Nora Shao_L4A

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1 DC-DC Boost: Diode/Transistors, Loads, and Inductors

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Student Number: [redacted]

Lab Section: L4A

[27]:
```python
# @title
%%capture
from IPython.display import Image
from google.colab import drive
import os
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt

drive.mount('/content/drive/')
path = 'drive/My Drive/UBC ENPH Y2/ENPH259/Lab4/'
file_name = 'Nora Shao_L4A.ipynb'

assert file_name in os.listdir(path)

def img_path(img_name):
  return path + img_name
```

2 Pre-lab

Description: In your own words (i.e. not the interweb's words or your BFF's words) describe qualitatively how the DC-DC boost circuit shown below in Fig. 1 is able to produce a larger voltage at Vout as compared to Vin. You are welcome (and encouraged!) to use figures/pictures for your explanation. Assuming an ideal square wave input to the MOSFET gate with period To, qualitatively plot the corresponding ideal voltage (as a function of time) across the diode.

Solution:

a) If we pretend the circuit starts operation with the square wave off and the MOSFET closed, so once the circuit stablizes, the inductor acts as a short and the capacitor as a fully charged open-circuit, with all the current from V_{in} going through R_L. We see this circuit in Figure 3, where at t = 0+, the capacitor acts as a short circuit, but when the circuit stablizes, the capacitor acts as an open circuit.

Then when the square wave input is on and opening the MOSFET switch, the MOSFET shorts the current from the voltage source to ground, which means no current flows through the capacitor or R_L. Figure 2 shows the equivalent circuit for when the MOSFET is open. In this process, the inductor is charged.

Figure 4 shows the other side of the circuit while this is happening. The capacitor also starts discharing through R_L, since the back-biased diode doesn't allow any current to flow to the other section of the circuit.

So when the square wave input in off and the MOSFET switch closes, rending that branch an open-circuit, the inductor tries to maintain the (large) current that was going through it before by acting as an additional voltage source in series with V_in, while the capacitor continues discharging as yet another voltage source through R_L. Thus we now have three voltage sources instead of just V_in powering R_L and increasing V_{out}.

b) Figure 5 shows the time relationship of the voltage over the diode as a function of time compared to the input voltage from the signal generator. The voltage over the diode decreases as the capacitor charges and the current in the circuit (Figure 3) decreases. However, the 0 V in Figure 5 for the diode voltage plot should be shifted, as the diode's voltage drop does not become 0 - rather, a steady value related to R_L.

[28]:
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Image(filename = img_path("L4A_DC-DC Boost circuit.png"))
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[28]:

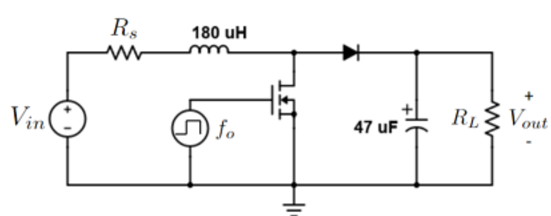

Figure 1: DC-DC boost Circuit

[29]:
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Image(filename = img_path("open MOSFET circuit.jpg"))
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[29]:

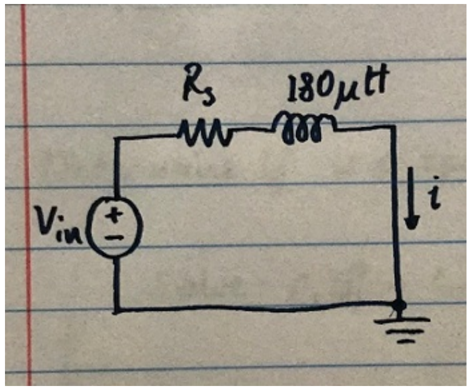

Figure 2: Equivalent circuit of DC-DC boost in Figure 1 when MOSFET is open

[30]:
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Image(filename = img_path("L4A_closed MOSFET circuit.png"))
```

[30]:

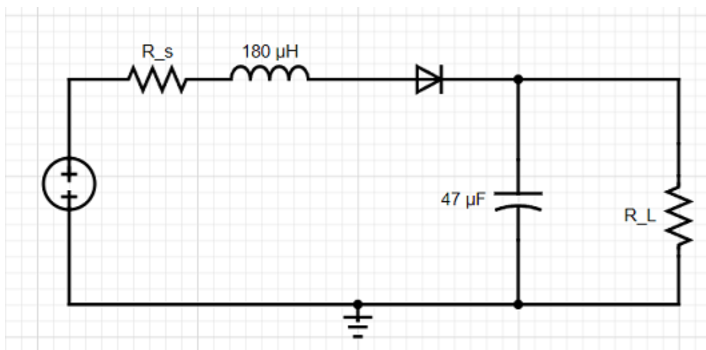

Figure 3: Equivalent circuit of DC-DC boost in Figure 1 when MOSFET is closed

[31]:
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Image(filename = img_path("L4A_open MOSFET circuit load.jpg"))
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[31]:

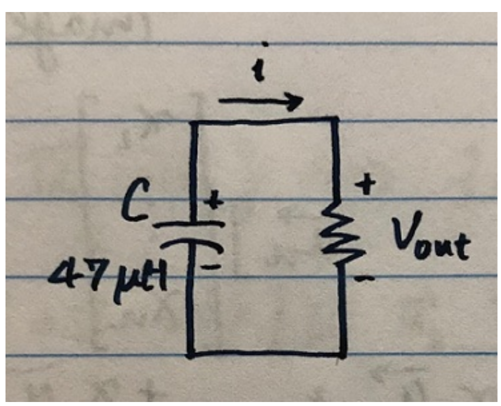

Figure 4: Equivalent circuit of Capacitor-resistor side of DC-DC boost in Figure 1 when MOSFET is open

[32]:
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Image(filename = img_path("L4A_voltage over time vs. time.jpg"))
```

[32]:

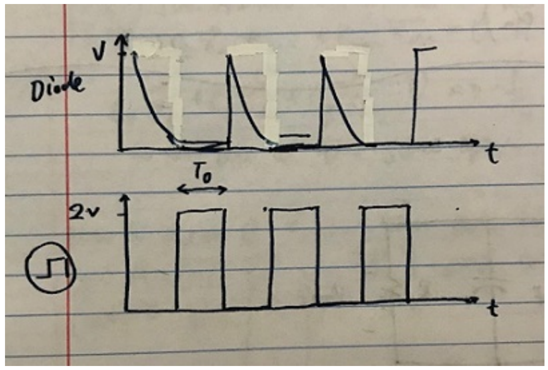

Figure 5: Voltage over diode vs. time (top) and input signal from square wave generator vs. time (top), not-to-scale

3 Troubleshooting

4 Experiment

4.1 Circuit Construction

Procedure:

- I set up the circuit in Figure 1 on the breadboard, but I modified it to make the construction with the materials I had more feasible. The finished circuit can be seen in Figure 6.
  - The leg(s) of both the MOSFET and the diode were too thick to fit into the sockets of the breadboard, so I had to plug them into a spring terminal connector which then plugged into the breadboard.
  - I first found the MOSFET's datasheet to confirm how it worked, which told me the gate terminal leg was actually above the drain and source
  - Because the gate terminal of the actual MOSFET was above the drain and source terminals, I had to figure out a way to wire my components so they were connected to the drain terminal but isolated from the gate. To do this, I cut and stripped wires to connect components on the breadboard instead of relying on the breadboard's internal connections.
- For the signal generator turning the MOSFET on and off, I stripped and connected a wire to the same breadboard column as the MOSFET's gate terminal. I connected a BNC cable to the breakout board's Wavegen 1 output and attached its positive lead to the other end of the wire.

- I followed the lab instructions in configuring the output signal. On Waveforms, I set it to a square wave with 20 kHz frequency. However, I arbitraily set the amplitude and offset to 2 V (so we wouldn't have negative input voltage)

- To perform the voltage measurement across R_L, I connected a BNC cable to the breakout board's Scope 1+ channel and used the red and black probes, with the back probe grounded.
- When I wasn't reading anything across R_L, I realized I had made a few mistakes setting up the circuit
  - First, when looking around the breakout board and my circuit, I noticed the LED next to the V_{in} terminal on the breakout board was off, so I thought my circuit wasn't receiving any input voltage. Through **TS1**, I realized V_{in} was indeed on and not the problem
  - Then I used DMM to perform a continuity check and realized the latter half of the circuit (diode and beyond) was completely isolated from the top half. I figured this issue out in **TS2**.
  - Eventually, I got a boost, but at around 3 V, when in the lab, we were told the boost should be around 7 V. I figured this out in **TS4**, where I first switched my one BNC cable measurement out for two BNC cables connected to the breakout board's Scope 1+ and Scope 1-. Then, I grounded the MOSFET's source terminal. This fixed measurement can be seen performed in Figure 7
- Now, I read ~7 V on Waveforms as V_{out} and I concluded my circuit was *finally* working.

Troubleshooting:

TS1: The LED next to the V+ output on the breakout board wasn't turning on, so I thought no voltage was going through the circuit, for whatever reason. I checked WaveForms, toggled the 'Master Enabler On/Off' button, but the LED was still off.

Then I figured maybe there was something wrong with the circuit, but when I just placed the power and gnd termainals across the shunt resistor, WaveForms shut off the output due to the overcurrent (which made sense since the shunt resistor had such low resistance), so there was a voltage output. I confirmed this with the DMM's probes against the terminals. The TA suggested maybe the 2 V I was outputting wasn't enough to turn on the LED, and when I changed the output on WaveForms to 5 V, the LED *did* turn on, so I concluded that the LED just needed more than 2 V to turn on.

TS2: Using the continuity setting on the DMM, I placed the red and black leads at various points on the circuit. Above and below my shunt resistor, R_S, they beeped, but they didn't beep when I placed one on one leg of the inductor and the other on the top leg of the diode. I realized I didn't even fully understand how my components were connected, and that the diode wasn't connected to anything. I fixed this by adding a wire on the breadboard connecting its top leg to the bottom leg of the inductor.

TS4:

a) I wasn't reading a stable voltage across the resistor, and the voltage I was reading was also around 3 V rather than the expected 7 V. Mr. Jones first set my scope source to Wavegen C1, which stabilized my reading, but kept it at 7 V.

b) Then the TA theorized that the square wave voltage I was applying to the gate terminal of the MOSFET was not enough to turn the MOSFET on, so we experimented with different amplitudes of the square wave. When this didn't change anything, he looked at how I was measuring V_{out} with the red and black probes of one cable connected to Scope 1+. He explained to me that I should be making a differential measurement, and I could do that either by setting Scope 1- to GND, or to use only the red probes from two BNC cables, one measuring the top leg of the load resistor and one measuring the bottom leg of the load resistor. This didn't do anything.

c) Finally, a friend looked at my circuit and pointed out I wasn't grounding the source of my MOSFET, which is import as when the MOSFET turns on, the current should be shorted to ground through the MOSFET's source terminal, in the process 'charging' the inductor. Without ground, it's unknown where the current was actually going, as I was still seeing a boost in the circuit (3 V), so the inductor was obviously still trying to maintain some higher current going through it when the MOSFET was open.

[33]:
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Image(filename = img_path("L4A_blank circuit setup.jpg"))
```

[33]:

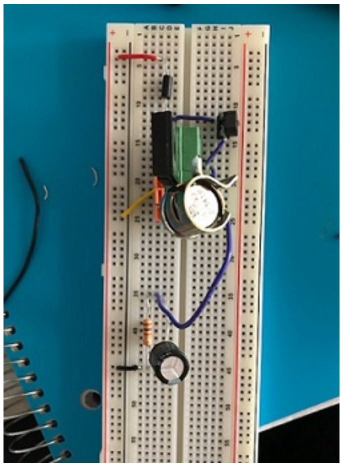

Figure 6: DC-DC boost circuit setup on breadboard

[34]:
```
Image(filename = img_path("L4A_circuit load measurement setup.jpg"))
```

[34]:

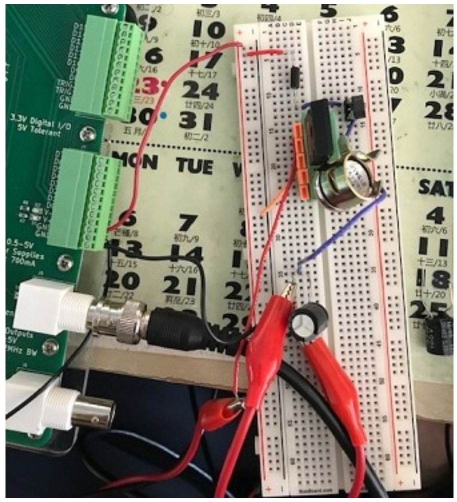

Figure 7: Differentially measuring V_{out} over R_L on the circuit

Results:

So while the input voltage to the circuit was 2 V, I measured $7.2 \pm \frac{0.05}{\sqrt{3}}$ V across R_L. The second decimal place frequently flickered, hence the division by $\sqrt{3}$.

Understanding: How the DC-DC boost circuit works is that it uses a staggered charging and discharging cycle for different components capable of storing energy/voltage to compound the net input voltage going through R_L.

When the MOSFET is closed, V_{in} supplies current throughout the circuit, to the capacitor and R_L, until the capacitor fully/mostly charges. Then the MOSFET opens and all the current shorts through the MOSFET to ground through R_S's very low resistance, resulting in a high current. When the MOSFET closes again, the inductor detects the significant increase in resistance (from R_L) and thus decrease in current, and compensates for that by acting as an additional voltage source in series with V_{in}, which we call V_L. After all, we have

$$V_L = L\frac{di}{dt},$$

where V_L is the voltage drop across the inductor. When new resistance is introduced in a circuit, $\frac{di}{dt}$ is negative, so V_L is negative, and actually increases the circuits input voltage. Thus, since R_L has additional voltage sources than just V_{in}'s 2 V, V_{out} will naturally be greater as well.

[35]:
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Image(filename = img_path("L4A_half working boost.png"))
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[35]:

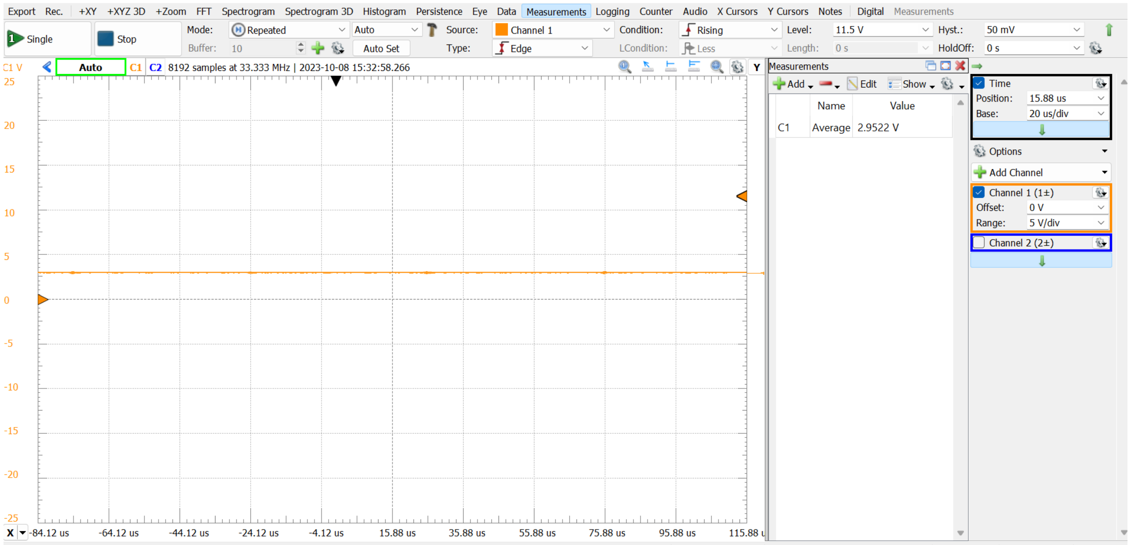

Figure 8: DC-DC Boost without grounding MOSFET's source

[36]:
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Image(filename = img_path("L4A_voltage over load.png"))
```

[36]:

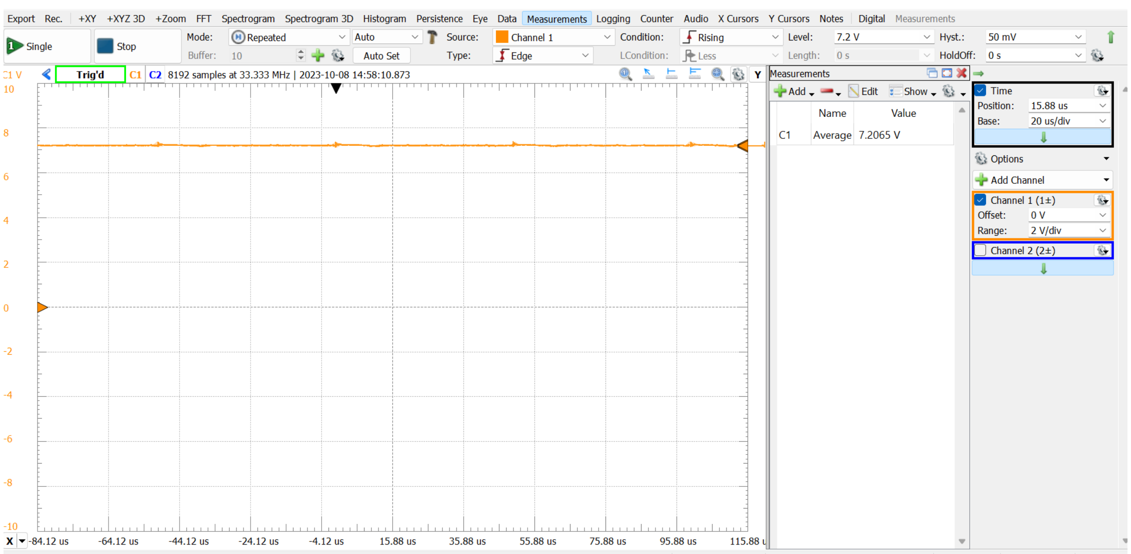

Figure 9: V_{out} measured across R_L for working DC-DC Boost circuit

4.2 Tasks

4.2.1 Task #1: Ripple

Problem: Determine the peak-to-peak ripple of V_{out} and how to reduce it.

Solution: Both capacitors and inductors resist rapid changes in voltage in a circuit due to their ability to store voltage and discharge it depending on a change in current. While capacitor are more 'reluctant' to change the voltage across them since it takes time to build up charge to change their voltage, inductors actively resist changes in current by acting as a voltage source to counteract these changes. Thus, while either work well at stabilizing voltages, an inductor would be better.

Procedure & Results:

However, since I don't have an extra inductor, I just added another 47 μF capacitor in parallel with the existing parallel to increase the capacitance of the circuit and stabilize the voltage across it and this R_L. How it works is shown in the diagram in Figure 10, and the actually setup on the breadboard is visible in Figure 11.

- I read the voltage across R_L using the same way in the other tasks
- I used Waveform's peak-to-peak measurement feature to measure the peak-to-peak fluctuation of V_L
- Then I added a second 47 μF capacitor in parallel with R_L and the original capacitor, and using the same voltage and time scale, I measured the peak to peak voltage fluctation again.

Indeed, the peak-to-peak voltage of the voltage across V_{out} decreased from ~0.3 V to ~0.2 V. We can see the original peak to peak variation of V_{out} measured in Figure 12 and the new peak to peak variation of V_{out} in Figure 13.

Understanding: The capacitor *was* effective in decreasing V_L's instability, although adding more capacitors would likely be even more effective. In the 'solution' section, I explained how the additional capacitor helped suppress rapid voltage changes; it takes time for the voltage across capacitors to change since they rely on the buildup of current. This effect on voltage extends to any parallel components we measure, which in this case is R_L.

As well, the fact that adding a second capacitor in parallel with the first had pretty much no effect on V_{out} suggests the capacitance of the capacitors don't actually affect the 'boost' of the circuit. This makes sense as no matter the capacitance of the capacitor, at most it can store 2 V. The capacitor is primarily responsible for discharging through R_L and maintaining its voltage when the MOSFET is open, while we've established that it's the inductor desire to maintain a higher current through the circuit that boosts V_{out} and charges the capacitor.

[37]:
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Image(filename = img_path("L4A_new capacitor circuit.jpg"))
```

[37]:

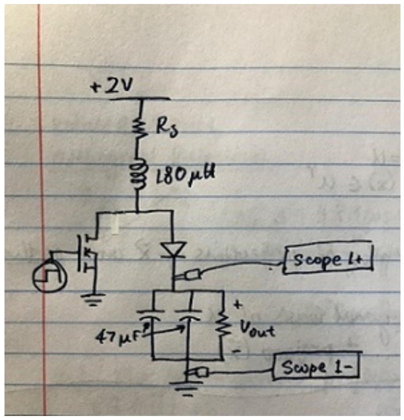

Figure 10: Circuit diagram for lowering peak-to-peak variations in V_{out}

[38]:
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Image(filename = img_path("L4A_two capacitor setup.jpg"))
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[38]:

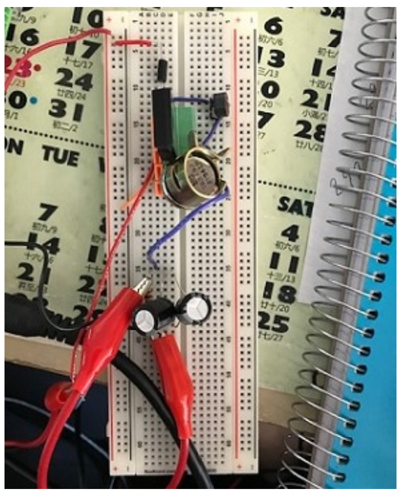

Figure 11: Measuring V_{out} with an additional capacitor in parallel

[39]:
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Image(filename = img_path("L4A_og p2p of vout.png"))
```

[39]:

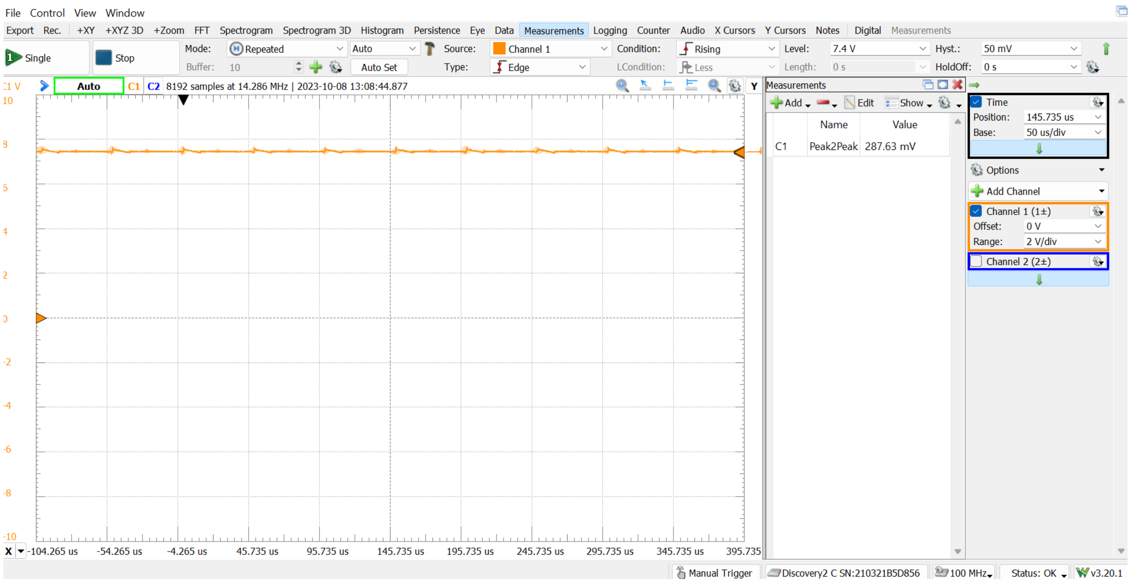

Figure 12: Initial average peak to peak variation of V_{out}

[40]:
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Image(filename = img_path("L4A_lower p2p of vout.png"))
```

[40]:

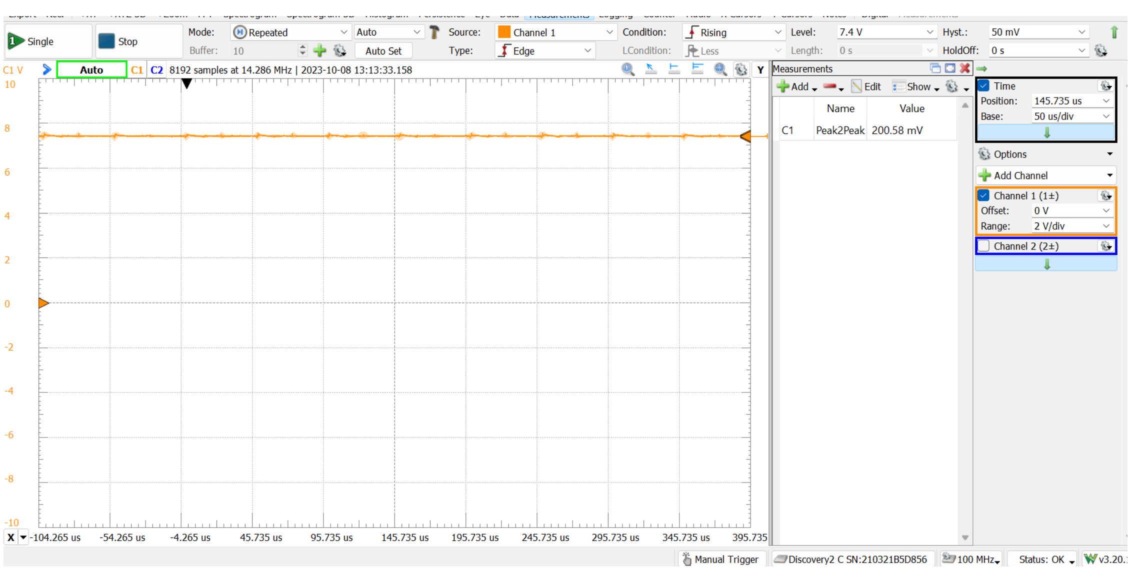

Figure 13: Average peak to peak variation of V_{out} with additional capacitor

4.2.2 Task #2: Internal Circuit Voltage Measurements

Procedure:

- I performed a differential measurement with the red probes of BNC cables attached to the breakout board's Scope 1+ and Scope 1- over several of the circuits components, ensuring Scope 1+'s probe measured the positive lead of components and vice versa with Scope 1-.

  - I did this across R_L
  - I did this across the diode
  - I did this across the inductor, but I had to connect Scope 1-'s lead to the drain terminal of MOSFET and Scope 1+'s lead to the negative end of the R_S, since the inductor had insufficient conductive surfaces above the breadboard
  - To measure the MOSFET's input voltage, I directly attached Scope 1+'s probe to the wire Wavegen 1's red probe was attached to (which was actually outputting the square wave signal), and connected Scope 1-'s probe to another ground wire connected to the AD2 breakout board. I found a spike downwards in the middle of the MOSFET's off period, which I experimented in TS5, but realized that it's just part of the behavior of the circuit.

- I stablized the readings by triggering and adjusting the 'Level' of the reading. I found that moving the cursor on the right up to the level the waveform on the scope was mostly located at helped stabilize the reading.
- Each time I read a measurement on WaveForm's scope and confirmed it was correct, I clicked the 'Add Reference' button on the right and the channel that was reading the voltages I wanted (in this case, Channel 1).
- When I had all the measurements, I offset them so it was easier to compare them with each other and against time, but made sure the scale for each was the same.

TS5: When I measured the input from the MOSFET/signal generator, I initially had a vaguely square wave shape but with a spike in the middle of the off-period. I moved the spring terminal connector block around and found that at different connections, the shape of the square wave changed. Interestingly, I found that if I tipped either side of its two rows of legs up, the oscilliscope's reading of the voltage going into the MOSFET's gate changed. While raising the right side of the connector block destablized the reading, adding 'squiggles' to the square wave. Raising the other side actaually stablized the reading, sharpening the square wave.

Then I just directly connected Scope 1+'s probe to the red lead connected to Wavegen 1 that was outputting the square wave signal, which I then unconnected from the MOSFET. This game me a stable, sharp, square wave, and I realized that it was the connection with the MOSFET that added the spikes to my readings.

Results: Our different voltage drop measurements are visible in Figure 14, with a legend of which graphs are which components' voltage drops on the side.

Understandings:

If all our voltage drops were in phase, we could base the behaviour of the inductor, diode, and R_L off the behaviour, or duty cycle, of the input signal going into the MOSFET. However, with some reasoning, I believe the voltage comparisons in Figure 14 are off by a phase shift. This was confirmed by Mr. Jones in class, who explained that when we triggered the waveform for each voltage reading, we changed the time when the scope 'refreshed' the readins. However, qualitatively, each graph should still be correct, just not acting at the same time as the other graphs.

MOSFET: The voltage over the MOSFET is working as expected in the shape of the square wave. However, for some reason we see a downards spike in the middle of the MOSFET's off period. I'm not sure entirely what causes this spike, but it likely has something to do with the inductor's response to the MOSFET's change in voltage. We will go over this in class next week so I'll figure it out then.

Inductor: The inductor's voltage seems in phase with the MOSFET's.

When the MOSFET opens, it shorts the negative leg of the inductor straight to ground, and the only resistance in that circuit is R_S, which is very low. To maintain the low current the inductor was used to when the MOSFET was closed and R_L meant the resistance of the circuit was much larger, the inductor acts as a large forward drop, so the net input voltage into the circuit is lowered. This is why we see the spike in the inductor voltage drop as soon as the MOSFET's voltage turns on.

Interestingly, we see another sections in the inductor's voltage variation beyond just the changes when the MOSFET opens and closes. Halfway through when the MOSFET is off and the inductor is connected to the diode, R_L, and the capacitors, we see the inductor voltage drop to a negative value. Before this point, the inductor voltage stayed the same through the MOSFET closing. This should be because the voltage difference between the bottom of the inductor and the top plate of the capacitors isn't beyond the diode's forward voltage, so the diode doesn't conduct and the inductor actually doesn't 'see' the additional resistance R_L introduces and feel the need to compensate. Once the diode does conduct though, the inductor's voltage drop immediately turns negative, which we expect.

Diode: The diode's voltage measurement is likely off from the MOSFET's by a phase shift in time. When the MOSFET opens, it acts as a short-circuit to ground. The positive leg of the diode is connected to this short-circuit to ground, so it is effectively grounded. However, the negative leg of the diode is connected to the positive plate of the capacitor on the right side of the circuit, which starts to discharge, so we end up in a situation where the negative end of the diode is at a higher voltage than its positive end. This gives us a negative voltage, even though Figure 14 shows us a spike in positive voltage over the diode when the MOSFET turns on.

V_{out}: The voltage over R_L is mostly stable at ~7 V. There are occasionally small points of turbulence when the MOSFET turns on, which can likely be explained by its primary source switching from V_{in} and the inductor to the capacitor. It's not clear exactly why this creates a voltage fluctuation, though.

[41]:
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Image(filename = img_path("L4A_correct voltage comparisons.png"))
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[41]:

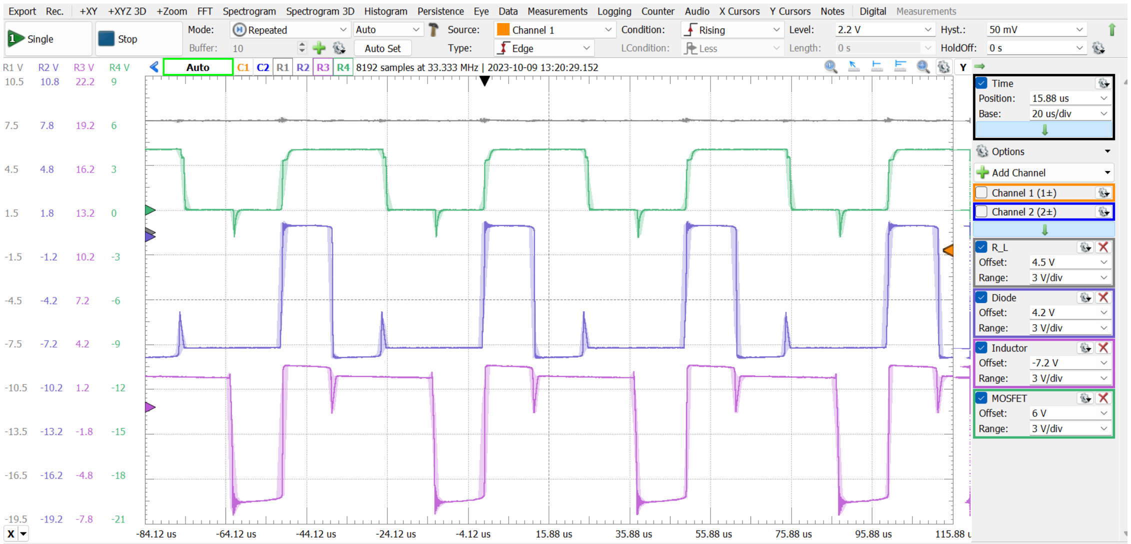

Figure 14: Voltage drop comparisons (in order, from top to bottom) between R_L (V_{out}), diode, inductor, and MOSFET

4.2.3 Task #3: Power Efficiency

- We know the formula for efficiency is $\frac{P_{out}}{P_{in}}$, so we must determine a way to get these values

Procedure & Measurements:

- For P_{in}, I used V_{in} as 2 V, which was the voltage the AD2 breakbout board inputted into the circuit, and I_{in} as the total current going through the circuit. I measured I_{in} using the voltage drop across R_S and the value of R_S, 0.1 Ω, since we know $I = \frac{V}{R}$.
  - I performed this differential measurement with the red probes from the BNC cables, with the one connected to Scope 1+ above R_S and the one connected to Scope 1- to the lower leg R_S.
  - I used Waveform's 'Average' measurement function to determine the voltage across the resistor, which the scope initially read as ~40 mV,
  - Then I zoomed in as far as I could with the graph still (somewhat) stable, and Waveforms settled on $7.2 \pm \frac{0.05}{\sqrt{3}} mV$, but the last value flickered a lot. This measurement can be seen in Figure 16.
- To find P_{out}, I just used V_{out} over R_L and R_L, since the formula $P = IV = \frac{V^2}{R} = I^2R$ tells us we can use any two of the voltage, current, and resistance over a branch to find its power.
  - I measured R_L for further accuracy with the DMM and the legs of R_L against my hand.
  - I measured $0.994 \pm \frac{0.0005}{\sqrt{6}}\ k\Omega$.

[42]:
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Image(filename = img_path("L4A_shunt resistor measurement setup.jpg"))
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[42]:

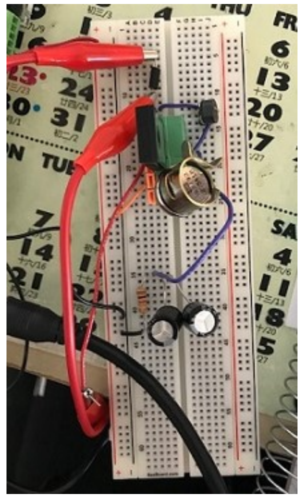

Figure 15: Measuring voltage over shunt resistance for input current of circuit

[43]:
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Image(filename = img_path("L4A_voltage over shunt resistor.png"))
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[43]:

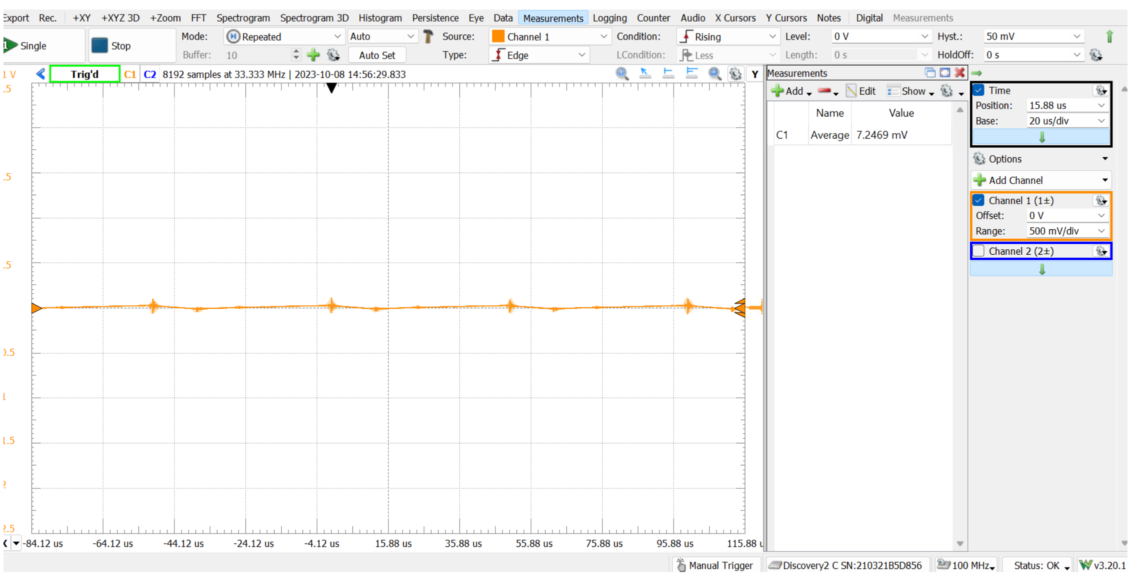

Figure 16: Voltage drop over shunt resistor R_S

Results & Calculations:

We calculate efficiency, η, as

$$\eta = \frac{P_{out}}{P_{in}} \times 100\%.$$

We have

$$P_{in} = I \times V_{in} = \frac{V_S}{R_S} \times V_{in}.$$

Plugging in our values, we get

$$P_{in} = \frac{0.0072 \pm \frac{0.00005}{\sqrt{3}} V}{0.1\ \Omega} \times 2\ V,$$

which evaluates (using an online uncertainty propagation calculator: https://uncertaintycalculator.com/) to

$$P_{in} = 0.1440 \pm 0.0006\ W.$$

We calculate P_{out} with the same formula rearranged, giving us

$$P_{out} = \frac{V_{out}^2}{R_L},$$

which we plug in our values to get

$$P_{out} = \frac{(7.2 \pm \frac{0.05}{\sqrt{3}}\ V)^2}{0.994 \pm \frac{0.0005}{\sqrt{3}} k\Omega},$$

which evaluates (and using an online uncertainty propagation calculator: https://uncertaintycalculator.com/) to

$$0.0522 \pm 0.0004\ W.$$

Going back to our original equation, we get

$$\eta = \frac{0.0522 \pm 0.0004\ W}{0.1440 \pm 0.0006\ W} \times 100\%,$$

which finally evaluates to

$$\eta = 36.3 \pm 0.3\%.$$

Understanding: An efficiency of 36.3% is low, but plausible. If our efficiency was over 100%, then I would know something is wrong. Power in the circuit can be lost anywhere from the resistance of other components or wires to the efficiency of the capacitors and inductor, which ideally should completely discharge all the energy it stores, but will likely lose some in the process of charging or discharging. Transforming energy (which the inductor and capacitor do via the magnetic and electric fields, respectively) is a very easy way to lose energy in the process.

This result initially surprised me as I naively assumed since $V_{out} > V_{in}$, P_{out} would also be greater than P_{in}, but in retrospect that doesn't make sense. Power has to come from somewhere, and usually is lost somewhere along a circuit rather than mysteriously gained. This result satisfies the conservation of energy, which we would expect. Even if $V_{out} > V_{in}$, our input power is still greater than the output power.

4.2.4 Task #4: Load Efffects

Procedure:

- I switch out the 1 $k\Omega$ load resistor for a 5 $k\Omega$ resistor from home
- Using the red probes from the Scope 1+ and Scope 1- BNC cables, I perform a differential voltage measurement over the resistor with the Scope 1+'s red probe above the resistor and the Scope 1-'s red probe below the probe (at ground), just like how I did it in the Task #1.

[44]:
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Image(filename = img_path("L4A_changed load setup.jpg"))
```

[44]:

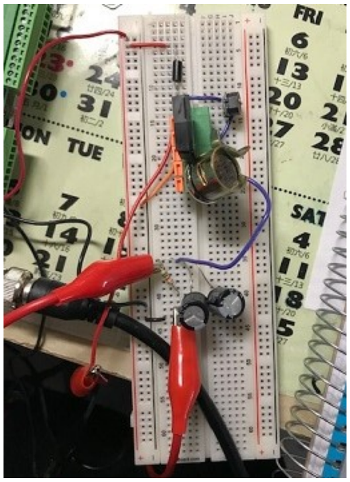

Figure 17: Measuring V_{out} over 5 $k\Omega$ resistor

Results:

Measuring the voltage across the 5 $k\Omega$ resistor, I found that V_{out} was higher than when I used a 1 $k\Omega$ resistor, at around 11.5 V

But when I decrease the symmetry of the signal generator controlling the MOSFET from 50% to 10%, V_{out} rapidly decreased to ~3 V.

Understanding:

Regarding the first part, when we changed the resistance of R_L to 5 $k\Omega$, V_{out} increased significantly to ~11 V rather than ~7 V

It makes sense that when the 'on' period of the MOSFET decreases, so does the effect of the circuit's boost. The MOSFET spends more time acting as an open-circuit and less time as a short circuit, which means V_{in} and the inductor spend more time going through/discharging R_L rather than 'charging' the inductor. Then, the MOSFET spends less time as a short-circuit, so the inductor likely won't have enough time to 'get used' to the decreased resistance of the new system. Since the inductor wanting to maintain the increased current in this state once the MOSFET closes again is the most significant component in 'boosting' V_{out}. It's possible the inductor is still acting as a voltage drop over the short-circuit in Figure 2 to counteract the newly decreased resistance and increasing current before the MOSFET closes again and the current (which hasn't had enough time to increase despite the inductor's best efforts) starts to decrease again.

[45]:
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Image(filename = img_path("L4A_changed load initial.png"))
```

[45]:

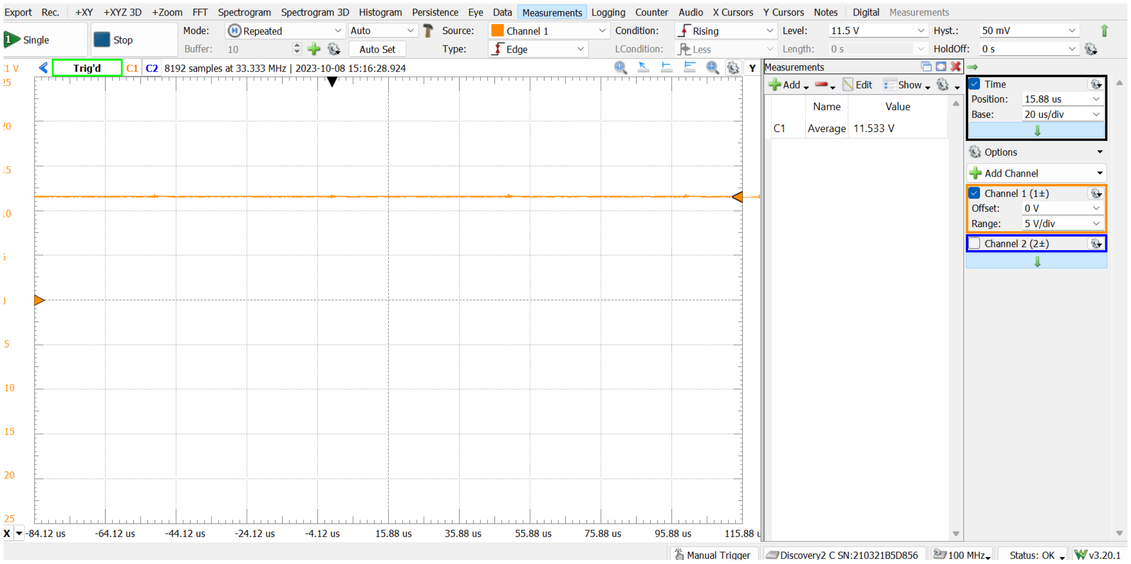

FIgure 18: V_{out} over 5 $k\Omega$ R_L

[46]:
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Image(filename = img_path("L4A_changed load changed symmetry.png"))
```

[46]:

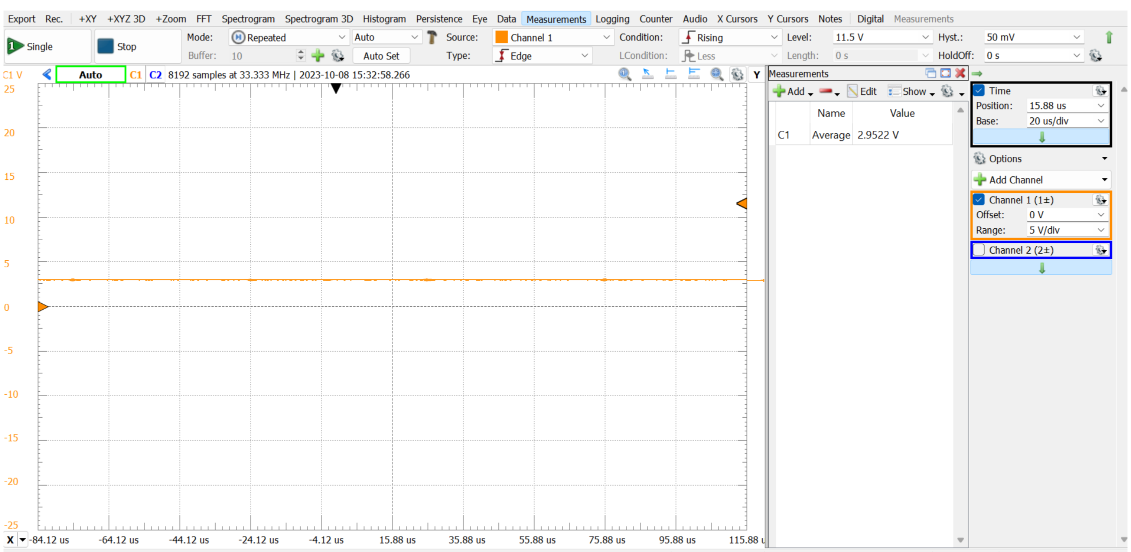

Figure 19: V_{out} over 5 $k\Omega$ resistor when duty cycle of signal controlling MOSFET is changed to 10% instead of 50%

5 Conclusion

5.0.1 Circuit Construction

In the first part of the lab, we actually had to construct the DC-DC boost circuit in Figure 1. At the start, we ran into a few roadblocks with how to connect the MOSFET and diode's thicker legs into the breadboard, but learned how to use the materials around us - most notably the spring connector - to help us construct the circuit.

I was also taught a lesson in making sure to read components datasheets, since I assumed the middle leg of the MOSFET was, similarly to the VN2106 MOSFET we used in Lab 3, the gate, whereas the gate terminal was actually the top leg.

I spent a long time debugging the circuit, but in the end, what blocked me was basic understanding of how the DC-DC boost circuit worked. I struggled translating the abstract circuit diagram in Figure 1 to an actual circuit on the breadboard and didn't realize I needed to use a wire to connect the inductor and diode instead of expecting the connector block to connect them for me. As well, I forgot to ground the source terminal of the MOSFET.

5.0.2 Task 1:

Here, I applied my understanding of how capacitors work to lower the instability of V_{out}. Interestingly, I found that adding a capacitor in parallel didn't affect the value of V_{out} at all, which confirmed to me that it was only the inductor that was really responsible for the 'boost' to V_{out}'s 7 V compared to V_{in}'s 2 V, while the capacitor was responsible for maintaing this boost while R_L is unconnected to the rest of the circuit (when the MOSFET opens).

5.0.3 Task 2:

In Task 2, we had a chance to actually confirm and understand the operation of our circuit via a piecewise analysis of the voltage drop behavior of different circuit components over time. I measured the voltage drops across R_L (basically just V_{out}, the diode, inductor, and MOSFET.

I based my analyses on the voltage drops of the other components over that of the MOSFET's, since the MOSFET turning on and off and what controls the circuit. In this process, I realized I conducted my experiemtn wrong in that my triggering each subsequent voltage measurement resulted in a time phase shift from each other. However, I could still quantitatively analyse each component's voltage graph.

I realized that the circuit didn't work exactly how I expected it to as the behaviour of components like the diode actually affected components like the inductor.

We leave the spike in the middle of the MOSFET's off period as a mystery left to be explained in class next week.

5.0.4 Task 3:

Here, we experimented with the efficiency of our circuit by comparing P_{in} against P_{out}. We measured the voltage over R_S, the shunt resistor, to determine the net current throughout the circuit, and we used this value and our input voltage to calculate P_{in}. We used V_{out} and R_L to calculate P_{out}.

We found that even though the circuit was a ‘boost’, and $V_{out} > V_{in}$, the power V_{in} was supplying was still significantly larger than the power we received through V_{out}. I was initially surprised by this, but thinking of it, realized it’s not possible for P_{out} to be greater than P_{in} in an ineffective (mostly) closed system like the circuit. Power can be lost via transformations to other forms like heat, but it can’t be gained out of nowhere, hence satisfying the conservation of energy. We still had a relatively low efficiency at around 36%, which makes sense, as our equipment isn’t exactly ideal or even close to it, leading to quite a bit of power loss throughout the circuit.

I concluded that most of the power loss probably occured in the inductor and capacitor, which are resposible for actively transforming energy.

5.0.5 Task 4:

In Task 4, we examined the behaviour of the circuit as we changed several parameters, namely the resistance of our load, R_L, and the duty cycle of the input signal controlling the MOSFET.

We found that the larger R_L was, the larger V_{out} was, which makes sense, as the voltage drop over a resistor is proportional to the resistor’s resistance.

However, when we decreased the duty cycle of the signal controlling the MOSFET from 50% to 10%, we found that the V_{out} drastically decreased from ~12 V to ~3 V. This actually made sense, as when the MOSFET is on, the current through the inductor is very large, and its in this process of trying to maintain this large current that the inductor boosts the circuit when the MOSFET is closed. But when we decrease this ‘charging’ time and increase the time the inductor ‘discharges’ through R_L, we naturally end up with a lower boost.

[25]:
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%%capture
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↪texlive-latex-recommended texlive-plain-generic pandoc
```

[26]:
```
# @title
# Capture to prevent lots of output... Remove this if troubleshooting!
%%capture

pdf_file_name = file_name.split('.')[0]+'.pdf'  # Same as file_name with .ipynb␣
↪changed to .pdf
!rm $file_name
!rm $pdf_file_name

import os

full_path = os.path.join(path, file_name)
!cp  "$full_path" ./
```

```
!jupyter nbconvert "$file_name" --to pdf
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