PROBLEMS ENCOUNTERED

The only problem I encountered during this pre-lab was how to properly set up the circuits which was solved by watching a tutorial video on how to rotate components and introduce SPICE directives into the circuit.

INTRODUCTION

This lab explored the use of LTspice to analyze various circuits and investigates the effects of voltage division, o-scope resistances, and resistor tolerances on circuit behavior. The primary objective of this lab was to model resistor networks using DC operating point simulations to observe the node voltages and understand how changes in circuits impact electrical performance. One of the key concepts that was explored was the loading effect which is how o-scopes input resistance alters the expected output voltage. Additionally, this lab explored Monte Carlo Simulations to model real-world resistor tolerances which demonstrated how this can also affect node voltages across various trials.

DISCUSSION

3.4 Pre-lab First Section

This section has us installing LTspice and generating node voltages for various circuit combinations. The main goal of this is to familiarize ourselves with LT spice and understand how o-scopes and tolerances can affect results. I used larger significant figure values for this due to a large amount of the voltages only fluctuating by the thousandths or ten-thousandth place.

3.4.1 Modeling Simple Circuits

Nodes	Node voltage w/o 1 MΩ resistor	Node voltage w/ 1 MΩ resistor at node A	Node voltage w/ 1 MΩ resistor at node B	Node voltage w/ 1 MΩ resistor at node C	Node voltage w/ 1 MΩ resistor at node D
A	4.40355 V	4.3854 V	4.3944 V	4.40031 V	4.40322 V
B	3.13452 V	3.1216 V	3.1059 V	3.12438 V	3.13348 V
C	1.86548 V	1.85779 V	1.84845 V	1.84845 V	1.86373 V
D	0.596447 V	0.593988 V	0.591 V	0.591 V	0.593988 V

***Table 1**: Node voltages for each circuit in Figures 1 through 5.*

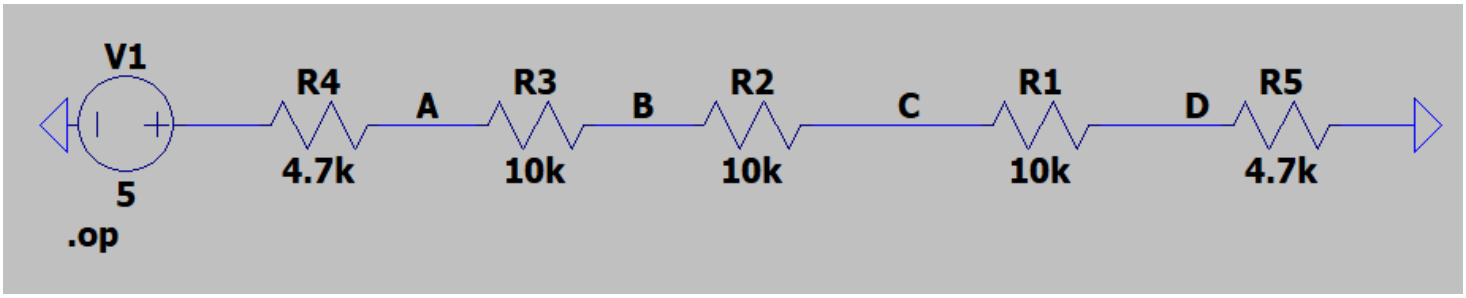


***Figure 1**: Resistor ladder example*

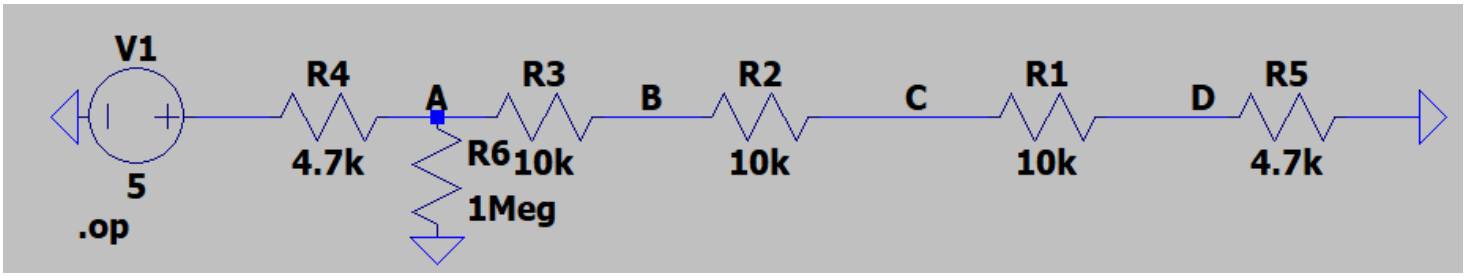


***Figure 2**: Resistor ladder w/1 MΩ resistor at node A*

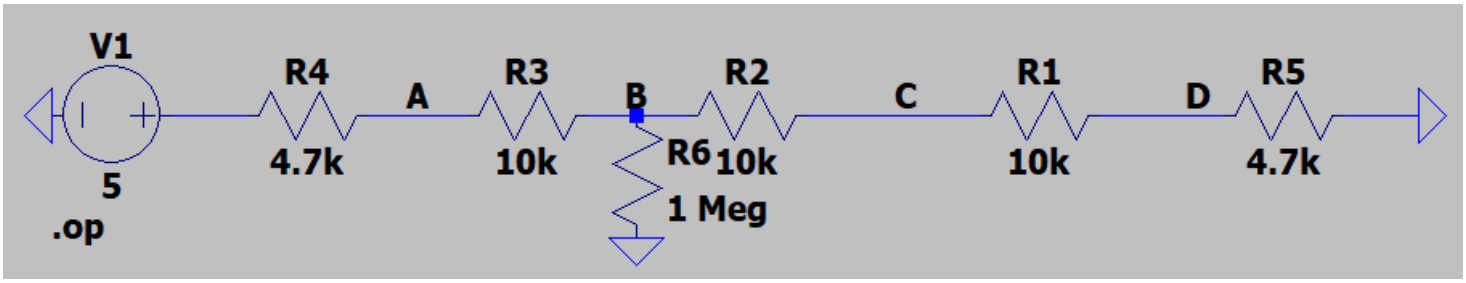


***Figure 3**: Resistor ladder w/1 MΩ resistor at node B*

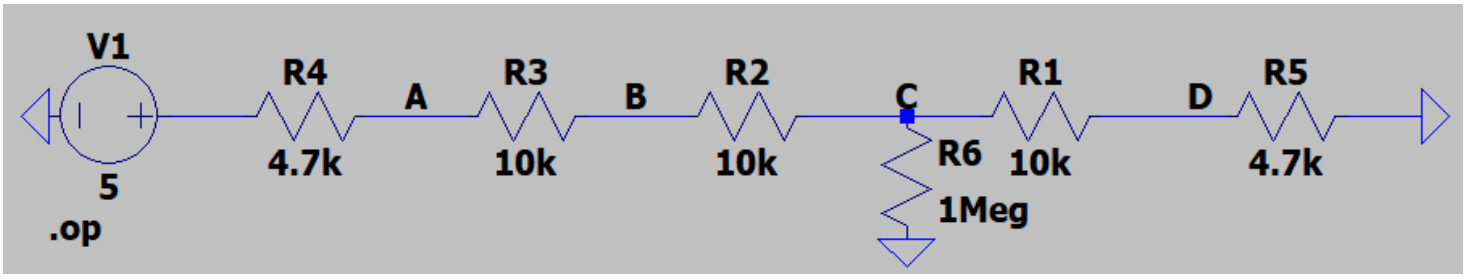


***Figure 4**: Resistor ladder w/1 MΩ resistor at node C*

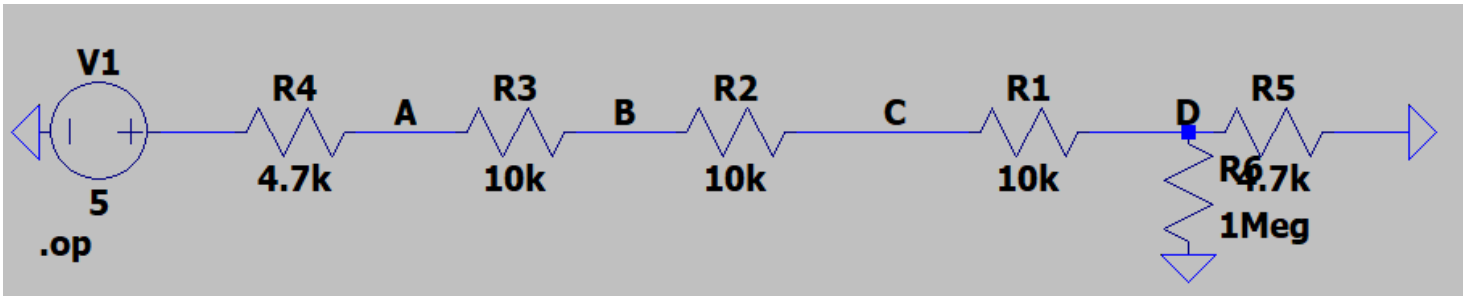


***Figure 5**: Resistor ladder w/1 MΩ resistor at node D*

3.4.2 LTspice Variables

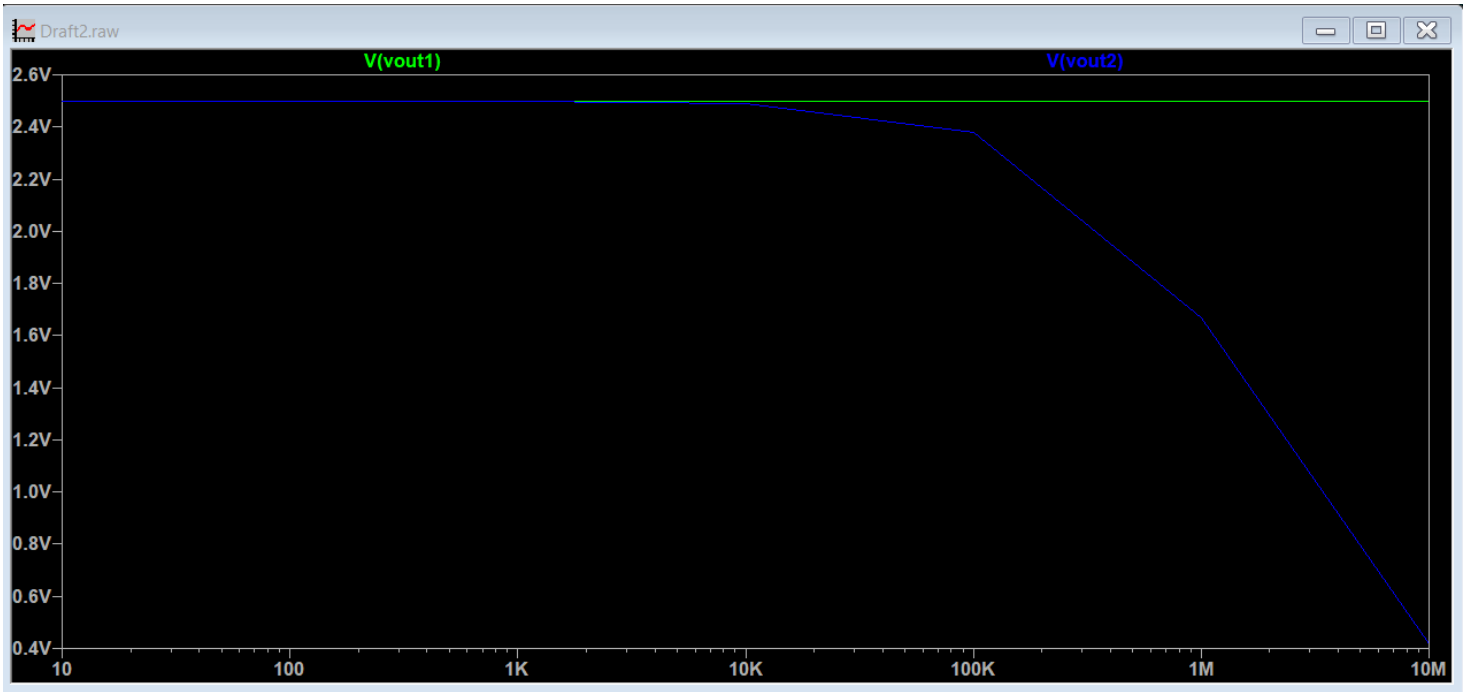


***Figure 6**: Outputted graph from applying a step of 10, 100, 1k, 10k, 100k, 1Meg, & 10Meg Ohm to the circuits shown in Figure 7*

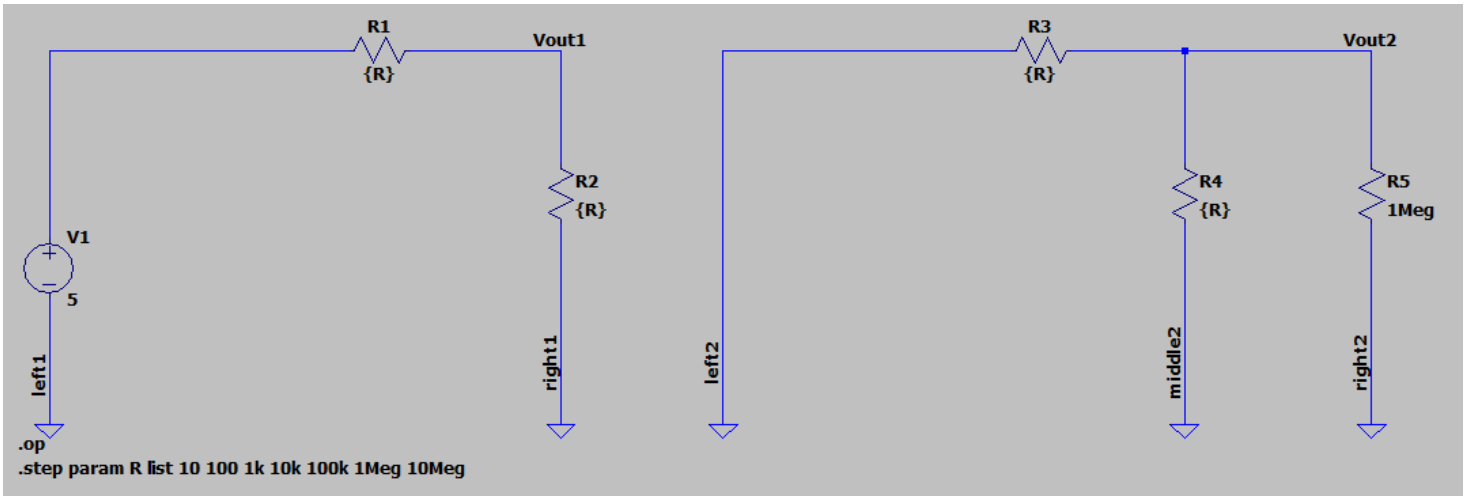


***Figure 7**: 2 Circuits simulating with a spice directive to plot voltage differences with and without a hypothetical o-scope probe.*

3.4.3 Monte Carlo Simulations

Node	Vmax	Vmin
A	4.4476211389 V	4.36215305328 V
B	3.22821354866 V	3.03787326813 V
C	1.95770704746 V	1.77942121029 V
D	0.637887060642 V	0.553106427193 V

***Table 2**: Maximum and minimum voltage values of Nodes A through D in the circuit shown in Figure 9.*

```
vamax: MAX(V(A))=4.44762611389 FROM 1 TO 1000
vamin: MIN(V(A))=4.36215305328 FROM 1 TO 1000
vbmax: MAX(V(B))=3.22821354866 FROM 1 TO 1000
vbmin: MIN(V(B))=3.03787326813 FROM 1 TO 1000
vcmax: MAX(V(C))=1.95770704746 FROM 1 TO 1000
vcmin: MIN(V(C))=1.77942121029 FROM 1 TO 1000
vdmax: MAX(V(D))=0.637887060642 FROM 1 TO 1000
vdmin: MIN(V(D))=0.553106427193 FROM 1 TO 1000
```

***Figure 8**: Outputted max and min voltages from each node. Derived from the circuit in Figure 9.*

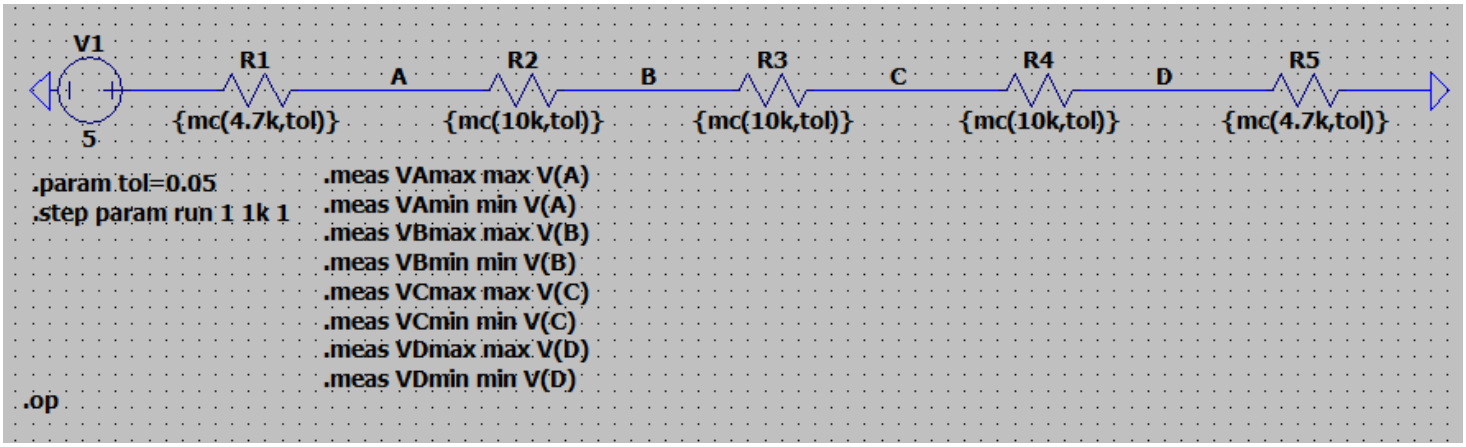


***Figure 9**: Simple ladder resistor circuit with varied resistances used to show how voltages can fluctuate due to resistor tolerances.*

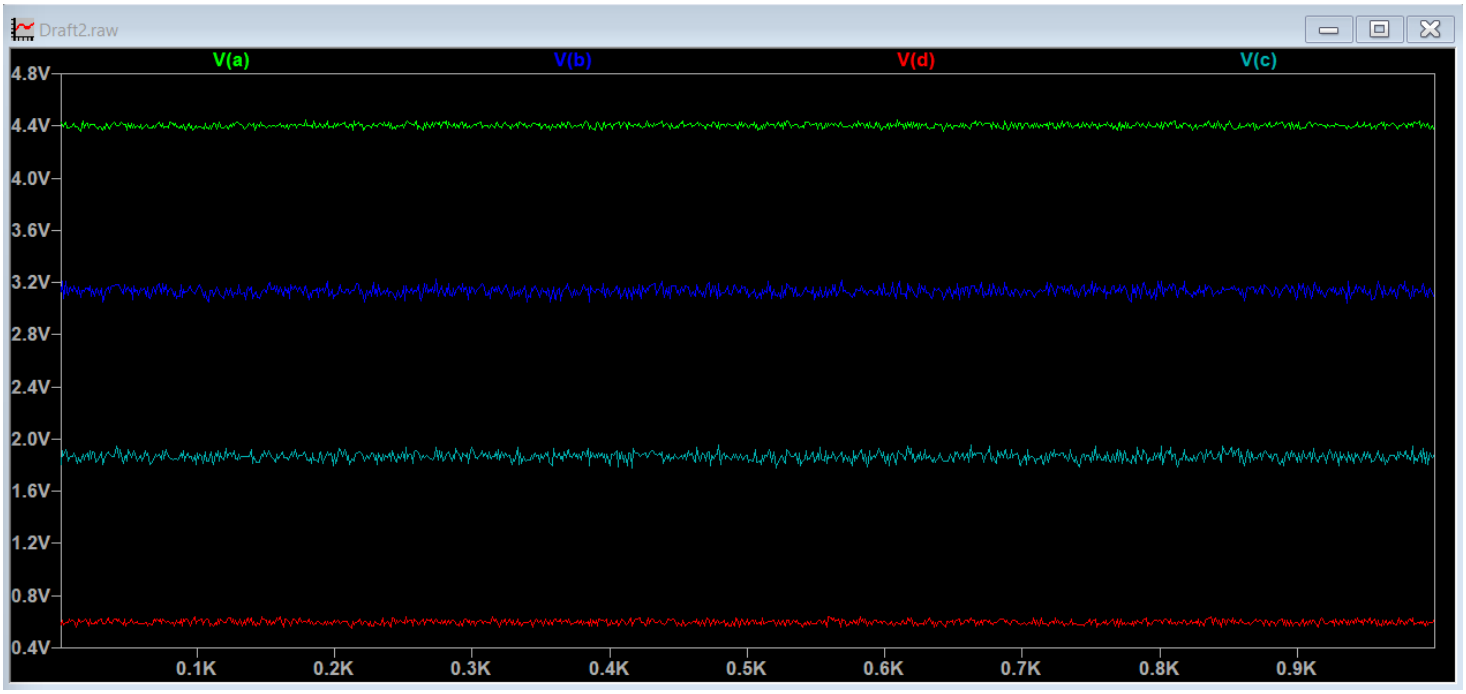


***Figure 10**: Outputted graph from running a .op of Figure 9.*

3.5 In-lab

3.5.1 Equivalent Resistance

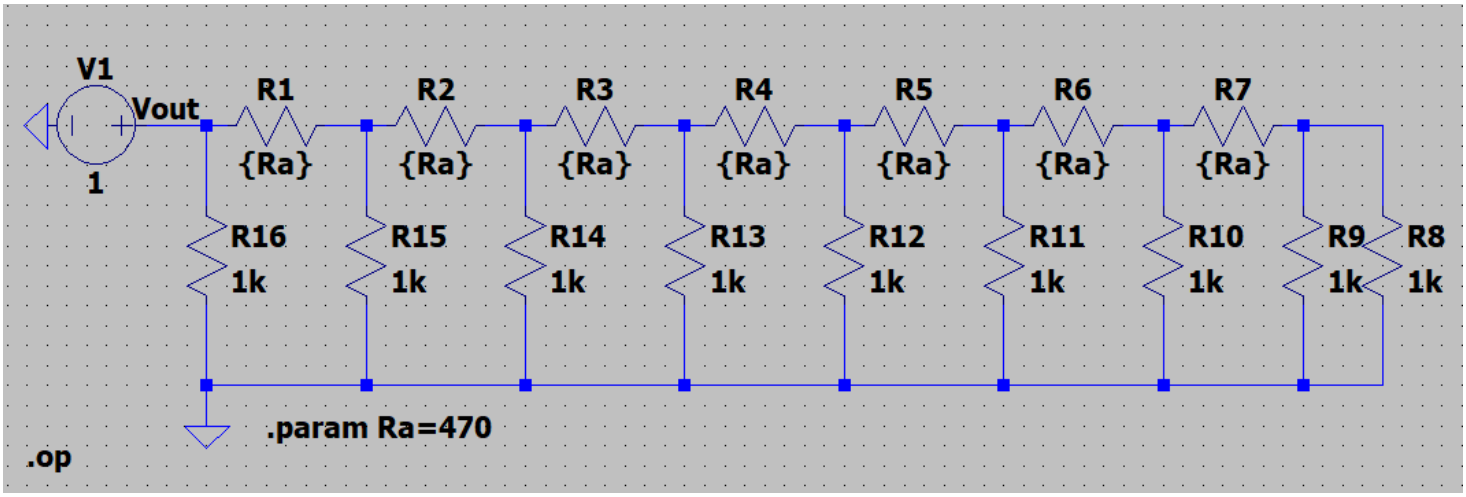


***Figure 11**: Equivalent resistor circuit for subsequent calculations of equivalent resistance value.*

```
--- Operating Point ---

V(n001):        0.510278        voltage
V(n002):        0.260386        voltage
V(n003):        0.132875        voltage
V(n004):        0.067815        voltage
V(n005):        0.0346283       voltage
V(n006):        0.0177169       voltage
V(n007):        0.00913241      voltage
V(vout):        1               voltage
I(R1):          -0.00104196     device_current
I(R10):         1.77169e-05     device_current
I(R11):         3.46283e-05     device_current
I(R12):         6.7815e-05      device_current
I(R13):         0.000132875     device_current
I(R14):         0.000260386     device_current
I(R15):         0.000510278     device_current
I(R16):         0.001           device_current
I(R2):          -0.000531685    device_current
I(R3):          -0.0002713      device_current
I(R4):          -0.000138425    device_current
I(R5):          -7.061e-05      device_current
I(R6):          -3.59817e-05    device_current
I(R7):          -1.82648e-05    device_current
I(R8):          9.13241e-06     device_current
I(R9):          9.13241e-06     device_current
I(V1):          -0.00204196     device_current
```

***Figure 12**: Outputted information for the above circuit in Figure 11.*

Req = (Vtest) / (-Is)

= (1) / (-0.00204196)

= 489.73 Ω

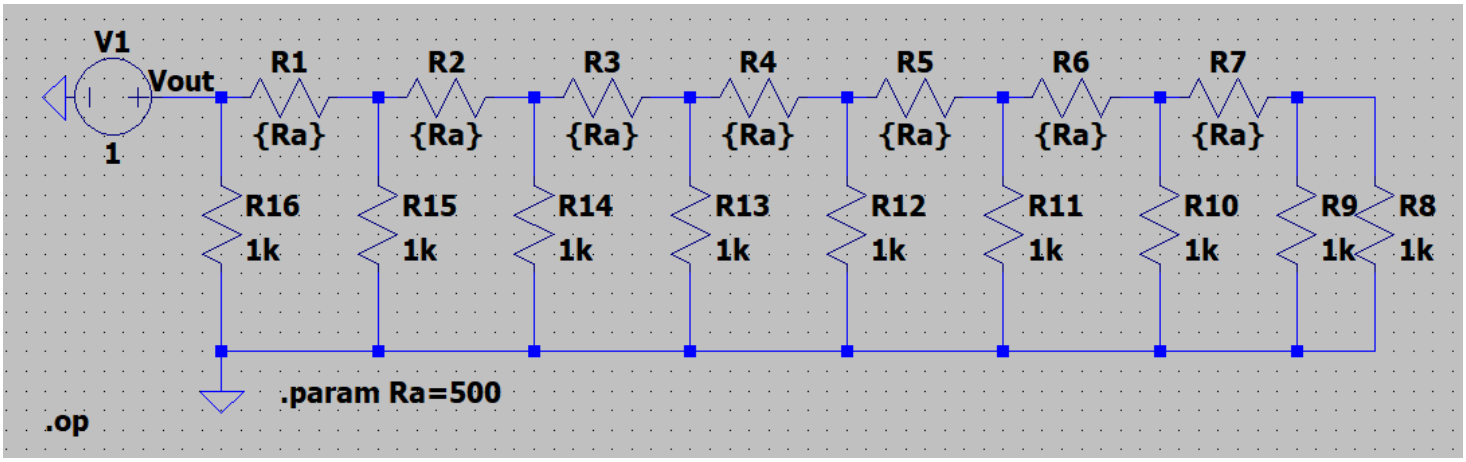


***Figure 13**: Equivalent resistor circuit for subsequent calculations of equivalent resistance values.*

```
--- Operating Point ---

V(n001):        0.5             voltage
V(n002):        0.25            voltage
V(n003):        0.125           voltage
V(n004):        0.0625          voltage
V(n005):        0.03125         voltage
V(n006):        0.015625        voltage
V(n007):        0.0078125       voltage
V(vout):        1               voltage
I(R1):          -0.001          device_current
I(R10):         1.5625e-05      device_current
I(R11):         3.125e-05       device_current
I(R12):         6.25e-05        device_current
I(R13):         0.000125        device_current
I(R14):         0.00025         device_current
I(R15):         0.0005          device_current
I(R16):         0.001           device_current
I(R2):          -0.0005         device_current
I(R3):          -0.00025        device_current
I(R4):          -0.000125       device_current
I(R5):          -6.25e-05       device_current
I(R6):          -3.125e-05      device_current
I(R7):          -1.5625e-05     device_current
I(R8):          7.8125e-06      device_current
I(R9):          7.8125e-06      device_current
I(V1):          -0.002          device_current
```

***Figure 14**: Outputted information for the above circuit in Figure 13.*

$$Req = (Vtest) / (-Is)$$

$$= (1) / (-0.002)$$

$$= \mathbf{500\ \Omega}$$

3.5.2 Monte Carlo with Different Tolerances

	1%	0.05%	0.005%
A max	4.41256856918	4.40400648117	4.4035987854
A min	4.39540100098	4.40314722061	4.40351247787
B max	3.15334844589	3.1546037674	3.13461208344
B min	3.11527466774	3.13355660439	3.13442158699
C max	1.88380551338	1.8663970232	1.86557364464
C min	1.84826350212	1.86462128162	1.86539614201
D max	0.60458368063	0.596851766109	0.596487224102
D min	0.587578773499	0.596000850201	0.596402108669

***Table 3**: Maximum and minimum voltage values of Nodes A through D in the circuit shown in Figure 9 with multiple tolerances.*

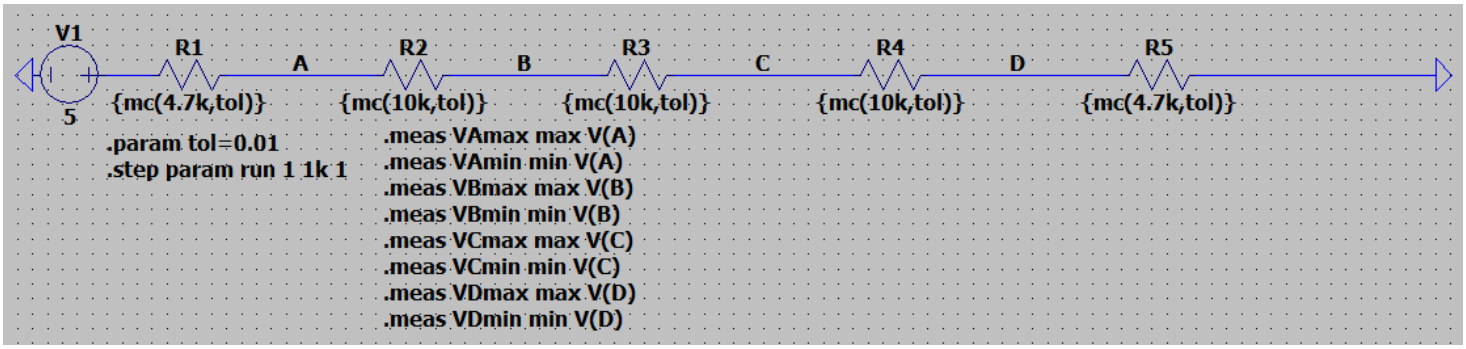


***Figure 15**: Simple circuit used to measure voltages at different nodes based on various tolerances*



***Figure 16**: Figure 15 set to 1% tolerance.*



***Figure 17**: Figure 15 set to 0.05% tolerance.*



***Figure 18**:Figure 15 set to 0.005% tolerance.*

3.5.3 Resistor Costs

Tolerance	Price Per 500Ω (7 tot)	Price per 1kΩ (9 tot)	Total
1%	$0.10	$0.10	$1.60
0.1%	$1.55	$0.70	$17.15
0.05%	$21.62	$18.83	$320.81

***Table 4**: Calculations for the total resistor costs of varied tolerances sourced from DigiKey and Mouser.*

Discussion Question: Resistor variations in the R-2R ladder causes the circuits currents and voltages to change based upon the resistance values used. Along with this, tighter tolerances do allow for much more accurate values for currents and voltages, however, can be significantly more expensive. When buying components, the most important considerations are the tolerances and associated costs but other important ones are the manufacturer, especially considering their reliability and track record along with the quantity provided to make a cost-benefit analysis.

CONCLUSION

In this lab we primarily worked on the basics of LTspice with simple circuits. These labs focused on analyzing the impacts that various things have on the circuit's currents and voltages which included tolerances, resistor values, o-scope internal resistances, and multiple trials. All of these labs were utilized to demonstrate the impacts that these have and show us the various sections of LTspice.