Circuits Lab 4

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Experiment 1: Bipolar Transistor Matching

In this experiment, we diode-connected each of the four transistors in the MMPQ3904 quad npn bipolar transistor array, and using channel 1 of the SMU, we sweeped the collector current of each transistor from 1nA to 1mA and measured the corresponding base voltage.

We graphed the base voltage against the collector current to find the current-voltage characteristics of each transistor in the MMPQ3904 Transistor Array.

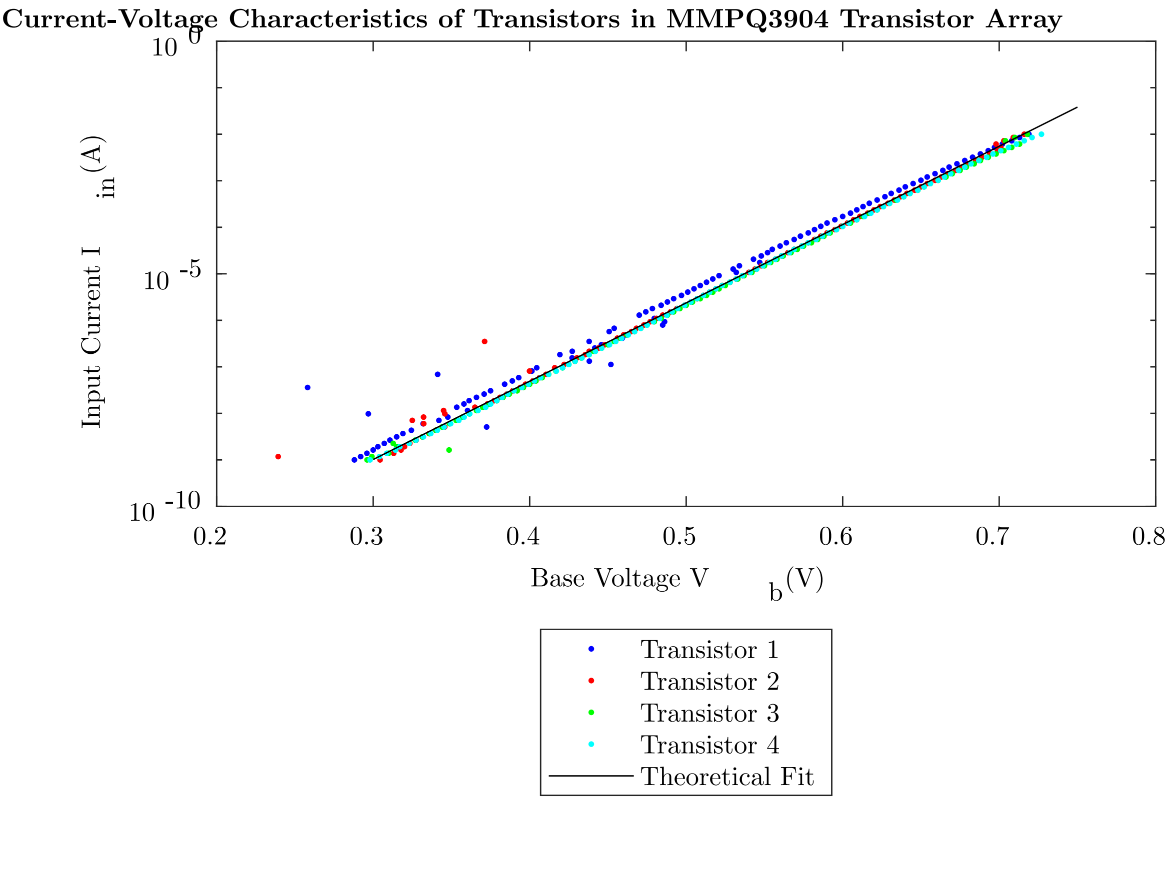

Figure 1: A semilog y-axis plot of the current-voltage characteristics of each transistor in MMPQ3904 Transistor Array

To extract I_s and U_T from this graph, we first created a theoretical fit for each transistor's voltage-current characteristics. Using Prelab 4, we found the expression between base voltage and collector current: $I_c = I_s e^{\frac{1}{U_T}}$. Using the exponential **fit()** function for each measured curve on Figure 1, we could find an expression in the following form: ae^{bx}. For each of the curves, we can extract a as I_s and b as $\frac{1}{U_T}$. After extracting I_s and U_T, we created the following table:

Transistor	I_s (A)	U_T (V)
Transistor 1	1.6955×10^{-14}	0.0264
Transistor 2	9.0714×10^{-15}	0.0258
Transistor 3	9.2288×10^{-15}	0.0260
Transistor 4	1.2611×10^{-14}	0.0265

Table 1: Extracted Transistor Values for I_s and U_T for each transistor in our MMPQ3904 Array.

In addition, we used theoretical fits to calculate the percentage difference between the mean current and the current going through each transistor as a function of base voltage, with the following equation: $\textit{percentage difference} = \frac{|mean(I)-I_i|}{mean(I)}$. We created the following graph for base voltage against the current percentage difference.

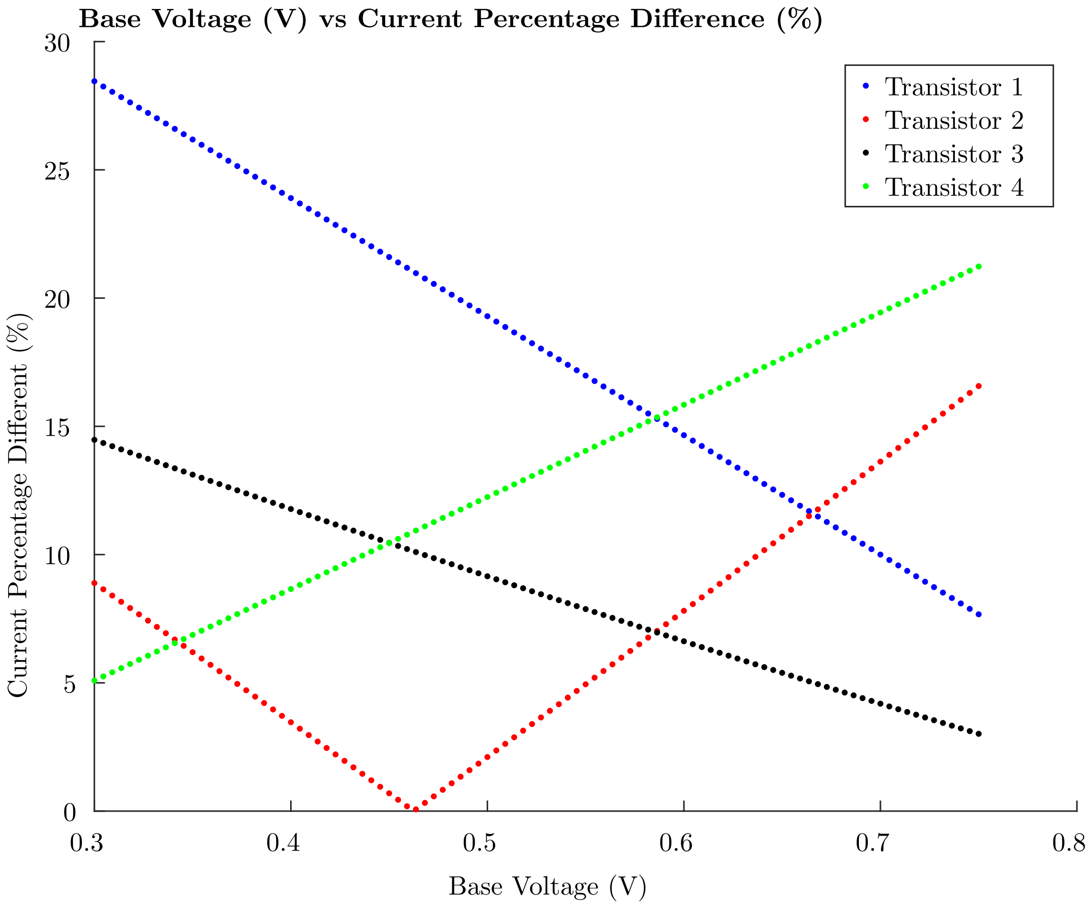

Figure 2: Current Percentage Difference (%) over Base Voltage (V) for each of the four transistors in our MMPQ3904 Transistor Array.

As we see in Transistor 1 and 3, as we increase the base voltage, the percentage difference between mean current and transistor current decreases. On the other hand, for transistor 2 and transistor 4, the percentage difference between mean current and individual transistor current generally increases.

Experiment 2: Translinear Circuit 1

In this experiment, we constructed and analyzed a translinear circuit using four npn bipolar transistors (MMPQ3904). Specifically, we are studying the relationship between the output current I_z and the input currents I_x and I_y. To begin, we constructed the translinear circuit described in 4.1b, using four npn transistors. However, since we are using one SMU channel to measure current, we can only generate current for one other source, and so we need to create an adjustable current source and sink to supply the second current input in the circuit.

To start with, we create a current sink to replace I_y. We set the voltage V_{in} at 5V $\cdot \frac{3k\Omega}{47k\Omega} = 319$ mV using a voltage divider with resistor values of 47kΩ and 3kΩ. Then, using resistors of values 30kΩ, 62kΩ, and 91kΩ, we generate current sinks of 10.6, 5.15, and 3.51 micro amps. The output current of the current sink is derived by $I_y = \frac{V_{in}}{R}$, where $V_{in} = 0.3V$. To measure the output current I_z as a function of the input current I_x, we measure I_z as we sweep over I_x for the three different values of I_y that we generated.

To create a theoretical fit, we used the translinear principle for current relations in a translinear circuit. This gave us the relation

$$I_z = \sqrt{I_x I_y}$$

We know the constant values of I_y and we can take the sweeped values of I_x to create a set of theoretical values of I_z.

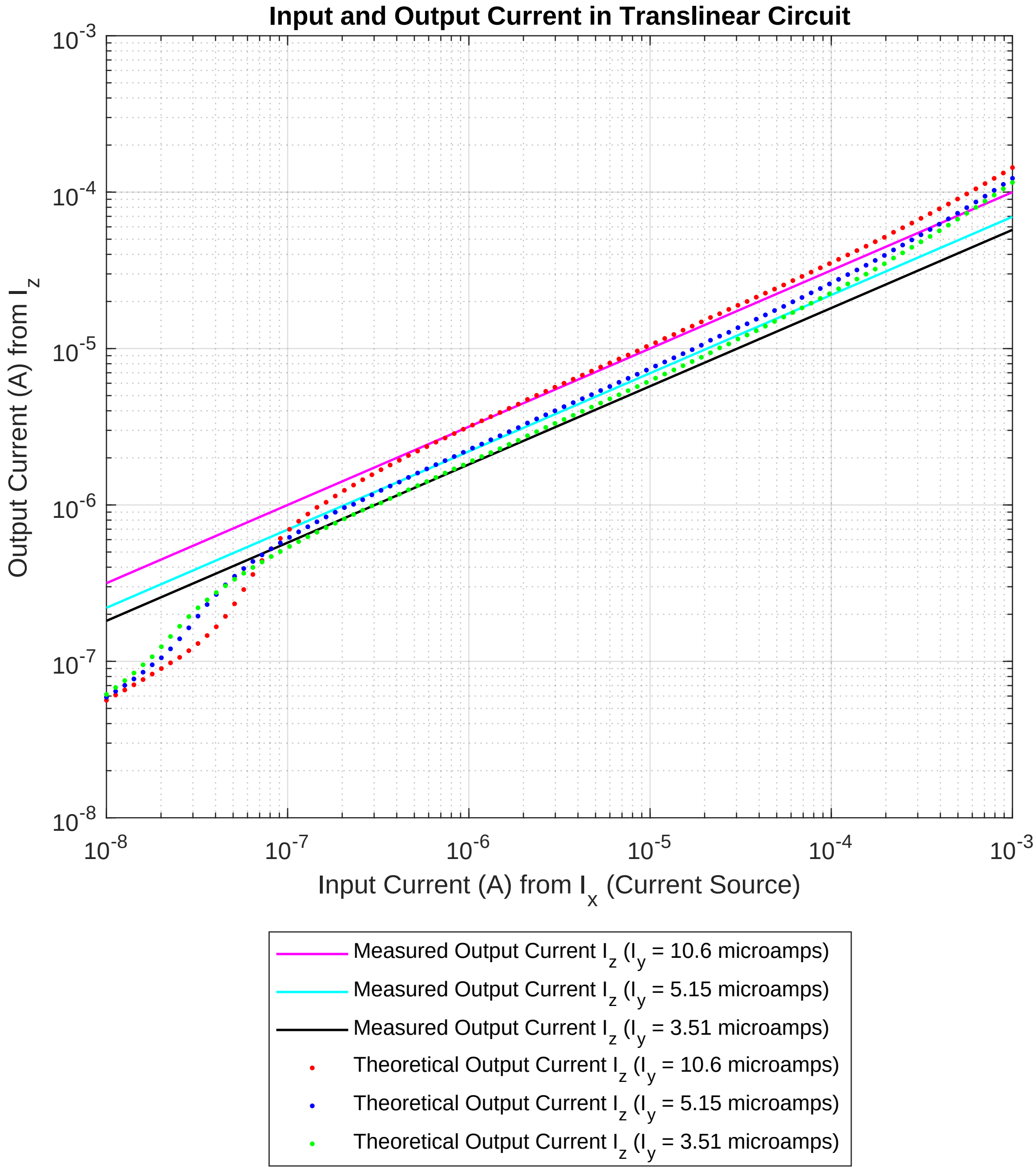

Figure 3: A loglog plot of measured and theoretical current relations between the input current I_x (current source) and output I_z with constant values of I_y (current sink).

The measured and theoretical output currents match, which is what we expected. In logspace, as I_x increases, I_z increases by half as many decades. This means I_z is proportional to $\sqrt{I_x}$. Additionally, there is a bit of a dip at the lower input current.

For the second part of the experiment, we created a current source for I_x, and then we used the SMU to create a current sink input for I_y. We set the voltage input for the current source V_{in} at 2.5V using two identical 30kΩ resistors in a voltage divider, and then calculated the current value given the current source relation where $V_{DD} = 5V$:

$$I_x = \frac{V_{DD} - V_{in}}{R},$$

derived in Prelab 4. We generate current sources of 83.3, 40.3, and 27.5 micro-amps. To measure the output current I_z as a function of the input current I_y, we measure I_z as we sweep over I_y for the three different values of I_x that we generated. We used the same translinear relation of $I_z = \sqrt{I_x I_y}$ for current relations to create theoretical fits for this circuit, as well.

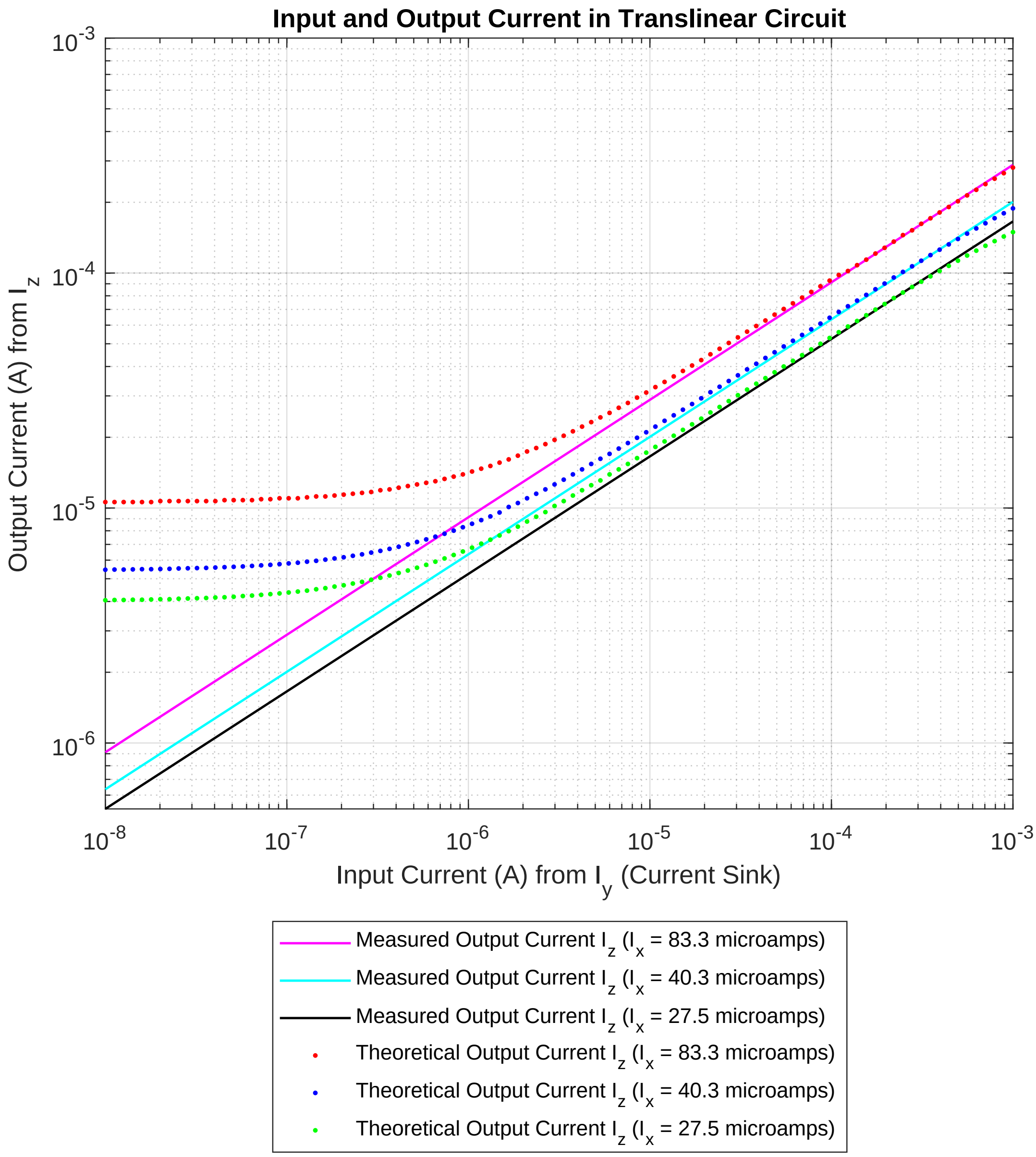

Figure 4: A loglog plot of measured and theoretical current relations between the input current I_y (current sink) and output I_z with values of I_y (current source). Note that since I_y is a current source, the input current is negative. However, we decided to negate the input current to better demonstrate the relation between I_x and I_y.

The measured and theoretical output currents match, which is what we expected. In logspace, as I_y increases in magnitude, I_z increases by half as many decades. This means I_z is proportional to $\sqrt{I_y}$. Additionally, there is a bit of a divergence upwards at the lower input current.

Experiment 3: Translinear Circuit 2

In the next experiment, we constructed and analyzed a second translinear circuit using the same MMPQ3904 transistor array. Specifically, we are studied the relationship between the output current I_z and the input currents I_x and I_y. To begin, we constructed the translinear circuit described in 4.1c, using the four npn transistors. Similarly, as in Experiment 2, we are using one SMU channel to measure current, one to act as the current source or current sink, and then we have the prebuilt current source and sink. We use the same generated currents in Experiment 3: 10.6, 5.15, and 3.51 micro amps for the current sink, and 83.3, 40.3, and 27.5 micro-amps for the current source.

To find the ideal fits, we can use the translinear principle to find that

$$I_z = \frac{I_x^2}{I_y},$$

as described in the prelab.

We can begin by analyzing the relationship between I_x and I_z by sweeping over values of I_x for three different constant values of I_y, as shown in Figure 5. This is to analyze the effect of I_x on I_z.

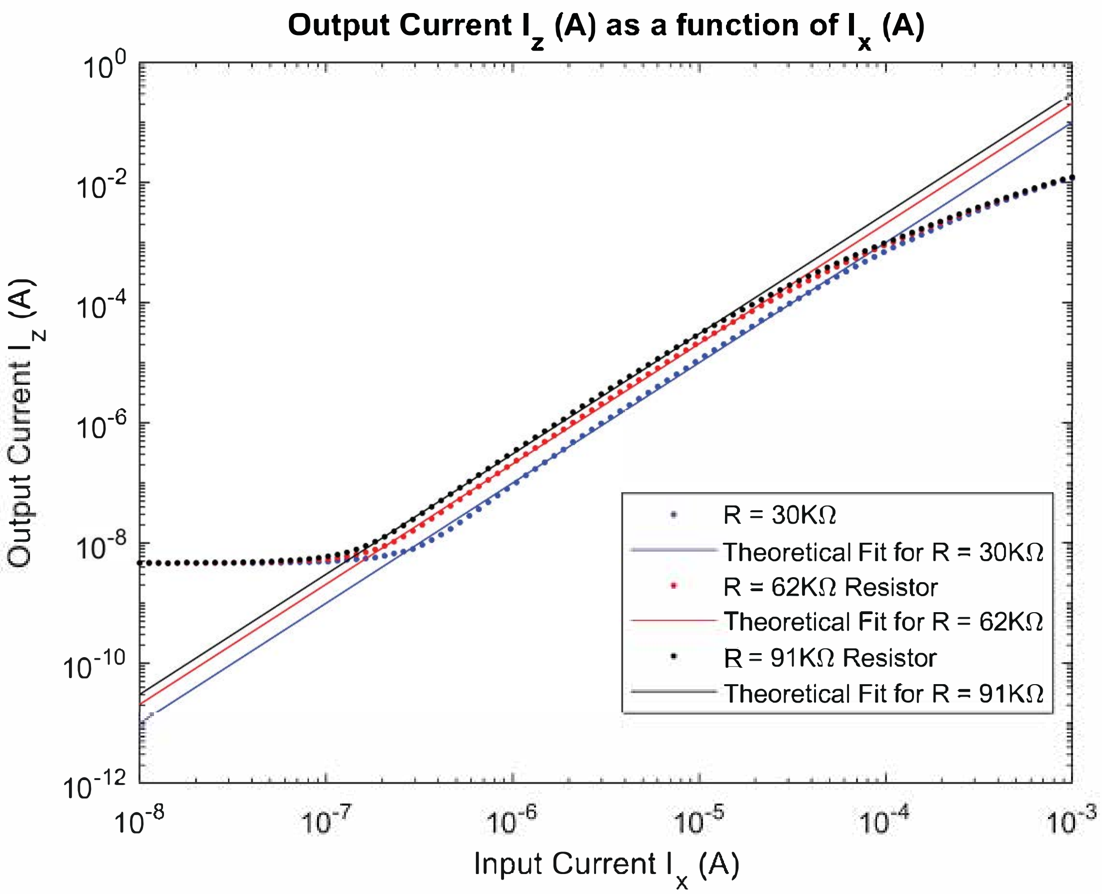

Figure 5: A loglog plot of measured and theoretical current relations between the input current I_x (current source) and output I_z with constant values of I_y (current sink).

The measured and theoretical output currents match, which is what we expected. In logspace, as I_x increases in magnitude, I_z increases by twice as many decades. This means I_z is proportional to I_x^2. Additionally, the measured data deviates from the theoretical fit at the beginning and end of our data collection. This is perhaps due to leakage current with low currents or thermal effects at higher currents.

For the second part of experiment 3, we can use our current source to provide constant values of I_x and sweep over values of I_y, as shown in figure 6. This is to analyize the effect of I_y on I_z.

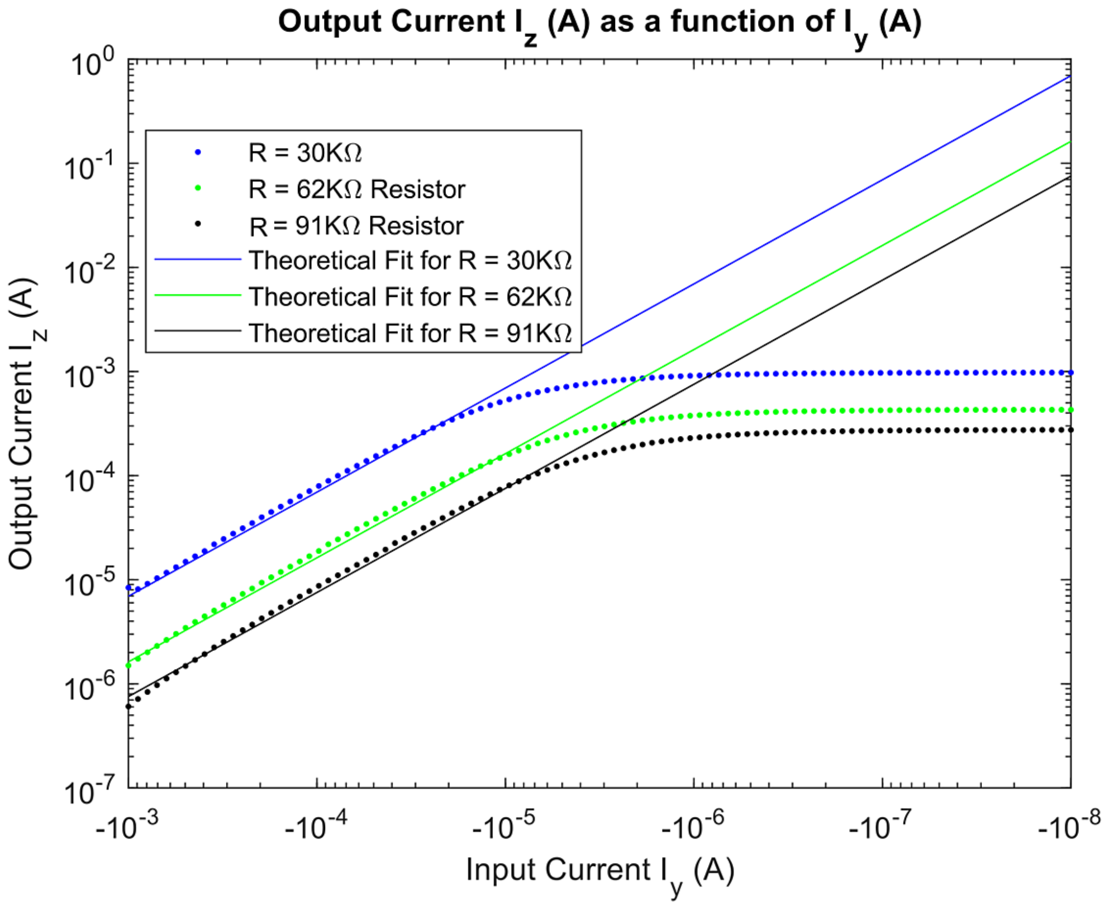

Figure 6: A loglog plot of measured and theoretical current relations between the input current I_y (current sink) and output I_z with constant values of I_x (current source). Note that the current for I_y is negative.

The measured and theoretical output currents match, which is what we expected. In logspace, as I_y increases in magnitude, I_z decreases by an equal amount of decades. This means I_z is proportional to I_y^{-1}. However, the measured data deviates from the theoretical fit at the lower input currents, for about half of our data. This behavior is unexpected and could be caused by leakage currents.