EE11L : Experiment 1

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1. **Kirchoff's Laws Analysis of Circuits** **(PDF Stated OPTIONAL)**

1.1 Build the circuit illustrated in Figure 3 with the following resistor values:
R1 = 1000Ω, R2 = 100Ω, R3 = 470Ω, R4 = 1000Ω, R5 = 680Ω, R6 = 100Ω

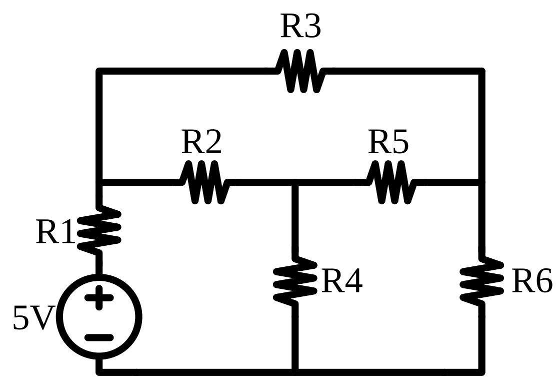


Fig.4. Kirchoff's Laws Analysis

1.2 Using Kirchoff's Voltage and Current Laws, find the theoretical values of the voltage and current across each resistor. Note: You may define the polarities of the V and I across the components. Please fill in your **calculation** here:

	V[V]	I[A]	R[Ω]
R1			
R2			
R3			
R4			
R5			
R6			

1.3 Measure each of the voltages and currents you have calculated and compare the theoretical and experimental values.

	V[V]	I[A]	R[Ω]
R1			
R2			
R3			
R4			
R5			
R6			

Experiment setup

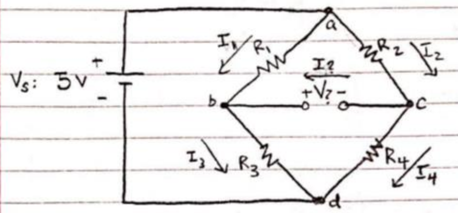
Please attached necessary pictures (at most two pictures) here. Illustrate how the experiment is setup, and label the components and their values.

2. **Wheatstone Bridge**

2.1 Derive the output voltage (in terms of the four resistances) of the Wheatstone Bridge circuit illustrated below using Kirchoff's Laws.

2 WHEATSTONE BRIDGE

i) Derive output VOLTAGE



KCL $I_1 = I_3$, $I_2 = I_4$

node (b): $I_1 + I_? - I_3 = 0$

node (c): $I_2 - I_? - I_4 = 0$

KVL mesh upper: $I_2R_2 + I_?R_? - I_1R_1$ $I_1R_1 = I_2R_2$

mesh lower: $I_4R_4 - I_3R_3 - I_1R_1$ $I_3R_3 = I_4R_4$

VOLTAGE DIVIDER TO FIND $V_?$

$$V_? = \frac{R_4}{R_4+R_2}V_s - \frac{R_3}{R_1+R_3}V_s$$

ONLY IF ALL VALUES ARE KNOWN

$$V_? = \left(\frac{R_4}{R_4+R_2} - \frac{R_3}{R_1+R_3}\right)V_s$$

$R_4 = \left(R_3/R_1\right)\cdot R_2$ ⇒ When Potentiometer V ⇒ balanced to zero

$I_3 = I_1 + I_?$

$I_2 = I_? + I_4$

$(I_? + I_4)R_2 + I_?R_? - I_1R_1$

$I_4R_4 - (I_1 + I_?)R_3 - I_1R_1$

$$\begin{bmatrix} R_1+R_3 & 0 \\ -R_1 & R_2 \\ R_3 & -R_4 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \end{bmatrix} = \begin{bmatrix} V_s \\ V_o \\ V_o \end{bmatrix}$$

$$\left[\begin{array}{cc|c} 1 & 0 & V_s/R_1+R_3 \\ 0 & R_2+R_4 & V_s \\ - & - & - \end{array}\right] = \left[\begin{array}{cc|c} 1 & 0 & V_s/R_1+R_3 \\ 0 & 1 & V_s/ \\ - & - & - \end{array}\right]$$

$$V_o = -R_1\left(\frac{V_s}{R_1+R_3}\right) + R_2\left(\frac{V_3}{R_2+R_4}\right) = V_s\left(\frac{R_2}{R_2+R_4} - \frac{R_1}{R_1+R_3}\right)$$

$$V_o = V_s\left(\frac{R_3}{R_2+R_4} - \frac{R_1}{R_1+3}\right)$$

The output voltage = ___________

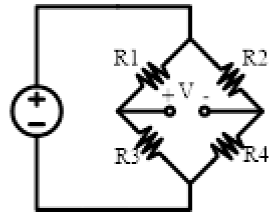


Fig.5. Wheatstone Bridge

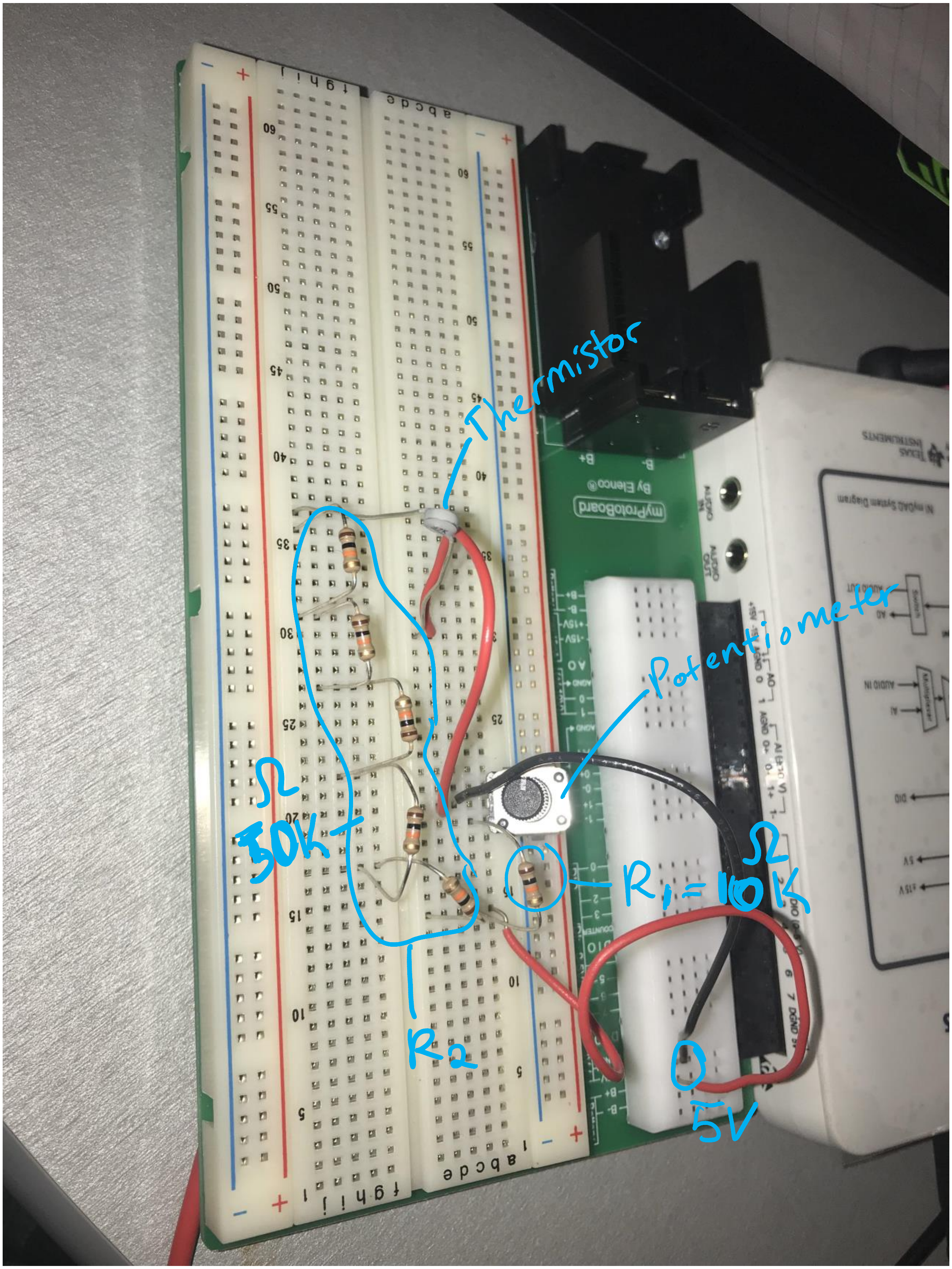
2.2 Use a thermistor in place of one of the resistors in the Wheatstone Bridge. The thermistor is a sensor that varies in resistance based on temperature. Build a sensor circuit using the 5V power supply and available resistors such that the output is roughly 0 volts at room temperature, and a higher voltage (>0V) at body temperature. If you have issues balancing the Wheatstone Bridge voltage, you may consider using a potentiometer (variable resistor).

Hint: You may use the following setup:

1. Set R1= 10K Ω, R2= 33K Ω
2. Replace R3 with a potentiometer and R4 with a thermistor.
3. Balance the output voltage until V= 0 by adjusting R3, under room temperature
4. With your fingers hold the thermistor (body temperature now), the resistance of R4 varies. Observe the output voltage V
5. Note: This is just an example setup. You are encouraged to design your own setup.

Experiment setup

Please attached necessary pictures (at most two pictures) here. Illustrate how the experiment is setup, and label the components and their values.


Thermistor
Potentiometer
30kΩ
$R_1 = 10k\Omega$
R_2
5V

2.3 Discussion (Answer in only 3-4 short sentences).
What are the advantages and disadvantages of Wheatstone bridge temperature sensing circuit compared to a temperature sensing circuit (shown below) consisting of the series connection of the thermistor (R1) and a resistor (with constant value) (R2). The output of this new circuit (OUT) is the voltage across R2 (OUT = V_{R2}).

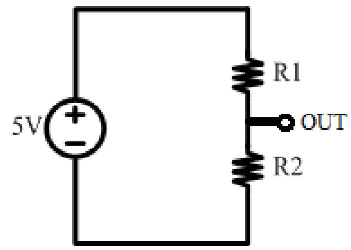


Fig 6. Temperature sensing circuit

The value of R2 is equal to the value of R1 (thermistor) when its temperature is equal to the room temperature which you are working at. In other words, the output voltage at room temperature is 2.5V.

Response:
The advantages of using the wheatstone bridge temperature sensing circuit is that you will receive more precise measurements of temperature because of a larger range of values that the circuit can sense through the output voltage. However, the disadvantages of the wheatstone bridge include the fact that the circuit is complex and requires a potentiometer to be calibrated before sensing the temperature.

The advantages of using the temperature sensing circuit in series are that it is a simple circuit to design and requires minimal circuit elements to create. However, the disadvantages of this circuit include the fact that the range of output voltages is extremely narrow, which means that the temperature measurements are not very precise.

3. **Superposition**

Build the circuit illustrated in Figure 7. Use the 5V DC source and the provided current source to build the following circuit. Note that the current source uses the analog ground of the +/-15V supply, so a common ground should be established with the 5V supply. R1 = 680 Ω, R2 = 1000 Ω, R3 = 470 Ω

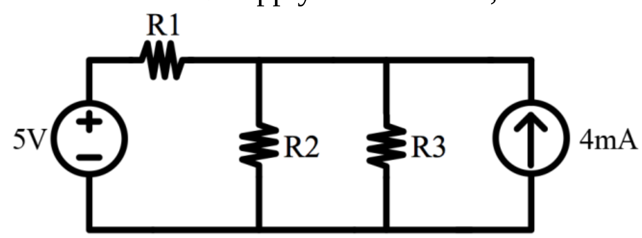


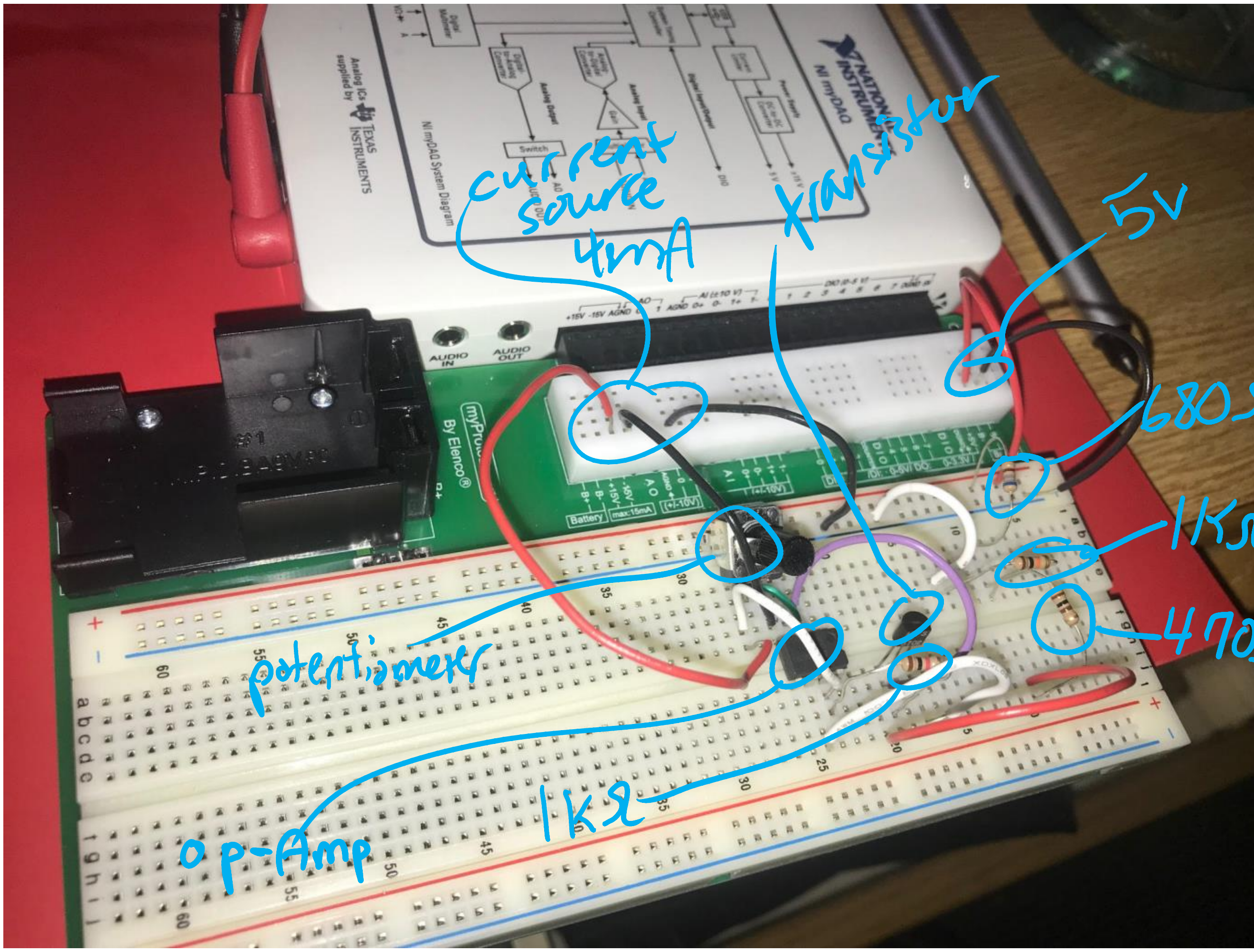
Fig.7. Superposition Test Circuit

3.1 Measure the voltage and current across the middle resistor (R_2) with both sources in place.
3.2 Short circuit the 5V source, and once again record the voltage and current across the middle resistor (R_2**)**.
3.3 Replace the 5V source, and open circuit the 4mA source. Repeat measurements across the middle resistor.

Sources	**V_{R2}[V]**	**I_{R2}[A]**
5V only	1.54 V	1.54 mA
4mA only	0.91 V	0.91 mA
Sum of above	2.45 V	2.45 mA
Both	2.45 V	2.45 mA

Experiment setup

Please attached necessary pictures (at most two pictures) here. Illustrate how the experiment is setup, and label the components and their values.



4. Thevenin/Norton Equivalent

Build the circuit illustrated in Figure 8 with the following resistor values:
$R_1 = 3.3k\Omega$, $R_2 = 470\Omega$, $R_3 = 1k\Omega$, $R_4 = 10k\Omega$, $R_5 = 2.2k\Omega$
Measure and record the values of resistance of each resistor you use.

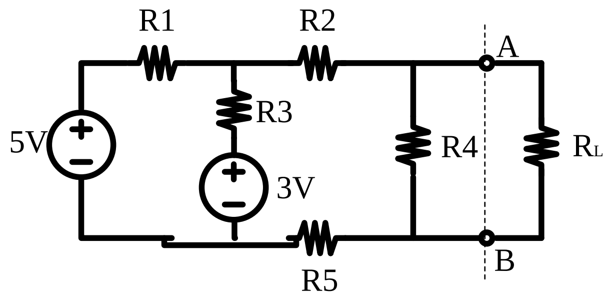
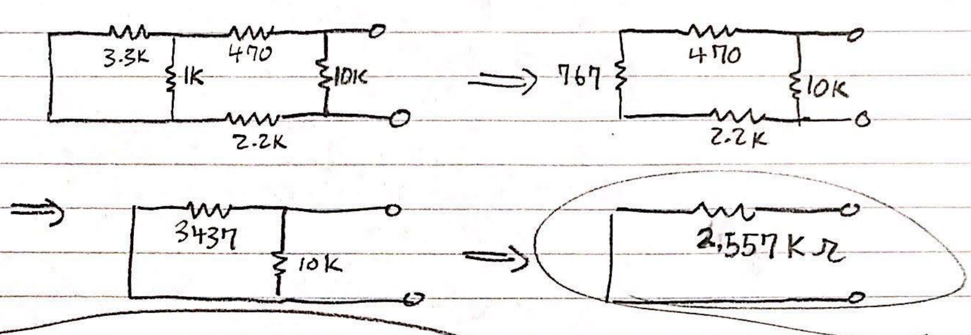


Fig.8. Thevenin/Norton Equivalent Analysis Circuit

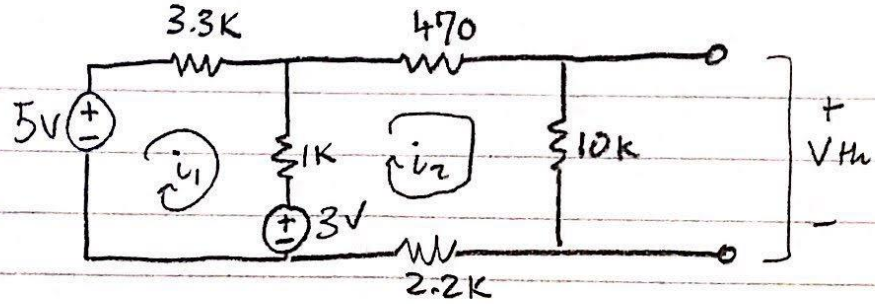
4.1 Find the Thevenin equivalent voltage, Norton equivalent current, and Thevenin resistance values using theoretical analysis, and record these values in the second row of the table below. Also measure the actual values of the open circuit voltage, short circuit current, and equivalent resistance across the nodes A and B of the circuit using the DMM function of the myDAQ.

Thevenin/Norton Equivalent Circuits

R_{th} → SC the sources and remove the load



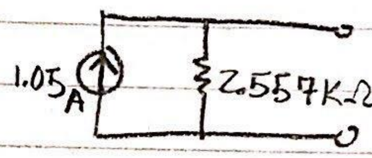
$\boxed{R_{thevenin} = 2.557 K\Omega}$



$5 = i_1\, 3.3K - 1K\, i_2 + 3$

$2 = (3.3K)\, i_1 + (-1K)\, i_2$

$i_{NORTON} = 1.05\,A$



$3 = (1k)\, i_2 + (470 + 10K + 2.2K)\, i_3$

$3 = (1k)\, i_2 + (12.67k)(i_1 + i_2)$ $\quad i_3 = 0.258\,A$

$3 = (12.67k)\, i_1 + (13.67k)\, i_2$

$V_{Thevenin} = i_3 R_4 = 0.258\,mA\,(10{,}000) = 2.58\,V$

$P_{consumed} = \frac{V^2}{R}$

4.2 Choose a load resistance R_L and measure the voltage and current across the load.

4.3 Build the Thevenin equivalent circuit (if you do not have a resistor matching the required value, use a potentiometer and adjust the resistance to the desired value, and be sure to ground the unused pin of the potentiometer). Use the function generator's DC offset function as a variable power supply for your Thevenin equivalent circuit (set the amplitude of the signal to 0V, such that the signal is DC only). Verify the equivalency by measuring the voltage and current across the load resistor, and compare with the results of the original circuit.

4.4 Repeat the above step with the Norton Equivalent Circuit.

R_1 [Ω]	R_2 [Ω]	R_3 [Ω]	R_4 [Ω]	R_5 [Ω]
3.2k Ω	460 Ω	.988k Ω	9.83k Ω	2.14k Ω

V_{TH} [V]	I_N[mA]	$R_{TH/N}$ [Ω]
2.58 V V	1.05 mA	2.557k Ω
V_{OC}[V]	**I_{SC}[mA]**	**R_{eq}[Ω]**
0.85 V	0.34 mA	2.52k Ω

R_L [Ω]	V_L [V] (Original Circuit)	V_L [V] (Thevenin Eq. Ckt)	V_L [V] (Norton Eq. Ckt)
10k	0.68 V	0.71 V	0.7 V

I_L [mA] (Original Circuit)	I_L [mA] (Thevenin Eq. Ckt)	I_L [A] (Norton Eq. Ckt)
0.21	0.20	0.20

4.5 Place a 10kΩ variable potentiometer as the load for the circuit in Figure 8 (the original circuit). Vary the potentiometer across 5 different resistance values of approximately $0.5R_{TH}$, $0.8\ R_{TH}$, R_{TH}, $1.2R_{TH}$, and $1.5R_{TH}$. Record the resistance values you use, as well as the voltage across the load. Compute the power consumption for each resistance value as well.

R_L [Ω]	V_L [Ω]	P_L[W]
1.47k	0.30 V	0.0000612244898
1.95k	0.36 V	0.00006646153846
2.59k	0.43 V	0.00007138996139
3.00k	0.47 V	0.00007363333333
3.97k	0.52 V	0.00006811647355

4.6 Discussion

4.6.1 How did the voltage and current across the load compare between the original circuit and Thevenin equivalent circuit?

Response:

The voltage and current across the load were almost identical between the original and thevenin equivalent circuits. There were only slight variations in the voltage output due to systemic errors such as wire resistances and/or imperfect current/voltage sources.

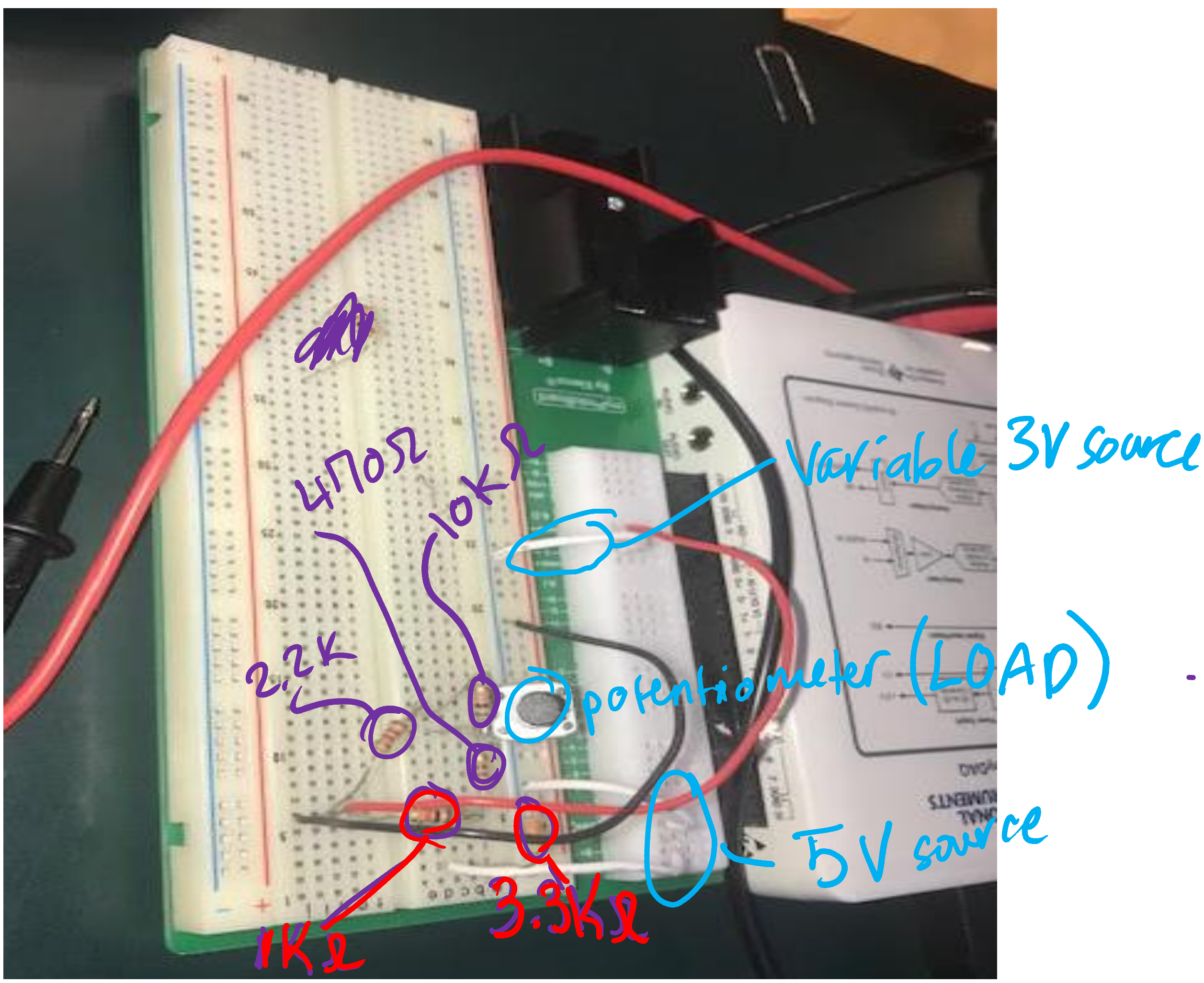
4.6.2 If our goal is to achieve maximum power dissipation across the load resistance, what load is the best choice? How does this value compare with the Thevenin equivalent resistance?

Response:

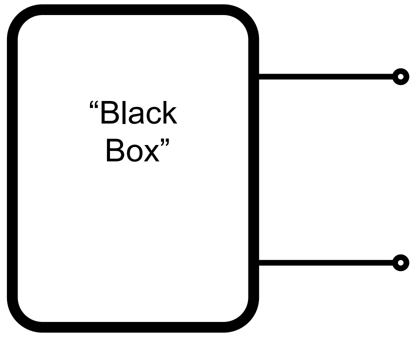
Based on the table above, the 3.00k ohm Load dissipated the most power. Interestingly enough, the closer to the value of the thevenin equivalent resistance that the load is, the more power is dissipated. In other words, as the load is close to the thevenin equivalent resistance, more power will be dissipated.

Experiment setup

Please attached necessary pictures (at most two pictures) here. Illustrate how the experiment is setup, and label the components and their values.



5. **Black Box Equivalence**



5.1 The myDAQ power source is non-ideal. As such, a Thevenin Equivalent circuit may be constructed as a more accurate model.

5.2 Experimentally determine the Thevenin Equivalent Resistance and Thevenin Voltage of the myDAQ 5V power supply. Verify the accuracy of the Thevenin Equivalent circuit by measuring the voltage across a chosen load resistor.

(Hint: To model the power source, you can test it for two different load resistors e.g. 1000Ω and 470Ω. Do not make short the output of the power supply.)

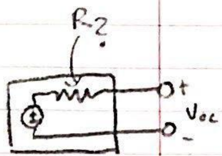
5.3 Experimentally determine the Norton Equivalent Resistance and Norton Current. Verify the accuracy of the equivalent by measuring the current across a chosen load.

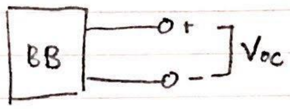
- To model the Norton equivalent, use the following loads: 1000Ω and 470Ω
- Consider that you will have to readjust the current after switching the load

Black Box Equivalent

THEVENIN

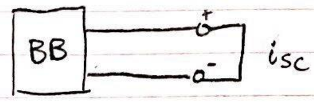
$R_{Thevenin}$ use open circuit voltage





$\Rightarrow$ $V_{oc} = V_{Th} \approx 4.99\,V$

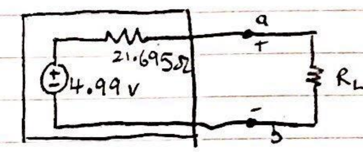
use short circuit current



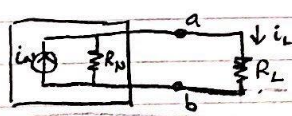
$\approx 0.23\,A$

$R_{Th} = V_{oc}/i_{sc}$, $V_{oc} = V_{th}$

$R_{Th} = 4.99V / 0.23\,A = 21.695\,\Omega$



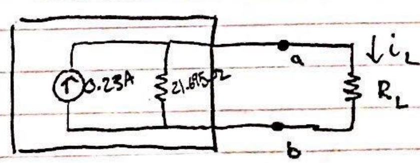
NORTON

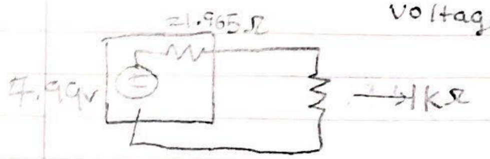


use the thevenin equivalent to find I_N and R_N

$R_N = R_{TH} = \frac{V_{oc}}{I_{sc}} = 21.695\,\Omega$

$i_N = \frac{V_{th}}{R_{th}} = i_{sc} = 0.23\,A$



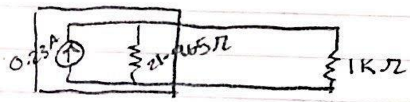


voltage divider to confirm values

$$\left(\frac{1000}{1021.965}\right)4.99 = 4.8827\text{V}$$

Theoretical Voltage Across 1kΩ: 4.8827V, Actual: 4.83V

Theoretical Voltage Across 470Ω: 4.7672V, Actual: 4.81V



current divider to confirm values

$$\left(\frac{21.49}{1000}\right)(0.23A) = 0.049\ A$$

Theoretical Amp Across 1kΩ= 4.9 mA., Actual: 4.9 mA
Theoretical Amp Across 470Ω: 10.2mA, Actual: 10 mA

1k, R_{L1}		470, R_{L2}	
0.99k		460	
V R_{L1}	V R_{L2}	V_{TH}	R_{TH}
4.83 V	4.81 V	4.99 V	21.965 ohm
I R_{L1}	I R_{L2}	I_N	R_N
4.9 mA	10.6 mA	0.23 A	21.965 ohm

R_{L1} [Ω]		R_{L2} [Ω]	
V_{RL1} [V]	V_{RL2} [V]	V_{TH} [V]	R_{TH} [Ω]
I_{RL1} [mA]	I_{RL2} [mA]	I_N[mA]	R_N [Ω]

Experiment setup

Please attached necessary pictures (at most 3 pictures) here. Illustrate how the experiment is setup, and label the components and their values.