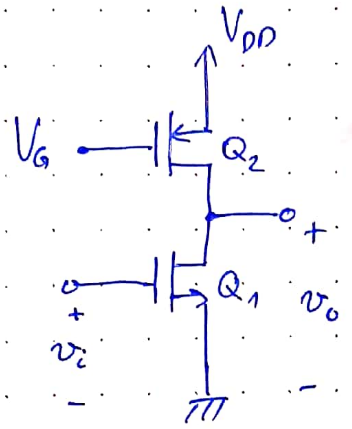
N. B. Dang Huy Date: 13/3/20

Analog Electronics

Quiz #2

Question 1.



i) Q_2 functions as a constant current source to bias Q_1

ii) Q_1 has Common Source configuration

iii) For Q2 (PMOS):

$$I_D = \frac{1}{2}\mu_p C_{ox}\frac{W}{L}(V_{SG_2} - |V_{tp}|)^2$$

$$= \frac{1}{2} \times 90 \times 22.3 \times (V_{DD} - V_G - |V_{tp}|)^2$$

$$= \frac{1}{2} \times 90 \times 22.3 \times (1.8 - 1 - 0.5)^2$$

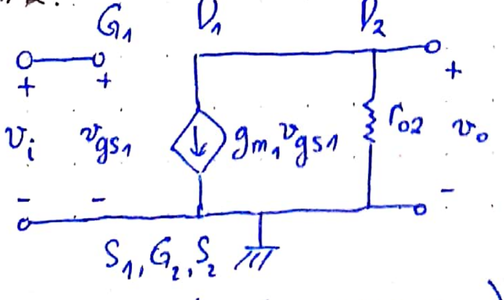
$$\approx 90.32\ (\mu A)$$

iv) $r_{o2} = 500\,k\Omega = \frac{|V_{A2}|}{I_D} \Leftrightarrow |V_{A_2}| = 500^{k\Omega} \times 90.32^{\mu A}$
$\approx 45.16\ (V)$

v) $g_{m_1} = \frac{2I_D}{V_{OV}} = \frac{2 \times 90.32^{\mu A}}{0.3^V} \approx 0.6^{mA/V}$

Question 2.

i)



(The question doesn't mention r_{o1})

ii) $v_o = -g_{m_1} v_{gs1} r_{o2}$

$\Leftrightarrow v_o/v_i = -g_{m_1} r_{o2}$
$= -0.6 \times 500 = -300$

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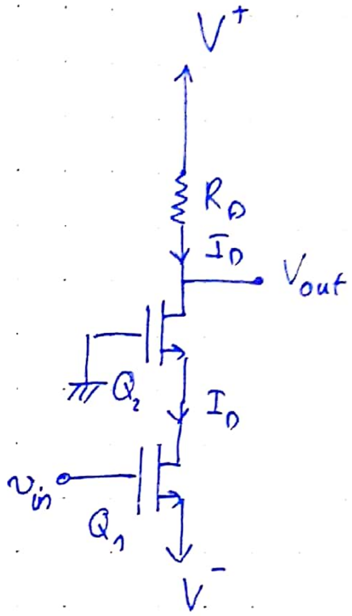
iii) Output impedance

$$R_o = r_{o_2} = 500^{k\Omega}$$

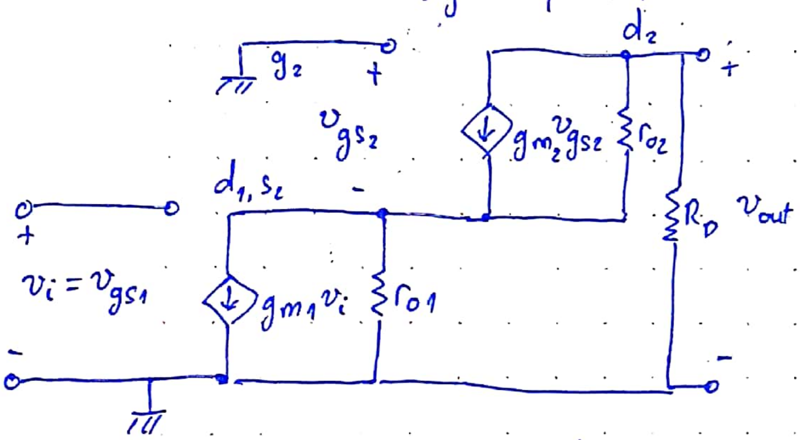
Question 3.

i) Cascode Amplifier circuit.

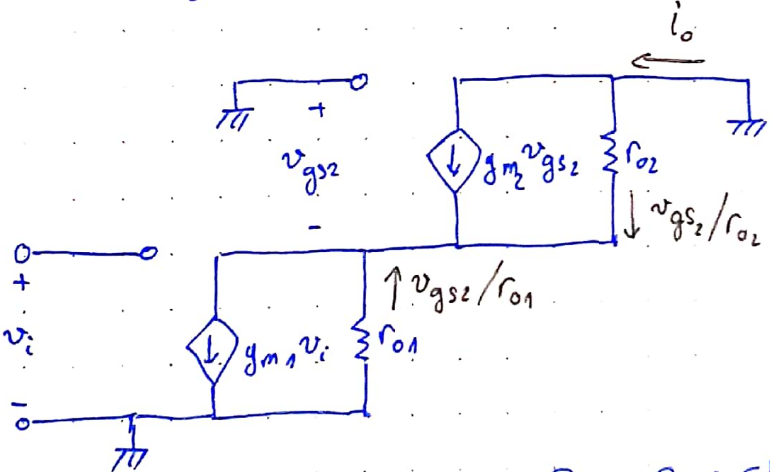


ii) $r_{o1} = r_{o2} = \dfrac{V_A}{I_D} = \dfrac{100^V}{0.5^{mA}} = 200^{k\Omega}$

iii) Small-signal equivalent circuit:



Short d_2 to ground, $i_o = G_m v_i$



$$g_{m1} = g_{m2} = g_m = \frac{2I_D}{V_{ov}} = \frac{2 \times 0.5^{mA}}{V_{GS} - V_t} = 1^{mA/V}$$

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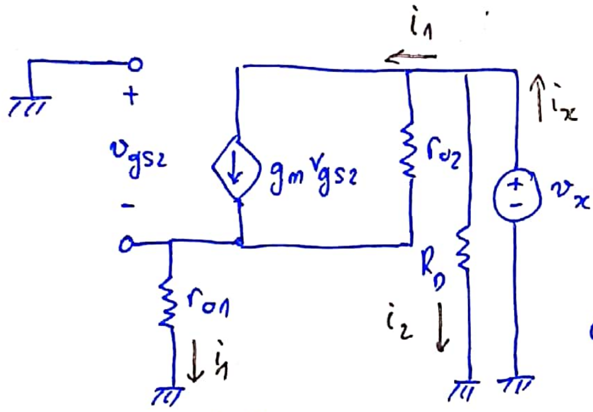
- $g_m v_i = \dfrac{v_{gs2}}{r_{o1}} + \dfrac{v_{gs2}}{r_{o2}} + g_m v_{gs2}$

  Because $g_m \gg \left(\dfrac{1}{r_{o1}}, \dfrac{1}{r_{o2}}\right)$ $\Rightarrow g_m v_i \simeq g_m v_{gs2}$

- $i_o = g_m v_{gs2} + v_{gs2}/r_{o2} \simeq g_m v_{gs2} \simeq g_m v_i$

Therefore, $G_m \simeq g_m = 1\,mA/V$

- Deactivate active source, connect test source v_x to d_2 to calculate R_o



$$\begin{cases} v_x = i_1 r_{o1} + (i_1 - g_m v_{gs2}) r_{o2} \\ v_{gs2} = -i_1 r_{o1} \end{cases}$$

$$\Rightarrow v_x = i_1 \underbrace{(r_{o1} + r_{o2} + g_m r_{o1} r_{o2})}_{R_{eq1}}$$

$$\Leftrightarrow v_x = i_1 R_{eq1} = i_x \frac{R_D}{R_D + R_{eq1}} R_{eq1}$$

$$\Leftrightarrow R_o = \frac{v_x}{i_x} = \frac{R_D R_{eq1}}{R_D + R_{eq1}} = \frac{R_D}{R_D/R_{eq1} + 1} \simeq R_D = 4\,(k\Omega) \quad (\text{Because } R_{eq1} \gg R_D)$$

iv) $A_v = \dfrac{v_o}{v_i} = \dfrac{-G_m R_o v_{gs1}}{v_{gs1}} = -G_m R_o = -1\,mA/V \times 4\,k\Omega = -4$

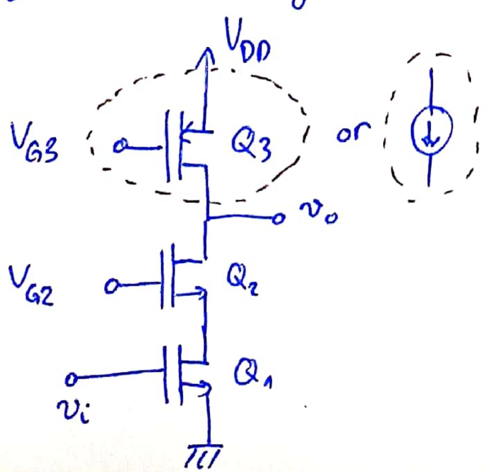
Question 4.

i) If R_D is replaced by an ideal voltage source

$$\Rightarrow \begin{cases} G_m \simeq g_m \text{ (not change)} \\ R_o = R_{eq1} \simeq g_m r_{o1} r_{o2} = g_m r_o^2 \end{cases}$$

$\Rightarrow A_{v_o} = -G_m R_o = -(g_m r_o)^2 \Rightarrow$ Magnitude of gain increases a lot.

ii)



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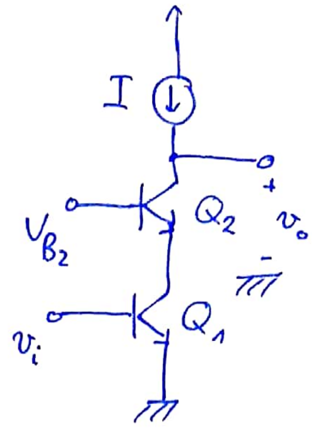
Question 5.

i) $I_{C_2} \approx I_{E_2} = I_{C_1} \approx I_{E_1} = I = 1(mA)$

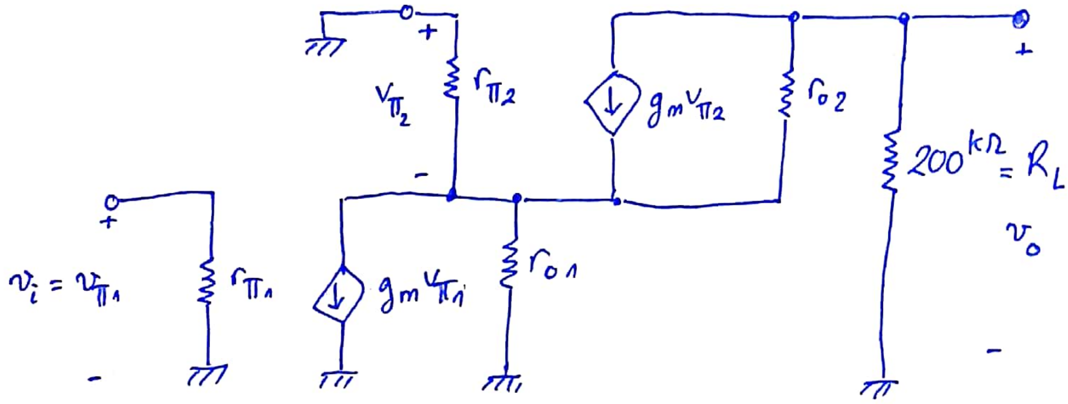
$r_{\pi_1} = r_{\pi_2} = \frac{V_T}{I_B} = \frac{\beta V_T}{I} = \frac{100 \times 25^{mV}}{1^{mA}} = 2.5^{k\Omega} = r_\pi$



ii) $r_{o_1} = r_{o_2} = \frac{V_A}{I_C} = \frac{V_A}{I} = \frac{50^V}{1^{mA}} = 50^{k\Omega} = r_o$

iii) $g_{m_1} = g_{m_2} = g_m = \frac{I_C}{V_T} = \frac{1^{mA}}{25^{mA}} = 0.04^{A/V}$

iv) Small-signal equivalent circuit:



Shortening c_2 to GND to calculate G_m of equi. circuit: Based on the slide,

$$G_m \approx g_{m_1} = g_m = 0.04^{A/V}$$

Connect a test source v_x to the circuit (with R_L)

$$\Rightarrow R_o \approx [(g_{m_2} r_{o_2})(r_{o_1} // r_{\pi_2})] // R_L$$

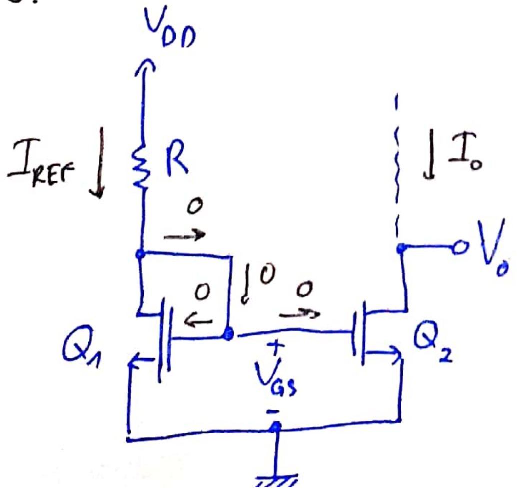
$$= [(0.04 \times 50^k)(50^k // 2.5^k)] // (200^k)$$

$$\approx 192^{k\Omega}$$

$$A_V = -G_m R_o = -0.04 \times 192^k \approx -7680$$

Question 6.

a)



i) $R = \frac{V_{DD} - V_{DS1}}{I_{REF}} = \frac{V_{DD} - V_{GS}}{I_{REF}} = \frac{3.3 - 1.2}{120^{\mu}} \approx 17.5^{k\Omega}$

ii) $I_{D_1} = \frac{1}{2} k_n' \left(\frac{W}{L}\right)_1 (V_{GS} - V_{t1})^2$

$\Leftrightarrow 120^{\mu} = \frac{1}{2} \times 200^{\mu} \left(\frac{W}{L}\right)_1 (1.2 - 0.8)^2$

$\Leftrightarrow \left(\frac{W}{L}\right)_1 \approx 7.5$

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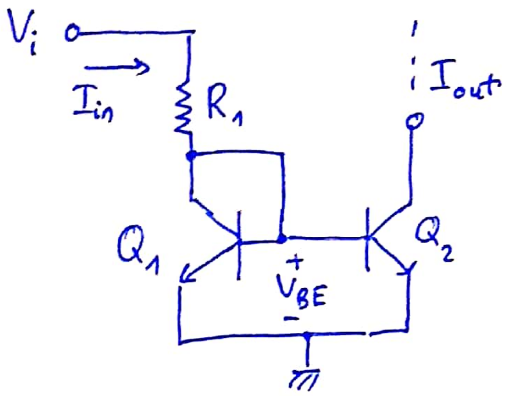
Question 6 (cont)

iii) $\frac{I_o}{I_{REF}} = \frac{(W/L)_2}{(W/L)_1} \Leftrightarrow \frac{100}{120} = \frac{(W/L)_2}{7.5} \Rightarrow (W/L)_2 = 6.25$

b)



i) $I_{IN} = \frac{V_i - V_{BE}}{R_1} \Leftrightarrow R_1 = \frac{5^V - 0.7^V}{2^{mA}} = 2.15^{k\Omega}$

ii) $\frac{I_o}{I_{REF}} = \frac{1}{1 + \frac{2}{\beta}} \Leftrightarrow I_o \simeq I_{REF} = I_{in} = 2^{mA}$

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