2025 Electronics II Exam-4 Reference Solution
13th June, 2025

1.

a. $I_1 = \dfrac{24 - V_{GS4}}{R_1} = k_n(V_{GS4} - V_{Th})^2$

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

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

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

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

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

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

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

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

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

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

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

$$g_{m2} = 2\sqrt{K_n I_{D2}} = 2\sqrt{(0.2)\left(\frac{0.375}{2}\right)}$$
$$= 0.387 \text{ mA/V}$$

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

$\Rightarrow A_{d1} = 7.74$

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

$$g_{m3} = 2\sqrt{K_n I_{D3}} = 2\sqrt{(0.2)(0.235)}$$
$$= 0.434 \text{ mA/V}$$

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

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

$\Rightarrow \underline{A_d = -3.73}$

$R_o = r_{o4} = \dfrac{1}{\lambda I_Q} = \dfrac{1}{(0.02)(0.375)} = 133 \text{ k}\Omega$

$$A_{cm1} = \frac{-g_{m2} R_D}{1 + 2g_{m2} R_o} = \frac{-(0.387)(40)}{1 + 2(0.387)(133)}$$
$$= -0.149$$

$A_{cm} = (-0.149)(-0.482) \Rightarrow \underline{A_{cm} = 0.0718}$

b. $v_d = v_1 - v_2 = 0.3 \sin \omega t$

$v_{cm} = \dfrac{v_1 + v_2}{2} = 2 \sin \omega t$

$v_{03} = A_d v_d + A_{cm} v_{cm}$

$= (-3.73)(0.3) + (0.0718)(2)$

$\Rightarrow \underline{v_{03} = -0.975 \sin \omega t \text{ (V)}}$

Ideal, $A_{cm} = 0$

$v_{03} = A_d v_d = (-3.73)(0.3)$

Or

$\Rightarrow \underline{v_{03} = -1.12 \sin \omega t \text{ (V)}}$

2.

$$R_i = r_{\pi 1} + (1+\beta) r_{\pi 2}$$

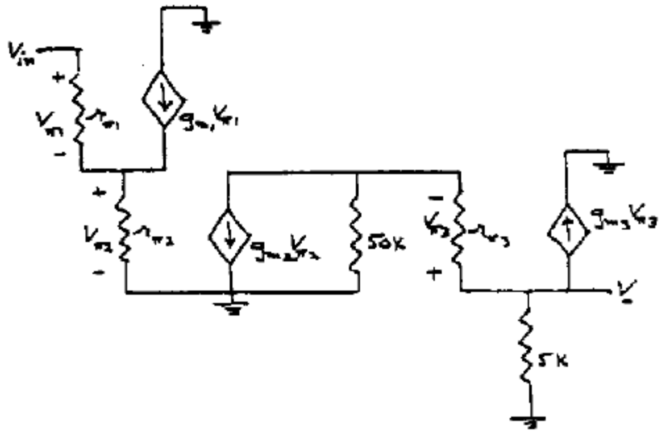
$$r_{\pi 2} = \frac{(100)(0.026)}{0.5} = 5.2 \text{ k}\Omega$$

$$r_{\pi 1} = \frac{(100)(0.026)}{(0.5/100)} = \frac{(100)^2(0.026)}{0.5} = 520 \text{ k}\Omega$$

$$R_i = 520 + (101)(5.2) \Rightarrow \underline{R_i \cong 1.05 \text{ M}\Omega}$$

$$R_0 = 5 \left\| \frac{r_{\pi 3} + 50}{101}, \quad r_{\pi 3} = \frac{(100)(0.026)}{1} = 2.6 \text{ k}\Omega \right.$$

$$R_0 = 5 \left\| \frac{2.6 + 50}{101} = 5 \| 0.521 \Rightarrow \underline{R_0 = 0.472 \text{ k}\Omega} \right.$$



$$V_0 = -\left(\frac{V_{\pi 3}}{r_{\pi 3}} + g_{m3} V_{\pi 3}\right)(5)$$

$$V_0 = -V_{\pi 3}\left(\frac{1+\beta}{r_{\pi 3}}\right)(5) \quad (1)$$

$$\frac{V_{\pi 3}}{r_{\pi 3}} = g_{m2} V_{\pi 2} + \frac{(V_0 - V_{\pi 3})}{50}$$

$$g_{m2} V_{\pi 2} = V_{\pi 3}\left(\frac{1}{r_{\pi 3}} + \frac{1}{50}\right) - \frac{V_0}{50} \quad (2)$$

$$V_{\pi 2} = \left(\frac{V_{\pi 1}}{r_{\pi 1}} + g_{m1} V_{\pi 1}\right) r_{\pi 2}$$

$$= V_{\pi 1}\left(\frac{1+\beta}{r_{\pi 1}}\right) r_{\pi 2} \quad (3)$$

and

$$V_{in} = V_{\pi 1} + V_{\pi 2} \quad (4)$$

$$g_{m2} = \frac{0.5}{0.026} = 19.23 \text{ mA/V}$$

Then

$$V_0 = -V_{\pi 3}\left(\frac{101}{2.6}\right)(5) \quad (1)$$

$$\Rightarrow V_{\pi 3} = -V_0(0.005149)$$

And

$$19.23 V_{\pi 2} = -V_0(0.005149)\left(\frac{1}{2.6} + \frac{1}{50}\right) - \frac{V_0}{50} \quad (2)$$

$$= -V_0(0.02208)$$

Or $V_{\pi 2} = -V_0(0.001148)$

And

$$V_{\pi 1} = V_{in} - V_{\pi 2} = V_{in} + V_0(0.001148) \quad (4)$$

So

$$-V_0(0.001148) = [V_{in} + V_0(0.001148)]\left(\frac{101}{520}\right)(5.2) \quad (3)$$

$$-V_0(0.001148) - V_0(0.001159) = V_{in}(1.01)$$

$$\Rightarrow \underline{A_v = \frac{V_0}{V_{in}} = -438}$$

3.

From Eq. 10.105

$$A_v = \frac{-g_m^2}{\frac{1}{r_{o3}r_{o4}} + \frac{1}{r_{o1}r_{o2}}}$$

$$g_m = 2\sqrt{\left(\frac{k_n'}{2}\right)\left(\frac{W}{L}\right)I_{D1}}$$

$$= 2\sqrt{(0.050)(20)(0.08)}$$

$$g_m = 0.5657\ mA/V$$

$$r_o = \frac{1}{\lambda I_D} = \frac{1}{(0.02)(0.08)} = 625\ \text{K}$$

$$A_v = \frac{-(0.5657)^2}{\frac{1}{(625)^2} + \frac{1}{(625)^2}} = \frac{-0.3200}{2(0.00000256)}$$

$$A_v = -62{,}500$$

4.

a. For $v_1 = v_2 = 0$ and neglecting base currents

$$R_E = \frac{-0.7-(-10)}{0.15} \Rightarrow \underline{R_E = 62\ \text{k}\Omega}$$

b.

$$A_d = \frac{v_{02}}{v_d} = \frac{\beta R_C}{2(r_\pi + R_B)}$$

$$r_\pi = \frac{\beta V_T}{I_{CQ}} = \frac{(100)(0.026)}{0.075} = 34.7\ \text{k}\Omega$$

$$A_d = \frac{(100)(50)}{2(34.7+0.5)} \Rightarrow \underline{A_d = 71.0}$$

$$A_{cm} = -\frac{\beta R_C}{r_\pi + R_B}\left[\frac{1}{1+\frac{2R_E(1+\beta)}{r_\pi + R_B}}\right]$$

$$= -\frac{(100)(50)}{34.7+0.5}\left[\frac{1}{1+\frac{2(62)(101)}{34.7+0.5}}\right] \Rightarrow \underline{A_{cm} = -0.398}$$

$$CMRR_{dB} = 20\log_{10}\left|\frac{71.0}{0.398}\right| \Rightarrow \underline{CMRR_{dB} = 45.0\ \text{dB}}$$

c.

$$R_{id} = 2(r_\pi + R_B)$$

$$R_{id} = 2(34.7+0.5) \Rightarrow \underline{R_{id} = 70.4\ \text{k}\Omega}$$

Common-mode input resistance

$$R_{icm} = \frac{1}{2}\left[r_\pi + R_B + 2(1+\beta)R_E\right]$$

$$= \frac{1}{2}\left[34.7+0.5+2(101)(62)\right] \Rightarrow \underline{R_{icm} = 6.28\ \text{M}\Omega}$$