Introduction to Microcircuits
Lab 9: A Current-Mirror Differential Amplifier

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1 Experiment 1

In this experiment, we constructed a current-mirror amplifier with an nMOS differential pair, two pMOS current mirros, and an nMOS current mirror. We set the bias voltage of the differential pair so that the bias current is on the order of microamps — moderate inversion. Then, we connected the inverting input to a constant voltage source and swept the noninverting input from one rail to the other, measuring V_{out} for three values of voltage on the inverting input. Below, in figure 1, we plotted all three voltage transfer characteristics. Compared to lab 8's simple differential amplifier, the behavior of this differential amplifier is much more sharp.

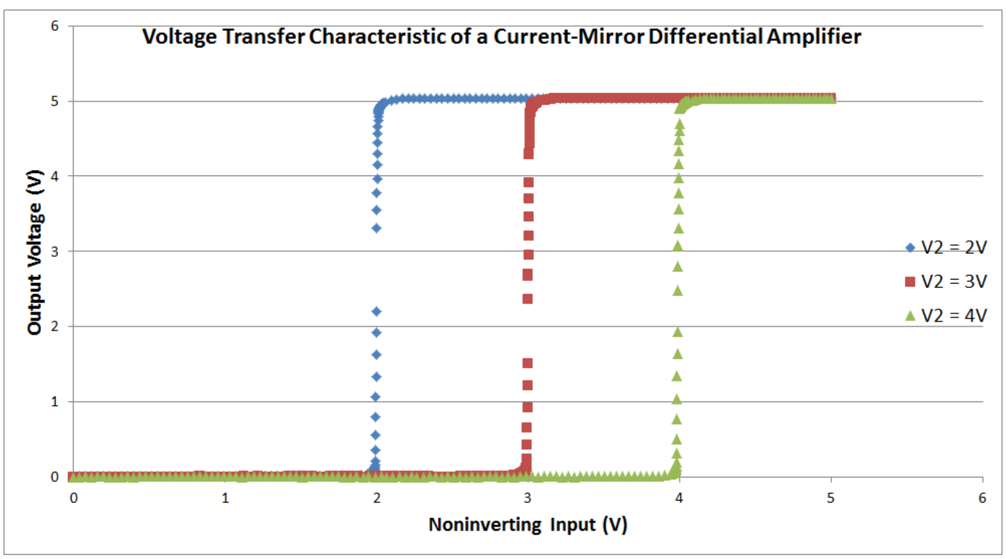

Figure 1: The voltage transfer characteristic of a current-mirror differential amplifier, as the inverting input was set at three different values; 2V, 3V, and 4V.

2 Experiment 2

In this experiment, we chose a single value for the inverting input, and swept the noninverting input around it, while measuring V_{out}. The differential-mode voltage gain of this circuit was extrapolated from the slope of the line fit to the steep part of the curve of this plot, as shown in figure 2 below. The slope of the fit is approximately 273.14. We will compare this approximation of the voltage gain to once calculated with the incremental output resistance and transconductance gain as written in the following paragraphs.

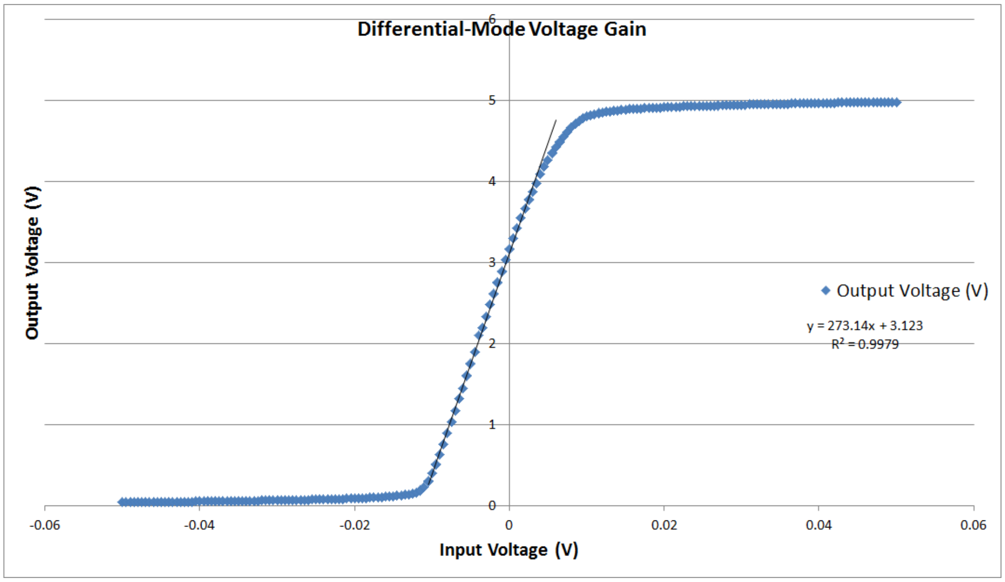

Figure 2: The best-fit approximation of the differential-mode voltage gain of a current-mirror differential amplifier.

Next, we set the differential-mode input voltage to zero and measured the current flowing into the output as V_{out} was swept from rail to rail. We then fit a line to the shallow part of this CV characteristic to determine the incremental output resistance of the circuit, as shown in figure 3 below. The value we extracted for the output resistance, R_o, is equivalent to the inverse of the slope;

$$R_{out} = \frac{1}{2.6041 * 10^{-7}} = 3.8400 * 10^{6}\Omega$$

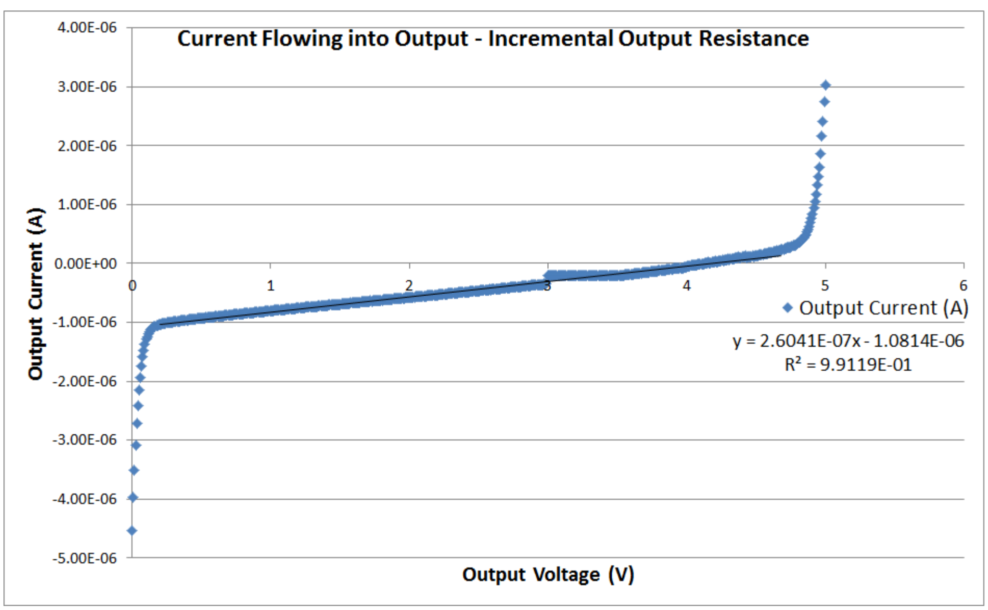

Figure 3: The current-voltage characteristic of the current-mirror differential amplifier.

Next, we fixed the output voltage and measured the current flowing out of the amplifier as the differential voltage was swept around zero. We fit a straight line to the resulting curve to extract the incremental transconductance gain, as shown in figure 4 below. As can be seen in the plot, the extracted value for the incremental transconductance gain is;

$$G_m = 5.8823 * 10^{-5} \mho$$

The value is positive rather than negative — the data in the graph is flipped, due to the way that we measured the output current of the circuit. And the limiting values are approximately $7.59 * 10^{-6}$ A and $-7.193 * 10^{-6}$ A for the positive and negative directions, respectively.

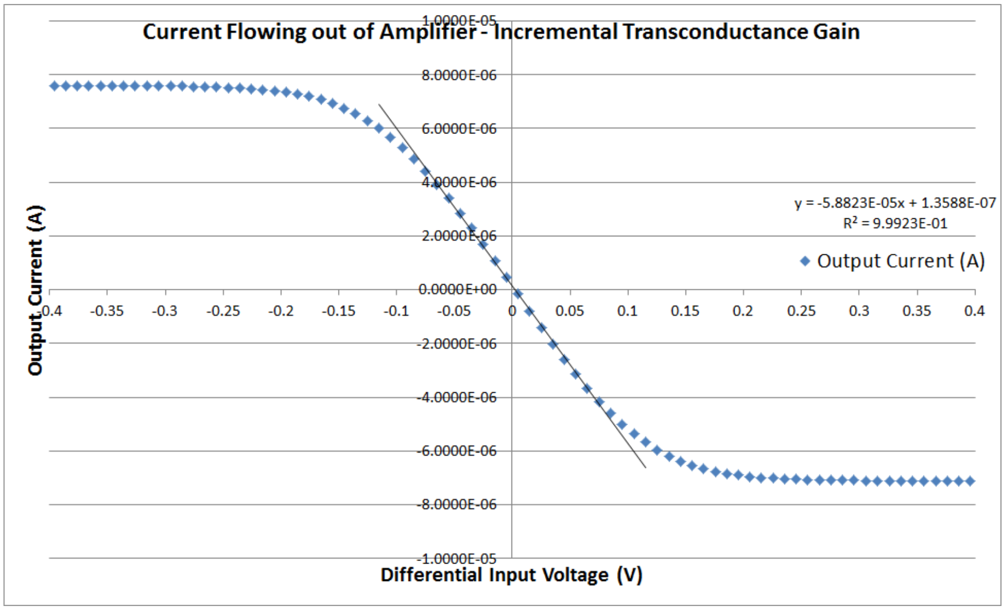

Figure 4: The best-fit line of the incremental transconductance gain of the current-mirror differential amplifier. Note that this graph is flipped (bias was flipped when measuring).

From our incremental output resistance and our incremental transconductance gain, we computed the differential-mode voltage gain:

$$A_{dm} = \frac{\partial V_{out}}{\partial V_{dm}} = R_{out} G_m$$

$$A_{dm} = 3.8400 * 10^6 \Omega * -5.8823 * 10^{-5} \mho = 225.880$$

This is on the same order of magnitude of our "measured" differential-mode voltage gain from the best fit line, which was 273.14. The differential-mode gain from this current-mirror differential-amplifier is slightly higher than the gain we saw in the simpler amplifier in lab 8, which was 170.311.

3 Experiment 3

The amplifier's inverting input was connected to the output to form a unity-gain follower, and a 1nF capacitor was connected from the output to ground in order to analyze the step response.

First the step response was measured with a square-wave amplitude of 100mV with an offset of 2V. Both the input waveform and the buffered output are shown in figure 5. The response is fairly symmetrical, with similar but not identical time constants. The amplifier does exhibit approximately linear behavior. Since the time constant τ of an RC circuit is simply $\tau = RC$, then $\tau = \frac{1}{G_m} C = 1.7E - 5$ where G_m is the transconductance gain calculated in experiment 2 and C is the capacitance at the output, which is 1nF. This calculated τ is quite close to the time constants calculated from the data in figure 5

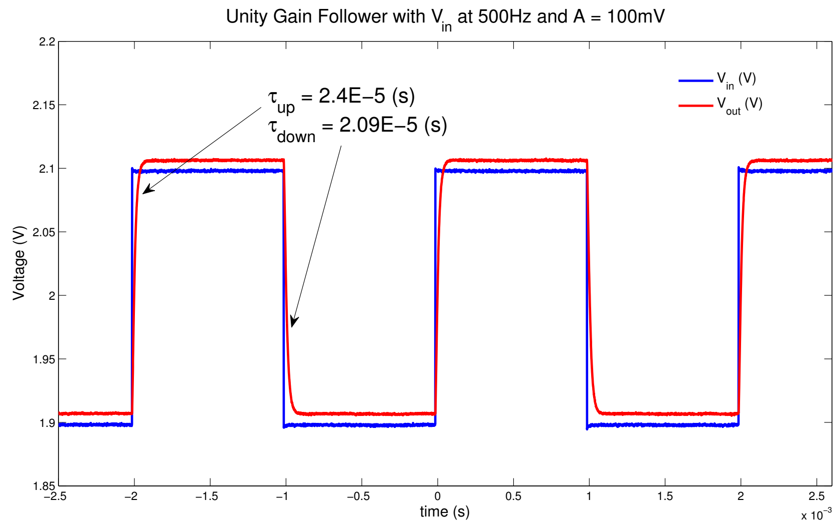

Figure 5: The step response of the circuit as a unity gain follower with V_{in} at 500Hz and amplitude of 100mV.

Next the step response was measured with a square-wave amplitude of 1V with an offset of 2V. Both the input waveform and the buffered output are shown in figure 6. The response is is somewhat symmetrical qualitatively, but the slew rates are different by about a factor of 1.5.

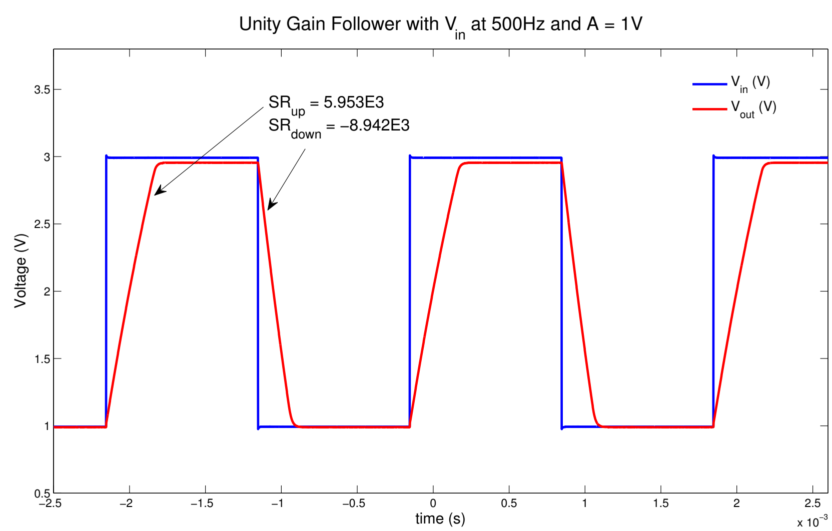

Figure 6: The step response of the circuit as a unity gain follower with V_{in} at 500Hz and amplitude of 1V.

4 Discussion