EXAMPLE: DESIGN A 2-STAGE OP. AMP FOR THE FOLLOWING

SPECIFICATIONS: $V_{DD} = V_{SS} = 1.5V$, $C_L = 1pF$, $\omega_0 \geq 2\pi \times 100MHz$

$a_{dm} > 1000$, v_o SWING $> 2V$, $V_{ICM} = 0V$, $PM \simeq 45°$

PARAMETERS

$I_{sq_n} = 80nA$, $I_{sq_p} = 20nA$

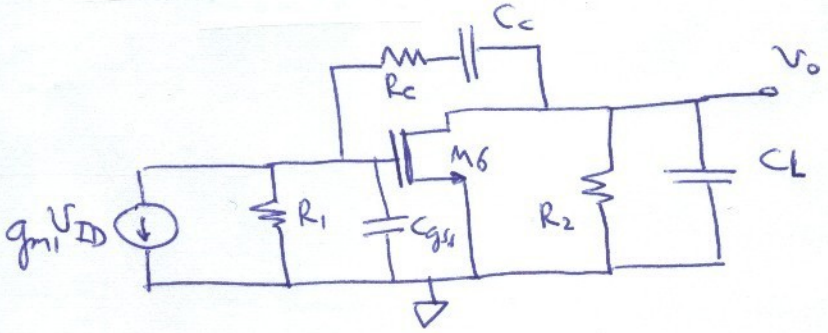
$V_{thn} = 0.65V$, $V_{thp} = -0.65V$

$n_n \simeq n_p \simeq 1.2$

$\left|\frac{\partial X_D}{\partial V_{DS}}\right|_{n-p} \simeq 0.06 \frac{\mu m}{V}$

SOLUTION:

1, SOME MORE DETAILS ABOUT FREQUENCY RESPONSE/STABILITY.



- ASSUME $C_c \gg C_{gs6}$
- $R_1 = r_{o4} \| r_{o2}$
- $R_2 = r_{o6} \| r_{o7}$

POLES:

$$p_1 \simeq -\frac{1}{g_{m6} R_2 R_1 C_c}$$ DOMINANT POLE

$$p_2 \simeq -\frac{g_{m6}}{C_L}$$ ← THIS ENDS UP BEING @ ω_0 LOCATION

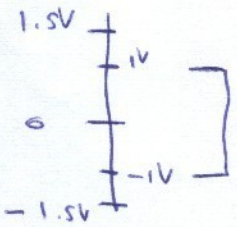
$$p_3 \simeq -\frac{1}{R_c C_{gs6}}$$ VERY HIGH FREQ. (NO EFFECT)

$$z = \frac{1}{\left(\frac{1}{g_{m6}} - R_c\right) C_c}$$ MAKE $R_c = \frac{1}{g_{m6}} \Rightarrow$ ZERO MOVES TO ∞

$\therefore$ FOR $\omega_0 \geq 2\pi \times 100MHz \Rightarrow -2\pi \times 100MHz \geq -\frac{g_{m6}}{C_L}$

$g_{m6} \geq 0.628\,mS$

$g_{m6} = \frac{2I_S}{nV_T}\left(\sqrt{1+i_{f6}} - 1\right)$ → WILL TRY SELECTING $i_{f6} = 100$ TO REDUCE AREA.



$\Rightarrow V_{DSSAT6} \leq 0.5V$

$V_{DSSAT6} = V_T\left[\sqrt{1+i_{f6}} + 3\right]$

$i_{f6\,MAX} = 262$ (WOULD BE OK WITH 100)

LOW-FREQ. GAIN: ASSUME L IS THE SAME FOR ALL TRANSISTORS

$$a_{dm} \simeq \frac{\cancel{2}}{(n\cancel{V_T})^2} \frac{1}{\sqrt{1+i_{f1}}+1} \frac{1}{\sqrt{1+i_{f6}}+1} \frac{L^2}{\frac{\cancel{4}}{2}\left|\frac{\partial X_D}{\partial V_{DS}}\right|^2}$$

- WE'LL TRY USING MODERATE INVERSION FOR M_1, M_2: $i_{f1} = 10$

$$\therefore L_{MIN} = nV_T\left|\frac{\partial X_D}{\partial V_{DS}}\right| \sqrt{2\left(\sqrt{1+i_{f1}}+1\right)\left(\sqrt{1+i_{f6}}+1\right)} \sqrt{a_{dm}}$$

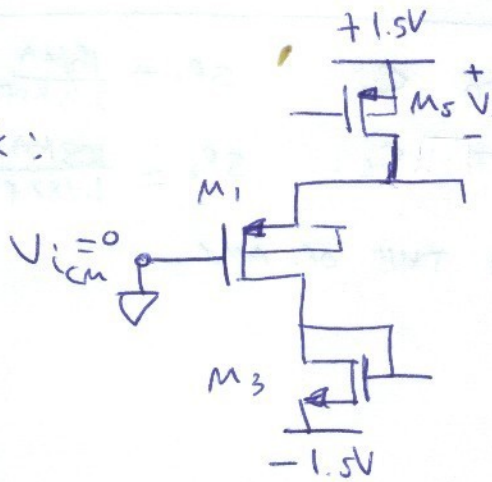
$\simeq 0.58\mu m \Rightarrow$ TAKE $L = 1\mu m \Rightarrow a_{dm} \cong 3000$ (SHOULD BE OK)

- MUST CHOOSE INVERSION LEVEL OF MIRROR TRANSISTORS M_5, M_7.

CHOOSE NEAR STRONG INVERSION (SAVE AREA)

$i_{f5} = i_{f7} = 100$

- CHECK V_{icm} IS OK:



M_5 V_S MAX: $1.5V - |V_{DSAT5}| - |V_{GS1}|$

SUM $< 1.5V$

MIN: SHOULD BE OK, LEFT AS EXERCISE

- FIND $|V_{GS_1}|$:

$$|V_p| = \frac{V_G - |V_{thp}|}{n} = 0.71\,V \qquad (V_G = 1.5\,V)$$

$$\frac{|V_p| - |V_s|}{V_T} = f(i_{F1}) = 2.15 \Rightarrow |V_s| = 0.65\,V = |V_{DS_5}| \qquad (V_s \text{ REFERRED TO } V_{DD})$$

∴ WE HAVE ENOUGH ROOM TO KEEP M_5 ACTIVE WHEN $V_{ICM} = 0V$

- FIND $\left(\frac{W}{L}\right)$ FOR ALL TRANSISTORS ⇒ MUST SELECT TAIL CURRENT

$$\left(\frac{W}{L}\right)_1 = \left(\frac{W}{L}\right)_2 = 20 \Rightarrow I_{D1} = \underbrace{20nA}_{I_{sqp}} \times \underbrace{20}_{\left(\frac{W}{L}\right)_1} \times \underbrace{10}_{i_{F1}} = 4\mu A$$

$$I_T = 2 I_{D1} = 8\mu A$$

$$\left(\frac{W}{L}\right)_3 = \left(\frac{W}{L}\right)_4 = \frac{4\mu A}{80nA \times \underbrace{100}_{i_{F3}=i_{F4}=i_{F6}}} = 0.5 \Rightarrow \text{TOO SMALL} \Rightarrow \text{DOUBLE } I_T$$

$$I_T = 16\mu A \Rightarrow \begin{cases} \left(\frac{W}{L}\right)_1 = \left(\frac{W}{L}\right)_2 = 40 \\ \left(\frac{W}{L}\right)_3 = \left(\frac{W}{L}\right)_4 = 1 \end{cases}$$

- $\left(\frac{W}{L}\right)_5 = \frac{16\mu A}{20nA \times 100} = 8$

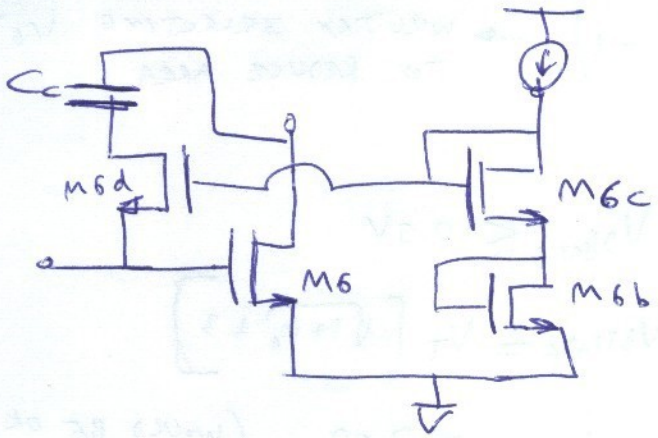
$$g_{m6} = 0.628\,mS = 2 \times \frac{I_{sqn}\left(\frac{W}{L}\right)_6}{n V_T}\left(\sqrt{1+100} - 1\right)$$

$$\left(\frac{W}{L}\right)_6 = 13.5 \Rightarrow I_{D6} = 80nA \times 13.5 \times 100 = 108\mu A \qquad \text{(COULD USE SOME MARGIN)}$$

$$\left(\frac{W}{L}\right)_7 = \frac{108\mu A}{20nA \times 100} = 54$$

$$R_c = 1592\,\Omega$$

$$C_c = \frac{g_{m1}}{g_{m6}} C_L = \frac{0.118\,mS}{0.628\,mS} \times 1pF = 0.187pF \qquad \text{(MAY NEED TO CONSIDER } C_{gd_6} \text{ HERE)}$$

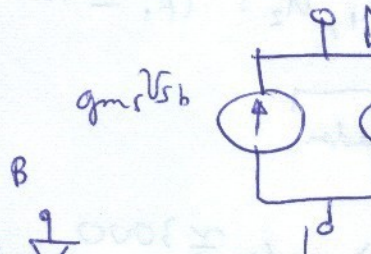


$I_{D6d} = 0 \Rightarrow i_{f6d} = i_{r6d}$

$$\frac{V_{P6d} - V_{G6}}{V_T} = \frac{V_{P6d} - V_{G6}}{V_T}$$

$g_{ms6d} = g_{md6d}$ (SAME AS M6)

$g_{mg6d} = 0$



$$i_o = -g_{ms} V_{sb} + g_{md} V_{db} = g_{ms}(V_{db} - V_{sb}) = g_{ms} V_{ds}$$

$\therefore$ M6d EQUIVALENT TO A RESISTOR $R_{eq} = \frac{1}{g_{ms6}} = \frac{1}{n\, g_{m6}}$

SLEW RATE:

DUE TO C_c: $SR_1 = \frac{16\mu A}{0.187pF} = 85 \frac{V}{\mu s}$ ← LIMITING FACTOR

DUE TO C_L: $SR_2 = \frac{108\mu A}{1.187pF} = 90 \frac{V}{\mu s}$ ← ONLY GOING UP

$SR \cong 85 \frac{V}{\mu s}$ FOR THIS OP. AMP.