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 10k\(\Omega\) 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  

\[
I_D = K (V_{GS} - V_t)^2 
\]

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

\[
V_{DD} = 4V \text{ or } 8V 
\]

\[
\begin{align*}  
  V_{DS} & \quad \text{R}_D \quad 10k\Omega \\
  I_D \quad \text{G} \quad \text{D} \\
  \text{G} \quad \text{S} \\
\end{align*} 
\]

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](image)

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](image)
**Measurement of \( V_{t0} \) 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 \( V_{Rb} \)) for the cases \( V_{DD} = 4V \) and \( V_{DD} = 8V \). Use the expression you obtained in the first part of the prelab to compute \( V_{t0} \) and \( K \). Repeat this for all three MOSFETs (#1, #2, and #3) identifying each MOSFET with its own \( V_{t0} \) 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 MOSFET pair for \( Q_3 \) and \( Q_4 \), i.e., two MOSFETs having approximately the same \( V_{t0} \) and \( K \). Measure \( I_{D3} \) and \( I_{D4} \) (by measuring the voltages across \( R_{D3} \) and \( R_{D4} \)). Using the expression for \( I_{D3} \) and \( I_{D4} \) obtained in the prelab, and the \( V_{t0} \) and \( K \) values determined experimentally, compute \( I_{D3} \) and \( I_{D4} \). 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 \( g_m = I_{D4} / (V_{GS}-V_1) \).

Let \( v_{g1} = v_{g2} = v_{cm} = 1.0 \sin(2\pi ft) \ V, f = 1 \ \text{kHz} \). 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 \( v_{g1} = 0.1 \sin(2\pi ft) \ V, f = 1 \ \text{kHz} \), 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 \( A_d = v_{d2}/v_d \) where \( v_d \) 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.

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