Name: SOLUTIONS

*EECS 140*

Midterm #1

Fall 1998

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Use these values unless otherwise stated:

$V_{TN} = .5V$ ; $V_{TP} = -.5V$

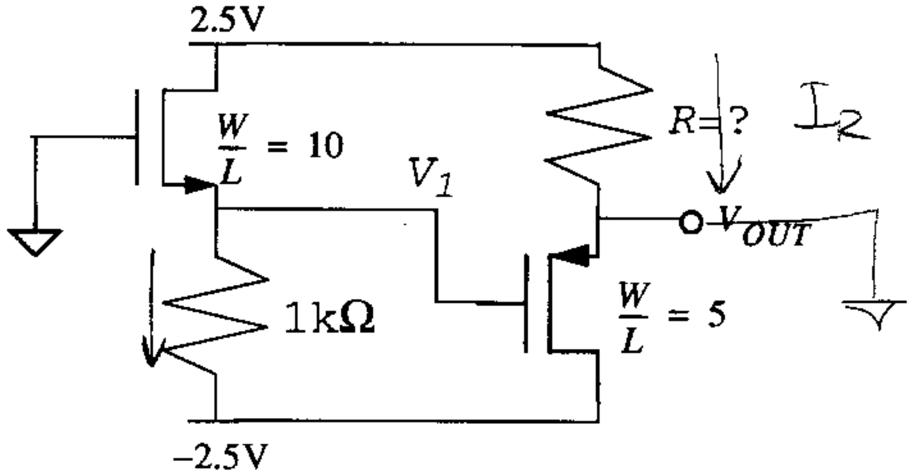
$k_n = k_p = 100\ \mu A/V^2$

$\lambda_n = \lambda_p = .01$

$\gamma = 0$

| | | | |
|---|---|---|---|
| **1**a) | −1.74 | **4**a) | −100 |
| b) | 6.5kΩ | b) | $-4.2\times10^{-7}$ |
| **2**a) | 122kΩ | **5**a) | 1 |
| b) | 1.72 V. , .72V. | b) | .33 (.50 OK) |
| c) | 76Ω | c) | −.5 |
| d) | $10^6$ | **6**) | 500Ω |
| **3**a) | 710 | **7**a) | .027V. |
| b) | 14kΩ | b) | −.17V. |
| | | c) | .47% (.67% OK) |

1)




What is the voltage at $V_1$? $-1.74\,V$.

$$\frac{V_1-(-2.5)}{1k} = \frac{k'}{2}10(0-V_T-V_1)^2$$

$$.5V_1^2-.5V_1-2.375=0$$

$$V_1=-1.74 \quad (\cancel{2.74})$$

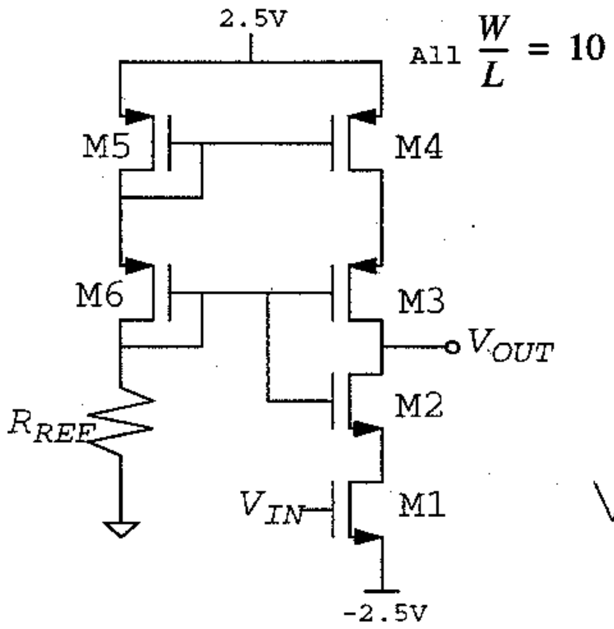
What is the resistance $R$, which sets $V_{OUT}$=0V?

R= $6.5\,k\Omega$

$$I_R = \frac{2.5}{R} = \frac{k'}{2}5\,(\underbrace{0-1.74}_{V_{SG}}\underbrace{+.5}_{-V_T})^2$$

$$R=\frac{2.5}{3.8\times10^{-4}}=6.5k\Omega$$

2)




$$V_{dSAT5} = \left(\frac{2I_D}{k' W/L}\right)^{1/2} = \left(\frac{2 \cdot 10\times10^{-6}}{10^{-4}\, 10}\right)^{1/2} = .14$$

a) What is $R_{REF}$ so that $I_{DS}$=10μA?

$R_{REF}$ 122 kΩ

$$V_{G6} = V_{DD} - 2(V_T + V_{dSAT}) = 2.5 - 2(.5 + .14) = 1.22\text{ V.}$$

$$R_{REF} = \frac{V_{G6}}{I} = \frac{1.22}{10\mu A} = 122 k\Omega$$

b) What is the maximum swing at $V_{OUT}$ which has high gain?

$V_{OUT,MAX}$ 1.72V. $V_{OUT,MIN}$ .72V.

$$V_{OUT,MAX} = V_{DD} - (V_T + V_{dSAT}) - V_{dSAT}$$

$$= 2.5 - (.5 + .141) - .141 = 1.72\text{ V.}$$

$$V_{OUT,MIN} = V_{G6} - V_T = 1.22 - .5 = .72\text{ V.}$$

c) what is the output resistance?

$R_{OUT}$ $7G\Omega$

$$r_o = \frac{1}{\lambda I_D} = 10M\Omega \qquad g_m = \frac{2I_D}{V_{dSAT}} = 141\,\mu A/V$$

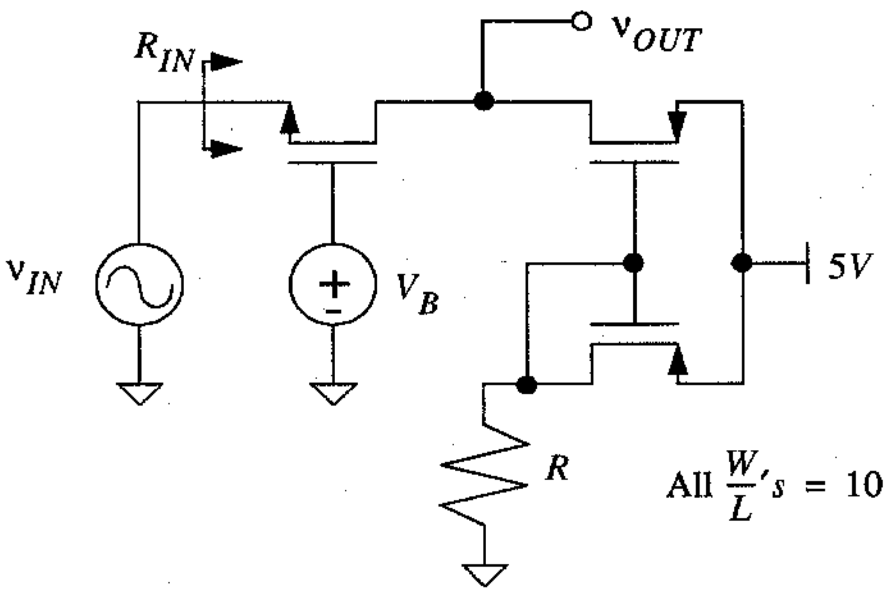
$$R_{OUT} = R_{O1} \| R_{O2} \approx r_{O3} r_{O4} g_{m3} \| g_{m2} r_{O2} r_{O1}$$
$$\approx \frac{14.1G\Omega}{2} = 7G\Omega$$

d) What is the gain? $10^6$

$$G_m = -(1+\chi)\, g_m = -g_m$$

$$A_v = -g_m R_{OUT} = 141\,\mu A/V \cdot 7G\Omega$$
$$= 10^6$$

3)




Assume $R$ is chosen so that the currents are 10 μA and $V_B$ is chosen to set the DC volt~~t~~age at $v_{OUT}$ = 2.5 V

$r_o = 10\,M\Omega$

$g_m = 141\ \mu A/V$

a) What is the gain $v_{OUT}/v_{IN}$? 710

$G_m = g_m$

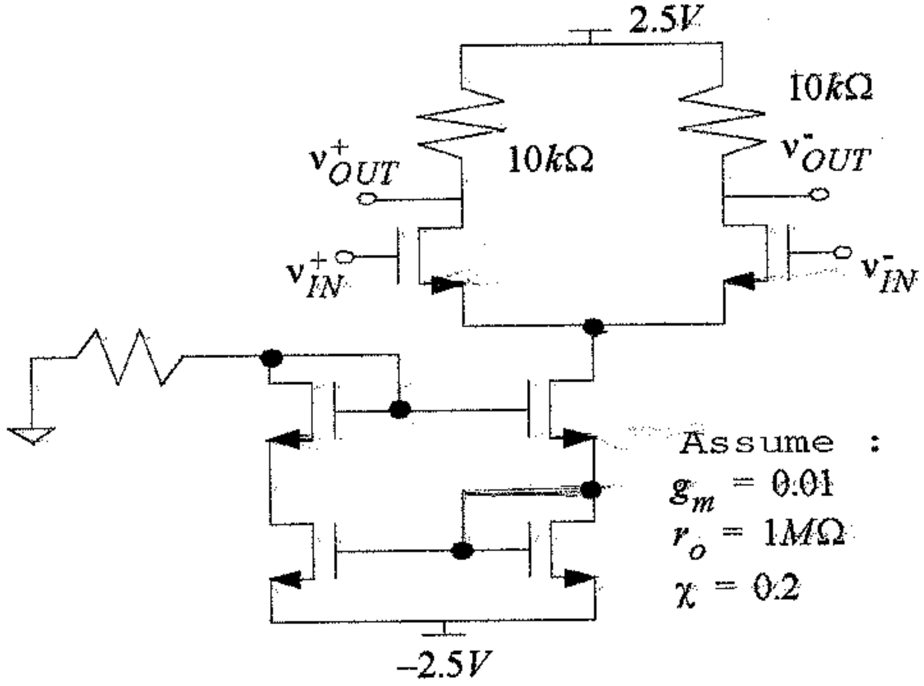
$R_{OUT} = r_o \| r_o = 5\,M\Omega$

$A_v = G_m R_{OUT} = 710$

b) What is $R_{IN}$? $14.1\,k\Omega$

$$R_{in} = \frac{r_o + R_s}{1+(1+\chi)g_m r_o} = \frac{2r_o}{1+g_m r_o} \approx \frac{2}{g_m} = 14.1\,k\Omega$$

4)

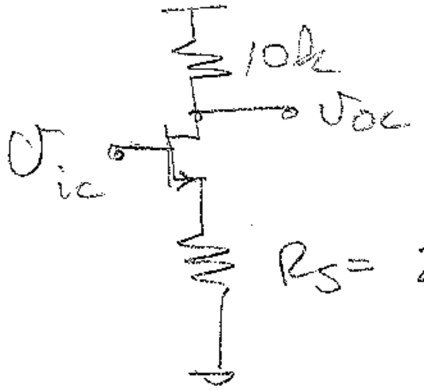



Assume :
$g_m = 0.01$
$r_o = 1M\Omega$
$\chi = 0.2$

a) $A_{dm}$ = $\underline{-100}$

$$A_{dm} = -g_m R_{OUT} = -(.01)(10k \| 1M\Omega)$$
$$= -100$$

b) $A_{cm}$ = $\underline{-4.2\times10^{-7}}$



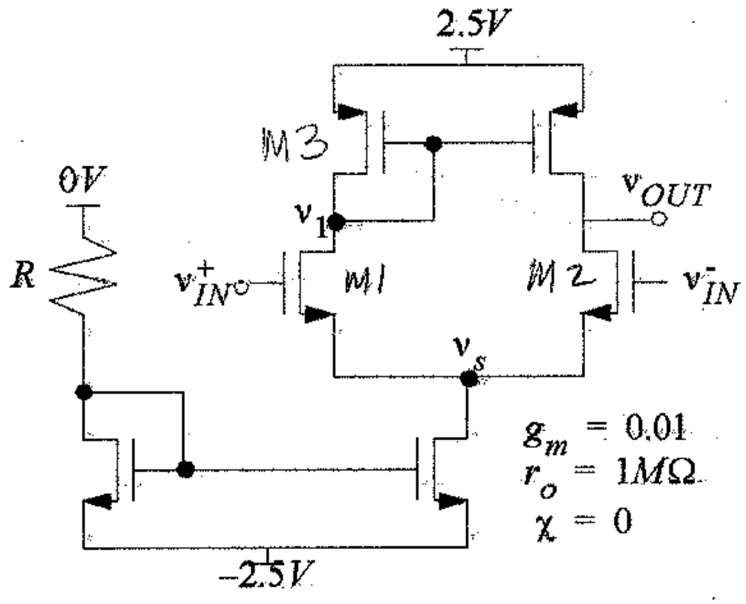

$$G_m = \frac{-g_m}{1+(1+\chi)g_m R_S} \approx -\frac{.01}{(1.2)(.01)\times 20\times10^9}$$
$$= -4.2\times10^{-11}$$

$$R_S = 2(g_m r_o^2) = 20\times10^9\,\Omega$$

$R_{OUT}$ OF A WILSON SOURCE

$$A_{cm} = -G_m R_{OUT} = -(4.2\times10^{-11})(10^4) = -4.2\times10^{-7}$$

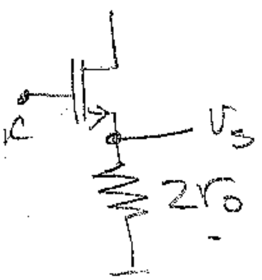
5)



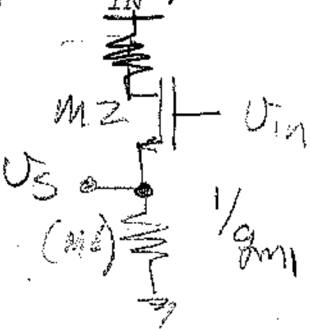

$g_m = 0.01$
$r_o = 1M\Omega$
$\chi = 0$

a) If $v_{IN}^+ = v_{IN}^- = v_{IN}$, what is $v_s/v_{IN}$? 1

$$\frac{v_s}{v_{in,c}} = \frac{g_m}{g_m(1+\chi)+\frac{1}{R_s}+\frac{1}{r_o}} = \frac{.01}{.01+\frac{1}{2r_o}+\frac{1}{r_o}} \approx 1$$




b) If $v_{IN}^+ = 0V$ and $v_{IN}^- = v_{IN}$, what is $v_s/v_{IN}$? .33




$G_m R_{out} = .33$

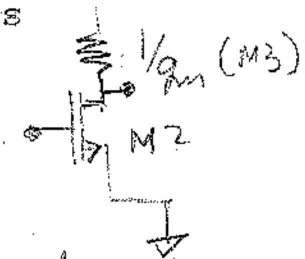
$G_m = g_m$

$R_{out} = r_o \| 1/g_{m1} \| \frac{2}{g_{m2}}$

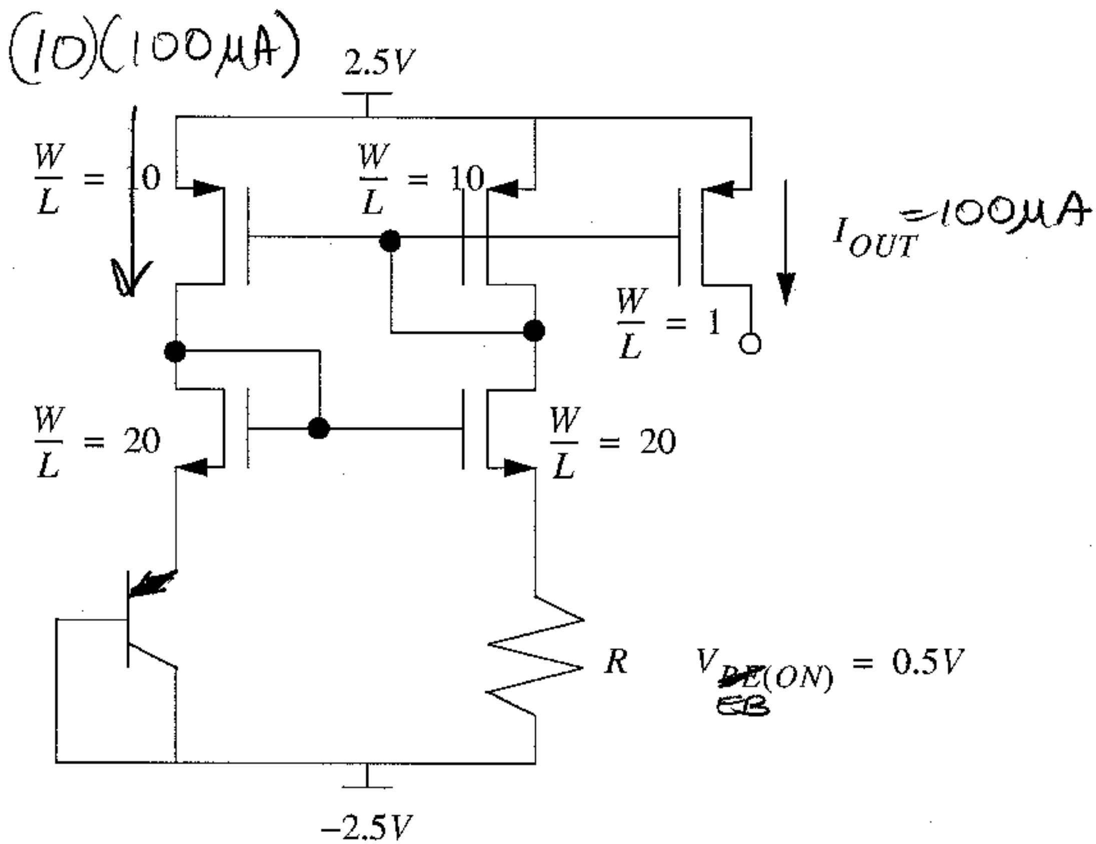
$= \frac{.33}{g_m}$

c) If $v_{IN}^+ = +v_{IN}/2$ and $v_{IN}^- = -v_{IN/2}$, what is $v_1/v_{IN}$? $-1$

$$\frac{v_1}{v_{in}} = -g_m R_{out} = -(.01)\left(\frac{1}{.01}\right) = -1$$



6)



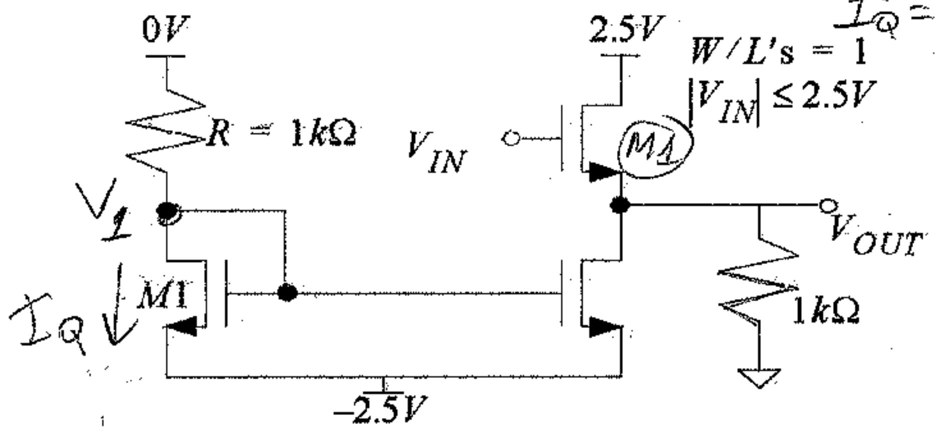

What is the value of $R$ so that

$I_{OUT}$ = 100μA? $R$ 500Ω

$$R = \frac{V_{EB(ON)}}{(100\mu A)10} = \frac{.5}{.1\times10^{-4}\times10} = 500\Omega$$

$$I_Q: \quad -\frac{V_1}{R} = \frac{k'}{2}\left(V_1-(-2.5)-V_T\right)^2$$
$$= \frac{k'}{2}\left(V_1+2\right)^2$$
$$V_1^2+24V_1+4=0 \qquad V_1 = .17\,V,$$
$$I_Q = .17\,mA$$

7)




a) What is the most positive voltage that $V_{OUT}$ can achieve? $\underline{.027\text{ Volts}}$

$$V_{OUT,MAX} = V_{DD}-V_T-V_{DSAT,1} = 2 - \left[\frac{2\left(I_Q+\frac{V_{OUT}}{1k}\right)}{k'\,W/L}\right]^{1/2}$$

$$\left(2-V_{OUT,MAX}\right)^2 = \frac{2\left(I_Q+V_{OUT}/1k\right)}{k'\,W/L} \; ; \quad V_{OUT,M}^2 - 24V_{OUT,M} + .64 = 0$$

$$\underline{V_{OUT,MAX} = .027\,V}$$

b) What is the most negative voltage that $V_{OUT}$ can achieve? $\underline{-.17\,V}$

$$V_{OUT\,MIN} = -I_Q R_L = -(.17m)(1k) = -.17\,V$$

C) If R is chosen so the current through M1 is 0.1mA, what is the efficiency of this circuit? $\text{EFF} = \frac{3.5\times10^{-6}}{750\times10^{-6}}\times100\% = \underline{.47\%}$ (Assume the output must be centered around 0V)

$$\left(2-V_{OUT,M}\right)^2 = \frac{2\left(.1\times10^{-3}+10^{-3}V_{OUT}\right)}{10^{-4}}$$

$$V_{OUT,MAX}^2 - 24V_{OUT,MAX} + 2 = 0$$

$$V_{OUT,MAX} = .084\,V$$

$$P_{SUPPLY} = 3(2.5)(.1mA) = .75\,mW$$

$$P_{LOAD} = \frac{V_{OUT,MAX}^2}{2R_L} = \frac{(.084)^2}{2\times10^3} = 3.5\,\mu W$$