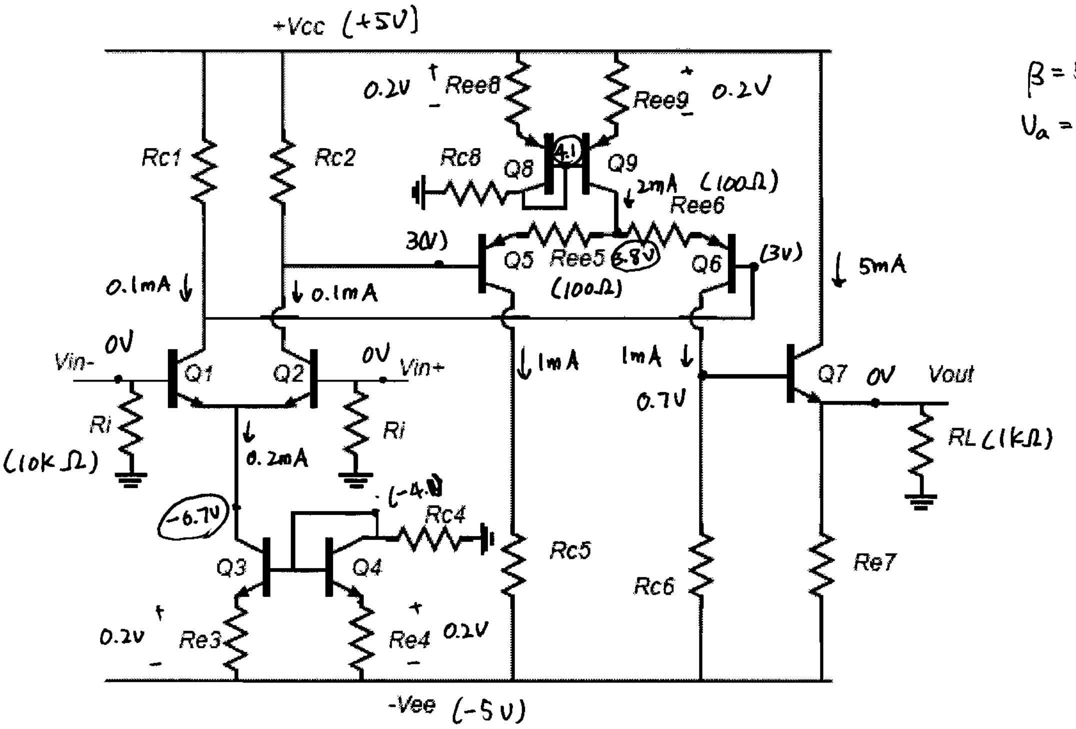
ECE 137A (W07)

HW #6 solutions

1.

$\beta = 500$

$V_a = 100$



a) all resistor value

$R_{e7} = \frac{5}{5mA} = \boxed{1k\Omega}$ // $R_{c6} = \frac{5.7}{I_{c6} - \underbrace{\cancel{I_{B7}}}_{small}} = \boxed{5.7k\Omega}$ // $R_{c5} = R_{c6} = \boxed{5.7k\Omega}$
(symmetric differential amp)

$R_{ee9} = \frac{0.2}{2mA} = \boxed{100\Omega}$ // Let $I_{Rc8} = I_{Rc9} = 2mA$
$R_{c8} = \frac{4.1}{2mA} = \boxed{2.05k\Omega}$ // $R_{EE8} = \frac{0.2V}{\underbrace{I_{Rc8}}_{2mA} - \underbrace{\cancel{I_{b9}}}_{small}} = \boxed{100\Omega}$

$R_{c2} = \frac{5-3}{0.1mA} = \boxed{20k\Omega}$ // $R_{c1} = R_{c2} = \boxed{20k\Omega}$

$R_{E3} = \frac{0.2}{0.2mA} = \boxed{1k\Omega}$ // Let $I_{Re4} = I_{E3}$
$R_{E4} = R_{E3} = \boxed{1k\Omega}$ // Let $I_{Rc4} = I_{c3}$
$R_{c4} = \frac{4.1}{0.2mA} = \boxed{20.5k\Omega}$

stage 3 : emitter follower.

$$A_{U3} = \frac{R_{Leq}}{\underbrace{R_{Leq}}_{(1K/\!/1K)} + \underbrace{r_e}_{\frac{26}{5}}} = \boxed{0.99}$$

$$R_{in\,7} = (\beta+1)(R_{Leq} + r_e) = \boxed{253.1\ (k\Omega)}$$

Stage 2 : Diff. Amp.

$$A_{v2} = \frac{(\overbrace{R_{C6}}^{5.7k\Omega} /\!/ \overbrace{R_{in\,7}}^{253.1k\Omega})}{2(\underbrace{R_{ee6}}_{100\Omega} + \underbrace{r_e}_{\frac{26mV}{1mA}})} = \frac{5.6k\Omega}{252} = \boxed{22.2}$$

$$R_{in,diff2} = (\beta+1)\,2\,(r_e + R_{ee5}) = \boxed{126k\Omega}$$

common mode.

$$A_{cm2} = \frac{\overbrace{(R_{C6} /\!/ R_{in7})}^{5.6k}}{\underbrace{r_e + R_{ee6}}_{126} + 2R_{out9}} = \boxed{0.013}$$

where $R_{out9} = \dfrac{(\overset{100}{V_A} + \overset{1}{V_{CE}})}{\underset{2mA}{I_C}}\left[1 + \dfrac{\overset{100}{R_{EE9}}}{\underset{\frac{26}{2}}{r_e}}\right] = \boxed{439\ k\Omega}$

$$R_{in2,cm} = (\beta+1)(r_e + R_{ee6} + R_{out9})$$
$$= \boxed{219\ M\Omega}$$

Stage 1. : Diff. Amp.

$$A_{v1} = \frac{(R_{C1} /\!/ R_{in,diff2})}{2 \cdot r_e} = \frac{17.3k\Omega}{2 \cdot 260} = \boxed{33.27}$$

$$A_{cm1} = \frac{(\overset{(20k\Omega)}{R_{C1}} /\!/ \overset{219M}{R_{in,cm2}})}{\cancel{r_e} + 2R_{out3}} \simeq \frac{R_{C1}}{2R_{out3}} = 2\times10^{-3}$$

where $R_{out3} = \dfrac{(\overset{100}{V_A} + \overset{4.8-0.7=4.1}{V_{CE}})}{\underset{0.2mA}{I_C}}\left[1 + \dfrac{\overset{1k\Omega}{R_{e3}}}{\underset{130}{r_e}}\right] = \boxed{4.5\ M\Omega}$

Thus,

$$A_{diff} = A_{v1} \cdot A_{v2} \cdot A_{v3} = (33.27)(22.2)(0.99) = 731.2$$

$$A_{cm} = A_{cm1} \cdot A_{cm2} \cdot A_{v3} = (2 \cdot 10^{-3})(0.013)(0.99) = 2.6 \times 10^{-5}$$

$$CMRR = \frac{A_{diff}}{A_{cm}} = \frac{731.2}{2.6 \times 10^{-5}} = 2.8 \times 10^{7} = \boxed{149.1\ dB}$$

Finally

$$R_{out,amp} = R_{in,emitter7} \,//\, R_{e7}.$$

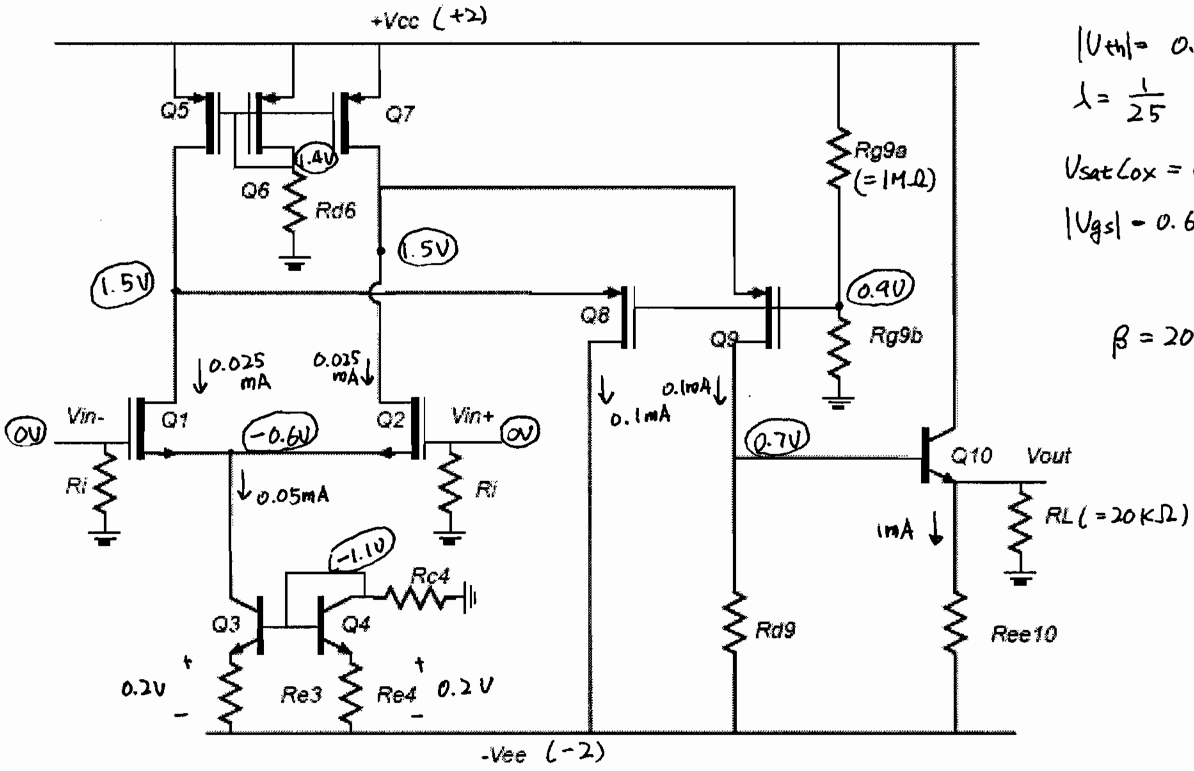
$$R_{in,emitter7} = \left(r_e + \frac{R_{B7}}{\beta+1} \right) = \overset{\frac{26}{5}}{r_e} + \frac{\overset{5.7\,k\Omega}{R_{c6} // R_{out6}}}{\beta+1}$$

$$\text{where} \quad R_{out6} = \frac{V_A + \overset{3}{V_{CE}}}{\underset{1mA}{I_c}} \left(1 + \frac{\overset{100}{R_{ee6}}}{\underset{\frac{26m}{1m}}{r_e}} \right) = 500\,k\Omega$$

$$\therefore \ R_{in,emitter7} = 11\,\Omega$$

$$\therefore \ R_{out,amp} = R_{in\ emitter7} \,//\, R_{e7} = \boxed{10.9\,\Omega}$$

prob 2.



$|V_{th}| = 0.3$

$\lambda = \frac{1}{25}$

$V_{sat} C_{ox} = 0.5$

$|V_{gs}| = 0.6$

$\beta = 200$

FET width

for Q_1, Q_2 (n-channel)

$$I_D = (V_{sat} \cdot C_{ox}) \cdot W_g (V_{gs} - V_{th}) (1 + \lambda V_{DS}) \Rightarrow W_g = \frac{\overset{0.025mA}{I_D}}{(V_{sat} \cdot C_{ox})(0.3)(1 + \frac{1}{25} 2.1)}$$

$$W_{g1} = W_{g2} = \boxed{0.15 \mu m}$$

for Q_5, Q_6, Q_7, Q_8, Q_9 (p-channel)

$$I_D = (V_{sat} \cdot C_{ox}) W_g (-(\underset{-0.6}{V_{gs}} - \underset{-0.3}{V_{th}}))(1 + \lambda V_{SD}) \Rightarrow W_g = \frac{I_D}{0.5(0.3)(1 + \lambda V_{SD})}$$

$$W_{g5} = W_{g7} \Big|_{\substack{I_D = 0.025mA \\ V_{SD} = 0.5V}} = \boxed{0.163 \mu m}$$

$$W_{g6} \Big|_{\substack{I_D = 0.025mA \\ V_{SD} = 0.6}} = \boxed{0.163 \mu m}$$

$$W_{g8} \Big|_{\substack{I_D = 0.1mA \\ V_{SD} = 3.5V}} = \boxed{0.585 \mu m}$$

$$W_{g9} \Big|_{\substack{I_D = 0.1mA \\ V_{SD} = 0.8V}} = \boxed{0.646 \mu m}$$

Resister Value.

$$R_{d9} = \frac{2.7\,V}{0.1\,mA} = \boxed{27\,K\Omega} \quad , \quad R_{ee10} = \frac{2}{1mA} = \boxed{2K\Omega}$$

$$2 \cdot \frac{R_{g9b}}{R_{g9b} + R_{g9a}} = 0.9\,(V) \Rightarrow R_{g9b} = \boxed{818.2\,K\Omega}$$

$$R_{d6} = \frac{1.4}{0.025mV} = \boxed{56\,K\Omega}$$

$$R_{e3} = \frac{0.2}{0.05mA} = \boxed{4\,K\Omega} = R_{e4}. \quad , \quad R_{c4} = \frac{1.1\,(V)}{0.05mA} = \boxed{22\,K\Omega}$$

(b) small signal analysis.

Q10 :

$$A_{v10} = \frac{\overbrace{R_{ee10} /\!/ R_L}^{1.82K}}{R_{ee10} /\!/ R_L + \underbrace{r_e}_{26}} = \boxed{0.99.}$$

$$R_{in10} = (\beta+1)\,(r_e + R_{ee10} /\!/ R_L) = \boxed{370.6\,K\Omega}$$

Q9 :

$$A_{v9} = \underbrace{g_m}_{0.323} \,(R_{d9} /\!/ R_{in10}) = \boxed{8.13}$$

$$R_{in9} = 1/g_m = \boxed{3.1\,K\Omega}$$

Q2, Q1 : Diff. stage.

$$A_{D1} = \frac{\overbrace{R_{out7}}^{huge.} /\!/ R_{in9}}{2} \cdot \underbrace{g_m}_{0.075} = \boxed{0.11}$$

$$R_{in,D} = \infty$$

$$A_{CM1} = \frac{\overbrace{R_{out7} /\!/ R_{in9} /\!/ R_{out\,drain2}}^{huge}}{1/\underbrace{g_m}_{0.075} + 2\,R_{out3}} \simeq \frac{R_{in9}}{1/g_m + 2R_{out3}} = \boxed{7.2 \times 10^{-3}}$$

where

$$R_{out3} = \frac{(\overbrace{V_A + V_{CE}}^{1.2V})}{\underbrace{I_{c3}}_{0.05}} \left(1 + \frac{\overbrace{R_{e3}}^{4K\Omega}}{\underbrace{g_{m3}}_{\frac{26}{0.05} = 520}}\right) = 208K\Omega$$

(c) output impedance.

$$R_{out\,amp} = R_{ee10} \,//\, R_{in,emitter10}$$

where $R_{in,emitter10} = r_e + \frac{R_{d9} \,//\, R_{out,drain9}}{\beta+1}$ (26, 27k)

where $R_{out,Drain9} = \frac{[1/\lambda + V_{DS}]}{I_D}\left(1 + g_m(R_{inD7} \,//\, R_{inD2})\right)$

$\cdots \doteq$ large. (huge)

$\therefore R_{in,emit10} = 26 + \frac{27K}{201} = \boxed{39.4\Omega}$

$\therefore R_{out\,amp} = 39.4\Omega \,//\, 2k = \boxed{38.6\Omega}$

(d) Signal Swing

Q10) $\Delta V_{CE} = V_{CE} - V_{sat} = 2 - 0.5 = 1.5(V) \uparrow$ (sat)

$\Delta V_{cutoff} = 1mA\,(2k//20k) = 1.82 \downarrow$ (cutoff)

Q9) $V_{sat\ (knee)} = V_G + |V_{th}| = 0.9 + 0.6 = 1.5(V)$

$\therefore \Delta V_D = 1.5 - 0.7 = 0.8(V) \uparrow$

$\Delta V_{out}\downarrow = 0.1mA\,(\underset{27k}{R_{d9}} \,//\, \underset{370k}{R_{in10}}) = -2.51(V) \downarrow$

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pinchoff Q2) biased @ 0.025mA. Decreasing this to zero

will increase I_{s9} by $0.025mA \times \frac{R_{inD7}}{\underset{huge}{R_{inD7}} + R_{in9}} \doteq 0.025.$

This will increase output voltage (V_{B10}) by $0.025mA \times R_{d9} = 0.68(V)\uparrow$

pinchoff Q1) biased @ 0.025mA.

Decreasing this to zero will increase the current in Q2 by 0.025mA

which will decrease the current in Q9 by $0.025mA \cdot \frac{R_{inD5}}{R_{inD5} + R_{in9}} \simeq 0.025mA$

which will decrease the output voltage (V_{B10})

$= -0.68(V) \downarrow$

$\therefore$ Overall : $\boxed{\pm 0.68(V)}$