Rafi Rahman

Electronics System – Lab Reports

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Experiment #1

Objective

To understand the basic principles of simple electric circuits. We test Ohm's Law, Kirchhoff's Voltage and Current Laws, and the Voltage and Current Divider Rules in this experiment.

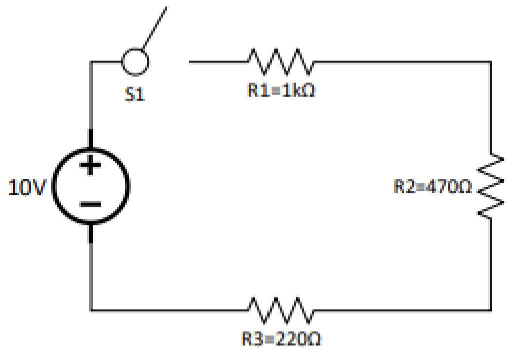
Materials

- Terminal board
- Variable power supply
- Ammeter
- Digital voltmeter
- 220 Ω, 470 Ω, and 1000 Ω resistors

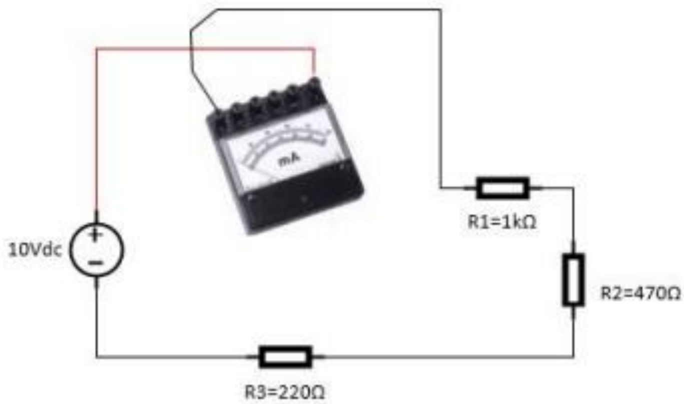
Procedure

Part 1:

1. A circuit is set up with three resistors in series as shown below.



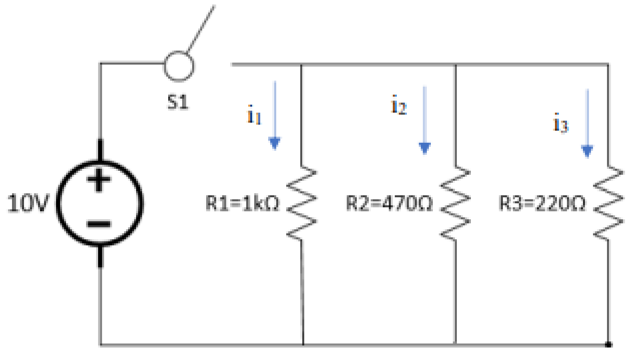
2. Assuming that S_1 is closed, the main current flowing through the circuit and the voltages across each resistor are all calculated.
3. The power supply is adjusted to 10 V_{DC}. An ammeter is connected in series to the circuit as shown below.



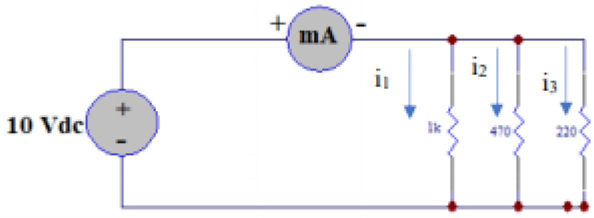
4. The main current flowing through the circuit is recorded. The ammeter is removed and S_1 is closed. The voltage across each resistor is then measured.
5. Using KVL, the voltage values from Steps 2 and 4 are verified.

Part 2:

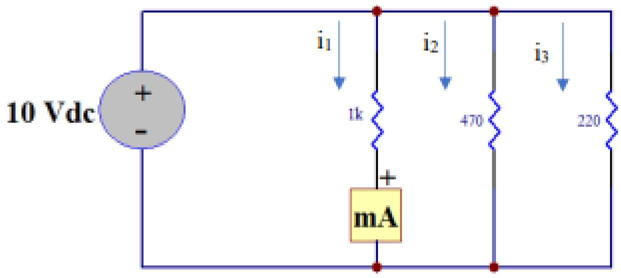
1. A circuit is set up with three resistors in parallel as shown below.



2. Assuming S_1 is closed, the main current flowing through the circuit and currents i_1, i_2, and i_3 are all calculated.
3. The power supply is adjusted to 10 V_{DC} and an ammeter is connected to the circuit in series as shown below. The value of the main current is recorded.



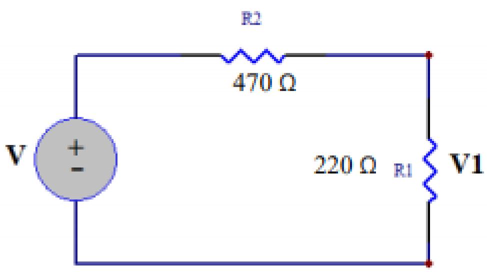
4. For i_1, the ammeter is removed and reconnected next to its resistor as shown below. The value of i_1 is recorded. The same is done for i_2 and i_3.



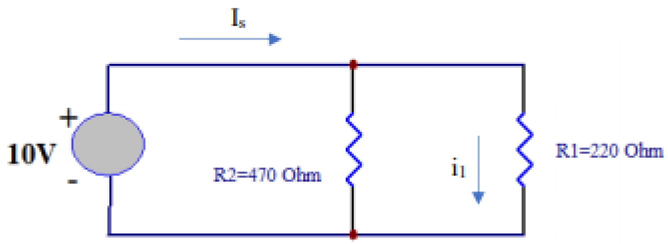
5. The current values from Steps 2 and 4 are verified using KCL.

Part 3:

1. The following series circuit is constructed ($V = 10$ V).



2. Voltage V_1 is calculated using the Voltage Divider Rule, then measured in the physical circuit using a voltmeter.
3. The circuit is reconstructed into a parallel circuit as follows.



4. Current I_S and i_1 are calculated, then I_S and i_1 are measured in the physical circuit using an ammeter, which is connected to the circuit next to R_1.

Tabulated Data

All values are in 3 significant figures.

Part 1:

	Calculated Value	Measured Value
I (Main current)	10.0/(1000 + 470 + 220) = 0.00592 A = 5.92 mA	5.75 mA
V_1	0.00592*1000 = 5.92 V	5.75 V
V_2	0.00592*470 = 2.78 V	2.70 V
V_3	0.00592*220 = 1.30 V	1.27 V
V_T	10.0 V	

Part 2:

	Calculated Value	Measured Value
I (Main current)	10.0*(1/1000 + 1/470 + 1/220) = 0.0767 A = 76.7 mA	76.8 mA
I_1	10.0/1000 = 0.01 A = 10 mA	9.98 mA
I_2	10.0/470 = 0.0212 = 21.2 mA	20.0 mA
I_3	10.0/220 = 0.0455 mA = 45.5 mA	44.0 mA
V_T	10.0 V	

Part 3:

	Calculated Value	Measured Value
Series		
V_1	10.0*220/(220 + 470) = 3.19 V	3.30 V
V_T	10.0 V	

Parallel		
I_S	10.0(220 + 470)/(220*470) = 0.0667 A = 66.7 mA	66.9 mA
I_1	0.0667*470/(220 + 470) = 0.0454 A = 45.4 mA	44.9 mA
V_T	10.0 V	

Analysis

Part 1:
According to KVL, for a closed loop series path, the algebraic sum of all the voltages around the loop is equal to zero. Therefore, the voltages across each resistor should sum up to the total voltage, aka the voltage from the power supply.
5.75 + 2.70 + 1.27 = 9.72 ≈ 10 V
Looks about right. The measured values are also pretty close to the calculated values.

Part 2:
According to KCL, the net current flowing into a node/junction must be equal to the net current flowing out of it. In that case, the currents going through each resistance should sum up to a value equal to that of the main current.
9.98 + 20.0 + 44.0 = 73.98 < 76.7 mA
A bit off, but still somewhat close. The error is likely due to the resistor values being slightly inaccurate. The measured values are also pretty close to the calculated values.

Part 3:
The measured values are quite close to the calculated values.

Conclusion

The purpose of this experiment was to understand the basic principles of simple electric circuits, and to test Ohm's Law, Kirchhoff's Voltage and Current Laws, and the Voltage and Current Divider Rules. To do this, we constructed different series and parallel circuits, and compared our measured values that we got from the circuits to the calculated values that we found beforehand. The data tells us that the aforementioned laws and rules hold up decently and are applicable in practical situations. From this experiment, I got a better understanding of electric circuits and how I can use different rules and laws related to circuits to solve problems within circuits.

Experiment #2/3

Objective

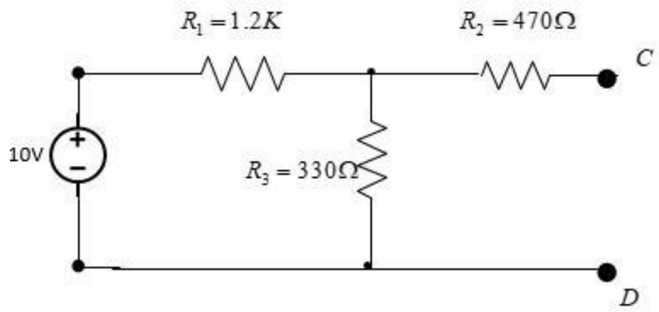
To verify Thevenin's Theorem, Norton's Theorem, and the Maximum Power Transfer Theorem.

Materials

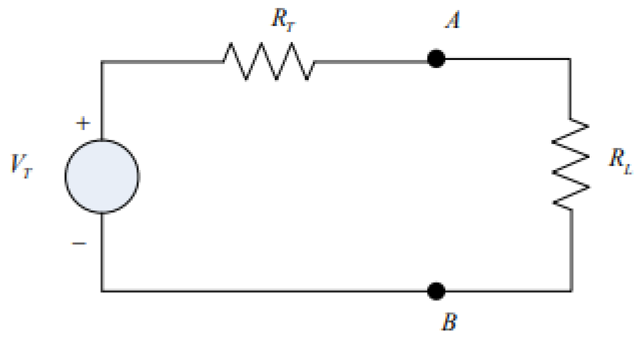
- Terminal board
- Variable power supply
- Decade resistance box
- YEW ammeter
- Digital voltmeter
- Constant current source
- 1.2 kΩ, 1 kΩ, 470 Ω, and 330 Ω resistors

Procedure

1. The Thevenin equivalent circuit and the Norton equivalent circuit are drawn for the following circuit, and the Thevenin voltage (V_{TH}), Norton current (I_N), and the equivalent resistance (R_E) are all found. The voltage drop (V_L) and current (I_L) are then calculated for a load resistance of 1 kΩ across CD.

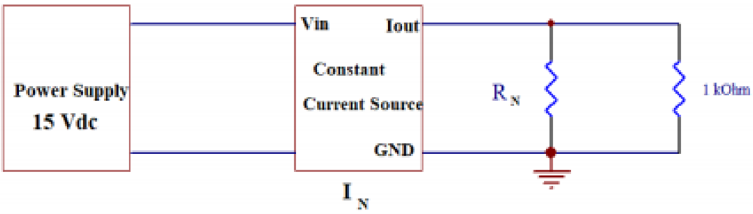


2. The circuit is physically constructed on the terminal board.
3. The power supply is set to 10 V and connected to the circuit. The open circuit voltage across CD (V_{TH}), the short circuit current at CD (I_N), and the output resistance (with the power supply removed and AB shorted) across CD (R_E) are all measured.
4. A 1 kΩ resistor is connected as load resistance across CD. V_L and I_L are measured.
5. The power supply is set to the V_{TH} value calculated in Step 1. The decade resistance box is set to the R_E value calculated in Step 1. The Thevenin equivalent circuit is constructed as follows and the 1 kΩ resistor is connected as the load.

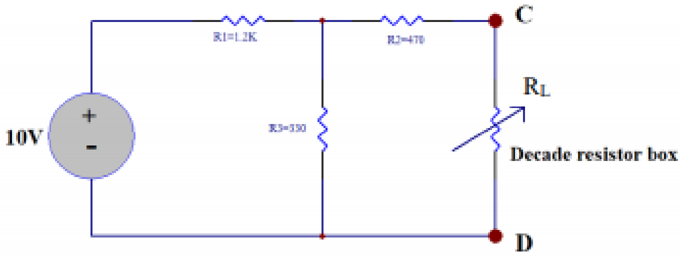


6. V_L and I_L are measured for the Thevenin circuit.
7. The power supply is set to 15 V_{DC} and the constant current source is connected to the power supply. The ammeter is connected across the output terminal of the constant current source. The Norton equivalent

circuit is constructed as shown below. The 1 kΩ resistor is once again connected as the load.



8. V_L and I_L are measured for the Norton circuit.
9. A new circuit is constructed as follows:



10. The decade resistance box is connected across CD as the R_L. For various values of R_L, V_{CD} is measured, and the power dissipated in R_L (P) is calculated. By plotting a graph of P as a function of R_L, the value of R_L for maximum power transfer is determined.

Tabulated Data

Preliminary work (Step 1):

V_{TH}	2.16 V
I_N	2.97 mA
R_E	729 Ω
V_L	1.2 V
I_L	1.2 mA

Original circuit (Steps 3 and 4):

V_{TH}	2.08 V
I_N	2.9 mA
R_E	727 Ω
V_L	1.2 V
I_L	1.2 mA

Thevenin equivalent circuit (Step 6):

V_L	1.32 V
I_L	1.2 mA

Norton equivalent circuit (Step 8):

V_L	1.22 V
I_L	1 mA

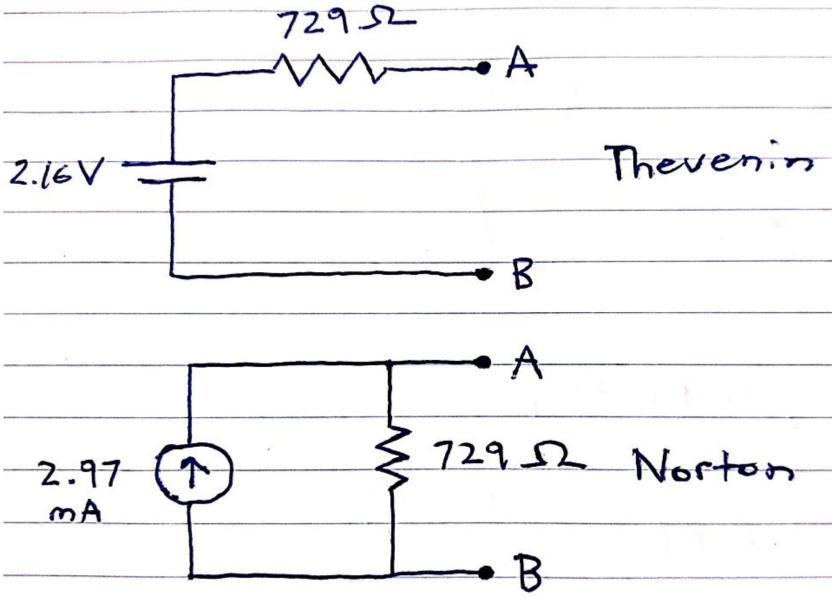
Step 10:

R_L (Ω)	V_{CD} (V)	Power (mW)
100	0.252	0.635
200	0.453	1.026
300	0.612	1.248

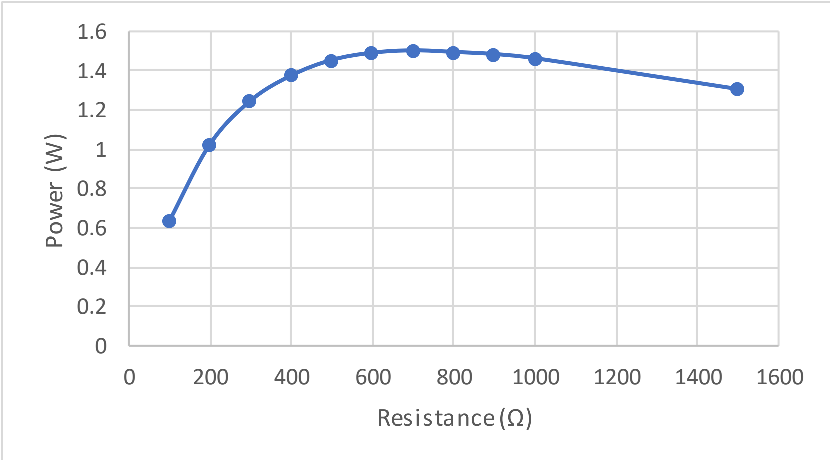
400	0.742	1.376
500	0.853	1.455
600	0.946	1.492
700	1.026	1.504
800	1.094	1.496
900	1.156	1.485
1000	1.210	1.464
1500	1.400	1.307

Analysis

Preliminary work:



Graph for Step 10:



The experimental measurements are very similar to the theoretically determined values, as we can see in the Tabulated Data section. Not only that, but the experimental load values for the Thevenin circuit and the Norton circuit are very close to the experimental load values found for the original circuit.

From the chart, we can see that the power transfer peaks at around 700 Ω and goes down from there. Thus, we can conclude that the load resistance must be somewhere around 700 Ω for maximum power transfer, which agrees with what is expected from the Maximum Power Transfer Theorem, which is 729 Ω.

Conclusion

The purpose of this lab was to verify Thevenin's Theorem, Norton's Theorem, and the Maximum Power Transfer Theorem. We tested these theorems by forming circuits around these theorems, measuring the required values, and comparing the measured values to the theoretical values calculated beforehand. The data obtained from this experiment tells us that the theorems we tested hold up true in practical situations. From this experiment, I learned about the aforementioned theorems, how to solve questions related to those theorems, and the use of equipment such as decade resistance boxes.

Experiment #4/5

Objective

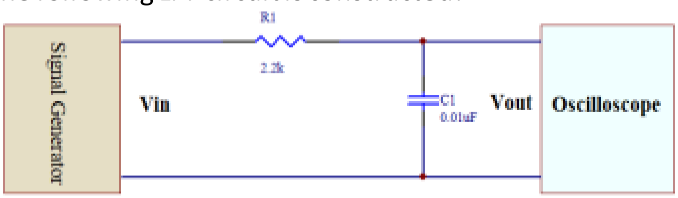
To investigate the characteristics of Low Pass Filter (LPF), High Pass Filters (HPF), and Band Pass Filter (BPF) circuits.

Materials

- Breadboard
- Function generator
- Oscilloscope
- 2.2 kΩ and 10 kΩ resistors
- 0.01 uF and 0.47 uF capacitors
- 4.7 mH inductor

Procedure

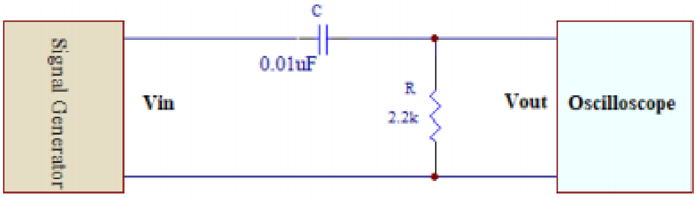
1. The following LPF circuit is constructed:



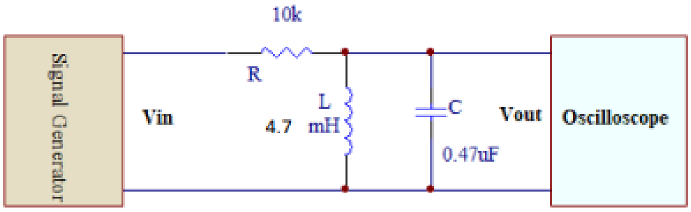
2. The signal generator is set to a sine wave with a peak-to-peak value of 5 V. V_O (peak-to-peak) is measured for frequencies from 100 Hz to 15 kHz. The results are plotted into a graph of gain, calculated using the formula $20*log(V_{OUT}/V_{IN})$, as a function of frequency. The cut-off frequency (f_C) is determined at 3 dB.
3. The theoretical cut-off frequency is calculated using the equation below:

$$f_c = \frac{1}{2\pi RC}$$

4. Steps 1 to 3 are repeated for the HPF circuit below. V_O measurements are taken for frequencies up to 20 kHz instead of 15 kHz.



5. A BPF circuit is constructed as seen below.



6. Step 2 is repeated for a frequency range of 1.6 to 6.2 kHz, and V_O, instead of gain, is plotted against frequency. The cut-off frequency is determined at 0.707*V_{MAX}.
7. Using the graph created in Step 6, the bandwidth, aka, the distance between the upper and lower 3-dB points, and the resonance frequency (f_R), aka the frequency at which V_O is maximum, are determined.
8. The quality factor (Q) is determined using the following ratio:

$$\frac{f_r}{\Delta_f}$$

Tabulated Data

All values are in 3 significant figures.

LPF (Step 2):

f (Hz)	V_{IN} (V)	V_{OUT} (V)	V_{OUT}/V_{IN}	Gain (dB)
100	5.28	5.28	1.00	0.00
200	5.28	5.28	1.00	0.00
300	5.28	5.28	1.00	0.00
400	5.28	5.28	1.00	0.00
500	5.28	5.28	1.00	0.00
600	5.28	5.28	1.00	0.00
700	5.28	5.20	0.985	-0.133
800	5.28	5.12	0.970	-0.267
900	5.28	5.12	0.970	-0.267
2000	5.28	4.88	0.924	-0.684
3000	5.28	4.68	0.886	-1.05
4000	5.28	4.48	0.848	-1.43
5000	5.28	4.16	0.788	-2.07
6000	5.28	3.84	0.727	-2.77
7000	5.28	3.52	0.667	-3.52
8000	5.28	3.28	0.621	-4.14
9000	5.28	3.04	0.576	-4.80
10000	5.28	2.88	0.545	-5.26
11000	5.28	2.72	0.515	-5.76

HPF (Step 4):

f (Hz)	V_{IN} (V)	V_{OUT} (V)	V_{OUT}/V_{IN}	Gain (dB)

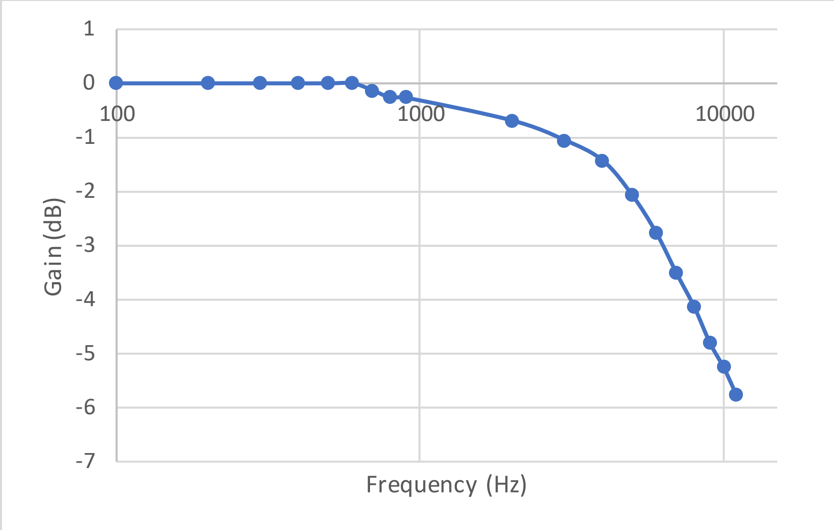
100	5.28	0.16	0.0303	-30.4
200	5.28	0.24	0.0455	-26.8
300	5.28	0.32	0.0606	-24.3
400	5.28	0.40	0.0756	-22.4
500	5.28	0.48	0.0909	-20.8
600	5.28	0.52	0.0985	-20.1
700	5.28	0.64	0.121	-18.3
800	5.28	0.64	0.121	-18.3
900	5.28	0.80	0.151	-16.4
1000	5.28	0.88	0.167	-15.6
2000	5.28	1.44	0.273	-11.3
3000	5.28	2.08	0.394	-8.09
4000	5.28	2.60	0.492	-6.15
5000	5.28	3.04	0.576	-4.80
6000	5.28	3.36	0.636	-3.93
7000	5.28	3.60	0.682	-3.33
8000	5.28	3.84	0.727	-2.77
9000	5.28	4.00	0.756	-2.41
10000	5.28	4.16	0.788	-2.07
11000	5.28	4.24	0.803	-1.91
12000	5.28	4.32	0.818	-1.74
13000	5.28	4.48	0.848	-1.43
14000	5.28	4.48	0.848	-1.43
15000	5.28	4.48	0.848	-1.43

BPF (Step 6):

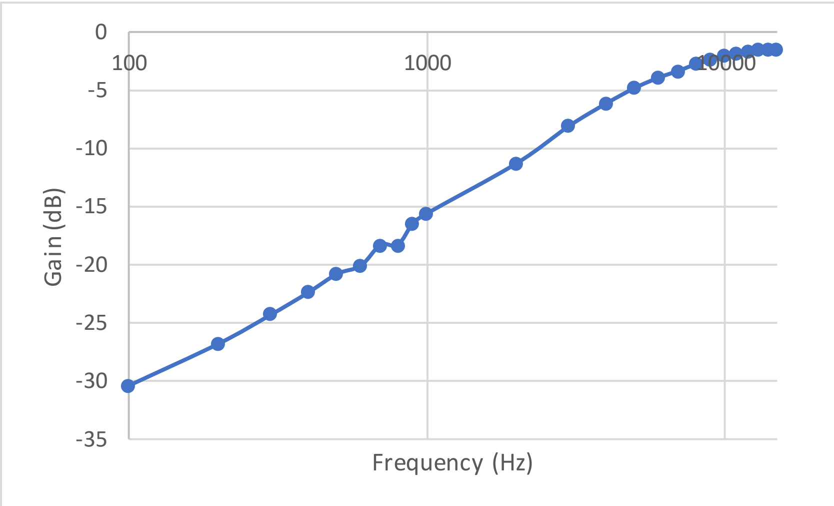
f (Hz)	V_{IN} (V)	V_{OUT} (mV)
1600	5.20	56.0
1800	5.20	72.0
2000	5.20	72.0
2200	5.20	84.0
2400	5.20	96.0
2600	5.20	120
2800	5.20	156
3000	5.20	236
3400	5.20	464
3800	5.20	192
4200	5.20	134
4600	5.20	104
5000	5.20	84.0
5400	5.20	76.0
5800	5.20	72.0
6200	5.20	64.0

Analysis

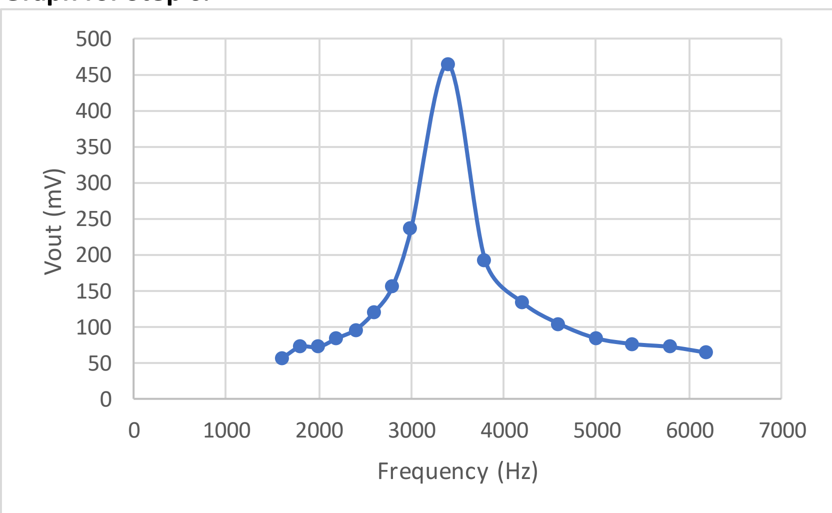
Graph for Step 2:



Graph for Step 4:



Graph for Step 6:



For the LPF, the cut-off frequency from our results appears to be somewhere around 7000 Hz. By using the equation, f_C was determined to be 7230 Hz, rounded to 3 significant figures. This theoretical value seems to agree quite closely to the experimental value. The circuit is called a Low Pass Filter due to the fact it passes signals with frequencies lower than the cut-off frequency, which is observable in the graph.

For the HPF, the cut-off frequency from our results appears to also be somewhere around 7000 Hz. By using the equation, f_C was determined to be 7230 Hz, rounded to 3 significant figures. This theoretical value also seems to agree quite closely to the experimental value. The circuit is called a High Pass Filter due to the fact it passes signals with frequencies higher than the cut-off frequency, which is observable in the graph.

For the BPF, the cut-off frequency appears to be somewhere around 3100 Hz. From out calculations, the bandwidth is somewhere around 1200 Hz, the resonance frequency somewhere around 3400 Hz, which makes the quality factor somewhere around 2.83.

Conclusion

In this lab, we investigated the characteristics of Low, High, and Band Pass Filters. We did this by building these circuits, testing them, and solving problems related to them. From the data, we can see that the theory behind these circuits hold true in practical scenarios, along with the properties of these circuits that we can observe. In this lab, I learned more about AC filter circuits, as well as the various properties of AC filter circuits and how to solve problems related to AC filter circuits. I also learned how to use a function generator and oscilloscope, as well as the use of inductors and capacitors in circuits.

Experiment #6

Objective

To understand the operation of diodes and illustrate the techniques of half-wave and full-wave rectification, as well as the filter of a rectified AC signal to produce a steady DC result.

Materials

- Terminal board
- IEC power supply
- 1N4004 rectifier diodes
- 3.3 kΩ resistor
- Digital oscilloscope
- Digital multimeter
- 0.47 uF disc ceramic, 4.7 uF electrolytic, and 100 uF electrolytic capacitors.

Procedure

1. The following circuit is constructed on the terminal board:

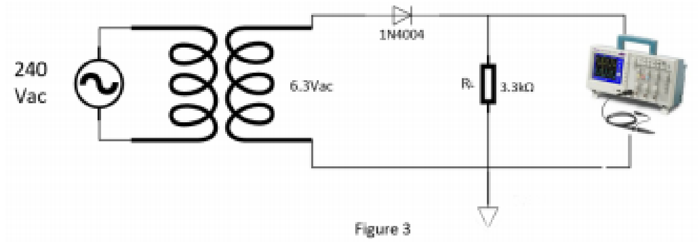


Figure 3

2. Both channels of the digital oscilloscope are set to DC. The waveforms and their period, amplitude, and peak-to-peak values are recorded for each channel.
3. A new circuit is built as follows:

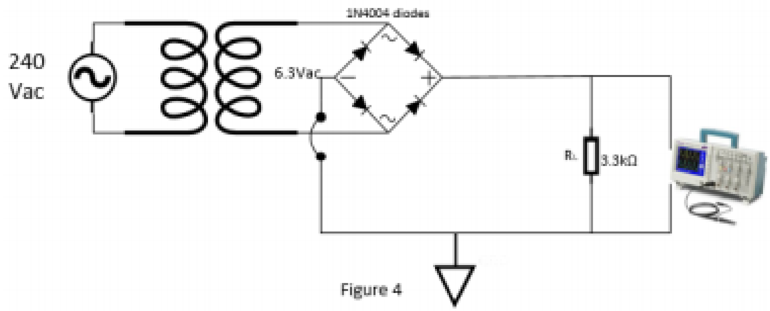


Figure 4

4. For this circuit, only the Channel 1 is used to record the waveform. Using the digital oscilloscope with Channel 1 set to DC, the waveform and its period, amplitude, and peak-to-peak value are recorded.
5. The 0.47 uF disc ceramic capacitor across R_L similar to the way shown below. The effect of placing the capacitor is observed, and the waveform and ripple voltage (V_R) are recorded using the oscilloscope. The digital multimeter is used to measure V_{DC} across the capacitor.

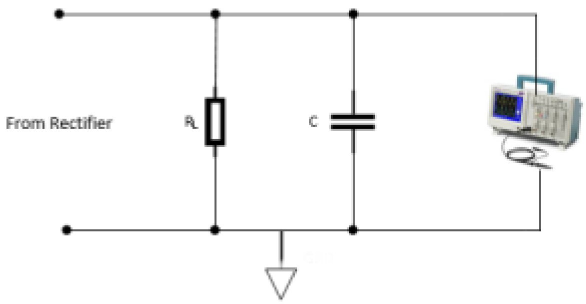


Figure 5

6. Step 5 is repeated for the 4.7 uF electrolytic and 100 uF electrolytic capacitors.
7. The ripple factor (r) is calculated using the equation below for each capacitor.

$$r = \frac{V\,(RMS)}{V_{DC}} = \frac{V_{r(p-p)}}{2\sqrt{3}V_{DC}}$$

Tabulated Data

All values in 3 significant figures.

Steps 5 to 7:

C (uF)	V_{DC} (V)	V_R (V)	r
0.47	4.60	7.20	0.452
4.70	6.43	2.80	0.126
100	7.37	0.600	0.0235

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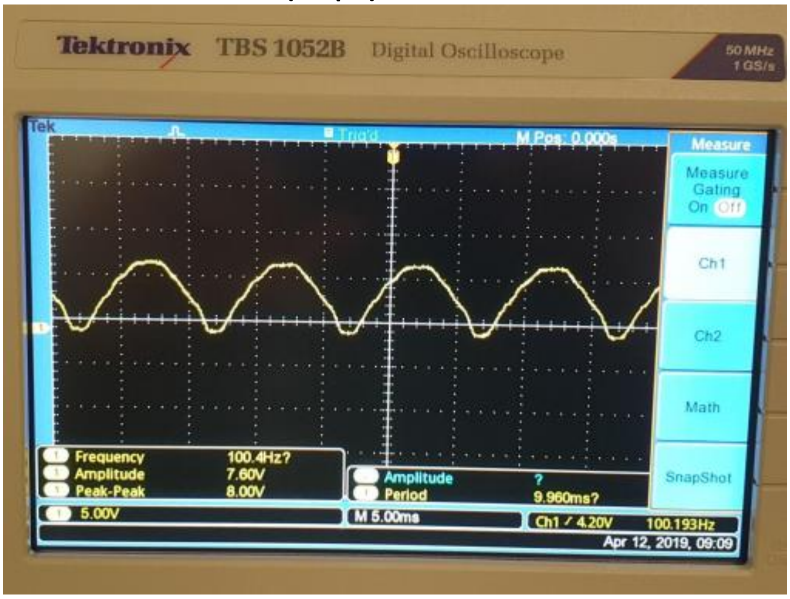
Analysis

Half-wave rectification (Step 2):

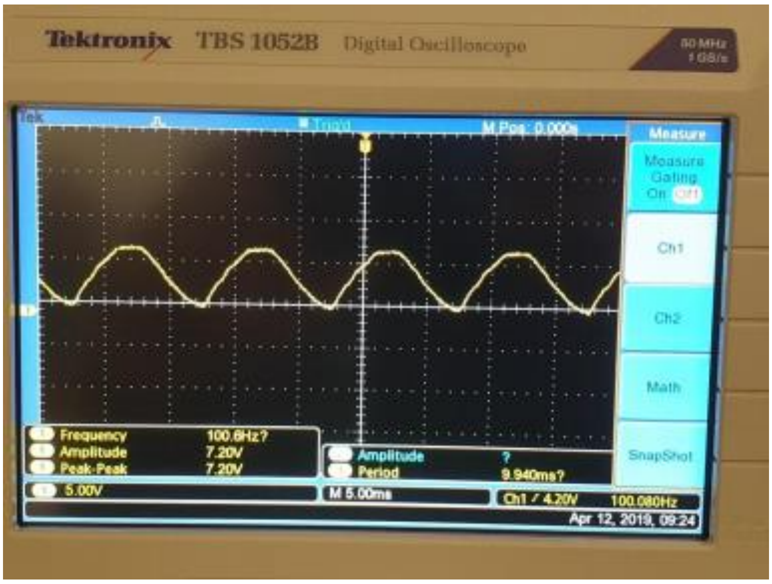
As the name suggest, the Channel 2 output wave is half of the original input wave.

Full-wave rectification (Step 4):

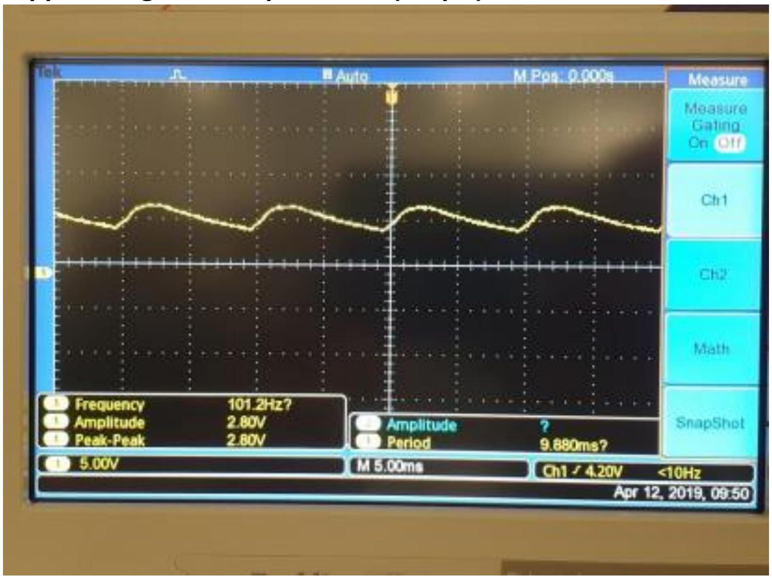


For the full-wave rectifier, we get a full sinusoidal wave as an output.

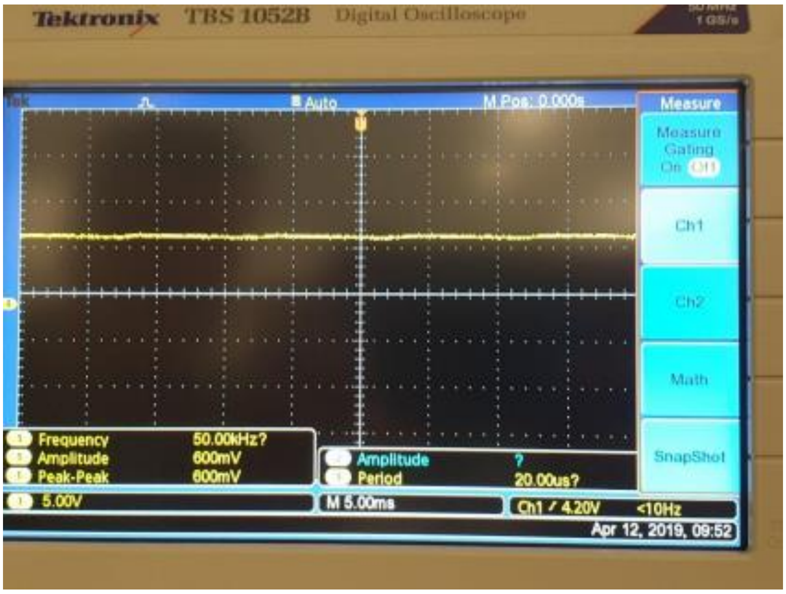
Ripple with 0.47 uF capacitance (Step 5):



Ripple using 4.7 uF capacitance (Step 6):



Ripple using 100 uF capacitance (Step 6):



It is clear from our results that as the capacitance increases, the ripple factor decreases, effectively creating a DC out of an AC.

Conclusion

The purpose of this lab was to understand the operation of diodes, and to illustrate the techniques of half-wave and full-wave rectification, and the filter of a rectified AC signal to produce a steady DC result. We tested all this by building circuits and observing results that we got from our oscilloscope. From the data, it is clear what half-wave and full-wave rectifiers do, and how capacitors can cause ripple effects in the waves when filtering them, with higher capacitance causing more stable signals from an AC, effectively producing a DC. From this experiment, I learned more about diodes, rectification, and filtration, and I was shown further applications of lab equipment such as the oscilloscope.

Experiments #8/9

Objective

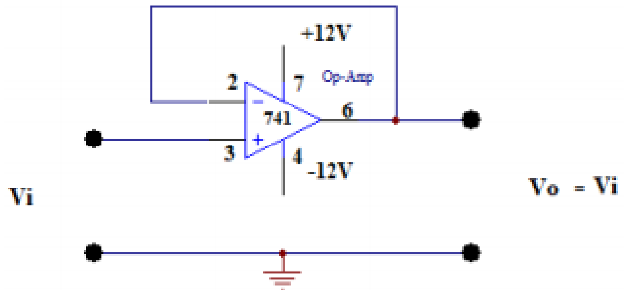
To understand how an operational amplifier (op-amp) works and the applications of it, and gain experience in using a basic integrated circuit package in a few different configurations.

Materials

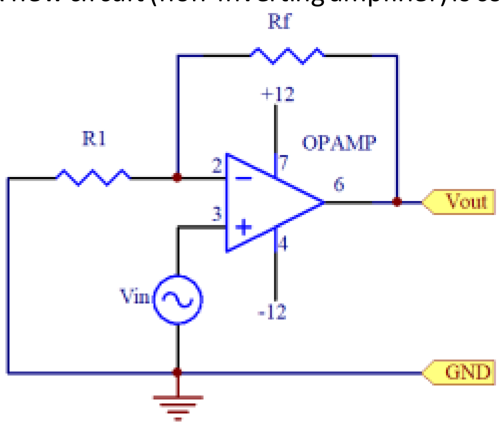
- 741 op-amp
- 1 kΩ, 2 kΩ, 4.7 kΩ, 10 kΩ, and 22 kΩ resistors
- Breadboard with +12 V power supplier built in
- Digital multimeter
- AA battery
- Oscilloscope
- Function generator

Procedure

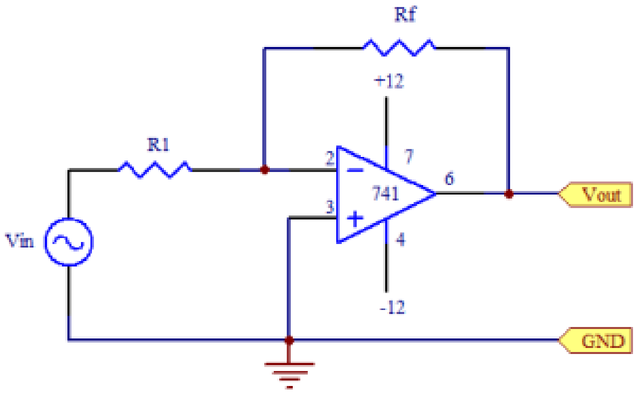
1. The following voltage follower circuit is constructed:



2. The function generator is used to apply an input voltage of 5 V_{P-P} to Pin 3 of the op-amp with a frequency of 1 kHz and Channel 1 of the oscilloscope is used to connect it as the input signal, while Channel 2 is used to connect to the output voltage, aka Pin 6.
3. The input and output signals displayed on the oscilloscope are recorded, along with the amplitude and phase of the two signals.
4. A new circuit (non-inverting amplifier) is constructed as shown below.



5. The 10 kΩ resistor is used as R_1, the 4.7 kΩ is used as R_F (feedback resistor), and 0.4 V_{P-P} sinusoidal signal with 1 kHz frequency is used as V_{IN}.
6. The oscilloscope, which is connected to V_{OUT} via Channel 1 and V_{IN} via Channel 2, is used to measure the amplitude of V_{OUT} with changing values of V_{IN}. The waveforms are recorded.
7. The voltage gain (A_V) in the circuit is calculated using the equation below and is compared to the results obtained in Step 6.
   $A_v = 1 + \frac{R_f}{R_1},$
8. The peak-to-peak V_{OUT} is recorded for when V_{IN} is equal to 2 V_{P-P}.
9. Step 8 is repeated for 10 kΩ and 22 kΩ resistors as R_F, with A_V being calculated for each resistor.
10. A new circuit (inverting amplifier) is created as shown below. R_1 = 10 kΩ, R_F = 22 kΩ, and V_{IN} is the same as what was used in the last circuit.



11. Steps 6 to 9 are repeated for the circuit for all R_F values, except with the equation shown below being used to calculate the gain. The phase relationship between the input signal and output signal is observed and noted.
12. A new circuit (summing amplifier) is created, with R_F = 2 kΩ, R_1 = R_2 = 1 kΩ. A 1.5 V AA battery is used as V_1. A DC power supply is used for V_2, set to 3 V_{DC}. The digital multimeter is used to measure the output voltage for V_1 = +1.5 V and V_2 = -1.5 V.

Tabulated Data

All values in 3 significant figures.

Voltage follower:

	Peak to Peak (V)	Amplitude (V)
Input	5.28	5.12
Output	5.28	5.12

Non-inverting amplifier:

V_{IN} (V)	0.400	0.600	0.800	1.00	1.20	1.40	1.60	1.80	2.00
V_{OUT} (V)	0.588	0.882	1.18	1.47	1.76	2.06	2.35	2.65	2.94

R_F (kΩ)	A_V	V_{OUT} (Peak to Peak) (V)
4.70	1.47	3.00
10.0	2.00	4.12
22.0	3.20	6.48

Inverting amplifier:

V_{IN} (V)	0.400	0.600	0.800	1.00	1.20	1.40	1.60	1.80	2.00
V_{OUT} (V)	-0.900	-1.36	-1.80	-2.24	-2.68	-3.14	-3.58	-4.00	-4.40

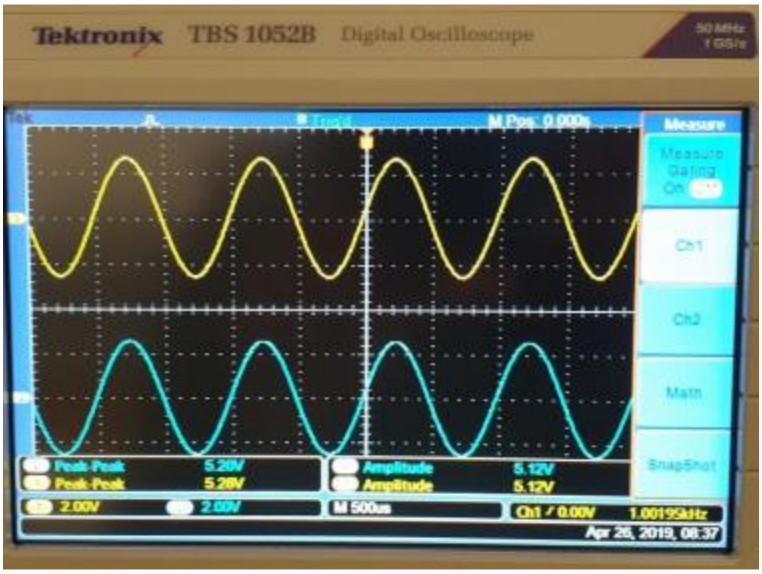
R_F (kΩ)	A_V	V_{OUT} (Peak to Peak) (V)
4.70	-0.470	1.00
10.0	-1.00	2.08
22.0	-2.20	4.48

Summing amplifier:

V_1 (V)	V_2 (V)	V_{OUT} (Peak to Peak) (V)
+1.50	+3.00	-9.07 (Theoretical: -9)
-1.50	+3.00	-2.65 (Theoretical: -3)

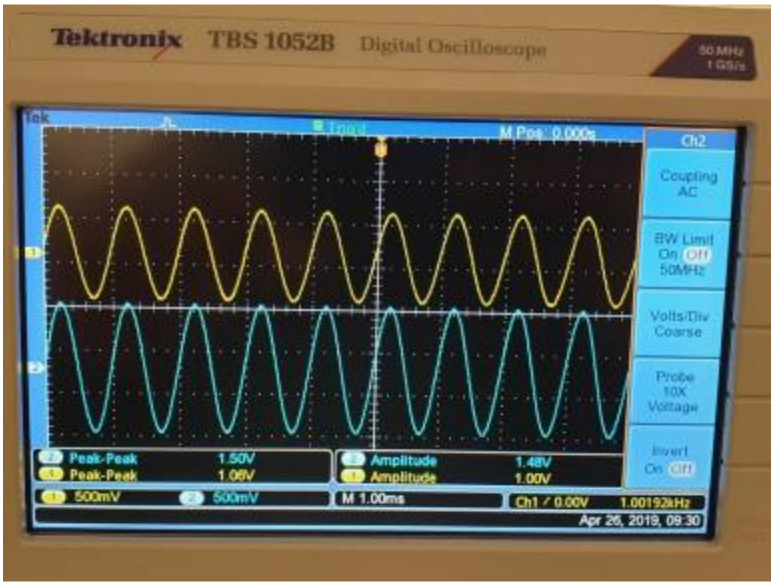
Analysis

Voltage follower:



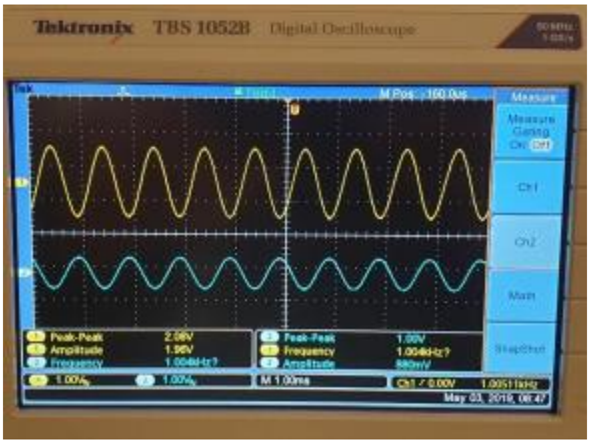
The output is the exact same as the input. They also have the same peak-to-peak and amplitude values.

Non-inverting amplifier:



The output has a larger peak-to-peak value than the input. The voltage gain is calculated to be 1.47. This checks out when comparing to our results. As R_F increases, the voltage gain increases, in turn resulting in a higher amplitude.

Inverting amplifier:



The output has basically been turned upside down to the input and has a larger, but negative V_{OUT} compared to the V_{IN}. It also has a phase delay of π, or 180 degrees. The gain is calculated to be -2.2, and when compared to the results we obtained in the table, it checks out. As R_F increases, the value of gain negatively decreases, resulting in a negative increase in the output's amplification.

Summing amplifier:
The output is a DC signal, the result of summing an AC and a DC signal. When calculated theoretically, the V_{OUT} values we obtained in the experiment turn out to be valid.

Conclusion

The purpose of this experiment was to understand the how an op-amp works, to gain experience in using a basic integrated circuit package in several different configurations, and op-amp applications. This was tested by constructing several circuits with different op-amp configurations and testing different R_F values for these circuits. The oscilloscope and digital multimeter were used to record data. The data fully agrees with the theory behind the op-amp configurations. From this lab, I learned more about op-amps, the theory behind them, different op-amp configurations, and the applications of op-amps, as well as how to integrate op-amps into circuits.