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Electric Circuits (ENGR 210)

Final Project

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Abstract

This report describes the design of two circuits, Circuit 1 and Circuit 2, that meet the requirements specified in the project description. The theoretical values of the output voltages of the two circuits are calculated and compared to the simulation results. The two circuits are then cascaded, and the theoretical value of the output voltage of the cascaded circuits is calculated and compared to the simulation results. The simulation show that the theoretical values are very close to the simulation results.

1 Problem Statements

Design two circuits, Circuit 1 and Circuit 2, that meet the following requirements:

1. Circuit 1 should have an output voltage, V_{o1}, equal to K_a times the input voltage, V_{i1}.
2. Circuit 2 should have an output voltage, V_{o2}, equal to K_b times the input voltage, V_{i2}.
3. The values of K_a and K_b can be found in a provided resource, and each circuit should use a different value for K_a and K_b.
4. The circuits should adhere to the following design constraints:
   (a) Resistors with resistance values ranging from 1KΩ to 10KΩ can be used.
   (b) If an op-amp is used, only one op-amp is allowed.
   (c) The circuits should be designed using the fewest components possible.
5. Use the two circuits you have designed in part 1, cascade them.
   Is the equation $V_{o2} = K_a \cdot K_b \cdot V_{i1}$ satisfied?
   (a) Verify your answer using LTspice.
   (b) Explain why the answer is 'YES' or 'NO'.
   (c) If your answer is 'NO', redesign the circuit to meet the requirements in part 1 and satisfy the equation $V_{o2} = K_a \cdot K_b \cdot V_{i1}$.

2 Part 1

Table 1: Circuit 1 and Circuit 2 parameters

K_a	K_b	V_{i1}	V_{i2}
2.4	0.65	1V	1V

Based on the requirements in Section 1 and the provided parameters in Table 1, the first circuit needs to have an output voltage, V_{o1}, equal to 2.4 times the input voltage, V_{i1}, and the second circuit needs to have an output voltage, V_{o2}, equal to 0.65 times the input voltage, V_{i2}. This means that the first circuit needs to be an amplifier with a gain of 2.4, and the second circuit needs to be an attenuator with a gain of 0.65.

2.1 Circuit 1

As mentioned, the first circuit needs to be an amplifier with a gain of 2.4. To achieve this, an operational amplifier (op-amp) is used. The op-amp is configured in a non-inverting amplifier configuration. The gain of the non-inverting amplifier is given by Equation 1.

$$K_a = A_v = 1 + \frac{R_2}{R_1} \tag{1}$$

The gain of the non-inverting amplifier is equal to the ratio of the feedback resistor, R_2, and the input resistor, R_1, plus one. The feedback resistor is connected between the output of the op-amp and the inverting input of the op-amp. The input resistor is connected between the inverting input of the op-amp and the input voltage, V_{i1}. The output voltage, V_{o1}, is connected between the output of the op-amp and the inverting input of the op-amp.

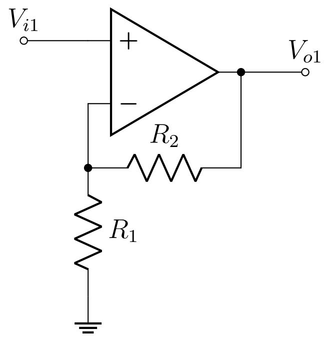

Figure 1: Non-inverting amplifier

Since the input voltage, V_{i1}, is 1V, the output voltage, V_{o1}, needs to be 2.4V. The feedback resistor is chosen to be 1KΩ, and the input resistor is chosen to be 1.4KΩ. The gain of the non-inverting amplifier is then shown in Equation 2

$$1 + \frac{1.4K\Omega}{1K\Omega} = 2.4 \tag{2}$$

However, the op-amp needs to be supplied with voltage. VCC is connected to the positive supply voltage, and -VCC is connected to the negative supply voltage. VCC is equal to 5V, and -VCC is equal to -5V. As the input voltage, V_{i1}, is 1V, the output voltage, V_{o1}, will be 2.4V so 5V is enough to supply the op-amp.

2.2 Circuit 2

As mentioned, the second circuit needs to be an attenuator with a gain of 0.65. To achieve this, a voltage divider is used. The voltage divider is made up of two resistors, R_1 and R_2. The output voltage, V_{o2}, is connected between the two resistors, and the input voltage, V_{i2}, is connected to one of the resistors. The output of the voltage divider is given by Equation 3.

$$V_{o2} = V_{i2} \cdot \frac{R_2}{R_1 + R_2} \tag{3}$$

It is possible, then, to rewrite the equation to solve for R_2 as shown in Equation 4. The input voltage, V_{i2}, is 1V, and the output voltage, V_{o2}, needs to be 0.65V. The value of R_1 is chosen to be 1KΩ, and the value of R_2 is then calculated to be 1.857KΩ.

$$R_2 = \frac{V_{o2} \cdot R_1}{V_{i2} - V_{o2}} = \frac{0.65 \cdot 1K\Omega}{1V - 0.65V} = 1.857K\Omega \tag{4}$$

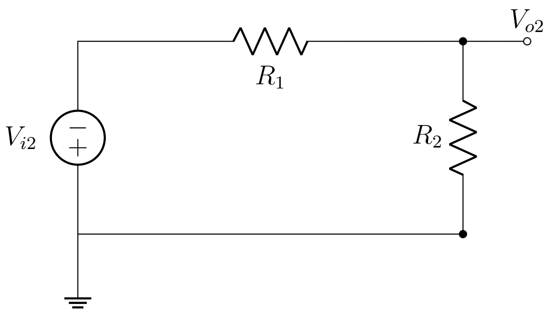

Figure 2: Voltage divider

2.3 LTspice Simulation

The two circuits are simulated using LTspice. The simulation circuit is shown in Figure 3. The simulation results are shown in Listing 1.

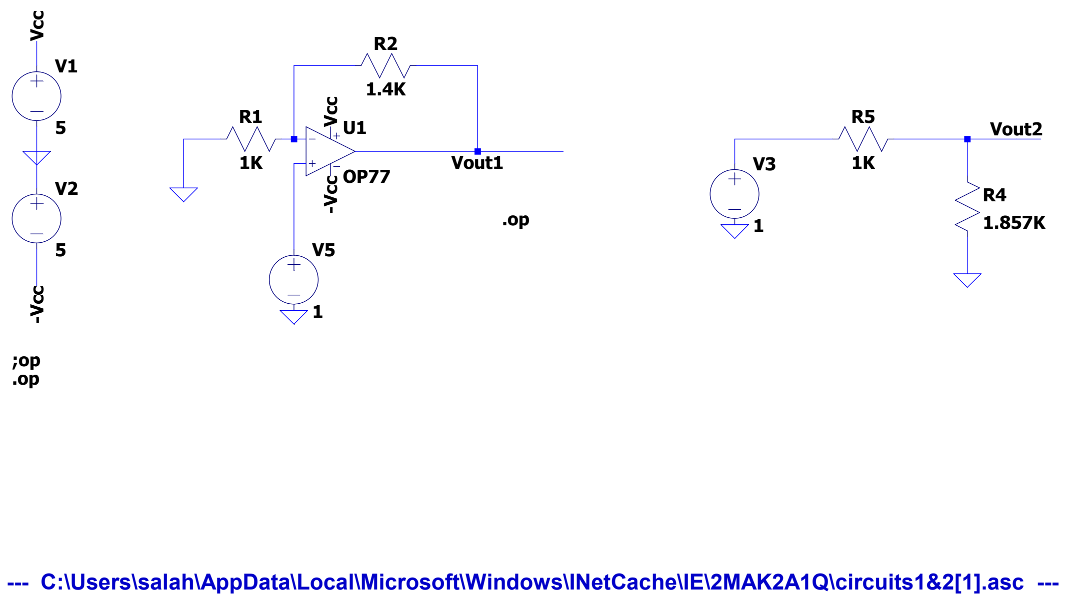

Figure 3: LTspice simulation results of the two circuits

```
       --- Operating Point ---

V(n001):      1.00001      voltage
V(n003):      1    voltage
V(vcc):   5    voltage
V(-vcc):      -5   voltage
V(vout1):     2.40003      voltage
V(vout2):     0.649983     voltage
V(n002):      1    voltage
I(R5):    -0.000350018     device_current
I(R4):    0.000350018      device_current
```

```
I(R2):   0.00100001  device_current
I(R1):   0.00100001  device_current
I(V3):   -0.000350018    device_current
I(V5):   -1.34601e-009   device_current
I(V2):   -0.00075    device_current
I(V1):   -0.00175001     device_current
Ix(u1:1):    1.34601e-009    subckt_current
Ix(u1:2):    1.046e-009  subckt_current
Ix(u1:99):   0.00175001  subckt_current
Ix(u1:50):   -0.00075    subckt_current
Ix(u1:39):   -0.00100001     subckt_current
```

Listing 1: LTspice simulation results of the two circuits

From the simulation results, it can be seen that the output voltage, V_{o1}, is 2.40003V and the output voltage, V_{o2}, is 0.649983V. These values are very close to the theoretical values of 2.4V and 0.65V, respectively. Table 2 shows the simulation results.

Table 2: LTspice simulation results

V_{i1}	1V
V_{i2}	1V
V_{o1}	2.40003V
V_{o2}	0.649983V

3 Part 2

3.1 Cascading the two circuits

The output voltage, V_{o1}, is connected to the input voltage, V_{i2}, of the second circuit. The output voltage, V_{o2}, is then measured. The expected result is that the output voltage, V_{o2}, is equal to $K_a \cdot K_b \cdot V_{i1}$, which is equal to 1.56V, as shown below.

$$V_{i1} = 1V \tag{5}$$

$$V_{i2} = V_{o1} = K_a \cdot V_{i1} \tag{6}$$

$$= 2.4 \cdot 1V = 2.4V \tag{7}$$

$$V_{o2} = V_{i2} \cdot \frac{R_2}{R_1 + R_2} \tag{8}$$

$$= 2.4V \cdot \frac{1.857K\Omega}{1K\Omega + 1.857K\Omega} \tag{9}$$

$$= 1.56V. \tag{10}$$

3.2 LTspice Simulation

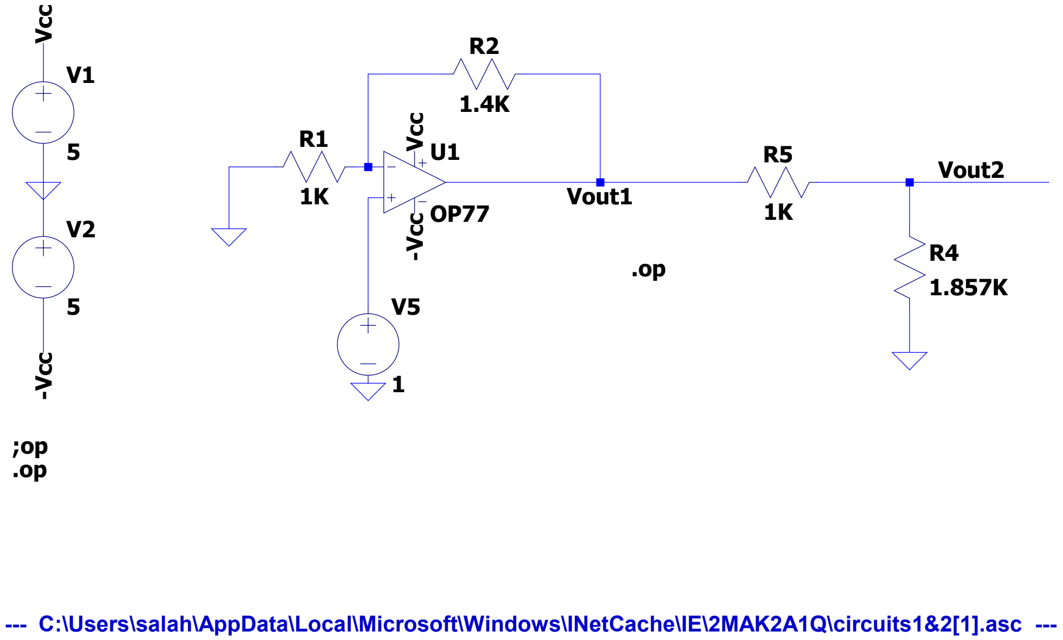

Figure 4: LTspice simulation results of the cascaded circuits

```
       --- Operating Point ---

V(n001):      1.00001      voltage
V(n003):      1    voltage
V(vcc):   5    voltage
V(-vcc):      -5   voltage
V(vout):      2.40003      voltage
V(n002):      1.55997      voltage
I(R5):    -0.000840051     device_current
I(R4):    0.000840051      device_current
I(R2):    0.00100001   device_current
I(R1):    0.00100001   device_current
I(V5):    -1.34601e-009    device_current
I(V2):    -0.00075     device_current
I(V1):    -0.00259006      device_current
Ix(u1:1):     1.34601e-009     subckt_current
Ix(u1:2):     1.046e-009   subckt_current
Ix(u1:99):    0.00259006   subckt_current
Ix(u1:50):    -0.00075     subckt_current
Ix(u1:39):    -0.00184006      subckt_current
```

Listing 2: LTspice simulation results of the cascaded circuits

From the simulation results, it can be seen that the output voltage, V_{o1}, is 2.40003V and the output voltage, V_{o2}, is 1.55997V. These values are very close to the theoretical values of 2.4V and 1.56V, respectively. Table 3 shows the simulation results. From these results, it can be seen that the equation $V_{o2} = K_a \cdot K_b \cdot V_{i1}$ is satisfied.

Table 3: LTspice simulation results

V_{i1}	1V
V_{o1}	2.40003V
V_{o2}	1.55997V

$$V_{o2} = K_a \cdot K_b \cdot V_{i1} = 2.4 \cdot 0.65 \cdot 1V = 1.56V \tag{11}$$