PSET 9 solutions

P9.7 (a) $V_{out} = 0 \Rightarrow V_A = 0.7V$

$V_{BIAS} - V_A = V_{GS}$

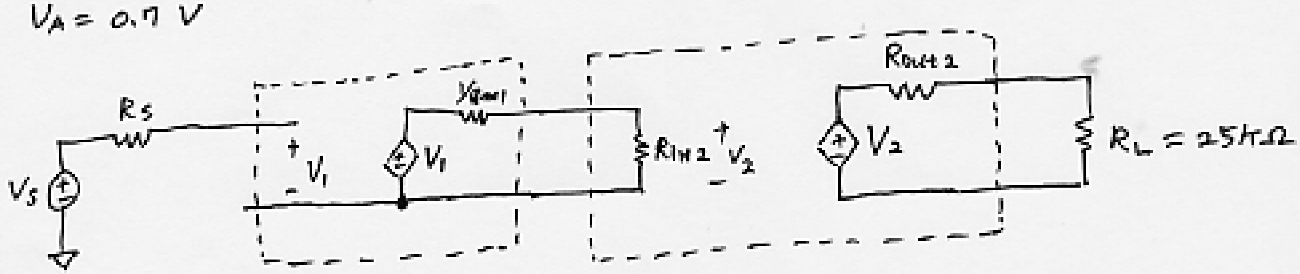
$I_D = \frac{\mu_n C_{ox}}{2} \frac{W}{L} (V_{GS} - V_{Tn})^2$ # ignoring λ_n

$150\mu = \frac{100\mu}{2} \cdot \frac{20}{5} (V_{GS} - V_{Tn})^2 \Rightarrow V_{GS} - V_{Tn} = 0.866$ $\therefore V_{GS} = 1.566$ V

$\therefore V_{BIAS} = V_{GS} + V_A = 1.566 + 0.7 = \underline{2.266 (V)}$

(b) $V_A = 0.7$ V

(C)



$g_{m1} = \sqrt{2 \cdot \mu_n C_{ox} \frac{W}{L} \cdot I_D} = 346.4 \mu A/V$ $\therefore 1/g_{m1} = \underline{\underline{2.8868 k\Omega}}$

$R_{in2} = r_{\pi 2} + \beta_o (r_{o2} \| r_{oc} \| R_L)$

$g_{m2} = \frac{I_C}{V_{TH}} = \frac{150\mu}{25mV} = 6 mA/V$, $r_{\pi 2} = \frac{\beta_o}{g_{m2}} = 12.5 k\Omega$

$r_{o2} = \frac{V_A}{I_C} = \frac{50}{150\mu} = 333.3 k\Omega$

$\therefore R_{in2} = 12.5k\Omega + 75 \times (333.3k\Omega \| 500k\Omega \| 25k\Omega) = \underline{\underline{1.679 M\Omega}}$

$R_{out2} = \frac{1}{g_{m2}} + \frac{1}{g_{m1}} \cdot \frac{1}{\beta_o} = \underline{\underline{205.16\Omega}}$

(d) $\frac{V_{out}}{V_s} = \frac{1.679 M\Omega}{1.679M\Omega + 2.8868k\Omega} \cdot \frac{25k\Omega}{25k\Omega + 205.16\Omega} \fallingdotseq 0.99$

P9.8 (a) $V_{GS} = V_A - V_{out} = V_A$ $\because V_{out} = 0$

$\frac{\mu_n C_{ox}}{2} \frac{W}{L} (V_{GS} - V_{Tn})^2 = 150\mu A \Rightarrow V_{GS} - V_{Tn} = 0.866$

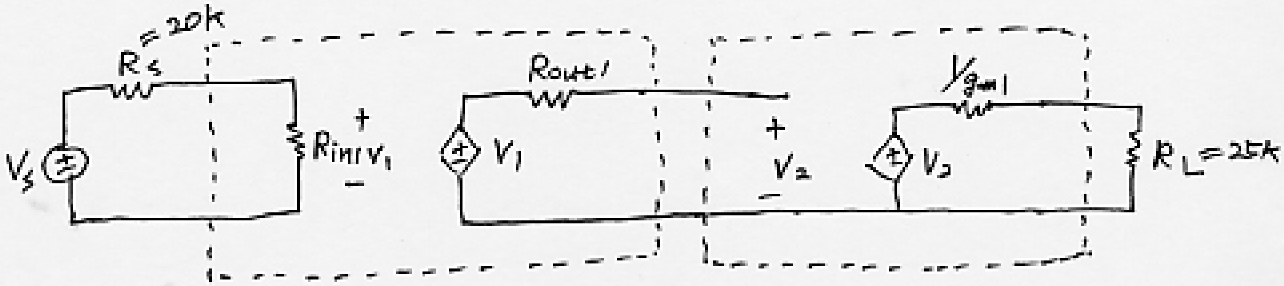
$V_A = 0.866 + V_{Tn} = 1.566V$

$V_{BIAS} - V_A = V_{BE}$

$\therefore V_{BIAS} = 0.7 + 1.566 = 2.266 (V)$

P9.8 (b) $V_A = 1.566\,(V)$

(c)

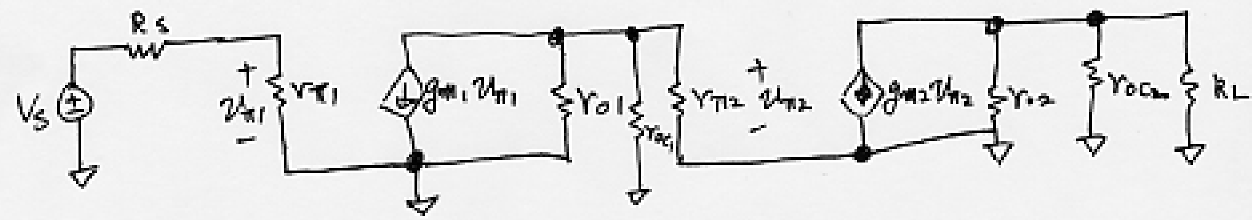


$R_{in1} = 1.679\,M\Omega$ $\quad R_{out1} = 205.16\,\Omega$ $\quad 1/g_{m1} = 2.8868\,k\Omega$

↳ from P9.7

(d) $$\frac{V_{out}}{V_s} = \frac{1.679\,M\Omega}{1.679\,M\Omega + 20\,k\Omega} \cdot \frac{25\,k\Omega}{2.8868\,k\Omega + 25\,k\Omega} = 0.886$$

P9.9 (a)



$$g_{m1} = \frac{100\,\mu A}{25\,mV} = 4\,mA/V \qquad g_{m2} = \frac{250\,\mu A}{25\,mV} = 10\,mA/V$$

$r_{\pi 1} = 25\,k\Omega$ $\qquad r_{\pi 2} = 10\,k\Omega$

$r_{o1} = 200\,k\Omega$ $\qquad r_{o2} = 80\,k\Omega$

(b) $R_{in} = r_{\pi 1} = 25\,k\Omega$

(c) $R_{out} = r_{o2} \,//\, r_{oc} = 80\,k\Omega \,//\, 250\,k\Omega = 60.61\,k\Omega$

(d) $$A_{v,\,intrinsic} = g_{m1}\,(r_{o1} \,//\, r_{oc1} \,//\, r_{\pi 2}) \cdot g_{m2}\,(r_{o2} \,//\, r_{oc2})$$

$$= 4\,mA/V\,(9.434\,k\Omega) \cdot 10\,mA/V \cdot (60.61\,k\Omega)$$

$$= 22.87 \times 10^3$$

(e) $$A_v = \left(\frac{r_{\pi 1}}{R_s + r_{\pi 1}}\right) g_{m1}\,(r_{o1} \,//\, r_{oc1} \,//\, r_{\pi 2})\; g_{m2} \cdot (r_{o2} \,//\, r_{oc2} \,//\, R_L)$$

$$= 0.5 \times 4\,mA/V \times 9.434\,k\Omega \times 10\,mA/V \times 8.854\,k\Omega$$

$$= 1.67 \times 10^3$$

P 9.14

(a) $R_S \cong g_{m1} \cdot r_{o1} \cdot r_{o2}$

$$g_{m1} = \sqrt{2 \cdot \mu_p C_{ox} \frac{W}{L} \cdot I_D} = \sqrt{2 \times 80\mu \times 10 \times 100\mu} = 400\mu A/V$$

$$r_{o1} = r_{o2} = \frac{1}{\lambda_p \cdot I_D} = \frac{1}{0.03 \times 100\mu} = 333.3 k\Omega$$

$\therefore R_S \cong 44.4 M\Omega$

(b) $\frac{W}{L}$ for M_{2B} = 10 doesn't change

$\frac{W}{L}$ for $M_2 = 10/5 = 2$

(c) $g_{m1} = \sqrt{2 \times 80\mu \times 10 \times 20\mu} = 178.89 \mu A$

$$r_{o1} = r_{o2} = \frac{1}{0.03 \times 20\mu} = 1.667 M\Omega$$

$\therefore R_S \cong 497.1 M\Omega$

P 9.17 Ignore the channel length modulation for the bias point calculation.

(a) $I_D = \frac{\mu_p C_{ox}}{2} \frac{W}{L} (V_{SG} + V_{TP})^2$

$V_D = V_G = I_D \times 6k\Omega - 3V = 0V$

$\therefore V_{SG} = 3V$

$500\mu A = \frac{25\mu}{2} \times \frac{W}{L} \times (3 - 0.7)^2$

$\therefore \frac{W}{L} = 7.56$

(b) $I_{D3} = \frac{25\mu}{2} \times \frac{100}{2} \times (V_{SG} - 0.7)^2 = 500\mu A$

$\therefore (V_{SG} - 0.7)^2 = 0.8$

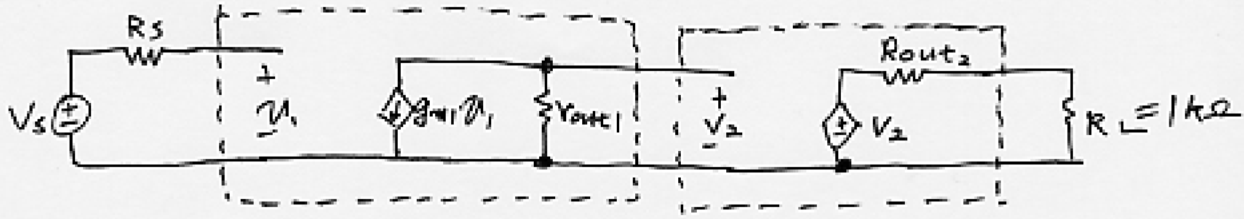
$V_{SG} = 1.6$, $V_S = 0V$ $\therefore V_G = -1.6 (V)$

(c) $500\mu A = \frac{50\mu}{2} \times \frac{40}{2} \times (V_{GS} - V_{Tn})^2$

$V_{GS} - V_{Tn} = 1$ $\therefore V_{GS} = 1 + 0.7 = 1.7V$

$V_G = 1.7 - 3 = -1.3 (V) = V_{BIAS}$

P9.17 (d)



$$g_{m1} = \sqrt{2\mu_n C_{ox} \frac{W}{L} \cdot I_D} = \sqrt{2 \times 50\mu \times \frac{40}{2} \times 500\mu A} = 1\,mA/V$$

$$r_{out1} = r_{o1} \,//\, r_{o2} = \frac{1}{\lambda_n I_D + \lambda_p I_D} = 33.3\,k\Omega$$

$$R_{out2} = \frac{1}{g_{m3}} = \frac{1}{\sqrt{2 \cdot \mu_p C_{ox} \frac{W}{L} \cdot I_D}} = 632.46\,\Omega$$

(e)

$$A_v = -g_{m1} \cdot r_{out1} \cdot \frac{R_L}{R_L + R_{out2}}$$

$$= -1\,mA/V \times 33.3\,k\Omega \times \frac{1k\Omega}{1k\Omega + 632.46\Omega}$$

$$= -20.4$$

(f) $R_{out2,new}$ should be $\frac{1}{2} \times R_{out,original}$.

$\therefore$ g_{m3} must be twice.

$\therefore$ $\frac{W}{L}$ must be 4 times