Problem Practice 2

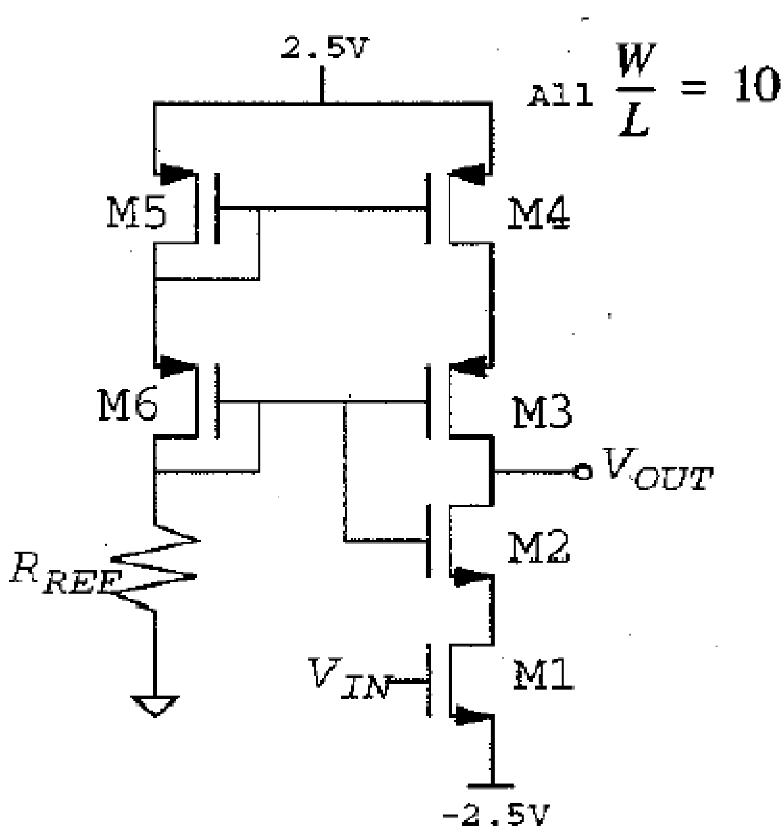
Differential Pairs and Current Sources

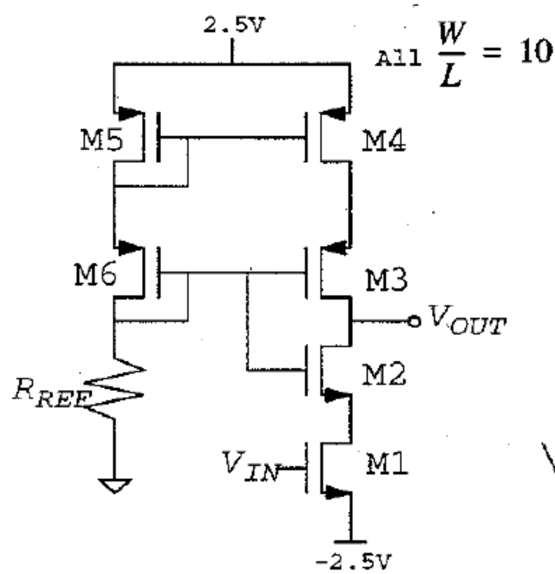
Problem 1. A) What is RREF So that IDS_M6 = 10uA ?

B) What is the Maximum Voltage Swing at the Vout ?

C) What is the output resistance ?

D) What is the gain ?





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

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

R_{REF} 122kΩ

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

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

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

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

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

$$= 2.5 - (.5 + .141) - .141 = 1.72\,V.$$

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

c) what is the output resistance?

R_{OUT} 7GΩ

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

$$R_{OUT} = R_{O1} \| R_{O2} \approx r_{O3} r_{O4} g_{m3} \| g_{m2} r_{O2} r_{O1}$$

$$\approx \frac{14.1 G\Omega}{2} = 7G\Omega$$

d) What is the gain? 10^6

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

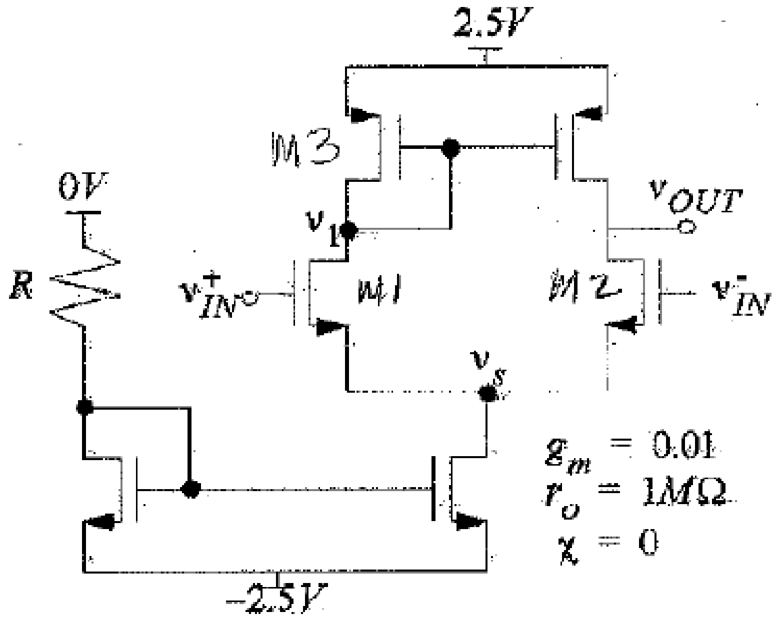
$$A_v = -g_m R_{OUT} = 141\,\mu A/V \cdot 7G\Omega$$

$$= 10^6$$

Problem 2 1) If VIN+ = VIN- = VIN, what is Vs/VIN ?

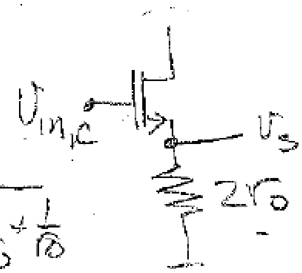
2) If VIN+ = 0V and VIN- = VIN, what is Vs/VIN ?

3) If VIN+ = VIN/2 and VIN- = -VIN/2, What is V1/VIN ?



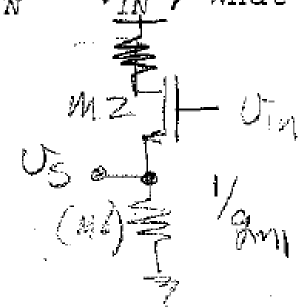
a) If $v_{IN}^+ = v_{IN}^- = v_{IN}$, what is v_S/v_{IN}? 1

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



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

$G_m R_{out} = .33$

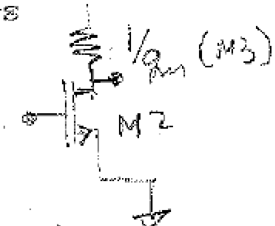


$G_m = g_m$

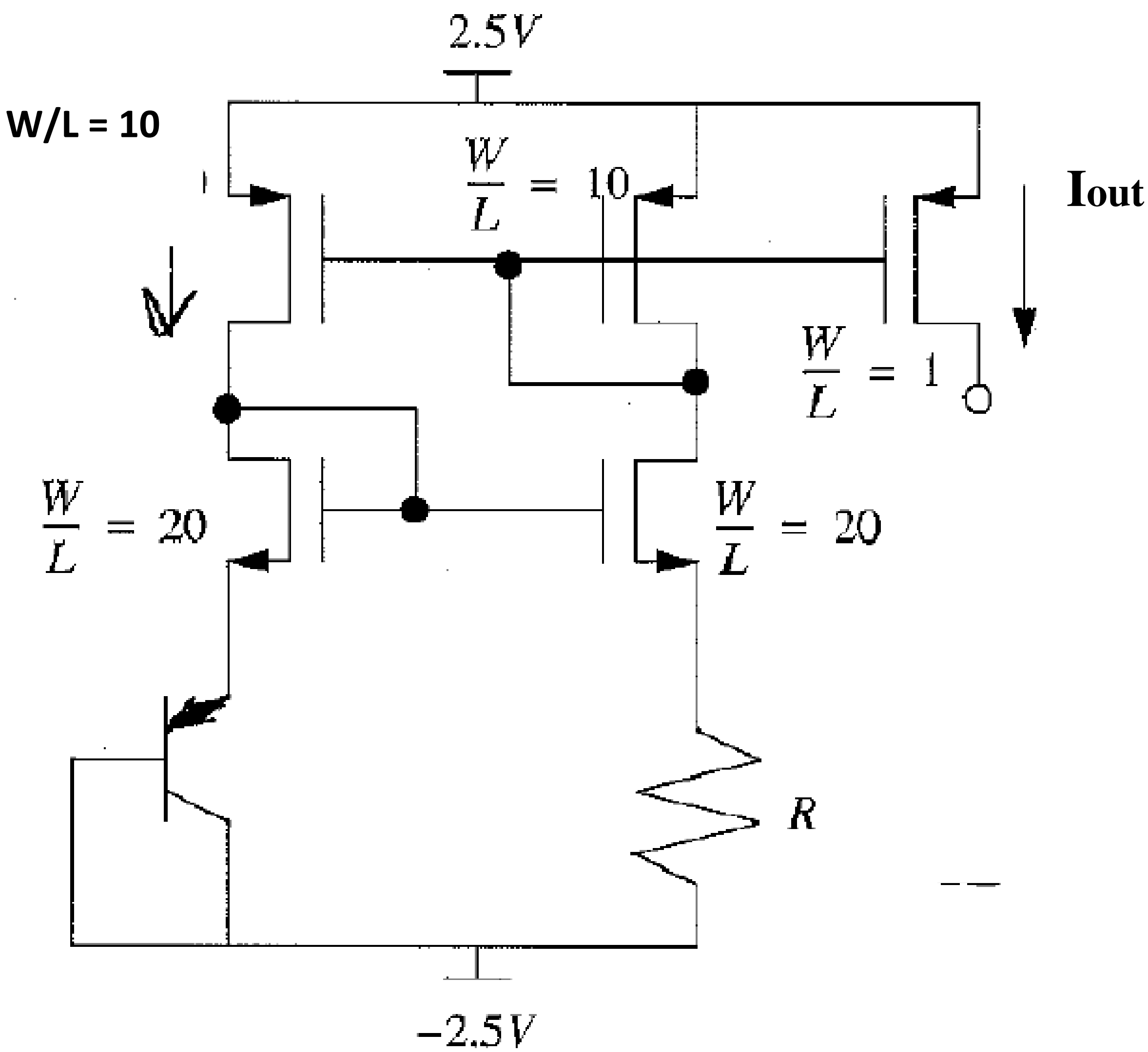
$R_{out} = r_{o1} \| 1/g_{m1} \| \frac{2}{g_{m2}} = \frac{.33}{g_m}$

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

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



Problem 3 What is the value of R so that Iout = 100uA ?



What is the value of R so that

$I_{OUT} = 100\mu A$? R <u>500Ω</u>

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

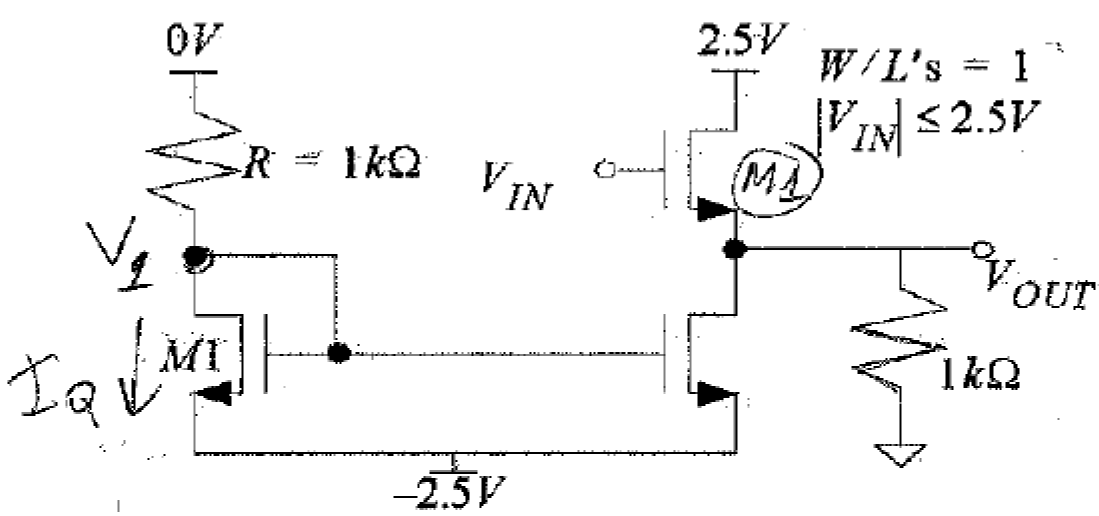
$$I_Q: \quad -\frac{V_1}{R} = \frac{k'}{2}\left(V_1 - (-2.5) - V_T\right)^2$$

$$= \frac{k'}{2}(V_1 + 2)^2$$

$$V_1^2 + 24V_1 + 4 = 0 \qquad V_1 = .17\,V,$$

$$I_Q = .17\,mA$$

Problem 4. What is Vout,max ? What is Vout,min ? If R is chosen so that current through M1 is 0.1mA, what is the efficiency of this circuit assuming the output must be centered around 0V ?



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

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

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

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

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

$$V_{OUTMIN} = -I_Q R_L = -(.17mA)(1k) = -.17V$$

C) If R is chosen so the current through $M1$ is 0.1mA, what is the efficiency of this circuit? $EFF = \frac{3.5\times10^{-6}}{750\times10^{-6}} \times 100\% = .47\%$
(Assume the output must be centered around 0V)

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

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

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

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

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