NAME and SID Solution Set

Note: Use the device parameters given in class. Vt=+/-0.5V, unCox=200uA/V2, upCox=100uA/V2, lambda0=0.02 1/V

1. (30pts) Design an amplifier with a low frequency gain of at least 100 and a unity gain frequency of 5 GHz with a 10pF load. Use an NMOS-input common-source amplifier with a PMOS current source load. You may use one resistor in your circuit, and assume a 5V supply, but all other devices must be FETs (no ideal voltage source, current sources, etc.). Try to minimize the size WIDTH of your transistors. All overdrive voltages (Vov or Vdsat) must be between 0.1 and 0.5 volts.

- Calculate the values for gm, ro, Id, and Vdsat that you will use.
- Draw a schematic of your design and clearly label all components (R= …, W/L=…)
- Fill in the table with the data about each of your FETs.

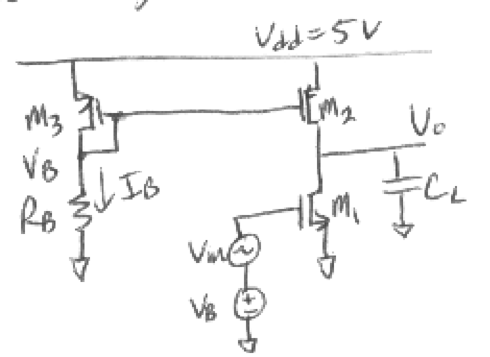
$g_m = \frac{2I_D}{V_{dsat}}$ $r_o = \frac{1}{\lambda I_D}$

Specs: single stage NMOS CS amp

$|A_{vo}| \geq 100$ V/V $f_u = 5$ GHz $C_L = 10$pF

Transistor	W	L	Vdsat	gm	ro
M_1	3140um	1um	0.5V	0.314S	637Ω
M_2	6280um	1um	0.5V	0.314S	637Ω
M_3	628um	1um	0.5V	31.4mS	6.37kΩ
R_B	—	—	—	—	510Ω

Proposed design:



For M_2, use 10 M_3 devices in parallel.

Unity gain spec: $f_u = \frac{g_{m1}}{2\pi C_L}$

$\Rightarrow g_{m1} = 2\pi C_L f_u = 0.314$ S ← pretty big!

Gain spec: $|A_{vo}| = g_{m1} R_o = g_{m1} \cdot (r_{o1} \| r_{o2}) = g_{m1} \left(\frac{1}{\lambda_n I_{D1}} \| \frac{1}{\lambda_p I_{D1}} \right)$

$\Rightarrow$ Assume $\lambda_n = \lambda_p$ (thus $L_1 = L_2$) For $L_1 = L_2 = 1\mu m$, $\lambda = 0.02\ V^{-1}$

Then $|A_{vo}| = g_{m1} \frac{1}{2\lambda I_{D1}} = \frac{2I_{D1}}{V_{dsat1}} \frac{1}{2\lambda I_{D1}} = \frac{1}{V_{dsat1}\lambda}$

↑ Note that you could assume that λ is constant here so you could have used L=0.35

$\Rightarrow V_{dsat1} = \frac{1}{|A_{vo}|\lambda} = 0.5$ V

$I_{D1} = \frac{g_{m1} V_{dsat1}}{2} = 78.5$ mA $\Rightarrow \left(\frac{W}{L}\right)_1 = \frac{2 I_{D1}}{\mu_n C_{ox} V_{dsat1}^2} = 3140$

Since Vdsat must be 0.5V or less, choose $V_{dsat2} = 0.5$V to minimize $\left(\frac{W}{L}\right)_2$

$\Rightarrow \left(\frac{W}{L}\right)_2 = 2\left(\frac{W}{L}\right)_1 = 6280$ (since $\mu_p C_{ox} = \frac{1}{2}\mu_n C_{ox}$)

For simplicity and power/area savings, choose $I_B = \frac{1}{10} I_{D1} = 7.85$mA

$\Rightarrow \left(\frac{W}{L}\right)_3 = 628$ $R_B = \frac{V_B}{I_B} = \frac{V_{dd} - |V_{GS3}|}{I_B} = \frac{5V - 1V}{7.85mA} \cong 510\Omega$

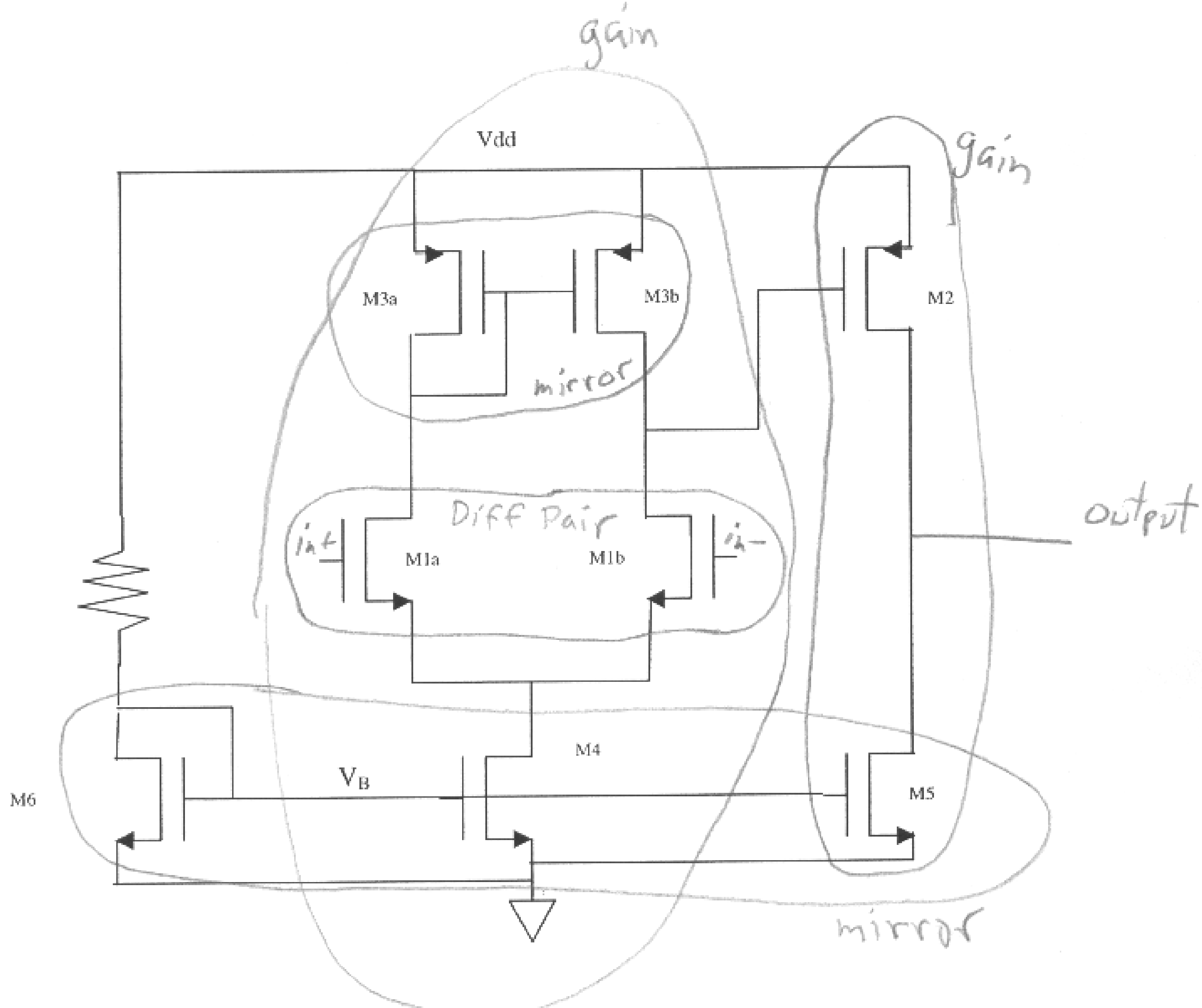
2. **(25pts)** For the amplifier shown below,

- 10 **Circle and label all differential pairs, current mirrors, gain stages.**
- 5 **Label the input(s) and the output(s)**
- **Which devices make up the bias network:**

5 R, M6, M4, M5

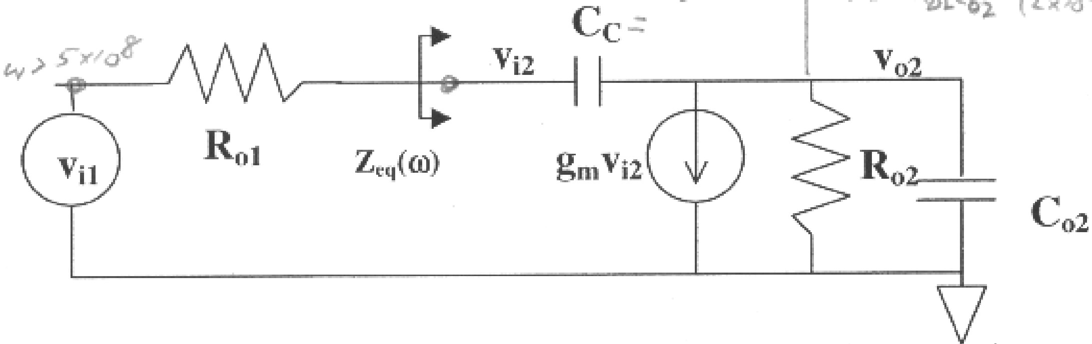
- **Which transistors are in the signal path:**

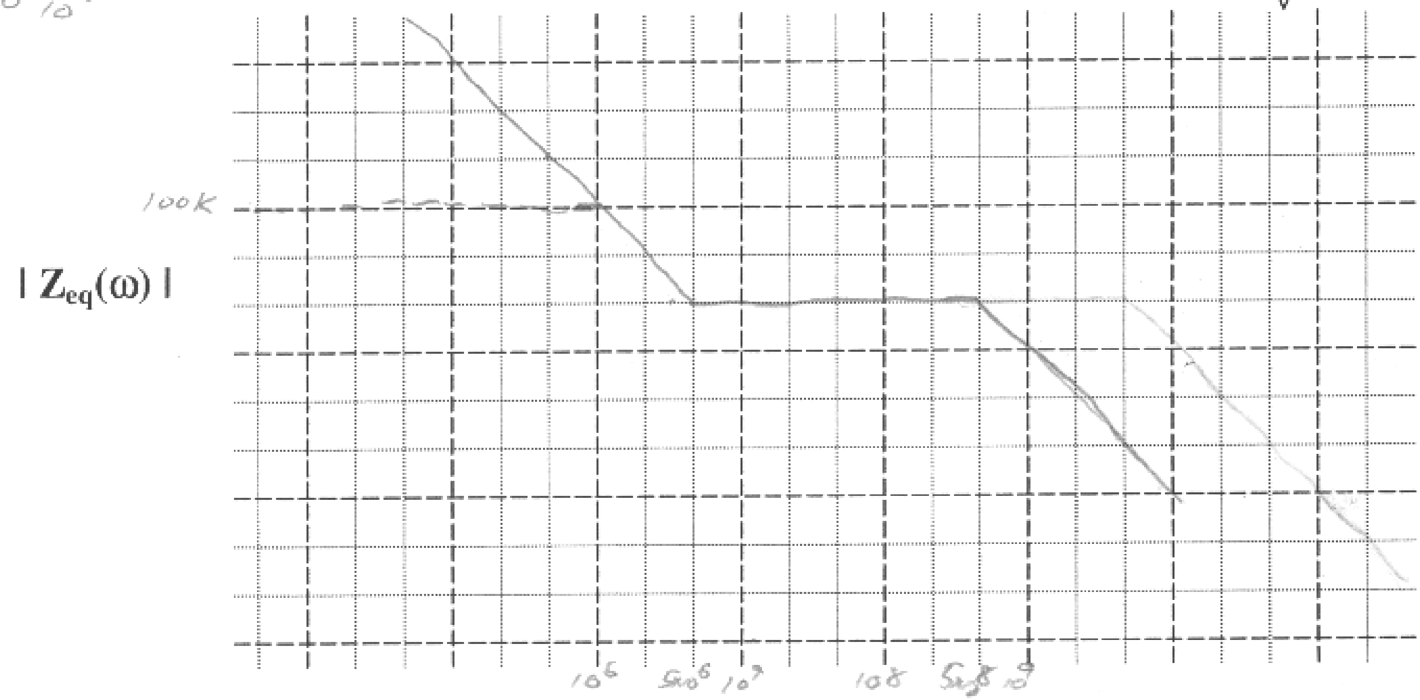
5 M1AB, M3AB, M2

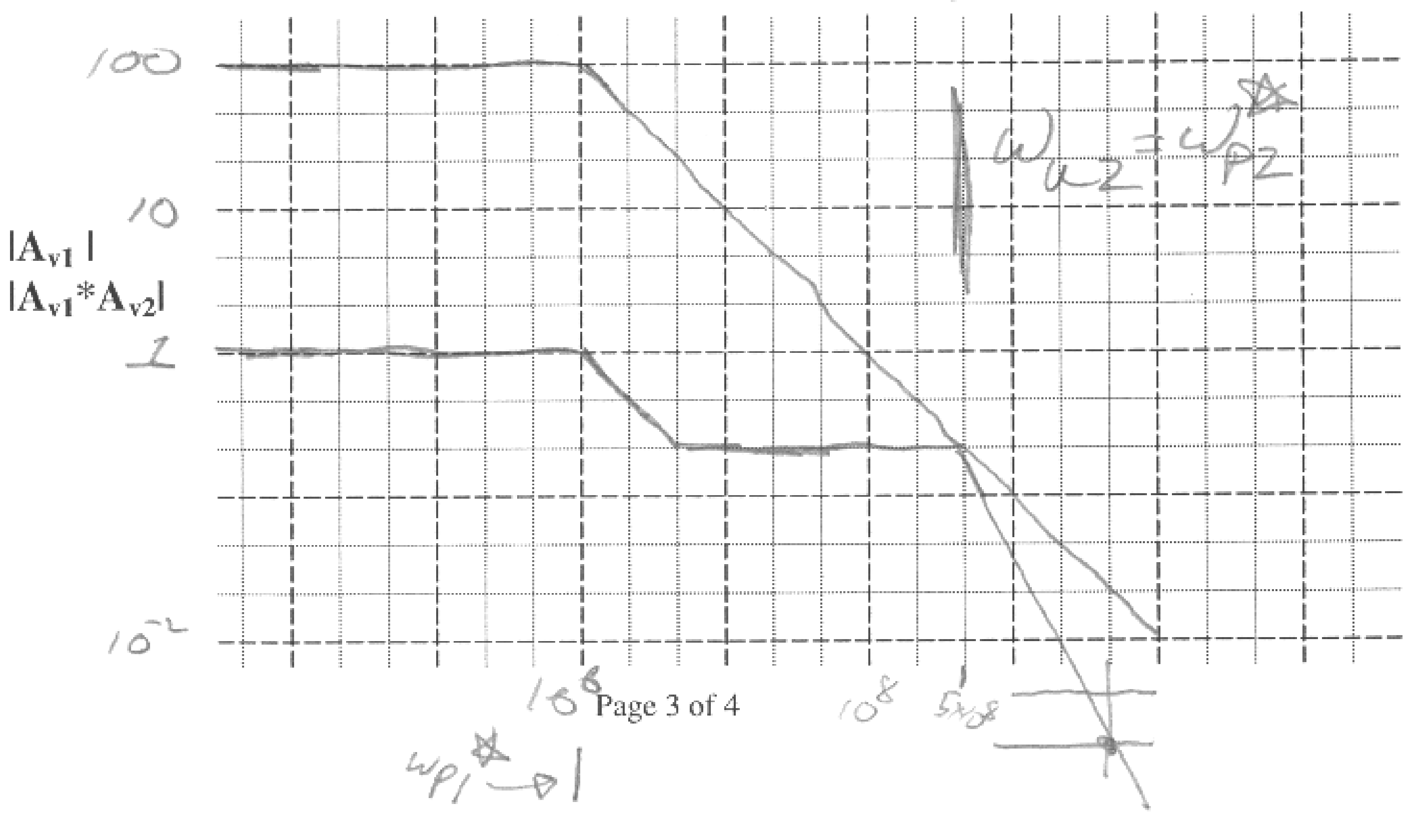


2 mirrors
2 gain stages
1 diff pair
1 output
2 inputs

3) (30pts) For the amplifier below assume that g_m**=500microS, R_{o1}=100kOhm, R_{o2}= 200kOhm, C_{o2}= 1pF, C_C= 0.1pF**. In the top plot draw the magnitude of the **impedance** $Z_{eq}(\omega)$ seen looking into the capacitor at node Vi2, and in the lower plot draw the magnitude of the **first stage gain,** v_{i1} to v_{i2}, and the **total gain,** v_{i1} to v_{o2}. **LABEL AXES, poles, and magnitudes CLEARLY!**







4. (15 points)

A. You have a single stage MOS amplifier with a low frequency gain of 100, a pole frequency of 5MHz, and an output capacitance of 1pF. Calculate the unity gain frequency, the transconductance gm, and the output resistance Ro.

See plot below which is a general single pole amp system AC response.

Given: $|A_{vo}| = g_m R_o = 100$ $\quad \omega_p = \frac{1}{R_o C_L} = 2\pi \times 5\ \text{MHz}$ $\quad C_L = 1\text{pF}$

From plot and above: $\Rightarrow$ $\boxed{R_o = \frac{1}{\omega_p C_L} = 31.8\ \text{k}\Omega}$ $\Rightarrow$ $\boxed{g_m = \frac{|A_{vo}|}{R_o} = 3.14\ \text{mS}}$

$\boxed{\omega_u = \frac{g_m}{C_L} = 3.14\ \text{G rad/s} \Rightarrow f_u = 500\ \text{MHz}}$

B. You need to design a single-stage amplifier with a gain of 5 at 10^9 rad/sec, and a DC gain of 50. Calculate the unity gain frequency, the pole frequency, and the gain at 10^7 rad/sec and 10^{10} rad/sec.

Given: $|A_{vo}| = |g_m R_o| = 50$ $\quad A_v(10^9\ \text{rad/s}) = 5$

From plot and above: Gain-Bandwidth = constant for single pole amp

$GBW = 5 \times 10^9\ \text{rad/s}$

$\Rightarrow$ $\boxed{\omega_u = 5 \times 10^9\ \text{rad/s} \Rightarrow f_u = 795.8\ \text{MHz}}$ $\quad \boxed{\omega_p = \frac{GBW}{|A_{vo}|} = 10^8\ \text{rad/s}}$

$\boxed{A_v(10^{10}\ \text{rad/s}) = \frac{GBW}{10^{10}\ \text{rad/s}} = 0.5\ \text{V/V}}$

$\boxed{A_v(10^7\ \text{rad/s}) = A_{vo} = 50\ \text{V/V}}$ $\leftarrow$ below pole by a decade

C. You have a single-stage amplifier with an output resistance of 10^7 Ohms, a transconductance of 10mS, and a unity gain frequency of 10^9 rad/sec. What is the DC gain, the pole frequency, and the outputcapacitance?

Given: $R_o = 10^7\ \Omega$ $\quad g_m = 10\ \text{mS}$ $\quad \omega_u = \frac{g_m}{C_L} = 10^9\ \text{rad/s}$

From plot and above: $\Rightarrow$ $\boxed{|A_{vo}| = |g_m R_o| = 10^5\ \text{V/V}}$

$\boxed{C_L = \frac{g_m}{\omega_u} = 10\ \text{pF}}$

$\boxed{\omega_p = \frac{1}{R_o C_L} = 10^4\ \text{rad/s} \Rightarrow f_p = 1.59\ \text{kHz}}$