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EECS 140 Final Exam

Name: Solutions

Fall 1996

$k_n = k_p = 10^{-4}\ A/V^2$
$\gamma_n = \gamma_p = 0$
$\lambda_n = \lambda_p = .01$
$V_{Tn} = V_{Tp} = 1V.$

$C_{gd} = 1ff$
$C_{db} = 10ff$
$C_{gs} = 100ff$
$C_{gb} = 5ff$
$C_{sb} = 10ff$

1) a) 3.6 Volts
b) W/L 6.2

2) a) V_{MIN} 1.7 Volts
V_{MAX} 3.7 Volts
b) 10^6

3) a) $(W/L)_{M1}$ 100
$(W/L)_{M2}$ 100
b) V^-_{MIN} −2.9
V^+_{MAX} +2.9

4) R 600Ω

5) C_c 1000pf

6) I_{REF} 25μA

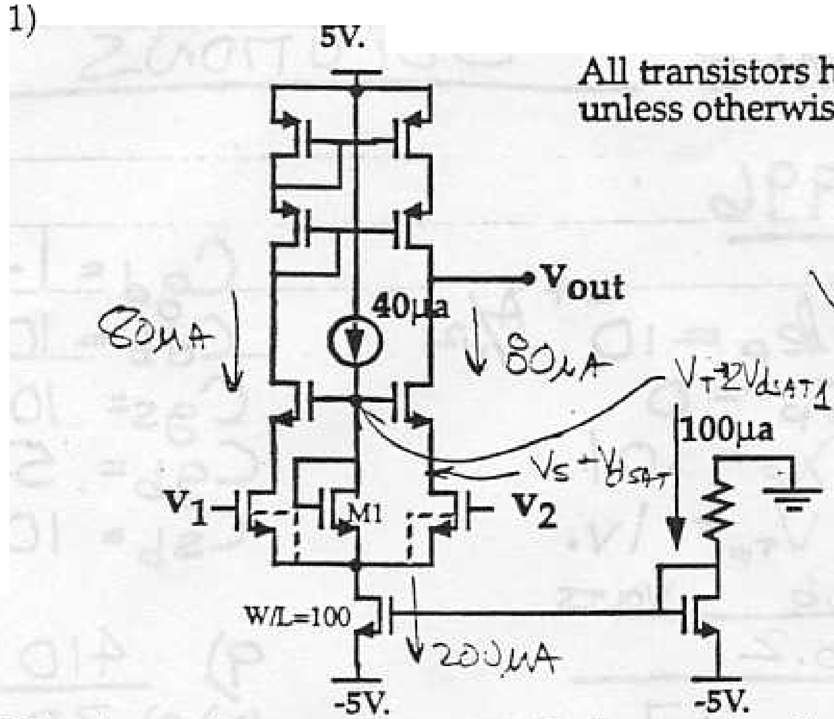
7) a) 97k RAD/SEC
b) 9.4 M RAD/SEC

8 a Shunt-Shunt
b) V_{out}/i_{in} 710
c) R_{IN} 1Ω

9) 40 RAD/SEC

10) a) 20 Volts/μsec
b) 90 Degrees

1)



All transistors have W/L=50, unless otherwise indicated

$$V_{dSAT} = \left(\frac{2\,I_{ds}}{k'\,W/L}\right)^{1/2} = .18\text{V.} \qquad I_{ds}=80\mu A,\ W/L=50$$

a) What is maximum value at v_{out} in the positive direction which still has all transistors in saturation?

$$V_o \qquad 5-(V_T+2V_{dSAT}) = 3.64$$

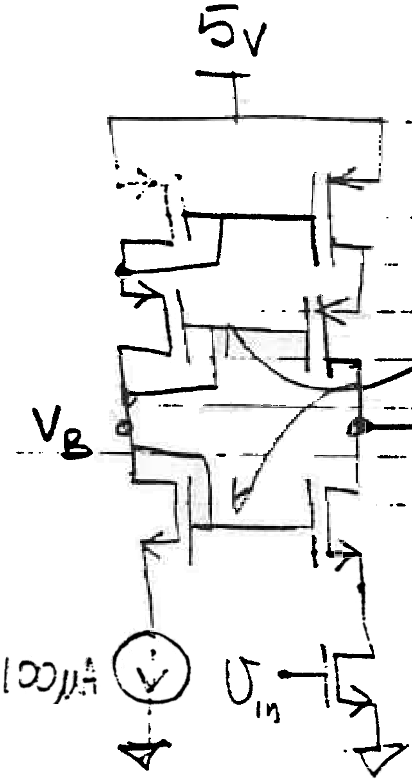
b) Choose the W/L of M1 to maximize the swing at v_{out} in the negative direction which has all transistors in saturation?

$$\cancel{V_T} + V_{dSAT,M} = \cancel{V_T} + 2V_{dSAT}$$

$$V_{dSAT\ M1} = .36\text{V.}$$

$$\left(\frac{2\ 40\times10^{-6})}{10^{-4}(W/L)}\right)^{1/2} = .36 \qquad \underline{W/L = 6.2}$$

2)



ALL W/L's = 100

$5 - 2V_T - 2V_{dSAT} = V_B = 2.72V$

$$V_{dSAT} = \left(\frac{2 \times 10^{-4}}{10^{-4} \cdot 10^{2}}\right)^{1/2} = .14V.$$

WHAT IS THE RANGE OF DC VOLTAGES AT V_{OUT} OVER WHICH THE GAIN IS MAXIMUM?

VMIN 1.72 VMAX 3.72

$$V_{MIN} = V_B - V_T = 1.72V$$

$$V_{MAX} = V_B + V_T = 3.72V.$$

b) WHAT IS THAT MAXIMUM GAIN? 10^6

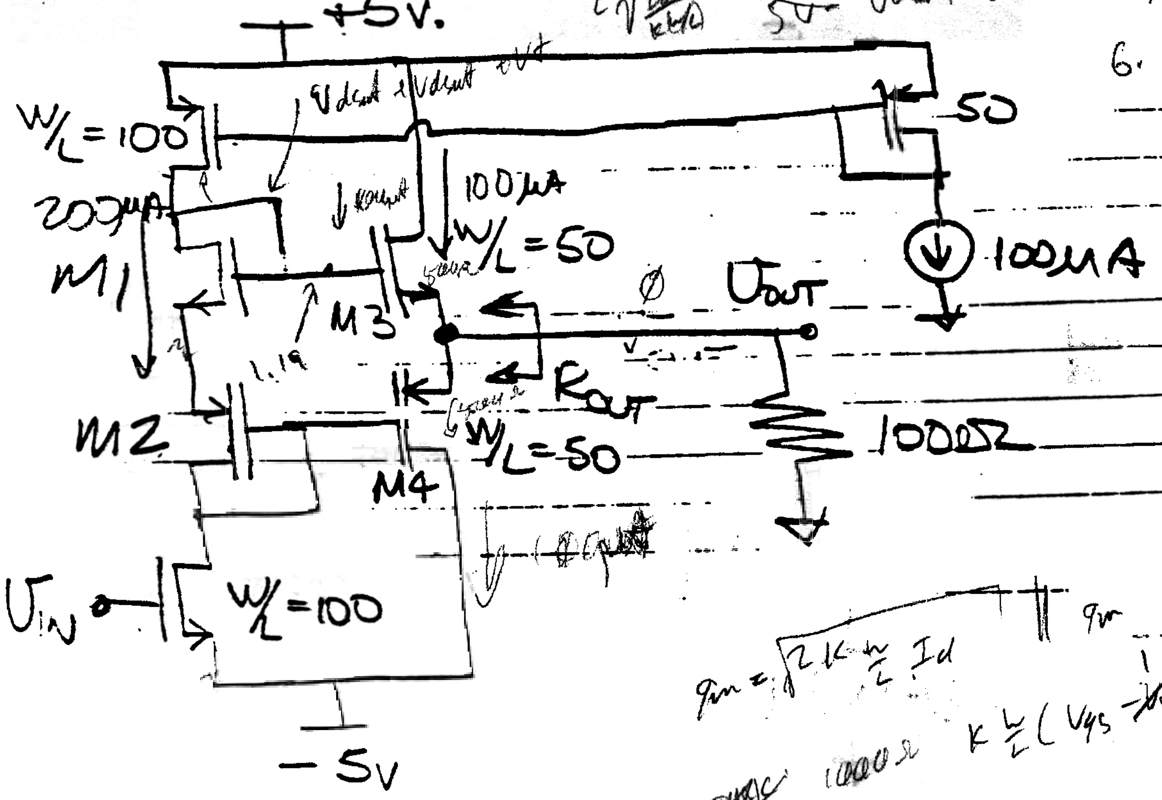
$$R_{out} = \frac{r_o(g_m r_o)}{2}$$

$$A_V = g_m R_{out} = \frac{(g_m r_o)^2}{2} = \frac{2 k' W/L I_{ds}}{2} \cdot \frac{1}{\lambda^2 I_{ds}^2}$$

$$= 10^6$$

6.

3)



$g_m = \sqrt{2 K \frac{W}{L} I_d}$ $\quad K \frac{W}{L}(V_{gs} - V_T)(1+2 V_{ds})$ $\quad$ 1000Ω

a) ASSUME V_{in} IS SET SO THE OUTPUT IS AT 0 VOLTS, WHAT ARE THE W/L'S OF M1 & M2 SO THAT THE OUTPUT RESISTANCE, R_{OUT} = 500Ω?

M1 100

M2 100

$R_{out} = \frac{1}{2 g_m} = 500\Omega$

$g_m\ 1k\Omega = \left(2k'\left(\frac{W}{L}\right)_{M3} I_{ds_3}\right)^{1/2} = 10^3$

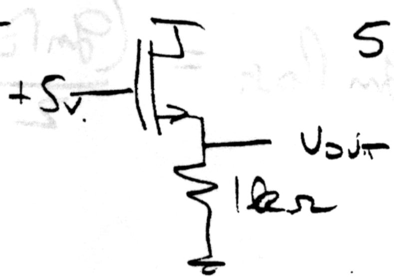
$I_{ds_3} = 10^{-4} A = 100\mu A$

$\left(\frac{W}{L}\right)_{M_1} = 2\left(\frac{W}{L}\right)_{M_3}$ FOR $I_{DS_1} = 2 I_{ds_3}$

= 100 SAME FOR M2 & M4

b) ASSUME W/L OF M1 & M2 = 50, THEN WHAT ARE THE MAXIMUM POSITIVE AND MINIMUM NEGATIVE VOLTAGES (DEVICES CAN GO INTO LINEAR REGION) IF V_{IN} GOES BETWEEN +5V. TO −5V. V_{MIN} −2.93 V $\quad V_{MAX}$ +2.93V

SYMMETRICAL



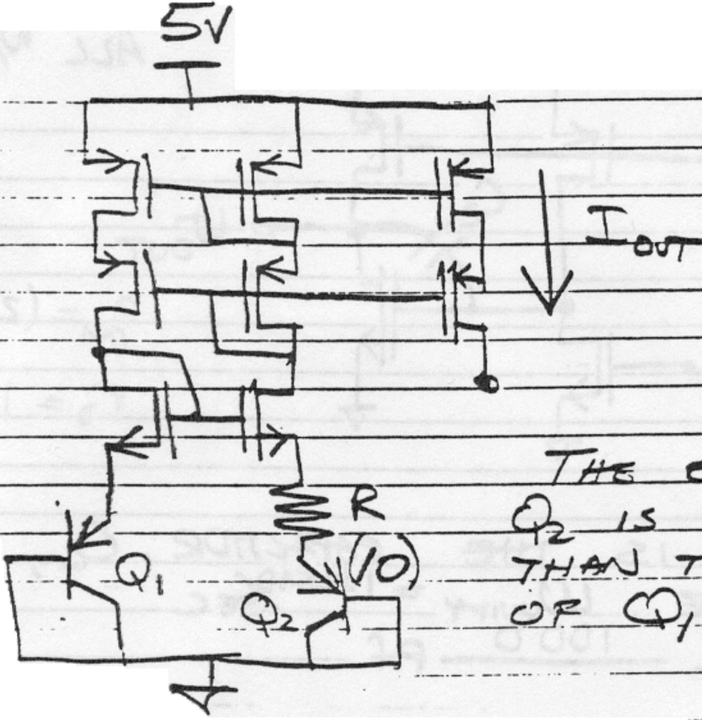
$5 - V_T - V_{dsAT} = V_{OUT}$

$4 - \left(\frac{2 V_{OUT}}{10^3 k' W/L}\right)^{1/2} = V_{OUT}$

$4 - V_{OUT}^{1/2}(.63) = V_{OUT}$

ITERATE → $V_{OUT} = 2.93$

4)



ALL W/L's = 100

THE EMITTER OF Q_2 IS 10 TIMES LARGER THAN THE EMITTER OF Q_1

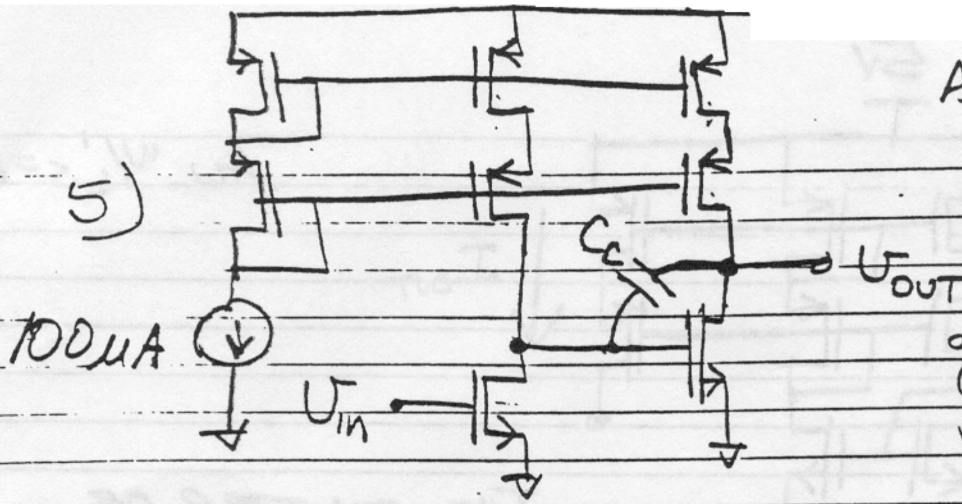
WHAT IS THE VALUE OF R SO THAT $I_{OUT} = 100\,\mu A$ __600Ω__

$V_T \ln \frac{I}{I_s} = V_T \ln \frac{I}{10 I_{s1}} + IR$

$\frac{V_T}{2} \ln 10 \quad I \qquad R = \frac{V_T \ln 10}{I} = \frac{.026 \ln 10}{10^{-4}}$

$= 600\,\Omega$

5)



ALL W/L's = 50

$g_m = (2 \cdot 10^{-4} \cdot 50 \cdot 10^{-4})^{1/2}$
$= 10^{-3}$

$r_o = 10^6$

WHAT IS THE CAPACITOR, C_C, WHICH WILL GIVE $\omega_{UNITY} = 1 \text{ kRAD/SEC}$

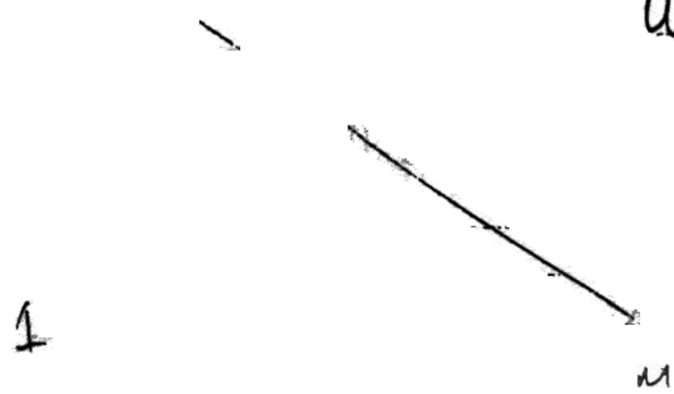
C_C 1000 pf

(ω_{UNITY} = OPEN LOOP UNITY GAIN FREQUENCY)

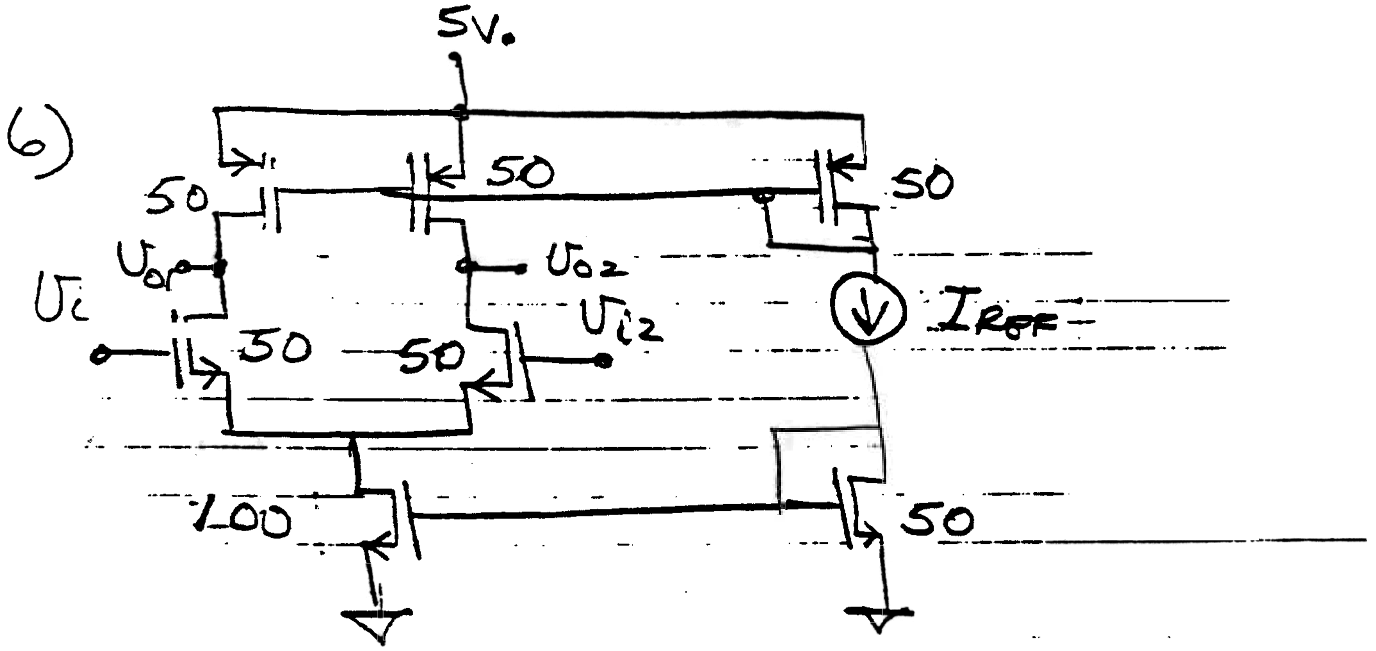
$a_o \; (g_m r_o)^2 \; 10^6$

$$\omega_c = \frac{(g_m r_o)^2}{10^6} = \frac{1}{r_o (g_m r_o C_c)}$$

$$C_c = \frac{g_m}{10^6} = 10^{-9} f$$



6)



WHAT IS THE CURRENT, I_{REF}, WHICH GIVES A COMMON MODE REJECTION RATIO (CMRR) OF 60dB? ________

$$CMRR = \frac{A_{dm}}{A_{cm}} = \frac{g_{m2}\frac{r_{o4}}{2}}{\frac{g_{m2} r_{o4}}{1 + 2 g_{m2} r_{o1}}}$$

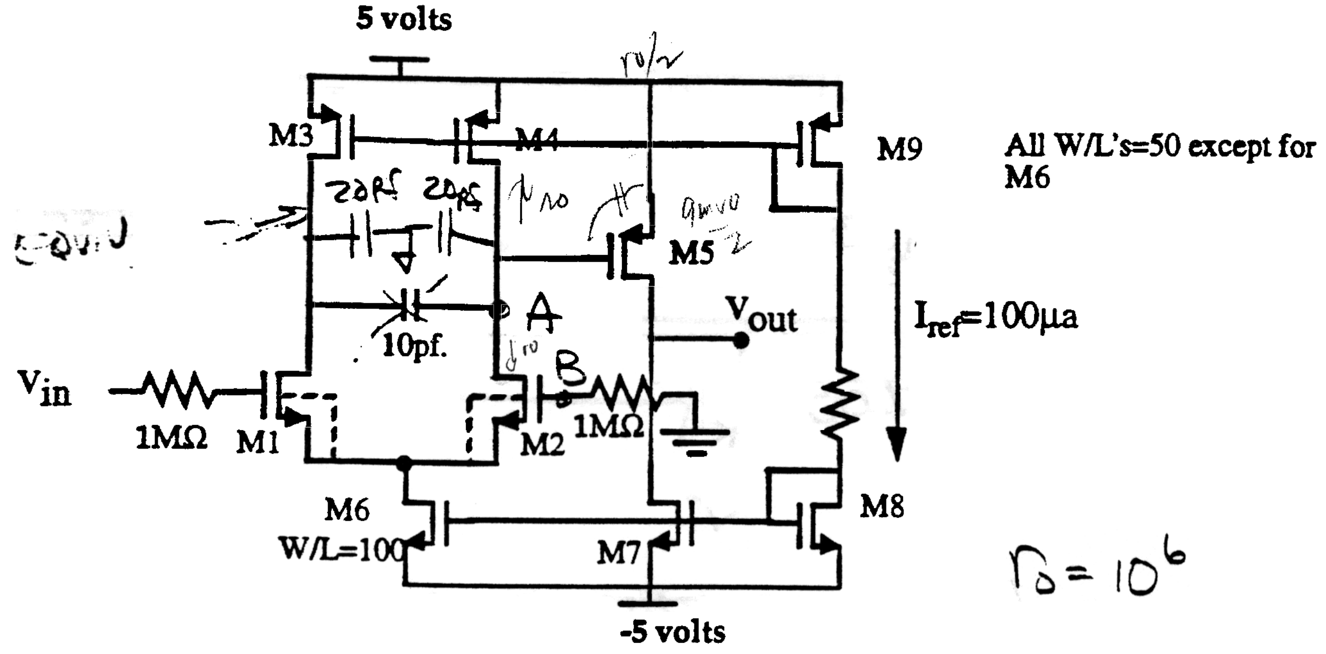
$$r_{o1} = \frac{r_{o4}}{2}$$

$$= \frac{1 + g_{m2} r_{o4}}{2} \approx \frac{g_{m2} r_{o4}}{2} = 10^3$$

$$\frac{\left(2 k' W/L \, I_{DS}\right)^{1/2}}{I_{ds}\lambda} = 2 \times 10^3$$

$I_{ds} = 25 \mu A$

Problem 7)



a) Where is the first pole of v_{out}/v_{in}? 97 kRAD/SEC

NODE A

$$C_A = \left(C_{gs5} + C_{gd5}\frac{g_m r_o}{2} + 20pf\right)$$

$$= 20.6\,pf$$

$$\omega_1 = \frac{1}{\frac{r_o}{2} C_A} = \frac{2}{10^6 \cdot 20.6pf} = 97\times10^3$$

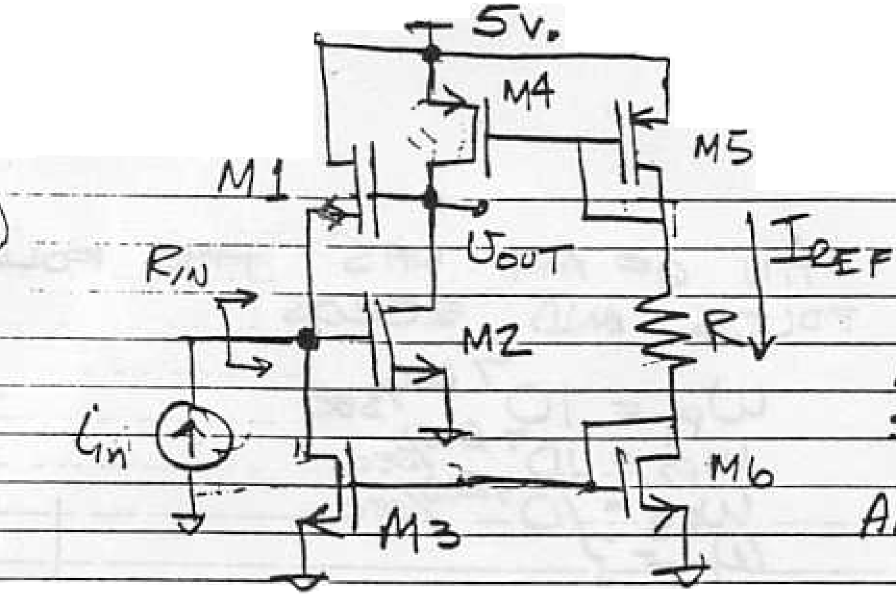
b) Where is the second pole? 9.4 MEG RAD/SEC

NODE B

$$\omega_2 = \frac{1}{\frac{r_o}{2}\left(C_{gs2} + C_{gb2} + C_{gd2}\right)} = \frac{1}{\frac{10^6}{2}(106\,ff)}$$

$$= 9.4\ \text{MRAD/SEC}$$

8)



ASSUME R IS CHOSEN SO $I_{REF} = 100\mu A$.

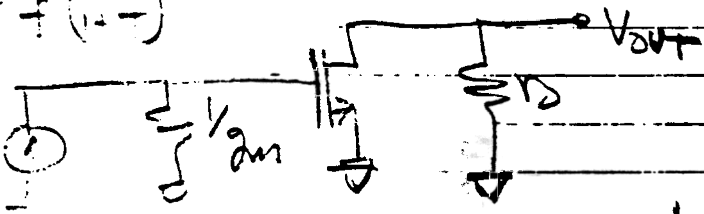
ALL W/L's = 100

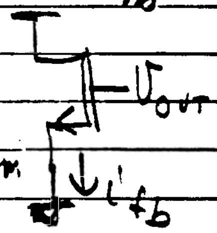
ANALYZE THIS CIRCUIT CONSIDERING M1&M3 AS THE PROVIDING FEEDBACK AND M2&M4 AS THE BASIC AMPLIFIER

a) WHAT KIND OF FEEDBACK IS THIS SHUNT-SHUNT

b) WHAT IS THE CLOSED LOOP GAIN, $\frac{V_{OUT}}{i_{in}}$?

$\frac{V_{out}}{i_{in}} = \frac{1}{f}\left(\frac{T}{1+T}\right) = 710\,\Omega$





$f = \frac{i_{fb}}{V_{out}} = g_m$

c) WHAT IS R_{IN} $1\,\Omega$

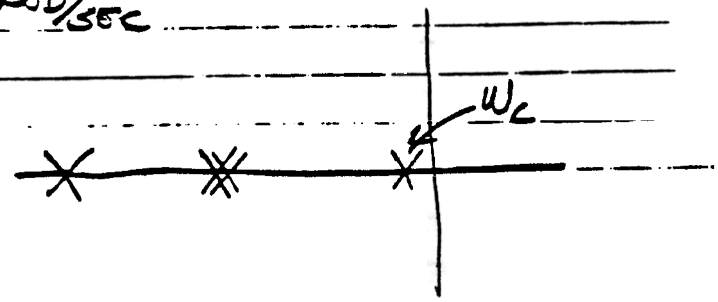
$$a_o f = \left(\frac{1}{g_m}\right)\left(g_m \frac{r_o}{2}\right)\left(g_m\right) = \frac{g_m r_o}{2} = 500 \gg 1$$

$$g_m = \sqrt{(2 \cdot 10^{-4} \cdot 100 \cdot 100\mu A)} = 1.4 \times 10^{-3}$$

$$R_{IN} = \frac{1/g_m}{1+T} \approx \frac{1/g_m}{g_m r_o/2} = \frac{2}{g_m^2 r_o} = \frac{2}{2\times10^{-6}\cdot 10^6} = 1\,\Omega$$

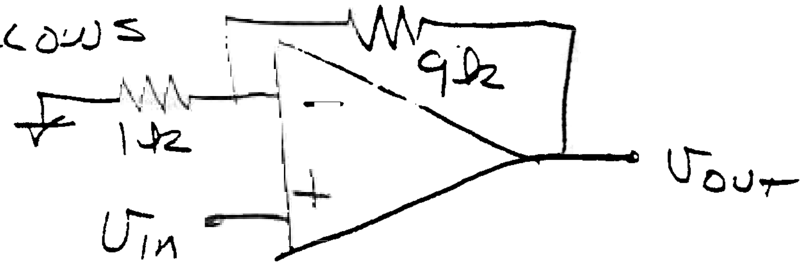
9) AN OP AMP HAS THE FOLLOWING POLES AND ZEROS

$\omega_{P1} = 10^7$ RAD/SEC
$\omega_{P2} = 10^7$ RAD/SEC
$\omega_{P3} = 10^9$ RAD/SEC
$\omega_C = ?$



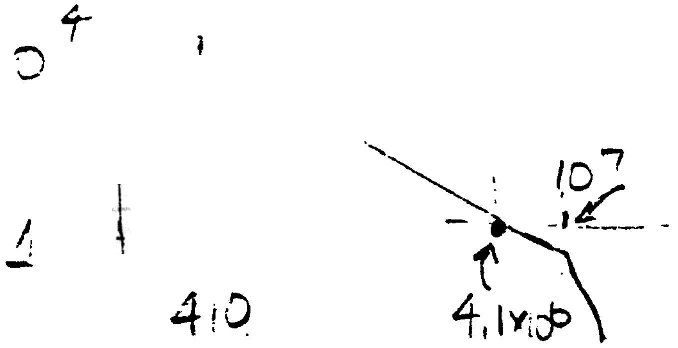
AND THE OPEN LOOP GAIN $a_0 = 10^5$

IF THE OP AMP IS CONNECTED AS FOLLOWS



AT WHAT FREQUENCY SHOULD A COMPENSATION POLE BE ADDED SO THAT THE PHASE MARGIN IS 45°? ω_C ________ RAD/SEC 410 RAD/SEC

$$T = a_0 f = 10^5 \cdot (.1) = 10^4$$

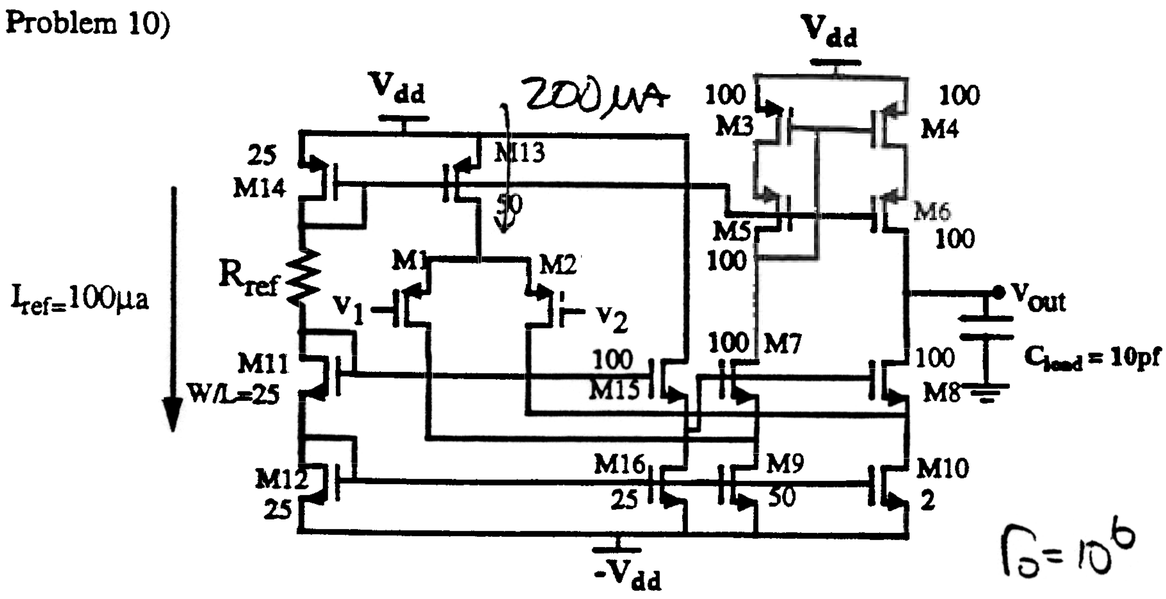


CONTRIBUTION FROM EACH POLE AT 10^7 SHOULD BE 22.5°

$$\tan^{-1}\frac{\omega}{10^7} = 22.5^\circ$$

$$\omega = 10^7 \tan 22.5^\circ$$
$$= 4.1\times10^6$$

Problem 10)



$r_o = 10^6$

$g_m = 1.4 \times 10^{-3}$

a)What is the minimum slew rate of this circuit? 20 V/

$$\frac{dV}{dt} = \frac{I}{C_{LOAD}} = \frac{2 \times 10^{-4}}{10^{-11}} = 20\ V/\mu s$$

b)What is the phase margin of this circuit? 90°

$$R_{OUT} = r_o(g_m r_o) \,\|\, r_o\left(g_m \frac{r_o}{2}\right)$$

$$= .47 \times 10^9\ \Omega$$

$210 \cdot a_o = 1.2 \times 10^8$

1

90°

$$\omega_d = \frac{1}{.47 \times 10^9 \cdot 10^{-11}} = 210\ \text{rad/sec}$$

$$\omega_{NO} \approx \frac{1}{\frac{1}{g_m}(121ff)}$$

$$= \frac{1.4 \times 10^{-3}}{1.2 \times 10^{-13}} \approx 1 \times 10^{10}$$

$\omega_{NO} = 10^{10}$

$$a_o = g_m R_{OUT} = 1.4 \times 10^{-3} \cdot .47 \times 10^9 = 6.6 \times 10^5$$