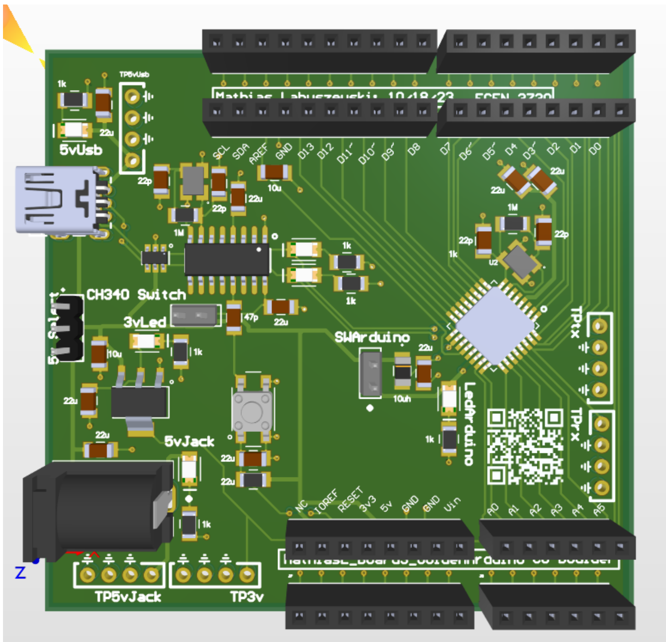

Figure 4: 3d Board layout

5.5 Manufactured board

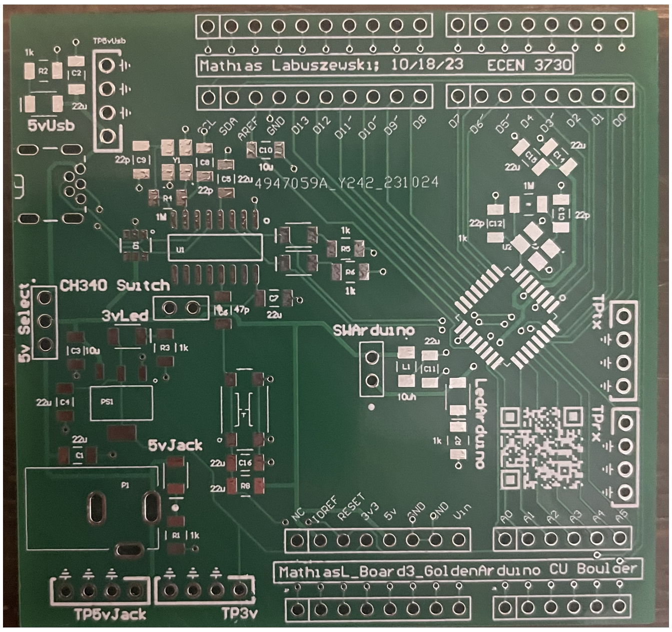

Figure 5: Physical Board 3

5.6 Assembled board

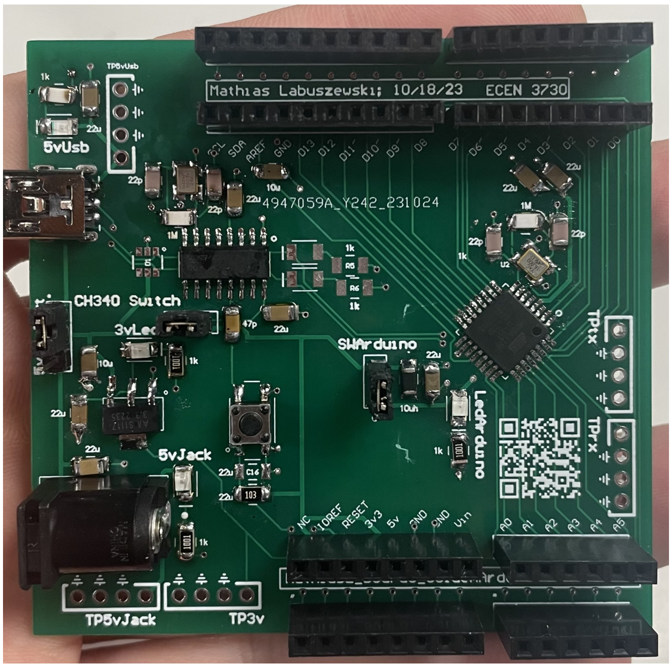

Figure 6: Assembled and working board 3

5.7 Board being tested

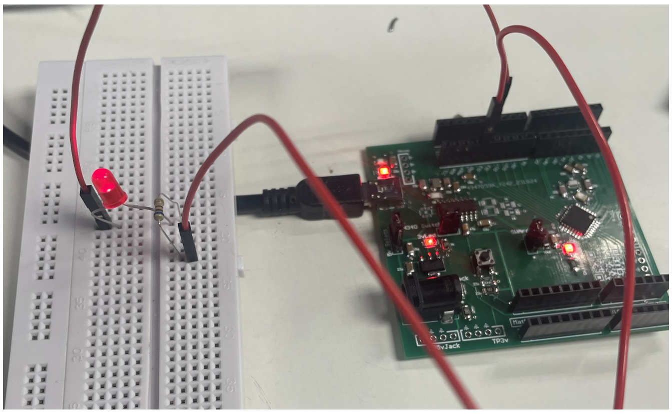

Figure 7: Testing Board 3

6 Board Layout

6.1 Things that went well

My board layout was very compact. I did not want a very big board, as that would be easy to do and not very fun. I tried challenging myself to it in the footprint of a normal Arduino Uno. My component placement was ok. I was able to get parts very close together, such as the crystals. However, I did make a lot of mistakes.

6.2 Things that went bad

My first mistake was the Rx and Tx lines. The Rx and Tx lines from the CH340 to Arduino are nominal high. So if we want to see communication we should have them be pull-up leds. I connected mine to the ground. The other mistake I made was my silkscreen. Some of the components I labeled incorrectly. Personally, I would just leave the default assigned part net, but we are required to add component value identifiers. Routing lines under IC's is also bad for noise.

7 Assembly and Bring up

7.1 Things that went well

The board assembly did not pose any difficulties to me. I soldered everything relatively quickly. However testing was another story.

7.2 Things that went bad

My first issue was with communicating with the board. We are using a CH340 module, that facilitates communication between the Arduino and the usb. This is a very poorly designed IC and there are lots of counterfeits on the market. The ones that were provided seem to be counterfeits, as I replaced 2 of them and neither worked. Instead, I de-soldered a CH340 off of a working separate module, and it worked. My second issue was with the capacitor on the RESET line for the reset button. I had too big of a value, and it was not letting the RESET line be pulled to a low enough voltage over the short time span the CH340 pulls it down.

8 Next Designs

For my next designs, I will stick to one silk screen labeling and will refine my schematic.

9 Measurements

9.1 Initial measurements

First I will take some measurements to make sure my Arduino is working.

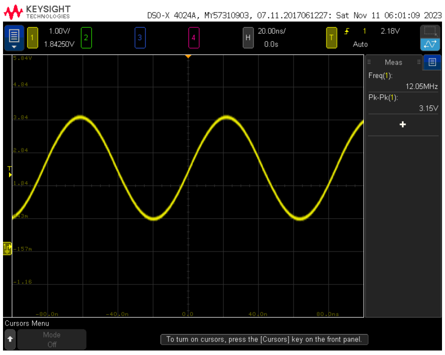

Figure 8: 12Mhz Ch340 Clock

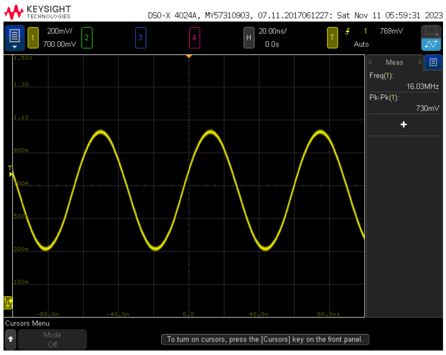

Figure 9: 16Mhz Arduino Clock

Both the Arduino and CH340 clocks are operating at their desired frequencies.

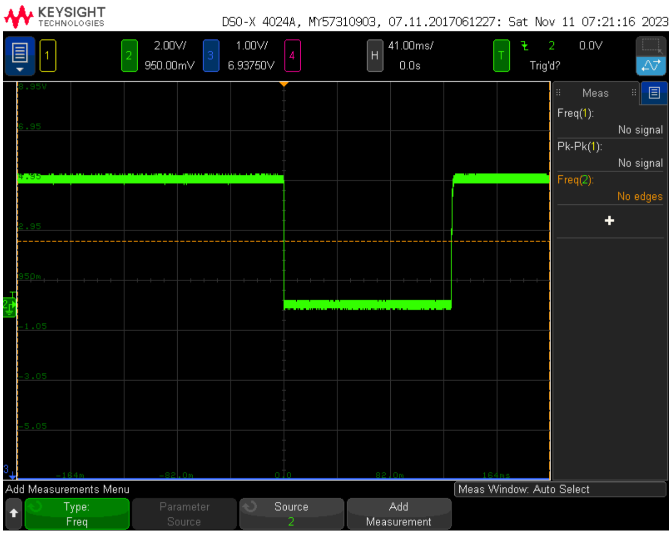

Figure 10: Reset Line

Reset line functionality works.

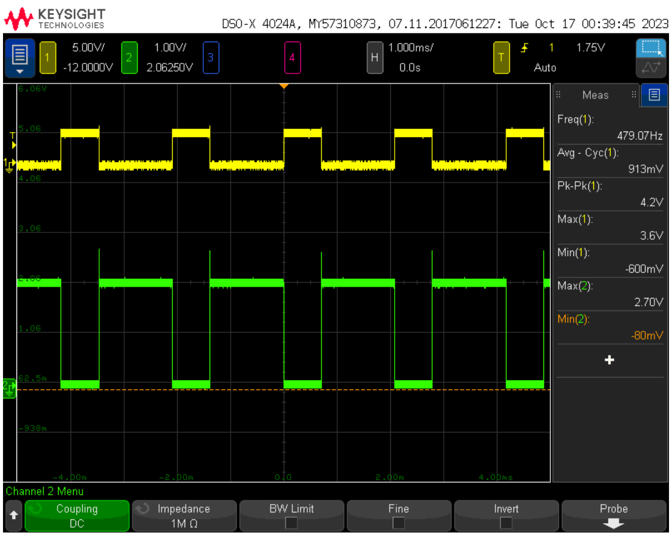

Figure 11: General Outputs

The PWM works on the general IO of the microcontroller.

My custom Arduino works as intended, and does everything it needs to. It communicates over usb, and new code can be uploaded.

9.2 Commercial Board vs Our board

To compare our Arduino with a commercial board we will take measurements of noise on the commercial board and our board, and compare.

We will use a circuit given to us that is a shield for the Arduino. The shield will place high currents and lots of synchronous signals, and we can measure the differences.

9.2.1 Multiple IO switching

We will switch multiple IO and measure the impact they have on the micro controller. There are pins that are held HI and LO and we can see any induced noise.

9.2.2 Commercial

Green - Scope Trigger point, IO switching Blue - Quiet hi Yellow - Quiet low

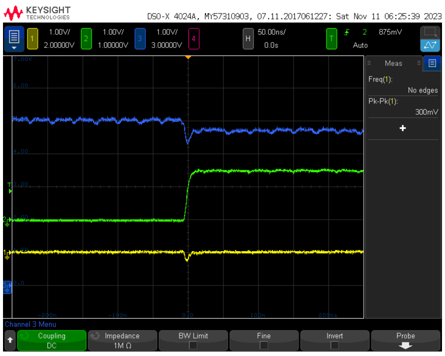

Figure 12: Rising edge

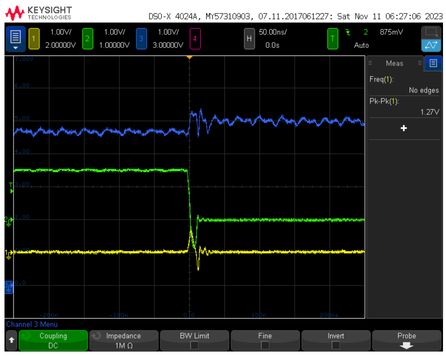

Figure 13: Falling edge

9.2.3 My board

Green - Scope Trigger point, IO switching Blue - Quiet hi Yellow - Quiet low

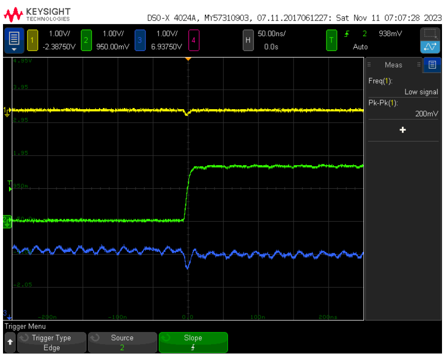

Figure 14: Rising edge

Figure 15: Falling edge

We see the noise is reduced by an amount. The rise times are also slightly faster. The noise on the low line is much less during the falling edge, and the ripple on the high line is also reduced. The voltage remains more constant on my board, due to the better placement of decoupling IC's. There is around a 20% improvement on my board. The commercial board has more noise due to a non-continuous return plane.

9.2.4 IO switching and 5v line

With the same IO switching we will measure the 5v rail and look at the noise induced.

9.2.5 Commercial

Green - Scope Trigger point, IO switching Blue - Quiet hi Yellow - 5v Rail

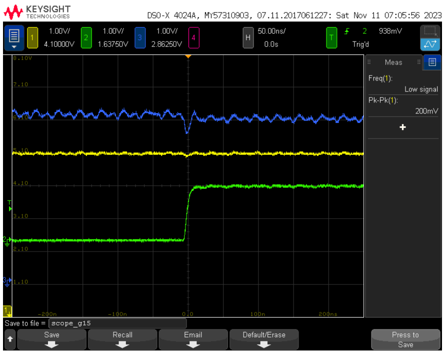

Figure 16: Rising edge

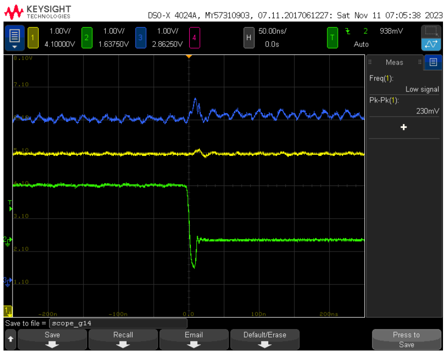

Figure 17: Falling edge

We see the noise on the 5v rail has an amount of noise in it. We see during the falling edge the 5v rail actually has a little bit of a spike. This is dangerous and can damage components.

9.2.6 My board

Green - Scope Trigger point, IO switching Blue - Quiet hi Yellow - 5v Rail

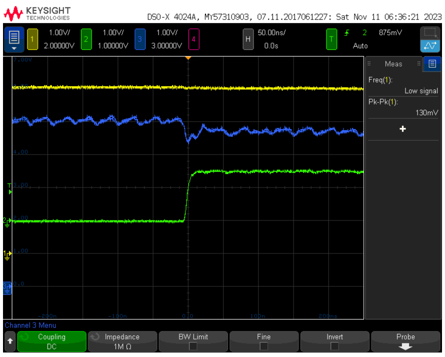

Figure 18: Rising edge

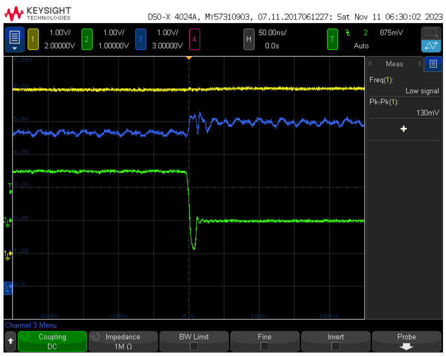

Figure 19: Falling edge

We see the noise is almost gone. The rail is very smooth and there are no spikes during the falling or rising edge. This is due to good grounding and placing capacitors close to each IC. The commercial board has a non-continuous return plane.

9.2.7 Slammer Circuit

Now we will measure the noise due to a big current draw on the Arduino. There is a mosfet getting triggered and driving a large current. This will create a large transient and we will see lots of noise.

9.2.8 Commercial

Green - Scope Trigger point, IO switching Blue - Quiet hi Yellow - 5v Rail

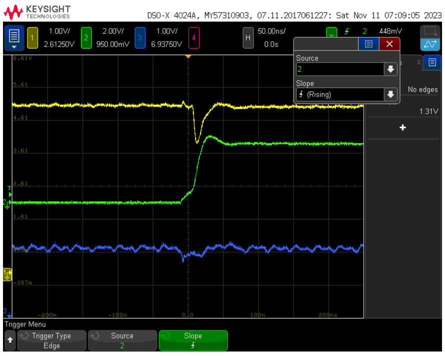

Figure 20: Rising edge

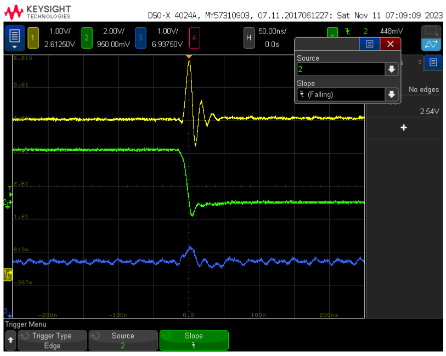

Figure 21: Falling edge

We see the noise on the 5v rail has a lot of noise. During the rising and falling there are big spikes in noise. During the falling edge, there is around 3v of noise! This is because the current does not have a short low impedance path to ground. Quiet high has lots of ripple as well.

9.2.9 My board

Yellow - Scope Trigger point, IO switching Blue - Quiet hi Green - 5v Rail

Figure 22: Rising edge

Figure 23: Falling edge
https://www.overleaf.com/project/651a265c6376647c35525cc6

The noise on the 5v rail has been reduced by over 50% compared to the commercial board. This is due to a low impedance path for the current to flow to the ground, as well as a better decoupling capacitor layout.

9.2.10 EMI

We can use a probe in a loop to act as an antenna to pick up any near-field emissions generated by the board. We will measure during IO switching.

9.2.11 Commercial

Green - Scope Trigger point, IO switching Blue - EMI

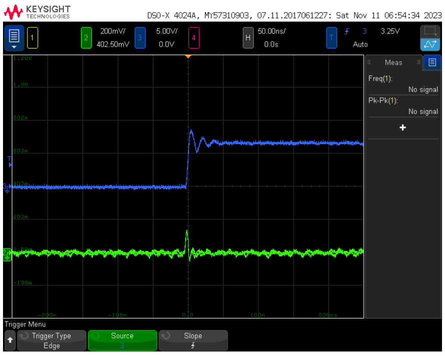

Figure 24: Rising edge

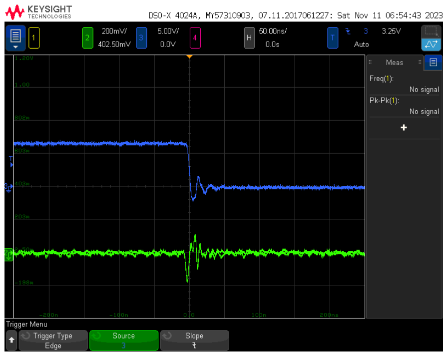

Figure 25: Falling edge

We see there is a fair bit of stray EMI leaking out from the board. At its peak, there is around 20mv of EMI being picked up by the probe. This is a lot. This is because the commercial board does not have a continuous return plane, leaking lots of EMI and creating ground bounce.

9.2.12 My board

Green - Scope Trigger point, IO switching Yellow - EMI

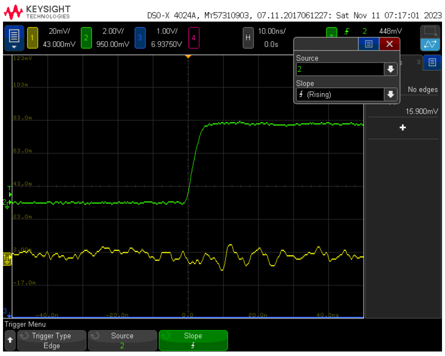

Figure 26: Rising edge

Figure 27: Falling edge

The scale has been enlarged by a lot, and we see no EMI generated from my board. This is due to having a continuous return plane and better grounding.

10 Analysis

With the above results, I can conclude my board did work and function close to correctly as outlined in the POR. The only thing that did not work well was the assembly of the board. Next time I will double-check and make sure the schematic is correct before having the board manufactured. We were also limited due to having a two-layer board. A four-layer board would have been easier to route, given the small board size I chose.

The hard error I made was pulling the Rx and Tx leads to ground. For future boards, I plan to check over each net, and make sure there is nothing silly. I should have caught both of these errors.

I had a lot of soft errors. From routing to component picking, I can fix a lot. When routing signals, I need to make sure I do not route signals under the IC s and route signal pairs with the same length. I also need to make sure I don't put too big of capacitor values on components where timing matters and is critical.

11 Summary of Findings

- Power Rail Stability: The board successfully delivered a stable power rail voltage of approximately 3.3 V, and 5v.
- Arduino Functionality: The board was able to run and have code loaded onto it.

- Arduino Performance: The board had low noise and good switching characters.
- Board Layout: The layout of the board helps achieve a good function circuit.
- Measurement Accuracy: All measurements aligned closely with the initial design. All signals were measured using a 10x probe with spring tip.

12 Impact of Layout

The experiment clearly demonstrated the critical importance of layout decisions in minimizing switching noise.

Layout plays a crucial role in controlling emi, ground bounce, and power rail noise, and ensuring the proper operation of electronic circuits. The results highlight the significance of adhering to best design practices, such as proper component placement and decoupling capacitor positioning to mitigate switching noise and maintain signal integrity.

13 Conclusion

In this lab experiment, we set out to build our own complete circuit. We explored the influence of layout decisions on switching noise in a PCB. We designed a board that worked better and was cheaper per board than a commercial off-the-shelf equivalent. We also saw first hand how best design practices make a big impact on the performance of a board.