Lab 5: Capacitors and MOSFETs

Tuesday, September 9, 2025 8:54 PM

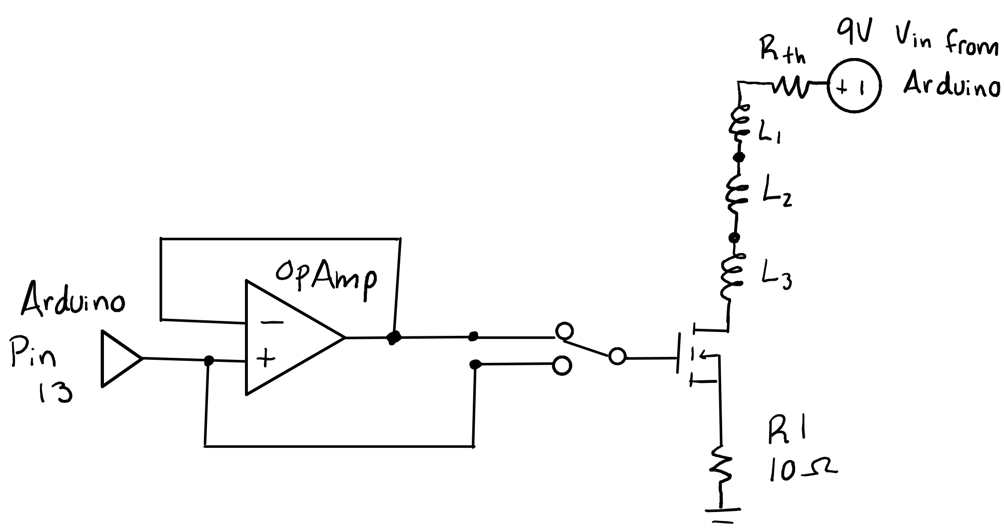
Objective

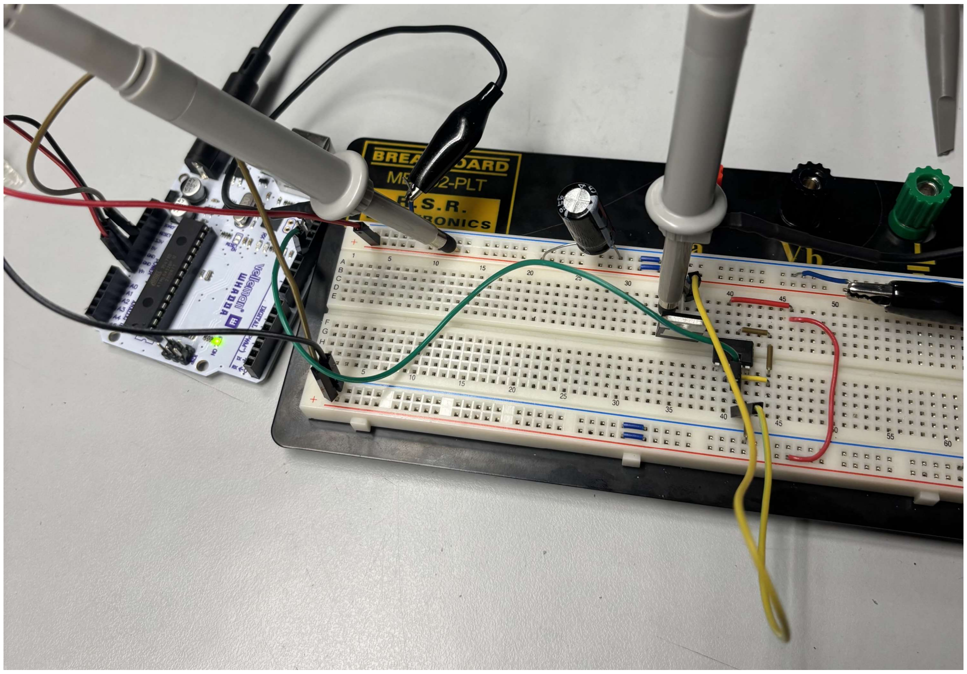
The objective of this lab was to see how decoupling capacitors effect voltage noise of a circuit, and determine how to select the right capacitor to mitigate the effects of voltage noise. A 1 ms on and 20 ms off signal from the Arduino gives us a 4.76% duty cycle ($Duty\ Cycle = \frac{T_{on}}{T} = \frac{1\ ms}{21\ ms} = 4.76\%$) which is then connected to an op amp, whose output feeds the base of the MOSFET. This slow output of an op amp turning on the MOSFET will cause the transistor to quickly pull from the 9V power rail to the collector. This sudden change in current results in a "ringing" thaty is visible in the signal rise time, which sought to mitigate by adding a decoupling capacitor across the 9V rail. The inductive nature of the wires beneathe the breadboard resist sudden changes in current, which can be reduced by adding decopling capacitors.

Component List

- MCP601 Op amp
- TIP41c MOSFET
- 10 ohm resistor
- 1uF capacitor
- 1000 uF capacitor
- Jumper wires
- Solderless breadboard
- Oscilloscope
- x2 Scope probe

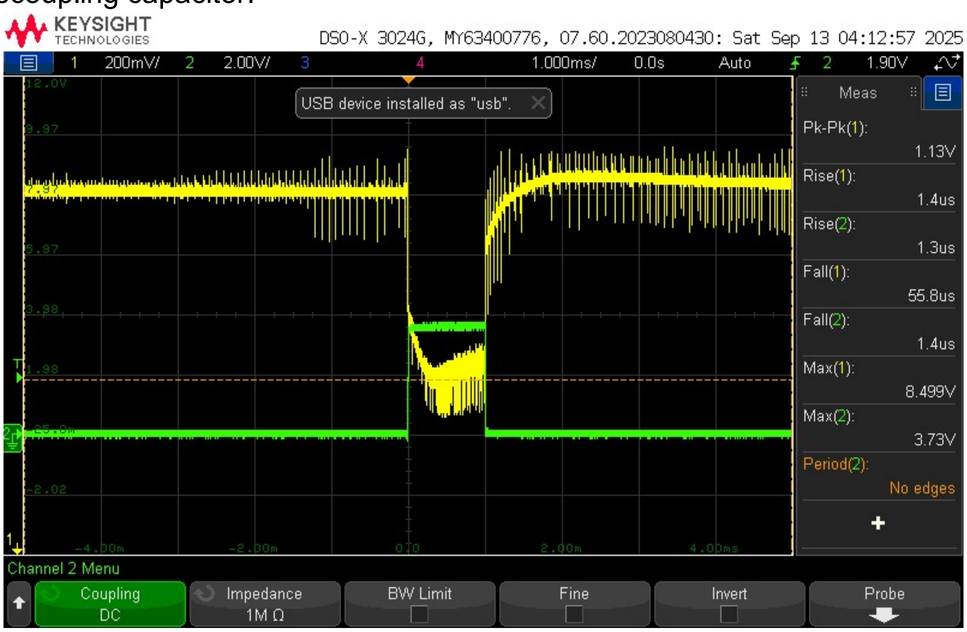
Circuit Photo and Back of Napkin Sketch



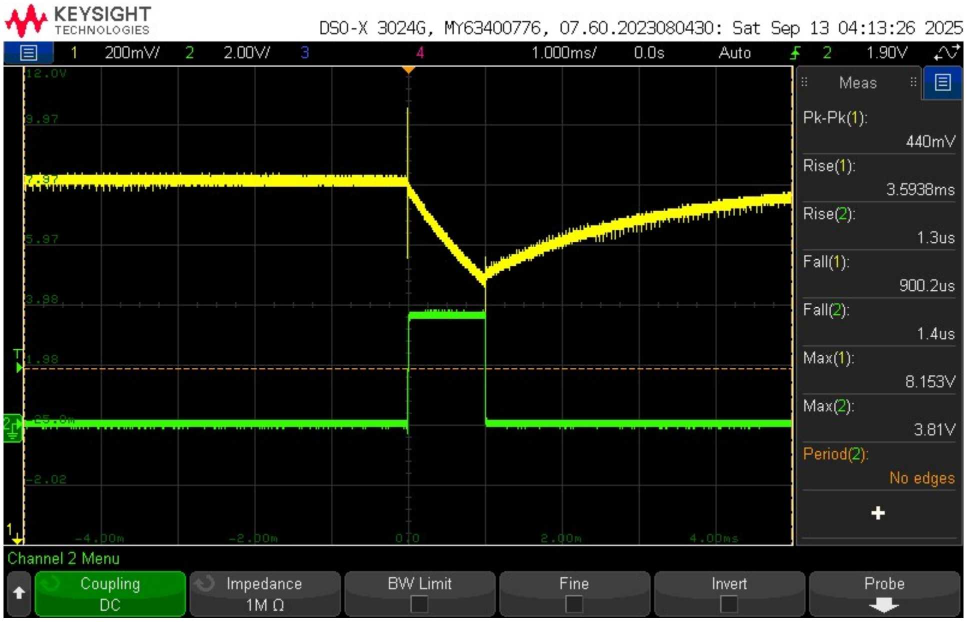


For switching noise, probe channel 1 is viewed as the measurement across the 9V power rail and channel 2 is the voltage across the emitter of the transistor, connected to the output of the op amp. It's very clear from comparing these two screen captures the immense impact adding a decoupling capacitor has, namely reduction in voltage noise and switching noise:

No decoupling capacitor:

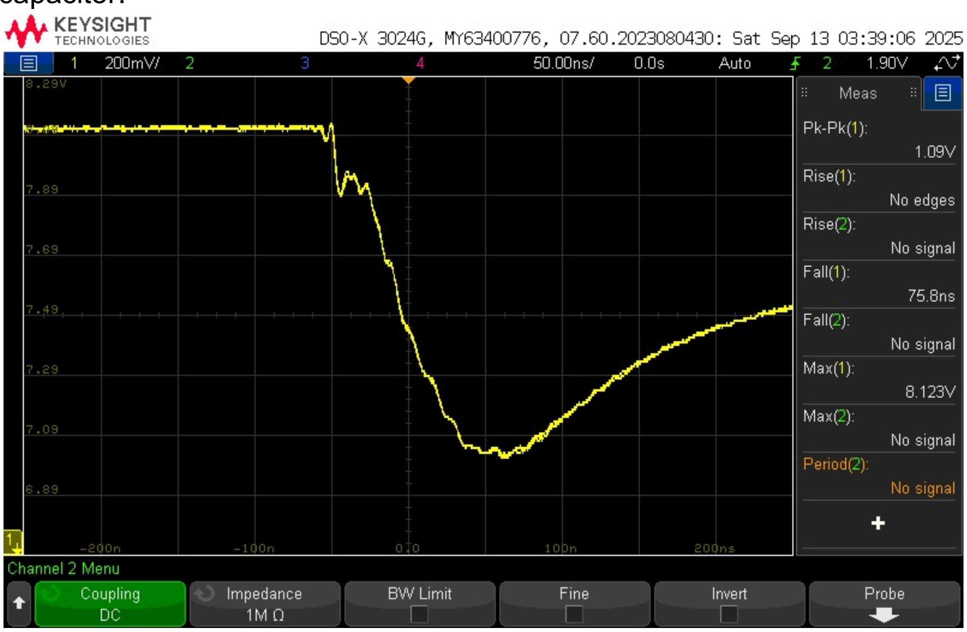


1000 uF capacitor:



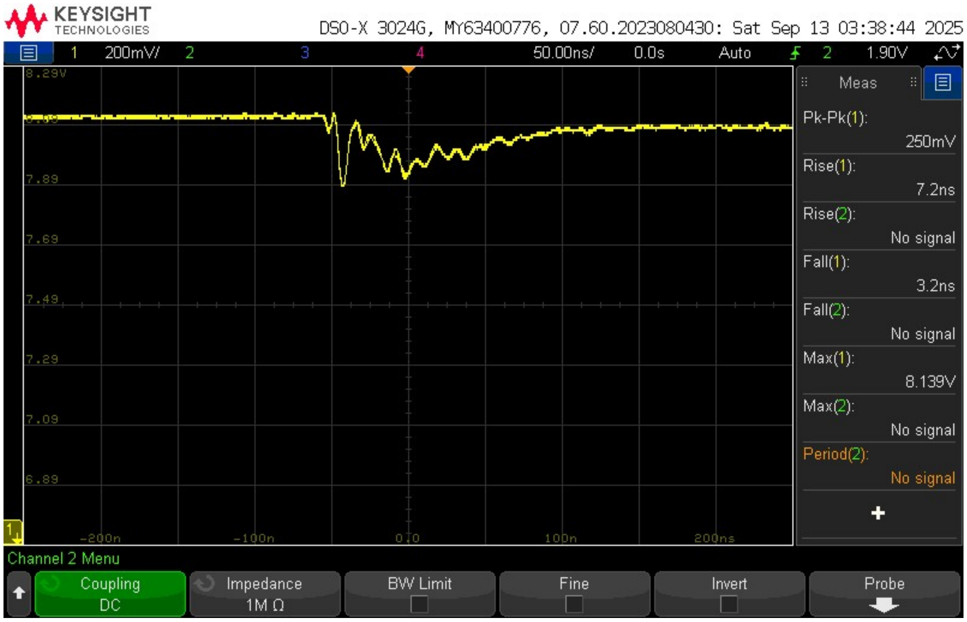
The impact on the switching noise of the 1 uF vs 1000 uF capacitor can be seen in the following screen captures:

1 uF capacitor:

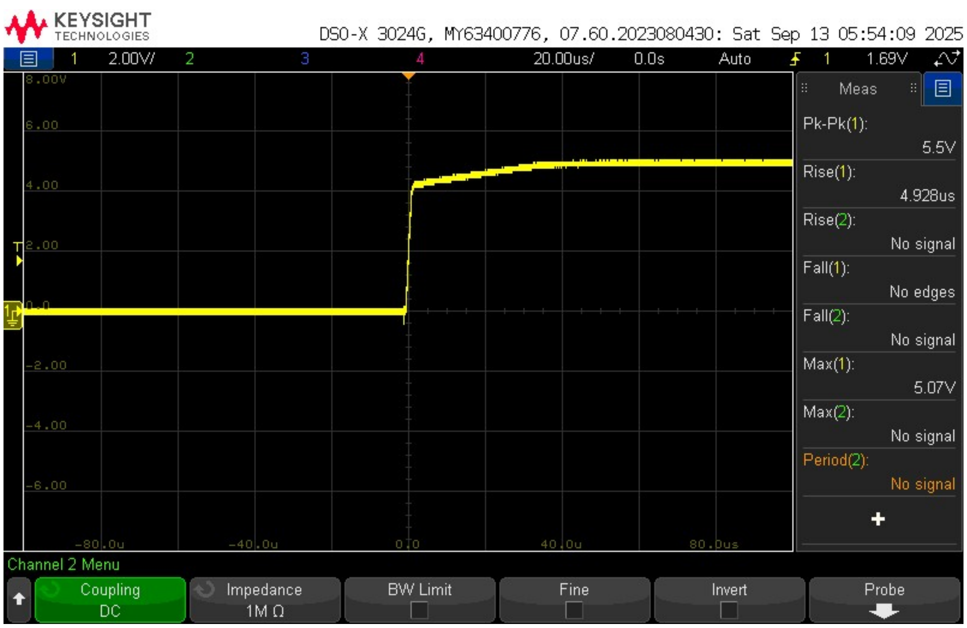


1000 uF capacitor:

Fast:



We can see that the ringing and voltage droop are greatly reduced with the 1000 uF capacitor. This is due to the greater amount of charge that can be held on each plate of the larger capacitor the moment the transistor turns on, having much less of an effect on the sudden pull of electrons from the supplied voltage from the 9V rail, as they are also supplied from being stored in the decoupling capacitor.



The Thevenin voltage of the 9 V power supply was measured by probing the open circuit voltage across the 9V power rail, which was determined to be 8.3 V. The load voltage was measured by taking the voltage across the 10 Ohm resistor placed between the emitter and ground. This value was determined to be 4.1 V.

$$R_{th} = R_L \frac{V_{th} - V_L}{V_L}$$

$$R_{\mathrm{th}} = 10\Omega \frac{8.3V - 4.1V}{4.1V}$$

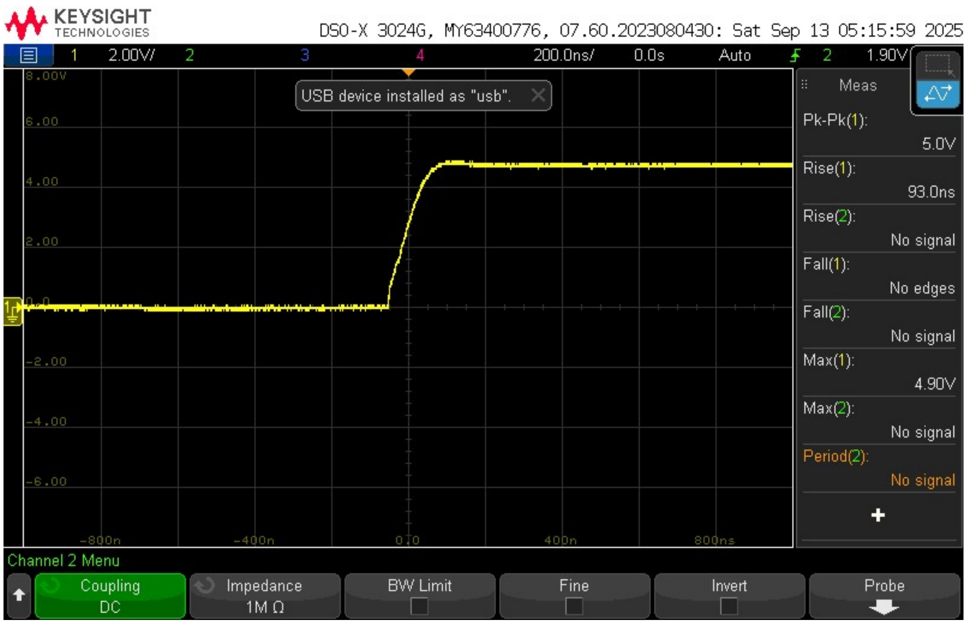
R_{th} = 10.2 Ohms

The loop inductance of the power path can be calculated by finding the rise time of the 5% duty cycle signal from the op amp to the base of the transistor. The following formula gives the inductance value:

$$\Delta V = L\frac{\mathrm{d}I}{\mathrm{d}t}$$

Where $\Delta V = 8.2V, \mathrm{dI} = \frac{4.1\,V}{10\,\Omega} = 410\,mA, dt = 93\,ns\ (as\ seen\ in\ the\ scope\ capture\ below)$.

$$\Delta V = \frac{8.2\,V}{0.41\,A} \times 93\,ns = \mathbf{1.86\,uH}$$



Conclusion

In this lab, we continued to deepen our understanding of the effects of real (rather than ideal) circuit components and their wirings, as well as how our measurement instruments my also influence what we see. Because this is not an ideal circuit, the abrupt change in current from the power rail, or the switching noise, or causes