Homework Assignment No. 8 - Solutions

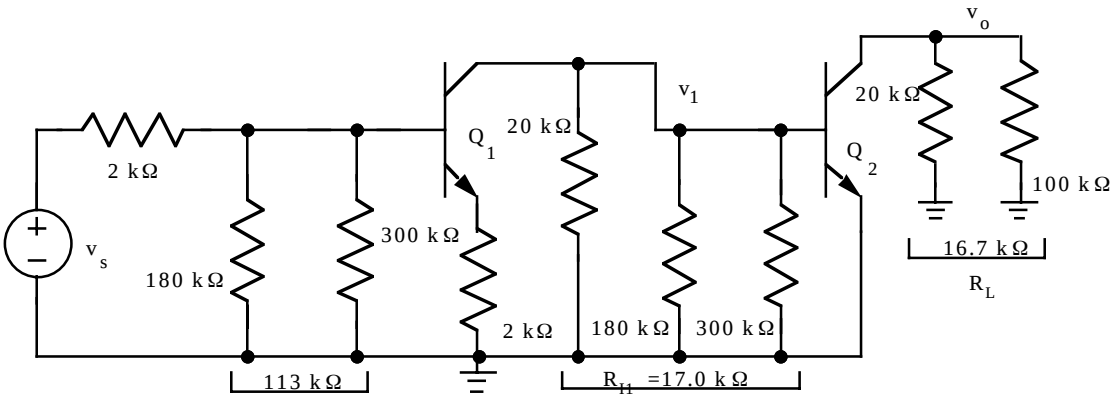
15.9 Note that the dc equivalent circuits are identical for Q_1 and Q_2.

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

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

$$V_{CE} = 15 - 2\text{x}10^4 I_E - 2\text{x}10^4 I_C = 5.71\text{V}$$

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



$$\mathbf{v_{th}} = \mathbf{v_s}\frac{113\text{k}\Omega}{113\text{k}\Omega + 2\text{k}\Omega} = 0.983\mathbf{v_s} \quad | \quad R_{th} = 113\text{k}\Omega \| 2\text{k}\Omega = 1.97\text{k}\Omega$$

$$\frac{\mathbf{v_1}}{\mathbf{v_s}} = -0.983\frac{\beta_{o1}(R_{I1} \| r_{\pi 2})}{R_{th} + r_{\pi 1} + (\beta_{o1} + 1)R_5} = -0.983\frac{100(17\text{k}\Omega \| 10.8\text{k}\Omega)}{1.97\text{k}\Omega + 10.8\text{k}\Omega + (101)2\text{k}\Omega} = -3.02 v_s$$

$$\frac{\mathbf{v_o}}{\mathbf{v_1}} = -g_{m2}R_L \quad | \quad R_L = 100\text{k}\Omega \| 20\text{k}\Omega = 16.7\text{k}\Omega \quad | \quad \frac{\mathbf{v_o}}{\mathbf{v_1}} - 40(232\mu\text{A})(16.7\text{k}\Omega) = -154 v_1$$

$$A_v = \frac{\mathbf{v_o}}{\mathbf{v_s}} = (-3.02)(-154) = +465 \quad | \quad R_{OUT} = 20\text{k}\Omega \| r_{o2} \cong 20\text{k}\Omega$$

$$R_{IN} = R_{B1} \| \left(r_{\pi 1} + (\beta_{o1} + 1)R_5\right) = 113\text{k}\Omega \| \left[10.8\text{k}\Omega + (101)2\text{k}\Omega\right] = 73.8\text{k}\Omega$$

15.14

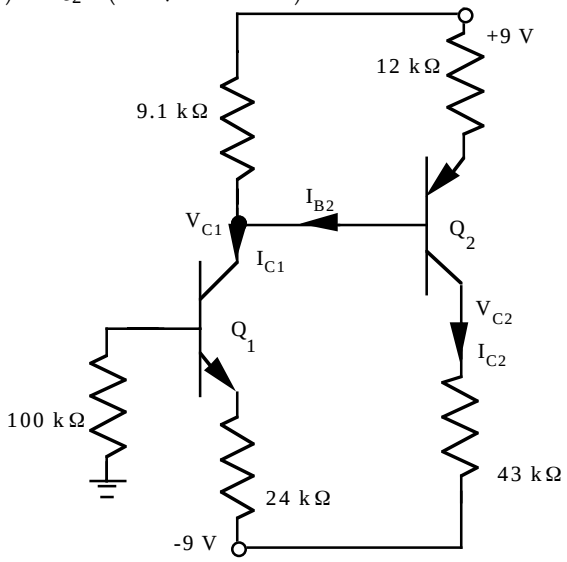
$$I_{C1} = 80\frac{0.7-(-9)}{100+81(24)}\frac{V}{k\Omega} = 325\mu A \;\;|\;\; V_{EQ2} = 9 - 9100I_{C1} = 6.04V \;\;|\;\; R_{EQ2} = 9.1k\Omega$$

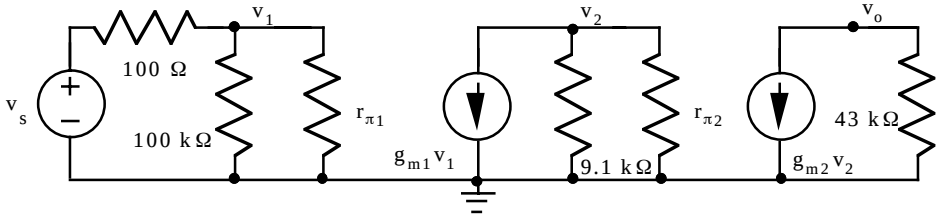
$$I_{C2} = 80\frac{9-0.7-6.04}{9.1+81(12)}\frac{V}{k\Omega} = 184\mu A \;\;|\;\; V_{C1} = 9 - 9.1k\Omega(I_{C1} - I_{B2}) = 6.06V$$

$$V_{E1} = -9 + I_{E1}(24k\Omega) = -1.10V \;\;|\;\; V_{CE1} = 6.06 - (-1.10) = 7.16V$$

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

Q_1: $(325\mu A, 7.16V)$ Q_2: $(184\mu A, 7.85V)$





$$g_{m1} = 40(325\mu A) = 13.0mS \;\;|\;\; r_{\pi 1} = \frac{80}{13.0mS} = 6.15k\Omega$$

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

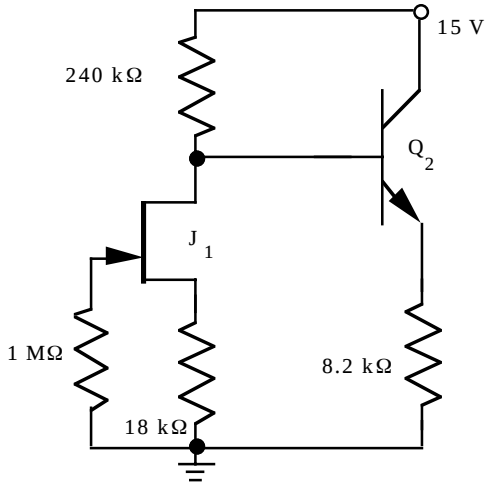
$$\mathbf{v_{th}} = \mathbf{v_s}\frac{100k\Omega}{100\Omega + 100k\Omega} = 0.999\mathbf{v_s} \;\;|\;\; R_{th} = 100k\Omega \| 100\Omega = 99.9\Omega$$

$$\mathbf{v_o} = -g_{m2}R_{C2}\mathbf{v}_2 = -(7.36mS)(43k\Omega)\mathbf{v}_2 = -317\mathbf{v}_2$$

$$\mathbf{v}_2 = -\mathbf{v_{th}}\frac{80(R_{C1} \| r_{\pi 2})}{R_{th} + r_{\pi 1}} = -0.999\mathbf{v_s}\frac{80(9.1k\Omega \| 10.9k\Omega)}{99.9\Omega + 6.15k\Omega} = -63.5\mathbf{v_s}$$

$$A_v = \frac{\mathbf{v_o}}{\mathbf{v_s}} = -317(-63.5) = +2.01 \times 10^4 \;\text{ or }\; 86.1\ dB$$

15.17 dc equivalent circuit:



We assume saturation for J_1 and forward-active region operation for Q_2.

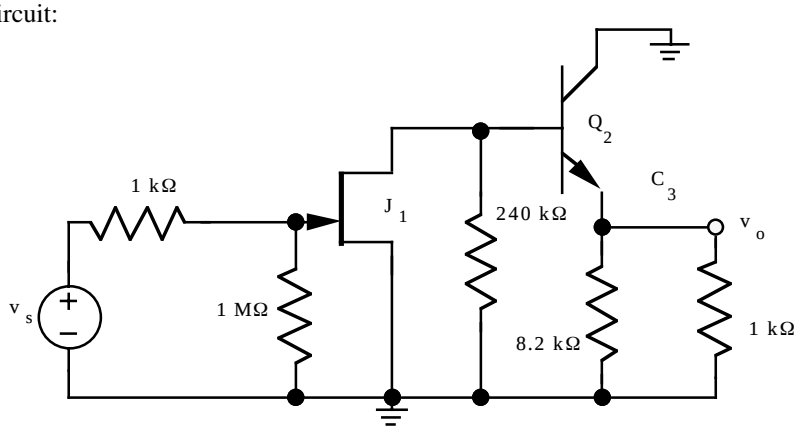
$$I_{DS1} = I_{DSS}\left(1 - \frac{V_{GS1}}{V_P}\right)^2 \;|\; I_{DS1} = 0.005\left(1 - \frac{-18000 I_{DS1}}{-1}\right)^2 \rightarrow I_{DS1} = 50\mu A$$

$$V_{EQ2} = 15 - I_{DS1}(240k\Omega) = 3.00V \;|\; R_{EQ2} = 240k\Omega \;|\; I_{C2} = 100\frac{3 - 0.7}{240 + 101(8.2)}\frac{V}{k\Omega} = 215\ \mu A$$

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

$$V_{DS1} = 2.48 - (50\mu A)(18k\Omega) = 1.58\ V \;|\; V_{GS1} - V_P = -(50\mu A)(18k\Omega) + 1 = 0.1\ V \rightarrow M_1 \text{ is saturated.}$$

ac equivalent circuit:



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

$$A_{V1} = \frac{\mathbf{v_1}}{\mathbf{v_s}} = -\frac{10^6}{10^6 + 10^3} g_{m1} R_{L1} = -\frac{10^6}{10^6 + 10^3} g\left[R_{D1} \| \left(r_{\pi 2} + (\beta_{o2} + 1)R_{L2}\right)\right]$$

$$R_{L2} = R_{E2} \| R_L = 8.2k\Omega \| 1k\Omega = 891\Omega \;|\; A_{V1} = (-1.00mS)\left[240k\Omega \| \left(11.6k\Omega + 101(891\Omega)\right)\right] = -71.4$$

$$A_{V2} = \frac{\mathbf{v_o}}{\mathbf{v_1}} = +\frac{101(0.891k\Omega)}{11.6k\Omega + 101(0.891k\Omega)} = 0.886 \;|\; A_V = -71.4(0.866) = -63.2 \;|\; R_{IN} = 1\ M\Omega$$

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

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

Problem 15.17 - Continued

$$(b)\ A_{V1} = \frac{\mathbf{v_1}}{\mathbf{v_s}} = -\frac{10^6}{10^6 + 10^3}\frac{g_{m1}R_{L1}}{1 + g_{m1}R_5}$$

$$A_{V1} = -0.999\frac{(1.00\,\text{mS})\left[240\,\text{k}\Omega \| \left(11.6\,\text{k}\Omega + 101(0.891\,\text{k}\Omega)\right)\right]}{1 + (1.00\,\text{mS})(18\,\text{k}\Omega)} = -3.75$$

$$A_{V2} = \frac{\mathbf{v_o}}{\mathbf{v_1}} = +\frac{101(0.891\,\text{k}\Omega)}{11.6\,\text{k}\Omega + 101(0.891\,\text{k}\Omega)} = 0.886 \ \mid\ A_V = -3.75(0.866) = -3.25$$

15.30

$$(a)\ I_C = \alpha_F I_E = \frac{1}{2}\frac{\beta_F}{\beta_F + 1}\frac{12 - V_{BE}}{R_{EE}} = \frac{1}{2}\frac{100}{101}\frac{12 - 0.7}{2.7\text{x}10^5} = 20.7\ \mu\text{A} \ \mid\ V_C = 12 - 3.3\text{x}10^5 I_C = 5.17\text{V}$$

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

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

$$R_{ID} = 2r_\pi = 2\frac{\beta_o V_T}{I_C} = 2\frac{100(0.025\text{V})}{20.7\mu\text{A}} = 243\ \text{k}\Omega \ \mid\ R_{OD} = 2R_C = 660\ \text{k}\Omega$$

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

$$A_{dd} = -\frac{g_m R_C}{2} = -137 \ \mid\ A_{cd} = A_{cc} \ \mid\ \text{CMRR} = \left|\frac{-137}{-0.604}\right| = 227$$

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

15.32

$$(a)\ I_E = \frac{1}{2}\frac{1.5 - 0.7}{75\text{x}10^3}\frac{\text{V}}{\Omega} = 5.33\mu\text{A} \ \mid\ I_C = \alpha_F I_E = \frac{60}{61}I_E = 5.25\mu\text{A}$$

$$V_{CE} = 1.5 - 10^5 I_C - (-0.7) = 1.68\text{V} \mid \text{Q - Pt: } (5.25\mu\text{A}, 1.68\text{V})$$

$$(b)\ g_m = 40I_C = 0.210\,\text{mS} \ \mid\ r_\pi = \frac{60}{g_m} = 286\,\text{k}\Omega \ \mid\ A_{dd} = -g_m R_C = -0.210\,\text{mS}(100\,\text{k}\Omega) = -21.0$$

$$A_{cc} = -\frac{\beta_o R_C}{r_\pi + (\beta_o + 1)2R_{EE}} = -\frac{60(100\,\text{k}\Omega)}{286\,\text{k}\Omega + 61(150\,\text{k}\Omega)} = -0.636$$

$$\text{For differential output: CMRR} = \left|\frac{-21.0}{0}\right| = \infty$$

$$\text{For single - ended output: CMRR} = \left|\frac{\frac{-21.0}{2}}{-0.636}\right| = 16.5,\ \text{a paltry 24.4 dB!}$$

$$R_{ID} = 2r_\pi = 572\,\text{k}\Omega \ \mid\ R_{IC} = \frac{r_\pi + (\beta_o + 1)2R_{EE}}{2} = \frac{286 + 61(150)}{2}\,\text{k}\Omega = 4.72\ \text{M}\Omega$$

$$R_{OD} = 2R_C = 200\ \text{k}\Omega \ \mid\ R_{OC} = \frac{R_C}{2} = 50\,\text{k}\Omega$$