Board 3 Report
Golden Arduino Board

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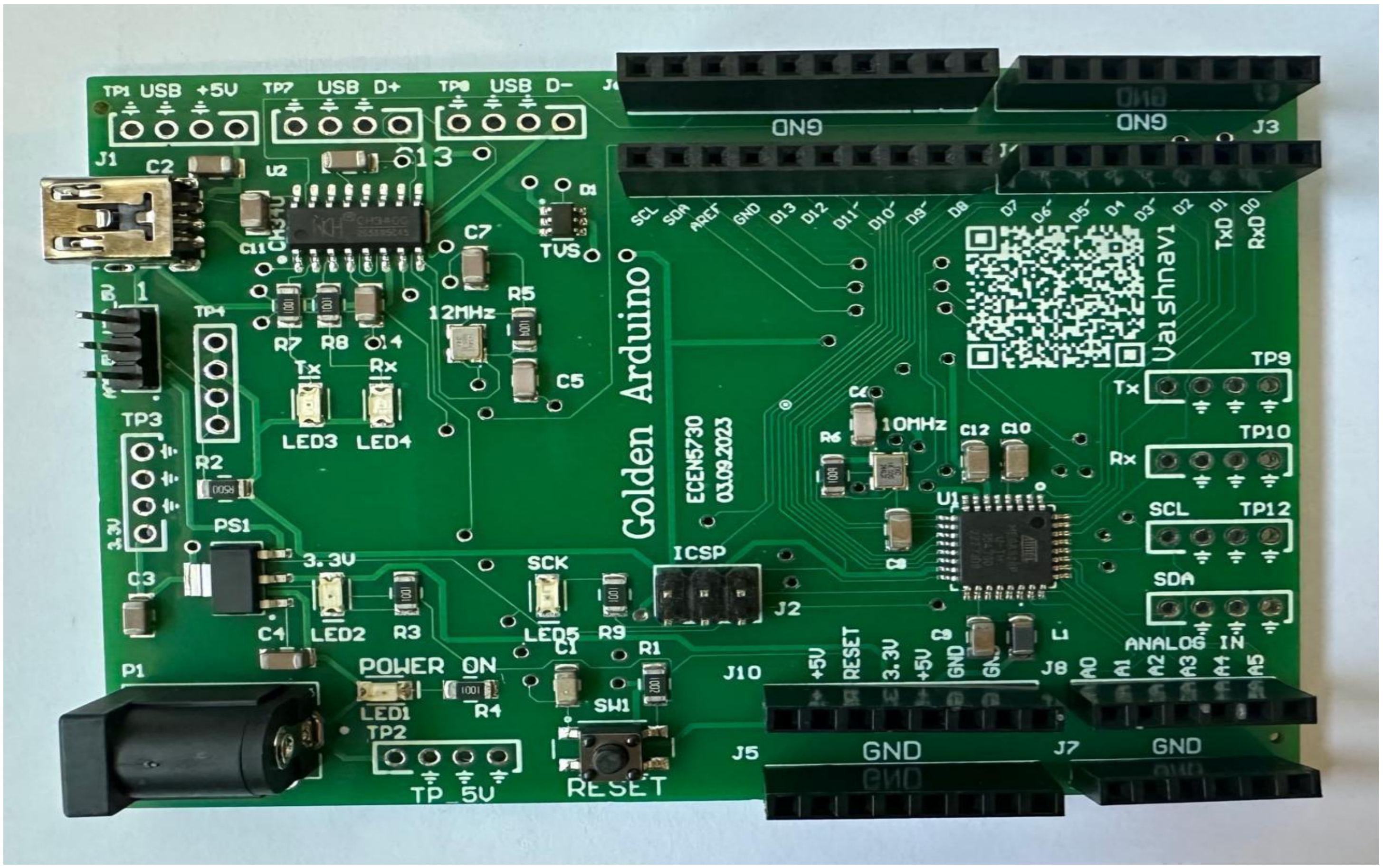


Golden Arduino Board

Objective

- To practice the entire prototype design flow
- Practice reading datasheets to get useful information and realize the ambiguity in datasheets. Consider adding features to the design to provide options to evaluate design features.
- Design “Golden Arduino” that has the same connectivity specs as the commercial Arduino but has features for better noise control, assembly, testing, and bring-up.

Specifications

- Atmega 328 microcontroller
- CH340g USB to UART interface chip
- 16 MHz resonator for generating a clock. A 12 MHz resonator for the CH340g.
- Appropriate decoupling capacitors
- Connector for the SPI and boot-loading pins
- TVS chip to protect the data pins from ESD
- Power from the power plug or the USB connector, but not both at the same time
- Reset switch with a debounce capacitor
- 3.3 V LDO, not used by a component on the board, but available on one of the header pins.
- Header sockets that match the location of the standard Arduino board so that you can plug a shield into your Uno board
- Board Size: 3.5x2.5
- Test points on USB, I2C, and UART lines
- In-rush current monitoring
- Ferrite bead filter to the AVCC of the 328

Schematic

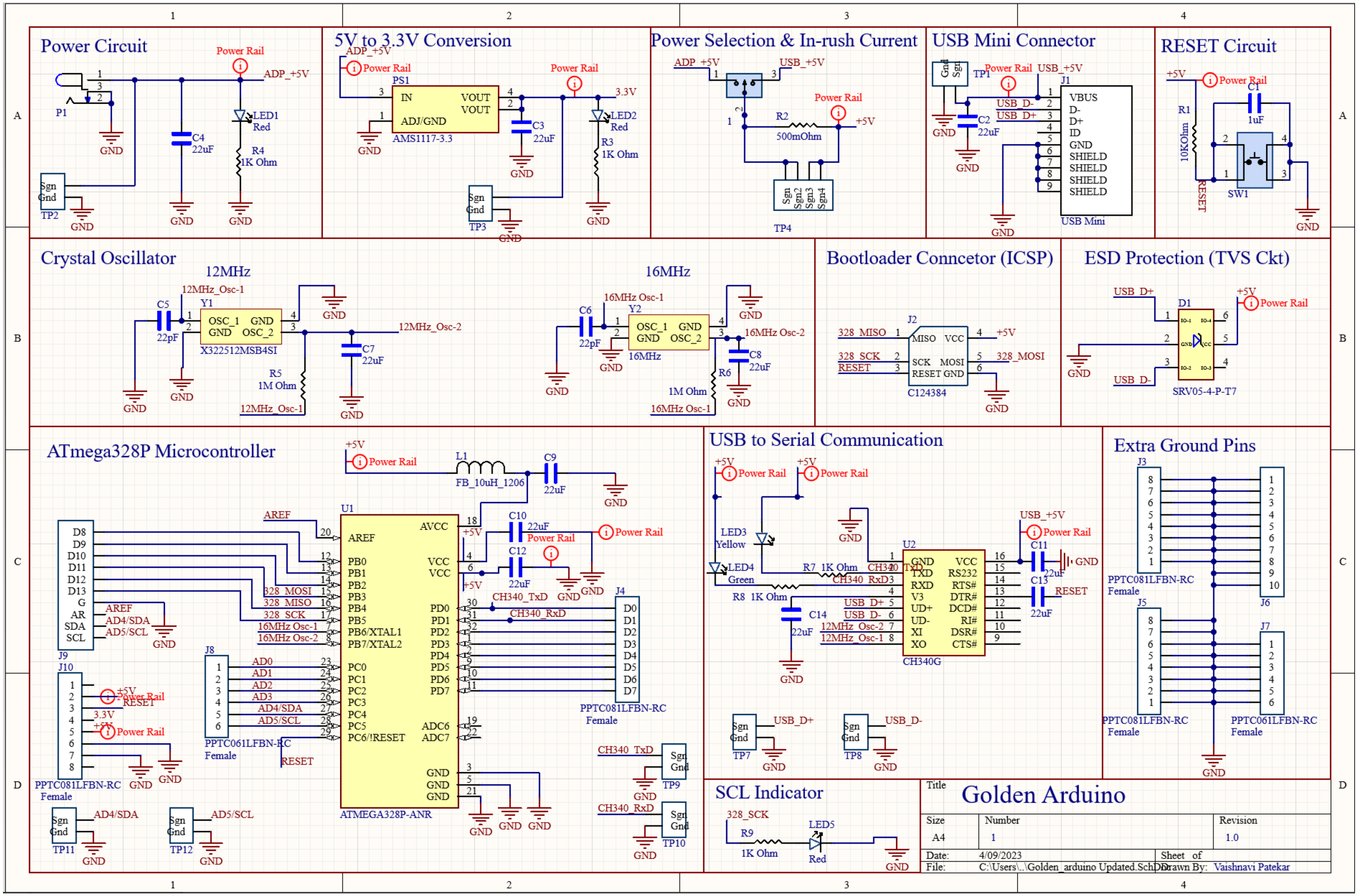


Figure 1: Schematic for Golden Arduino Board

Layout

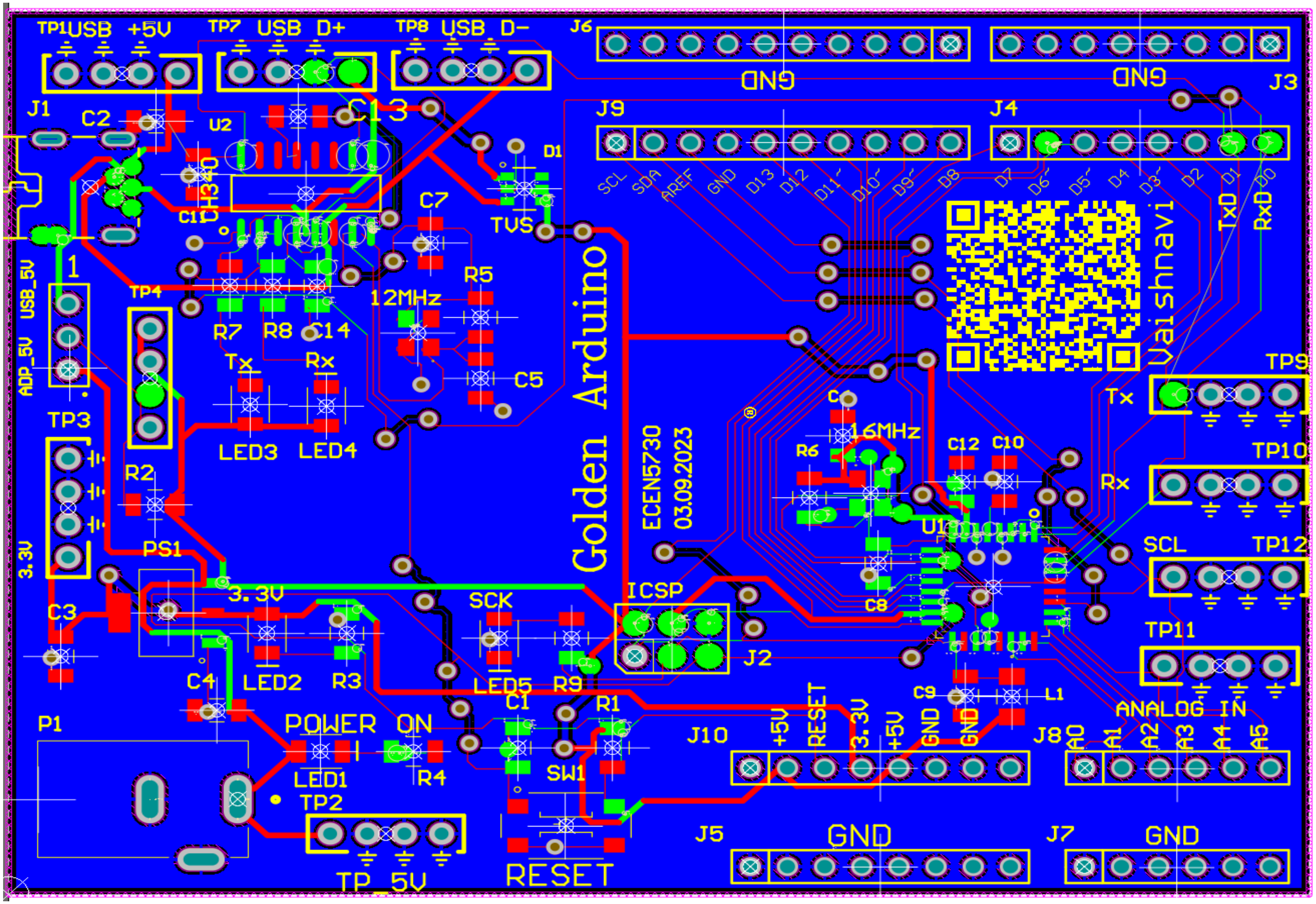


Figure 2: Layout for Golden Arduino Board

3D View Of the Board Layout

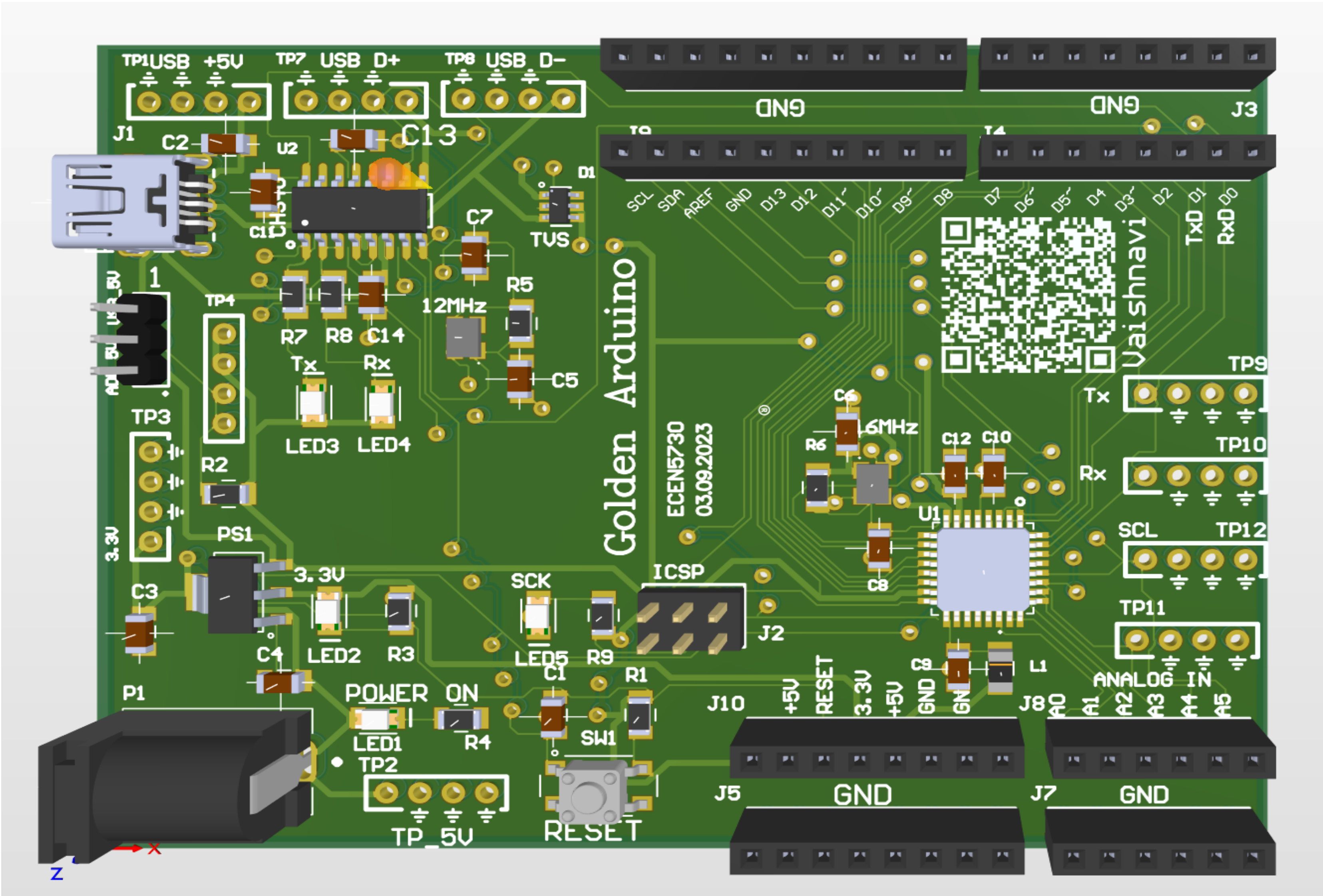


Figure 3: 3D view of the Layout for the Golden Arduino Board

Bare PCB Board from JLC

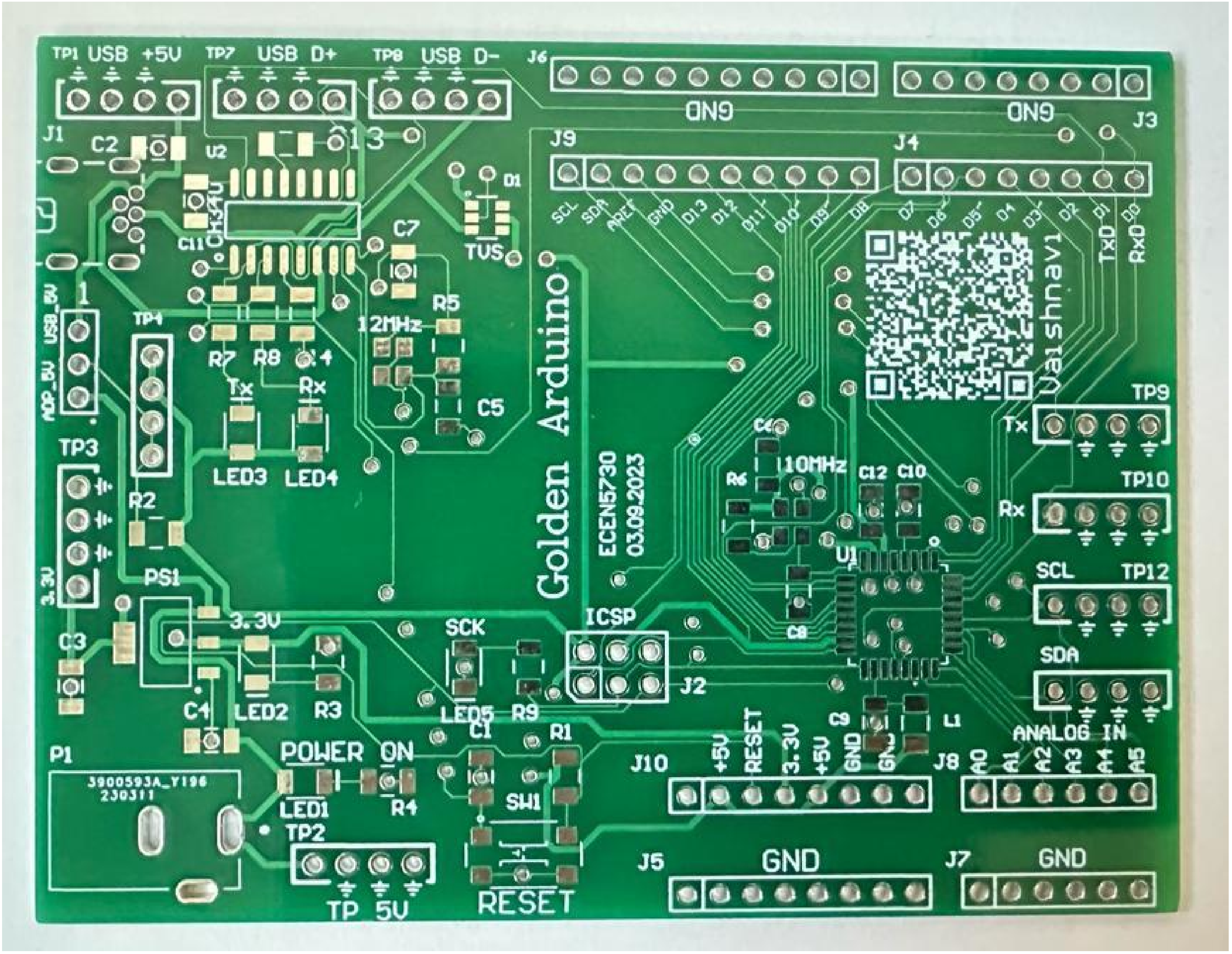


Figure 4: Bare PCB Board from JLC

Assembled PCB Boards

Self-Assembled Board

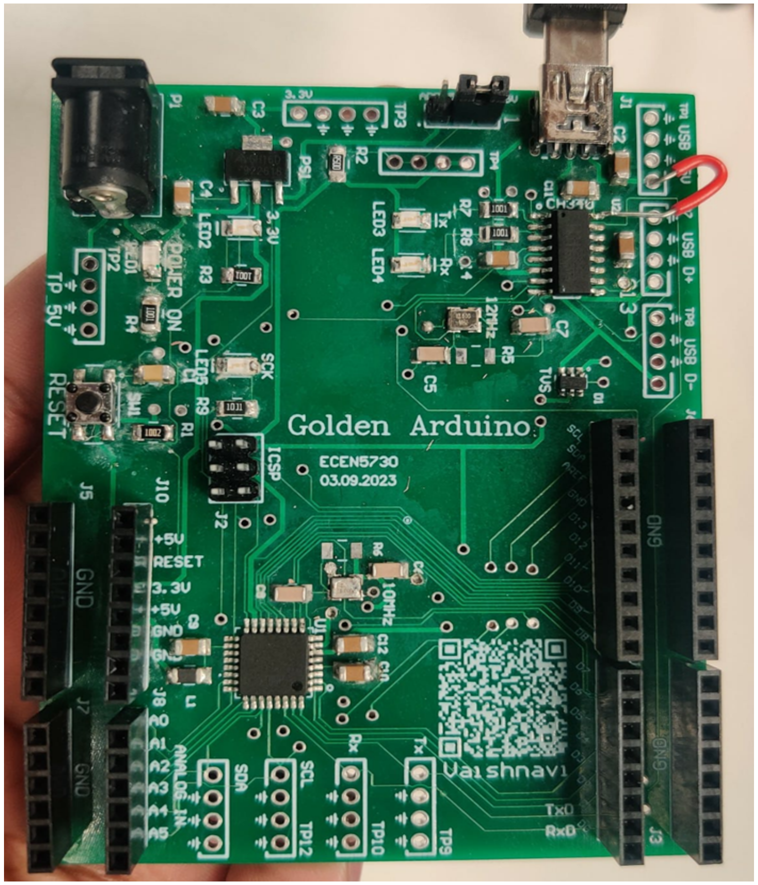


Figure 5: Self-Assembled Board

JLC Machine Assembled Board

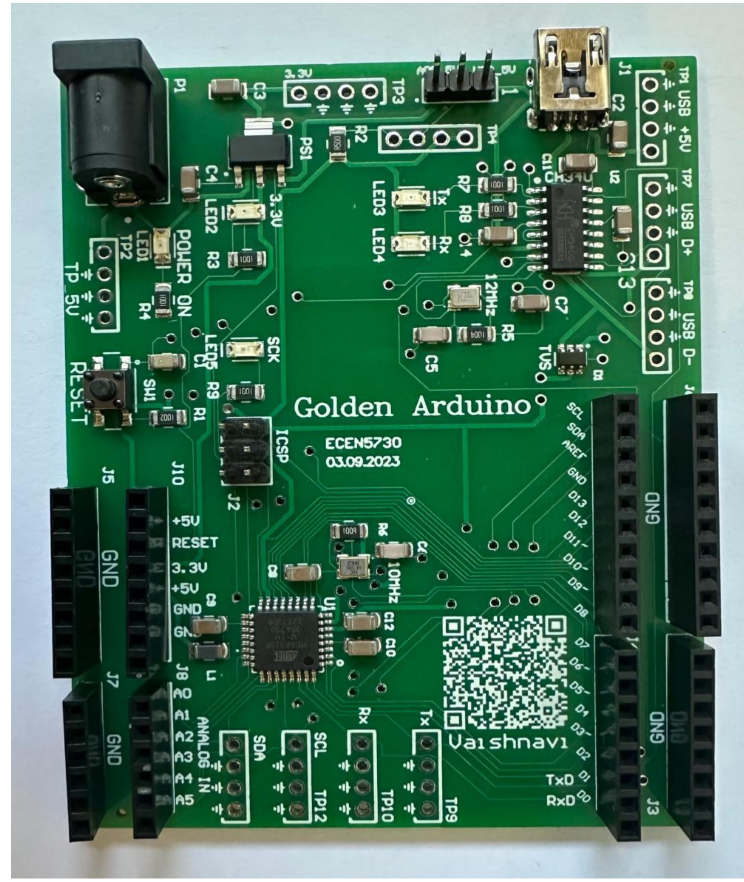


Figure 6: Assembled Board from JLCPCB

Key features of the Golden Arduino Board Design

- The decoupling capacitor's location is in near proximity to the Golden Arduino layout helps in reducing switching noise whereas it is placed far away for the commercial layout due to which the difference in the amount of switching noise is observed
- For the Golden Arduino layout, the bottom layer is poured with copper and acts as a continuous return ground plane (using a continuous return plane as a part of best design practice) and the commercial layout uses an uneven return due to which significant difference in near field emissions and switching noise is observed and proved in the Testing section of the report.

What does it mean to work?

A commercial Arduino should be able to operate on the board at a minimum level. In order to do this, the Arduino must be able to boot up, upload fresh code, and work properly. Additionally, for the purpose of attaching a shield, the header pins on the board should correspond to those on a commercial Arduino.

List of the non-commodity parts

Sr. No.	Part Name & Data-sheet Link	Reference Number
1.	Atmega328	ATMEGA328P-ANR
2.	USB to Serial	CH340G
3.	Crystal Oscillators 16Mhz	X322516MLB4SI
4.	Crystal Oscillators 12Mhz	X322512MSB4SI
5.	TVS diode	SRV05-4
6.	LDO	AMS1117

Bring Up

The bring-up process involved the following steps:

1. Connection test on bare-board
2. Place the 1206 components and solder them precisely
3. Connection test after the component soldering
4. Boot-loading the controller using a commercial Arduino

Test & Analysis of Assembled Board

- ### Testing Blinky code on Golden Arduino

After the successful boot-loading of the Arduino board, blinky code was dumped on the board to test.

Arduino Code for Board under Test - Blinky Example

```
void setup()
{
DDRB = B00111111;
pinMode(7, OUTPUT);
digitalWrite(7, LOW);
}
void loop()
{
PORTB = B00111101;
delayMicroseconds(4);
PORTB = B00000001;
delay(1);
digitalWrite(7, HIGH);
delayMicroseconds(400);
digitalWrite(7, LOW);
delay(10);
}
```

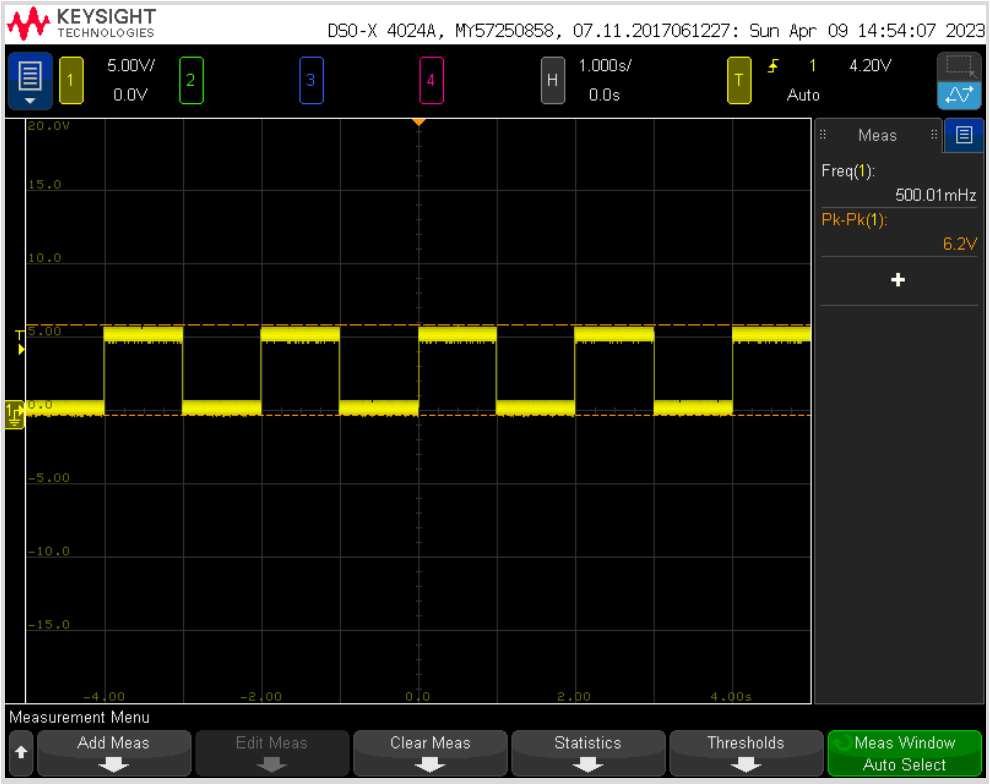
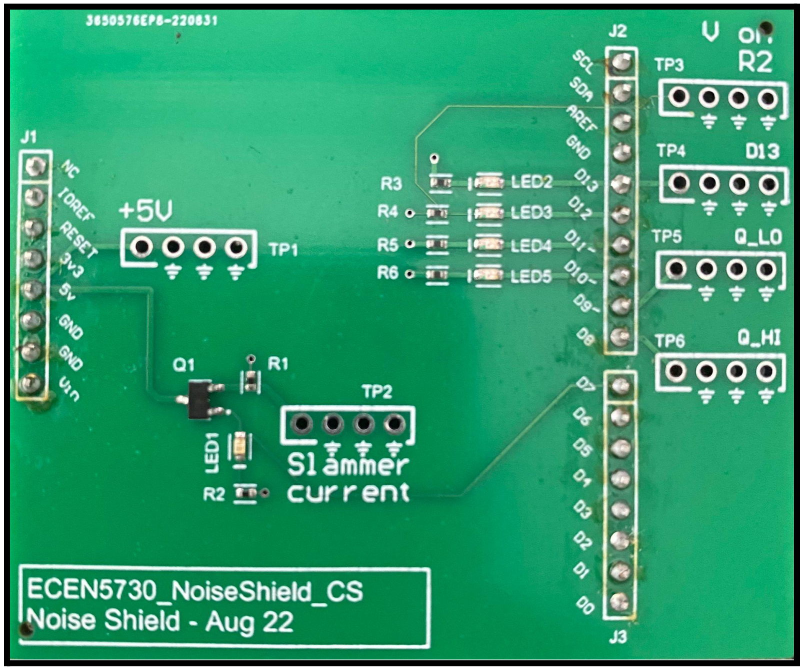
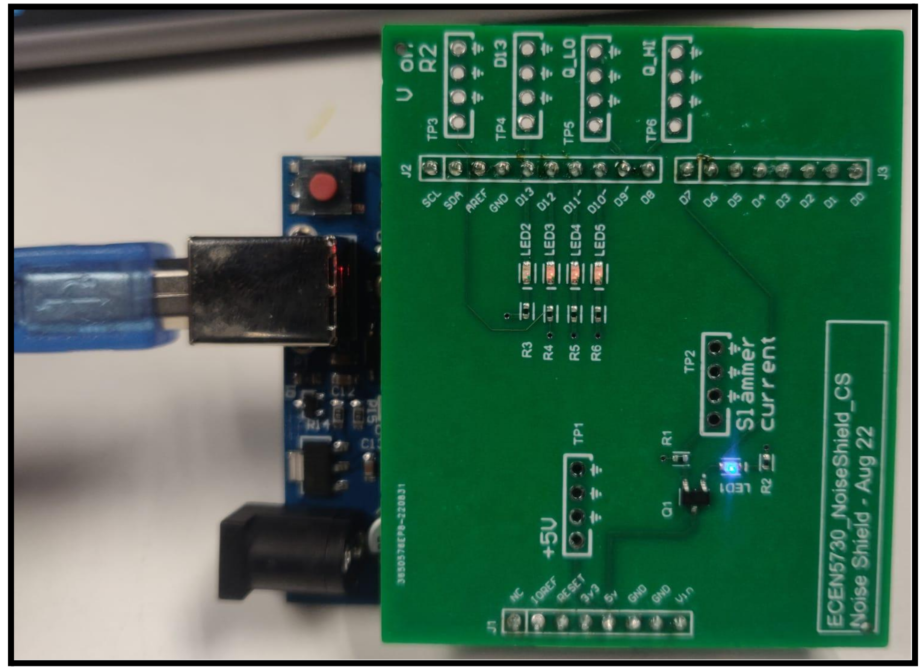


Figure 7: Switching Output of Blilnky code on digital pin 13

From the trace above, we can observe that the switching waveform is as per the expectation of Blinky code.

Test Shield used to measure noise





Figures 8 &9: Test Shield used to measure noise on both Arduino Boards

Figure above depicts the shield used to measure noise on commercial Arduino as well as Golden Arduino board.

Output Analysis & Testing of the Board

Current through test Resistor

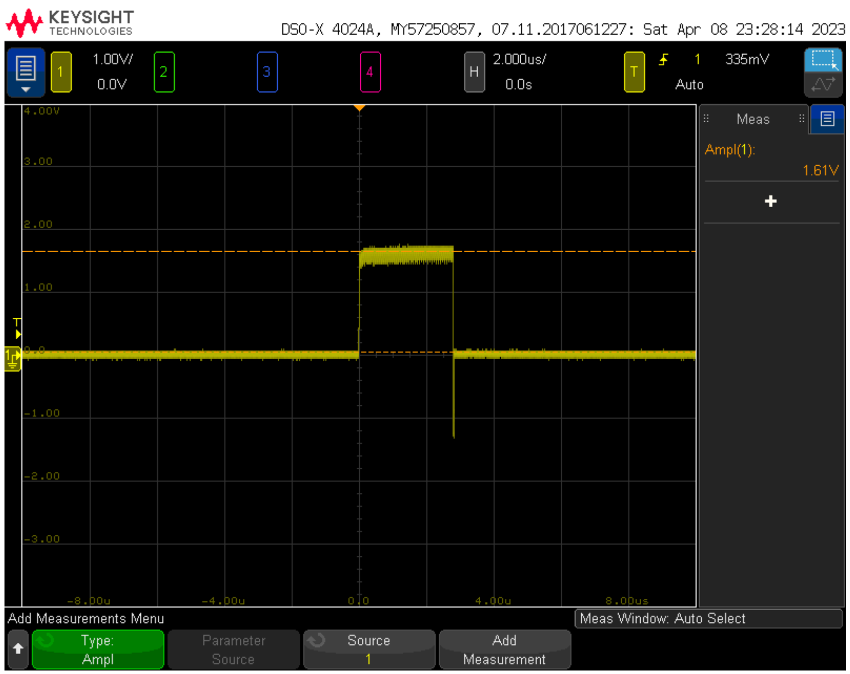


Figure 10: Commercial Arduino Board: Current across 63ohm Resistor

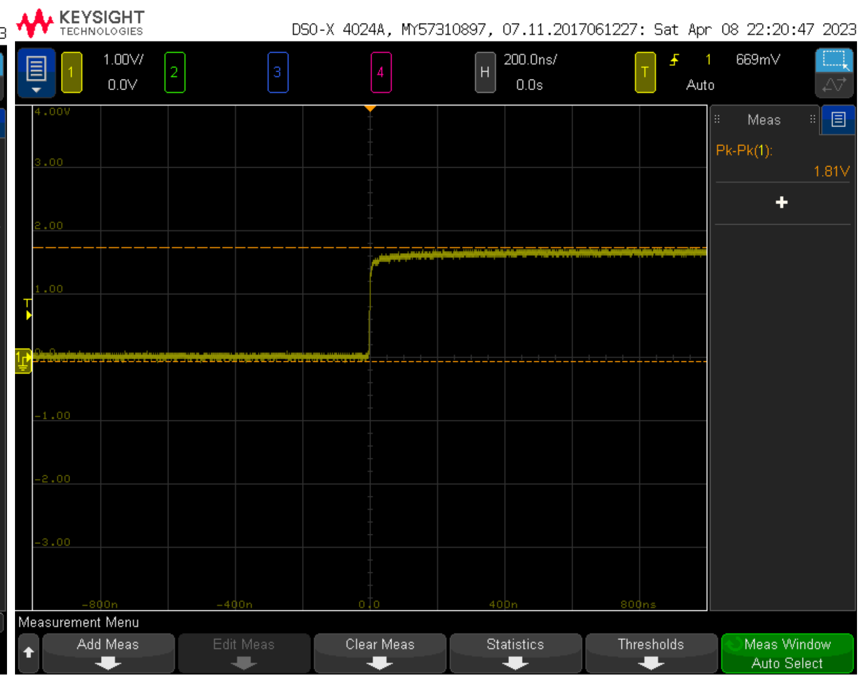


Figure 11: Golden Arduino Board: Current across 63ohm Resistor

In Figure 10, the Voltage drop across the 63-ohm resistor is around 1V.

Current through the 63-ohm resistor, I = V / R

I = 1/63;

I ~= 16mA

In Figure 11, the Voltage drop across the 63-ohm resistor is around 1.9V.

Current through a 63-ohm resistor, I = V / R

I = 1.9/63

I ~= 30mA

Switching Noise on Quiet Low Signals

When triggered on Rising Edge

For all the scope traces below, the yellow trace depicts the trigger signal i.e. the switching on pin D13 of Arduino and the other trace shows the signal for noise measurement under various conditions.

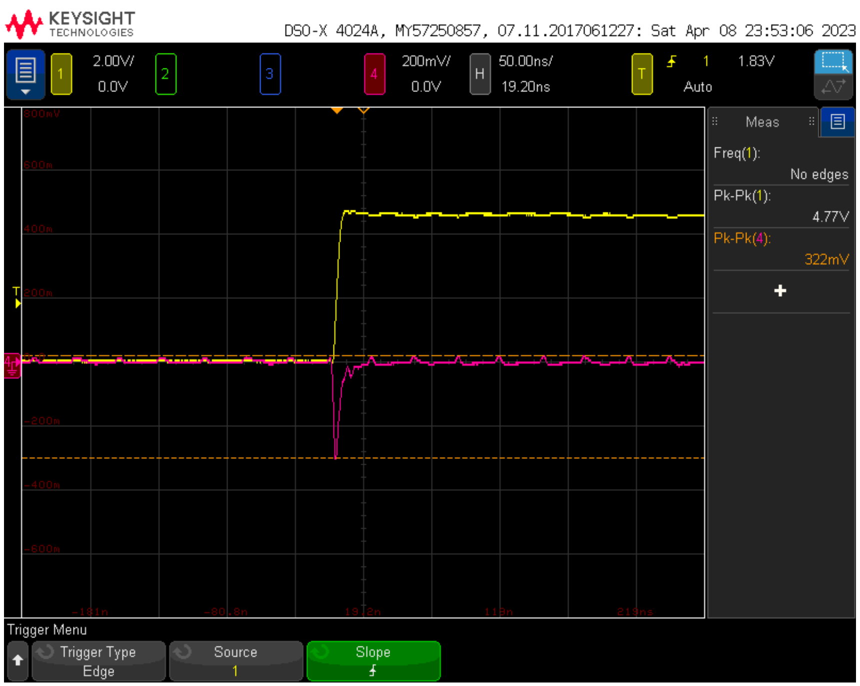


Figure 15: Switching noise on the quiet low pin for rising edge (Commercial)

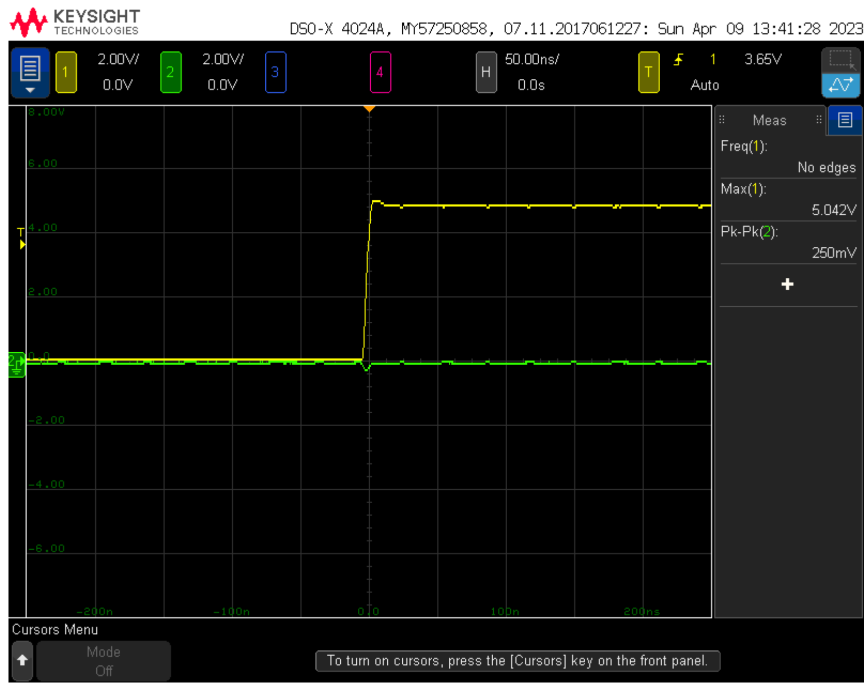


Figure 16: Switching noise on the quiet low pin for rising edge (Golden)

Triggered on Falling Edge

Figure 17: Switching noise on the quiet low pin for falling edge (Commercial)

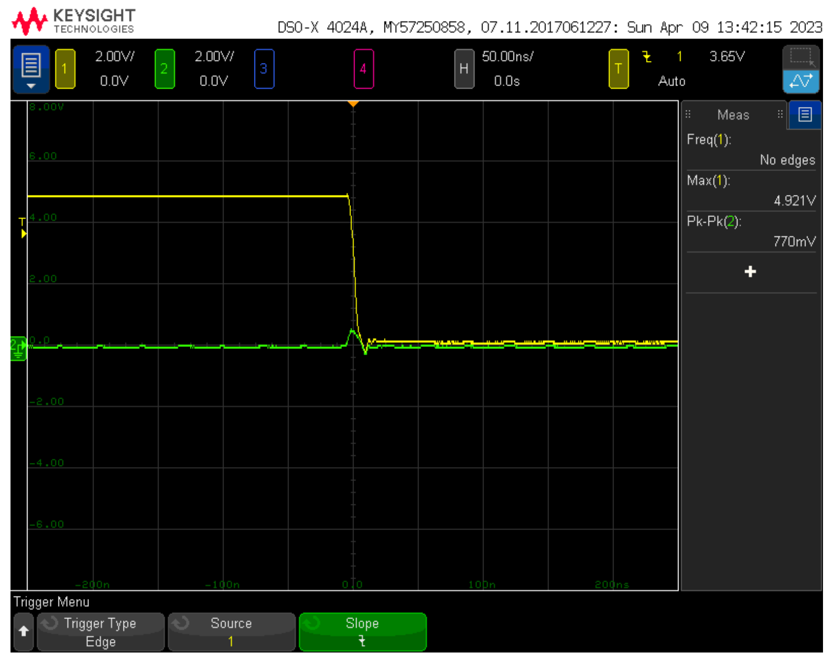


Figure 18: Switching noise on the quiet low pin for falling edge (Golden)

Switching noise on Power Rail
Triggered on Rising Edge

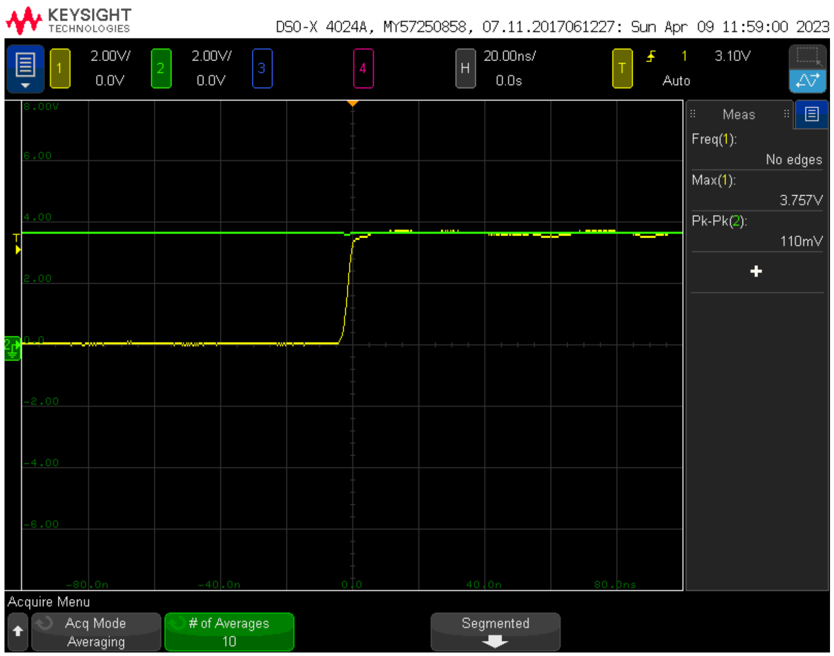


Figure 19: Switching noise on 5v power rail on rising edge green trace (Commercial Arduino)

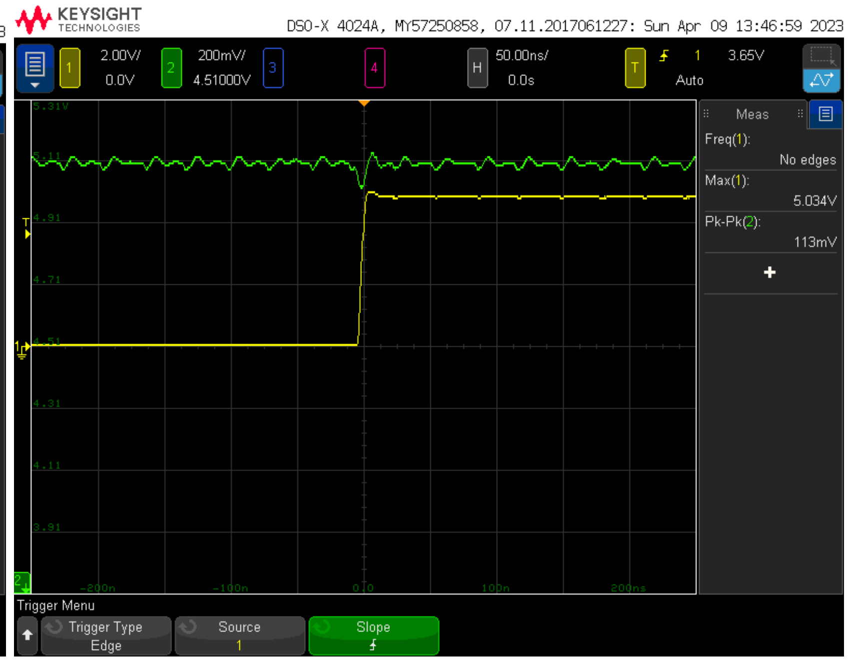


Figure 20: Switching noise on 5v power rail on rising edge green trace (Golden Arduino)

Triggered on Falling Edge

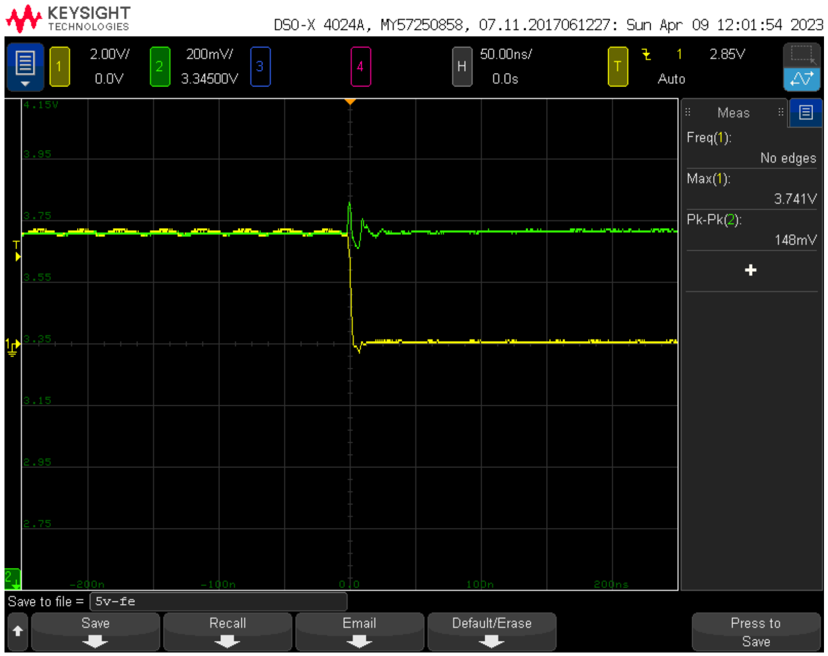


Figure 21: Switching noise on 5v power rail on falling edge green trace (Commercial Arduino)

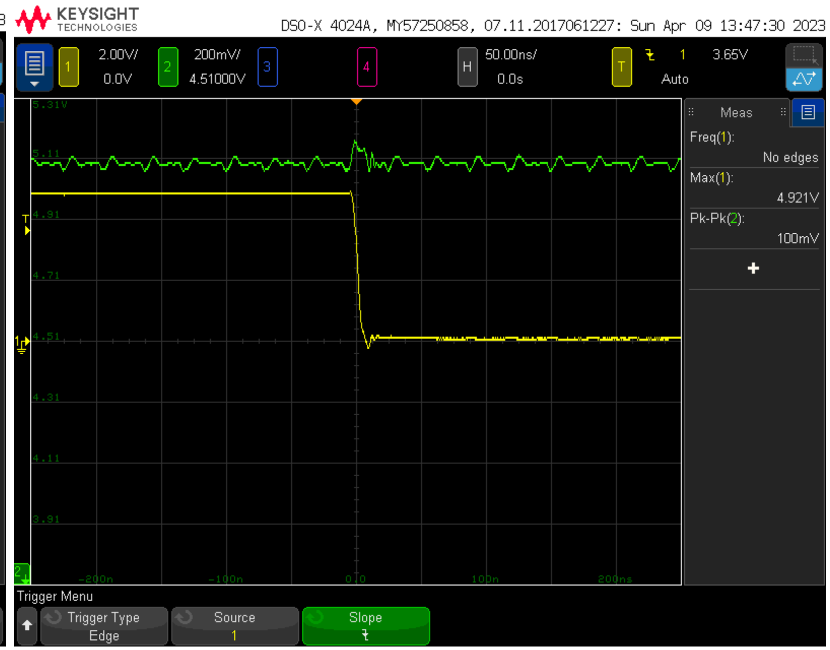


Figure 22: Switching noise on 5v power rail on falling edge green trace (Golden Arduino)

Readings from Traces in figure 15 to figure 22:

Property	Switching Noise on Commercial Arduino	Switching Noise on Golden Arduino	Percentage Noise Difference
Quiet-Low: Rising Edge	322mV	250mV	22.36%
Quiet-Low: Falling Edge	1.15V	770mV	25.33%
5v Power Rail: Rising Edge	110mV	~110mV	~0%
5v Power Rail: Falling Edge	148mV	100mV	32.43%

Table 1: Comparison of switching noise on commercial vs golden Arduino Board

After observing readings in the table above, it can be observed that the commercial Arduino board contains more noise as compared to the golden arduino.

Causes of more noise in Commercial Arduino Board:

- Poor placement of the components like decoupling capacitors that ain't placed in close proximity to Vcc.
- No continuous return path

Since we have taken care of these artifacts in our Golden arduino design, we can observe comparatively lesser noise.

Noise measurement when the Microcontroller itself is the aggressor

In the following traces, the Yellow trace denotes the trigger signal i.e. slammer circuit pin connected to a 10-ohm resistor and the green trace shows the noise measuring signal.

1. Noise on On-die 5v when triggered on Rising Edge

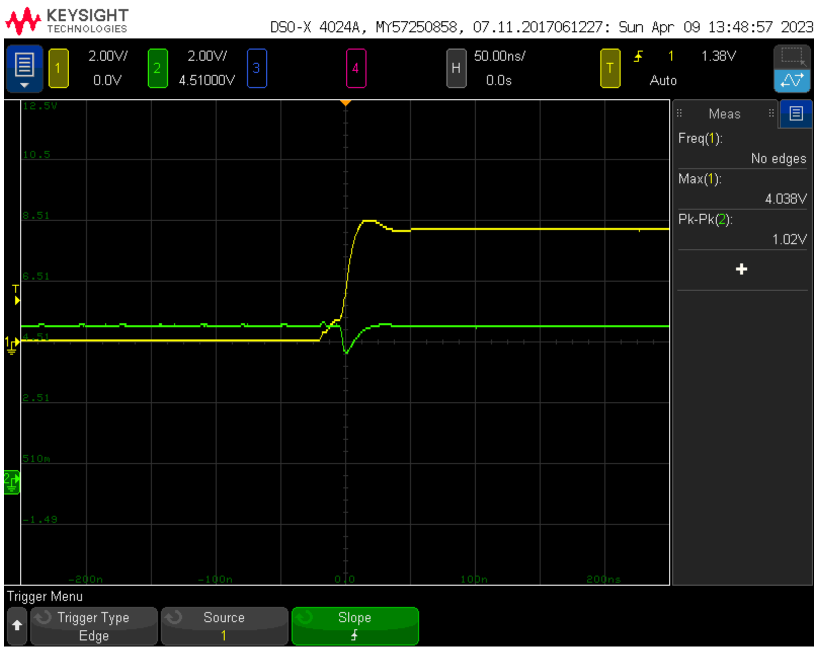


Figure 23: Noise on On-die 5v when the board is itself is the aggressor (Commercial Arduino)

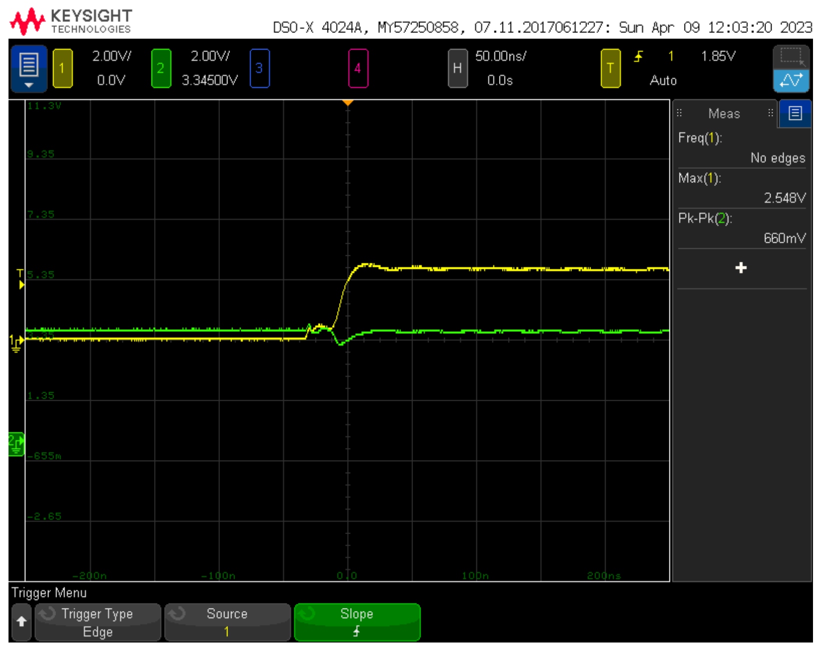


Figure 24: Noise on On-die 5v when the board is itself is the aggressor (Golden Arduino)

2. Noise on On-die 5v when triggered on Falling Edge

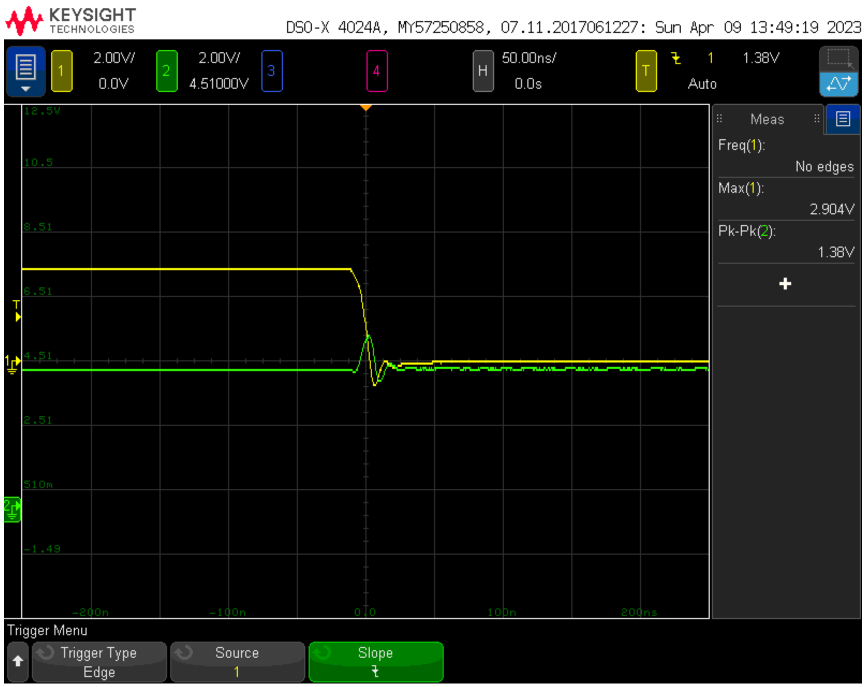


Figure 25: Noise on On-die 5v when the board is itself is the aggressor (Commercial Arduino)

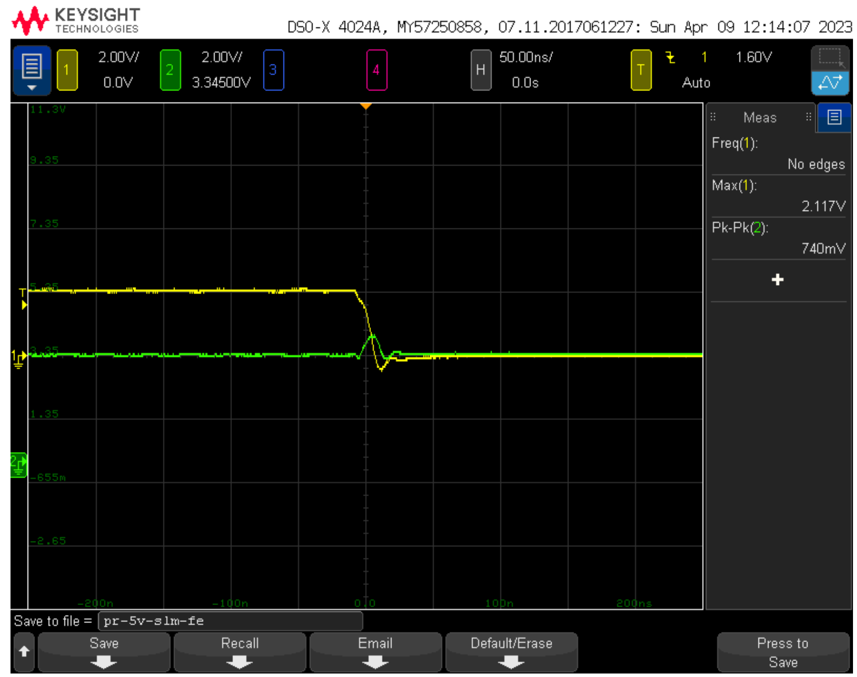


Figure 26: Noise on On-die 5v when the board is itself is the aggressor (Golden Arduino)

3. Noise on Quiet-High when triggered on Rising Edge

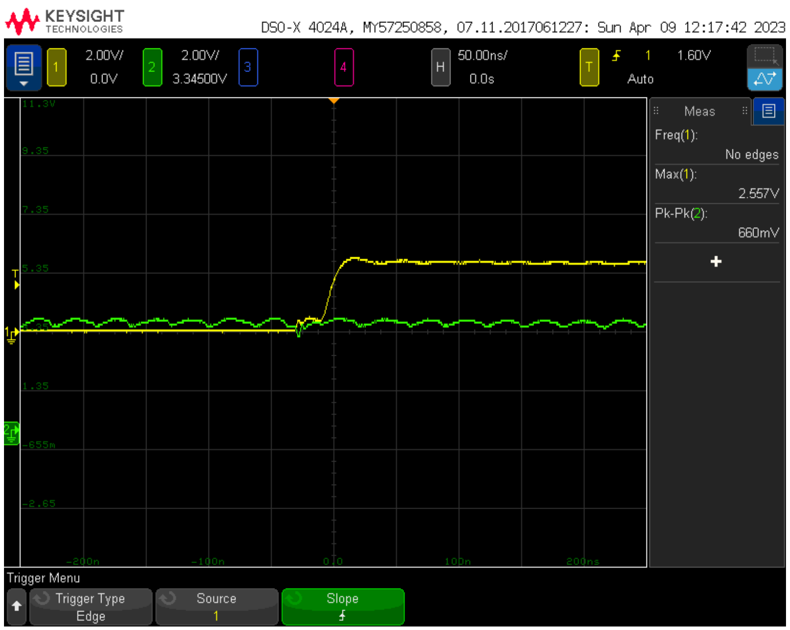


Figure 27: Noise on Q-High the board itself is the aggressor (Commercial Arduino)

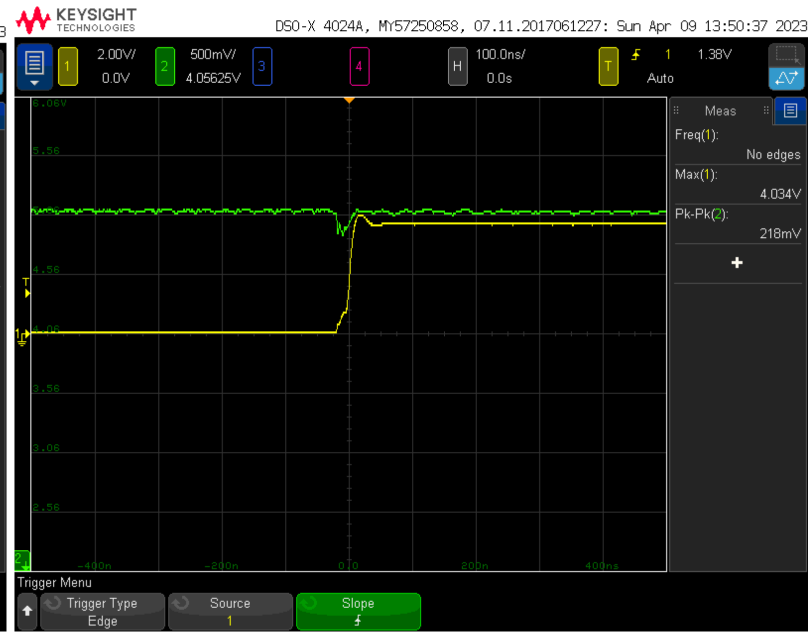


Figure 28: Noise on Q-High when the board itself is the aggressor (Golden Arduino)

4. Noise on Quiet - High when triggered on Falling Edge

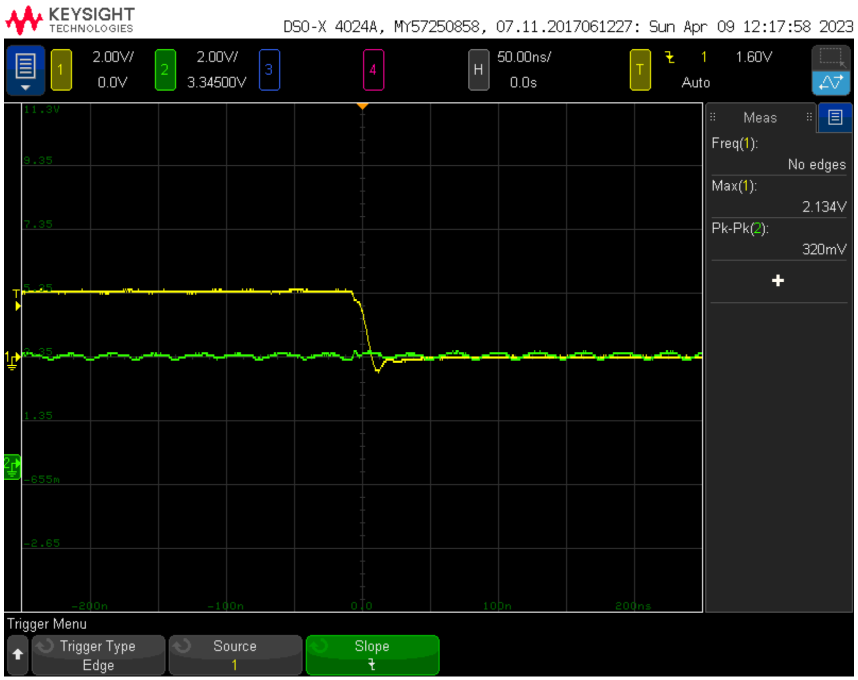


Figure 29: Noise on Q-High the board itself is the aggressor (Commercial Arduino)

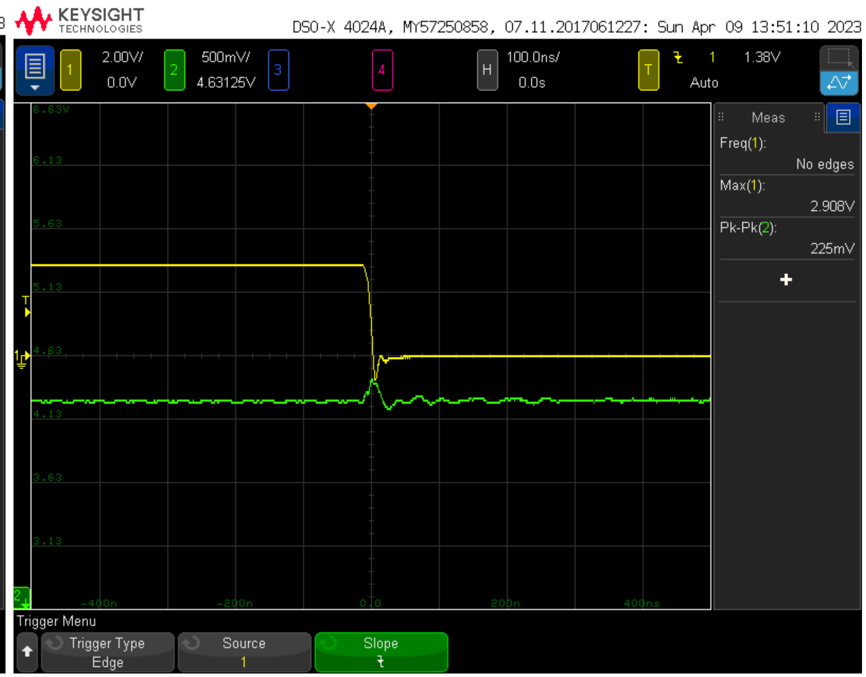


Figure 30: Noise on Q-High when the board itself is the aggressor (Golden Arduino)

Readings from Traces in Figure 23 to figure 30:

Property	Switching Noise on Commercial Arduino	Switching Noise on Golden Arduino	Percentage Noise Difference
5V rising edge	1.02V	660mV	34%
5V falling edge	1.38V	740mV	46.37%
Quiet High: Rising Edge	660mV	218mV	66.96%
Quiet High: Falling Edge	320mV	225mV	29.68%

Table 1: Comparison of switching noise on commercial vs golden Arduino Board

After observing readings in the table above, it can be observed again that the commercial Arduino board contains more noise as compared to the golden arduino.

Near Field Emission Measurement

In the below figures, the yellow trace is the trigger i.e. switching signal on digital pin 13 whereas the green trace shows the behavior of a victim line that is sensitive to near field emissions.

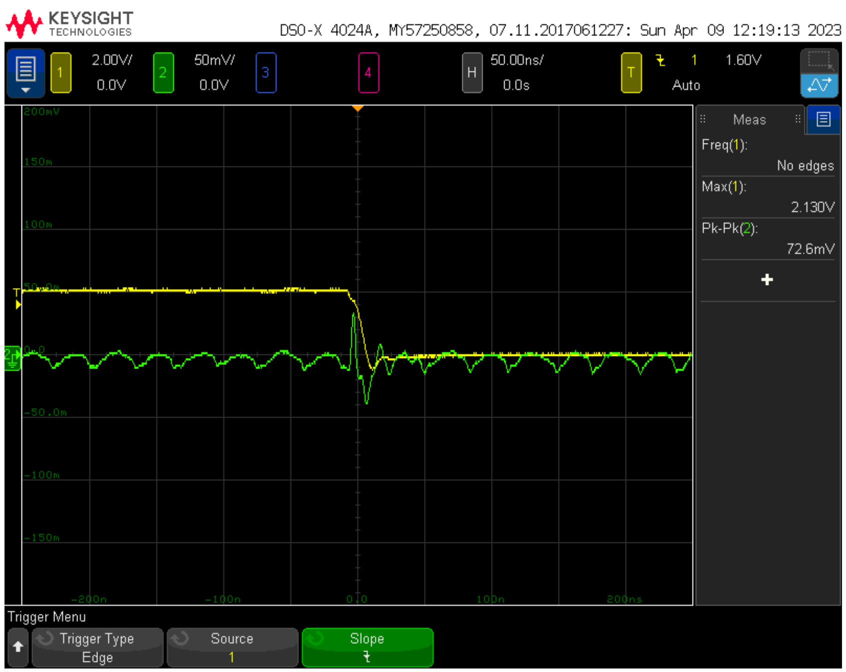


Figure 31: Near Field Emission (Commercial arduino board)

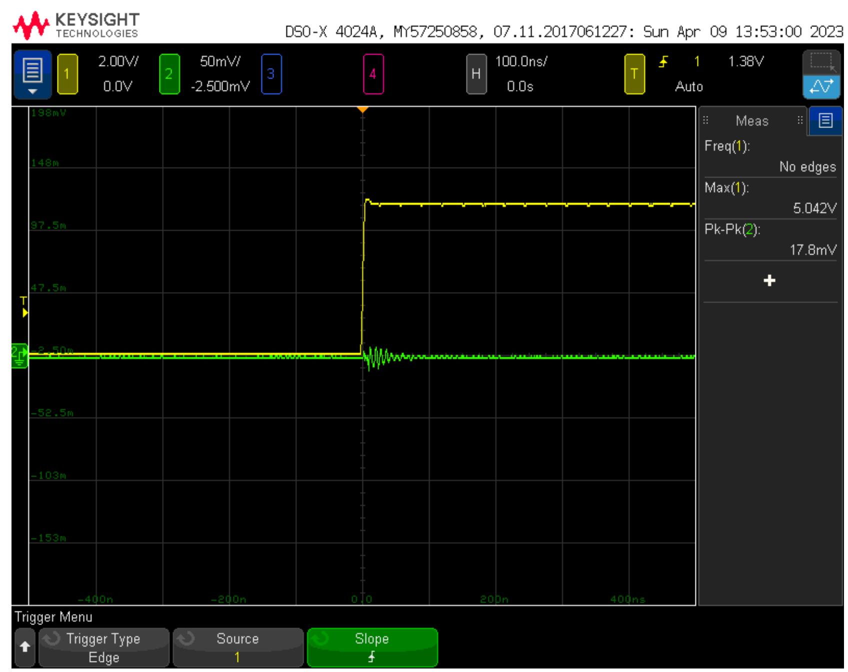


Figure 32: Near Field Emission (Golden arduino board)

To find near field and distant field emissions, the test code can be run on Golden Arduino and Arduino boards. This can be accomplished by using a probe as a victim loop. The output of the trigger can be seen on channel 2 (green), and it allows us to determine the times when there is a maximum change in emission. The near field emissions from commercial

Arduinos emit about 72.6mV, as seen in channel 1 (yellow), whereas the trace of the Golden Arduino emits about 17.6mV. The Golden Arduino emits 17.6 mV or 24.27% of the emission of a commercial Arduino.

In-Rush Current Measurement

For in-rush current measurement, a sense resistor was added in series and two 10x probes were connected to the high and low-voltage sides of the sense resistor.
Current Sense Resistor Value: 500 mOhm

Figure 33: In-rush current Measurement on Golden Arduino Board

In Figure 33 above,

Yellow Trace ➜ Voltage on the high end of the sense resistor

Green Trace ➜ Voltage on the high end of the sense resistor

Pink Trace ➜ Voltage difference between the two

Voltage across Current Sense Resistor ~= 2.3 V

Hence, In-rush current, I can be measured as,
I = (V1-V2)/R

= (2.3)/0.5

= 4.6A

<u>For golden arduino board, In-Rush Current, I = 4.6A</u>

Mistakes Made & Final Working Board Image

- Critical detailed design review is very crucial. I made the wrong connections for USB_Tx, USB_Rx, and MCU Tx, Rx.
- Net Label to the USB chip for the 5V power supply wasn't correctly connected, hence I had to externally connect a shirt wire to power up the USB chip.
- Firm soldering is very important, I could not get my 16Mhz oscillator working in the 1st solder go. It worked after resoldering it.

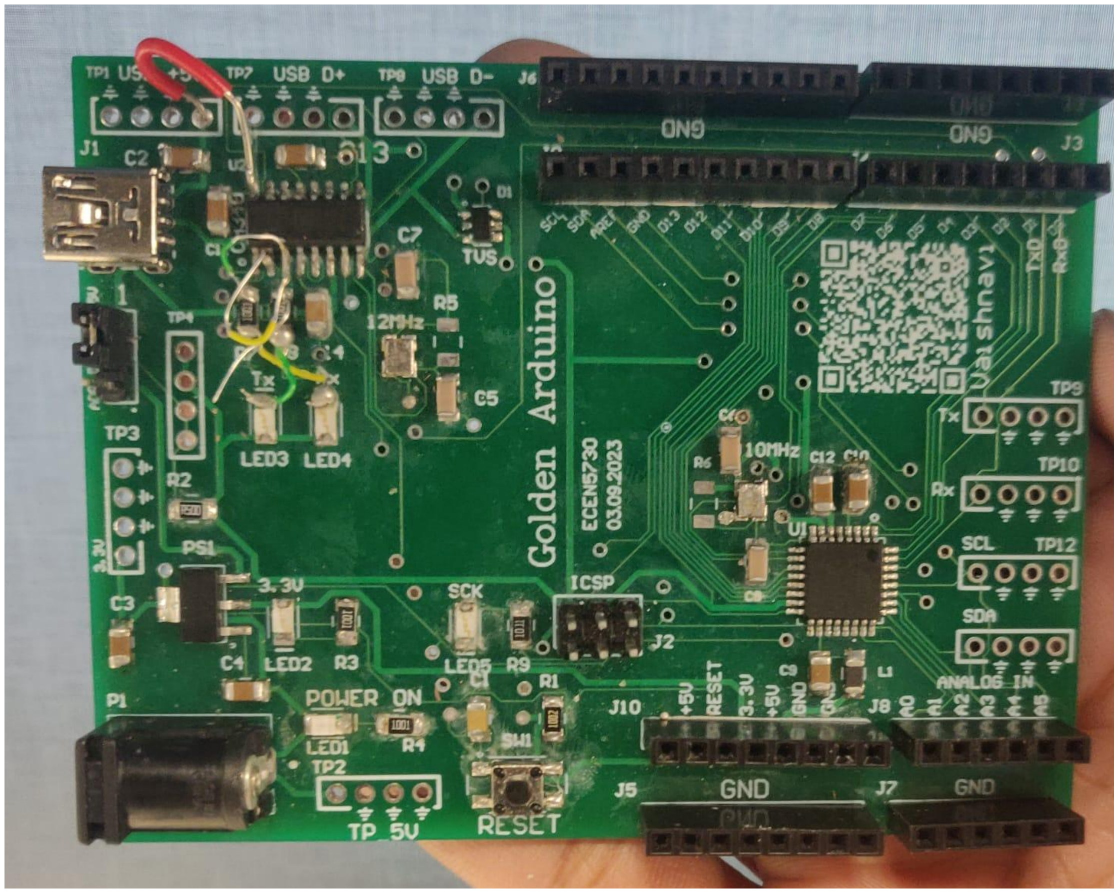


Figure 34: Hand-assembled working board

What worked after assembly and testing?

The list of features and capabilities that were anticipated to operate on the final-built Golden Arduino Board is given below. These belonged to POR and were verified using various test points on the board and from the peripherals of the IC for the pins without a specific test point.

Sr. No.	Function	Working Status
1.	Power Rail: 5V & 3.3V	Yes
2.	Power Select (Adapter/USB)	Yes
3.	Oscillators - 12Mhz & 16Mhz	Yes
4.	USB detection on host PC	Yes
5.	Boot loading	Yes
6.	Dumping Blinky Code through IDE over USB	Yes
7.	Reset Circuitry	Yes
8.	TVS for ESD Protection	Yes
9.	LDO Circuit	Yes
10.	Reduction in Switching Noise	Yes
11.	Reduction in Near Field Emissions	Yes

After a power connection to USB and correcting the Tx, and Rx connections, the board worked correctly as per the expectations and was successfully boot-loaded and programmed, fulfilling all the necessary requirements.

Key Learnings

- Understood a complete design approach to the development of an arduino board.
- This design project assisted in comprehending the value of a good layout and the reason why commercial designs shouldn't be always referred to as ideal.
- Simple design principles, like using a continuous common return ground plane, placing decoupling capacitors, addressing loop inductance, etc., can have a significant impact on the circuit's quality.
- When designing the PCB, the near-field emission effect should be considered since it creates far-field emission, which interferes with EMC regulations.

References

- *CU ECEN-4/5730 Spring 2023 Workbook by Prof. Eric Bogatin*
- *Bogatin's Practical Guide to Prototype Breadboard and PCB Design by Eric Bogatin, published by Artech House Copyright: 2021 ISBN: 9781630818487*