Lab Experiment #3: Electrical Circuit Theorems
Electrical Circuit Theorems

I. Objective

In this experiment, the students will analyze, construct and test dc resistive circuits to gain further insight and hands-on experience on electrical circuits as well as to verify some of the circuit theorems they learn in class such as the **Superposition Principle**, **Thevenin** and **Norton Equivalent Circuits** and **Maximum Power Transfer Theorem**.

II. Procedure

PART A: Superposition Principle

**Pre-lab Assignment A.1:** For the circuit shown in Fig. 1, calculate the voltage $V_2$ across the resistor $R_2$ using the superposition principle. Provide your work step by step and box your answers.

**Pre-lab Assignment A.2:** For the circuit shown in Fig. 1, reverse the polarity of the 5 V dc voltage source and redo pre-lab assignment A.1. (Hint: You can use the results of Pre-lab 1.a.) Box your answers.

**Lab Experiment A.1:** Construct the resistive circuit shown in Fig. 1. Using the LCR meter, measure and record the actual values of the resistors $R_1$, $R_2$, and $R_3$ used in your circuit. To verify the superposition principle, measure and record the voltage $V_2$ for the following three cases (record your measurements in Table 1 form as provided below):

(a) When $V_{s1}$ voltage is on and $V_{s2}$ is off. (Voltage source “off” means you disconnect the voltage source from the circuit and short the terminals where this voltage source was connected. **Warning:** Do not short the terminals of the voltage source itself!)

(b) When $V_{s1}$ voltage is off and $V_{s2}$ is on.

(c) When both $V_{s1}$ and $V_{s2}$ voltages are on.

![Figure 1. A resistive circuit excited by two dc voltage sources.](image-url)
Table 1. Measured $V_2$ values in the circuit shown in Figure 1.

<table>
<thead>
<tr>
<th>$V_2$ (V)</th>
<th>$V_2$ (V)</th>
<th>$V_2$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Vs1 on and Vs2 off)</td>
<td>(Vs1 off and Vs2 on)</td>
<td>(Both Vs1 and Vs2 on)</td>
</tr>
</tbody>
</table>

Check to see if superposition holds. Also check to see if your measured $V_2$ values agree with the $V_2$ values calculated in your pre-lab assignment A.1 (i.e., calculate percentage error between the calculated and the measured $V_2$ values).

**Lab Experiment A.2:** Reverse the polarity of the 5 V voltage source in your circuit and repeat the same $V_2$ measurements done in Lab Experiment A.1, parts (a), (b) and (c). Again record your measurements in Table 2 form as provided below.

Table 2. Measured $V_2$ values in the circuit shown in Figure 1 where the polarity of the 5 V voltage source is reversed.

<table>
<thead>
<tr>
<th>$V_2$ (V)</th>
<th>$V_2$ (V)</th>
<th>$V_2$ (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Vs1 on and Vs2 off)</td>
<td>(Vs1 off and Vs2 on)</td>
<td>(Both Vs1 and Vs2 on)</td>
</tr>
</tbody>
</table>

Check to see if superposition holds. Also check to see if your measured $V_2$ values agree with the $V_2$ values calculated in your pre-lab assignment A.2.

**PART B: Thevenin, Norton & the Maximum Power Transfer Theorem**

**Pre-lab Assignment B.1:** For the circuit shown in Fig. 2, find the Thevenin and Norton equivalent circuits seen between terminals A and B. Draw each equivalent circuit separately with the appropriate values provided. Provide your work step by step and box your results.

![Image of the circuit](https://via.placeholder.com/150)

**Figure 2.** A resistive circuit excited by a dc voltage source.

**Pre-lab Assignment B.2:** For the circuit shown in Fig. 2, find the optimum value of the external load resistance $R_{L,\text{opt}}$ to be connected between the terminals A and B so that it receives maximum power from the circuit. What is $P_{L,\text{max}}$? (Hint: Use the results of pre-lab assignment B.1.)
**Lab Experiment B.1:** Construct the circuit shown in Fig. 2. Using the LCR meter, measure and record the actual values of the resistors used in your circuit. Verify the Thevenin and Norton equivalent circuits obtained in pre-lab assignment B.1 by measuring the open-circuit voltage $V_{OC}$ and short-circuit current $I_{SC}$ between terminals A and B.

Table 3. Measured values of $V_{OC}$, $I_{SC}$ and $V_L$, and calculated value of $R_T$ (or $R_N$) and $P_L$ in the circuit shown in Figure 2.

<table>
<thead>
<tr>
<th>$V_{OC}$ (V)</th>
<th>$I_{SC}$ (mA)</th>
<th>$R_T$ or $R_N$ ($\Omega$)</th>
<th>$V_L$ (V)</th>
<th>$P_L$ (mW)</th>
</tr>
</thead>
</table>

**Lab Experiment B.2:** Connect a load resistance with the optimum value $R_{L,\text{opt}}$ between terminals A-B in the original circuit shown in Fig. 2. Measure the voltage $V_L$ across $R_{L,\text{opt}}$ and use it to verify the $P_{L,\text{max}}$ value calculated in pre-lab assignment B.2.

**PART C: Maximum power to a load resistance with fixed value**

**Pre-lab Assignment C:** In Fig. 3, assume that the load resistance $R_L$ has a fixed value given by $R_L=1 \text{ k}\Omega$.

(a) How much power is being delivered to $R_L$? Show your work step by step.

(b) Your job is to introduce a single external resistor $R_{ext}$ into the circuit with an appropriate value to maximize power delivery to the 1 k\Omega load. What is the value of $R_{ext}$? (Hint: The external resistor could even be a piece of wire.) Where should it be connected? With the external resistor properly connected to the circuit, what is $P_{L,\text{max}}$? (Note that this problem is different than the maximum power transfer theorem.) Show your work and box your results!

**Lab Experiment C:** Verify the results of pre-lab assignment 3 experimentally. Measure and record the load voltage $V_L$ and the current $I_L$ with and without the external resistance connected and calculate the load power using $P_L = V_L I_L$ in each case. Approximately how much percent did the load power increase due to the introduction of the external resistance $R_{ext}$ into the circuit?

Table 4. Measured values of $V_L$ and $I_L$, and calculated values of $P_L$ in the circuit shown in Figure 3.

<table>
<thead>
<tr>
<th>$V_L$ (V) (no $R_{ext}$)</th>
<th>$V_L$ (V) (with $R_{ext}$)</th>
<th>$I_L$ (mA) (no $R_{ext}$)</th>
<th>$I_L$ (mA) (with $R_{ext}$)</th>
<th>$P_L$ (mW) (no $R_{ext}$)</th>
<th>$P_L$ (mW) (with $R_{ext}$)</th>
<th>% $P_L$ increase</th>
</tr>
</thead>
</table>
III. Discussions & Conclusion

In this section, discuss the various aspects of Experiment #3 and make some conclusions. In your write-up, you should at least address the following questions:

1. What was the objective of this experiment and was the objective achieved?
2. Did any of your measurements have more than 5% error? What was your maximum % error?
3. What sources of error may have contributed to the differences between the theoretical values and the measured values?
4. Other comments relevant to this experiment.

Figure 3. A circuit with a fixed load resistance having a value $R_L=1 \, \text{k}\Omega$. 

![Circuit diagram](image)

$V_S=5 \, \text{V}$

$R_S=3 \, \text{k}\Omega$

$I_L$

$R_L=1 \, \text{k}\Omega$

$V_L$