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Section 007
Lab 06
Lab 6: MOSFET Operational Amplifier
Mar 11, 2021

Abstract

This report will cover building an operational amplifier piece by piece, starting with the branched current mirror, then the active load differential amplifier, common source amplifier, and finally the source follower. This operational amplifier is built completely out of p-channel and n-channel MOSFETs, which are in the ALD1105, ALD1106, and ALD1107 chips.

Most importantly, this lab will show you how to test each part of the circuit each step of the way. Testing circuits step by step is an important convention to practice, as it will often save you the headache of debugging a giant circuit at the end of the project, which is often frustrating. This lab will show you what your measurements should look like so that you can compare and know you're on the right track!

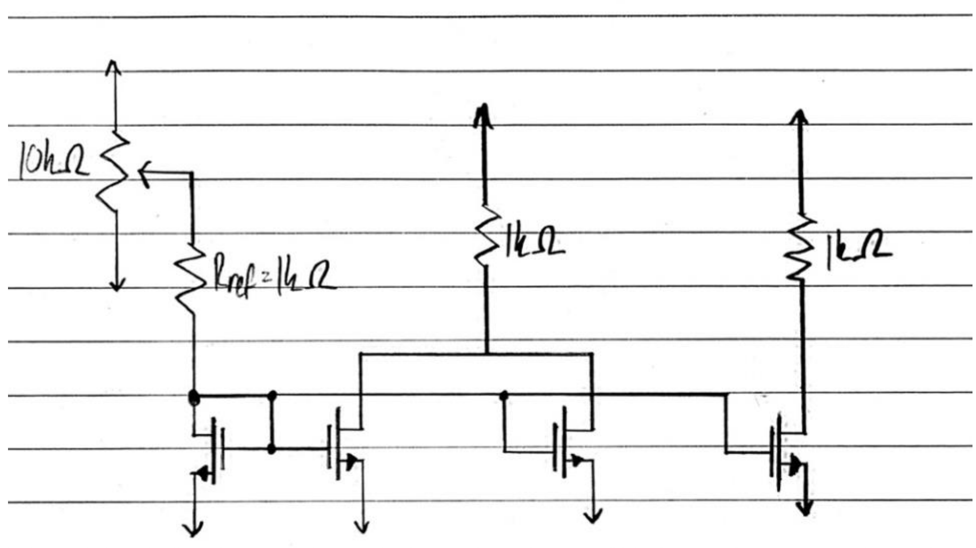
Task 6.5.1:
Objective

This section will demonstrate how to build and test a multi-branch current mirror.

Procedure

First, the AD2 was connected to a computer and wired up to the breadboard. The circuit shown below in figure 1 was constructed.

FIGURE 1



Multi-branch current mirror using 4 NMOS transistors

Next, the current going through R_{ref} was set to be 200 microamps, and the currents through the two 1kΩ resistors were measured.

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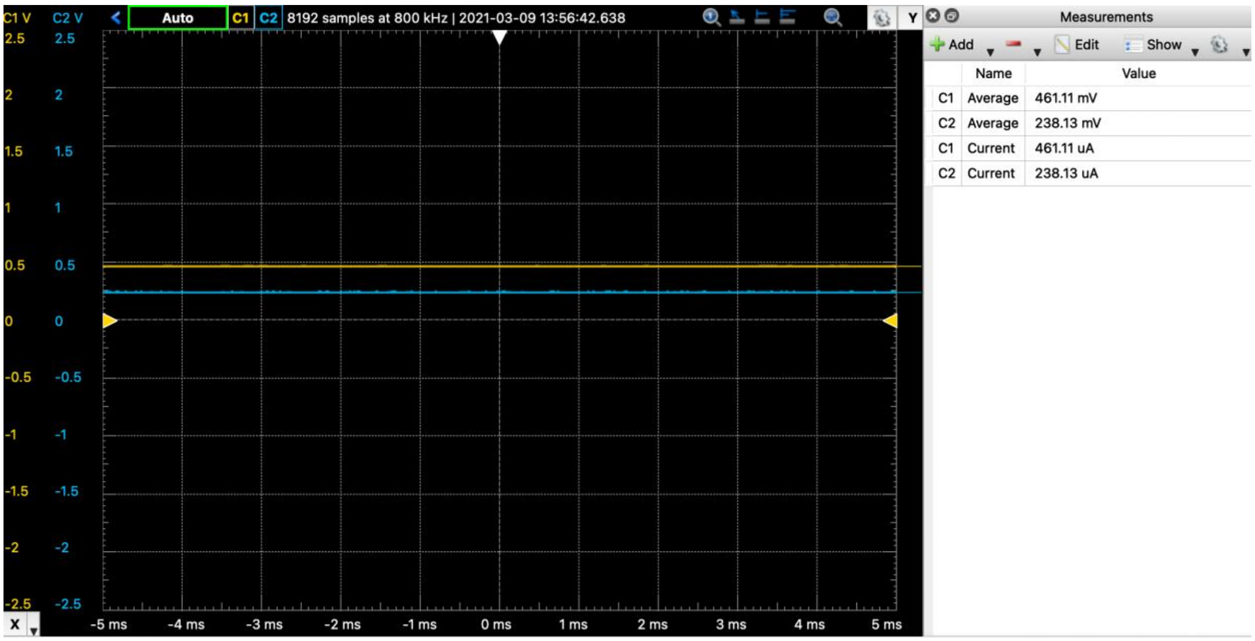
Results/Calculations

After setting the current through R_{ref} to be 200 microamps, the measurements of the currents through the two test resistors were taken and are shown below in figure 2.

FIGURE 2



Currents through the test resistors. The orange channel is Rtest1 and the blue channel is Rtest2

Shown above, the current through R_{test1} is 461 microamps and the current through R_{test2} is 238 microamps. $R_{test1} \approx 2R_{test2}$ holds true, but since R_{ref} is 200 microamps, the percent error for R_{rest1} is 15.25% and 19% for R_{rest2}. This percent error is likely due to the built-in resistance of the AD2, which I not factored into the design. The smaller percent error of 3.15% between the two test resistors is quite small and is likely due to the fact that the transistors are not *exactly* the same.

Conclusions

This task was successful because the current mirror was constructed correctly and is working as expected. Additionally, the percent error has a known source of being from the built-in resistance of the AD2.

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Task 6.5.2:

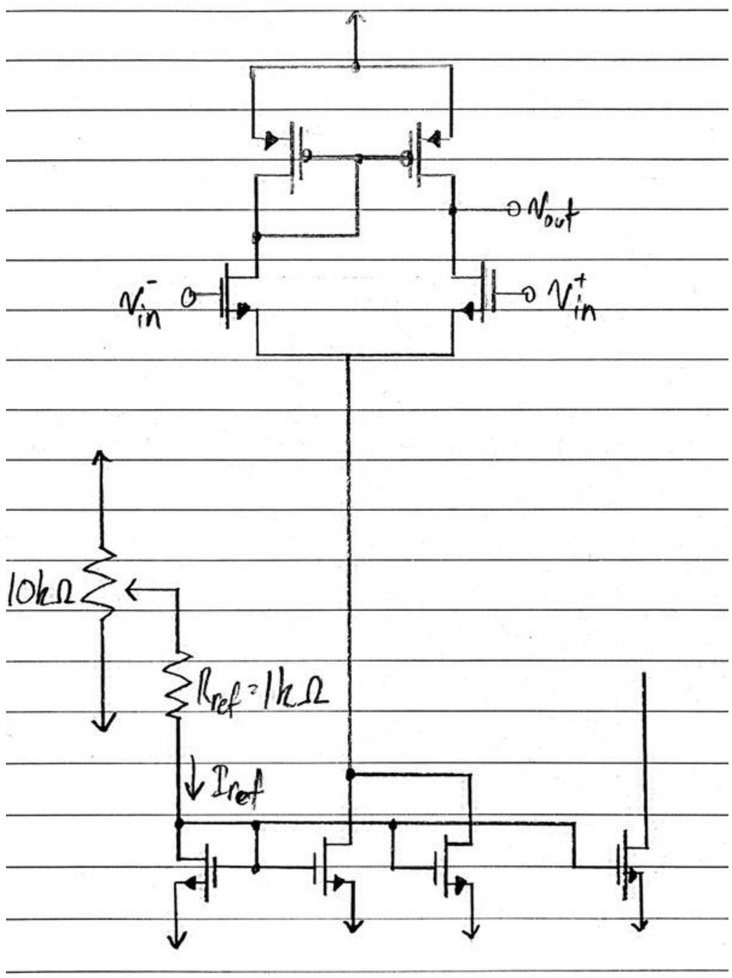
Objective

This section will demonstrate how to build and test an active load differential amplifier.

Procedure

Picking up from the previous task, the active load differential amplifier was built and connected properly to the multi-branch current mirror. The existing circuit is shown below in figure 3.

FIGURE 3



Multi-branch current mirror with active load differential amplifier

Once the active load differential amplifier was added to the circuit, the single ended gain was measured using a sine wave at 100Hz that has an amplitude of 10mV.

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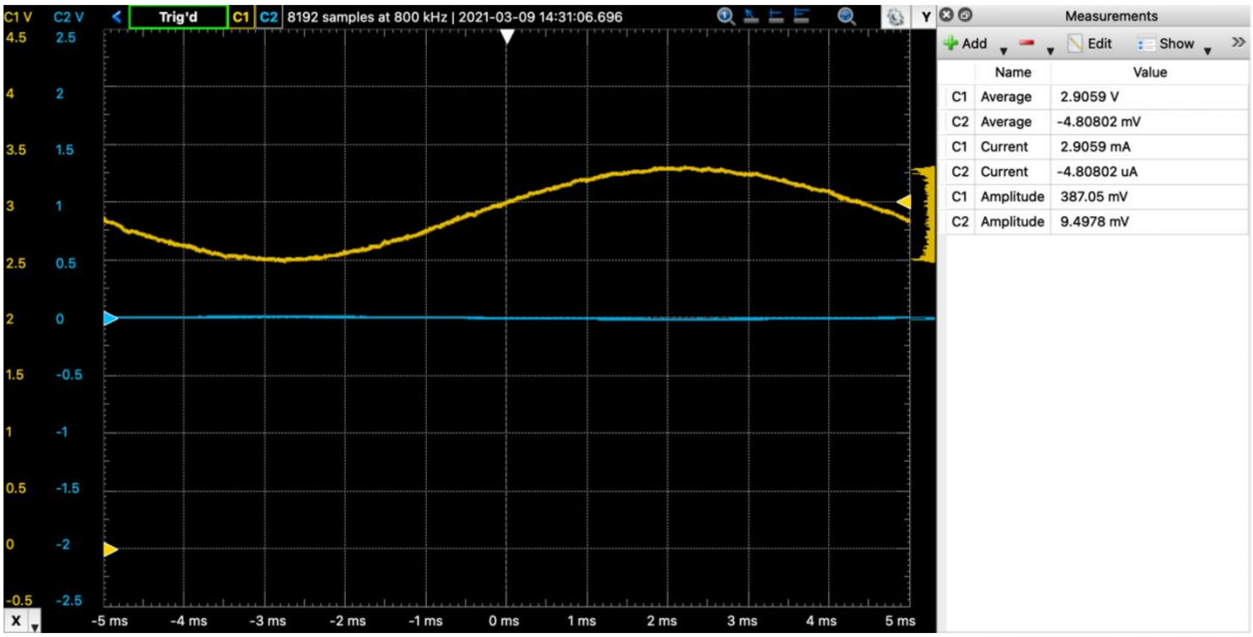
Results/Calculations

The measurement of the single ended gain with a sine wave at 100Hz with a 10mV amplitude is shown below in figure 4.

FIGURE 4



The orange channel (channel 1) is the output of the diff amp and the blue channel (channel 2) is the input

Here we can see that the amplitude of the output is 387.05mV, while the input is only 9.4978mV (which is close to our specified 10mV). These measured values give us a single-ended gain of 40.75!

Conclusions

This task was successful because we were able to correctly build and test an active load differential amplifier, getting a gain of 40.75.

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Task 6.5.3:

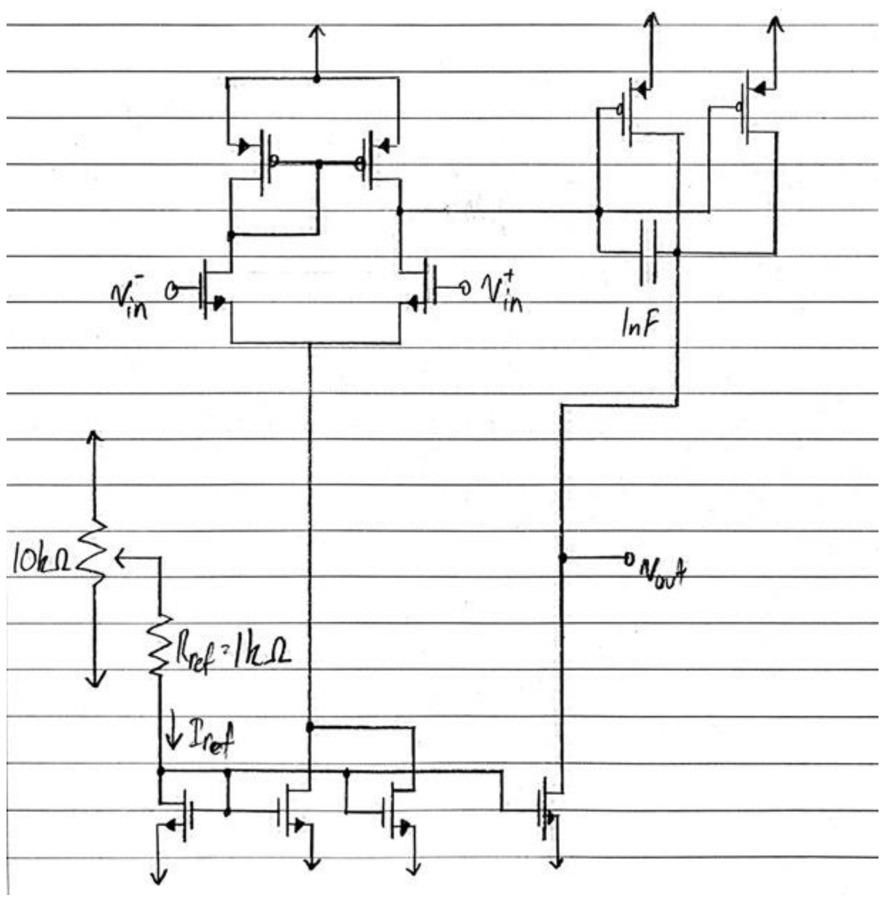
Objective

This section will demonstrate how to implement the common source amplifier into the operational amplifier circuit. It will also explain the behavior of the circuit and justify the outputs waveforms.

Procedure

First the gain of the common source amplifier and the overall gain from the first two stages of the amplifier were estimated. Next, the common source amplifier was added to the circuit shown in the previous task and is shown below in figure 5.

FIGURE 5



Multi-branch current mirror with an active load differential amplifier and a common-source simplifier

After the circuit was constructed, V^-_{in} was grounded and DC voltages between -2V and 2V were applied to V^+_{in} and the output was measured. Next, an input voltage of 2sin(2π100) was applied to V^+_{in} and the resulting output was plotted.

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Results/Calculations

The estimated gain of the common source amplifier was calculated using the equation shown below.

$$A_v = g_m(r_o||r_o)$$

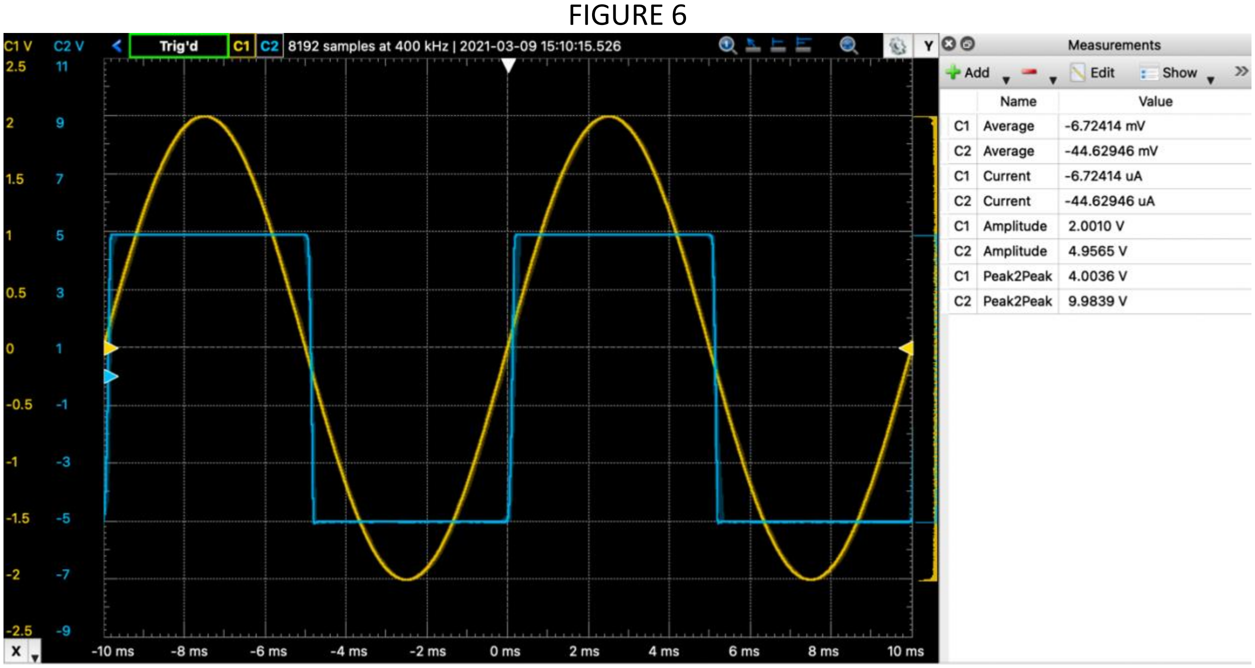
Which gives us:

$$A_v = g_m\left(\frac{4}{\lambda_p I_{bias}}||\frac{4}{\lambda_p I_{bias}}\right) = g_m\left(\frac{2}{\lambda_p I_{bias}}\right) = \frac{g_m 250}{I_{bias}} = \frac{66.5}{\sqrt{I_{bias}}}$$

Plugging in the measured value of 460mA for I_{bias}, A_v is calculated to be 98.049. We can now multiply this by the gain of the active load differential amplifier in order to get the gain of both circuits in series, giving us a total expected gain of about 1436.

When V^-_{in} was grounded and DC voltages between -2V and 2V were applied to V^+_{in}, we notice that the output is +5V when V^+_{in} is ≥ 0 and -5V when $V^+_{in} < 0$. This phenomenon is more easily visualized when a 4V peak-to-peak sine wave is applied to V^+_{in}, which is shown below in figure 6.

FIGURE 6



The orange channel (channel 1) is the input and the blue channel (channel 2) is the output from the voltage amplifier

Here we can see that whenever the input sine wave is positive, the output is +5V and whenever the input is negative, the output is -5V. Because the gain of this circuit is so large and it cannot go any higher than 5V or any lower than -5V, the output looks like a square wave. Although it *looks* like a square wave, it is more accurately described as a sine wave with a peak-to-peak voltage of about 5744V (total gain * peak-to-peak of the input) that is cut off at 5V and -5V.

Conclusions

This task was successful because we were able to accurately build the common-source amplifier. We know this is true because we were able to test the device and understand the output, which looks like a square wave but is really the same shape of the input wave, just much larger and cut off at 5V and -5V.

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Task 6.5.4:

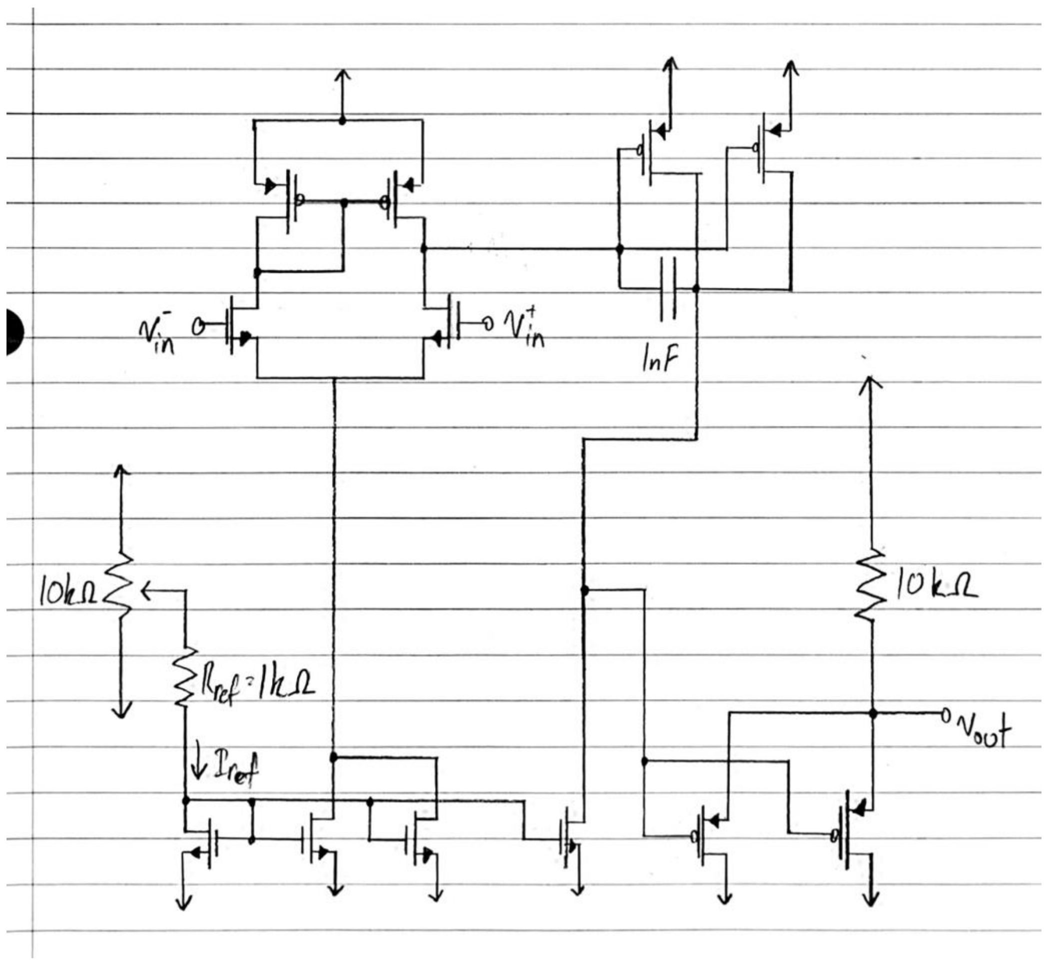
Objective

This section will demonstrate how to correctly build and implement the source follower into the operational amplifier to complete its construction.

Procedure

The source follower was constructed and added to the circuit built in the previous task. Shown below in figure 7 is the final version of the operational amplifier.

FIGURE 7



Complete operational amplifier circuit

Once the circuit construction was completed, V^{-}_{in} was grounded and a 4V peak-to-peak sine wave at 100Hz was applied to V^{+}_{in}. The output of the circuit was measured and plotted.

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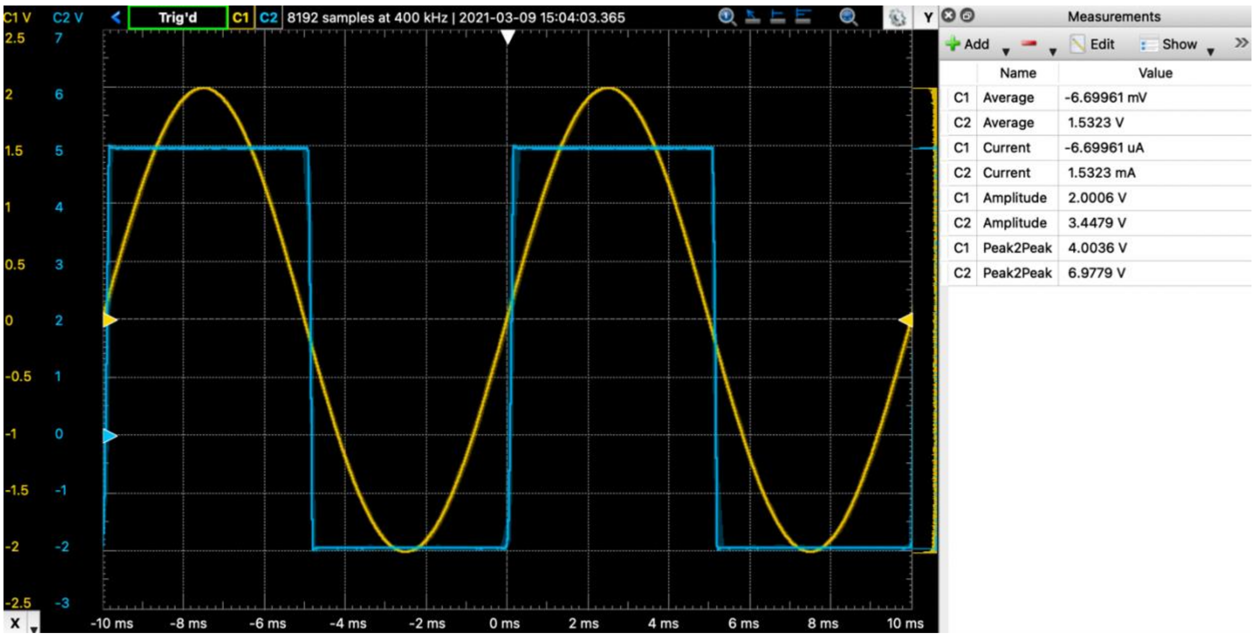
Results/Calculations

The plot resulting from the 4V peak-to-peak sine wave at 100Hz connected to V^{+}_{in} while V^{-}in was grounded is shown below in figure 8.

FIGURE 8



The orange channel (channel 1) is the input and the blue channel (channel 2) is the output from the source follower

Here we can see that the resulting output wave still looks like a square wave, except instead of ranging from +5V to -5V, this square wave ranges from +5V to -2V.

Conclusions

This task was executed successfully as we were able to construct the circuit and identify the change in the output waveform.

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Task 6.5.5:

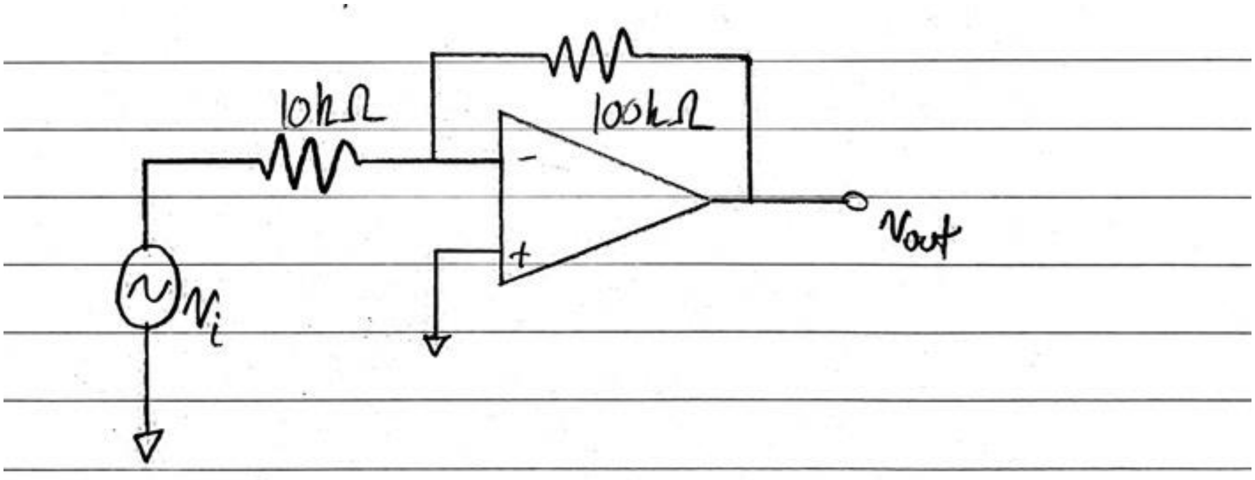
Objective

This section will demonstrate how to use negative feedback in order to make the operational amplifier have a gain of -10.

Procedure

Using the circuit shown in figure 7 as an operational amplifier, we can construct the circuit shown below in figure 9 to get a gain of -10.

FIGURE 9



An operational amplifier with a gain of -10 using a negative feedback loop

Once the amplifier was constructed, the gain was measured and the percent error was calculated.

Results/Calculations

Shown below in figure 10 is an oscilloscope screenshot showing the input and output of the operational amplifier. Notice the gain calculation, which is a custom function that was coded just for this purpose.

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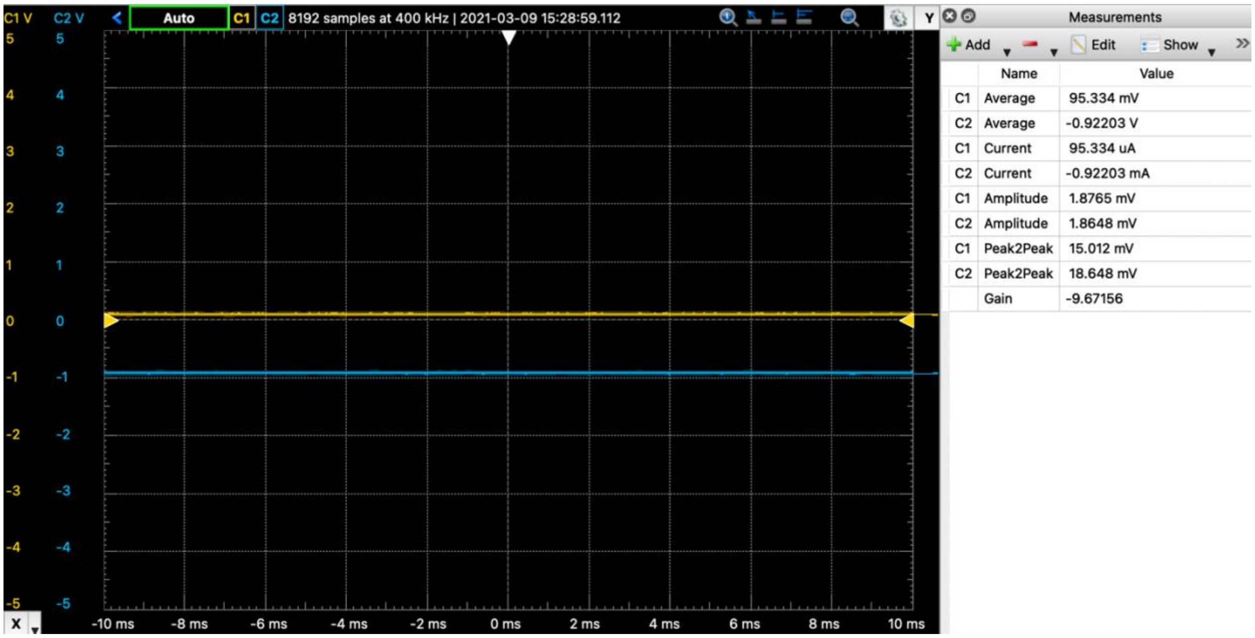
FIGURE 10



The orange channel (channel 1) is the input and the blue channel (channel 2) is the output. Notice the gain measurement on the right

The gain measurement shown on the right shows us that we are measuring a gain of -9.67156, which is a 3.28% error. These are great results!

Conclusions

This task was successful as the percent error calculation was a mere 3.28%, which shows that our operational amplifier was built correctly and up to the desired specifications!