

UNIVERSITY OF UTAH
ELECTRICAL AND COMPUTER ENGINEERING DEPARTMENT

ANALOG INTEGRATED CIRCUITS LAB

LAB 2

Current Mirrors and Source Followers

Objective: In this lab, you will characterize two important and commonly-used CMOS subcircuits: the current mirror and the source follower. You should review sections 3.1 and 3.3 in Johns & Martin.

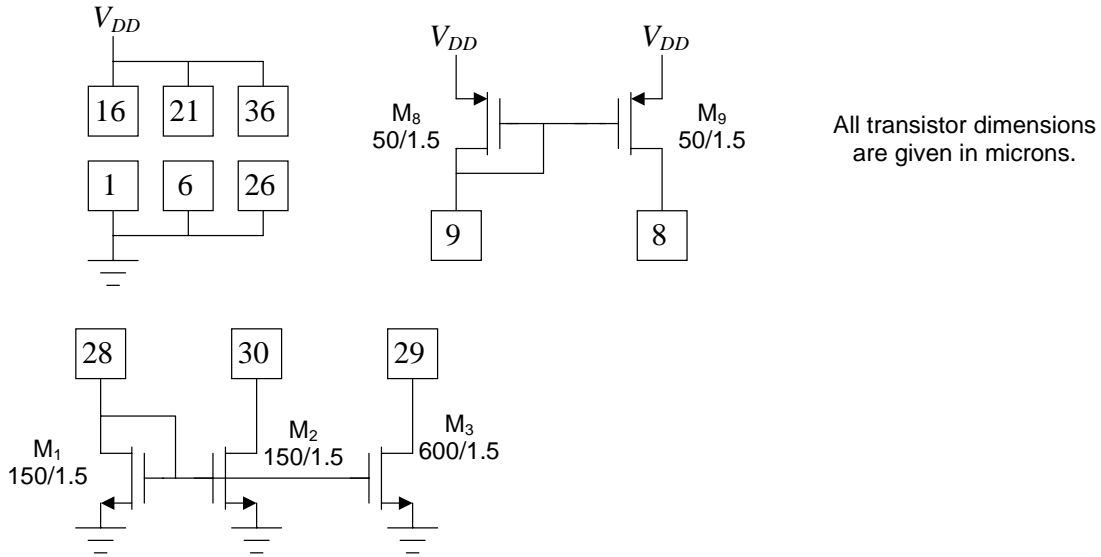
Power: We will once again be using a single-polarity power supply for this lab. Connect pins 1, 6, and 26 to ground. Connect pins 16, 21, and 36 to $V_{DD} = 5.0$ V. (Use the +25V power supply for V_{DD}). Leave these power connections in place for all experiments.

Before starting the experiments below, read the handout on the HP 33120A function generator and the handout on the HP 34401A multimeter. Do not proceed beyond this point until you have read all of these handouts and understand the operation of these instruments.

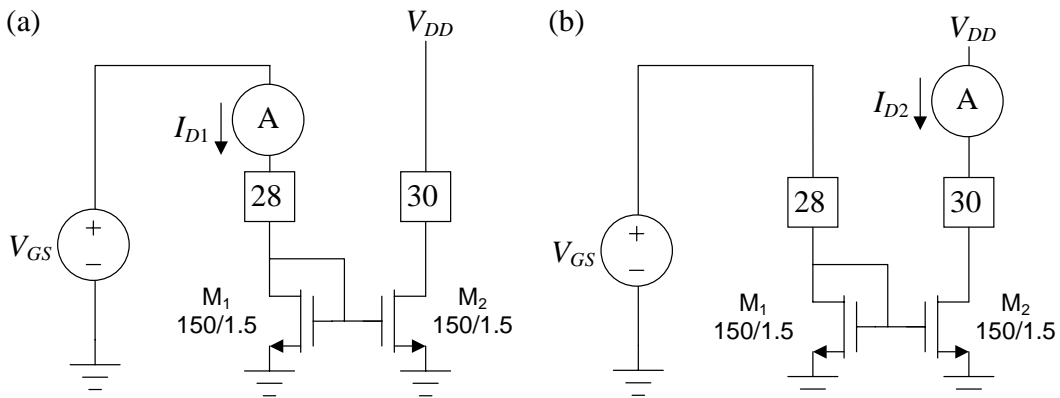
Experiment 1: Current Mirrors

The following figure shows the subcircuits on Chip A that we will use for this characterization of MOSFET current mirrors. **Be sure to connect pins 1, 6, and 26 to ground, and pins 16, 21, and 36 to V_{DD} (5.0 V) for all the experiments in this assignment.**

Pin-out for Lab 2, Experiment 1 – Chip A



(a) Simple n MOS current mirror. First, connect a voltage source and ammeter as shown in part (a) of the figure below. You may wish to use the HP function generator as the voltage source. If so, remember to set it to HIGH-Z load mode (see handout).



Find the value of V_{GS} that gives you a drain current close to $10 \mu\text{A}$. Record this value of V_{GS} along with the exact value of I_{D1} . Repeat this for ten current values: $10 \mu\text{A}$, $20 \mu\text{A}$,

30 μA , ... 100 μA . Now, using this table you have constructed, you can set the input current I_{D1} to any of these ten values.

Reposition the ammeter to measure the output current I_{D2} , as shown in part (b) of the above figure. Measure the I_{D2} for all ten input currents. Let's call I_{D1} " I_{in} " and I_{D2} " I_{out} ".

- Plot I_{out} vs. I_{in} , including a linear fit. (Make sure with any circuit plot to put the input on the x axis and the output on the y axis.)
- What is the slope of this line?
- What would you expect it to be, based on the circuit design?

The drain voltage of M_2 is currently at 5.0 V. Using another voltage source, set the drain voltage of M_2 to 0.8 V, and repeat the previous measurements.

- Plot I_{out} vs. I_{in} , including a linear fit.
- What is the slope of this line now?
- Is it closer to the ideal value?
- What is the reason for the improvement? (Hint: What is the drain voltage of M_1 ? What effect does drain voltage have on drain current?)

(b) Weighted $n\text{MOS}$ current mirrors. Repeat the above experiment (leaving the drain voltage at 0.8 V for a more precise measurement) with M_3 (pin 29) as the output. (Note that you don't have to repeat the I_{D1} measurements.)

- Again, plot I_{out} vs. I_{in} , including a linear fit.
- What is the slope of this line?
- What would you expect it to be, based on the circuit design?

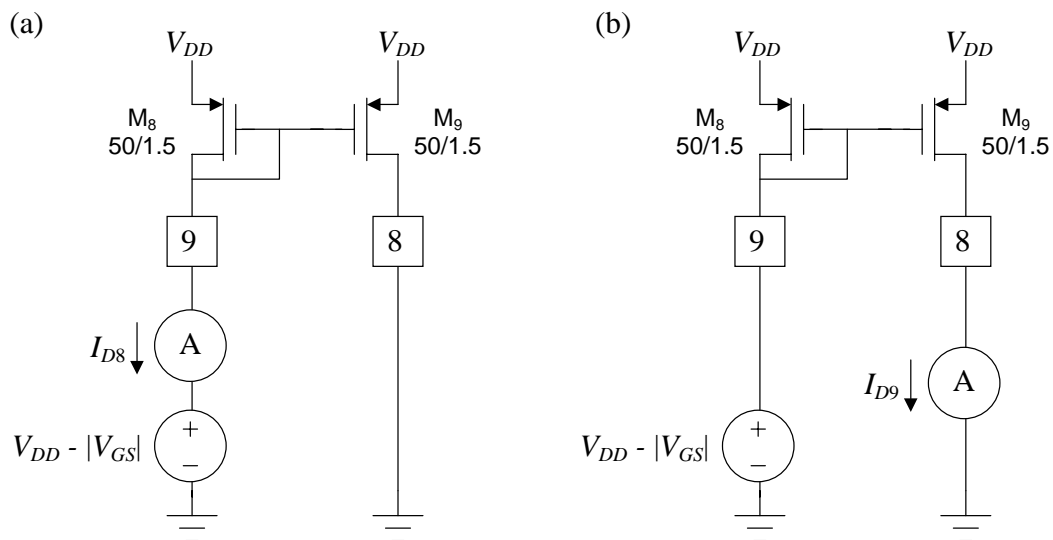
(c) $p\text{MOS}$ current mirror. Set up your instruments as shown in part (a) of the figure below. Find the values of V_{GS} that result in input currents of 10 μA , 20 μA , 30 μA , ... 100 μA . Now measure the output currents for these input currents [part (b) of the figure].

- Plot I_{out} vs. I_{in} , including a linear fit.
- What is the slope of this line?
- What would you expect it to be?

The drain voltage of M_9 is currently at ground, resulting in a V_{DS} of -5.0 V. Using another voltage source, set the drain voltage of M_9 to 3.8 V, which will give a V_{DS} of -1.2 V. Repeat the previous measurement.

- Plot I_{out} vs. I_{in} , including a linear fit.
- What is the slope of this line now?

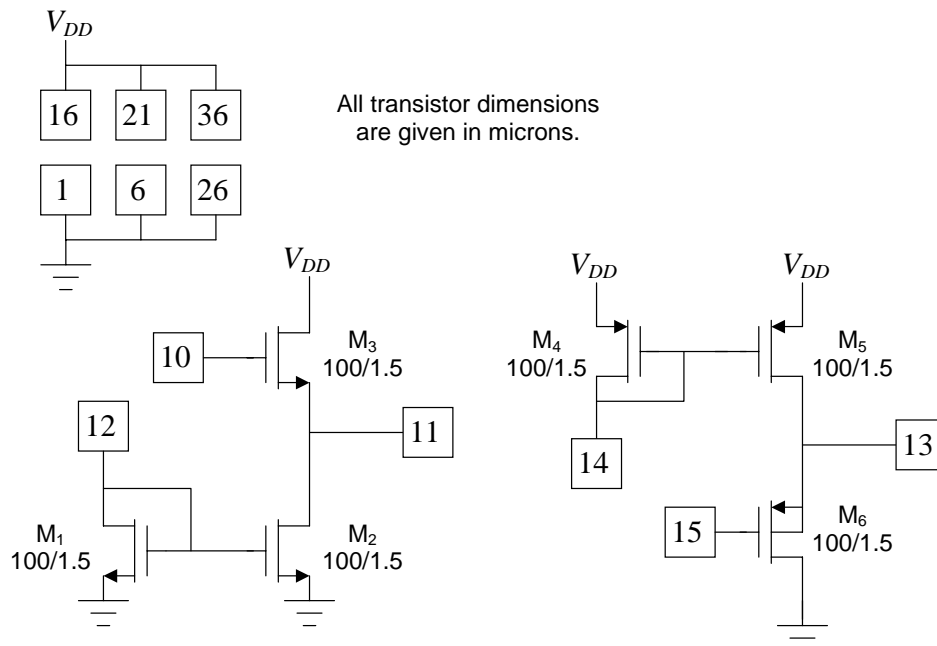
- Is it closer to the ideal value?
- What is the reason for the improvement? (Hint: What is the value of V_{DS} for M_8 ?)



Experiment 2: Source Followers

The following figure shows the subcircuits on Chip A that we will use for this characterization of MOSFET source followers:

Pin-out for Lab 2, Experiment 2 – Chip A



(a) *n*MOS source follower. Note that the *n*MOS source follower shown above is the *n*MOS transistor M_3 , which is biased by the M_1 - M_2 *n*MOS current mirror. For this

experiment, we will bias M_3 with a drain current of $100 \mu\text{A}$. Using a voltage source and ammeter, find a voltage for pin 12 that results in an input current of $100 \mu\text{A}$. Fix pin 12 to this voltage for the remainder of this experiment. What value of V_{GS1} gives M_1 a drain current of $100 \mu\text{A}$? Using the $n\text{MOS}$ threshold voltage V_{T0} you measured in Lab 1, calculate V_{eff} for M_1 . You will need this value for a later calculation. For now, note that M_1 and M_2 have the same value of V_{GS} . Also note that since M_1 , M_2 , and M_3 have the same W/L ratio and same drain current (assuming no current flows out of pin 11), they *all* must have the same value of V_{eff} (assuming they are all in saturation). This follows from the basic expression $I_D = (1/2)\mu C_{ox}'(W/L)V_{eff}^2$.

Now attach a different voltage source to the source follower input V_{in} (pin 10). Sweep V_{in} from 0 to $+5.0 \text{ V}$ in 0.1 V increments and record the output voltage V_{out} (pin 11) at each step.

- Plot V_{in} vs. V_{out} .
- Is the output voltage higher or lower than the input voltage?
- By how much?
- Over what input voltage range does the source follower work properly with no saturation (“hitting the power supply rails”) at the output?
- What is the slope of this transfer function?
- Why is the slope less than one?

By subtracting V_{out} from V_{in} , you can calculate V_{GS3} at each point. Since $V_{eff} = V_{GS} - V_t$, you can use your value of V_{eff} calculated above to derive M_3 's threshold voltage V_t at each point in your experiment. Also, note that V_{out} is equivalent to the source-to-body voltage V_{SB} of M_3 .

- Plot M_3 's threshold voltage V_t vs. V_{SB} .

This gives an excellent picture of the body effect. Remember, the body effect equation is:

$$V_T = V_{T0} + \gamma \left(\sqrt{|2\Phi_F| + V_{SB}} - \sqrt{|2\Phi_F|} \right) \quad (1)$$

- Add a theoretical fit to the plot using this equation. Use $|2\Phi_F| = 0.8 \text{ V}$, and find a value of γ that fits your data well.
- How does this value of gamma compare to the one you measured in Lab 1? (This is a more accurate experiment for measuring gamma.)

(b) $p\text{MOS}$ source follower. Note that the $p\text{MOS}$ source follower shown above is the $p\text{MOS}$ transistor M_6 , which is biased by the M_4 - M_5 $p\text{MOS}$ current mirror. For this experiment, we will bias M_6 with a drain current of $100 \mu\text{A}$. Using a voltage source and ammeter, find a voltage for pin 14 that results in an input current of $100 \mu\text{A}$. Fix pin 14 to this voltage for the remainder of this experiment.

Note that since we are using an n -well CMOS process, we can connect the body (well) of M_6 to its own source, even though its source is “floating” (i.e., not tied to a fixed power supply).

- How does this compare to the n MOS source follower?
- What effect would you expect this to have on the circuit’s performance?

Now attach a different voltage source to the source follower input V_{in} (pin 15). Sweep V_{in} from 0 to +5.0 V in 0.1 V increments and record the output voltage V_{out} (pin 13) at each step.

- Plot V_{in} vs. V_{out} .
- Is the output voltage higher or lower than the input voltage?
- By how much?
- Over what input voltage range does the source follower work properly with no saturation (“hitting the power supply rails”) at the output?
- What is the slope of this transfer function?
- Why does the gain of the p MOS source follower differ from the gain of the n MOS source follower?

Now, using the value of p MOS threshold voltage V_{t0} you measured in Lab 1, calculate V_{eff} for the transistors in this experiment. Use this value to calculate the threshold voltage V_t for M_6 at each point.

- Plot V_t vs. V_{out} .
- Does the threshold voltage change with V_{out} ?
- Why or why not?
- What is the value of V_{SB} for M_6 in this experiment?

REPORT

Each lab group (two students) should submit a lab report that is separate from the lab notebook. (In this class, lab notebooks will not be turned in.) The report should be typed, not handwritten, although it is acceptable to add neat handwritten notes to figures where appropriate (e.g., to label different curves). Lab reports are due in your lab section one week after a two-week lab ends.

Begin your lab report with a title page containing your names, email addresses, T.A., lab section, and the title of the lab. Next, write one or two paragraphs outlining the overall goal of the lab. Describe how you performed each experiment, listing any problems you encountered and how you overcame them. Figures are preferably included in line with the text. You should number the figures and refer to them from the text.

- Every sentence labeled with a “bullet” like this indicates either a figure you should include or an answer you should explicitly provide in your report.

The grading for Lab 2 will be as follows:

MATLAB Plots (9): 5 points each

Answers (29): 1 point each

Introduction and conclusion: 5 points

Format, flow, and coherency: 5 points

Spelling, grammar, neatness: 5 points

Total: 89 points

Your lab report should contain a description of all experiments performed, data plots (with fits) requested throughout this assignment, and a discussion of how the measured data (and fit parameters) compare with circuit theory.