Electrical Engineering 110L Circuits Measurements Lab

Lab 2: Kirchhoff's Laws and Equivalent Circuits; Sensors

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1 Objective

The objective of this lab is to understand voltage and current divider rules. Be able to test the validity of Norton and Thevenin equivalent circuits and measuring the resistivity of a photoresistor. We will verify Kirchhoff's laws in the experiment as well. Given a circuit we will simplify the circuit into a Norton and Thevenin equivalent circuits and test it. We will also be using a voltage divider circuit to perform light sensor. In one experiment we will be measuring the skin's resistance. This basically concludes this week's experiment.

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2 Theory

In this lab we will be using a resistor which is an element of the circuit that converts energy of electrons to heat. This is governed by the equation:

[1] $P = I^2R = V^2/R = VI$	|| I = current (A), P = power (W), R = resistance (Ω)
[2] $V = IR$	|| V = voltage (V)
[3] $I_{meter} = I_{total}*R_{shunt}/(R_{shunt}+R_{meter})$	|| (This equation will be use find maximum current I.)
[4] $V = (P*R)^{1/2}$	|| Max voltage can be applied to resistor (derive from [1])
[5] $V_{R1}=R1/(R1+R2)*V_{tot}$	|| Voltage divider (note: one possible form)
[5] $I_{R1}=R2//(R1+R2)*I_{tot}$	|| Current divider (note: one possible form)
[6] $R_{eq}=R_1*R_2/(R_1+R_2)$	|| Equivalent resistance for parallel

Reading resistor's value will require understanding of the color values. This is the general equations that give the resistor's resistance. $R = (1^{st}2^{nd})x10^{3rd}\ \Omega \pm 4^{th}$
The 1^{st} denote the first color band, 2^{nd} denote the second color band and so on. Plugging in the values into the respective location will give the resistance and tolerance of the resistor.

Norton's Circuit – In this lab we will be testing this theory and verifying in during the experiment. We will try to simplify a given circuit into a I_{Nort} and R_{eq}.

Thevenin's Circuit - In this lab we will be testing this theory and verifying in during the experiment. We will try to simplify a given circuit into a V_{Th} and R_{eq}.

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3 Procedure

Lab experiment 1:

In this first experiment we setup the circuit base on our pre-lab design for question 4. We then measure all the voltages and currents in the circuit using the DMM and the milliammeter.

Lab experiment 2:

Search for an equivalent resistance seen by the source for the circuit built in experiment 1. Connect a single resistor near the R_{eq} to the source.

Lab experiment 3:

In this part we test build a Norton and Thevenin equivalent circuit for testing. First we build the original circuit and measure the various currents and voltages. Next we build the equivalent Norton and Thevenin circuits and measure its currents and voltages. This data is later used to compare the validity of the Norton and Thevenin circuit.

Lab experiment 4:

Obtain resistor greater than 1MΩ. Hold the resistor with both hand griping onto the probes each lead (this will make the person holding the resistor be in parallel with the resistor). Next, measure the resistor's resistance and record the data (note: do not touch the lead).

Lab experiment 5:

Obtain two DMM for this experiment. Choose a resistor less than 100Ω and another greater than 100kΩ and measure both the voltage and resistance with the two DMM simultaneously.

Lab experiment 6:

In this part of the experiment we set up a circuit in which the output is 0 V when the photoresistor is in the dark and about 50% of the voltage when expose to the room light. To do this we will create a series circuit. Find a resistor similar to the photoresistor's resistance when expose to light. Place this in series with the photoresistor. In this configuration the each resistor share 50% of the power supply voltage since their resistance are the same under light.

Lab experiment 7:

In this step we try to measure the resistance of the photoresistor's resistance by placing it in the dark. The darkness will increase the photoresistor's resistance so measure the resistance after it has stabilized.

Lab experiment 8:

In this part of the experiment we will be trying to measure the human body's infrared light transmission from the hand. To proceed with this experiment place your hand on the photoresistor to transmit the infrared light.

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4 Data, Data Analysis, and Discussion

Lab experiment 1:

Using the 4.8 Ω shunt and 44.7Ω milliammeter we measured the following:

	Pre-Lab	Measured Value	Calculated Value	% error
V_{source}	10 V	10+/-.5 V	---	
R1	100 Ω	99.5+/-.05 Ω	---	

R2	1000 Ω	998+/-.5 Ω	---	
$I_{milliammeter}$	.881 mA	.92+/-.005mA	---	
I_{total}	9.1 mA	9.5+/-.1mA	9.1+/-.5 mA	4.4%
V across R1	0.91 V	.903+/-.0005 V	0.91+/-.05 V	0.77%
V across R2	9.09 V	9.13+/-.005 V	9.09+/-.5 V	0.44%

Table 1: Circuit with series resistors

The data we obtain is closely related and within the range of the calculation. It should be noted that the total current of the circuit is 9.1 mA with an error of .5mA (calculated from the error propagation equation) due to fluctuation in device precision. With a .5mA error this put us within the 9.5mA range that we measured. (I<u>f table are unclear explanation are provided in the error analysis.</u>)

	Pre-Lab	Measured Value	Calculated Value	% error
V_{source}	10 V	10+/-.5 V	---	
R1	330 Ω	327.4+/-.05 Ω	---	
R2	100 Ω	99.5+/-.05 Ω	---	
R3	330 Ω	327.9+/-.05 Ω	---	
I_1	24.6mA	25.1+/-.5mA	24.8+/-1.2mA	1.2%
I_2	18.9mA	18.7+/-.5mA	19.0+/-0.9mA	1.6%
I_3	5.7mA	5.5+/-.5mA	5.77+/-0.3mA	4.7%
V across R1	8.11 V	8.15+/-.005 V	8.11+/-0.4 V	0.49%
V across R2	1.89 V	1.895+/-.005 V	1.89+/-0.1 V	0.26%
V across R3	1.89 V	1.895+/-.005 V	1.89+/-0.1 V	0.26%

Table 2: Circuit with series and parallel resistors

It seems like the Kirchhoff's laws hold in our experiment and falls within the uncertainty found using the error propagation equation. Adding up the 18.7mA and 5.5mA we get 25.5mA which is clearly within the range of the 25.1mA before the junction. In the same way the calculated value for the experiment also match with the measured value. Again this verifies Kirchhoff's laws.

Lab experiment 2:

In this section we are supposed to find an equivalent circuit to the first two.
Series equivalent: Using 1 Ω shunt. (Note all measured value to test equivalent)

Resistors	1.197+/-.0005kΩ
Voltage across R	10.04+/-.005V
Current	8.63+/-0.5 mA

Table 3: Series equivalent of Table 1

Note that in this lab experiment we were unable to find a 1.1kΩ resistor to test our circuit. Because of this problem we switch to the 1.2kΩ. In calculating it the value turns out to be a bit off. Due to this issue we got a different current but overall the current is still similar.

Parallel equivalent: Using 1 Ω shunt.

	Measured Value
Resistors	395+/-.5Ω
Voltage across R	10.02+/-.005V

Current	25.6+/-0.05 mA

Table 4: Parallel equivalent of Table 2

In this experiment we were able to find a similar resistor that is equivalent to the equivalent resistance of the setup in the table 2 data. Because of this the total current correlates to I_1 in table 1.

Lab experiment 3:

In this experiment we measured the I_{load} and V_{load} for later comparison when we build the equivalent circuit.

	Pre-Lab	Measured Value	Calculated Value	% error
I_{source}	100 mA	100.6+/-.05 V	---	
R1	47 Ω	47.1+/-.05 Ω	---	
R2	100 Ω	99.5+/-.05 Ω	---	
R3(load)	330 Ω	326.3+/-.05 Ω	---	
I_{load}	9.85mA	10.59+/-.5mA	10.0+/-.1mA	5.9%
V_{load}	3.25 V	3.295+/-.005 V	3.27+/-0.04 V	0.76%

Table 5: The table shows the measured value for figure 16 (setup in the lab manual).

V_{Th}	4.64+/-.11V
$V_{Th(expected)}$	4.7V
% error	1.28%

Table 6: The table shows the measured value for figure 16 (setup in the lab manual).

	Pre-Lab	Measured Value	Calculated Value	% error
V_{source}	10 V	10+/-.5 V	---	
R1	47 Ω	47.1+/-.05 Ω	---	
R2	47 Ω	99.5+/-.05 Ω	---	
R3(load)	100 Ω	326.3+/-.05 Ω	---	
I_{load}	37.2mA	38.4+/-.5mA	37.6+/-.5mA	2.13%
V_{load}	3.73 V	3.205+/-.05 V	3.7+/-.04 V	13.4%

Table 7: The table shows the measured value for figure 17 (setup in the lab manual).

V_{Th}	4.64+/-.11V
$V_{Th(expected)}$	4.7V
% error	1.28%

Table 8: The table shows the measured value for figure 17 (setup in the lab manual).

In this lab we got consistent data with the calculated value from the pre-lab. Apparently there were some problems with the V_{load} measurement. There is a % error of 13.4% which is quite large. This could be due to poor connection. We also notice that each time we use the DMM to measure the resistance of a resistor each time there is a few ohm different.

Lab experiment 4:

	Measured Value
R1	2.205+/-.0005 MΩ

R_{eq}	1.832+/-.0005 MΩ
R_{body}	10.83+/-.021 MΩ

Table 9: Data for determining the body resistance

Using the parallel equivalent resistance formula [6] we can manipulate the equation algebraically to calculate for the body resistance. After getting the resistance if we have a potential difference of 50V we will have about 4.6μA (microAmps).

Lab experiment 5:
R1 = 70+/-.5 Ω (for R<100Ω) V1 = .022+/-.0005V
R1 = 1.839+/-.0005 MΩ (for R<100kΩ) V2 = .19+/-.005V
When measuring the higher resistor there is a higher current sent from the DMM compare to when measuring the lower resistor there is a lower current sent out.

Lab experiment 6:
Photo-resistor: R_{light}= 464.3+/-.05Ω R_{dark}= 26.4+/-.3kΩ
Resistor in series with photo-resistor = 472.3Ω
Voltage without cover is 2.655V across the photo-resistor.

- Part 1 we are trying to get the V=0 in the dark we got the voltage up to .088V. (Lowest value we could achieve)
- Part 2 changing voltage by 1V (in light):

Voltage (V)	R
4+/-.005V	2.016+/-.005Ω
5+/-.005V	2.573+/-.005Ω
6+/-.005V	2.984+/-.005Ω

Table 10: Voltage data table for photo-resistor

It seems like there is an increment of about .5V for every increment in one voltage in the DC power supply. This should not be surprising since in light both the photo-resistor and the chosen resistor have about equal resistance so the voltage of the power supply is split about evenly between them.

Lab experiment 7:
The lowest recorded voltage for the resistor connected in series with the photo-resistor is .088V (when DC is at 5V) so the photo-resistor max resistance is ***R_{dark}= 26.4+/-.3kΩ***. This solution is derive from the voltage division equation $R_{photo\text{-}resistor}=(R*V_{tot}-V_{resistor}*R)/V_{resistor}$.

Lab experiment 8:
With one hand the voltage is .741V and with two hands the voltage is .464V. So this means that our hand is actually effectively in blocking the light. This is the reason why the voltage was able to change. The voltage signal is lower with two hand compare to 1 hand. This mean we will have resistance of:
1 hand R=2.7+/-.3kΩ 2 hands R=4.6+/-.5kΩ

5 Error Analysis

If the general equation is $F(x_1, x_2, \ldots, x_n)$ then the error for F (identified as σ_F) would be given by the following error propagation equation:

$$\sigma_F = \sqrt{(\frac{dF}{dx_1}\sigma_{x_1})^2 + (\frac{dF}{dx_2}\sigma_{x_2})^2 + \cdots + (\frac{dF}{dx_n}\sigma_{x_n})^2}$$

Lab experiment 1:

In this first part of the experiment we build a circuit similar to the pre-lab question. Apparently there were no perfect resistor and we obtain one as close to the desire resistance as possible to begin the experiment.

- Pre-lab - column presents the expected value calculated from the chosen resistors and DC voltage.
- Measured Value – presents the value measured using either the milliammeter or the DMM and calculated using the measured values.
- Calculated Value – are calculated from the resistances and DC voltage supply. In our case all of the values fall within range of the error from the error propagation equation.

Parallel Equivalent:

- The measured value for the $I_{milliammeter}$ is used to calculate the I_1, I_2, and I_3. The error for this is calculated using the error propagation formula on the following equation:
- [equation 3 (alternate form)] $I_{total} = I_{meter} * (R_{shunt}+R_{meter})/R_{shunt}$
- In the calculated section we used the measured DC's voltage and the resistor's resistance to calculate the current that should be going through the circuit's branches.

Lab experiment 2:

- It seems that equivalent circuits are possible to obtain by having an equivalent resistor to replace our other resistors. This is clearly shown in our parallel equivalent circuit.
- Though the series example does prove similar its resistor's resistance is close to the 1.2kΩ which is different than the desired 1.1kΩ. This does lead to slightly different value it was still close enough to show the effect of equivalent circuits and similar current.

Lab experiment 3:

The experiment for lab 3 and its error calculation are display on the table. The errors are calculated from the error propagation formula given above.

Lab experiment 4-8:

They were either equipment error or simple calculation using the error propagation equation given above.

6 Conclusions

In this lab our experiments were quite successful. Basically we were able to verify the equivalent of both Norton's and Thevenin's equivalent circuits. We were able to apply current and voltage division laws. In our testes we also were able to demonstrate Kirchhoff's laws. We were able to convert a complex circuit to a simple Norton's and Thevenin's circuit. We were also able to design a light sensor and change the resistance by placing it in a dark environment.