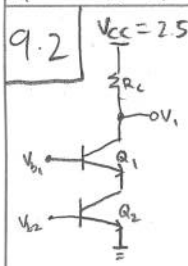
9.2



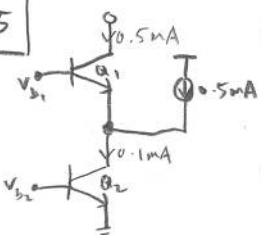
(a) bias current: 0.5 mA $\quad V_T \ln\left(\frac{I_C}{I_S}\right) = V_{BE}$

$V_{b2} = V_{BE_2} = V_T \ln\left(\frac{I_B/\alpha^2}{I_S}\right) = (0.026)\ln\left(\frac{0.00051}{6E-17}\right) = \boxed{0.774V}$

$V_{b1} = V_{CE_2} + V_{BE_1} = V_{b2} - 0.3 + V_{BE_1} = 0.774 - 0.3 + (0.026)\ln\left(\frac{0.0005}{6E-17}\right) = \boxed{1.248V}$

(b) $V_{CB} > 0.3 \quad V_1 = V_{b1} - 0.3 = 0.948 \quad V_{CC} - I_b R_C = V_1 \quad 2.5 - 0.0005R_C = 0.948 \quad R_C = \boxed{3104\Omega}$

9.5



$\beta = 100 \quad V_A = 5V \quad I_{C1} = 0.0005 \quad I_{C2} = 0.0001$

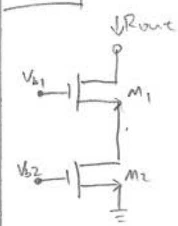
$R_{out} = g_{m1} r_{o1} (r_{o2} \| r_{\pi 1}) \qquad g_{m1} = \frac{I_{C1}}{V_T} \qquad r_{o1} = \frac{V_A}{I_{C1}}$

$r_{o2} = \frac{V_A}{I_{C2}} \qquad r_{\pi 1} = \frac{\beta V_T}{I_{C1}}$

$g_{m1} = 0.019231 \quad r_{o1} = 1E4 \quad r_{o2} = 5E4 \quad r_{\pi 1} = 5200$

$R_{out} = (0.019231)(1E4)\frac{(5E4)(5200)}{5E4 + 5200} = \boxed{906k\Omega}$

9.12 $R_{out} \geq 50k\Omega$; $I_b = 0.5mA$; $\mu_n C_{ox} = 100E-6$; $\frac{W}{L} = \frac{20}{0.18}$ maximum tolerable $\lambda_{1,2}$

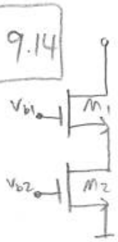


$R_{out} \approx g_{m1} r_{o1} r_{o2} \geq 50k \qquad I_b = I_{D1} = I_{D2} = 0.5mA$

$g_{m1} = \sqrt{2\mu C_{ox} \frac{W}{L} I_D} = 0.003333$

$r_{o2} = r_{o1} = \frac{1}{I_D \lambda} \qquad \left(\frac{1}{(5E-4)\lambda}\right)\left(\frac{1}{(5E-4)\lambda}\right)(0.003333) \geq 50k \qquad \boxed{\lambda \leq 0.516 V^{-1}}$

9.14 $\left(\frac{W}{L}\right)_1 = \frac{30}{0.18} \quad \left(\frac{W}{L}\right)_2 = \frac{20}{0.18} \quad I_b = 0.5mA \quad \mu_n C_{ox} = 100E-6 \quad V_{TH} = 0.4$



(a) $I_{D2} = 0.5mA \quad V_{b2} = V_{GS} \qquad I_{D2} = \frac{1}{2}\mu_n C_{ox} \frac{W}{L_2}(V_{GS} - V_{TH})^2 \Rightarrow 5E-4 = \frac{1}{2}(100E-6)\left(\frac{20}{0.18}\right)(V_{b2} - 0.4)^2$

$\boxed{V_{b2} = 0.7V} \qquad V_{DS2} = V_{GS2} - V_{TH} = 0.3V$

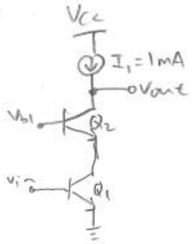
$V_{b1} = V_{GS1} + V_{DS2} \qquad I_{D1} = \frac{1}{2}\mu_n C_{ox} \frac{W}{L_1}(V_{GS1} - V_{TH})^2 \Rightarrow 5E-4 = \frac{1}{2}(100E-6)\left(\frac{30}{0.18}\right)(V_{GS1} - 0.3)^2 \quad V_{GS1} = 0.645$

$\boxed{V_{b1} = 0.945V}$

(b) $R_{out} = g_{m1} r_{o1} r_{o2} \qquad g_{m1} = \sqrt{2\mu_n C_{ox}\frac{W}{L_1} I_{D1}} = \sqrt{2(100E-6)\left(\frac{30}{0.18}\right)(5E-4)} = 0.004082$

$r_{o1} = \frac{1}{I_{D1}\lambda} = \frac{1}{(5E-4)(0.1)} = 2E4 = r_{o2} \qquad \boxed{R_{out} = 1.63M\Omega}$

9.21 $A_V = 500$ $\quad \beta_1 = \beta_2 = 100$ $\quad I_1 = 1mA$ $\quad$ Find minimum $V_{A_1} = V_{A_2}$



$$A_V = -g_{m_1} r_{o_1} g_{m_1}(r_{o_1} \| r_{\pi_2}) \qquad g_{m_1} = \frac{I_{C1}}{V_T} = 0.038462$$

$$r_{o_1} = \frac{V_A}{I_{C_1}} \qquad r_{\pi_2} = \frac{\beta}{g_{m_2}} = \frac{\beta V_T}{I_{C_2}} = 2600$$

$$500 = -(0.038462)^2 \frac{V_A}{0.001} \frac{\frac{V_A}{I_{C_1}} \cdot 2600}{\frac{V_A}{I_{C_1}} + 2600} \qquad \boxed{V_A = 0.65\ V^{-1}}$$

9.37 $$I_1 = \frac{1}{2} \mu C_{ox} \frac{W}{L} \left(\frac{R_2}{R_1 + R_2} V_{DD} - V_{TH} \right)^2$$

$$\frac{dI_1}{dV_{TH}} = -\mu C_{ox} \frac{W}{L} \left(\frac{R_2}{R_1 + R_2} V_{DD} - V_{TH} \right)$$

The issue, is more serious at lower voltages, because as V_{DD} goes down, V_{TH} will be relatively larger. This would mean that V_{TH} would control more of the sensitivity.

9.46 (a) $$I_{copy} = \frac{n I_{REF}}{1 + \frac{1}{\beta}(n+1)} = \frac{5 I_{REF}}{1 + \frac{6}{\beta}} = \frac{\beta}{\beta + 6} 5 I_{REF}$$

(b) $$I_{copy} = \frac{\frac{1}{5} I_{REF}}{1 + \frac{1}{\beta}\left(\frac{6}{5}\right)} = \frac{I_{REF}}{5\left(1 + \frac{6}{5\beta}\right)} = \frac{I_{REF}}{5 + \frac{6}{\beta}} = \frac{\beta}{5\beta + 6} I_{REF}$$

(c) $$I_{copy} = \frac{3}{2} I_{C,REF} \qquad I_2 = \frac{5}{2} I_{C,REF} \qquad I_{REF} = I_{C,REF} + I_{B,REF} + I_{B1} + I_{B2}$$

$$= I_{C,REF} + \frac{I_{C,REF}}{\beta} + \frac{I_{copy}}{\beta} + \frac{I_2}{\beta} = I_{C,REF} + \frac{I_{C,REF}}{\beta} + \frac{3 I_{C,REF}}{2\beta} + \frac{5 I_{C,REF}}{2\beta} = I_{C,REF}\left(1 + \frac{1}{\beta} + \frac{3}{2\beta} + \frac{5}{2\beta}\right)$$

$$= \frac{2}{3} I_{copy} \left(\frac{5+\beta}{\beta}\right) \qquad \boxed{I_{copy} = \frac{3}{2} I_{REF} \left(\frac{\beta}{5+\beta}\right)}$$