Lab 6: MOS Differential Amplifier

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Experiment 1: Voltage Transfer Characteristics

Process

We constructed a differential amplifier with an nMOS differential pair and a pMOS current mirror and set the bias voltage accordingly. We connect V_2 to a constant voltage source and sweep V1 from ground to V_{DD}, measuring V_{out} for $V_2 = 1.25V, 1.35V, 1.45V$.

Analysis

When $V_1 > V_2$ the output current would increase as the non-inverting input is dominant. V_{out} will therefore continue to increase until the transistor M_4 leaves the saturation region. The point We expect the output to be pinned at V_{DD} after a specific threshold for each value of V_2.

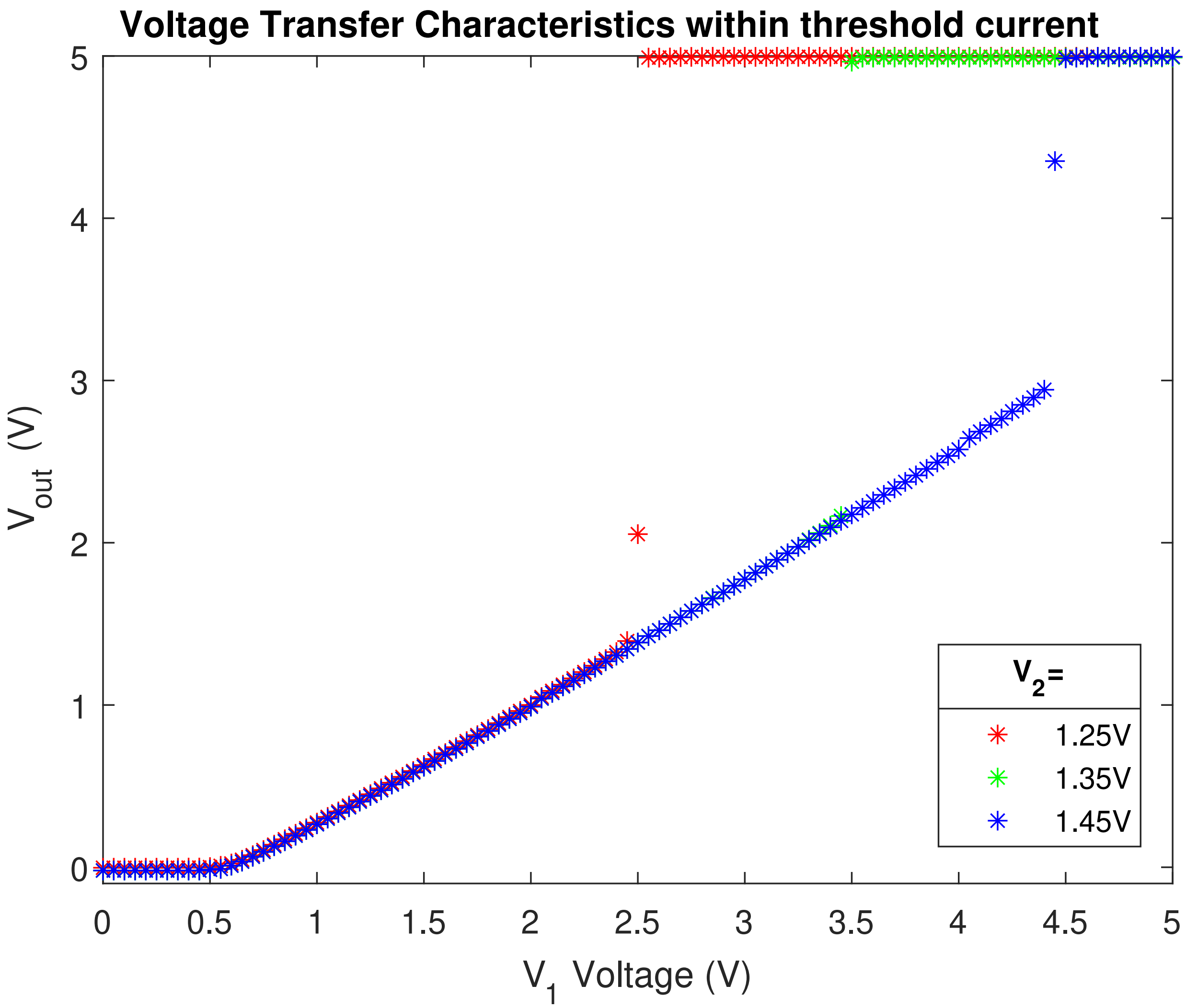

Figure 1: Voltage-transfer Characteristic for different values of V_2 at within threshold current. We can see that for all three values of V_2 when V_{out} is below $V_{DD} - V_{SD}, sat$ but above $\kappa(V_1 - V_b) - V_{DS}, sat$, the relationship between V_1 and V_{out} is linear, but when not in these bounds, the gain is zero and the output is pinned at either V_{DD} or ground. This fits our analysis of the differential pair as per the prelab and is expected. The minimal points during the transition region out of saturation is a result of us not taking enough points at this interval.

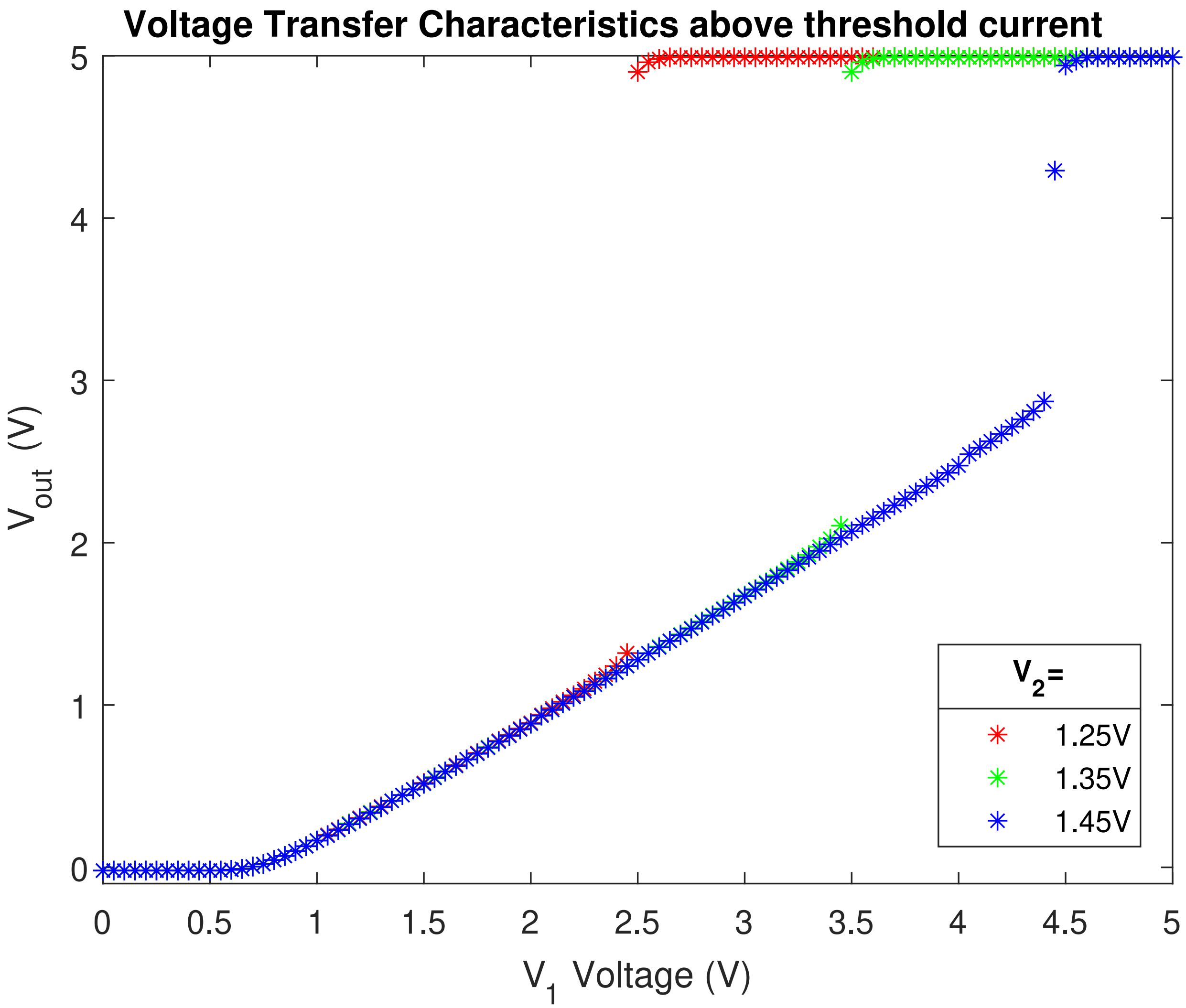

Figure 2: Voltage-transfer Characteristic for different values of V_2 at within threshold current. This plot follows similar behaviour to Figure 1, but we can see that the relationships are not all as equal to each other as they were when the circuit was within threshold current.

Experiment 2: Transconductance, Output Resistance, and Gain

Process

There were multiple parts to this experiment. First, we swept V_1 around a single value of V_2 and measured V_{out}. We then set the differential-mode input voltage to zero and measured the output current of the amplifier I_{out} while sweeping V_{out} from one rail to the other. We then fixed the output voltage to 1.25V and measured the current flowing out of the amplifier I_{out} as V_1 was swept around V_2.

Analysis

We can calculate the incremental differential-mode voltage gain of the circuit by taking the extracted parameters from figures 4 and 5. We are using the following relationship:

$$A_{dm} = R_{out} G_m$$

Where:

- A_{dm} is the incremental differential-mode voltage gain
- R_{out} is the incremental output resistance, calculated as $\frac{\partial V_{out}}{\partial I_{out}}$
- G_m is the incremental trans-conductance gain, calculated as $\frac{\partial I_{out}}{V_{dm}}$

In Figure 4, a straight line was fitted to the shallow part of the output current–voltage characteristic, and the reciprocal of this gradient was extracted as R_{out}.

In Figure 5, a straight line was fitted to the curve around where $V_1 = V_2$, and the gradient of this line was extracted as G_m.

Calculating A_{dm} using these extracted parameters and Equation gives:

$$A_{dm} = -0.00024415 \times 736.53 = -0.1798 \tag{1}$$

This is not at all close to the value of A_{dm} taken from the VTC in Figure 3.

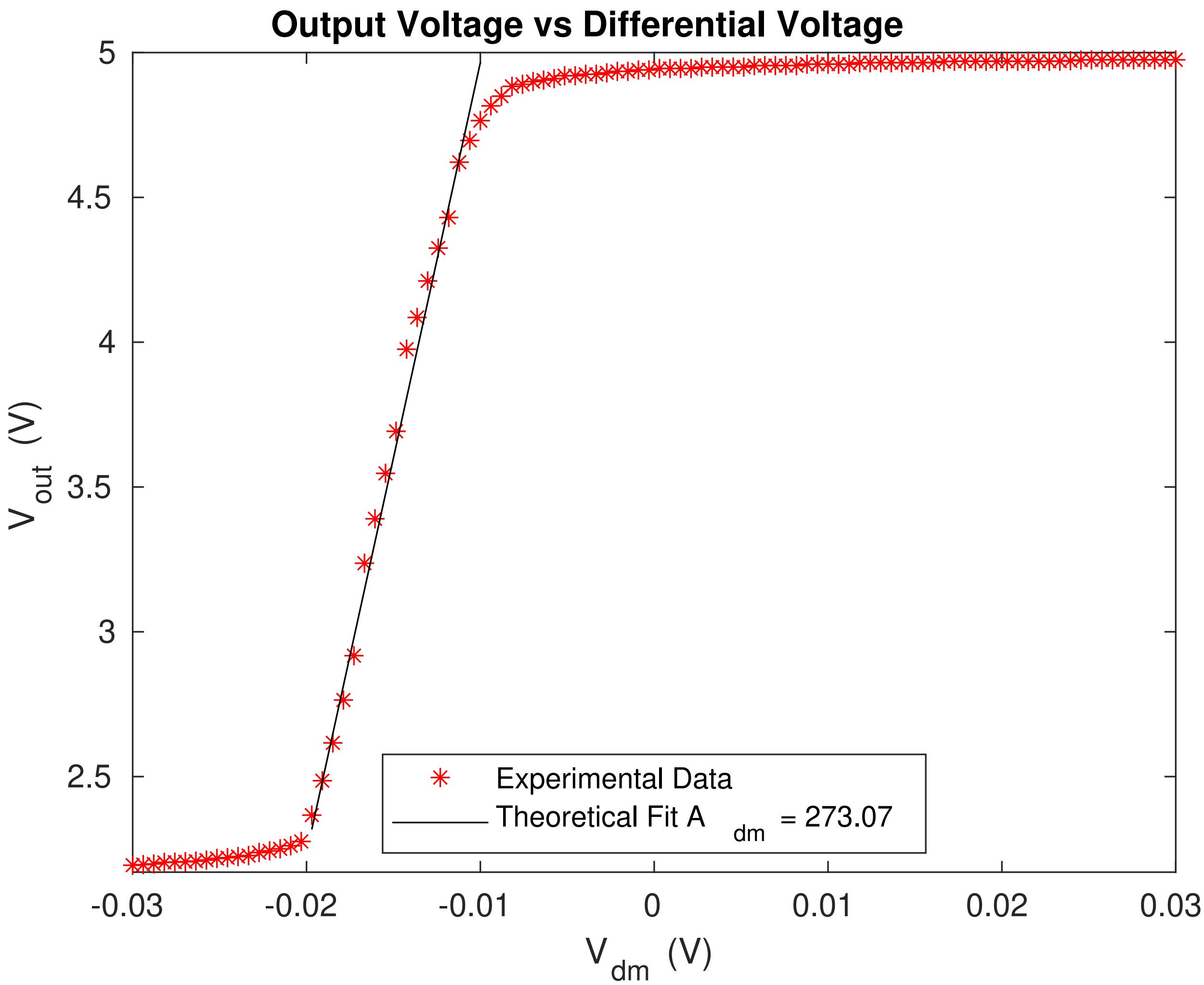

Figure 3: V_{out} vs V_{dm}. Line was fit to the steep part of the curve to determine the differential voltage gain as per the analysis, yielding a value of 273.07.

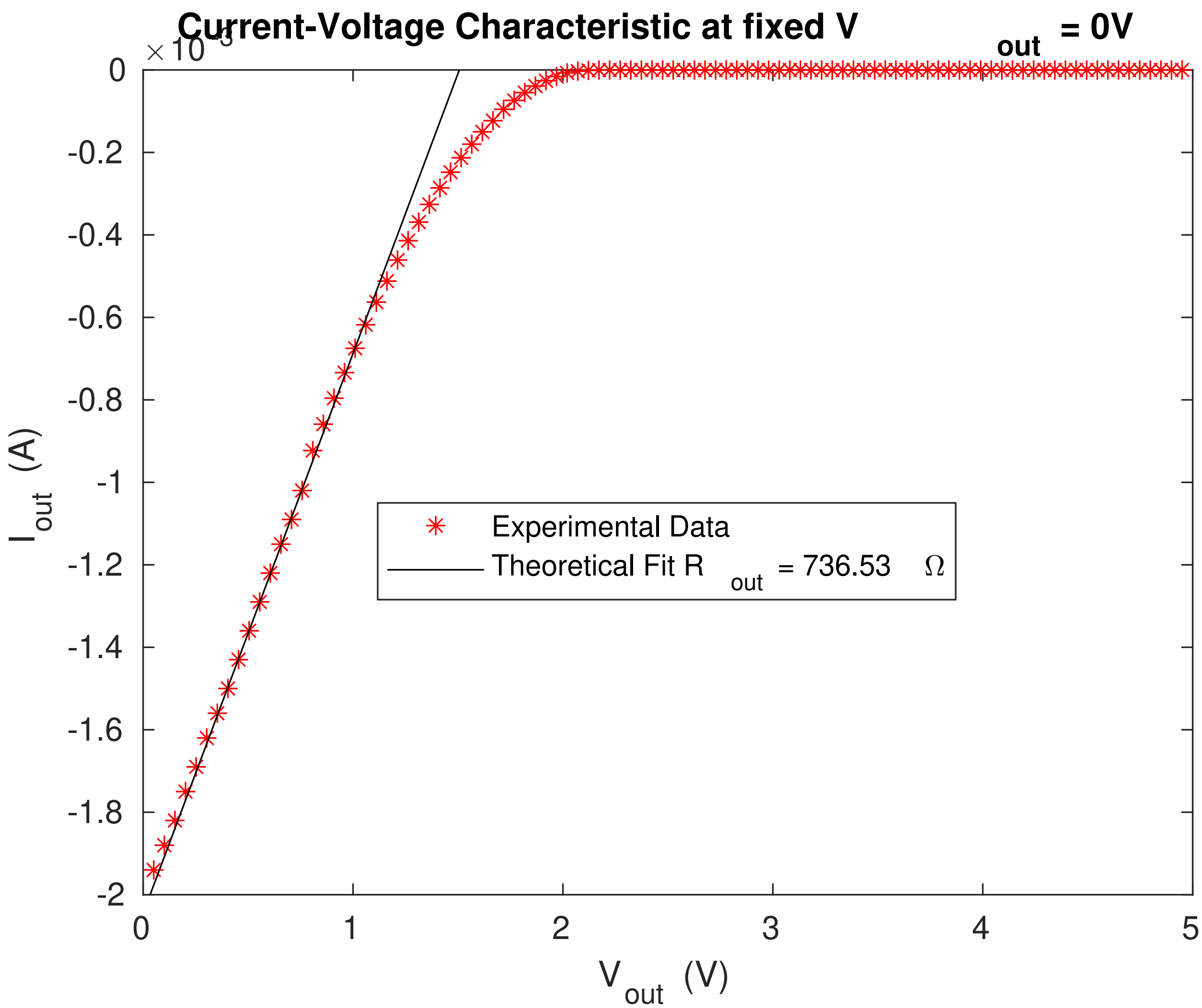

Figure 4: I_{out} vs V_{out}. R_{out} was calculated according to the analysis and we calculated a value of around 736.53Ω based on our data. The accuracy of this value is skewed by the fact that the theoretical fit does not capture the full diagonal, but when extending the points used to fit the equation the results were the same.

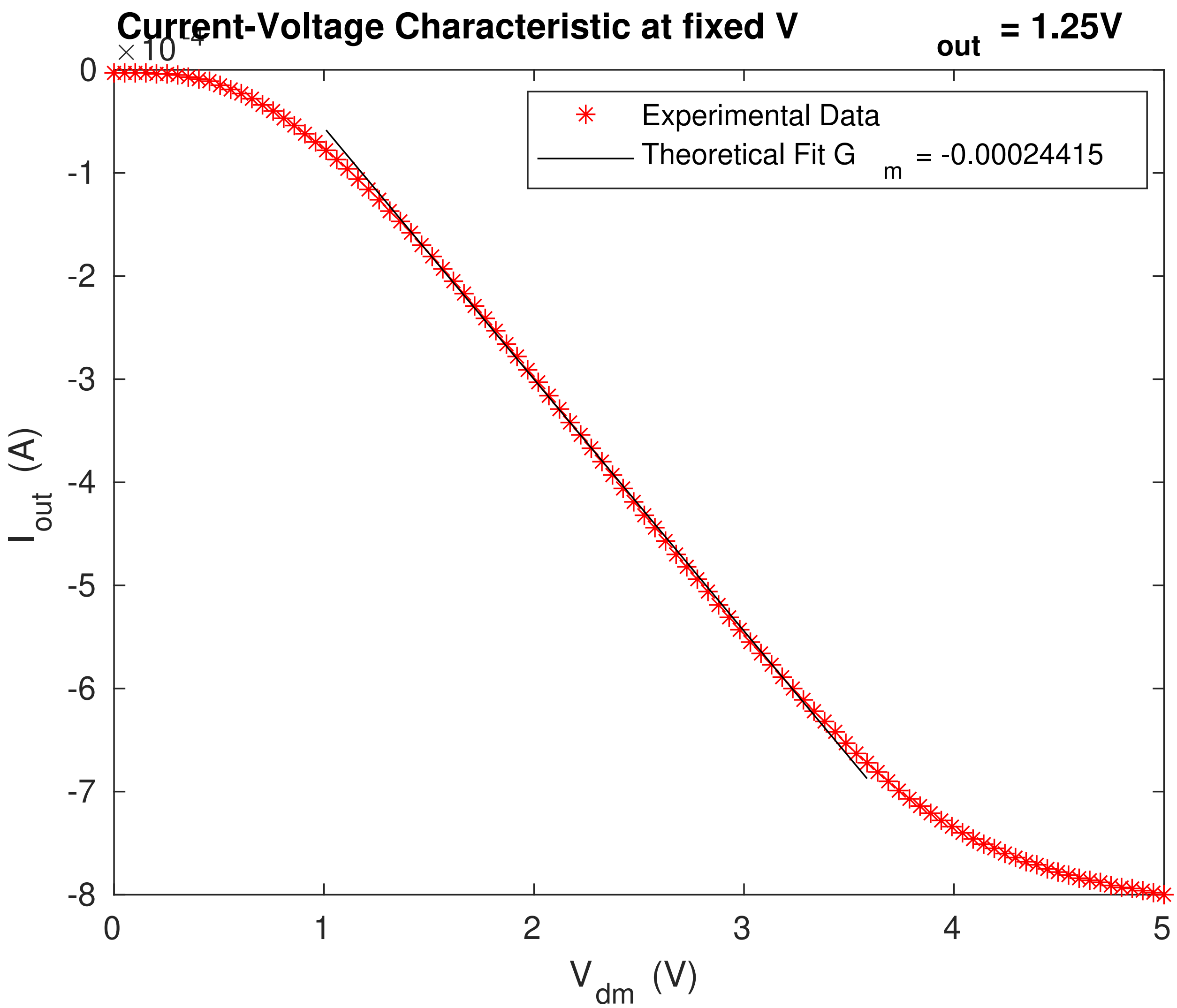

Figure 5: I_{out} vs V_{dm}. G_m was calculated from the gradient of the theoretical fit line as per the analysis, yielding a value of -0.00024415 for the incremental trans-conductance gain. This value being incredibly small is due to the line fit choosing the dense linear relationship and ignoring the rest of the shape of the curve, the flatter the line is, the larger this G_m value would be.

Experiment 3: Unity-Gain Follower

Process

We reconfigured our amplifier as a unity-gain follower by connecting the output to the inverting input terminal and swept V_{in} from 0 to 5 volts, measuring V_{out}.

Analysis

In a unity gain follower, the output is fed directly back to the negative input. This feedback ensures that the op-amp works to make its inverting input match with the non-inverting input. Since the inverting and non-inverting inputs are at the same voltage V_{in}, the gain of the VTC should be 1, and Figure 6 reflects this.

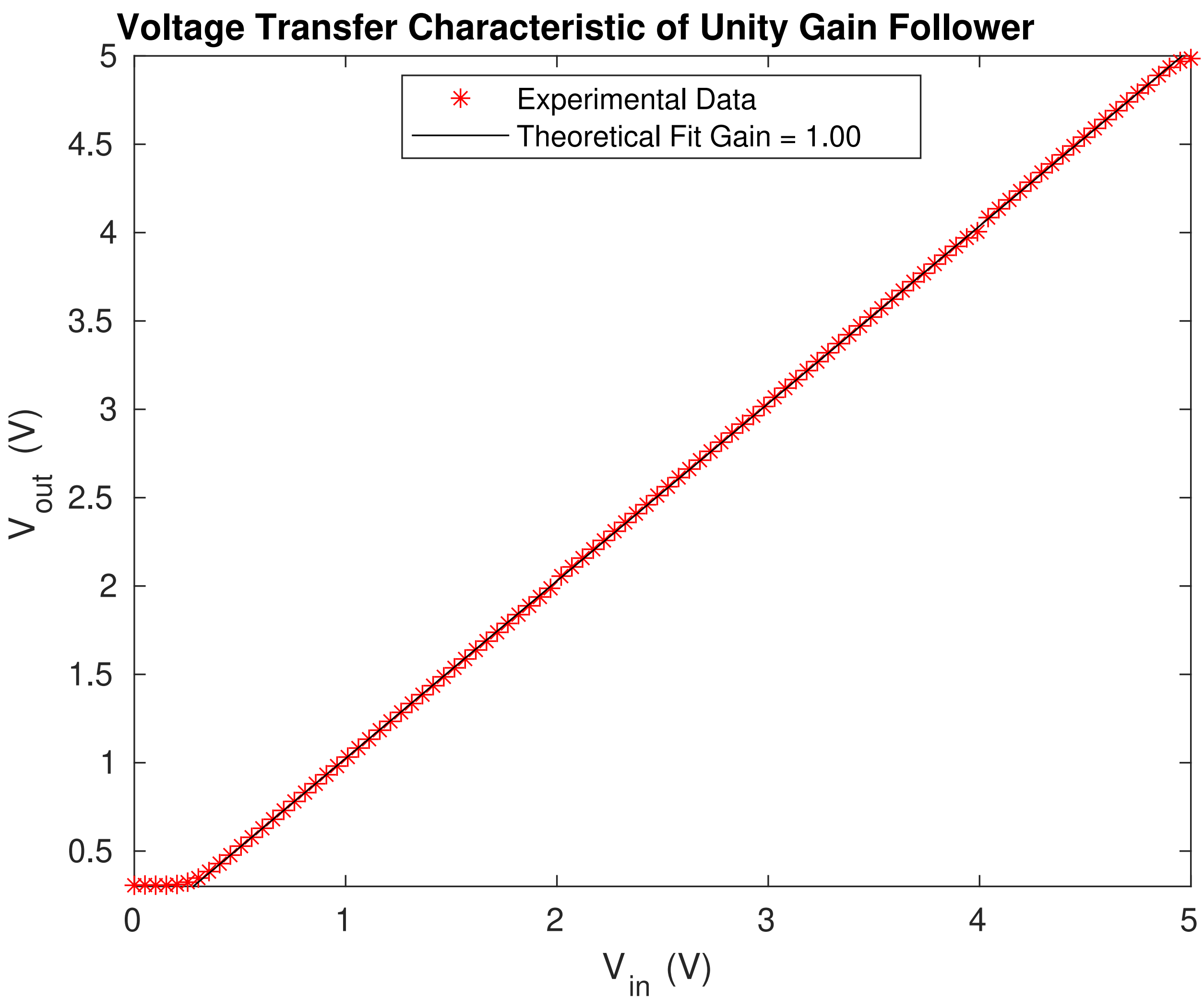

Figure 6: V_{out} vs V_{in} for unity gain follower. There is a small period, roughly between $V_{in} = 0$ and $V_{in} = 0.25$ where the gain is 0. There are many reasons that this could have occurred, such as the turn-on characteristics of the circuit, or the bias currents in the circuit. The gain was calculated as the gradient of the theoretical best fit $\frac{V_{out}}{V_{in}}$. We can see that it is indeed one and follows expected behaviour.