Sol. for the cascode amp...

Shen Jiaqi
Zhang Xinwei
Dr. Mario Alberto García-Ramírez

1 The basics

M_1:K_n=10mA/V^2,$V_{TN} = 2$ V, λ=0.02V^{-1}
Q_2:β_F =150 ,V_A=80 V, V_{BE}=0.7V
Q_3:β_F = 80,V_A=60 V, V_{BE}=0.7V

Analyze this multistage amplifier.
Q-points
M_1:Q(I_D ,V_{DS})=(5.00 mA, 10.9V)
$V_{GS} = -I_D R_{S1} = -0.2I_D$
$I_D = \frac{K_n}{2}(V_{GS} - VTN)^2 = 5(V_{GS} - VTN)^2$
$V_{GS}^2 + 5V_{GS} + 4 = 0$
$V_{GS} = -1$
$I_D = 5(V_{GS} - VTN)^2 = 5(-1 - (-2)^2 = 5$ mA
$V_{DS} = 15 - I_D(R_{D1} + R_{S1}) = 15 - 5(0.62 + 0.2) = 10.9$V

Q_2: Q(I_{C2}, V_{CE2})=(1.51 mA, 5.47 V)
$15\frac{R_2}{R_1+R_2} = I_{B2}(R_1 \mid\mid R_2) + V_{BE2} + (\beta_{F2} + 1)I_{B2}R_{E2}$
$I_{B2} = \frac{15\frac{22}{22+78} - 0.7}{(22\|78) + (150+1)1.6} \approx 1.005 \times 10^{-2}$mA $I_{C2} = \beta_{F2}I_{B2} = 150 \cdot 1.005 \times 10^{-2} \approx 1.51(mA)$
$I_{E2} = I_{B2} + I_{C2} = 1.005 \times 10^{-2} + 1.51 \approx 1.52$ (mA)
$V_{CE2} = 15 - I_{C2}R_{C2} - I_{E2}R_{E2} = 15 - 1.51 \cdot 4.7 - 1.52 \cdot 1.6 \approx 5.47$V

Q_3:Q(I_{C3}, V_{CE3})=(1.96 mA, 8.45 V)
$15\frac{R_4}{R_3+R_4} = I_{B3}(R_3 \mid\mid R_4) + V_{BE3} + (\beta_{F3} + 1)I_{B3}R_{E3}$
$I_{B3} = \frac{15\frac{120}{91+120} - 0.7}{(91\|120) + (80+1)3.3} \approx 2.454 \times 10^{-2}$mA $I_{C3} = \beta_{F3}I_{B3} = 80 \cdot 2.254 \times 10^{-2} \approx 1.96(mA)$
$I_{E3} = I_{B3} + I_{C3} = 2.454 \times 10^{-2} + 1.96 \approx 1.98$ (mA)
$V_{CE3} = 15 - I_{E3}R_{E3} = 15 - 1.98 \cdot 3.3 = 8.45$V

Small Signal Parameters

$M_1 : g_{m1} = \frac{2I_D}{V_{GS} - V_{TN}} = \frac{2 \cdot 5}{-1 - (-2)} = 10$mS
$r_{01} = \frac{1/\lambda + V_{DS}}{I_D} = \frac{1/0.02 + 10.9}{5} \approx 12.2k\Omega$
$Q_2 : q_{m2} = \frac{I_{C2}}{V_T} = \frac{1.51}{25m} = 60.4mS$
$r_{\pi 2} = \frac{\beta_{o2}}{g_{m2}} = \frac{150}{60.4} = 2.48k\Omega$

$r_{o2} = \frac{V_{A2}+V_{CE2}}{I_{C2}} = \frac{80+5.47}{1.51} = 56.6k\Omega$
$Q_3 : g_{m3} = \frac{I_{C3}}{V_T} = \frac{1.96}{25m} = 78.4mS$
$r_{\pi 3} = \frac{\beta_{o3}}{g_{m3}} = \frac{80}{78.4} = 1.02\Omega$
$r_{o3} = \frac{V_{A3}+V_{CE3}}{I_{C3}} = \frac{60+8.45}{1.96} = 34.9k\Omega$

Voltage gain
$A_v = \frac{v_0}{v_i} = \frac{v_1}{v_i}\frac{v_2}{v_1}\frac{v_3}{v_2}\frac{v_0}{v_3} = \frac{R_G}{R_I+R_G} A_{vt1}^{CS} A_{vt2}^{CE} A_{vt3}^{CC}$
$A_{vt1}^{CS} = \frac{v_2}{v_1} \approx -g_{m1}(R_{D1} \,||\, R_{B2} \,||\, r_{\pi 2}) = -10(0.62 \,||\, (78 \,||\, 22) \,||\, 2.48) = -4.82$
$\mu_{f1} = -g_{m1} r_{o1} = 10 \cdot 12.2 = 122$
$A_{vt2}^{CE} = \frac{v_3}{v_2} \approx -g_{m2}(R_{C2} \,||\, R_{B3} \,||\, r_{\pi 3} + (1+\beta_{o3})(R_{E3} \,||\, R_L))$
$= -60.4(4.7 \,||\, (91 \,||\, 120) \,||\, [1.02(1+80)(3.3 \,||\, 0.25)]) \approx -213$
$\mu_{f2} = -g_{m2} r_{o2} = 60.4 \cdot 56.6 = 3419$
$A_{vt3}^{CC} = \frac{v_0}{v_3} \approx \frac{(g_{m3}(R_{E3}||R_L)}{1+g_{m3}(R_{E3}||R_L)} = \frac{78.4(3.3||0.25)}{1+78.4(3.3||0.25)} = 0.95$
$A_v = \frac{1000}{10+1000}(-4.82)(-213)(.95) = 966$

Input Resistance
$R_{in} = R_{in1}^{CS} = R_G = 1M\Omega$

Output resistance
$R_{out} = R_{out3}^{CC} = R_{E3} \,||\, (r_{\pi 3} + R_{th3})/(\beta_{03}+1) = 3.3 \,||\, (1.02+4)/(80+1) = 61\Omega$ $R_{Th3} = R_{B3} \,||\, (R_{C2} \,||\, r_{o2}) = (91 \,||\, 120) \,||\, (4.7 \,||\, 56.6) = 4k\Omega$

Current Gain
$A_i = \frac{i_0}{i_i} = \frac{V_0(R_I+R_{in})}{v_i R_L} = A_v \frac{R_I+R_{in}}{R_L} = 966\frac{10+1000}{0.25} = 3.90 \times 10^6$

Power Gain
$A_p = \frac{v_0 i_0}{v_i i_i} = A_v A_i = 966 \cdot 3.90 \times 10^6 = 3.99 \times 10^9$