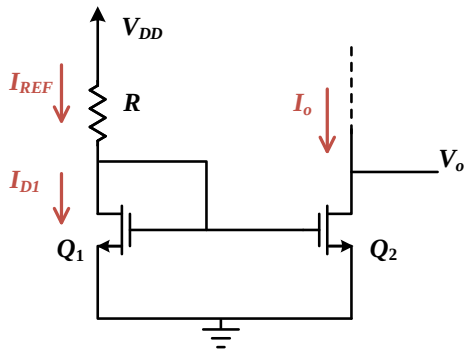
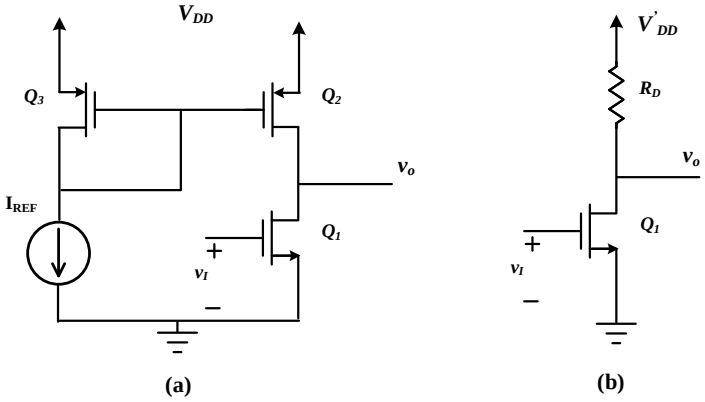
1. (20 points) Current Mirror
Using two matched MOS transistors with $W = 10\mu m$, $L = 1\mu m$, $k_n' = 400\mu A/V^2$, and $V_t = 0.5V$, design the circuit below to provide $I_o = 100\mu A$. $V_{DD} = 1.8V$.



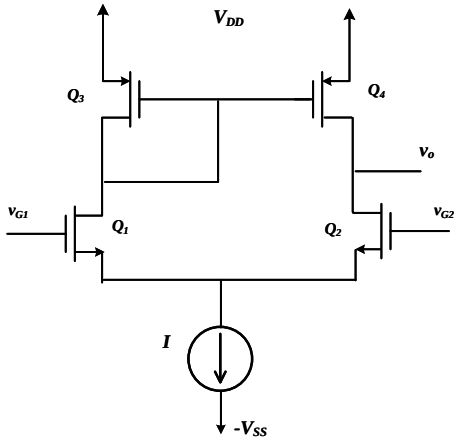
   (a) (8 points) Neglect the early effect. Calculate the required value for R.
   (b) (6 points) Calculate the lower bound of V_o.
   (c) (6 points) Consider early effect, $V_A = 6V$, calculate the output resistance of the mirror.

2. (20 points) Basic Gain Cell
For the circuit (a) below, Q_2 and Q_3 are matched. Let $V_{DD} = 1.8V$, $V_{tn} = -V_{tp} = 0.5V$, $\mu_n C_{ox} = 4\mu_p C_{ox} = 400\mu A/V^2$, $|V_A| = 6V$ for all transistors, and $I_{REF} = 120\mu A$.

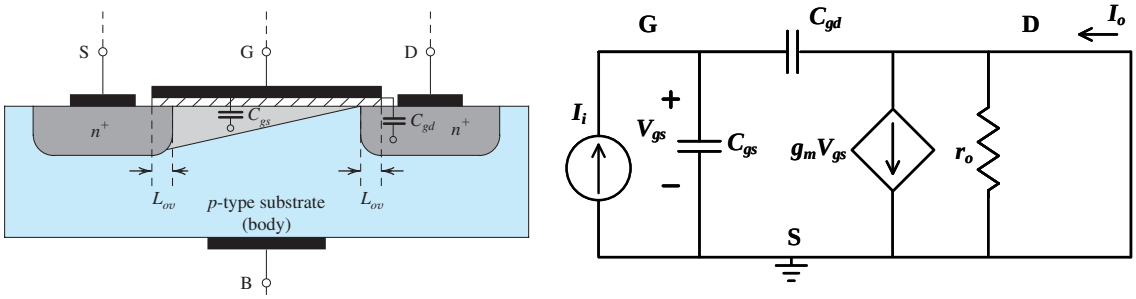


   (a) (8 points) Find the dc component of v_I and the W/L ratios so that all transistors operate at $|V_{OV}| = 0.3V$.
   (b) (6 points) Determine the small-signal voltage gain.
   (c) (6 points) If the current-source load is replaced with R_D connected to a power supply V'_{DD} as shown in Fig (b), find R_D and V'_{DD} to keep I_D, the voltage gain, and the output signal swing unchanged.

3. (20 points) Differential Amplifier
The differential amplifier below is biased with $I = 150\mu A$. All transistors have $L = 0.5\mu m$, and Q_1 and Q_2 have $W/L = 20$. The circuit is fabricated in a process for with $\mu_n C_{ox} = 4\mu_p C_{ox} = 400\mu A/V^2$, and $|V'_A| = 6V/\mu m$.
   (a) (10 points) Find $g_{m1,2}$, r_{o2}, and r_{o4}.
   (b) (10 points) Calculate the differential gain A_d.



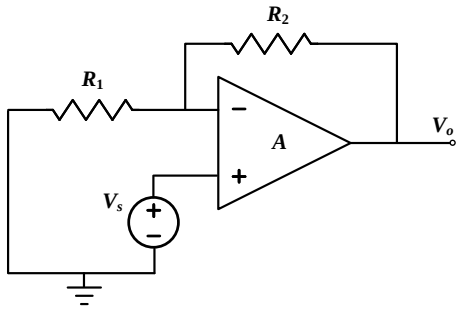
4. (20 points) Frequency Response
For an n-MOSFET in saturation. $t_{ox} = 3nm$, $L = 0.15\mu m$. $W = 1.5\mu m$, $L_{ov} = 0.03\mu m$.



(a) (10 points) Calculate the following capacitances C_{ox}, C_{ov}, C_{gs} and C_{gd}.

(b) (10 points) Assume MOSFET operates at $100\mu A$, calculate the unity gain frequency, f_T.

5. (20 points) Feedback
Given a non-inverting op-amp with feedback shown below. Assume the op amp has infinite input resistance and zero output resistance. $R_1 = 10k\Omega$, $R_2 = 40k\Omega$.



(a) (10 points) Calculate the feedback factor β and the ideal closed-loop gain A_f.

(b) (10 points) If the open-loop gain $A = 10^4 V/V$, find the loop gain, the amount of feedback, and the actual value of A_f. By what percentage does A_f deviate from the ideal value?