# ECE 2100 Lab 2

# Thévenin and Norton Equivalents

Updated, 2/3/23 DR

**Introduction**

In this exercise we will try to verify Thévenin and Norton equivalents in the laboratory using actual components and sources. You will be asked to make calculations, and then to make measurements to verify that these calculations are valid. Then you will test out your design skills by designing and conducting an experiment to verify the theory of maximum power transfer.

This laboratory exercise is a study of equivalent circuits. Equivalent circuits are common throughout circuits and electronics. An equivalent circuit is used to replace another circuit, or part of a circuit, and is in some way simpler, easier to analyze, or more useful in that particular case. If the circuit that is substituted is truly equivalent, the behavior outside the equivalent circuit remains the same before and after the replacement. It is equivalent in no other sense, however, and the behavior *within* the equivalent circuit may be unrelated to the circuit it replaces.

## Research Questions

|  |
| --- |
| Can the theorem of Thevenin and Norton Equivalent Circuits be verified using actual circuit components in the laboratory? |
| Can the theorem of maximum power transfer be verified? |

## Materials

¼ [W] resistors (number required in parentheses):

8.2[kΩ] (1) 3.9[kΩ] (1)

10[kΩ] (3) 5.6[kΩ] (1)

1[kΩ] (3) 2.7[kΩ] (1)

1.5[kΩ] (1) 15[kΩ] (1)

2.2[kΩ] (1) 10[kΩ] Potentiometer (1)

## Methods

## In this experiment we will make measurements necessary to find the Thevenin and Norton Equivalent Circuits at a specified pair of terminals for *two different circuits*. We will compare the measurement results to calculations of the Thevenin and Norton equivalents. In addition, we will measure the current through *three load resistors* connected to the circuit, and we will compare these currents with the currents predicted by the Equivalent circuits. Finally, we will design and conduct an experiment to verify the theory of maximum power transfer.

***Data***

## The data we collect will be the open circuit voltage and short circuit current needed to calculate the equivalent circuits. We will also measure load current through three resistors connected to the circuits.

***Data Analysis***

## We will use the theorem of Thevenin and Norton Equivalent Circuits to calculate the Thevenin and Norton Equivalents. Information on how to perform these calculations can be found on Canvas->Documentation->Thevenin\_and\_Norton\_Equivalents.pdf

## Pre-Lab

Look at Steps 1, 2, 7, and 8 for pre-lab instructions.

## Procedure and Results

***Calculated Thevenin and Norton Equivalents: Circuit 1***

**Step 1:** Pre-lab: Calculate the Thévenin and Norton Equivalents for the circuit shown in Figure 1 with respect to terminals a and b. Record your answers in the form of equivalent circuit diagrams, that is, draw and label the Thévenin voltage and resistance, and the Norton current and resistance, and clearly label the terminals a and b in each case. Later you will enter these calculated values in Table 1 (Step 3).



**Figure 1:**  First of Two Circuits Used in the Experiment.

***Measured Thevenin and Norton Equivalents: Circuit 1***

**Step 2:** **Pre-lab:** Assume that resistors with values of 1[kΩ], 2.2[kΩ], and 10[kΩ] are to be connected, one at a time, to terminals a and b in the circuit in Figure 1. Calculate the currents that would flow through each of these resistors. In Step 6 you will enter them in Table 3.

**Step 3:** Build the circuit in Figure 1 on your prototyping board. Measure the open circuit voltage and the short circuit current between the terminals a and b. Record your measurements in Table 1. In the second column, enter the calculated values from Step 1. Also, find the percent error between the measured values and the calculated values. Use the calculated values as the reference.

# **Table 1:** Open Circuit Voltage and Short Circuit Current; Circuit 1

|  |  |  |  |
| --- | --- | --- | --- |
|  | Measured values | Calculated values | *% error* |
|  |  |  |  |
|  |  |  |  |

**Step 4:** Find the Thévenin and Norton equivalents for this circuit using measurements made in Step 3. Record your answers in the form of equivalent circuit diagrams.

**Step 5:** Measure the Thévenin resistance by connecting an ohmmeter at terminals a, b - ***but see the important note below first!!***  Record your answer in Table 2 below. Calculate and enter the Thevenin resistance value obtained from Step 1 calculations of the open-circuit voltage and short-circuit current. Find the percent error between the measurement and the calculated value.Use the calculated value as reference.

***Important Note:*** *To find the equivalent resistance you need to "deactivate" the independent sources in your circuit. Be careful here! Turning the power supply off may not give you the results you expect, because the output of the power supply does not behave like a short circuit when its power is removed. Another likely suggestion is to turn the input voltage from the power supply to zero. However, if it does not go to exactly zero, it will behave as a source in the circuit. This will cause errors in your ohmmeter reading.* ***The proper procedure here is to remove the power supply from the circuit and replace the connection with a wire (short circuit).*** *But again, be careful!* ***Do not short the output of the DC power supply****; this can damage the supply.*

# **Table 2:** Thévenin Resistance for circuit 1

|  |  |  |  |
| --- | --- | --- | --- |
|  | Measured in  Step 5 | Obtained from Calculated | *% error* |
| Thévenin  resistance |  |  |  |

**Step 6:** Enter the calculated current values from Step 2 into Table 3. Next, connect a 1[kΩ] resistor between terminals a and b in the circuit of Figure 1 and measure the current through it. Repeat this step using a 2.2[kΩ] resistor and a 10[kΩ] resistor. Record your measurements in Table 3.

# **Table 3:** Current Measurement; Circuit 1

|  |  |  |  |
| --- | --- | --- | --- |
|  | 1[k] | 2.2[k] | 10[k] |
| calculated current |  |  |  |
| measured current |  |  |  |

***Calculated Thevenin and Norton Equivalents: Circuit 2***

**Step 7:** **Pre-lab:** Calculate the Thévenin and Norton Equivalents for the circuit in Figure 2 with respect to terminals a and b. Record your answers in the form of equivalent circuit diagrams.



Figure 2: Second Circuit Used in this Experiment

**Step 8: Pre-lab:** Assume that resistors with values of 1[kΩ], 2.2[kΩ], and 10[kΩ] are to be connected between terminals a and b in the circuit in Figure 2, one at a time. Calculate the currents that would flow through each of these resistors. Later you will enter these values into Table 6 (Step 12).

***Measured Thevenin and Norton Equivalents: Circuit 2***

**Step 9:** Build the circuit in Figure 2 on your prototyping board. Note in particular the power supplies and be sure that both of them are "floating" with respect to ground. (To be *floating* means that neither side of the supply is connected to ground.) Measure the open-circuit voltage and the short-circuit current between terminals a and b using your multimeter. Record your measurements in Table 4. Enter the calculated values from Step 7 in the second column. Also, find the percent difference between the measured values and the calculated values. Use the calculated values as a reference.

# **Table 4:** Open Circuit Voltage and Short Circuit Current; Circuit 2

|  |  |  |  |
| --- | --- | --- | --- |
|  | Measured values | Calculated from  Step 7 | *% error* |
|  |  |  |  |
|  |  |  |  |

**Step 10:** Find the Thévenin and Norton equivalents for this circuit using your measurements in Step 9. Record your answers in the form of equivalent circuit diagrams.

**Step 11:** Measure the Thévenin resistance using the ohmmeter (see Step 5 as to how to do this). Record your answer in Table 5 below. Calculate and enter the Thevenin resistance from the calculations of the open circuit voltage and short circuit current from Step 7. Find the percent error between the measurement and the calculated value.Use the calculated value as reference.

# **Table 5:** Thévenin Resistance; Circuit 2

|  |  |  |  |
| --- | --- | --- | --- |
|  | Measured in  Step 11 | Obtained from calculated *vOC*, *iSC* | *% error* |
| Thévenin  resistance |  |  |  |

**Step 12:** Enter the calculated current values from Step 8 into Table 6. Next, connect a 1[kΩ] resistor between terminals a and b and measure the current through it. Repeat this step using a 2.2[kΩ] resistor and a 10[kΩ] resistor. Record your measurements in Table 6.

# **Table 6:** Current Measurement; Circuit 2

|  |  |  |  |
| --- | --- | --- | --- |
|  | 1[k] | 2.2[k] | 10[k] |
| Calculated current |  |  |  |
| Measured current |  |  |  |

***Design: Verifying Maximum Power Transfer***

**Step 13:** This step is purposely left open-ended, so you can practice your design skills. In this step, you will verify the theory of maximum power transfer, which states that if a load resistance across output terminals a and b matches the equivalent resistance of a circuit as seen from a and b, the maximum power possible will be transferred to the load resistor.

Design and test this theory by:

1. Building a circuit and finding the equivalent resistance at terminals a and b.
2. Attaching a potentiometer (or various load resistances) to terminals a and b and measuring the power transferred to the load resistance. Make sure you are not exceeding the power ratings of the load resistances.
3. Plotting power absorbed by load resistor vs. load resistance

Describe your experimental setup. Include the plot of power vs. resistance in your report. Is the theory of maximum power transfer verified with your results?

***Conclusions***

1. Revisit the research questions.

2. There are always some errors involved in making measurements. The important thing is to be able to recognize when the errors are in a reasonable range and when they are not. Are your errors reasonable? Explain your answer in terms of the percent errors generated in this lab.

3. How does the characterization of the circuit as a Thévenin or Norton's equivalent simplify the prediction of the response of a circuit?

4. What is one application where maximum power transfer is useful to consider in design? You can do some internet research to answer this.

5. Discuss any problems or unexpected results you encountered in this lab.