Department of Electrical and Computer Engineering

University of Colorado at Boulder

ECEN5730 - Practical PCB design

PDN and Crosstalk

Report

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1 Objective / Purpose of Lab

Purpose of this lab is to measure the loop-to-loop cross talk between two loops and exercise your understanding of the principles of mutual inductance and what design features will reduce this common source of noise.
Build a simple slammer circuit which will draw a fast transient current from the power rail, which happens on each clock edge.

1. To measure the switching noise on the power rail when there is a large current transient.
2. To see the difference in switching noise for different dI/dt values of current transient. To estimate how much capacitance is needed to provide adequate local charge storage.
3. Short rise time current transients have a larger dI/dt and show more power rail noise than long rise time current transients.
4. When there is a step change in the current on the power rail there is more noise generated than just from the dI/dt. There is also an IR drop from the Thevenin resistance of the VRM and power rail.
5. The voltage on the power rail spikes up when the current in the power rail turns off.

here is block diagram of the PDN circuit,

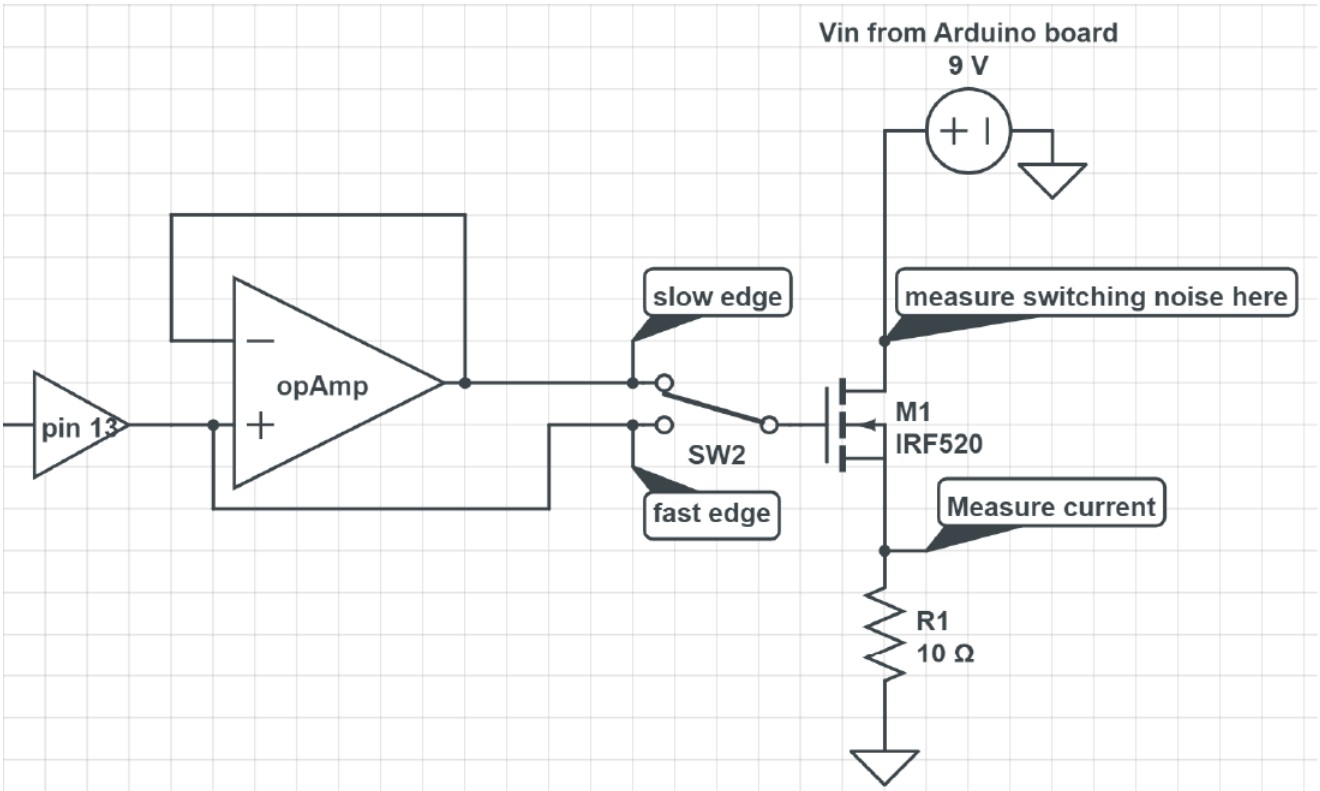

Figure 1: PDN circuit block diagram from book

2 Component listing

2.1 For Lab Crosstalk and Thevenin R

Component Name	Usecase
1 x BNC to BNC Probe	For Signal Generator
1 x 10x Probe	For Oscilloscope
1 x 100 Ω Resistance	Load Resistance

Table 1: Lab Crosstalk

2.2 For Lab PDNs

Component Name	Usecase	Symbol	Value
1 x Capacitor	Filter Capacitor	C1	10μF
1 x T272 OPAmp	Slow slew rate opAmp	U1	-
1 x Resistor	Current limiting Resistor	R1	10Ω
1 x N channel MOSFET	For Switching	T1	IRL520

Table 2: Lab PDN

3 Calculations

Thevenin resistance is the resistance of an entire network reduced to two terminals.

3.1 Calculating Thevenin Resistance

With Independent Sources: Temporarily remove the load resistance (if any) from the circuit. Replace all voltage sources with short circuits and all current sources with open circuits. The resistance seen across the terminals is the Thevenin resistance R_{th}.
Isolation of Circuit: Initially, the load resistance is removed to isolate the circuit. This step is to calculate the inherent resistance of the circuit.

Voltage Without Load Resistance	Voltage With Load Resistance
1.01V	0.680V

Table 3: voltage with and without load resistance

Voltage Measurements: Without Load Resistance: The open-circuit voltage Voc is measured across the terminals, which is equivalent to the Thevenin voltage Vth
With Load Resistance: The circuit voltage Vload is measured again after reintroducing the load resistance.

$$R_{th} = R_{load}\left(\frac{V_{th} - V_{load}}{V_{load}}\right)$$

So first we will measure voltage without load resistance

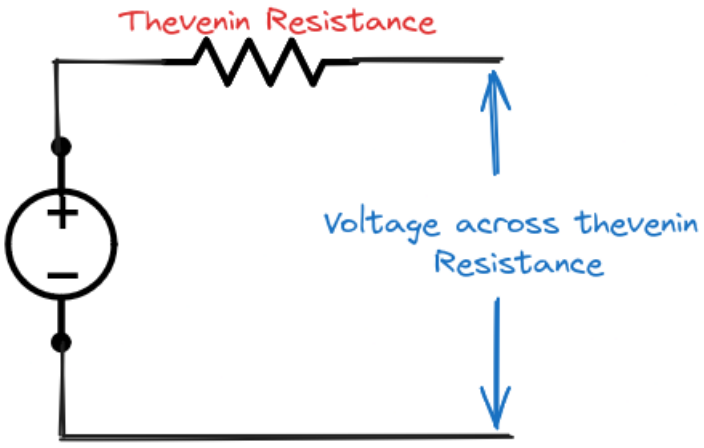

Figure 2: Voltage measurement without load resistance

We got around 1.01V of voltage in without load Resistance R_{load}.
Now we will measure Thevenin voltage with load resistance R_{load} of 100Ω.

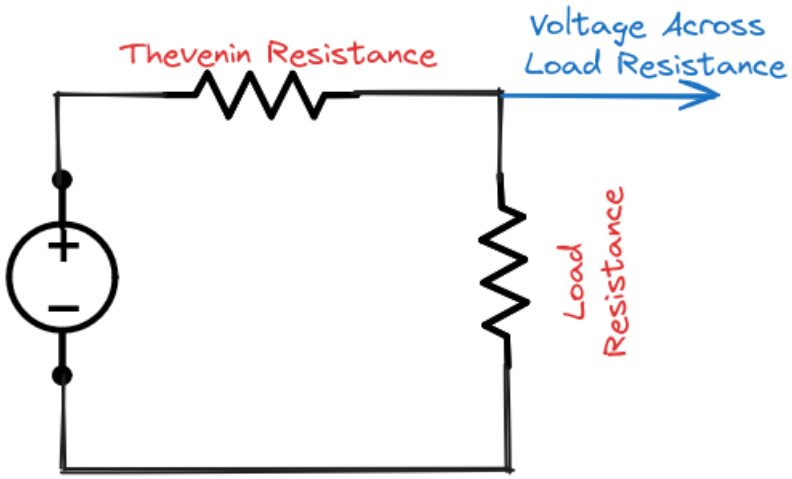

Figure 3: Voltage drop due to load resistance

This time, We got around voltage drop of 0.680V across the load resistance
and putting values in the equation **??** will give us,

$$R_{th} = 100\left(\frac{1.01 - 0.680}{0.680}\right)$$

$$R_{th} = 100 \cdot 0.68529$$

$$\boxed{R_{th} = 48.529\Omega}$$

So conclusion is that the R_{th} of power supply would be around 50Ω.

3.2 Cross Talk

for the cross talk lab we used signal generator as input to oscilloscope and we shorted the output of waveform generator and oscilloscopes and we put the loop of the probes to signal generator and due to switching of

the voltage and current, new current (noise) was generated in the other loop (L) and this noise due to loop inductance is called crosstalk

dI/dT Impact: The rate of change of current (dI/dT) plays role in the intensity of the crosstalk. Higher dI/dT values, typically found in short rise time current transients, result in more pronounced power rail noise.In our case large loop inductance is causing crosstalk currents to induce in oscilloscope loop

Circuit Behavior: This behavior aligns with the principle that circuits requiring power rapidly can induce significant voltage fluctuations and noise on the power rail.

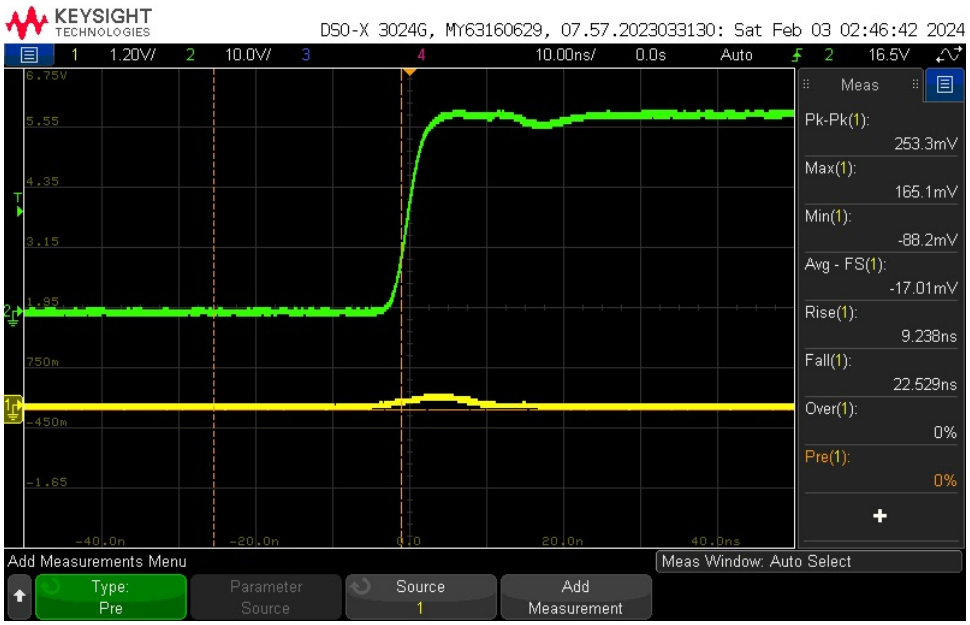

Figure 4: Noise/Crosstalk in Oscilloscope Probe

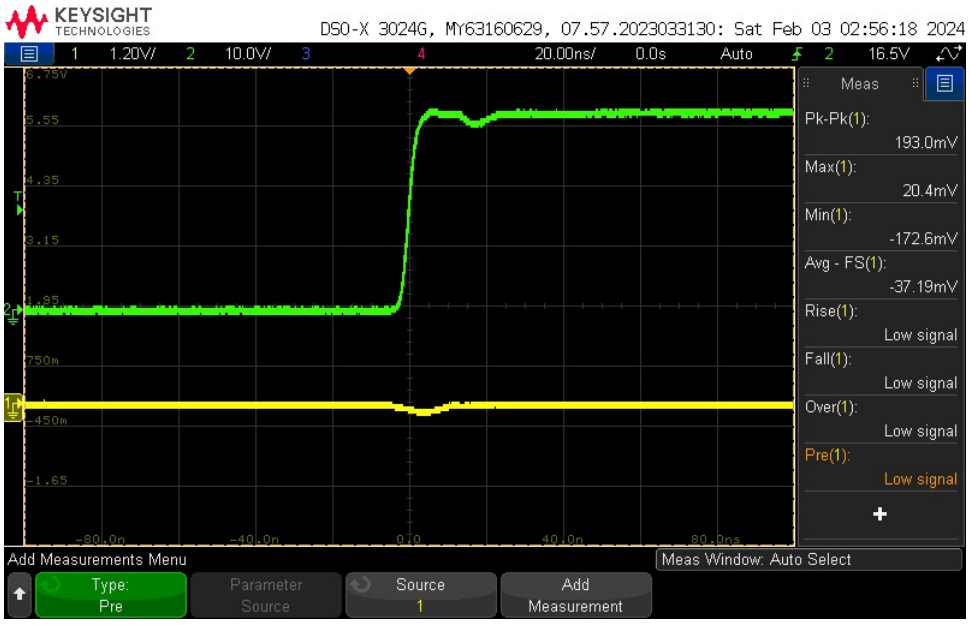

Figure 5: Noise/Crosstalk in Oscilloscope Probe - 2

3.3 Calculating Power rail noise due to switching

The experiments focused on understanding the behavior of a slammer circuit on a solder less breadboard with focus switching noise, power consumption, and the effects of different rise times and decoupling capacitors. Rise and Fall time for Arduino digital output is mentioned below

	Rise Time	Fall Time
Arduino	13ns	25ns
OPAmp	1.4μs	1.4μs

Table 4: Rise-time and Fall-time

And according to data-sheet opAmp's slew rate was around 1.5 μsec/V , From the observation we can see that the rising and falling edge compliance with the data-sheet
Current going through Resistor was measured with the series Ammeter, here is the results of Ammeter

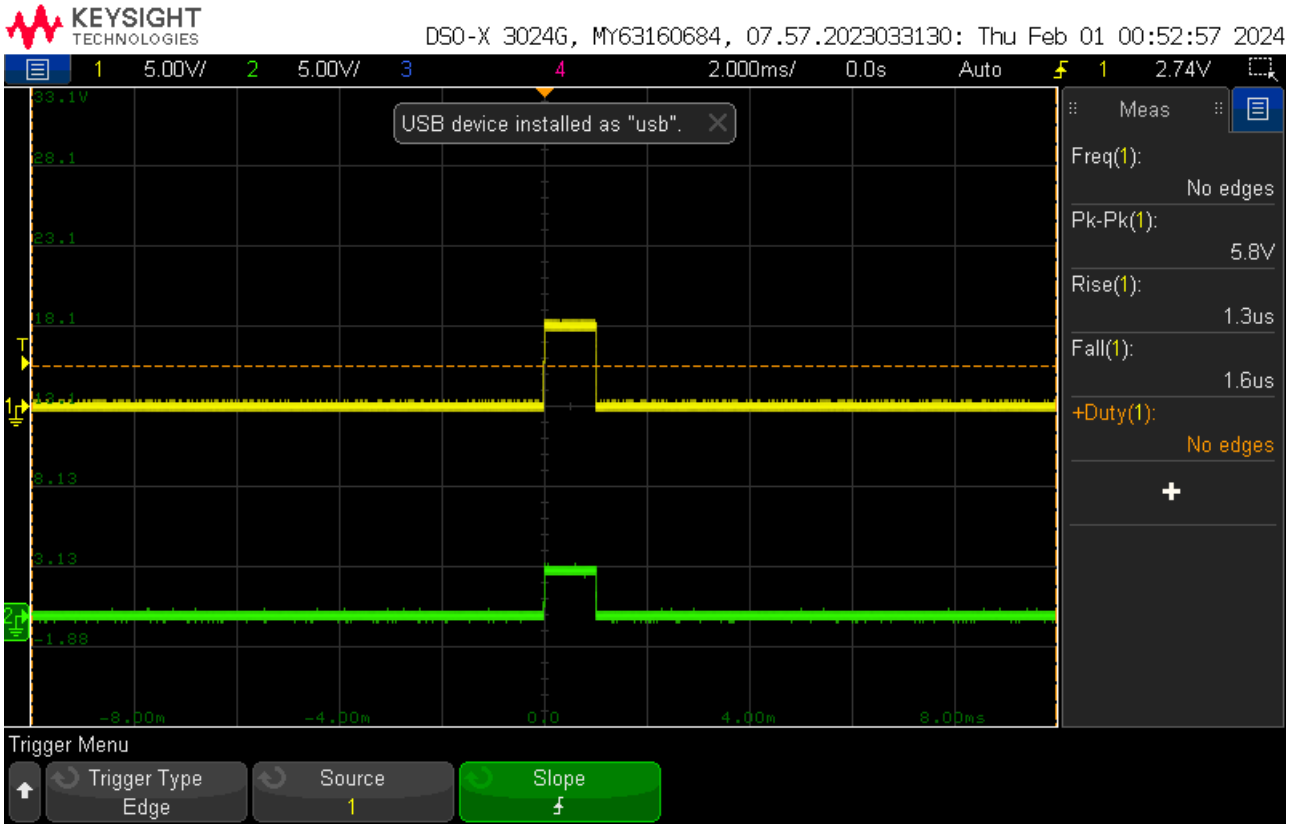

Figure 6: OpAmp Output and MOSFET Gate

Two Driver Signals to Transistor's Base: The setup included two signals to drive the MOSFET: the raw input from the Arduino and the buffered output from the opAmp follower. The rise and fall times of these signals were measured, and their impact on the circuit's performance was observed.

3.4 Initial Measurement with Slow Rise Time Signal:

The slow rise time signal from the opAmp output was first connected to the MOSFET gate. The voltage at the opAmp output was measured, showing a long rise time.
here is the noise on the power rail due to slower rising edge

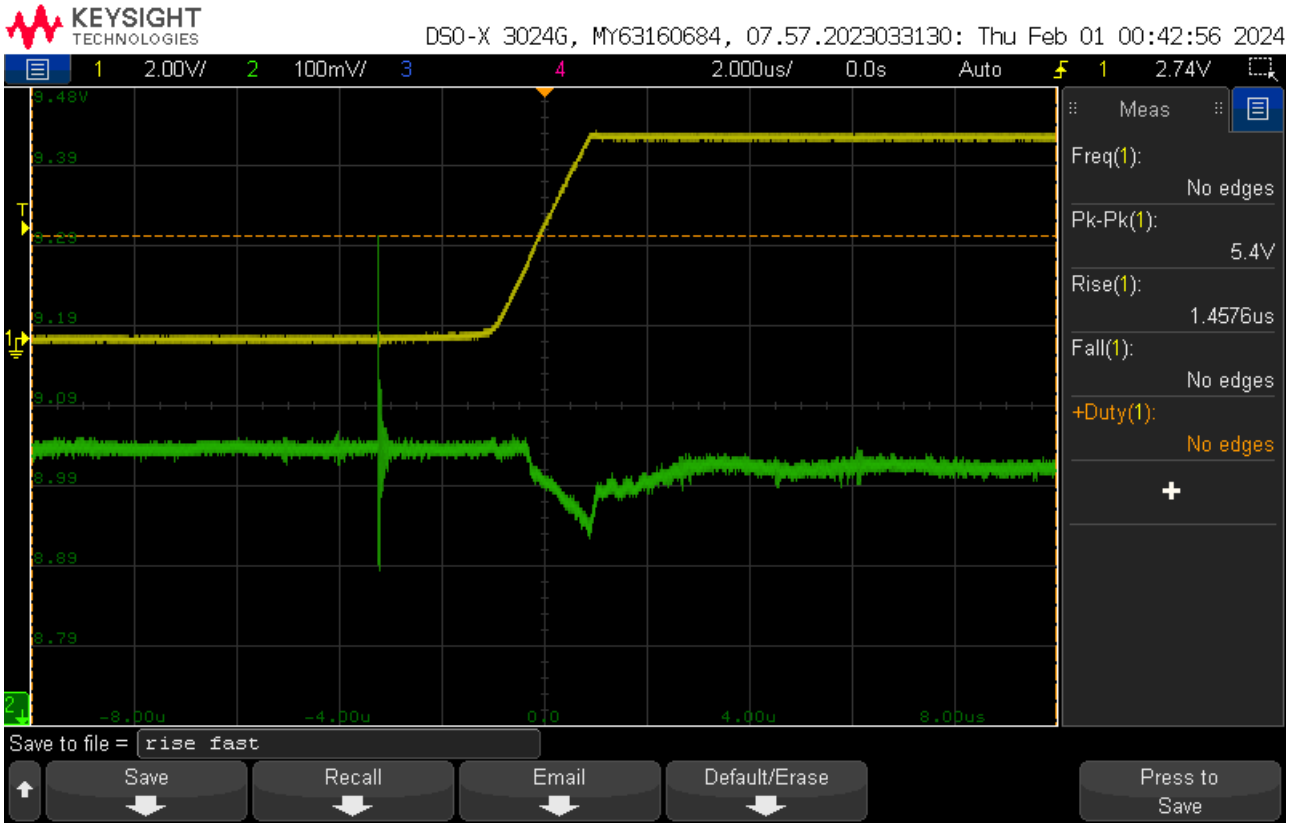

Figure 7: slower rising edge

here is the noise on the power rail due to slower falling edge

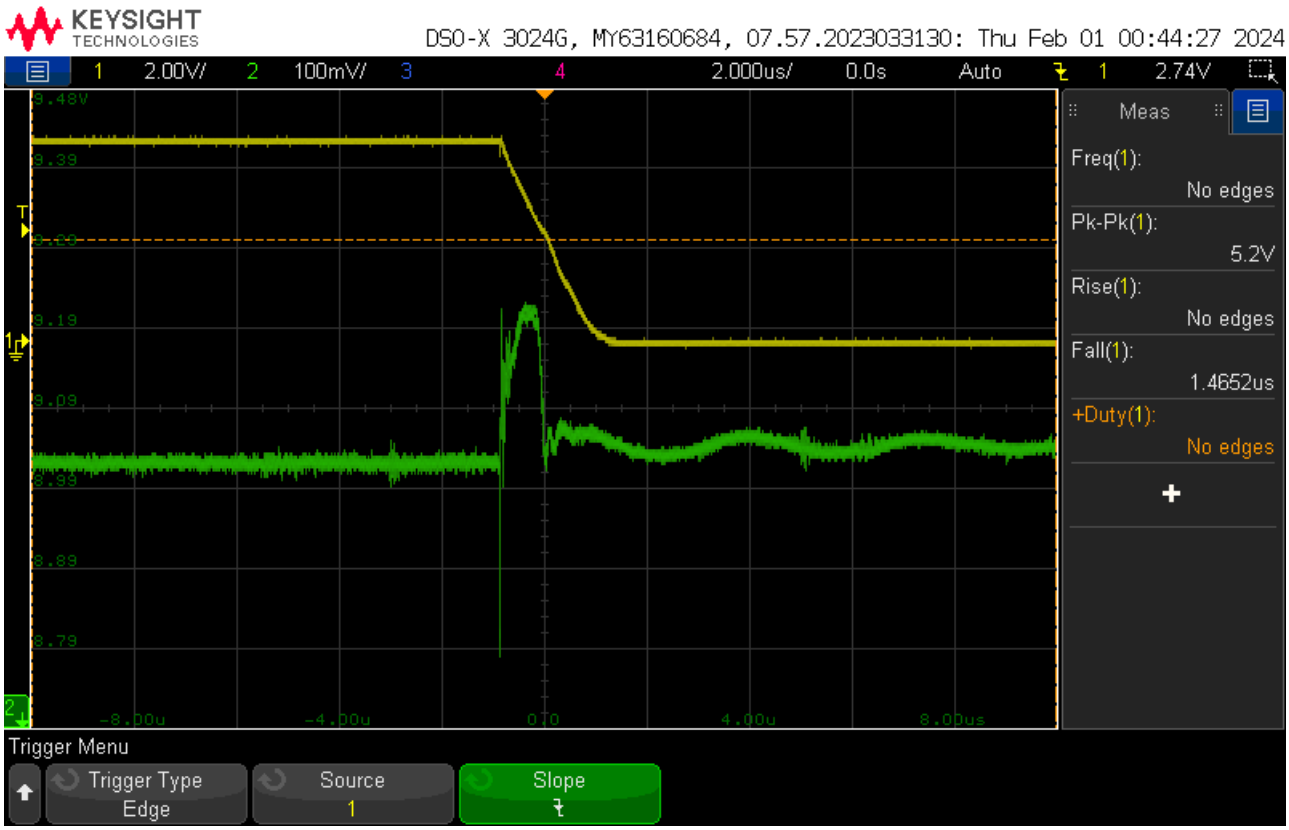

Figure 8: slower falling edge

Noise due to slow rising and falling edge does not cause much of fluctuations on power rail of the bread

board and reason is dI/dt is not changing abruptly and causing high mutual impedance in the power rail.

3.5 Measurement with Fast Rise Time Signal:

The fast rise time signal from the Arduino output was directly connected to the MOSFET gate. The voltage at the Arduino output was measured, showing a fast rise time.

Noise on the power rail due to fast rising edge

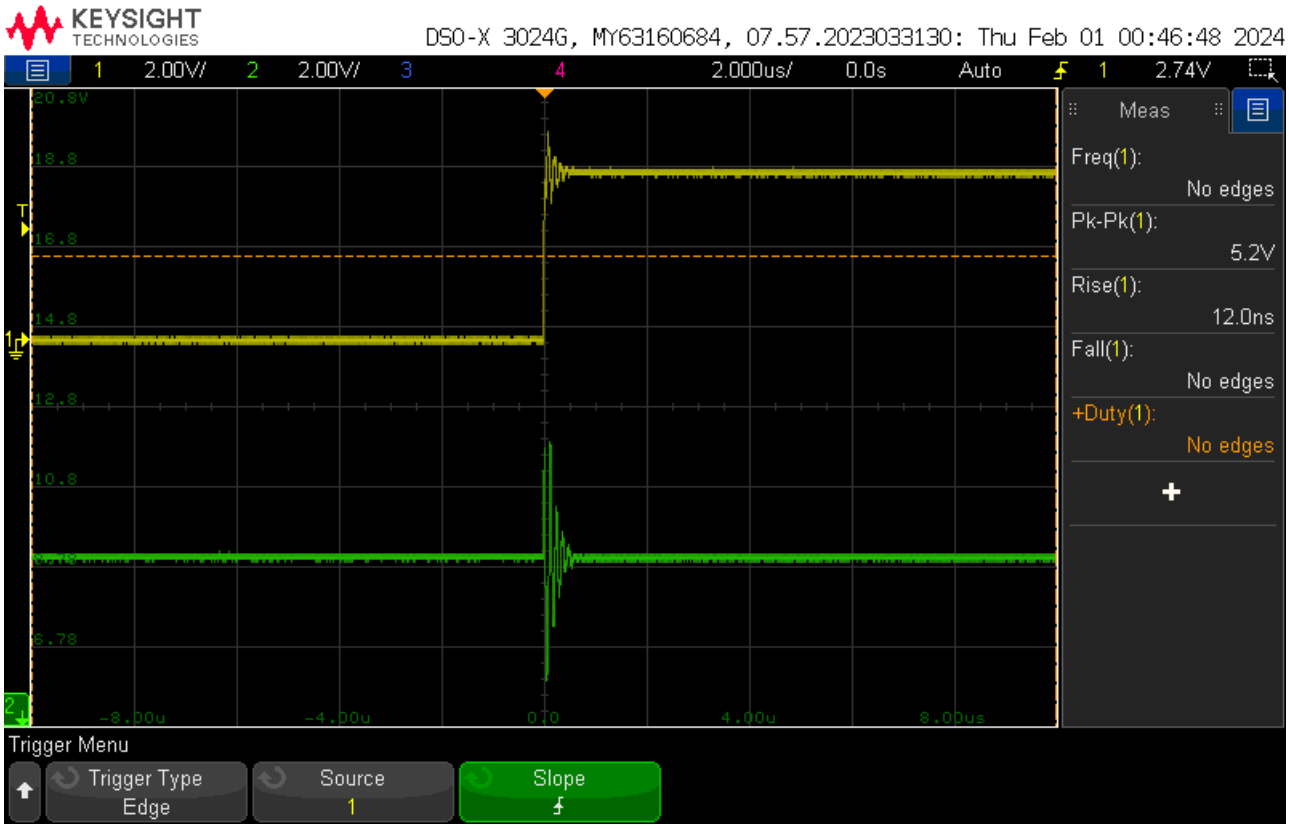

Figure 9: fast rising edge

here is the noise on the power rail due to fast falling edge

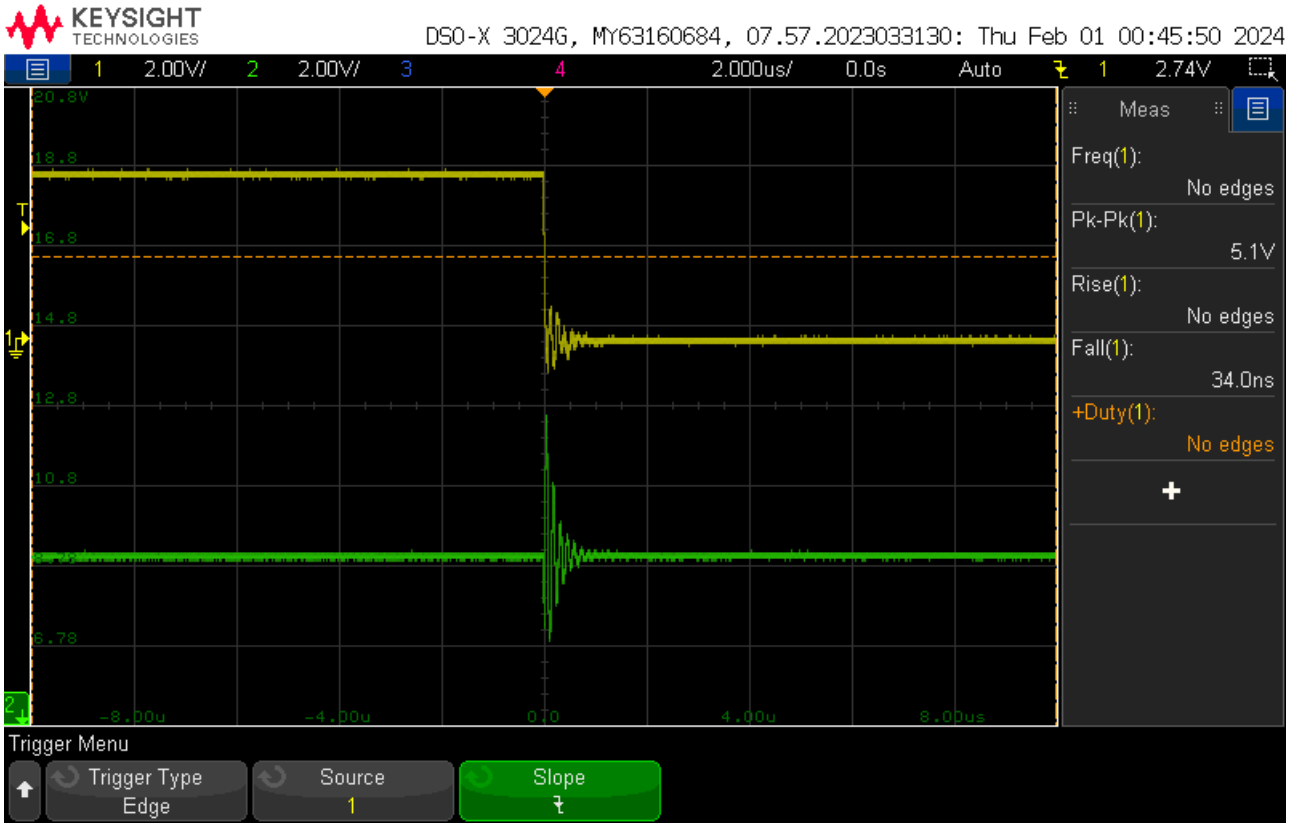

Figure 10: fast falling edge

Here we can see the noise is very high due to fast switching and this was measured around 300mV peak to peak voltage noise on power rail

3.6 Adding Decoupling Capacitors

here is the noise on the power rail due to slower rising edge with 10μF capacitor added in the power rail as close as to opAmp.

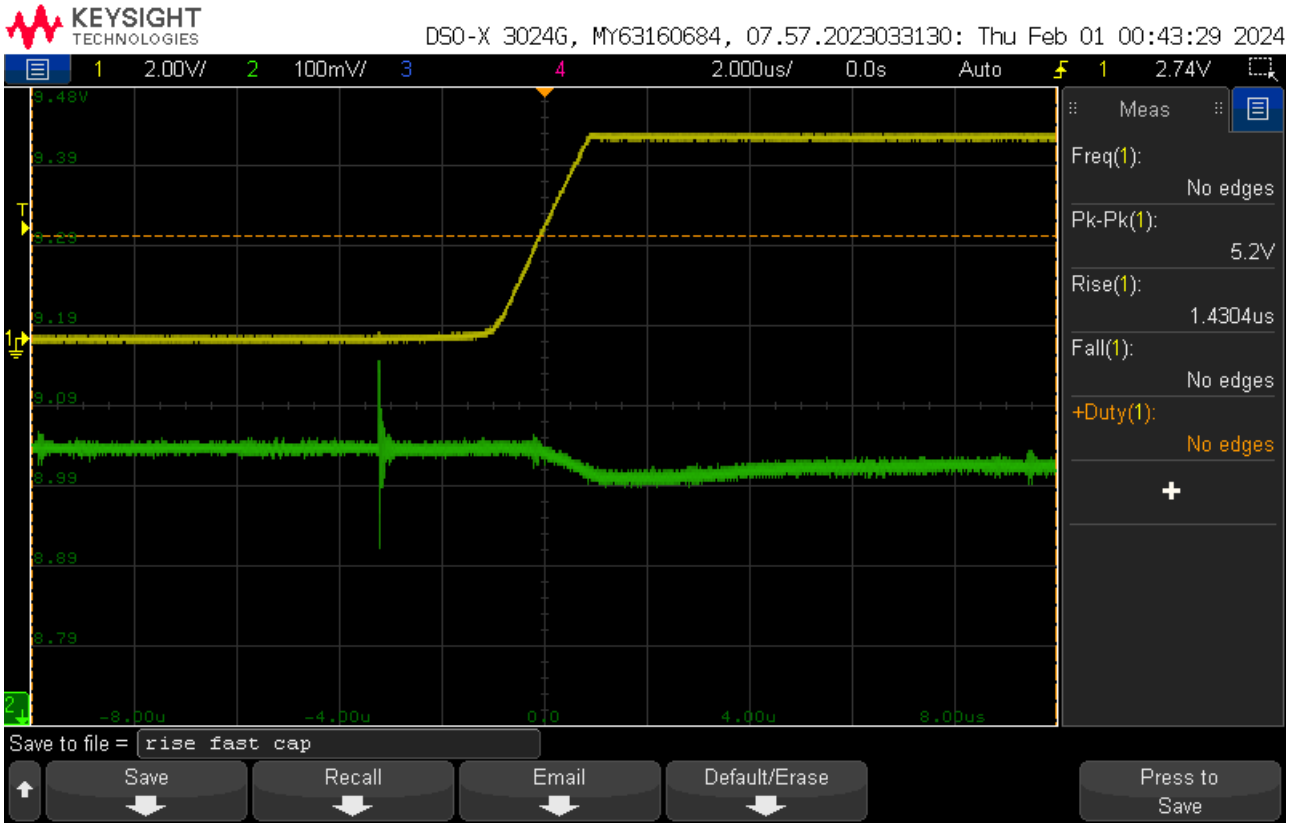

Figure 11: slower rising edge with capacitor added

here is the noise on the power rail due to slower falling edge with 10μF capacitor added in the power rail as close as to opAmp.

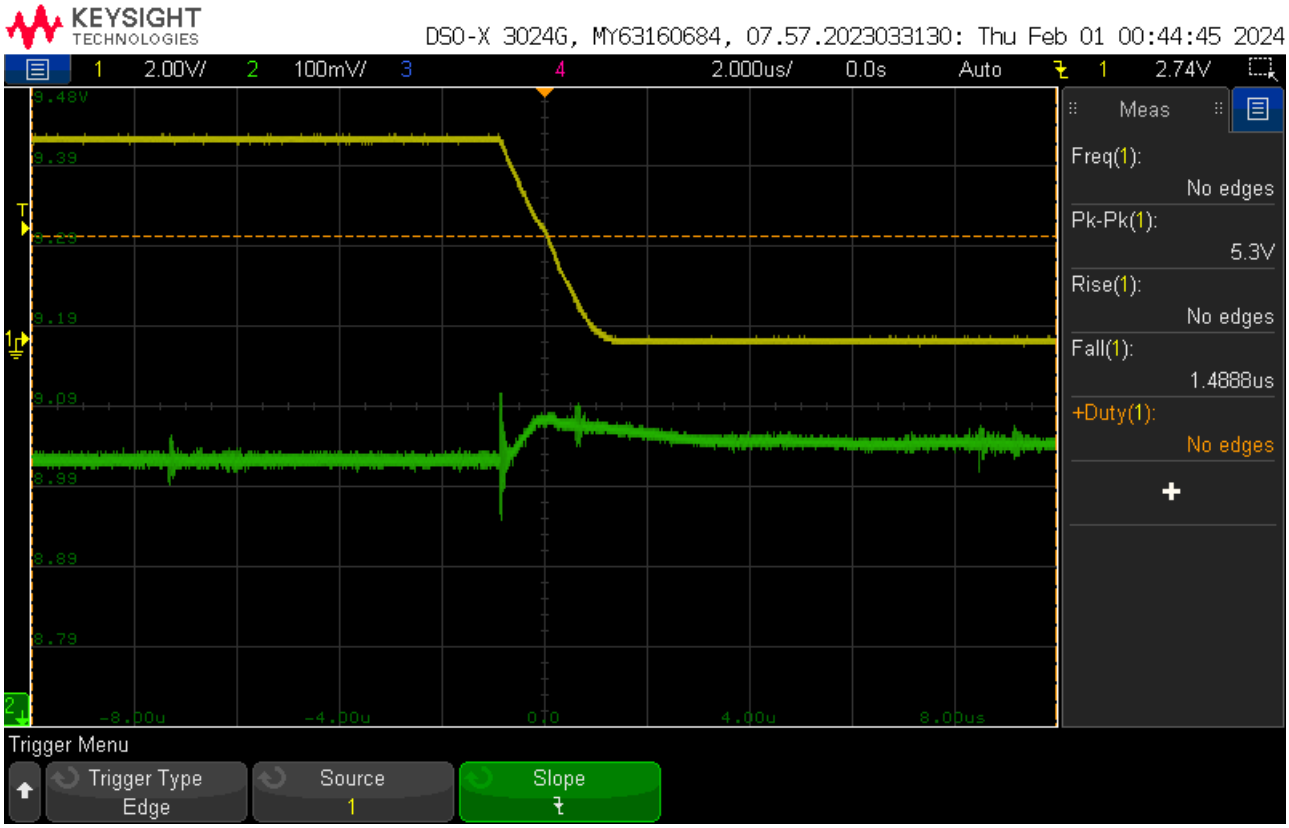

Figure 12: slower falling edge with capacitor added

here is the noise on the power rail due to **fast rising edge** with 10μF capacitor added in the power rail as close as to opAmp.

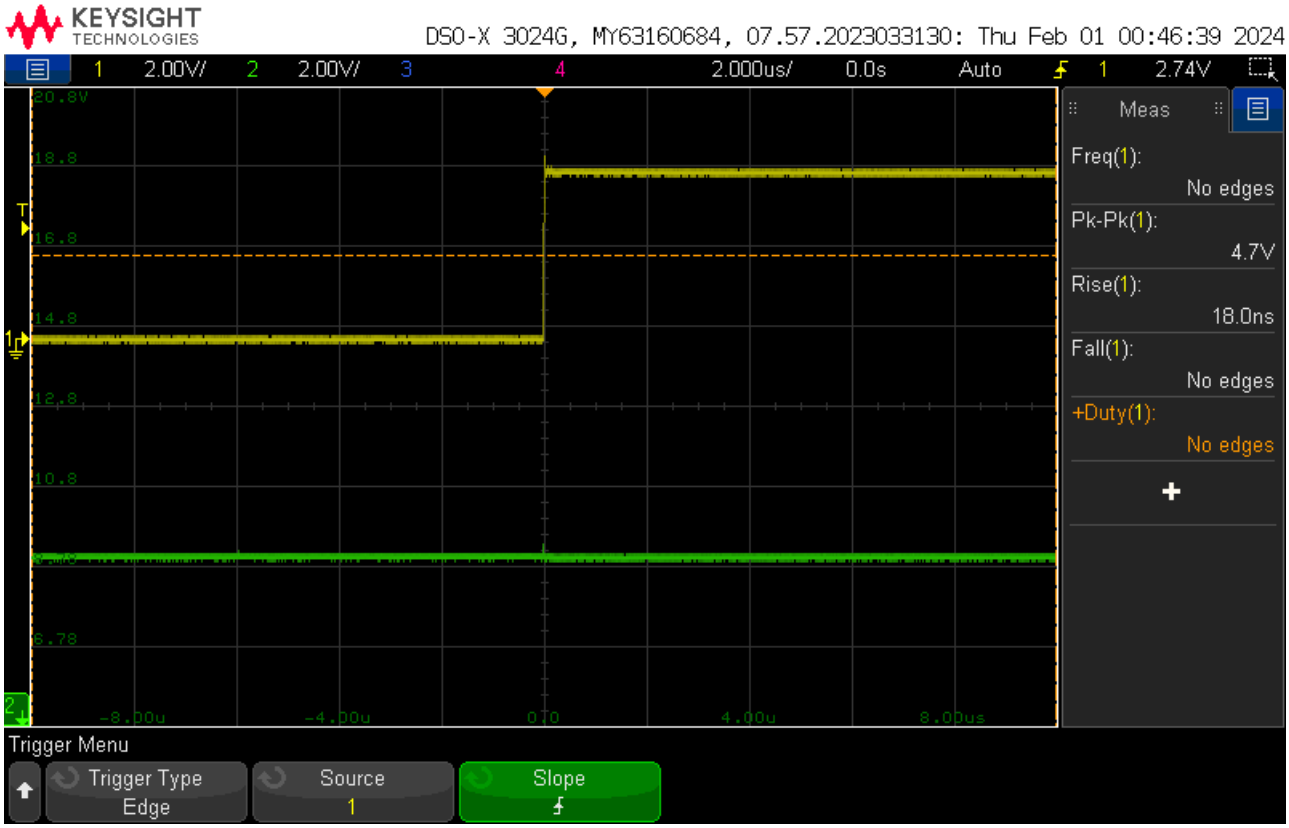

Figure 13: fast rising edge with capacitor added

here is the noise on the power rail due to **fast falling edge** with 10μF capacitor added in the power rail as close as to opAmp.

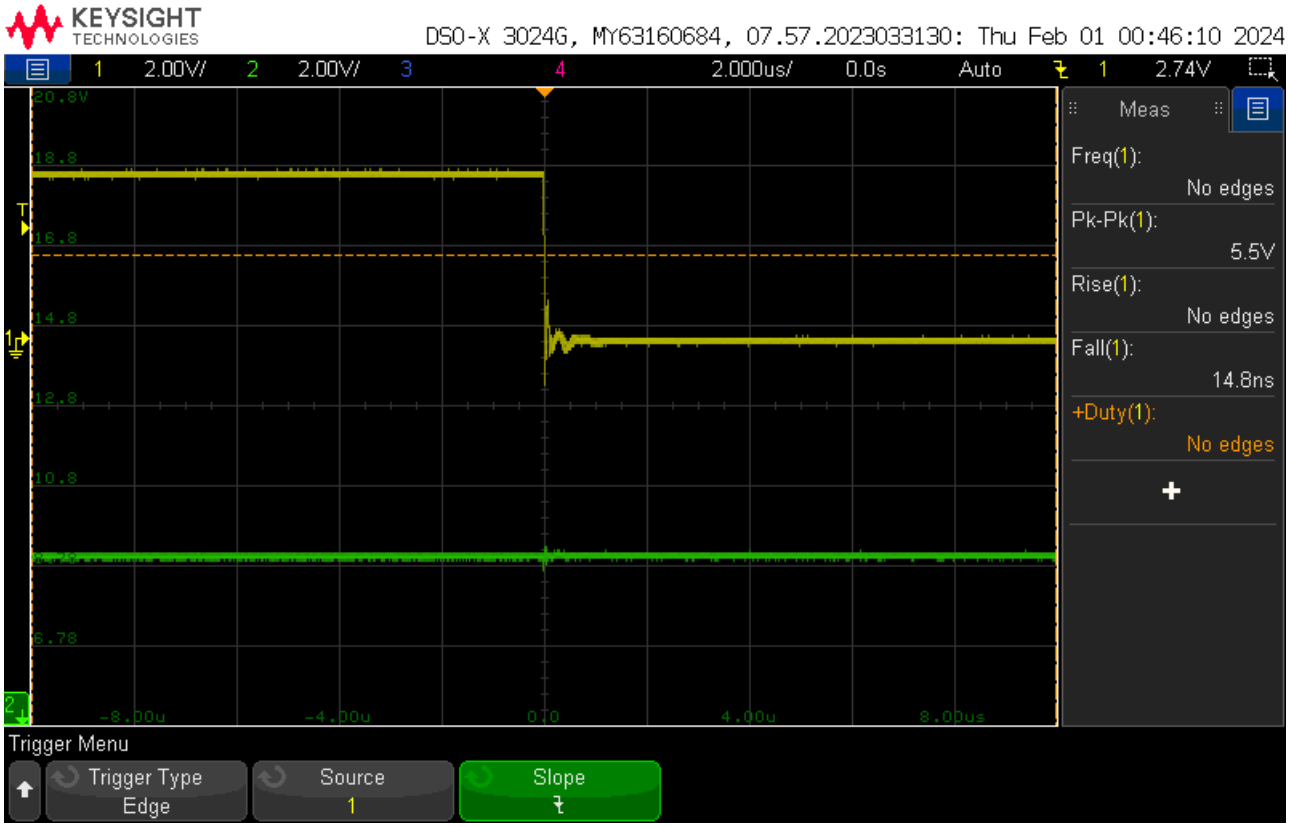

Figure 14: fast falling edge with capacitor added

3.7 Observation of Switching Noise Characteristics:

This observed behavior in the circuit is attributed to the power demand dynamics. When the circuit requires power, particularly during high consumption periods, there is a corresponding drop in voltage along the voltage rail. This voltage drop, in turn, is the primary cause of the observed noise on the power rail. The extent of this voltage fluctuation and the resultant noise is directly related to the current demand of the circuit at any given moment. Such fluctuations are particularly pronounced during instances of sudden or high current draw, which are common in circuits with rapidly switching components or those undergoing transient states. This phenomenon underscores the importance of stable power supply design and the implementation of noise mitigation strategies, such as decoupling capacitors, to maintain consistent voltage levels and minimize noise interference in the power rail.

3.8 Estimating Decoupling Capacitor Size

During the time of the rising or falling edge, dt, when there will be inductive switching noise, we want all of the current I to come from the capacitor, so none of it has to flow through the rest of the inductance of the power rail. However, this current only needs to flow during the rising or falling edge. If we want to limit the voltage drop, during the dt time, to 0.4 V, for example, the capacitance C we need is calculated as follows: (From the lab manual)

$$C = \frac{I \times dt}{\Delta V} = \frac{0.4 \times 1\,\mu\text{sec}}{0.4\,V} = 1\,\mu F \tag{1}$$

3.9 Decoupling Capacitor Location

A notable observation was the reduction in noise levels when a 10 µF capacitor was placed close to the opAmp, that causes charge storage in smoothing out voltage fluctuations caused by rapid current changes.

4 Conclusion

The lab demonstrated the characteristics of noise how it is generated how it affects the circuit and how it can be reduced, by removing loop inductance adding decoupling capacitor, also keeping in mind the rise time and fall time of the elements while designing the circuit

1. **Effects of Rise and Fall Times:**

   The speed at which signals in a circuit change, called rise and fall times, can affect how much noise is seen in the power supply. Faster changes tend to create more noise.

2. **Role of Decoupling Capacitors:**

   We learned that capacitors can help reduce noise in a circuit. Their size and where they are placed in the circuit can make a big difference in how effective they are.

3. **Analyzing Noise:**

   By looking at different types of noise on the power rail, we understood more about how circuits can affect power supplies. We saw that noise can change depending on many factors, like how fast a signal changes or where components are locate

4. **Understanding Crosstalk:**

   The lab provided a clear demonstration of crosstalk, an unwanted phenomenon where a signal in one circuit or channel creates an undesired effect in another.

Breadboard Implementation:

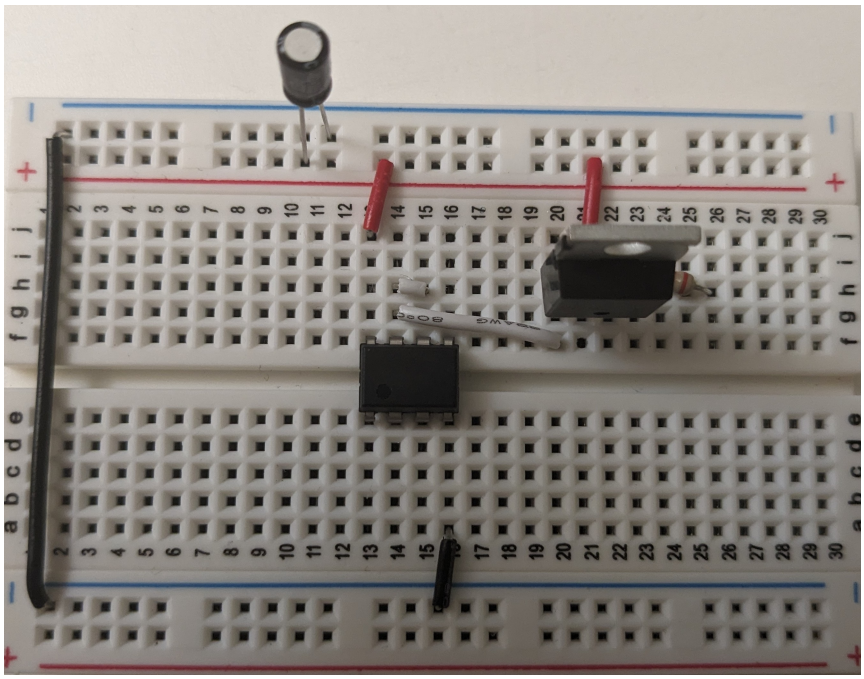

Figure 15: Breadboard Implementation