Circuits Lab 4

Theo Thompson and Dan Kearney

3.3.13

Experiment 1

Our first experiment compared transistors on the same MAT14 transistor array. For each npn transistor, we tied the collector to the +5V power rail and grounded the emitter. We swept the base voltage from .25V to .65V to characterize the transistor. One way of measuring how well matched transistors are is to measure β and I_s. To do this, we calculated the collector current using KCL:

$$I_e = Ib + I_c$$

We then calculated β:

$$\beta = \frac{I_b}{I_c}$$

To calculate I_s, we used the following relationship:

$$I_c = I_s e^{\frac{V_{be}}{U_t}}$$

Where V_{be} is the base-emitter voltage that we sourced with the SMU. The results of our calculation are summarized in the table below.

β	I_s
875.52	$2.01 * 10^{-13}$
875.64	$2.07 * 10^{-13}$
877.97	$2.10 * 10^{-13}$
875.66	$2.07 * 10^{-13}$

Beta is very consistent across the four transistors. We calculated the standard deviation of β to be 1.18, which is about .1%. The standard deviation of I_s is $3.78 * 10^{-15}$, which is about 3.6%. These deviation values suggest that the transistors in the MAT14 transistor array are very well matched. To further investigate β across all 4 resistors, we plotted β as a function of base voltage in figure 1. The plot shows that β is well matched across all operation regions of the transistors.

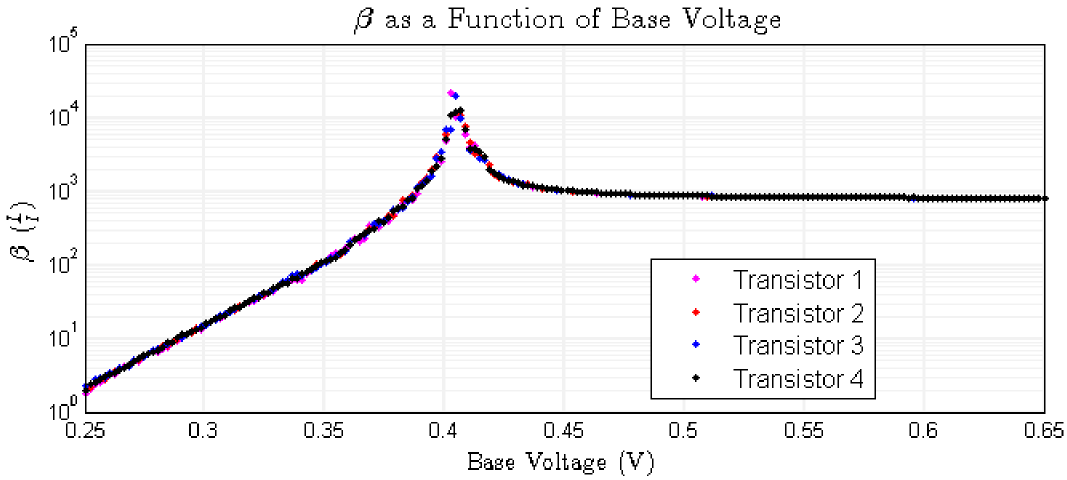

Figure 1: β as a function of V_{be} across all 4 devices.

Next, we wanted to investigate the similarity of currents between the devices. Figure 2 shows the base and collector currents for all 4 transistors on the same plot. The currents are almost identical.

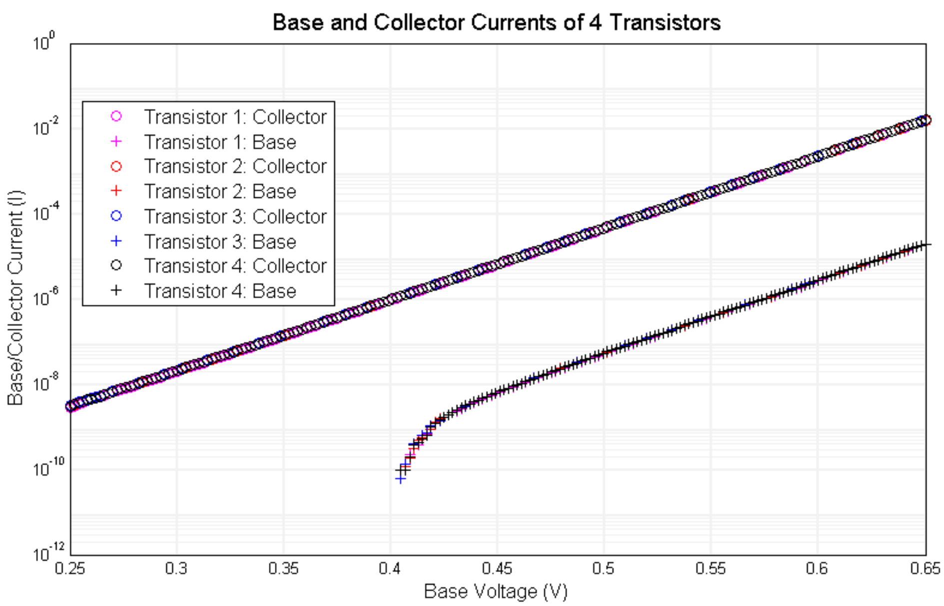

Figure 2: The base and collector currents of all 4 transistors in response to a base voltage sweep.

The similarity of the transistors' currents is better illustrated in figure 3. This plot shows the percentage difference of each transistor's collector current from the mean value. The collector currents are within a 2% tolerance of the mean.

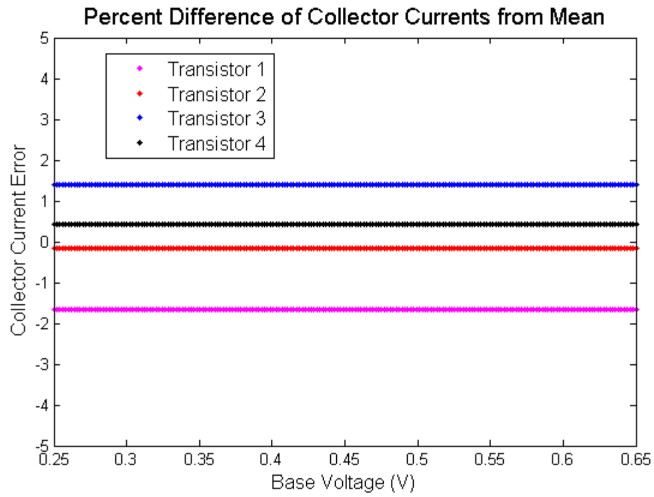

Figure 3: The percent error between each transistor's collector current and the mean value.

This experiment confirms that the transistors on the MAT14 are relatively very similar. This allows us to carry on with our experiments under the assumption that all 4 transistors are well matched.

Experiment 2

In experiment 2, we analyzed the first translinear circuit, shown in Figure 4.

tl1.png

Figure 4: Translinear circuit 1.

Configuration 1: Sweeping I_x

For our first configuration of the first circuit, we held the current I_y constant using a current sink that we made using the circuit shown in Figure 5. We sourced I_x using the SMU and measured the current I_z with the SMU as well.

sink.png

Figure 5: Our current sink.

We held that current sink constant by choosing our V_{in} and our R values such that we could produce a wide range of currents. We held I_y constant and used the SMU to sweep I_x over several orders of magnitude of current. We did this for three values of I_y that scaled three orders of magnitude.

From our prelab, we expect that this translinear circuit obeys the equation $I_x I_y = I_z^2$. As a result, when we hold I_y constant, we expect $I_z = \sqrt{I_x I_y}$.

Our experiment result, and our theoretical expectation, are shown in Figure 6.

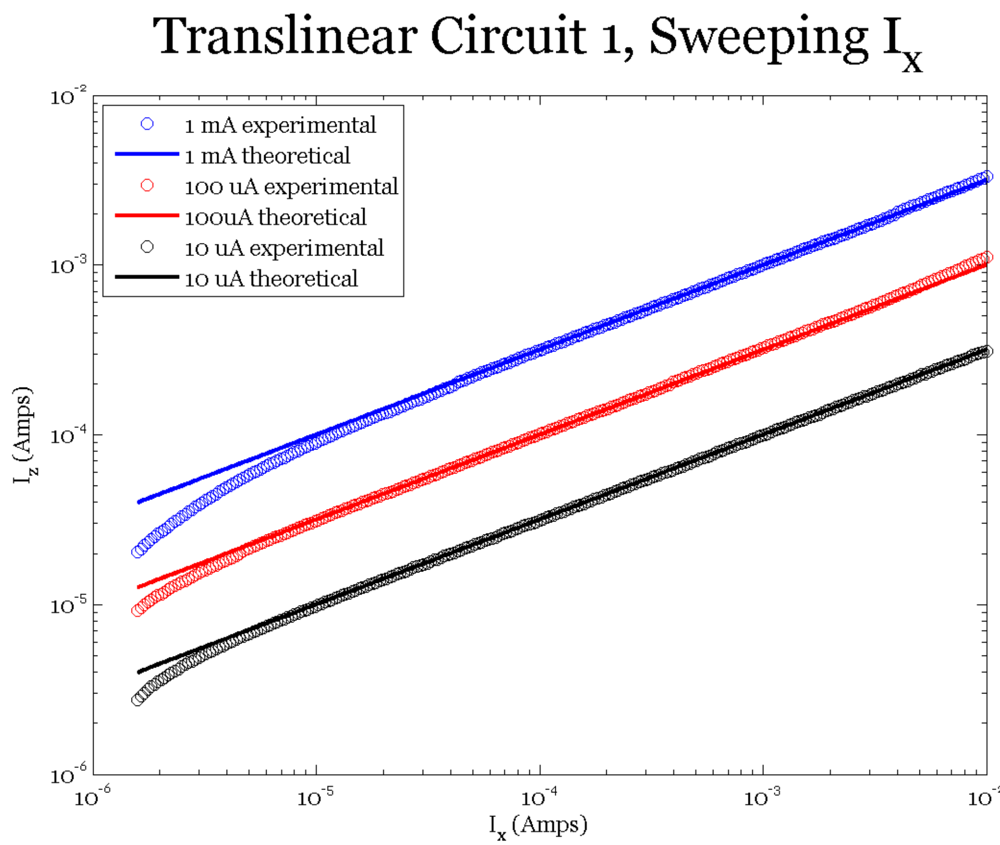

Figure 6: Translinear circuit 1, holding I_y at the values shown in the legend.

In general, this circuit behaves as we would expect from our analysis. At small input currents, the output current is a little lower than expected, but we can expect that low currents are difficult for the SMU to write and read accurately.

Configuration 2

Next, we took the same circuit from before and replaced the current sink with one channel of the SMU, such that we could sweep I_y, and held I_x constant with a current source that we built. Our current source is shown in Figure 7.

source.png

Figure 7: Our current source.

We chose appropriate values of V_{in} and R such that we could sweep our I_y over several orders of magnitude, as in configuration 1.

Again, we expected, from the prelab, that $I_z = \sqrt{I_x I_y}$. Our results are shown in Figure 8.

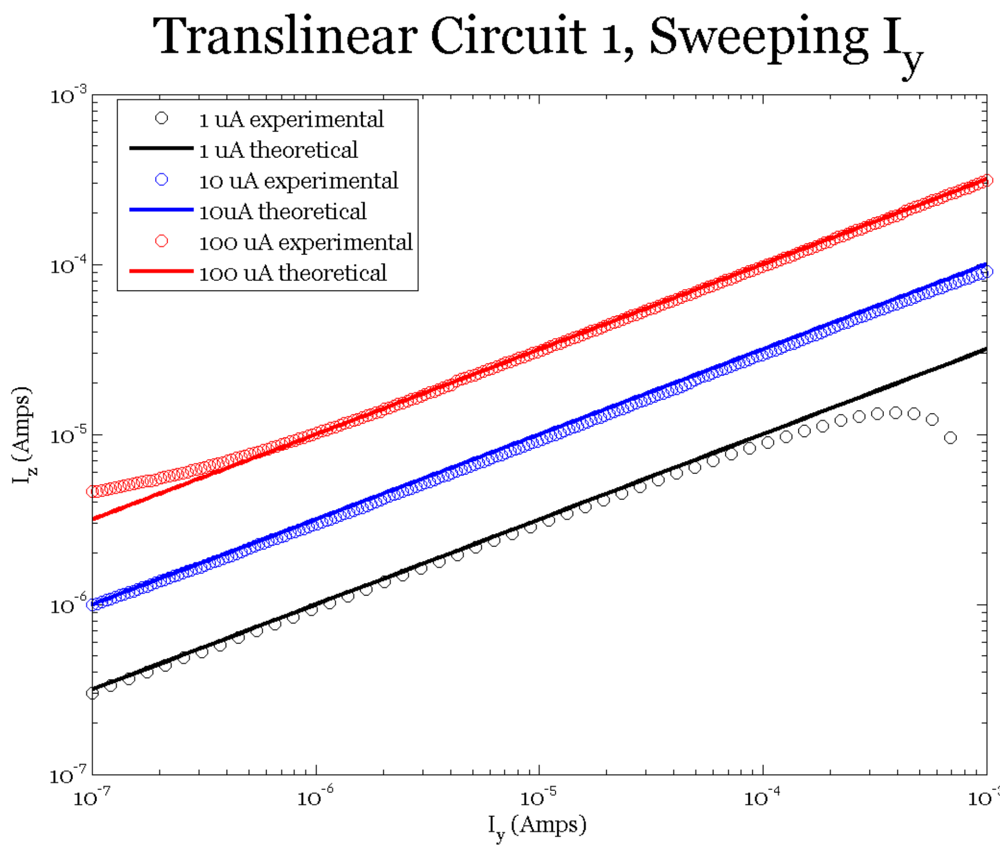

Figure 8: Translinear circuit 1, holding I_x at the values shown in the legend.

This circuit behaved well for low I_x currents. The expected and theoretical approaches are almost indistinguishable for $I_x = 10\mu A$. However, for high I_x, we found that the circuit broke down at high I_y and started to decrease. We believe that the dichotomy of very small measurement and very high output might have caused the SMU to fail.

Translinear Circuit 2

We then repeated the experiments with a slightly different circuit, shown in Figure 9.

tl2.png

Figure 9: Translinear circuit 2.

As we did before, we used one channel of the SMU to sweep one of the currents in the circuit while holding the other current constant using current source or sink we built.

Configuration 1

In the first configuration, we held I_y constant with our hand-built current sink and swept I_x with the SMU.

From the prelab, we expect this circuit to follow $I_x^2 = I_z I_y$. As a result, holding I_y constant should yield $I_z = \frac{I_x^2}{I_y}$, which means that I_z will increase linearly on a log-log scale as we sweep I_x. Our results are in Figure 10.

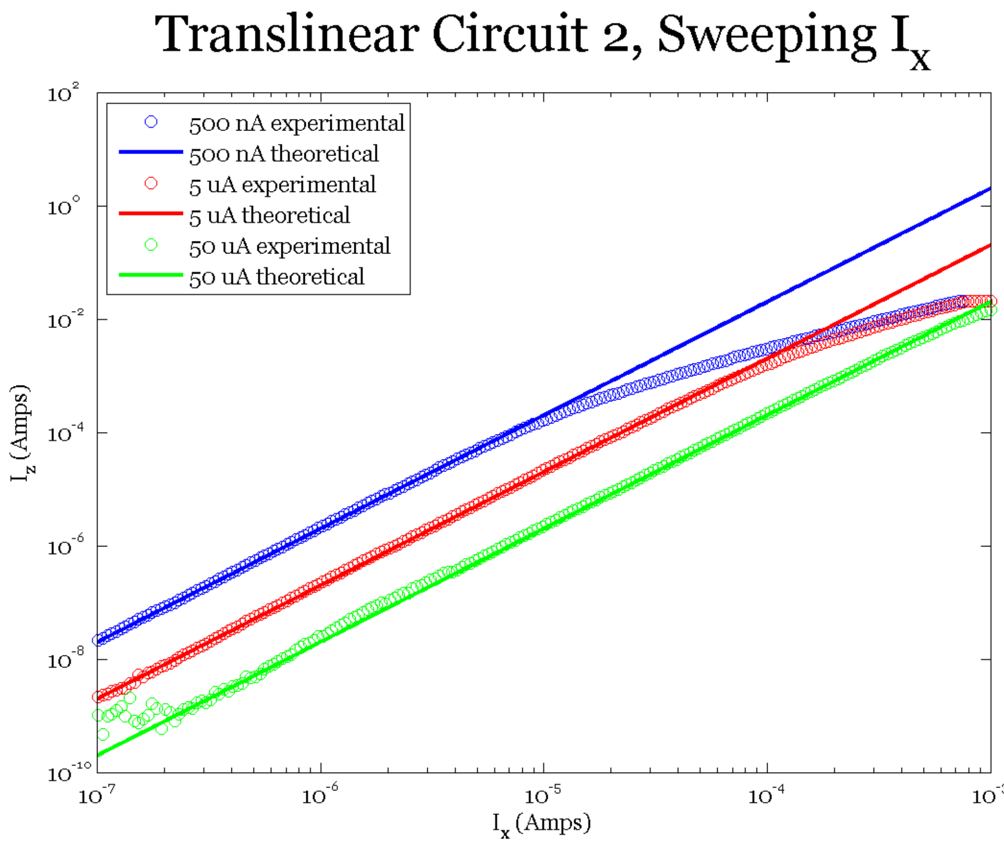

Figure 10: Translinear circuit 2, holding I_y at the values shown in the legend.

We swept over a high dynamic range (five orders of magnitude) and found that the data matched the theoretical expectation very well for the majority of the range of our input current values. We found that decreasing I_y caused the current to increase more slowly as we increased I_x, which we can attribute to the difficulty in sourcing nanoamps of current while measuruing millamps of current.

Configuration 2

We then switched our circuit around such that our current source was holding I_x constant and the SMU swept I_y over a high dynamic range. Again, we expect $I_z = \frac{I_x^2}{I_y}$, which means that I_z should decrease linearly on a log-log scale as we sweep I_y. Our results can be seen in Figure 11.

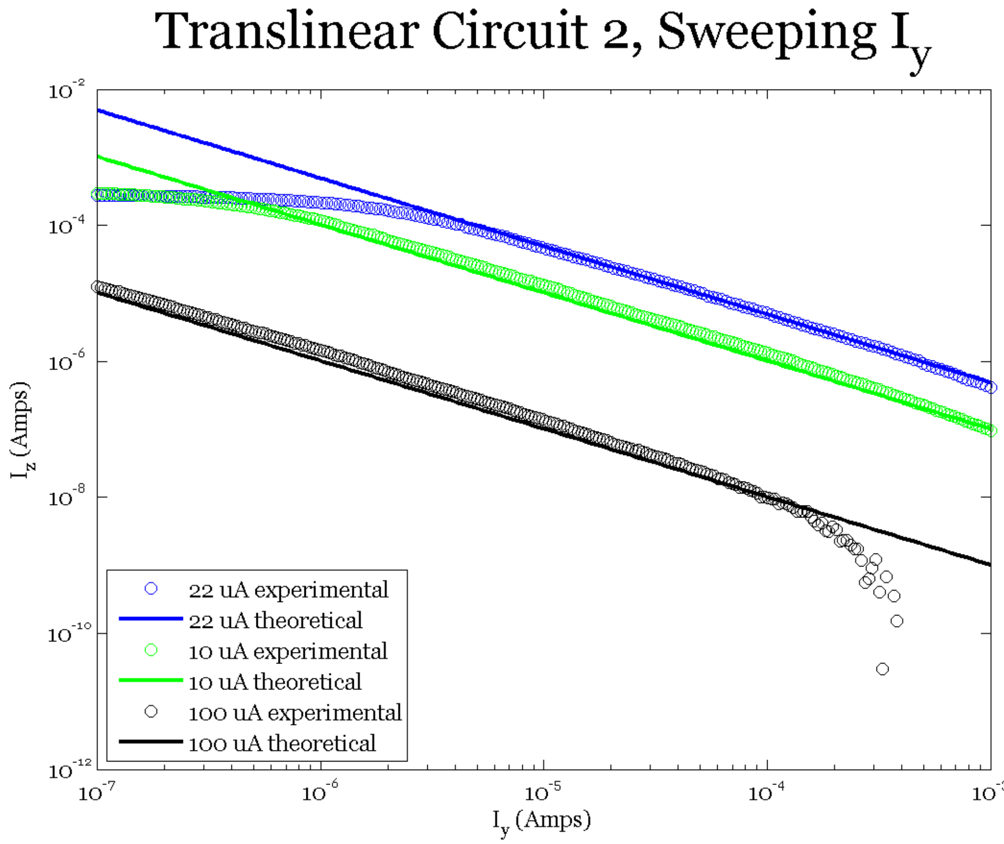

Figure 11: Translinear circuit 2, holding I_x at the values shown in the legend.

This was our worst-behaved configuration. We found that we if we decreased I_x below around 20 uA, I_z was dominated by the non-linear region we believe is in error. If we increased I_x to more than 100 uA, we found that I_z was very noisy for large input values. As a result, we only measured I_y for I_x at values of 22 uA, 10 uA, and 100 uA.