EXPERIMENT 6
Electrical Measurements: Thevenin Equivalent Circuits

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The objectives of this experiment are to:

- Review Thevenin's and Norton's theorems
- Learn how to experimentally determine the Thevenin and Norton equivalent circuits for a linear circuit

I. Background

Suppose we have a linear circuit with a port designated by terminals A-B as shown in Figure 1(a). According to Thevenin's Theorem, named after French telegraph engineer M. L. Thevenin, we can replace this linear circuit by a simple circuit consisting of an independent voltage source in series with a resistor. This simple circuit in Figure 1(b) is referred to as a Thevenin equivalent circuit. In this figure, V_{oc} is referred to as the open-circuit voltage, and R_{Th} is called the Thevenin resistance. Norton's theorem is named after E. L. Norton, a scientist with Bell Telephone Laboratories. The Norton equivalent circuit is composed of an independent current source in parallel with a resistor, as shown in Figure 1(c). Here I_{sc} is referred to as the short-circuit current. The variables are related by the following equation: $V_{oc} = R_{Th} I_{sc}$.

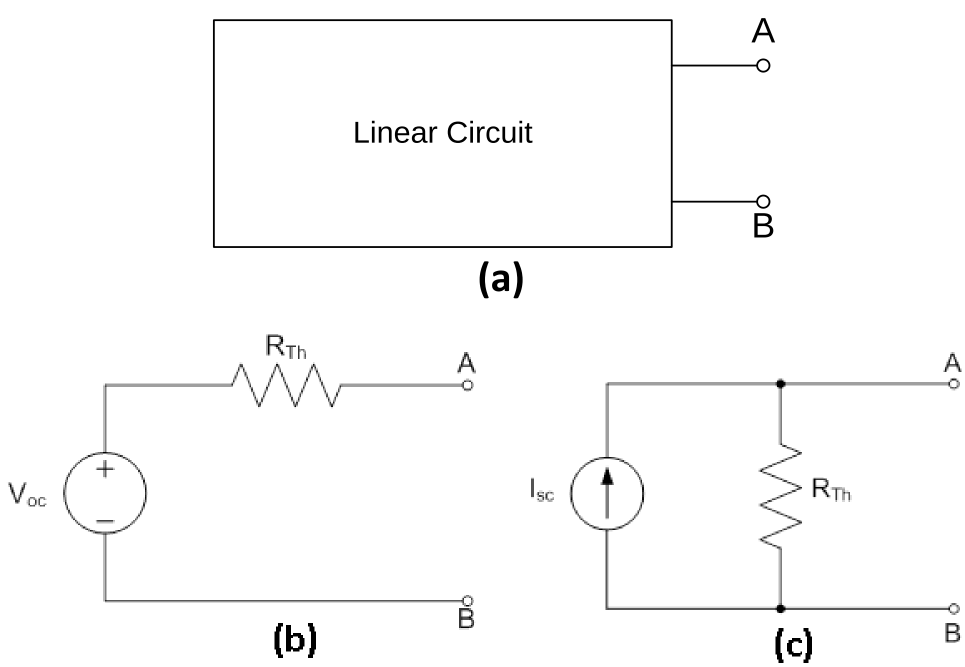

Figure 1: (a) Linear circuit, (b) Thevenin equivalent circuit, and (c) Norton equivalent circuit

Though these results sound very simple, they have enormous impact on our circuit analysis techniques. If we examine any network from a pair of terminals or port, we know that with respect to those terminals, the entire network is equivalent to a simple circuit consisting of independent voltage source in series with a resistor (Thevenin's equivalent circuit) or an independent current source in parallel with a resistor (Norton's equivalent circuit).

II. Experimental Determination of the Thevenin Equivalent Circuit

To determine the Thevenin or Norton equivalent circuit for a linear circuit, we need to determine two of the three parameters: V_{oc}, I_{sc}, or R_{Th}. Because the terminals are open and, therefore, no current flows, it is relatively easy to measure V_{oc} (since there will be no voltage drop across R_{Th}). A multimeter can be set to measure voltage and connected to the terminals A-B to measure the open-circuit voltage as shown in Figure 2. The symbol for a voltmeter is the circle containing the V.

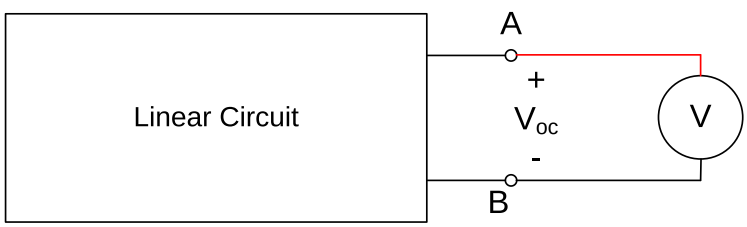

Figure 2. Measuring the Open-circuit Voltage

The Thevenin resistance could be measured if we could deactivate all of the sources inside the linear circuit. For many circuits or networks, it is not practical to do this. We could measure the short-circuit current by placing an ammeter across the terminals. However, any time we place a short circuit on the terminals of a device, we run the risk of permanently damaging that device. As a result, we do not attempt to measure the short-circuit current. There is another way to determine the Thevenin resistance. As seen in Figure 3, if we connect a resistance R_{load} to the Thevenin equivalent circuit whose value is equal to R_{Th}, then the voltage at the terminals A-B is equal to $V_{oc}/2$. Let's now connect a variable resistor to our linear circuit as shown in Figure 4 and vary it until the voltage at terminals A-B is equal to $V_{oc}/2$. Disconnect the variable resistor from the linear circuit and measure its resistance with the multimeter to obtain the Thevenin resistance.

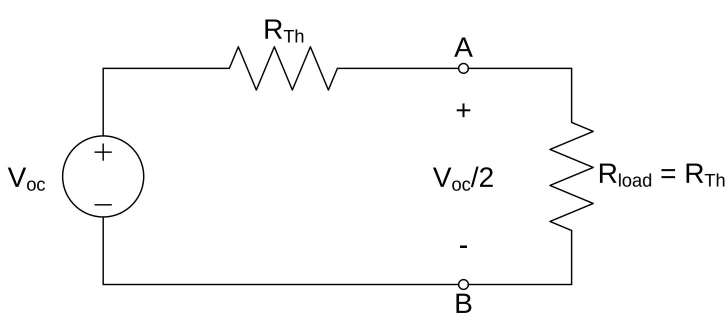

Figure 3: V_{AB} equals $V_{oc}/2$ when $R_{load} = R_{Th}$

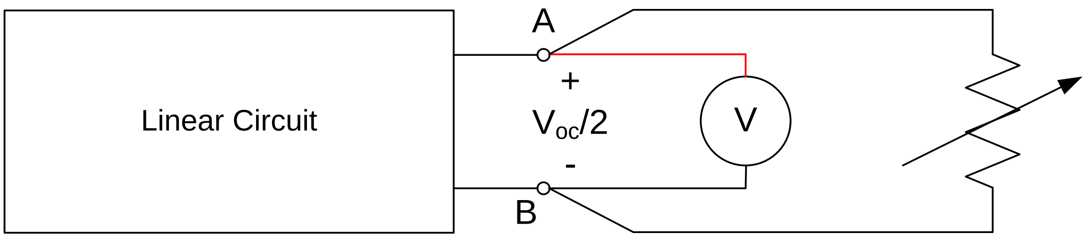

Figure 4. Determining the Thevenin Resistance

In this lab experiment, you will be using the variable resistor (also known as a “potentiometer” or “pot”) shown in Figure 5. This is a 10 kΩ variable resistor, meaning its range is from 0 Ω to approximately 10 kΩ (these may be closer to 10.5 kΩ). It has three pins. The resistance between pin 1 and pin 3 is fixed at the variable resistor’s max resistance; in this case, approximately 10 kΩ. Pin 2 is connected internally to the pot’s “wiper”. As you turn the screw on the end (the “wiper control”), this wiper moves, splitting the total resistance between pin1-pin2 and pin2-pin3. Although our pot is not circular, Figure 6 illustrates this. You may use either pin1-pin2 or pin2-3 for your variable resistor.

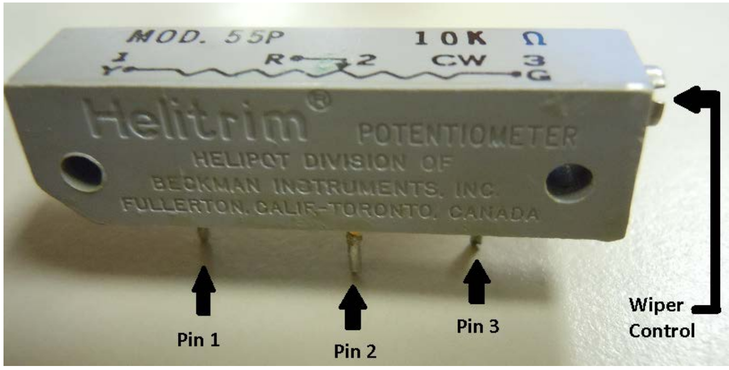

Figure 5: Variable Resistor

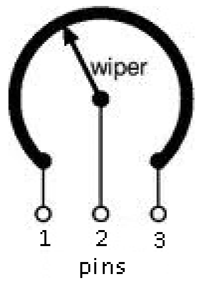

Figure 6: Illustration of How Variable Resistors Work

__Warning:__ Turning variable resistor’s wiper all the way to one end creates a short circuit between two of the pins. Be careful not to place a short somewhere that you should not!

__Warning:__ It is easy to break the wiper on the variable resistor by continuing to turn the wiper after it has reached either extreme; i.e., do not continue to turn the wiper once you have reached either 0 Ω or 10 kΩ.

III. Lab Exercises

1) Show the mathematical derivation for how we know the voltage at two nodes will be $V_{oc}/2$ when a resistor, R_{load}, is connected to those nodes that is equal to R_{Th}. Hint: Begin by drawing the generic Thevenin Equivalent Circuit with R_{load} attached to the two nodes (similar to Figure 3) and write out the voltage divider equation.

2) Measure and record the resistance between pin1-pin2 and between pin2-pin3 of your variable resistor. What value do these sum to? Measure the resistance between pin1-pin3 to check (this value should be close to the previous summation). Individuals' pin1-pin2 and pin2-pin3 resistance measurements will vary depending on where your wiper happens to be currently set. (Everyone's summation should be close to 10 kΩ, though.)

In the lab, there are three sets of black boxes: set #1, set #2, and set #3. There are four (almost) identical black boxes in each set. Complete steps 3 & 4 for one black box from each of the three sets.

3) We will experimentally determine the Thevenin equivalent circuit for the black box at terminals B1-B2. Connect the 15V supply (which is approximately 15.5V) on the NI ELVIS Board to terminals A1-A2 as shown in the schematic in Figure 7 (to do so, you will need to use the NI ELVIS Board's banana jacks). Figure 8 shows images of one way this can be done. Turn on the component box and
   - Measure the voltage of the power supply on the NI ELIVIS Board (call this Vs; you'll need this for part 4).
   - Measure the voltage at terminals B1(+)-B2(-). This is V_{oc}.
   - Calculate $V_{oc}/2$.

   Turn off the the board, connect the variable resistor to B1-B2 (BANANA C-BANANA D), then turn the board back on. Measure the voltage drop across the variable resistor as you vary its resistance. Once you are measuring $V_{oc}/2$,
   - <u>Disconnect</u> the variable resistor from B1-B2.
   - Measure the variable resistor's resistance. This is R_{Th}.
   - Draw the Thevenin equivalent circuit, showing values for V_{oc} and R_{Th}.
   - Calculate I_{sc} and draw the Norton equivalent circuit.

   Figure 9 shows images of how one may wire the circuit to make necessary measurements. Include all measurements, calculations, and circuits in your lab report.

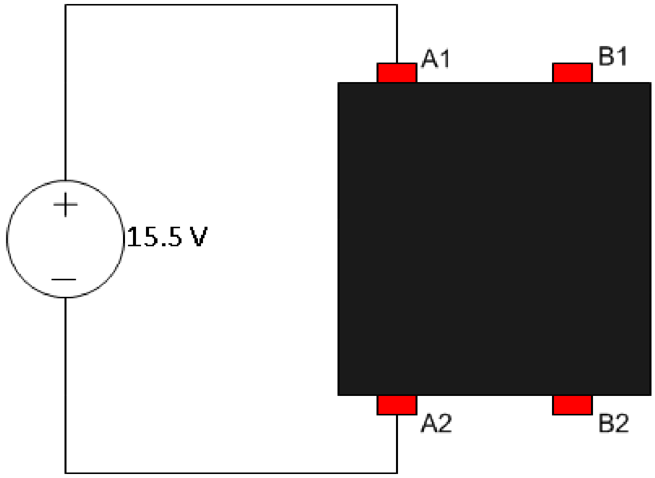

Figure 7: Black Box with Source Connected

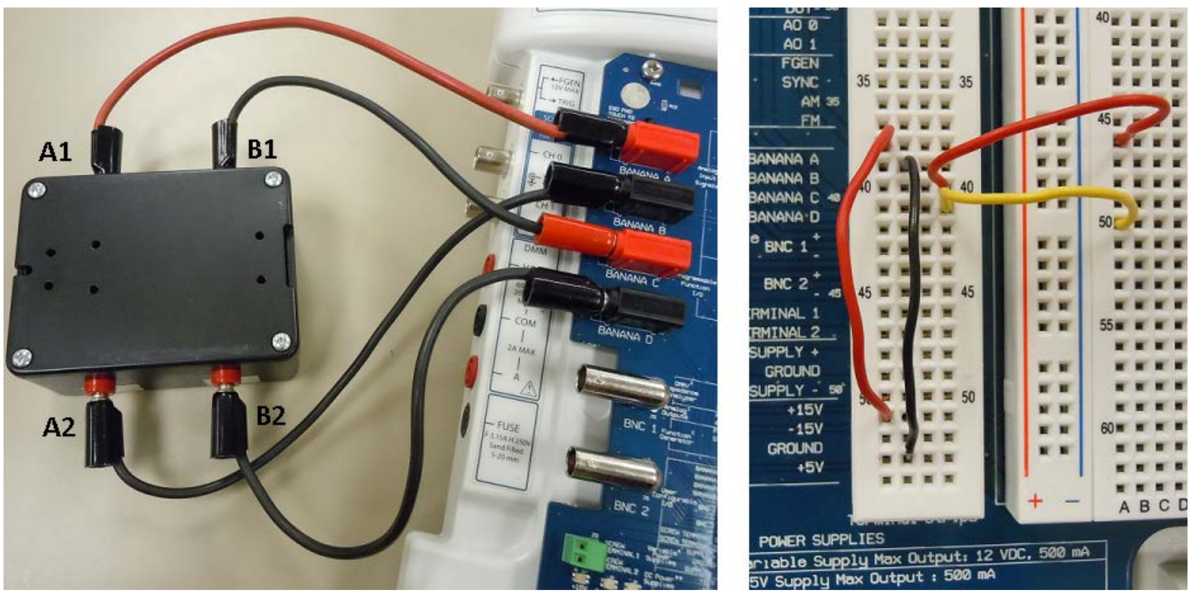

Figure 8: Connecting Vs to A1-A2 of Black Box and Preparing to Make Measurements at B1-B2

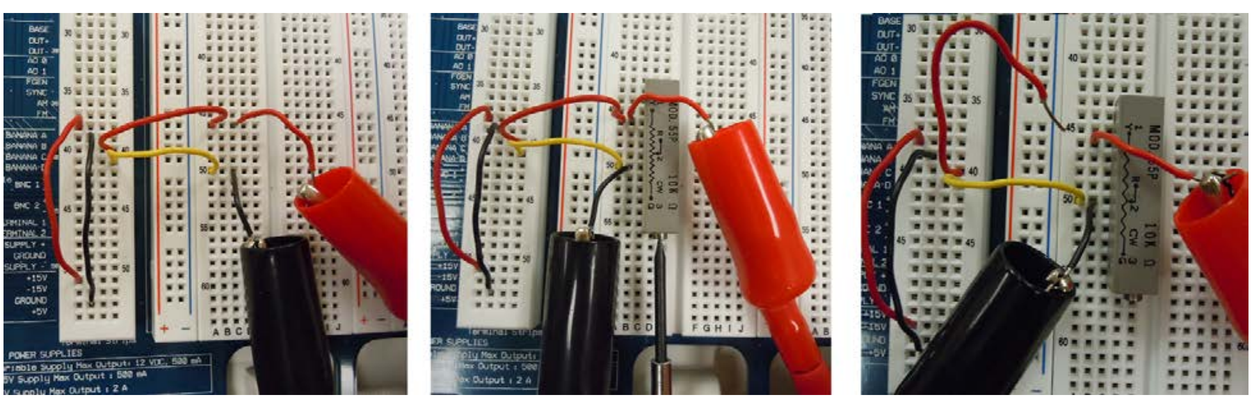

Figure 9: From Left to Right: DMM measuring Voc; DMM measuring voltage while varying pot until measuring Voc/2; measuring Rth <u>after</u> turning off power and disconnected pot from circuit

4) Disconnect all connections to the black box. Remove the cover of the black box using a screwdriver. Draw a schematic for the circuit inside the box. Be sure to label all terminals (A1, A2, B1, B2). Determine the approximate value of the resistors using their color-code (notice that all the resistor values <u>are</u> the same) and add them to your schematic. Screw the cover back on the black box. Now calculate the Thevenin equivalent circuit as seen at terminals B1-B2. Use the measured value of the NI ELVIS power supply that was connected at A1-A2 in your calculations (what we called Vs). Compare your calculated values of Voc and Rth to the measured values and record your observations in your report.

Repeat steps 3 & 4 for a black box from each set (one from set #1, one from set #2, and one from set #3). You should have experimentally determined and calculated the Thevenin Equivalent Circuit for three black boxes.

5) Now knowing what you do about this specific black box, is it possible to measure the Thevenin resistance at B1-B2 directly from the black box? If so, explain how you would do it? If not, why not? Hint: keep in mind that you have access to the only power supply "in" the black box (Vs connected at A1-A2).