Nora Shao_Lab1A_Final

September 16, 2023

[35]:
```python
# @title
from IPython.display import Image
import numpy as np
import pandas as pd
import matplotlib.pyplot as plt
import pandas as pd
import os

from google.colab import drive
drive.mount('/content/drive')

dir_path = 'UBC ENPH Y2/ENPH259/Lab1'  # change this to your data directory␣
 ↪path - e.g. ENPH259/Lab1
ddir = f'/content/drive/MyDrive/{dir_path}'

print(os.listdir(ddir))
```

```
Drive already mounted at /content/drive; to attempt to forcibly remount, call
drive.mount("/content/drive", force_remount=True).
['Lab1Template.ipynb', 'Screenshot 2023-09-14 234012.png', 'IMG_3112.jpg',
'Screenshot 2023-09-15 001316.jpg', 'IMG_3113.jpg', 'IMG_3114.jpg', 'Screenshot
2023-09-15 092713.png', 'Screenshot 2023-09-15 094457.png', 'Square wave
measurements.png', 'Square wave period.png', 'Nora Shao_Lab1A_Final.ipynb',
'Period tick marks.png', 'prelab actual measurements.jpg', 'Case 2 circuit.jpg',
'Case 1 circuit.jpg', 'Case 2 setup.jpg', 'L1A_Actual Square Wave Data.csv',
'good load setup.jpg', 'good load circuit.jpg', 'bad load setup.jpg', 'voltage
divider.jpg', 'bad load circuit.jpg']
```

#Lab #1: Introduction to Laboratory Electronics

Name: Nora Shao

Partners at Table: [redacted]

#1. Experiment Description and Prelab ##1.1: Description

1.2 Prelab Problem: Design a voltage divider circuit to reduce the +5 V DC (V_{in}) from the power supply to approximately +3.3 V (V_{out}) using 3 resistors of the SAME value.

1.3 Prelab Problem: Fill in tables in Figure 3 with Figure 1 as a reference circuit.

1.3 Prelab Problem: Take a screenshot of the WaveForms setup.

##**1.2 Prelab: Voltage Divider** Since in a series circuit,

$$V_{drop} = IR = V_{in} \times \frac{R}{R_{net}},$$

we have

$$V_{out} = \frac{R_2 + R_3}{R_1 + R_2 + R_3} \times V_{in}.$$

Solution: See Figure 2, where R1 = R2 = R3.

##**1.3 Prelab: AC/DC/GND**

Solution: See Figure 3 for direct answers. Justifications are as follows.

Case #1:

1. A:B - We solve as a usual circuit with $V_{\text{drop}} = IR$, and $I = \frac{5v+2v}{3k\Omega}$, so $V_{drop} = \frac{2}{3} \times 7v \approx 4.7v$.
2. C:A - The voltmeter just traverses the entire circuit, but with the polarity of the probes reversed relative to the signs of the circuit's voltage, so we get negative times the circuit's voltage.
3. B:C - We solve as a usual circuit with $V_{\text{drop}} = IR$, and $I = \frac{5v+2v}{3k\Omega}$, so $V_{drop} = \frac{1}{3} \times 7v \approx 2.3v$.
4. B:A - The same situation in #1 but with reversed polarities, so negative, thus, we get -4.7 v.

Case #2: 1. A:B -First, since A is grounded, we have a short from 5v to GND there. However, the rest of the circuit now goes from ground to -2v, effectively a 2v-potential difference. Calculating as a normal circuit with $V_{in} = 2v$, we have $V_{drop} = IR = \frac{2v}{3k\Omega} \times 2k\Omega \approx 1.3v$. But because of the short at one of the jumpers, a multimeter will still show 0v. 2. C:A - First, there is a short from C's ground to the -2v, but we ignore that for the top half of the circuit. Since we grounded C, instead of +5 v to -2 v as the potential, we have +5v to 0v, which is just +5v. 3. B:C - Since we grounded B, the rest of the circuit is effectively cut off, so we just have a 0v to -2v circuit. The voltmeter spans one end of V_{in} to V_{out}, so 2v is just the measured potential difference. But because of the short at one of the jumpers, a multimeter will still show 0v. 4. B:A - Grounding B separates the +5v input and -2v input as parallel rather than series wires, so we just have a ground to +5v connection from B to A. Thus, -5v.

##**1.4 Prelab: Analog Discovery 2**

See Figure 4.

[36]:
```
Image(filename='drive/My Drive/UBC ENPH Y2/ENPH259/Lab1/Screenshot 2023-09-15
↪001316.jpg')
```

[36]:

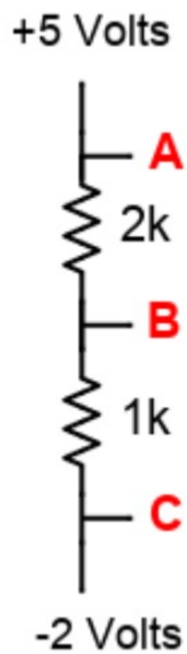


Figure 1: Prelab 1.3 Reference Circuit Diagram

[37]:
```
Image(filename='drive/My Drive/UBC ENPH Y2/ENPH259/Lab1/IMG_3113.jpg')
#print("Figure 1. Voltage divider circuit for 1.2 Prelab")
```

[37]:

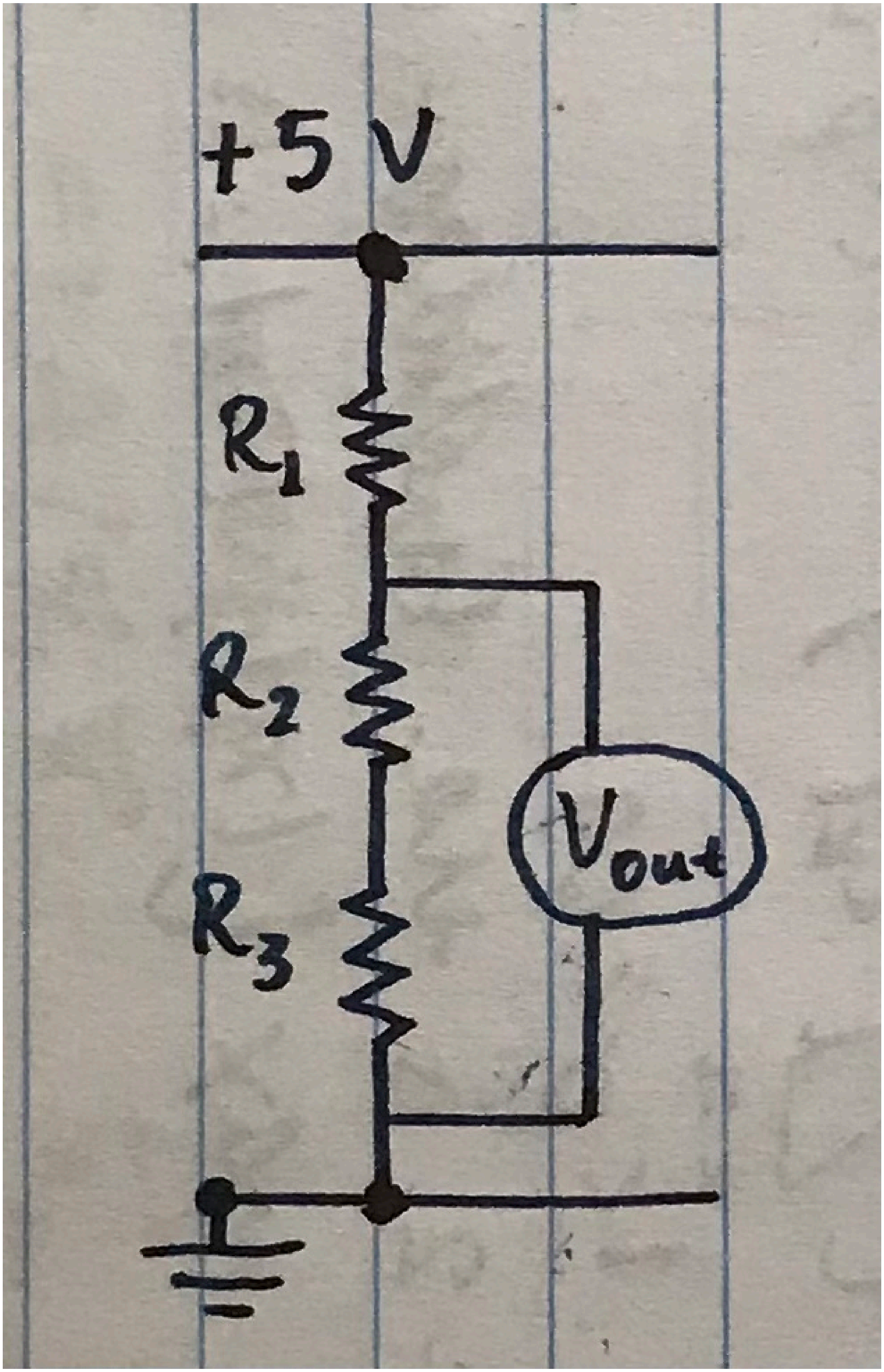
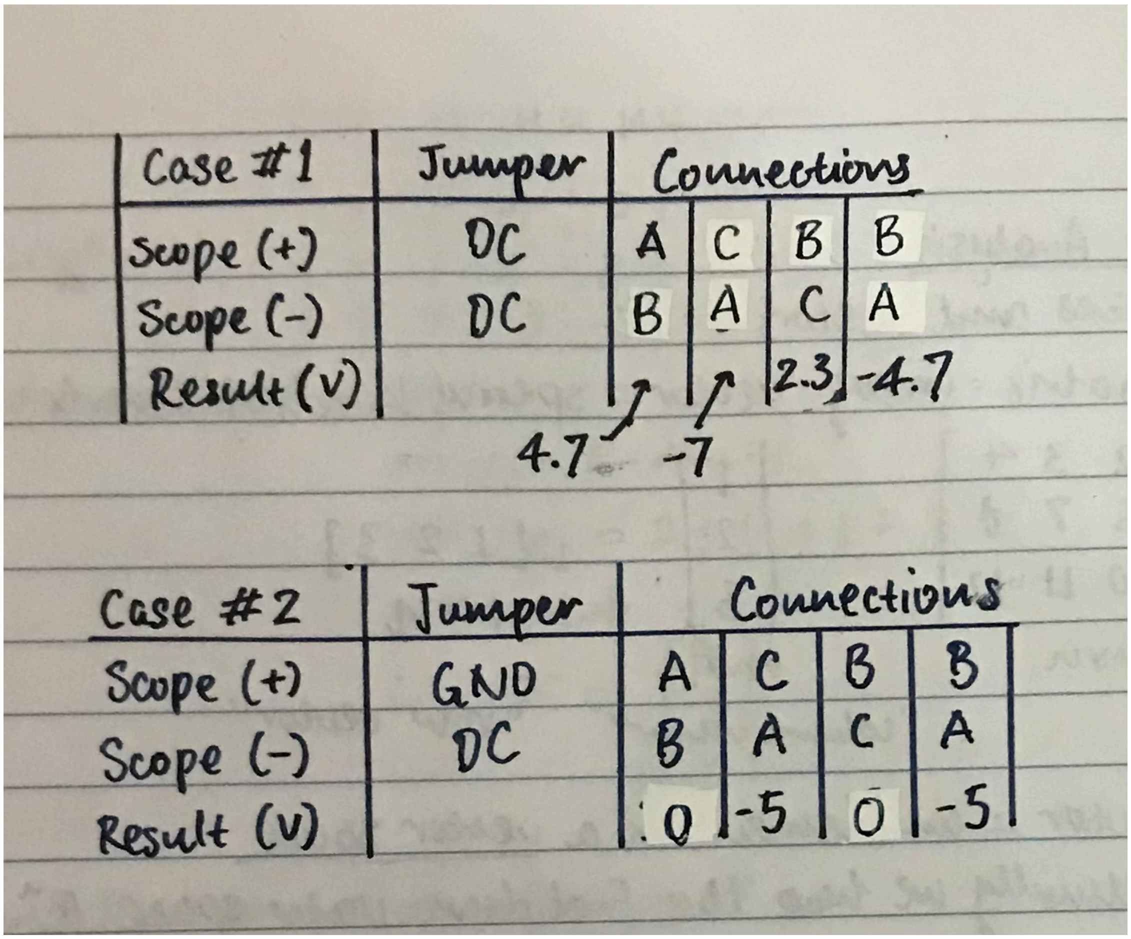

+5 V
R1
R2
R3
Vout

Figure 3: Voltage divider circuit for 1.2 Prelab

[38]:
```python
Image(filename='drive/My Drive/UBC ENPH Y2/ENPH259/Lab1/IMG_3114.jpg')
```

[38]:



Case #1	Jumper	Connections			
Scope (+)	DC	A	C	B	B
Scope (-)	DC	B	A	C	A
Result (V)		4.7	-7	2.3	-4.7

Case #2	Jumper	Connections			
Scope (+)	GND	A	C	B	B
Scope (-)	DC	B	A	C	A
Result (V)		0	-5	0	-5

Figure 3: Prelab 1.3 - Circuit Exercises

[39]:
```python
Image(filename='drive/My Drive/UBC ENPH Y2/ENPH259/Lab1/Screenshot 2023-09-14␣
↪234012.png')
#print("Figure 3. WaveForms")
```

[39]:

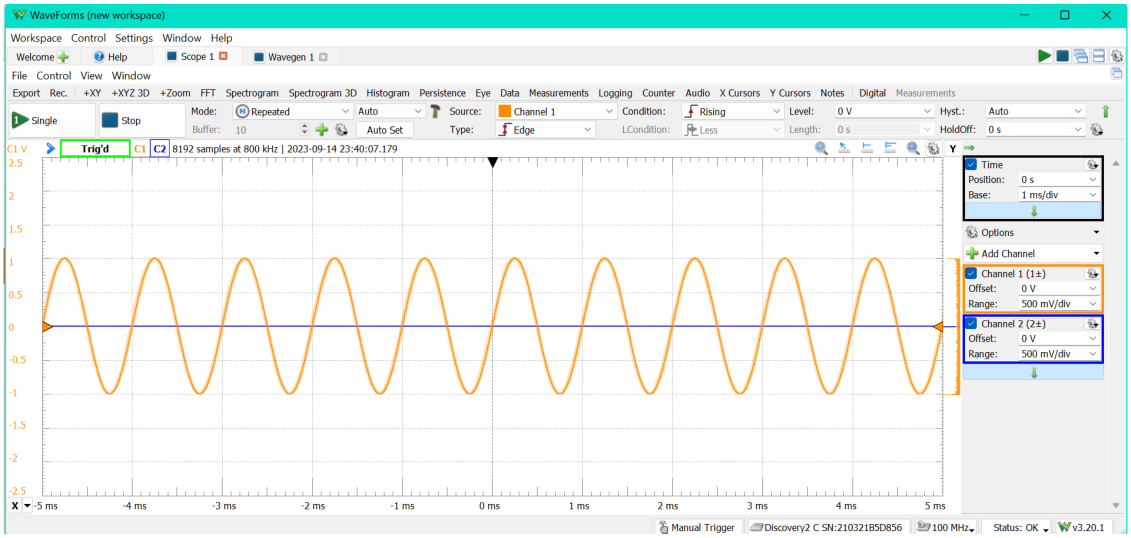


Figure 4: Prelab 1.4 - WaveForms screenshot

[40]:
```
# @title
# prelab13 = pd.DataFrame({'Case #1': 'Scope (+)', 'Scope (-)', 'Result'})
# prelab13 = pd.concat([prelab1.3, pd.DataFrame(np.random.randn(10, 4),␣
↪columns={'Jumper', 'Connections'})],
#                    axis=1)


# prelab13 = pd.DataFrame({
#     "Jumper": ["DC", "DC", ""],
#     "Connections": ['|A|B|C|D|', '|A|B|C|D|', '|A|B|C|D|'],

# })
# prelab13.style \
#   .format(precision=3, thousands=".", decimal=",") \
#   .format_index(str.upper, axis=1) \
#   .relabel_index([ 'Scope (+)', 'Scope (-)', 'Result'], axis=0)
```

#2. Oscilloscope and AWG

##2.1: Task #1: 50 KHz SineWave

###Set-up I plugged the pins of the AD2 board into the breakout board, then a female-to-female cable from the Scope 1+ output to the Wavegen 1 input. Then you plug the the AD2 into your computer via the USB-B cord.

On the WaveForms software, we output a 50kHz wave with an amplitude of 1 V (which translates to 2V peak-to-peak), and open the Scope to see the output for Channel 1.

###Amplitude To measure the amplitude, we use the Y cursors from peak-to-peak, determine their difference, then divide by 2. We increase the resolution of the scope so the measurement is more accurate.

Figure 6 shows the cursors which gives a peak-to-peak voltage of 1.9861 +/- 0.00005 V. Accounting for how as a single analog measurement, we divide the raw uncertainty by $\sqrt{6}$, to get 1.9861 $/pm$ (±)* 0.00002 v.

Corrections: - The screenshot in Figure 6 was taken before I zoomed in further on the scope for more accuracy. - Also, since manually moving the cursors makes it an analog measurement depending on the scope graph's resolution rather than the decimal places my previous error statement was made on. Since the major tick marks are 25 mV apart, and there are 10 minor tick marks, we have an uncertainty of 2.5 mV. Dividing by $\sqrt{6}$, we get 1.02 mV. Thus, the proper reading for peak-to-peak amplitude is 1.9861 $\pm$ 0.001 V.

*LaTeX Typo.

###Period To measure the period: - we use the X cursors, setting up one at the trough of the wave, and the other at the next trough - Zoom in as much as possible to ensure you're getting the very bottom of the trough. As we are eyeing this, this brings additional error potential. - Take the distance between the two cursors, which gives us 20.006 μs. The tick marks are 1.1 μs apart, so we take half of that, 0.55 μs as our uncertainty. - Since it's a single analog measurement, we divide by $\sqrt{6}$ to get 20 $\pm$ 0.2 μs

###Quick Measurements - Using the Measurements tab, we add the peak-to-peak voltage and period measurement and include the mean. - This was done just by selecting the predefined measurements - The peak-to-peak voltage shows 1.99 v with the 3rd and 4th decimal places flickering between 1 and 0. The mean is wildly off at around 1.5 v, which could be atributed to the flickering of the scope, meaning there are 0v values in there lowering the mean p2p voltage being read. Thus, we have 1.991 $\pm$0.001 v due to the flickering. As a digital measurement, the uncertainty should be divided by $\sqrt{3}$, so we actually get 1.991 $\pm$ 0.0006 V. - The period is stable at 20.000 μs with the uncertainty in the last digit. Dividing by $\sqrt{3}$, we get a reading of 20.000 $\pm$ 0.0005 μs.

(Describe the steps you took to setup your AD2 and the connections you made with the pins. Sketch this setup.)

(Describe how you took measurements and their results)

(Note any difficulties or troubles and how they were corrected)

##**2.2 Task #2: 200 KHz Square Wave**

###Amplitude - Set the amplitude of the square wave to 2.5 V, since that is half of 0 to 5 V. On symmetry, I selected 10%, which represented the 10% duty cycle. I eyed the input wave to ensure these parameters were set correctly. - I zoomed in as much as possible while noise was minimized, so the top and bottom of the square wave were stable enough to place the Y cursors - If I zoomed in too much, the graph would start to flicker wildly, but zooming out and setting the trigger level to a voltage significantly lower than the amplitude stabilized it. - Measured 4.9834 V, but the resolution of the ticks are 0.002 V, so we have 4.983 +/- 0.001 V. Dividing by $\sqrt{6}$ since the cursors make it an analog measurement, we get 4.983 $\pm$ 0.0006 V. - The voltage resolution and reading can be seen in Figure 7

###Period - Used X cursors to find the period, and we also zoomed in until the signal was too unstable to properly measure with the cursors.

See Figure 13, for the data plot of the output square wave - I had to manually go into the csv and delete the header rows so just the data would be in the csv.

(Describe you adjusted the AWG to produce desired output)

(Display plot within this notebook)

(Note any difficulties or troubles and how they were corrected)

##2.3 Task #3: Differential vs GND references

###Set-up Differential: - I set up the circuit on the breadboard shown in Figure 9 and with the setup shown in Figure 11. But since Figure 11 shows case 2's setup, for case 1, the Scope (+) output is just set to DC instead of GND - On the breadboard, I connected V+ (positive supply) and V- (negative supply) as power and ground - On WaveForms, I enabled the Supplies output and configured voltage input to V+ as +5 V and V- as -2V. - I had an issue where the positive supply was one (the light beside the connector was on), but the negative one wasn't, and I tried tightening the connector, but it turns out the issue was that the AD2 had a loose connection with the breakout board.

GND - I set up the circuit on the breadboard shown in Figure 9 and with the setup shown in Figure 11. - On WaveForms, I enabled the Supplies output and configured voltage input to V+ as +5 V and V- as -2V. - Scope (+) is set to GND now, so it's grounded - Scope (-) is just a DC probe that reads voltage

Results - See Figure 12 for the raw results the AD2 reported - Uncertainties (Case #1): - A-B measurement: Since the AD2 is 14-bit and it reported 4.7 V, we have an uncertainty of $4.7 \times \frac{1}{2^{14}} \times \frac{1}{\sqrt{3}}$ V, which gives us a reading of 4.7 ± 0.0002 V. Same idea goes for the other measurements - C-A: -6.968 V $\pm$ (-6.968) $\times \frac{1}{2^{14}} \times \frac{1}{\sqrt{3}}$ V, or -6.968 $\pm$ (-6.968) $\times$ 0.0002 V. - B-C: 2.36 V $\pm$ (2.36) $\times \frac{1}{2^{14}} \times \frac{1}{\sqrt{3}}$ V $= 2.36 \pm 0.00008$ V. - B-A: This is just the A-B measurement with reversed polarity, so we have -4.7 $\pm$ 0.0002 V - All the differential measurements were what I calculated in the pre-lab

Conceptual Question: The main difference between Case #1 and Case #2 is that the Scope (+) is grounded in Case #2. While the two probes just act as a normal voltmeter in Case #1, in Case #2, the 'grounding' of one of the probe effectively leads to a floating voltage point at the location of the grounding probe, so the probe reading is effectively just the voltage at the Scope (-) probe, not the voltage difference. The breakout board doesn't actually ground the probe. - I thought that the Scope (+) probe would actually act as a GND which the power supply would short to when the probe was placed at A or C (directly adjacent to a power supply with no resistor load), so the AD2 would just read 0V. It turns out the 'ground' probe just makes the supplies act as a floating voltage, so WaveForm reads the voltage *at* Scope (-) rather than the voltage between Scope (+) and Scope (-).

[41]:
```
Image(filename='drive/My Drive/UBC ENPH Y2/ENPH259/Lab1/Screenshot 2023-09-15␣
↪092713.png')
```

[41]:

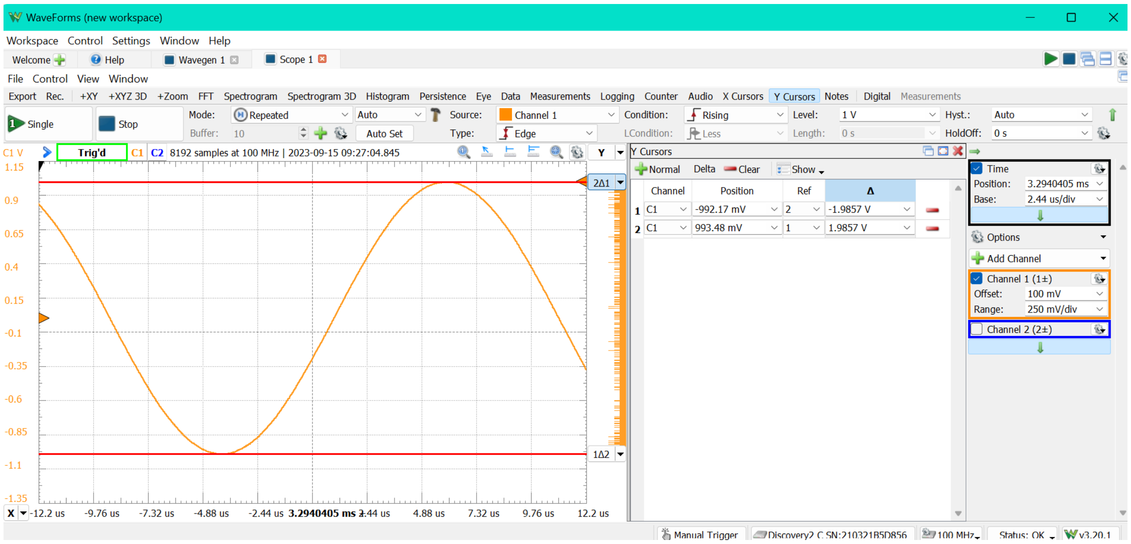


Figure 5: Measuring Peak-to-Peak Voltage with Y Cursors

[42]:
```
Image(filename='drive/My Drive/UBC ENPH Y2/ENPH259/Lab1/Screenshot 2023-09-15␣
↪094457.png')
```

[42]:

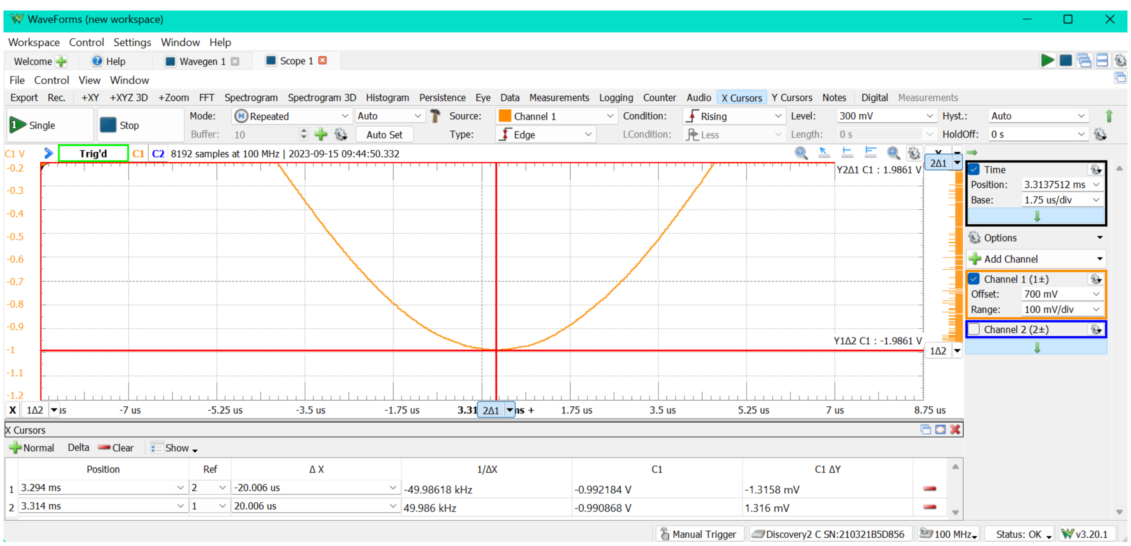


Figure 6: Measuring Period of Output With X Cursors

[43]:
```
Image(filename = 'drive/My Drive/UBC ENPH Y2/ENPH259/Lab1/Square wave␣
↪measurements.png')
```

[43]:

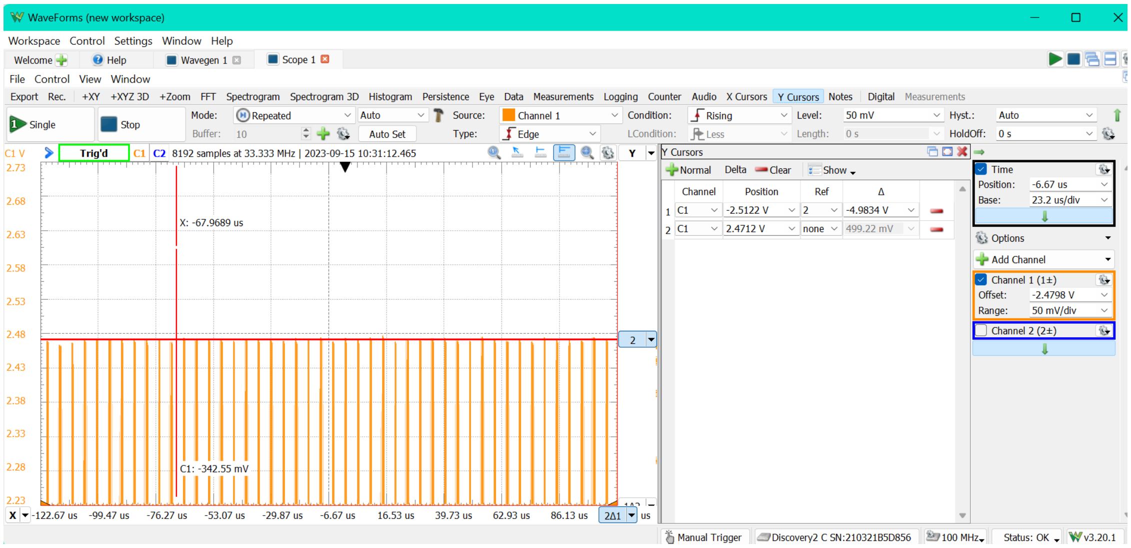


Figure 7: Measuring the Peak to Peak Amplitude of Square Wave Output

[44]:
```
Image(filename = 'drive/My Drive/UBC ENPH Y2/ENPH259/Lab1/Square wave period.
↪png')
```

[44]:

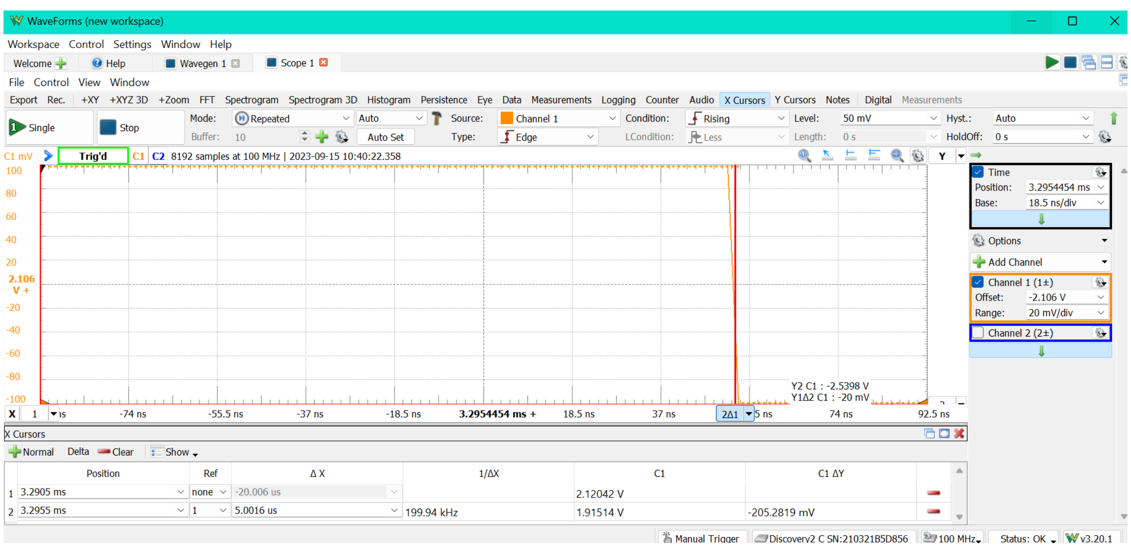


Figure 8: Measuring Period of Square Wave Output

[45]:
```
Image(filename = 'drive/My Drive/UBC ENPH Y2/ENPH259/Lab1/Case 1 circuit.jpg')
```

[45]:

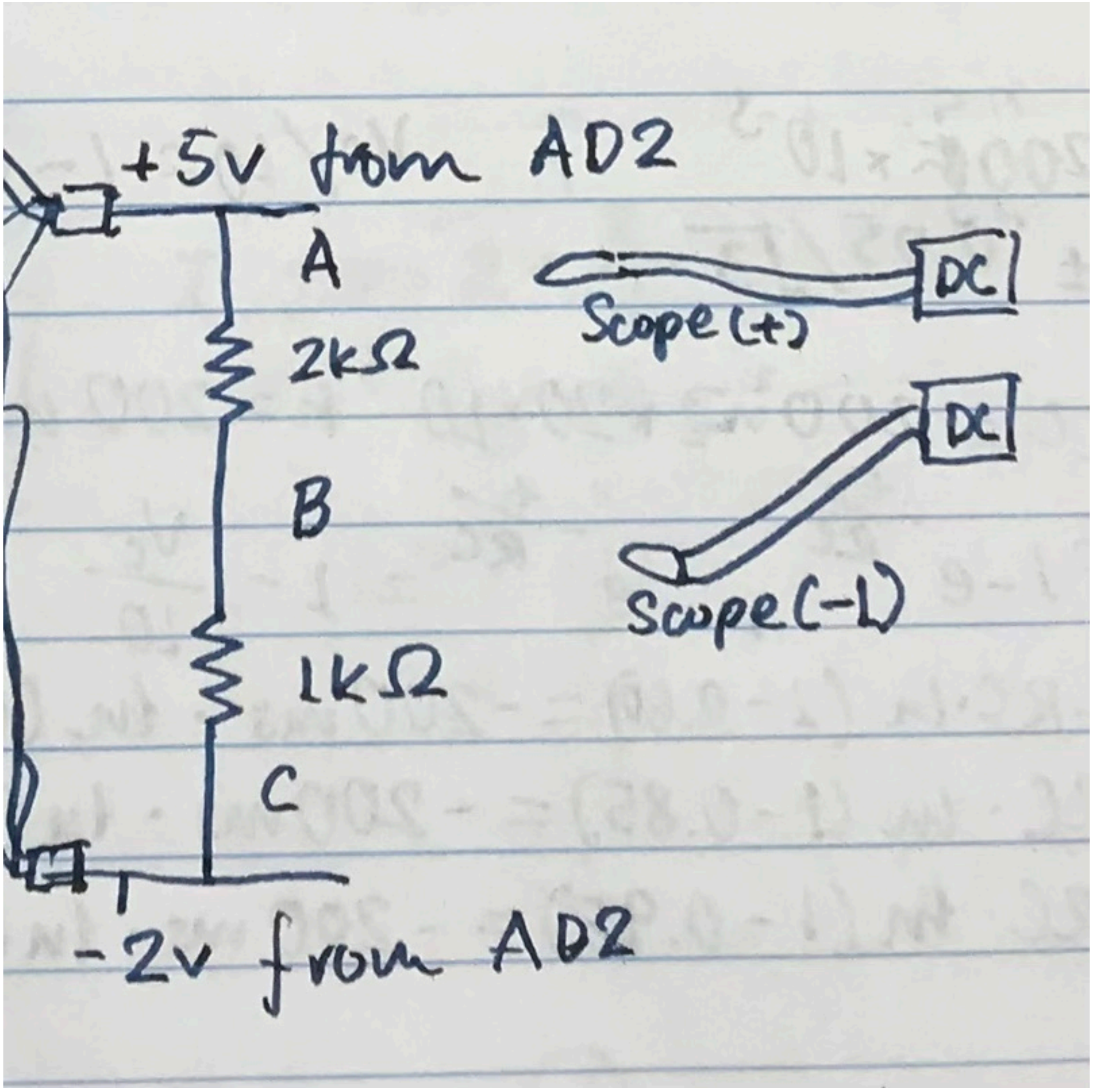


Figure 9: Case #1 Circuit Diagram

[46]:
```
Image(filename = 'drive/My Drive/UBC ENPH Y2/ENPH259/Lab1/Case 2 circuit.jpg')
```

[46]:

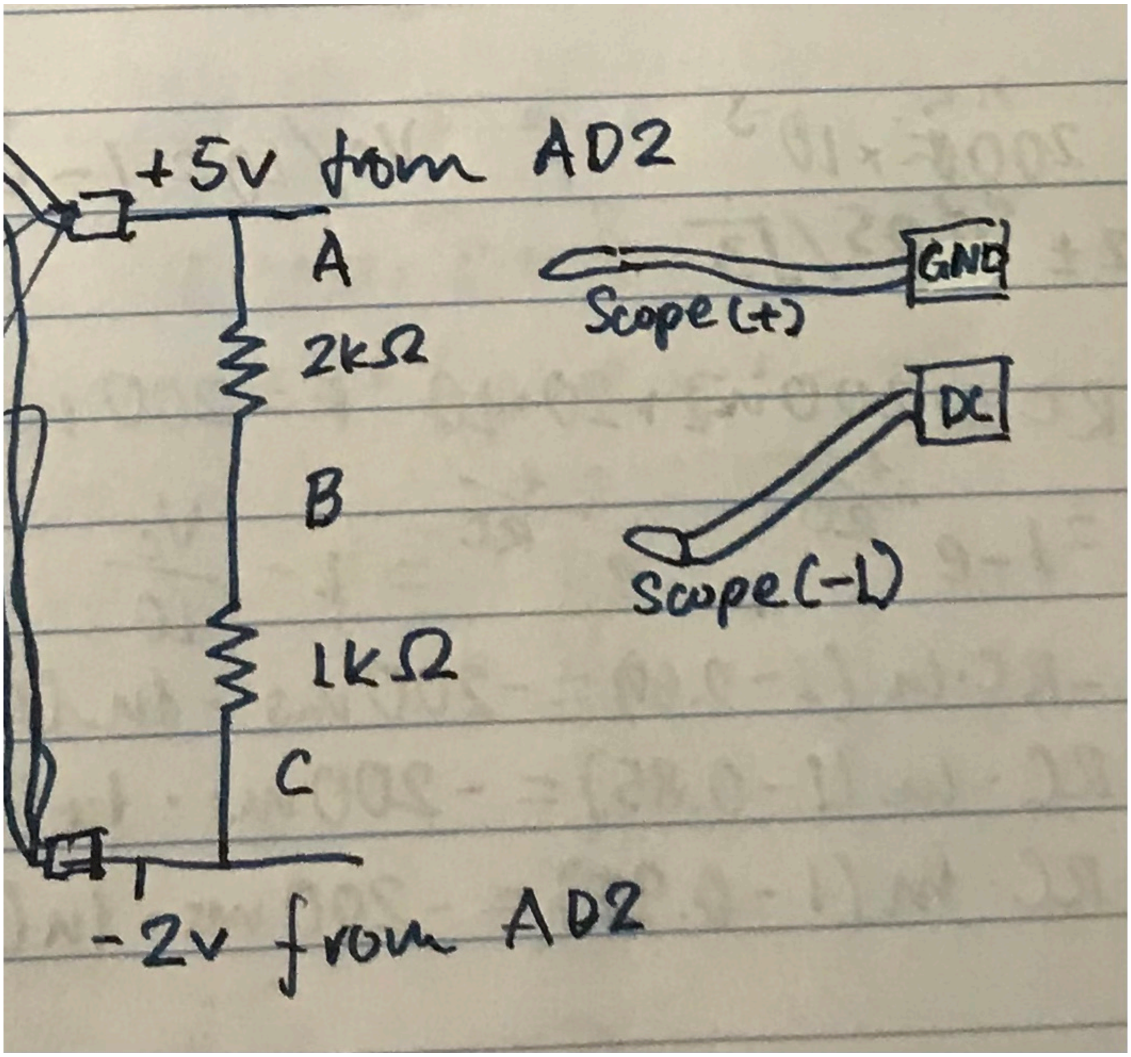


Figure 10: Case #2 Circuit Diagram

[47]:
```
Image(filename = 'drive/My Drive/UBC ENPH Y2/ENPH259/Lab1/Case 2 setup.jpg')
```

[47]:

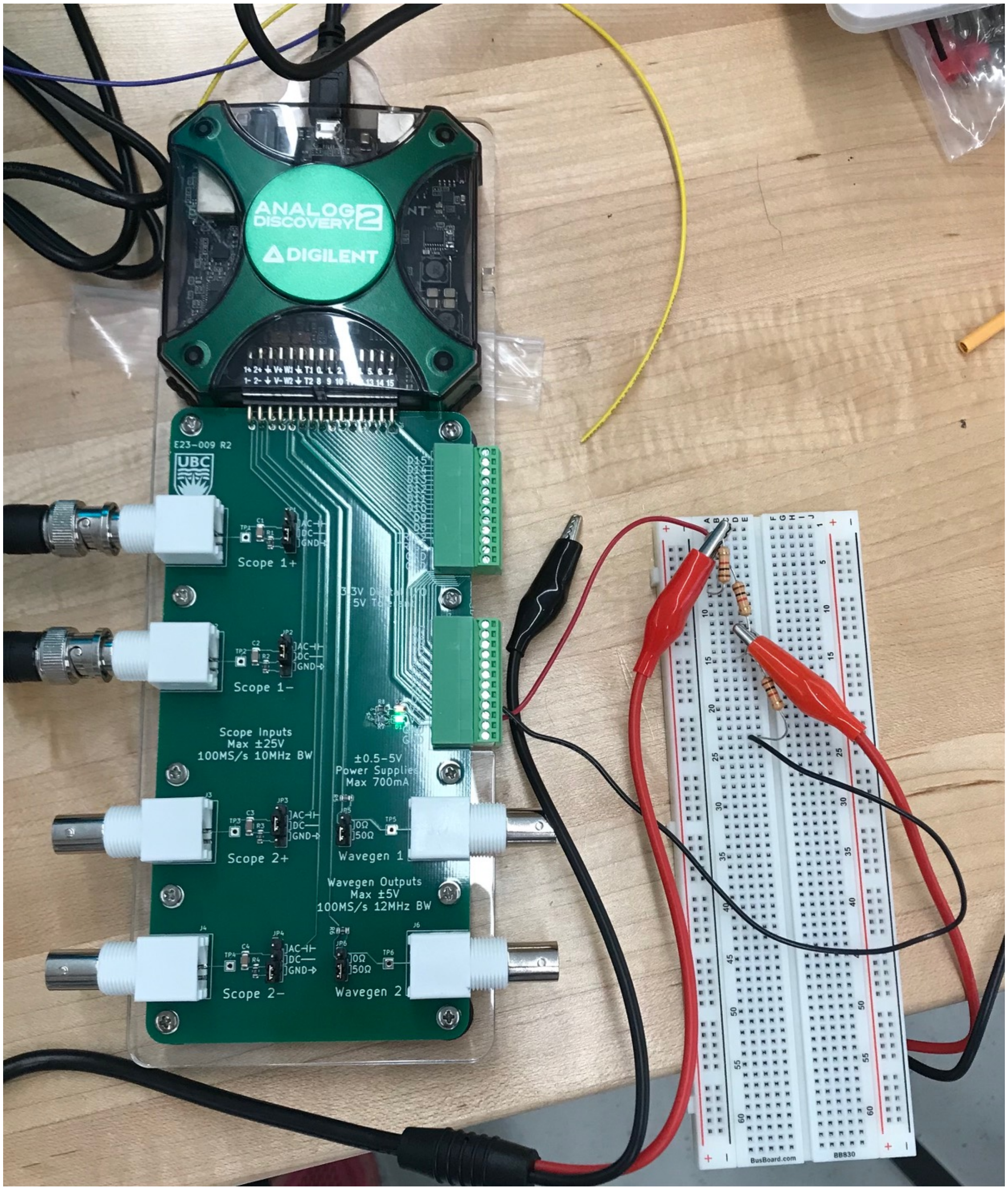
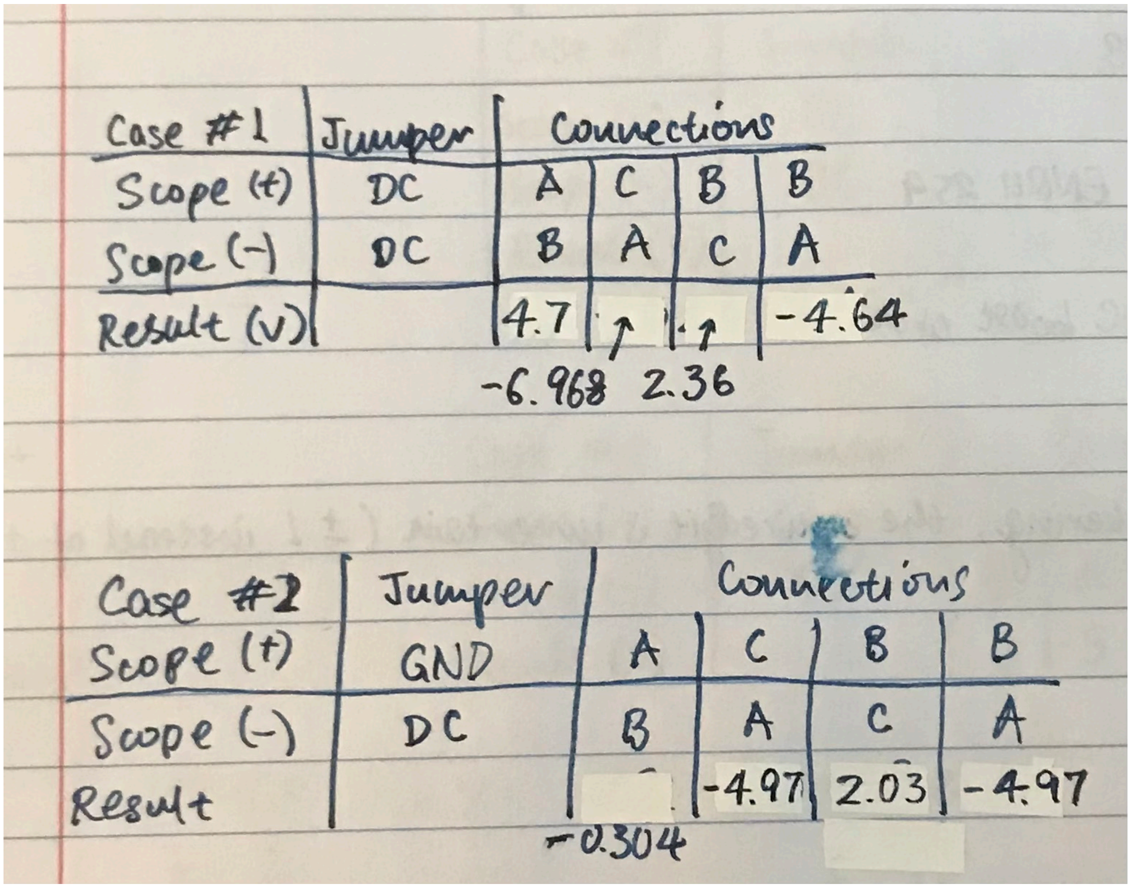


Figure 11: Case #2 Circuit Setup with Breakout Board and Breadboard

[48]:
```
Image(filename = 'drive/My Drive/UBC ENPH Y2/ENPH259/Lab1/prelab actual␣
↪measurements.jpg')
```

[48]:



Case #1	Jumper	Connections			
Scope (+)	DC	A	C	B	B
Scope (-)	DC	B	A	C	A
Result (V)		4.7	-6.968	2.36	-4.64

Case #2	Jumper	Connections			
Scope (+)	GND	A	C	B	B
Scope (-)	DC	B	A	C	A
Result		-0.304	-4.97	2.03	-4.97

Figure 12: Actual Differential and GND Reference Measurements for 2.3

[49]:
```
# @title
graph312 = pd.read_csv('drive/My Drive/UBC ENPH Y2/ENPH259/Lab1/L1A_Actual␣
↪Square Wave Data.csv')
plt.figure(figsize=(14, 6))
plt.plot(graph312['Time (s)'], graph312['Channel 1 (V)'], linestyle='-')
plt.xlabel('Time (s)')
plt.ylabel('Channel 1 Output (V)')
plt.title('Channel 1 Voltage Against Time Output')
plt.grid(True)
plt.show()
```

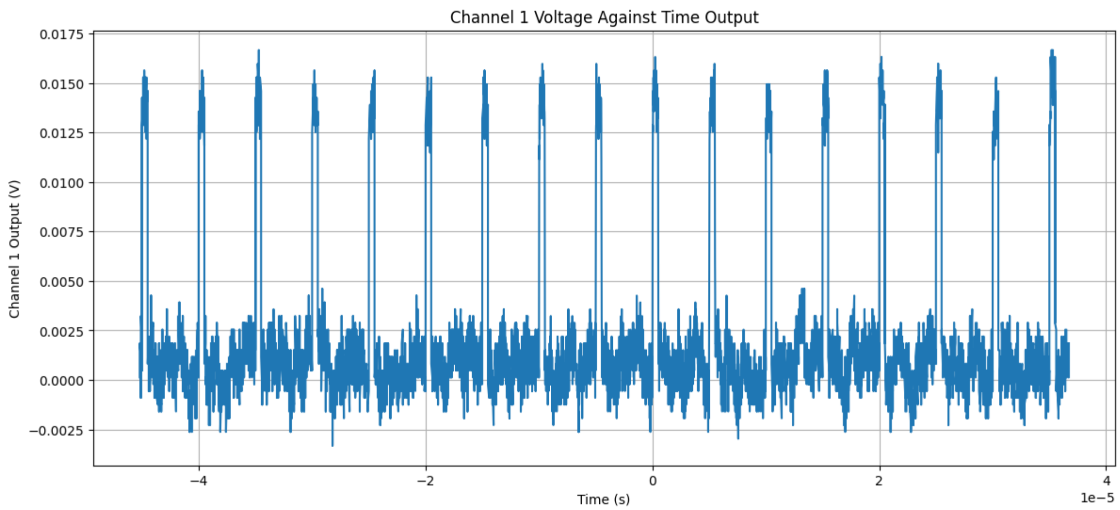


Figure 13: Output Voltage vs. Time Data from Channel 1 for 200 kHz Square Wave.

#3. DC Voltage Divider ##3.1 Task #4: Unloaded Voltage Divider ###Setup See Figure 4 for the circuit diagram I am setting up. Figure 14 shows the setup on the breadboard. I set the Scope (+) and (-) as DC probes and instead of using V- and V+ as power supplies, used V+ as +5v (adjusted using WaveForm) and the GND connector, since Waveform doesn't let V- be 0 V.

###Results Data - R1: 997 $\pm$ 4 Ω. - Measured 0.997 $k\Omega$ with the DMM with instrument error of 6.985 Ω (using the DMM error formula) - Digital measurement so divided error by $\sqrt{3}$ - R2: 984 $\pm$ 4 Ω - Measured 0.984 $k\Omega$ with the DMM with instrument error of 6.92 Ω - Digital measurement so divided error by $\sqrt{3}$ - R3: 986 $\pm$ 4 Ω - Measured 0.985 $k\Omega$ with the DMM with instrument error of 6.93 Ω - Digital measurement so divided error by $\sqrt{3}$ - Voltage across board: 5.028 $\pm$ 0.0002 V - Read with AD2, so instrument uncertainty is 5.028 V $\times$ $\frac{1}{2^{14}}$. Divided by $\sqrt{3}$ since it's a digital measurement, we get the uncertainty. - Notes - The values on the DMM would often slowly flicker, decreasing by 1 Ω each second, until it finally settled at a value. The contact of my hand with the resistor may have affected its resistance, even though it should be a very small effect.

Expected output voltage: 3.34 $\pm$ 0.01. - Formula: $\frac{R3+R2}{R1+R2+R3} \times V_{in}$ - Propagating uncertainty using an online calculator and the above formula gives us the expected output voltage.

Actual output voltage: 3.352 $\pm$ 0.0001 - Uncertainty: 3.352 $\times$ $\frac{1}{2^{14}}$ / $\sqrt{3}$ = 0.0001

The measured output voltage seems more reliable due to the significantly lower uncertainty and higher precision. This is because the AD2 directly takes the uncertainty instead of calculating with measured values (which may or may not change due to things like temperature or being connected to each other)

Conceptual Question: - I measured the resistance of the resistors with the DMM's probes against its legs on my hand because the conductive circuit within the breadboard the resistors are connected to when they're attached to the breadboard may affect the measured resistance.

Approximately: $V_{in} = 5.028v$ and $R_{net} = R1 + R2 + R3 = 997\Omega + 984\Omega + 986\Omega = 2967\Omega$. Thus, since net $P_{lost} = I^2 \times (R1 + R2 + R3) = \frac{V^2}{R_{net}} = (\frac{5.028^2 v^2}{2967\Omega} = 0.0084$ W.

Since $P_{lost} = I^2 \times (R2 + R3)$, and we can't decrease R2 or R3, we must decrease I. We can't change the V_{in}, so we can decrease the current flowing through the voltage divider by increasing the net resistance. As long as R1 = R2 = R3, the voltage divider will output 3.3 V, so if we increase the resistor's resistance, we have $P_{lost} = \frac{V^2}{R_{net}}$ and R_{net} increases, so P_{lost} decreases.

##**3.2 Task #5: Loaded Voltage Divider**

NOTE: I didn't get a 10k Ω resistor from the front so I connected 2 5k Ω resistors (at home) in series. I checked the resistance of the resitors with the DMM.

Figure 15 and 16 show the circuit diagram and setup. Since the load should be in parallel with R2 and R3 to get the 3.3 V output, we have the simulated load (resistor) in parallel. However, the voltage divider isn't outputting 3.3 v anymore because the resistance of the load changes the net resistance of the circuit and thus its voltage behavior.

We can recalculate how to output 3.3 V with only 1kΩ and 10k Ω resistors where there is a 10k Ω load at the output. We observe that as long as the reduction resistor to voltage output resistance has a 1:2 ratio (as 2/3 × 5V = 3.33 V), we get a 3.33 V output. We thus get the equation

$$\frac{x}{y+10} = \frac{1}{2},$$

where y is how many k resistance is in parallel with the load and x is the resistors connected in series before them. We find that the most feasible values of x and y are 2.5, which we can build with 1kΩ resistors, and y as 10kΩ. Thus, we make the $2.5k\Omega$ with 4 $1k\Omega$ resistors as seen in Figure 17 and 18.

Checking the voltage output with the scope, we get 3.354 V, with is close enough to 3.33 V that we understand this setup works and outputs approximately 3.33 V *with* the load.

[50]:
```
Image(filename = 'drive/My Drive/UBC ENPH Y2/ENPH259/Lab1/voltage divider.jpg')
```

[50]:

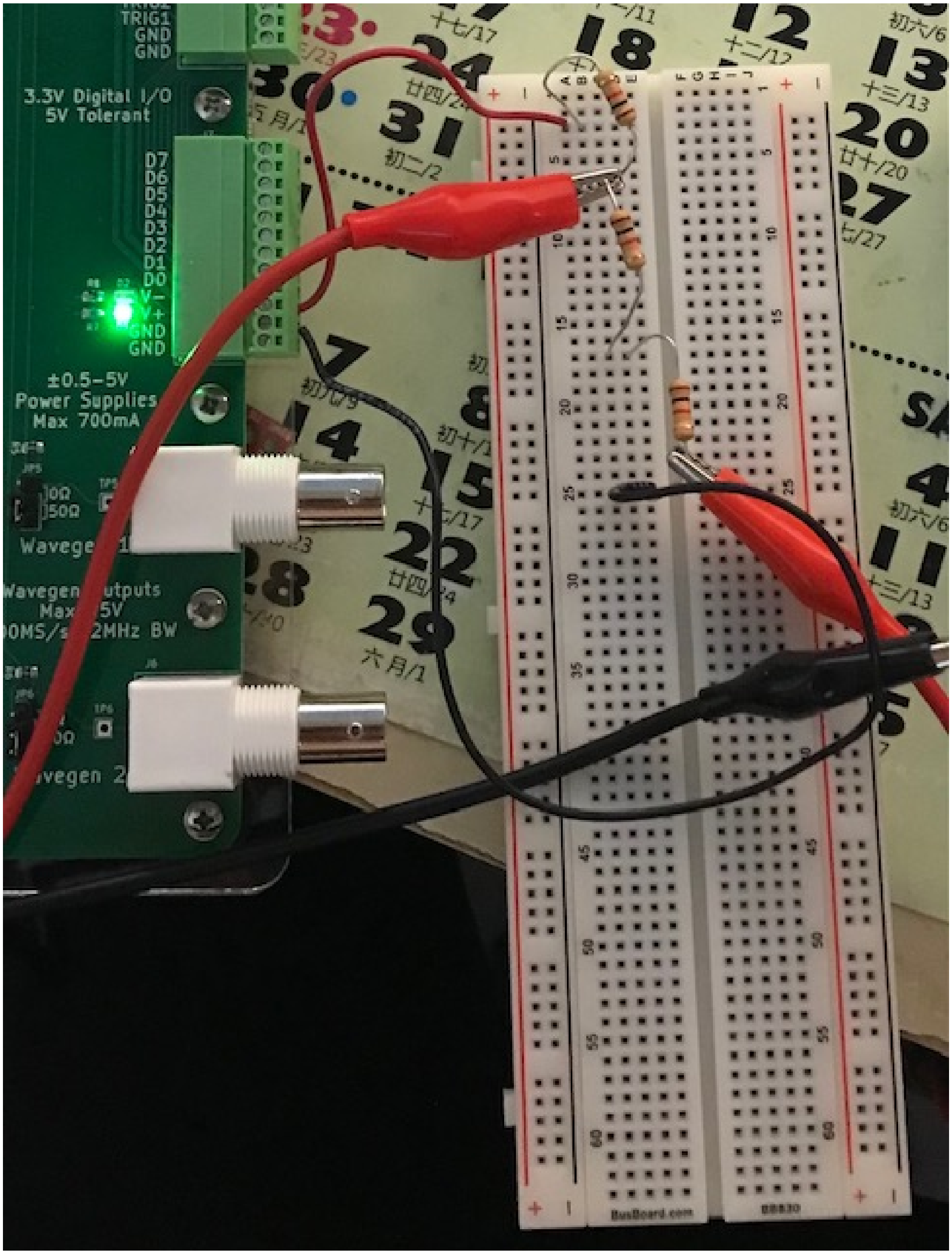


Figure 14: Voltage Divider Set-up.

[51]:
```
Image(filename = 'drive/My Drive/UBC ENPH Y2/ENPH259/Lab1/bad load circuit.jpg')
```

[51]:

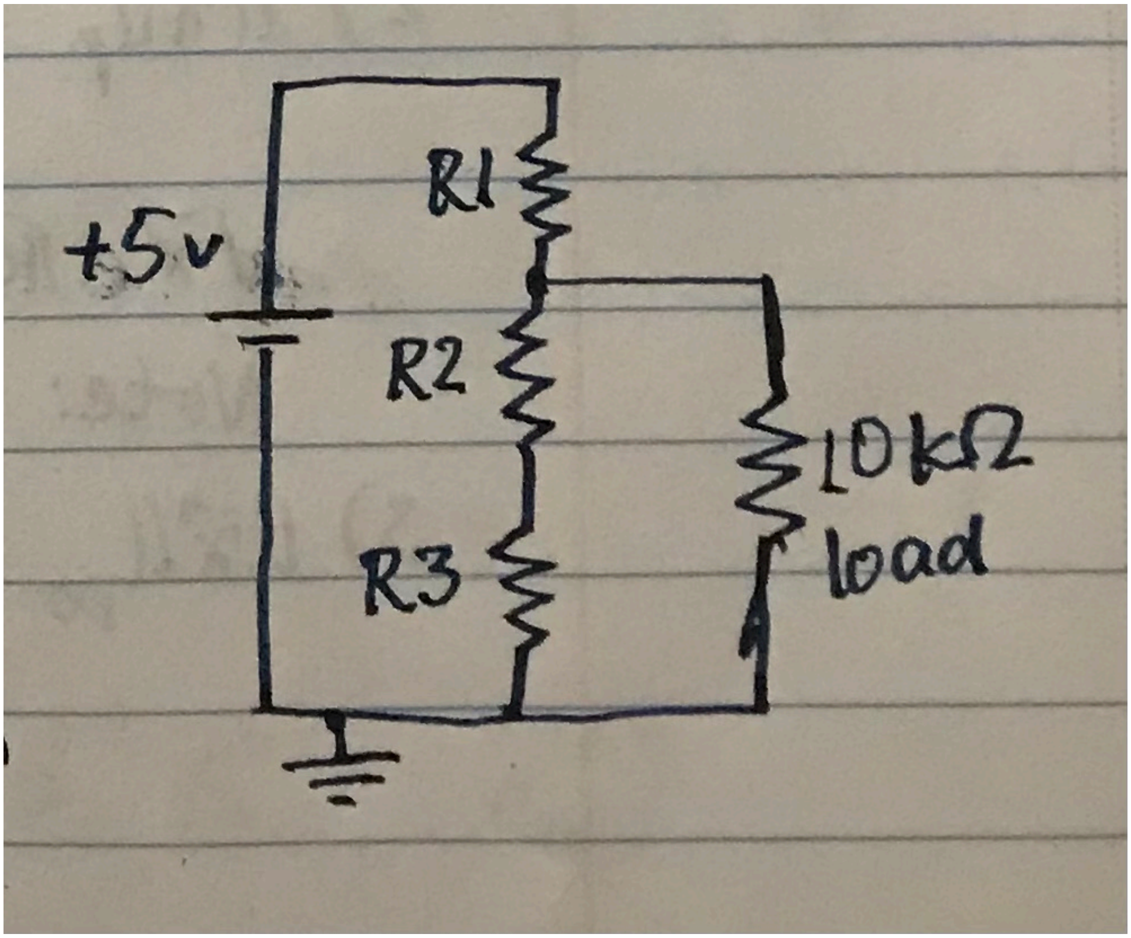


Figure 15: Loaded Voltage Divider Circuit

[52]:
```
Image(filename = 'drive/My Drive/UBC ENPH Y2/ENPH259/Lab1/bad load setup.jpg')
```

[52]:

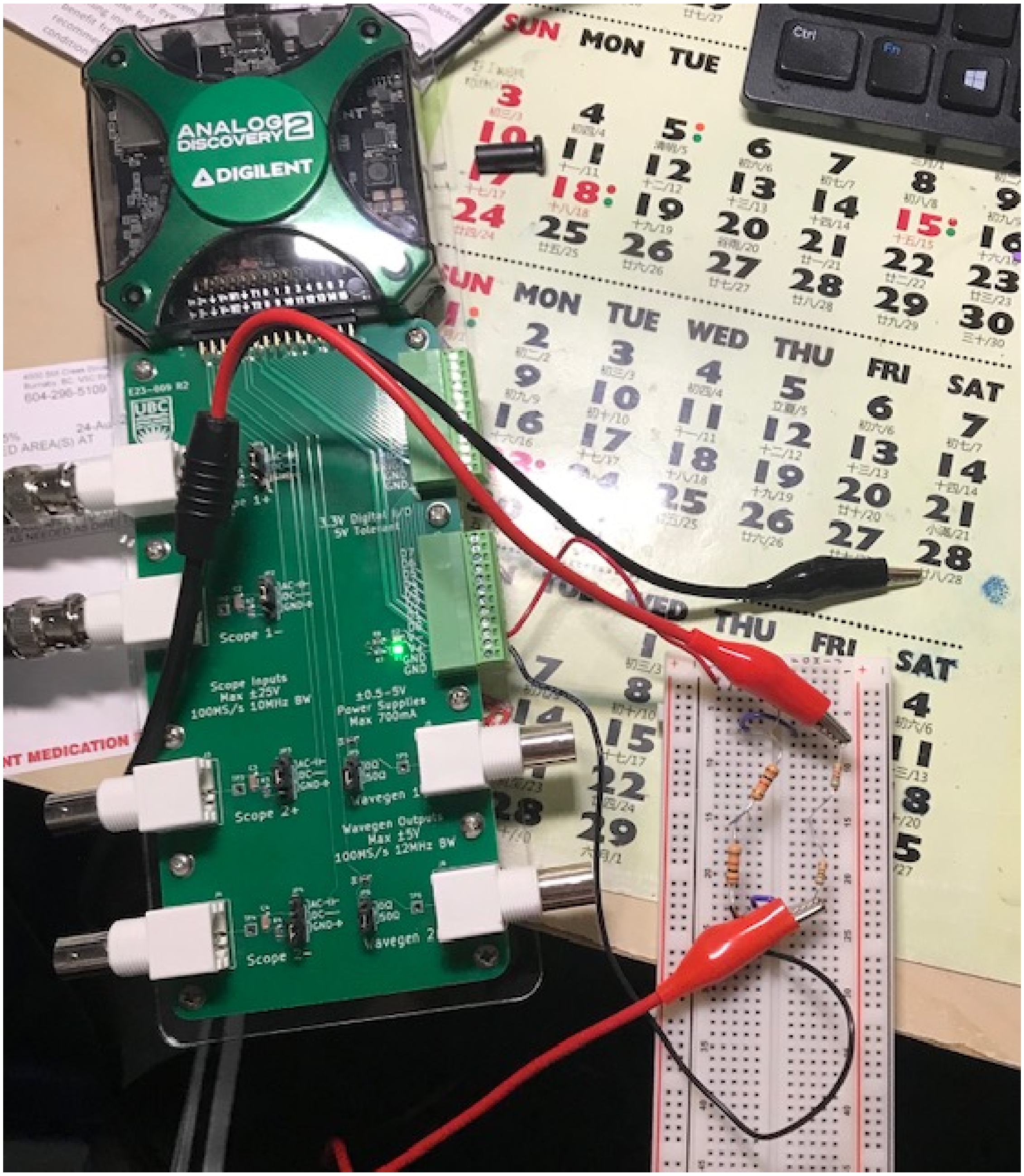
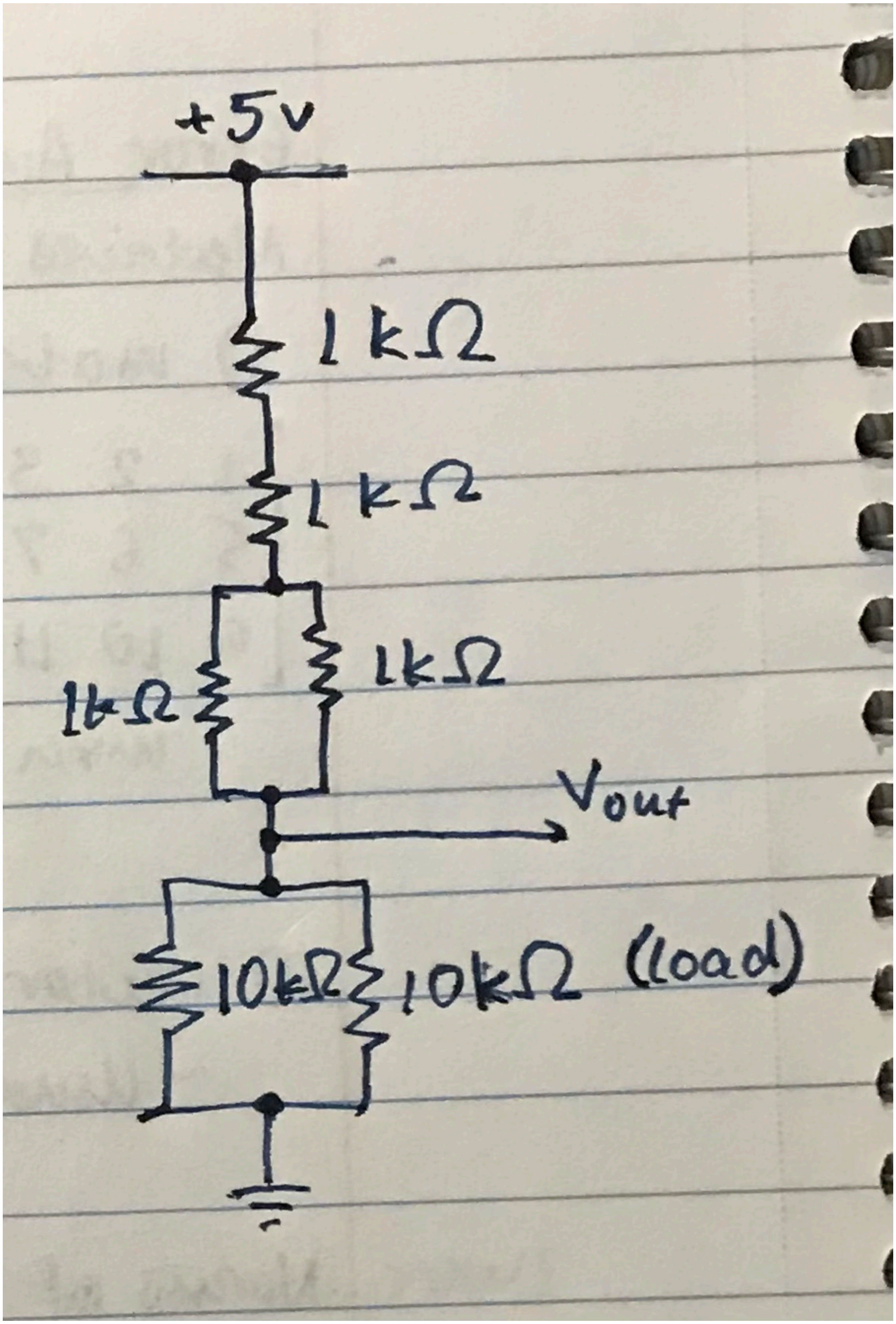


Figure 16: Loaded Voltage Divider Setup

[53]:
```
Image(filename = 'drive/My Drive/UBC ENPH Y2/ENPH259/Lab1/good load circuit.
↪jpg')
```

[53]:



+5v
1kΩ
1kΩ
1kΩ
1kΩ
Vout
10kΩ
10kΩ (load)

Figure 17: Corrected Voltage Divider Load Circuit.

[54]:
```
Image(filename = 'drive/My Drive/UBC ENPH Y2/ENPH259/Lab1/good load setup.jpg')
```

[54]:

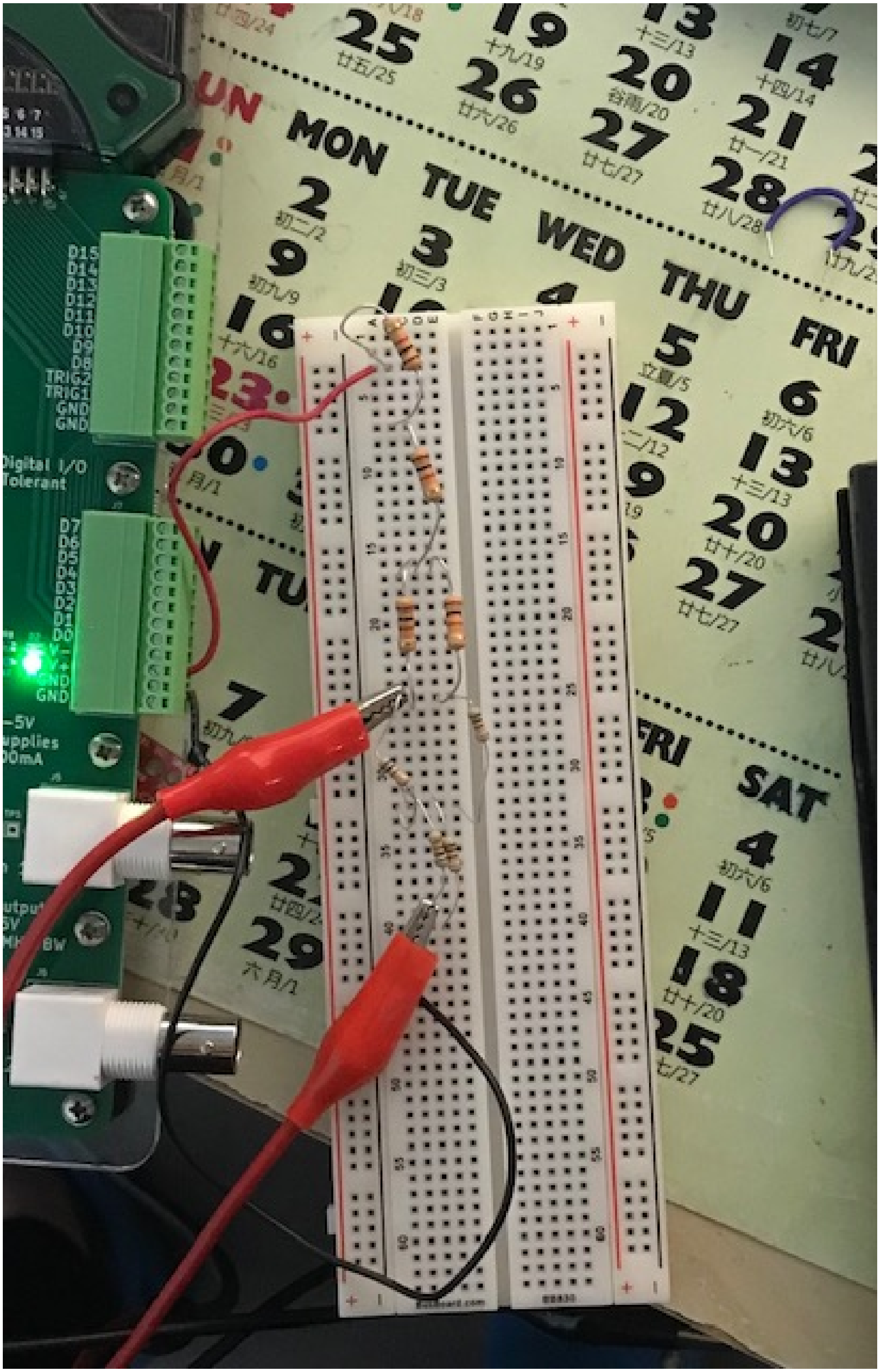

D15
D14
D13
D12
D11
D10
D9
D8
TRIG2
TRIG1
GND
GND
D7
D6
D5
D4
D3
D2
D1
D0
GND
GND
MON
TUE
WED
THU
FRI
SAT

Figure 18: Corrected Voltage Divider Load Circuit Setup.

##4. **Conclusion**

In this lab, we manually used cursors and digitally measured output values of the AD2 wave generator with the scope, and compared these values. It showed us how uncertainty in digital and analog measurements are determined then propagated.

We experimented with some circuit concepts that I didn't fully understand before. For example, I didn't understand how the breakout board worked theoretically. Hence, in the prelab, I could only guess (incorrectly) to its behaviour in the presence to the short, but I had to actually test it out to understand what floating voltage meant and what voltages the AD2 read - the actual voltage at the DC probe, not the voltage difference between the two probes. The 'grounding of one of the probes drastically changed the readings of the AD2 compared to the both DC probe case.

Then we tested out our voltage divider in a more real-world scenario, where this is a load, and understood why the actual calculation for a desired output, 3.33 V for us, is more complicated than in the pre-lab. I had to account for the resistance of the load as well.

As well, I understood how theoretical values, such as outputs we set in software or labels for components like resistors aren't 100% accurate so we should always check to improve the accuracy of our experiemts' results.

[55]:
```
base_path = r'/content/drive/My Drive/UBC ENPH Y2/ENPH259/Lab1/'  # This part␣
 ↪is always the same for a mounted google drive
file_name = 'Nora Shao_Lab1A_Final.ipynb'  # .ipynb filename that you want to␣
 ↪export to PDF
```

[ ]:
```
!apt-get install texlive-xetex texlive-fonts-recommended␣
 ↪texlive-latex-recommended texlive-plain-generic pandoc
```

[34]:
```
# @title
# Capture to prevent lots of output... Remove this if troubleshooting!
%%capture

# In case running multiple times, delete old files first
pdf_file_name = file_name.split('.')[0]+'.pdf'  # Same as file_name with .ipynb␣
 ↪changed to .pdf
!rm $file_name
!rm $pdf_file_name
# Dollar signs because references to local variables

import os
# Copy file to local environment
full_path = os.path.join(base_path, file_name)
!cp  "$full_path" ./
# Dollar signs because full_path contains a space in 'My Drive' part.
```

```
# Run nbconvert on local file to produce pdf file
!jupyter nbconvert "$file_name" --to pdf
#--template article
```