Introduction to Microcircuits
Lab 3: Resistors and Bipolar Transistors

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1 Experiment 1: Bipolar Transistor Characteristics

1.1 Experimental Setup

For the first circuit configuration, we'd like to sweep the Base voltage, V_b such that the Emitter current, I_e, ranges from about 10nA to 20mA. We can calculate the appropriate Base voltage, beginning by solving the ideal diode equation for the Emitter-Base junction. The ideal diode equation for the Emitter-Base junction states:

$$I_e = \frac{I_s}{\alpha} * e^{(V_b - V_e)/U_T}$$

We know that U_T is approximately 0.025 V, I_s is approximately 10^{-15} A and α is approximately 1, so:

$$I_e = I_s * e^{V_b/U_T}$$

$$V_b = U_T * log\frac{I_e}{I_s}$$

For 10 nA,

$$V_b = 0.025V * log\frac{10 * 10^{-9}A}{10^{-15}A} = 0.402952V$$

For 20 mA,

$$V_b = 0.025V * log\frac{20 * 10^{-4}A}{10^{-15}A} = 0.708104V$$

1.2 Results

We calculated the Collector current by KCL, which states:

$$I_e = I_b + I_c$$

The results of the calculation for I_c are in Fig. 1 below.

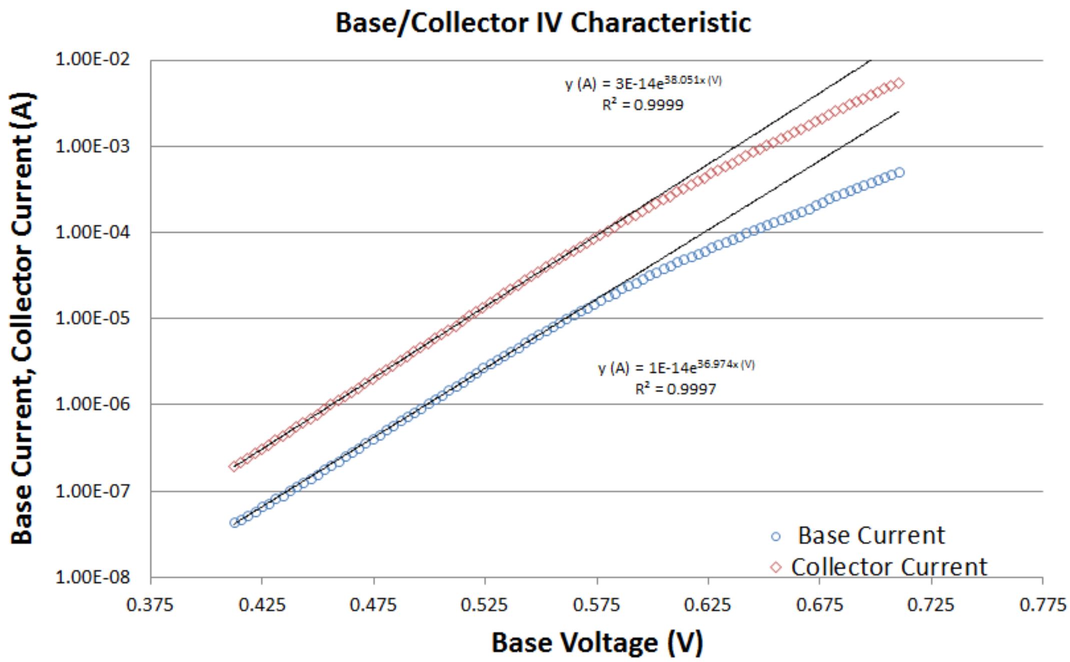

Figure 1: The semilog plot of both the collector and base current as a function of the base voltage.

The current gain across the the Collector-Base junction, β, is defined as:

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

Fig. 2 shows β changing with Base current.

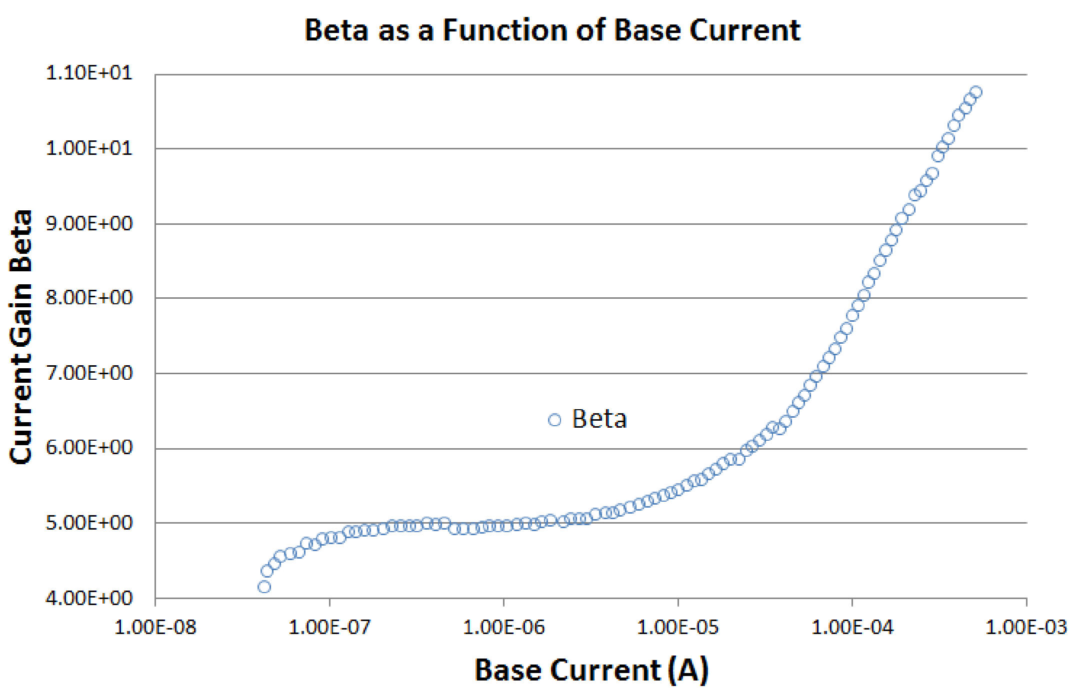

Figure 2: A plot of the current gain β as a function of Base current.

The incremental resistance was calculated using the equation:

$$r_b = \frac{dV_b}{dI_b}$$

where dV_b and dI_b were calculated from the data. The results are in Fig. 3.

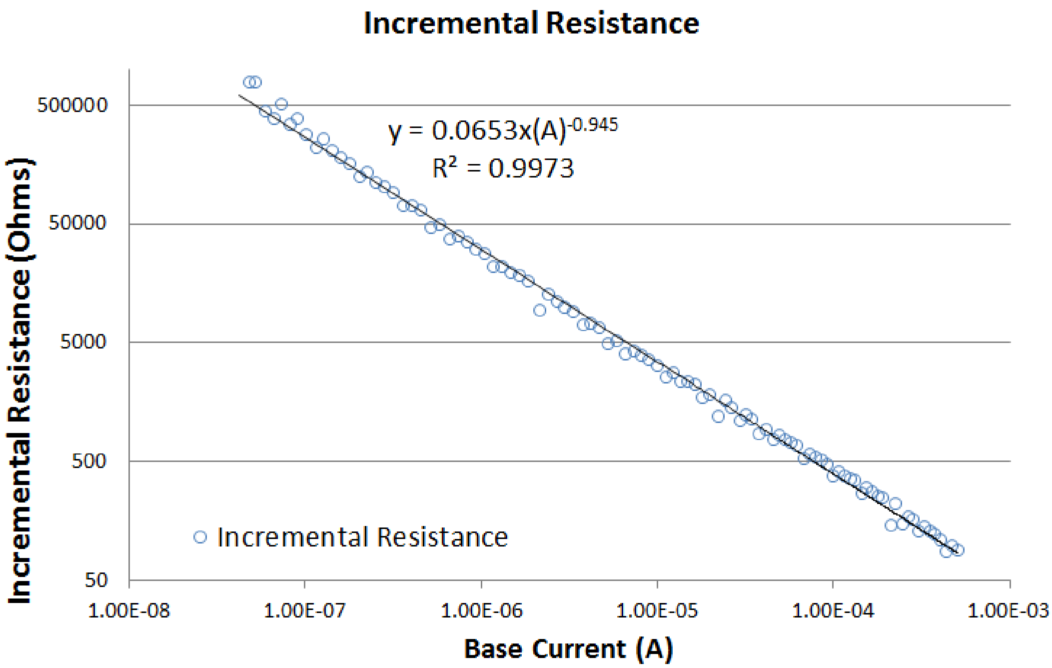

Figure 3: The voltage transfer characteristic of an emitter-follower circuit.

The incremental transductance gain was calculated using the equation:

$$g_m = \frac{dI_c}{dV_b}$$

where dV_b and dI_c were calculated from the data. The results are in Fig. 4.

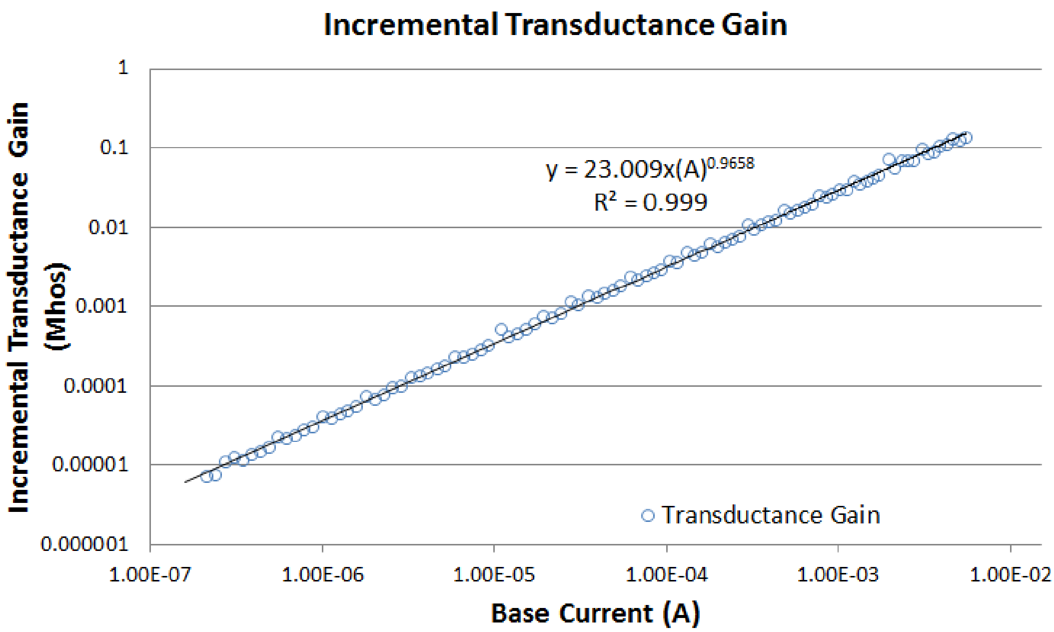

Figure 4: The voltage transfer characteristic of an emitter-follower circuit.

1.3 Discussion

The Collector current and the Base current in Fig. 1 follow exponential relationships with Base voltage, as seen in the theoretical fit equations. The R^2 values are close to 1, which is desirable in a good fit.

In Fig. 2, I expect the current gain, β, to effectively reach unity as I_b increases. This is actually easier to see in a linear plot, it was requested that the x-axis be plotted logarithmically.

The calculations done for incremental resistance, r_b, in Fig. 3, have a good power-equation theoretical fit with an R^2 value of 0.997. Similarly, the incremental transconductance gain power-equation theoretical fit has an R^2 value of 0.999.

2 Experiment 2: Emitter-Degenerative Bipolar Characteristic

2.1 Experimental Setup

We next configured our Bipolar Junction Transistor with a resistor between the Emitter and ground. This configuration was used to analyze the Emitter-Degenerated characteristic. Three resistors were used across three order of magnitude: 330, 1.07k, and 10k.

2.2 Results

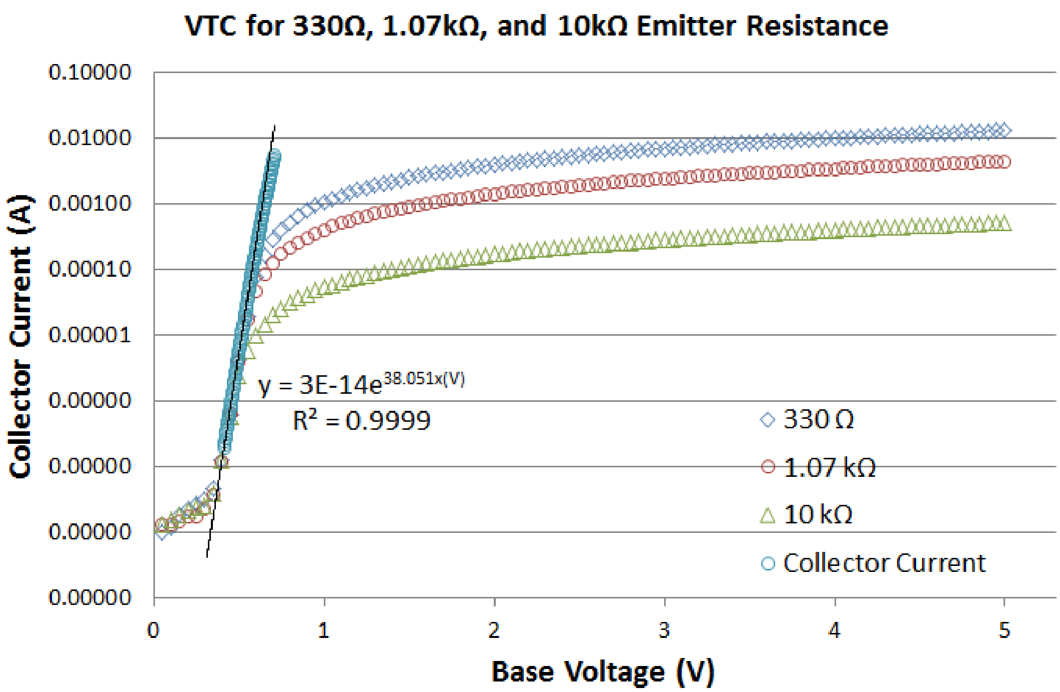

Figure 5: VTC for each of three emitter resistances (330ω, 1.07k, and 10k), along with the IV characteristic for I_c from Experiment 1.

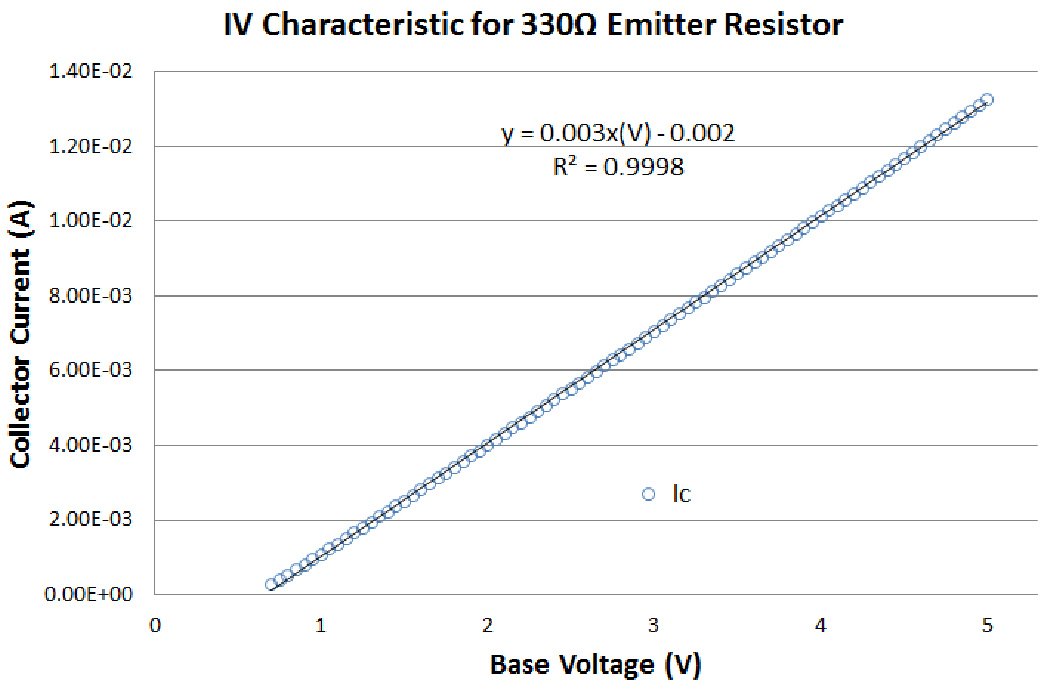

Figure 6: The current though the 330Ω resistor as a function of the base voltage.

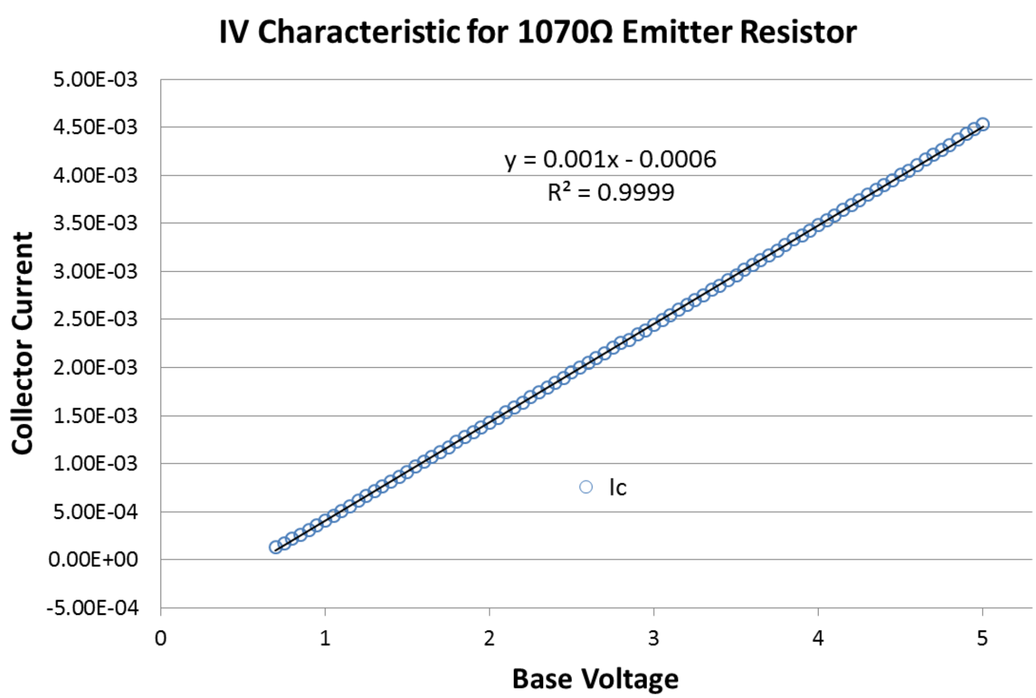

Figure 7: The current though the $1.07k\Omega$ resistor as a function of the base voltage.

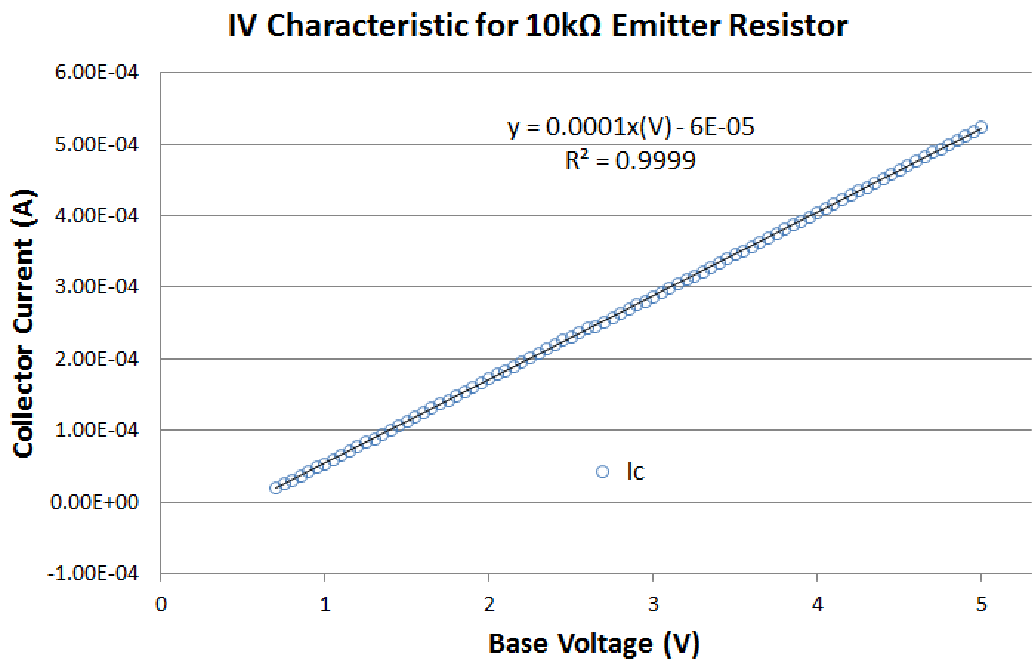

Figure 8: The current through the $10k\Omega$ resistor as a function of the base voltage.

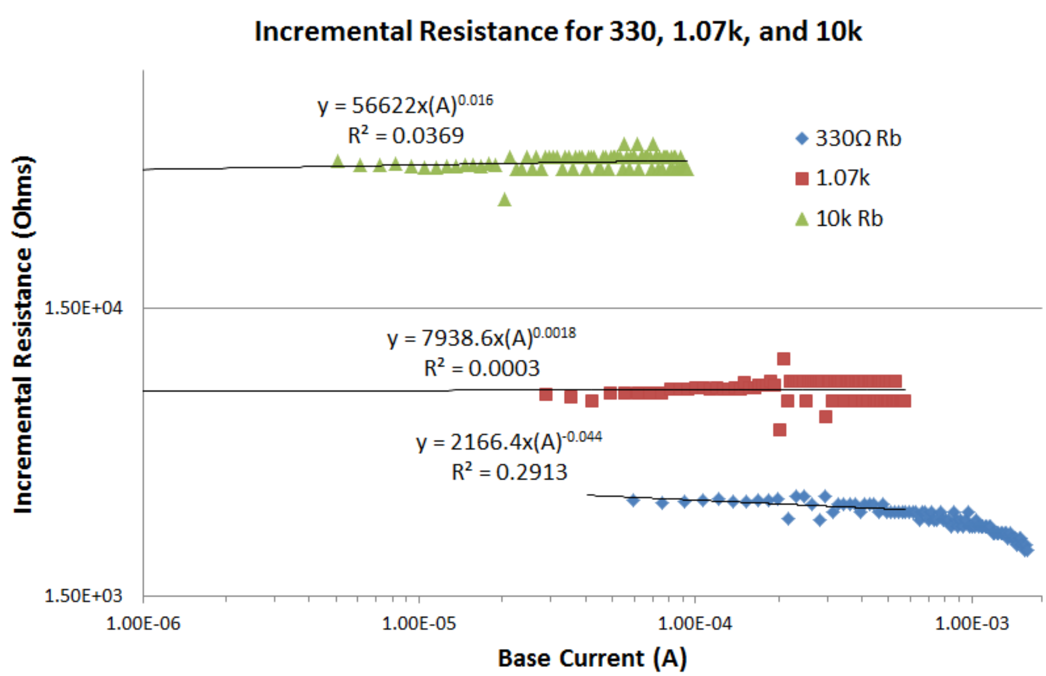

Figure 9: Incremental Resistance for each resistor configuration.

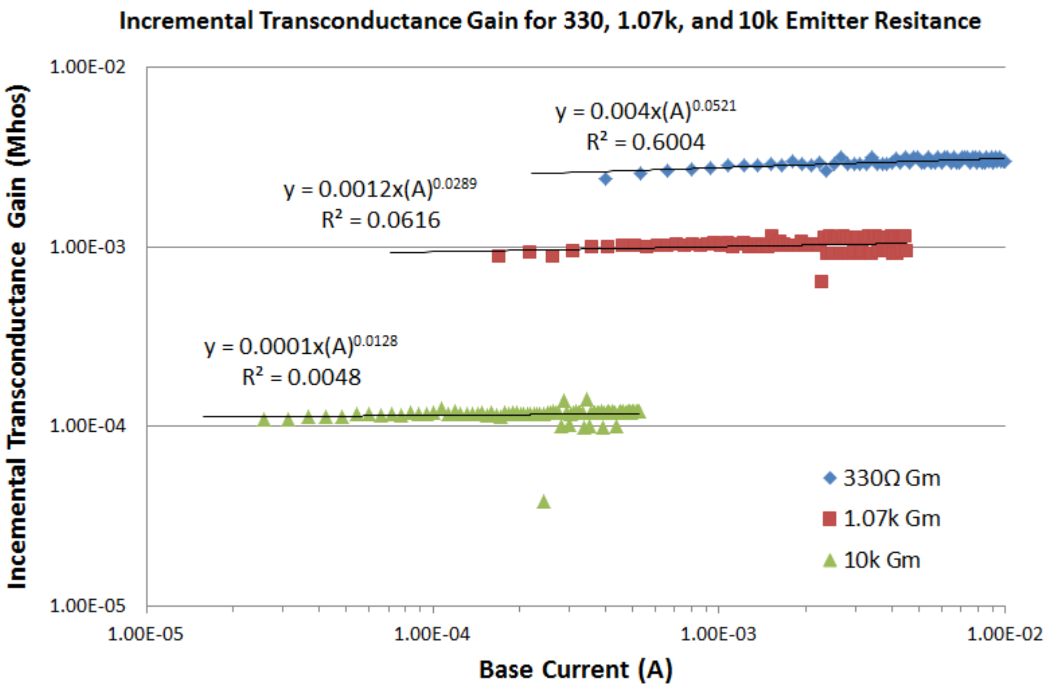

Figure 10: Incremental Transductance Gain for .

2.3 Discussion

The fits of the linear resistor plots are extremely close, with R^2 values of approximately 1.

In the log-log plot of the incremental resistance, the R^2 values of the fits are not too close to 1 due to the fact that the data is scattered, but they still give us a good approximation of the gain.

Likewise, the log-log plot of the incremental transconductance gain has lower R^2 values, but they still give us adequate approximations.

3 Experiment 3:

3.1 Experimental Setup

An emitter-follower circuit was built using a $10k\Omega$ resistor, and the output (emitter) voltage was measured as the input (base) voltage was swept from $0-5$V.

3.2 Results

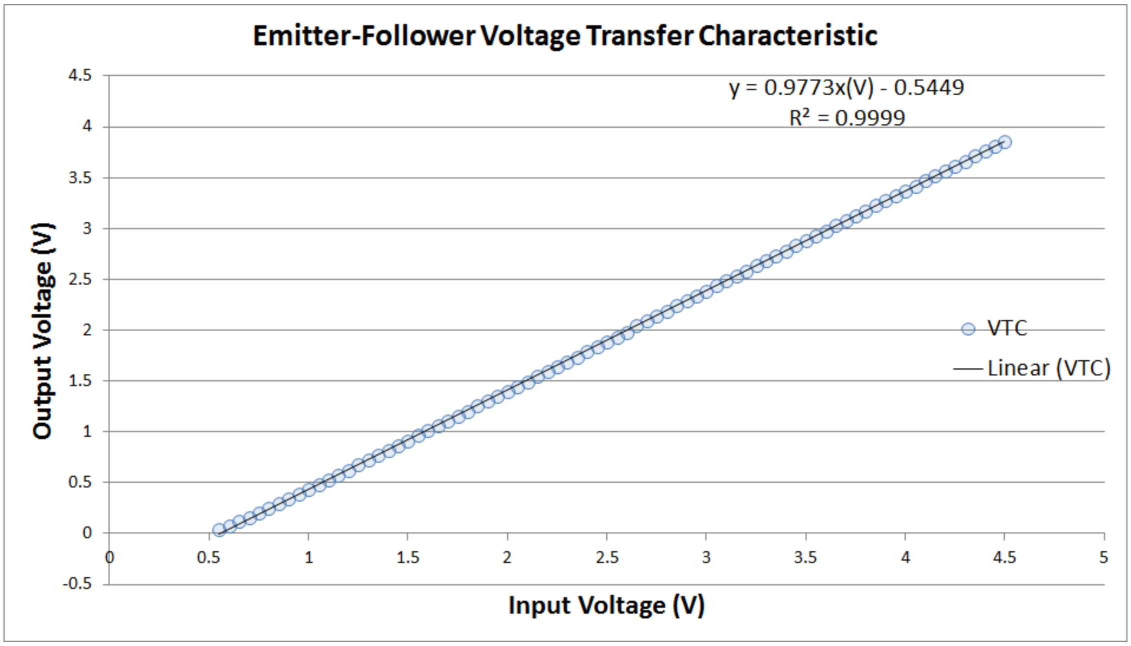

Figure 11: The voltage transfer characteristic of an emitter-follower circuit.

The theoretical fit in figure 11 suggests that the slope is approximately 1, meaning that the gain is close to unity. The fit's intercept is approximately 0.55 V. Because the voltage plateaued at $0 < \text{Vin} < 0.55\text{V}$ and $4.5 < \text{Vin} < 5\text{V}$, due to the 0.55 V lag and possibly the laptop USB's inability to source so much voltage, the data was removed during the trendline fit.

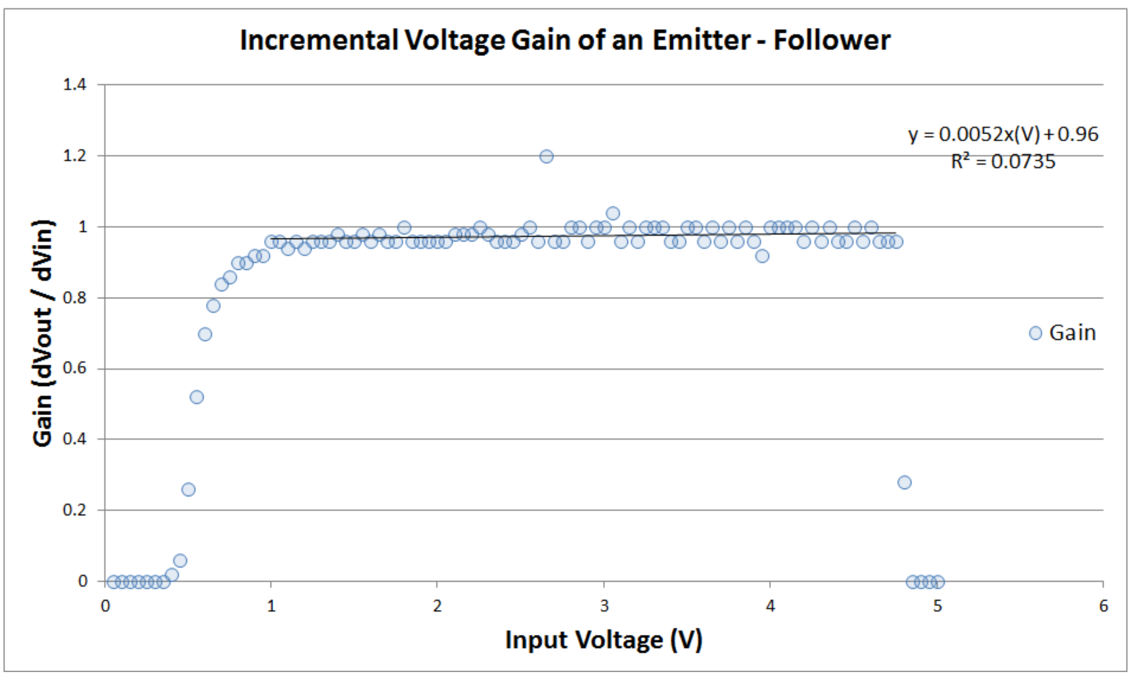

Figure 12: The incremental voltage gain of an emitter-follower circuit.

3.3 Discussion

The theoretical fit in figure 11 has an R^2 value of 0.999, matching the data quite well. From the fit, we see that the slope of the transfer characteristic is approximately 1 (the gain is unity), and the intercept is approximately 0.55 V – the output voltage lags behind the input voltage by approximately $.5 - .6$V. The difference (lag) between these two voltages could be explained as being due to the turn on voltage of the BJT (approximately .6V).

The fit in figure figure **??** has a much lower R^2 value, but the fit still suggests that the gain is essentially unity.

4 Experiment 4: Inverter Voltage Transfer Characteristics

4.1 Experimental Setup

Three additional resistors were chosen to match the resistor used in experiment 3; the final values were 10k, 20k, 30k, or 40k. Each of these resistors were connected in turn between the collector and rail to create a common-emitter amplifier (inverter). For each resistor, the voltage transfer characteristic was estimated via theoretical fit against the experimental data.

4.2 Results

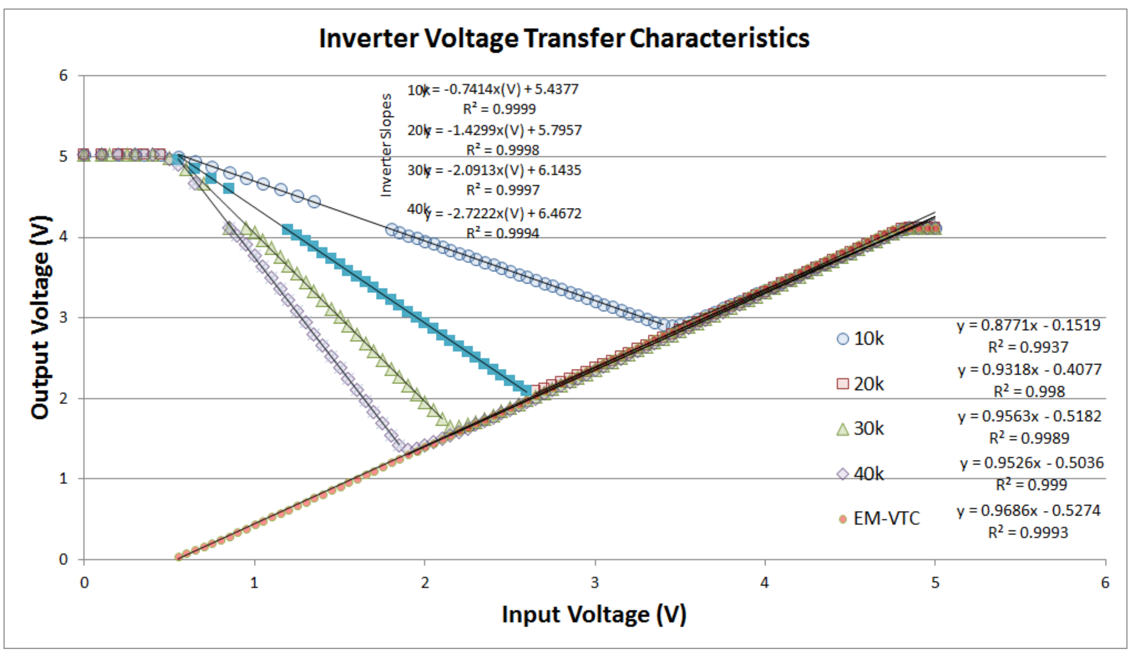

Figure 13: The voltage transfer characteristic of a common-emitter amplifier circuit.

From the data in figure 13, we see that the voltage is amplified and inverted depending on the collector resistor value. This behavior stops as soon as V_{in} increases above V_{out}; once V_{in} passes this threshold, the circuit behaves as the circuit from experiment 3, with a gain of approximately unity.

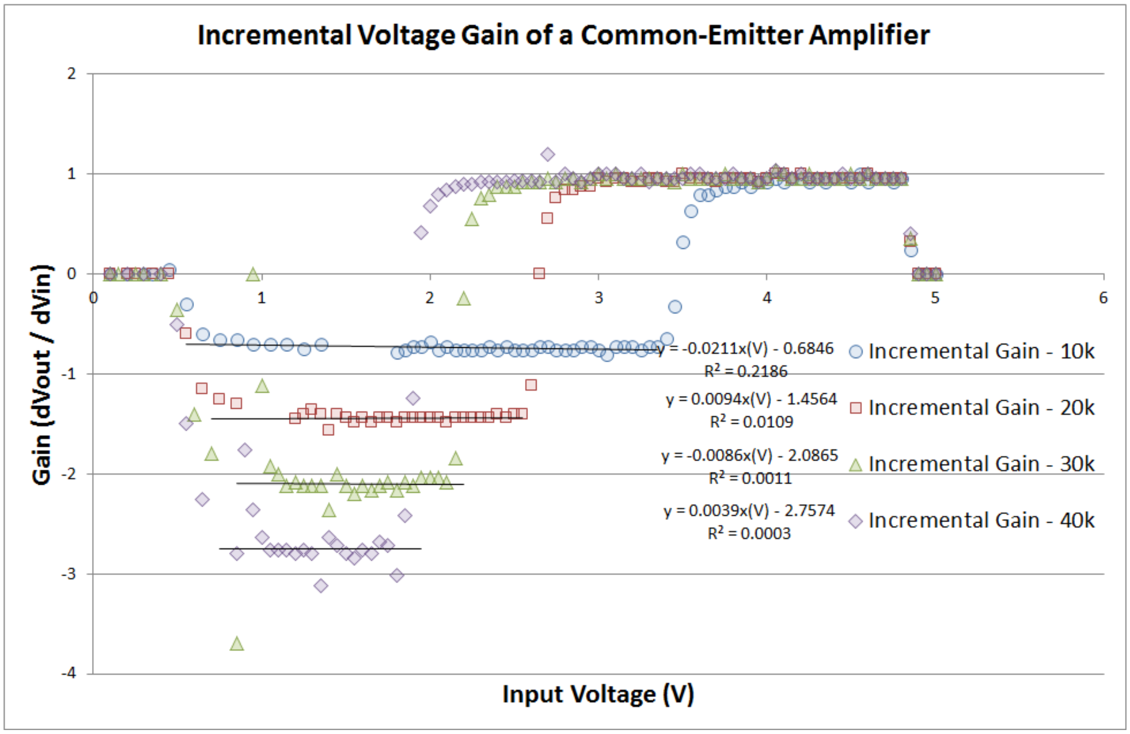

Figure 14: The incremental voltage gain of a common-emitter amplifier circuit.

Based on the theoretical fits of the data in figure 14, we can see that the incremental voltage gain, depending on the resistor used, is as follows:

- For $10k\Omega$, a gain of -0.685,
- For $20k\Omega$, a gain of -1.456,
- For $30k\Omega$, a gain of -2.086,
- For $40k\Omega$, a gain of -2.757. The resistor values are in increments of $10k\Omega$, and the gain increases in increments of approximately .7.

4.3 Discussion

The theoretical fits of the voltage transfer characteristic data have very high R^2 values, indicating that the fits are very accurate. The behavior of the amplifier

While the theoretical fits of the voltage gain data have very low R^2 values, they still give us a good idea of the incremental voltage gain of the circuit. They also demonstrate that as the resistance increases in consistent increments, the gain decreases in the same way.

5 Report Discussion

In this lab, we were able to characterize BJTs in a few common circuits, such as emitter-followers, common-collector amplifiers, and common-emitter amplifiers.

We learned that emitter-followers are essentially amplifiers with gains of unity, but with a short lag dependent on the turn-on voltage of the BJTs. These amplifiers would be useful for things such as voltage buffers, to prevent loading.

We also learned that common-emitter amplifiers, or inverters, only "invert" their input when the collector voltage is greater than the base voltage. Our results also suggest that unlike the emitter-follower, the gain (while "inverting") is not unity, but instead directly proportional to the collector's resistor value.