Alex Gieson
Section 007
Lab 07
Lab 7: Operation Amplifier Characterization
Mar 19, 2021

Abstract

This report will be useful to those learning about operational amplifiers and will go over the characteristics of the operational amplifier that was built in the previous lab. The schematic for the operational amplifier is shown in figure 1.

First, we test it as a buffer circuit to make sure that the operational amplifier is working as expected. In this task, we also go over the characteristics of the buffer circuit and when it might be useful.

Next, we measure the slew of the operational amplifier, which is essentially the rising and falling slope when it is transitioning between a high and low state. In this task, it is tested using a square wave.

In the next task, we measure the unity gain bandwidth by measuring the open loop gain and phase response using the network tool in waveforms. Using the generated plots, we are able to measure the unity gain bandwidth of the operational amplifier.

Lastly, we discover the inverse relationship between the gain bandwidth product (GBW) and gain. This is done using 3 different feedback resistor values that vary the gain and measuring the gain and wavelength at the -3dB point and -0.1dB point. These values are used to calculate the GBW.

Task 7.4.1:

Objective

This section will demonstrate how to build and test a buffer circuit, which is important when working with sensitive electronics.

Procedure

First, the AD2 was connected to a computer and wired up to the breadboard. The op amp circuit from the previous lab was used for this lab and is shown below in figure 1.

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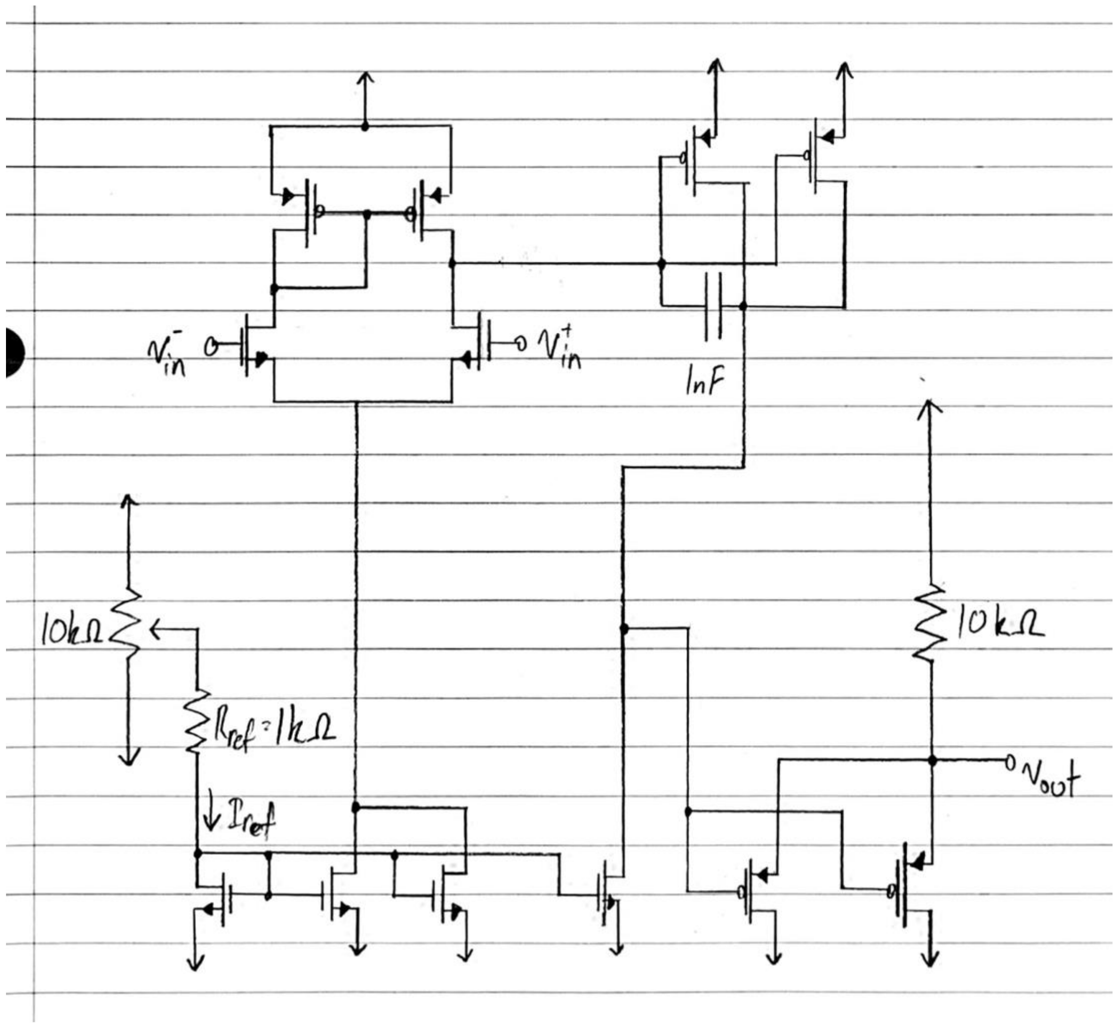
FIGURE 1



Operational amplifier circuit used in lab 6

I_{ref} was set to be 200µA. Next, the op amp buffer circuit shown below in figure 2 was constructed and a 500Hz 1V peak-to-peak sine wave was applied to V_{in}.

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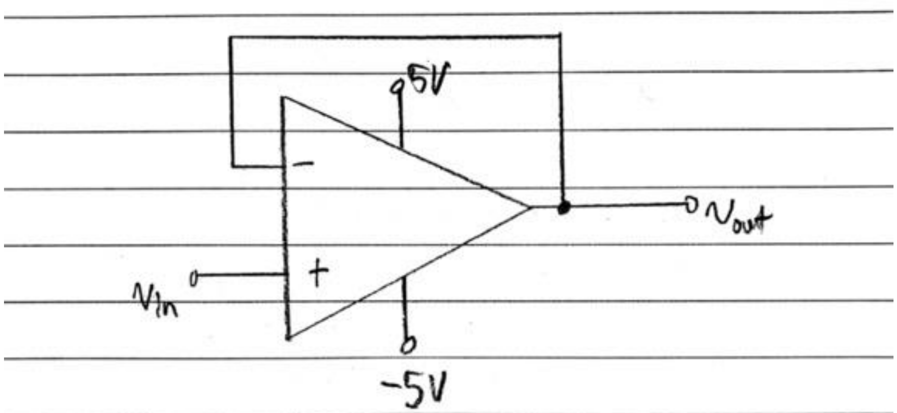
FIGURE 2



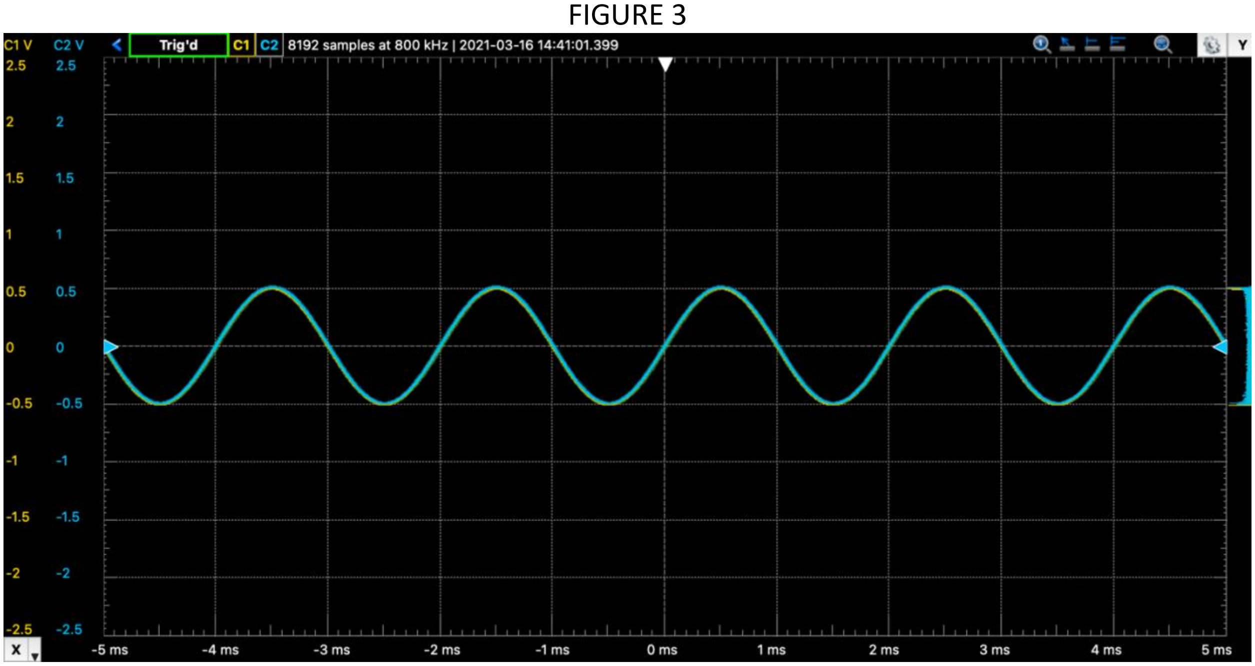
Op amp buffer circuit

V_{out} was recorded and measured in the oscilloscope.

Results/Calculations

The output measured from the op amp buffer circuit shown in figure 2 is displayed below in figure 3.

FIGURE 3



Vin and Vout of the op amp buffer circuit

Here we can see that the input and output signals are overlapping, which means they are the same. This output is what we would expect from an ideal operational amplifier, which is calculated by setting the + and – terminals of the op amp equal to each other, which would make V_{out} equal to the – terminal which is equal to the + terminal.

Conclusions

The op amp that was constructed acts like an ideal op amp would in the circuit shown in figure 2. The reasoning why the circuit shown in figure 2 is called a buffer circuit is because it acts like a buffer that relays the input signal to the output but cannot exceed 5V or go below -5V. This is important for sensitive electronics so that they cannot get damaged in case of a voltage spike.

Task 7.4.2:

Objective

This section will demonstrate how to accurately measure the slew rate of an operational amplifier.

Procedure

Using the same circuit from the previous task, a 1kHz 5V peak-to-peak square wave was applied to V_{in}. Using the oscilloscope, the transitions of the wave from low to high and high to low were zoomed in on and the slope of the transition was measured to obtain the slew rate values for rising and falling.

Results/Calculations

First, we observe the input and output of the op amp, which is shown below in figure 4.

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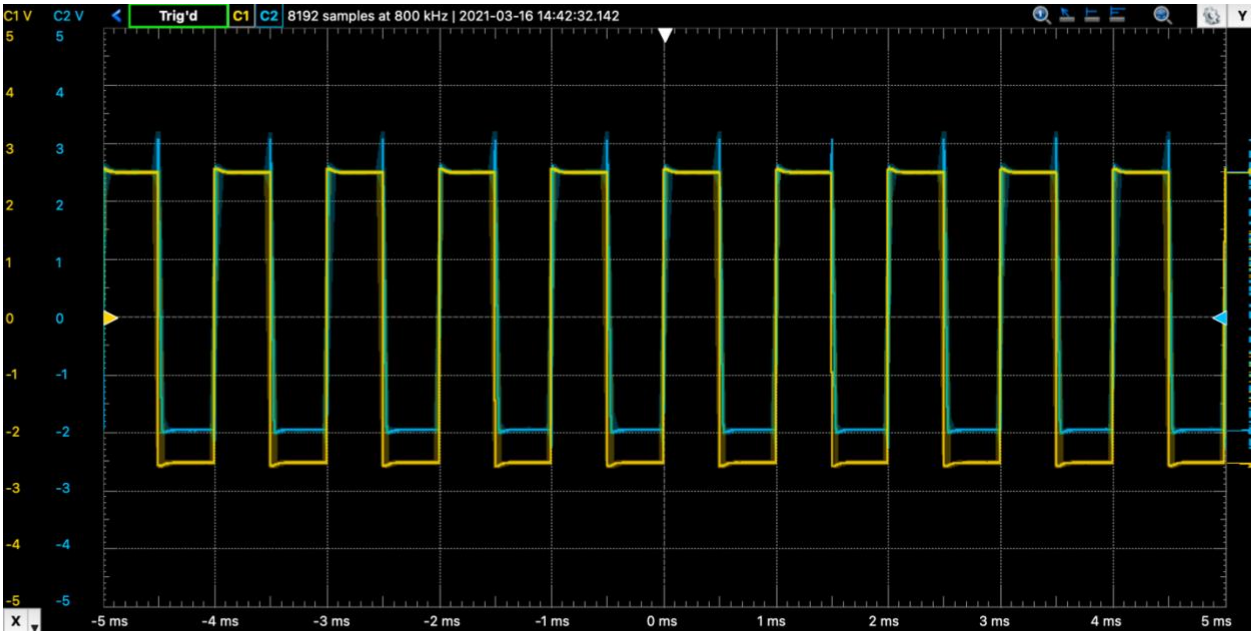
FIGURE 4

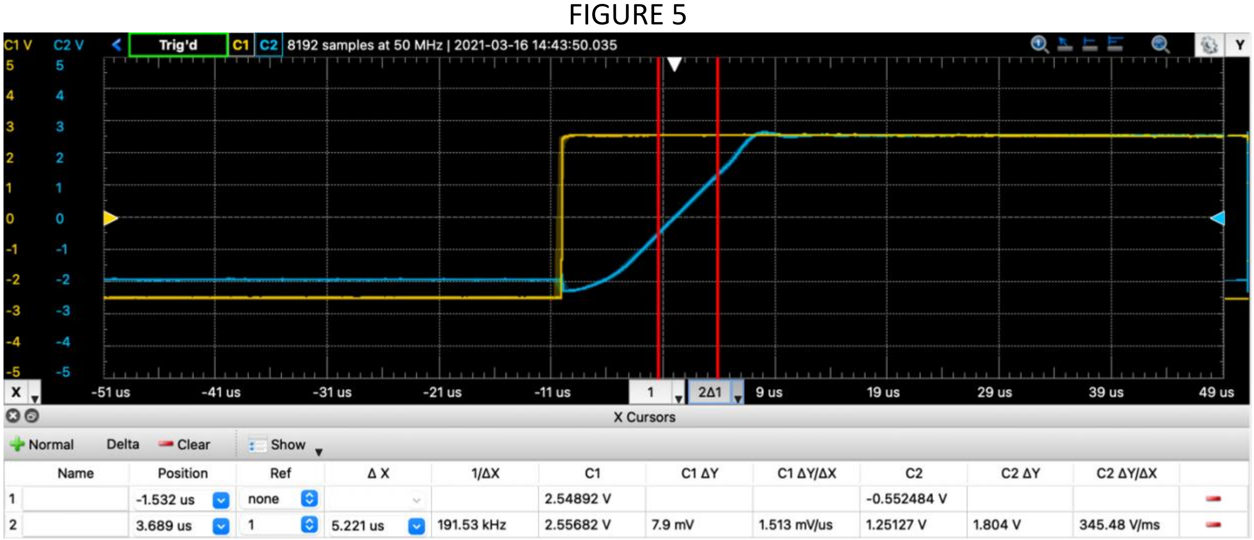


Input (orange line) and output (blue line) of the operational amplifier

Looking at the input and output, it looks like we would expect it to. Due to the source follower, the minimum output voltage is about -2, which is why it clips at the bottom of the wave. We can also see that the transitions are not as quick as the input wave is, which we will look closer at.

Zooming in to the oscilloscope at the rising edge of the wave, we can see that there is a clear slope of the line:

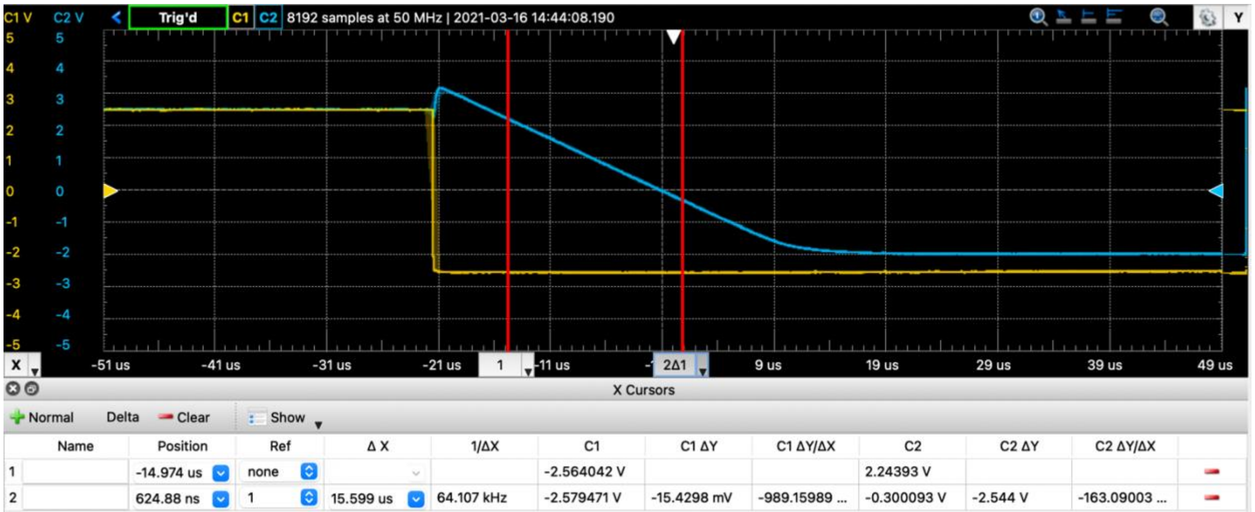
FIGURE 5



Transition of low to high showing measurements for slew rate

Here we can see that the blue line (output) does not transition as fast as the orange line (input). This is because the operational amplifier has a slew rate, and measuring with a cursors we get a slew rate of about 345.48 V/ms. Next, we will take a look at the falling edge, which is shown below in figure 6.

FIGURE 6



Transition of high to low showing measurements for the calculation of the slew rate

Again, we see that the blue line (output) does not transition as fast as the input (orange line). We have measured the slew rate with the cursors, which give us a value of about -163.09 V/ms.

Conclusions

The conclusions are that this task was successful as we were able to measure the rising and falling slew rate of the operational amplifier.

Task 7.4.3:

Objective

This section will demonstrate how to measure the unity gain bandwidth using the gain response of an operational amplifier.

Procedure

The operational amplifier was rewired to look like the circuit below shown in figure 7.

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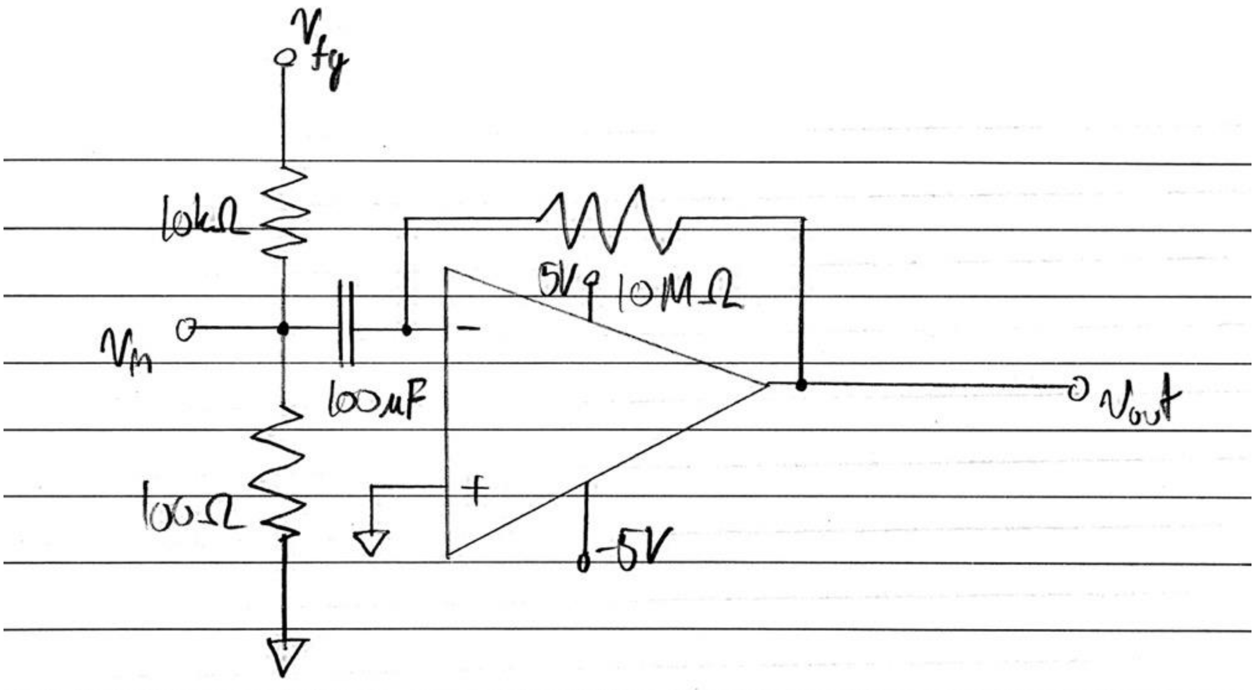
FIGURE 7



Open loop measurement circuit

A 100Hz 100mV peak-to-peak sine wave was applied to V_{fg}. The oscilloscope reading V_{in} and V_{out} is shown below in figure 8.

Next, the gain and phase response were measured and plotted from 10Hz to 500kHz. The values from this plot will help to characterize the operational amplifier and calculate the unity gain bandwidth.

Results/Calculations

First, the oscilloscope reading showing V_{in} and V_{out} is shown below in figure 8.

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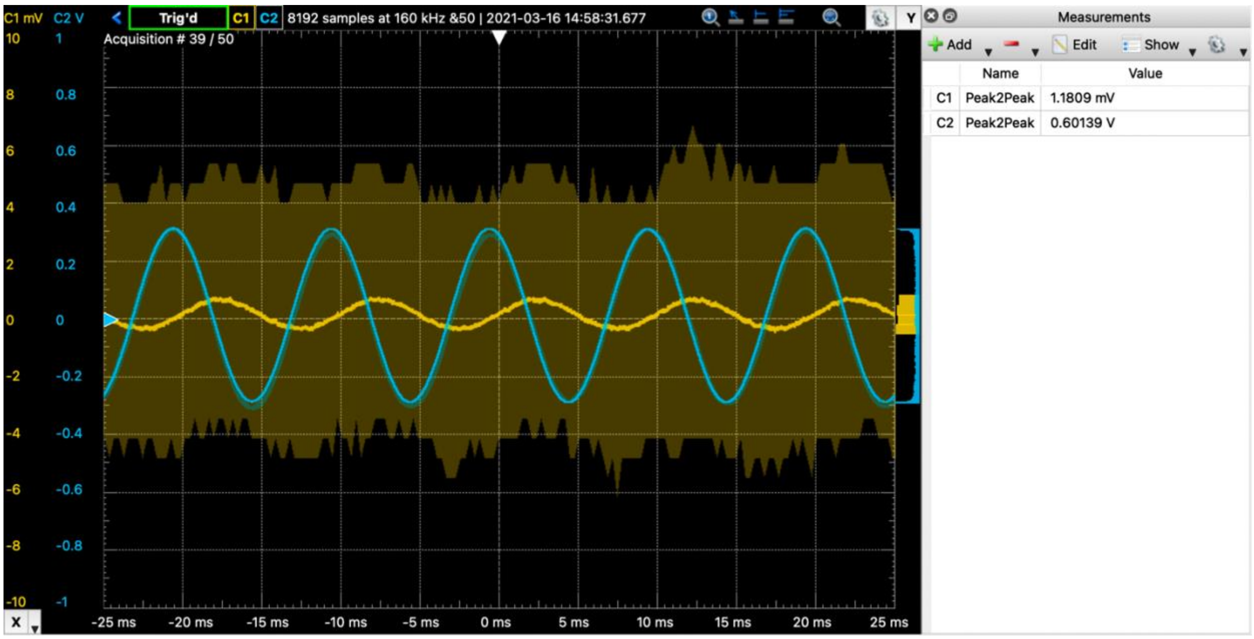
FIGURE 8



The orange wave is the input and the blue wave is the output

Looking at the measurements on the right of the oscilloscope, we can calculate the gain to be approximately 545. This, clearly, is a very large gain and is due, in part, to the 10 megaohm feedback resistor.

Next, the phase response was plotted, which is shown below in figure 9.

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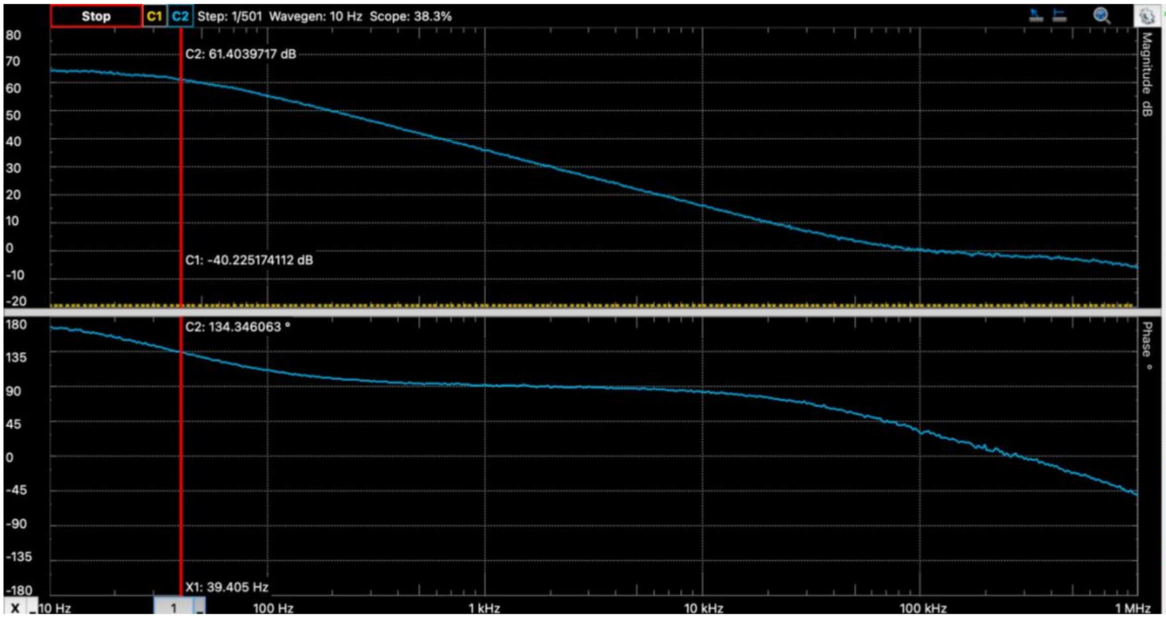
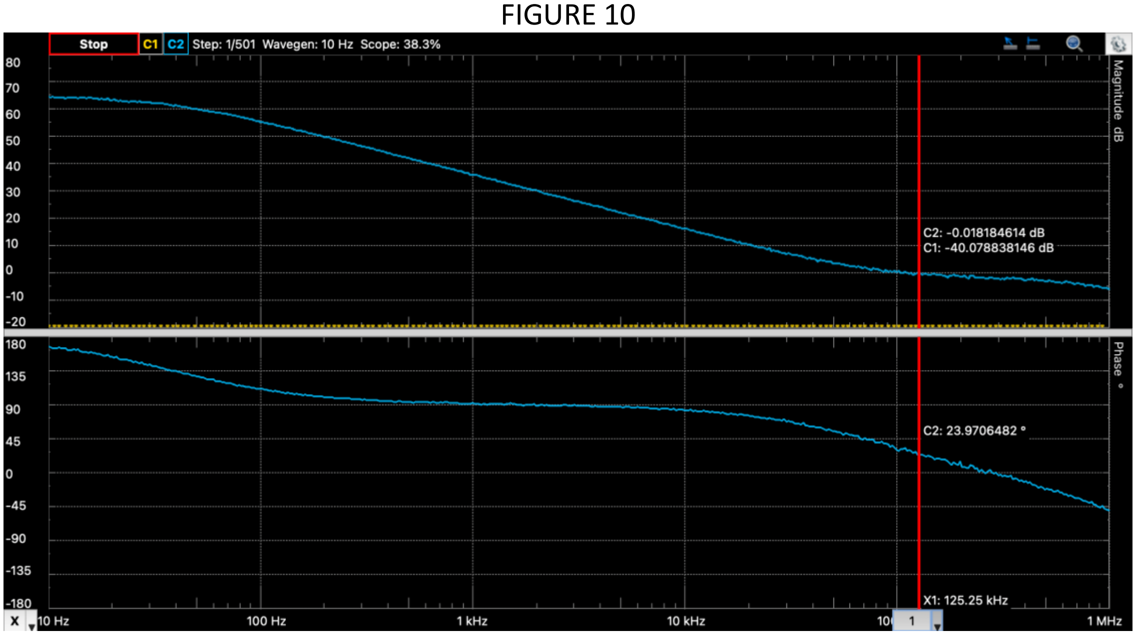
FIGURE 9



Gain and phase response of the op amp circuit from figure 7

Here, we can see the gain and phase response. The gain and phase decrease as the wavelength of the input decreases. Measured on the plot with the cursor is the -3dB point, which reads 61.4dB at 39.4Hz. At this point, the phase response is 134.3 degrees. Shown below in figure 10 shows the unity gain bandwidth measurement and the phase at that point.

FIGURE 10



Gain and phase response with a cursor at the unity gain bandwidth point

Here, we can see that the measured unity gain bandwidth is about 125.25kHz, and the phase at that point is 23.9 degrees.

Conclusions

This task was executed successfully as we were able to obtain the correct measurements with great accuracy using the oscilloscope.

Task 7.4.4:

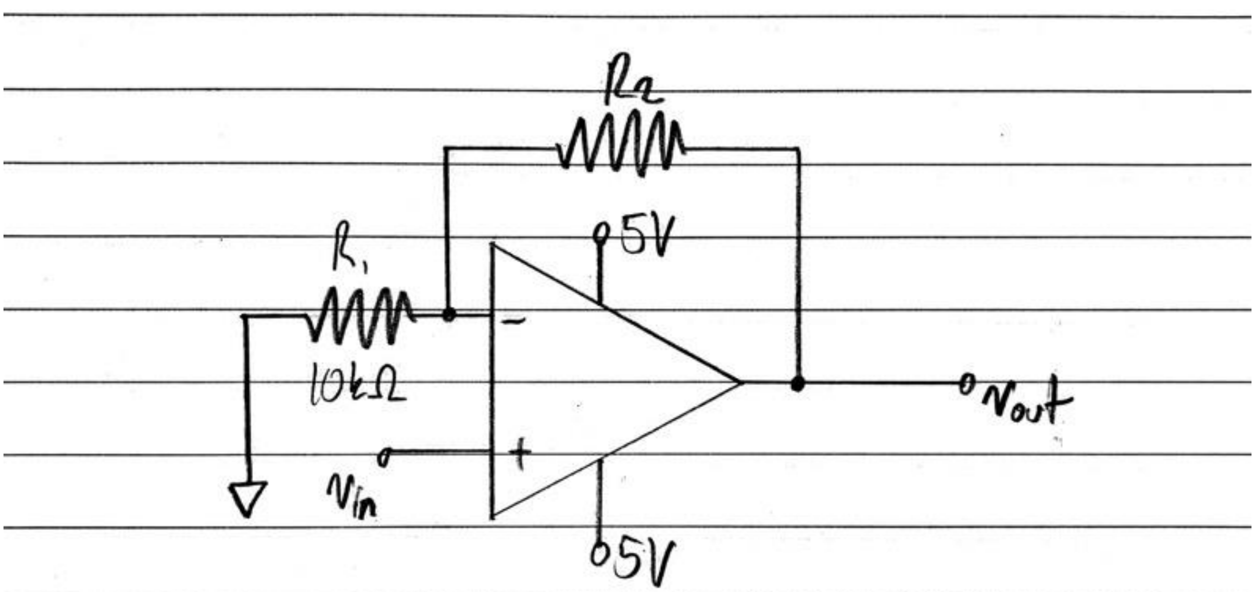
Objective

This section will demonstrate the relationship between gain bandwidth products and gain.

Procedure

The operational amplifier was wired together according to the circuit shown below in figure 11.

FIGURE 11



A non-inverting amplifier circuit

Multiple values were used for R_2, which were 100k ohms, 150k ohms, and 220k ohms. For each different resistor value, the gain versus frequency was plotted in order to measure the -3dB point and the phase at the -3dB point. For each resistor value the gain bandwidth product was measured.

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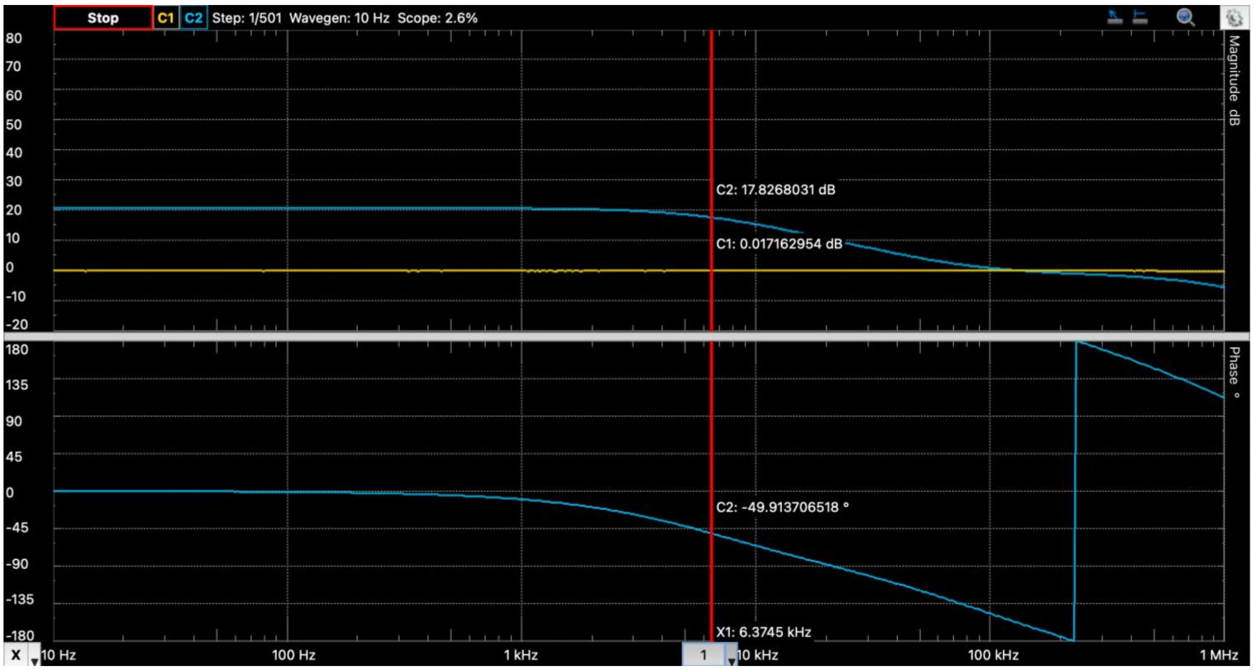
Results/Calculations

The expected gains of the amplifier with 100k, 150k, and 220k ohm resistors are 11, 16, and 23 respectively. These were calculated using the ideal op amp conditions and circuit analysis.

Shown below in figure 12 is the gain and phase response for the 100k ohm resistor.

FIGURE 12



Gain and phase response of the op amp with a 100k ohm resistor

Here, we can see that the -3dB point is at 17.82dB, which is at 6.3745kHz. The phase at this point is roughly -49.9 degrees. The GBW is calculated below using the -3dB definition:

$$\frac{6.3745kHz}{17.826dB} = \frac{6.3745kHz}{8.913} = 715.19Hz$$

And now using the -0.1dB definition:

$$\frac{2.135kHz}{20.762dB} = \frac{2.135kHz}{10.381} = 205.66Hz$$

Both of these measurements give us the maximum bandwidth of the entire operational amplifier circuit. Next, let's look at the gain and phase response for the 150k ohm feedback resistor, which is shown below in figure 13.

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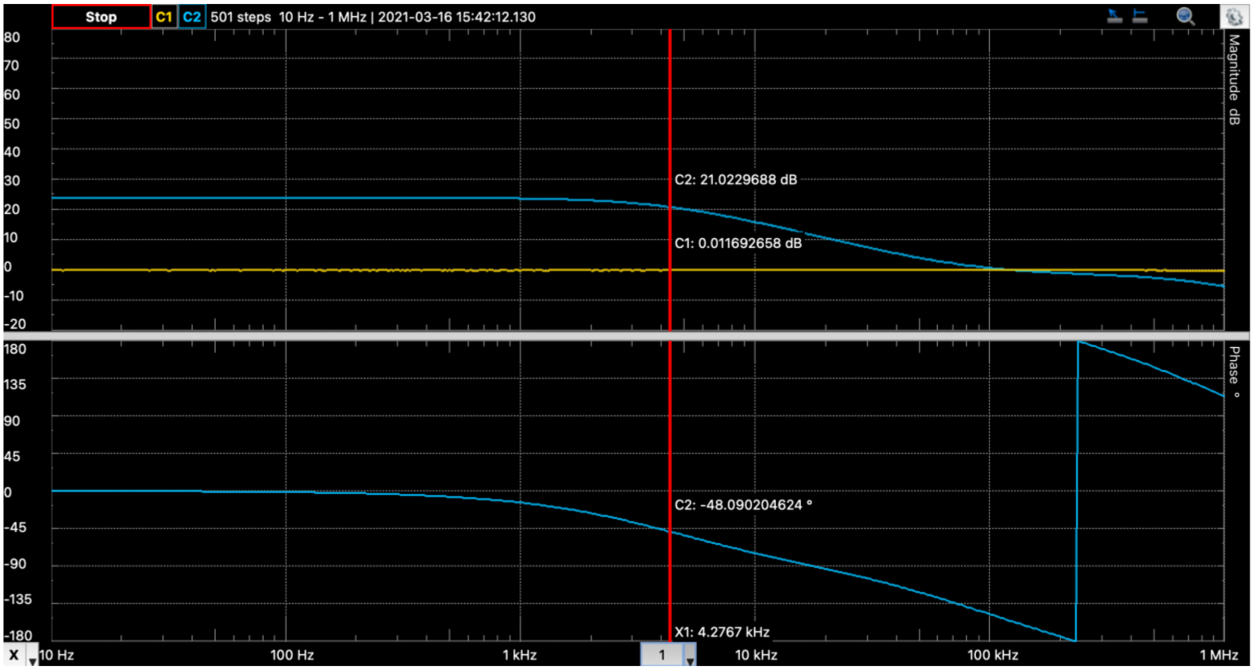
FIGURE 13



Gain and phase response for the op amp with the 150k ohm resistor

Here, we can see that the -3dB point is at 21.02dB, which is at 4.2767kHz. The phase at this point is roughly -48.09 degrees. The GBW is calculated below using the -3dB definition:

$$\frac{4.2767kHz}{21.026dB} = \frac{4.2767kHz}{11.246} = 380.28Hz$$

And now using the -0.1dB definition:

$$\frac{1.65kHz}{23.926dB} = \frac{1.65kHz}{15.714} = 104.998Hz$$

Both of these measurements give us the maximum bandwidth of the entire operational amplifier circuit. Next, let’s look at the gain and phase response for the 220k ohm feedback resistor, which is shown below in figure 14.

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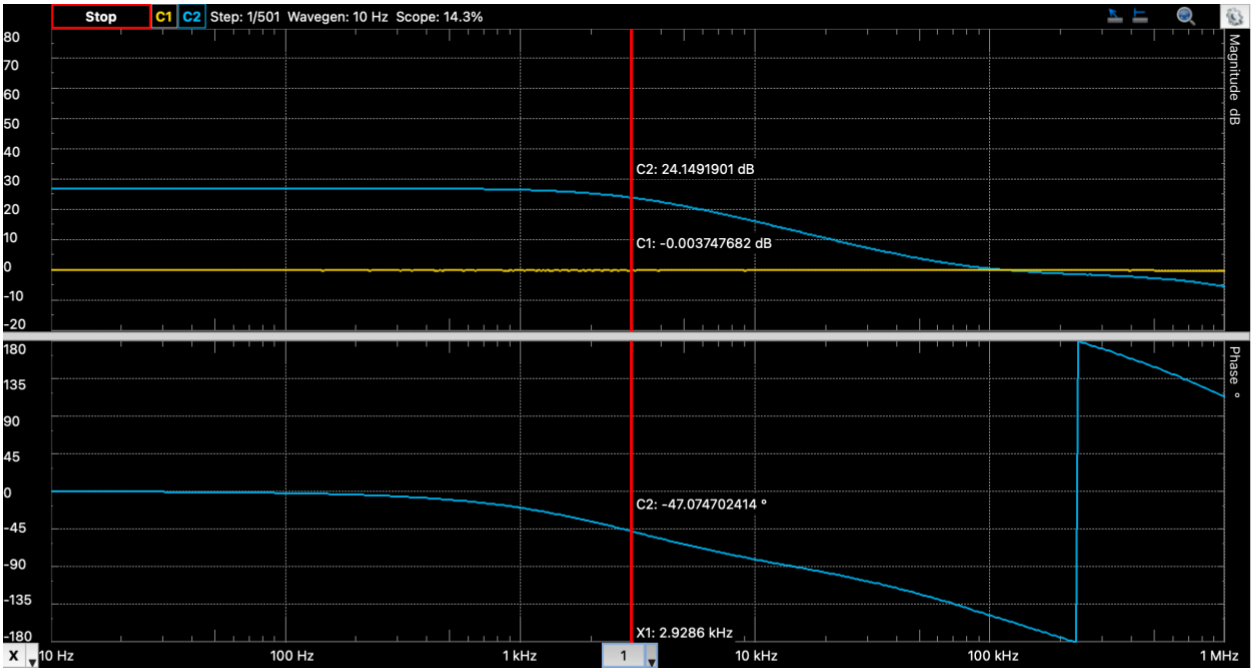
FIGURE 14



Gain and phase response with the 220k ohm resistor

Here, we can see that the -3dB point is at 24.149dB, which is at 2.9286kHz. The phase at this point is roughly -47.07 degrees. The GBW is calculated below using the -3dB definition:

$$\frac{2.9286kHz}{24.149dB} = \frac{2.9286kHz}{16.123} = 181.639Hz$$

And now using the -0.1dB definition:

$$\frac{1.45kHz}{27.149dB} = \frac{1.45kHz}{22.774} = 63.67Hz$$

Both of these measurements give us the maximum bandwidth of the entire operational amplifier circuit.

Now that we have calculated all the GBW's for all the different feedback resistor values, we can now compare how the GBW changes as a result of the gain. We can clearly see that as the gain of the op amp increases, the GBW decreases, so they are inversely related.

Conclusions

This task was successful because we were able to correctly measure the -3dB points and phases, as well as calculate the GBW for each resistor value. We were also able to identify that the relationship between the GBW and the gain of the circuit is an inverse relationship.