

ENGR2420 Lab 8 : A Simple MOS Differential Amplifier

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1 Experiment One : Voltage Transfer Characteristics

In this experiment, we constructed a differential amplifier with an nMOS differential pair and a pMOS current mirror. We set the inverting input, V_2 , to 2.5, 3.5, and 4.5 Volts, and we swept the value of the noninverting input, V_1 , between 0 Volts and 5 Volts and measured the output voltage of the circuit. We completed this procedure with the bias voltage of the differential pair, V_b , set to 0.65 Volts (at threshold) and 1.5 Volts (above threshold).

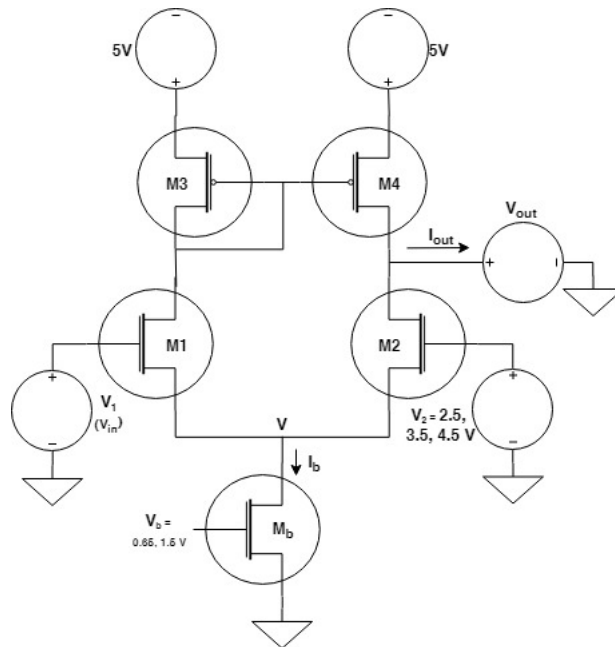


Figure 1: Experiment one schematic.

1.1 Results

We first measured the value of V_{out} with V_2 set to 2.5, 3.5, and 4.5 Volts with V_b set to 0.65 Volts so that the bias current was at the threshold.

Differential Amplifier Voltage Transfer Characteristic at Threshold ($V_b = 0.65$ Volts)

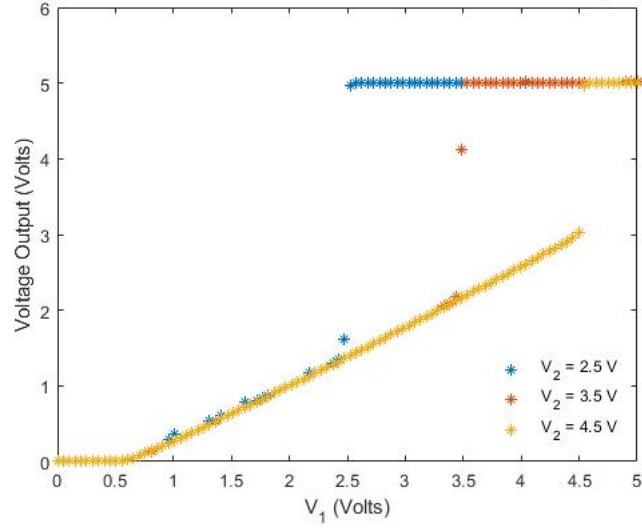


Figure 2: Voltage transfer characteristic, V_b at threshold.

We measured the value of V_{out} with V_2 set to 2.5, 3.5, and 4.5 Volts with V_b set to 1.5 Volts so that the bias current was above the threshold.

Differential Amplifier Voltage Transfer Characteristic above Threshold ($V_b = 1.5$ Volts)

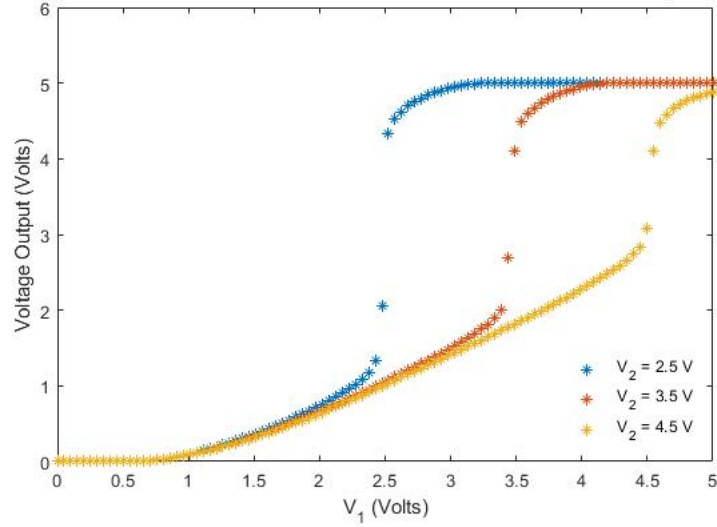


Figure 3: Voltage transfer characteristic, V_b above threshold.

1.2 Analysis

In theory, the differential amplifier's output voltage should remain close to ground when $V_1 < V_2$ until M_2 enters the Ohmic region, at which point V_{out} will equal V . After V_1 exceeds V_2 , the value of the voltage quickly rails to V_{dd} , or 5V. Our experimental data qualitatively reflects this general pattern in all three cases for both when the bias current is at and when it is above the threshold.

1.3 Discussion

When biased in strong inversion, the circuit displays similar behavior to when biased in weak and moderate inversion, where it quickly rails from low to high Voltage as V_1 increases and exceeds V_2 . While the actual transition is much more gradual in strong inversion than in weak inversion (because the voltage change lags when the bias voltage is above the threshold), the trend is the same.

2 Experiment Two : Transconductance, Output Resistance, and Gain

In this experiment, we measured the differential-mode voltage and output voltage to extract the differential-mode gain. Next, we measured the output current and output voltage to extract the incremental output resistance. Finally, we measured the differential-mode voltage and the output current to extract the incremental transconductance gain. To collect this data, we set $V_b = .65$ Volts and $V_2 = 3.5$ Volts and used the schematic seen in Figure 4.

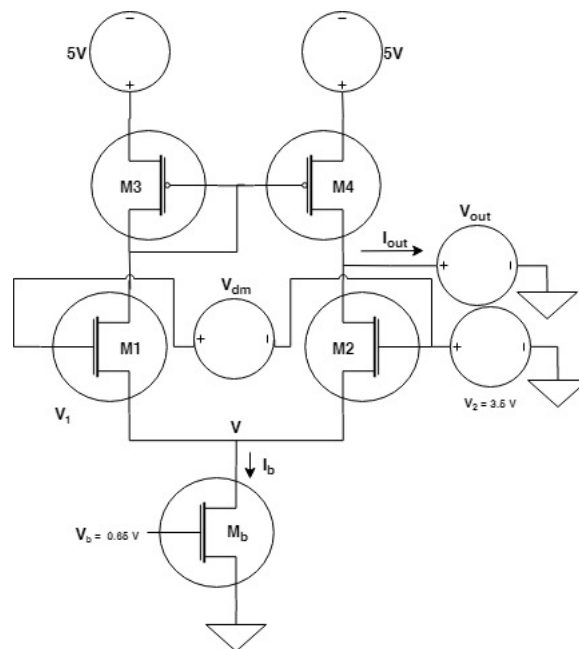


Figure 4: Schematic used to collect experimental data for Experiment 2.

2.1 Results

First, we plotted the differential-mode voltage vs. output voltage on linear axes. We found A_{dm} by fitting a line to the steep part of the curve and extracting the slope of that region. The differential-mode gain for the plot in Figure 5 is $A_{dm} = 138.6165$. Differential-mode gain does not have units because it is a ratio of voltages.

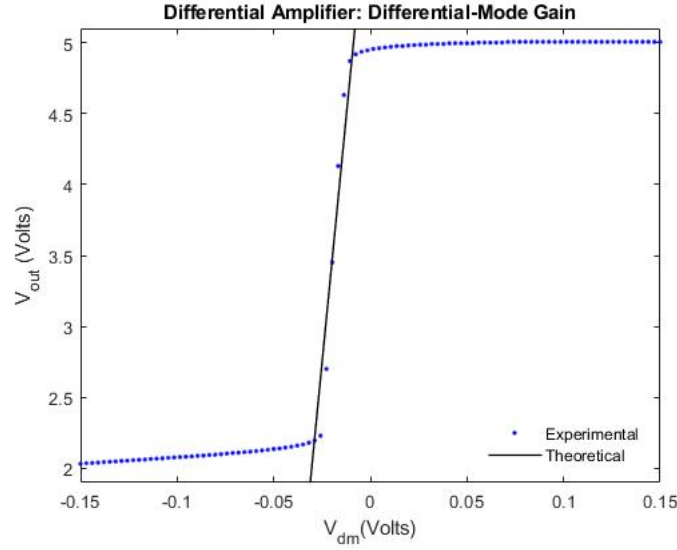


Figure 5: Output voltage vs. differential-mode voltage for the MOS differential amplifier

Next, we plotted the output current vs. output voltage on linear axes. We found the output resistance, R_{out} , by fitting a linear line to the shallow part of the curve and taking the inverse of the slope. The output resistance for the plot in Figure 6 is $R_{out} = 13.8843\text{M}\Omega$.

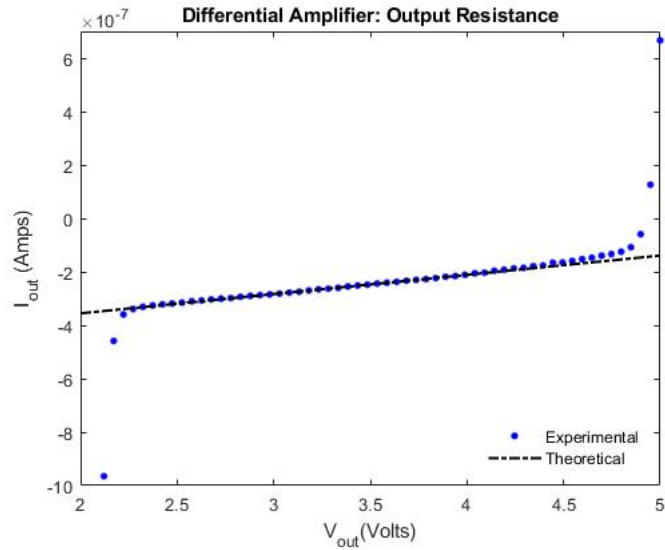


Figure 6: Output voltage vs. output current for the MOS differential amplifier

Finally, we plotted the differential-mode voltage vs. the output current. We found G_m by fitting a straight line to where $V_1 = V_2$ and extracting the slope. The incremental transconductance slope of the plot in Figure 7 is $G_m = 0.00001287\text{S}$.

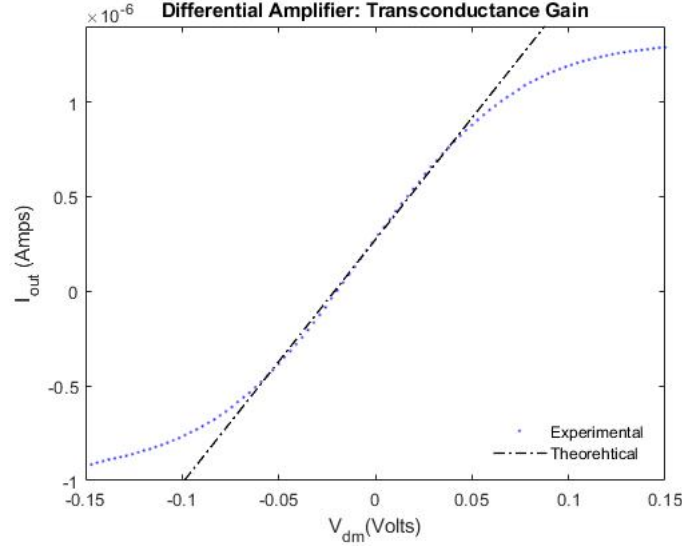


Figure 7: Differential-mode voltage vs. output current for the MOS differential amplifier

2.2 Analysis

The equation for incremental differential-mode voltage gain of the circuit can be calculated using the equation below.

$$A_{dm} = \frac{\delta V_{out}}{\delta V_{dm}} = \frac{\delta V_{out}}{\delta I_{out}} \times \frac{\delta I_{out}}{\delta V_{dm}} = R_{out} \times G_m$$

By using the values we extracted in Figure 6 and Figure 7, we were able to calculate the value of differential-mode voltage gain. Then we compared it to the value extracted from Figure 5. The extracted value of A_{dm} was 138.6165 and the value calculated was $A_{dm} = 178.7195$. To quantify the difference between those values we used the percent error equation and found a 28.93% error between our theoretical (extracted) and experimental (calculated) values.

$$\text{Percent Error} = \frac{|(\text{Theoretical} - \text{Experimental})|}{\text{Experimental}} \times 100$$

2.3 Discussion

The percent error between the calculated value and extracted value of A_{dm} for the data we collected was 28.93%. This percent error makes sense due to the way we extracted R_{out} and G_m . We used MATLAB's *polyfit* function on specific parts of the curves in Figure 6 and Figure 7 to extract the values. The range of data points used in the *polyfit* function were qualitatively found. This means there is some level of error between experimental and theoretical R_{out} and G_m . The error in those extracted values explains why the percent error between the calculated and extracted A_{dm} is almost 30%.

3 Experiment Three : Unity-Gain Follower

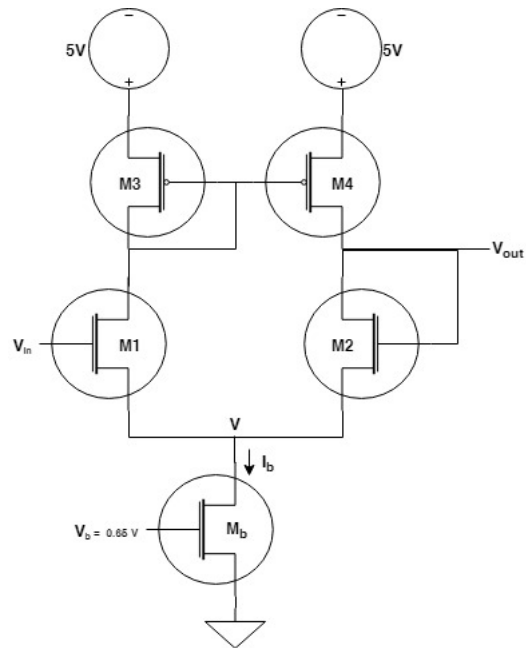


Figure 8: Experiment 3 schematic

3.1 Results

Figure 9 shows a plot of the output voltage as a function of the input voltage for our unity gain follower circuit.

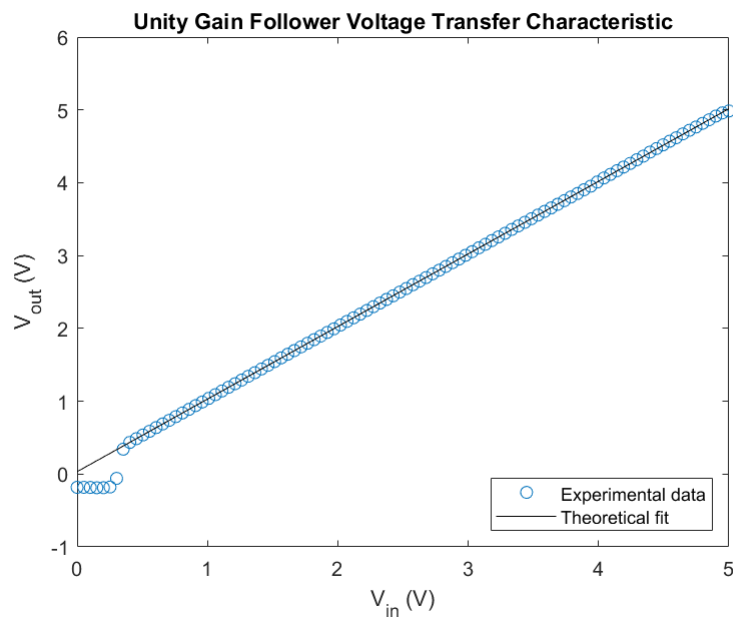


Figure 9: Transfer function for unity gain follower circuit.

Figure 10 shows a plot of $V_{out} - V_{in}$ as a function of V_{in} , which is the offset voltage of the unity gain follower.

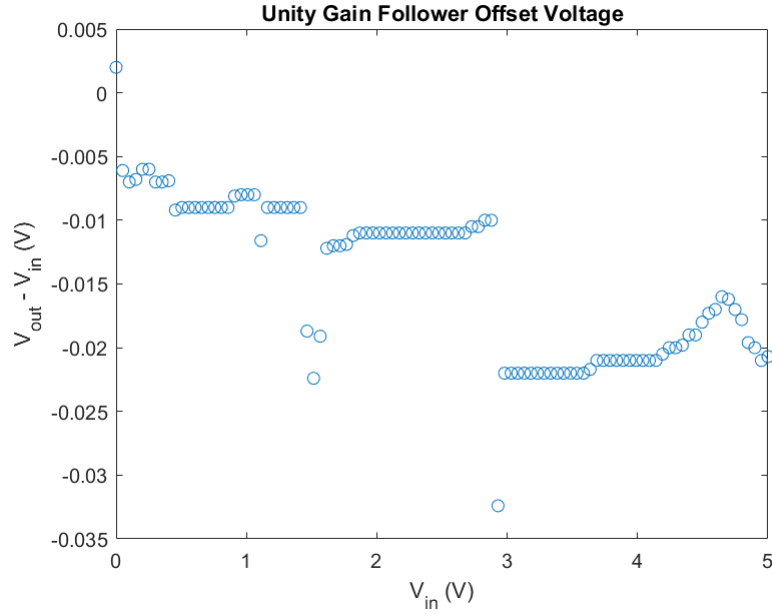


Figure 10: Voltage offset for unity gain follower circuit.

3.2 Analysis

For the voltage transfer characteristic, we fit a line to the linear part of the plot using the *polyfit* function in MATLAB to find the slope, and we found that the slope of the line is 0.9966. We would expect an ideal unity gain follower to have a slope of 1, so we calculated percent error with the following equation:

$$\text{Percent Error} = \left| \frac{1 - 0.9966}{1} \right| \cdot 100 = 0.34\%$$

For the offset voltage plot, we plotted $V_{out} - V_{in}$ as a function of V_{in} to see how the unity gain follower differs from unity at each point as we sweep V_{in} .

3.3 Discussion

The voltage transfer characteristic has an incremental gain of 0.9966, which is quite close to the expected value of 1. We calculated a 0.34% error.

The voltage offset has values that are all close to zero, with the largest value being $-0.0324V$. The absolute value of the voltage offset increases as V_{in} increases, which suggests that for higher input voltages the unity gain is less accurate.