LABORATORY #7
THEVENIN EQUIVALENTS AND MAXIMUM POWER TRANSFER

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ABSTRACT

In this lab, the Thevenin equivalent of a two-source, ten-resistor network was found three different ways and then checked against a CircuitLab simulation. The open-circuit voltage measured 10.05 V, and the Thevenin resistance came out to 338.16 Ω from V_{OC}/I_{SC}, 337.20 Ω from a direct ohmmeter reading, and 340.95 Ω from a 10 V test source. All three agree within 1.1% of one another and within 1.5% of the simulated 342.02 Ω. Loads of 100 Ω, approximately R_{TH}, and 820 Ω were then connected to both the original circuit and a Thevenin equivalent built from a supply and series resistors. Both delivered the most power to the matched load, 73.60 mW and 75.54 mW respectively, against a theoretical maximum of 74.67 mW. All data were reduced and plotted in Excel, and the two circuits agreed at every load to within 2.6%.

♦ INTRODUCTION

The goal of this lab is to take a circuit that is genuinely annoying to analyze and replace it with something trivial. Thevenin's theorem promises that any linear network, no matter how tangled, looks like one voltage source behind one resistor from the point of view of its load [3]. That is a strong claim, and it is worth testing on real hardware with real meters.

The circuit studied here contains two 6 V sources and ten resistors arranged in bridge-like structures. Series and parallel combinations cannot collapse it, and a hand solution would require Δ–Y transformations [1]. Instead, its Thevenin equivalent was measured experimentally using three methods, compared against a CircuitLab simulation, and then put to work: loads of 100 Ω, R_{TH}, and 820 Ω were connected to both the original circuit and its equivalent to verify the maximum power transfer theorem.

♦ THEORY

Thevenin's Theorem

Any linear two-terminal network of sources and resistors can be replaced by an ideal voltage source V_{TH} in series with a resistance R_{TH}. The source voltage is simply what appears across the open terminals once the load is removed:

$$V_{TH} = V_{OC}$$

Three Ways to Find R_{TH}

The first method shorts the output terminals, measures the current that flows, and divides:

$$R_{TH} = V_{OC} / I_{SC}$$

The second turns off every independent source, replacing voltage sources with short circuits, and reads the resistance between the terminals with an ohmmeter. This only works when the circuit has no dependent sources, which is true here. The third also turns the sources off, but then applies a known test voltage and measures the resulting current:

$$R_{TH} = V_{TEST} / I_{MEASURED}$$

For a linear circuit all three must agree. When they do not, the disagreement says

something about the measurement rather than the theorem, which makes the comparison worth doing.

Maximum Power Transfer

With the network in Thevenin form, the power delivered to a load R_L follows from the voltage divider:

$$P_L = V_{TH}^2 R_L / (R_{TH} + R_L)^2$$

Setting the derivative with respect to R_L to zero shows that power peaks when $R_L = R_{TH}$, where

$$P_{max} = V_{TH}^2 / (4R_{TH})$$

At that point, half of the source's power is dissipated inside R_{TH}. Matching is ideal for pulling the most signal out of an antenna or an amplifier stage, but it is a poor way to build a power supply; nobody wants a phone charger that runs at 50% efficiency on purpose.

♦ PROCEDURE

The specification and procedure are given in the Laboratory #7 handout [1]. Wiring diagrams, simulation screenshots, the Excel workbook, and the signed worksheet are included in the Appendix.

I. The circuit was built on a breadboard with two 6 V supplies in series and the 820 Ω load removed from terminals A and B (Fig. 3).

II. The open-circuit voltage V_{OC} and the short-circuit current I_{SC} were measured across A and B, and R_{TH} was computed.

III. Both supplies were disconnected and replaced with jumper wires (Fig. 4), and R_{TH} was read directly with an ohmmeter.

IV. With the sources still shorted, a 10 V test source was applied across A and B (Fig. 5). V_{TEST} and the resulting current were measured, and R_{TH} was computed.

V. The supplies were restored, and loads of 100 Ω, approximately R_{TH}, and 820 Ω were connected in turn while V_L and I_L were recorded.

VI. A Thevenin equivalent was built from a DC supply and series resistors chosen as close to R_{TH} as possible, and the same three loads were measured again.

VII. The original network was simulated in CircuitLab to find V_{OC} and I_{SC} (Figs. 6 and 7), and the Thevenin equivalent was simulated with each load (Figs. 8 through 10).

VIII. All measurements were entered into an Excel workbook, where R_{TH}, load power, and theoretical power were computed with live formulas and plotted (Figs. 1, 2, and 11 through 13).

♦ RESULTS

Table 1 lists the raw measurements for each method alongside the resulting Thevenin resistance. All values were recorded on the in-lab worksheet (Figs. 14 and 15) and entered into Excel, where every derived quantity is computed by formula.

Table 1: Thevenin Parameter Measurements

Method	Measured Quantities	Computed R_{TH} (Ω)
V_{OC} and I_{SC}	V_{OC} = 10.050 V, I_{SC} = 29.720 mA	338.16
Ohmmeter (sources shorted)	Direct reading	337.20
Test voltage	V_{TEST} = 10.002 V, I_{MEAS} = 29.336 mA	340.95
CircuitLab simulation	V_{OC} = 9.922 V, I_{SC} = 29.010 mA	342.02

Table 2 compares all four results. The ohmmeter and test-voltage methods only produce R_{TH}, so the V_{TH} listed for them is the measured open-circuit voltage. Percent differences are taken relative to the simulation and to the mean of the three bench methods.

Table 2: Comparison of V_{TH} and R_{TH} by Method

Method	V_{TH} (V)	R_{TH} (Ω)	% Diff. vs. Simulation	% Diff. vs. Bench Mean
V_{OC} and I_{SC}	10.050	338.16	−1.13%	−0.18%
Ohmmeter	10.050	337.20	−1.41%	−0.46%
Test voltage	10.050	340.95	−0.31%	+0.64%
CircuitLab simulation	9.922	342.02	—	+0.96%
Bench mean	**10.050**	**338.77**	**−0.95%**	**—**
Bench std. deviation	**—**	**1.95**	**—**	**—**

Fig. 1 is the Excel chart of the same R_{TH} values. The vertical axis starts at 330 Ω so that the spread is visible; on a zero-based axis all four bars would look identical.

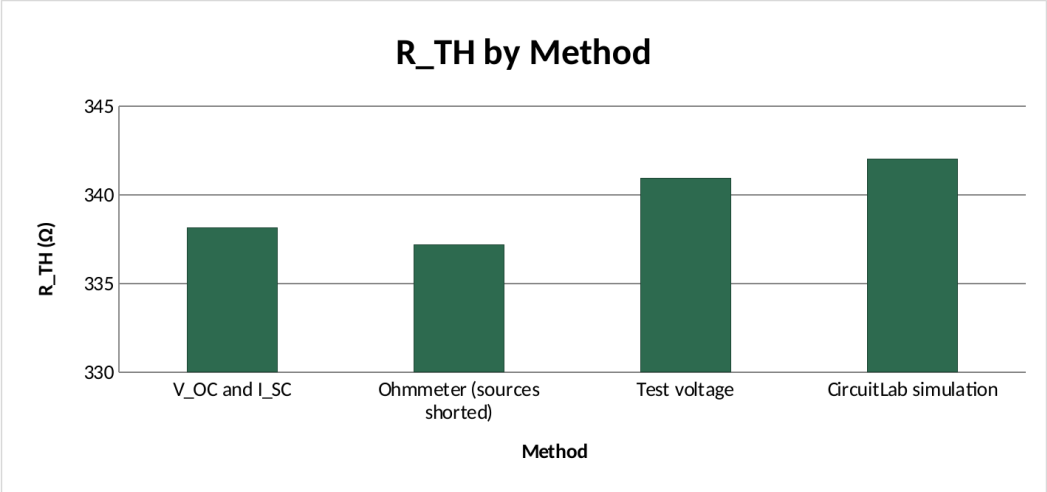


Fig 1. ***Excel chart of R_{TH} by method (Thevenin Parameters sheet)***

Tables 3 and 4 give the load measurements for the original circuit and for the Thevenin equivalent. Power is computed as $P_L = V_L I_L$, and the effective load resistance V_L/I_L is listed because the physical resistors differed slightly from their nominal values. The theoretical power uses V_{TH} = 10.05 V and R_{TH} = 338.16 Ω at each effective load.

Table 3: Load Power, Original Circuit

Nominal R_L	V_L (V)	I_L (mA)	Effective R_L (Ω)	P_L (mW)	P_{theory} (mW)	% Diff.
100 Ω	2.2544	22.754	99.08	51.30	52.35	−2.00%
≈ R_{TH}	5.0570	14.555	347.44	73.60	74.66	−1.41%
820 Ω	7.0878	8.6383	820.51	61.23	61.73	−0.82%

Table 4: Load Power, Thevenin Equivalent Circuit

Nominal R_L	V_L (V)	I_L (mA)	Effective R_L (Ω)	P_L (mW)	P_{theory} (mW)	% Diff.
100 Ω	2.2422	22.543	99.46	50.55	52.46	−3.64%
≈ R_{TH}	5.0815	14.866	341.82	75.54	74.67	+1.17%
820 Ω	7.1654	8.7228	821.46	62.50	61.70	+1.30%

Table 5 lists the CircuitLab results for the Thevenin equivalent with V_{TH} = 10 V and R_{TH} = 338.2 Ω. Since the simulator uses ideal parts, its results match the power equation in the Theory section to within rounding.

Table 5: Simulated Thevenin Equivalent (CircuitLab)

R_L (Ω)	V_L (V)	I_L (mA)	P_L (mW)	P_{theory} (mW)
100	2.282	22.82	52.08	52.08
338.2	5.000	14.78	73.92	73.92
820	7.080	8.63	61.13	61.13

Fig. 2 is the Excel plot requested in Step 14 of the handout. Rather than plotting only three points, the theoretical curve for P_L was added so the location of the peak is obvious, and every measured and simulated point was overlaid on it.

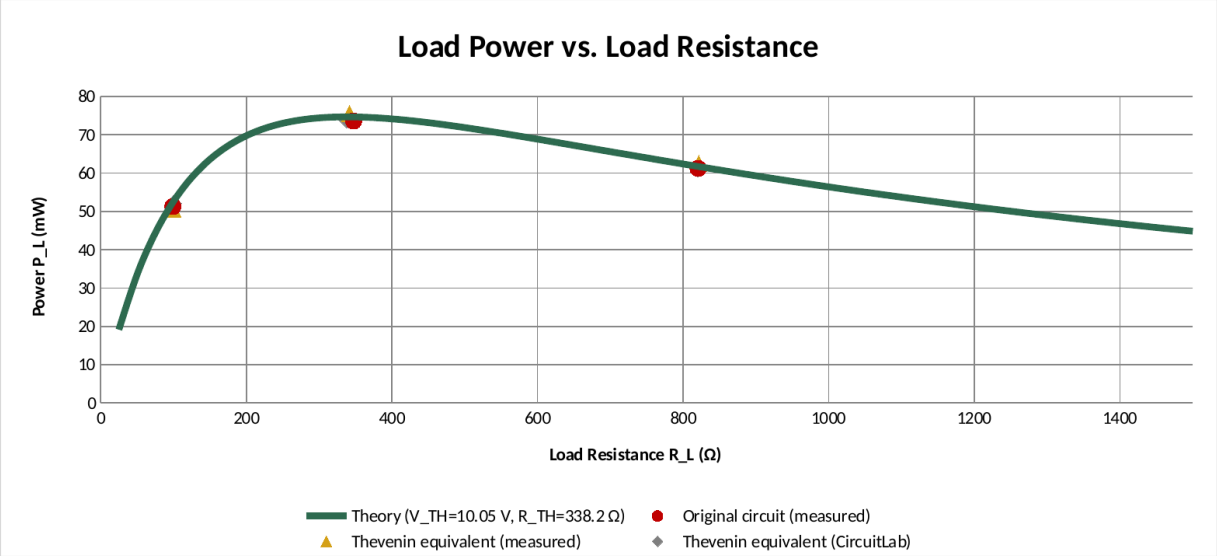


Fig 2. ***Excel plot of load power versus load resistance (Power Curve sheet)***

Table 6 summarizes the power delivered at each load by every version of the circuit.

Table 6: Summary of Load Power

Load	Original (mW)	Thevenin Eq. (mW)	Simulation (mW)	Theory (mW)
100 Ω	51.30	50.55	52.08	52.61
≈ R_{TH}	73.60	75.54	73.92	74.67
820 Ω	61.23	62.50	61.13	61.75
Peak at	**$R_L \approx R_{TH}$**	**$R_L \approx R_{TH}$**	**$R_L = R_{TH}$**	**$R_L = R_{TH}$**

♦ DISCUSSION

Agreement Between Methods

The three bench values of R_{TH} span only 3.7 Ω, with a standard deviation of 1.95 Ω, so the methods agree to about 1%. The pattern in the small differences is worth a closer look. The ohmmeter reading was the lowest at 337.2 Ω, and it is the only method that puts no ammeter in the current path. Both the short-circuit and test-voltage methods route current through the meter's internal shunt, which adds a few ohms in series with the network. That makes the measured current slightly small, and dividing by it inflates R_{TH}.

The test-voltage method also measured V_{TEST} at the supply terminals rather than directly across A and B, so lead and breadboard contact resistance were folded into its result as well. A 3.7 Ω spread is about what one would expect from a real meter on a real breadboard; the theorem itself held up fine.

Comparison With Simulation

Every bench value of R_{TH} came in below the simulated 342.02 Ω, by 0.3% to 1.4%. CircuitLab assumes each resistor is exactly its nominal value, while the physical resistors carry a ±5% tolerance. The ohmmeter result, the cleanest measurement of the passive network, suggests that this particular set of resistors ran about 1.4% low as a group, well inside tolerance. As a check, the network was also solved by nodal analysis, which

reproduced the simulation: V_{OC} = 9.922 V, I_{SC} = 29.01 mA, and R_{TH} = 342.0 Ω.

The measured V_{OC} of 10.05 V was 1.3% above the simulated 9.922 V. Because V_{OC} scales linearly with the source voltages, this difference is explained if each supply output sat about 0.08 V above 6 V, which is ordinary for a bench supply knob. Resistor tolerance also shifts the internal dividers that set V_{OC}.

Maximum Power Transfer

Both circuits delivered the most power to the load nearest R_{TH}, exactly as predicted. In the original circuit, the matched load received 73.60 mW, compared with 51.30 mW at 100 Ω and 61.23 mW at 820 Ω. That peak sits only 1.4% below the theoretical 74.67 mW, even though the load used was 347.4 Ω rather than 338 Ω. The mismatch barely matters because the curve in Fig. 2 is very flat near its peak; a 2.7% error in load resistance costs less than 0.1% of the available power.

Fig. 2 also shows that the curve is steep below R_{TH} and gentle above it. Undershooting the load resistance is therefore much more costly than overshooting it: dropping from 338 Ω to 100 Ω loses about 30% of the power, while climbing to 820 Ω, more than twice as far away, loses only about 17%.

The Thevenin equivalent tracked the original circuit within 1.5% to 2.6% at every load, which confirms the equivalence. Its matched-load reading of 75.54 mW is slightly above the theoretical maximum, which is impossible for an exact 10.05 V source behind 338.16 Ω. The equivalent's supply was most likely set a little above 10.05 V, or its series resistance came out slightly below R_{TH}; either one raises the available power.

♦ CONCLUSION

From its output terminals, a fairly tangled two-source resistor network behaves like a 10.05 V source behind about 338 Ω. Three independent bench methods agreed within 1% of one another and within 1.5% of simulation, and the small differences trace back to familiar culprits: ammeter burden, resistor tolerance, and imperfect supply settings. Both the original network and its Thevenin equivalent delivered peak power to the matched load, 73.60 mW and 75.54 mW against a theoretical 74.67 mW. The theorem did exactly what it promised, and not a single Δ–Y transformation was harmed in the process.

♦ ACKNOWLEDGEMENTS

The objective, background, circuit, and procedure were given and paraphrased from the ECE 263L Laboratory #7 handout [1]. Simulations were performed in CircuitLab [2], and all data reduction and plotting were done in Microsoft Excel.

♦ REFERENCES

[1] Dept. of Electrical and Computer Engineering, ECE 263L: Linear Circuit Theory I Laboratory, Laboratory #07: Thevenin Equivalent Circuits. Valparaiso, IN, USA: Valparaiso University.

[2] CircuitLab, Inc., CircuitLab Online Circuit Simulator and Schematic Editor. [Online]. Available: https://www.circuitlab.com

[3] C. K. Alexander and M. N. O. Sadiku, Fundamentals of Electric Circuits, 7th ed. New York, NY, USA: McGraw-Hill, 2021.

APPENDIX

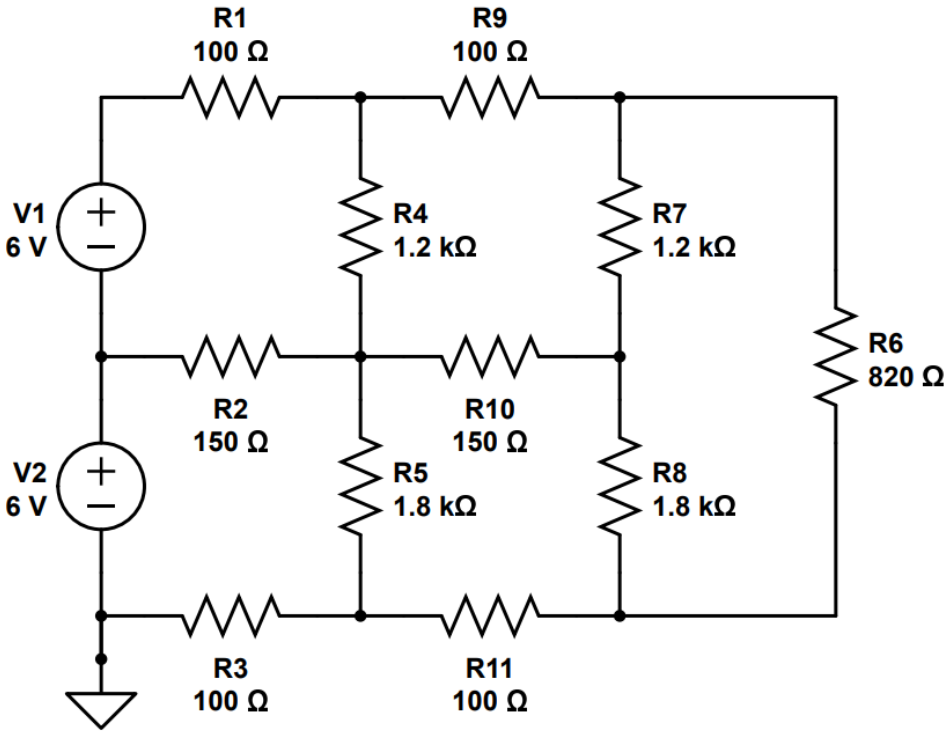


Fig 3. ***Laboratory #7 circuit with terminals A and B across the 820 Ω load [1]***

APPENDIX

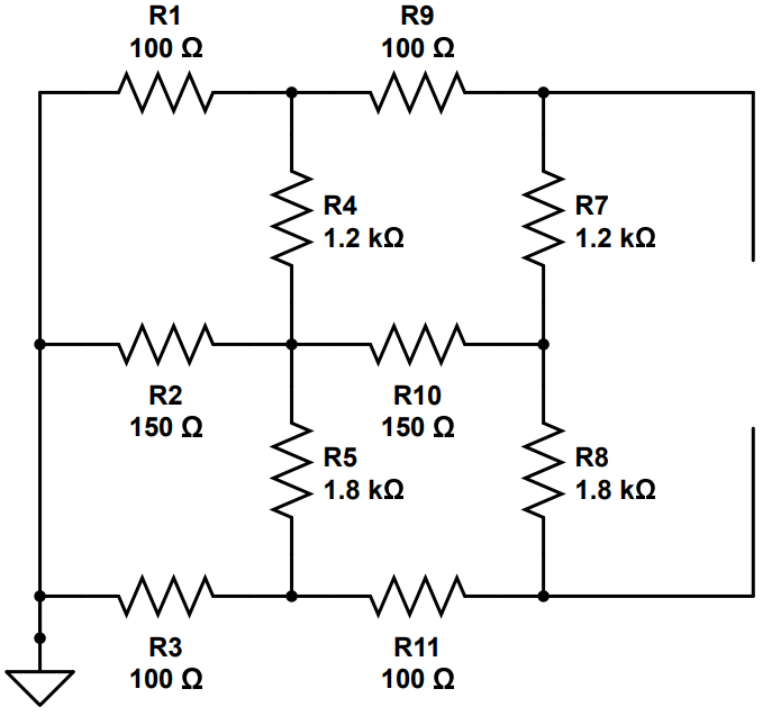


Fig 4. ***Sources replaced by short circuits for the direct ohmmeter measurement of R_{TH} [1]***

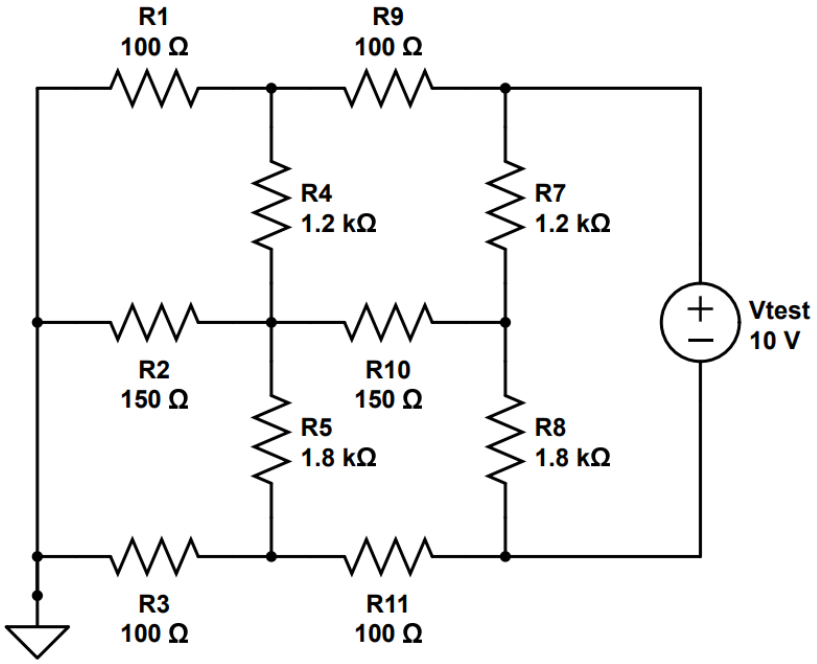


Fig 5. ***Sources shorted and a 10 V test source applied across A and B [1]***

APPENDIX

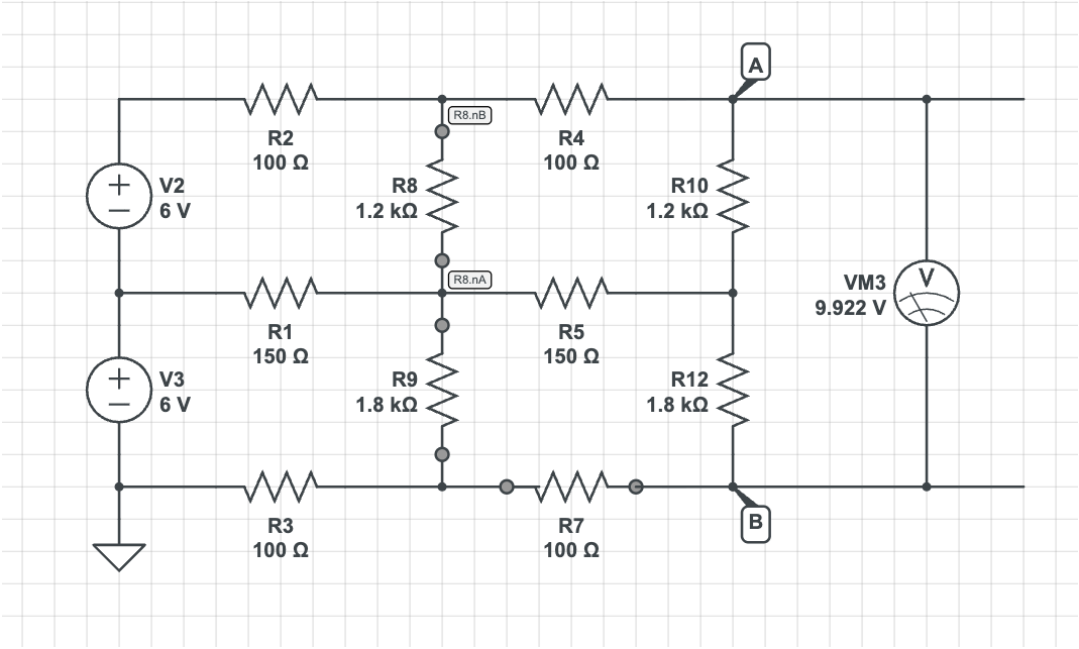


Fig 6. ***CircuitLab simulation of the original circuit, V_{OC} = 9.922 V***

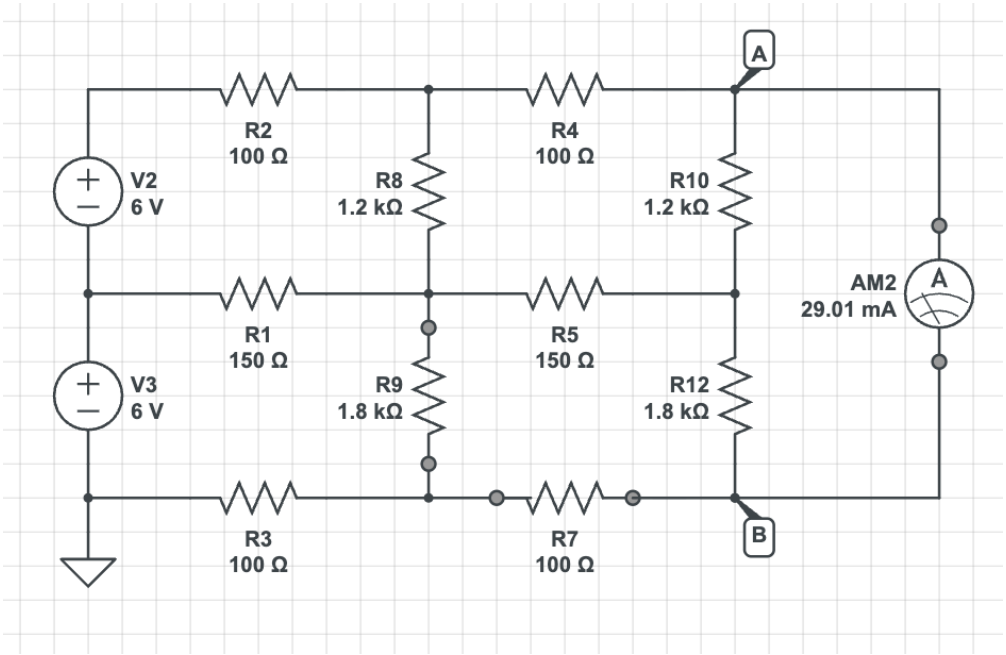


Fig 7. ***CircuitLab simulation of the original circuit, I_{SC} = 29.01 mA***

APPENDIX

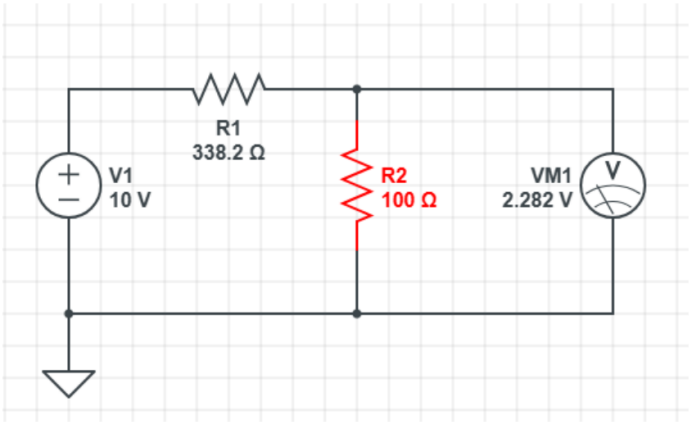


Fig 8. ***CircuitLab Thevenin equivalent with R_L = 100 Ω, V_L = 2.282 V***

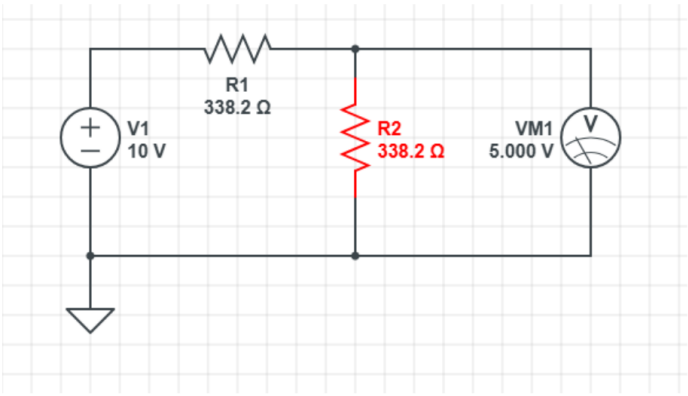


Fig 9. ***CircuitLab Thevenin equivalent with $R_L = R_{TH}$ = 338.2 Ω, V_L = 5.000 V***

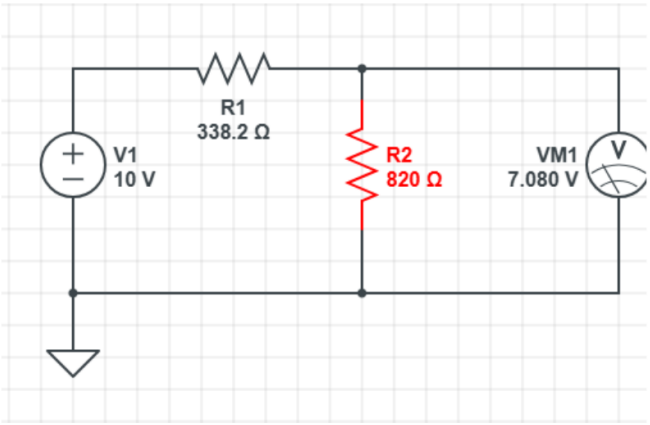


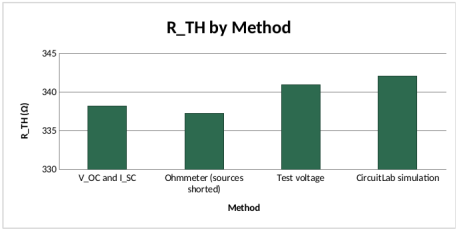
Fig 10. ***CircuitLab Thevenin equivalent with R_L = 820 Ω, V_L = 7.080 V***

APPENDIX

Lab 7 – Thevenin Parameters (Measured and Simulated)

Blue = measured/simulated input values (from lab worksheet & CircuitLab). Black = formulas.

Quantity	Value	Unit	Notes
V_OC (measured)	10.050	V	Step 2, open-circuit across A–B
I_SC (measured)	29.720	mA	Step 2, short-circuit A–B
R_TH = V_OC / I_SC	338.156	Ω	Step 3
R_TH (ohmmeter, sources shorted)	337.200	Ω	Step 5
V_TEST (measured)	10.002	V	Step 7
I_MEASURED	29.336	mA	Step 7
R_TH = V_TEST / I_MEASURED	340.946	Ω	Step 8
V_OC (CircuitLab, corrected)	9.922	V	tep 17, original circuit (corrected model)
I_SC (CircuitLab, corrected)	29.010	mA	tep 17, original circuit (corrected model)
R_TH (CircuitLab) = V_OC / I_SC	342.020	Ω	Step 17



Comparison of Methods (Step 9 / Step 18)

Method	V_TH (V)	R_TH (Ω)	% Diff R_TH vs. Simulation	% Diff R_TH vs. Mean of Bench Methods
V_OC and I_SC	10.050	338.16	-1.13%	-0.18%
Ohmmeter (sources shorted)	10.050	337.20	-1.41%	-0.46%
Test voltage	10.050	340.95	-0.31%	0.64%
CircuitLab simulation	9.922	342.02	0.00%	0.96%
Mean of bench methods	10.050	338.77		
Std. deviation of bench R_TH		1.95		

Note: Methods 2 and 3 do not produce V_TH on their own; V_TH for those rows is the measured open-circuit voltage.

Fig 11. ***Excel workbook, Thevenin Parameters sheet (blue values are measured inputs)***

Power Delivered to Load – Original Circuit (Steps 11–13)

P is recomputed as V_L × I_L. Effective R_L shows the actual resistance of the physical load used.

Step	Nominal R_L (Ω)	V_L (V)	I_L (mA)	Effective R_L = V/I (Ω)	P_L = V·I (mW)	P theory (mW)	% Diff vs. Theory
12	100	2.2544	22.754	99.08	51.30	52.35	-2.00%
13	338.156	5.0570	14.555	347.44	73.60	74.66	-1.41%
11	820	7.0878	8.638	820.51	61.23	61.73	-0.82%

Max theoretical power P_max = V_TH² / (4·R_TH) (mW): **74.67**

Power Delivered to Load – Thevenin Equivalent Circuit (Step 16)

Thevenin equivalent built from a DC supply and series resistors approximating R_TH.

Step	Nominal R_L (Ω)	V_L (V)	I_L (mA)	Effective R_L = V/I (Ω)	P_L = V·I (mW)	P theory (mW)	% Diff vs. Theory
16	100	2.2422	22.543	99.46	50.55	52.46	-3.64%
16	338.156	5.0815	14.866	341.82	75.54	74.67	1.17%
16	820	7.1654	8.723	821.46	62.50	61.70	1.30%

Max theoretical power P_max = V_TH² / (4·R_TH) (mW): **74.67**

Fig 12. ***Excel workbook, Power – Original and Power – Thevenin Eq sheets***

CircuitLab Simulation – Thevenin Equivalent (V_TH = 10 V, R_TH = 338.2 Ω)

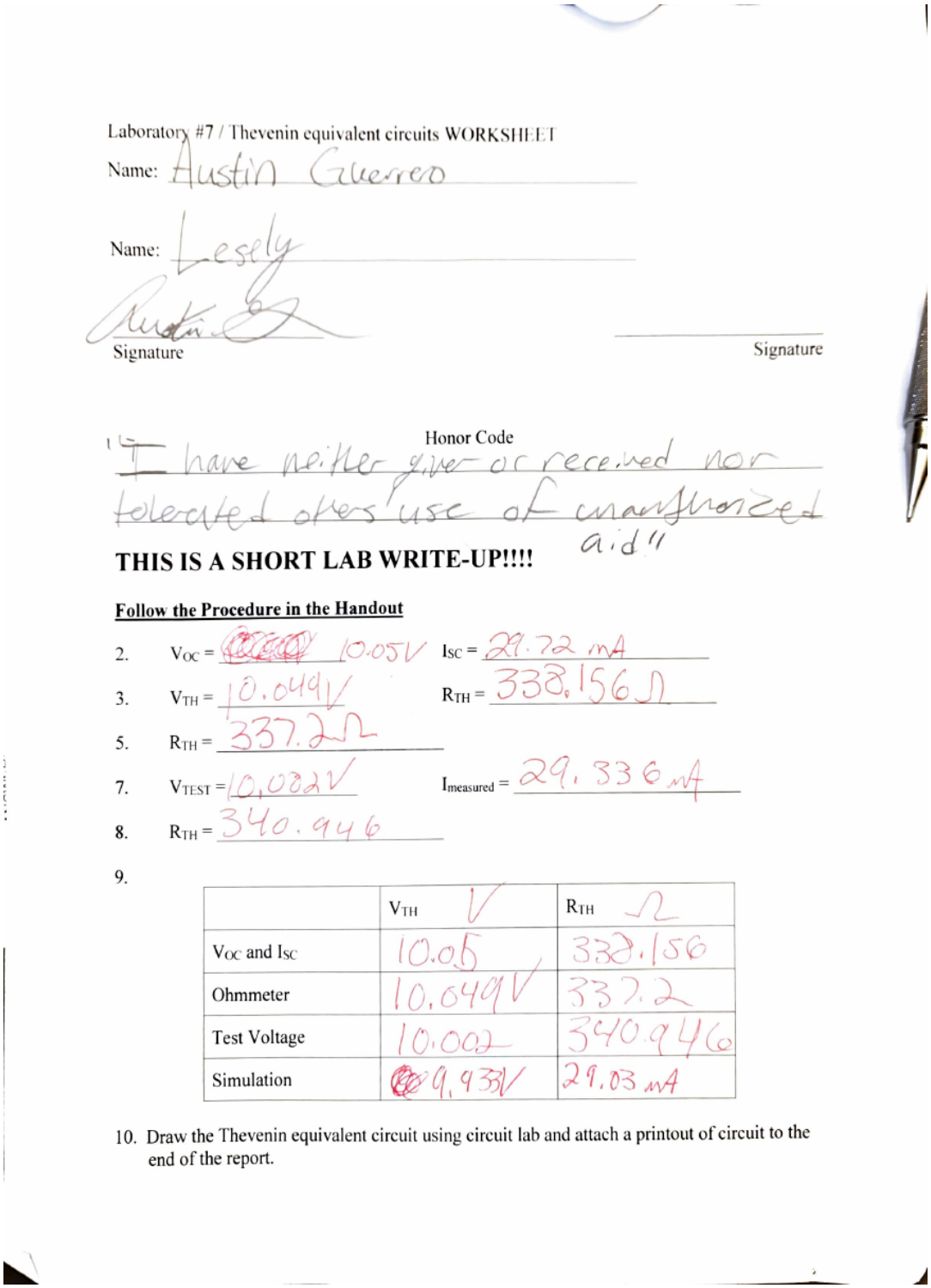
Simulated load voltage read from CircuitLab voltmeter; current and power computed.

V_TH (sim) 10 R_TH (sim) 338.2

R_L (Ω)	V_L (V)	I_L (mA)	P_L (mW)	P theory (mW)
100	2.282	22.82	52.08	52.08
338.2	5.000	14.78	73.92	73.92
820	7.080	8.63	61.13	61.13

Fig 13. ***Excel workbook, Simulation sheet***

APPENDIX



Laboratory #7 / Thevenin equivalent circuits WORKSHEET

Name: Austin Guerrero

Name: Lesely

Signature

Signature

Honor Code

"I have neither given or received nor tolerated others use of unauthorized aid"

THIS IS A SHORT LAB WRITE-UP!!!!

Follow the Procedure in the Handout

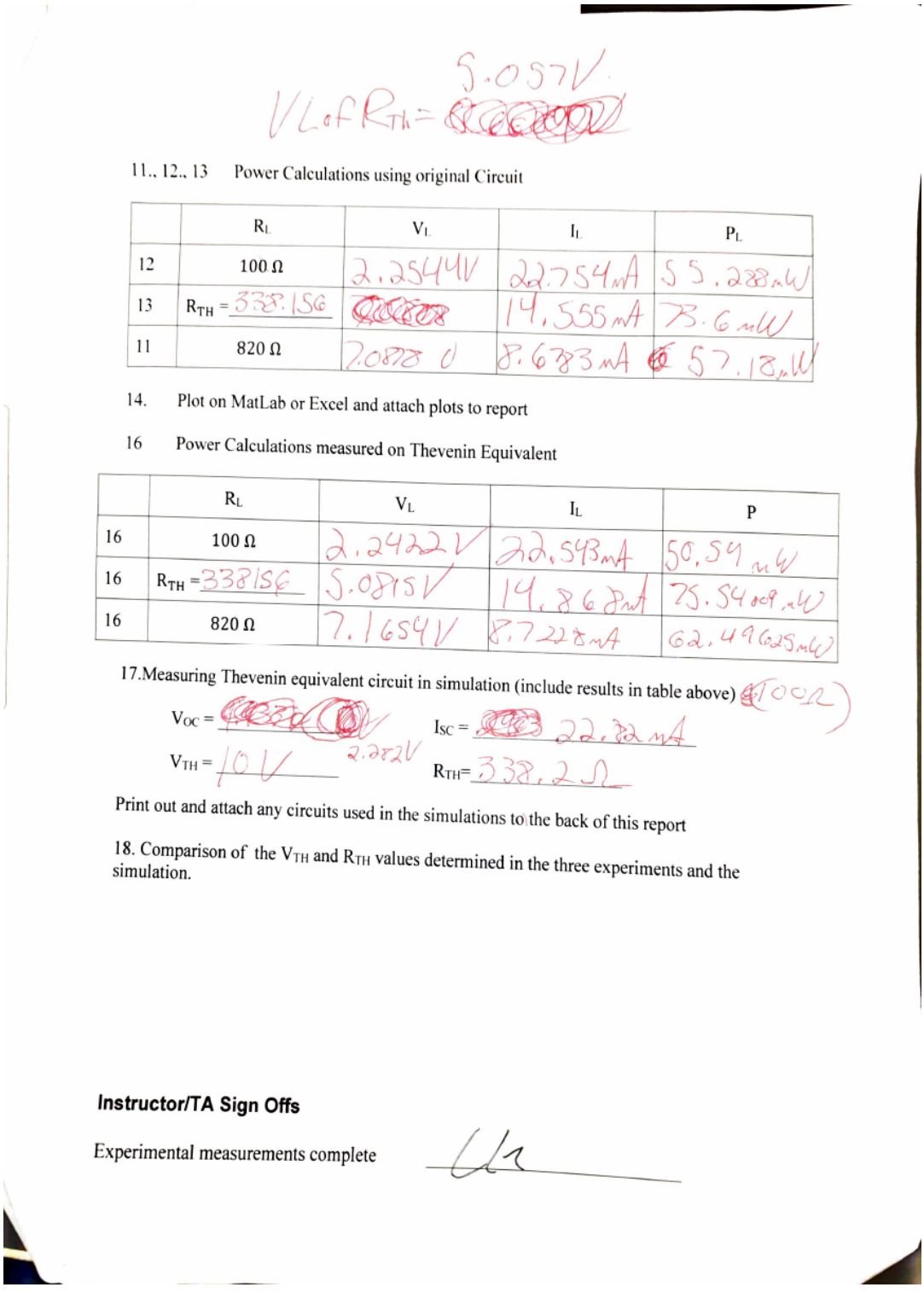
2. V_{OC} = 10.05V I_{SC} = 29.72 mA
3. V_{TH} = 10.049V R_{TH} = 338.156 Ω
5. R_{TH} = 337.2Ω
7. V_{TEST} = 10.002V $I_{measured}$ = 29.336 mA
8. R_{TH} = 340.946
9.

	V_{TH} V	R_{TH} Ω
V_{OC} and I_{SC}	10.05	338.156
Ohmmeter	10.049V	337.2
Test Voltage	10.002	340.946
Simulation	9.933V	29.03 mA

10. Draw the Thevenin equivalent circuit using circuit lab and attach a printout of circuit to the end of the report.

Fig 14. ***Signed in-lab worksheet, page 1, with names, signature, and honor code***

APPENDIX



V L of R_{TH} = 5.057V

11., 12., 13 Power Calculations using original Circuit

	R_L	V_L	I_L	P_L
12	100 Ω	2.2544V	22.754mA	51.288mW
13	R_{TH} = 338.156	[illegible]	14.555mA	73.6mW
11	820 Ω	7.0878 V	8.6383mA	57.18mW

14. Plot on MatLab or Excel and attach plots to report

16 Power Calculations measured on Thevenin Equivalent

	R_L	V_L	I_L	P
16	100 Ω	2.2422V	22.543mA	50.54mW
16	R_{TH} = 338.156	5.0815V	14.862mA	75.54009mW
16	820 Ω	7.1654V	8.7228mA	62.49625mW

17.Measuring Thevenin equivalent circuit in simulation (include results in table above) (100Ω)

V_{OC} = [illegible] 2.282V I_{SC} = 22.82mA

V_{TH} = 10V R_{TH} = 338.2Ω

Print out and attach any circuits used in the simulations to the back of this report

18. Comparison of the V_{TH} and R_{TH} values determined in the three experiments and the simulation.

Instructor/TA Sign Offs

Experimental measurements complete

Fig 15. ***Signed in-lab worksheet, page 2 with TA sign-off***