Lab 4: Single-Stage Integrated Circuit Amplifier

EECS 170LB

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1 Introduction

Two MOSFET circuits are analyzed. First, a PMOS current mirror is considered. Bias simulations are run for different transistor widths to characterize the purpose of the current mirror and the effect that changing MOSFET widths has on the circuit's operation. Then, a common source amplifier with a PMOS current mirror is analyzed. It is properly biased before its gain is determined. Further simulations then characterize the voltage transfer characteristics and state space of operating points for the circuit.

2 PMOS Current Mirror

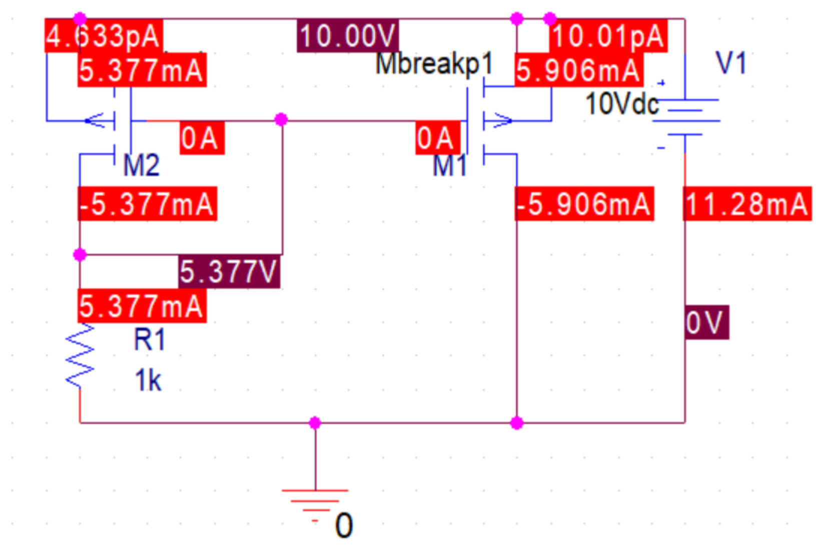

Figure 1: PMOS Current Mirror Bias Simulation

A current mirror takes an input current i_{in} and produces an output current i_{out} such that $i_{in} \approx i_{out}$. However, looking at figure (1), which current, whether it is the current through M_2 or M_1, is i_{in} or i_{out} is ambiguous. In order to determine which is truly the input current, a known current must be supplied through one transistor.

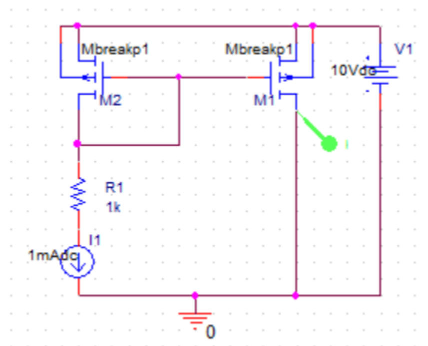

Figure 2: Known Current Supplied to M_2

Figure 3: i_{M2} versus i_{M1}

The green line is i_{M1}, and the red line is i_{M2}. They are plotted against the known current i_{M2}.

Across a range of current, $i_{M1} \approx i_{M2}$ when i_{M2} is the known current. Suppose that i_{M1} is fixed instead.

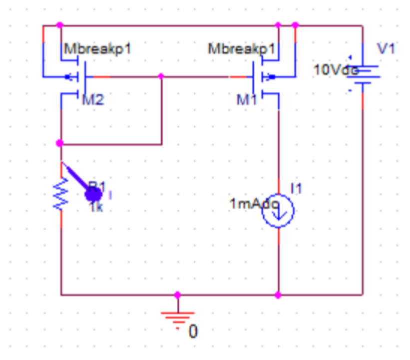

Figure 4: Known Current Supplied to M_1

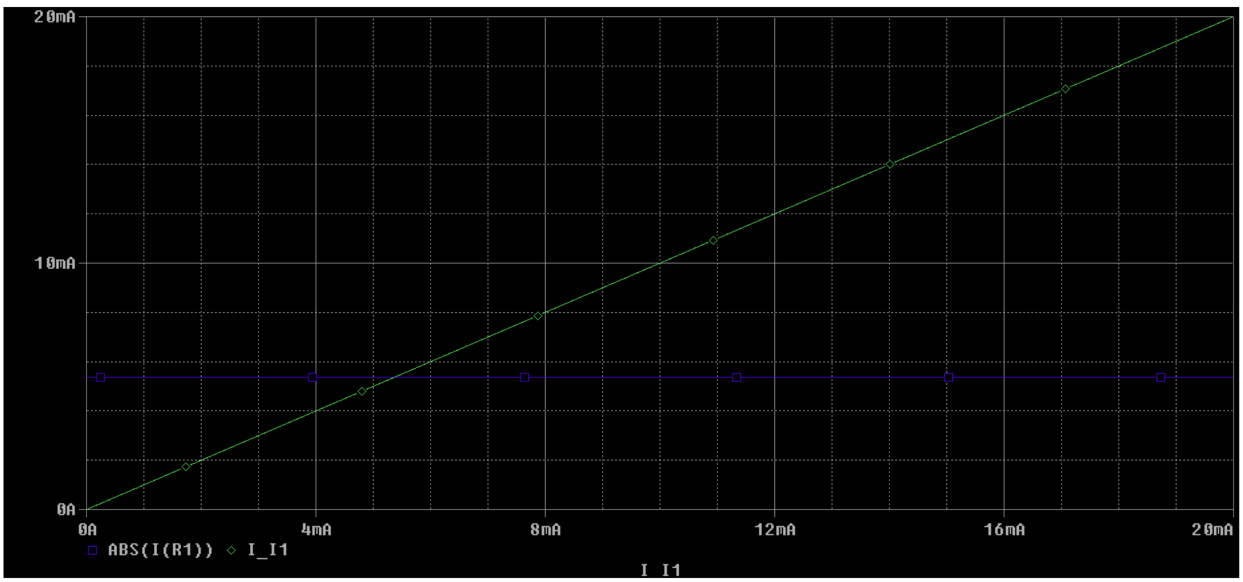

Figure 5: i_{M1} versus i_{M2}

The green line is i_{M1}, and the blue line is i_{M2}. They are plotted against the known current i_{M1}.

Here, i_{M2} remains constant, regardless of the value of i_{M1}. Therefore, setting the value of i_{M2} determines the value of i_{M1}, but setting the value of i_{M1} has no effect on the value of i_{M2}. So, the current through the transistor M_2 is the input current being mirrored (5.377mA), and the current through the transistor M_1 is the output current that mirrors i_{M2}.

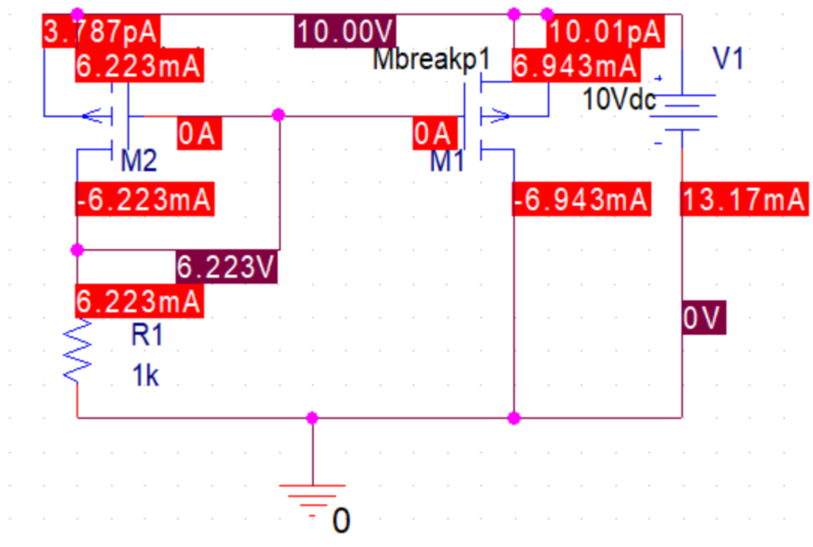

Figure 6: Doubling the Width of the MOSFETs

Suppose the width of each transistor, M_1 and M_2, is doubled. More current flows through each transistor. Widening transistors allows more charge to flow through a given channel in a fixed time interval. So, 6.223mA is the new current value being mirrored.

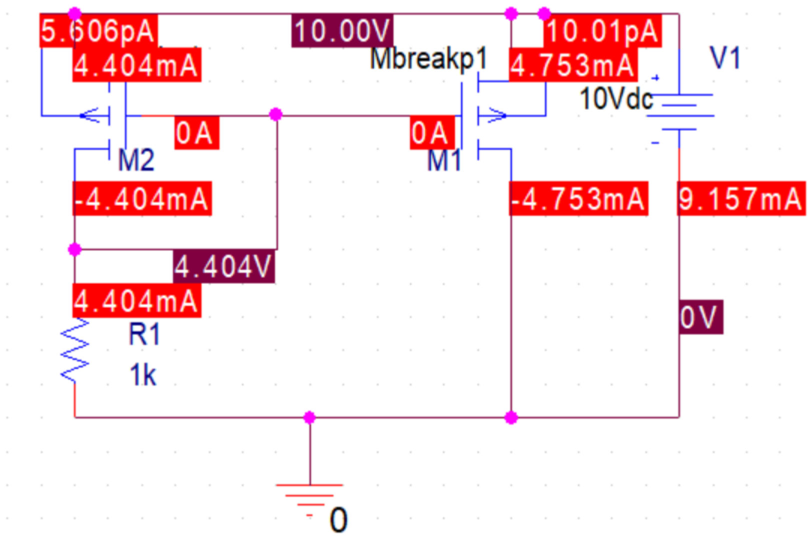

Figure 7: Halving the Width of the MOSFETs

If the width of each transistor is now halved, fewer charges are able to flow through a channel per unit time. So, less current flows through each transistor. 4.404mA is the new current value being mirrored.

Table (1) presents the mirrored current values at different $\frac{W}{L}$ ratios. Clearly, increasing $\frac{W}{L}$ for the transistors increases the mirrored current values because of the mechanics described above, namely that wider channels allow more charges to flow per unit time, leading to more current ceteris paribus.

Table 1: i_{in} at Various $\frac{W}{L}$ Values

Width-to-Length Ratio [unitless]	Mirrored Current [mA]
5	4.404
10	5.377
20	6.223

3 Common-Source Amplifier with PMOS Current Mirror

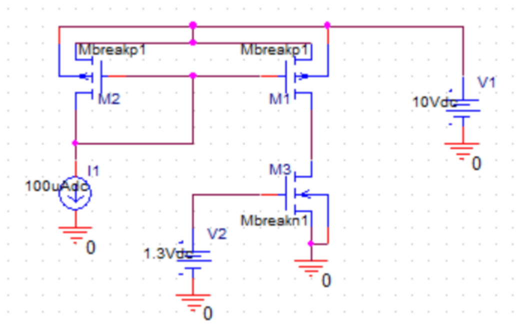

Figure 8: Common-Source Amplifier with PMOS Current Mirror

The input voltage V_2 is swept from 0V to 10V to determine the voltage transfer characteristic.

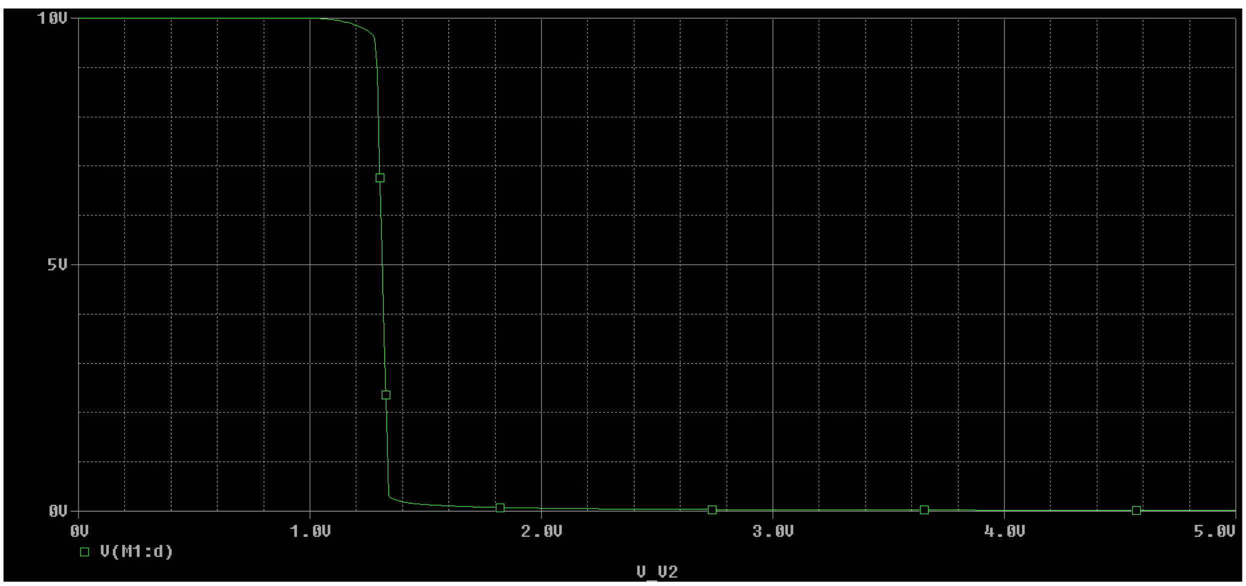

Figure 9: Voltage Transfer Characteristic

The amplifier is biased at about 1.3116V when V_{out} is biased at approximately $\frac{V_{DD}}{2} = 5$V. A bias simulation is run, and its results are used to calculate the small signal parameters in table (2).

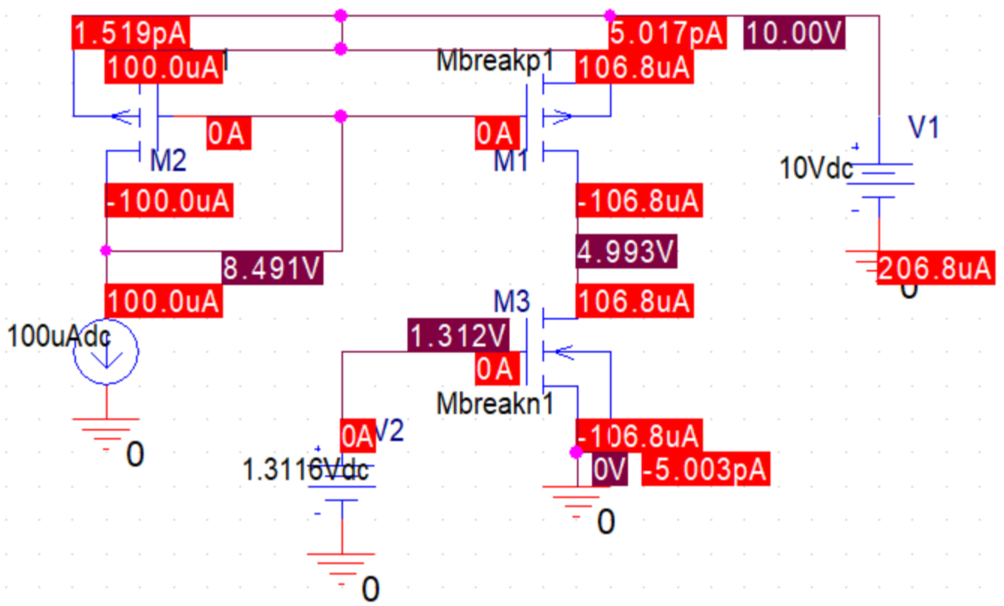

Figure 10: Figure (8) Circuit Bias Simulation

Table 2: Small-Signal Parameters of Figure (8) Circuit

Transistor	gm [mA/V]	ro [kOhm]
M1	0.38175	515
M2	0.38175	515
M3	0.624	514

After analyzing the small-signal model of the circuit in figure (8) using Kirchhoff's Current Law, the following equations are used to acquire the small-signal gain:

$$-0.624V_{in} - \frac{V_{out}}{514} + 0.38175V_{sg} + \frac{0 - V_{out}}{515} = 0 \tag{1}$$

$$\frac{V_{sg}}{515} + 0.38175V_{sg} = 0 \tag{2}$$

After solving equations (1) and (2), the gain is determined to be:

$$A = \frac{V_{out}}{V_{in}} \approx -160[\frac{V}{V}] \tag{3}$$

The low-frequency, small-signal gain can be determined through simulation as well. A 1V amplitude signal is applied. Therefore, its output voltage's numerical value at low frequencies times -1 is the gain since $|A| = |\frac{V_{out}}{V_{in}}| = |\frac{V_{out}}{1}| = |V_{out}|$.

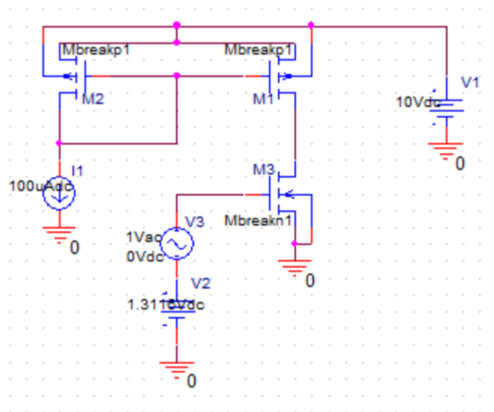

Figure 11: AC Signal Version of Circuit in Figure (8)

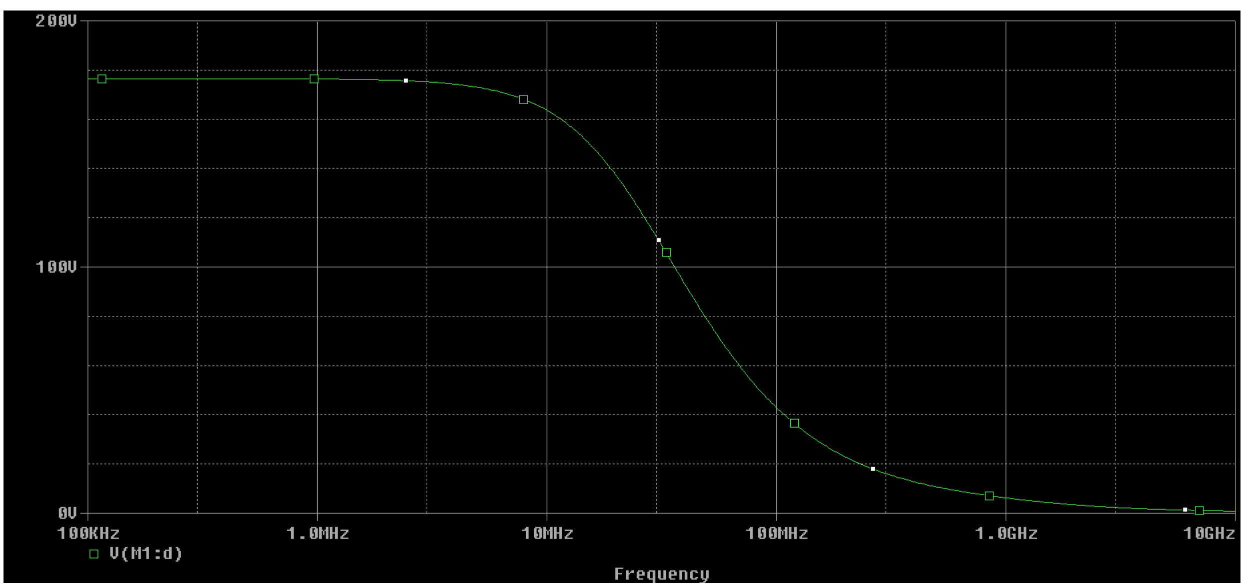

Figure 12: AC Sweep of Circuit in Figure (11)

From figure (12), the gain is estimated to be about $-177[\frac{V}{V}]$. This gain is a bit larger in magnitude than what is expected from the small-signal model of the amplifier. After turning off each SPICE model parameter one-by-one, none seems to be directly responsible for this increased gain. Some inner-working of the transistor model is likely different from the small-signal model used for the calculations, though the two are reasonably close together.

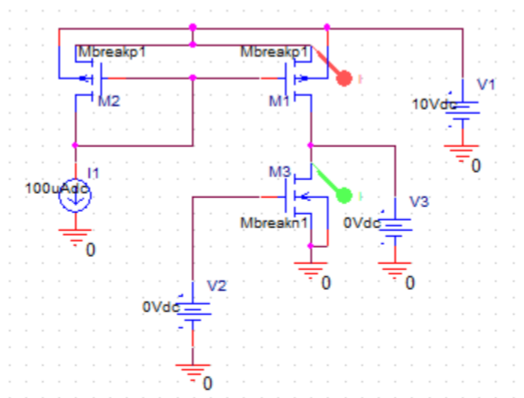

Figure 13: Circuit Used for Load-Line Simulation

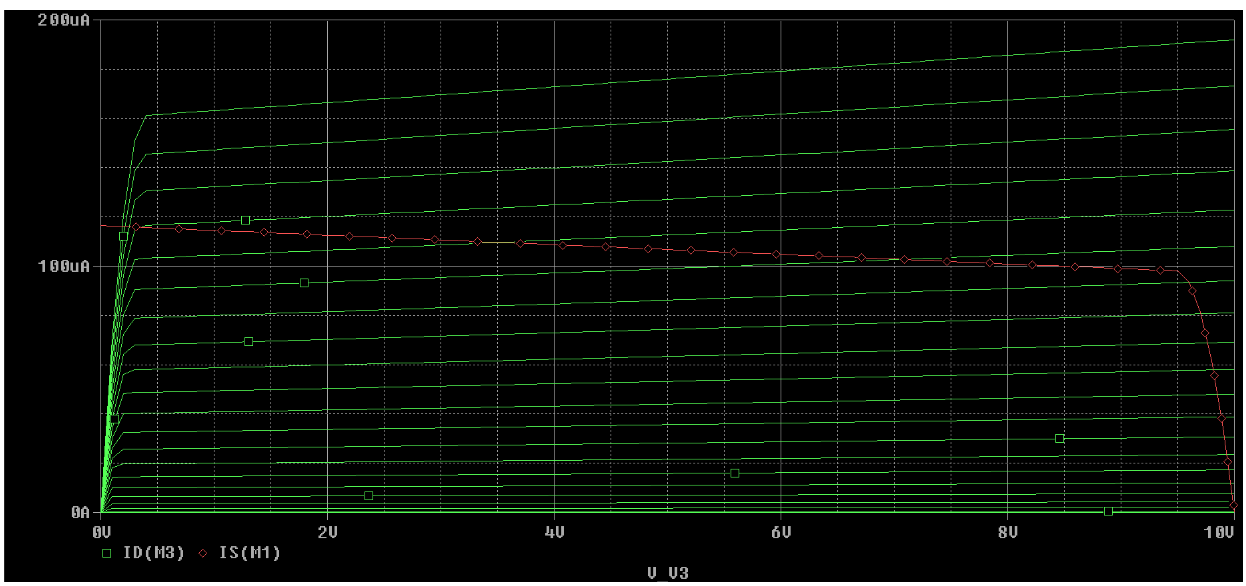

Figure 14: DC Sweep of V_{out} with Load Line

The load line, the source current to M_1, is in red, whereas the curves for different V_{in} values representing the drain current through M_3 are in green. V_{out} is on the x-axis, whereas the current is on the y-axis.

The simulation demonstrates the various potential operating points for the circuit. If a particular V_{out} is desired, then the drain current is simply the y-value at the intersection of the load line in red (i.e. the source current through

M_1) and one of the M_3 drain current curves in green. The particular M_3 drain current curve at which the intersection occurs corresponds to a particular V_{in}, the applied input voltage to achieve such an operating condition.

4 Conclusion

The purpose of the current mirror is to take an input current i_{in} and produce an identical output current i_{out}. Changing the width of transistors in the current mirror simply increases the currents when widened or decreases the currents when narrowed. By carefully controlling the widths of different transistors, it is conceivable that an arbitrary output current whose magnitude is proportional to the input current can be produced.

The common source amplifier with the PMOS current mirror operates like a typical common-source amplifier. Its gain turns out to be rather high for a common-source amplifier, which may have to do with the addition of the PMOS current mirror. The simulation gain ends up being higher than the calculated gain. The reasons for this are unclear and likely have to do with the inner workings of the MOSFET model and not one of the specified parameters since different parameter values were defaulted and yielded similar results.