EE100B
Experiment 1

A MOSFET Differential Amplifier

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Objective

To explore the use of MOSFETs, analog differential amplifiers and current mirrors. The objective is achieved by examining an analog differential amplifier with a current mirror as the current source, all implemented using MOSFETs.

Equipment

2 MOSFET Arrays (MC14007UB), 5 10kΩ resistors, function generator, oscilloscope, digital multimeter, DC power supply, breadboard

Prelab

Read the sections of your textbook relevant to this laboratory session.

Estimation of V_t and K

In the circuit shown in Figure L1.1, if the voltage V_{DS} (=V_{GS}) and the current I_D are known for two different values of V_{DD}, the parameters V_t and K can be computed from

$$I_D = K\left(V_{GS} - V_t\right)^2$$

Write out the expressions for V_t and K in terms of I_D and V_{GS}.

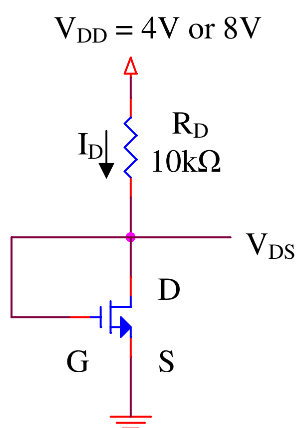

Figure L1.1 A MOSFET Circuit at DC

Current mirror

The circuit shown in Figure L1.2 is a current mirror. Assuming V_t and K have been determined as the expressions you obtained in the prelab above, write the expression for I_{D3}. If the two MOSFETs have the same geometry, what is the current I_{D4}?

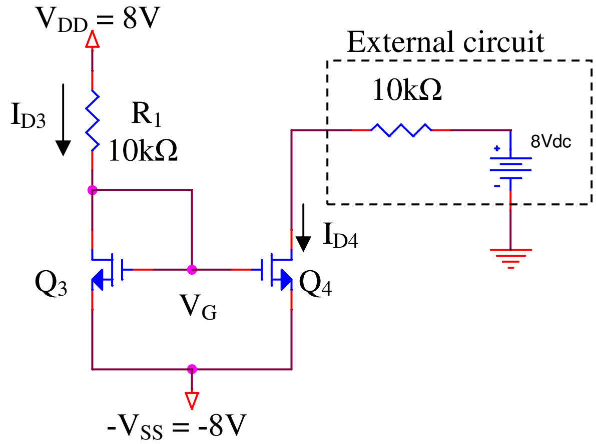

Figure L1.2 A Current Mirror

Laboratory Procedure

Figure L1.3 shows the pin assignments and schematic of the MC14007UB MOS array. The array consists of 6 transistors, 3 p-channel and 3 n-channel. One critical point to note is that pins 14 and 7, being the substrate connections of all of the p-channel and all of the n-channel devices, respectively, must be connected appropriately, no matter what use is made of any device. In particular, pin 14 must be connected to the most positive supply in use, and pin 7 to the most negative, even if not all the MOSFETs are used. Note also that the voltage between pin 14 and pin 7, must be limited to 18V, otherwise internal voltage breakdown may result. For safety's sake, maintain this total supply value at or below 16V.

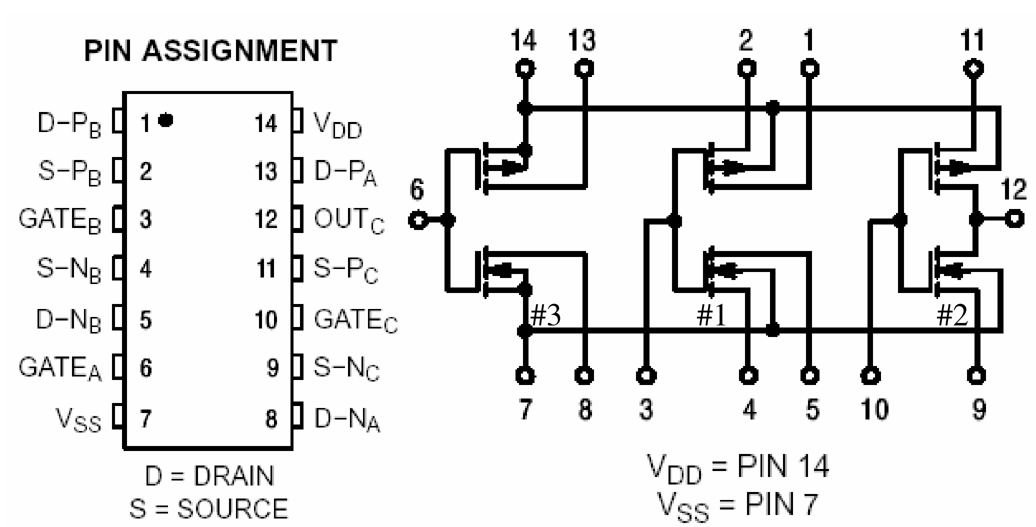

Figure L1.3 The MC14007UB MOS Array

Measurement of Vt_0 and K

Note: Because the most negative voltage is the ground in Figure L1.1, pin 7 in Figure L1.3 must be connected to ground.

Assemble the circuit as shown in Figure L1.1. Measure V_{DS} and I_D (by measuring V_{R_D}) for the cases V_{DD} = 4V and V_{DD} = 8V. Use the expression you obtained in the first part of the prelab to compute V_{t_0} and K. Repeat this for all three MOSFETs (#1, #2, and #3) identifying each MOSFET with its own V_{t_0} and K values.

Current mirror

Note: Because the most negative voltage is $-V_{SS}$ in Figure L1.2, pin 7 in Figure L1.3 must be connected to $-V_{SS}$.

Assemble the circuit as shown in Figure L1.2. Use a matched n-channel MOSFEET pair for Q_3 and Q_4, i.e., two MOSFETs having approximately the same V_{t0} and K. Measure I_{D_3} and I_{D_4} (by measuring the voltages across R_{D_3} and R_{D_4}). Using the expression for I_{D_3} and I_{D_4} obtained in the prelab, and the V_{t0} and K values determined experimentally, compute I_{D_3} and I_{D_4}. Compare your computation with the measurements, noting percentage of error.

Do not dismantle this circuit as most of it will be used in the next section of the laboratory experiment.

Voltage Gains

Assemble the circuit as shown in Figure L1.4 using n-channel MOSFETs #1 and #2 in the other chip for Q_1 and Q_2. Note than n-channel MOSFET #3 cannot be used as Q_1 and Q_2. Pin 7 in Figure L1.3 must be connected to $-V_{SS}$, because the most negative voltage in Figure L1.4 is $-V_{SS}$. All the body terminals (terminal B) of the n-channel MOSFET are connected internally to pin 7. As a result, once pin 7 is connected to $-V_{SS}$, the connection of the B terminal to Q_1 and Q_2 is automatically taken care of. Recall that a 5kΩ resistance can be found by placing 2 10kΩ resistors in parallel.

Let $v_{g1} = v_{g2} = 0V$. Measure V_{D1}, V_{D2} and V_S. Verify that the two channel currents are approximately the same, $I_{D1} \approx I_{D2} \approx I_{D4}/2$. Calculate $g_m = I_{D4}/ (V_{GS} - V_t)$.

Let $v_{g1} = v_{g2} = v_{cm} = 1.0 \sin(2\pi ft)$ V, f = 1 kHz. Measure v_{d1} and v_{d2} (signal voltage only) where v_{d1} and v_{d2} stand for the signal voltage at the drain of Q_1 and Q_2, respectively. Determine the common mode gain $A_{cm} = v_{d2}/v_{cm}$.

Let $v_{g1} = 0.1 \sin(2\pi ft)$ V, f = 1 kHz, and v_{g2} = 0V. Measure v_{d1} and v_{d2} (signal voltage only) where v_{d1} and v_{d2} stand for the signal voltage at the drain of Q_1 and Q_2, respectively. Determine the common single-ended differential voltage gain $Ad = v_{d2}/v_d$ where vd is the differential signal (i.e., $v_d = v_{g1} - v_{g2}$), and the differential output differential voltage gain, $A_{dd} = (v_{d2} - v_{d1})/v_d$. Determine the common mode rejection ratio.

$$\text{CMRR} = 20 \log |A_d/A_{cm}|.$$

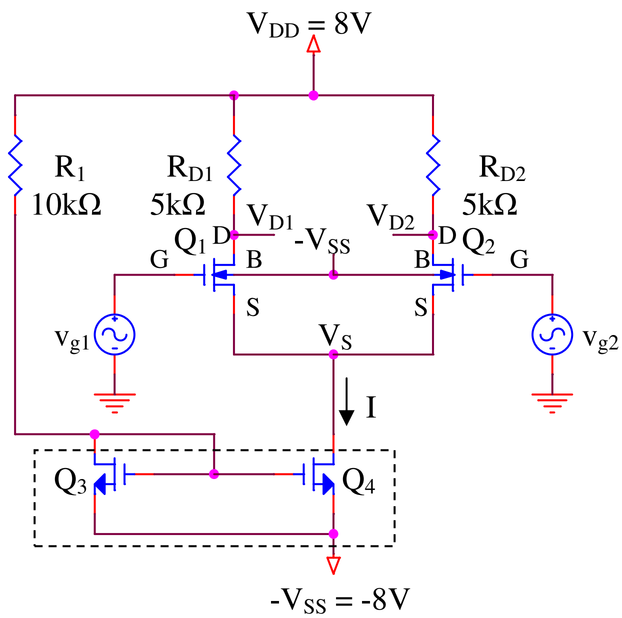

Figure L1.4 A Differential Amplifier

Discussion

For each section of the lab procedure, calculate the percent error between the theoretical and the experimental results. You may wish to verify your DC and small signal analysis using PSpice. Include all sources of error in your discussion (e.g., the accuracy of the model, meter accuracy, temperature, etc.).

Conclusion

Present your conclusion on the characteristics and operation of MOSFET amplifiers based on your findings from the experiment.