Homework Assignment No. 8 - Solutions

Problem 15.10 (15.9) of the text.

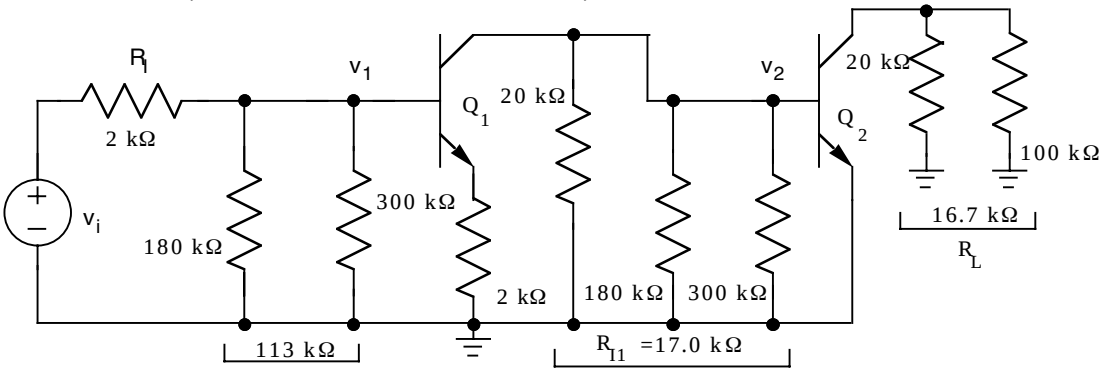
Note that the dc equivalent circuits are identical for Q_1 and Q_2.

$$V_{EQ} = \frac{180k\Omega}{180k\Omega + 300k\Omega}15V = 5.63V \quad | \quad R_{EQ} = 180k\Omega \| 300k\Omega = 113\ k\Omega$$

$$I_B = \frac{5.63 - 0.7}{113 + 101(20)}\frac{V}{k\Omega} = 2.31\mu A \quad | \quad I_C = 100I_{B1} = 232\mu A \quad | \quad I_E = 101I_{B1} = 234\mu A$$

$$V_{CE} = 15 - 2x10^4 I_E - 2x10^4 I_C = 5.71V$$

$$r_\pi = \frac{100(0.025V)}{232\mu A} = 10.8k\Omega \quad | \quad r_o = \frac{(70 + 5.71)V}{232\mu A} = 326k\Omega$$



$$A_v = \left(\frac{R_{in}}{2k\Omega + R_{in}}\right)A_{vt1}A_{vt2}$$

$$A_{vt1} = \frac{v_2}{v_1} = -\frac{\beta_{o1}(R_{I1} \| r_{\pi 2})}{r_{\pi 1} + (\beta_{o1} + 1)R_5} = -\frac{100(17k\Omega \| 10.8k\Omega)}{10.8k\Omega + (101)2k\Omega} = -3.10$$

$$A_{vt2} = \frac{v_o}{v_2} = -g_{m2}R_L \quad | \quad R_L = 100k\Omega \| 20k\Omega = 16.7k\Omega \quad | \quad A_{vt2} = -40(232\mu A)(16.7k\Omega) = -155$$

$$R_{in} = R_{B1} \| \left(r_{\pi 1} + (\beta_{o1} + 1)R_5\right) = 300k\Omega \| 180k\Omega \| \left[10.8k\Omega + (101)2k\Omega\right] = 73.6k\Omega$$

$$A_v = \left(\frac{73.6k\Omega}{2k\Omega + 73.6k\Omega}\right)(-3.10)(-155) = +468 \quad | \quad R_{out} = 20k\Omega \| r_{o2} = 20k\Omega \| 326k\Omega = 18.8k\Omega$$

Problem 15.17 (15.14 careful, second edition has parts b and c) of the text.

$$I_{C1} = 80\frac{0.7 - (-9)}{100 + 81(24)}\frac{V}{k\Omega} = 380\mu A \quad | \quad V_{EQ2} = 9 - 9100I_{C1} = 5.54V \quad | \quad R_{EQ2} = 9.1k\Omega$$

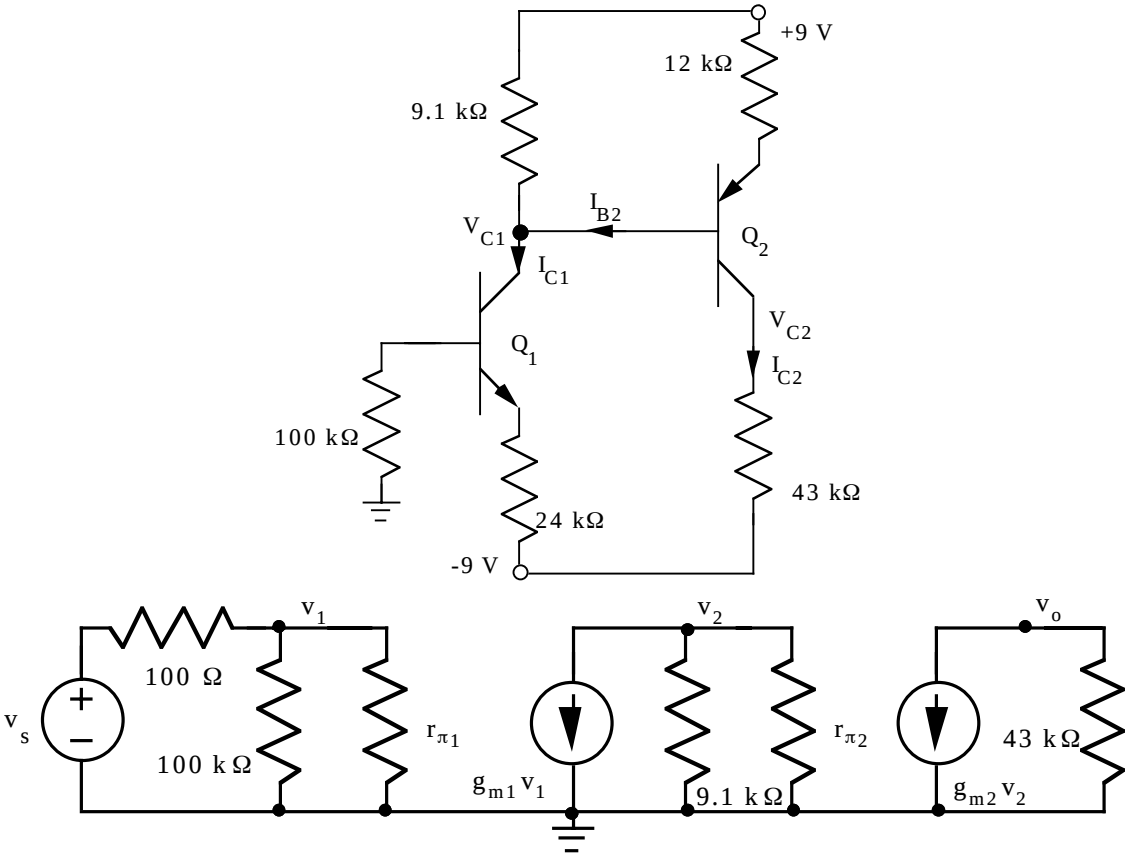
$$I_{C2} = 80\frac{9 - 0.7 - 6.04}{9.1 + 81(12)}\frac{V}{k\Omega} = 184\mu A \quad | \quad V_{C1} = 9 - 9.1k\Omega(I_{C1} - I_{B2}) = 5.54V$$

$$V_{E1} = -9 + I_{E1}(24k\Omega) = 0.12V \quad | \quad V_{CE1} = 5.54 - (0.12) = 5.42V$$

$$V_{C2} = -9 + I_{C2}(43k\Omega) = -1.09V \quad | \quad V_{E2} = V_{C1} + 0.7 = 6.76V \quad | \quad V_{EC2} = 7.85V$$

$$Q_1: (380\mu A, 7.16V) \quad Q_2: (184\mu A, 7.85V)$$

Problem 15.17 - Continued



$$g_{m1} = 40(380\mu A) = 15.2mS \quad | \quad r_{\pi 1} = \frac{80}{15.2mS} = 5.26k\Omega$$

$$g_{m2} = 40(184\mu A) = 7.36mS \quad | \quad r_{\pi 2} = \frac{80}{7.36mS} = 10.9k\Omega$$

$$R_{in} = 100k\Omega \| r_{\pi 1} = 100k\Omega \| 5.26k\Omega = 5k\Omega$$

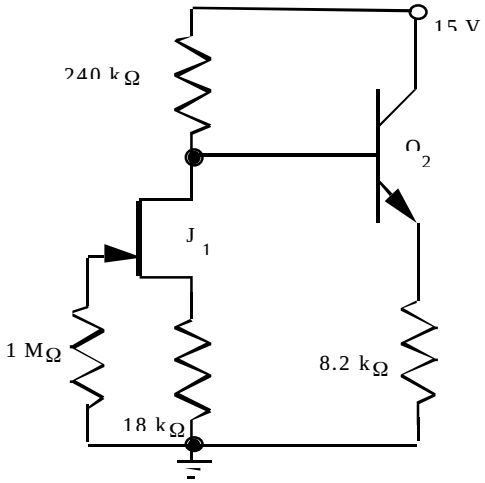
$$v_o = -g_{m2}R_{C2}v_2 = -(7.36mS)(43k\Omega)v_2 = -317v_2$$

$$v_2 = -g_{m1}(R_{C1} \| r_{\pi 2})\left(\frac{R_{in}}{100\Omega + R_{in}}\right)v_s = -15.2mS(9.1k\Omega \| 10.9k\Omega)\left(\frac{5k\Omega}{100\Omega + 5k\Omega}\right) = -73.9v_s$$

$$A_v = \frac{v_o}{v_s} = -317(-73/9) = +2.343\ x\ 10^4 \quad or \quad 87.4\ dB$$

Problem 15.20 (15.17) of the text.

dc equivalent circuit:



We assume active region operation for J_1 and Q_2.

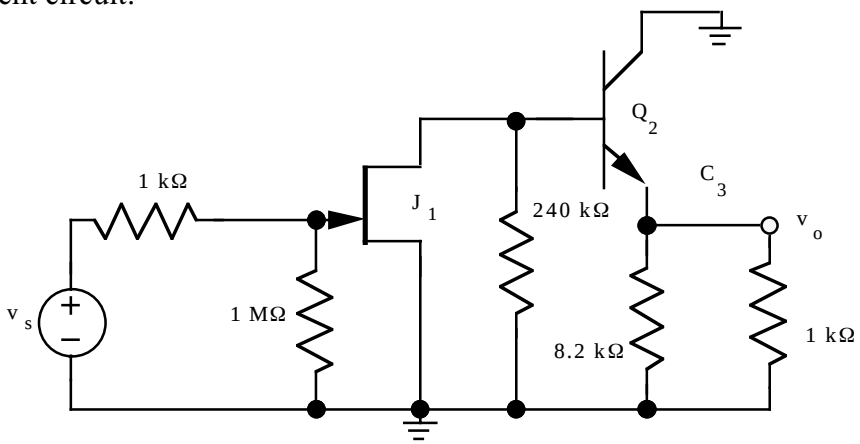
$$I_{D1} = I_{DSS}\left(1 - \frac{V_{GS1}}{V_P}\right)^2 \;\; | \;\; I_{D1} = 0.005\left(1 - \frac{-18000 I_{D1}}{-1}\right)^2 \rightarrow \; I_{D1} = 50\mu A$$

$$V_{EQ2} = 15 - I_{D1}(240k\Omega) = 3.00V \;\; | \;\; R_{EQ2} = 240k\Omega \;\; | \;\; I_{C2} = 100\frac{3 - 0.7}{240 + 101(8.2)}\frac{V}{k\Omega} = 215 \; \mu A$$

$$V_{CE2} = 15 - 8200 I_{E2} = 13.2 \; V \;\; | \;\; \text{Checking } V_{DS1}: \; V_{D1} = 15 - (50 + 2.15)(\mu A)(240k\Omega) = 2.48 \; V$$

$$V_{DS1} = 2.48 - (50\mu A)(18k\Omega) = 1.58 \; V \;\; | \;\; V_{GS1} - V_P = -(50\mu A)(18k\Omega) + 1 = 0.1 \; V \rightarrow J_1 \text{ is in pinchoff.}$$

ac equivalent circuit:



Problem 15.20 - Continued

$$g_{m1} = \frac{2}{|-1|}\sqrt{(5mA)50\mu A} = 1.00mS \quad | \quad r_{\pi 2} = \frac{100(0.025V)}{215\mu A} = 11.6k\Omega$$

$$A_{v1} = \frac{v_1}{v_i} = -\frac{10^6}{10^6 + 10^3} g_{m1} R_{L1} = -\frac{10^6}{10^6 + 10^3} g_{m1}\left[R_{D1} \| \left(r_{\pi 2} + (\beta_{o2} + 1)R_{L2}\right)\right]$$

$$R_{L2} = R_{E2} \| R_L = 8.2k\Omega \| 1k\Omega = 891\Omega \quad | \quad A_{v1} = (-1.00mS)\left[240k\Omega \| \left(11.6k\Omega + 101(891\Omega)\right)\right] = -71.4$$

$$A_{v2} = \frac{v_o}{v_1} = +\frac{101(0.891k\Omega)}{11.6k\Omega + 101(0.891k\Omega)} = 0.886 \quad | \quad A_v = -71.4(0.866) = -63.2 \quad | \quad R_{in} = 1\ M\Omega$$

$$R_{out} = R_{E2} \left\| \frac{R_{th2} + r_{\pi 2}}{\beta_{o2} + 1} = 8.2k\Omega \right\| \frac{240k\Omega + 11.6k\Omega}{101} = 8.2k\Omega \| 2.49k\Omega = 1.91\ k\Omega$$

Note : R_{out} and A_v would be lower if r_{o1} were also included.

$$(b)\ A_{v1} = \frac{v_1}{v_i} = -\frac{10^6}{10^6 + 10^3} \frac{g_{m1} R_{L1}}{1 + g_{m1} R_5}$$

$$A_{v1} = -0.999 \frac{(1.00mS)\left[240k\Omega \| \left(11.6k\Omega + 101(0.891k\Omega)\right)\right]}{1 + (1.00mS)(18k\Omega)} = -3.75$$

$$A_{v2} = \frac{v_o}{v_1} = +\frac{101(0.891k\Omega)}{11.6k\Omega + 101(0.891k\Omega)} = 0.886 \quad | \quad A_v = -3.75(0.866) = -3.25$$

Problem 15.43 (15.30) of the text.

$$(a)\ I_C = \alpha_F I_E = \frac{1}{2}\frac{\beta_F}{\beta_F + 1}\frac{12 - V_{BE}}{R_{EE}} = \frac{1}{2}\left(\frac{100}{101}\right)\left(\frac{12 - 0.7}{2.7x10^5}\right) = 20.7\ \mu A \quad | \quad V_C = 12 - 3.3x10^5 I_C = 5.17V$$

$$V_{CE} = V_C - (-0.7V) = 5.87V \quad | \quad \text{Q} - \text{Point} = (20.7\mu A,\ 5.87V)$$

$$(b)\ A_{dd} = -g_m R_C = -40(20.7\mu A)(330k\Omega) = -273$$

$$R_{id} = 2r_\pi = 2\frac{\beta_o V_T}{I_C} = 2\frac{100(0.025V)}{20.7\mu A} = 243\ k\Omega \quad | \quad R_{od} = 2R_C = 660\ k\Omega$$

$$(c)\ A_{cc} = -\frac{\beta_o R_C}{r_\pi + (\beta_o + 1)2R_{EE}} = -\frac{100(330k\Omega)}{122k\Omega + 2(101)270k\Omega} = -0.604$$

$$A_{dd} = -\frac{g_m R_C}{2} = -137 \quad | \quad A_{cd} = A_{cc} \quad | \quad CMRR = \left|\frac{-137}{-0.604}\right| = 227 \text{ or } 47.1 \text{ dB (very low)}$$

$$R_{ic} = \frac{r_\pi + (\beta_o + 1)2R_{EE}}{2} = \frac{122k\Omega + 2(101)270k\Omega}{2} = 27.3\ M\Omega$$

Problem 15.71 (15.52 - γ and $2\phi_F$ are given in second edition) of the text.

$(a)\ V_{SS} - V_{GS} = 2I_{DSS}R_{SS}\ \ |\ \ V_{GS} = V_{TN} + \sqrt{\dfrac{2I_D}{K_n}}\ \ |\ \ V_{SS} = 2I_{DSS}R_{SS} + V_{TN} + \sqrt{\dfrac{2I_D}{K_n}}$

$V_{TN} = V_{TO} + \gamma\left(\sqrt{V_{SB} + 0.6} - \sqrt{0.6}\right) = V_{TO} + \gamma\left(\sqrt{2I_{DSS}R_{SS} + 0.6} - \sqrt{0.6}\right)$

Solving iteratively with $R_{SS} = 220k\Omega\ \ |\ \ K_n = 400\dfrac{\mu A}{V^2}\ \ |\ \ V_{TO} = 1V\ \ |\ \ \gamma = 0.75\sqrt{V}$ yields

$I_D = 20.3\mu A\ \ |\ \ V_{GS} - V_{TN} = 0.319V\ \ |\ \ V_{TN} = 2.74V\ \ |\ \ V_{GS} = 3.05V$

$V_{DS} = 12 - (330k\Omega)I_{DS} - (-V_{GS}) = 8.35V > 0.319V$ - Active region $\ |\$ Q - pt : $(20.3\mu A,\ 8.35V)$

$(b)\ g_m = \dfrac{2I_D}{V_{GS} - V_{TN}} = \dfrac{2(20.3\mu A)}{0.319V} = 0.127mS\ \ |\ \ A_{dd} = -g_m R_D = -(0.127mS)(330k\Omega) = -41.9$

$A_{cc} = -\dfrac{g_m R_D}{1 + 2g_m(1+\eta)R_{SS}} = -\dfrac{(0.127mS)(330k\Omega)}{1 + 2(0.127mS)(220k\Omega)} = -0.737$ assuming $\eta = 0$

For a differential output : $A_{dm} = A_{dd} = -41.9\ \ |\ \ A_{cm} = 0\ \ |\ \ CMRR = \infty$

For a single - ended output : $A_{dm} = \dfrac{A_{dd}}{2} = -21.0\ \ |\ \ A_{cm} = A_{cc} = -0.737$

$CMRR = \dfrac{21.0}{0.737} = 28.4\ \ |\ \ CMRR_{db} = 29.1\ dB\ \ |\ \ R_{id} = \infty\ \ |\ \ R_{ic} = \infty$