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PHYX 315
04/12/2019

Lab 8: Operational Amplifier

Introduction

The purpose of this lab was to construct different types of circuits using a 741 op-amp to analyze the voltage and current. Figure 1 demonstrates the inverting amplifier circuit, Figure 2 demonstrates the constant voltage source circuit, and Figure 3 demonstrates the constant current source circuit. Two DAQ assistants in LabView were used to measure input and output voltage to compare theoretical and calculated values.

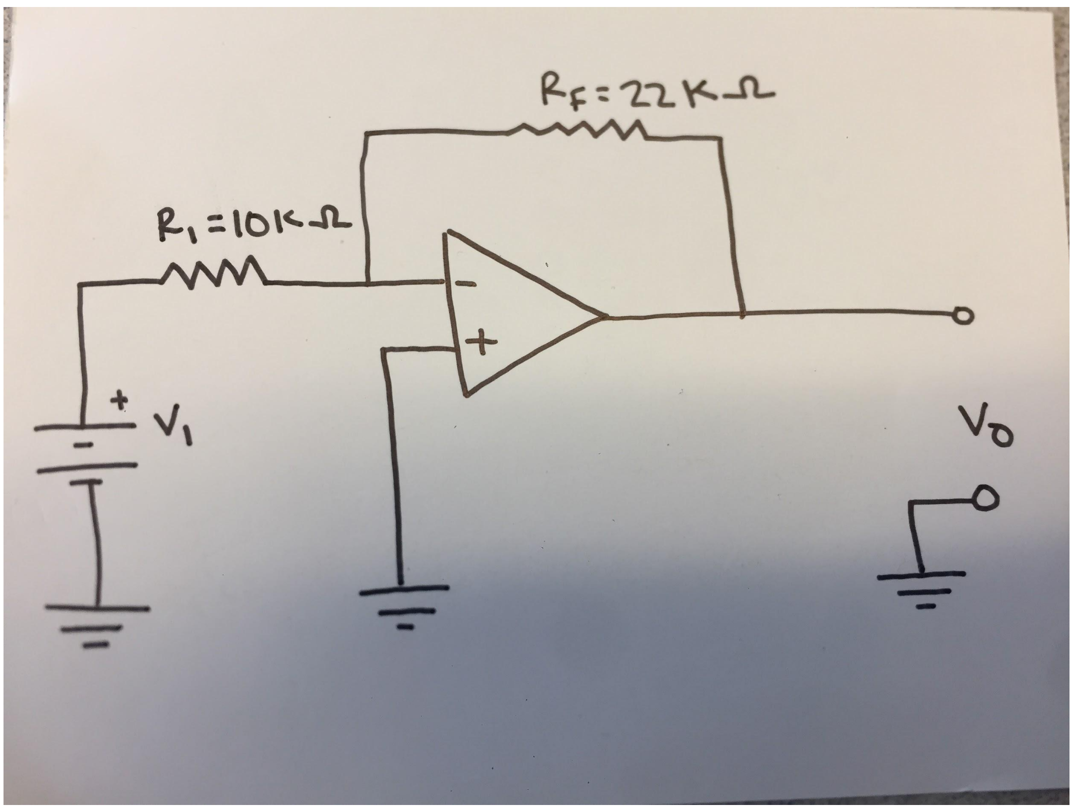

Figure 1. Inverting amplifier circuit schematic (Mola, lab handout, 2019).

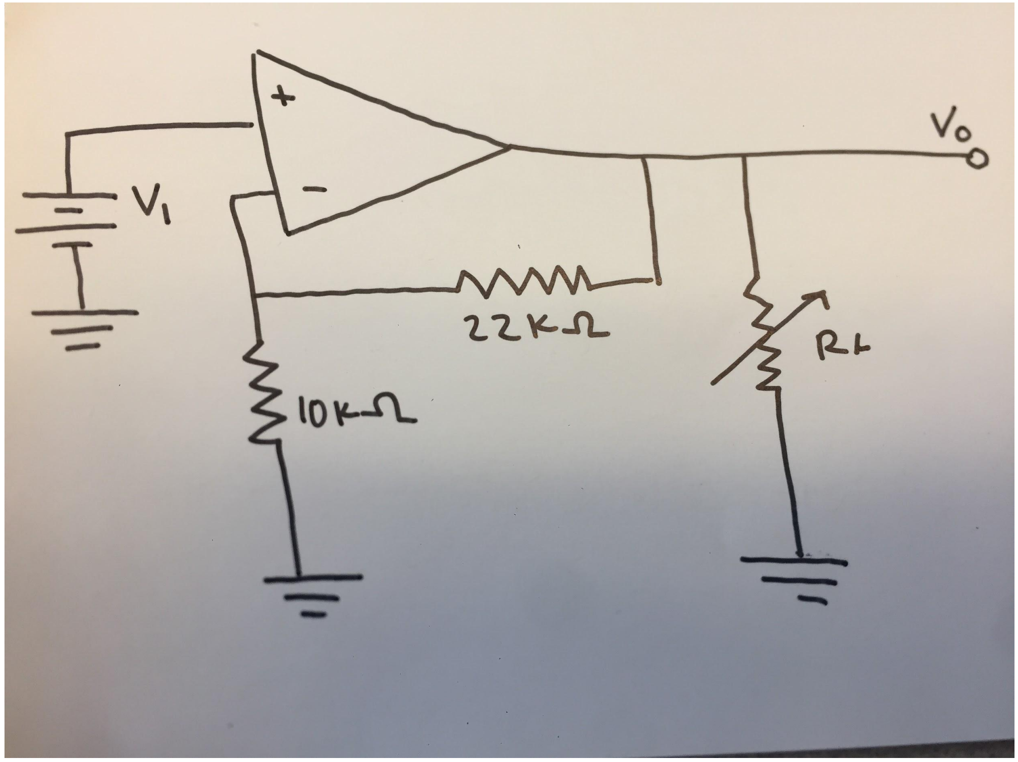

Figure 2. Constant voltage source circuit schematic (Mola, lab handout, 2019).

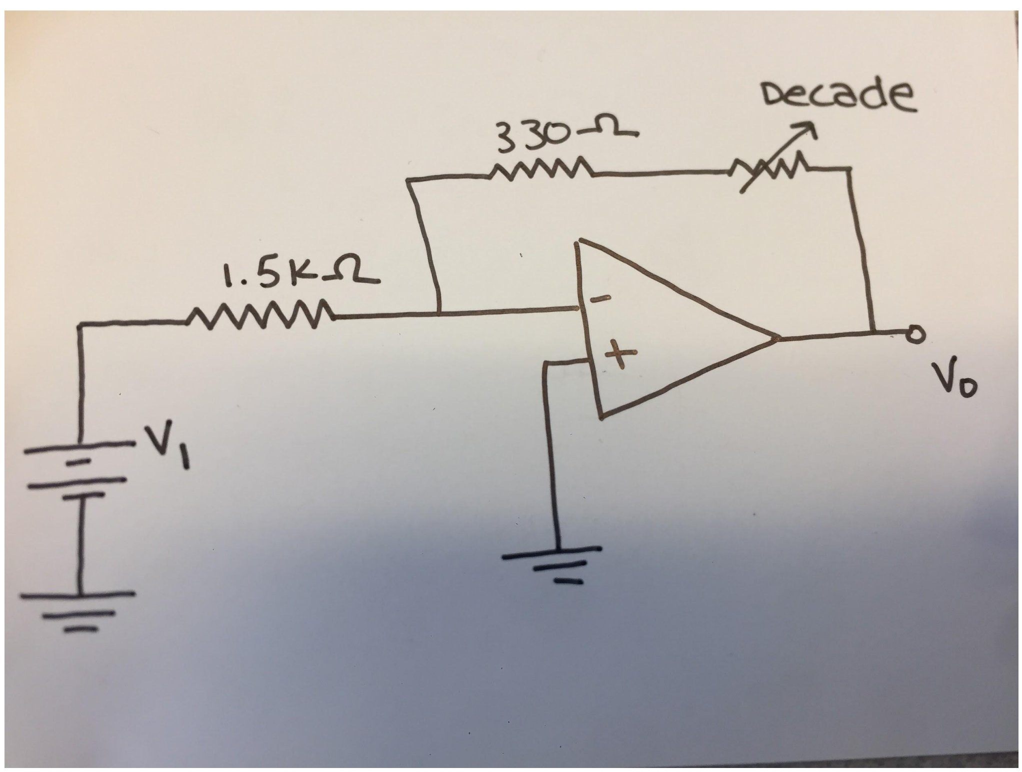

Figure 3. Constant current source circuit schematic.

Methodology

Operational amplifiers, or op-amps, are a useful and versatile tool. While a single transistor can perform some similar functions, op-amps are much better suited to some applications. Some of their beneficial characteristics include more ideal input and output impedances, greater gain, and a more stable output voltage. In this lab, we explored their amplifying properties and their limits of operation.

The first part of the lab involved constructing the inverting amplifier circuit shown in Figure 1. The op-amp is designed to adjust its output voltage, which is connected to the inverting input by a feedback resistor, to make the two input voltages equal. When the non-inverting input is grounded, this is equivalent to setting the center tap of the voltage divider R_1 and R_f at a voltage of zero. To satisfy this condition, a positive signal voltage requires that the output be negative, and vice versa. In addition, because no current flows into the input terminals, the voltage gain depends on the ratio between the two resistors, as given by the following equation:

$$gain = \frac{V_{out}}{V_{in}} = -\frac{R_f}{R_1}$$

In the second part of the lab, we constructed the non-inverting amplifier circuit shown in Figure 2. In this case, the input signal is applied at the non-inverting input, while the output is wired to the inverting input through the feedback resistor, which is connected to ground through an additional resistor. Again, these two resistors create a voltage divider; however, in this configuration, a positive signal voltage requires a positive output voltage, and vice versa.

Unlike single transistor amplifiers, the output of an op-amp maintains a steady voltage over a wide range of load resistances. However, under low enough load, the device will be unable to supply the necessary current, and the output voltage will begin to drop. For the LM741, this maximum current is around 25mA; using this value, we calculated the theoretical minimum load and compared it with our experimental measurements.

Our circuit in Part 3 was similar to the inverting amplifier in Part 1, but this time we made the feedback resistor variable. Increasing the feedback resistance increases the output voltage, but it also impedes the output current; within the device's operating conditions, these effects cancel out, and the output current remains constant. However, above a certain resistance, the gain will exceed the power supply's maximum voltage, and the output will remain constant. As the feedback resistance continues to increase, the output current begins to drop.

Results

The actual resistances of the resistors used compared to their theoretical values are displayed in Table 1. For the circuit in Figure 1, the theoretical and experimental gain were found and are shown in Table 2. Output voltage for the circuit in Figure 2 was determined through expected and measured values and is shown in Table 3. The calculated and experimental minimum resistance for the load resistor for the circuit in Figure 2 is shown in Table 4. Table 5 contains data points of how output voltage and current changed as the resistance on the decade box changed. Table 6 contains the experimental and theoretical value for the resistance at max voltage.

Table 1. Theoretical and measured resistance values.

R theoretical value [Ω]	R measured value [Ω]
10 k	9.84 k
22 k	22.09 k
1.5 k	1.48 k
330	326.4

Table 2. Experimental and theoretical gain for the inverting amplifier circuit.

V_i [V]	V_o [V]	experimental gain	theoretical gain	percent difference in gain [%]
-1	2.24478	2.245	2.245	6.18E-03
2	-4.48763	2.244		4.92E-02

Table 3. Expected and measured output voltage for the constant voltage source circuit.

$V_{o,\ expected}$ [V]	V_I [V]	$V_{o,\ measured}$ [V]	Percent difference in V_o [%]
5	1.54	4.993	0.14

Table 4. Experimental and calculated value for the minimum load resistance for the constant voltage source circuit.

$R_{L\ min,\ experimental}$ [Ω]	V_o [V]	I [A]	$R_{L,\ calulated}$ [Ω]	Percent difference in R_L
200	5.193	0.026	208	3.8

Table 4. Comparison between the current shown on LabView and the theoretical current for the constant current source circuit.

V_i [V]	$I_{device,\ LabView}$	$I_{device,\ theoretical}$	Percent Difference in I_{device} [%]
3	2.02E-03	2.00E-03	1.0

Table 5. Current and output voltage resulting from changing the resistance on the decade box for the constant current source circuit.

R_{decade} [Ω]	V_o [V]	I [mA]
0	0.66	2.02
0.5k	1.68	2.02
1.0k	2.69	2.02
2.0k	4.73	2.02
3.0k	6.76	2.02
4.0k	8.78	2.02
5.0k	10.63	1.99
6.0k	12.83	2.03
7.0k	13.84	1.89
8.0k	14.13	1.70
9.0k	14.37	1.54
10.0k	14.57	1.41

Table 6. Measured and experimental resistance when the max voltage is 15V.

V_{max} [V]	$R_{experimental}$ [Ω]	$R_{theoretical}$ [Ω]
15.00	~7.0k	7.17k

Discussion

Using the resistance and voltage data in Tables 1 and 2, as well as the gain equation given in the Methodology section, we calculated both the theoretical and experimental values for the gain of our inverting amplifier. These values were in remarkably close agreement, with errors on the order of a hundredth of a percent.

Our design for the non-inverting amplifier also gave results very close to the expected values, particularly for the output voltage. At 200Ω, our experimental value for the minimum load was also very close to our theoretical value of 208Ω. However, it is important to bear in mind that there is a much larger degree of error associated with this measurement; choosing an experimental threshold load is a somewhat arbitrary decision, and we easily could have chosen a value tens of ohms higher or lower than we did. Still, it shows that our calculations characterized the circuit very well.

Part 3 also gave results that closely agreed with theory. Our measured currents and maximum resistances both matched our predictions on the order of about a percent. Again, the choice of maximum resistance was again somewhat arbitrary, but it still demonstrates the validity of our analysis of the op-amp circuit.

Conclusion

In this lab we applied the basic theory of op-amps learned in lecture to physical circuits. Our results demonstrated that, while the theory is based on some simplifying assumptions that are not strictly true, it is a very accurate characterization of these devices. They also support the fact that op-amps approximate ideal amplifiers much better than single-transistor amplifiers; the gains were larger, the outputs were steadier, and the leakage currents at the inputs were likely less significant.