University of Colorado Boulder

Electrical and Computer Engineering

University of Colorado Boulder

ECEN3730 Practical PCB Design Manufacture

LABORATORY REPORT

Lab 5 Report: PDN noise and capacitors

Student Name: Mathias Labuszewski

Lecturer in charge:

Arielle Blum

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1 Introduction

In this lab, we investigate the behavior of a simple slammer circuit, which draws transient current from a power rail. This phenomenon mimics what occurs when an integrated circuit (IC) rapidly changes its current consumption, such as during I/O signal switching or computational operations synchronized with clock edges.

2 Objectives and Learning Outcomes

2.1 Objectives:

1. To construct a circuit illustrating the origin of switching noise in the power path and the influence of loop inductance.
2. To measure the switching noise on the power rail during large current transients.
3. To explore the role of loop inductance between the IC and decoupling capacitors.
4. To observe differences in switching noise for various dI/dt values of current transients.
5. To estimate the required capacitance for effective local charge storage.

3 Methodology

3.1 Slammer Circuit

- When there is a rapid change in current on a wire, a rapid change in the magnetic and electric field is created and can affect other parts of a circuit. We recreate this event using a micro controller and a current switching device. Pictured below is the schematic for this circuit.

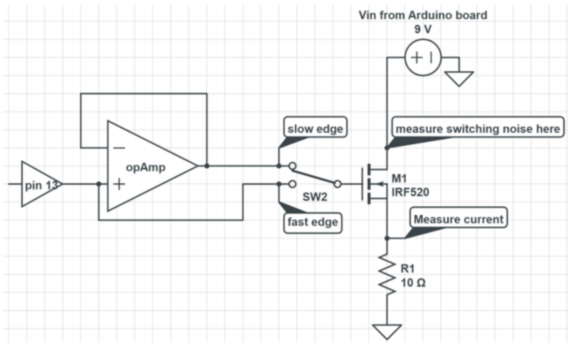

Figure 1: Slammer Circuit used in lab

- The slammer circuit rapidly turns on and off a high-power switching device, placing a large transient on the supply voltage rail. This will introduce noise into the circuit.
- Using an Arduino we can generate a waveform from one of the output ports to trigger the circuit. We will target a 50Hz 5% duty cycle square wave. The rise time of the Arduino will be much faster than the rise time of the opAmp. This way we can explore two scenarios.

3.2 Building the circuit

3.2.1 Components used

- OpAmp - TLV2721
- NPN Transistor - 41C
- Resistor - 10Ω
- Cap - 1Uf, 330Uf
- Arduino - UNO
- Oscilloscope

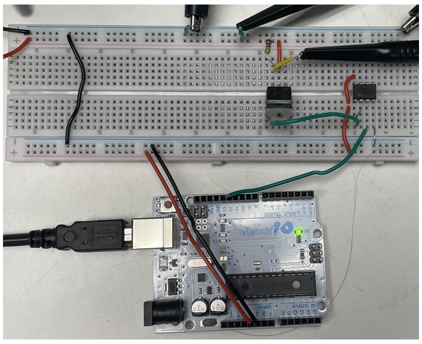

Figure 2: Slammer Circuit assembled on solderless breadboard

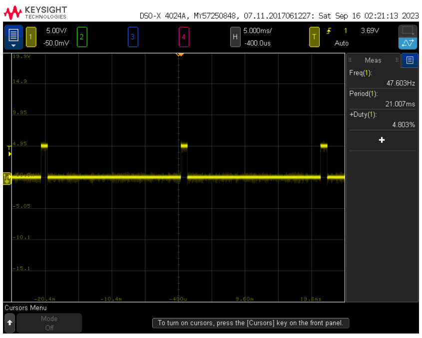

Figure 3: Output waveform fed into slammer circuit

3.3 Measurements and Outcomes

3.3.1 Inital Measurements

- Without the transistor connected to either of the outputs we can see the rise and fall times of both the slow and fast inputs.

Case	Expected	Measured
Slow Rise Time	2.5µs	2.46µs
Fast Rise Time	5ns	5.1ns

- With the transistor connected, we can see the rise and fall times of both the slow and fast inputs.

Case	Expected	Measured
Slow Rise Time	2.5µs	2.46µs
Fast Rise Time	5ns	20ns

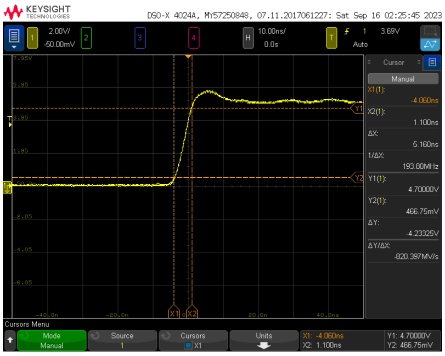

Figure 4: Fast rise time - 5.1ns

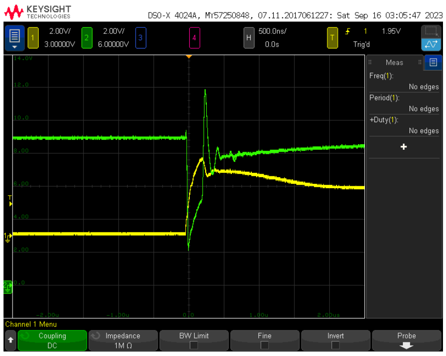

Figure 5: Fast rise time connect up to transistor - 20ns

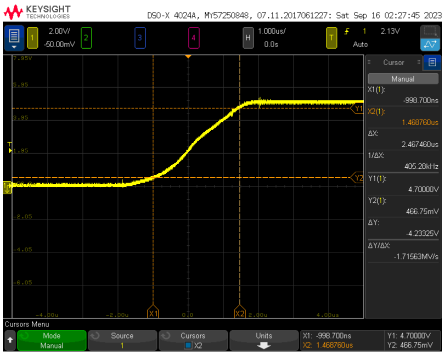

Figure 6: Slow rise time - 2.46us

Figure 7: Slow rise time connect up to transistor - 2.3us

Signal pin (Yellow)

9v Power rail (Green)

3.3.2 Reducing Noise

- From figures 5 and 7 we can see when the transistor is switching a high current load, there is lots of noise generated. So much so that in the fast noise case the power rail voltage (green) drops to 0v. There is such a big demand for current, the voltage drops. In an ideal circuit, this would never happen, however, in the real world, we have inductance and capacitance. The inherent inductance of the wires and breadboard is what is causing this noise.
- We can reduce the noise we measure by having local storage. This allows the circuit to have large transients by reducing the inductance of the path from the power to the load-drawing component. By placing a capacitor near the transistor, there is much less loop inductance, and the noise is greatly reduced.

Signal pin (Yellow)

9v Power rail (Green)

Figure 8: Slow with 1uf cap place far away from transistor

Figure 9: Slow with 1uf cap place close to transistor

Figure 10: Fast with 1uf cap place far away from transistor

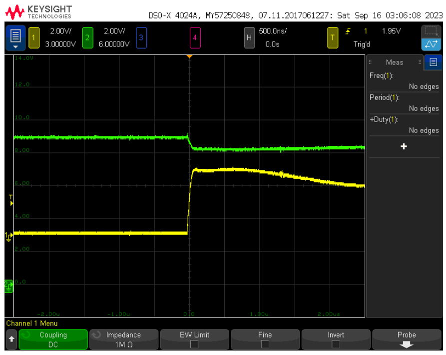

Figure 11: Fast with 1uf cap place close to transistor

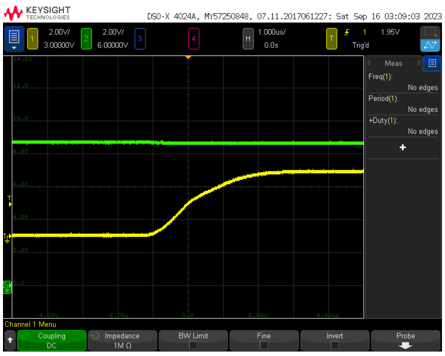

Figure 12: Slow with 1000uf cap place far away from transistor

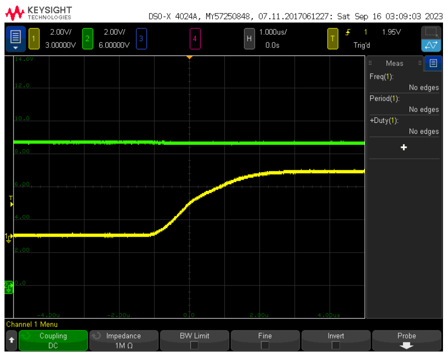

Figure 13: Slow with 1000uf cap place close to transistor

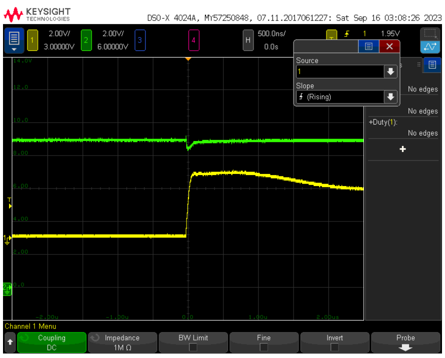

Figure 14: Fast with 1000 cap place far away from transistor

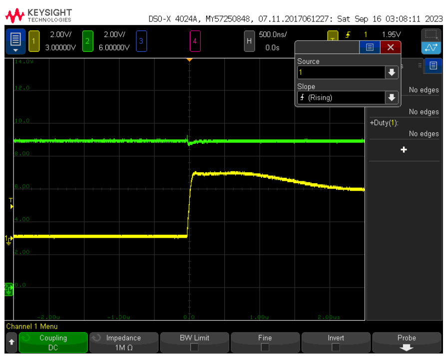

Figure 15: Fast with 1000uf cap place close to transistor

- We can see the capacitors greatly reduce noise on the power rail. We also see the higher value 1000uf cap does a better job of eliminating noise. This would be because the 1uf cap does not have enough energy storage.
- The closer the cap is to the device using it, the more the noise is reduced. Here there is not too much of an impact, however, we still do see it.

4 Results

4.1 Experimental observations

- Finding the Thevenin model of a circuit oftentimes gives insight into the circuit and helps simplify the circuit. The equivalent model is shown:

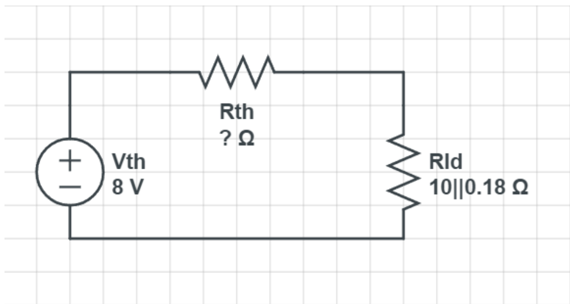

Figure 16: Slammer Circuit
thevenin equivalent

- We can use results from the experiments. I will use the fast no-capacitor case (fig 5) to find these values. This will show us the relatively large values of the circuit parameters.
- Finding the Thevenin resistance.
  - Voltage no load (fig 5) - Vth = 9v
  - Voltage with load (fig 5) - Vth = 8.2v
  - Load resistance - Rl = 10Ω || 0.18Ω(Rds of transistor)
  - **Thevenin resistance - Rth = 0.82Ω**
- Finding the loop inductance:
  - ΔV = $L * \frac{Di}{Dt}$
  - ΔV = 9v - 8.2v = 0.8v
  - Di = 365ma (fig 5)
  - Dt = 20ns (fig 5)
  - **L = 457nH**
- Finding the minimum decoupling capacitance:
  - $C = \frac{Dt}{Dv} * I$
  - Dt = 20ns (fig 5)
  - Di = 365ma (fig 5)
  - ΔV = 0.5v (max voltage droop)
  - **C = 15uF**

4.2 Takeaways

- Put the decoupling capacitor as physically near to the IC it is decoupling as practical.
- Depending on the circumstances of the circuit, decoupling capacitance of at least 1 uF was used, followed by as much capacitance as was practicable.
- Short rise time current transients exhibit higher dI/dt and greater power rail noise than long rise transients.
- Noise is generated from transients, regardless of the direction of change in voltage.
- Decoupling capacitors are a must-have for the circuit.