Introduction to Microcircuits
Lab 1: Resistors and Resistive Networks

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Abstract

In this lab we characterized simple resistor circuits using an SMU. We learned to sweep voltage and current with the SMU and measure resulting voltage/current. In order to use the SMU for these purposes, we created some code that can be found at https://github.com/bringsyrup/CircuitsLabs/tree/master/lab1. We also borrowed some code from Thomas Nattested (found at https://github.com/dimitdim/ElectronAdventures/blob/master/lab1/experiment4.py)

1 Experiment 1: Resistance Measurement

1.1 Experimental Setup

For this experiment, we chose a resistor with a nominal resistance of 280Ω. The resistor was measured with the Keithley sourcemeter, and then was measured with a probe as a -5 to +5 voltage was swept across it.

1.2 Results

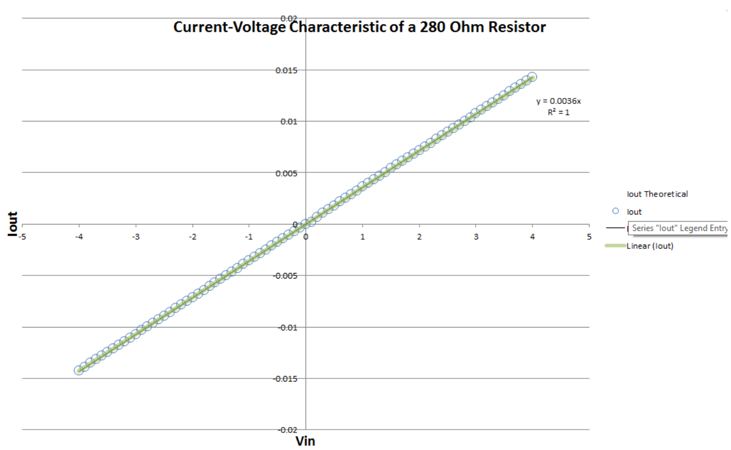

Figure 1: The IV characteristic for a nominal 280Ω resistor.

The Keithley sourcementer produced a measurement of 279.9Ω. The 50 point sweep using the SMU produced data as shown in figure . A trendline was fitted to this figure, with a slope of 0.0036 and an R^2 of 1.
The resistance value we measured with the Keithley sourcemeter was only .1Ω less than the nominal value. The following calculation presents the error:

$$\frac{280\Omega - 279.9\Omega}{280\Omega} * 100 = 0.036\%$$

We found that the theoretical graph, which was found using Microsoft Excel, deviated very little from the actual data taken with the 50 point sweep. The R^2 value for the trendline is effectively 1. We can use this slope to calculate the resistance, given that:

$$\frac{I_{out}}{V_{in}} = \frac{1}{R}$$

therefore,

$$R = \frac{V_{in}}{I_{out}} = \frac{1}{0.0036} = 277.7\overline{7}\Omega.$$

The error calculation is as follows:

$$\frac{280\Omega - 277.77\Omega}{280\Omega} * 100 = 0.793\%$$

1.3 Discussion

Although both measurements land fairly close to the nominal resistance of the resistor, the SMU voltage sweep and trendline method is likely more accurate, especially because it measures many different times over varying voltages.It would only be less accurate if the resistance varied with voltage, or by some other reason (such as heat). Fortunately, the current-voltage characteristic of this resistor was extremely linear, with only one or two unusual deviations from the expected values (see: a measurement slightly above $V_{in} = 0$). The nominal voltage printed on the resistor is undoubtedly the least accurate, as it does not account for the tolerance of the resistance.
It is also important to consider the precision of our measurements. For example, the Keithley sourcementer was set to show two decimal places while it was used to measure the resistor, while the SMU was capable of measuring many more decimal places.

2 Experiment 2: Resistive Voltage Division

2.1 Experimental Setup

In this experiment, we built a 1:3 voltage divider, where R_1 had a value of $2R$, and R_2 had a value of R. With this setup, the theoretical value of V_{out} should equal a third of V_{in}. We verified this by wiring three Bourne resistors in series and measuring the output voltage after the second resistor.

We swept V_{in} from -5V t 5V at 101 discrete intervals across the 1:3 voltage divider, measuring V_{out} at each interval.

2.2 Results

The sweep produced data as shown in figure . A trendline was applied to the data, with a slope of 0.3337, and an R^2 value of 0.9999. The error calculation is as follows:

$$\frac{\frac{1}{3}V - .3337V}{\frac{1}{3}V} * 100 = -.11\%$$

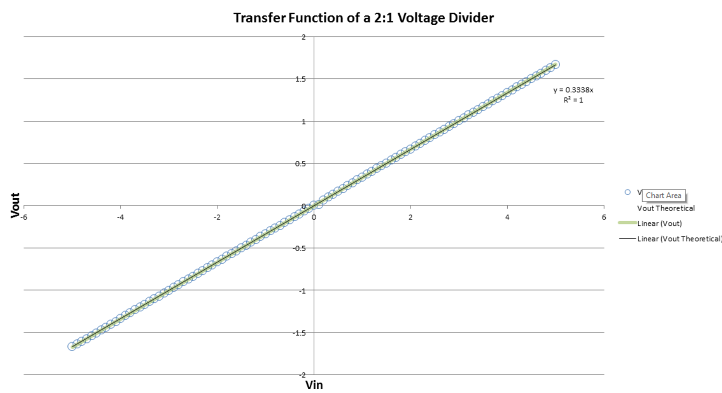

Figure 2: The voltage divider was characterized by plotting V_{out} vs. V_{in}

2.3 Discussion

The voltage divider produced the expected data, with a gain ratio of $\frac{V_{out}}{V_{in}} = \frac{1}{3}$ theoretical and .3337 observed. The possible mismatch in value can be calculated with the following equation:

$$\left|\frac{\delta\gamma}{\gamma}\right| = (1-\gamma)\left(\left|\frac{\delta R_1}{R_1}\right| + \left|\frac{\delta R_2}{R_2}\right|\right)$$

As seen in the prelab, a divider ratio of $\frac{1}{3}$ has a mismatch of $\pm 6.67\%$ or ± 0.0222V. Our voltage measurement definitely falls within tolerance.

3 Experiment 3: Resistive Current Division

3.1 Experimental Setup

Similarly to the voltage divider, current can also be divided. We did this by wiring three Bourne resistor in parallel, where R_1 had a value of $2R$ and R_2 had a value of R. We then applied a swept current, I_{in}, across the parallel resistors, from -0.0001A to 0.0001A at 101 intervals. Output current, I_{out}, was measured through the third resistor.

3.2 Results

The sweep produced data as shown in figure . A trendline was applied to the data, with a slope of 0.66667, and an R^2 value of 0.9999. The error calculation comes out to effectively zero.

$$\frac{\frac{2}{3}V - .66667V}{\frac{2}{3}V} * 100 = -.005\%$$

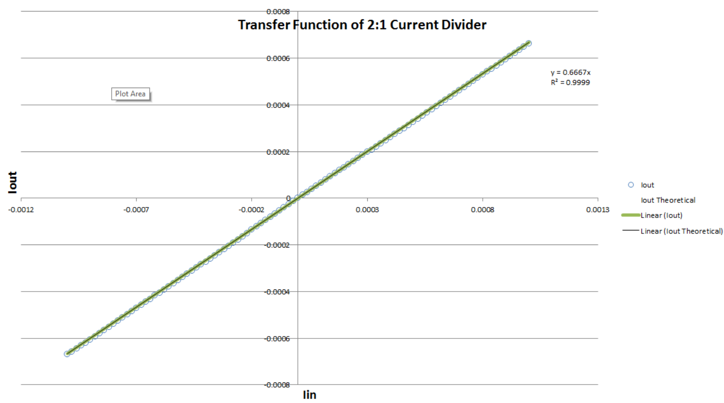

Figure 3: The current divider was characterized by plotting I_{out} vs. I_{in}

3.3 Discussion

The current divider produced the expected results, with a gain ratio of $\frac{I_{out}}{I_{in}} = \frac{2}{3}$ theoretical and .66667 observed. The error was effectively zero, because there was almost no difference between the expected and observed value, and the value definitely falls within tolerance.

4 Experiment 4: R-2R Ladder Network

4.1 Experimental Setup

We created a 4-bit R2R ladder circuit to characterize the currents through each branch of the ladder as a function of input voltage. Measurements were taken through the 2R resistors in each branch.

4.2 Results

We took data from all four branches as voltage was swept from -5V to +5V at 101 discrete intervals. For this, we used a python script by Thomas N., the link to which was provided in the abstract. This unique code, which recorded far more data than asked for, provided Fig. 4. It is clear that each successive branch has half the current of the previous branch.

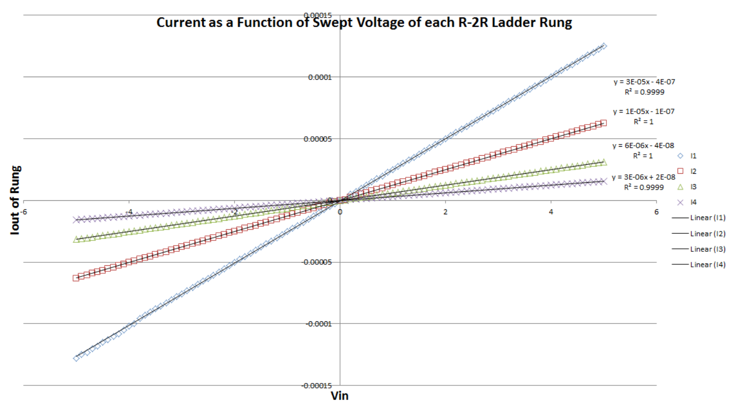

Figure 4: The raw measurements for each branch, showing I_{out} versus V_{in}

Fig. 5 below shows a semilog plot of I_{out} versus V_{in} using some of the data points from Fig. 4. Similarly to the previous figure, this figure clearly shows that each current is half the value of the current through the ladder rung in the position before it. The current out also varies proportionally with the current in.

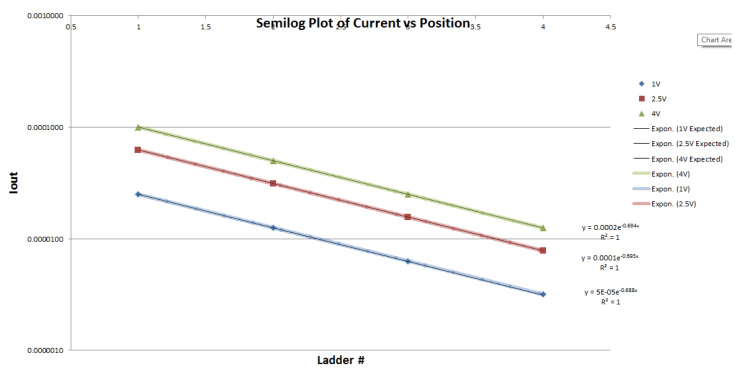

Figure 5: A semilog plot of I_{out} versus location in the circuit.

4.3 Discussion

This lab gave us quite a bit of insight into resistor value accuracy and tolerance, and the resistive ladder networks used in D/A converters and similar circuits. Our experiments proved that although the currents and voltages measured from their respective dividers might not be 100% true to the expected value due to the mismatch in resistor values, they will come pretty close if the resistor falls within tolerance.