CMPE 110 Lab 5: Op-amp Circuits

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***Abstract*—The purpose of this lab project is to learn the different types of op-amp circuits.**

I. INTRODUCTION

This lab project is based on the implementation of a voltage sensor amplifier, input/output isolation with unity gain, voltage sensor amplifier with signal and reference inputs, and summation amplifier with 2 sensor inputs circuits. Furthermore, the provided handout prompted questions with each circuit's procedure, which we will try to answer throughout our discussion section.

A. Parts List

- Resistors
- LT1014
- Grounding components
- Generators (see each circuit for further details)

II. DESCRIPTION OF THE CIRCUITS' SCHEMATICS

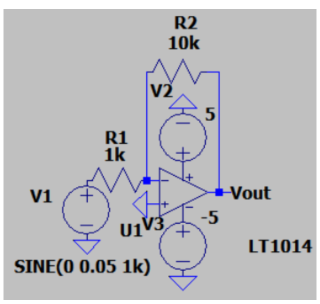

Figure 1. Voltage sensor amplifier circuit with an amplification of -10 circuit (Part 1). Resistance values calculated using $\frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1}$.

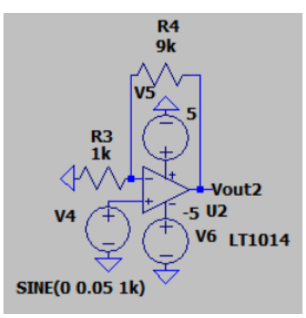

Figure 2. Voltage sensor amplifier circuit with an amplification of +10 circuit (Part 2). Resistance values calculated using $\frac{V_{out2}}{V_{in}} = -\frac{R_3+R_4}{R_3}$.

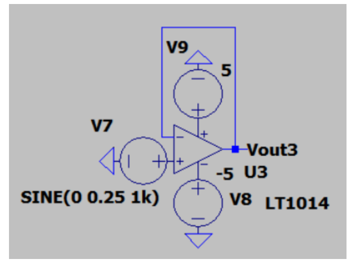

Figure 3. Input/output isolation circuit with unity gain circuit (Part 3).

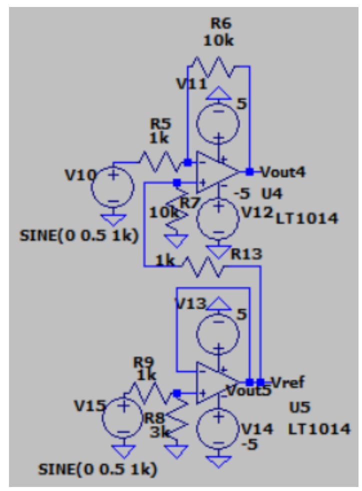

Figure 4. Voltage sensor amplifier with signal and reference inputs circuit (Part 4). Resistance values calculated using $V_{out4} = -\frac{R_6}{R_5}V_{10} + \frac{R_7}{R_5} * \frac{R_5+R_6}{R_{13}+R_7} * V_{out5}$, $V_{out4} = -10(V_{10} - V_{ref})$, and $V_{ref} = 0.75 * V_{10}$.

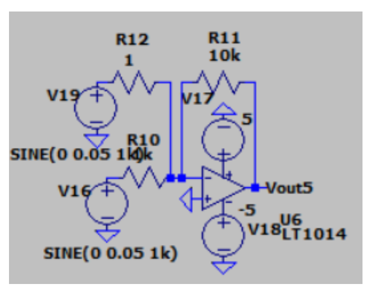

Figure 5. Summation amplifier with 2 sensor inputs (Part 5).

III. WAVEFORMS AND RESULTS

Part 1:

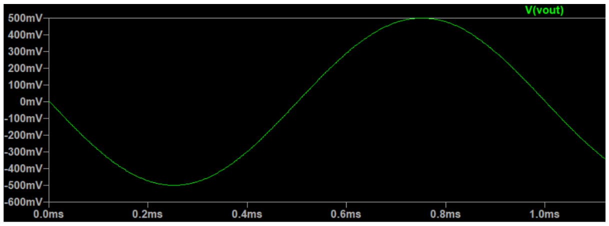

Figure 6. Part 1's circuit. Source at 0.05V, 1 KHz.

Resistor	Resistance (KΩ)
R_1	1
R_2	10

Table 1. Resistors in Part 1's circuit. Resistance values calculated using $\frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1}$.

Frequency (KHz)	Vout's peak-to-peak voltage (V)	Gain
1	1	10
10	1	10
100	0.7	7
1000	0.03	0.3

Table 2. Gain in Part 1's circuit.

Frequency (KHz)	Vout's peak-to-peak voltage (V)	Gain
1	1.1	11

Table 3. Gain in Part 1's circuit after swap.

Part 2:

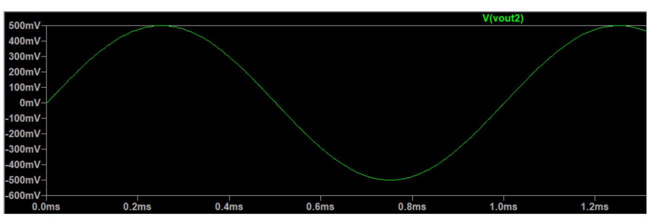

Figure 7. Part 2's circuit. Source at 0.05V, 1 KHz.

Resistor	Resistance (KΩ)
R_3	1
R_4	9

Table 4. Resistors in Part 2's circuit. Resistance values calculated using $\frac{V_{out2}}{V_{in}} = -\frac{R_3+R_4}{R_3}$.

Frequency (KHz)	Vout's peak-to-peak voltage (V)	Gain
1	1	10
10	1	10
100	0.8	8
1000	0.06	0.6

Table 5. Gain in Part 2's circuit.

Frequency (KHz)	Vout's peak-to-peak voltage (V)	Gain
1	0.9	9

Table 6. Gain in Part 2's circuit after swap.

Part 3:

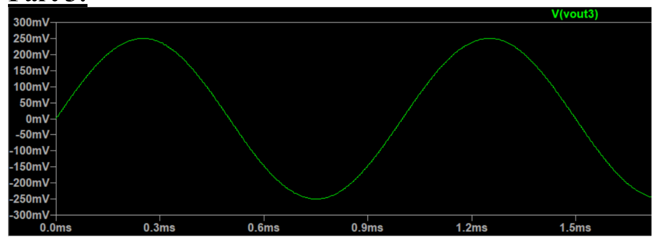

Figure 8. Part 3's circuit. Source at 0.25V, 1 KHz.

Vin (V)	Vout's peak-to-peak voltage (V)
0.25	0.5
0.5	1
1	2

Table 7. Vout's peak-to-peak voltage in Part 3's circuit.

Vin (V)	Vout's peak-to-peak voltage (mV)
0.25	0.9

Table 8. Gain in Part 3's circuit after swap.

Part 4:

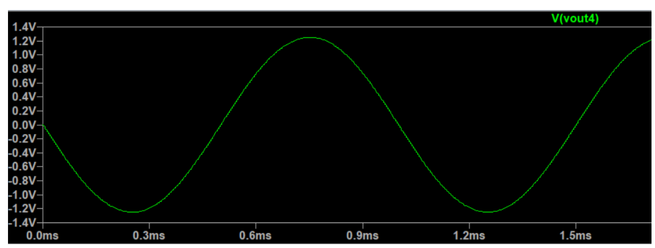

Figure 9. Part 4's circuit. Source at 0.5V, 1 KHz, and Vout4 = 1.25 V.

Resistor	Resistance (KΩ)
R_5	1
R_6	10
R_7	10
R_{13}	1
R_A	1
R_B	3

Table 9. Resistors in Part 3's circuit. Resistance values calculated using $V_{out4} = -\frac{R_6}{R_5}V_{10} + \frac{R_7}{R_5} * \frac{R_5+R_6}{R_{13}+R_7} * V_{out5}$, $V_{out4} = -10(V_{10} - V_{ref})$, and $V_{ref} = 0.75 * V_{10}$.

Resistor	Resistance (KΩ)
R_5	1
R_6	10
R_7	10
R_{13}	1
R_A	1
R_B	1

Table 10. Resistors in Part 3's circuit. Resistance values calculated using $V_{out4} = -\frac{R_6}{R_5}V_{10} + \frac{R_7}{R_5} * \frac{R_5+R_6}{R_{13}+R_7} * V_{out5}$, $V_{out4} = -10(V_{10} - V_{ref})$, and $V_{ref} = 0.5 * V_{10}$.

Resistor	Resistance (KΩ)
R_5	1
R_6	10
R_7	10
R_{13}	1
R_A	3
R_B	1

Table 11. Resistors in Part 3's circuit. Resistance values calculated using $V_{out4} = -\frac{R_6}{R_5}V_{10} + \frac{R_7}{R_5} * \frac{R_5+R_6}{R_{13}+R_7} * V_{out5}$, $V_{out4} = -10(V_{10} - V_{ref})$, and $V_{ref} = 0.25 * V_{10}$.

Part 5:

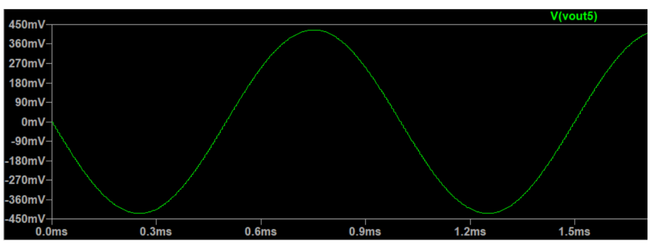

Figure 10. Part 5's circuit. Source at 0.5V, 1 KHz, and Vout5 = 0.425 V.

(KΩ)					(V)	
R_{10}	R_{11}	R_{12}	R_A	R_B	V_{ref}	V_{out5}
1	1	1	1	3	$0.75V_{19}$	0.425
1	1	1	1	1	$0.5V_{19}$	0.300
1	1	1	3	1	$0.25V_{19}$	0.175

Table 12. Resistors in Part 5's circuit. The calculations for these values were covered throughout the waveforms and results for Part 4.

IV. DISCUSSION

Part 1:

- No theoretical-practical inconsistencies found when implementing the non-swapped circuit.
- The gain drops as frequency increases because it affects the amplifier's internal capacitors, which ultimately affects the output.
- Once the connections are swapped at the input, the $\frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1}$ relationship we observed at 1 and 10 KHz no longer applies, as the circuit becomes a non-inverting amplifier and we should use the $\frac{V_{out}}{V_{in}} = -\frac{R_3+R_4}{R_3}$ relationship instead.

Part 2:

- No theoretical-practical inconsistencies found when implementing the non-swapped circuit.
- The gain drops as frequency increases because it affects the amplifier's internal capacitors, which ultimately affects the output.
- Once the connections are swapped at the input, the $\frac{V_{out}}{V_{in}} = -\frac{R_3+R_4}{R_3}$ relationship we observed at 1 and 10 KHz no longer applies, as the circuit becomes an inverting amplifier and we should use the $\frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1}$ relationship instead.

Part 3:

- No theoretical-practical inconsistencies found when implementing the non-swapped circuit.
- Once the connections are swapped at the input, the $\frac{V_{out}}{V_{in}} = -\frac{R_3+R_4}{R_3}$ relationship we observed at 1 and 10 KHz no longer applies, as the circuit becomes an inverting amplifier and we should use the $\frac{V_{out}}{V_{in}} = -\frac{R_2}{R_1}$ relationship instead.

Part 4:

- No theoretical-practical inconsistencies found.
- This circuit is a combination two op-amp circuits: An input/output isolation circuit with unity gain acting as a source for a voltage sensor amplifier with signal and reference inputs circuit.
- The resistors' calculations included, to a certain extent, a trial and error approach in order to achieve the required equalities.

Part 5:

- No theoretical-practical inconsistencies found.
- This circuit is a combination of two op-amp circuits: An input/output isolation circuit with unity gain acting as a source for a summation amplifier with 2 sensor intputs.
- The resistors' calculations were covered in Part 4, given we are reusing part of Part 4's circuit (mainly, the input/output isolation circuit with unit gain part).

V. DESCRIPTION OF THE LEARNING EXPERIENCE

While the first three parts for this lab had instructions that were straightforward and objective—meaning they'd be easier to implement and that it would be less likely to commit errors in the implementation—the last two parts, Part 4 and 5, were more vague.
Parts 1 through 3 could be considered stand-alone concepts, where a single type of circuit was implemented, but the challenge behind Parts 4 and 5 was that their circuits was

two different types of op-amp circuits put together. This required us to further consider other relationships and solutions that are not as straightforward as the techniques we used to complete and analyze Parts 1 through 3.

All in all, this was a fruitful experience where we not only were exposed to challenging op-amp circuits, but also simpler instances of the same types of circuits. This further develops our intuition that we can create composite circuits for all sorts of applications by cascading different types of circuits together, as we see convenient.

VI. CONCLUSION

In conclusion, we learned that—in LTspice—the theoretical relationships for op-amp circuits we learned in class hold true. We can use the relationships we learned to create different op-amp circuits with different gains, and even continue to use these gains as input for other op-amp circuits—as we mentioned before, cascading op-amp circuits input was one of the most challenging parts of this lab.

Finally, this lab taught us that, in practice—in LTspice—we could implement circuits that output values virtually equal to the ones we theoretically calculated. This is not only reassuring, but also an indicator that our circuits are performing as we meant them to perform.