2019 Electronics II Exam3 Solution

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1.

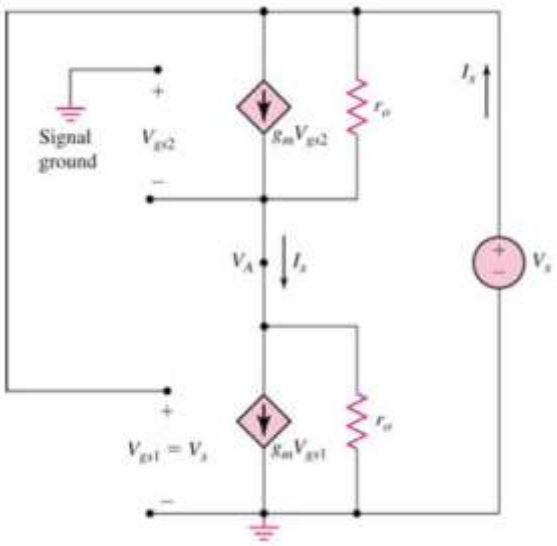
$$A_v = \frac{-g_m^2}{\frac{1}{r_{o3}r_{o4}} + \frac{1}{r_{o1}r_{o2}}}$$

$$g_m = 2\sqrt{\left(\frac{0.1}{2}\right)(25)(0.08)} = 0.6325\,\text{mA/V}$$

$$r_o = \frac{1}{\lambda I_D} = \frac{1}{(0.04)(0.08)} = 312.5\,\text{k}\Omega$$

$$A_v = \frac{-(0.6325)^2}{\frac{1}{(312.5)^2} + \frac{1}{(312.5)^2}} = \frac{-0.40}{2(0.00001024)} = -19{,}531$$

2.



(1) $$I_x = \frac{V_x - V_A}{r_o} + g_m V_{gs2}$$

$$I_x = \frac{V_A}{r_o} + g_m V_{gs1}$$

(2) $$V_{gs1} = V_x,\ V_{gs2} = -V_A$$

So

(1) $$I_x = \frac{V_x}{r_o} - V_A\left(\frac{1}{r_o} + g_m\right)$$

(2) $$I_x = \frac{V_A}{r_o} + g_m V_x \Rightarrow V_A = r_o\left[I_x - g_m V_x\right]$$

Then

$$I_x = \frac{V_x}{r_o} - r_o\left(I_x - g_m V_x\right)\left(\frac{1}{r_o} + g_m\right)$$

$$I_x = \frac{V_x}{r_o} - r_o\left[\frac{I_x}{r_o} + g_m I_x - \frac{g_m}{r_o}\cdot V_x - g_m^2 V_x\right]$$

$$I_x = \frac{V_x}{r_o} - I_x - g_m r_o I_x + g_m V_x + g_m^2 r_o V_x$$

$$I_x\left[2 + g_m r_o\right] = V_x\left[\frac{1}{r_o} + g_m + g_m^2 r_o\right]$$

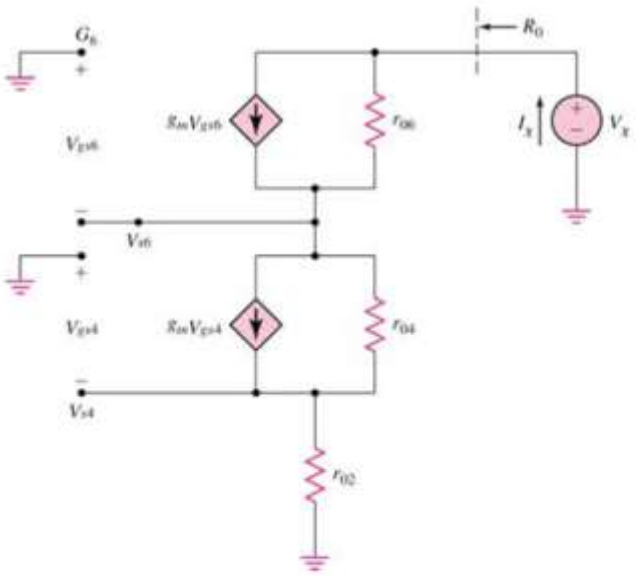
Since $g_m >> \frac{1}{r_o}$

$$I_x\left[2 + g_m r_o\right] \cong V_x\left(g_m\right)\left(1 + g_m r_o\right)$$

Then $\frac{V_x}{I_x} = R_o = \frac{2 + g_m r_o}{g_m\left(1 + g_m r_o\right)}$

Usually, $g_m r_o >> 2,$ so that $R_o \cong \frac{1}{g_m}$

3.



$$V_{gs4} = -I_X r_{02}$$

$$V_{S6} = \left(I_X - g_m V_{gs4}\right) r_{04} + I_X r_{02}$$

$$= \left(I_X + g_m I_X r_{02}\right) r_{04} + I_X r_{02}$$

$$V_{S6} = I_X \left[r_{02} + \left(1 + g_m r_{02}\right) r_{04} \right] = -V_{gs6}$$

$$I_X = g_m V_{gs6} + \frac{V_X - V_{S6}}{r_{06}} = \frac{V_X}{r_{06}} - V_{S6}\left(g_m + \frac{1}{r_{06}} \right)$$

$$I_X = \frac{V_X}{r_{06}} - I_X \left(g_m + \frac{1}{r_{06}} \right) \left[r_{02} + \left(1 + g_m r_{02}\right) r_{04} \right]$$

$$I_X \left\{ 1 + \left(g_m + \frac{1}{r_{06}} \right) \left[r_{02} + \left(1 + g_m r_{02}\right) r_{04} \right] \right\} = \frac{V_X}{r_{06}}$$

$$\frac{V_X}{I_X} = R_0 = r_{06} + \left(1 + g_m r_{06}\right) \left[r_{02} + \left(1 + g_m r_{02}\right) r_{04} \right]$$

$$I_0 \approx I_{REF} = 0.2 \text{ mA} = 0.2\left(V_{GS} - 1\right)^2$$

$$V_{GS} = 2 \text{ V}$$

$$g_m = 2K_n \left(V_{GS} - V_{TN}\right) = 2\left(0.2\right)\left(2 - 1\right) = 0.4 \; mA/V$$

$$r_{02} = r_{04} = r_{06} = \frac{1}{\lambda I_0} = \frac{1}{\left(0.02\right)\left(0.2\right)} = 250 \text{ k}\Omega$$

$$R_0 = 250 + \left[1 + \left(0.4\right)\left(250\right)\right] \times \left\{ 250 + \left[1 + \left(0.4\right)\left(250\right)\right]\left(250\right) \right\}$$

$$R_0 = 2575750 \text{ k}\Omega \Rightarrow \underline{R_0 = 2.58 \times 10^9 \, \Omega}$$

4.

$$I_{D2} = \frac{\left(W/L\right)_2}{\left(W/L\right)_1} \cdot I_{REF} = \frac{9}{15}(200) \Rightarrow \underline{I_{D2} = 120\ \mu\text{A}}$$

$$I_O = \frac{\left(W/L\right)_4}{\left(W/L\right)_3} \cdot I_{D2} = \left(\frac{20}{9}\right)(120) \Rightarrow \underline{I_O = 267\ \mu\text{A}}$$

$$I_O = 266.7 = \left(\frac{40}{2}\right)(20)\left(V_{SG4} - 0.6\right)^2$$

$$V_{SG4} = 1.416\ \text{V}$$

$$V_{SD4}(\text{sat}) = 1.416 - 0.6 \Rightarrow \underline{V_{SD4}\left(\text{sat}\right) = 0.816\ \text{V}}$$
