ECE 20007 Lab 5 Report

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003 (Yi Xie)

Abstract

For this lab, we had three tasks. The first task explored the usage of op amp and how a voltage buffer is used and when to use it. In order to actually know what a buffer does, we used a speaker so that we can actually hear the sound produced before and after the addition of the buffer. We used the function generator to play a signal then measured the voltage across the speaker. Then we added the voltage buffer and tested if the speaker becomes louder or quieter. The result was that with the buffer added, the sound became quieter. For the second task, we were asked to design a Thevenin equivalent circuit then develop our own method. For the third task, we used LTspice to draw out the circuit, then simulate and plot it.

1. Objectives

1.1 Loading with a real signal

For this task we used a practical buffer to measure the effects of loading. We used the LF356N op amp as the buffer. Buffers are used because the source may reach its limit before the desired voltage is achieved. To avoid that, we use the voltage buffer to transform the source resistance of the function generator to a smaller one. That way, power would not be consumed by the source's internal resistor. Tools used during this task are the function generator, LF356N op amp, speaker and decoupling capacitors.

1.2 Thevenin equivalent circuit design

The technical objectives of this experiment include developing a design that measures the Thevenin equivalent circuit and then apply the design to find the Thevenin equivalent circuit then draw it out. Thevenin and Norton Theorem are two heavyweight theorems in the electrical engineering field so this would be an important task to remember.

1.3 Simulate the superposition principle with SPICE

This task we would be revolving around superposition. This is a superposition practice using LTSPICE. We have to draw figure 5.31 in the lab manual using LTspice and then run simulations according to the parameters given. Then we have to plot it and compare it with the wave forms we got.

2. Theory

2.1 Loading with a real signal

The theory behind this task is that because a large source resistance may cause loading and to avoid that we usually can increase the amplitude of the source. But then another problem rises: the source may reach its limit before the desired voltage is achieved. Then a significant power would be consumed by the source's internal resistor(R_{th}), and that would be wasteful of power. So to prevent this from happening, we use a voltage buffer.

2.2 Thevenin equivalent circuit design

The Thevenin Theorem states that a particular node in a linear circuit has an equivalent circuit which contains only one independent voltage source in series with a resistor. This means that no matter how complex the circuit is, it is possible to simplify it down to a circuit with only one voltage source and one series resistance. This theorem makes it easier for us to understand complex circuits and allows us to quickly determine what would happen to that one single resistor.

2.3 Simulate the superposition principle with SPICE

The superposition principle states that for multiple input linear systems, the output is a linear combination of the responses due to each input.[1] Superposition is helpful when doing circuit analysis. When we have a complicated circuit, we can use superposition to simplify it down to circuits with only one source each. By simplifying the circuit, it's easier for us to understand the circuit and make changes or calculations on it.

3. Procedure

3.1 Loading with a real signal

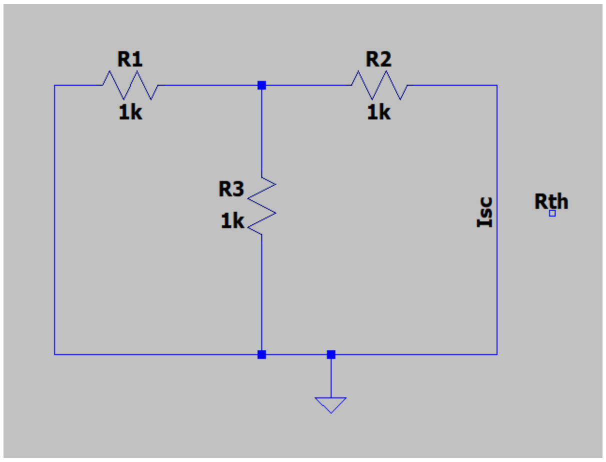
We generated a signal using the function generator then measured the RMS voltage across the speaker. To do this, we have to set the function generator to the correct parameters. Then we directly connect the function generator to the speaker to measure the RMS voltage without the buffer. Then we construct a circuit involving the LF365N op amp. From there, we can connect the function generator and the speaker to the op amp. Then we use the Digit Multimeter to measure the RMS voltage across the speaker again.

We had a theoretical value of the RMS voltage derived from the given equation so we calculated the percent error to determine whether the value we got was what we should be getting. We then added the buffer and repeated the process of measuring RMS voltage again. Then we calculated the percent error to make sure our values are correct.

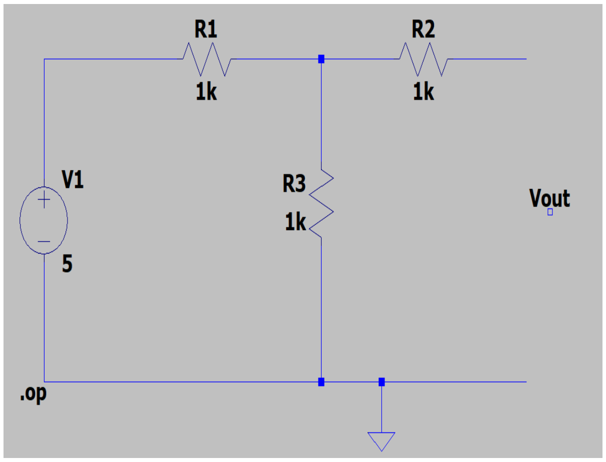
3.2 Thevenin equivalent circuit design

To design the circuit in figure 5.33 in the lab manual, we started by figuring out the resistance for each resistor. Usually, we were given the resistance of each resistor and we have to use it to figure out the Thevenin equivalent resistance and Thevenin equivalent voltage. But in this case, it's different. Since the instructions already gave us the Thevenin equivalent voltage of 2.5 V and a Thevenin equivalent resistance of 1.5 kΩ, we work it backwards. We know that there are two resistors in parallel and one in series and the equivalent resistance has to equal to 1.5 kΩ, we deduced that the resistors are 1 kΩ each. Then with the correct resistors, we built our circuit like figure 5.33 and measured the V_s.

The method I designed was that I start by deactivating the voltage source as you can see in the picture below on the left.



(a) Find R_{th}



(b) Find V_{oc}

Figure 1: Steps to find Thevenin equivalent circuit

Then simplify the circuit's resistors down to one single resistor and that would be the Thevenin resistance (R_{th}). Next, we need to find the Thevenin Voltage (V_{oc}). We do that by reactivating the sources, which is shown in Figure 1b. Finally, we can compute the V_{oc}

3.3 Simulate the superposition principle with SPICE

First, we would use LTspice to draw out figure 5.31 in the lab manual then we set it according to the specified parameters. Then we simulate it. That will generate plots.There would be plots for sine, triangle and DC wave. Then we would have one final wave where all three waves are combined. We then compare the plot with the plot from pre-lab. This task explores the superposition principle. We compare the plots from SPICE and pre-lab so that we can verify the superposition principle.

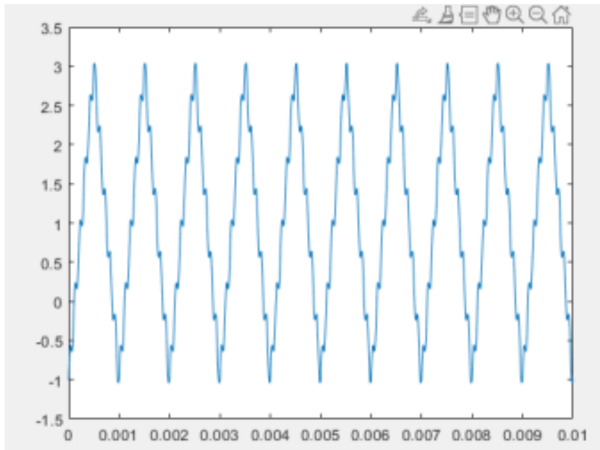


Figure 2: Graph from pre-lab

4. Results and Discussion

4.1 Loading with a real signal

The RMS voltage across the speaker I got is 24.231 mV. The theoretical value can be calculated using the value we got from the amplitude of the signal $250mV sin(2\pi \times 2000t)$

$$\frac{250}{\sqrt{2}} = 176.78mV \tag{1}$$

So no, I was not expecting the RMS voltage to be this low. The percent error could be calculated by

$$\frac{\mid theoretical - experimental \mid}{theoretical} \times 100 = \%error \tag{2}$$

$$\frac{|176-24.231|}{176} \times 100 = 86.2\%$$

The huge percent error is due to the power lost because of overloading, which is why we need to add a buffer to avoid this from happening. After adding the buffer, the RMS voltage I got was 152.3 mV, which is a lot closer to the theoretical value. Using Equation 2, we know that the percent error is 13.85%, which is a lot better than when not using a buffer.

The sound is louder when the buffer was added. This is reasonable because the addition of buffer is to reduce power lost. By reducing the amount of power lost, we have a higher voltage, which should correspond to a louder speaker as it gets more power. Then we have to estimate the Thevenin equivalent resistance of the buffer output using the voltage division equation.

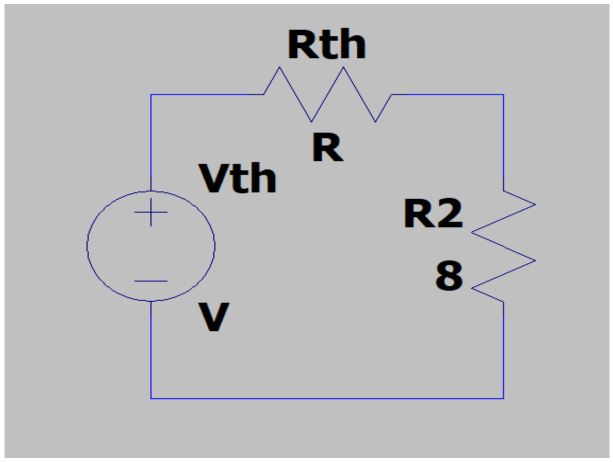


Figure 3: Circuit to find R_{th}

$$V_{out} = V_{in} \times \frac{R_L}{R_th + R_L} \tag{3}$$

Using Equation 3 and the variables $R_L = 8\Omega$, $V_{out} = 152.3$ mV, $V_{in} = 176.78$ mV, we find $R_{th} = 1.3\ \Omega$.

4.2 Thevenin equivalent circuit design

For task 2, we got $V_s = 4.7$ V, R_1=R_2=R_3=1 kΩ, which makes sense. For the Thevenin equivalent circuit to equal 1.5 kΩ, the resistors will need to be 1 kΩ since 2 are in parallel and 1 is in series. We can verify that by this equation:

$$\frac{1k \times 1k}{1k + 1k} + 1k = 1.5k \tag{4}$$

I then applied my design to get the Thevenin equivalent circuit.

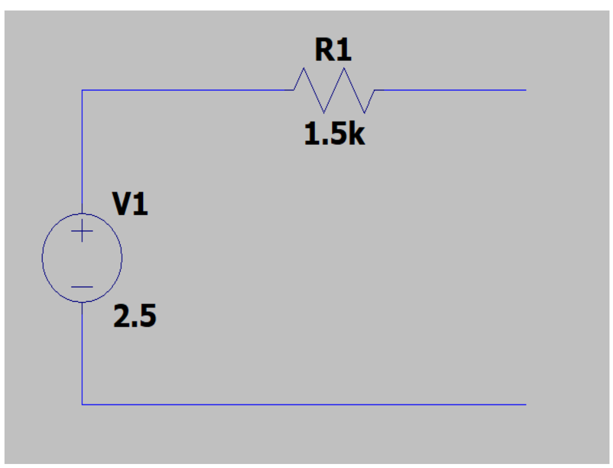
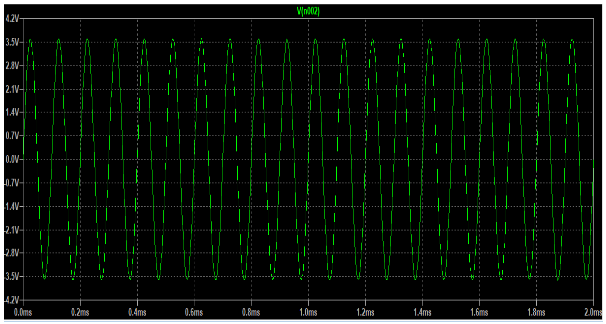


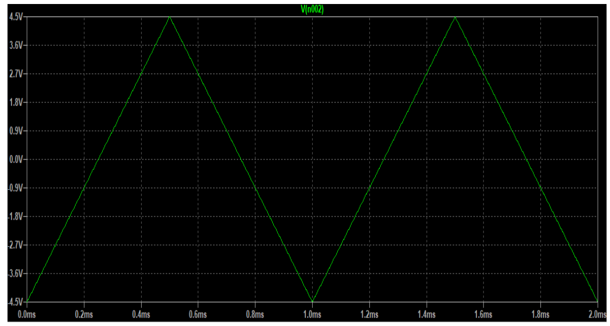
Figure 4: Thevenin equivalent circuit

4.3 Simulate the superposition principle with SPICE

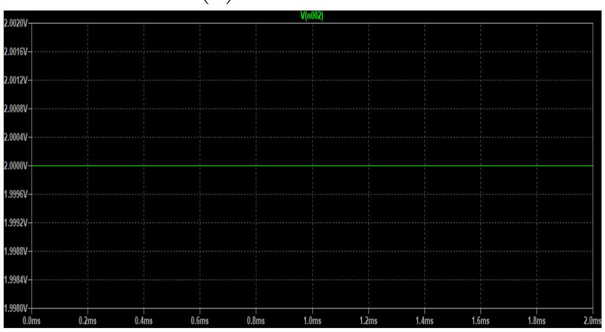
I got 3 separate waves for sine, triangle and DC. Then I combined them to form a saw-tooth wave.



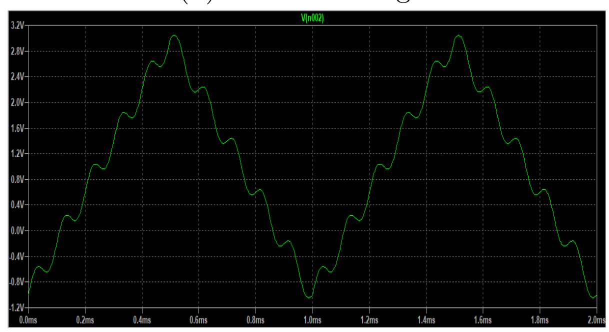
(a) Plot for sine wave



(b) Plot for triangle wave



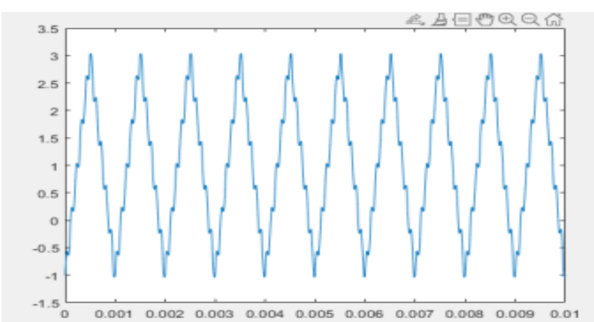
(c) Plot for DC wave



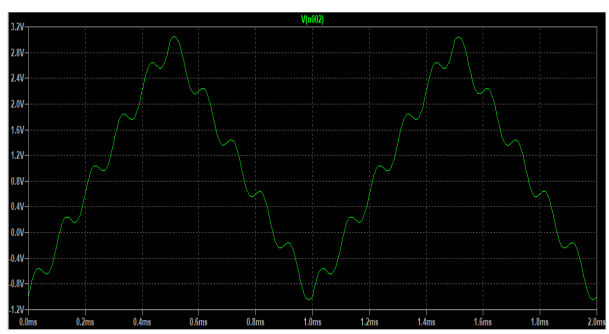
(d) Plot for combined wave

Figure 5: Plots for sine, triangle, DC and combined wave

So if we compare Figure 5d and Figure 2, we can see that the shape is similar, which thus proves that my plots are correct. Then we can see that these results are consistent with the superposition principle.



(a) Plot from pre-Lab



(b) Plot for combined wave

Figure 6: Comparing plot from pre-Lab and plot from SPICE side by side

5. Conclusion

5.1 Loading with a real signal

For task 1, we explored the use of a buffer in a circuit. We compared the RMS voltage across the speaker with and without a buffer. The results correspond with the theory that the speaker should have more power when the buffer is added. The addition of the buffer lessened the amount of power lost to the circuit's internal resistor which resulted in more voltage given to the speaker and therefore makes it louder.

5.2 Thevenin equivalent circuit design

For task 2, we verified the Thevenin theorem. This task was a bit different than usual tasks where we were given the resistance of resistors and we need to compute the Thevenin equivalent voltage and resistance. This time, we were given the Thevenin equivalent voltage and resistance, we need to find the V_s, R_1, R_2, R_3. But then all we have to do is work backwards and we know which resistors are in parallel and in series. So we just have to make the resistors equal to 1.5k. After figuring out the resistance, we found the Thevenin equivalent circuit.

5.3 Simulate the superposition principle with SPICE

For task 3, we used LTspice to draw the circuit and did simulations on it. We made 4 plots, one for each type of wave corresponding to the input from pre-lab question 1 and 1 plot where we combined all three types of waves together. The result is consistent with the graph I got for pre-lab. The graph produced was a saw-tooth shaped wave and it is a reasonable graph because we're combining the sine, triangle and DC wave. Therefore meaning it is consistent with the superposition principle.

References

[1] Brooke A. Parks Andrew D. Balmos Sutton R. Hathorn. *Electrical Engineering Fundamentals Laboratory I*. ISBN: 9781733438902.