Thevenin's Theorem

&

Maximum Power Transfer

Lab 003

Electrical Networks

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Objective

The objective of this laboratory exercise is to verify the validity of Thevenin's Theorem via comparison of experimental and theoretical results. In addition we demonstrated the effect of Maximum Power Transfer, once the condition of $R_L = R_{Th}$ was satisfied.

Theory

Thevenin's Theorem states that it is possible to simplify any linear circuit, no matter how complex, to an equivalent circuit with just a single voltage source and series resistance connected to a load. The qualification of "linear" is identical to that found in the Superposition Theorem, where all the underlying equations must be linear (no exponents or roots). If we're dealing with passive components (such as resistors, and later, inductors and capacitors), this is true. However, there are some components (especially certain gas-discharge and semiconductor components) which are nonlinear: that is, their opposition to current changes with voltage and/or current. As such, we would call circuits containing these types of components, nonlinear circuits. Thevenin's Theorem is particularly useful in the analysis of power systems and other circuits where one particular resistor in the circuit (called the "load" resistor) is subject to change, and re-calculation of the circuit is necessary with each trial value of load resistance, to determine voltage across it and current through it.

The Maximum Power Transfer Theorem states that the maximum amount of power will be dissipated by a load resistance when that load resistance is equal to the Thevenin/Norton resistance of the network supplying the power. If the load resistance is lower or higher than the Thevenin/Norton resistance of the source network, its dissipated power will be less than the maximum.

Materials

Resistors	External Variable DC Power Supply	Digital Multimeter
100 Ω	12 Volts	Breadboard
220 Ω	16 Volts	Jumper Wires
2.2 kΩ	20 Volts	
330 Ω	24 Volts	
470 Ω		
1 kΩ Potentiometer		
10 kΩ Potentiometer		

Procedure

In this laboratory, the circuit labeled as **Figure 001** shown below was constructed and used in Part I of this experiment. Prior to the construction of this circuit, our team was asked to measure each resistor selected to construct the circuit and record the measured values. This data would be later used to calculate margin of error in our measurements.

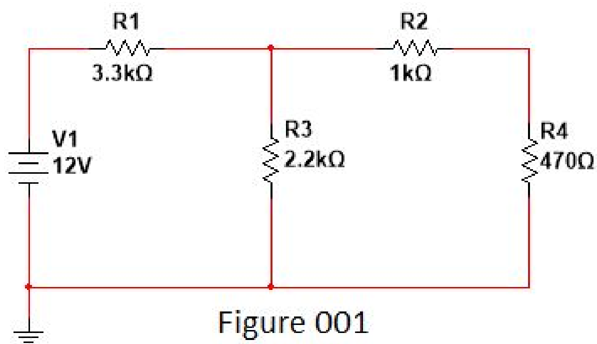


Figure 001

$R_{1(\text{Measured})}$	3.255Ω
$R_{2(\text{Measured})}$	2.195Ω
$R_{3(\text{Measured})}$	1.001Ω
$R_{4(\text{Measured})}$	462Ω

Then, transformed the circuit into our Thevenin Equivalent Circuit shown below. Calculations were performed in order to find the value of the Thevenin Resistance and Thevenin Voltage. The Load voltage stays the same because it is not used in our calculations to find the Thevenin Resistance. **Figure 001(b)** shows the Thevenin Equivalent circuit used:

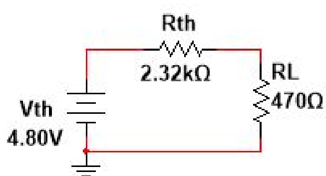


Figure 001(a) - Thevenin Equivalent Circuit.

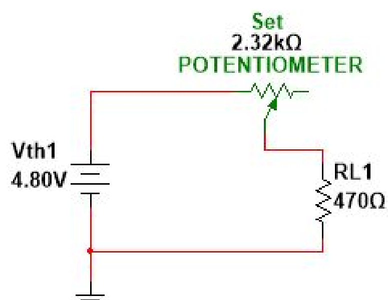


Figure 001(b) - Thevenin Equivalent Circuit using variable resistor.

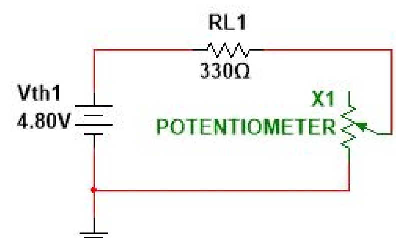
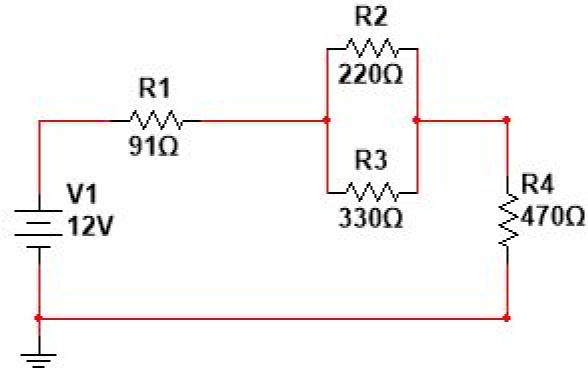


Figure 002

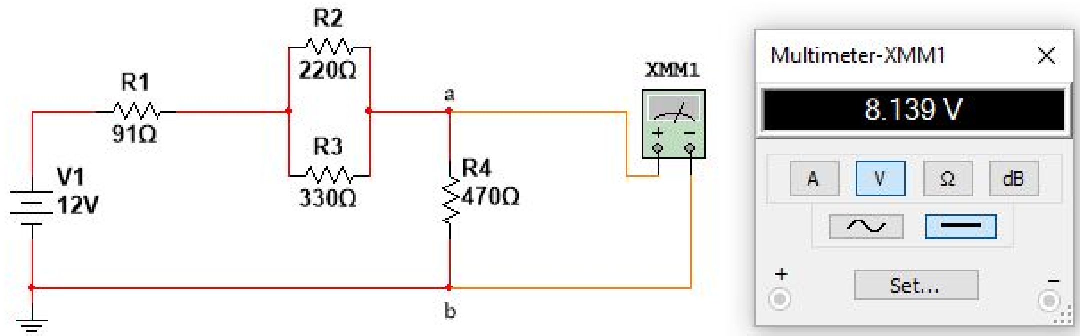
In Part 2, we verified the Maximum Power Transfer Theorem, which states that "*maximum amount of power will be dissipated in the load resistance when the value of the load resistance is exactly equal to the resistance of the power source.*" Upon construction of the circuit shown in **Figure 002**, we collected the measured voltage across the various load resistances and deduced the power dissipated by said resistor. We then, demonstrated the relationship between the resistance and power transmission on the graph shown in **Graph 12.1.**

In Part 3 of this laboratory exercise we verified the conditions for maximum power transfer using simulation software *MultiSim 14*.

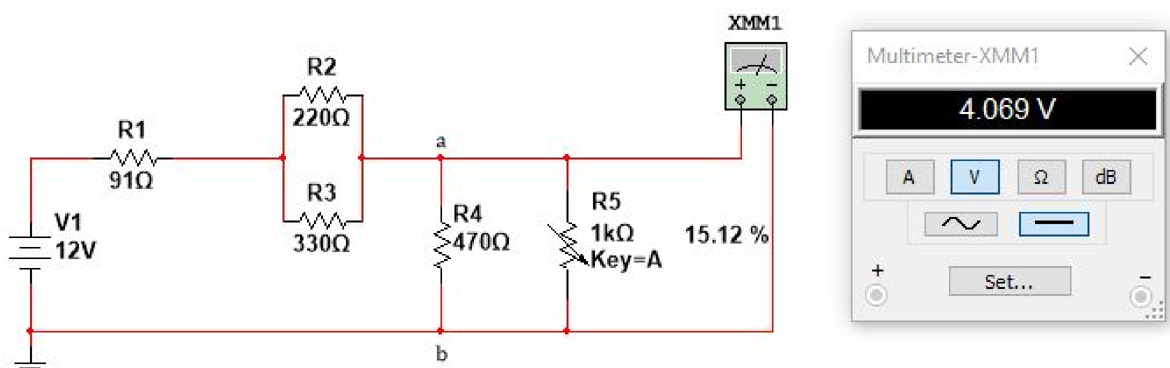
First we constructed the following circuit:



Next we determined the Thevenin voltage (E_{Th}) by measuring the open circuit voltage V_{ab}:



Afterwards we determined the Thevenin resistance R_{Th} by introducing a 1 kΩ potentiometer and adjusted the resistance until the potential difference reached half of the Thevenin voltage ($E_{Th.}$).



Next we verified the conditions at which the circuit would undergo maximum power transfer by varying the resistance values of the potentiometer and measuring the varying voltage across said potentiometer. From the voltages we deduced the power across this load resistance and graphed the resistance vs. power & the resistance vs. voltage (as shown in **Graph 12.2** and **12.3**)

Results

Table 12.1

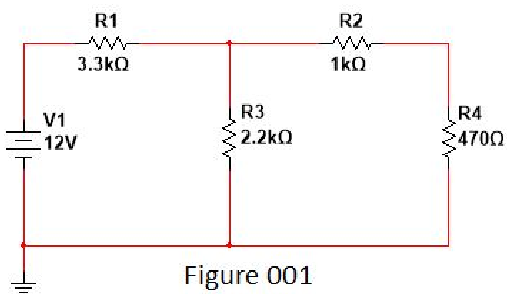


Figure 001

$$R_{Th} = R_3 + \frac{R_1 R_2}{R_1 + R_2} = 1K\Omega + \frac{(3.3K\Omega)(2.2K\Omega)}{3.3K\Omega + 2.2K\Omega} = 2.32K\Omega$$

$$E_{Th} = V_{R_2} = \frac{V_1 R_2}{R_1 + R_2} = \frac{2.2K\Omega}{3.3K\Omega}(12V) = 4.80V$$

	Calculated	Measured	% Difference
E_{Th}	4.80V	4.83V	0.62%
R_{Th}	2.32kΩ	2.31kΩ	0.43%

Table 12.2

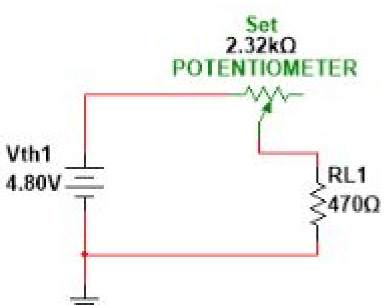


Figure 001(b) - Thevenin Equivalent Circuit using variable resistor.

$$I = \frac{V_T}{R_{Th} + R_L} = \frac{4.80\text{ V}}{2.32\text{ k}\Omega + 470\ \Omega} = \frac{4.80\text{ V}}{2.790\text{ k}\Omega} \cong 1.72\text{ mA}$$

I_L	$I_{L\ (Series\text{-}Parallel)}$
1.72mA	1.72 mA

Table 12.3

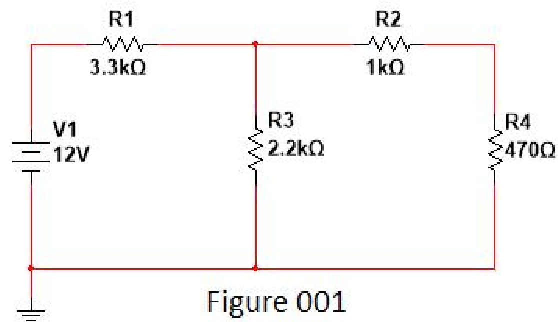
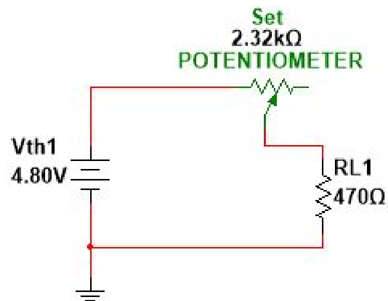


Figure 001



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$$I_L = \frac{V_T}{R_L} = \frac{.796\ \text{V}}{470\ \Omega} \cong 1.64\ \text{mA}$$

	V_L	I_L (From V_L)
Original (Figure 001)	0.806V	1.7mA
Thevenin Equivalent (Figure 001(b))	0.796V	1.64mA

Table 12.4

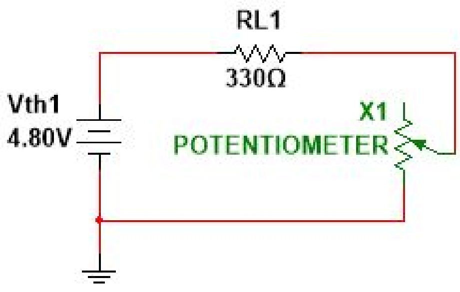


Figure 002

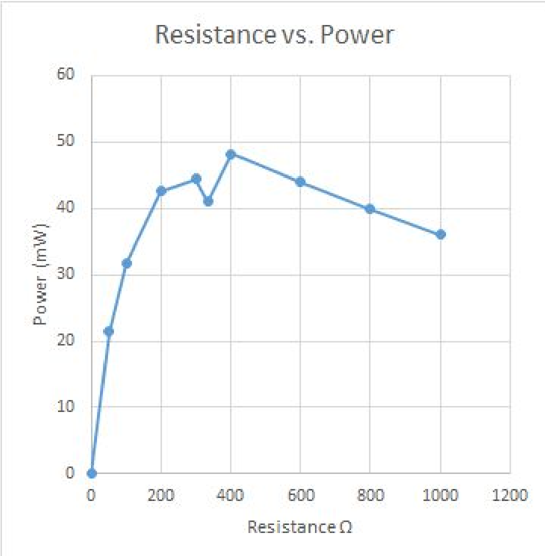
$$P_L = \frac{v_l^2}{R_L} = \frac{(1.036)^2}{50\Omega} = 24.47mW$$

$R_L(\Omega)$	V_L(V)	P_L (mW)
0	0	0
50	1.036	24.47
100	1.78	31.684
200	2.92	42.632
300	3.65	44.408
$R_{L(Measured)} = 334$	3.7	40.99
400	4.39	44.18
600	5.14	44.03
800	5.65	39.9
1000	6	36

Table 12.5

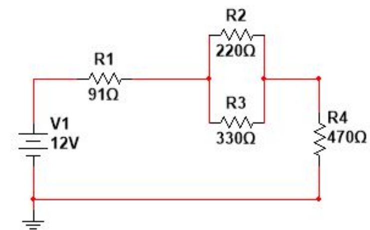
	Theory	**Experimental**
R_L	330 **Ω**	400 **Ω**
V_L	4 **V**	4.39 **V**

Graph 12.1



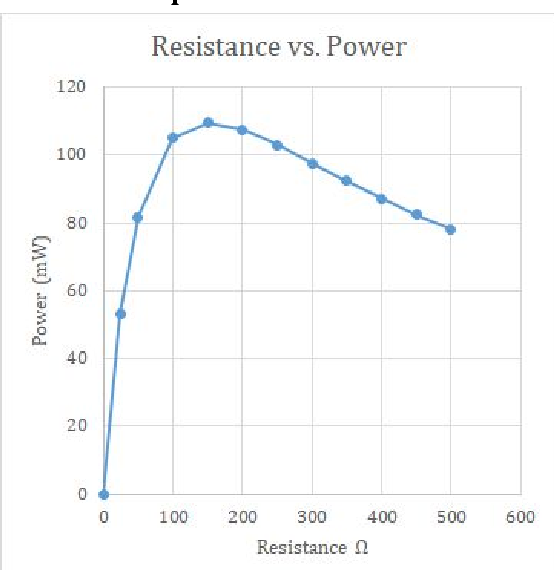
Graph 12.1 demonstrates the increase of power transmission as the load resistance reaches the Thevenin resistance and it's gradual decrease as the impedance exceeds R_{Th}. The data represented is based on the circuit constructed shown in Figure 002.

Graphs 12.2 and 12.3 are based on the following circuit below:

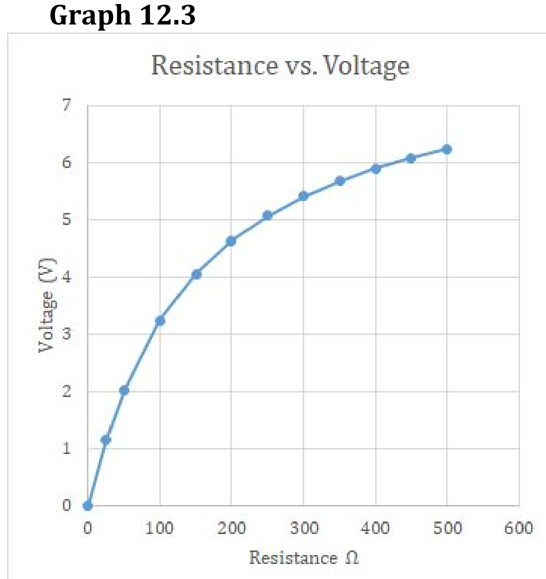


These graphs demonstrate the validity of the *Maximum Power Transfer Theorem and the increase of potential difference across the load resistor as the resistance increased.*

Graph 12.2



Graph 12.3



Conclusion

In this laboratory exercise we were successful in implementing a Thevenin equivalent circuit using Thevenin's theorem, which demonstrated characteristics similar to the original circuit. We also verified the occurrence of maximum power transfer at which the load resistance reached the same impedance of the Thevenin resistance and a voltage potential half of the Thevenin voltage.

References

- "Thevenin's Theorem." *All About Circuits*, www.allaboutcircuits.com/textbook/direct-current/chpt-10/thevenins-theorem/.
- "Maximum Power Transfer Theorem." *All About Circuits*, www.allaboutcircuits.com/textbook/direct-current/chpt-10/maximum-power-transfer-theorem/.
- "Maximum Power Transfer Theorem in DC Theory." *Basic Electronics Tutorials*, 3 May 2018, www.electronics-tutorials.ws/dccircuits/dcp_9.html.