Board 4 Report

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Contents

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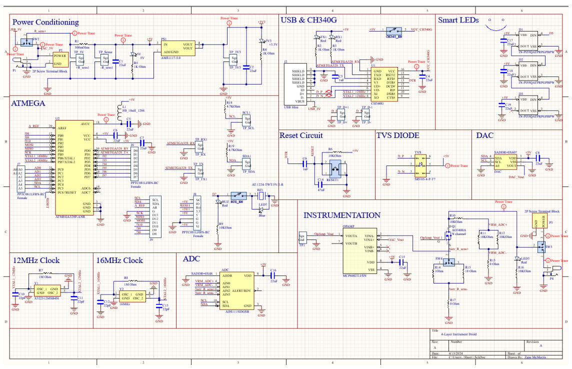
1 Project Overview

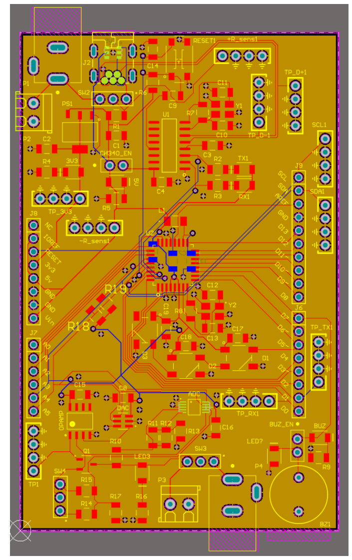
In this lab, I compared my Arduino design to a commercially available design from Elegoo. To compare the two boards, I used the provided noise shield, which I drove with various signals, and then measured a variety of signals. Rise & fall time, Crosstalk, switching noise, and near-field emissions were the most important attributes that I compared across the boards. Assembling and testing my board for whether or not it ”worked” was an important step in this lab as well, and I faced some difficulty in getting my board to wake up for the first time.

1.1 What it means to work

1. 5V is delivered to the board through the standard barrel-jack connector, and through the Mini USB connector
2. The 5V source can be chosen between the barrel jack and the USB connector. This 5V source is then passed through the current resistor and indicates the 5V power LED
3. 3.3V is generated from the LDO and illuminates an LED
4. Both the 16MHz and 12MHz clocks generate steady clock signals when power is applied
5. Assuming no code is uploaded to the board, all other lights should not be illuminated
6. Plugging a USB into the board and my laptop causes Windows to detect a COM port. This tells us that CH340G is functional.
7. Uploading code without touching the board works. Reset needing to be pressed indicates bad component selection for the reset circuit.
8. TX and RX LEDS illuminate during the upload process and periodically if there are Serial.printX statements.
9. GPIOs can be driven from the ATMEGA using code uploaded to the board

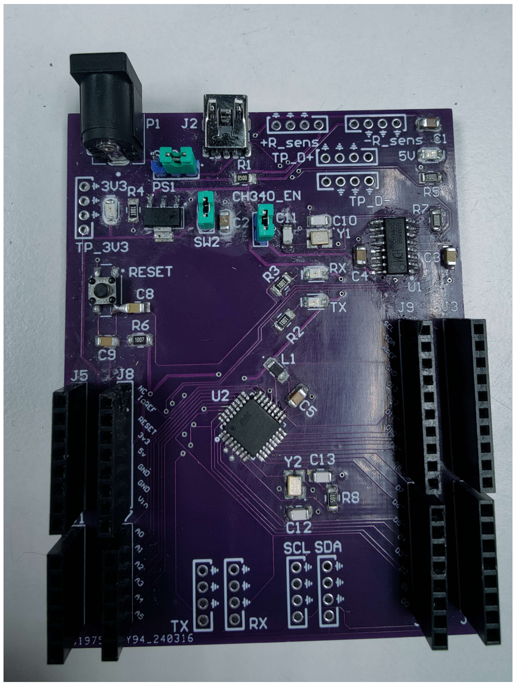


(a) Board Schematic

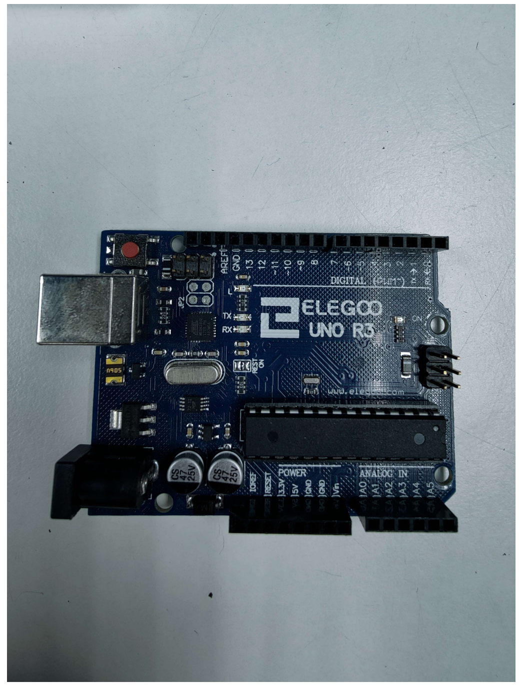


(b) Board Layout

Figure 1: My board designed in Altium



(a) My PCBA



(b) Commercial Board

Figure 2: The Arduinos used throughout this lab

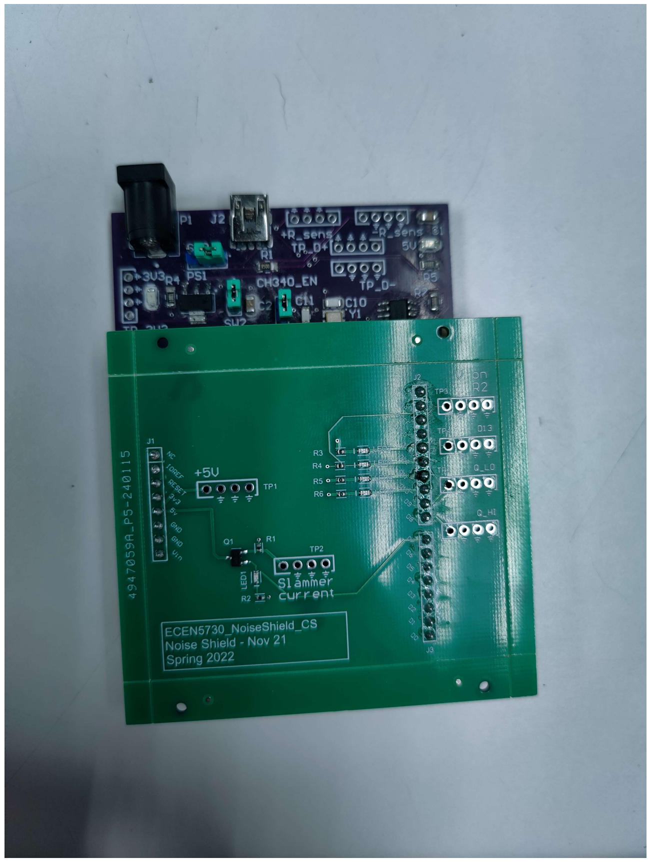


Figure 3: My PCBA with the shield attached

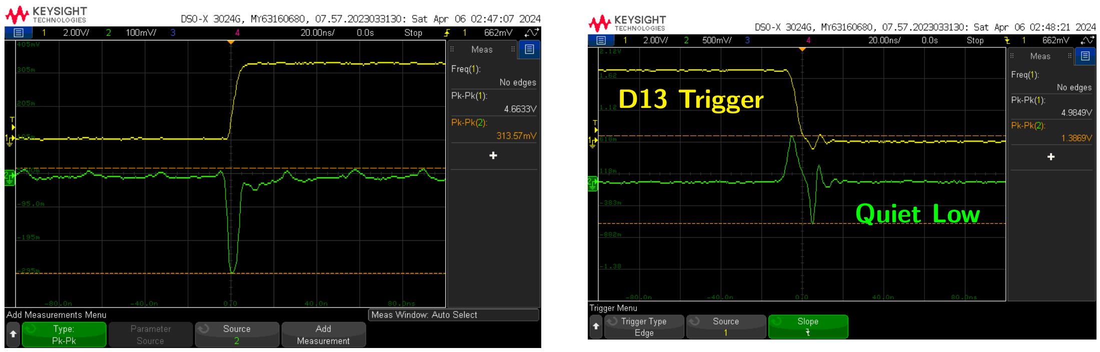
2 Exp 1: Rise & Fall Time Analysis

To conserve space in this report, I will not include scope shots of the rising and falling edges of the signal I measured. The results in the following table explain the rise and fall times that I measured on both boards. The waveforms between the two boards were nearly indistinguishable, and I saw no worrying artifacts.

Board	Rise Time	Fall time
Commercial Board	5.2ns	5.7ns
Golden Arduino	3.8ns	5.2ns
% Diff	-26.9%	-8.7%

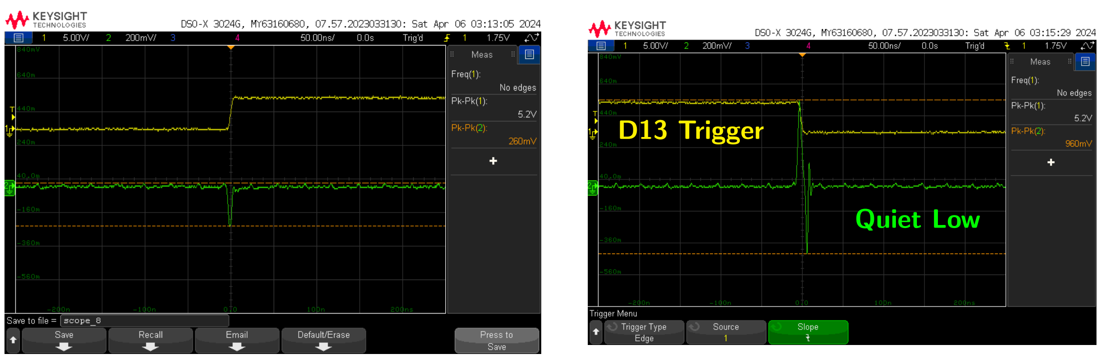
These measurements show that my board is fast on both the rising and falling edges of the signal. The cause of this is likely my more direct trace routing and more spaced-out traces. The commercial board is smaller than mine and, as a result, will have more inductive coupling between traces, potentially leading to longer rise and fall times. My board has faster rise and falls, which means it has a greater $\frac{di}{dt}$ because they're going to the same voltage in both cases. This greater $\frac{di}{dt}$ means that my board, if all other things are equal, should have *more* noise, but throughout the rest of this lab, it will become evident that my board's design performs much better than the commercial board.

3 Quiet Low & Quiet High Analysis



(a) QLO Rising Edge (b) QLO Falling Edge

Figure 4: Commercial Board Quiet Low Measurements

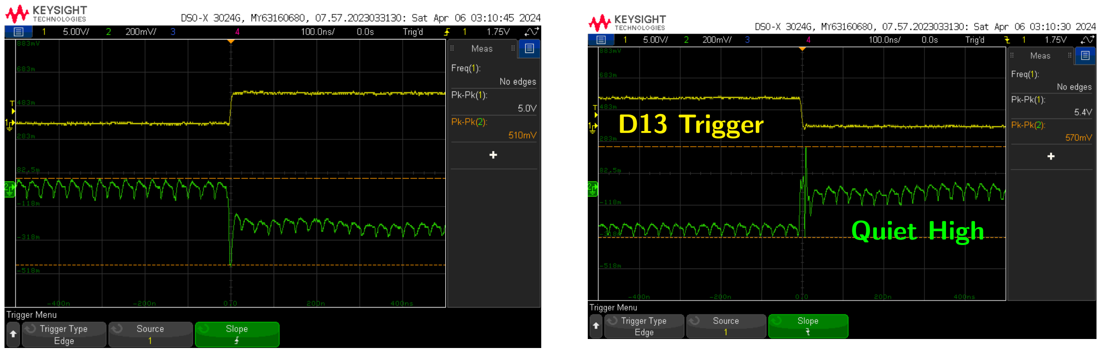


(a) QLO Rising Edge (b) QLO Falling Edge

Figure 5: My Board Quiet Low Measurements

The features between the two boards are similar in shape, but the magnitude of the peak-to-peak (P2P) noise on the quiet-low rail was greater than the P2P voltage by a considerable margin, which is detailed in the table below. The commercial board not only had greater noise, but it also lasted longer, which is best seen in the falling edge of the signal. The artifact lasts about 30 nanoseconds on the commercial instead of 15 nanoseconds on my design. This experiment shows again that my nearly uniform return plan and meticulous detail in the placement of return vias paid off in greater signal integrity.

Board	Rising Edge	Falling Edge
Commercial Board	313mV	1.387V
Golden Arduino	260mV	960mV
% Diff	-16.9%	-30.7%



(a) QHI Rising Edge

(b) QHI Falling Edge

Figure 6: Commercial Board Quiet High Measurements

(a) QHI Rising Edge

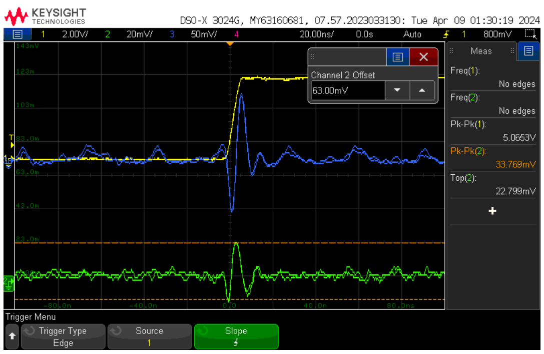
(b) QHI Falling Edge

Figure 7: My Board Quiet High Measurements

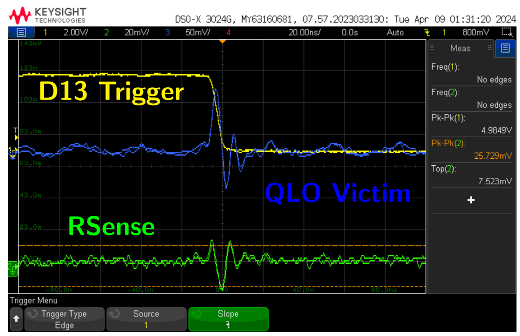
Similar to the case of the quiet-low, the quiet-high noise between the two boards is similar in shape but varies in amplitude. The values of the noise are summarized in the table below. Interestingly, in this step of the lab and for the rest of the duration of it, a strange, low-voltage periodic noise made its way into my measurements for both the commercial Arduino and my board. My initial thought for the source of this noise was the laptop I was using as a power supply to both boards. The laptop was plugged into power during the experiment, though, and it should have never entered low-battery mode. I wish I had done a more thorough analysis of this noise in the lab, but I was too preoccupied with getting all these measurements in a timely manner. Crudely measuring the period of the signal yields a period of about 33nsec (Just more than three humps per 100nsec division). A period of 33nsec corresponds to a frequency of 30MHz, much higher than the pedestrian 60hz that our power grid operates at. The two clock sources onboard are 16MHz and 12MHz, which are too low to be the source directly. Perhaps the source is due to reflections from the 16MHz crystal oscillator in both cases, but that doesn't explain why it wasn't apparent in the first measurements. Because the noise affected both boards equally, I continued with the lab.

Board	Rising Edge	Falling Edge
Commercial Board	510mV	570mV
Golden Arduino	310mV	480mV
% Diff	-39.2%	-14.8%

4 Exp2: Quiet-Low Crosstalk Analysis

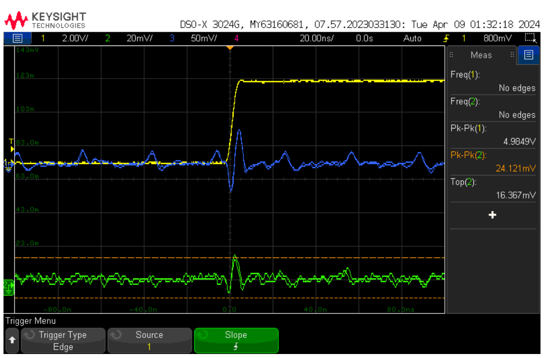


(a) Agressor Rising Edge

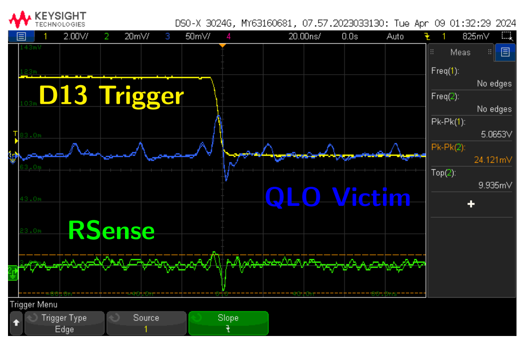


(b) Aggressor Falling Edge

Figure 8: Quiet-Low Crosstalk on Commercial Arduino



(a) Agressor Rising Edge



(b) Aggressor Falling Edge

Figure 9: Quiet-Low Crosstalk on My Arduino

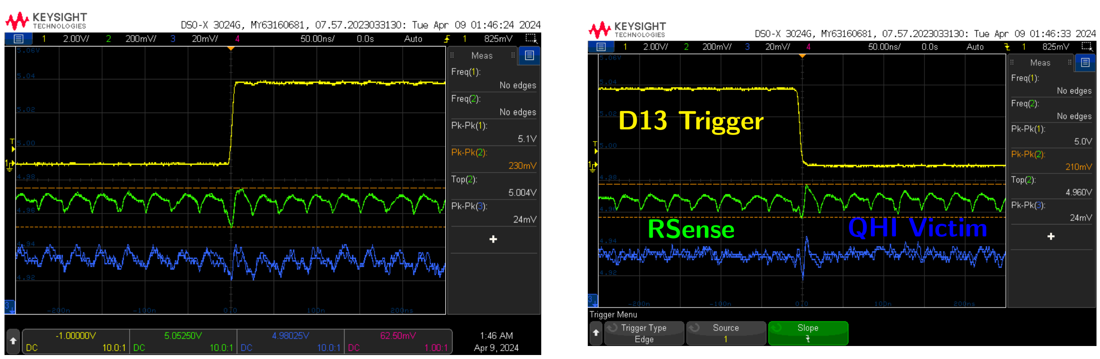
The quiet-low noise on the two boards looked pretty similar, with the identifying features being the most similar so far in the report and with magnitudes of P2P noise being the closest yet. However, the crosstalk was still greater on the commercial board than mine. The primary source of this noise is the coupling between traces on the board and imperfections in the MOSFET that introduce more inductance in the signal's path. My traces were likely a bit shorter and potentially further apart due to my board's larger footprint and abundance of routing space.

This is the first measurement of the voltage across the 50Ω sense resistor on the shield. By measuring the tops of the peaks, we can find the current going through the shield and the power it uses. Using $I = \frac{V}{R}$, I found the following currents, summarized in the table below. The percentage difference switches sign because the direction change in current is flipped in the two cases. The percent difference between the two cases is 30%, which is the higher end of all the measurements I've gathered. Finally, I included a table of estimates of the P2P measurements of the victim line because I forgot to include the actual measurements from the scope.

Board	**Rising Edge**	**Falling Edge**
Commercial Board	456µA	150µA
Golden Arduino	328µA	198µA
% Diff	-28.0%	+32.0%

Board	**Rising Edge**	**Falling Edge**
Commercial Board	170mV	250mV
Golden Arduino	200mV	200mV
% Diff	+17.6%	-20%

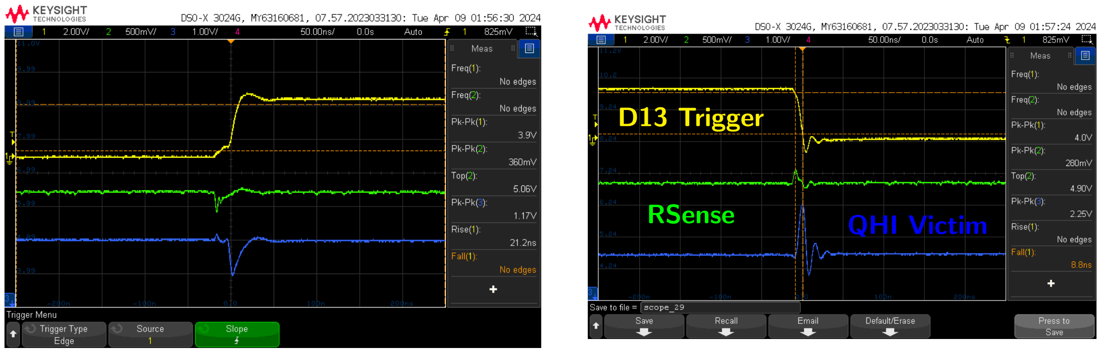
5 Exp3: Quiet-High Crosstalk Analysis



(a) Agressor Rising Edge

(b) Aggressor Falling Edge

Figure 10: Quiet-High Crosstalk on Commercial Arduino



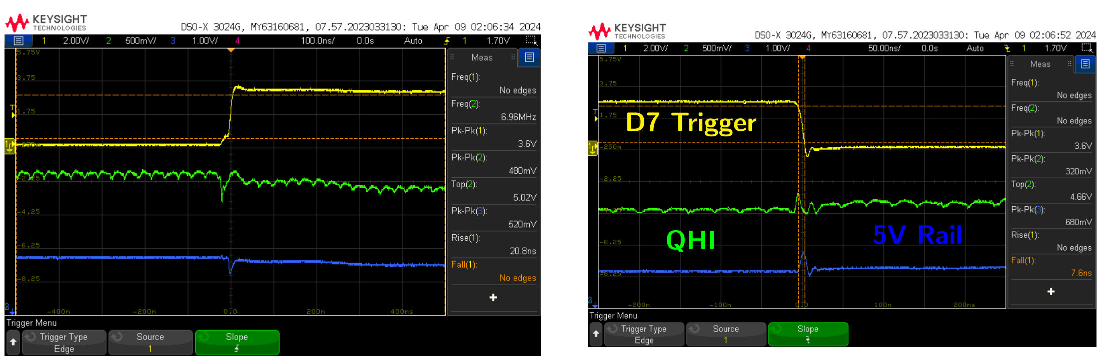
(a) Agressor Rising Edge (b) Aggressor Falling Edge

Figure 11: Quiet-High Crosstalk on My Arduino

The most interesting thing about this measurement is that my quiet-high noise was nearly 100x greater than the commercial board's. One simple explanation is that I didn't probe the quiet-high line; all we see is environmental noise. However, the y-axis is offset by nearly 5V, meaning that the quiet-high baseline is where we expect it to be, and the measurement is really that strange. The summary of P2P data is in the table below. The final feature of these two plots is that the $\tilde{3}$3MHz artifact disappears for my board and stays away mostly, while the commercial board stays affected for the rest of the lab.

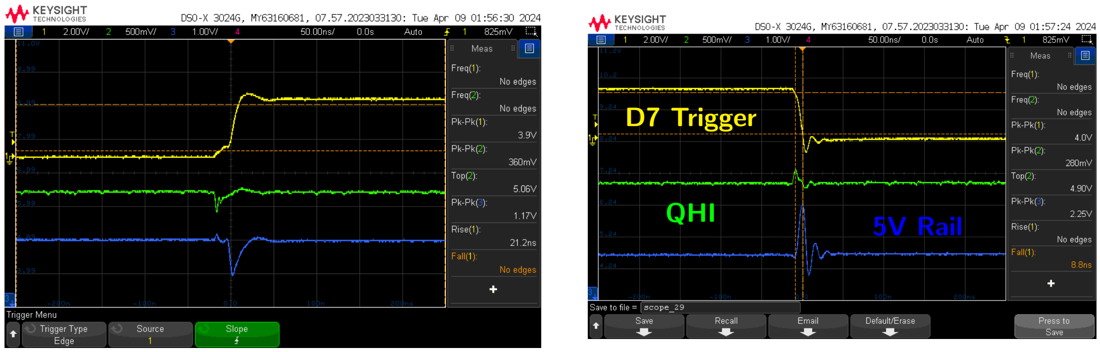
Board	Rising Edge	Falling Edge
Commercial Board	24mV	24mV
Golden Arduino	1.17 %	2.25V
% Diff	48,000,000%	93,000,000%

6 Exp 4: PDN Switching Noise



(a) Agressor Rising Edge (b) Aggressor Falling Edge

Figure 12: PDN Switching Noise on Commercial Arduino



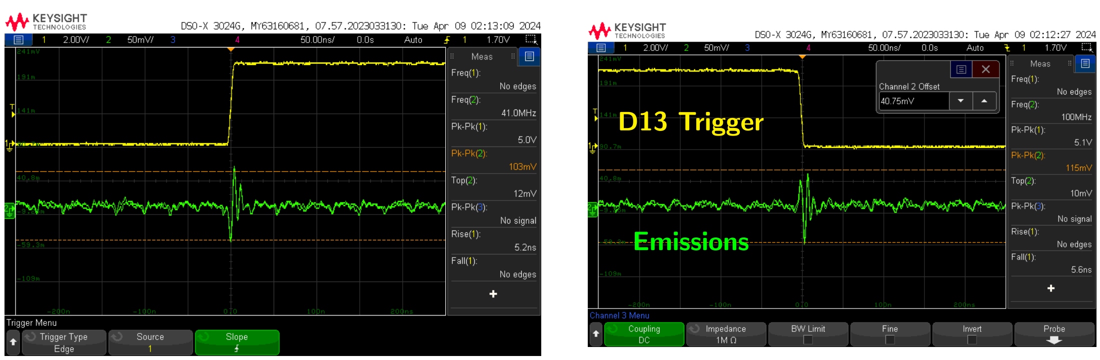
(a) Agressor Rising Edge (b) Aggressor Falling Edge

Figure 13: PDN Switching Noise on My Arduino

The PDN switching noise is another measure of the total trace inductance and capacitance over the signal path. Generally, having less inductance and less switching noise is better. This experiment highlighted another shortcoming of my board by outperforming it in this experiment. A summary of P2P measurements can be found in the table below.

Board	**Rising Edge**	**Falling Edge**
Commercial Board	520mV	680mV
Golden Arduino	1.17V %	2.25V
% Diff	125%	230.9%

7 Near-Field Emissions Analysis



(a) Agressor Rising Edge (b) Aggressor Falling Edge

Figure 14: PDN Switching Noise on Commercial Arduino

(a) Agressor Rising Edge (b) Aggressor Falling Edge

Figure 15: PDN Switching Noise on My Arduino

I also measured near-field emissions on my last board because I purposefully made a little stub antenna. I used the same inductive loop in both experiments, and I can roughly compare what a purposeful, though not well-created, stub looks like against accidental emissions.

The P2P voltage generated by my antenna was 106 mV. Looking at the table below that summarizes P2P voltage, we can see that the commercial board had similar emissions. My board had about a third of the magnitude of the commercial board.

Board	**Rising Edge**	**Falling Edge**
Commercial Board	103mV	115mV
Golden Arduino	32.2mV %	35.6mV
% Diff	-68%	-69

8 Conclusion

Overall, I enjoyed designing, laying out, and bringing up a more complicated board. There were many more pieces to get wrong, and I think I learned some valuable lessons from the mistakes I made on this board that I attempted to rectify on my fourth and final boards. The results of the experiments comparing the two boards didn't declare either one an outright winner because they both had some victories. I am happy with how my board performs and excited to measure my final board of the semester.