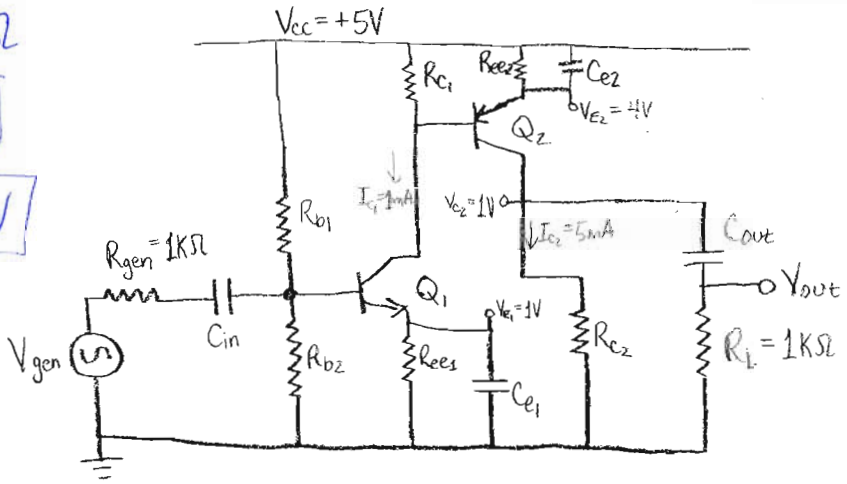
ECE 137A
Winter '07 - HW#5

(1) $\beta = 50$, $V_A = 50V$, $V_{cc} = +5V$, $R_{gen} = 1K\Omega$, $R_L = 1K\Omega$,

$I_{c_1} = 1mA$, $I_{c_2} = 5mA$, $V_{E_2} = 4V$, $V_{c_2} = 1V$, $V_{E_1} = 1V$,

$R_{b_1} \| R_{b_2} = 10K\Omega$



$*V_{b_1} = V_{E_1} + V_{BE} \approx 1.7V$

$*V_{b_2} = V_{c_1} = V_{E_2} - V_{BE} = 3.3V$

a) Find $R_{b_1}, R_{b_2}, R_{c_1}, R_{c_2}, R_{ee_1}, \& R_{ee_2}$?

$\Rightarrow$ Assume that I_B is negligible... So, $V_{b_1} = \frac{R_{b_2}}{R_{b_1} + R_{b_2}} \cdot V_{cc}$ & $\frac{R_{b_1} \cdot R_{b_2}}{R_{b_1} + R_{b_2}} = 10K\Omega$

Solving Equations gives $R_{b_1} = 29.412\,K\Omega$ & $R_{b_2} = 15.152\,K\Omega$

$\rightarrow R_{ee_1} = \frac{V_{E_1}}{I_E} = \frac{1V}{1.02mA} = 980\Omega$

$R_{c_1} = \frac{V_{cc} - V_{c_1}}{I_{c_1} - I_{b_2}} = \frac{5V - 3.3V}{1mA - 0.1mA} = 1889\Omega$

$\rightarrow R_{c_2} = \frac{V_{c_2}}{I_{c_2}} = \frac{1V}{5mA} = 200\Omega$

$R_{ee_2} = \frac{V_{cc} - V_{E_2}}{I_{E_2}} = \frac{5V - 4V}{5.1mA} = 196\Omega$

b) $g_{m_2} = \frac{I_{c_2}}{V_{th}} \approx 0.193\ S$,

$R_{CE_2} = \frac{V_{EC_2} + V_A}{I_{c_2}} = \frac{3V + 50V}{5mA} = 10.6\,K\Omega$

$\frac{V_{c_2}}{V_{b_2}} = g_{m_2} \cdot \left(R_{CE_2} \| R_{c_2} \| R_L\right) = 31.67\ \frac{V}{V}$

$R_{in_2} = (\beta + 1) \cdot r_e \approx 259\Omega$ (264 Ω o.k. also)

c) $R_{CE_1} \approx \infty$ & $g_{m_1} = \frac{I_{c_1}}{V_{th}} = \frac{1mA}{V_{th}} \approx 0.0387\ S$ $\Rightarrow$ $\frac{V_{c_1}}{V_{b_1}} = -g_m \cdot \left(R_{c_1} \| R_{in_2}\right) \approx -8.81\ \frac{V}{V}$

$R_{in,Q_1} = (\beta + 1) \cdot r_e \approx 51 \cdot \frac{V_{th}}{I_{E_1}} \approx 1.293\,K\Omega$

$R_{in_1} = R_{b_1} \| R_{b_2} \| R_{in,Q_1} = 1.145\,K\Omega$

(1) con'd

d) $V_{in} = \frac{R_{in_1}}{R_{in_1} + R_{gen}} \cdot V_{gen} \Rightarrow \boxed{\frac{V_{in}}{V_{gen}} = \frac{R_{in_1}}{R_{in_1} + R_{gen}} \approx 0.534}$

$\rightarrow \frac{V_{out}}{V_{in}} = \frac{V_{c_2}}{V_{b_2}} \cdot \frac{V_{c_1}}{V_{b_1}} = 31.67 \frac{V}{V} \cdot -8.81 \frac{V}{V} \approx \boxed{-279 \frac{V}{V}}$

$\rightarrow \frac{V_{out}}{V_{gen}} = \frac{V_{out}}{V_{in}} \cdot \frac{V_{in}}{V_{gen}} = -279 \frac{V}{V} \cdot 0.534 \approx \boxed{-149 \frac{V}{V}}$

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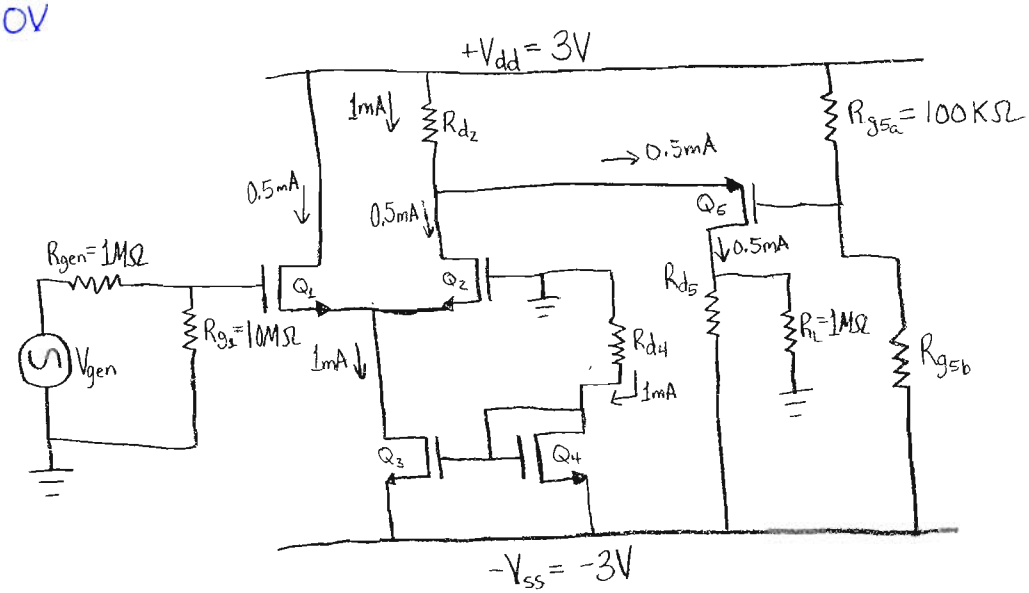
(2) $V_{dd} = -V_{ss} = 3V$, $V_t = \pm 0.3V$, $\lambda = 0$, $R_{g_1} = 10M\Omega$, $R_L = 1M\Omega$, $R_{g_{5a}} = 100K\Omega$, $R_{gen} = 1M\Omega$, $V_{sat} \cdot C_{ox} = 0.25 mA/V{\cdot}\mu m$, $W_g = 4\mu m$ for $Q_1 - Q_4$, $W_{g_5} = 8\mu m$, $I_{D_1} = I_{D_2} = I_{D_5} = 0.5mA$, $V_{s_5} = 2V$, $V_{D_5} = 0V$



a) Find $R_{d_2}, R_{d_4}, R_{d_5}$, & $R_{g_{5_b}}$

$V_{gs} = \frac{I_D}{V_{sat} \cdot C_{ox} \cdot W_g} + V_t \Rightarrow V_{gs_3} = V_{gs_4} = 1.3V \Rightarrow V_{D_4} = -V_{ss} + V_{gs_3} = -1.7V$

$\boxed{R_{d_4} = \frac{0 + 1.7V}{1mA} \approx 1700\Omega}$ $\boxed{R_{d_2} = \frac{+V_{DD} - V_{s_5}}{1mA} = 1K\Omega}$ $\boxed{R_{d_5} = \frac{V_{D_5} + V_{ss}}{0.5mA} = 6K\Omega}$

$V_{g_5} = V_{s_5} + V_{gs_5} = 2V - 0.55V = 1.45V$

So... $\frac{+V_{dd} - V_{g_5}}{R_{g_{5a}}} = \frac{V_{g_5} + V_{ss}}{R_{g_{5b}}} \Rightarrow \boxed{R_{g_{5_b}} \approx 287.097 K\Omega}$

(2) con'd

b) $Q_1 \Rightarrow \boxed{I_{D_1} = 0.5mA,\ V_{D_1} = +V_{dd} = 3V,}$

$\rightarrow V_{S_1} = V_{S_2} = -V_{gs_2}$ & $V_{gs_2} = \frac{I_{D_2}}{V_{sat} \cdot C_{ox} \cdot W_g} + V_t = 0.8V \Rightarrow \boxed{V_{S_1} = -0.8V}$

$\boxed{V_{g_1} = V_{g_2} = 0V}$ (for same current)

$Q_2 \Rightarrow \boxed{I_{D_2} = 0.5mA,\ V_{D_2} = V_{S5} = 2V,\ V_{g_2} = 0V,\ V_{S_2} = V_{S_1} = -0.8V}$

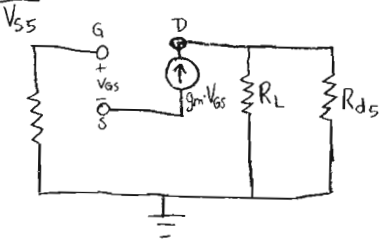
$Q_3 \Rightarrow \boxed{I_{D_3} = I_{D_1} + I_{D_2} = 1mA,\ V_{D_3} = V_{S_1} = V_{S_2} = -0.8V,\ V_{g_3} = -I_{D_4} \cdot R_{d_4} = -1.7V,\ V_{S_3} = -V_{SS} = -3V}$

$Q_4 \Rightarrow \boxed{I_{D_4} = I_{D_3} = 1mA,\ V_{D_4} = V_{g_3} = V_{g_4} = -1.7V,\ V_{S_4} = -V_{SS} = -3V}$

$Q_5 \Rightarrow \boxed{I_{D_5} = 0.5mA,\ V_{D_5} = 0V,\ V_{g_5} = V_{gs_5} + V_{S_5} = 1.45V,\ V_{S_5} = 2V}$

c) $R_{in_5} = \frac{1}{g_{m_5}} \| R_{d_2} = \frac{1}{0.25\frac{mA}{\mu m V} \cdot 8\mu m} \| 1K\Omega \approx \boxed{333\,\Omega}$

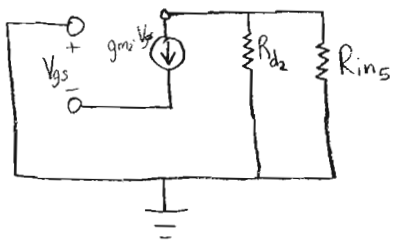
Find $\frac{V_{D5}}{V_{S5}}$



$V_{d_5} = g_{m_5} \cdot V_{gs_5} \cdot (R_L \| R_{d_5})$ & $V_{ds_5} = -V_{gs_5}$

$\Rightarrow \frac{V_{d_5}}{V_{S5}} = -g_{m_5}(R_L \| R_{d_5}) \approx \boxed{-11.93\ \frac{V}{V}}$

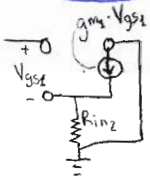
d) $R_{in_2} = \frac{1}{g_{m_2}} = \frac{1}{0.25\,mA/V{\cdot}\mu m \cdot 4\mu m} \approx \boxed{1K\Omega}$



$V_{d_2} = -g_{m_2} \cdot V_{gs_2} \cdot (R_{d_2} \| R_{in_5})$ & $V_{S_2} = -V_{gs_2}$

$\Rightarrow \frac{V_{d_2}}{V_{S2}} = g_{m_2} \cdot (R_{d_2} \| R_{in_5}) \approx \boxed{0.25\ \frac{V}{V}}$

e) $\boxed{R_{in_1} = \infty}$ $g_{m_1} = g_{m_2}$ & $V_{S_1} = g_{m_1} \cdot V_{gs_1} \cdot R_{in_2} = g_{m_1} \cdot R_{in_2} \cdot (V_{g_1} - V_{S_1}) = \frac{g_{m_1} \cdot R_{in_2} \cdot V_{g_1}}{1 + g_{m_1} \cdot R_{in_2}}$



$\Rightarrow \frac{V_{S_1}}{V_{g_1}} = \frac{g_{m_1} \cdot R_{in_2}}{1 + g_{m_1} \cdot R_{in_2}} = \frac{R_{in_2}}{\frac{1}{g_{m_1}} + R_{in_2}} \approx \boxed{0.5\ \frac{V}{V}}$

(2) con'd

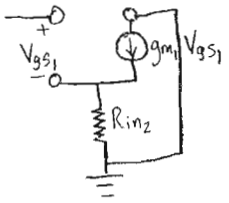
f) Find $\frac{V_{in}}{V_{gen}}$, $\frac{V_{out}}{V_{in}}$, $\frac{V_{out}}{V_{gen}}$ ... ?

$$\rightarrow V_{in} = \frac{R_{g1}}{R_{g1}+R_{gen}} \cdot V_{gen} \Rightarrow \frac{V_{in}}{V_{gen}} = \frac{R_{g1}}{R_{g1}+R_{gen}} \approx \boxed{0.909\ \frac{V}{V}}$$

$$\rightarrow \frac{V_{out}}{V_{in}} = \frac{V_{ds5}}{V_{s5}} \cdot \frac{V_{d2}}{V_{s2}} \cdot \frac{V_{s1}}{V_{g1}} \approx \boxed{-1.49\ \frac{V}{V}}$$

$$\rightarrow \frac{V_{out}}{V_{gen}} = \frac{V_{in}}{V_{gen}} \cdot \frac{V_{out}}{V_{in}} \approx \boxed{-1.36\ \frac{V}{V}}$$

g) Find max signal swing of amp. ... ?



- Clipping for Q_1:

$\Delta V_{out}\downarrow_{max}$ occurs when $I_D = 0mA$

$\Delta V_{out}\downarrow_{max} = I_{DQ} \cdot R_{in_2} = 0.5mA \cdot 1K\Omega = \underline{0.5V}$

$\Delta V_{out}\uparrow_{max}$ occurs when $V_{dg} = -V_t = -0.3V$, $V_{dg_Q} = 3V - 0V = 3V$

& $V_{ds} = V_{dg} + V_{gs} \Rightarrow V_{ds} = V_{dg} + V_g - V_s \Rightarrow V_g = V_d - V_{dg}$

$\Delta V_{out}\downarrow_{max} = (V_d - V_{dg_Q} - V_{gs}) - (V_d - V_{dg} - V_{gs}) = V_{dg} - V_{dg_Q} = -0.3V - 3V = \underline{-3.3V}$

Q_1 is limited by current...

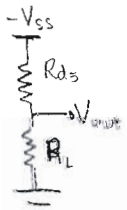
- Clipping for Q_2: when $I_D = 0mA \rightarrow \Delta V_{out}\downarrow_{max} = \Delta I_D \cdot (R_{in_5} \| R_{d_2}) = \underline{0.125V}$

when $V_{dg} = -V_t$, $V_{ds} = V_{dg} + V_{gs} = -0.3V + 0.8V = 0.5V$

$\Delta V_{out}\uparrow_{max} = V_{ds_Q} - V_{ds} = 2.8V - 0.5V = \underline{2.3V} \Rightarrow$ Current is the limiting factor

Now $\Delta V_{out}\downarrow_{max_1} \cdot \frac{V_{D2}}{V_{S2}} = 0.5V \cdot 0.25 = \underline{0.125V} \Rightarrow Q_1$ is limiting up to this point

- Clipping for Q_5: when $I_D = 0mA$, $V_{out} = \frac{-3V \cdot R_L}{R_{ds} + R_L} \approx \underline{-2.98V}$, $V_{out_Q} = 0V$



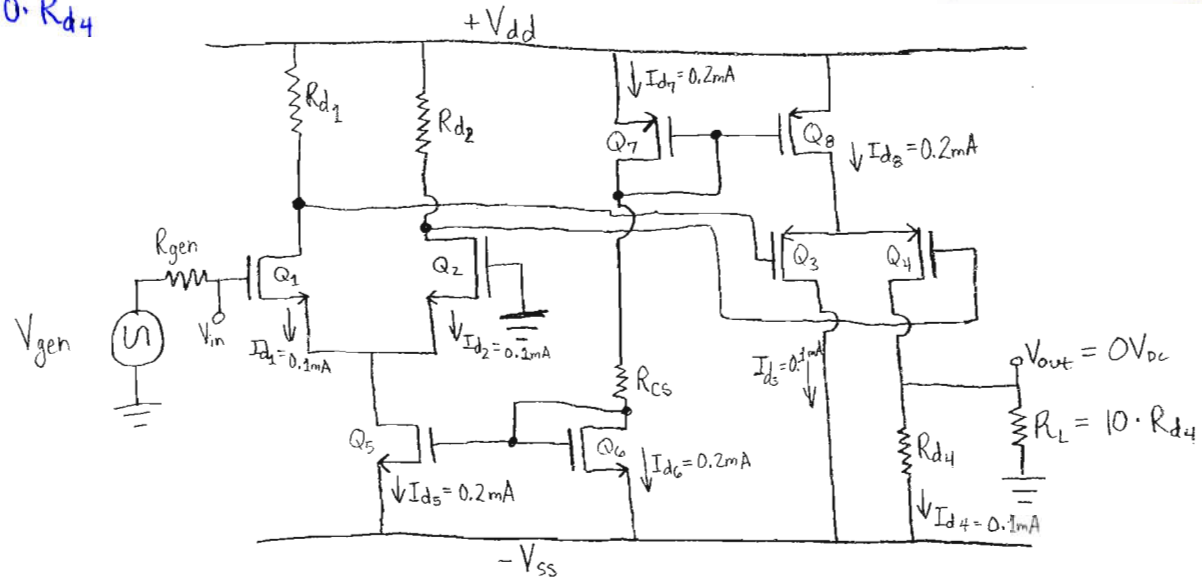
$\Delta V_{out}\downarrow_{max} = -2.98V$ (Current limiting)

$\Delta V_{out}\downarrow_{max} = V_{dg_Q} - V_t = -1.45V - 0.3V = \underline{-1.75V}$

$\Rightarrow \Delta V_{out}\downarrow_{max} \cdot \frac{V_{DS}}{V_{SS}} = 0.125V \cdot -11.93 \approx -1.49V$

$\Rightarrow \boxed{V_{out\,max} = -1.49V \cdot 2 = 2.98\ V_{p\text{-}p}}$ Q_1 limits the output voltage swing

(3) $V_{dd} = V_{ss} = 1.5V$, $V_t = \pm 0.3V$, $V_{sat} \cdot C_{ox} = 0.5mA/\mu m \cdot V$, $W_g = 2\mu m$, $\lambda = 0$, $I_{D_6} = 0.2mA$, $V_{D_1} = V_{D_2} = +0.5V$, $V_{out} = 0\ V_{DC}$, $R_L = 10 \cdot R_{d_4}$



a) $I_{d_6} = V_{sat} \cdot C_{ox} \cdot W_g \cdot (V_{gs_6} - V_t) \Rightarrow V_{gs_6} \approx 0.5V$

& $I_{d_6} = I_{d_7} = V_{sat} \cdot C_{ox} \cdot W_g \cdot (-V_{gs_7} + V_t) \Rightarrow V_{gs_7} \approx -0.5V$

$$R_{CS} = \frac{V_{dd} + V_{gs_7} - V_{gs_6} + V_{ss}}{I_{D_6}} = \frac{1.5V - 0.5V - 0.5V + 1.5V}{0.2mA} = \boxed{10\ K\Omega}$$

$$R_{d_4} = \frac{V_{out} + V_{ss}}{I_{d_4}} = \frac{0 + 1.5V}{0.1mA} = \boxed{15K\Omega} \Rightarrow \boxed{R_L = 150\ K\Omega}$$

$$R_{d_1} = \frac{V_{dd} - V_{d_1}}{I_{d_1}} = \frac{1.5V - 0.5V}{0.1mA} = \boxed{10K\Omega} \qquad \boxed{R_{d_2} = R_{d_1} = 10K\Omega}$$

b) $Q_1 \Rightarrow \boxed{I_{d_1} = 0.1mA,\ V_{d_1} = 0.5V,\ V_{gs} = 0.4V \text{ \& } V_g = 0V \Rightarrow V_s = -0.4V}$

$Q_2 \Rightarrow \boxed{I_{d_2} = 0.1mA,\ V_{D_2} = 0.5V,\ V_{g_2} = 0V,\ V_{s_2} = -0.4V}$

$Q_3 \Rightarrow \boxed{I_{d_3} = 0.1mA,\ V_{d_3} = -1.5V,\ V_{g_3} = V_{d_1} = 0.5V,\ V_{gs_3} = -0.4V \Rightarrow V_{s_3} = -V_{gs_3} + V_{g_3} = 0.9V}$

$Q_4 \Rightarrow \boxed{I_{d_4} = 0.1mA,\ V_{d_4} = 0V,\ V_{g_4} = V_{d_2} = 0.5V,\ V_{s_4} = V_{s_3} = 0.9V}$

$Q_5 \Rightarrow \boxed{I_{d_5} = 0.2mA,\ V_{d_5} = V_{s_1} = -0.4V,\ V_{g_5} = V_{g_6} = V_{gs_6} - V_{ss} = 0.5V - 1.5V = -1V,\ V_{s_5} = -V_{ss} = -1.5V}$

$Q_6 \Rightarrow \boxed{I_{d_6} = 0.2mA,\ V_{d_6} = V_{g_6} = -1V,\ V_{s_6} = -V_{ss} = -1.5V}$

(3) con'd... b) con'd...

$Q_7 \Rightarrow$ $I_{d_7} = 0.2mA,\ V_{d_7} = V_{g_7} = V_{gs_7} + V_{dd} = +1V,\ V_{s_7} = V_{dd} = 1.5V$

$Q_8 \Rightarrow$ $I_{d_8} = 0.2mA,\ V_{d_8} = V_{s_8} = 0.9V,\ V_{g_8} = V_{g_7} = 1V,\ V_{s_8} = V_{dd} = 1.5V$

c) Find A_v of $\frac{Q_3}{Q_4}$ ...? $\rightarrow A_v = \frac{g_m \cdot R_{Leq}}{2}$ & $R_{Leq} = R_{d_4} \| R_L \approx 13.636K\Omega$

$\Rightarrow A_v = \frac{1mS \cdot 13.636K\Omega}{2} \approx \boxed{6.\overline{81}}$

d) Find A_v of $\frac{Q_1}{Q_2}$ ...? $A_v = \frac{g_m \cdot R_{d_1}}{2} + \frac{g_m \cdot R_{d_2}}{2} \approx \boxed{10}$

e) Find $\frac{V_{in}}{V_{gen}}$, $\frac{V_{out}}{V_{in}}$, & $\frac{V_{out}}{V_{gen}}$ ...?

$\frac{V_{in}}{V_{gen}} = 1 \frac{V}{V}$

$\frac{V_{out}}{V_{in}} = A_{V_{1,2}} \cdot A_{V_{3,4}} = 68.\overline{18} \frac{V}{V}$

$\frac{V_{out}}{V_{gen}} = 68.18 \frac{V}{V}$