Board 3 — Golden Arduino

ECEN 5730 – Practical PCB Design
Student: *Nikhil Kishor Sawane* • **Date:** *11/10/2025*

Objective

The goal of this project is to design and build a fully operational Arduino Uno–compatible board, following the structured seven-step PCB design methodology. The design emphasizes robust layout practices to enhance electrical performance and reliability. The completed “Golden Arduino” will be evaluated and compared against a commercial Arduino Uno to assess improvements in noise performance, stability, and overall robustness.

Plan of Record (POR)

The custom Arduino board will include the following key features and components:

- A barrel power jack to accept an external AC-to-5 V DC adapter for board power.
- A USB Mini-B connector with an integrated TVS diode for PC connectivity and ESD protection.
- A 3.3 V low-dropout (LDO) regulator to generate a regulated 3.3 V rail available at header pins.
- A power-selection switch allowing the user to choose between USB and 5 V adapter input.
- An ICSP (In-Circuit Serial Programming) header for bootloading the ATmega328 microcontroller.
- The ATmega328 MCU paired with the CH340G USB-to-UART interface for serial communication.
- A 0.5 Ω sense resistor and corresponding test point to observe inrush current during power-up.
- A reset circuit with a tactile pushbutton for manual MCU reset.
- A ferrite bead filter on the AVCC pin to isolate analog power from digital noise.
- Clock sources: 16 MHz crystal for the ATmega328 and 12 MHz crystal for the CH340G.
- Indicator LEDs for the 5 V rail, 3.3 V regulator output, and USB power status.
- Test points for major signals including 5 V, 3.3 V, SPI, I^2C, UART, and USB D+/D– lines.
- Isolation header pins connected to the ATmega328 for easier debugging and subsystem testing.

Components Required / Bill of Materials (BOM)

The following components were used to build the Golden Arduino board. Standard 1206 package sizes were selected for ease of manual soldering and rework.

1. Microcontrollers & Interfaces
   - ATmega328P microcontroller
   - CH340G USB-to-UART converter
2. Voltage Regulation
   - AMS1117-3.3 LDO voltage regulator
3. User Interface Components
   - Tactile pushbutton switch for reset
   - Female header sockets for Arduino-compatible pin access
4. Passive Components
   - Resistors: 1 kΩ ×5, 10 kΩ ×1, 1 MΩ ×2, 0.5 Ω ×1 (current-sense resistor)
   - Capacitors: 1 μF ×1, 22 μF ×9, 22 pF ×4
5. Indicators
   - LEDs ×5 for power, LDO, and USB status indication
6. Connectivity
   - DC power jack (for 5 V adapter input)
   - USB Mini-B female connector
7. Clock Sources
   - 16 MHz crystal oscillator (ATmega328P)
   - 12 MHz crystal oscillator (CH340G)
8. Protection and Filtering
   - Ferrite bead (10 μH) for AVCC analog filtering
   - TVS diode (TPD3E001DRLR) for USB ESD protection
9. Miscellaneous
   - Shorting jumpers (flags) for circuit isolation and configuration

Napkin Sketch

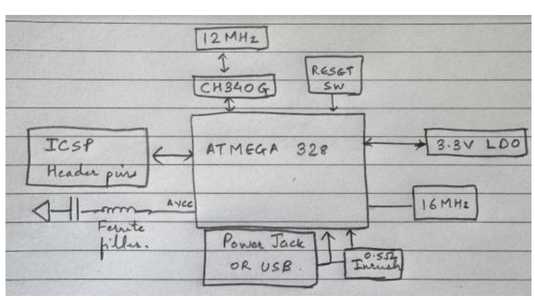


Figure 1 - Napkin sketch

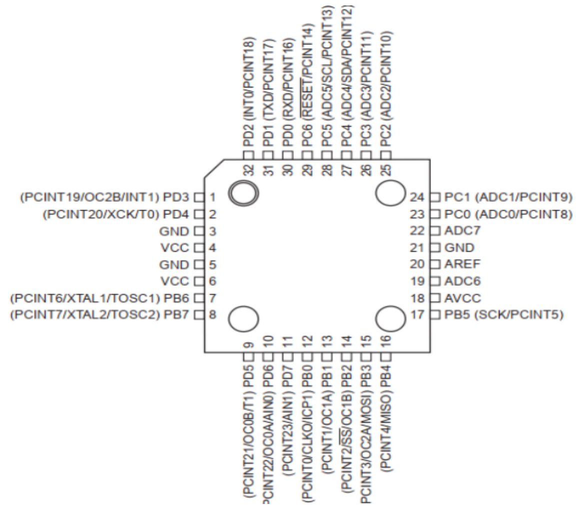


Figure 2 – Atmega 328 pinout

Schematic

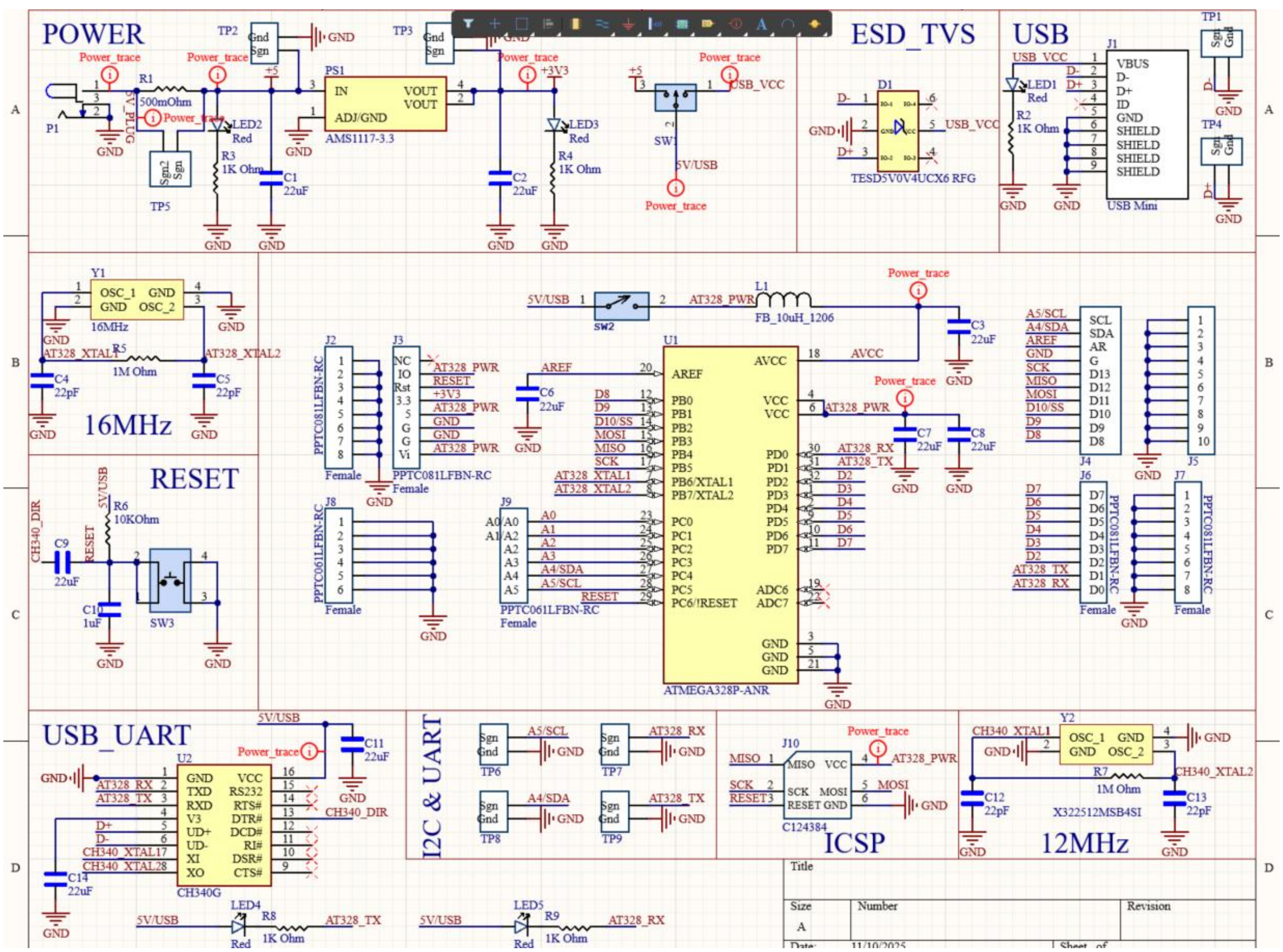


Figure 4 Arduino Uno Schematic in Altium software

Layout

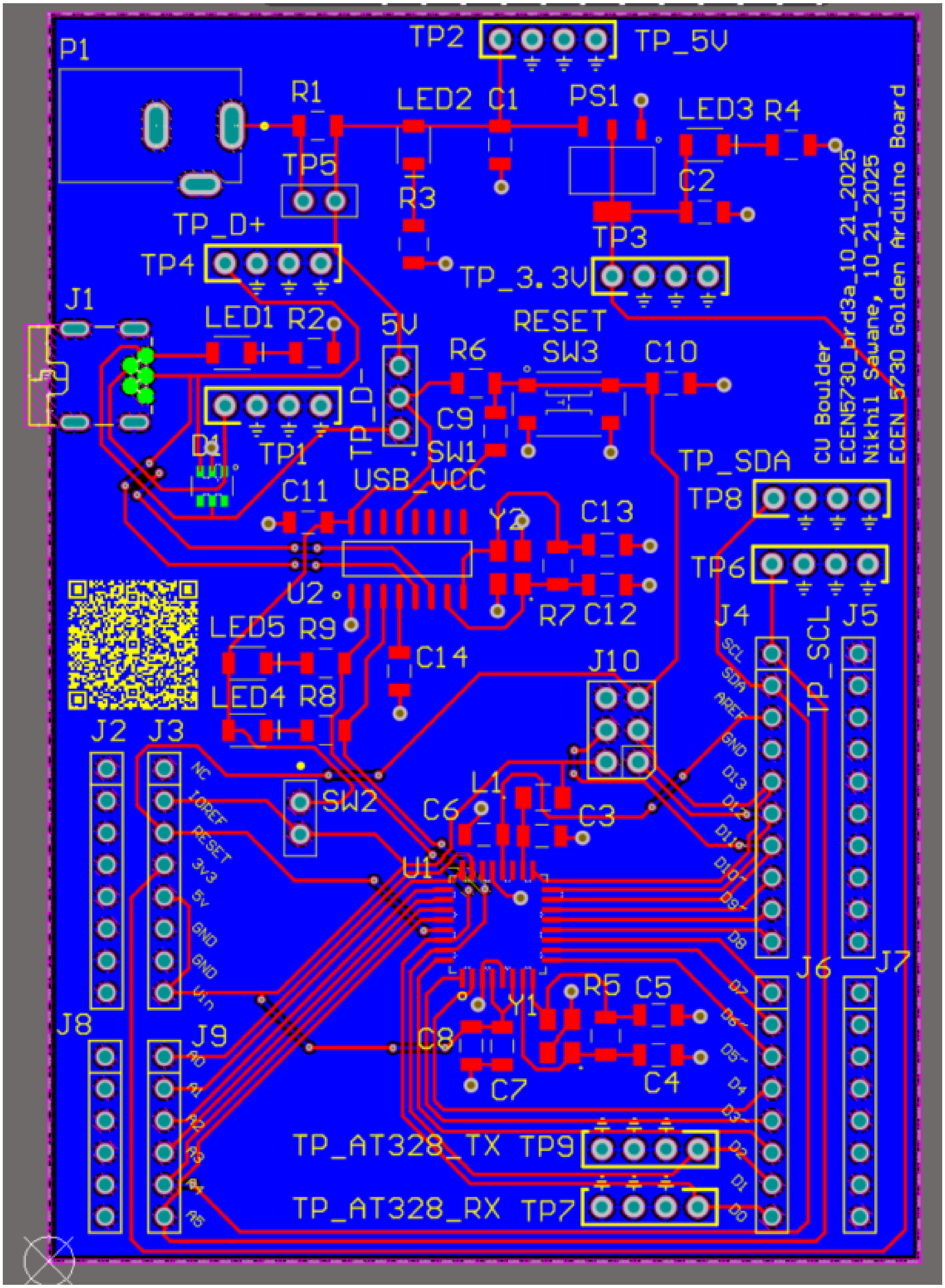


Figure 5 Arduino Uno layout done in Altium Software

Board Assembly

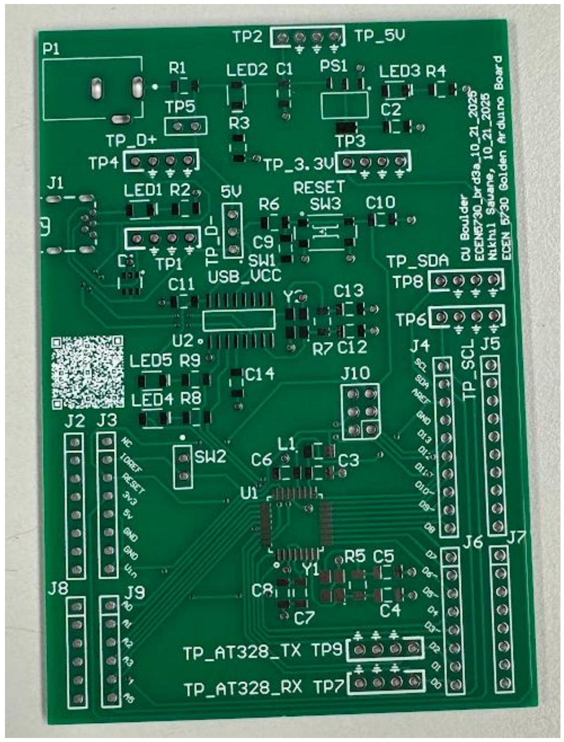


Figure 6 Unassembled board

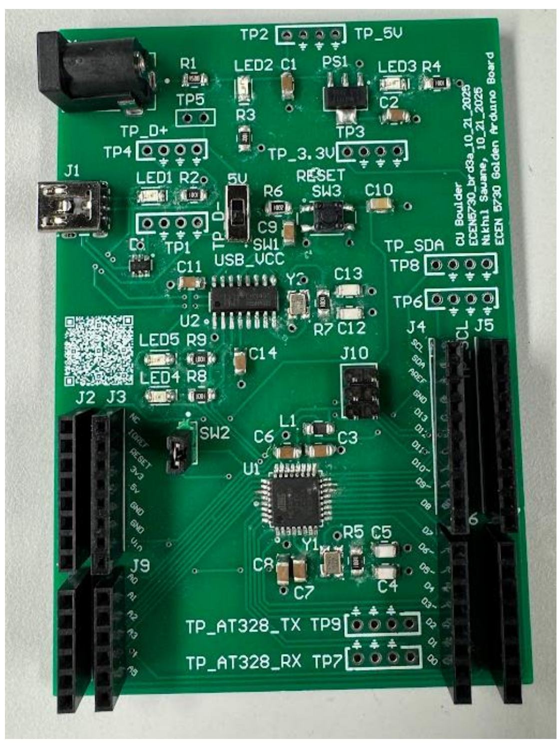


Figure 7 Assembled board

Functional Verification/ What it means to work

1. When power is applied, the indicator LEDs corresponding to the 5 V and 3.3 V rails illuminate, confirming stable supply generation. When the board is powered via USB, the USB status LED (LED1) also turns on to indicate an active USB connection.
2. The board can be powered either through a 5 V DC adapter connected to the barrel jack or through the USB port. The 5 V rail voltage can be monitored at test point TP1, while the regulated 3.3 V output from the LDO can be measured at TP2.
3. To program and initialize the ATmega328 microcontroller, a commercial Arduino Uno configured as an ISP (In-System Programmer) is used. Bootloading is performed via the ICSP/SPI header pins, converting the microcontroller into a fully functional Arduino-compatible device.
4. After successful bootloading, the 16 MHz crystal oscillator operates at its nominal frequency, enabling the ATmega328 to execute sketches uploaded from the Arduino IDE without errors.

Bootloader Procedure

The ATmega328 microcontroller on the custom board was programmed using a commercial Arduino Uno configured as an ISP (In-System Programmer). The procedure followed is outlined below:

1. Hardware Connections
    - Connect SCK → SCK, MISO → MISO, and MOSI → MOSI between the commercial Arduino and the new board.
    - Tie VCC (5 V) on the commercial Arduino to the 5 V header socket of the new board, and GND → GND to complete the power reference.
    - Connect pin 10 of the commercial Arduino to the RESET header pin of the new board.
2. Software Configuration
    - Connect the commercial Arduino to the PC and open the Arduino IDE.
    - Navigate to File → Examples → 11.ArduinoISP, and upload this sketch to the commercial Arduino.
    - In the IDE, select Tools → Programmer → “Arduino as ISP.”
    - Ensure the correct Board and Port are selected for the new Arduino.
3. Bootloading
    - Click “Burn Bootloader.” The process transfers the Arduino Uno bootloader onto the ATmega328 on the new board.

- After successful programming, the 16 MHz crystal oscillator begins oscillation, confirming that the microcontroller is running properly and ready to accept sketches via USB.

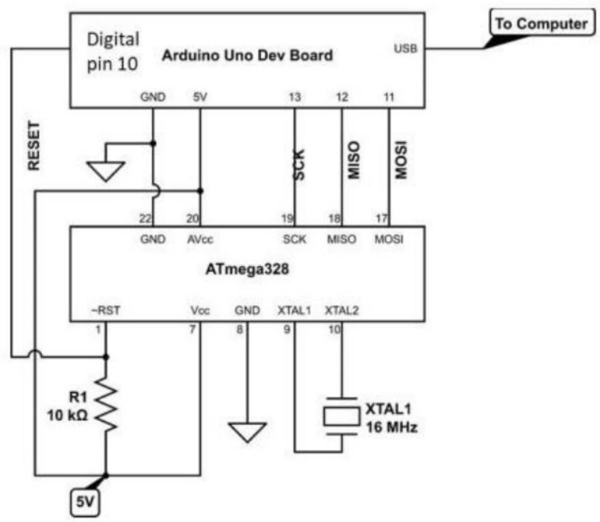


Figure 8 Bootloader setup

<u>**Bring-Up & "What Worked"**</u>

After assembly and bootloading, the Golden Arduino operated as intended with full functionality verified through initial power-up and programming tests.

1. Power Indicators:
   Upon applying power, the 5 V, 3.3 V, and USB indicator LEDs illuminated as expected, confirming stable voltage regulation and correct power-path operation.
2. Bootloading Success:
   The ATmega328 microcontroller was successfully bootloaded using the Arduino-as-ISP configuration via the ICSP header. Communication between the CH340G interface and the microcontroller was verified through the serial link.
3. Firmware Upload and Testing:
   A simple Blink test program was uploaded using the Arduino IDE. The program executed correctly, toggling the onboard LED connected to digital pin D13, thereby confirming that the clock circuit, reset network, and bootloader were functioning correctly.
4. System Stability:
   No abnormal heating, noise, or power irregularities were observed during bring-up. The system remained stable when powered through both the USB and external 5 V adapter, validating power-path integrity and decoupling design.

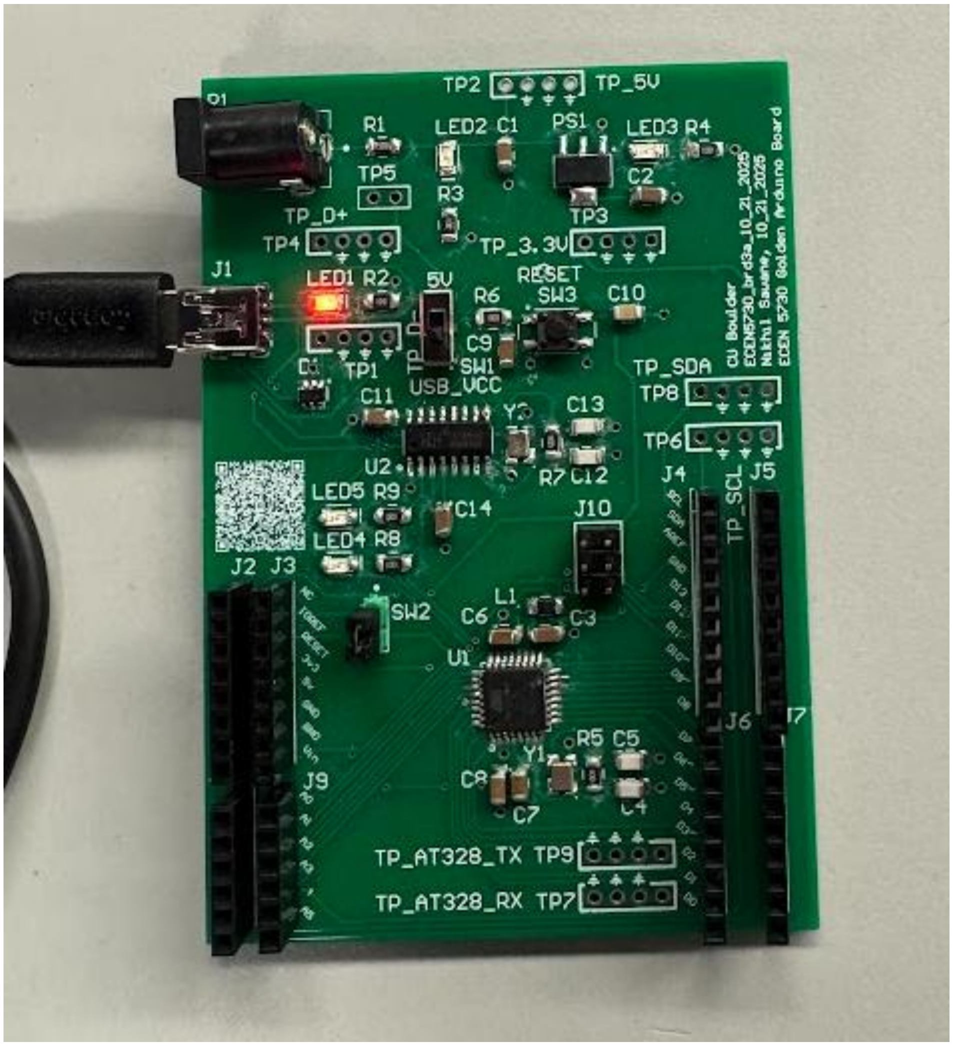


Figure 9 Fully Functioning board

Observed Issue / What Did Not Work

During testing, the board functioned correctly under most conditions; however, one issue was identified related to the 3.3 V regulator supply path:

- The 3.3 V LDO (AMS1117) produced the correct output when powered via the barrel jack, but it failed to operate when the board was powered solely through the USB port.
- Upon inspection of the schematic, it was determined that the net connection from the 5 V/USB power-selection switch (SW1) to the LDO input was omitted. As a result, the regulator received no input voltage when powered from USB.

- This issue does not affect overall functionality, as the system can still be powered through the barrel jack during code uploads. However, the missing connection limits full dual-power operation.

Temporary Workaround:

For full functionality, connect the barrel jack supply when uploading code via USB, ensuring that the 3.3 V rail remains active.

Measurement Method, Results, Scope Shots and Analysis

A series of oscilloscope measurements were conducted to verify the functionality of the power rails, communication interfaces, and transient responses of the Golden Arduino. The results are summarized below.

1. Power Rails (5 V and 3.3 V)

The **5 V (yellow)** and **3.3 V (green)** rails were measured at **TP1** and **TP2**, respectively. Both rails remained steady under no-load and light-load conditions, confirming that the power regulation circuits were functioning correctly and that the decoupling capacitors effectively reduced ripple on both rails.

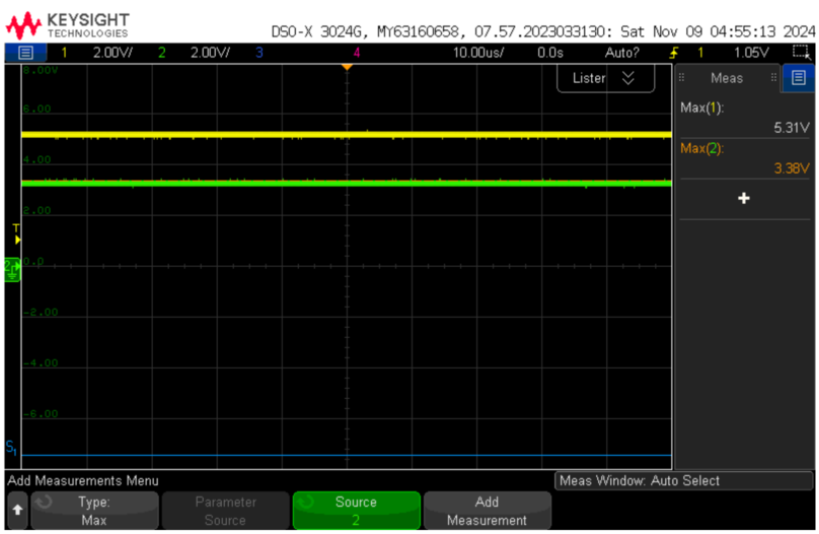


Figure 10 Power Rails (5V and 3.3V)

2. UART and USB Signals

UART and USB signal integrity were verified during data transfer between the PC and the board.

- UART signals were probed at TP7 (RX) and TP9 (TX).
- USB data lines (D+ and D–) were observed at TP3 and TP4.

The captured waveforms showed clean logic transitions and proper voltage swing, validating that the CH340G interface correctly handles USB-to-UART conversion and that the ESD-protected data lines maintain signal quality.

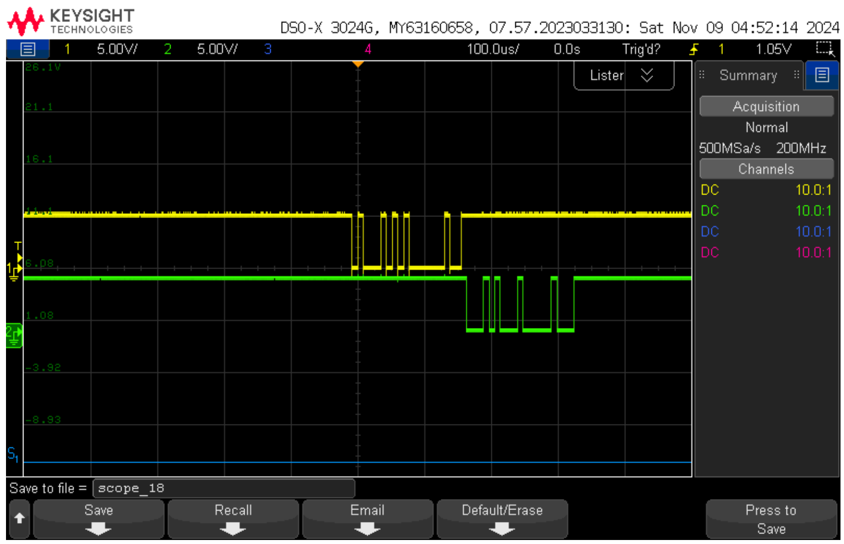


Figure 11 UART signal, yellow - RX, green-TX

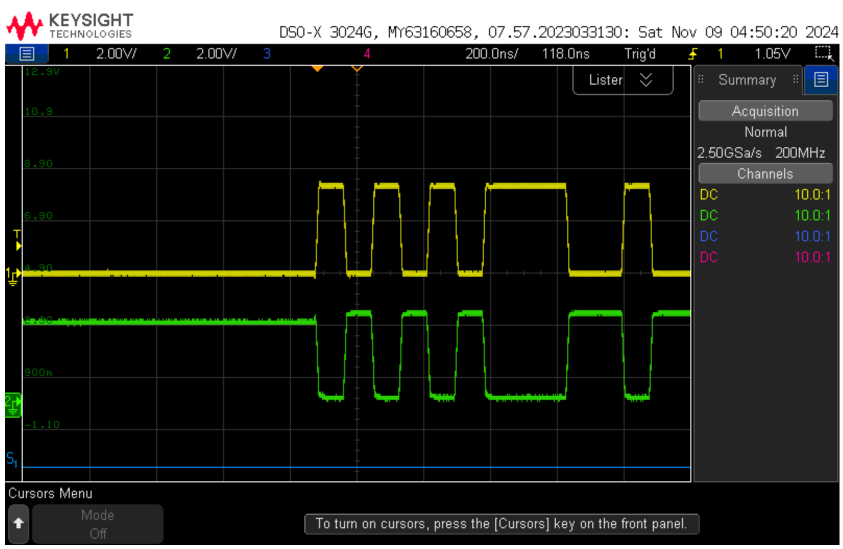


Figure 12 USB signals, yellow - D-, Green- D+

3. Inrush Current Measurement

The inrush current during initial power-up was measured across the 0.5 Ω sense resistor using differential channels on the oscilloscope.

- The yellow trace represented the high side of the resistor, while the green trace captured the low side.
- A math channel was used to compute the voltage difference (ΔV).

From the waveform, the inrush voltage difference was approximately 2.3301 V, giving an inrush current of:

$$I_{inrush} = \frac{2.3301}{0.5} = 4.6602 \text{ A}$$

This short current spike corresponds to the charging of on-board decoupling capacitors and is within acceptable limits for USB and 5 V adapter operation.

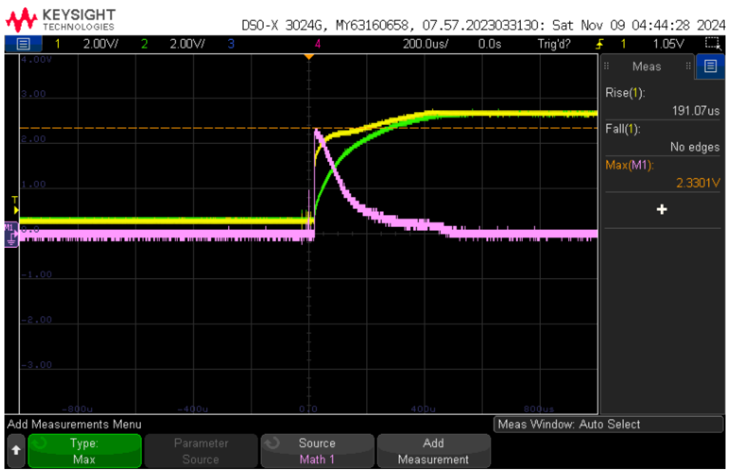


Figure 13 Inrush current

Measurements Using Shield Board (Switching Noise and Near-Field Emissions)

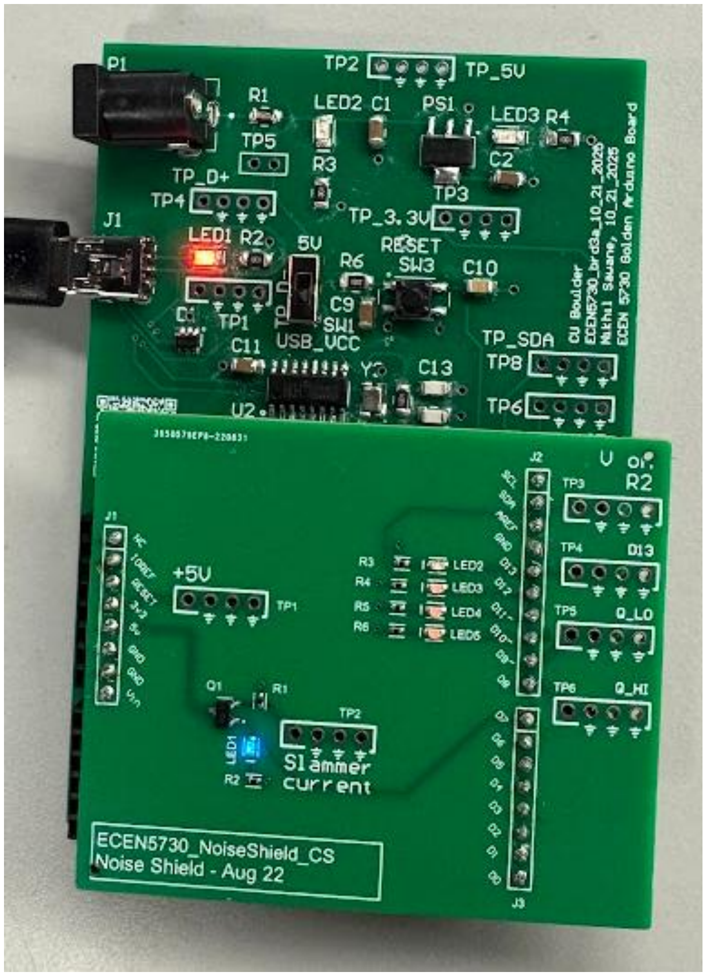
To evaluate the dynamic behavior of the Golden Arduino during I/O switching, a shield measurement board was used. This breakout shield connects directly to the Arduino header sockets and provides controlled resistive loads and a switching MOSFET circuit for current analysis.

Shield Board Setup

The shield includes:

- Three **49 Ω resistors** connected individually to **digital pins D12, D11, and D10**, each driving an LED.
- A **1 kΩ resistor and LED** connected to **D13**, used as a **trigger signal** (TP4).
- A **MOSFET slammer circuit** with a **10 Ω sense resistor** on its source; the gate is driven by **D7**, and the drain connects to the **5 V rail**.

This configuration allows simultaneous monitoring of digital I/O switching, inrush events, and rail noise during both static and dynamic operation.




```
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 14 Shield board fitted into Arduino Uno.

4. Near-Field Emission (NFE) Measurement

The near-field emissions were captured to compare radiated noise between the **commercial Arduino Uno** and the **Golden Arduino**.

- Channel 1 (yellow) was used as the **trigger (D13 signal)**.
- A **10× probe** with its tip shorted to ground was used on **Channel 4 (pink)** as a field probe.
- The probe was placed directly beneath each board to sense the local magnetic field variations during switching.

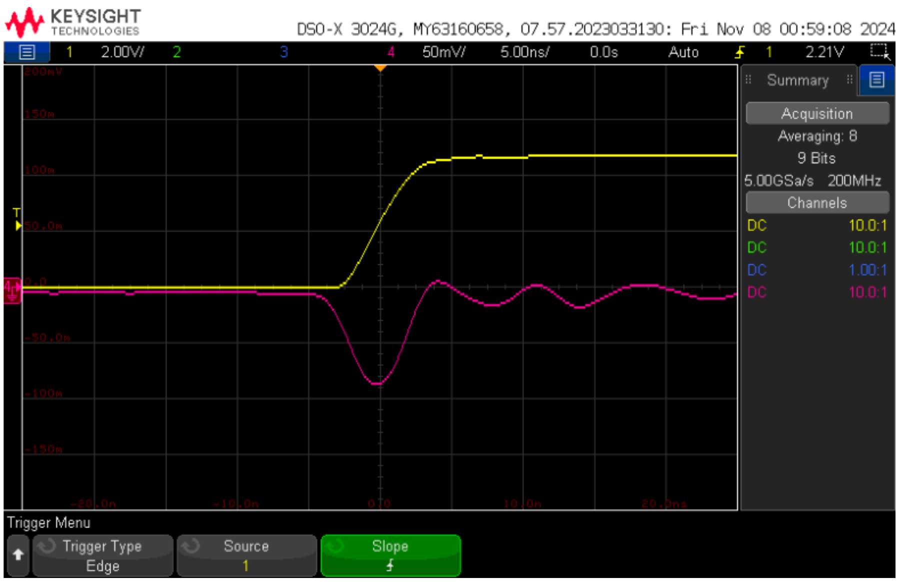


Figure 15 Rising Edge NFE of commercial Arduino

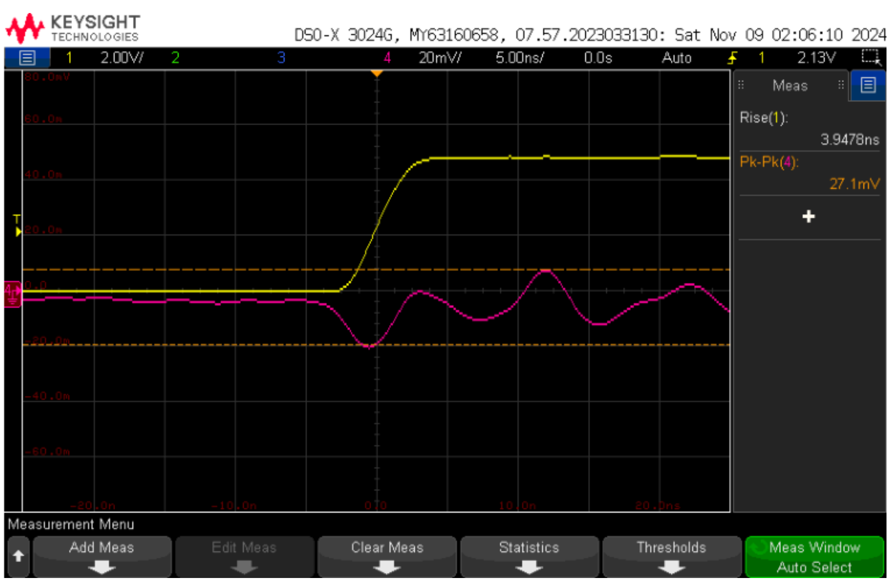


Figure 16 Rising Edge NFE of Golden Arduino

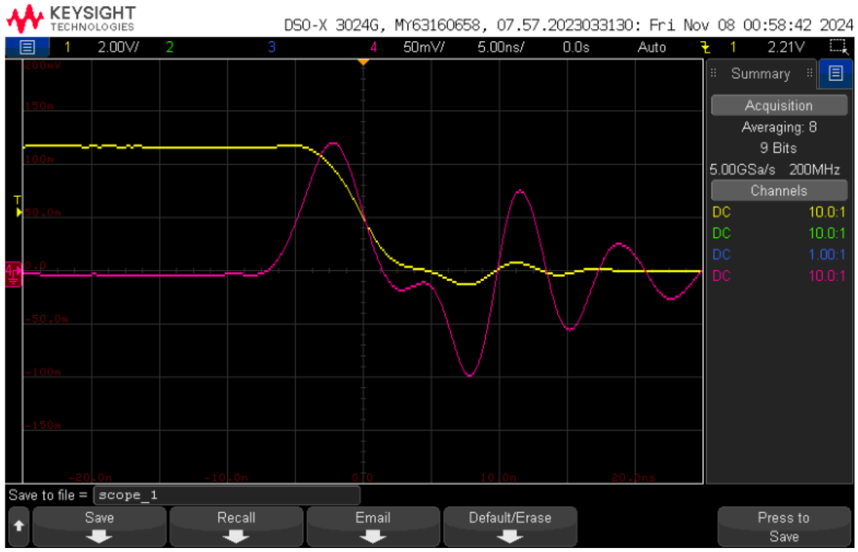


Figure 17 Falling Edge NFE of commercial Arduino

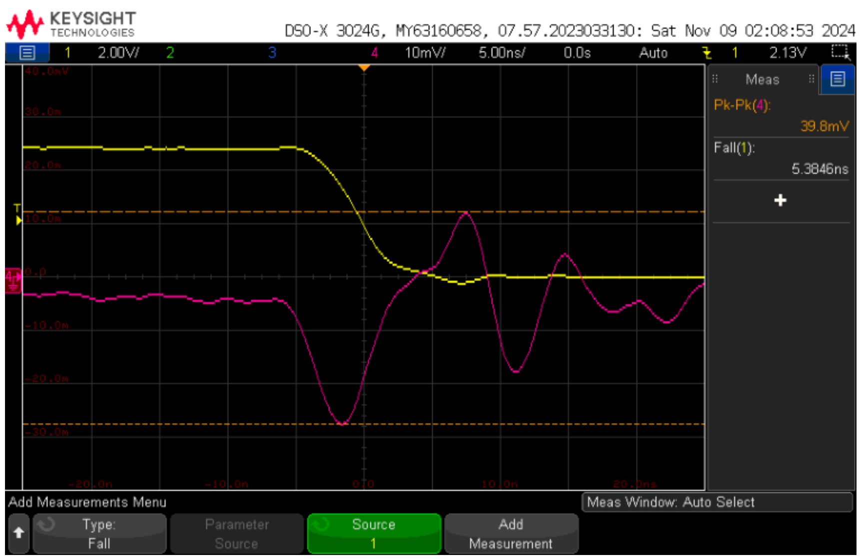


Figure 18 Falling Edge NFE of Golden Arduino

Measurement Type	Commercial Arduino (mV)	Golden Arduino (mV)
Rising Edge NFE	100	27
Falling Edge NFE	200	40

Waveforms show that the **Golden Arduino exhibits significantly lower near-field emissions** compared to the commercial Uno during both rising and falling edges, indicating reduced loop inductance and improved power-return path design.

5. Current Through Shield Load

The current flowing through each **49 Ω resistor** (connected to D12, D11, and D10) was observed using the voltage measured across one resistor.
With an average voltage of **1.8 V**, the current through each resistor is:

$$I = \frac{1.8}{49} = 36.7 \text{ mA}$$

This confirms that all three digital outputs drive equivalent currents, ensuring consistent I/O loading during switching tests.

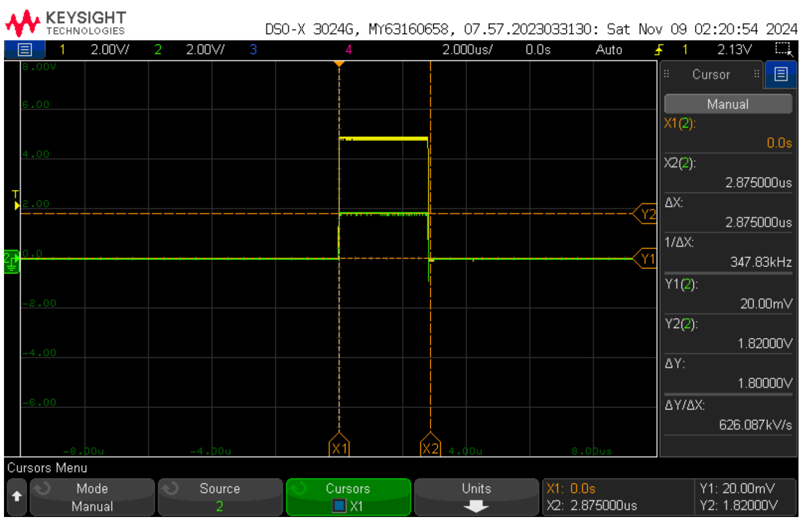


Figure 19 Voltage across 49Ω resistor on shield

<u>Switching Noise (Quiet High / Quiet Low)</u>

To evaluate the effect of simultaneous I/O switching on power integrity, multiple digital output pins (D13, D12, D11, D10) were toggled using the shield board. The test setup replicates realistic high dI/dt transitions and helps visualize how switching noise couples into the power and ground networks.

During this test, the **MOSFET slammer circuit** was disabled (D7 signal commented out), ensuring that only the I/O pins were actively switching.

- The **D13 output** served as the **trigger (TP4)**.
- **TP1 (blue)** captured the **on-board 5 V rail**,
- **TP6 (pink)** monitored the **on-die 5 V (Q_high)**, and
- **TP5 (green)** measured the **ground reference (Q_low)**.

6. **Rising Edge Measurements**

For rising-edge transitions, the **Golden Arduino** demonstrated noticeably lower switching noise compared to the commercial Uno.
The reduced amplitude is attributed to a **continuous ground plane**, **optimized decoupling capacitor placement**, and **shorter return loops**, all of which minimize transient voltage spikes.

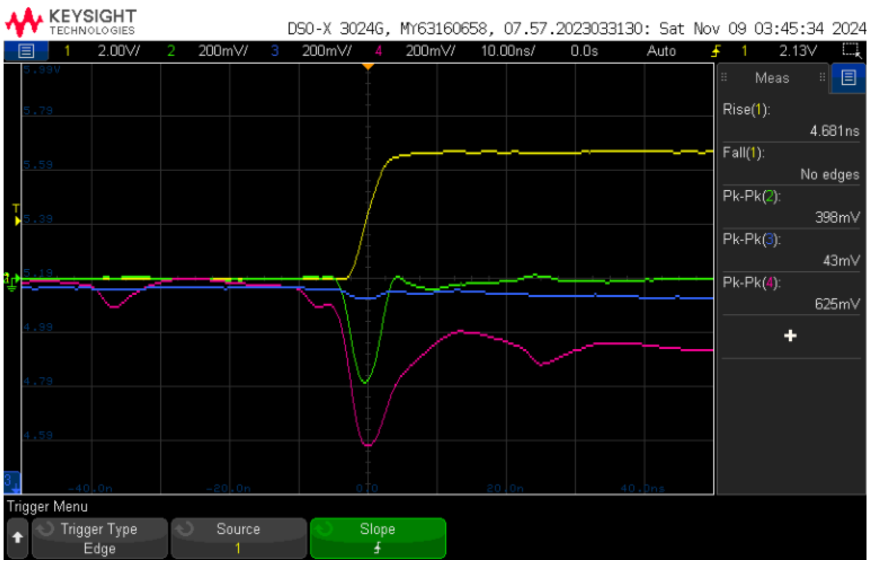


Figure 20 Commercial Arduino I/O Sw_noise for rising edge

Figure 21 Golden Arduino I/O Sw_noise for rising edge

Parameter	Commercial Arduino	Golden Arduino
Rise Time (ns)	4.5	4.0
Quiet Low (mV p-p)	398	261
Quiet High (mV p-p)	625	390
On-board 5 V (mV)	43	139

Falling Edge Measurements

During falling-edge transitions, the Golden Arduino again exhibited superior performance, particularly in noise suppression and waveform stability.

The lower ground bounce and reduced overshoot indicate effective decoupling and improved PDN (Power Distribution Network) impedance.

Figure 21 Golden Arduino I/O Sw_noise for rising edge

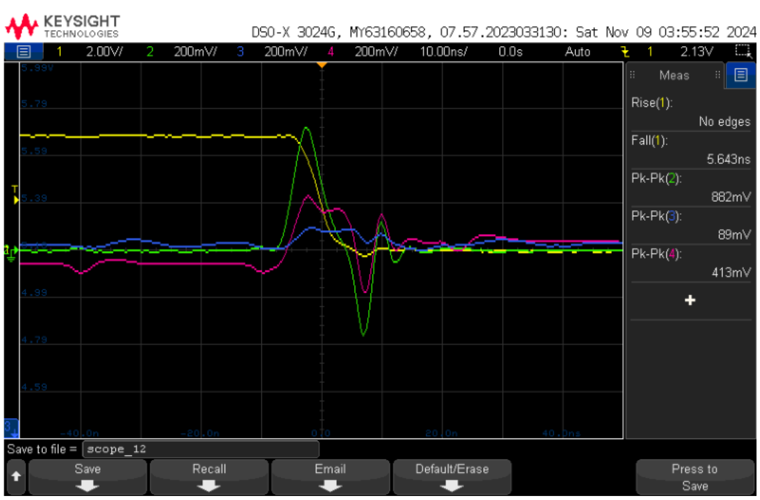


Figure 23 Golden Arduino I/O Sw_noise for falling edge

Parameter	Commercial Arduino	Golden Arduino
Fall Time (ns)	4.8	5.6
Quiet Low (mV p-p)	1.4	830
Quiet High (mV p-p)	531	413
On-board 5 V (mV)	59	89

Analysis

The data confirms that the **Golden Arduino** effectively mitigates switching noise through proper component placement, low-impedance power routing, and solid grounding.
Even though slight differences in rise/fall times were observed, they fall within the acceptable range for the ATmega328's drive capabilities. Overall, the results demonstrate that the optimized PCB layout contributes directly to quieter signal transitions and enhanced EMI performance.

<u>MOSFET Switching and Slammer Circuit Analysis</u>

To further examine the board's transient response under dynamic load conditions, the **MOSFET slammer circuit** on the shield board was activated.
In this mode, the MOSFET's gate is driven by **digital pin D7**, and its **source** includes a **10 Ω sense resistor**. The circuit rapidly switches current from the **5 V rail**, simulating a step-load transient to stress the power distribution network (PDN).

- **Yellow (Channel 1):** Gate drive signal from D7 (trigger reference)
- **Pink (Channel 2):** On-die 5 V rail (Q_high, measured at TP6)
- **Green (Channel 3):** On-board 5 V rail (measured at TP1)

The following waveforms and analysis compare the commercial Arduino Uno and the Golden Arduino boards during both rising and falling edge transitions.

7. **Rising Edge Performance**

During the rising-edge event, the **Golden Arduino** exhibited smoother waveform transitions and reduced voltage disturbance on the on-die rail.
The slower but cleaner rise (higher rise time but lower peak noise) suggests better energy storage and damping through local decoupling capacitors.

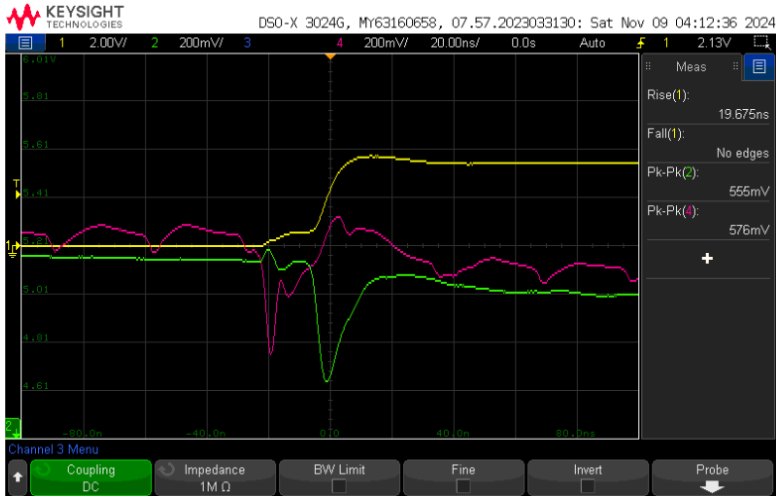


Figure 24 Commercial Arduino Mosfet Sw_noise for rising edge

Figure 25 Golden Arduino Mosfet Sw_noise for rising edge

Measurement	**Commercial Arduino**	**Golden Arduino**
Rise Time (ns)	19.6	26.2
Quiet High (mV p-p)	576	317
On-board 5 V (V)	0.55	1.5

Falling Edge Performance

In the falling-edge scenario, the Golden Arduino also displayed superior PDN stability. The voltage dip on the 5 V rail was smaller and recovered more quickly than that of the commercial board, demonstrating improved transient response and lower loop inductance in the power traces.

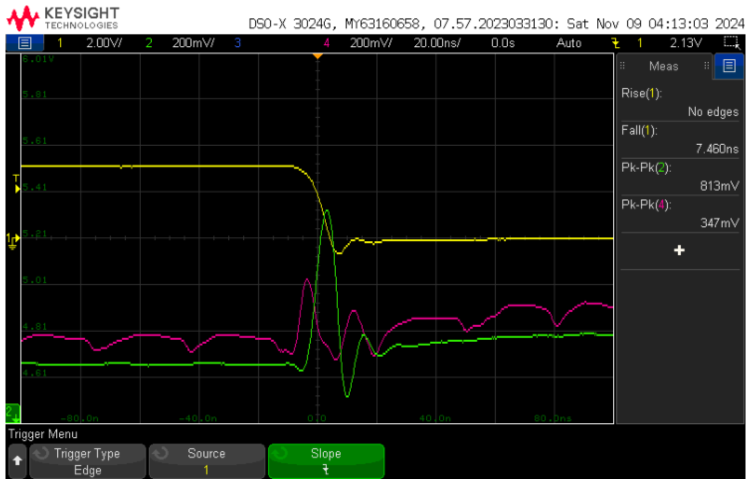


Figure 26 Commercial Arduino Mosfet Sw_noise for falling edge

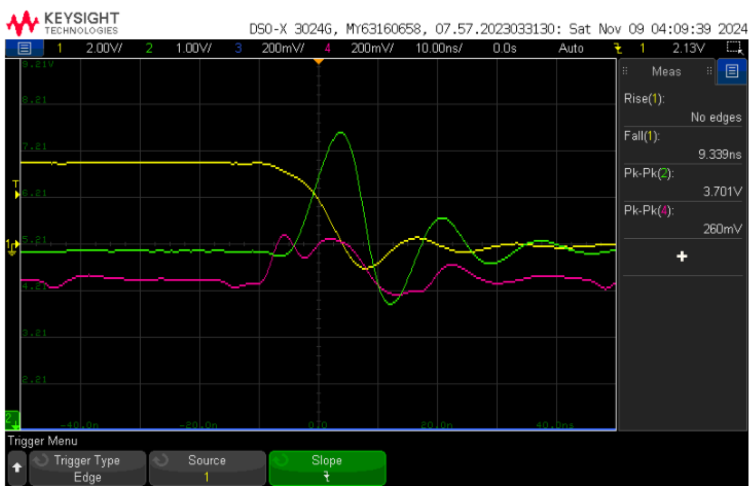


Figure 27 Golden Arduino Mosfet Sw_noise for falling edge

Measurement	**Commercial Arduino**	**Golden Arduino**
Fall Time (ns)	7.5	9.3
Quiet High (mV p-p)	347	260
On-board 5 V (mV)	813	3.7

Observations

- The Golden Arduino's **on-die 5 V rail** maintained better regulation under rapid current transients, owing to tighter **decoupling capacitor placement** and **shorter current return paths**.
- While the **on-board 5 V rail** showed higher amplitude variation during slammer operation (due to longer trace distance), the **on-die voltage ripple** was significantly reduced compared to the commercial Arduino.
- The results confirm that layout optimization—especially decoupling placement and via distribution—plays a critical role in minimizing transient-induced voltage noise.

8. Thevenin Resistance of the 5 V Pin

To estimate the internal source resistance of the **5 V output rail**, Thevenin's equivalent resistance was determined experimentally using voltage measurements under both no-load and loaded conditions.

Test Setup

The voltage on the **5 V rail** was measured at **test point TP1**, while a controlled load was applied using the **MOSFET slammer circuit** on the shield board. The corresponding current was calculated from the voltage drop across the **10 Ω sense resistor**.

- **Vth (no-load voltage)** = 5.24 V
- **Vload(loaded voltage)** = 4.89 V
- **Vsense (across 10 Ω resistor)** = 3.5 V

The load current is therefore:

$$I_{load} = \frac{V_{sense}}{R_{sense}} = \frac{3.5}{10} = 0.35\ \text{A}$$

Using Thevenin's equivalent model:

$$R_{th} = \frac{V_{th} - V_{load}}{I_{load}} = \frac{5.24 - 4.89}{0.35} = 1.0\ \Omega$$

Interpretation

The **Thevenin resistance of approximately 1 Ω** represents the internal resistance of the Golden Arduino's 5 V rail, which includes contributions from:

- The voltage regulator’s output impedance,
- Power trace resistance, and
- Connector and via parasitics.

This value indicates that under load conditions, the 5 V pin experiences a small voltage drop proportional to current draw, consistent with the design expectations for a single-layer 5 V distribution path on a compact PCB.

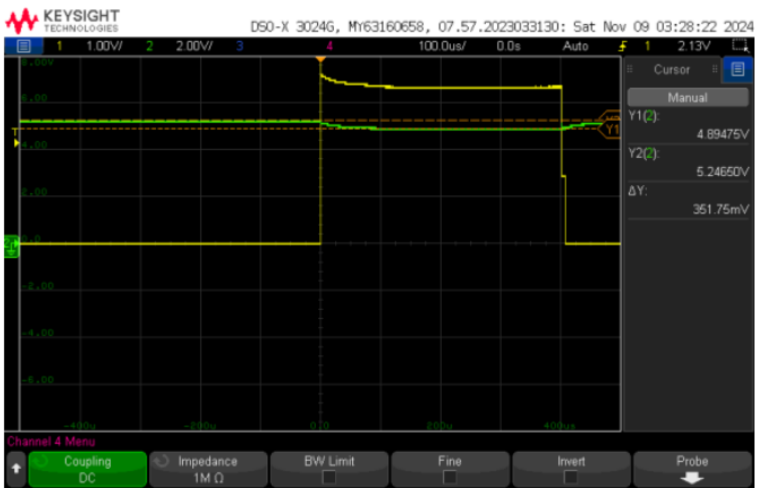


Figure 28 Voltage on 5V rail – TP1 (green)

Best Design Practices Implemented

Throughout the design and layout of the Golden Arduino, careful attention was given to PCB design fundamentals that directly influence noise performance, reliability, and manufacturability. The following key practices were implemented:

1. Component Standardization:
   Wherever possible, identical resistor and capacitor values were reused to minimize the number of unique parts, simplifying both procurement and assembly.
2. Optimized Decoupling:
   All ICs, including the ATmega328 and CH340G, were placed with decoupling capacitors positioned within 2 mm of their power pins.
   The AVCC pin was isolated using a ferrite bead filter, ensuring that analog and digital noise were separated effectively.
3. Power and Ground Integrity:
   A continuous, uninterrupted ground plane was used on the bottom layer to minimize loop inductance. Multiple stitching vias were added near high-frequency return paths to improve current distribution and reduce EMI.

4. Power Routing:
   Power traces were sized appropriately for their current requirements — 20 mil width for high-current 5 V paths and 6 mil width for signal routing, achieving a balance between current-carrying capacity and routing density.
5. Accessibility and Debugging:
   Clearly labeled test points were included for all major power rails and communication buses (SPI, I^2C, UART, USB).
   Indicator LEDs and isolation switches were added to simplify debugging and system verification.
6. Mechanical and Assembly Considerations:
   1206 passive components were used throughout to make manual soldering and rework easier while maintaining compact board dimensions.
7. Signal Integrity:
   The 16 MHz crystal connected to the ATmega328 was routed symmetrically to its XTAL pins, minimizing clock skew and oscillator imbalance.
   The crystal traces were kept short and parallel, with equal loading capacitors placed symmetrically to maintain timing stability.
8. Noise Suppression:
   The ferrite bead filter on AVCC, along with 22 µF bulk capacitors at both the 5 V and 3.3 V headers, ensured low ripple and improved power rail damping against transient switching currents.

What worked / What didn’t

While the Golden Arduino achieved its design goals and demonstrated strong electrical performance, several refinements could further enhance functionality, manufacturability, and measurement accuracy in future revisions:

1. Expanded Power Rail Decoupling:
   Add additional bulk capacitors near the 5 V, 3.3 V, and VIN header pins to improve transient response and further suppress noise during rapid load switching.
2. Compact Layout Optimization:
   The overall PCB size can be reduced by optimizing component placement and tightening routing around the USB interface and regulator section without compromising thermal performance.
3. Improved Power Path Integration:
   Ensure that the 3.3 V LDO input is properly tied to the output of the 5 V/USB

selection switch, allowing the 3.3 V rail to remain active under both USB and barrel-jack operation.

4. Minimization of Cross-Unders:
   Although only two cross-unders were required, future versions could achieve a fully continuous return plane by adjusting component orientation and via placement.
5. Mechanical and Usability Enhancements:
   Consider upgrading to a USB-C connector for improved mechanical durability and universal cable compatibility.
6. Enhanced Measurement Accessibility:
   Additional labeled test points could be added near the AVCC filter, XTAL lines, and LDO output to simplify high-frequency probing and noise analysis.
7. EMI Shielding Option:
   Provide mounting points for an optional grounded metal shield above the microcontroller region to further reduce near-field emissions.

Conclusions & Recommendations

The Golden Arduino was successfully designed, fabricated, assembled, and validated through a structured seven-step PCB design process. The board met all functional objectives, including stable power regulation, successful bootloading, and compatibility with the Arduino development environment.

Compared to a commercial Arduino Uno, the Golden Arduino demonstrated significantly lower switching noise and near-field emissions, confirming the effectiveness of best design practices such as optimized decoupling, symmetric crystal routing, and a continuous ground plane. The measured results verified stable operation of both the 5 V and 3.3 V rails, proper USB communication, and consistent clock performance.

Although one minor issue was identified with the 3.3 V regulator power path, it was easily corrected in post-analysis and will be resolved in future revisions. Overall, the project highlights how careful PCB layout and component placement can substantially improve signal integrity, EMI performance, and system robustness.

The finalized design serves as a “gold standard” reference board, combining electrical reliability with ease of debugging—fully embodying the design principles emphasized throughout the ECEN 5730 Practical PCB Design course.
