Practical PCB Design and Manufacture

Lab 5 Report: PDN noise and capacitors

Objective / Purpose of the Lab:

- This lab's main purpose is to construct a circuit to showcase the generation of switching noise in the power path and to understand the influence of loop inductance. It aims to assess the switching noise levels on the power rail due to significant current transients and to investigate how loop inductance affects the connection between the integrated circuit and decoupling capacitors. Additionally, the lab examines the impact of different rates of change in current transients on switching noise and determine the necessary capacitance for effective local charge storage.

Component Listing:

- Solderless Breadboard
- Arduino UNO (For 5V power supply and to trigger the source)
- IRL520N (N-channel MOSFET)
- TLV272 (Dual Operational Amplifier)
- Resistor (10 Ω)
- Capacitors (1µF and 1000µF)
- Connecting wires
- Oscilloscope

Napkin Sketch:

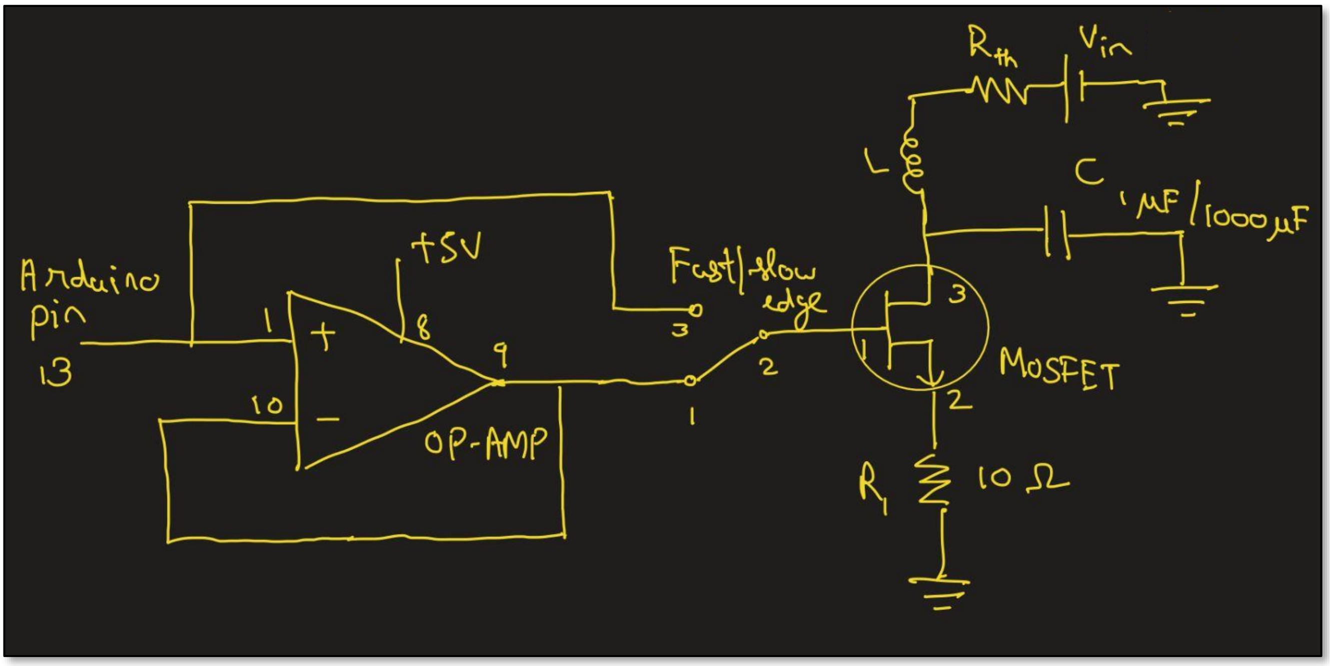
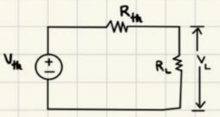


Fig – 1: PDN and Slammer Circuit

Calculations:

1) Thevenin's Circuit model



$$R_{th} = \frac{R_1 (V_{th} - V_1)}{V_1}$$

$V_{th} = 4.85V$, $V_1 = 4.4V$

$$\therefore R_{th} = 10\left(\frac{4.85 - 4.4}{4.4}\right)$$

$$\therefore R_{th} = 1.02\ \Omega$$

2) Loop inductance of the power path,

$V_1 = 4.4V$, V = Voltage across $10\ \Omega$ resister $= 1.77V$ (As shown in Fig-3)

$$\therefore I = \frac{V_1 - V}{R} = \frac{4.4 - 1.77}{10} = 263mA$$

Voltage drop across the inductor, $\Delta V = L\frac{di}{dt}$

$\Delta V = 4.4V - 2.5V = 1.9V$ (for fast rise time signal)

$di = 263mA$

$dt = 5.86ns$ (as seen from Fig-3 for fast edge)

$$\therefore L = 1.9 \times \frac{5.86ns}{263mA} = 42.33nH$$

Arduino Code to Drive Pin 13:

```
void setup() {
  pinMode(13, OUTPUT);
}
void loop() {
  digitalWrite(13, HIGH);
  delay(1);
  digitalWrite(13, LOW);
  delay(20);
}
```

Scope Shots with Analysis:

- As we can see in Fig-2, there is not much difference between the switching noise of 1µF and 1000µF capacitor. This is because the capacitance value determines the ability of a capacitor to store and release electrical energy and not its ability to filter out high frequency noise.

Fig – 2: Switching noise of 1µF and 1000µF capacitor

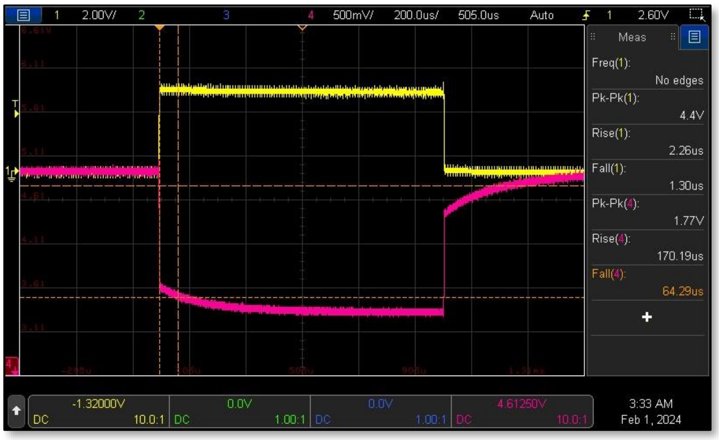


Fig – 3: Fast edge with 1µF capacitor

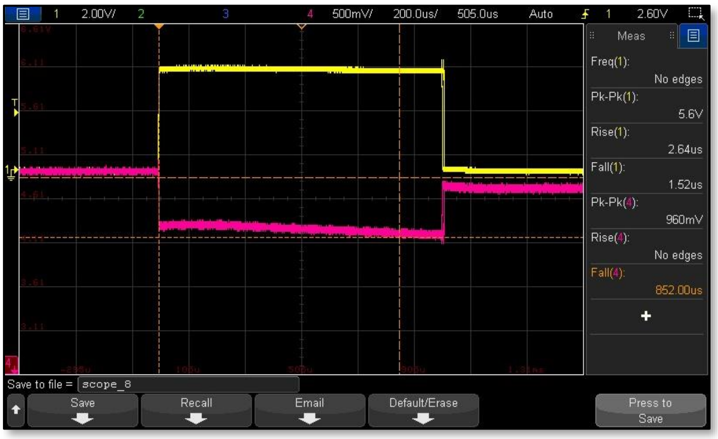


Fig – 4: Fast edge with 1000µF capacitor

- As we can see in Fig-5, the difference in switching noise when using a 1uF and 1000uF capacitor is due to its's impedance and the way it affects the circuit's frequency response.
- Impedance is a measure of how much a component opposes the flow of current in an AC circuit. For a capacitor, impedance is inversely proportional to frequency. This means that as frequency increases, impedance decreases.
- When a 1uF capacitor is connected in a circuit, it has a relatively high impedance at low frequencies, which means it opposes the flow of current less. As a result, the circuit's frequency response is affected less by the capacitor, and the switching noise is less attenuated. On the other hand, a 1000uF capacitor has a much lower impedance at low frequencies, which means it opposes the flow of current more. This results in a greater attenuation of the switching noise, resulting in a quieter output.
- Figures 6 and 7 below show a closer view of the fast edge difference between the two different capacitors and differences in the rise time, peak-to-peak voltage.

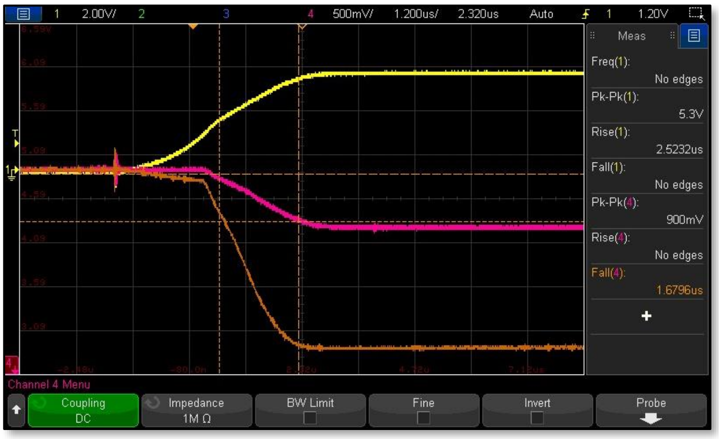


Fig – 5: Difference in the Fast edge of both 1µF and 1000µF capacitor

Fig – 6: Closer view of Fast edge with 1µF capacitor

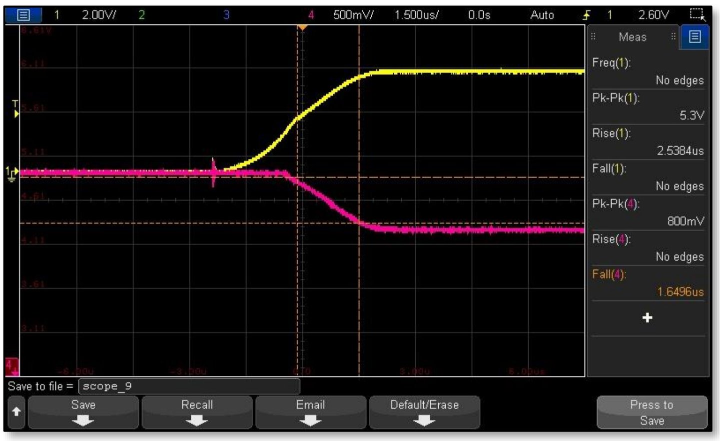


Fig – 7: Closer view of Fast edge with 1000µF capacitor

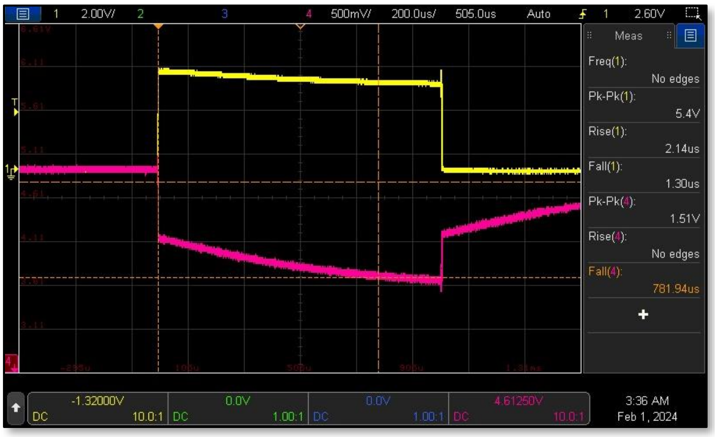


Fig – 8: Slow edge with 1μF capacitor

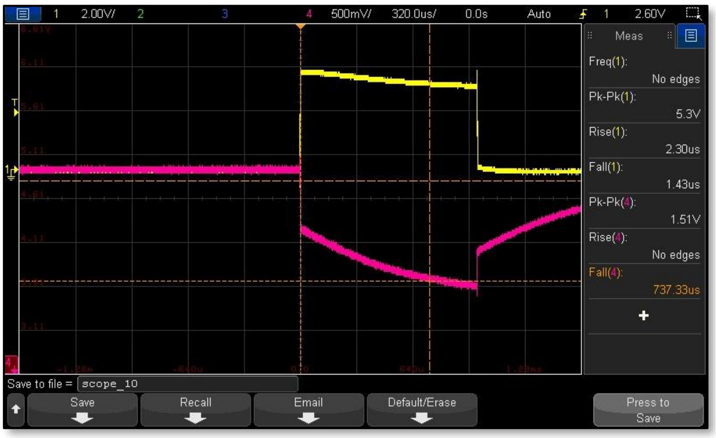


Fig – 9: Slow edge with 1000μF capacitor

- From the Figures above, the switching noise difference between the slow edge and fast edge in the circuit is due to the way the capacitors are discharging and the frequency response of the circuit. When the switch is closed, the 1uF capacitor starts discharging through the 1Ω resistor, and the voltage across the capacitor decreases exponentially over time. The rate at which the voltage decreases is determined by the time constant of the circuit, which is given by the formula:

  $\tau = RC$, where τ is the time constant, R is the resistance, and C is the capacitance.
- In short, the switching noise difference between slow and fast edge rates is primarily due to the faster transitions of fast edges, which generate higher frequency components, leading to more significant electromagnetic interference, power supply noise, and signal integrity issues. Fast edges can cause overshoot, ringing, and ground bounce due to the rapid change in current and the inductive and capacitive effects in the circuit, making noise management more challenging compared to slow edges.

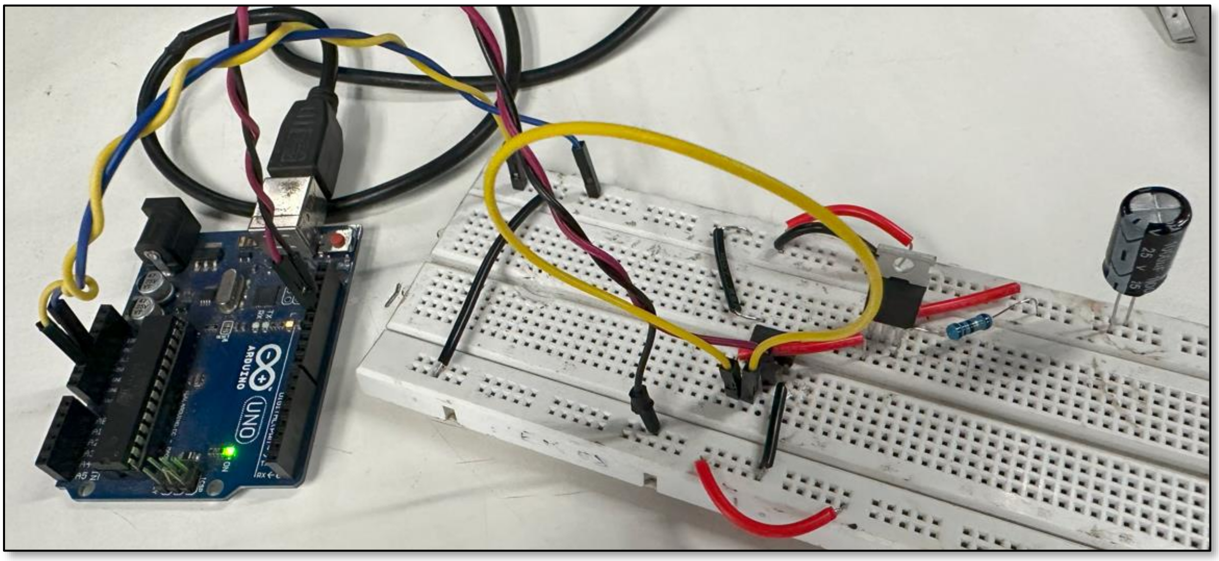


Fig – 10: SBB Board connections

Conclusion / Inference:

- As we increase the value of the capacitor, we see a minute reduction in the noise.
- We see a difference between noise when measuring at the fast edge vs the slow edge primarily due to the faster transitions of fast edges, which generate higher frequency components, leading to more significant electromagnetic interference, power supply noise, and signal integrity issues.
- Also, when moving a decoupling capacitor further from its intended IC can reduce its effectiveness in suppressing noise, stabilize voltage levels, and provide quick power bursts.