Electronic Measurement Instruments & Elementary Circuit Theory 2

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(2nd Week Pre-Experiment Lab Report)

I. RESEARCH QUESTIONS

a. Understanding the principles of electronic measuring instruments and basic equipment and being able to use them.

b. Conducting basic experiments on circuits using the *NI ELVIS* circuit board (*NI ELVIS* being a prototyping board used in testing circuits[1]), and thus understanding the usage of it. Additionally, understanding the fundamental concepts behind elementary circuit theory.

II. THEORY

A. Thevenin's Theorem

1. *Thevenin's theorem*

Thevenin's Theorem states that any linear electrical network can be replaced by a single voltage source V_{TH} in series with a single resistance R_{TH}, known as the Thevenin equivalent circuit. This equivalent circuit has the same voltage-current characteristics at the terminals as the original network.

The Thevenin voltage V_{TH} can be found by open-circuiting the terminals and measuring the voltage across them, while the Thevenin resistance R_{TH} can be found by turning off all independent sources and calculating the equivalent resistance seen from the terminals. Some important formal mathematical definitions in Thevenin's theorem are the following. *Thevenin voltages* can be defined as

$$V_{\mathrm{TH}} = V_{\mathrm{OC}}$$

where V_{OC} is the open-circuit voltage across the terminals. On the other hand, *Thevenin resistance* can be formally defined as

$$R_{\mathrm{TH}} = \frac{V_{\mathrm{SC}}}{I_{\mathrm{SC}}}$$

where V_{SC} is the short-circuit voltage across the terminals and I_{SC} is the short-circuit current flowing through the terminals. To end, the Thevenin equivalent circuit thus simplifies complex circuits for analysis and design, enabling engineers to focus on terminal behavior without considering internal details.

B. Wheatstone Bridges and Maximum Power Transmission

1. *Wheatstone Bridges*

The *Wheatstone Bridge* is a circuit used in measuring resistance. It consists of four resistors connected to form a bridge, with an excitation voltage applied across one diagonal and a measuring instrument connected across the other diagonal. The bridge is balanced when the ratio of resistances in one side equals the ratio in the other side. Mathematically, the Wheatstone bridge is represented as:

$$\frac{R_1}{R_2} = \frac{R_3}{R_4}$$

When balanced, the voltage across the measuring instrument is zero. This condition is exploited to measure an unknown resistance R_x connected in one arm of the bridge, given by:

$$R_x = R_3 \left(\frac{R_2}{R_1} \right)$$

The Wheatstone bridge provides a highly accurate method for resistance measurement, widely used in scientific and engineering fields.

2. *Maximum Power Transmission*

Maximum power transfer states that the maximum power is transferred from a source to a load when the load resistance equals the internal resistance of the source. Mathematically, the condition for maximum power transfer is achieved when the load resistance R_L equals the internal resistance R_S of the source. At this condition, the power delivered to the load P_L is maximized and can be calculated as:

$$P_L = \frac{V_{\mathrm{TH}}^2}{4R_S}$$

where V_{TH} is the Thevenin voltage of the source.

[1] Personal notes and records are in red text.

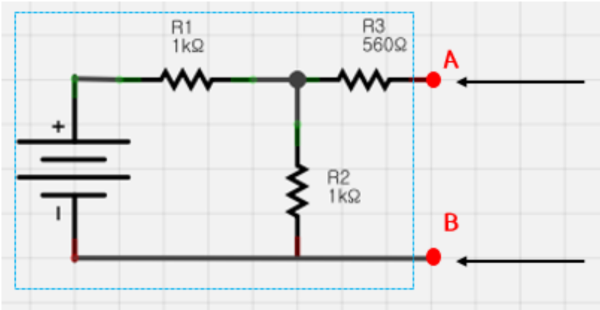

FIG 1-1. Thevenin's Theorem.

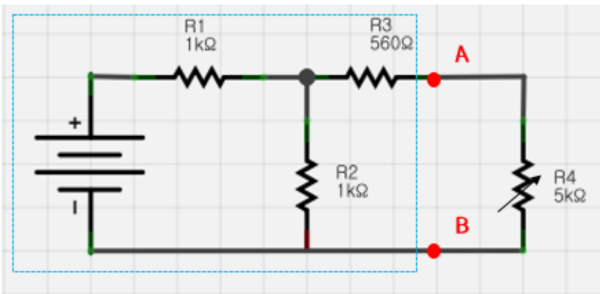

FIG 1-2. Thevenin's Theorem.

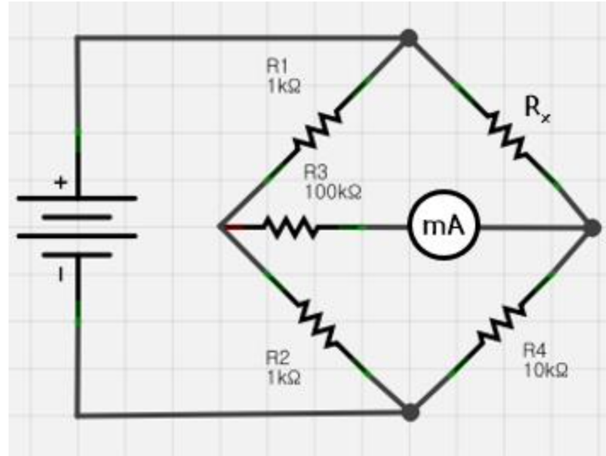

FIG 2. Wheatstone Bridges and Maximum Power Transmission.

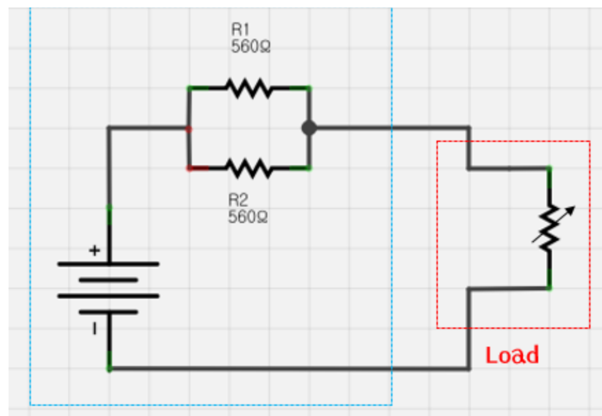

FIG 2. Wheatstone Bridges and Maximum Power Transmission.

III. METHODOLOGY

A. Thevenin's Theorem

1. Construct the circuit of Figure 1-2. Measure the resistances at terminals A and B without applying power (measurement using a multimeter may not accurately measure the resistance if external power is applied). The measured resistance at this time is the equivalent resistance R_{TH} of the Thevenin equivalent circuit.

2. Supply a power of 10 V and measure the voltage at terminals A and B. The measured voltage at this time is the Thevenin equivalent voltage V_{TH}.

3. Add a variable resistor to Figure 1-1 to construct the circuit as shown in Figure 1-2. Apply power and measure the voltage across R_4. Set the value of R_4 to three arbitrary cases. Utilize the Thevenin equivalent circuit composed of the Thevenin equivalent voltage V_{TH} and the equivalent resistance R_{TH} connected in series to calculate the voltage across R_4 and compare it with the previously measured value.

4. Set the value of R_4 to be half of the voltage supplied by the power source, and measure the resistance in Figure 1-2. Discuss the significance of this resistance measurement (the significance in this measurement lies in the fact that a decrease in voltage or current through the resistance decreases the amount of power loss due to thermal heating).

5. *Optional Experiment* Reflecting on the preceding experimental procedures, contemplate a method to measure the internal resistance of a function generator and then proceed to measure the internal resistance of the *NI ELVIS* function generator.

B. Wheatstone Bridges and Maximum Power Transmission

1. Construct the circuit shown in Figure 3.

2. The resistor R_3 serves to limit the current flowing through the ammeter. Initially, adjusting R_3 may degrade the sensitivity of the instrument, but shorting R_3 increases its sensitivity for final adjustment.

3. Choose three arbitrary resistances as R_X. Adjust the voltage to 10 V and place the variable resistor R_4 at its maximum position. Then, adjust the variable resistor until the ammeter reads zero.

4. After removing R_3 and connecting the wires directly,

readjust R_4 until the ammeter reading reaches zero. (By removing the large resistance, a higher current can flow, allowing for a more sensitive measurement of the ammeter's value.)

5. Measure the resistance of the variable resistor R_4 at this point. Repeat the previous experiment for the three different resistors R_X.
6. Construct the circuit shown in Figure 4.
7. Apply a 5 V voltage and vary the variable resistor while using two multimeters to measure the voltage and current across the load. Utilize the measured current and voltage to investigate how the power changes with the variation in the load resistance. Through the maximum power transfer circuit experiment, calculate and compare the conditions under which the greatest power is delivered to confirm whether they match.
8. Set R_1 and R_2 to two arbitrary cases, each with different values, and repeat the previous experiment. Try setting R_1 and R_2 to different values for each case.

[1] Halliday, D., Resnick, R., and Krane, K. Physics, volume 2. *Wiley, 2nd Edition* (2010), pp. 845–852.

[2] The Sogang University Physics Department. Experimental physics 1 manual. *"Electronic Measurement Instruments, Elementary Circuit Theory 2"*.

[3] Wikipedia. Maximum power transfer theorem. https://en.wikipedia.org/wiki/Maximum_power_transfer_theorem.

[4] Wikipedia. Thévenin's theorem. https://en.wikipedia.org/wiki/Th%C3%A9venin%27s_theorem.

[5] Wikipedia. Wheatstone bridge. https://en.wikipedia.org/wiki/Wheatstone_bridge.