EECS 140
MIDTERM 2
FALL 1998

Name : SOLUTIONS

Assume the W/L = 10 for all transistors unless otherwise indicated.

$V_{TN} = V_{TP} = 0.5V$

$k_n' = k_p' = 100\mu A/V^2$

$\gamma_n = \gamma_p = 0$

$\lambda_n = \lambda_p = 0.01$

$C_{GS} = 100ff$

$C_{GD} = C_{GB} = C_{DB} = C_{SB} = 10ff$

(4) 1a. V_{max} = 3.08

(4) b. V_{min} = 3.65

(4) c. 47 %

(10) 2. W/L = .43

(5) 3. R_{out} = 37MΩ

(5) v_{out}/v_{in} = 3.4×10^3

(5) 4. ω_{p1} = 1.9k RAD/SEC

(5) ω_{p2} = 110k RAD/SEC

(4) 5a. SHUNT-SHUNT

(4) b. f = -1×10^{-4}

(4) c. T' = 210

(10) 6. w_c = 450 RAD/SEC

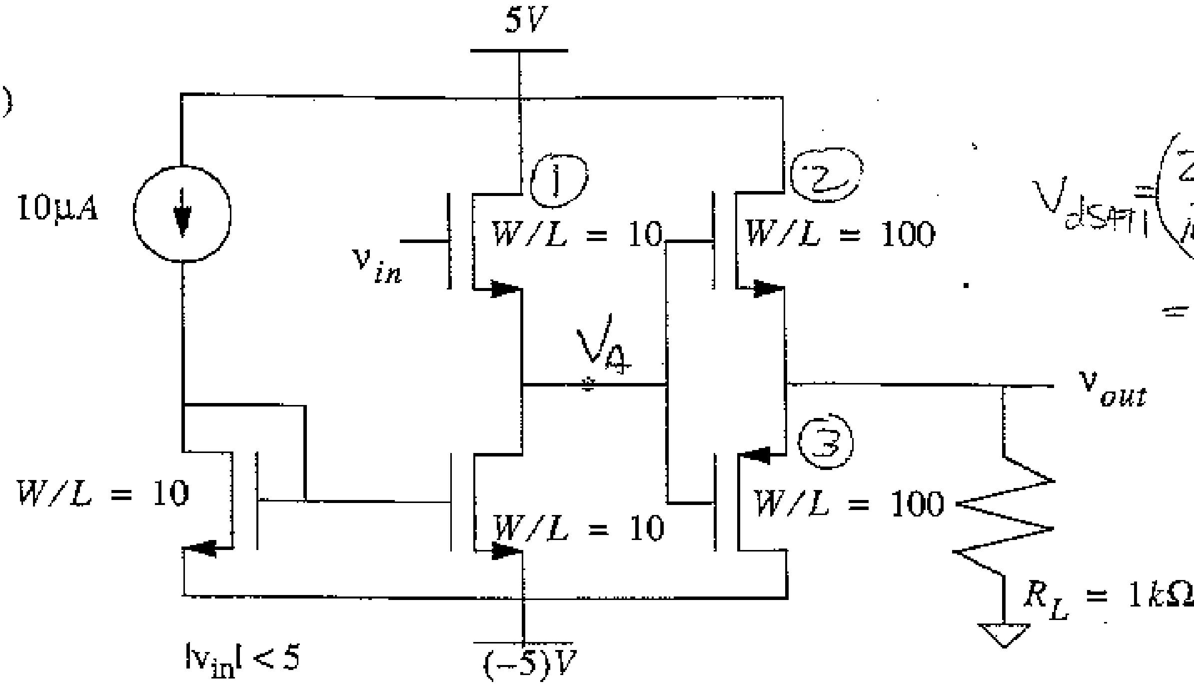
(4) 7. A_{dm} = 21

(4) A_{cm} = .5

(4) v_{out}/v_{in} = -10.2

SHOW YOUR WORK!!

1)



$|v_{in}| < 5$

$V_{dSAT1} = \left(\frac{2(10\mu A)}{100\mu A/V^2 \cdot 10}\right)^{1/2} = .14$

1. What is the maximum voltage at V_{out} ? 3,08V.

$V_{OUT,MAX} = V_{IN,MAX} - (V_T + V_{dSAT1}) - (V_T + V_{dSAT2})$

$= 5 - .5 - .14 - .5 - V_{dSAT2}$

$= 3,86 - \left(\frac{2 V_{OUT}/R_L}{k' \cdot 100}\right)^{1/2}$

$V_{OUT}^2 - 7,9 V_{OUT} + 14,9 = 0$ $\quad V_{OUT} = $ ~~4,84~~, 3,08

2. What is the minimum voltage ? −3,65

ASSUME M3 IN LINEAR, $V_A = -5$

$V_{OUT} = -5 + V_T + V_{dSAT3} = -4,5 + \left(\frac{2 V_{OUT}/R_L}{k' \cdot 100}\right)^{1/2}$

$V_{OUT}^2 + 9,2 V_{OUT} + 20,7 = 0$

$V_{OUT} = -3,65$, ~~−5,55~~

3. What is the efficiency of this circuit ? 47 %

PUSH PULL

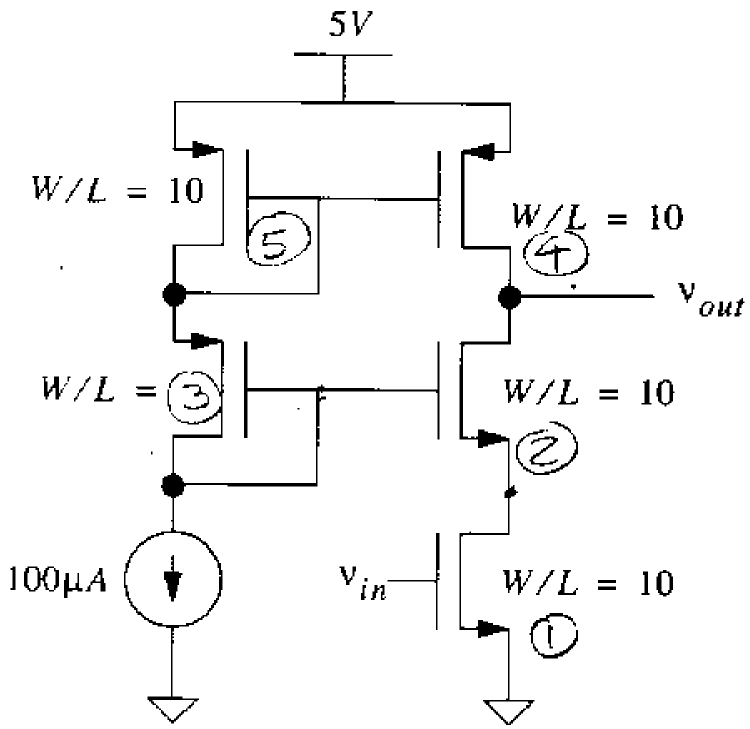
MAX SWING ± 3,08V.

$P_{SUPPLY} = 2(10V \cdot 10\mu A) + (2)\,5\,\frac{1}{\pi}\frac{V_o}{R_L}$

$= 4\times10^{-4} + 10^{-2}\,\frac{3,08}{\pi} = 10\,mW$

$P_L = \frac{V_o^2}{2R_L} = \frac{1}{2}\frac{(3,08)^2}{10^3} = 4.7\,mW$ $\quad \eta = \frac{P_L}{P_{SUPPLY}} = 47\%$

2)



What is the value of the missing W/L so that the output swing is maximum? W/L = .43

$$V_{1,sat}(100\mu A) = \left(\frac{2(100)\,\mu A}{100\,\mu A/V^2 \cdot 10}\right)^{1/2} = .45V.$$

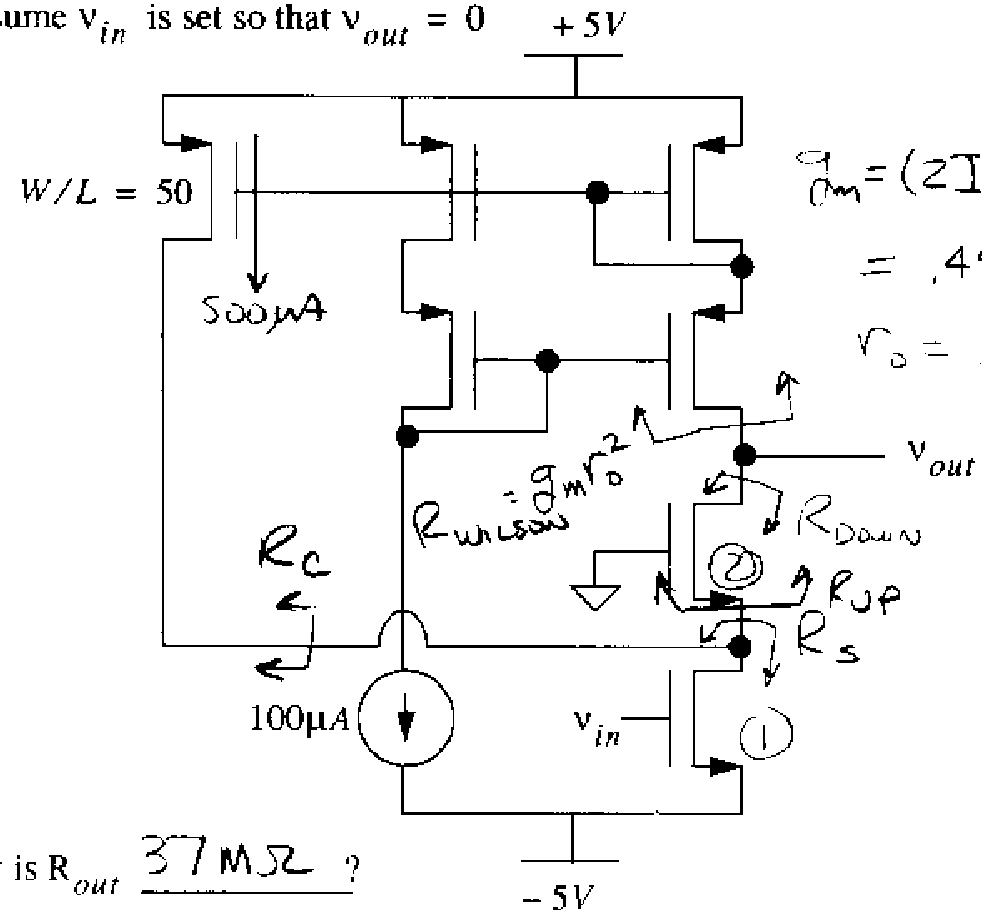
$$5 = V_{dSAT1} + (V_{dSAT2} + V_{T2}) + (V_{dSAT3} + V_{T3}) + (V_{dSAT5} + V_{T5})$$

$$V_{dSAT3} = 5 - (1.5) - 3(.45) = 2.15$$

$$= \left(\frac{2(100)}{100\,(W/L)}\right)^{1/2}$$

$$\left(W/L\right)_3 = .43$$

3) Assume v_{in} is set so that $v_{out} = 0$



$g_m = (2 I_D k' \frac{W}{L})^{1/2}$

$= .45 \times 10^{-3}$ 25

$r_o = \frac{1}{\lambda I_D} = \frac{1}{(.01)(100\mu)}$

$= 1 M\Omega$

a) What is R_{out} <u>37 MΩ</u> ?

$R_{WILSON} = .45 \times 10^{-3} \times 10^{12} = 450 M\Omega$

$R_S = \frac{1}{\lambda 5 (100\mu A)} \| \frac{1}{\lambda 6 (100\mu A)} = 91 k\Omega$

$R_{DOWN} = (g_{m_2} R_S) r_{o_2} = .45 \times 10^{-3} \times 91 \times 10^{3} \times 10^{6} = 41 M\Omega$

b) What is $\frac{v_{out}}{v_{in}}$ <u>3,400</u> ?

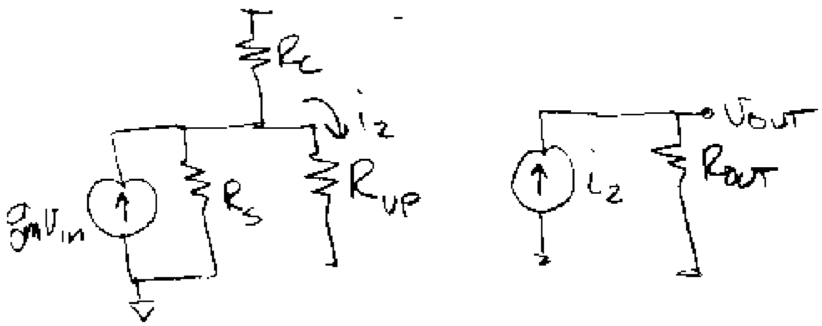
$R_{OUT} = R_{WILSON} \| R_{DOWN}$

$= 450 M\Omega \| 41 M\Omega$

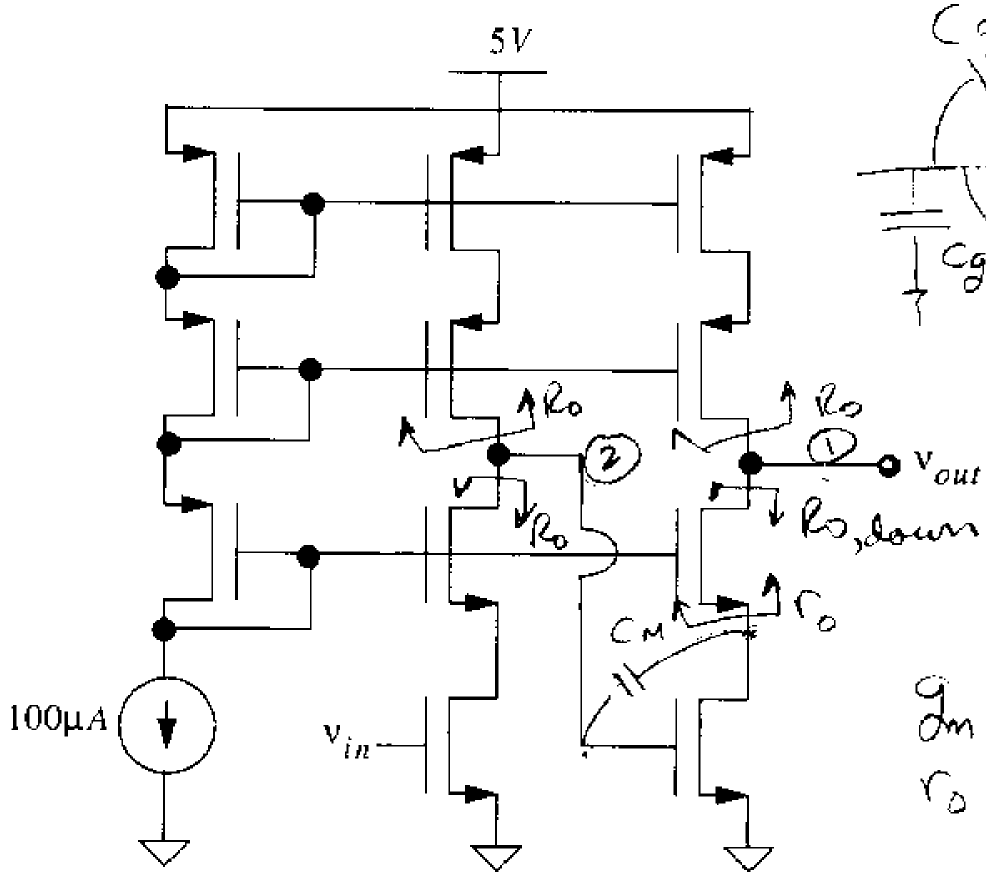
$= 37 M\Omega$

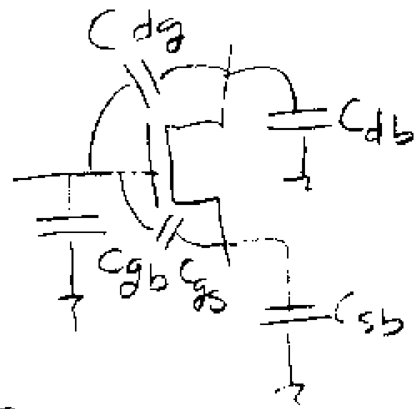
$$\frac{v_{out}}{v_{in}} = g_m \frac{R_S \| R_C}{R_{UP} + R_S \| R_C} R_{OUT} = (2 \times 600\mu A \times 100\mu A/V^2 \cdot 10)^{1/2} \left(\frac{1/1}{1/1 + 1} \right) 37 M\Omega$$

$= 3.4 \times 10^{3}$



4)





$g_m = .45 \times 10^{-3}$

$r_o = 10^6$

What are the 2 lowest poles of this circuit?

ω_{p1} 110 kRAD/SEC

ω_{p2} 1.9 kRAD/SEC

$C_1 = 2(C_{db} + C_{gd}) = 40ff$

$R_o = g_m r_o^2 = .45 \times 10^{-3} \cdot 10^{12}$

$= 450M\Omega$

ASSUMING ALL IN SATURATION

$$\omega_{p1} = \frac{1}{\left(\frac{R_o}{2}\right) C_1} = \frac{1}{225 \times 10^6 \cdot 40 \times 10^{-15}}$$

$= 110k$ RAD/SEC

$$\omega_{p2} = \frac{1}{\frac{R_o}{2}(C_1 + C_M + C_{gb} + C_{cgs})}$$

$C_M = g_m (r_o \| r_o) C_{gd} =$

$= .45 \times 10^{-3} \times 10^6/2 \times 10ff$

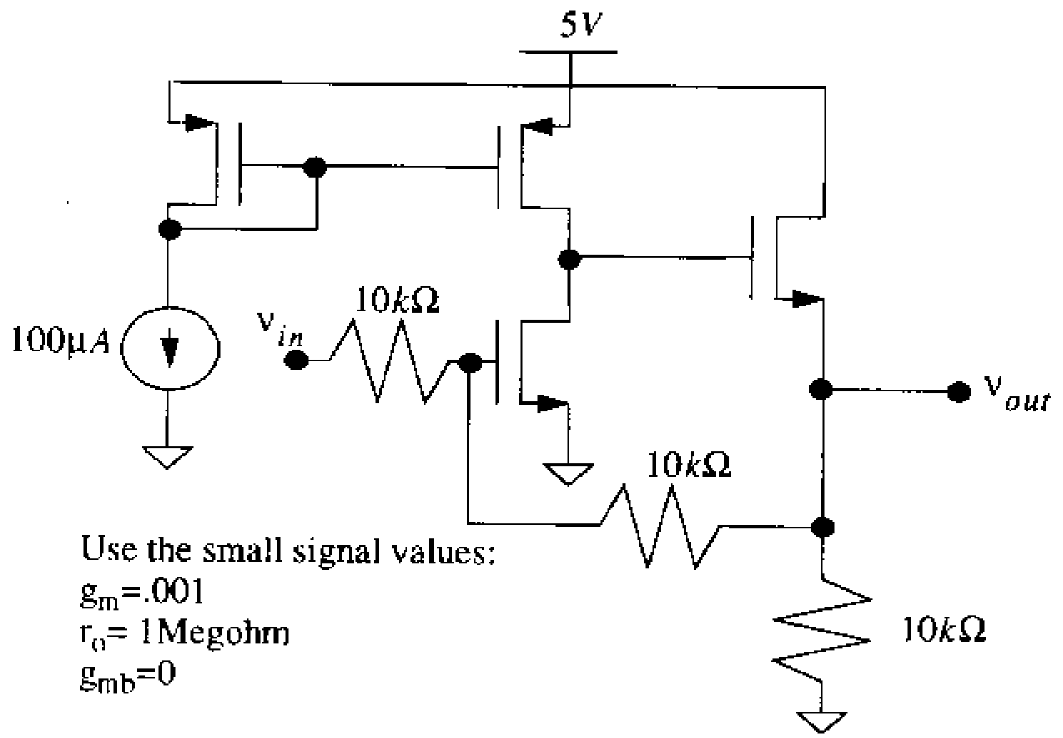
$= 2250 ff$

$$\omega_{p2} = \frac{1}{(225 \times 10^6 \times (40ff + 2250ff + 10ff + 100ff)}$$

2400 ff

$= 1.9$ kRAD/SEC

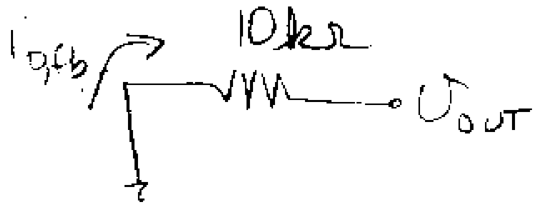
5)



Use the small signal values:
$g_m = .001$
$r_o = 1$ Megohm
$g_{mb} = 0$

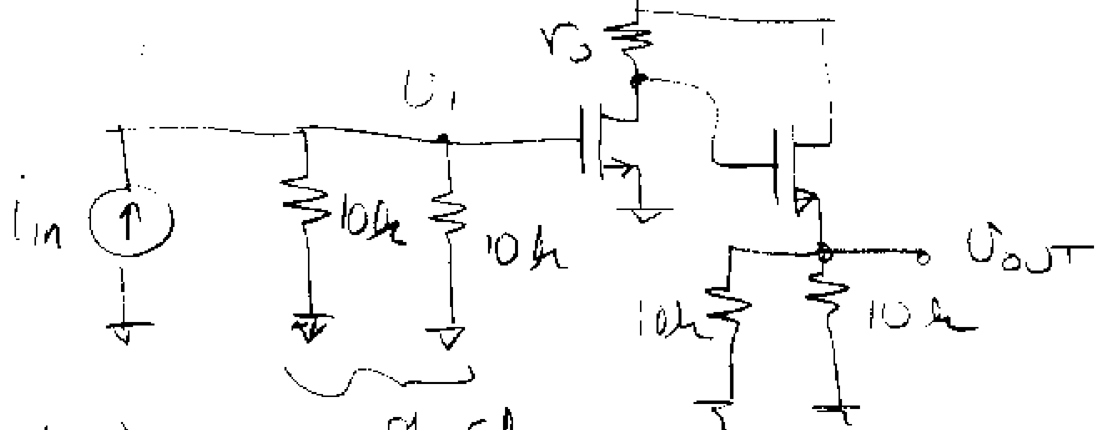
a) What kind of feedback is this? SHUNT - SHUNT

b) What is the value of f ? f $-.1 \times 10^{-3}$ 25



$f = \frac{i_{o,fb}}{v_{out}}$

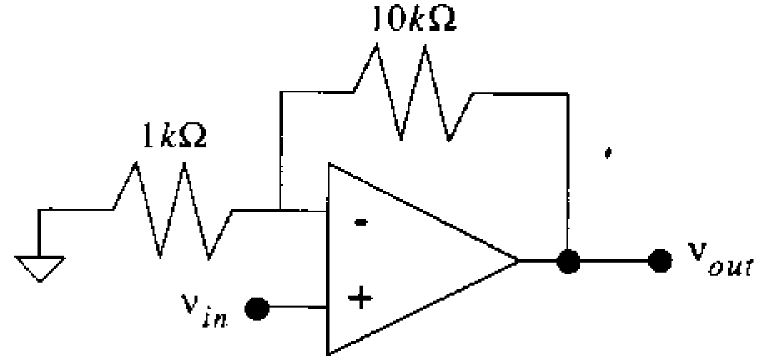
c) What is the loop gain including loading T .210 ?



$$a' = -(5k)\, g_m \left(\frac{r_o}{2}\right) \frac{g_m 5k}{1 + g_m 5k} = 5 \times 5 \times 10^5 \left(\frac{5}{6}\right) = -2.1 \times 10^6$$

$$t' = +2.1 \times 10^2$$

6)



The above basic amplifier has the following characteristics:

$R_{in} = \infty$

$R_{out} = 0\Omega$

The transfer function is :

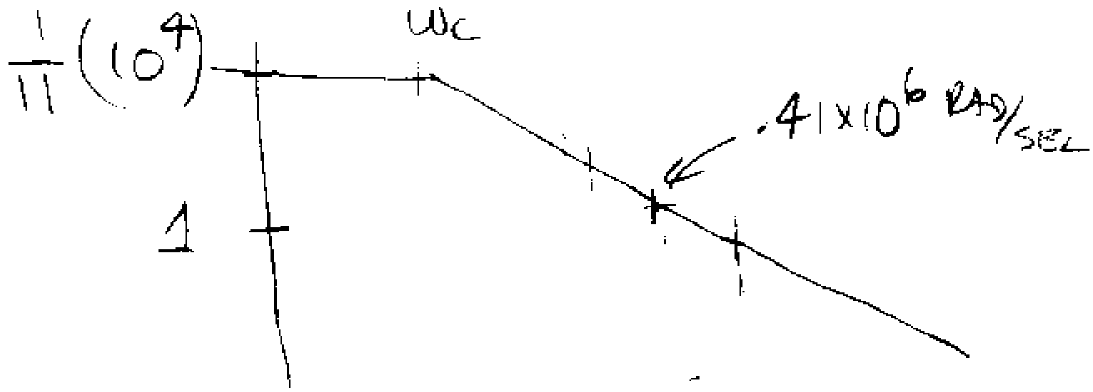
$$H(\omega) = \frac{10^4 \cdot \left(1 - \frac{j\omega}{1 \times 10^6}\right)}{\left(1 + \frac{j\omega}{10^6}\right) \cdot \left(1 + \frac{j\omega}{10^8}\right) \cdot \left(1 + \frac{j\omega}{\omega_c}\right)}$$

← rhp zero

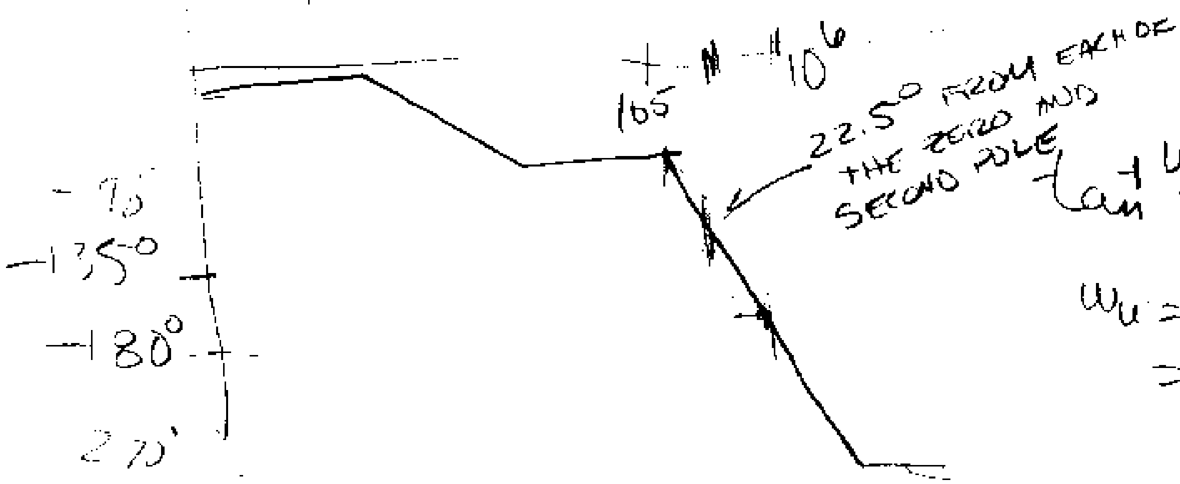
$$f = \frac{1k}{10k + 1k} = \frac{1}{11}$$

What is the location of ω_c so that the phase margin is 45° ?

ω_c 450 RAD/SEC



$$\omega_c = \frac{.41 \times 10^6}{(10^4)\,1/11} = 450 \text{ RAD/SEC}$$

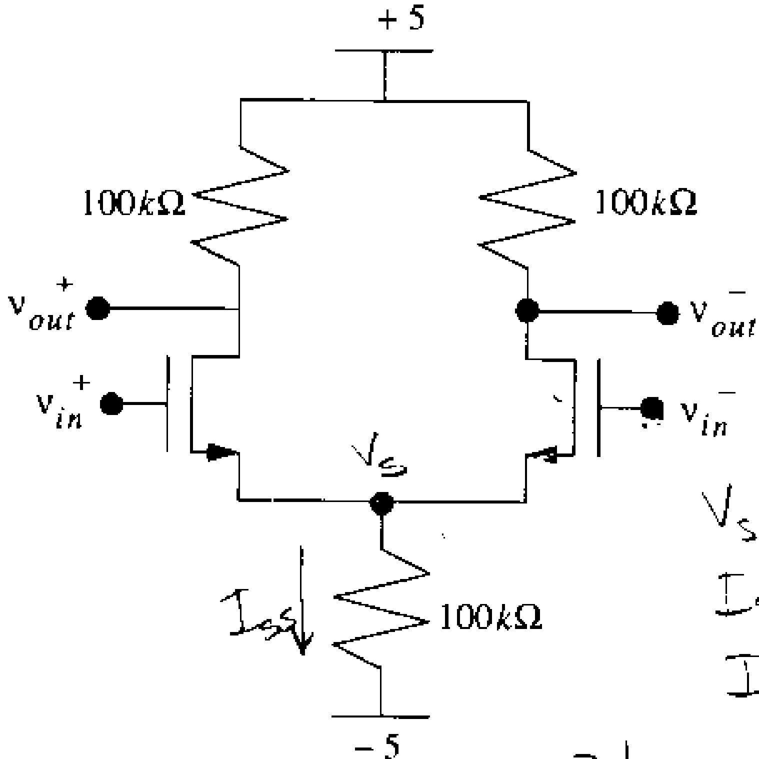


$$\tan^{-1}\frac{\omega_u}{10^6} = 22.5^\circ$$

$$\omega_u = 10^6 \tan 22.5^\circ = .41 \times 10^6$$

7)

Assume $V_{ic}=0$



$V_s \approx 4.5$

$I_{SS} = 45\mu A$

$I_{ds} \approx 22.\mu A$

a) What is the differential mode gain? A_{dm} 21

$g_m = (2 I_{ds} k' W/L)^{1/2} = .21 \times 10^{-3}$

$r_o = \frac{1}{.01 \cdot 22 \times 10^{-6}} = 4.5 \times 10^{6}\,\Omega$

$R_{out} = r_o \| 100k\Omega \approx 100k\Omega$

b) What is the common mode gain? A_{cm} .5

$$\frac{g_m 100k}{1 + 2 g_m 100k} \approx \frac{100k}{200k} = .5$$

c) If $v_{in+} = v_{in}$, $v_{in-} = 0$, what is $\left(v_{out}^- / (v_{in})\right)$ -10.25 ?

$$v_{out}^- = A_{cm} v_{ic} - \frac{A_{dm}}{2} v_{id}$$

$v_{ic} = \frac{v_{in}}{2}$

$v_{id} = v_{in}$

$$= .5\left(\frac{v_{in}}{2}\right) - \frac{21}{2}(v_{in}) = (.25 - 10.5)\, v_{in}$$

$$= -10.25\, v_{in}$$