

Objective:

To design a fully functional Arduino Uno board with seven step design process with best design practices and compare its robustness with a commercial board.

Plan of Record (POR)

The circuit should have,

1. A power plug for “AC to 5V DC” to supply power for the board.
2. A USB mini-B with TVS diode for connecting to PC
3. 3.3 LDO for providing 3.3V which can be used from header pins.
4. A switch to select between 5V/USB supply.
5. ICSP header pin for bootloading ATMEGA 328
6. ATMEGA 328 microcontroller and CH340g for USB to UART.
7. 0.5-ohm sense resistor and a test point to measure inrush current
8. A reset circuitry
9. A ferrite filter on AVCC pin.
10. Crystal: 16MHz for ATMEGA328 and 12MHz for CH340g
11. Indicator LED for the power supply, LDO and USB.
12. Test points for 5v rail, 3.3V, SPI, I2C, UART, USB (D+, D-)
13. Isolation header pins for ATMEGA328.

- 9. Crystals 16MHz and 12MHz
- 10. Ferrite bead-10uH
- 11. TVS diode - TPD3E001DRLR

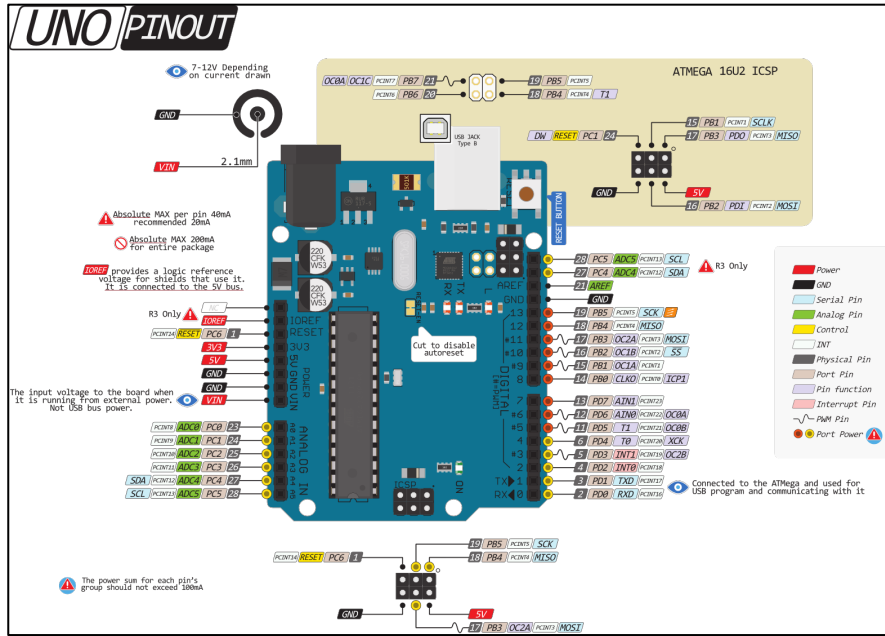


Figure 4_0: Arduino Uno Schematic in Altium software

Layout:

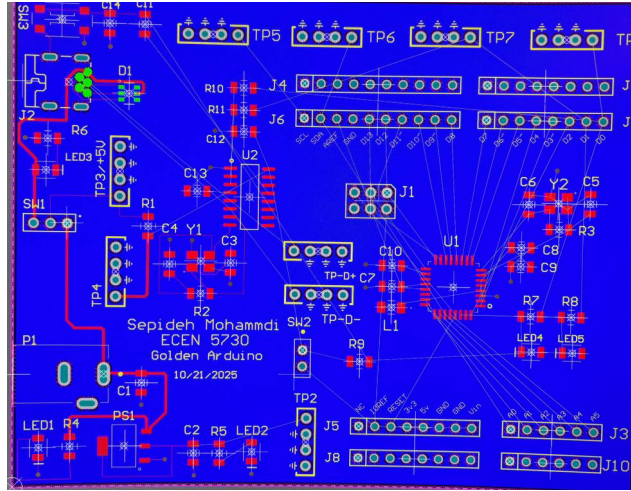


Figure 4_1: Arduino UNO layout in Altium designer

Before and after assembling:

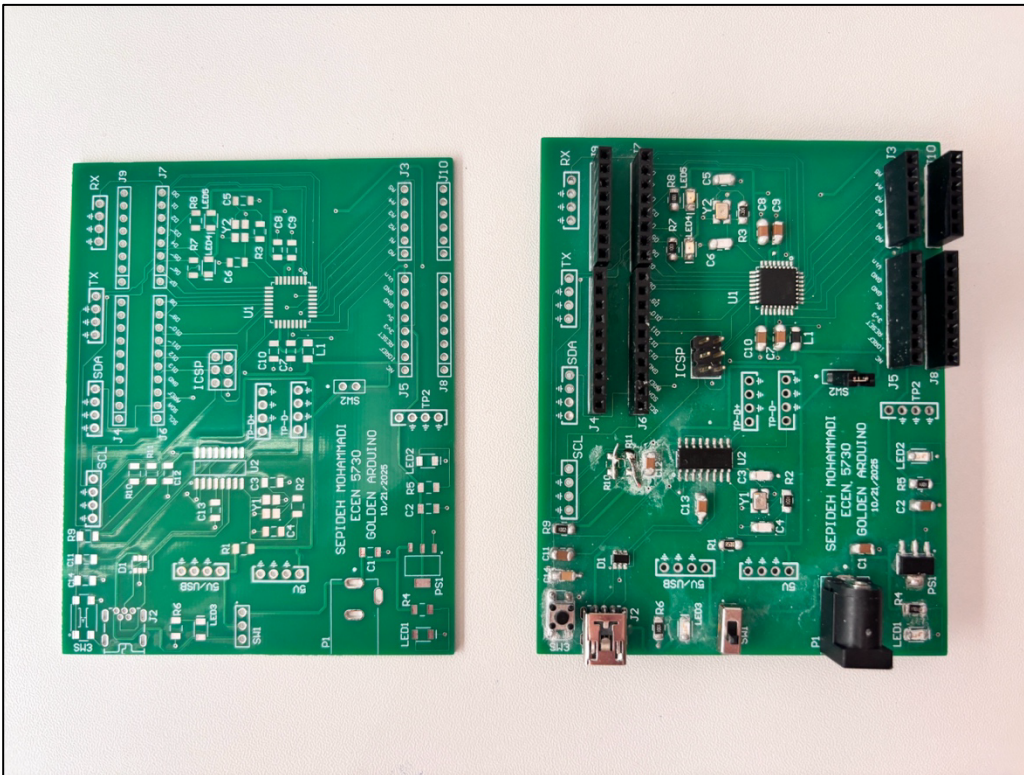


Figure 4: before assembling

Figure 5: after assembling

What did not work?

3.3V works on the power jack. But did not work on the USB supply as the net is not included from the 5V/USB switch (SW1) to LDO. So, for full functionality, connect the power jack after uploading the code which is an easy solution.

Scop shots and Analysis:

1. 5V (Yellow) and 3.3V (Green) rail measured at TP2 and TP1 respectively.

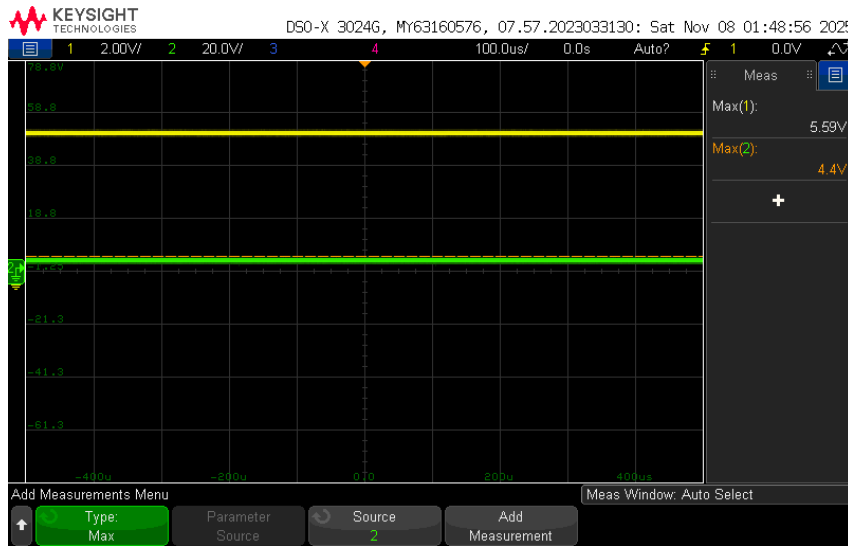


Figure 10: Power Rails (5V and 3.3V)

2. UART Signals and USB signals: UART signals and USB signals are sniffed from TP7,9 and TP3,4 respectively when the code is uploaded. It is captured using Normal trigger mode.

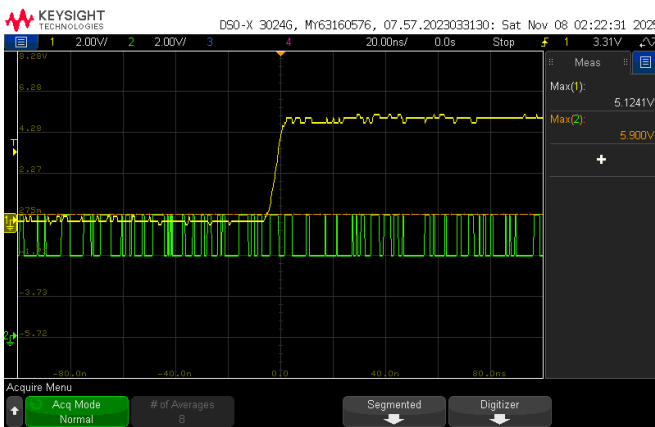


Figure 11: UART signal, yellow TX, green RX

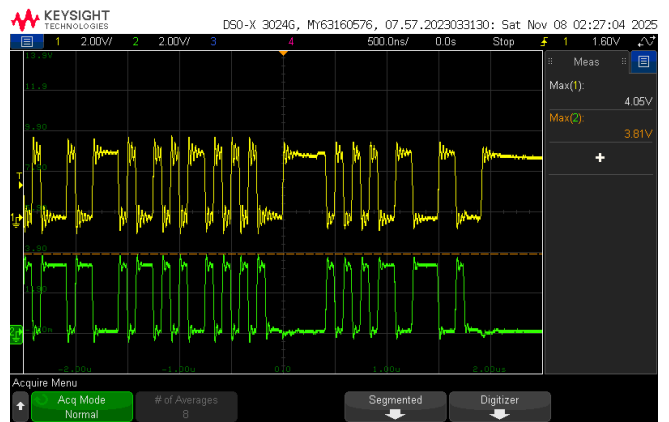


Figure 12: USB signals, D- green, D+ yellow

- Inrush current: With normal trigger mode, the inrush current sunk by the decoupling capacitors is captured across 0.5Ω. In Figure 13, Yellow is the high side of the resistor, green is the low side, and pink is the math function that subtracts the high side from the low side. So, **Inrush current= 1.607/0.5 = 3.214A!**

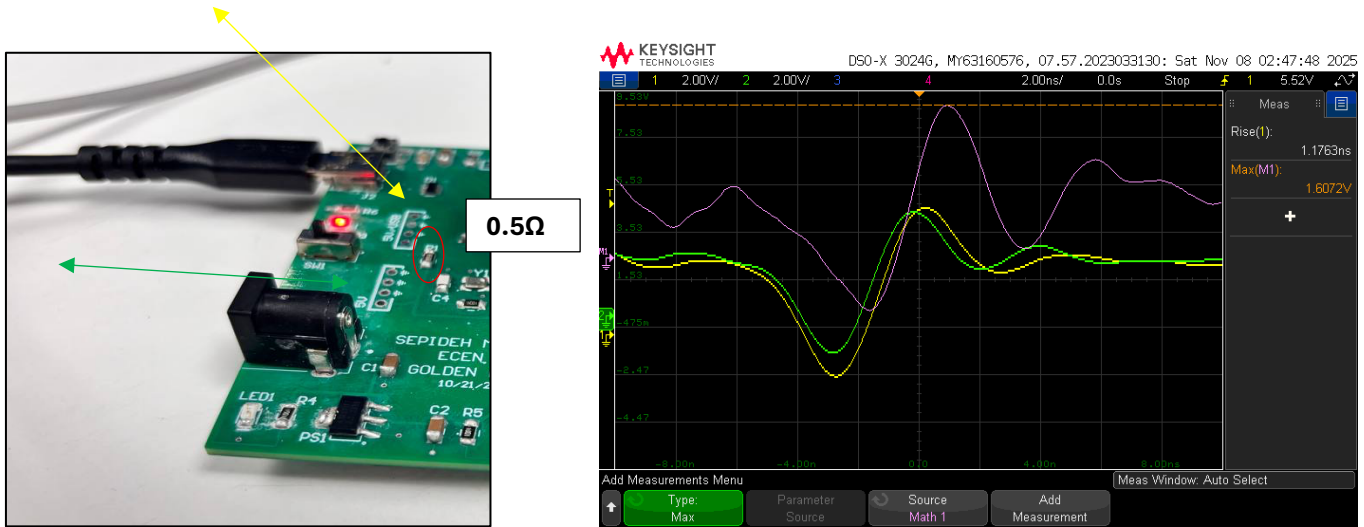
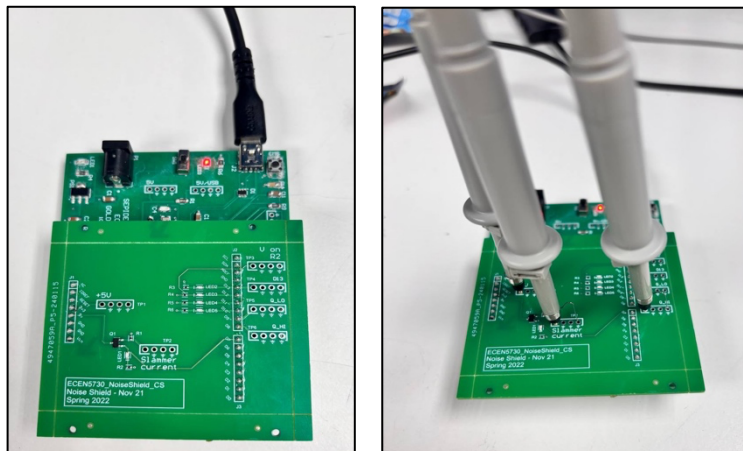


Figure 13: Inrush Current

WITH SHIELD BOARD ON TOP OF ARDUINO UNO,

For the following measurements, a special shield board- a breakout board that fits into Arduino header sockets is used as shown in figure 14. It consists of three 49Ω separately connected to D12, D11, and D10 driving LEDs. D13 is connected to 1KΩ with LED which is used as a trigger (TP4 on shield). Using the code, each digital pin is programmed to give a square signal and D9 is always pegged low (Q_low) and D10 pegged high (Q_high).



```

void setup() {
  DDRB = B00111111; // Set pins D8-D13 as outputs (bits 0-5)
  pinMode(7, OUTPUT); // D7 will be used for the slammer circuit
  digitalWrite(7, LOW);
}

void loop() {
  PORTB = B00111101; // D13, D12, D11, D10 = HIGH; D9 = LOW; D8 = HIGH
  delayMicroseconds(4);

  PORTB = B00000001; // Only D8 = HIGH (others LOW)
  delay(1);

  digitalWrite(7, HIGH); // Trigger slammer circuit on D7
  delayMicroseconds(400);
  digitalWrite(7, LOW);

  delay(10);
}

```

Figure 14: Shield board fitted into the Golden Arduino

It also has a MOSFET with a 10Ω sense resistor on its source. The gate signal is driven by D7, indicated by LED1 and its Drain is connected to the 5V pin.

- Near-Field Emission: D13 (TP4) is used as a trigger(yellow). 10X probe connected to the Channel 2 (green) and its tip is shorted to its ground and it is kept under Arduino. Due to the mutual coupling of radiations emitted by Arduino, it captures the noise.

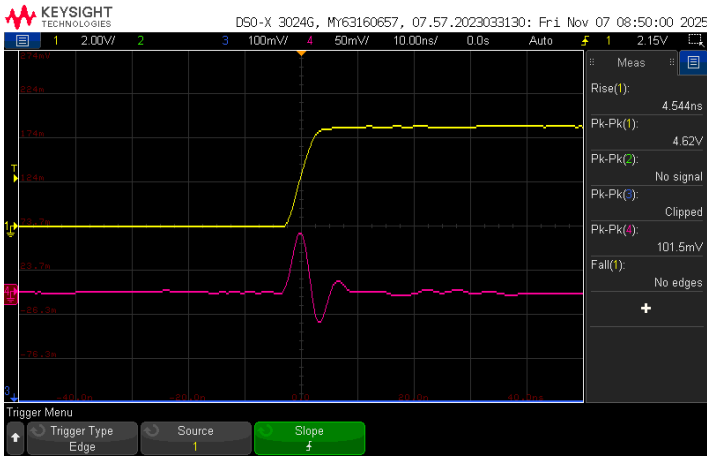


Figure 15: Rising Edge NFE of commercial Arduino.

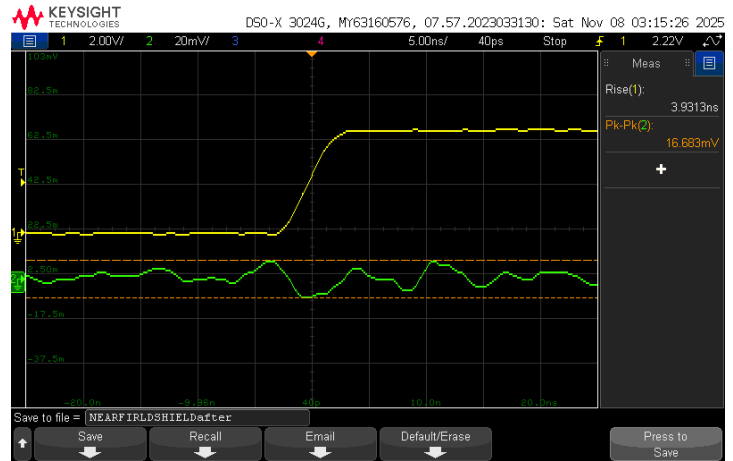


Figure 15: Rising Edge NFE of Golden Arduino



Figure 17: Falling Edge NFE of commercial Arduino

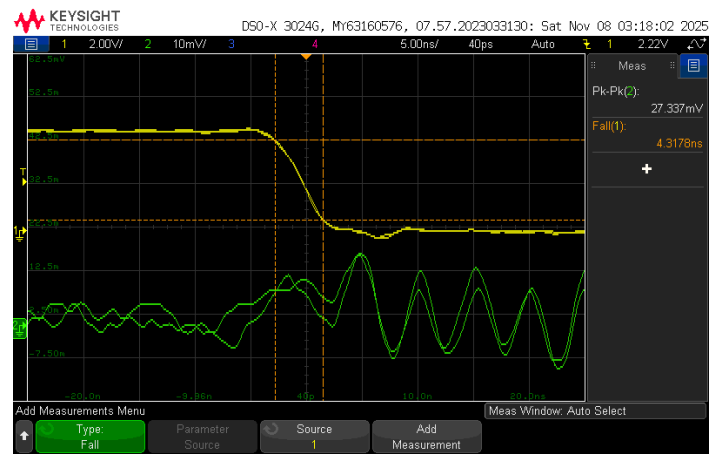


Figure 18: Falling Edge NFE of Golden Arduino

Measurements	Commercial Arduino	Golden Arduino
Near field rising edge(mV)	101	16.68
Near field -falling edge(mV)	169	27.337

From the table, it is evident that Golden Arduino has very less emissions than the commercial Arduino on both rising and falling edges.

- Current across R4 (49Ω) on the shield connected to D12 Pin: In figure 19, yellow is the trigger (D13) and green is the voltage across the 49Ω resistor (TP3 on shield). So, the current = $1.71/49 = 34.89\text{mA}$ for both boards. This same current flows across D11 and D10 since they are connected with the same resistors and LEDs.

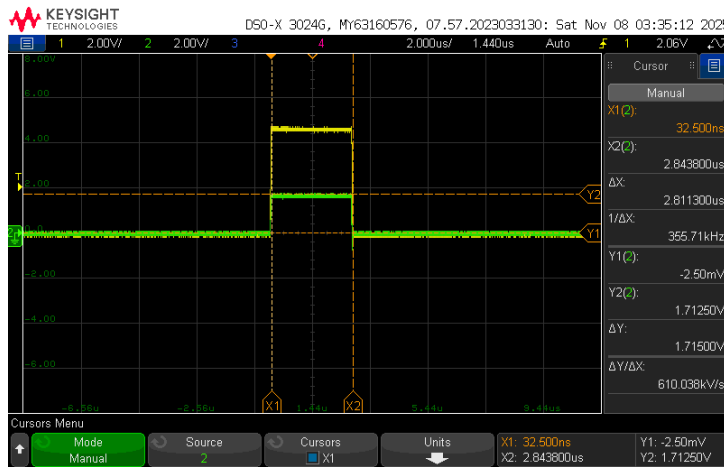


Figure 19 Voltage across 49Ω resistor on shield

WHEN THE I/Os OF ARDUINO IS SWITCHING: The code is modified to keep switching D13, D12, D11, D10 and MOSFET is turned OFF (D7 is commented in code). Due to simultaneous switching currents on the pins D12, D11, D10 has shown above, there is di/dt which causes mutual coupling leading to switching noise on 5V rail (On board – blue (TP1) and On-die (Q_high) – pink (TP6)) and ground (green- (Q_low-TP5)). Yellow is the trigger (D13-TP4).

- Rising Edge's Quiet low and Quiet high:

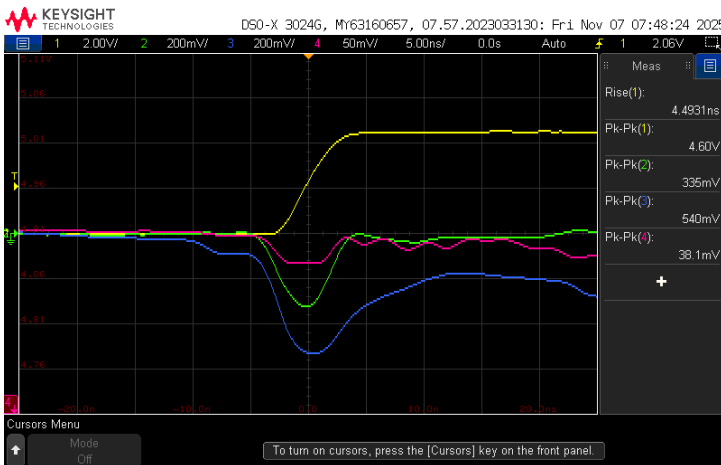


Figure 20: Commercial Arduino I/O Sw_noise for Rising time

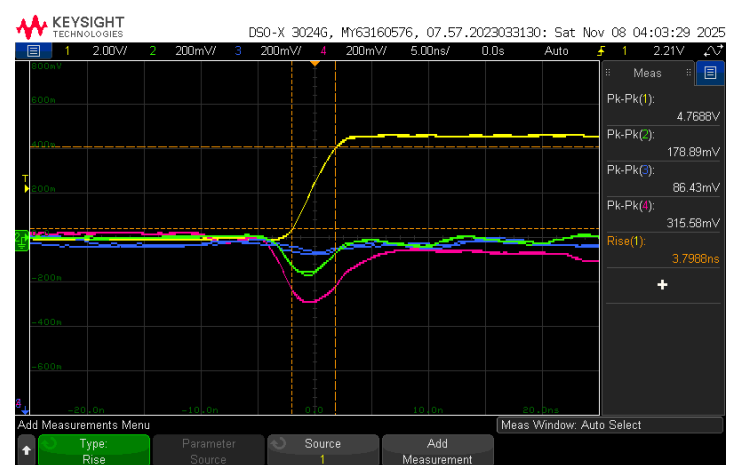


Figure 21: Golden Arduino I/O Sw_noise for Rising time

Measurements	Commercial Arduino	Golden Arduino
Rise time (ns)	4.49	3.79
Quiet low: Vp-p (mV)	355	179
Quiet high: Vp-p (mV)	540	315
On board 5V(mv)	38	86

The data shows that the switching noise is lower in Golden Arduino because of best design practices such as continuous ground plane. On-board noise is lower than Q_High (On-die 5V) in both boards and this is why where we measure for switching noise on the PDN matters.

7. Falling Edge's Quiet low and Quiet high:

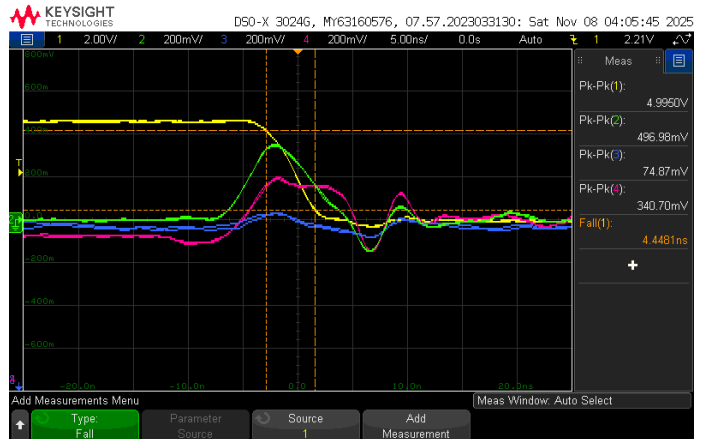
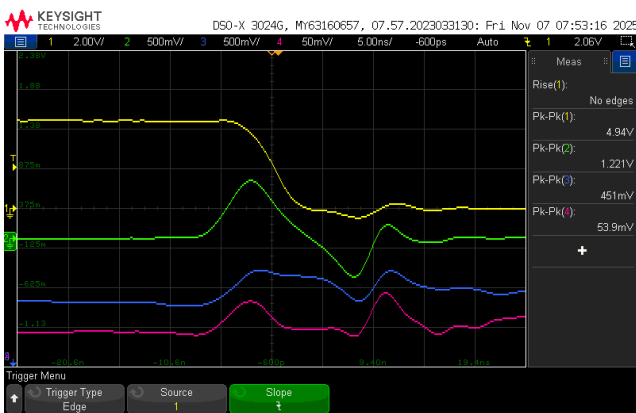


Figure 22: Commercial Arduino I/O Sw_noise for falling time

Figure 23: Golden Arduino I/O Sw_noise for falling time

Measurements	Commercial Arduino	Golden Arduino
Rise time (ns)	9.30	4.45
Quiet low: Vp-p (mV)	1.221	496.98
Quiet high: Vp-p (mV)	451	340.70
On board 5V(mv)	53.9	75

From the observed data, Golden Arduino mitigates more switching noise than commercial Arduino.

WHEN THE MOSFET IS SWITCHING: Code is modified to turn OFF D13, D12, D11, D10 and MOSFET is turned ON (D7 alone is switching). Yellow is the trigger (voltage across 10Ω

which appears as the D7 drives the gate), pink is the On-die 5V (TP6) and green is the On-board 5V (TP1).

8. Rising Edge's Q_high and On-board 5V:

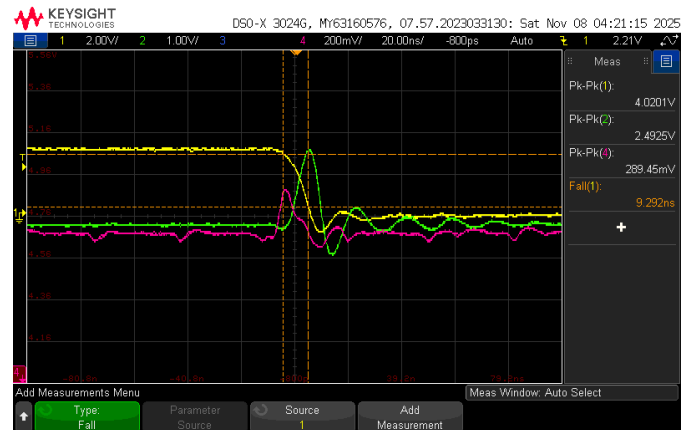
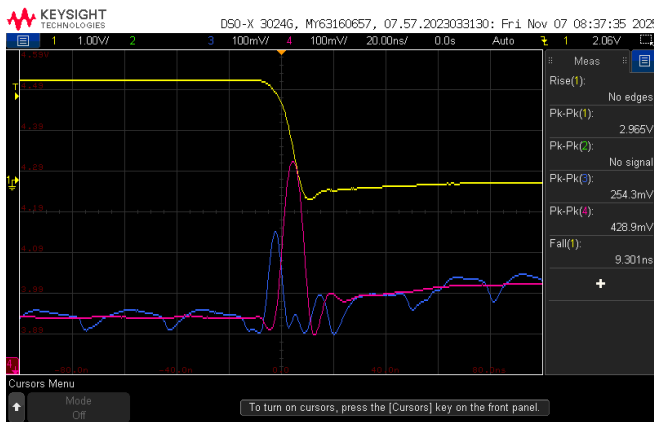


Figure 24: Commercial Arduino Mosfet Sw_noise for rising

Figure 2: Golden Arduino Mosfet Sw_noise for rising time

Measurements	Commercial Arduino	Golden Arduino
Rise time (ns)	22	22.6
Quiet high: Vp-p (mV)	520	361.81
On board 5V(V)	0.35	1.2

9. Falling Edge's Q_high and On-board 5V:



Measurements	Commercial Arduino	Golden Arduino
Rise time (ns)	9.30	9.30
Quiet high: Vp-p (mV)	254.3	289
On board 5V(V)	0.43	2.49

When the slammer circuit is ON, on-board rail noise is higher as the board is longer and the nearest decoupling capacitor from the drain is far. But Q_high has a little bit more switching noise in Golden Arduino for both is almost the same (9.30 for rising time , and for the falling edge is 22ns).

10. Thevenin Resistance of 5V pin on the Golden Arduino header.

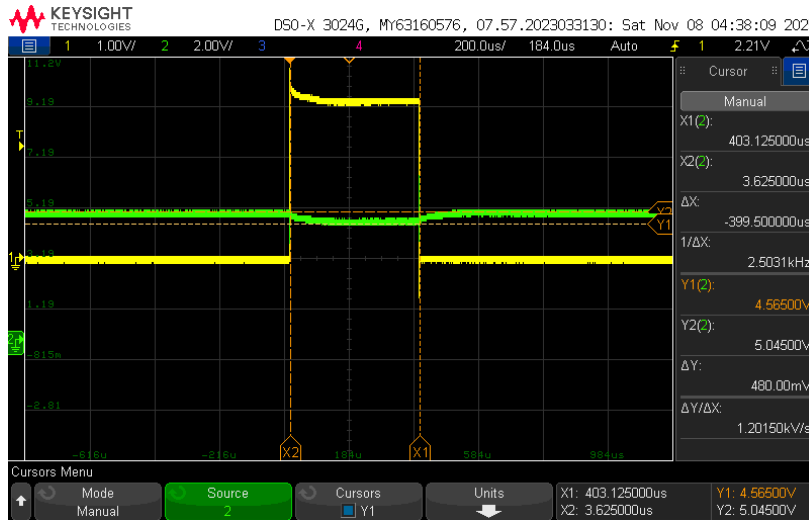


Figure 28: Voltage on 5V rail-TP1(green)

$$R_{th} = (V_{th} - V_{load}) / I_{load}$$

From figure 28 V_{th} is the no-load voltage on 5V rail – TP1 (Y2) = 5.04V

V_{load} is the voltage when the slammer circuit is ON (Y1) = 4.56V

$I_{load} = \text{Voltage across } 10\Omega \text{ (Yellow – TP2)} / 10\Omega = 0.48 / 10 = 0.048\text{A}$

$$R_{th} = (5.04 - 4.56) / 0.048 = 1\ \Omega$$

$$R_{th} = 1\ \Omega$$

The 5V pin on Arduino Uno has an internal resistance of $1\ \Omega$ and whenever a load is connected/ draws current, there would be a voltage drop across the internal resistance according to the voltage division rule.

Best Design Practices

1. Reduced the number of unique components during selection.
2. Placed decoupling capacitors close to ICs; added a ferrite bead on the AVCC pin to minimize noise.
3. Labeled all test points to prevent connection errors.
4. Added indicator LEDs and isolation switches for easier debugging.
5. Used a continuous ground return plane.
6. Limited cross-unders to only two (none is ideal).
7. Used 20 mil traces for power lines (high current capacity) and 6 mil traces for signal lines (high routing density and low cost).
8. Selected 1206-sized parts for easy manual soldering.

Possible Improvements

1. Add decoupling capacitors near the 5 V, 3.3 V, and Vin header pins.
2. Reduce the overall board size.
3. Eliminate remaining cross-unders through better component placement.
4. Enable the LDO supply for both USB and power jack inputs to support either power source.

Conclusion

By following good design practices, a **Golden Arduino** was developed that is more robust against EMI and on-die switching noise than commercial Arduinos.