ECE 220 Laboratory 3

Thevenin Equivalent Circuits, Constant Current Source, and Inverting Amplifier

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Please follow all rules, procedures and report requirements as described at the beginning of the document entitled ECE 220 Laboratory 1.
Always wear your safety glasses when performing your lab experiments.

Prelab Part 1

Consider the circuit shown below in Figure 1. We will consider three values for the load resistor R_L. These values are $1.5\ k\Omega$, $7.5\ k\Omega$, and $200\ k\Omega$.

a) Calculate v_L in Figure 1, for each of the three values for R_L. You may use any method you like, <u>except</u> for Thevenin/Norton or source transformations.
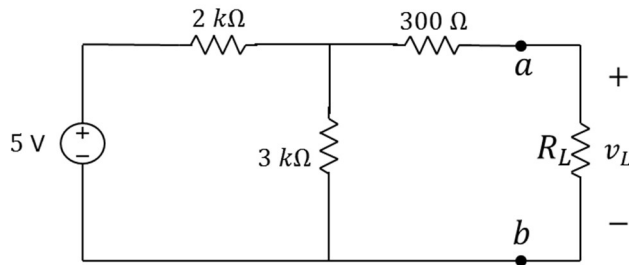

Figure 1. Original circuit.

Now consider the circuit in Figure 1 from the point of view of R_L. That is, consider the circuit with respect to the terminals labeled a and b with the load resistor removed. We know from class that we can compute the Thevenin equivalent of this circuit as shown below in Figure 2.

b) Calculate the required values of v_{Th} and R_{Th}.
c) Attach the three values for R_L (one at a time) in Figure 2, and calculate v_L for each.
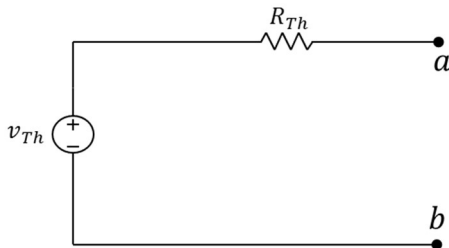

Figure 2. Thevenin equivalent circuit.

Prelab Part 2

All semester, we have been talking about current sources. We will now see how to make one. In this part, we consider a simple constant current source. Consider the circuit shown in Figure 3 below. Assume as usual that the op amp is ideal. Assume the power rails are set to ± 5 V. The left portion of the circuit uses the positive power rail, a 240 Ω resistor, and an LED to create a roughly constant input voltage (2.1 V) to the op amp circuit on the right. We could use a voltage source for this, but in the lab, we will already be using both channels of the power supply for $\pm V_{cc}$.
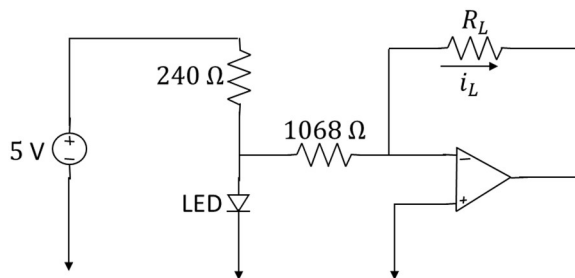
a) Calculate the load current i_L in Figure 3.

Figure 3. Constant current source.

Note that your calculated value of i_L is independent of the load resistor R_L. Thus, from the point of view of the load resistor, the circuit is acting as a constant current source. However, there is a maximum value of R_L for which this will be true. Hint: Think about the power rails.

b) Calculate the maximum value of R_L for which i_L will remain constant.

We will verify your calculations using PSpice. Start a new PSpice project as you have done before, and draw the circuit of Figure 4 below. The PSpice part name for the op amp is uA741. Don't forget that you can use the 'v' hotkey to mirror the op amp part vertically. This puts the inverting input (and the negative power supply pin) on the top. As before, we use three diodes to simulate an LED.

We introduce a new trick this time. The right side of the circuit shows two voltage sources connected together with a ground between them. The top node is labeled +supply, while the bottom node is labeled –supply. These labels are introduced by clicking
Place->Power
A new window will open. From the scroll down list, select the part VCC. As always, ignore the library name. Enter a name (in the middle near the bottom of the window). In Figure 4, the names +supply and –supply are used, but you can choose any names you like.
Click OK
Place labels (one at a time - with different names) above and below the voltage sources as shown in Figure 4. The 'v' hotkey may be useful here as well. Wire the labels to the voltage

sources. You can now place the same labels elsewhere in the circuit. This has the same effect as connecting wire between all labeled pins of the same name. In particular, see the labels connected to the op amp power supply pins. The purpose of this trick is to avoid cluttering your drawing with lots of voltage sources and/or having to cross wires.

Set up a DC sweep for the load resistor using the same procedure we have used in previous labs. Do a linear sweep of the load resistor from 100 Ω to 3 $k\Omega$ with a step size of 100 Ω. Put a current marker on the left pin of the load resistor as shown in Figure 4, and run PSpice. The resulting graph should show i_L as a function of R_L. The load current should remain constant at the value you calculated above until the load resistor approaches the maximum value you calculated above. The load current should then decrease as the load resistance is increased further.

Note that the load current starts decreasing before R_L actually reaches the maximum value that you calculated above. Think about why this occurs. Hint: Look at the output voltage of the op amp.
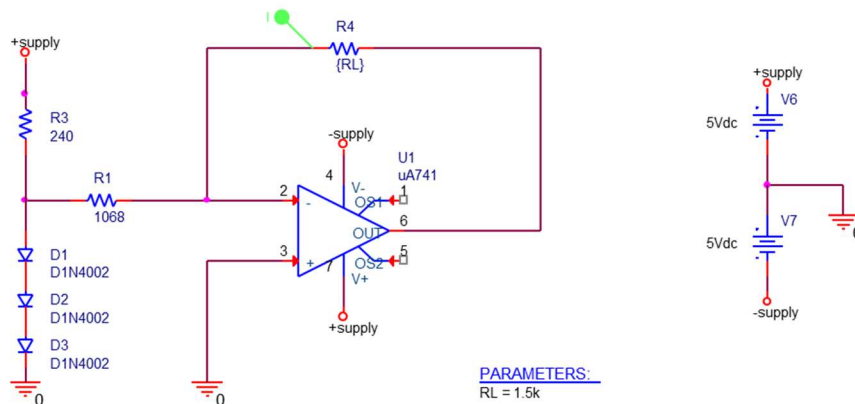
c) Print your graph.

Figure 4. PSpice schematic.

Prelab Part 3

Figure 5 below shows an inverting amplifier circuit. Assume power rails of ± 5 V.

a) Calculate the value of v_o in Figure 5.

Note that this value does not depend on R_L.

Do a PSpice simulation of the circuit in Figure 5. Make a graph of v_0 as a function of R_L. To do

this, perform a sweep of R_L from 1 Ω to 500 Ω, with a step size of 1 Ω. You will note that v_0 is constant for all values of R_L above some minimum value. At this minimum value of R_L, the output current of the op amp reaches its maximum value. The op amp cannot provide more current to hold the voltage constant for smaller values of R_L.

b) Print your graph.

c) Use the minimum value of R_L noted above to calculate the maximum output current that can be provided by the op amp (according to PSpice). Note: You would normally just look up i_{max} in the data sheet for the op amp.
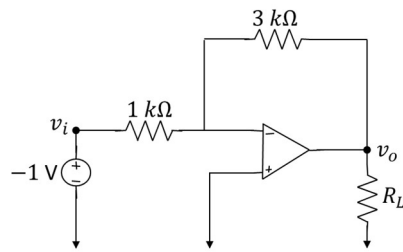

Figure 5. Inverting amplifier.

Prelab Grading

Part 1
a)   3 pts
b)   2 pts
c)   3 pts

Part 2
a)   3 pts
b)   3 pts
c)   4 pts

Part 3
a)   1 pt
b)   4 pts
c)   2 pt

                        _____
                        25 total pts

Lab 3 Data Sheet

Please follow all rules, procedures and report requirements as described at the beginning of the Lab 1 Data Sheet.

Lab Grading: Data Sheet = 15 pts; Explanation = 10 pts.

Lab Part 1

$v_{oc} =$	$i_{sc} =$	$R_{Th} =$

1 pt each

$R_L = 1.5\ k\Omega$	$R_L = 7.5\ k\Omega$	$R_L = 200\ k\Omega$
$v_L =$	$v_L =$	$v_L =$

0.5 pt each

$R_{Th} =$

1 pt

$R_L = 1.5\ k\Omega$	$R_L = 7.5\ k\Omega$	$R_L = 200\ k\Omega$
$v_L =$	$v_L =$	$v_L =$

0.5 pt each

Lab Part 2

$R_L = 100\ \Omega$	$R_L = 1\ k\Omega$	$R_L = 2\ k\Omega$	$R_L = 10\ k\Omega$
$i_L =$	$i_L =$	$i_L =$	$i_L =$

0.5 pt each

Lab Part 3

v_i	$v_p =$	$T =$	$v_i(t) =$
v_o	$v_p =$	$T =$	$v_o(t) =$

1 pt each

Buzzer and volume control work: Y / N (circle one)
0.5 pt

Lab Experiments

Lab Part 1

Build the circuit of Figure 1. Leave the load resistor off. Use the DMM to measure v_{oc} and i_{sc}. Record these values in your data sheet. Remember, an ideal volt meter looks like a resistor with value $R = \infty$ (open circuit), while an ideal current meter looks like a resistor with value $R = 0$ (short circuit). While the DMM is not ideal, it is pretty good. Thus, you can connect it directly to terminals a and b to measure the relevant quantities. Use your measured values to compute R_{Th}. Think about Method 1. Record your calculated value of R_{Th} on your data sheet.

Connect R_L having values 1.5 $k\Omega$, 7.5 $k\Omega$, and 200 $k\Omega$ (one at a time). Use the DMM to measure the value of v_L for each value of R_L. Record these values on your data sheet.

Now, remove the voltage source (and load resistor) from your circuit. Replace the voltage source by a piece of wire (short). Use the DMM to measure R_{Th} as the resistance between terminals a and b. Think about Method 2. Record this value on your data sheet.

Build the circuit of Figure 2. Connect R_L having values 1.5 $k\Omega$, 7.5 $k\Omega$, and 200 $k\Omega$ (one at a time). Use the DMM to measure the value of v_L for each value of R_L. Record these values on your data sheet.
Have your TA initial your results.
Online students: take photos of your circuits and DMM showing each of your recorded values.

Lab Part 2

Build the circuit shown in Figure 4. Use ± 5 V for the power rails. In Figure 4, three regular diodes were used to simulate an LED in PSpice. When building this circuit in the lab, use one LED. We will use an LM358N op amp for this part. We used μA741 in the prelab because there is no model for the LM358N in the "lite" version of PSpice. For your convenience, the pin diagram of the op amp is shown below in Figure 6. Some discussion about the voltage sources in Figure 4 may be helpful. The power supply in the on-campus lab has two sets of outputs which can be used as two different voltage sources. Each set of outputs has a black terminal, a red terminal, and an (earth) ground terminal. As discussed in class, the "triangle" symbol that we use to mark the reference (0 V) node is different than earth ground. We do not need an earth ground in this (or any other) 220 lab. Thus, make sure that the metal straps attached to the earth ground terminals on the power supply are not connected to any of the red or black terminals. Then use a cable to connect the black (negative) terminal of one voltage source to the red (positive) terminal of the other voltage source. These two terminals that are connected

together then form your reference node, NOT the earth ground terminal. This is illustrated in Figure 7.

Use the DMM to measure i_L for four different values of $R_L = 100 \, \Omega$, $1 \, k\Omega$, $2 \, k\Omega$ and $10 \, k\Omega$. Record these values on your data sheet, and have your TA initial it.

On-campus students: take a photo of your circuit and DMM showing each of your recorded measurements.

1 – Output 1
2 – Inverting input 1
3 – Non-inverting input 1
4 – Negative power supply
5 – Non-inverting input 2
6 – Inverting input 2
7 – Output 2
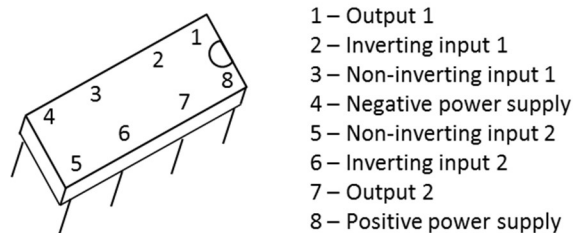8 – Positive power supply

Figure 6. LM358N op amp pin diagram. Note: The chip contains two op-amps. We will use only one of them for this part.

Figure 7. Power supply connections.

Lab Part 3

Build the circuit shown below in Figure 8. Use ± 5 V for the power rails. Note the changes in this circuit as compared to the one in Figure 5 of the prelab. Connect a $10 \, k\Omega$ pot as a variable resistor as shown. Initially, set the pot so that the feedback resistor is $10 \, k\Omega$. Use the scope to view v_i on channel 1. Set the scope to trigger on channel 1 with positive slope and 0 level so that v_i looks like a sin (not cos, or other). Now, connect channel 2 of the scope to v_o. Measure and record the amplitude and period of both v_i and v_o. Note that v_o is inverted with respect to v_i, as expected. Write an equation for both of these voltages.

Now, vary the pot setting to see its effect on v_i and v_o. Make sure to investigate pot settings below $1 \, k\Omega$.

Change the function generator from a sin wave to a square wave at the same frequency and amplitude (0.5 V peak, 1.0 V peak-to-peak). Again, observe the effect that varying the pot

settings has on v_i and v_o.

Replace the $20\ k\Omega$ resistor with a Piezo buzzer. Observe the effect of varying the pot setting. Observe the effect of varying the frequency of the square wave.

Have the TA initial your results.

Online students: make a video (with audio) that shows the buzzer getting louder and softer, as well as the frequency changing higher and lower.
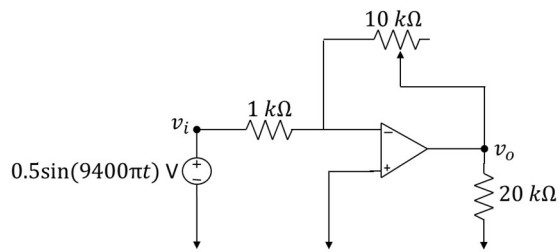

Figure 8. Inverting amplifier with volume control.