NAME SOLUTIONS

EECS 140 FALL 2003
RW BRODERSEN

ASSUME ALL $\frac{W}{L}$'s = 10 UNLESS OTHERWISE SPECIFIED

$k_n' = k_p' = 10^{-2}\ A/V^2$, $V_{TN} = -V_{TP} = .3V.$

$2\phi_f = .6V.$, $\lambda = .05$, $\gamma = .1\ V^{1/2}$

SHOW WORK. MAKE APPROX FOR $\pm 10\%$ ACCURACY

(5) 1 a 2.6
(5) b .015

(10) 2 a 33kΩ

(10) 3 a MAX 1.68V MIN .44V.
(5) b $4 \times 10^6$

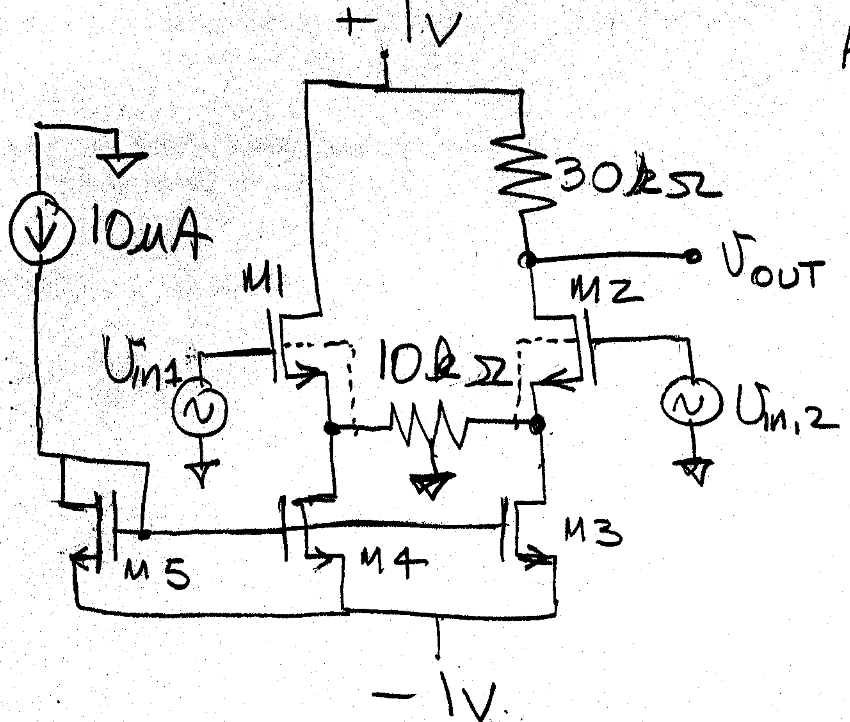
(5) 4 a 120 μA
(10) b 40 %

(10) 5 a $3.3 \times 10^5$, $3.3 \times 10^5$, $2.5 \times 10^6$ RAD/SEC
(10) b 6.8μf
(5) 6. a .0014 s.
(5) b 25
(5) c 366Ω

(5) 7 ω $10^{10}$ RAD/SEC
(5) R 100

(5) 8 $R_{OUT}$ .332Ω
(5) $v_{out}/v_{in}$ 1.11

## PROBLEM 1 (10)




ALL $\left(\frac{W}{L}\right)'s = 10$

DC VOLTAGE AT $v_{in1,2}$ IS 0V.

$g_m = (2k' \frac{W}{L} 10\mu A)$
$= 1.41 \times 10^{-3}$

$V_{dSAT} = \left(\frac{2 I_{DS}}{k' W/L}\right)^{1/2} = .014V$

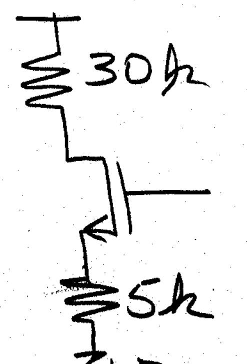
$r_o = \frac{1}{.05 \times 10\mu A} = 2 \times 10^6$

(5) a) WHAT IS THE GAIN $\frac{v_{OUT}}{v_{in1} - v_{in2}}$?

2.6

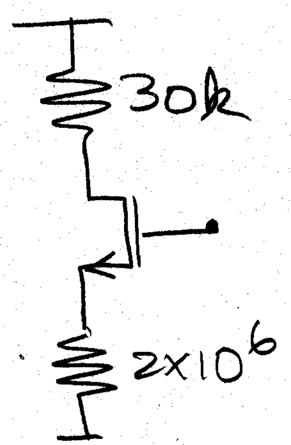
$$\frac{v_o}{v_{in,d}} = \frac{1}{2}\left(\frac{g_m 30 \times 10^3}{1 + g_m 5k\Omega}\right)$$

$= 2.62$



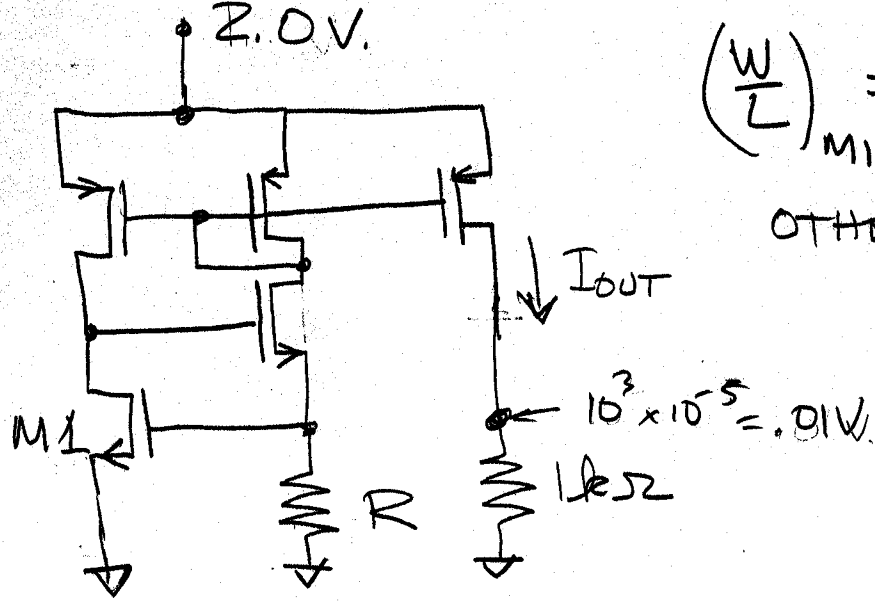

(5) b) WHAT IS THE GAIN $\frac{v_{OUT}}{(v_{in1} + v_{in2})/2}$?

.015




$$\frac{v_{OUT}}{v_{in,c}} = \frac{g_m 30k}{1 + g_m 2 \times 10^6} = .015$$

PROBLEM 2. (10)




$$\left(\frac{W}{L}\right)_{M1} = 100$$

OTHERS, $\frac{W}{L} = 10$

a) WHAT IS THE VALUE OF R SO THAT $I_{OUT} = 10\mu A$? 33kΩ

$$I_{OUT} = 10\mu A = (1+\lambda V_{ds})\, I^{o}_{OUT}$$

$$10\mu A = (1.1)\, I^{o}_{OUT}$$

$$I^{o}_{OUT} = 9.09 \times 10^{-6}$$

$$R = \frac{V_T}{I^{o}_{OUT}} = \frac{.3}{9.09 \times 10^{-6}} = 33k\Omega$$

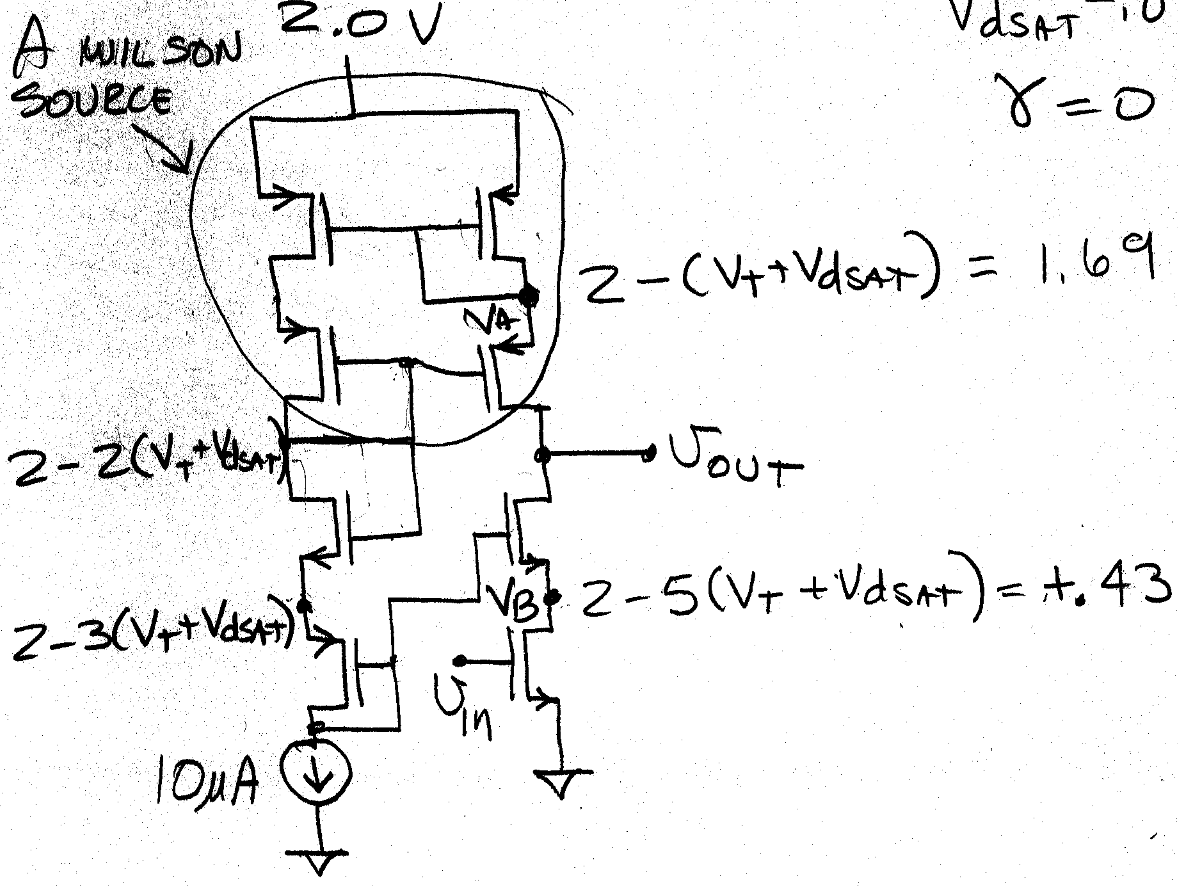
$$V_{DSAT}\Big|_{\frac{W}{L}=100} = \left(\frac{2 \times 9.1 \times 10^{-6}}{10^{-2} \times 10^{2}}\right)^{1/2} = 4.3 \times 10^{-3}$$

SMALL ENOUGH TO NEGLECT

## PROBLEM 3 (15)

$V_{dsat} = .014V.$

$\gamma = 0$




(10) a) WHAT IS THE VOLTAGE RANGE AT $V_{OUT}$ FOR ALL TRANSISTORS TO BE IN SATURATION? 1.68 MAX .44 MIN

$$V_{MAX} = V_A - V_{dsat}$$

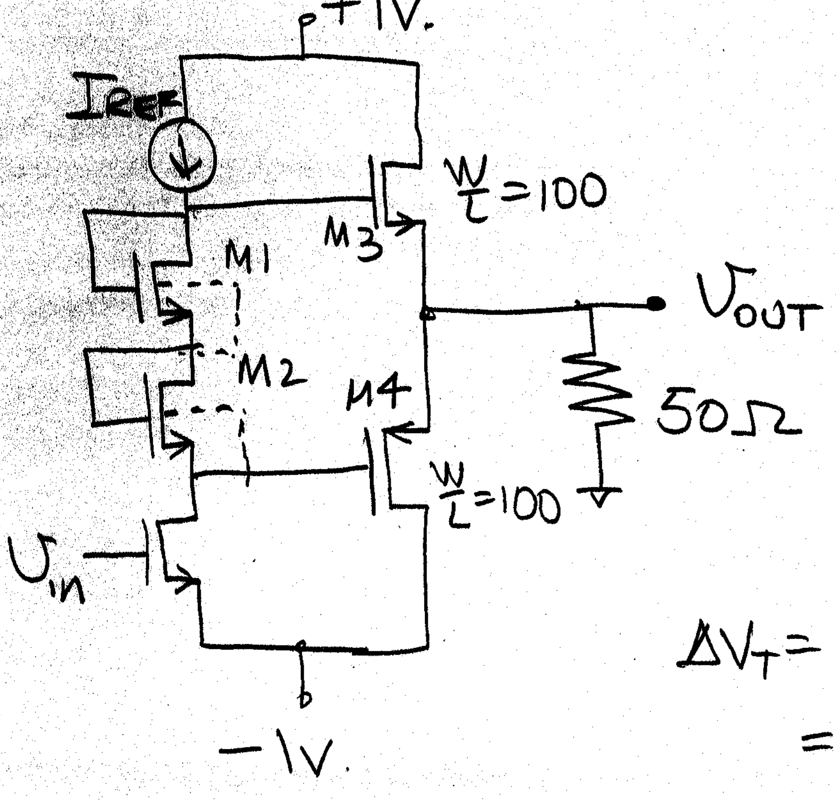
$$V_{MIN} = V_B + V_{dsat}$$

(5) b) WHAT IS THE GAIN, $\frac{V_{OUT}}{V_{in}}$, IF $V_{OUT}$ IS AT 1V.

$$A_v = g_m\left(\frac{g_m r_o^2}{2}\right) = 4 \times 10^6$$

4)

PROBLEM 4 (15)




$$\Delta V_T = \gamma\left[(.6+1)^{1/2} - (.6)^{1/2}\right)$$
$$= .049\text{V},$$

(5) a) WHAT IS IREF SO THERE IS NO CROSSOVER DISTORTION AT $V_{OUT} = 0V$.

$$2\left(V_{TO,M1} + V_{dSAT,M1}\right) = 2\left(V_{TO} + \Delta V_T\right)_{M3} + 2\underbrace{V_{DSAT,M3}}_{=0 \text{ WHEN } V_{OUT}=0}$$

(THE 2's BECAUSE, M1 = M2 & M3 = M4)

$$V_{DSAT,M1} = \Delta V_T$$

$$\left(\frac{2 I_{REF}}{k' W/L}\right)^{1/2} = .049 \quad ; \; I_{REF} = 120\,\mu A$$

(10) b) WHAT IS THE EFFICIENCY OF THIS CIRCUIT IF $I_{REF} = 10\,\mu A$ (IGNORE CROSSOVER DISTORTION)

NEXT PAGE

(SHOW WORK ON NEXT PAGE)

PROBLEM 4 (CONT.)

FIND $V_{MIN}$

$$V_{MIN} = -1 + V_{DSAT}^{(10mA)} + V_T + V_{DSAT}^{I_{OUT}}$$

$$= -50(I_{OUT})$$

$$I_{OUT} = 1 - .014 - .3 - \underbrace{\Delta V_T}_{} - \left(\frac{2 I_{OUT}}{4}\right)^{1/2}$$

APPROX THIS BY $\frac{.05}{2} = .025$

$$I_{OUT} = \frac{\left[.66 - (2 I_{OUT})^{1/2}\right]}{50}$$

$$= .013 - .02 (2 I_{OUT})^{1/2}$$

| GUESS | ANS |
|---|---|
| 20 ma | 9 ma |
| 9 ma | 10.3 |
| 10.3 | 10.1 ma |

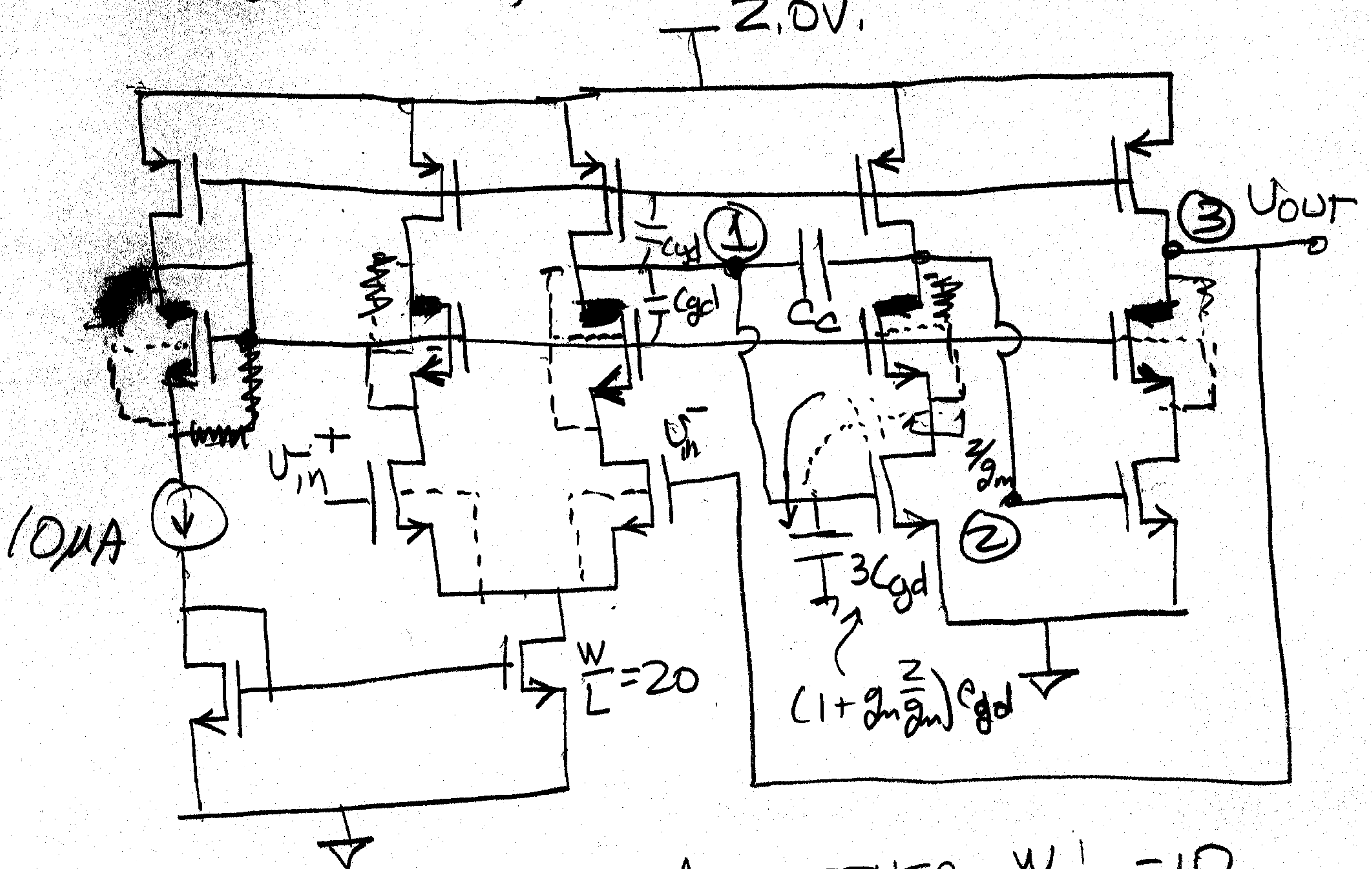
$$V_{NEG} = -(10.1 ma)\, 50$$
$$= .51 V.$$

FOR PUSH PULL

$$\text{EFFICIENCY} = \frac{\pi}{4} \frac{\hat{V}_{O,PK}}{V_{DD}} = 40\%$$

$$\boxed{P_{LOAD} = \frac{\hat{V}_o^2}{2R} \qquad EFF = \frac{P_{LOAD}}{P_{SUPPLY}} \qquad P_{SUPPLY} = \frac{2}{\pi} V_{DD} \frac{\hat{V}_o}{R}}$$

PROBLEM 5 (20)




ALL OTHER $\frac{W}{L}$'s $=10$

$C_{GS} = 1pf$

$C_{GD} = .1pf$

ALL OTHER C's = 0

ASSUME ALL DEVICES IN SAT.

(10) a) OPEN THE LOOP (DISCONNECT THE CONNECTION TO $V_{in}^-$) WHAT ARE THE 3 LOWEST POLES? SET $C_c = 0$.

$$W_{p1} = W_{p2} = \frac{1}{(g_m r_o^2 \| r_o)(2C_{GD} + C_{GS} + 3C_{GD})}$$

$$= \frac{1}{2\times10^6\ (1.5pf)} = 3.3\times10^5 \frac{RAD}{SEC}$$

$$W_{p3} = \frac{1}{(r_o \| g_m r_o^2)(2C_{gd})}$$

$$= 2.5\times10^6\ RAD/SEC$$

(10) b) CLOSE THE LOOP AND WHAT IS THE VALUE OF $C_c$ FOR $45^o$ OF PHASE MARGIN

PROBLEM 5 (CONT.)

$$a_v' = \frac{g_m r_o}{2}(g_m r_o)^2 = 11.3 \times 10^9$$

WITH FEEDBACK CONNECTION
NODE 3 POLE MOVES TO

$$\omega_{P3} = \frac{1}{2\times10^6\,(\underbrace{C_{GS}+3C_{gd}}_{\text{FROM } V_{in}^- \text{ NODE}}+2C_{GD})}$$

$$= 3.3\times10^5 \text{ RAD/SEC}$$

NODE 1 IS THE COMPENSATION POLE
AND NODE 2 IS SPLIT - HAS $1/g_m$ AS RESISTANCE

$$\omega_C = \frac{\omega_{P3}}{a_v'(1)} = 2.9\times10^{-5}$$

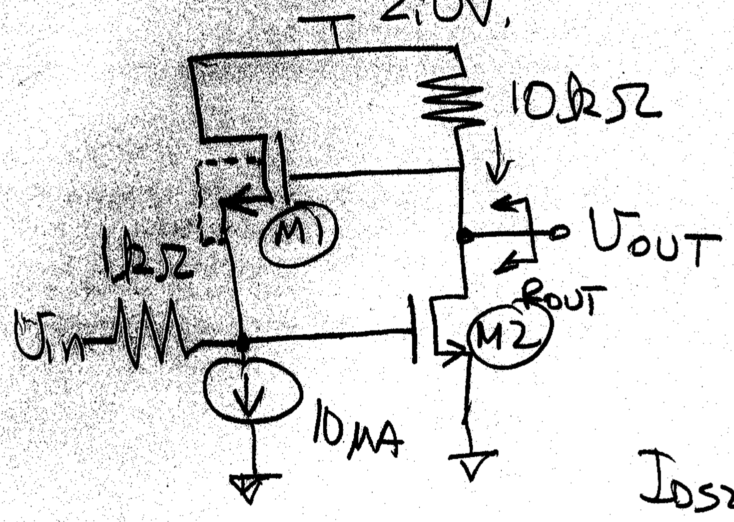
← VERY LOW BECAUSE OF THE VERY HIGH GAIN - DIFFICULT TO MAKE STABLE

FOR 45° OF PHASE MARGIN

$$\omega_C = \frac{1}{(g_m r_o)C_c\, r_o}$$

$$C_C = \frac{1}{(2830)\,2\times10^6 \times 2.9\times10^{-5}} = \underline{\underline{6.8\,\mu f}}$$

PROBLEM 6 (15)




$\frac{W}{L}$'s = 10

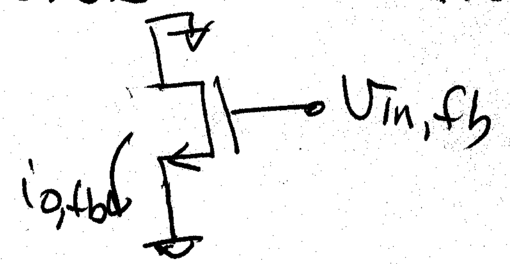
ASSUME $V_{in}$ IS SET SO $V_{OUT}$ IS AT 1.0 V.

$I_{DS2} = 100\mu A$ $\quad g_{m2} = 4.5 \times 10^{-3}$ 25

$r_{o2} = 200k\Omega$

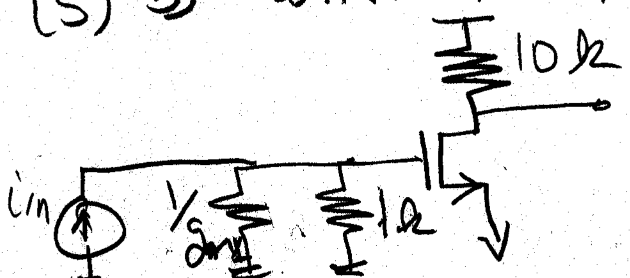
USE FEEDBACK ANALYSIS TECHNIQUES.

(5) a) WHAT IS f?




$f = g_{m1} = .0014$

(5) b) WHAT IS THE LOOP GAIN WITH LOADING?




$\frac{V_{OUT}}{i_{in}} = \left[(1/g_{m1}) \| 1k\right] g_{m2}(10k \| r_{o2})$

$= 17.8 \times 10^3 = a_R$

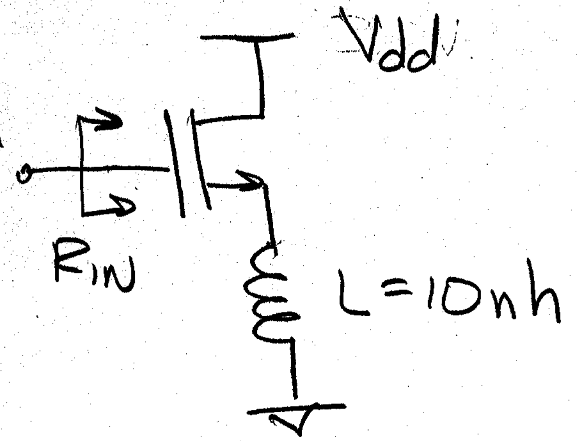
$T = a_R f_g = g_{m1} a_r$

$= 25$

(5) c) WHAT IS $R_{OUT}$

$$R_{OUT} = \frac{10k \| 200k\Omega}{1 + T} = 366\Omega$$

PROBLEM 7 (10)




$C_{gs} = 1\,pf$

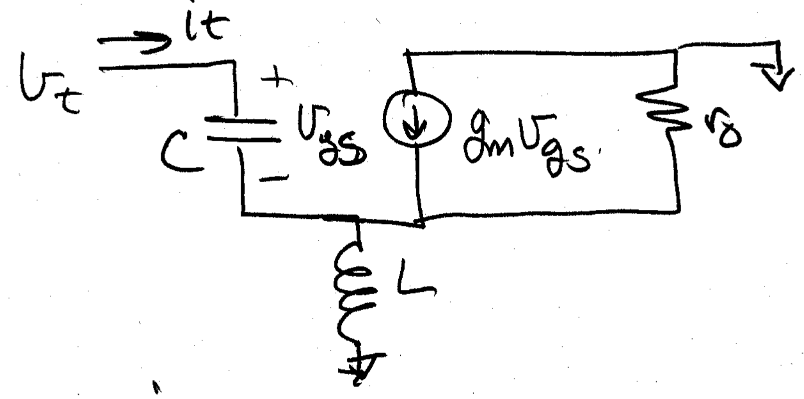
IGNORE OTHER C's

$g_m = 10^{-2}\,\mho$

$r_o = 10^4\,\Omega$

AT WHAT FREQUENCY IS $R_{IN}$ PURELY RESISTIVE AND WHAT IS THE VALUE

(5) $\omega_R =$ ________ (5) R ________




$$v_{gs} = \frac{i_t}{sC_{gs}}$$

$$v_t = \frac{i_t}{sC_{gs}} + g_m v_{gs}\,(sL \| r_o) + i_t\,(sL \| r_o)$$

$$= i_t\left(\frac{1}{sC_{gs}} + (sL\|r_o) + g_m\left(\frac{sL\|r_o}{sC_{gs}}\right)\right)$$

LETS ASSUME $|r_o| \gg |sL|$ LIKELY SINCE RF IMPEDANCES ARE ON THE ORDER OF 50Ω

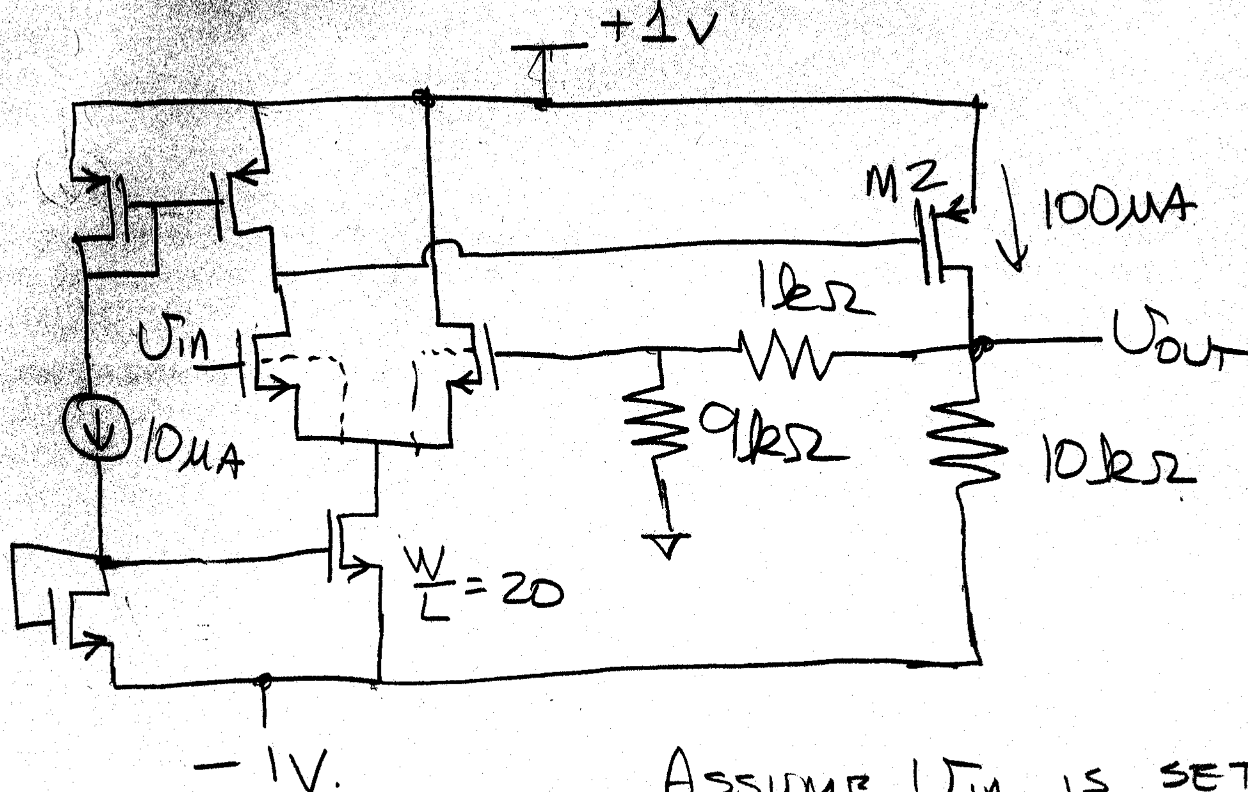
$Z_{IN} = \frac{1}{sC_{gs}} + sL + g_m \frac{L}{C_{gs}}$ ; IF $\frac{1}{j\omega C_{gs}} + j\omega L = 0$ THEN

$$Z_{IN} = g_m \frac{L}{C_{gs}} = 100\Omega$$

THIS HAPPENS $\omega = \frac{1}{(LC)^{1/2}} = 10^{10}$ RAD/SEC

CHECKING $|sL| = |10^{10} \times 10^{-8}| = 100\Omega \ll r_o$

Problem 8




Assume $V_{in}$ is set so $V_{OUT} = 0V$.

(5) a) What is $R_{OUT}$

$$R_{OUT} = \frac{10k \| 200k \| 10k)}{1+T} = \frac{4.9k}{15\times10^3} = .33\Omega$$

$$f = \frac{9k}{1k+9k} = .9$$

$$a_v = \left(\frac{g_m r_0}{2}\right)\frac{1}{2} g_{m2} (10k \| 10k \| 200k) = 15.6\times10^3$$

$$T = a_v f = \cancel{14}\times10^3$$

(5) b) What is $\frac{V_{OUT}}{V_{IN}}$?

$$\frac{V_{OUT}}{V_{in}} = \frac{1}{f}\,\frac{T}{1+T} \approx \frac{1}{.9} = 1.11$$