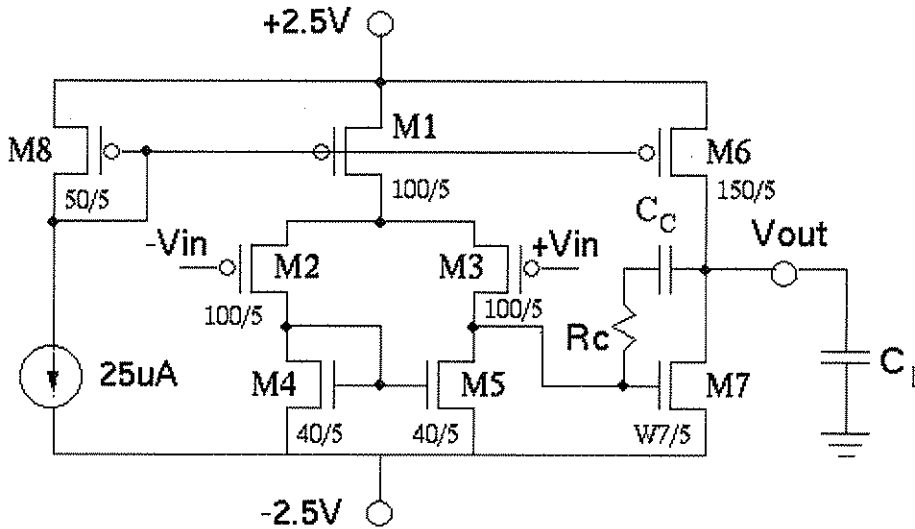


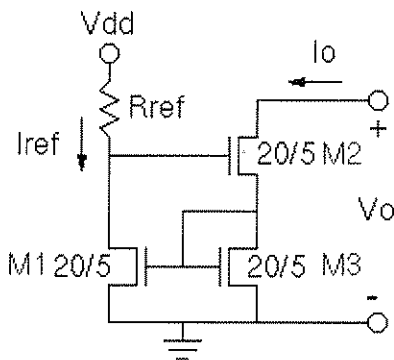
Name: .....

1) Two-stage CMOS Opamp



- a) Determine the missing  $W_7$  value and calculate the resulting dc gain  $A_0$  (a numerical value is required).
- b) What is the value of the positive slew rate  $SR+$  of this amplifier if  $C_C=2.5pF$  and  $C_L=5pF$ , respectively?
- c) Find the approximate position of the **dominant pole** (i.e., the lowest pole) of the given CMOS opamp. Indicate the value of the pole in Hz.

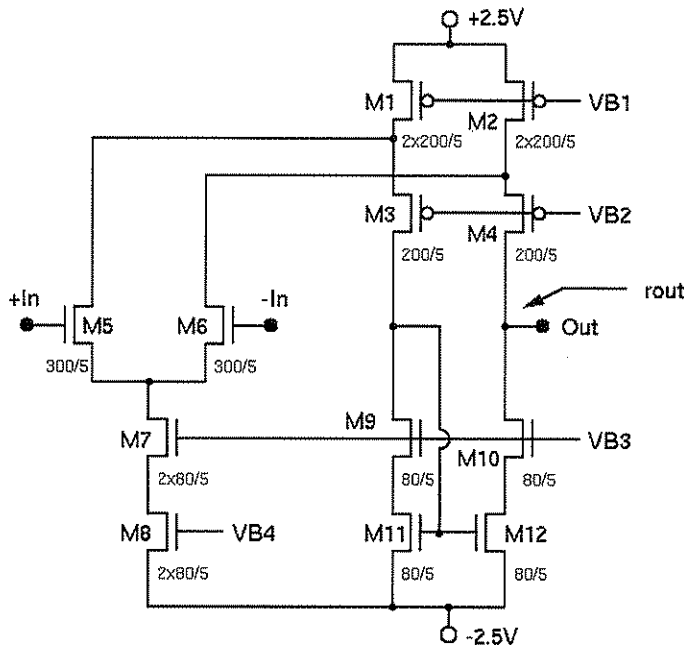
2) Current Source



- $V_{dd} = 5\text{ V}$
- $R_{ref} = 250\text{ k}\Omega$
- $V_{tn} = +1.0\text{ V}$
- $\frac{1}{2}\mu_n C_{ox} = 40\text{ }\mu\text{A}^2/\text{V}$
- $\lambda_n = 4 \times 10^{-2}\text{ 1/V}$

- Establish the necessary dc equations and determine the value of the reference current  $I_{ref}$  for the given transistor dimensions. **Neglect the body effect** in your calculations.
- Sketch an ac equivalent circuit (use  $g_{mi}$  and  $r_{oi}$  as the only ac equivalent device parameters) and find a symbolic expression for the **output resistance**  $r_{out} = V_o / i_o$ .
- Does the output current change if you were to include the body effect in part a)? (Do not carry out any computations, but justify your answer with one valid argument).

### 3) Folded-Cascode Amplifier



- Determine the equivalent resistance  $r_{out}$  between node **Out** and ac ground (express  $r_{out}$  as a function of the  $g_m$ 's and  $r_o$ 's of the corresponding devices). Use the device parameters listed at the bottom of page 2 to find a numerical value for  $r_{out}$  if  $I_1 = I_8 = 100 \mu A$ .
- Derive a symbolic expression for the unity-gain bandwidth UGB and compute its value (expressed in Hz) if the amplifier drives a capacitive load of 3 pF. ( $I_1 = I_8 = 100 \mu A$ ).
- What is the **maximum linear** output range (peak-to-peak voltage) of this circuit? Use the parameters listed on page 2 to find the numerical value ( $I_1 = I_8 = 100 \mu A$ ).

Use the following device parameters for all numerical problems:

$V_{tn} = +0.7V$	$\mu_n C_{ox} = 100 \mu A/V^2$	$\lambda_n = 0.05V^{-1}$	$\gamma_n = 0.6V^{-1/2}$
$V_{tp} = -0.9V$	$\mu_p C_{ox} = 40 \mu A/V^2$	$\lambda_p = 0.05V^{-1}$	$\gamma_p = 0.6V^{-1/2}$
$\phi_{Fn} = 0.4V$	$\phi_{Fp} = 0.4V$		

$$1) \quad a) \quad \frac{(W/L)_1}{(W/L)_6} = \frac{(W/L)_4 + (W/L)_5}{(W/L)_7}$$

$$\therefore \| W_7 = 120 \|$$

$$| A_0 = g_{m7} r_{O7} \parallel r_{O5} \times g_{m7} r_{O6} \parallel r_{O7} |$$

$$\therefore \| A_0 = 80 \times 80 = 6,400 \|$$

2

$$\left. \begin{array}{l} r_{O7} = 800k\Omega \\ r_{O5} = 800k\Omega \\ g_{m7} = 200\mu S \\ f_{m7} = 600\mu S \\ r_{O6} = 267k\Omega \\ r_{O7} = 267k\Omega \end{array} \right|$$

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$$b) \quad \| s^* r^+ = \frac{I_{out}}{C_c + C_L} = 10 V/\mu S \|$$

3

$$c) \quad \left| \omega_p \cong \frac{1}{C_c g_{m7} \cdot r_{O3} \parallel r_{O5} \cdot r_{O6} \parallel r_{O7}} \right|$$

$$\therefore | \omega_p = 2\pi \times 2 \text{ kHz} |$$

$$| f_p \cong 2 \text{ kHz} |$$

3

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2) a) KVL:  $I_{ref} \pi_{ref} + V_{as2} + V_{as3} = V_{dd}$  (1)

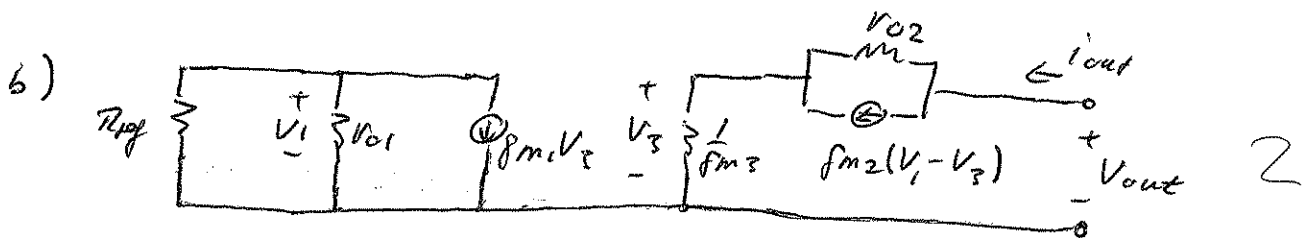
Device:  $I_{ref} = \frac{1}{2} \mu C_{ox} \left(\frac{W}{L}\right)_{2,3} [V_{as} - V_t]_{2,3}^2$  (2)

(2)  $\therefore V_{as2} = V_{as3} = V_t + \sqrt{\frac{2 I_{ref}}{\mu C_{ox} \left(\frac{W}{L}\right)_{2,3}}}$  (3) 2

(3)  $\rightarrow$  (1)  $\therefore I_{ref} \pi_{ref} + 2V_t + 2\sqrt{\frac{2 I_{ref}}{\mu C_{ox} \left(\frac{W}{L}\right)_{2,3}}} = V_{dd}$  (4) |

or  $\left| I_{ref} + \sqrt{I_{ref}} \frac{2}{\pi_{ref}} \sqrt{\frac{2}{\mu C_{ox} \left(\frac{W}{L}\right)_{2,3}}} - \frac{V_{dd} + 2V_t}{\pi_{ref}} = 0 \right|$

$\therefore \| I_{ref} \approx 10 \mu A \|$  2



$V_1 = \left(-\frac{V_1}{\pi_{ref}} - g_{m1} V_3\right) r_{o1}$  (1)

$V_3 = i_{out} \frac{1}{g_{m3}}$  (2)

$V_{out} = [i_{out} - g_{m2}(V_1 - V_3)] r_{o2} + i_{out} \frac{1}{g_{m3}}$  (3) 2

$\therefore \left| r_{out} = \frac{V_{out}}{i_{out}} = \left[1 + \frac{g_{m2}}{g_{m3}} \left(1 + \frac{g_{m1} r_{o1}}{1 + r_{o1}/\pi_{ref}}\right)\right] r_{o2} + \frac{1}{g_{m3}} \right|$

$\| r_{out} \approx \frac{g_{m2}}{g_{m3}} \frac{g_{m1} r_{o1}}{1 + r_{o1}/\pi_{ref}} r_{o2} \|$  1

c) Body Effect increases  $V_{as2}$

$\therefore I_{ref}$  slightly decreases. 2

$$3) a) \quad \left| \tau_{out} = \tau_{op} \parallel \tau_{on} \right| \quad \left| \tau_{op} = f_{m4} \tau_{o4} \tau_{o2} \right|$$

$$\left| \tau_{on} = f_{m10} \tau_{o10} \tau_{o12} \right|$$

$$\left| \begin{array}{l} f_{m4} = f_{m10} = 400 \mu\text{s} \\ \tau_{o2} = 200 \text{ k}\Omega \\ \tau_{o12} = 400 \text{ k}\Omega \\ \tau_{o4} = 400 \text{ k}\Omega \\ \tau_{o10} = 400 \text{ k}\Omega \end{array} \right|$$

4

$$\therefore \left\| \tau_{out} \approx 21.3 \text{ M}\Omega \right\| \quad |$$

$$b) \quad \left| U_{GB} = A_0 \cdot \omega_p \right|$$

$$\left| A_0 = g_{m5,6} \cdot \tau_{out} \right|$$

$$\left| \omega_p = \frac{1}{\tau_{out} C_L} \right|$$

$$\therefore \left| U_{GB} = \frac{f_{m5,6}}{C_L} \right|$$

$$\left| f_{m5,6} \approx 775 \mu\text{s} \right|$$

$$\therefore \left\| U_{GB} \approx 258 \text{ Mrad/s} \right\|$$

$$\left\| = 2\pi \times 41.1 \text{ MHz} \right\|$$

$$c) \quad V_{p-p,max} = V_{dd} + V_{ss} - 4 \cdot V_{DSsat}$$

$$V_{DSsat} = \sqrt{\frac{2I_D}{\mu C_{ox}(W/L)}} \approx 0.25 \text{ V}$$

$$\therefore \left\| V_{p-p,max} = 4 \text{ V} \right\|$$

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