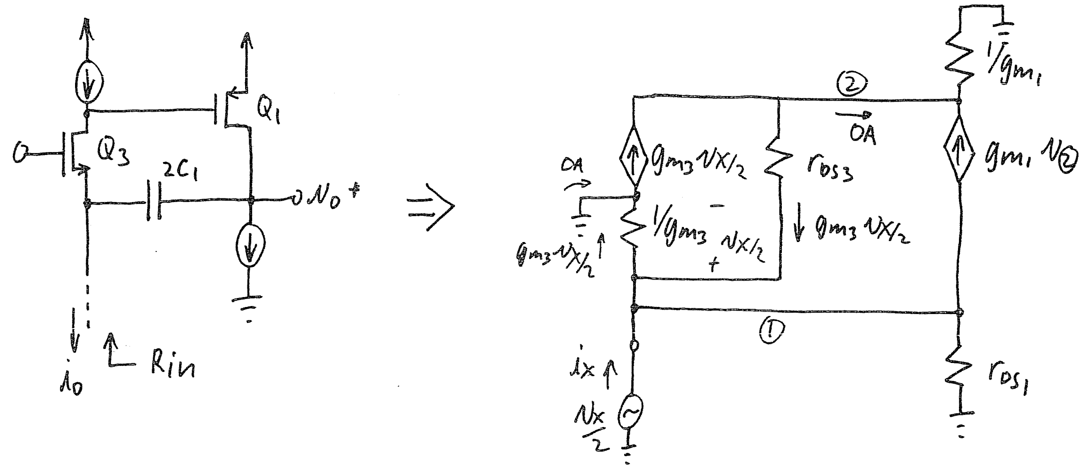
Chapter 15 – Problems

15.1) Show $R_{in} \approx 2/(g_{m3}^2 r_{DS})$

$\because$ circuit is perfectly symmetric, we only need to look at one half.



(capacitor $2C_1$ is modelled as a short circuit)

KCL①: $\quad i_x - \cancel{g_{m3}\frac{v_x}{2}} + \cancel{g_{m3}\frac{v_x}{2}} - g_{m1} v_② - \frac{v_x/2}{r_{DS1}} = 0 \quad \boxed{1}$

But $\quad v_② = \frac{v_x}{2} + g_{m3}\frac{v_x}{2} r_{DS3} \quad \boxed{2}$

$\boxed{2} \rightarrow \boxed{1}$ $\quad i_x - g_{m1}\left(\frac{v_x}{2} + g_{m3} r_{DS3}\frac{v_x}{2}\right) - \frac{v_x}{2 r_{DS1}} = 0$

$\therefore \; i_x = \frac{1}{2}\left(g_{m1} + g_{m1} g_{m3} r_{DS3} + \frac{1}{r_{DS1}}\right) v_x$

$\therefore \; R_{in} \triangleq \frac{v_x}{i_x} = \frac{2}{g_{m1}(1 + g_{m3} r_{DS3}) + 1/r_{DS1}} \approx \frac{2}{g_{m1}(1 + g_{m3} r_{DS3})}$

$\approx \frac{2}{g_{m1} g_{m3} r_{DS3}}$

$\therefore \; \underline{R_{in} \approx 2/(g_{m3}^2 r_{OS})}$ $\quad$ Q.E.D.

(<u>Note</u>: g_{m3} is matched to g_{m2})

15.2) $H(s) = \dfrac{k_1 s + k_0}{s + \omega_0}$

$\because$ DC gain $= \dfrac{k_0}{\omega_0} \equiv 10$

$\therefore \quad k_0 = 10\omega_0$

$\because$ no finite zeros

$\therefore \quad k_1 = 0$

$\therefore \quad H(s) = \dfrac{10\omega_0}{s + \omega_0}$

From the design equations found in Figure 15.9 and $\omega_0 = 15\,MHz \times 2\pi = 94.25 \times 10^6$ rads/sec

$C_X = C_A \dfrac{k_1}{1-k_1} = 0$

$C_A \equiv 5pF$

$G_{m1} = k_0 (C_A + C_X) = 10 \times 94.25 \times 10^6 (5 \times 10^{-12})$

$= 4.71\ mA/V$

$G_{m2} = \omega_0 (C_A + C_X) = 94.25 \times 10^6 (5 \times 10^{-12})$

$= 0.47\ mA/V$

15.3) $H(s) = \dfrac{k_0}{s^2 + \frac{\omega_0}{Q} s + \omega_0^2}$ ($k_1 = k_2 = 0$ for low pass)

$H(0) = \dfrac{k_0}{\omega_0^2} \equiv 5 \Rightarrow k_0 = 5\omega_0^2$

$\omega_0 = 2\pi \times 10MHz = 62.8 \times 10^6$ rads/sec

$Q = 1$

Select reasonable values for C_A and C_B

Let $C_A = C_B \equiv 2pF$ ($C_X = 0 \because$ LP filter)

Then $G_{m1} = \omega_0 C_A = 62.8 \times 10^6 \times 2 \times 10^{-12} = 0.13\ mA/V$

$G_{m2} = \omega_0 C_B = 0.13\ mA/V$

$G_{m3} = \dfrac{\omega_0 C_B}{Q} = 0.13\ mA/V$

$G_{m4} = k_0 C_A / \omega_0 = 5\omega_0 C_A = 0.63\ mA/V$

$G_{m5} = 0$

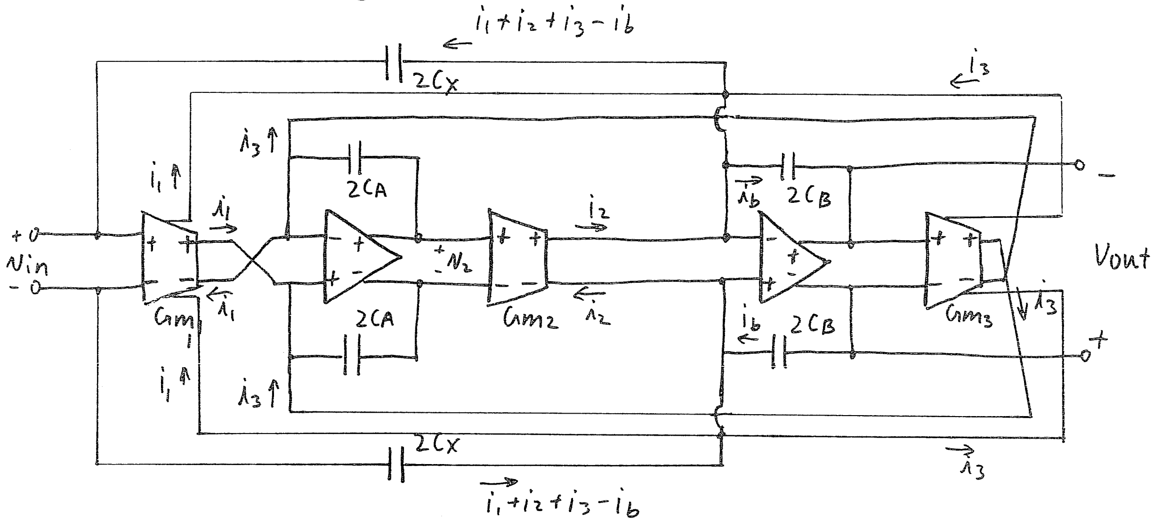
15.4) Derive design equations for Fig. 15.24.

$$i_1 = G_{m1} V_{in} \quad \boxed{1} \qquad i_3 = -G_{m3} V_{out} \quad \boxed{2}$$

$$V_2 = \frac{2(i_1 + i_3)}{2sC_A} = \frac{i_1 + i_3}{sC_A} \quad \boxed{3}$$

$$i_2 = G_{m2} V_2 \quad \boxed{4}$$

$$V_{out} = i_B / sC_B \quad \boxed{5}$$



KVL from V_{in} through $2C_X$ capacitors:

$$V_{in} + \left(\frac{i_1+i_2+i_3-i_b}{2sC_X}\right) \times 2 = 0$$

$$\text{or} \quad i_b = i_1 + i_2 + i_3 + sC_X V_{in} \quad \boxed{6}$$

$\boxed{6} \to \boxed{5}$

$$\therefore V_{out} = \frac{i_b}{sC_B} = \frac{i_1 + i_2 + i_3 + sC_X V_{in}}{sC_B} \quad \boxed{7}$$

$\boxed{1}, \boxed{2}, \boxed{4} \to \boxed{7}$

$$= \frac{G_{m1} V_{in} + G_{m2} V_2 - G_{m3} V_{out} + sC_X V_{in}}{sC_B}$$

$$\therefore sC_B V_{out} = G_{m1} V_{in} + \frac{G_{m2}}{sC_A}\left(G_{m1} V_{in} - G_{m3} V_{out}\right) - G_{m3} V_{out} + sC_X V_{in}$$

$$\left(sC_B + \frac{G_{m2} G_{m3}}{sC_A} + G_{m3}\right) V_{out} = \left(G_{m1} + \frac{G_{m1} G_{m2}}{sC_A} + sC_X\right) V_{in}$$

$$\left(s^2 C_A C_B + G_{m2} G_{m3} + sG_{m3} C_A\right) V_{out} = \left(sG_{m1} C_A + G_{m1} G_{m2} + s^2 C_X C_A\right) V_{in}$$

$$\therefore \frac{V_{out}}{V_{in}} = \frac{C_X C_A s^2 + C_A G_{m1} s + G_{m1} G_{m2}}{C_A C_B s^2 + C_A G_{m3} s + G_{m2} G_{m3}}$$

$$\frac{V_{out}}{V_{in}} = \frac{s^2 \frac{C_X}{C_B} + s\frac{G_{m1}}{C_B} + \frac{G_{m1} G_{m2}}{C_A C_B}}{s^2 + s\frac{G_{m3}}{C_B} + \frac{G_{m2} G_{m3}}{C_A C_B}}$$

[which is similar to Eq (15.24)]

(cont.)

15.4 (cont.)

Equating our result to the generic second-order transfer function

$$H(s) = \frac{V_{out}}{V_{in}} = \frac{k_2 s^2 + k_1 s + k_0}{s^2 + \frac{\omega_0}{Q} s + \omega_0^2}$$

Gives the following design equations:

$$k_2 = \frac{C_X}{C_B} \Rightarrow C_X = k_2 C_B$$

$$k_1 = \frac{G_{m1}}{C_B} \Rightarrow G_{m1} = k_1 C_B$$

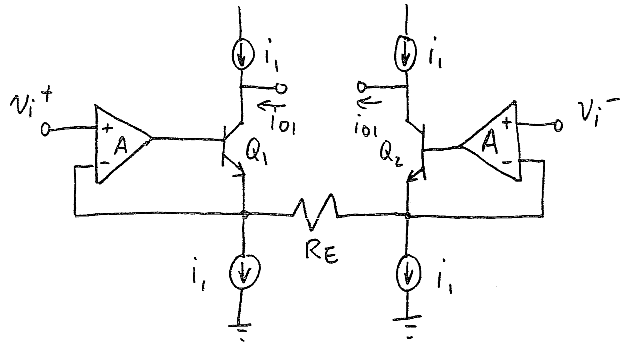
$$k_0 = \frac{G_{m1} G_{m2}}{C_A C_B} \Rightarrow G_{m2} = \frac{k_0 \cancel{C_B} C_A}{k_1 \cancel{C_B}} = \frac{k_0}{k_1} C_A \quad (k_1 \neq 0)$$

$$\omega_0^2 = \frac{G_{m2} G_{m3}}{C_A C_B} \Rightarrow G_{m3} = \frac{C_A C_B}{G_{m2}} \omega_0^2 = \frac{\cancel{C_A} C_B}{\frac{k_0}{k_1} \cancel{C_A}} \omega_0^2 = \frac{k_1}{k_0} C_B \omega_0^2 \quad (k_0 \neq 0)$$

$$\frac{\omega_0}{Q} = \frac{G_{m3}}{C_B} \Rightarrow \frac{\omega_0}{Q} = \frac{\frac{k_1}{k_0} \cancel{C_B} \omega_0^{\cancel{2}}}{\cancel{C_B}}$$

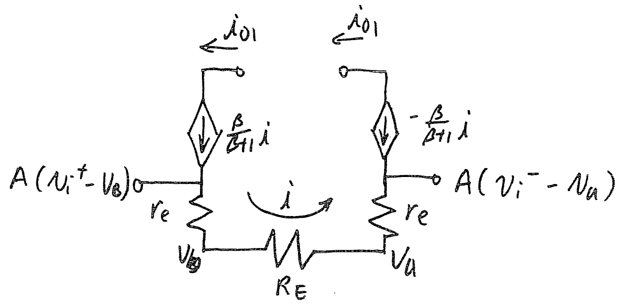
$$\omega_0 Q = \frac{k_0}{k_1}$$

15.5)



Find g_m

Small signal model:



$$i = \frac{A(v_i^+ - V_b - v_i^- + V_a)}{2r_e + R_E}$$

But $V_b - V_a = i R_E$

$$\therefore\ i = \frac{A(V_{id} - i R_E)}{2r_e + R_E} \qquad \text{where } V_{id} \triangleq v_i^+ - v_i^-$$

$$i(2r_e + R_E + A R_E) = A V_{id}$$

$$\therefore\ \frac{V_{id}}{i} = R_E + \frac{2r_e + R_E}{A}$$

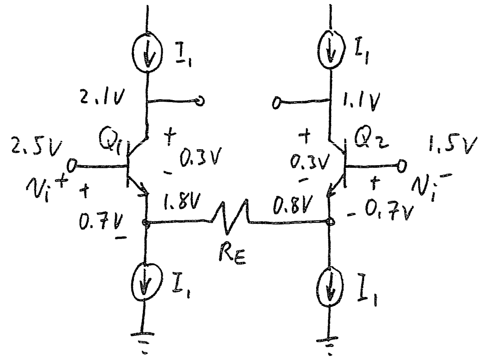
Now $i_{o1} = \frac{\beta}{\beta+1} i$

$$\therefore\ G_m \triangleq \frac{i_{o1}}{v_{id}} = \frac{i_{o1}}{i} \times \frac{i}{v_{id}} = \frac{\beta}{\beta+1} \times \frac{1}{R_E + \left(\frac{2r_e + R_E}{A}\right)}$$

Given β and $A \gg 1$

$$G_m \approx \frac{1}{R_E}$$

15.6) Find minimum collector voltages.



Given $V_i = \pm 1V$ and $V_{cm} = 2V$

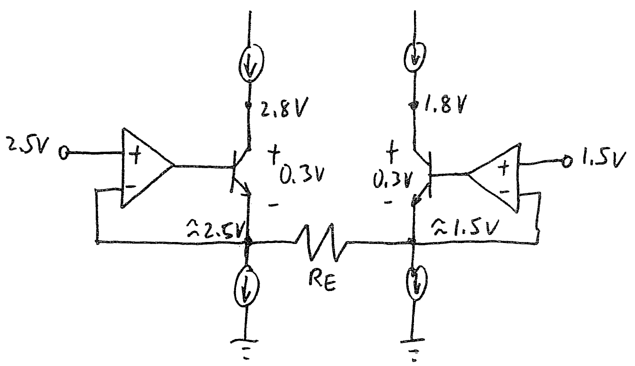
Consider the worse-case scenario where $v_i^+ = 2.5V$ and $v_i^- = 1.5V$

(Assume $V_{CEsat} = 0.3V$)

From the diagram, we need $V_{C1} \geq 2.1V$

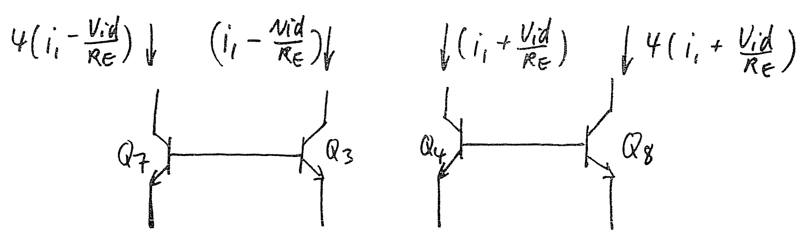
$\therefore$ the minimum collector voltage is 2.1V

For Figure 15.13, we see that $V_{C1} \geq 2.8V$



$\therefore$ the minimum collector voltage is 2.8 V

15.7) Given the base-emitter areas of Q_7 & Q_8 are 4 times larger than those of Q_3 & Q_4, we achieve a simple scaling of currents where



$\therefore i_{o1} = \frac{4V_{id}}{R_E} \Rightarrow G_m = 4/R_E$

15.8) Find I_1 and I_2

Q_1, Q_2, Q_5 and Q_6 have stable bias currents and only Q_3 and Q_4 have currents that vary significantly with the input signal.

$\therefore$ Ensure I_{C3} is within 20% of nominal which is I_1

Now when $V_i = 500\,mV$,

$$I_{C3} = I_1 - \frac{V_i}{R_E} \geq 0.8\, I_1$$

$$\therefore \quad I_1 \geq 5\, V_i/R_E$$

Given

$$G_m = 1/R_E = 1\,mA/V$$

$$R_E = 1\,k\Omega$$

and $\quad I_1 \geq 5 \times 500\,mV/1\,k\Omega$

$\therefore$ $I_1 \geq 2.5\,mA$ which is rather large.

We can reduce this by scaling Q_7 and Q_8 by 4 as in Problem 15.7. In this case,

$$G_m = 4/R_E \equiv 1\,mA/V$$

$$\therefore R_E = 4\,k\Omega$$

and $\quad I_1 \geq 5 \times 500\,mV/4\,k\Omega = 625\,\mu A$

The value of I_2 is not critical but should be small to prevent significant loading of bias current source I_1.

Let $\quad I_2 = 1/4\, I_1 = 156\,\mu A$

15.9) Find % error in output current.

From Eq (15.65),

$$G_m = \frac{8 I_1}{25 V_T} = \frac{8 \times 2mA}{25 \times 26mV} = 24.6\ mA/V$$

$\therefore$ Ideally, $i_o = G_m v_i = 24.6\ mA/V \cdot 0.048V$

$$i_o = 1.182\ mA$$

For the actual output current, i_o

$v_i = V_{be1} - V_{be2}$ where

$$V_{be1} = V_T \ln\left(\frac{I_{C1}}{4I_s}\right)$$

$$V_{be2} = V_T \ln\left(\frac{I_{C2}}{I_s}\right)$$

$$\therefore v_i = V_T \left(\ln\left(\frac{I_{C1}}{4I_s}\right) - \ln\left(\frac{I_{C2}}{I_s}\right)\right) = V_T \ln\left(\frac{I_{C1}}{4I_{C2}}\right)$$

$$\Rightarrow I_{C1} = 4e^{v_i/V_T} \times I_{C2}$$

Now $I_1 = I_{E1} + I_{E2} = \frac{\beta+1}{\beta}(I_{C1} + I_{C2})$

$$= \frac{\beta+1}{\beta}\left(4e^{v_i/V_T} + 1\right) I_{C2}$$

	similarly
$\therefore I_{C2} = \frac{\beta}{\beta+1} \times \frac{I_1}{1+4e^{v_i/V_T}}$	$I_{C3} = \frac{\beta}{\beta+1} \frac{I_1}{1+4e^{-v_i/V_T}}$
and $I_{C1} = \frac{\beta}{\beta+1} \times \frac{I_1}{1+1/4\, e^{-v_i/V_T}}$	$I_{C4} = \frac{\beta}{\beta+1} \frac{I_1}{1+1/4\, e^{-v_i/V_T}}$

$$i_o = -I_1 + I_{C1} + I_{C3} = 2mA\left(-1 + \frac{100}{101}\left(\frac{1}{1+1/4\, e^{-48/26}} + \frac{1}{1+4e^{-48/26}}\right)\right)$$

$$= 1.119\ mA$$

$$\therefore \%\ error = \frac{i_o - i_{o\,ideal}}{i_{o\,ideal}} = \frac{1.119 - 1.182}{1.182} = -5.3\%$$

15.10)

a) Find $G_m = \mu_n C_{ox} (W/L)_q (V_{gsq} - V_{tnq})$ where

$$V_{gsq} = V_{gq} - V_{sq} = V_c - V_{s1} = V_c - (v_i^+ - V_{tn1})$$
$$= V_c + V_{tn1} - v_i^+ \rightarrow \text{Assume } v_i^+ = v_i^- = 2.5V$$

for V_{tn1},

$$V_{tn1} = V_{tno} + \gamma(\sqrt{V_{SB1} + 2\phi_F} - \sqrt{2\phi_F}), \quad \text{Assume}$$
$$= 0.8 + 0.5(\sqrt{1.3+0.7} - \sqrt{0.7})$$
$$= 1.09\ V$$

$V_{SB1} \approx V_i^+ - 1.2V \approx 1.3V$

$$\therefore V_{SB1} = 2.5 - 1.09\ V = 1.4V$$

Close enough → assumption accurate

$$\therefore V_{gsq} = V_c + V_{tn1} - v_i^+ = 5 + 1.09 - 2.5$$
$$= 3.59\ V$$

$$V_{tnq} = V_{tno} + \gamma(\sqrt{V_{SB1} + 2\phi_F} - \sqrt{2\phi_F})$$
$$= 0.8 + 0.5(\sqrt{1.4+0.7} - \sqrt{0.7})$$
$$= 1.106\ V$$

$$\therefore G_m = \mu_n C_{ox} (W/L)_q (V_{gsq} - V_{tnq})$$
$$= 92 \times 10^{-6} (2)(3.59 - 1.106)$$
$$\therefore G_m = 0.46\ mA/V$$

b) Find i_{o1} when $v_i^+ = 2.6\ V$ & $3V$

$$i_{o1}\Big|_{v_i^+ = 2.6V} = G_m \times (v_i^+ - v_i^-)$$
$$= 0.46\ mA/V\ (2.6 - 2.5)$$
$$= 46\ \mu A$$

$$i_o\Big|_{v_i^+ = 3.0V} = G_m \times (v_i^+ - v_i^-)$$
$$= 0.46 \times (3.0 - 2.5)$$
$$= 230\ \mu A$$

(cont.)

c) Find true i_{o1} when $v_i^+ = 2.6V$ and $3.0V$

Assume that the threshold voltages of Q_1 and Q_9 remain equal to those found in part a).

i.e., $V_{tn1} = 1.09V$

$V_{tn9} = 1.106V$

$$i_{o1} = i_{o9} = \mu_n C_{ox} (W/L)_9 \left((V_{gs9} - V_{tn9}) V_{os9} - \frac{V_{os9}^2}{2} \right)$$

For $V_i^+ = 2.6V$:

$$V_{gs9} = V_C + V_{tn1} - v_i^+ = 5 + 1.09 - 2.6$$
$$= 3.58V$$

and $V_{os9} = 0.1V$

$$\therefore i_{o1} = 92\times10^{-6} \times (2)\left((3.58 - 1.106)\, 0.1 - \frac{(0.01)}{2} \right)$$
$$= 45\,\mu A$$

$$\%\ error = \frac{45-46}{46} \approx 2\%\ error$$

For $V_i^+ = 3.0V$:

$$V_{gs9} = 5 + 1.09 - 3.0$$
$$= 3.09V$$

and $V_{os9} = 0.5V$

$$\therefore i_{o1} = 92\times10^{-6} (2)\left((3.09 - 1.106) 0.5 - \frac{0.5^2}{2} \right)$$
$$= 160\,\mu A$$

$$\therefore \%\ error = \frac{160 - 230}{230} = -30\%\ error$$

15.11) Given

$$K_1/K_3 = 6.7 \Rightarrow \frac{\frac{\mu_n C_{ox}}{2}(W/L)_1}{\frac{\mu_n C_{ox}}{2}(W/L)_3} = 6.7$$

If $L_1 = L_2 \equiv L$,

$$\therefore \quad W_1 = 6.7\, W_3$$

To find W_3,

$$G_m = \frac{4k_1 k_3 \sqrt{I_1}}{(k_1+4k_3)\sqrt{k_1}} \equiv 0.3 \text{ mA/V}$$

$$\therefore \quad \frac{4\times 6.7 k_3^2 \sqrt{I_1}}{(6.7+4)\cancel{k_3}\sqrt{6.7k_3}} =$$

$$\sqrt{I_1 k_3} = 0.31\times10^{-3}$$

$$I_1 W_3 = \frac{(0.31)^2\times10^{-6}}{\frac{\mu_n C_{ox}}{2}\times 1/L} \qquad \text{If } L = 1\mu m$$

$$= \frac{0.31^2\times 2\times \cancel{10^{-6}}}{92\times\cancel{10^{-6}}} = 2.09\times10^{-3} \text{ mA}\cdot\mu m$$

Let $I_1 = 200\mu A$

$$\therefore \quad W_3 = \frac{2.09\times10^{-3}}{200\times10^{-6}} \approx 10\,\mu m = W_4$$

$$\therefore \quad W_1 = 6.7W_3 = 67\,\mu m = W_2$$

and $L = 1\mu m$

15.12) Find $G_m = 4K_{eq}(V_{c1} - V_{teq})$

Ignore body effect.

Now $\frac{1}{\sqrt{K_{eq}}} = \frac{1}{\sqrt{K_n}} + \frac{1}{\sqrt{K_p}}$ where $K_n = \frac{\mu_n C_{ox}}{2} W/L = \frac{92\times10^{-6}}{2}\times 10/2$

$$= 230\times10^{-6}$$

$$K_p = \frac{30\times10^{-6}}{2}\times 10/2 = 75\times10^{-6}$$

$$\therefore \quad \frac{1}{\sqrt{K_{eq}}} = 181.5$$

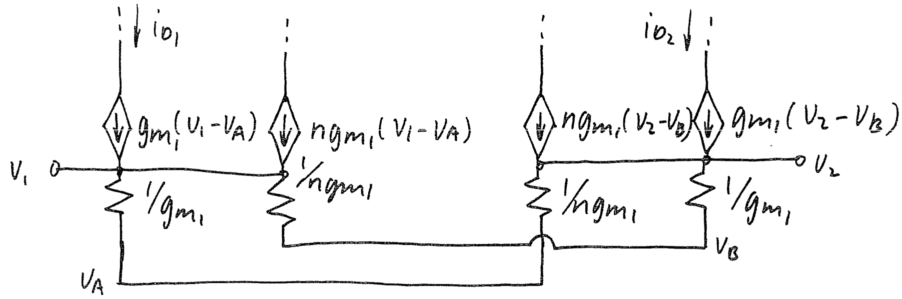
$$K_{eq} = 30\times10^{-6}$$

$$V_{teq} = V_{tn} - V_{tp} = 0.8 + 0.9V = 1.7V$$

$$\therefore \quad G_m = 4\times 30\times10^{-6}(2-1.7)$$

$$= 36\ \mu A/V$$

15.13) Show $G_m = \left(\frac{n}{n+1}\right) 4\sqrt{K I_B}$



$i_{D1} = \frac{V_1 - V_2}{1/g_{m1} + 1/ng_{m1}}$ and by symmetry, $i_{D2} = -i_{D1}$

$\therefore\ i_{D1} - i_{D2} = 2 \times \frac{V_1 - V_2}{1/g_{m1} + 1/ng_{m1}}$

$\therefore$ the transconductance, G_m

$$G_m \triangleq \frac{i_{D1} - i_{D2}}{V_1 - V_2} = \frac{2}{1/g_{m1} + 1/ng_{m1}} = \frac{2 g_{m1}}{1 + 1/n}$$

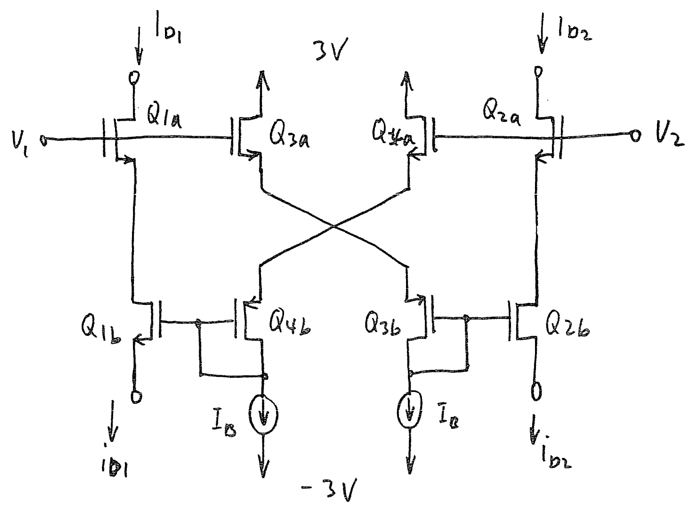
$$= \frac{2n}{n+1} g_{m1} \quad \text{where } g_{m1} = \sqrt{2 \mu_n C_{ox} W/L\, I_B}$$

$$= \sqrt{4 K I_B} \quad \text{for } K = \frac{\mu_n C_{ox}}{2}\frac{W}{L}$$

$\therefore\ G_m = \frac{2n}{n+1}\sqrt{4 K I_B}$

$G_m = \left(\frac{n}{n+1}\right) 4\sqrt{K I_B}$ Q.E.D.

(5.14)



Find the maximum differential voltage centred about 0V.

$$V_{eff4b} = V_{eff3b} = \sqrt{\frac{2I_B}{\mu_p C_{ox} W/L}} = \sqrt{\frac{2\times 50\times 10^{-6}}{30\times 10^{-6}\times 10/2}} = 0.816\,V$$

$$V_{eff4a} = V_{eff3a} = \sqrt{\frac{2I_B}{\mu_n C_{ox} W/L}} = \sqrt{\frac{2\times 50\times 10^{-6}}{92\times 10^{-6}\times 10/2}} = 0.466\,V$$

Assuming the voltage drops across current sources I_B can be as low as 0 volts, the minimum voltage level for V_1 and V_2 is

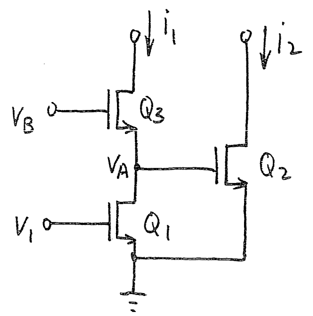
$$V_{1,2min} = V_{SS} + V_{I_B min} - V_{tp3,4b} + V_{eff3,4b} + V_{tn3,4a} + V_{eff3,4a}$$
$$= -3 + 0 + 0.9 + 0.816 + 0.8 + 0.466\,V$$
$$= -18\,mV$$

∴ the minimum level for V_1 and V_2 is $-18\,mV$ and because V_1 and V_2 are centred around 0V,

∴ the maximum differential voltage is

$$V_1 - V_2 = 18\,mV - (-18\,mV) = \underline{36\,mV}$$

15.15) Show $i_1 - i_2 = K(V_B - 2V_{tn})(2V_1 - V_B)$



$$i_{D1} = K(V_1 - V_{tn})^2$$

$$i_{D3} = K(V_B - V_A - V_{tn})^2$$

But $i_{D1} = i_{D3} \equiv i_1$

$$\therefore \cancel{K}(V_1 - V_{tn})^2 = \cancel{K}(V_B - V_A - V_{tn})^2$$

$$V_1 - \cancel{V_{tn}} = V_B - V_A - \cancel{V_{tn}}$$

or $\underline{V_A = V_B - V_1}$ $\boxed{1}$

$$i_{D2} = K(V_A - V_{tn})^2 \quad \boxed{2}$$

$$\boxed{1} \rightarrow \boxed{2} = K(V_B - V_1 - V_{tn})^2 \equiv i_2$$

$$\therefore i_1 - i_2 = K[(V_1 - V_{tn})^2 - (V_B - V_1 - V_{tn})^2]$$

$$= K[\cancel{V_1^2} - 2V_1V_{tn} + \cancel{V_{tn}^2} - (V_B^2 + \cancel{V_1^2} + \cancel{V_{tn}^2} - 2V_1V_B - 2V_BV_{tn} + 2V_1V_{tn})]$$

$$= K(-V_B^2 + 2V_1V_B - 4V_1V_{tn} + 2V_{tn}V_B)$$

$$\therefore \underline{i_1 - i_2 = K(V_B - 2V_{tn})(2V_1 - V_B)}$$

Q.E.D.

15.16) Refer to Figure 15.42 a) for schematic.

Given that we want a second-order low pass filter with a DC gain of 2,

$$H(s) = \frac{k_o}{s^2 + \frac{\omega_o}{Q}s + \omega_o^2} = \frac{2\omega_o^2}{s^2 + \frac{\omega_o}{Q}s + \omega_o^2} \quad \boxed{1}$$

From Eq. (15.161)

$$\frac{V_O}{V_i} = \frac{\frac{C_1}{C_B}s^2 + \frac{G_2}{C_B}s + \frac{G_1G_3}{C_AC_B}}{s^2 + \frac{G_5}{C_B}s + \frac{G_3G_4}{C_AC_B}} \quad \boxed{2}$$

(cont.)

15.16 (cont.)

Equating the coefficients of $\boxed{1}$ and $\boxed{2}$,

$$C_1 = G_2 = 0 \qquad \text{(i.e., remove components)}$$

$$C_A = C_B = 10\,pF$$

$$\frac{G_5}{C_B} = \omega_0 \Rightarrow G_5 = C_B\omega_0 = 10\times10^{-12}\times 2\pi\times 1MHz$$
$$= 63\ \mu A/V$$

Now $G_1 G_3 = 2C_A C_B \omega_0^2 = 2(10\times10^{-12})^2(2\pi\times 1MHz)^2$
$= 7.90\times10^{-9}$

and $G_3 G_4 = C_B C_B \omega_0^2 = 3.95\times10^{-9}$

If we let $G_3 = 100\ \mu A/V$,

$$G_1 = \frac{7.90\times10^{-9}}{100\times10^{-6}} = 79\ \mu A/V \quad \text{and}$$

$$G_4 = \frac{3.95\times10^{-9}}{100\times10^{-6}} = 40\ \mu A/V$$

Now transistor sizes,

$$G_i = \mu_n C_{ox}(W/L)_i (V_C - V_X - V_{tn})$$

$$\therefore G_1 = 92\times10^{-6}(W/L)_1(3-0.8) \equiv 79\ \mu A/V$$

$$\therefore \underline{(W/L)_1 = 0.39}$$

Similarly,

$$G_3 = 92\times10^{-6}(W/L)_3(3-0.8) = 100\ \mu A/V$$

$$\Rightarrow \underline{(W/L)_3 = 0.49}$$

$$\underline{(W/L)_4 = \frac{40\ \mu A/V}{92\times10^{-6}(3-0.8)} = 0.2}$$

$$\underline{(W/L)_5 = \frac{63\ \mu A/V}{92\times10^{-6}(3-0.8)} = 0.31}$$

and device G_2 is eliminated.

15.17) $$\% THD = \left[\frac{Pwr_{2MHz} + Pwr_{3MHz} + Pwr_{4MHz}}{Pwr_{fundamental}}\right]^{1/2}$$

$$= \left[\frac{V_{2MHz}^2 + V_{3MHz}^2 + V_{4MHz}^2}{V_{fundamental}^2}\right]^{1/2}$$

$$= \left[\frac{(1)^2 + (0.5)^2 + (0.3)^2}{1000^2}\right]^{1/2} = \frac{1.158}{1000}$$

$\therefore$ $\% THD = 0.12\%$

15.18) Find output signal level.

$$OIP_3 = IIP_3 + a_1$$

$$= 10dBm + 6dB$$

$$OIP_3 = 16dBm$$

Let $ID_3 = -60dB$

$$\therefore I_{D1} = OIP_3 + \frac{ID_3}{2} = 16dBm - \frac{60dB}{2}$$

$$= -14dBm$$

Thus, an output level of -14 dBm should be used.

15.19) Given: Input at $-4\,dBm$
output at $2\,dBm$ $(= I_{D1})$
Measured $ID_3 = -40\,dB$

$\therefore\ OIP_3 = I_{o1} - \frac{ID_3}{2} = 2\,dBm + \frac{40\,dB}{2}$.

$OIP_3 = 22\,dBm$ and

$IIP_3 = OIP_3 - a_1 = 22\,dBm - 6\,dB$

$IIP_3 = 16\,dBm$

For $ID_3 = -50\,dB$

$I_{o1} = OIP_3 + \frac{ID_3}{2} = 22\,dBm - 50/2$

$I_{o1} = -3\,dBm$

This corresponds to an input level of $-3\,dBm - 6\,dB = -9\,dBm$

If $N_o = -60\,dBm$, then

$SFDR = 2/3(OIP_3 - N_o)$

$= 2/3(22\,dBm + 60\,dBm)$

$= 55\,dB$

and $I_{o1}^* = SFDR + N_o = 55\,dBm - 60\,dBm$

$= -5\,dBm$

Thus the output signal level is $-5\,dBm$ and the SFDR is $55\,dB$.