2018 Electronics II Exam3 Solution

DCChang 2018/5/25

1.

a.

$$I_0 = I_{C1} \text{ and } I_{REF} = I_{C1} + I_{B3} = I_{C1} + \frac{I_{E3}}{1+\beta}$$

$$I_{E3} = I_{B1} + I_{B2} + \frac{V_{BE}}{R_2} = \frac{2I_{C1}}{\beta} + \frac{V_{BE}}{R_2}$$

$$I_{REF} = I_{C1} + \frac{2I_{C1}}{\beta(1+\beta)} + \frac{V_{BE}}{(1+\beta)R_2}$$

$$I_{REF} - \frac{V_{BE}}{(1+\beta)R_2} = I_0\left(1 + \frac{2}{\beta(1+\beta)}\right)$$

$$\underline{I_0 = \frac{I_{REF} - \frac{V_{BE}}{(1+\beta)R_2}}{\left(1 + \frac{2}{\beta(1+\beta)}\right)}}$$

$$I_{REF} = (0.70)\left(1 + \frac{2}{(80)(81)}\right) + \frac{0.7}{(81)(10)}$$

$$I_{REF} = 0.700216 + 0.000864$$

b.

$$\underline{I_{REF} = 0.7011\text{ mA}} = \frac{10 - 2(0.7)}{R_1} \Rightarrow \underline{R_1 = 12.27\text{ k}\Omega}$$

2.

$$V_{BE1} = (0.026)\ln\left(\frac{100\times10^{-6}}{5\times10^{-15}}\right) = 0.61669\text{ V}$$

$$V_{BE2} = V_{BE1} + I_{REF}R_E = 0.61669 + (0.1)(0.7) = 0.68669\text{ V}$$

$$I_O = \left(5\times10^{-15}\right)\exp\left(\frac{0.68669}{0.026}\right) \Rightarrow I_O = 1.477\text{ mA}$$

3.

$$I_{REF} = \frac{2.5 - V_{GS}}{15} = \left(\frac{0.08}{2}\right)(6)(V_{GS} - 0.5)^2$$

$$2.5 - V_{GS} = 3.6\left(V_{GS}^2 - V_{GS} + 0.25\right)$$

$$3.6V_{GS}^2 - 2.6V_{GS} - 1.6 = 0$$

$$V_{GS} = \frac{2.6 \pm \sqrt{6.76 + 23.04}}{2(3.6)}$$

$$V_{GS} = 1.12 \text{ V} (1.1193)$$

$$I_{REF} = \frac{2.5 - 1.1193}{15} \Rightarrow I_{REF} = 92.0 \ \mu\text{A} \ (92.05)$$

$$I_o = 92.0 \ \mu\text{A}$$

4.

$$I_{REF} = \left(\frac{80}{2}\right)(25)(V_{SG1} - 1.2)^2 = \left(\frac{80}{2}\right)(4)(V_{SG3} - 1.2)^2$$

$$V_{SG1} + 2V_{SG3} = 10 \Rightarrow V_{SG3} = \frac{10 - V_{SG1}}{2}$$

$$\text{Then } \sqrt{\frac{25}{4}}(V_{SG1} - 1.2) = \frac{10 - V_{SG1}}{2} - 1.2$$

$$3V_{SG1} = 6.8 \Rightarrow V_{SG1} = 2.27 \text{ V}$$

$$I_{REF} = \left(\frac{80}{2}\right)(25)(2.267 - 1.2)^2 \Rightarrow \underline{I_{REF} = I_O = 1.14 \text{ mA}}$$

5.

$$I_{REF} = K_n\left(V_{GS} - V_{TN}\right)^2$$

$$0.020 = 0.080(V_{GS} - 1)^2$$

$$V_{GS} = 1.5 \text{ V all transistors}$$

$$R_0 = r_{04} + r_{02}\left(1 + g_m r_{04}\right)$$

$$r_{02} = r_{04} = \frac{1}{\lambda I_0} = \frac{1}{(0.02)(0.020)} = 2500 \text{ k}\Omega$$

$$g_m = 2K_n\left(V_{GS} - V_{TN}\right) = 2(0.080)(1.5 - 1) \Rightarrow g_m = 0.080 \ mA/V$$

$$R_0 = 2500 + 2500\left(1 + (0.080)(2500)\right) \Rightarrow \underline{R_0 = 505 \text{ M}\Omega}$$

6.

$$I_{D2} = \frac{\left(W/L\right)_2}{\left(W/L\right)_1} \cdot I_{REF} = \frac{9}{15}(200) \Rightarrow \underline{I_{D2} = 120\ \mu\text{A}}$$

$$I_O = \frac{\left(W/L\right)_4}{\left(W/L\right)_3} \cdot I_{D2} = \left(\frac{20}{9}\right)(120) \Rightarrow \underline{I_O = 267\ \mu\text{A}}$$

$$I_O = 266.7 = \left(\frac{40}{2}\right)(20)(V_{SG4} - 0.6)^2$$

$$V_{SG4} = 1.416\ \text{V}$$

$$V_{SD4}(\text{sat}) = 1.416 - 0.6 \Rightarrow \underline{V_{SD4}(\text{sat}) = 0.816\ \text{V}}$$

7.

Solution: Since M_1 and M_2 are matched, then $I_O = I_{\text{REF}}$, and the transconductance is

$$g_m = 2\sqrt{K_n I_{\text{REF}}} = 2\sqrt{(1)(0.5)} = 1.41\ \text{mA/V}$$

The small-signal transistor conductances are

$$g_o = g_{o2} = \lambda I_{\text{REF}} = (0.01)(0.5) = 0.005\ \text{mA/V}$$

For $R_L = 100\ \text{k}\Omega$ ($g_L = 0.01$ mA/V), the voltage gain is

$$A_v = \frac{-g_m}{g_o + g_L + g_{o2}} = \frac{-1.41}{0.005 + 0.01 + 0.005} = -70.5$$