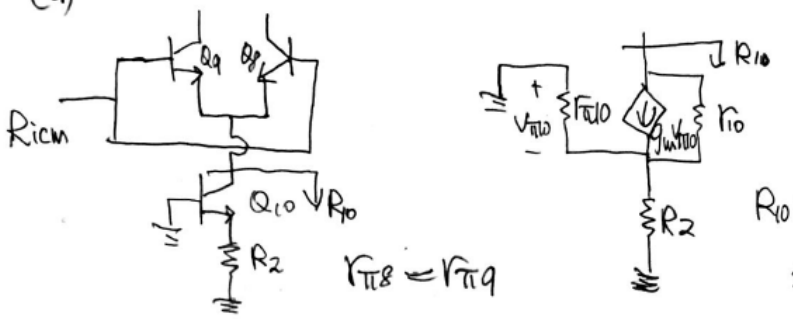
Electronics II Final Solution 2019/6/14 (2019/6/17 Update)

#1

(a)



$R_{10} = (r_{\pi 10} // R_2) + r_{10}(1 + g_{m10}(r_{\pi 10} // R_2))$

$\approx g_{m10} r_{10} (r_{\pi 10} // R_2)$

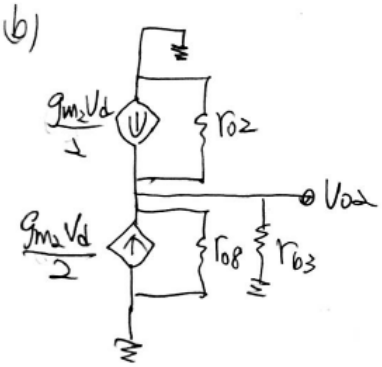
$rπ8 = rπ9$

$2R_{icm} = r_{\pi 9} + (1+\beta_9) \cdot 2R_0$

$R_{icm} \approx (1+\beta_9) R_0$

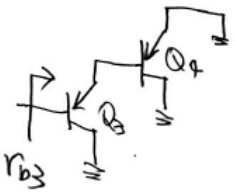
$= (1+\beta_9) \cdot g_{m10} \cdot r_{10} (r_{\pi 10} // R_2)$ #

(b)



$V_d = V_1 - V_2$, $g_{m2} = g_{m8}$

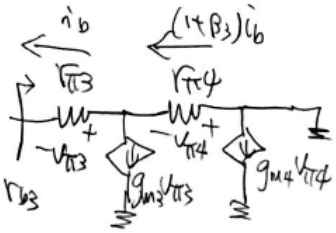
$V_{o2} = g_{m2} \cdot V_d (r_{o2} // r_{o8} // r_{b3})$



$r_{b3} = r_{\pi 3} + (1+\beta_3) r_{\pi 4}$

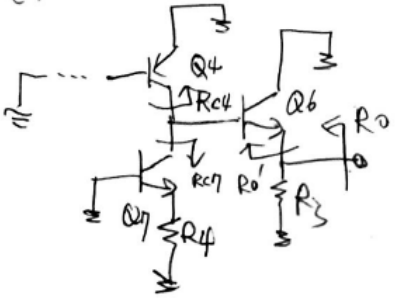
$= r_{\pi 3} + (1 + g_{m3} r_{\pi 3}) r_{\pi 4}$

$\frac{V_{o2}}{V_d} = g_{m2} [r_{o2} // r_{o8} // (r_{\pi 3} + (1+g_{m3} r_{\pi 3}) r_{\pi 4})]$ #



$g_{m3} r_{\pi 3} = \beta_3$

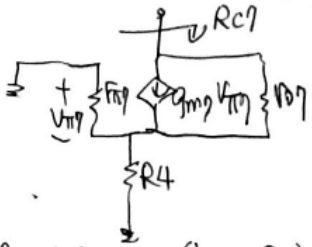
(c)



$R_{c4} = r_{o4}$

$R_{c7} = (r_{\pi 7} // R_4) + r_{o7}(1 + g_{m7}(r_{\pi 7} // R_4))$

$\approx g_{m7} \cdot r_{o7} (r_{\pi 7} // R_4)$



$R_o' = \frac{r_{\pi 6} + R_{c4} // R_{c7}}{1+\beta_6}$

$g_{m6} r_{\pi 6} = \beta_6$

$R_o = R_3 // R_o' = R_3 // \frac{r_{\pi 6} + R_{c4} // g_{m7} r_{o7} \cdot (r_{\pi 7} // R_4)}{1 + g_{m6} \cdot r_{\pi 6}}$ #

#2

$$R_0 = R_4 \left\| \left[\frac{r_{\pi 8} + \dfrac{r_{\pi 9} + r_{07} \,//\, R_{011}}{1+\beta}}{1+\beta} \right] \right.$$

$$r_{\pi 8} = \frac{\beta V_T}{I_{C8}} = \frac{(100)(0.026)}{1} = 2.6 \text{ k}\Omega$$

$$I_{C9} \approx \frac{I_{C8}}{\beta} = \frac{1}{100} = 0.01 \text{ mA}$$

$$r_{\pi 9} = \frac{(100)(0.026)}{0.01} = 260 \text{ k}\Omega$$

$$r_{07} = \frac{V_A}{I_Q} = \frac{100}{0.2} = 500 \text{ k}\Omega$$

$$r_{011} = \frac{V_A}{I_Q} = \frac{100}{0.2} = 500 \text{ k}\Omega$$

$$R_{011} = r_{011}\left[1 + g_m R'_E\right], \quad g_m = \frac{0.2}{0.026} = 7.69$$

$$r_{\pi 11} = \frac{(100)(0.026)}{0.2} = 13 \text{ k}\Omega$$

$$R'_E = 0.2 \| 13 = 0.197 \text{ k}\Omega$$

$$R_{011} = 500\left[1 + (7.69)(0.197)\right] = 1257 \text{ k}\Omega$$

Then

$$R_0 = 5 \left\| \left[\frac{2.6 + \dfrac{260 + 500 \,//\, 1257}{101}}{101} \right] \right.$$

$$= 5 \| 0.086$$

$$\Rightarrow \underline{R_0 = 0.085 \text{ k}\Omega}$$

#3

$$I_1 = \frac{24 - V_{GS4}}{R_1} = k_n \left(V_{GS4} - V_{Th}\right)^2$$

$$24 - V_{GS4} = (55)(0.2)(V_{GS4} - 2)^2$$

$$24 - V_{GS4} = 11\left(V_{GS4}^2 - 4V_{GS4} + 4\right)$$

$$11V_{GS4}^2 - 43V_{GS4} + 20 = 0$$

$$V_{GS4} = \frac{43 \pm \sqrt{(43)^2 - 4(11)(20)}}{2(11)} = 3.37 \text{ V}$$

$$I_1 = \frac{24 - 3.37}{55} = 0.375 \text{ mA} = I_Q$$

$$v_{02} = 12 - \left(\frac{0.375}{2}\right)(40) = 4.5 \text{ V}$$

$$\frac{v_{02} - V_{GS3}}{R_5} = I_{D3} = k_n \left(V_{GS3} - V_{Th}\right)^2$$

$$4.5 - V_{GS3} = (0.2)(6)\left(V_{GS3}^2 - 4V_{GS3} + 4\right)$$

$$1.2V_{GS3}^2 - 3.8V_{GS3} + 0.3 = 0$$

$$V_{GS3} = \frac{3.8 \pm \sqrt{(3.8)^2 - 4(1.2)(0.3)}}{2(1.2)} = 3.09 \text{ V}$$

$$I_{D3} = \frac{4.5 - 3.09}{6} = 0.235 \text{ mA}$$

$$g_{m2} = 2\sqrt{K_n I_{D2}} = 2\sqrt{(0.2)\left(\frac{0.375}{2}\right)}$$

$$= 0.387 \text{ mA/V}$$

$$A_{d1} = \frac{1}{2} g_{m2} R_D = \frac{1}{2}(0.387)(40) \Rightarrow A_{d1} = 7.74$$

$$A_2 = \frac{-g_{m3} R_{D2}}{1 + g_{m3} R_5}$$

$$g_{m3} = 2\sqrt{K_n I_{D3}} = 2\sqrt{(0.2)(0.235)}$$

$$= 0.434 \text{ mA/V}$$

$$A_2 = \frac{-(0.434)(4)}{1 + (0.434)(6)} = -0.482$$

$$\text{So } A_d = A_{d1} \cdot A_2 = (7.74)(-0.482) \Rightarrow \underline{A_d = -3.73}$$

#4

(a) $R = \dfrac{5-0}{0.25} = 20\,\text{k}\Omega$

$R_{E1} = \dfrac{-0.7-(-5)}{0.25} = 17.2\,\text{k}\Omega$

$R_C = \dfrac{5-0.7}{0.25} = 17.2\,\text{k}\Omega$

$R_{E2} = \dfrac{0-(-5)}{2} = 2.5\,\text{k}\Omega$

(b) $A_{d1} = \dfrac{\upsilon_{o2}}{\upsilon_d} = \dfrac{g_{m1}}{2}\left(R \| r_{\pi 3}\right)$

$g_{m1} = \dfrac{0.25}{0.026} = 9.615\,\text{mA/V}$

$r_{\pi 3} = \dfrac{(120)(0.026)}{0.25} = 12.48\,\text{k}\Omega$

$A_{d1} = \dfrac{(9.615)}{2}\left(20 \| 12.48\right) = 36.94$

$A_3 = -g_{m3}\left(R_C \| R_{i4}\right)$

$R_{i4} = r_{\pi 4} + (1+\beta)R_{E2}$

$g_{m3} = \dfrac{0.25}{0.026} = 9.615\,\text{mA/V}$

$r_{\pi 4} = \dfrac{(120)(0.026)}{2} = 1.56\,\text{k}\Omega$

$R_{i4} = 1.56 + (121)(2.5) = 304\,\text{k}\Omega$

$A_3 = -(9.615)(17.2 \| 304) = -156.5$

$A_4 = \dfrac{(1+\beta)R_{E2}}{r_{\pi 4} + (1+\beta)R_{E2}} = \dfrac{(121)(2.5)}{1.56 + (121)(2.5)} = 0.995$

Now $A_d = \dfrac{\upsilon_o}{\upsilon_d} = A_{d1} \cdot A_3 \cdot A_4 = (36.94)(-156.5)(0.995) = -5752$