University of Colorado Boulder
ECEE Department

ECEN 2250 - Introduction to circuits and electronics - Fall 2023
Location: Engineering Center, ECCR 1B40, MWF 2:30PM - 3:20PM
Instructor: Professor Eric Bogatin, Dr. Mona ElHelbawy
Lab #5
Lab Title: opAmps basics properties and circuits
Date of Experiments: October 16th, 2023
Names: Connor Sorrell

Experiment 1

a) Using the wavegen as the input to the non-inverting amplifier and testing different DC voltages, the input and output voltages read by the DMM voltmeter are as follows:
   - WG = 0 V:
     - Input = -0.4 mV
     - Output = 1.5 mV

   - WG = -1V:
     - Input = –1.003 V
     - Output = -1 V

   - WG = 1 V:
     - Input = 1.001 V
     - Output = 1.003 V

   - WG = 5V:
     - Input = 5 V
     - Output = 4.5 V

   All of these values make sense and were what I expected. The output, in each case, is very similar to the input voltage. This is because the spec of the opAmp is very good and working as designed - a voltage follower. Whatever voltage is inputted should always come out. The one time where this was not the case was with the 5V input, in which the output voltage was only 4.5V, because the voltage cannot exceed that of the rails.

b) Generating a 1 kHz sine wave with amplitude 1 V and offset 1 V using the wavegen and using it as the input to the follower: Before running the experiment, I expect to see a 1 V amplitude sine wave for both the input and output, because nothing should change the voltage significantly in this circuit. After simulating, I was right. The input and output waves are identical sine waves with amplitude of 1 V.

c) What we actually measured here is the slew rate of the opAmp. I found the slew rate to be 2V / 0.75 micro seconds, meaning the slew rate is 2.66 Volts/microsecond, which is what the opAmp is rated to. This is interesting because yet again we are reverse engineering in order to find what is really happening inside these parts, in this case we are measuring how fast the opAmp can truly “turn on” voltage.

d) No matter what the amplitude of our input sine wave is, the output voltage will never exceed 4.5V, because that is the voltage on the rails of the opAmp.

Section 2:

In this section, we changed the AD2 power supply to a 4V amplitude. We then adjusted the waveform input signal to be a 1 kHz triangle wave with an amplitude of 5V and a 0 V offset. Before running the simulation, I expected the input waveform to look like a triangle wave but cut off after 4V amplitude because the opAmp will not output past its rail voltage. So the waveform should show some saturation.

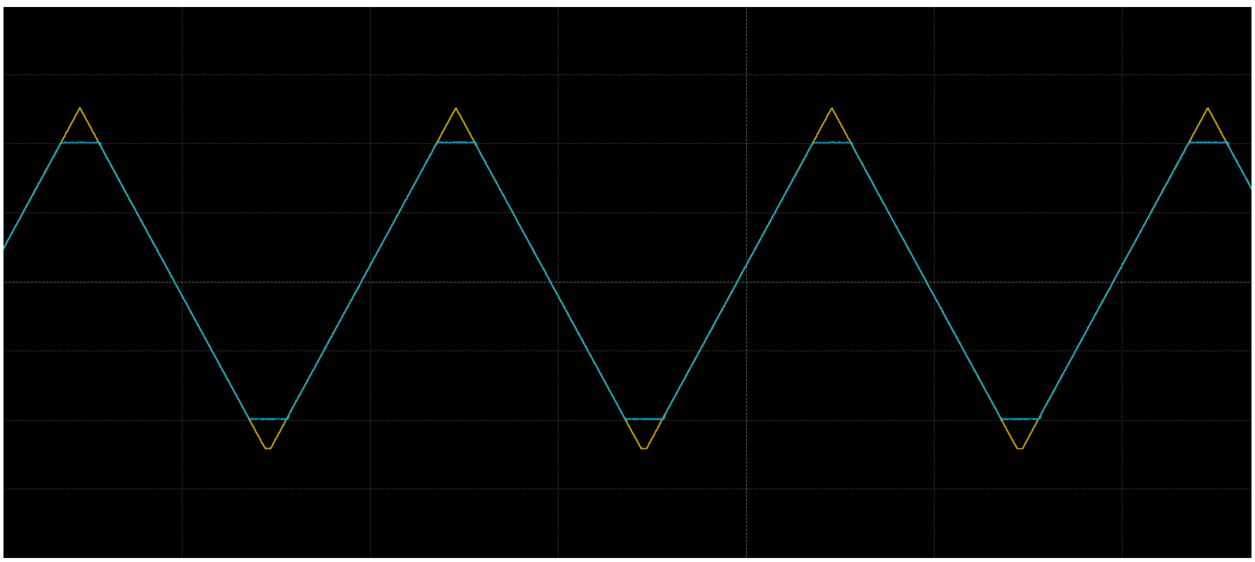

Figure 1.0.1: Screenshot of the input signal (yellow) and output waveform (blue)

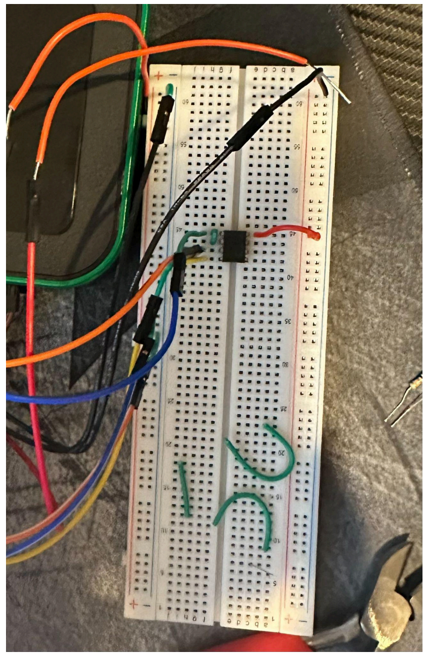

Figure 1.0.2: The opAmp circuit for the follower.

Experiment 2:

Section 1: Using the wavegen as a voltage source set to a 4V DC voltage, some measurements can be found.

a) What is the input voltage you measure with your AD2 scope? Measure it with your mark 1 eyeball and with the measurement function.

   Measuring the input voltage of the follower using channel 1 of the AD2 scope, I see that the input voltage is right around 4V, maybe a little higher. Using the measurement function, I found the input voltage of the follower to be 4.0165 V, which is what I expect it to be, because of the 4V DC supply.

b) What is the output voltage of your follower measured on chan 2 of the AD2?

   The output voltage of the follower, measured on channel 2 of the AD2, is 4.0159 V, which is yet again expected because this is a follower, meaning the voltage out should equal the voltage in.

c) Now add a 1 Meg series resistor between the Wavegen and the input to your follower. With the AD2 chan 1 still connected to the input of your follower, what do you expect to measure as the input and output of your follower? What do you measure, and why?

   Before adding a 1 Meg series resistor between the wavegen and the input to the follower, I expect the input and output voltage to remain the same. After putting the resistor in, my prediction was correct. The voltages stayed the same because the 1M ohm resistor doesn't do anything because it is in series, and the input resistance of the opAmp is already so large that adding more resistors in series is negligible.

d) Now disconnect the chan 1 input to your follower's input. What do you expect to measure as the output of your follower and why? What do you actually measure as the output?
   Before disconnecting the chan 1 input to the followers input, I expect to still measure a 4V output. Sure enough, I am right, and the output voltage is still 4V. This is because the chan 1 input is not determining the output, rather the wavegen is.

e) What do you interpret as the input resistance of the AD2 channel 1 input resistance?

I interpret the input resistance of the AD2 channel 1 input to be 1 M ohm.

f) Suppose the smallest change in output voltage you can measure is 10 mV between a direct connection of the Wavegen to input of your TLV272 follower and with a series 1 Meg resistor. What is the highest input resistance of the TLV272 you could measure? What is your estimate of the lower limit of the input resistance of the TLV272?

I measured 10 M ohms resistance. I would estimate that the TLV272 has near this resistance because the 1M ohm resistor only changes it by 10mV, so the input resistance must be much higher.

g) Connect your DMM as a voltage meter to measure the input voltage to the follower when the 1 Meg resistor is in series to the follower. Where do you connect the other terminal of the DMM to measure the input voltage of the follower?

To the ground because this is a single ended measurement.

h) How much did the follower's output voltage change when you connected the DMM to the input?

The followers output voltage changed from 4 V to 3.69V, meaning it changed by .31 V.

i) Why did the follower's output voltage change?

Because the DMMs voltmeter has a higher resistance than the AD3.

j) If you interpret this change assuming an input resistance to your DMM, what value of input resistance would you use to match your measurement? Hint: you might want to draw the equivalent circuit of the DMM, the voltage source, the series resistor and the input to the follower. This is situational awareness.

If we interpret this change assuming an input resistance to the DMM, we can use the equation P = V^2/R to find a suitable resistor to match the input resistance. Power needs to stay below 0.25 watts in order for the resistor to not heat up. Deriving the equation to R = V^2/P, we get R = (.31)^2/0.25 = .38 ohms ∓ 20%.

Section 2:

The unloaded output voltage of the follower driving an open circuit is an average of 481 mV with a max of 5V. Calculating the smaller resistor value I can add to the output so that the power consumption at a 100% duty cycle is 0.25 watts: R = V^2/P   R = 2.4^2/0.25 = 230 ohms. But, the closest resistor in our kit to 230 ohms is 220 ohms. Connecting this to the follower, I expect to see a relatively small change in output voltage, because if this were an ideal opAmp, I would expect to see no drop. After experimentation, the voltage does in fact drop because the resistor was added. I suspect this is because the output resistance of the TLV272 is very very small, so a 220 ohm resistor actually does have an impact.
Plugging the voltage drop in to find resistance: (220 ohms * Voltage change(.34 V))/3.66 V = 20 ohms which is my estimate for the output resistance of the TLV272.

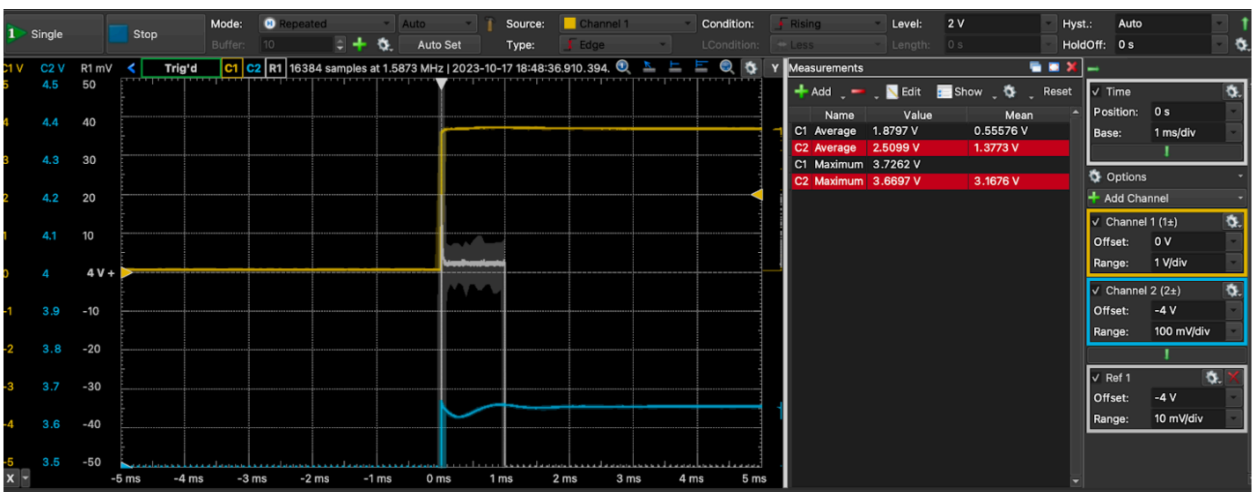

Figure 2.1.0: Capture of pulse signal output with no load and with the resistor attached. Zoomed in to show the trace of the voltage drop.

Experiment 3

Section 1:

a) What values of resistors did you use in your inverting amplifier?

To get a gain of 2, I will use a 10k resistor and a 4.7k resistor

b) Why did you select these values?

I selected these resistor values because the equation for gain value is (1 + Rf/Rs), so when Rf = 10k and Rs = 5k, the equation simplifies to (1+1) = 2

c) What do you measure as the input amplitude to your inverting amplifier?

Using the ad2 scope, I measured the input amplitude to be 1V

d) What is the output amplitude of your sine wave from the inverting amplifier?

Using the ad2 scope, I measured the output amplitude to be 2V

e) What else is different between the input and the output?

The output is just an inverse of the input signal.

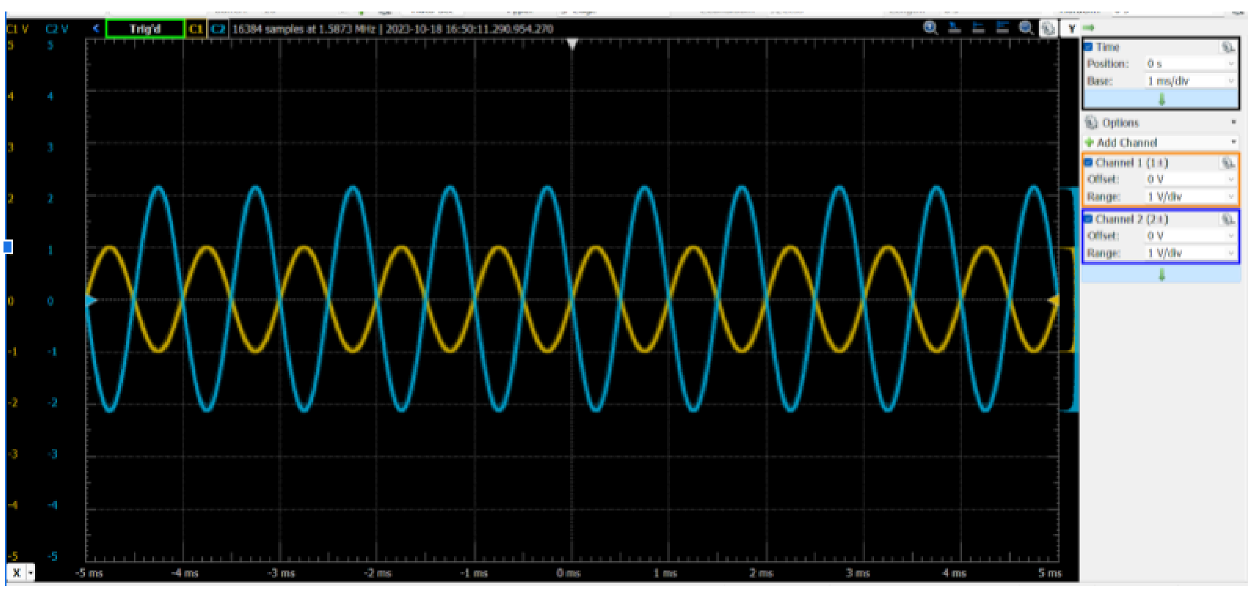

Figure 3.0.1: Shows the input and output waves of the inverting amplifier.

Circuit 2:

a) <u>What value resistors did you select and why?</u>

I selected three 10k resistors, because the gain needs to be equal to 1. The equation for solely the gain in the inverting summing amplifier, for each channel, is just simply Rf/Rs, so in each channel the gain is (10/10) = 1.

b) <u>What do you expect to see as the output of your summing amplifier?</u>

I expect to see an output with 2 signals where one is the inverse of the other. This is because it is an inverting summing amplifier. However, I should see clipping, meaning that channel 2s voltage (the output) should not ever be negative.

c) <u>Measure the output signal from your wave gen that has the sine wave in chan 1. Measure the output of your summing amplifier in chan 2. What is different between the summing amplifier output and the wave gen input on channel 1?</u>

Measuring the output signal from the sine wave in channel 1, and measuring the output of the summing amplifier in channel 2, some differences and similarities can be seen. First off, channel 1 is still a sine wave, which is expected. But, channel 2 looks like the inverse of channel 1, except it never goes into negative voltage values.

Section 2:

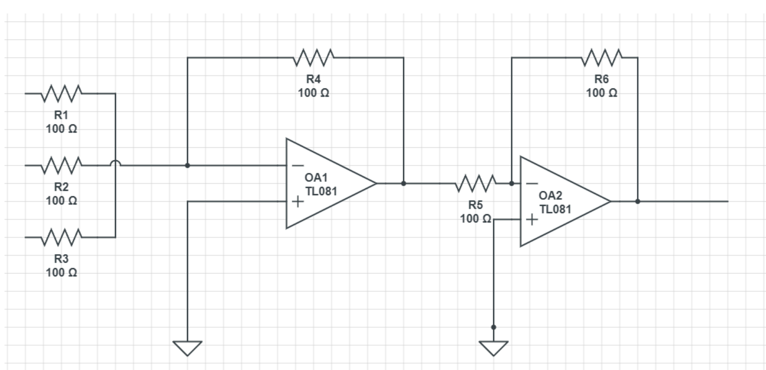

Figure 3.2.0: Non-inverting amp created using 2 inverting amps in series

On the breadboard, this circuit just has the Vout of one opAmp connecting to the Vin of another. This circuit was a bit confusing for me to make but a non-inverting amp is very useful so it was worth the task.

Experiment 4

Section 1:

a) In experiment 1, what is the name of the circuit you built?

The name of the circuit in experiment 1 is a transconductance amplifier.

b) How is the output voltage related to the input current?

The transconductance amplifier produces an output voltage that is proportional to the input current.

c) How did you verify the LED or photodiode was reverse biased?

I verified the LED was reverse biased by configuring it in the breadboard to where the LED was not on. In a forward biased configuration, the LED would be on and there would be a lot of current flowing.

d) With the LED covered, what was the output voltage and the input current?

With the LED covered, the voltage goes down. When it is not covered, the output voltage hovers around 3.5mV, however when it is covered from light, the output voltage drops to around 0.9mV. The current ideally should be 0, but it was around 1 nano-amp.

e) How effective is the LED as a light detector? If you have a photodiode, how effective is it as a photo detector?

An LED is somewhat effective as a light detector. It is not drastic, but covering it versus leaving it uncovered does show a slight output voltage drop.

Section 2:

a) With the TLV272 set up as a follower, and with no input to the p input, I measure an average voltage of .75V. Over 60 Hz pick up, the amplitude of the output voltage is roughly 290 mV. This is called a floating input because the input is essentially unused, no value is fixed.

b) Adding a short 2 inch length of wire to the input of the follower to serve as an antenna, the new value of the 60 Hz amplitude is around 1.52V.

c) To only be sensitive to a low frequency, (lower than 60Hz), I created a filter on my scope to filter out the high frequencies. Doing this shows dramatically less 60Hz noise, but still is effective in showing the lower frequency behavior.

d) When I move closer to the wire, the voltage spikes up. When I rub my shirt to create static energy and then move my hand near the wire, it spikes even more. Conversely, touching the ground wire lowers the voltage back to its original state. Bringing tape close to the wire causes the voltage to be negative, and this is because it must be negatively charged. However, my hand must be positively charged, because it makes the voltage rise. This lab is extremely cool because I never thought I'd be building a static electric field detector. It is very interesting to watch the wave signal on the scope as I get closer and further from the input wire. Not only did this lab teach me a lot about opAmps and detectors, but it shows how useful these are in the real world. I am also surprised by how simple this circuit is, because measuring the static electricity around me seemed like a very complex task before doing this experiment.

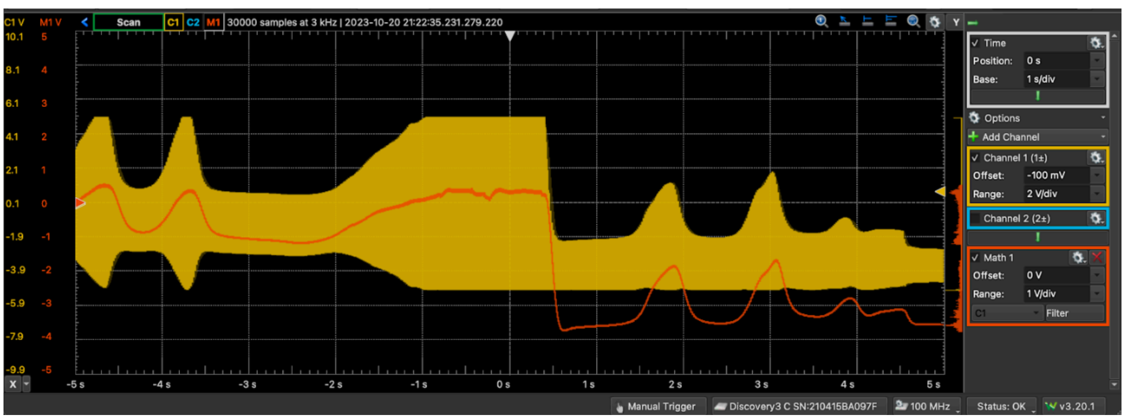

Figure 4.2.0: Screenshot of the scope trace when moving closer and further to the wire.

Figure 4.2.1: Shows the follower circuit built on the breadboard