# Resistors and Resistive Networks

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## 1 Introduction

The objective of this lab is to investigate the characteristics of three simple resistive circuits, voltage and current dividers and resistor ladders. We seek to examine these circuits through their I-V characteristics, voltage transfer characteristics, and current transfer characteristics.

## 2 Experiments

### 2.1 Experiment 1: Resistance Measurement

We obtained a $.25W$ $475\Omega$ resistor from the ECE Stockroom; The color code on the resistor confirmed the value. We then measured a resistance of $472.97\Omega$ with the Keithley 2400 SourceMeter. Finally, using the the homebrew SMU, we measured a resistance of $474.94\Omega$. This $474.94\Omega$ figure was found by taking 101 values along the current-voltage characteristic, fitting a line to that curve, and finally calculating the slope of that curve.

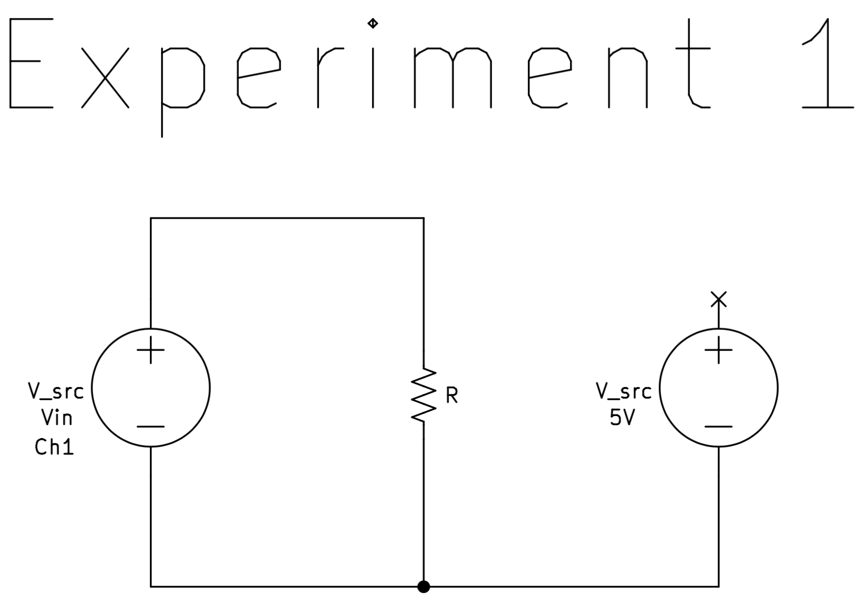


Figure 1: Schematic for Experiment 1

The team concluded that the measurements from the SourceMeter were the most accurate. We quickly eliminated the readout of the color bands as they represent an ideal value and do not account for the

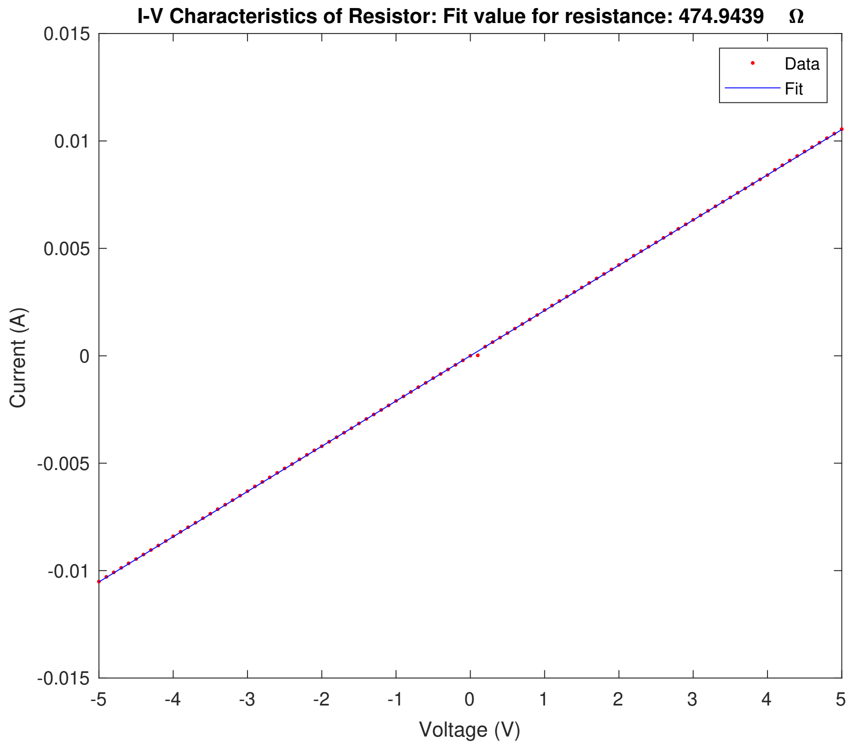


Figure 2: I-V Characteristic Plot for the resistor

variances caused by imperfections in the manufacturing or material. We hypothesized that the homebrew SMU board's measurements could be affected by impedance from the measurement probes and possible data losses over its USB connection. We also worked with the assumption that an expensive and popular tool used in industry would inherently be extremely accurate and reliable. Upon further reading, we discovered that benchtop source meters have extremely resolute control over the voltages and currents supplied to make resistive measurement.

## 2.2 Experiment 2: Resistive Voltage Division

Table 1 shows the measurements of the resistance of the 16 resistance values from two Bourns resistor array chips:

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Chip 1 | 9963Ω | 9961.7Ω | 9957.6Ω | 9947.8Ω | 9940.7Ω | 9943.5Ω | 9939.8Ω | 9949.6Ω |
| Chip 2 | 9942.7Ω | 9942Ω | 9945.2Ω | 9935.7Ω | 9941.4Ω | 9939.3Ω | 9930.7Ω | 9944.4Ω |

We calculated the average resistance of the 8 resistors on each chip and find that the average resistance of the first Bourns chip was 9950.462Ω. The average of 8 resistors on the second chip was 9940.175Ω. We compared the values between both chips by calculated the percent difference between the average resistance values of each chip - we found it to be 0.103436%.

In this section we constructed a resistive voltage divider with 2 resistors from our Bourns resistor array chip. We selected 2 resistor values that were very close in measured resistance values and constructed our two-way divider. We approximated the ratio between the components to have a 1:1 ratio, but the closest ratio we could achieve was 0.9999:1. The theoretical $V_{out}$ was 2.5V because our input voltage was 5V.

The theoretical divider ratio is .5:1. The actual ratio was found to be 0.50123:1 (unitless). The percent error here is .266%. This is reasonably consistent with the level of resistance mismatch that we observed in our resistor array. We measured $R_1$ to be 9945.2Ω and $R_2$ to be 9944.4Ω. As such the theoretical divider ratio is:

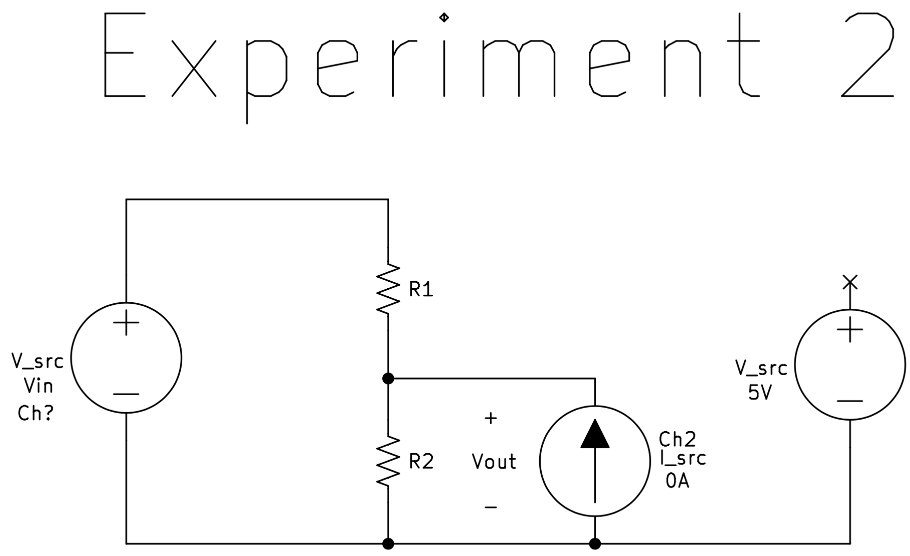


Figure 3: Schematic for Experiment 2

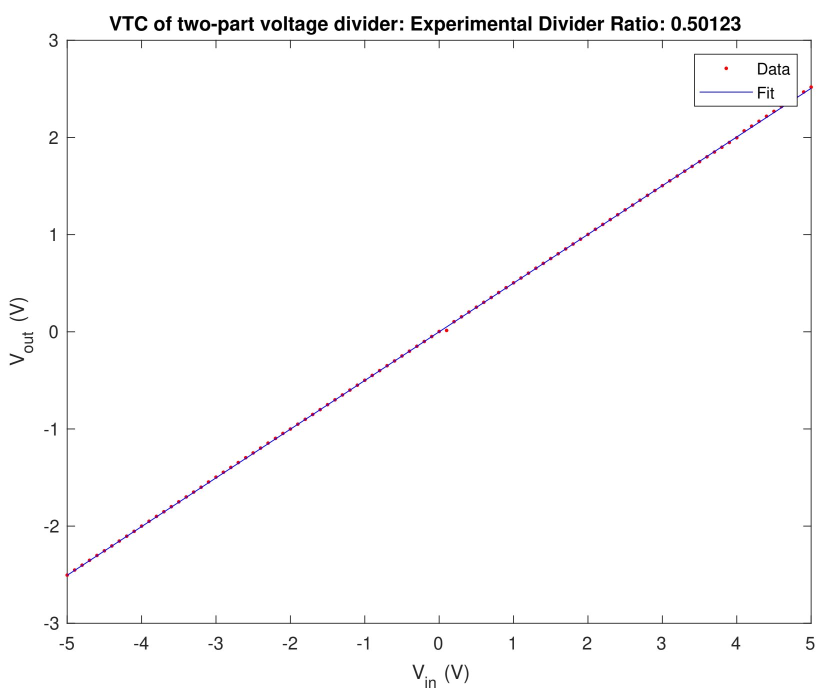


Figure 4: Voltage Transfer Characteristic Plot

$$\frac{R_2}{R_1 + R_2} = \frac{9944.4\Omega}{9944.4\Omega + 9945.2\Omega} = 0.4999 \tag{1}$$

One potential explanation for this discrepancy could be taking the measurement too early before letting the measurement settle.

## 2.3 Experiment 3: Resistive Current Division

In this section we constructed a resistive current divider by connecting two resistors from our Bourns resistor array chip in parallel. We used the same two resistor values from experiment 1.3.2. Again, we approximated the ratio between the components to have a 1:1 ratio, but the closest ratio we could achieve was 0.9999:1.

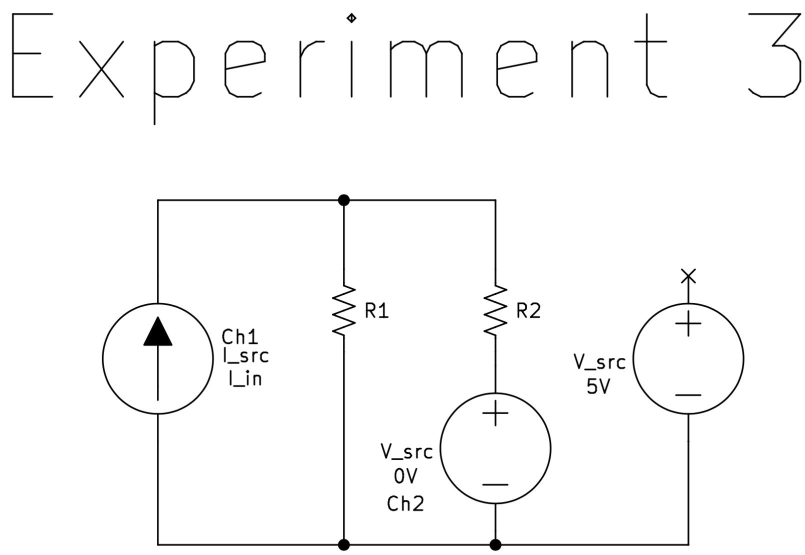


Figure 5: Schematic for Experiment 3

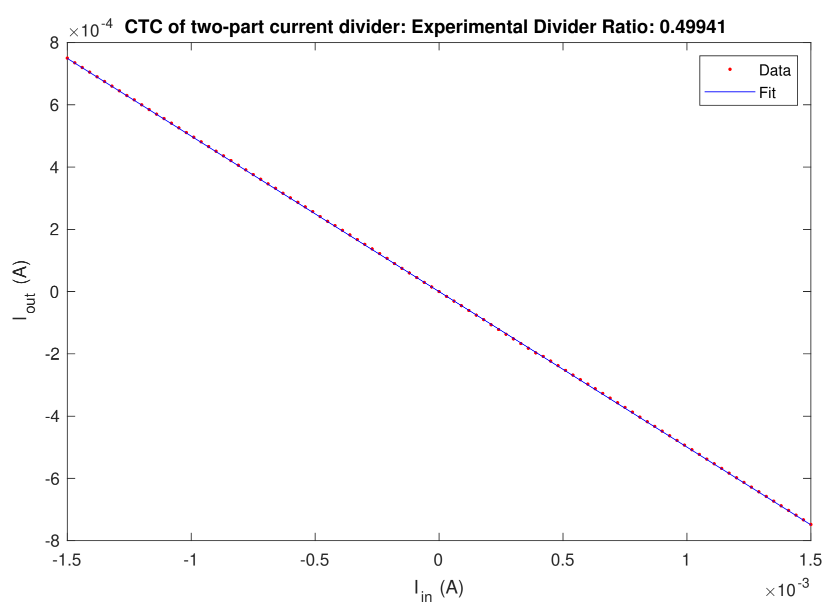


Figure 6: Current Transfer Characteristic Plot

The theoretical divider ratio is .5:1. The actual ratio was found to be 0.49941:1 (unitless). The percent error here is .118% This is reasonably consistent with the level of resistance mismatch that we observed in our resistor array

We measured $R_1$ to be 9945.2Ω and $R_2$ to be 9944.4Ω. As such the updated theoretical divider ratio is:

$$\frac{R_2||R_1}{R_2} = \frac{9944.4\Omega||9945.2\Omega}{9944.4\Omega} = 0.5000 \quad (2)$$

### 2.4 Experiment 4: R-2R Ladder Network

In this section we construct an R-2R ladder network with four 2R branches. The schematic is shown below:

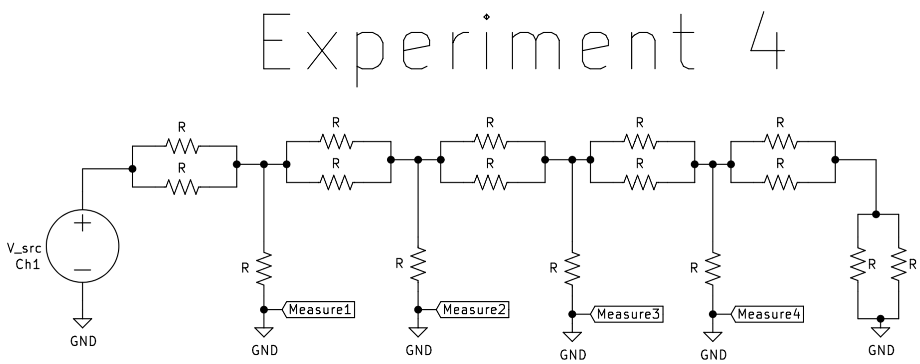


Figure 7: Schematic for Experiment 4

The current flowing through each branch of the ladder is shown in Figure 8, for two voltage inputs, 2.5V and 5V, on a x vs. log y scale. As found in the prelab, for a R:2R resistor ladder circuit, the current through each branch will be half of the current passing through the previous branch, i.e. each successive branch decreases the current by a factor of $\frac{1}{2}$. This relationship is used to find the theoretical currents seen in Figure 8.

To evaluate if the experimental data demonstrates the expected relationship, we took a linear fit of the $\log_2$(current) vs. the branch number. From that, we got a slope of -1 for both input voltages. This implies that for each increase in branch number, the current decreases by a factor of $2^{-1}$. This is exactly what we would expect for a R:2R ladder circuit, and this is further shown by how the experimental data matches the theoretical data near exactly.

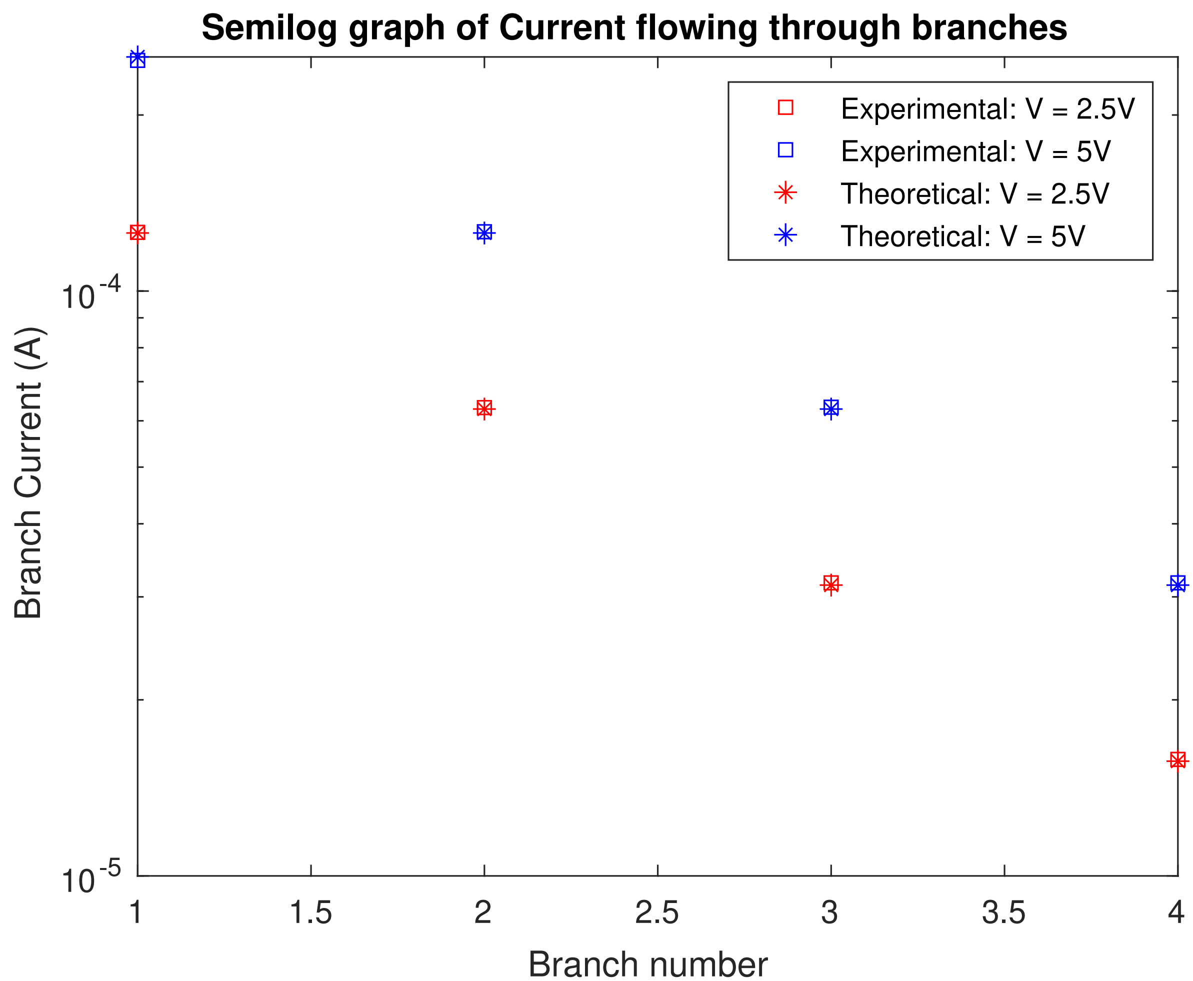


Figure 8: Semilog plot of branch currents for 2.5 and 5V inputs