Julia DiTomas
ECEN 3730 Lab 5
2025-01-31

1. Objective

The objective of this lab is to build a slammer circuit to periodically draw current from a power rail and measure the switching noise on this rail. We will then investigate the effect of rise time and decoupling capacitance on the switching noise.

2. Materials

i. Solderless breadboard (course kit)
ii. T2721 Op Amp (course kit)
iii. TIP41C Transistor (course kit)
iv. Capacitors/Resistors/Wires (course kit)
v. Arduino Uno + Power Supply (course kit)

3. Circuit

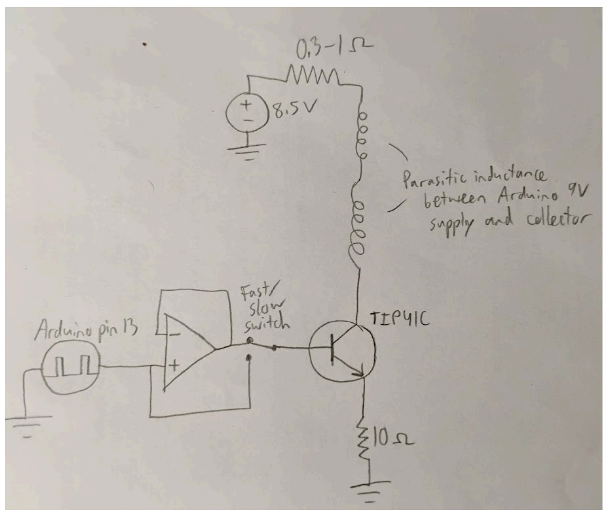

Figure 1: Slammer circuit schematic. The switch between the Arduino pin driving the pulse and the buffered output allows us to experiment with rise time.

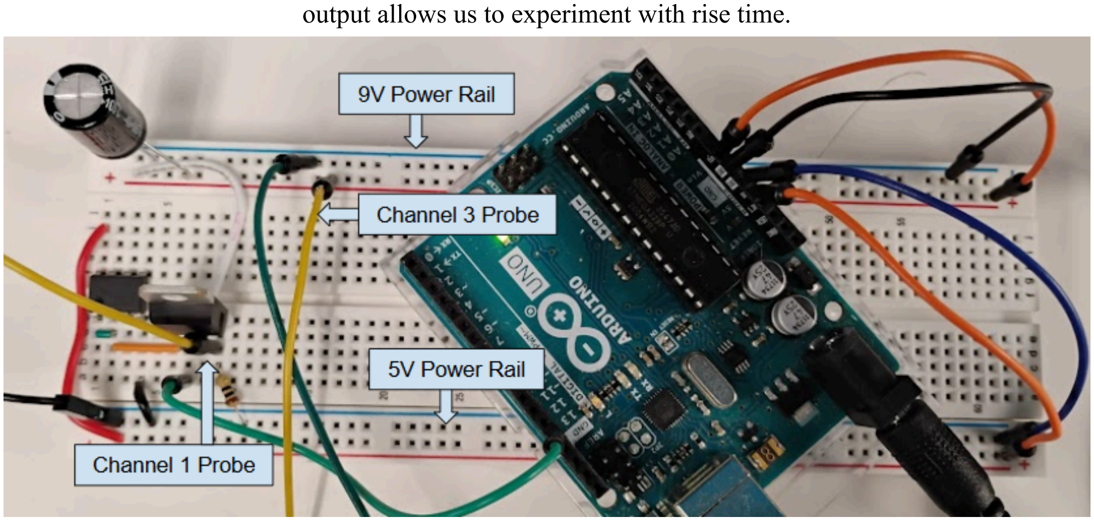

Figure 2: Circuit built on solderless breadboard and connected to oscilloscope, with Arduino pin 13 directly driving NPN transistor (bypassing opamp) and 1000 µF decoupling capacitor.

4. Results

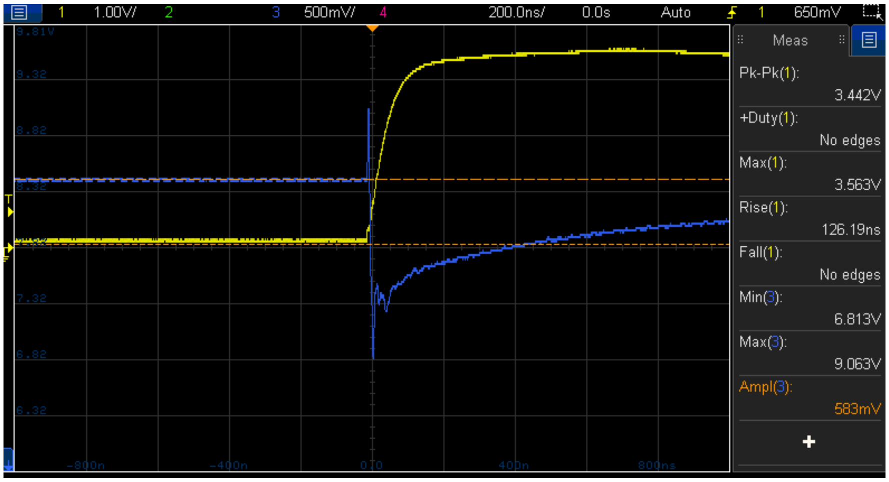

Figure 3: Voltage across sense resistor (yellow) and voltage measured on 9V power rail (blue) on fast rising edge directly from Arduino, with no decoupling capacitance.

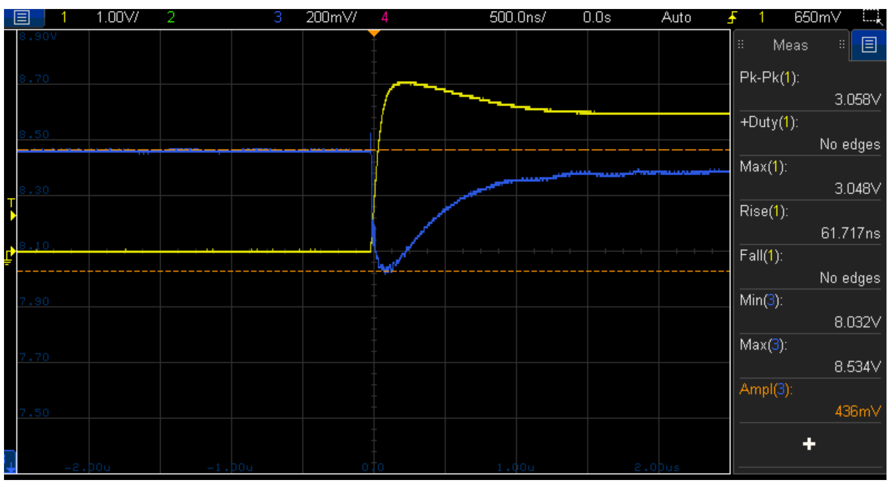

Figure 4: Voltage across sense resistor (yellow) and voltage measured on 9V power rail (blue) on fast rising edge directly from Arduino, with 1000 µF capacitor placed on power rail near connection to NPN collector.

Figures 3 and 4 show the effect of the decoupling capacitor. In Figure 3 (no capacitance), the power rail voltage drops by 1.5 V when the current is switched on. In Figure 4, because a 1000 µF provides a charge bank that does not need to travel across the entire power rail, the voltage only drops by 0.4 V.

From Figure 3, we can calculate the loop inductance of the path from the 9V output Arduino pin to the transistor. The rise time is 130 ns, the voltage across the 10 **Ω** sense resistor rises to 3.4 V, and the drop in the power rail voltage is 1.5 V.

$$i = \frac{3.4\,V}{10\,\Omega} = 0.34\,A$$

$$\frac{di}{dt} = \frac{0.34\ A}{130\ ns} = 2.6\frac{mA}{ns}$$

$$L\frac{di}{dt} = \Delta V$$

$$L = \frac{1.5\ V}{2.6\ \frac{mA}{ns}}$$

$$L = 580\ nH$$

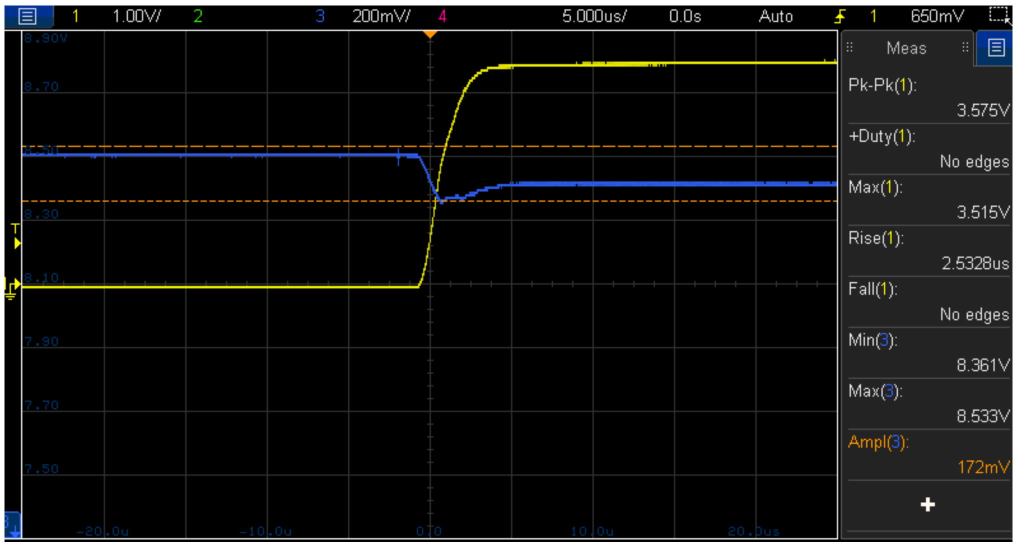

Figure 5: Voltage across sense resistor (yellow) and voltage measured on 9V power rail (blue) on slow rising edge from opamp, with 1000 µF capacitor placed on power rail near connection to NPN collector.

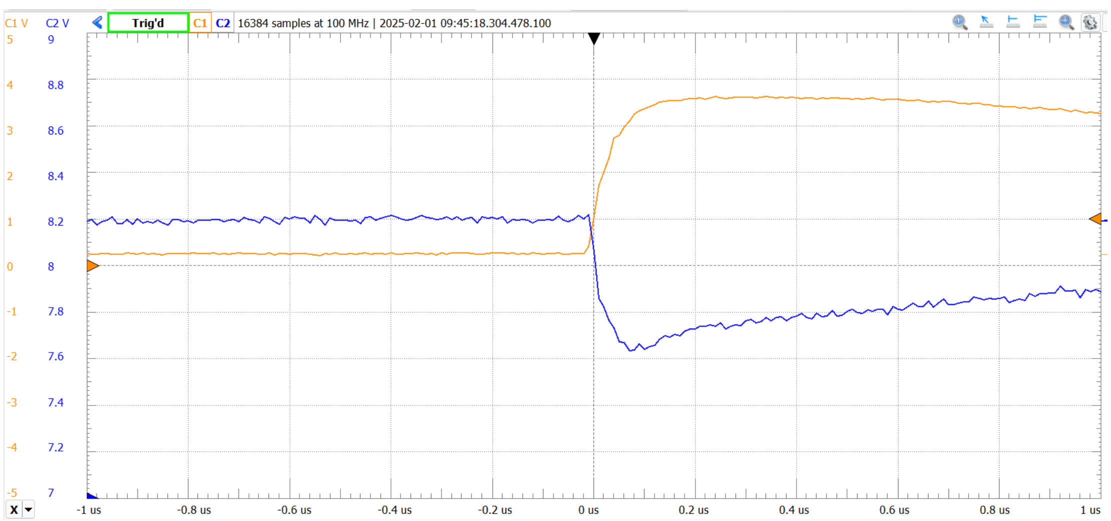

Figure 6: Voltage across sense resistor (orange) and voltage measured on 9V power rail (blue) on fast rising edge directly from Arduino, with 1 µF capacitor placed on power rail near connection to NPN collector.

Figure 5 illustrates how the buffered rising edge, which has a much slower rise time, creates a lot less switching noise on the power rail (the voltage drop is about 0.2 V, compared to 0.4 V from Figure 4). In Figure 6, we again used the fast rising edge, but replaced the 1000 µF capacitor with 1 μF. Since both capacitors have sufficient charge to provide the 0.35 A to the circuit initially, there is no change in the voltage drop between this measurement and that from Figure 4.

Finally, we use the measurements in Figure 4 to calculate the Thévenin equivalent circuit model of the Arduino 9V power supply. Assuming that when the transistor is off, there is no current flowing through the power rail, the Thévenin voltage is 8.5 V. When the circuit is drawing 0.3 A, the voltage on the power rail is 8.4 V, so the Thévenin resistance is $R_{TH} = \frac{\Delta V}{i} = \frac{0.1\,V}{0.3\,A} = 0.3\,\Omega$.

5. Conclusions

In this lab, we measured the switching noise on a power rail periodically supplying current through a slammer circuit. We found that the shorter rise time creates greater switching noise, since there is a higher rate of change of current. We also learned that we can decrease the switching noise with a decoupling capacitor, and that it is important to place this capacitor close to the device. When we tried placing it on the other end of the power rail, the switching noise decreased to some extent, but not as much as when it was right next to the transistor.

Our findings from this lab translate directly into design principles, such as placing decoupling capacitors near each device that will draw power, and selecting the smallest capacitor that will be sufficient for the given current draw and switching time (since going larger will not improve the circuit and will only take up more space).

I also learned to pay more attention when setting up my scope probes. Although I was very careful when building the circuit and had no mistakes there, for the first part of the lab I was measuring the voltage on the 5V power rail before realizing my error and retaking my measurements on the 9V rail.