LO-6

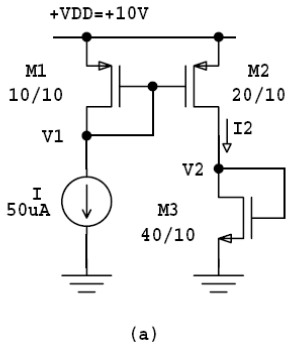
The Analysis and Design of Currents Mirrors and Active Loads

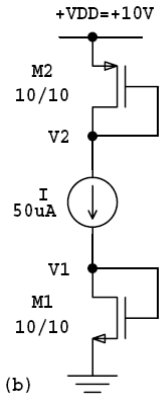
1. For the CMOS circuits shown in Figs. a,b,c,d, determine the operating modes (CUT-OFF, NONSAT, SAT) for all transistors. Find all labeled DC voltages and currents. Show all your work. For each of the circuits, put your results in a table. All devices have the same parameters;

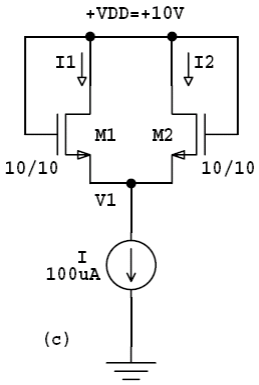
NMOS transistors: $\mu_n C_{ox} = 40\ \mu A/V^2$, $V_{TN} = 0.7V$

PMOS transistors: $\mu_p C_{ox} = 20\ \mu A/V^2$, $V_{TP} = -0.7V$

For both NMOS and PMOS transistors, channel-length modulation and body effects can be neglected, i.e., $\lambda \approx 0$, $\gamma \approx 0$. The DC bias voltage sources VDD, VSS and current sources are assumed ideal.







2. In the CMOS circuit shown below,

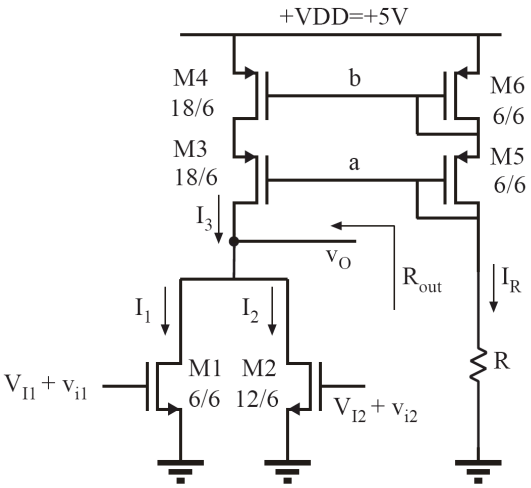
<u>NMOS transistors:</u>

$\mu_n C_{ox} = 50\ \mu A/V^2$, $V_{TN} = 1$ V, $\lambda_n = 0.02$ 1/V, $\gamma_n = 0$.

<u>PMOS transistors:</u>

$\mu_p C_{ox} = 16\ \mu A/V^2$, $V_{TP} = -1$ V, $\lambda_p = 0.02$ 1/V, $\gamma_p = 0$.

The supply voltage is $V_{DD} = 5$ V. The two input voltages have DC bias components V_{I1}, V_{I2}, and the small signal components v_{i1}, v_{i2}. The device sizes W/L in μm are shown in the Figure. *(State the approximations you made in solving the problem.)*



a) For $V_{I1} = V_{I2} = 1.4$ V, resistance R selected so that all devices operate in the active mode. Find the DC bias currents I_1, I_2, I_3, I_R, and the DC bias voltages V_a, V_b. Find R.

b) For $V_{I1} = V_{I2} = 1.4$ V, and R found in (a), find the range of the output voltages $V_{Omin} < V_O < V_{Omax}$, such that all devices operate in the active mode.

In parts (c) and (d) of the problem, you can assume that the circuit operates at the point found in (a), and that V_O is such that all devices are active.

c) Find the parameters g_{m1}, r_{ds1}, g_{m2}, r_{ds2}, in the small-signal models of the devices M1 and M2.

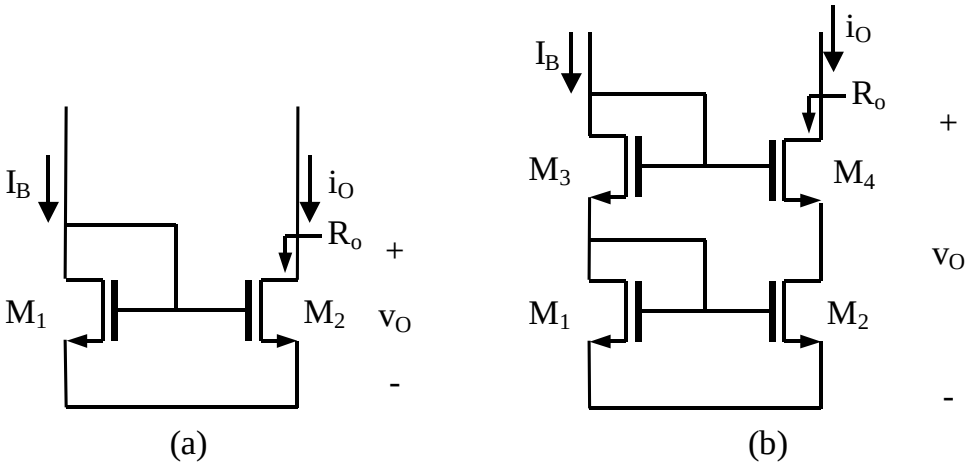
d) Find the small-signal output v_o as a function of the small-signal inputs v_{i1}, v_{i2}. Find the output resistance R_{out}.

e) If $V_{I1} = 5$ V and $V_{I2} = 0$ V, and R is as found in (a), determine operating modes of all devices. Justify your answers.

3. Consider the following current mirrors. This current mirrors are to be used as current sources.

For each current mirror

(i) Express $i_O=I_{OQ}$ in terms of the biasing current I_B where $I_B>0$.
(ii) Determine the limits on I_{OQ} and V_{OQ}.
(iii) What is the small signal equivalent resistance R_o seen from the output port.
(iv) Compare the results.



4. In the Wilson current mirror shown, assume the transistors' parameters are

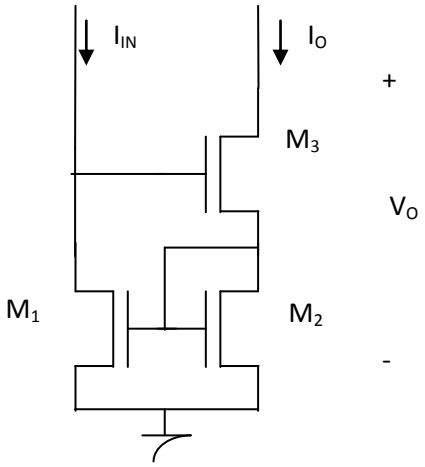
$$V_T = 0.75\ V,\ K_n = 48\ \mu A/V^2,$$

The aspect ratios are

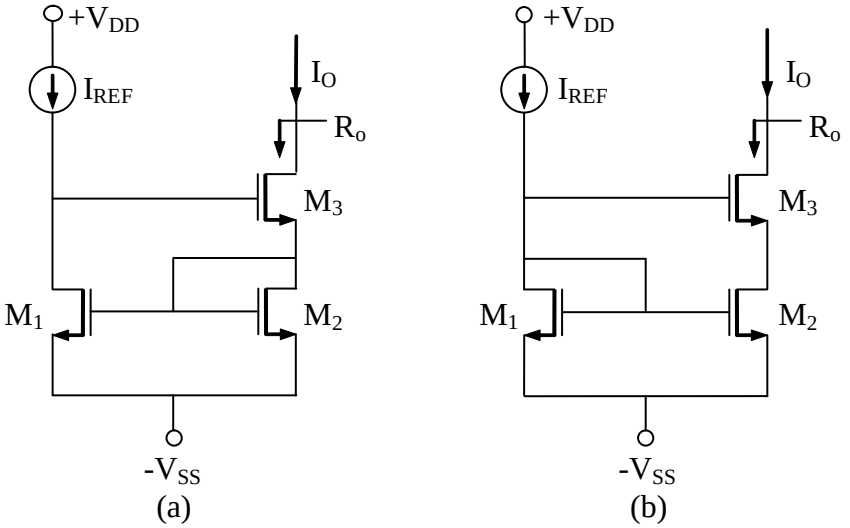
$$W_1/L_1 = W_2/L_2 = W_3/L_3 = 5$$

for M_1, M_2, and M_3 respectively.

Determine and plot the family of output current I_O characteristics as a function of V_O, where I_{IN} is the parameter to be varied to obtain the family of curves.

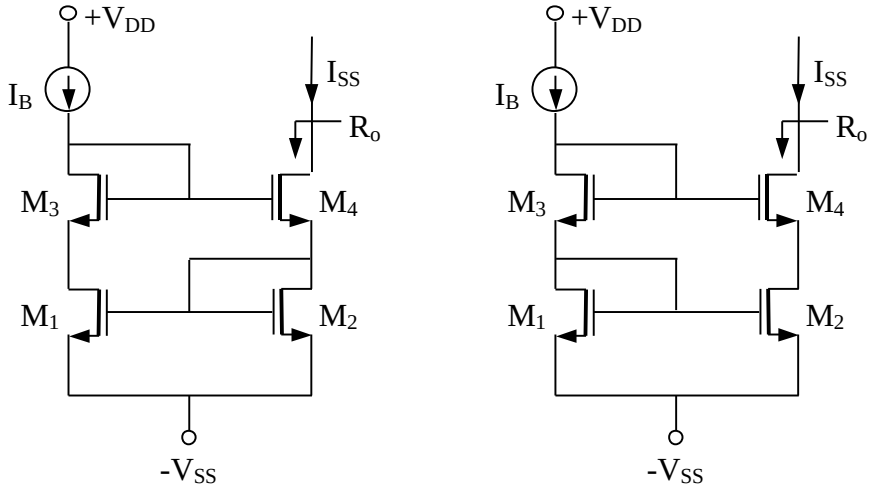


5. For the current sources given below, assume the transistors M_1, M_2, M_3 and M_4 are identical, i.e., they have the same process parameters and the same aspect ratios.



a) Express the output current I_O in terms of I_{REF} and the circuit and transistor parameters.
b) Assuming that $g_{m1} = g_{m2} = g_{m3} = g_m$ and $r_{ds1} = r_{ds2} = r_{ds3} = r_o$, determine the output resistances R_o's.
c) Compare the circuits given in (a) and (b).

6. For the current sources given below, compare the small signal output resistances as defined below. Assume M_1, M_2, M_3 and M_4 are identical, i.e., they have the same process parameters and the same aspect ratios.



For the circuits given in (a) and (b), assuming that

$g_{m1} = g_{m2} = g_{m3} = g_{m4} = g_m$

$r_{ds1} = r_{ds2} = r_{ds3} = r_{ds4} = r_o$

a) Express the output current I_{SS} in terms of I_B and the circuit and transistor parameters
b) Determine the output resistances R_o's, and compare them.