

Experiment 6

Real-World Considerations

OBJECTIVE

The objective of this experiment is to use SPICE to investigate and illustrate some of the concerns encountered when using real, versus ideal, components in some simple circuits.

What will you need?

EQUIPMENT

1 – Laptop Computer
with LTspice

INTRODUCTION

This experiment will involve two types of resistor ladder networks that are commonly used in digital to analog conversion:

1. A resistor string ladder, which is really nothing more than a voltage divider as shown in Figure 6.1, and

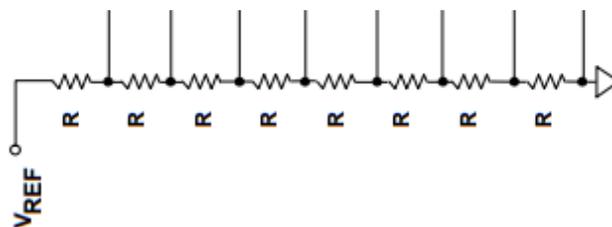


Figure 6.1. An 8-bit string ladder

2. An $R-2R$ ladder as shown in Figure 6.2.

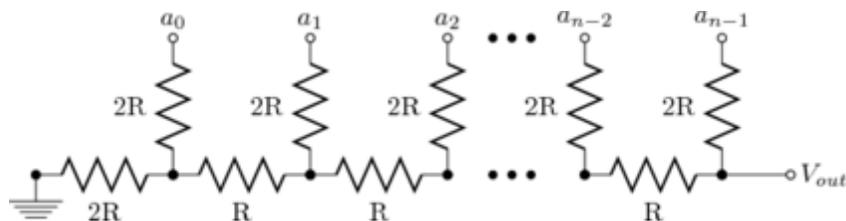


Figure 6.2. An n -bit $R-2R$ resistor ladder.

PRELIMINARY EXERCISES

Before coming to the lab, work the following problems. You may not begin the experimental procedure until these problems have been correctly solved and approved by your laboratory TA.

The Preliminary Exercises involve a 4-bit resistor string ladder.

Exercise 6.1. Loading Effect

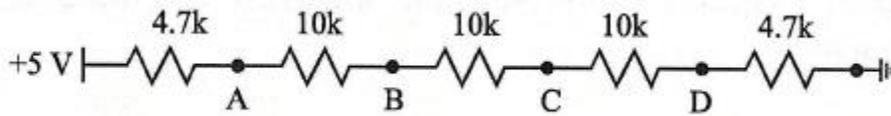


Figure 6.3: A 4-bit resistor string ladder.

- a. Using LTspice, build the circuit in Figure 6.3 and run a DC operating point simulation to determine the voltages at nodes A, B, C and D. Enter those node voltages in the “No load” column of Table 1.

Table 1. Resistor Ladder Node Voltages (from LTspice simulation)

	No load	With 1 MΩ load at node A	With 1 MΩ load at node B	With 1 MΩ load at node C	With 1 MΩ load at node D
V_A					
V_B					
V_C					
V_D					

- b. When physically measuring the node voltages for an actual *hardware* resistor ladder circuit in the lab, an oscilloscope or DMM would be used. The instrument used, together with its probes, is not ideal and presents a finite input resistance of, say, 1 MΩ (a typical value).
- i. Rerun the simulation to determine the four node voltages when a 1 MΩ resistor load is connected to node A, as shown in Figure 6.4 (a). Enter the results in Table 1.

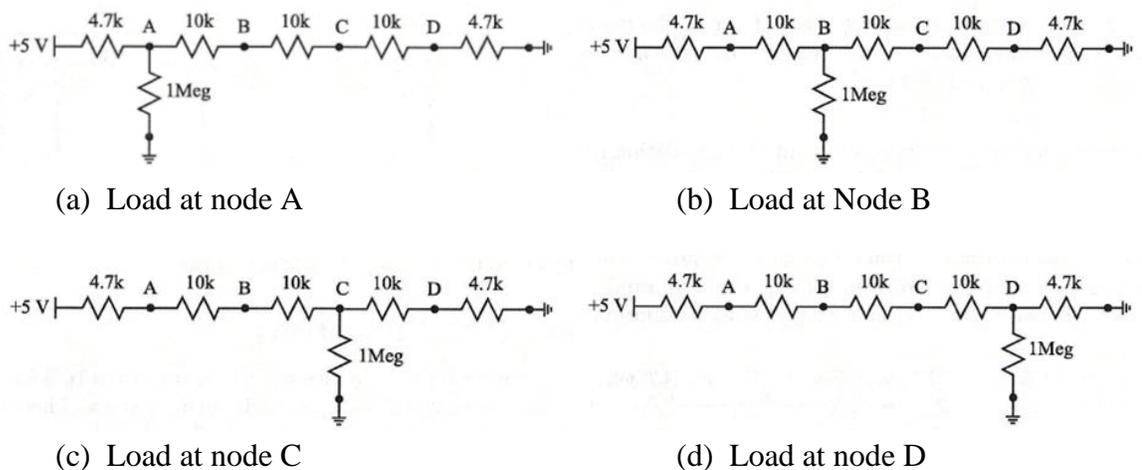


Figure 6.4: Resistor string ladder with a 1 MΩ resistor load attached at one of the nodes A through D in each diagram.

- ii. Repeat with the load connected sequentially to nodes B, C and D, as shown in Figures 6.4 (b) through (d). When you're done, there should be a total of five simulations with values determined for each of the four node voltages, V_A through V_D , for each simulation.
- iii. Explain any differences you see in the results.

Exercise 6.2. Loading Effect (Again)

There is clearly an effect caused by the finite input resistance of the measurement device. Using LTspice, let us attempt to quantify the effect as a function of resistance.

- a. Build the two voltage-divider circuits in Figure 6.5 in LTspice on the same schematic page. Note that the resistor values are a variable {R}, the source voltage is 5 V DC and each output node is labeled.
- b. Use the following SPICE directive in conjunction with a DC operating point simulation to sweep the resistors in both circuits.

```
.step param R list 10 100 1k 10k 100k 1Meg 10Meg
```

- c. Plot the voltages at V_{out1} and V_{out2} with a *logarithmic* x-axis. Save your circuits and the simulation results into a Word document, and submit this document as part of your pre-lab work.

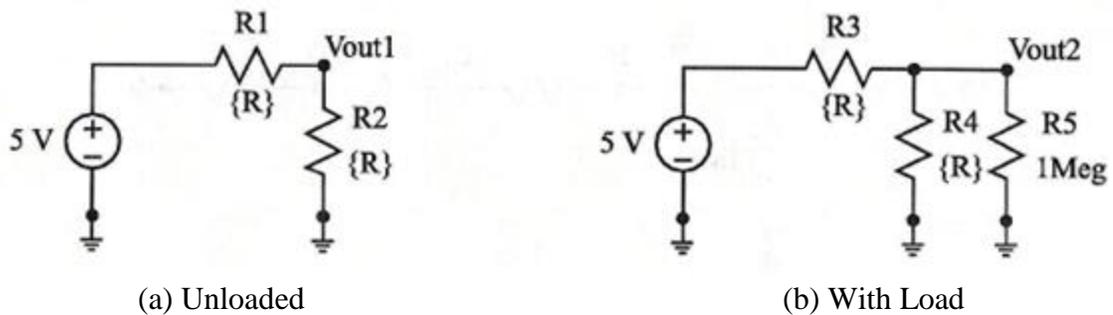


Figure 6.5: Circuits to test the loading effect of a measuring instrument having a $1\text{M}\Omega$ input resistance.

Exercise 6.3. Resistor Tolerance Effect

Resistors have tolerances for their values which can vary from 10% for generic through-hole resistors to as low as 0.005% for laser trimmed resistors. It is highly unlikely that you will *ever* encounter a resistor has a resistance *exactly* equal to its labeled value.

LTspice has a Monte Carlo function, $\{\text{mc}\{x,y\}\}$, that will generate uniformly-distributed random numbers, z , such that $x \times (1 - y) \leq z \leq x \times (1 + y)$. For example, $\{\text{mc}\{5,0.1\}\}$ will generate z values such that $5 \times (1 - 0.1) \leq z \leq 5 \times (1 + 0.1)$ or $4.5 \leq z \leq 5.5$.

- a. Construct the circuit shown in Figure 6.6, setting the resistor values to call the mc function as shown.

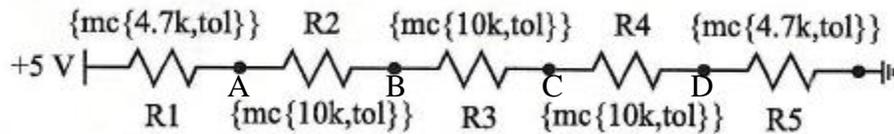


Figure 6.6: Resistor ladder with the resistor values assigned by the LTspice Monte Carlo function.

- b. Use the following SPICE directive in conjunction with a DC operating point analysis to randomize all the resistor values for 1000 trials.

```
.param tol=0.05          ←(tolerance = ± 5%)
.step param run 1 1k 1   ←(1000 separate runs)
```

- c. Plot all of the node voltages, A-D, on separate plot planes to view how the voltage at each node varies for each trial. Tabulate the voltage ranges for each node.
- d. Save your circuit and the simulation results into a Word document to be submitted as part of your pre-lab work.

PROCEDURE

Exercise 6.4. Inexact Values Effect on Equivalent Resistance

The equivalent resistance for an $R-2R$ ladder with all the digital bits tied to ground is R . (See Appendix T.) However, it is not always possible to obtain the resistor values desired for a particular design. Suppose, for example that you design an $R-2R$ ladder intending to use 500Ω and $1k\Omega$ resistors, but then you discover that 500Ω resistors are not available – in fact, they aren't even a standard value! (See Appendix D.) The nearest value you can get is 470Ω , so your actual circuit will look like the one in Figure 6.7. Calculating the equivalent resistance of that circuit is *not* trivial.

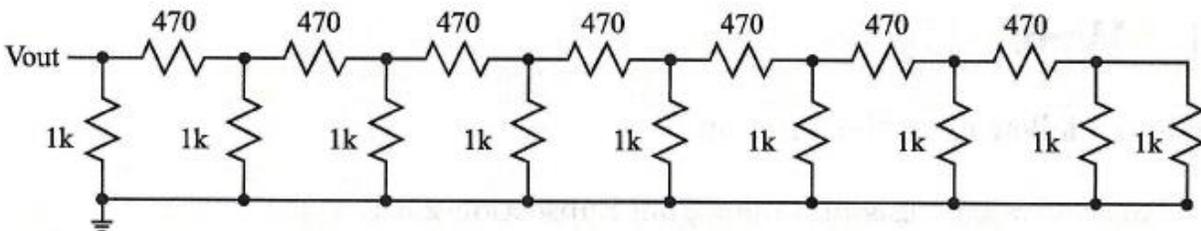


Figure 6.7: An 8-bit $R-2R$ ladder with all of the digital bits tied to ground.

1. Construct the 8-bit $R-2R$ ladder of Figure 6.7 in LTspice. Using a 1 V or 1 A test source (your choice) connected at the V_{out} node, run a DC operating point simulation and determine the equivalent resistance. ($1V \Rightarrow R=1/I$ or $1A \Rightarrow R=V$). Save the result.
2. Change the 470Ω resistors to 500Ω resistors, redo the simulation, and confirm that the ideal equivalent resistance is 500Ω .

Exercise 6.5. Resistor Tolerance Effect (Again)

Repeat the Monte Carlo simulations from Preliminary Exercise 6.3 using the tolerances listed in Table 2. Tabulate the voltage ranges at each node.

Table 2. Voltage Range with Different Resistor Tolerances

Resistor Tolerance	V_A		V_B		V_C		V_D	
	Min.	Max.	Min.	Max.	Min.	Max.	Min.	Max.
5 %								
1 %								
0.1 %								
0.05 %								
0.01 %								
0.005 %								

Exercise 6.6. Resistor Cost

Of course, having a tight resistor tolerance is naturally desirable, but an often-overlooked problem is the associated cost. Use the Digikey online catalog (<https://tinyurl.com/mb9hvs9>) to find the maximum and minimum unit cost for through-hole resistors having the tolerances listed in Table 3, and complete the table.

Table 3. Unit Cost Range for Through-Hole Resistors

Tolerance	Maximum Unit Cost	Minimum Unit Cost
5 %		
1 %		
0.1 %		
0.05 %		
0.01 %		
0.005 %		

REPORT

Include all circuit diagrams, simulation results, and any conclusions you can draw.

Be sure to discuss the effect of resistor variation on the resistor ladder and its associated node voltages, and the advisability/cost of using resistors with a narrow tolerance.

Please feel free to make suggestions for improvement of this document and/or the experiment it describes.