APPENDIX A

Sample Laboratory #0 Description – Resistor Properties

Objective:

To measure the resistances of standard off-the-shelf resistors to determine the resistor tolerances, to quantify the non-linear behavior of resistors, and to analyze a few simple resistive circuits.

Pre-lab preparation:

Part I – Voltage dividers

A. Design a resistive divider circuit with a divider ratio of Vin : Vout = 10:1 and an input impedance of 1 kΩ.

Part II – Resistance properties

B. Calculate the maximum value of DC voltage that can be applied to a 1 kΩ resistor that is rated for ¼ W.

Part III – Resistive pyramid

C. Consider a pyramid constructed with eight 1 kΩ resistors. Calculate the resistance along one side of the base of the resistive pyramid.

D. Use PSpice to verify your calculation from the previous pre-lab step (C).

Experimental procedure:

During this experiment, be certain that you:

- Ask the LA questions regarding any procedures about which you are uncertain.
- Turn off all power supplies any time that you make any change to the circuit.
- Arrange your circuit components neatly and in a logical order.
- Compare your breadboards with your circuit diagrams before applying power to the circuit.
- Complete the following tasks:

Part I – Voltage dividers

A. Construct the voltage divider and test its operation over a selection of DC voltages.

Part II – Resistance properties

B. Measure and record the resistances of 24 different 1 kΩ resistors.

C. Select the three resistors whose measured values are closest to 1 kΩ. Evaluate the hysterisis of the each resistor with the following procedure:

1. Connect a resistor to the power and connect digital multimeters to read the DC voltage and current.
2. Increase the voltage on the power supply in 1-2 V increments from 0 to 20 V every 30 seconds. Record the measured values at the end of 30 seconds.
3. Decrease the voltage on the power supply from 20 to 0 V every 30 seconds and record the voltage and current readings.

Part III – Resistive pyramid

D. Construct the resistive pyramid with the eight 1 kΩ resistors with the greatest deviation from the nominal value. Measure the resistance across each side of the base.

Post-lab analysis:

Generate a lab report following the sample report available in Appendix A. Mention any difficulties encountered during the lab. Describe any results that were unexpected and try to account for the origin of these results (i.e. explain what happened). In ADDITION, answer the following questions/instructions:

Part I – Voltage dividers

A. Was there any difference in the resistive divider for the various voltage signals that you applied? Why or why not?

Part II – Resistance properties

B. What was the average value and the standard deviation of all the 1 kΩ resistors?

C. Did the resistors exhibit any hysterises? If so, how and why?

Part III – Resistive pyramid

D. Are the resistances measured along the base of the pyramid consistent with the values for the resistors that you measured?

ENEE 205 Laboratory #0

Pre-Lab Report – Resistor Properties

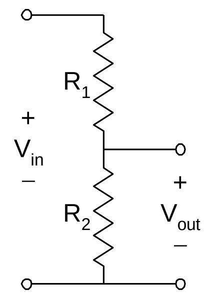
Lab date: January 12, 2020

Lab report: W. Lawson

Partner: A. Muñoz

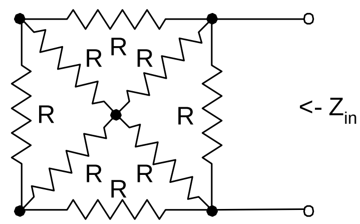
Pre-lab preparation:

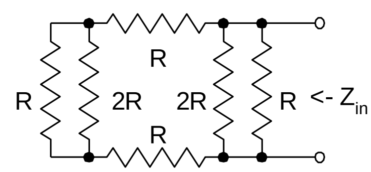
(1) *Design a resistive divider circuit with a divider ratio of Vin : Vout = 10:1 and an input impedance of 1 kΩ.* A schematic of the resistive divider is shown on the right. The input resistance is just the sum of the two resistors: $Z_{in} = R_1 + R_2$. The voltage divider rule gives: $V_{out}/V_{in} = R_2/(R_1 + R_2) = R_2/Z_{in} = R_2/1000 = 1/10$ or $R_2 = 100\,\Omega$ and hence $R_1 = 900\,\Omega$. Based on the resister values that are available for the lab, we will use a 100 Ω resistor and the series combination of a 220 Ω and a 680 Ω resistor.

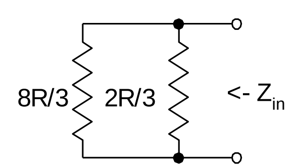


(2) *Calculate the maximum value of voltage that can be applied to a 1 kΩ resistor that is rated for ¼ W.* The power dissipated by a resistor is $P = V^2/R$. Since the maximum power is 1/4 W and the resistance is about 1 kΩ, the maximum allowable DC voltage should be $V = \sqrt{RP} = \sqrt{1000/4} \approx$ 15.81 V.

(3) *Consider a pyramid constructed with eight 1 kΩ resistors. Calculate the resistance along one side of the base of the resistive pyramid.* The pyramid circuit is shown on the right along with a number of simplified versions of the circuit. Symmetry tells us that the top of the pyramid has to be at half of the applied voltage (if we apply a voltage across the terminals indicated by Zin). Thus, the current in all 4 diagonal legs has to be the same, and we can disconnect the left diagonal pair from the right pair. This allows us to make a number of simplifications of series / parallel resistor combinations, to arrive at the final result of $Z_{in} = 8R/15$.

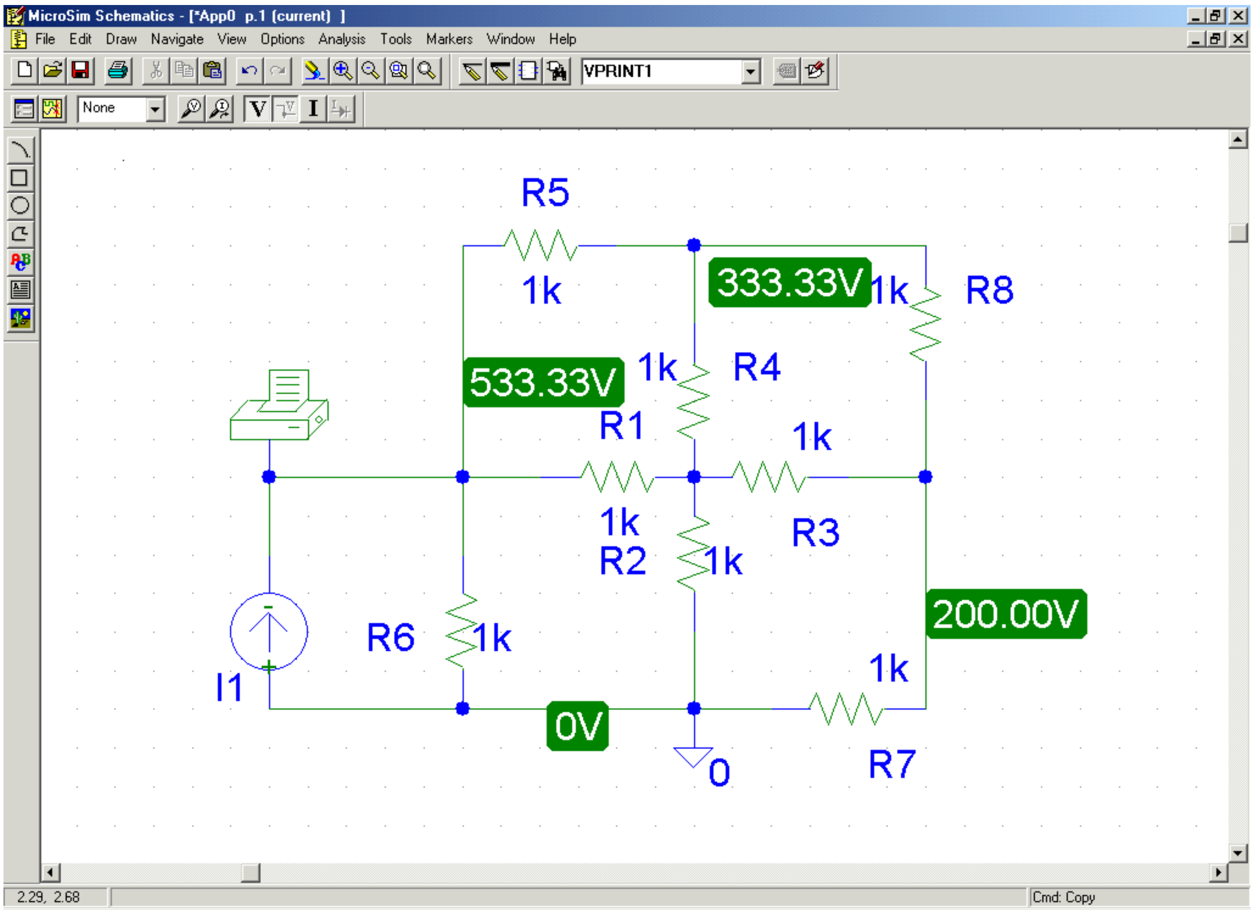






(4) *Use PSpice to verify your calculation from the previous pre-lab step (#3).*

The circuit was simulated in PSpice and the result is shown below. A DC current of I1 = 1A was injected into the node which connects R1, R5, and R6. The input impedance is the ratio of the voltage developed across this node to the input current. Theory states that the impedance should be 8 * 1000 / 15 Ω = 0.5333 kΩ, and therefore the voltage should be $V = IZ_{in}$ = 533.33 Volts, in perfect agreement with PSpice.



ENEE 205 Laboratory #0

Post-Lab Report– Resistor Properties

Lab date: January 14, 2020

Lab report: W. Lawson

Partner: A. Muñoz

Hardware:

The experiment required:

(1) variable DC power supply Elenco model #XP-666 (capable of 3A at 24V).

(2) DMM's Model # Fluke 8010A .

(1) breadboard

(24) carbon composition resistors. nominal value: 1 kΩ; tolerance: ±5%; power rating: 1/4 W.

(1) each; carbon resistors with nominal values of 100 Ω, 220 Ω, and 680 Ω.

Procedure:

Part I – Voltage dividers

(1) Used the resistance measuring capability of the DMM to measure and record the resistances of the three resistors in the divider. The results are given in Table I below.

(2) Constructed the voltage divider on the breadboard. Connected the power supply to the input of the divider and the DMM to the output of the divider.

(3) Measured the dependence of the output voltage on the input voltage for DC voltages in the range 0 – 20 V. Used meter on power supply to measure input voltage, used DMM to get output voltage. The results are given in Table II below.

Part II – Resistance properties

(4) Used the DMM to measure and record the resistances of all 24 resistors. See Table III for the results.

(5) Selected the three resistors whose values are closest to 1 kΩ.

  (a) connected each resistor across the power supply and connected one DMM in series and one DMM in parallel with the resistor as shown in Fig. A.1. Set the DMM's to read DC voltage and current, respectively.

(b) increased the voltage on the power supply in (nominally) 1 V increments from 1 to 20 V every 30 seconds.

(c) recorded the voltage and current readings on the DMM’s at the end of each 30 s period.

(d) decreased the voltage on the power supply in (nominally) 1 V increments from 20 to 1 V every 30 seconds.

(e) recorded the voltage and current readings on the DMM’s at the end of each 30 s period. the results are shown in Table IV and plotted in Fig. A.2.

Part III – Resistive pyramid

(6) Selected the eight resistors from Table III with the greatest deviation from 1 kΩ.

(7) Constructed the resistive pyramid on the breadboard with these □resistors. The configuration is shown in Fig. A.3.

(8) Measured the resistance across the four bases. The results are indicated in Fig. A.3 and listed in Table V.

Part IV – Wrap up

(9) Analyzed data and wrote report.

Experimental results:

Part I – Voltage dividers

Table I. Resistive values for the divide-by-10 voltage divider.

Nominal value (Ω)	Measured value (Ω)
100	98
220	225
680	705

Table II. Measured values of output voltage for divide-by-10.

Input voltage (V)	Output voltage (V)	Ratio input/output
2	0.195	10.26
4	0.375	10.67
6	0.573	10.47
8	0.800	10.00
10	0.994	10.06
12	1.14	10.53
14	1.31	10.69
16	1.52	10.53
18	1.68	10.71
20	1.82	10.99

Part II – Resistance properties

Table III. The nominal resistances of the 24 1 kΩ resistors:

resistor #	resistance(Ω)	resistor #	resistance(Ω)
1	1035	13	989
2	983	14	948
3	902	15	1033
4	1051	16	1064
5	921	17	1030
6	998	18	1022
7	1063	19	1019
8	1006	20	963
9	1012	21	927
10	955	22	1019
11	938	23	1102
12	1097	24	939

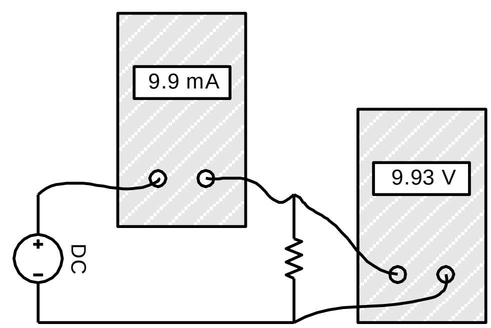


Figure A.1. Measurement Set-up

Table IV. The voltages and the currents for resistors #6, #8, and #13 for both increasing and decreasing voltage sweeps:

	Resistor # 6			Resistor # 8			Resistor # 13		
dial (V)	V (V)	I (mA)	R (kΩ)	V (V)	I (mA)	R (kΩ)	V (V)	I (mA)	R (kΩ)
1	1.015	1.017	0.998	1.002	0.996	1.006	0.957	0.968	0.989
2	1.995	1.999	0.998	1.973	1.961	1.006	2.018	2.040	0.989
3	3.039	3.043	0.999	3.082	3.062	1.007	3.084	3.116	0.990
4	4.024	4.027	0.999	3.999	3.971	1.007	4.045	4.084	0.990

	Resistor # 6			Resistor # 8			Resistor # 13		
dial (V)	V (V)	I (mA)	R (kΩ)	V (V)	I (mA)	R (kΩ)	V (V)	I (mA)	R (kΩ)
5	5.006	5.006	1.000	4.963	4.926	1.008	4.971	5.017	0.991
6	6.050	6.045	1.001	6.020	5.971	1.008	6.007	6.056	0.992
7	7.048	7.035	1.002	7.092	7.028	1.009	7.090	7.140	0.993
8	7.974	7.952	1.003	7.929	7.851	1.010	7.909	7.957	0.994
9	8.968	8.931	1.004	8.939	8.842	1.011	8.922	8.963	0.995
10	9.985	9.930	1.006	9.948	9.827	1.012	9.917	9.948	0.997
11	10.982	10.904	1.007	10.954	10.807	1.014	10.910	10.926	0.999
12	12.015	11.908	1.009	11.965	11.787	1.015	11.951	11.946	1.000
13	13.012	12.872	1.011	13.017	12.803	1.017	13.034	13.000	1.003
14	14.025	13.846	1.013	14.063	13.806	1.019	14.092	14.023	1.005
15	14.972	14.750	1.015	15.015	14.715	1.020	14.999	14.892	1.007
16	16.033	15.756	1.018	16.055	15.702	1.022	16.043	15.887	1.010
17	16.974	16.641	1.020	16.977	16.572	1.024	17.005	16.796	1.012
18	18.025	17.621	1.023	18.037	17.565	1.027	18.085	17.807	1.016
19	19.013	18.534	1.026	19.049	18.506	1.029	19.017	18.672	1.018
20	20.034	19.469	1.029	20.047	19.427	1.032	20.066	19.635	1.022
19	18.963	18.429	1.029	18.999	18.422	1.031	18.973	18.565	1.022
18	17.998	17.493	1.029	18.013	17.471	1.031	18.032	17.647	1.022
17	17.010	16.535	1.029	17.023	16.516	1.031	17.062	16.702	1.022
16	15.962	15.518	1.029	15.980	15.510	1.030	15.988	15.657	1.021
15	15.031	14.616	1.028	15.007	14.573	1.030	15.036	14.731	1.021
14	14.034	13.651	1.028	14.054	13.654	1.029	14.055	13.777	1.020
13	12.977	12.626	1.028	13.006	12.642	1.029	13.047	12.797	1.020
12	12.030	11.709	1.027	12.018	11.688	1.028	11.987	11.767	1.019
11	11.022	10.733	1.027	11.062	10.766	1.028	11.073	10.878	1.018
10	10.025	9.767	1.026	10.064	9.802	1.027	10.098	9.929	1.017
9	8.999	8.772	1.026	9.001	8.773	1.026	9.001	8.861	1.016
8	8.031	7.832	1.025	8.032	7.835	1.025	8.078	7.960	1.015
7	6.980	6.812	1.025	6.991	6.825	1.024	6.988	6.895	1.013
6	6.040	5.899	1.024	6.075	5.936	1.023	6.081	6.008	1.012
5	4.971	4.859	1.023	4.923	4.816	1.022	4.949	4.898	1.011
4	4.025	3.936	1.022	4.040	3.956	1.021	4.074	4.037	1.009
3	3.027	2.963	1.022	3.042	2.981	1.020	3.026	3.003	1.007
2	1.983	1.943	1.021	1.992	1.955	1.019	1.967	1.956	1.006
1	1.017	0.997	1.020	1.024	1.006	1.018	1.070	1.066	1.004

Table V. Measured resistances of the pyramid bases.

Side	Resistance (Ω)
1	508
2	549
3	543
4	498

Post-Lab Questions:

Part I – Voltage dividers

(A) The voltage divider ratio varied from 10.00 to 10.99. the average value was 10.49 and the standard deviation is 0.31. From the resistance measurements the value should be 10.49, which is in good agreement with the average measurement. We think that the main source of error is the measurement of the input voltage. The meter on the power supply was not adequate to make accurate measurements. In retrospect, another DMM should have been used. The 680 Ω resistor got warm at the larger voltages. this undoubtedly gave rise to the increased ratio near 20 V, but with the crude measurement scheme it wasn't possible to quantify this idea.

Part II – Resistance properties

(B) The average value of the resistance according to the DMM was 1.001 kΩ and the standard deviation was 55 Ω. This is essentially within the tolerance of the resistors.

(C) The resistance of the 3 resistors is plotted in Fig. A.2. The impedance always increases with increasing voltage and also exhibits a hysteresis effect, so that the resistance is not a unique function of voltage. The net change in resistance was always less than 3 %. This change is no doubt due to the dependence of resistance on temperature. In fact, the resistors got quite hot to the touch (no thermocouples / temperature probes were available to quantify the change).

Part III – Resistive pyramid

(D) The measured values of the input impedances are consistent with the actual resistances. The way we verified this was to insert the actual resistances into PSpice and to use the code to calculate the impedances. The results from the simulations are listed below the measured values in Fig. A.3. The error is always less than ½% and the difference is no doubt due to the measurement uncertainties.

Discussion and Conclusions

(E) After we finished the nonlinear resistance tests, we went back and checked the resistance of #6 with the DMM. It had nearly returned to its original value, indicating that no permanent damage was done.

(F) During the nonlinear test, one of the resistors was inadvertently subjected to 24 V for a short period of time and began to smoke, indicating that it is not a good idea to exceed the power rating of circuit components.

(G) In Part III, we inadvertently overlooked the 1102 Ω resistor. This had no effect on the results of the experiment; it only represents a small deviation from the instructions.

(H) The meters on power supplies are only useful for rough voltage settings; more accurate multimeters should be used when the precise value of voltage is important.

(I) If the value of a resistor is critical to a circuit, it should be hand-selected. It would be much better to design circuits which are not sensitive to the exact value (within the tolerances of the resistors).

(J) The resistance values change slightly well before the power rating is reached on a resistor. If a resistance value is critical to a circuit, the power rating of the resistor should be very conservative or some sort of cooling (fan, heat sink, etc.) should be supplied.

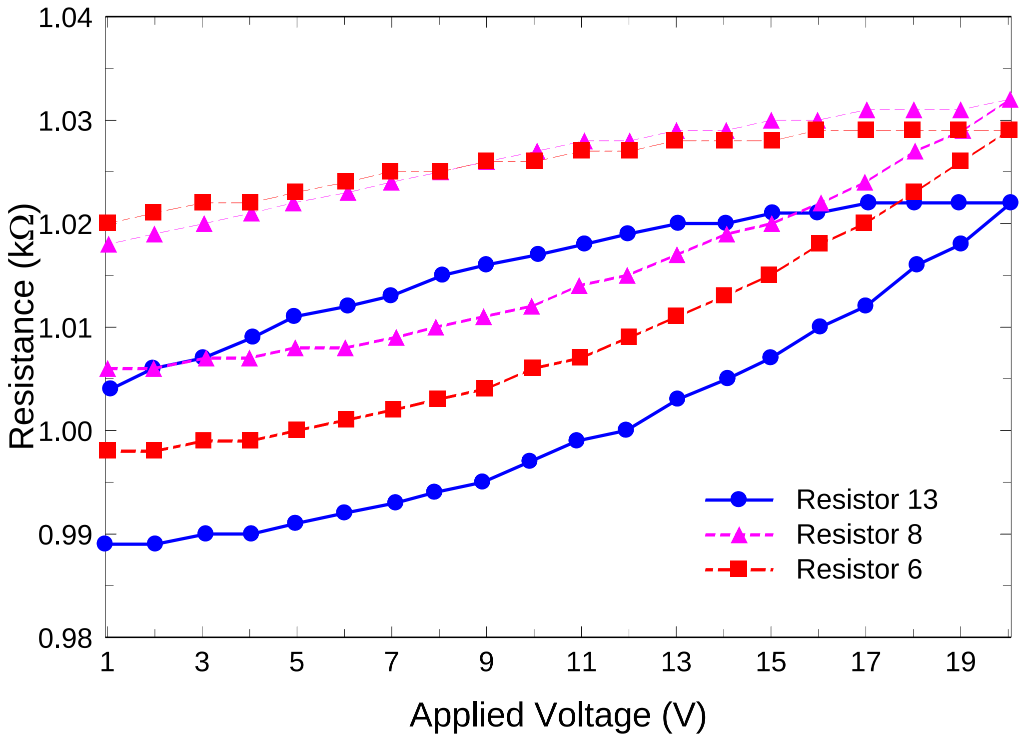


Figure A.2. The dependence of resistance on applied voltage for Resistors #6, #8, and #13. The lower branch of each curve occurs when the voltage is being increased and the upper branch occurs when the voltage is being decreased.

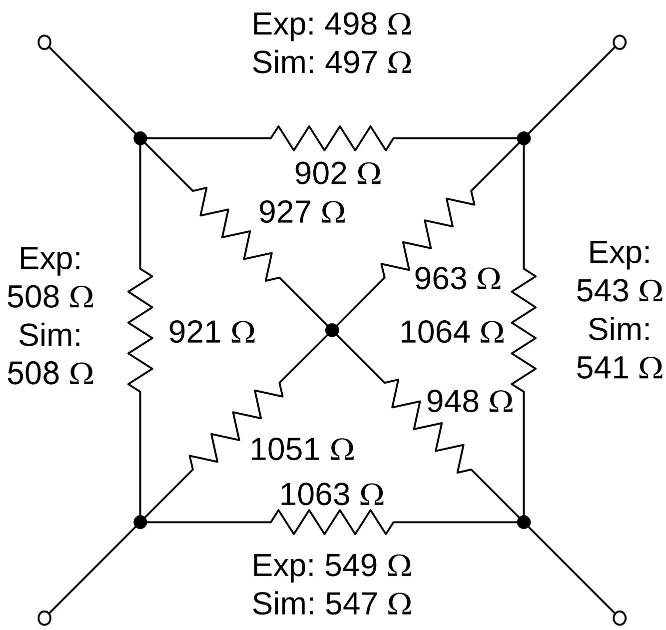


Figure A.3. Results of the resistive pyramid test and the corresponding PSpice simulations.