Homework Assignment No. 8 -Solutions

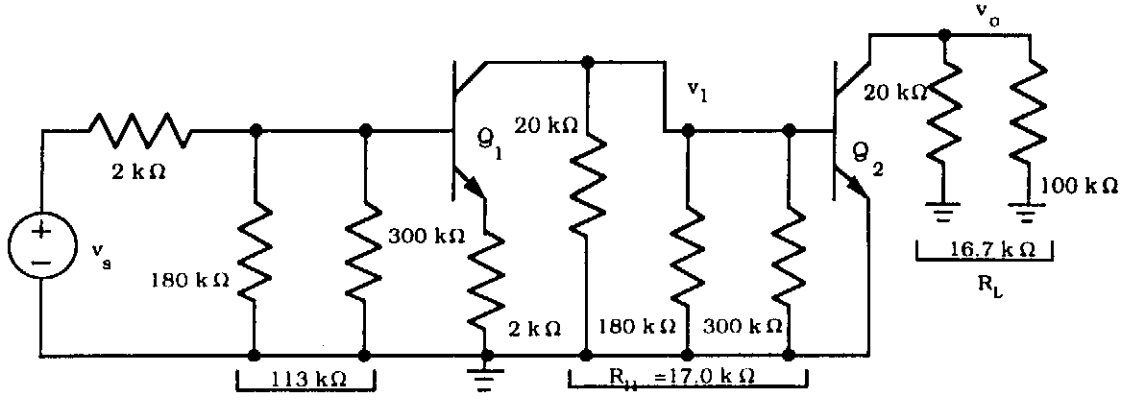
15.9 Note that the dc equivalent circuits are identical for Q_1 and Q_2.

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

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

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

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



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

$$\frac{v_1}{v_s} = -0.983 \frac{\beta_{o1}(R_{11} \| r_{\pi 2})}{R_{th} + r_{\pi 1} + (\beta_{o1} + 1)R_5} = -0.983 \frac{100(17k\Omega \| 10.8k\Omega)}{1.97k\Omega + 10.8k\Omega + (101)2k\Omega} = -3.02 v_s$$

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

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

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

15.14

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

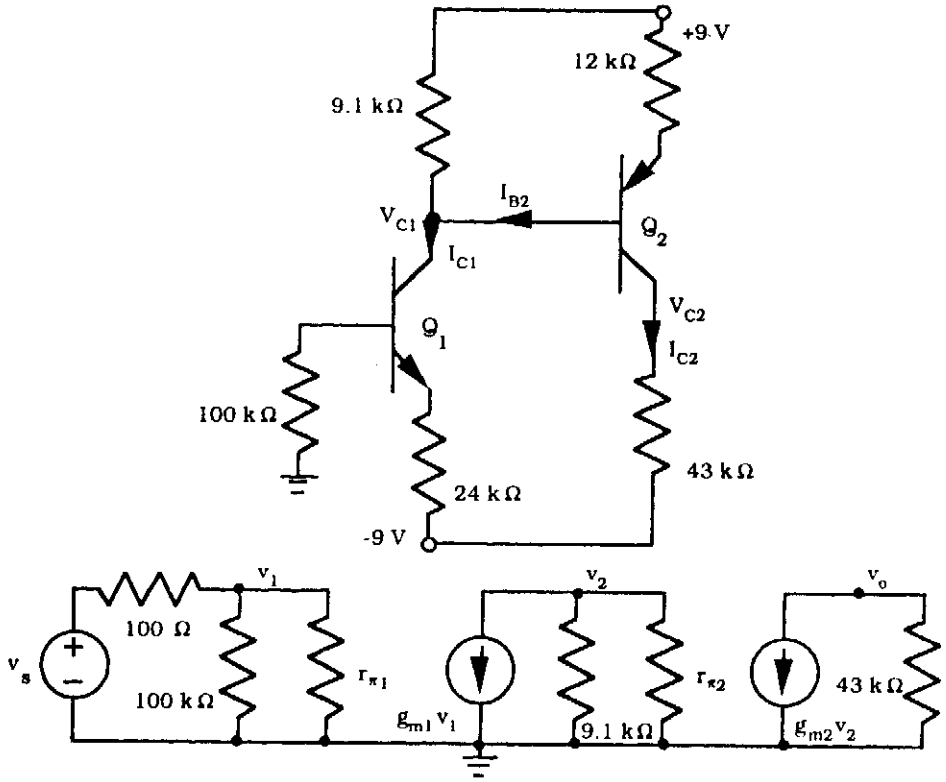
$$I_{C2} = 80 \frac{9 - 0.7 - 6.04}{9.1 + 81(12)} \frac{V}{k\Omega} = 184\mu A \;|\; V_{C1} = 9 - 9.1k\Omega(I_{C1} - I_{B2}) = 6.06V$$

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

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

Q_1: (325μA, 7.16V) Q_2: (184μA, 7.85V)

5.14 - Cont'd



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

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

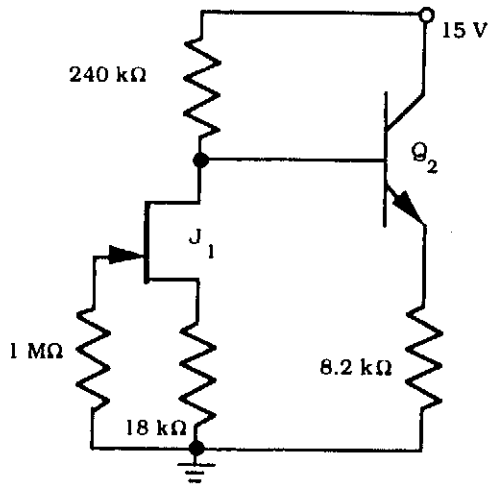
$$v_{th} = v_s \frac{100k\Omega}{100\Omega + 100k\Omega} = 0.999v_s \quad | \quad R_{th} = 100k\Omega \| 100\Omega = 99.9\Omega$$

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

$$v_2 = -v_{th}\frac{80(R_{C1}\|r_{\pi 2})}{R_{th} + r_{\pi 1}} = -0.999v_s \frac{80(9.1k\Omega \| 10.9k\Omega)}{99.9\Omega + 6.15k\Omega} = -63.5v_s$$

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

15.17 dc equivalent circuit:



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

Problem 15.17 - Continued

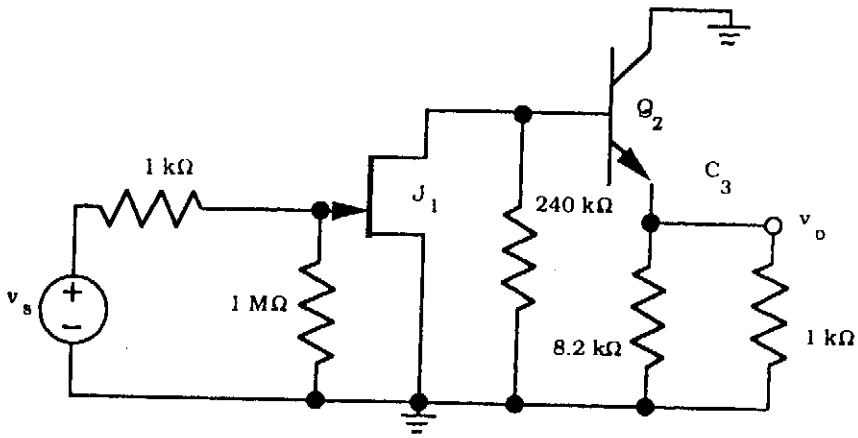
$$I_{DS1} = I_{DSS}\left(1 - \frac{V_{GS1}}{V_P}\right)^2 \;|\; I_{DS1} = 0.005\left(1 - \frac{-18000I_{DS1}}{-1}\right)^2 \rightarrow I_{DS1} = 50\mu A$$

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

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

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

ac equivalent circuit:



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

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

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

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

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

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

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

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

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

15.30

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

$V_{CE} = V_C - (-0.7V) = 5.87V$ | Q – Point = (20.7μA, 5.87V)

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

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

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

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

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

15.52

$2I_S = \frac{12-V_{GS}}{220k\Omega} \Rightarrow 2\frac{K_n}{2}(V_{GS}-V_{TN})^2 = \frac{12-V_{GS}}{220k\Omega}$ and for $K_n = 400\frac{\mu A}{V^2}$ and $V_{TN} = 1V$

$12 - V_{GS} = 88\left(V_{GS}^2 - 2V_{GS} + 1\right)$ or $88V_{GS}^2 - 175V_{GS} + 76 = 0$ and $V_{GS} = 1.348V$

$I_D = I_S = \frac{1}{2}\left(\frac{12-1.35}{220k\Omega}\right) = 24.2\mu A.$ $V_D = 12 - 3.3\text{x}10^5(I_D) = 4.01V$

$V_{DS} = 4.01 - (-V_{GS}) = 5.36V$ $(> V_{GS} - V_{TN})$. Q - Point = (24.2μA, 5.36V)

$g_m = \frac{2I_D}{V_{GS}-V_{TN}} = \frac{2(24.2\text{x}10^{-6})}{0.348} = 1.39mS$ | $A_{dd} = -g_m R_D = -1.39ms(330k\Omega) = -45.9$

$A_{cc} = -\frac{g_m R_D}{1+2g_m R_{SS}} = \frac{1.39ms(330k\Omega)}{1+2(1.39ms)(220k\Omega)} = -0.738$

For a differential output: $A_{dm} = A_{dd} = -45.9$ | $A_{cm} = 0$ | $CMRR = \infty$

For a single - ended output: $A_{dm} = \frac{A_{dd}}{2} = -23.0$ | $A_{cm} = A_{cc} = -0.738$

$CMRR = \frac{23.0}{0.738} = 31.2$ | $CMRR_{db} = 29.8\ dB$ | $R_{ID} = \infty$ | $R_{IC} = \infty$
