ECET 303
LAB MANUAL

Developed

by

Ronald H. Rockland, Ph.D.
INTRODUCTION

This manual is intended as a laboratory manual for ECET 303. For most labs, there are two parts – a Prelab Required and the Laboratory Assignment. The section entitled Prelab Required is intended to be done BEFORE the lab. You will be required to show the prelab before your group can begin the experiment. The purpose of the prelab is to give you an idea of what results you should obtain while performing the actual measurements. Since the prelab will count 15% of the laboratory grade, failure to have the prelab prior to starting the lab will result in your lab report having a maximum possible grade of 85%.

Parts list are shown for each lab, and in the beginning section there is an overall parts list. Your instructor will discuss how you will obtain the parts.
PARTS LIST FOR COURSE

If more than one item is required, the quantity is in the parenthesis. I would suggest that you have more than one each of resistors.

<table>
<thead>
<tr>
<th>Part</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Protoboard</td>
<td>White board to develop prototype circuits</td>
</tr>
<tr>
<td>Resistors</td>
<td>47 Ω, 100 Ω (2 ea), 470 Ω (2), 1 kΩ (4), 4700 Ω, 10 kΩ (2)</td>
</tr>
<tr>
<td>Wire</td>
<td>For protoboard wiring</td>
</tr>
<tr>
<td>Capacitors</td>
<td>0.1 μF (2), .01 μF (2)</td>
</tr>
<tr>
<td>Inductor</td>
<td>100 mH</td>
</tr>
</tbody>
</table>
LAB 1: MEASUREMENT OF OHM’S LAW, KCL AND KVL

Time Allotted: 1 week

Purpose:
To determine current and voltage measurements in both series and parallel resistive networks.

Method:
Create simple series and parallel resistive networks, and utilize a DC source and a DMM to measure both the voltage across the output resistor and current in the branch. Comparisons will be made between experimental and pre-lab calculations.

Equipment and Parts Required:
- 1 - Multimeter
- 1 - Protoboard
- 1 - Power Supply
- Resistors with values $47 \, \Omega$, $100 \, \Omega$ (2 ea), $470 \, \Omega$, $1000 \, \Omega$, $4700 \, \Omega$
- Wire

Prelab Required:
1. Review notes on error analysis from lecture.
2. From Figs. 1 and 2, calculate the expected values of $v_{R_2}^*$ and $i_{R_2}^*$, and fill in the tables on the next page. Place these values in the Expected Values section only.
3. Calculate the power delivered to $R_2$ for each of the two circuits, for the range of resistor values.

Laboratory Assignment:

![Fig. 1](image1)

![Fig. 2](image2)
1. For the circuit in Fig. 1, vary $R_2$ with the resistors as specified in the table below, and fill in the table below in the measured values section. Before measuring the voltage and current, measure the exact value of the resistor you are using. Create both tables (below) in Word, and fill in the actual values.

<table>
<thead>
<tr>
<th></th>
<th>Expected Values</th>
<th>Measured Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_2$</td>
<td>$v_{R_2}$</td>
<td>$i_{R_2}$</td>
</tr>
<tr>
<td>47 $\Omega$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 $\Omega$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>470 $\Omega$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000 $\Omega$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4700 $\Omega$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Plot $i_{R_2}$ vs. $v_{R_2}$.

3. Repeat steps 1 and 2 for the circuit in Fig. 2.

<table>
<thead>
<tr>
<th></th>
<th>Expected Values</th>
<th>Measured Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_2$</td>
<td>$v_{R_2}$</td>
<td>$i_{R_2}$</td>
</tr>
<tr>
<td>47 $\Omega$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 $\Omega$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>470 $\Omega$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1000 $\Omega$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4700 $\Omega$</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. Using PSpice, repeat the experiment.

5. Compare the values you obtained in this experiment vs. calculated values. Demonstrate that you can explain the differences through error analysis, taking into consideration tolerances of the resistors, accuracy of the meter, and of the power supply.

6. What are other types of errors that could occur in this experiment.

7. Design a different experiment, showing this capability, and run that experiment. The design should include a writeup, similar to this experiment.
LAB 2: ANALYSIS OF CIRCUITS

Time Alotted: 1 week

Purpose:
To understand the application of various circuit methods to solve actual problems.

Method:
Work with a variety of resistive circuits and mesh and/or nodal analysis.

Equipment and Parts Required:
- 1 - Power Supply
- 1 - Multimeter
- 1 - Protoboard
- 1 - Resistors with values 47 Ω, 100 Ω (2 ea), 470 Ω, 1000 Ω, 4700 Ω
- 2 - 10 kΩ resistors
- 2 - .01 µF capacitor
- Wire

Prelab Required:
1. Review Mesh and Nodal Analysis in text (will have a 5 minute quiz at the beginning of the lab, so be prepared with knowing these circuits).

Laboratory Assignment:
1. Working together as a group, first solve using mesh analysis the output voltage for the circuit on page 106 of the textbook, problem 3.42. However, use an input voltage of 1 V.
2. Use nodal analysis to solve the same problem.
3. Show the instructor your solutions before going onto the next steps.
4. Simulate the circuit in PSpice, and compare with your analysis.
5. Build the circuit, with comparable resistor values. Measure the resistor values you are going to use (they are probably different than the actual values in the problem), and using mesh analysis, solve for the actual voltage.
6. Compare and discuss the differences in values between the calculation performed in item 5 and the actual values.
7. Repeat items 1-6 for the circuit on page 103, problem 3.20, replacing the 2 mA current source with a 3 kΩ resistor, and replacing the 12 V voltage source with a 1.2 V voltage source.
8. Develop a circuit that would be different from the two circuits you just did, and repeat items 1-6. Originality counts in coming up with a circuit. Explain why you came up with that configuration.
LAB 3: THEVENIN/NORTON AND SUPERPOSITION

Time Allotted: 2 weeks

Purpose:
To understand the utilization of Thevenin and Norton equivalent circuits.

Method:
By building various resistive circuits and comparing them to their Thevenin equivalent a better understanding of this linear network theorem will develop.

Equipment and Parts Required:
• 1 – Power Supply
• 1 – Multimeter
• 1 – Protoboard
• Resistors: 100 Ω, 1 kΩ (4 ea.), 10 kΩ (2ea)
• Graph paper
• Blank sheets of paper and tape
• Wire

Note: Under Week 1, the tasks in Prelab Required are due for week 1 of the lab. The actual lab experiment is listed under Laboratory Assignment. Would suggest you get to at least item 4 for week 1 of the lab assignments. Week 2 in Prelab Required must be handed in before the second week of this lab.

Week 1:

Prelab Required:

a. Develop a general equation for both Thevenin and Norton equivalent for the circuit below, and then use a value of 1 kΩ for each resistor. Use 5 V as the input voltage.

b. Simulate the circuit in Fig. 1, its Thevenin equivalent, and its Norton equivalent, using PSpice. Print out the circuit diagram for each of the three circuits (the original circuit, the Thevenin equivalent, and the Norton equivalent), showing the output voltage across R_L.

c. Repeat for the circuit in Fig. 2. Again, first develop a general equation and then set the resistor value to 1 kΩ.
Week 2:

a. Develop a general equation for both Thevenin and Norton equivalent for the circuit in Fig. 3, and use a value of 1 KΩ for each resistor and 5 V as the input voltage. Redo with R₁ and Rₑ equal to 10kΩ.

b. Simulate the circuit in Fig. 1, the Thevenin equivalent, and the Norton equivalent using PSpice. Print out the circuit diagram for each of the three circuits (the original circuit, the Thevenin equivalent, and the Norton equivalent), showing the output voltage across Rₐ.

Laboratory Assignment:

1. For the circuit in Fig. 1, complete the table below, for the various values of Rₐ. All other resistors are equal to 1 kΩ.

<table>
<thead>
<tr>
<th>Rₐ</th>
<th>Vₑ₂(Rₐ)</th>
<th>Iₑ₃(Rₐ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open circuit</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 kΩ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 kΩ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100 Ω</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Short circuit</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2. Plot vₑ₂ vs iₑ₃ for the values of Rₐ listed above. Explain why the choices of Rₐ in the table above would help you determine the Thevenin equivalent circuit.

3. From this data, determine the Thevenin equivalent circuit, and compare it to the pre-lab calculations. Why is it different? Explain in terms of error analysis.

4. Repeat items 1-3 for the circuit in Fig. 2.

5. Create a similar circuit to Fig. 2, but use different values for the resistors (any other the resistors you have). Calculate the Thevenin equivalent, and repeat items 1-3.

6. Give this circuit to the group next to you, and cover up the resistors with the blank sheet of paper, so the other group can’t read the values. Have them perform items 1-3, and compare to your results. Did that group have to know the values of the resistors?

7. Repeat items 1-3 for the circuit in Fig. 3, with all other resistors equal to 1 kΩ.

8. In the circuit in Fig. 3, change R₄ to 100 Ω and 10 kΩ. Derive the Thevenin equivalent for this circuit with these new values, and verify experimentally. What effect did changing R₄ have on this circuit?
LAB 4: TIME RESPONSE OF AN RC AND RL CIRCUIT

Time Allotted: 2 week

Purpose of Lab:
This lab will compare the time response of an RC and RL circuit.

Method:
In the next two labs, RC and RL circuits will be studied as to their time response characteristics (rise and fall times) and their frequency characteristics (amplitude and phase). By looking at these characteristics for the same circuits, students will be able to determine the information obtained by each type of analysis.

Equipment and Parts Required:
- Function generator
- Oscilloscope
- Multimeter
- 1 - Breadboard
- Resistors with values 1 kΩ and 100 kΩ (2 ea)
- 0.1 µF capacitor (2 ea)
- Wire

Prelab Required (Note that the next two pages are prelabs for each week - the actual laboratory assignments begin with the title Laboratory Assignment):

Week 1 (Prelab):

1. Solve for \( v_o(t) \), as a function of \( v_{in}(t) \), for the circuits shown (Fig. 1-4), using the theoretical method discussed in lecture.

2. Solve for a unit step and a pulse response. Note that the output to a pulse response would be the sum of two unit steps, one delayed and inverted from the other. Solve for general values of R, C, and L.

3. Use the following values, and utilizing Excel, develop a graph for the output - \( R = 1 \text{ kΩ} \) and \( C = 0.1 \mu\text{F} \) for Fig. 1 and 3, and \( R = 1 \text{ kΩ} \) and \( L = 100 \text{ mH} \). Repeat the analysis for \( R = 100 \text{ kΩ} \).

Using the methods discussed in the lecture, the output voltage can be solved as a function of the input voltage. If the input voltage is a unit step, then after time \( t = 0 \) it appears to be a constant. The
Week 2 (Prelab):

1. Starting with a resistor value of 1 kΩ create the circuit in Fig. 1 in PSpice and attach a pulse voltage source to the input. Set the pulse amplitude to 1V, attach a marker to both the input and output voltages, and observe the graph.

2. Increase the pulse width until you see at least 4 time constants of the output (see the output reach maximum). You may need to adjust the repetition rate to do so. You should adjust the time between pulses so that there is no charge left on the capacitor.

3. Print out the circuit diagram from PSpice as well as the output graph from Probe.

4. Extrapolate the initial slope of the output pulse until the line intersects 1V, using the graph you just produced. Try using the cursor to measure time and a line label to create the line.

5. Measure the time between the start of the pulse and the time corresponding to the intersection of that line. Compare to the calculated time constant.

6. Measure the time between t=0 and when the output reaches 63%, and compare that to item 5 and the calculated time constant.

Laboratory Assignment (you should complete at least through item 6 for the first week):

1. Starting with a resistor value of 1 kΩ build the circuit in Fig. 1 and attach a function generator to the input. Set the pulse amplitude to 1V and display the input on channel A of the oscilloscope, and the output on channel B.

2. Increase the pulse width until you see at least 4 time constants of the output (see the output reach maximum). You may need to adjust the repetition rate to do so (or obtain a pulse generator). You should adjust the time between pulses so that there is no charge left on the capacitor.

3. Extrapolate the initial slope of the output pulse until the line intersects 1V. Measure the time between the start of the pulse and the time corresponding to the intersection of that line. Compare to the calculated time constant. (Will be covered in lecture prior to the lab).

4. Compare this time constant with the time measured between the start of the output waveform and 63% of the final value. What does this represent?

5. Change the output of the function generator to a triangular waveform and observe the output. Changing the frequency of the triangular waveform will change the slope of the ramp. Determine at what frequency the output starts or stops looking like the input.

6. How does this slope relate to the time constant of the circuit?

7. Change the resistor value to 100 kΩ and repeat items 1-5.

8. Repeat items 1-3 for the RL circuits in Fig. 2 and 4. First use a resistor value of 1 kΩ and then use a 100 kΩ.
Items 9-12 must be done only after the above items are completed. Call the professor over to observe your notes prior to starting the next 4 items.

9. Using $PSpice$ in the lab set the input to a triangular waveform and observe the output. There are several ways to obtain a triangular waveform in $PSpice$. One way is to use a pulse waveform, and adjust the rise time and fall time so they are very long (represent the slope of the triangular waveform). Then make sure that the pulse width is set so that you see a triangular waveform. Another way is to use a piecewise linear voltage source. Changing the frequency of the triangular waveform will change the slope of the ramp. Determine at what slope the output starts or stops looking like the input. How does this slope relate to the time constant of the circuit?

10. Print out the graph (if there is no printer then save this file for later printing). Show the professor the graph before proceeding.

11. Change the resistor value to 100 k$\Omega$ and repeat items 1-7.

12. Repeat items 1-7 for the RL circuits in Fig. 2 and 4. First use a resistor value of 1 k$\Omega$ and then use a 100 k$\Omega$. 
LAB 5: FREQUENCY ANALYSIS OF AN RC AND RL CIRCUIT

Time Allotted: 3 weeks

Purpose of Lab:
This lab will compare the time response and frequency response characteristics of an RC and RL circuit.

Method:
RC and RL circuits will be studied as to their time response characteristics (rise and fall times) and their frequency characteristics (amplitude and phase). By looking at these characteristics for the same circuits, students will be able to determine the information obtained by each type of analysis.

Equipment and Parts Required:
- Function generator
- Oscilloscope
- Multimeter
- 1 – Breadboard
- Resistor with values 1 kΩ and 100 kΩ (2 ea)
- 0.1 µF capacitor (2 ea)
- 100 mH inductor
- Wire

Prelab Required (Note that the next two pages are prelabs for each week - the actual laboratory assignments begin with the title Laboratory Assignment):

Week 1:

1. For the circuits in Figure 1-4, with the value of R=1 kΩ and C= 0.1 µF, derive the output if the input is a sinusoid, 2 V p-p, zero phase, and has a frequency of 500 Hz.
2. For the circuit in Figure 1, add a 1 kΩ resistor in parallel with the capacitor, and derive the output with the same signal as described in item 1.

Week 2:
1. For the circuits in Fig. 1-4, develop and print a Bode plot for all four circuits, using both values specified in item 1 of week 1. Change the resistor to 100 kΩ and recalculate (should have a total of 8 Bode plots). This is to be done theoretically, using Excel to create the Bode plots.
2. Repeat the Bode plots for item 1 of week 2, using PSpice. Compare results of your PSpice with the theoretical results from item 1, week 2.
3. Discuss how the Bode plots are different, especially where the break frequency is and how it relates to low or high frequencies. Discuss how this filtering is related to the transient analysis you did in items 1-7.

Week 3:
1. Utilizing PSpice, develop and print out a Bode plot for the circuit in Fig. 5. Discuss how this circuit is different from Fig. 1, and what would have been your theoretical prediction as to their response.

Laboratory Assignment (you should complete at least through item 6 for the first week):
1. Starting with a resistor value of 1 kΩ build the circuit in Fig.1. Set the function generator to produce a sine wave output, 2 V p-p, and a frequency of 500 Hz. Compare the results of this lab to the prelab analysis.
2. Repeat this analysis for the circuits in Figures 1-4.
3. Calculate the break frequency for each of these circuits, using a 0.1 µF capacitor and a 1 kΩ resistor. Set \( v_{in} \) to be a sinusoid with a peak to peak amplitude of 1V, and vary the frequency from 10 Hz to 10 KHz. Observe both the input and output on an oscilloscope, and collect at least five magnitude and phase angle points (need to calculate phase angle) above and below the break frequency.
4. Calculate the ratio of output/input for each frequency in terms of decibels, and plot both the magnitude and phase angle in Excel. Compare with the theoretical results from the prelab.
5. Measure the value at the calculated cutoff frequency, and measure the difference in both magnitude and phase between the cutoff frequency and 10 x the cutoff frequency.
6. Compare the calculated cutoff frequency with the experimental results and the PSpice results.
7. Change the resistor value to 100 kΩ and repeat items 1-4.
8. Repeat items 1-5 for the circuit in Fig. 2.
9. Discuss how the Bode plots are different, especially where the break frequency is and how it relates to low or high frequencies. Discuss how this filtering is related to the transient analysis you did in items 1-7.

10. Repeat items 1-5 for the circuit in Fig. 5.
LAB 6: AVERAGE AND RMS ANALYSIS

Time Allotted: 1 week

Purpose of Lab:
This lab will reinforce concepts on average and RMS measurements.

Method:
Different waveforms will be generated, and the average and RMS measurements will be compared theoretically and experimentally.

Equipment and Parts Required:
- Function generator
- Oscilloscope
- Multimeter
- 1 – Breadboard
- Resistors with values 1 kΩ and 100 kΩ (2 ea)
- 0.1 µF capacitor (2 ea)
- 100 mH inductor
- Semi-log paper (at least 8 sheets)
- Wire

Prelab Required (Note that the next two pages are prelabs for each week - the actual laboratory assignments begin with the title Laboratory Assignment):

1. Calculate the average and rms values for:
   a. A triangular waveform with a 50% duty cycle.
   b. A pulse waveform with a 10%, 20%, and 50% duty cycle
   c. A sine waveform

   All waveforms should have a pulse interval of 10 ms, and an amplitude of 1 volt peak (triangular and pulse) or 1 volt peak to peak (sine wave)

Laboratory Assignment:

1. Generate the waveforms as described in the pre-lab (week 4). Set up these waveforms utilizing the oscilloscope.
2. For each waveform, analyze the output using the multimeter, both on the DC scale and the AC scale.
3. Compare the readings to the theoretical results for average and rms. How do they compare?