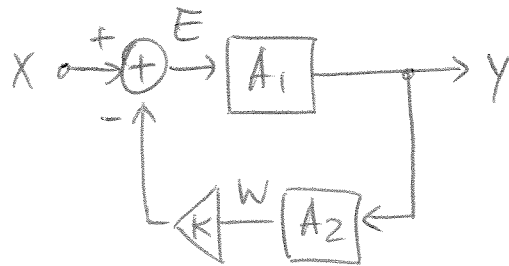


1. (a)

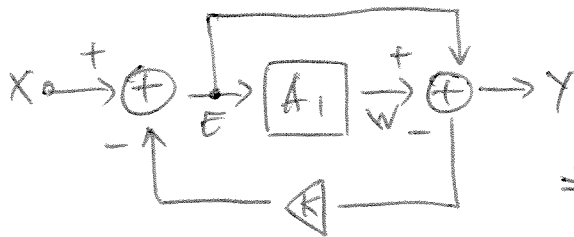


$$Y = A_1 E_1$$

$$= A_1 [X - Y A_2 k]$$

$$\Rightarrow \frac{Y}{X} = \frac{A_1}{1 + k A_1 A_2}$$

(b)

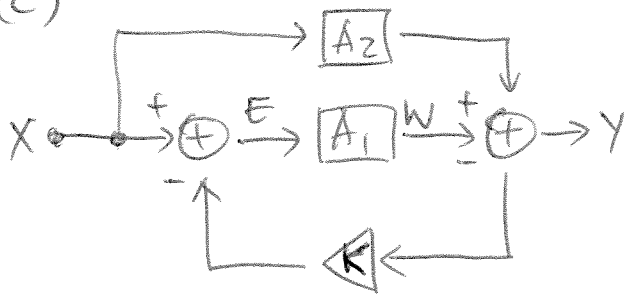


$$Y = E - A_1 W$$

$$= (X - kY) - A_1 (X - kY)$$

$$\Rightarrow \frac{Y}{X} = \frac{1 - A_1}{1 + (1 - A_1)k}$$

(c)

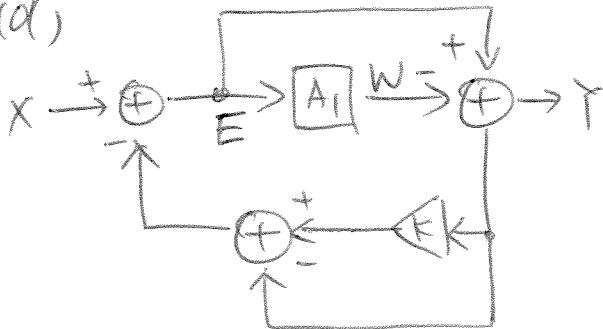


$$Y = X A_2 - W$$

$$= X A_2 - A_1 (X - Y k)$$

$$\Rightarrow \frac{Y}{X} = \frac{A_2 - A_1}{1 - A_1 Y}$$

(d)



$$Y = E - W$$

$$= (X - (kY - Y)) - A_1 [X - (kY - Y)]$$

$$\Rightarrow \frac{Y}{X} = \frac{(1 - A_1)}{1 + (k - 1)(1 - A_1)}$$

$$2. (a) \quad W = A_2 Y = A_2 [(X - KW)A_1]$$

$$\Rightarrow \frac{W}{X} = \frac{A_1 A_2}{1 + A_1 A_2 K}$$

$$(b) \quad W = A_1 X E = A_1 [X - K(\frac{W}{A_1} - W)]$$

$$\Rightarrow \frac{W}{X} = \frac{A_1}{1 + K(1 - A_1)}$$

$$(c) \quad W = A_1 E = A_1 [X - (A_2 X - W)K]$$

$$\Rightarrow \frac{W}{X} = \frac{A_1 (1 - A_2 K)}{(1 - A_1 K)}$$

$$(d) \quad W = A_1 E = A_1 [X - \{(\frac{W}{A_1} - W)K - (\frac{W}{A_1} - W)\}]$$

$$\Rightarrow \frac{W}{X} = \frac{A_1}{1 + (K-1)(1-A_1)}$$

$$3. (a) E = X - kA_2A_1E$$

$$\Rightarrow \frac{E}{X} = \frac{1}{1 + kA_2A_1}$$

$$(b) E = X - k[E - A_1E]$$

$$\Rightarrow \frac{E}{X} = \frac{1}{1 + k(1 - A_1)}$$

$$(c) E = X - k[A_2X - A_1E]$$

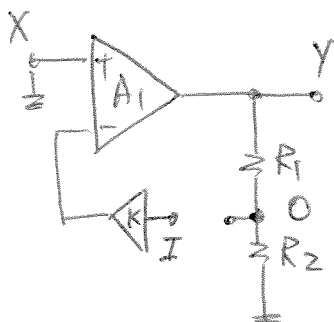
$$\Rightarrow \frac{E}{X} = \frac{1 - A_2k}{1 - A_1k}$$

$$(d) E = X - \{k[E - A_1E] - [E - A_1E]\}$$

$$\Rightarrow \frac{E}{X} = \frac{1}{1 + (k-1)(1-A_1)}$$

4.

(a)

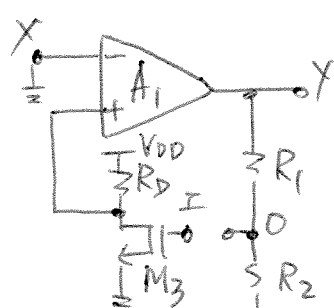


(X is grounded
in loop-gain calculation)

$$0 = Y \frac{R_2}{R_1 + R_2} = (-IK)A_1 \left(\frac{R_2}{R_1 + R_2} \right)$$

$$\Rightarrow -\frac{O}{I} = \text{Loop Gain} \\ = +KA_1 \left(\frac{R_2}{R_1 + R_2} \right)$$

(b)

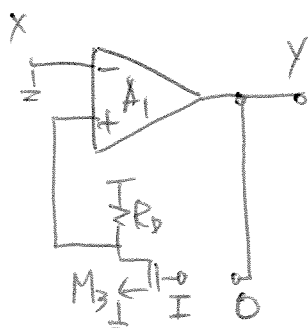


(X is grounded)

$$0 = Y \left(\frac{R_2}{R_1 + R_2} \right) \\ = -Iq_{m3}R_D A_1 \left(\frac{R_2}{R_1 + R_2} \right)$$

$$\Rightarrow -\frac{O}{I} = \text{Loop Gain} \\ = +g_{m3}R_D A_1 \left(\frac{R_2}{R_1 + R_2} \right)$$

(c)

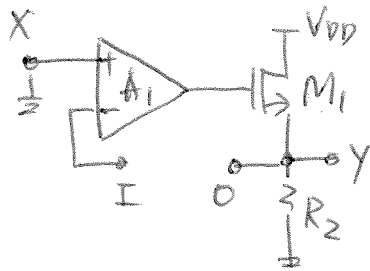


(X is grounded)

$$0 = Y = -Iq_{m3}R_D A_1$$

$$\Rightarrow -\frac{O}{I} = \text{Loop Gain} \\ = +g_{m3}R_D A_1$$

(d)



(X is grounded)

$$0 = Y = -I \times \frac{g_{m1} R_2}{1 + g_{m1} R_2} \times A_1$$

$$\Rightarrow -\frac{0}{I} = \text{Loop Gain}$$
$$= + A_1 \frac{g_{m1} R_2}{1 + g_{m1} R_2}$$

$$5. (a) \frac{Y}{X} = \frac{A_{o.L.}}{1 + \text{Loop Gain}} = \frac{A_1}{1 + A_1 K \left(\frac{R_2}{R_1 + R_2} \right)}$$

$$(b) \frac{Y}{X} = \frac{A_1}{1 + g_{m3} R_D A_1 \left(\frac{R_2}{R_1 + R_2} \right)}$$

$$(c) \frac{Y}{X} = \frac{A_1}{1 + g_{m3} R_D A_1}$$

$$(d) \frac{Y}{X} = \frac{A_1}{1 + A_1 \left(\frac{g_{m1} R_2}{1 + g_{m1} R_2} \right)}$$

b. $A_1 = 500$
 $R_1/R_2 = 7$

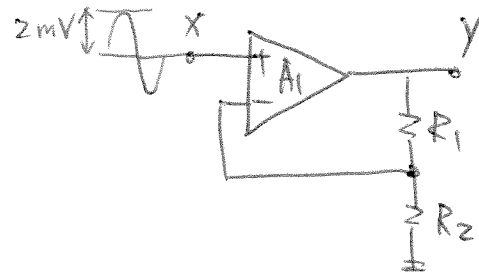
$$\frac{Y}{X} \approx 1 + \frac{R_1}{R_2} = 8$$

$$\Rightarrow \frac{R_2}{R_1 + R_2} = \frac{1}{8} = K$$

$$E = \frac{X}{1 + KA_1} = \frac{2\text{mV}}{1 + 500/8} \approx 0.031\text{ mV}$$

$\therefore$ Amplitude of feedback waveform
 $= X - E \approx 1.969\text{ mV}$

Amplitude of output waveform
 $= X \frac{A_1}{1 + KA_1} \approx 15.75\text{ mV}$



$$1. \quad A_{CL} = \frac{A_1}{1+A_1K}$$

$$\frac{dA_{CL}}{dA_1} = \frac{1}{(1+A_1K)^2} \Rightarrow dA_{CL} = \frac{dA_1}{(1+A_1K)^2}$$

$$\begin{aligned} \Rightarrow \frac{dA_{CL}}{A_{CL}} &= \frac{dA_{CL}}{\left(\frac{A_1}{1+A_1K}\right)} = dA_1 \left(\frac{1+A_1K}{A_1}\right) \left(\frac{1}{(1+A_1K)^2}\right) \\ &= \frac{(dA_1/A_1)}{(1+A_1K)} \end{aligned}$$

This equation implies that for a fractional change in A_{CL} , it is reduced by $(1+A_1K)$ compared to a fractional change in A_1 .

$$\Rightarrow 0.01 > \frac{0.2}{1+A_1K} \Rightarrow A_1K > 19$$

$$8. \quad A_{OL} = -g_m r_{o1} \quad (\text{max gain})$$

$$= -\frac{2}{\lambda V_{eff}}$$

$$A_{CL} = \frac{A_{OL}}{1 + A_{OL}K}$$

$$\frac{dA_{CL}}{d\lambda} = \frac{d}{d\lambda} \left(\frac{A_{OL}}{1 + A_{OL}K} \right) = \frac{\frac{2}{\lambda^2 V_{eff}}}{(1 + A_{OL}K)^2} = \frac{-A_{OL} \times \frac{1}{\lambda}}{(1 + A_{OL}K)^2}$$

$$\Rightarrow \frac{dA_{CL}}{A_{CL}} = \frac{-A_{OL} \times \frac{d\lambda}{\lambda}}{(1 + A_{OL}K)^2} \times \frac{(1 + A_{OL}K)}{A_{OL}} = \frac{-\frac{d\lambda}{\lambda}}{(1 + A_{OL}K)}$$

$\Rightarrow$ This implies a change in $\lambda \left(\frac{d\lambda}{\lambda} \right)$ leads to a change in A_{CL} $\left(\frac{dA_{CL}}{A_{CL}} = \frac{d\lambda}{\lambda} \cdot \frac{1}{(1 + \text{Loop Gain})} \right)$ in the opposite direction (i.e. the sign)

$$s_{90} > \frac{20\%}{1 + A_{OL}K} \Rightarrow \text{Loop Gain} = A_{OL}K > 3$$

9. From the question,

$$(1-10\%)A_0 = |A(j\omega')| \quad \text{where } \omega' = -1\text{-dB bandwidth frequency}$$

$$0.9A_0 = \frac{A_0}{|1+j\frac{\omega'}{\omega_0}|} = \frac{A_0}{\sqrt{1+(\frac{\omega'}{\omega_0})^2}}$$

$$\Rightarrow \omega' \cong 0.48\omega_0$$

$\Rightarrow$ This is the open-loop -1dB bandwidth.

Similarly,

$$0.9 \frac{A_0}{1+LG} = \left| \frac{Y}{X}(j\omega'') \right| \quad \text{where } \omega'' = -1\text{-dB bandwidth frequency}$$

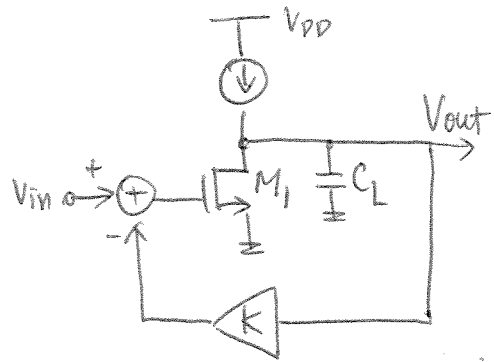
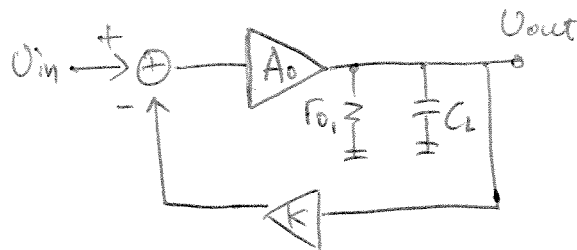
$$\begin{aligned} 0.9 \frac{A_0}{1+LG} &= \frac{\frac{A_0}{1+LG}}{\left| 1 + j \frac{\omega''}{\omega_0(1+LG)} \right|} \\ &= \frac{\frac{A_0}{1+LG}}{\sqrt{1 + \left[\frac{\omega''}{\omega_0(1+LG)} \right]^2}} \end{aligned}$$

L.G = Loop Gain

$$\Rightarrow \omega'' \cong 0.48\omega_0(1+LG)$$

$\therefore$ -1dB bandwidth is boosted (expected) by $(1+LG)$ in closed-loop measurement.

10. An equivalent circuit is shown below:



Open-loop transfer function (without feedback):

$$A(s) = \frac{A_0}{1 + \frac{s}{\omega_p}} = \frac{-g_{m1} r_{o1}}{1 + \frac{s}{r_{o1} C_L}}$$

$$\text{Loop Gain} = A_0 K = g_{m1} r_{o1} K$$

⇒ Closed-loop -3dB Bandwidth

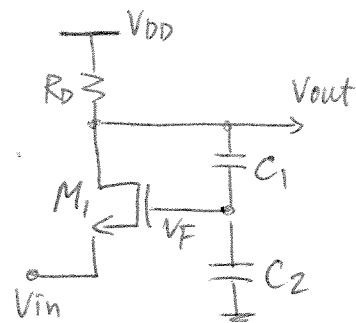
$$= B = (r_{o1} C_L)(1 + A_0 K) = r_{o1} C_L (1 + g_{m1} r_{o1} K)$$

$$\therefore K = \left(\frac{B}{r_{o1} C_L} - 1 \right) \times \frac{1}{g_{m1} r_{o1}}$$

11.

Feedforward System

M_1 & R_D (common-gate stage)



Sense Mechanism (Feedback):

$C_1 + C_2$ (capacitive divider)

$$\Rightarrow V_F = \frac{C_1}{C_2 + C_1} \times V_{out}$$

Comparison Mechanism: M_1 itself.

$$\text{Open-loop gain} = A_o = g_m R_D$$

$$\begin{aligned} \text{Closed-loop gain} &= \frac{V_{out}}{V_{in}} = \frac{A_o}{1 + K A_o} \\ &= \frac{g_m R_D}{1 + \frac{C_1}{C_1 + C_2} g_m R_D} \end{aligned}$$

$$\text{Open-loop } r_{in} = \frac{1}{g_m}$$

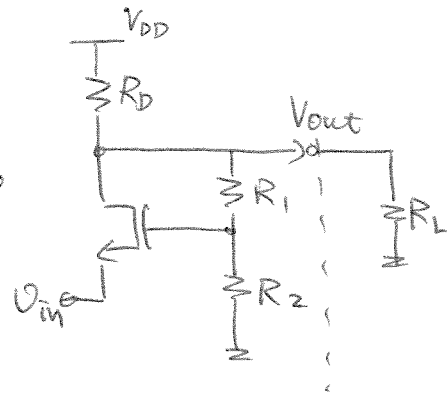
$$r_{out} = R_D$$

$$\begin{aligned} \text{Closed-loop } r_{in} &= r_{in,ol} \times (1 + K A_o) \\ &= \frac{1}{g_m} \left(1 + \frac{C_1}{C_1 + C_2} g_m R_D \right) \end{aligned}$$

$$r_{out} = \frac{r_{out,ol}}{(1 + K A_o)} = \frac{R_D}{1 + \frac{C_1}{C_1 + C_2} g_m R_D}$$

12.

Given: $\frac{\text{Gain}_{\text{loaded}} - \text{Gain}_{\text{loaded}}}{\text{Gain}_{\text{unloaded}}} = 10\%$
 $= 0.1$



$$\text{Gain}_{\text{unloaded}} \cong \frac{g_m R_D}{1 + \frac{R_2}{R_1 + R_2} g_m R_D} \quad (\text{assume } R_1 + R_2 \gg R_D)$$

$$\text{Gain}_{\text{loaded}} = \frac{g_m (R_D \parallel R_L)}{1 + \frac{R_2}{R_1 + R_2} g_m (R_D \parallel R_L)}$$

$$\therefore 0.1 = \frac{\frac{g_m R_D}{1 + \frac{R_2}{R_1 + R_2} g_m R_D} - \frac{g_m (R_D \parallel R_L)}{1 + \frac{R_2}{R_1 + R_2} g_m (R_D \parallel R_L)}}{\frac{g_m R_D}{1 + \frac{R_2}{R_1 + R_2} g_m R_D}}$$

After solving for R_L :

$$R_L = \frac{g_m R_D}{1 + \left(\frac{R_2}{R_1 + R_2} \right) g_m R_D}$$

$$13. \text{ Gain at } x_1 = \frac{500}{1+500K}$$

$$\text{Gain at } x_2 = \frac{420}{1+420K}$$

$$\Rightarrow \frac{\frac{500}{1+500K} - \frac{420}{1+420K}}{\frac{500}{1+500K}} < 0.05$$

$$\Rightarrow K > \frac{11}{2100}$$

$$A_{x_1} = \frac{500}{1+500(K)} = \frac{2625}{19} \approx 138.16$$

$$A_{x_2} = \frac{420}{1+420(K)} = \frac{525}{4} \approx 131.25$$

$$14. \quad y = \alpha_1 x - \alpha_3 x^3$$

$$(a) \quad \frac{\partial y}{\partial x} = \alpha_1 - 3\alpha_3 x^2$$

$$\left. \frac{\partial y}{\partial x} \right|_{x=0} = \alpha_1$$

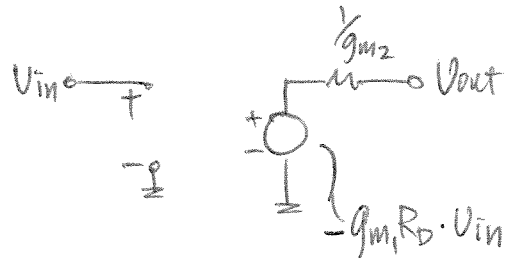
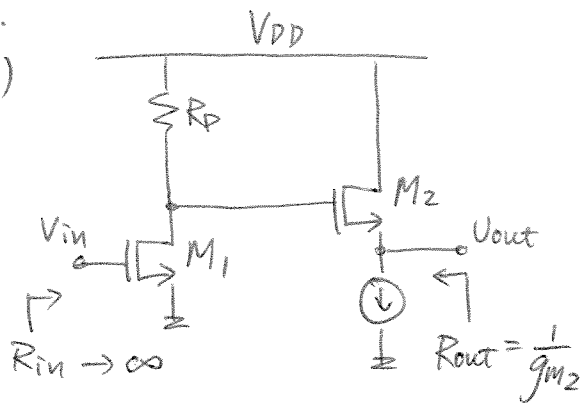
$$\left. \frac{\partial y}{\partial x} \right|_{x=\Delta x} = \alpha_1 \quad (\text{around } x=0)$$

$$(b) \quad \text{Closed-loop } |_{x=0} = \frac{\alpha_1}{1 + \alpha_1 K}$$

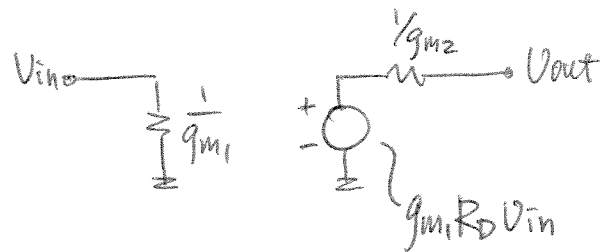
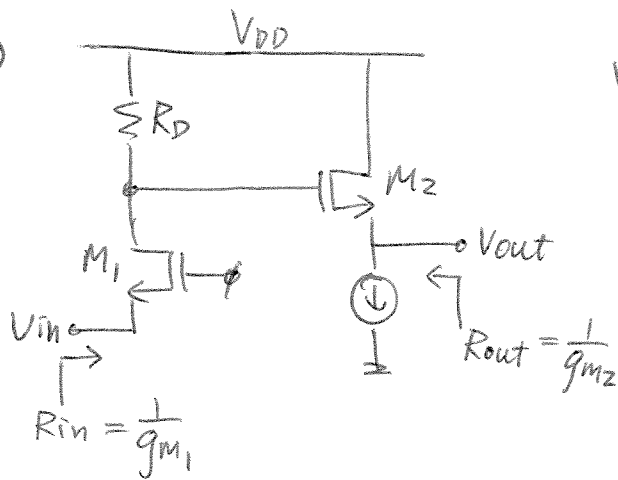
$$\text{Closed-loop } |_{x=\Delta x} = \frac{\alpha_1}{1 + \alpha_1 K} \quad (\text{around } x=0)$$

15.

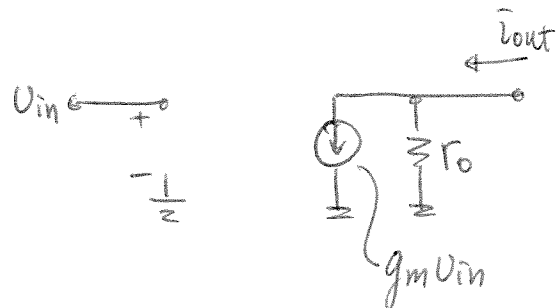
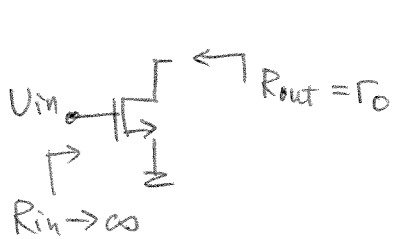
(a)



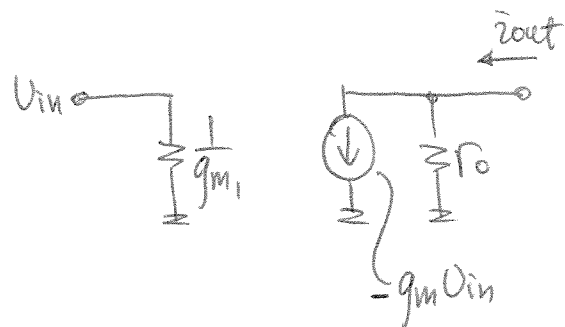
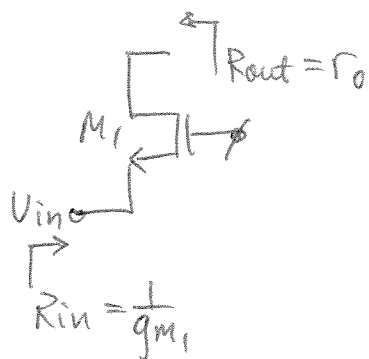
(b)



(c)

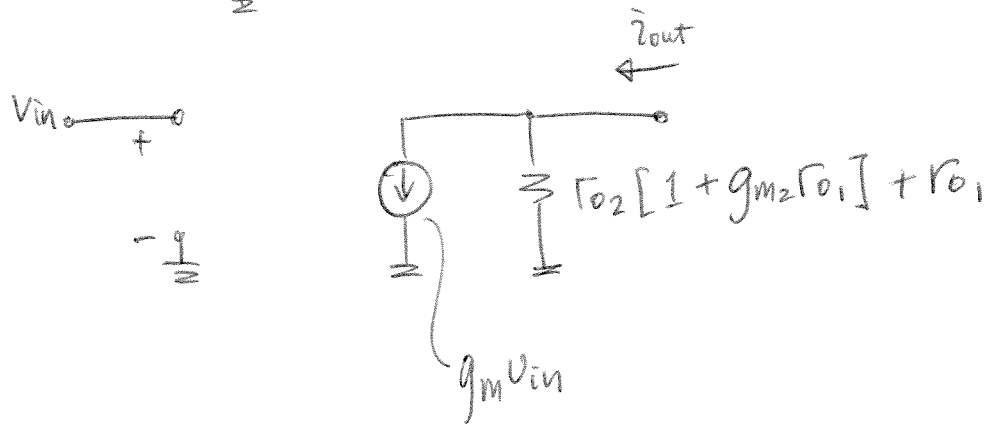
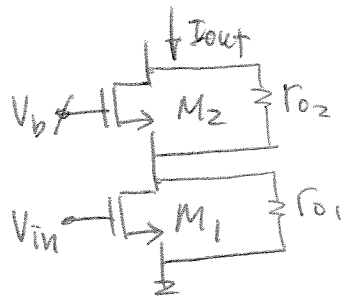


(d)

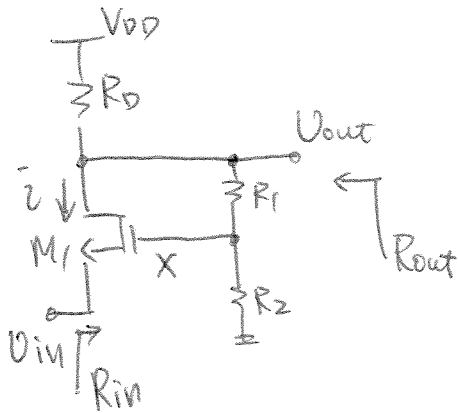


16.

$$\lambda > 0$$



17.

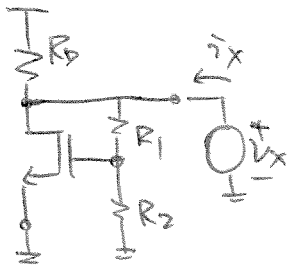


$$-V_{out} = \bar{i} [R_D \parallel (R_1 + R_2)]$$

$$\bar{i} = g_{m1}(V_x - V_{in}) = g_{m1}\left(V_{out} \times \frac{R_2}{R_1 + R_2} - V_{in}\right)$$

Combining the equations above yields:

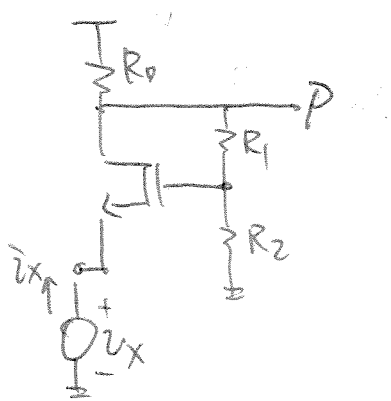
$$\frac{V_{out}}{V_{in}} = \frac{g_{m1}[R_D \parallel (R_1 + R_2)]}{1 + \frac{R_2}{R_1 + R_2} g_{m1}[R_D \parallel (R_1 + R_2)]} \triangleq A_v$$



By KCL,

$$\bar{i}_x = \frac{V_x}{R_1 + R_2} + \frac{V_x}{R_D} + g_{m1}\left(V_x \frac{R_2}{R_1 + R_2}\right)$$

$$\Rightarrow \frac{V_x}{\bar{i}_x} = R_{out} = [(R_1 + R_2) \parallel R_D] \left[1 + g_{m1} \frac{R_2}{R_1 + R_2} (R_D \parallel (R_1 + R_2)) \right]$$



By KCL,

$$\bar{i}_x = g_{m1} \left(v_x - v_p \frac{R_2}{R_1 + R_2} \right)$$

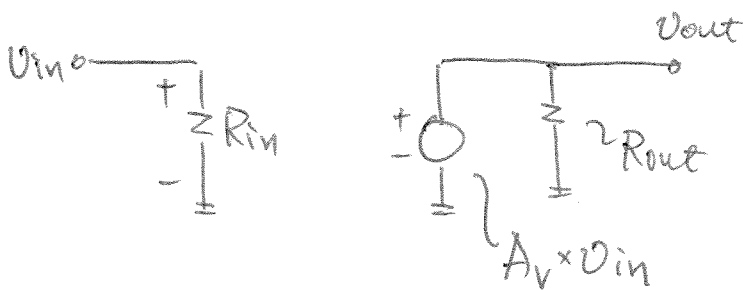
$$\Rightarrow v_p = \left(v_x - \frac{\bar{i}_x}{g_{m1}} \right) \left(\frac{R_1 + R_2}{R_2} \right) \quad \text{--- (1)}$$

$$\bar{i}_x = \frac{v_p}{R_D \parallel (R_1 + R_2)} \quad \text{--- (2)}$$

Substitute (1) into (2) & solve for $\frac{v_x}{\bar{i}_x}$:

$$\frac{v_x}{\bar{i}_x} = R_{in} = \frac{1}{g_{m1}} \left[1 + g_{m1} \left\{ R_D \parallel (R_1 + R_2) \right\} \frac{R_2}{R_1 + R_2} \right]$$

Model:



18. (a) Sense Mechanism : Current from M_3
Return Mechanism : Voltage to Gate of M_2 .

(b) Sense Mechanism : Voltage output (M_3)
Return Mechanism : Voltage to Gate of M_2 .

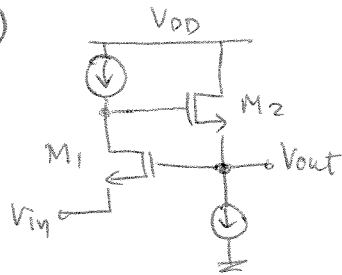
(c) Sense Mechanism : Current from M_3
Return Mechanism : Voltage to Gate of M_2 .

(d) Sense Mechanism : Current from M_3
Return Mechanism : Voltage to Gate of M_2 .

(e) Sense Mechanism : Voltage Divider ($\frac{R_2}{R_1+R_2}$)
Return Mechanism : Voltage to Gate of M_2 .

(f) Sense Mechanism : From Common Source of M_3
Return Mechanism : Voltage to Gate of M_2 .

19. (a)



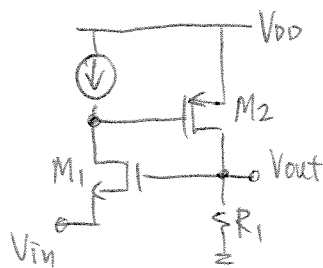
Sense Mechanism:

Voltage sensing at V_{out} .

Return Mechanism:

Voltage to Gate of M_1 .

(b)



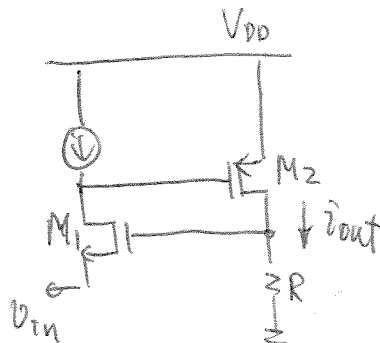
Sense Mechanism:

Voltage output from M_2 .

Return Mechanism:

Voltage to Gate of M_1 .

(c)



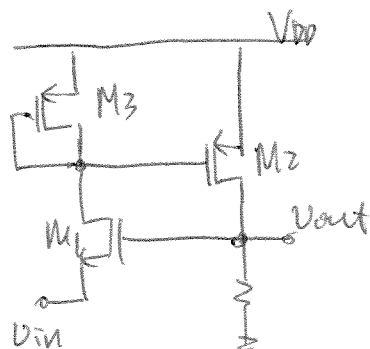
Sense Mechanism:

R_1

Return Mechanism:

Voltage to Gate of M_1 .

(d)



Sense Mechanism:

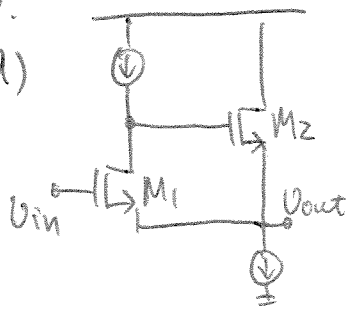
Voltage output of M_2

Return Mechanism:

Voltage to Gate of M_1

20.

(a)



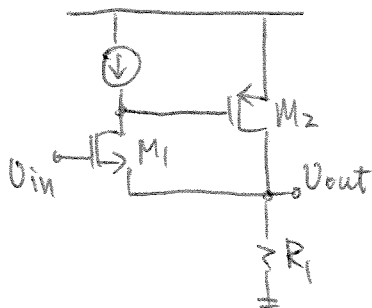
Sense Mechanism:

Voltage output of M_2

Return Mechanism:

Voltage to Source of M_1

(b)



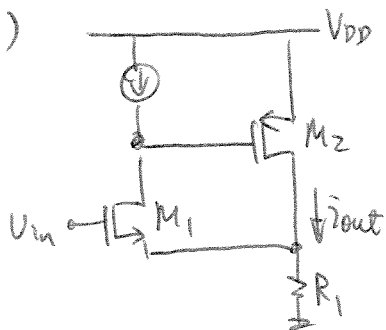
Sense Mechanism:

Voltage output of M_2

Return Mechanism:

Voltage to Source of M_1

(c)



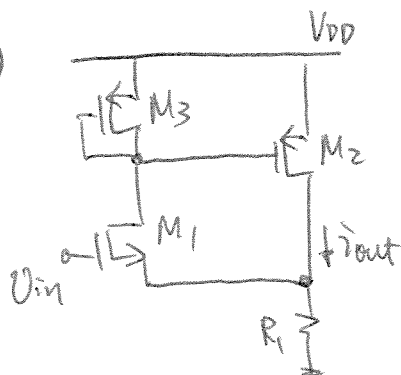
Sense Mechanism:

Current through R_1 .

Return Mechanism:

$i_{out} \times R_1$ to Source of M_1 .

(d)



Sense Mechanism:

Current through R_1 .

Return Mechanism:

$i_{out} \times R_1$ to Source of M_1

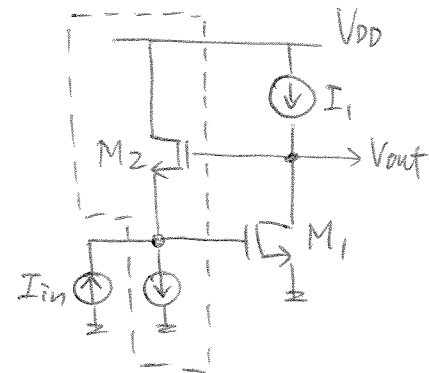
21. (a)

Sense Mechanism:

Gate of M_2 (Voltage)

Return Mechanism:

Current output of M_2 .



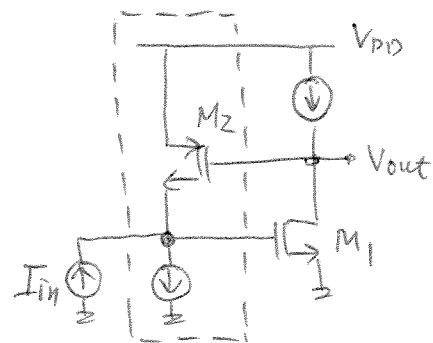
(b)

Sense Mechanism:

Gate of M_2 (Voltage)

Return Mechanism:

Current output of M_2 .



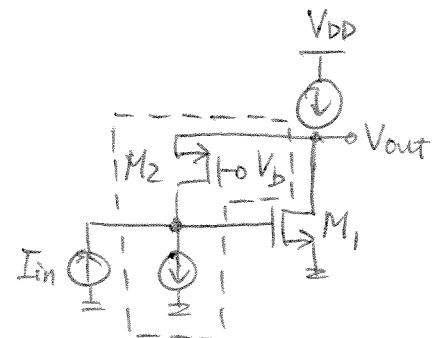
(c)

Sense Mechanism:

Source of M_2 (Voltage)

Return Mechanism:

Current output of M_2

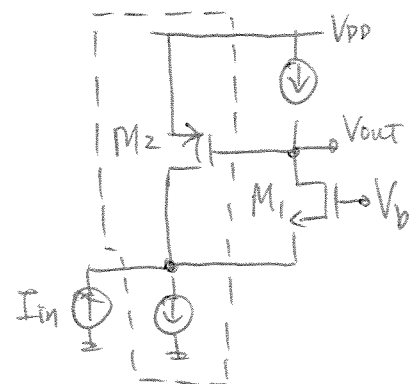


(d) Sense Mechanism:

Gate of M_2 (Voltage)

Return Mechanism:

Current output of M_2



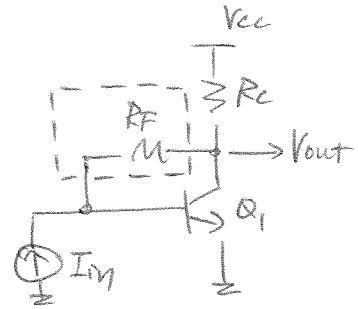
22.

(a) Sense Mechanism:

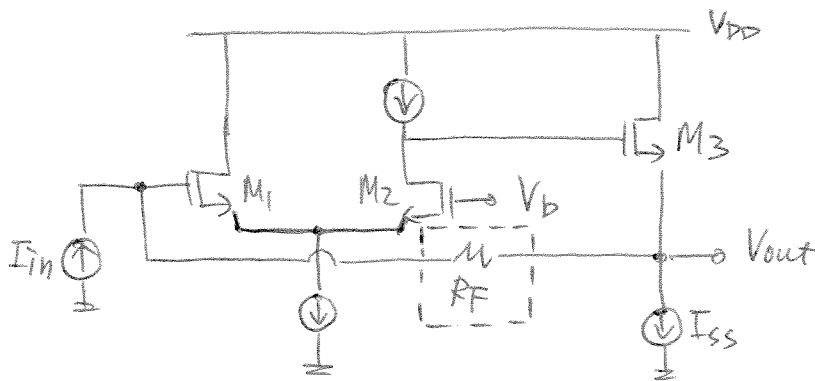
Resistor (R_F) - Voltage

Return Mechanism:

Current through R_F .



(b)



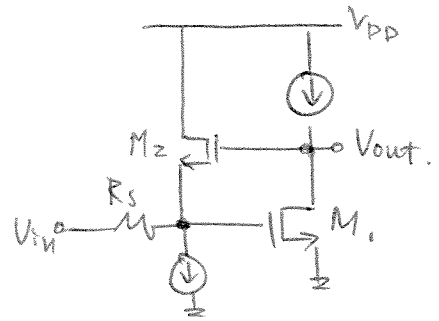
Sense Mechanism:

Resistor (R_F) - Voltage

Return Mechanism:

Current through R_F

23. First, recognize that
(a) both input & output
are voltages.



* V_{in} primarily drives the
Gate of M_1 .

Sequence: Suppose V_{in} increases by ΔV_{in}

$\Rightarrow V_{out}$ drops by $+g_{m1} \Delta V_{in} \times r_{o1}$ (Common-Source)

$\Rightarrow$ Source of M_2 decreases by same amount (Source follower)

$\therefore V_{in} \uparrow \Rightarrow V_{M1,D} \downarrow \Rightarrow V_{M1,G} \downarrow$
 $\Rightarrow$ effective V_{in} driving $M_{1,G} \downarrow$

$\Rightarrow$ negative feedback

(b) $V_{in} \uparrow \Rightarrow V_{out} \downarrow \Rightarrow V_{M2,G} \uparrow$

$\Rightarrow$ effective V_{in} driving $M_{1,G} \uparrow$

$\Rightarrow$ positive feedback.

(c) $V_{in} \uparrow \Rightarrow V_{out} \downarrow \Rightarrow V_{M1,G} \downarrow$

$\Rightarrow$ effective V_{in} driving $M_{1,G} \downarrow$

$\Rightarrow$ negative feedback.

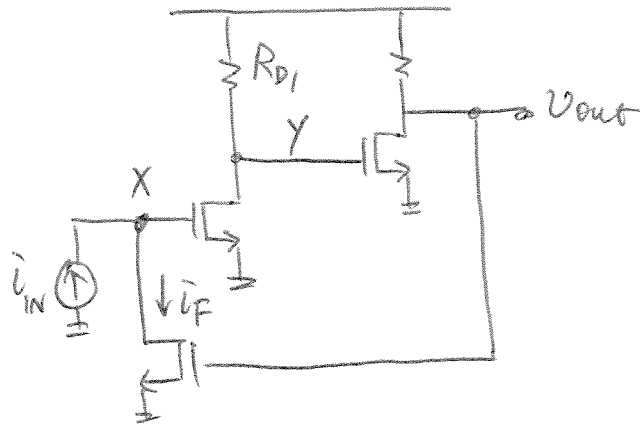
(d) $V_{in} \uparrow \Rightarrow V_{out} \uparrow$ (common-base, M_1)

$\Rightarrow V_{M1,S} \downarrow$

$\Rightarrow$ effective V_{in} driving $M_{1,S} \downarrow$

$\Rightarrow$ negative feedback.

24.



$i_{IN} \uparrow \Rightarrow v_X \uparrow \Rightarrow v_Y \downarrow \Rightarrow v_{OUT} \uparrow \Rightarrow i_F \uparrow$
 $\Rightarrow$ effective $v_X \downarrow$
 $\Rightarrow$ negative feedback.

25.

Figure 12.79

$\uparrow$ = increases by
 $\downarrow$ = decreases by

(a) $V_{in} \uparrow \Rightarrow V_{G,M3} \uparrow$

$\Rightarrow V_{out} \uparrow$ same amount (Emitter Follower)

$\Rightarrow$ effective $V_{in} (V_{G,M1} - V_{G,M2}) \downarrow$

$\Rightarrow$ Negative feedback.

(b) $V_{in} \uparrow \Rightarrow V_{G,M3} \uparrow$

$\Rightarrow V_{out} \uparrow$ by $\Delta V_{G,M3} \times g_{m3}(\Gamma_{O3} \parallel R_1)$

$\Rightarrow$ effective $V_{in} (V_{G,M1} - V_{G,M2}) \downarrow$

$\Rightarrow$ Negative feedback.

(c) Same as (b)

(d) Same as (a)

(e) $V_{in} \uparrow \Rightarrow V_{out} \uparrow$

$\Rightarrow V_{G,M2} \uparrow$ by $\Delta V_{out} \times \frac{R_2}{R_1 + R_2}$

$\Rightarrow$ effective $V_{in} (V_{G,M1} - V_{G,M2}) \downarrow$

$\Rightarrow$ Negative feedback.

- (f) $V_{in} \uparrow \Rightarrow V_{G,M_3} \uparrow$
 $\Rightarrow V_{out} \uparrow$ (Common-Source Stage)
 $\Rightarrow$ effective V_{in} ($V_{G,M_1} - V_{G,M_2}$) $\downarrow$
 $\Rightarrow$ Negative feedback.

Figure 12.80

- (a) $V_{in} \uparrow \Rightarrow V_{G,M_2} \uparrow$ (Common-Gate)
 $\Rightarrow V_{out} \uparrow$ (Source Follower)
 $\Rightarrow$ effective V_{eff} ($V_{in} - V_{out}$) $\downarrow$
 $\Rightarrow$ Negative feedback.
- (b) $V_{in} \uparrow \Rightarrow V_{G,M_2} \uparrow$ (Common-Gate)
 $\Rightarrow V_{out} \uparrow$ (Common Source)
 $\Rightarrow$ effective V_{eff} ($V_{in} - V_{out}$) $\downarrow$
 $\Rightarrow$ Negative feedback.
- (c) Same as (b)
- (d) $V_{in} \uparrow \Rightarrow V_{G,M_2} \uparrow$ (Common-Gate)
 $\Rightarrow V_{out} \uparrow$ (Common Source)
 $\Rightarrow$ effective V_{eff} ($V_{in} - V_{out}$) $\downarrow$
 $\Rightarrow$ Negative feedback.

Figure 12.81

(a) $V_{in} \uparrow \Rightarrow V_{G,M_2} \downarrow$ (Common Source)

$\Rightarrow V_{out} \uparrow$ (Source Follower)

$\Rightarrow$ effective V_{in} ($V_{in} - V_{out}$) $\uparrow$

$\Rightarrow$ Positive feedback.

(b) $V_{in} \uparrow \Rightarrow V_{G,M_2} \downarrow$ (Common Source)

$\Rightarrow V_{out} \uparrow$ (Common Source)

$\Rightarrow$ effective V_{in} ($V_{in} - V_{out}$) $\downarrow$

$\Rightarrow$ Negative feedback.

(c) Same as (b) ($V_{out} = I_{out} \times R_1$)

(d) $V_{in} \uparrow \Rightarrow V_{G,M_2}$ (Common Source)

$\Rightarrow V_{out} \uparrow$ (Common Source)

$\Rightarrow$ effective V_{in} ($V_{in} - V_{out}$) $\downarrow$

$\Rightarrow$ Negative feedback.

Figure 12.82

- (a) $\bar{i}_{in} \uparrow \Delta \Rightarrow V_{out} \downarrow$ (Common Source,
through current gain of M_1)
 $\Rightarrow \bar{i}_{D,M2} \downarrow$ (Source Follower, M_2)
 $\Rightarrow$ Counteracts the effect of $\bar{i}_{in}$
 $\Rightarrow$ Negative feedback.
- (b) $\bar{i}_{in} \uparrow \Delta \Rightarrow V_{out} \downarrow$ (Common Source,
through current gain of M_1)
 $\Rightarrow \bar{i}_{D,M2} \uparrow$ (Common Source, M_2)
 $\Rightarrow$ Enhances V_{out} through M_1
 $\Rightarrow$ Positive feedback.
- (c) $\bar{i}_{in} \uparrow \Delta \Rightarrow V_{out} \downarrow$ (Common Source,
through current gain of M_1)
 $\Rightarrow \bar{i}_{D,M2} \downarrow$ (Common Gate)
 $\Rightarrow$ Counteracts the effect of $\bar{i}_{in}$
 $\Rightarrow$ Negative feedback.
- (d) $\bar{i}_{in} \uparrow \Delta \Rightarrow V_{out} \uparrow$ (Common Gate)
 $\Rightarrow \bar{i}_{D,M2} \downarrow$ (Common Source)
 $\Rightarrow$ Counteracts the effect of $\bar{i}_{in}$
 $\Rightarrow$ Negative feedback.

Figure 12.83

(a) $\bar{i}_{IN} \uparrow \Delta \Rightarrow V_{out} \downarrow$ (Common Emitter)

$\Rightarrow R_F$ demands more current momentarily

$\Rightarrow$ effective $\bar{i}_{IN}$ into $Q_1 \downarrow$

$\Rightarrow V_{out} \uparrow$

$\Rightarrow$ Negative feedback.

(b) $\bar{i}_{IN} \uparrow \Delta \Rightarrow V_{G1, M3} \uparrow$ (Diff Pair Action)

$\Rightarrow V_{out} \uparrow$ (Source Follower)

$\Rightarrow V_{out}$ "tracks" behavior of $\bar{i}_{IN}$

(Current demanded by R_F from $\bar{i}_{IN} \uparrow$)

$\Rightarrow$ Positive feedback.

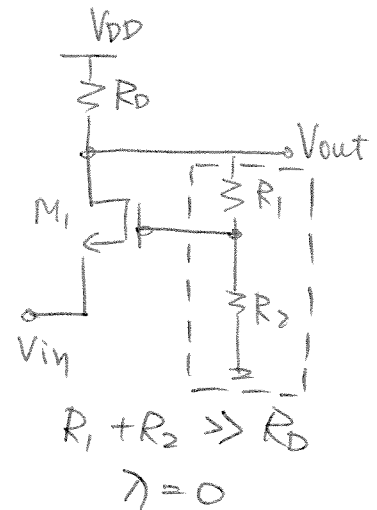
26.

(Without feedback)

$$\frac{V_{out}}{V_{in}} = A_{o.L.} = g_m R_D$$

Feedback factor, k :

$$k = \frac{R_2}{R_1 + R_2}$$



$$\Rightarrow A_{c.L.} = \left. \frac{V_{out}}{V_{in}} \right|_{c.L.} = \frac{A_{o.L.}}{1 + A_{o.L.} \cdot k} = \frac{g_m R_D}{1 + \frac{R_2}{R_1 + R_2} g_m R_D}$$

$$R_{in, closed} = \frac{1}{g_{m1}} \left(1 + \frac{R_2}{R_1 + R_2} g_m R_D \right)$$

$$R_{out, closed} = \frac{R_D}{1 + \frac{R_2}{R_1 + R_2} g_m R_D}$$

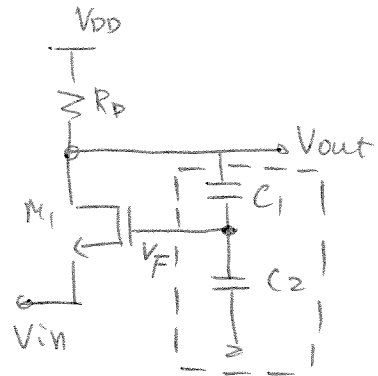
27.

(Without feedback)

$$A_{o.L.} = g_m R_D$$

Feedback factor, k :

$$k = \frac{C_1}{C_1 + C_2}$$



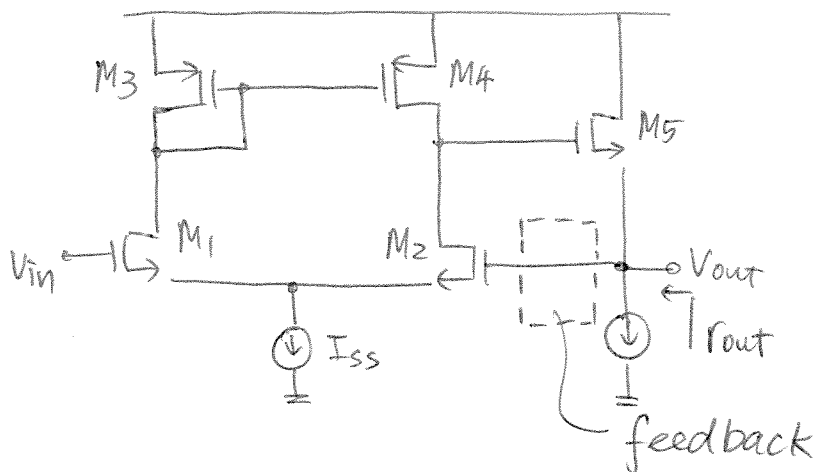
$\lambda = 0$
 C_1, C_2 small.

$$\Rightarrow A_{c.L.} = \left. \frac{V_{out}}{V_{in}} \right|_{c.L.} = \frac{A_{o.L.}}{1 + A_{o.L.} k} = \frac{g_m R_D}{1 + \frac{C_1}{C_1 + C_2} g_m R_D}$$

$$R_{in, closed} = \frac{1}{g_m} \left[1 + \frac{C_1}{C_1 + C_2} g_m R_D \right]$$

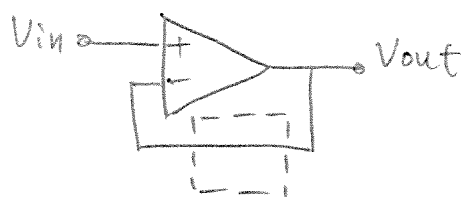
$$R_{out, closed} = \frac{R_D}{1 + \frac{C_1}{C_1 + C_2} g_m R_D}$$

28.



$\lambda > 0$
 r_{out} low.

Note that V_{out} is directly fed back to input:



$\therefore$ gain ≈ 1
 (a buffer)
 $\Rightarrow k = 1.$

A_{OL} (i.e. without feedback)

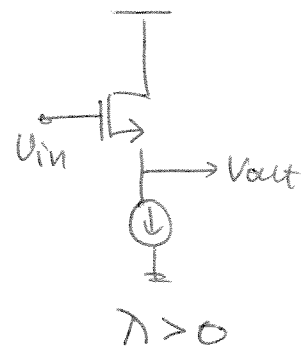
$$= g_{m1} (r_{o2} \parallel r_{o4}) \times \frac{g_{m5} r_{o5}}{g_{m5} r_{o5} + 1} \left(\approx g_{m1} (r_{o2} \parallel r_{o4}) \right)$$

$$\Rightarrow A_{CL} = \frac{A_{OL}}{1 + A_{OL} \cdot k} = \frac{g_{m1} (r_{o2} \parallel r_{o4}) \left(\frac{g_{m5} r_{o5}}{g_{m5} r_{o5} + 1} \right)}{1 + g_{m1} (r_{o2} \parallel r_{o4}) \left(\frac{g_{m5} r_{o5}}{g_{m5} r_{o5} + 1} \right)}$$

$$r_{out} = \frac{r_{out}(\text{no feedback})}{1 + A_{OL} \cdot k} = \frac{\left(\frac{1}{g_{m5}} \parallel r_{o5} \right)}{1 + g_{m1} (r_{o2} \parallel r_{o4}) \left(\frac{g_{m5} r_{o5}}{g_{m5} r_{o5} + 1} \right)}$$

$$\text{Gain} = A = \frac{g_m r_o}{g_m r_o + 1}$$

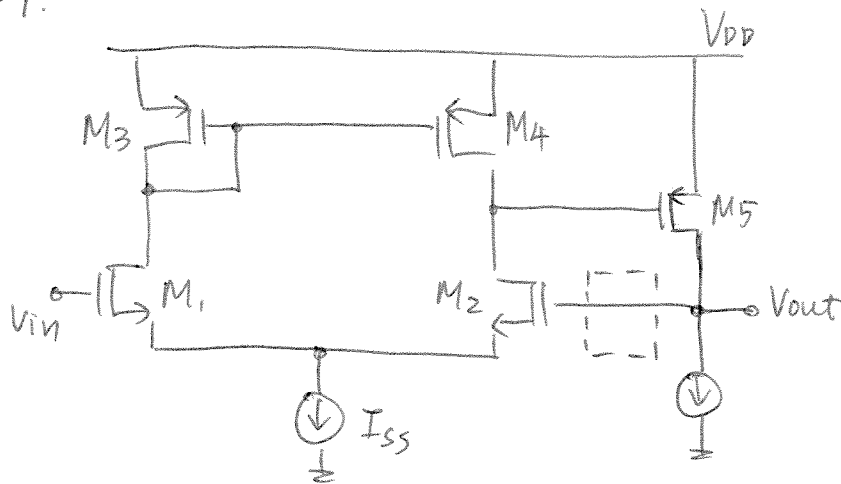
$$r_{out} = \frac{1}{g_m} \parallel r_o$$



In comparison, the amplifier's gain is reduced by $\frac{g_{m1}(r_{o2} \parallel r_{o4})}{1 + g_{m1}(r_{o2} \parallel r_{o4}) \left(\frac{g_{m5} r_{o5}}{g_{m5} r_{o5} + 1} \right)}$ times.

($= \frac{A_{c.L.}}{A}$). Output resistance of the amplifier is reduced by $\left[1 + g_{m1}(r_{o2} \parallel r_{o4}) \left(\frac{g_{m5} r_{o5}}{g_{m5} r_{o5} + 1} \right) \right]$ times.

29.



(a) By inspection,

$$V_{in} \uparrow \Rightarrow V_{G, M5} \uparrow$$

$$\Rightarrow \underline{V_{out} \downarrow} \quad (\text{Common Source})$$

$$\Rightarrow \text{effective } V_{in} (V_{in} - V_{out}) \uparrow \Rightarrow V_{G, M5} \uparrow$$

$\Rightarrow$ Positive feedback.

(b) $A_{o.L.}$ (without feedback)

$$= g_{m1} (r_{o2} \parallel r_{o4}) \times (-g_{m5} r_{o5})$$

$$K \text{ (feedback factor)} = 1$$

$$\Rightarrow \text{loop gain} = A_{o.L.} \times K = -g_{m5} r_{o5} \times g_{m1} (r_{o2} \parallel r_{o4})$$

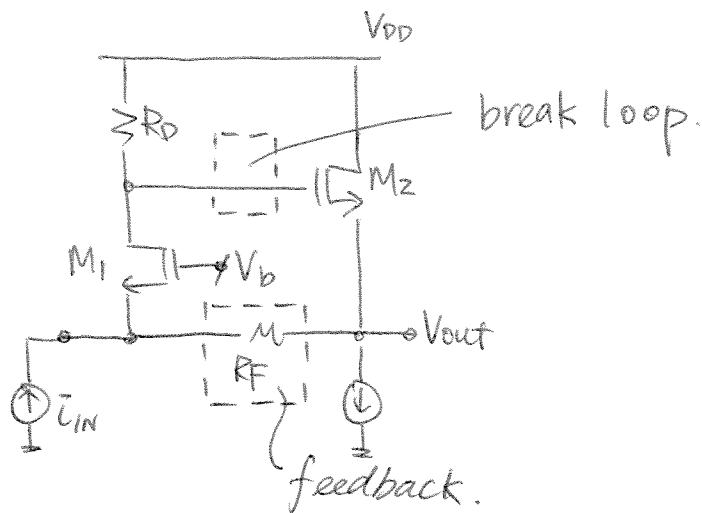
$\Rightarrow A_{c.L.}$ becomes negative $\Rightarrow$ Positive feedback.

$$A_{o.L.} \text{ (without feedback)} = -g_{m_1}(r_{o_1} \parallel r_{o_3}) \times (-g_{m_5}r_{o_5}) = g_{m_1}g_{m_5}(r_{o_1} \parallel r_{o_3})r_{o_5}$$

$$r_{in} \rightarrow \infty$$

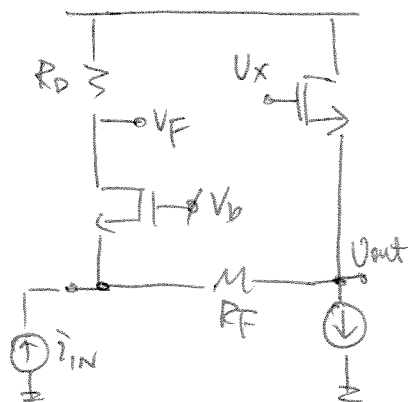
$$r_{out} = \frac{r_{out}(\text{no feedback})}{1 + A_{o.L.} \times K} = \frac{r_{o5}}{1 + g_{m1} g_{m5} (r_{o1} || r_{o3}) r_{o5}}$$

31.



- (a) $i_{IN} \uparrow \Rightarrow V_{G, M2} \uparrow$ (Common Gate; i_{IN} mostly flows to M_1 $\because$ resistance $= \frac{1}{g_m}$)
 $\Rightarrow V_{out} \uparrow$ (Source Follower)
 $\Rightarrow R_F$ momentarily provides more current to source of M_1)
 $\Rightarrow V_{G, M2} \uparrow$
 $\Rightarrow$ Positive feedback.

(b)



$$V_F = V_X \frac{g_{m1} R_D}{1 + g_{m2} (R_F + \frac{1}{g_{m1}})}$$

$$\Rightarrow -\frac{V_F}{V_X} = \text{Loop Gain} = - \frac{g_{m1} R_D}{1 + g_{m2} (R_F + \frac{1}{g_{m1}})}$$

$\therefore$ feedback is positive.

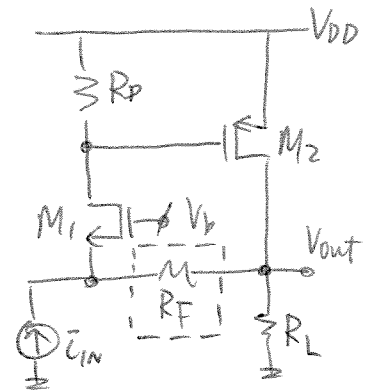
32.

(a) $\bar{v}_{IN} \uparrow \Delta \Rightarrow \Delta \bar{v}_{IN}$ mostly
flows in $\frac{1}{g_{m1}} \Rightarrow V_{G,M2} \uparrow$
(Common Gate)

$\Rightarrow V_{out} \downarrow$ (Common Source)

$\Rightarrow R_F$ momentarily demands
more current from $\bar{v}_{IN}$

$\Rightarrow$ Negative feedback.



$$\lambda = 0$$

$$R_F \gg 1.$$

$$(b) R_{o.L.} = \left. \frac{V_{out}}{\bar{v}_{IN}} \right|_{o.L.} = -R_D \times g_{m2} R_L$$

$$(c) \kappa \text{ (feedback factor)} = \frac{-1}{R_F}$$

$$\Rightarrow R_{c.L.} = \frac{R_{o.L.}}{1 + R_{o.L.} \times \kappa} = \frac{-R_D \times g_{m2} R_L}{1 + \frac{R_D}{R_F} g_{m2} R_L}$$

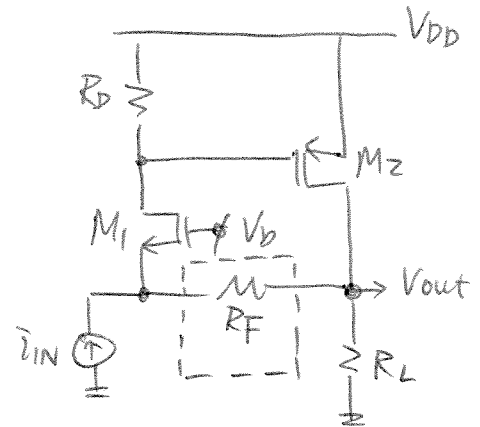
33.

$$R_{e.L.} = \frac{-g_{m2} R_D R_L}{1 + \frac{g_{m2} R_D R_L}{R_F}}$$

$$\text{loop gain} = \frac{g_{m2} R_D R_L}{R_F}$$

$$r_{in} \approx \frac{1}{g_{m1}}$$

$$\Rightarrow r_{in|c.L.} = \frac{1/g_{m1}}{1 + \frac{g_{m2} R_D R_L}{R_F}}$$



$$r_{out} \approx R_L \quad (R_F \text{ large})$$

$$r_{out|c.L.} = \frac{R_L}{1 + \frac{g_{m2} R_D R_L}{R_F}}$$

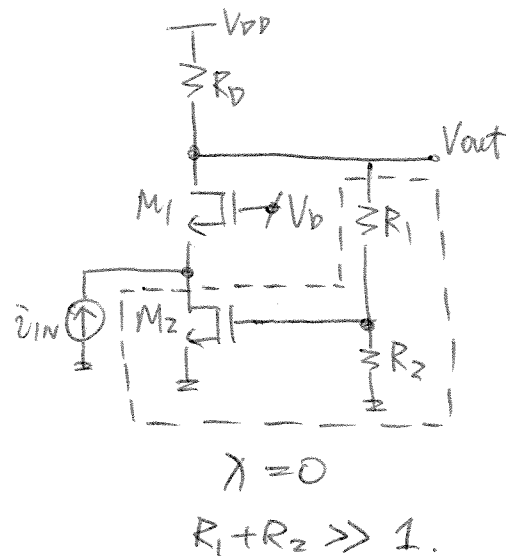
34.

$$R_{o.L.} = \frac{V_{out}}{\tilde{v}_{IN}} \text{ (no feedback)}$$

$$= R_D$$

K (feedback factor)

$$= g_{m2} \times \frac{R_2}{R_1 + R_2}$$



$$\Rightarrow R_{c.L.} = \frac{V_{out}}{\tilde{v}_{IN}} = \frac{R_D}{1 + R_D \times g_{m2} \frac{R_2}{R_1 + R_2}}$$

$$r_{in|c.L.} = \frac{1/g_{m1}}{1 + R_D \times g_{m2} \frac{R_2}{R_1 + R_2}}$$

$$r_{out|c.L.} = \frac{R_D}{1 + R_D \times g_{m2} \frac{R_2}{R_1 + R_2}}$$

35.

$$R_{o.L.} = \frac{V_{out}}{\bar{v}_{in}} \text{ (no feedback)}$$

$$= R_D$$

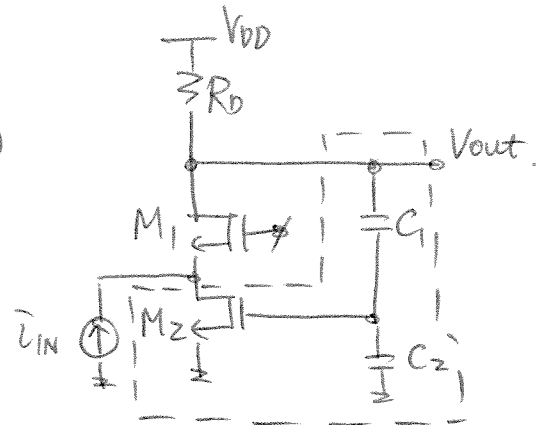
K (feedback factor)

$$= g_{m2} \times \frac{C_1}{C_1 + C_2}$$

$$\Rightarrow R_{c.L.} = \frac{V_{out}}{\bar{v}_{in}} = \frac{R_D}{1 + R_D \times g_{m2} \frac{C_1}{C_1 + C_2}}$$

$$\Gamma_{in|c.L.} = \frac{g_{m1}}{1 + R_D \times g_{m2} \frac{C_1}{C_1 + C_2}}$$

$$\Gamma_{out|c.L.} = \frac{R_D}{1 + R_D \times g_{m2} \frac{C_1}{C_1 + C_2}}$$



3b.

$$(a) G_{OL} = \frac{i_{out}}{v_{in}} = g_m A_1$$

(common emitter)

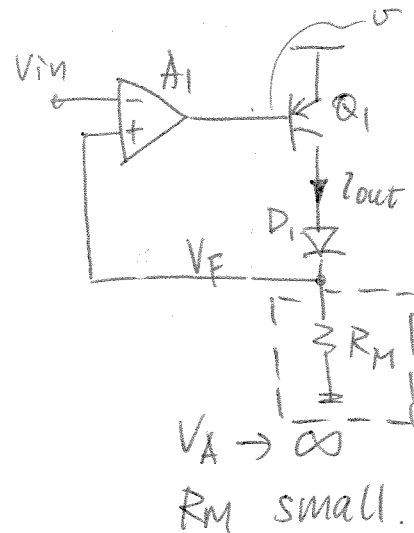
(b) K (feedback factor)

$$\Rightarrow V_F = i_{out} \times R_M$$

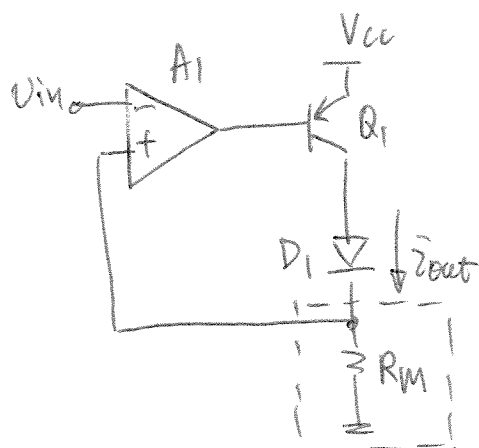
$$\Rightarrow K = \frac{V_F}{i_{out}} = R_M$$

$$\therefore \text{Loop Gain} = G_{OL} K = g_m A_1 R_M$$

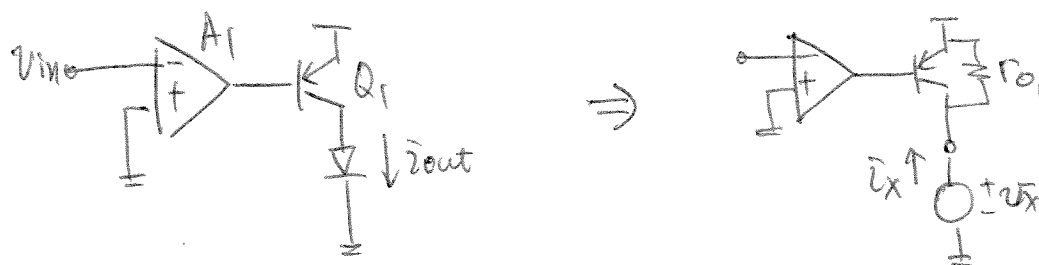
$$G_{CL} = \frac{G_{OL}}{1 + G_{OL} K} = \frac{g_m A_1}{1 + g_m A_1 R_M}$$



37.



Since R_M is small, the following circuit results:

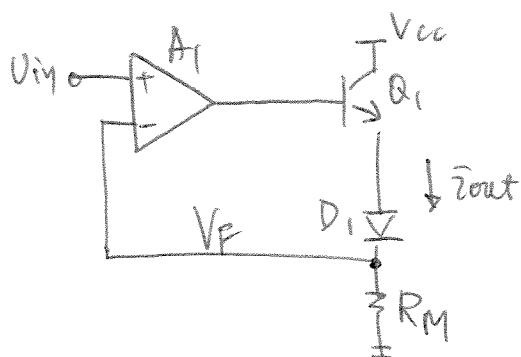


$$\therefore R_{out, OPEN} = \frac{V_x}{i_x} = r_{o1}$$

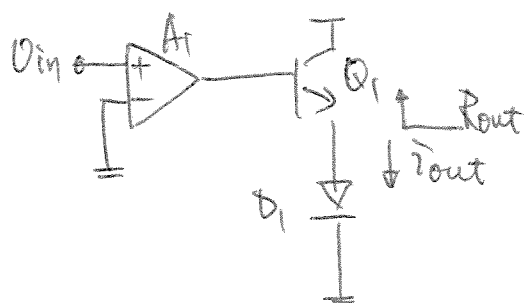
$$G_{OL} = \frac{i_{out}}{v_{in}} = A_1 g_{m1} \quad k = R_M$$

$$\begin{aligned} \therefore R_{out, CLOSED} &= R_{out, OPEN} (1 + G_{OL} k) \\ &= r_{o1} (1 + A_1 g_{m1} R_M) \end{aligned}$$

38.



Since R_M is small, the open-loop equivalent becomes the following:



$$G_{OL} = \frac{i_{out}}{V_{in}} \approx A_1 g_{m1}$$

$$R_{out} = \frac{r_T}{\beta + 1} \approx \frac{1}{g_{m1}}$$

$$K = \frac{V_F}{i_{out}} = R_M$$

$$\Rightarrow G_{CL} = \frac{G_{OL}}{1 + G_{OL}K} = \frac{A_1 g_{m1}}{1 + g_{m1} A_1 R_M}$$

$$\text{Loop Gain} = G_{OL}K = g_{m1} A_1 R_M$$

$$R_{out, \text{closed}} = \frac{1}{g_{m1}} (1 + g_{m1} A_1 R_M)$$

This circuit provides a much lower output resistance which in general is non-desirable (ideally any current source should have high impedance.)

39.

Using procedure in Ex 12.21

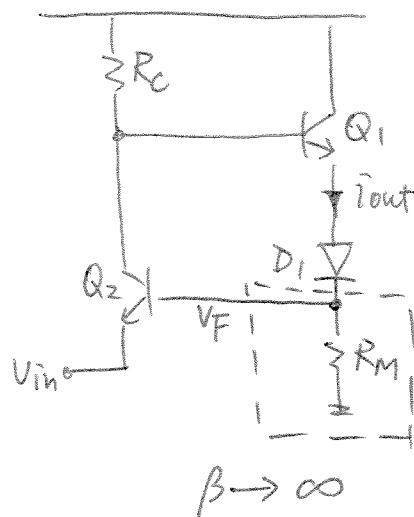
$$G_{o.l.} = \frac{\bar{i}_{out}}{V_{in}} = g_{m2} R_C \times g_{m1}$$

K (feedback factor)

$$= \frac{V_F}{\bar{i}_{out}} = R_M$$

$$\Rightarrow \text{loop gain} = G_{o.l.} \times K = g_{m1} g_{m2} R_C R_M$$

$$\Rightarrow \text{closed-loop gain } G_{c.l.} = \frac{g_{m1} g_{m2} R_C}{1 + g_{m1} g_{m2} R_C R_M}$$



Using procedure in Ex. 12.22

$$G_{o.L.} = g_{m1} g_{m2} R_C$$

$$K = R_M$$

$$r_{in}|_{o.L.} = \frac{1}{g_{m1}}$$

$$r_{out}|_{o.L.} \cong \frac{1}{g_{m2}}$$

$$r_{in}|_{c.L.} = \frac{1}{g_{m1}} (1 + g_{m1} g_{m2} R_C R_M)$$

$$r_{out}|_{c.L.} = \frac{1}{g_{m2}} (1 + g_{m1} g_{m2} R_C R_M)$$

40.

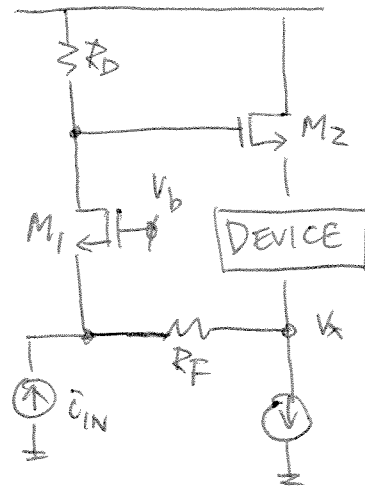
(a) $\bar{i}_{IN} \uparrow \Delta \Rightarrow$ Most of $\bar{i}_{IN}$ flows into $1/g_{m1}$

$\Rightarrow V_{G,M2} \uparrow$ (Common Gate)

$\Rightarrow V_x \uparrow$ (Source Follower)

$\Rightarrow R_F$ momentarily provides more current to Source of M_1

$\Rightarrow V_{G,M2} \uparrow \Rightarrow$ Positive feedback.

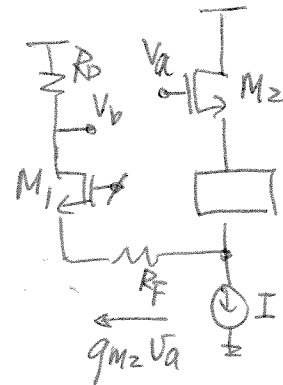


(b)

$$V_a \times g_{m2} \times R_D = V_b$$

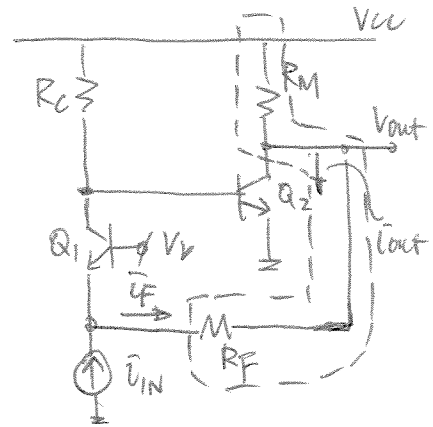
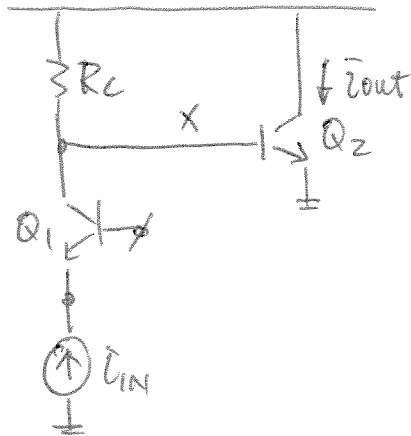
$$\Rightarrow \text{loop gain} = -\frac{V_b}{V_a} = -g_{m2} R_D.$$

Since loop gain is negative, feedback is positive.



41.

(a) The open-loop equivalent becomes:



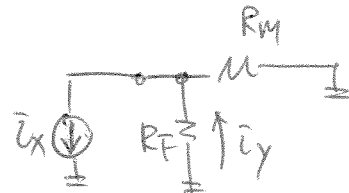
$V_A \rightarrow \infty$
 R_M small
 R_F large

$$A_I = \frac{\bar{i}_{out}}{\bar{i}_{IN}} = \frac{\bar{i}_{out}}{v_x} \times \frac{v_x}{\bar{i}_{IN}} \approx g_{m2} \times R_C$$

$$R_{in, OPEN} \approx \frac{1}{g_{m1}}$$

$$R_{out, OPEN} \rightarrow \infty \quad (\because V_{A2} \rightarrow \infty)$$

$$K = \frac{\bar{i}_y}{\bar{i}_x} = + \frac{(R_F \parallel R_M)}{R_F}$$

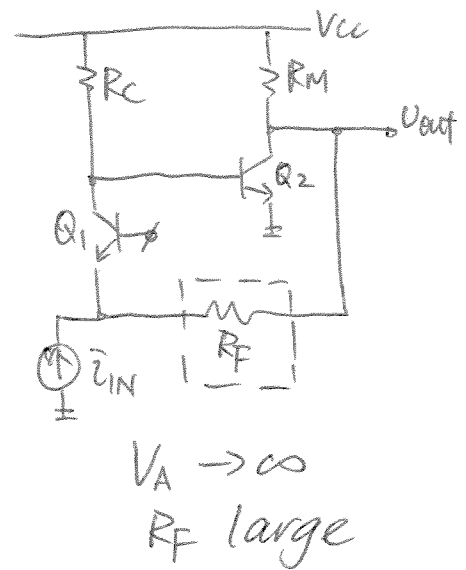
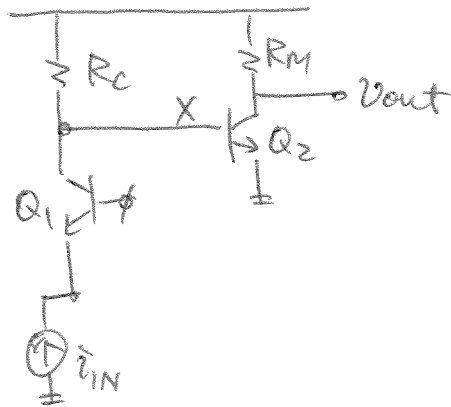


$$A_{CL} = \frac{A_I}{1 + A_I K} = \frac{g_{m2} R_C}{1 + g_{m2} R_C \frac{(R_F \parallel R_M)}{R_F}}$$

$$R_{in, CLOSED} = \frac{\frac{1}{g_{m1}}}{1 + g_{m2} R_C \frac{(R_F \parallel R_M)}{R_F}}$$

$$R_{out, CLOSED} \rightarrow \infty$$

(b) The open-loop equivalent becomes:



$$R_{OL} = \frac{V_{out}}{i_{IN}} = \frac{V_{out}}{V_X} \times \frac{V_X}{i_{IN}} \cong -g_{m2} R_M \times R_C$$

$$R_{in, OPEN} = \frac{1}{g_{m1}}$$

$$R_{out, OPEN} = R_M$$

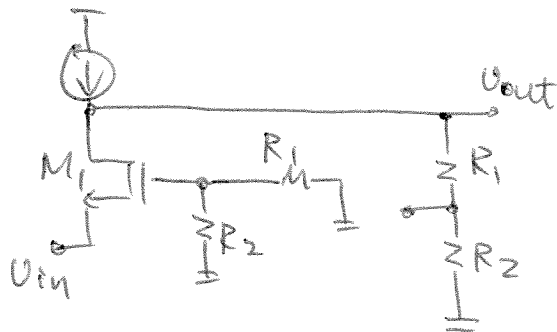
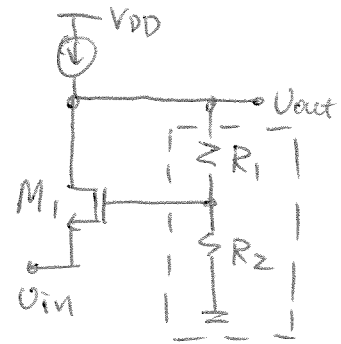
$$K = -\frac{1}{R_M}$$

$$R_{CL} = \frac{R_{OL}}{1 + R_{OL} K} = \frac{-g_{m2} R_M R_C}{1 + g_{m2} R_C}$$

$$R_{in, CLOSED} = \frac{1/g_{m1}}{1 + g_{m2} R_C}$$

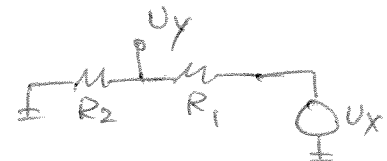
$$R_{out, CLOSED} = \frac{R_M}{1 + g_{m2} R_C}$$

42. Breaking the feedback network results in the following circuit:



Feedback factor

$$= K = \frac{V_y}{V_x} = \frac{R_2}{R_1 + R_2}$$



$$A_{o.L.} = +g_{m1}(R_1 + R_2)$$

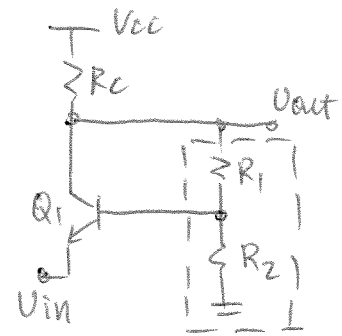
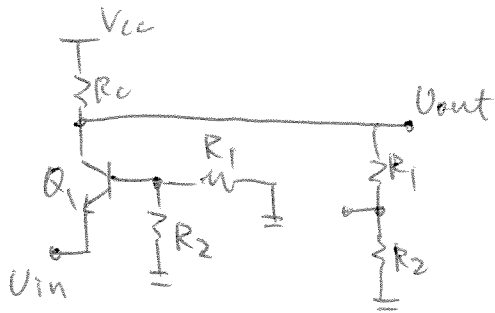
$$\text{Loop Gain} = A_{o.L.} K = g_{m1} R_2$$

$$\therefore A_{c.L.} = \frac{A_{o.L.}}{1 + A_{o.L.} K} = \frac{g_{m1}(R_1 + R_2)}{1 + g_{m1} R_2}$$

$$R_{in, \text{closed}} = \frac{1}{g_{m1}} (1 + g_{m1} R_2)$$

$$R_{out, \text{closed}} = \frac{R_1 + R_2}{1 + g_{m1} R_2}$$

43. Breaking the feedback network results in the following circuit:



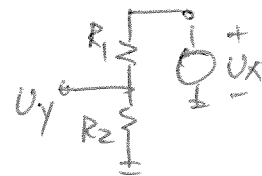
$$V_A \rightarrow \infty$$

$$1 \ll \beta < \infty$$

$$A_{OL} \approx g_{m1} [R_c \parallel (R_1 \parallel R_2)] \quad \text{since } \bar{v}_b \rightarrow 0 \ (\beta \gg 1)$$

Feedback factor

$$= k = \frac{U_Y}{U_X} = \frac{R_2}{R_1 + R_2}$$



$$R_{in, OPEN} = \frac{r_{\pi 1} + (R_1 \parallel R_2)}{\beta_1 + 1} \approx \frac{1}{g_{m1}} + \frac{R_1 \parallel R_2}{\beta_1 + 1}$$

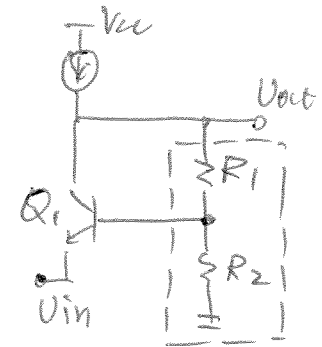
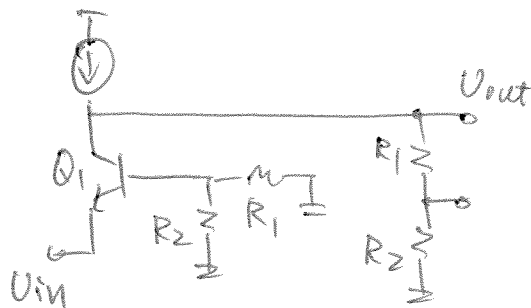
$$R_{out, OPEN} = R_c \parallel (R_1 + R_2)$$

$$\Rightarrow A_{CL} = \frac{A_{OL}}{1 + A_{OL}k} = \frac{g_{m1} [R_c \parallel (R_1 + R_2)]}{1 + g_{m1} [R_c \parallel (R_1 + R_2)] \times \frac{R_2}{R_1 + R_2}}$$

$$R_{in, CLOSED} = \left(\frac{1}{g_{m1}} + \frac{R_1 \parallel R_2}{\beta_1 + 1} \right) (1 + A_{OL}k)$$

$$R_{out, CLOSED} = \frac{R_c \parallel (R_1 + R_2)}{1 + A_{OL}k}$$

44. Breaking the feedback network results in the following circuit:



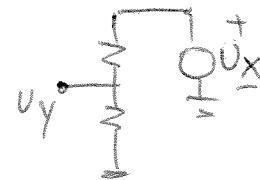
$$V_A \rightarrow \infty$$

$$1 \ll \beta < \infty$$

$$A_{OL} \cong g_{m1} (R_1 + R_2) \quad \text{since } i_b \rightarrow 0 (\beta \gg 1)$$

Feedback factor

$$= K = \frac{V_Y}{V_X} = \frac{R_2}{R_1 + R_2}$$



$$R_{in, OPEN} \cong \frac{1}{g_{m1}} + \frac{R_1 \parallel R_2}{\beta_1 + 1}$$

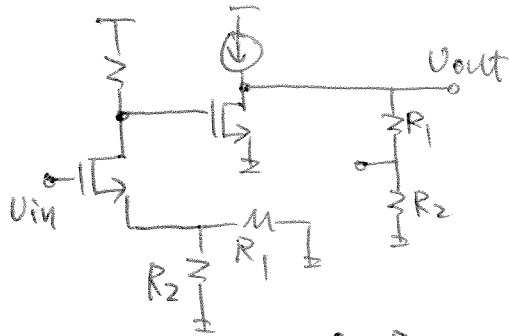
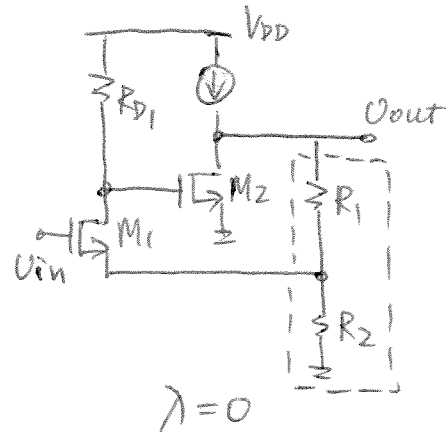
$$R_{out, OPEN} = R_1 + R_2$$

$$\Rightarrow A_{CL} = \frac{A_{OL}}{1 + A_{OL}K} = \frac{g_{m1} (R_1 + R_2)}{1 + g_{m1} R_2}$$

$$R_{in, CLOSED} = \left(\frac{1}{g_{m1}} + \frac{R_1 \parallel R_2}{\beta_1 + 1} \right) (1 + g_{m1} R_2)$$

$$R_{out, CLOSED} = \frac{R_1 + R_2}{1 + g_{m1} R_2}$$

45. Breaking the feedback network results in the following circuit:

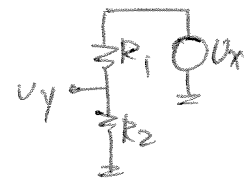


$$A_{OL} = \frac{-g_{m1} R_{D1}}{1 + g_{m1}(R_1 \parallel R_2)} \times -g_{m2}(R_1 + R_2)$$

$$K = \frac{V_Y}{V_X} = \frac{R_2}{R_1 + R_2}$$

$$R_{in, OPEN} \rightarrow \infty$$

$$R_{out, OPEN} = R_1 + R_2$$

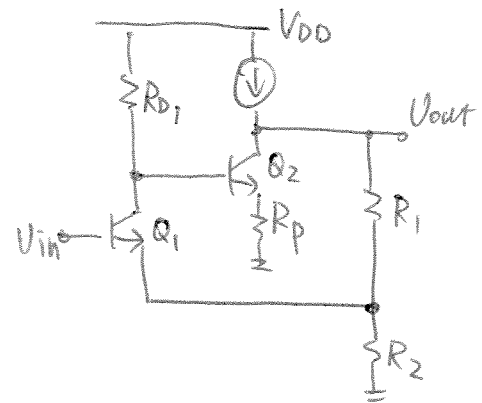
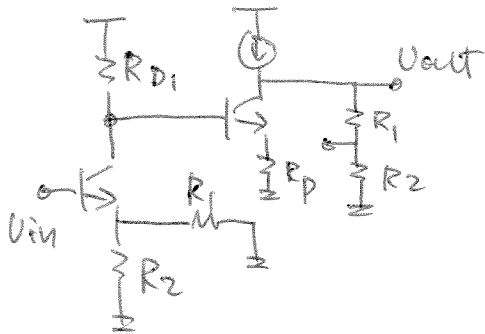


$$\therefore A_{CL} = \frac{A_{OL}}{1 + A_{OL}K} = \frac{\left[\frac{g_{m1} g_{m2} R_{D1} (R_1 + R_2)}{1 + g_{m1}(R_1 \parallel R_2)} \right]}{1 + \frac{g_{m1} g_{m2} R_{D1}}{1 + g_{m1}(R_1 \parallel R_2)}}$$

$$R_{in, CLOSED} \rightarrow \infty$$

$$R_{out, CLOSED} = \frac{R_1 + R_2}{1 + A_{OL}K}$$

4b. Breaking the feedback network results in the following circuit:

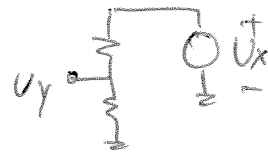


$$A_{OL} \cong \frac{-g_{m1} \times \{R_{D1} \parallel [\Gamma_{\pi 2} + (\beta_2 + 1)R_p]\}}{1 + g_{m1}(R_1 \parallel R_2)} \times \frac{-g_{m2}(R_1 + R_2)}{1 + g_{m2}R_p}$$

$$R_{in, OPEN} = \Gamma_{\pi 1} + (R_1 \parallel R_2)$$

$$R_{out, OPEN} = R_1 + R_2$$

$$K = \frac{V_Y}{V_X} = \frac{R_2}{R_1 + R_2}$$

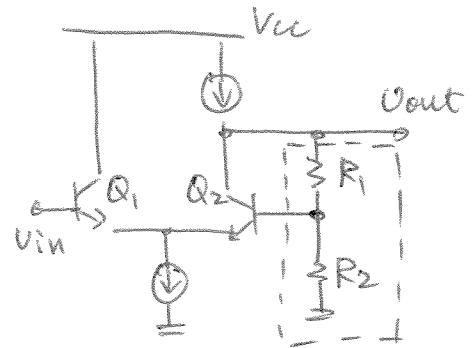


$$\Rightarrow A_{CL} = \frac{A_{OL}}{1 + A_{OL}K}$$

$$R_{in, CLOSED} = [\Gamma_{\pi 1} + (R_1 \parallel R_2)] (1 + A_{OL}K)$$

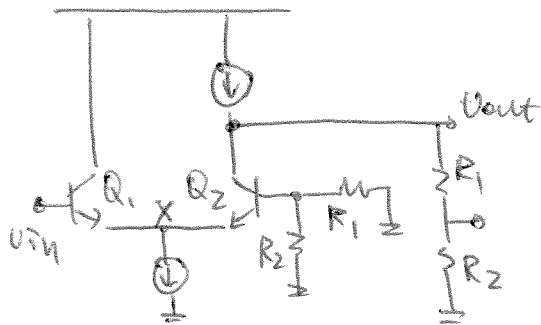
$$R_{out, CLOSED} = \frac{R_1 + R_2}{1 + A_{OL}K}$$

47. Breaking the feedback network results in the following circuit:



$(V_A \rightarrow \infty)$

$$K = \frac{R_2}{R_1 + R_2}$$



$$A_{OL} \cong \frac{g_{m1} \left(\frac{1}{g_{m2}} + \frac{R_1 \parallel R_2}{\beta_2 + 1} \right)}{1 + g_{m1} \left(\frac{1}{g_{m2}} + \frac{R_1 \parallel R_2}{\beta_2 + 1} \right)} \times \frac{g_{m2} (R_1 + R_2)}{1}$$

emitter follower
(Q_1) = $\frac{V_x}{V_{in}}$

common-base
stage (Q_2) = $\frac{V_{out}}{V_x}$

$$R_{in, OPEN} = r_{\pi 1} + (\beta_1 + 1) \left(\frac{1}{g_{m2}} + \frac{R_1 \parallel R_2}{\beta_2 + 1} \right)$$

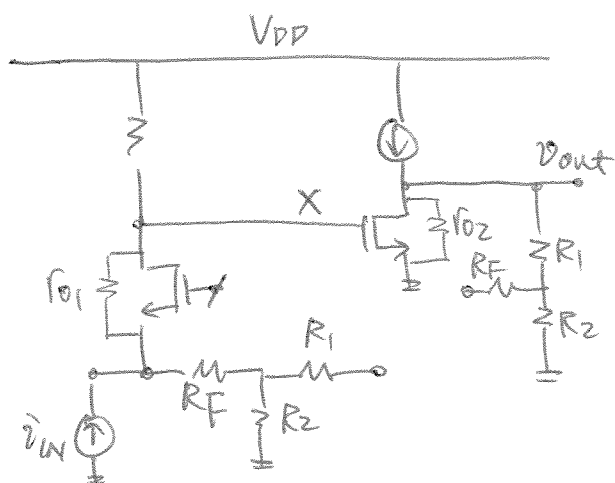
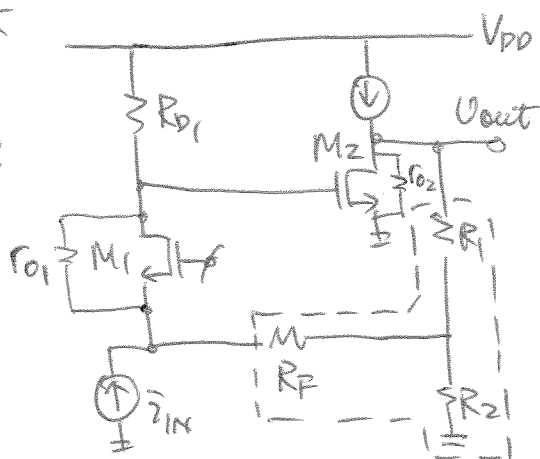
$$R_{out, OPEN} = R_1 + R_2$$

$$\therefore A_{CL} = \frac{A_{OL}}{1 + A_{OL} K}$$

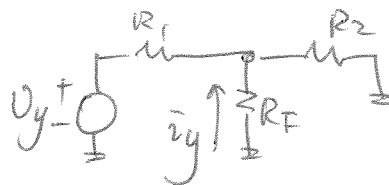
$$R_{in, CLOSED} = \left[r_{\pi 1} + (\beta_1 + 1) \left(\frac{1}{g_{m2}} + \frac{R_1 \parallel R_2}{\beta_2 + 1} \right) \right] \times (1 + A_{OL} K)$$

$$R_{out, CLOSED} = \frac{R_1 + R_2}{1 + A_{OL} K}$$

48. Breaking the feedback network results in the following circuit:



$$K = - \frac{(R_F \parallel R_2) / R_F}{R_F \parallel R_2 + R_1}$$



$$R_{OL} = \frac{V_{out}}{i_{IN}} = \frac{V_{out}}{V_X} \times \frac{V_X}{i_{IN}}$$

$$= -g_{m2} [r_{o2} \parallel (R_1 + R_2)] \times \left\{ \frac{\frac{1}{r_{o1}} + \frac{1}{R_{D1}}}{\frac{1}{r_{o1}} + g_{m1}} \times \left[\frac{1}{(R_F + R_2) \parallel \frac{1}{g_{m1}}} + \frac{1}{r_{o1}} \right] - \frac{1}{r_{o1}} \right\}$$

$$R_{in, OPEN} \cong \frac{1}{g_{m1}} \parallel (R_F + R_2) \parallel \frac{r_{o1}}{1 - g_{m1} R_{D1}}$$

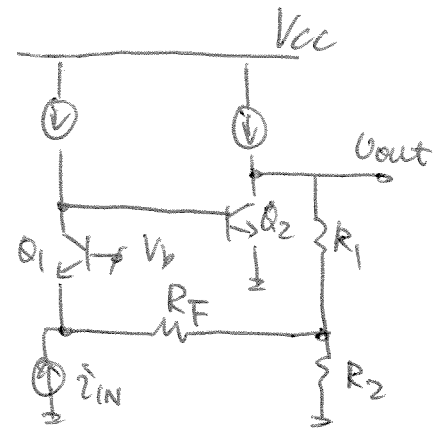
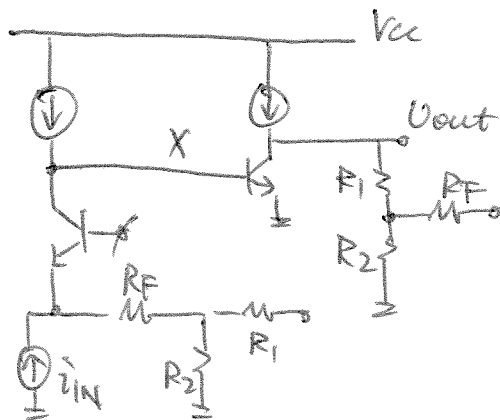
$$R_{out, OPEN} = r_{o2} \parallel (R_1 + R_2)$$

$$R_{CL} = \frac{R_{OL}}{1 + R_{OL} K}$$

$$R_{in, CLOSED} = \frac{R_{in, OPEN}}{1 + R_{OL} K}$$

$$R_{out, CLOSED} = \frac{R_{out, OPEN}}{1 + R_{OL} K}$$

49. Breaking the feedback network results in the following circuit:

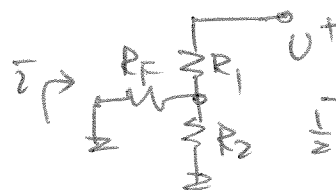


$$R_{OL} = \frac{V_{out}}{i_{IN}} = \frac{V_{out}}{V_X} \times \frac{V_X}{i_{IN}} = [-g_{m2}(R_1 + R_2)] \times [g_{m1}, r_{\pi2} \left\{ \frac{1}{g_{m1}} \parallel (R_F + R_2) \right\}]$$

$$R_{in, OPEN} = \frac{1}{g_{m1}} \parallel (R_F + R_2)$$

$$R_{out, OPEN} = R_1 + R_2$$

$$K = \frac{\tilde{v}}{v} = - \frac{(R_2 \parallel R_F) / R_F}{R_1 + (R_2 \parallel R_F)}$$



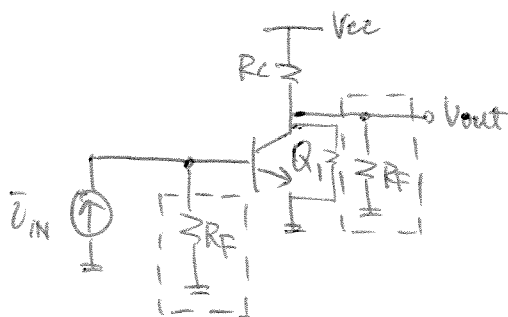
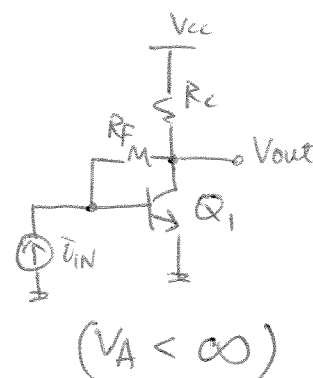
$$\therefore R_{CL} = \frac{R_{OL}}{1 + R_{OL}K}$$

$$R_{in, CLOSED} = \frac{\frac{1}{g_{m1}} \parallel (R_F + R_2)}{1 + R_{OL}K}$$

$$R_{out, CLOSED} = \frac{R_1 + R_2}{1 + R_{OL}K}$$

50. The feedback network consists of R_F .

Using the method discussed in lecture, break the circuit as follows:



This is the open-loop circuit with consideration of I/O loading.

- By inspection,

$$V_{out} = \bar{v}_c \times (R_C \parallel R_F \parallel r_o) \\ = -g_m (\bar{v}_{in} \times (R_F \parallel r_\pi)) \times (R_C \parallel R_F \parallel r_o)$$

$$\Rightarrow R_{o.L.} = \frac{V_{out}}{\bar{v}_{in}} = -g_m (R_F \parallel r_\pi) (R_C \parallel R_F \parallel r_o) \quad \text{--- (1)}$$

$$R_{in, open} = (R_F \parallel r_\pi) \quad R_{out, open} = (R_C \parallel R_F \parallel r_o)$$

- Feedback factor k :

$$k = \frac{v_x}{\bar{v}_x} = -\frac{1}{R_F}$$



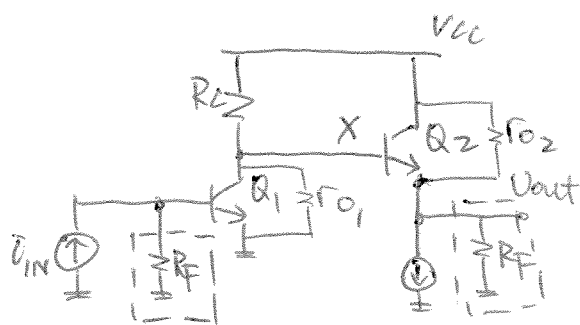
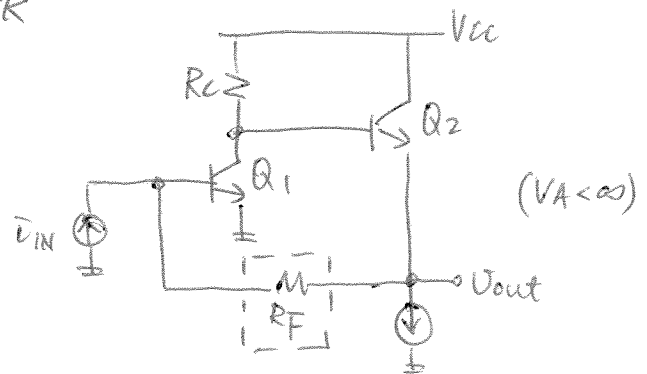
$$\therefore R_{c.L.} = \frac{R_{o.L.}}{1 + R_{o.L.} \times K} = \frac{-g_m(R_F \parallel r_{\pi})(R_C \parallel R_F \parallel r_o)}{1 + \frac{g_m(R_F \parallel r_{\pi})(R_C \parallel R_F \parallel r_o)}{R_F}}$$

$$R_{in, \text{CLOSED}} = \frac{(R_F \parallel r_{\pi})}{1 - \frac{R_{o.L.}}{R_F}} \quad R_{out, \text{CLOSED}} = \frac{(R_C \parallel R_F \parallel r_o)}{1 - \frac{R_{o.L.}}{R_F}}$$

where $R_{o.L.}$ is given by (1).

51. The feedback network consists of R_F .

Using the method discussed in lecture, break the circuit as follows :



This is the open-loop circuit with consideration of I/O loading.

- Gain of common-emitter stage:

$$\frac{v_X}{v_{IN}} = -g_{m1}(R_F \parallel r_{\pi 1}) \times \left\{ R_C \parallel r_{O1} \parallel [r_{\pi 2} + (\beta_2 + 1)(R_F \parallel r_{O2})] \right\}$$

- Gain of emitter-follower stage:

$$\frac{v_{OUT}}{v_X} = \frac{g_{m2}(R_F \parallel r_{O2})}{1 + g_{m2}(R_F \parallel r_{O2})}$$

$$\Rightarrow R_{o.L.} = \frac{v_X}{v_{IN}} \cdot \frac{v_{OUT}}{v_X}$$

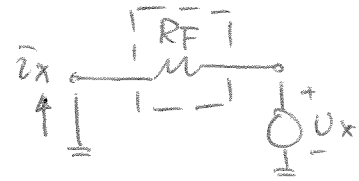
— (1)

$$R_{in, OPEN} = R_F \parallel r_{\pi 1}$$

$$R_{out, OPEN} \cong R_F \parallel r_{O2} \parallel \frac{1}{g_{m2}}$$

- Feedback factor k :

$$k = \frac{v_x}{\bar{v}_x} = -\frac{1}{R_F}$$



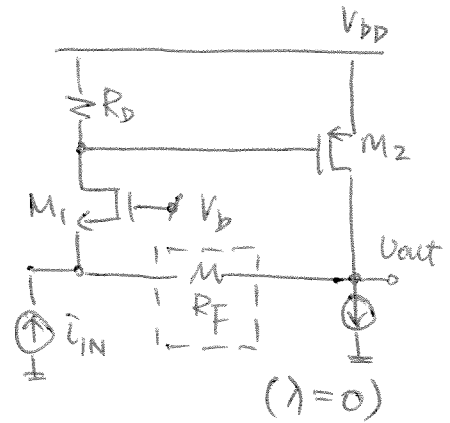
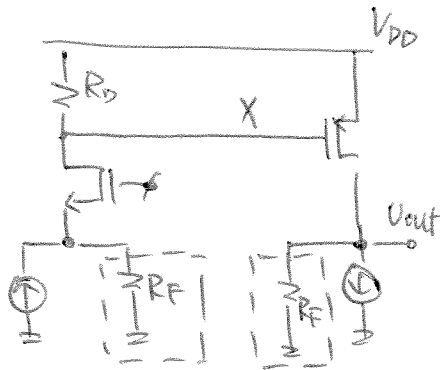
$$\therefore R_{o,L} = \frac{R_{o,L}}{1 + R_{o,L} \times k} = \frac{R_{o,L}}{1 - R_{o,L}/R_F}$$

$$R_{in,CLOSED} = \frac{(R_F \parallel \Gamma_{\pi_1})}{1 - \frac{R_{o,L}}{R_F}} \quad R_{out,CLOSED} = \frac{R_F \parallel r_{o2} \parallel \frac{1}{g_{m2}}}{1 - \frac{R_{o,L}}{R_F}}$$

where $R_{o,L}$ is given by (1).

52.

(a) Breaking the feedback loop results in the following circuit:



$$R_{o.L.} = \frac{V_x}{I_{IN}} \cdot \frac{V_{out}}{V_x}$$

$$= g_{m1} R_D \left(\frac{1}{g_{m1}} \parallel R_F \right) \times (-g_{m2} R_F)$$

$$R_{in, OPEN} = \frac{1}{g_{m1}} \parallel R_F$$

$$R_{out, OPEN} = R_F$$

- Feedback factor k :

$$k = \frac{V_x}{V_x} = -\frac{1}{R_F}$$

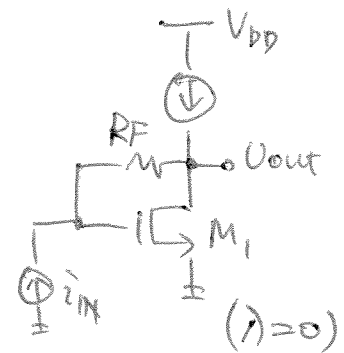
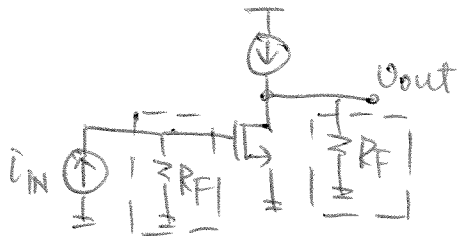


$$\Rightarrow R_{c.L.} = \frac{R_{o.L.}}{1 + R_{o.L.} \times k} = \frac{-g_{m1} g_{m2} R_D R_F \left(\frac{1}{g_{m1}} \parallel R_F \right)}{1 + g_{m1} g_{m2} R_D \left(\frac{1}{g_{m1}} \parallel R_F \right)}$$

$$R_{in, CLOSED} = \frac{\left(\frac{1}{g_{m1}} \parallel R_F \right)}{1 + g_{m1} g_{m2} R_D \left(\frac{1}{g_{m1}} \parallel R_F \right)}$$

$$R_{out, CLOSED} = \frac{R_F}{1 + g_{m1} g_{m2} R_D \left(\frac{1}{g_{m1}} \parallel R_F \right)}$$

(b) Breaking the feedback loop results in the following circuit:

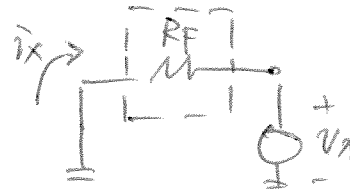


$$R_{o.L.} = \frac{V_{out}}{i_{IN}} = -g_m R_F R_F = -g_m R_F^2$$

$$R_{in, OPEN} = R_F \quad R_{out, OPEN} = R_F$$

- Feedback factor K :

$$K = \frac{V_x}{i_x} = -\frac{1}{R_F}$$

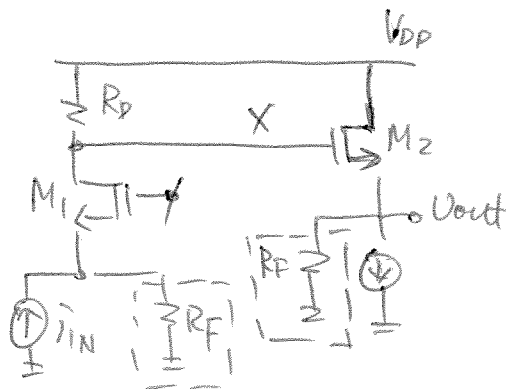


$$\Rightarrow R_{c.L.} = \frac{-g_m R_F^2}{1 + g_m R_F}$$

$$R_{in, CLOSED} = \frac{R_F}{1 + g_m R_F}$$

$$R_{out, CLOSED} = \frac{R_F}{1 + g_m R_F}$$

(c) Breaking the feedback loop results in the following circuit:



$$R_{in, OPEN} = \left(\frac{1}{g_{m1}} \parallel R_F \right)$$

$$R_{o.L.} = \frac{V_{out}}{i_{IN}} = \frac{V_x}{i_{IN}} \cdot \frac{V_{out}}{V_x}$$

$$= g_{m1} R_D \left(\frac{1}{g_{m1}} \parallel R_F \right) \times$$

$$g_{m2} \left(R_F \parallel \frac{1}{g_{m2}} \right)$$

$$R_{out, OPEN} = \left(R_F \parallel \frac{1}{g_{m2}} \right)$$

- Feedback factor K :

$$K = \frac{V_x}{i_x} = -\frac{1}{R_F}$$



(Note: Feedback is positive.)

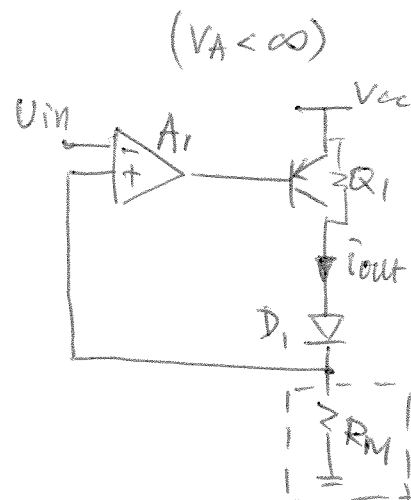
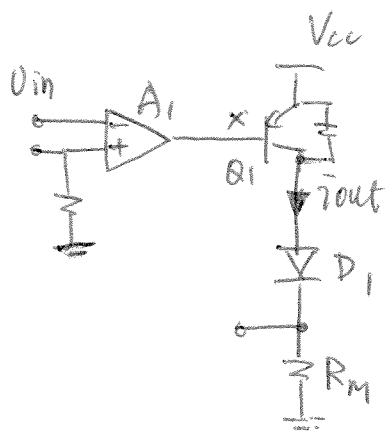
$$\Rightarrow R_{c.L.} = \frac{R_{o.L.}}{1 + R_{o.L.} \times K}$$

$$= \frac{g_{m1} g_{m2} R_D \left(\frac{1}{g_{m1}} \parallel R_F \right) \left(\frac{1}{g_{m2}} \parallel R_F \right)}{1 - g_{m1} g_{m2} \left(\frac{R_D}{R_F} \right) \left(\frac{1}{g_{m1}} \parallel R_F \right) \left(\frac{1}{g_{m2}} \parallel R_F \right)}$$

$$R_{in, CLOSED} = \frac{\left(\frac{1}{g_{m1}} \parallel R_F \right)}{1 - \frac{R_{o.L.}}{R_F}}$$

$$R_{out, CLOSED} = \frac{\left(\frac{1}{g_{m2}} \parallel R_F \right)}{1 - \frac{R_{o.L.}}{R_F}}$$

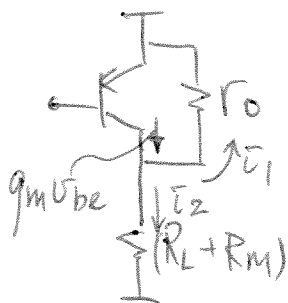
53. Breaking the feedback network (i.e. R_M) results in the following circuit:



$$G_{OL} = \frac{\bar{i}_{out}}{\bar{V}_{in}} = \frac{\bar{i}_{out}}{\bar{V}_x} \times \frac{\bar{V}_x}{\bar{V}_{in}} \quad (1)$$

$$= \underbrace{g_{m1} \times \frac{[R_L + R_M] \parallel r_{o1}}{(R_L + R_M)}}_{\text{(current division)}} \times (-A_1)$$

Note: current ($g_m V_{be}$) splits between r_o & $[R_L \text{ (impedance of } D_1) + R_M]$



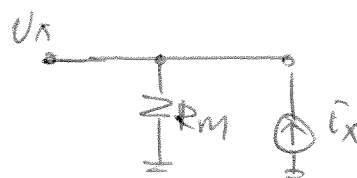
$$g_m V_{be} = \bar{i}_1 + \bar{i}_2$$

$$R_{in, OPEN} \rightarrow \infty$$

$$R_{out, OPEN} = r_{o1} + R_M$$

- Feedback factor K :

$$K = \frac{\bar{V}_x}{\bar{i}_x} = R_M$$



$$\therefore G_{o.L.} = \frac{G_{o.L.}}{1 + G_{o.L.} \times K} = \frac{G_{o.L.}}{1 + G_{o.L.} \times R_M}$$

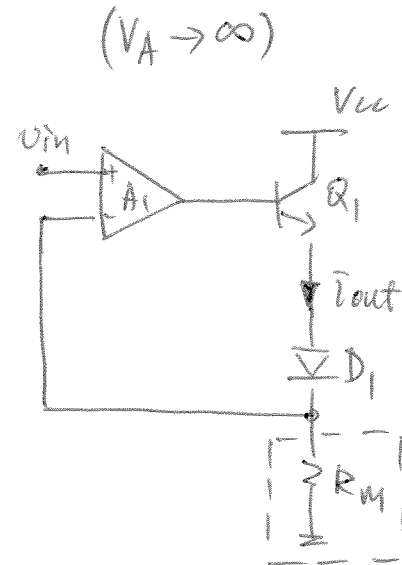
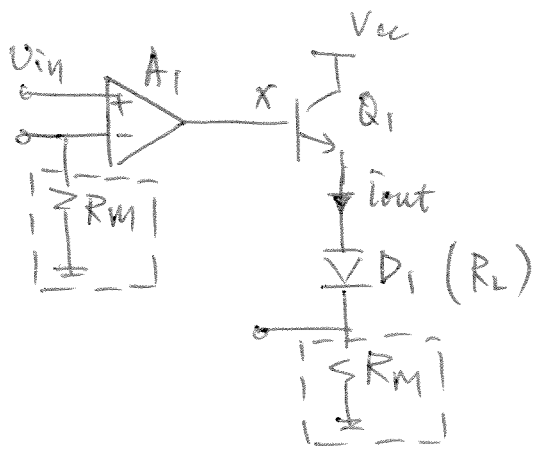
$$R_{in, CLOSED} \rightarrow \infty$$

$$R_{out, CLOSED} = (R_{o1} + R_M)(1 + G_{o.L.} \times R_M)$$

where $G_{o.L.}$ is given by (1)

54.

(a) Breaking the feedback loop results in the following circuit:



$$G_{o.L.} = \frac{i_{out}}{v_{in}} = \frac{i_{out}}{v_x} \cdot \frac{v_x}{v_{in}} = \frac{g_{m1}(R_L + R_M)}{1 + g_{m1}(R_L + R_M)} \times A_1$$

$$R_{in, OPEN} \rightarrow \infty$$

$$R_{out, OPEN} \approx R_M + \frac{1}{g_{m1}}$$

— Feedback factor k :

$$k = \frac{v_x}{i_x} = R_M$$

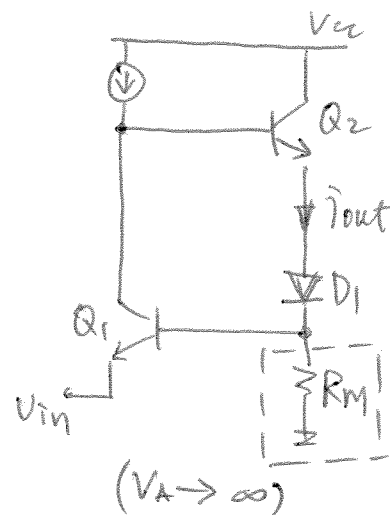
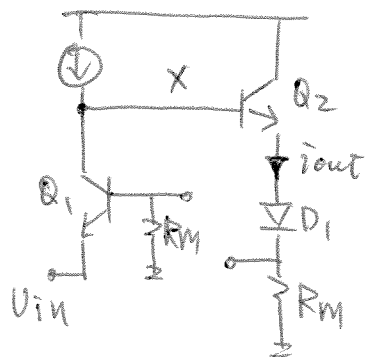


$$G_{c.L.} = \frac{G_{o.L.}}{1 + G_{o.L.} k} = \frac{G_{o.L.}}{1 + G_{o.L.} R_M}$$

$$R_{in, CLOSED} \rightarrow \infty$$

$$R_{out, CLOSED} = (R_M + \frac{1}{g_{m1}}) \times (1 + G_{o.L.} R_M)$$

(b) Breaking the feedback loop results in the following circuit:



$$G_{o.L.} = \frac{i_{out}}{v_{in}} = \frac{i_{out}}{v_x} \times \frac{v_x}{v_{in}} \approx \frac{g_{m2}(R_L + R_M)}{1 + g_{m2}(R_L + R_M)} \times g_{m1}[\tau_{\pi 2} + (\beta_2 + 1)(R_L + R_M)]$$

$$R_{in, open} = \frac{\tau_{\pi 1} + R_M}{\beta_1 + 1} \approx \frac{1}{g_{m1}} + \frac{R_M}{\beta_1 + 1}$$

$$R_{out, open} = \frac{1}{g_{m2}} + R_M$$

- Feedback Factor k :

$$k = \frac{v_x}{i_x} = R_M$$



$$\Rightarrow G_{c.L.} = \frac{G_{o.L.}}{1 + G_{o.L.} \times k} = \frac{G_{o.L.}}{1 + G_{o.L.} R_M}$$

$$R_{in, closed} = \left(\frac{1}{g_{m1}} + \frac{R_M}{\beta_1 + 1} \right) (1 + G_{o.L.} R_M)$$

$$R_{out, closed} = \left(\frac{1}{g_{m2}} + R_M \right) (1 + G_{o.L.} R_M)$$

55.

$$V_{out} = [-g_{m1}(V_{in} - V_x)R_D] \cdot [-g_{m2}\{r_{o2} \parallel (\frac{1}{g_{m1}} + R_L)\}]$$

(ignore r_{o1} for now) — (1)

$$\frac{V_{out} - V_x}{R_L} = \bar{i}_{out}$$

$$\Rightarrow V_{out} = \bar{i}_{out} R_L + V_x \quad \text{--- (2)}$$

$$\bar{i}_{out} = -g_{m1}(V_{in} - V_x) \Rightarrow V_{in} + \frac{\bar{i}_{out}}{g_{m1}} = V_x \quad \text{--- (3)}$$

- Substitute (2) & (3) into (1) and solve for

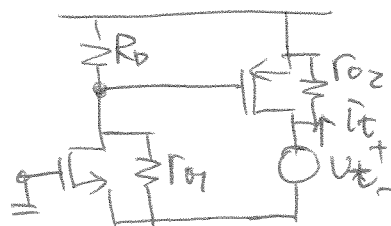
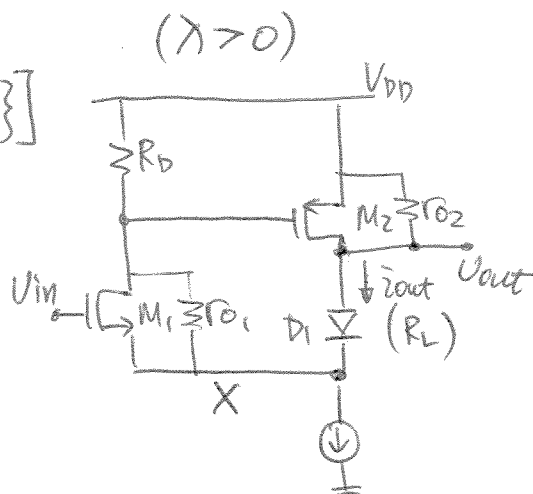
$$\frac{\bar{i}_{out}}{V_{in}} :$$

$$\frac{\bar{i}_{out}}{V_{in}} \cong - \frac{1}{R_L + \frac{1}{g_{m1}} + g_{m2}R_D \{r_{o2} \parallel (\frac{1}{g_{m1}} + R_L)\}} = G_{c.L.}$$

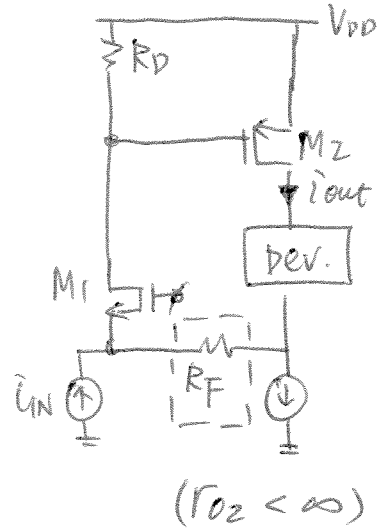
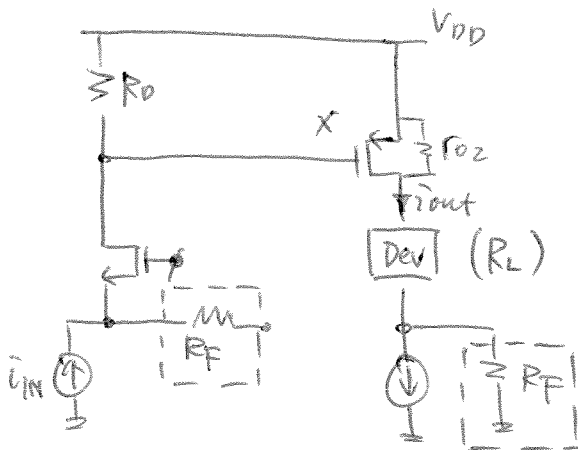
$$R_{in, closed} \rightarrow \infty$$

$$R_{out, closed}$$

$$= r_{o2} + \left(\frac{r_{o1} + R_D}{1 + g_{m1}r_{o1}} \right)$$



5b. Breaking the feedback loop results in the following circuit :



$$A_{I, o.L.} = \frac{\bar{i}_{out}}{\bar{i}_{in}} = \frac{\bar{i}_{out}}{V_x} \times \frac{V_x}{\bar{i}_{in}}$$

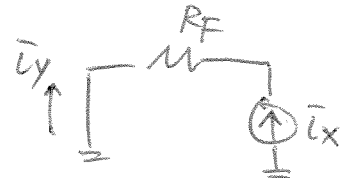
$$= -g_{m2} \times \frac{(R_L + R_F) \parallel r_{o2}}{(R_L + R_F)} \times R_D$$

$$R_{in, open} = \frac{1}{g_{m1}}$$

$$R_{out, open} = r_{o2} + R_F$$

- Feedback factor K :

$$K = \frac{\bar{i}_y}{\bar{i}_x} = -1$$

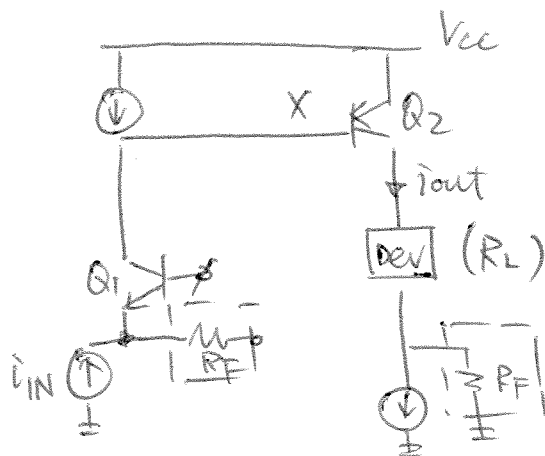


$$\Rightarrow A_{I, c.L.} = \frac{A_{I, o.L.}}{1 + A_{I, o.L.} \times K} = \frac{A_{I, o.L.}}{1 - A_{I, o.L.}}$$

$$R_{in, closed} = \frac{1/g_{m1}}{1 - A_{I, o.L.}}$$

$$R_{out, closed} = (r_{o2} + R_F)(1 - A_{I, o.L.})$$

57. Breaking the feedback loop results in the following circuit:



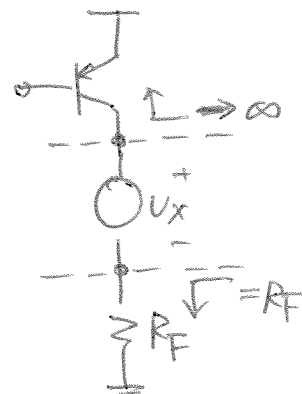
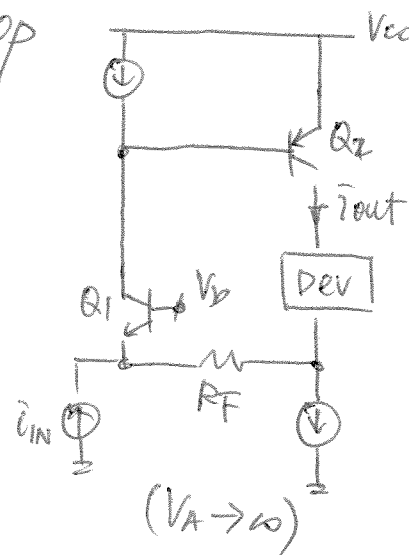
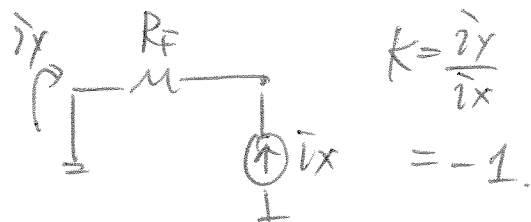
$$A_{I, o.l.} = \frac{i_{out}}{i_{in}} = \frac{i_{out}}{V_X} \times \frac{V_X}{i_{in}}$$

$$\cong -g_{m2} \times r_{\pi2} = \beta_2$$

$$R_{in, OPEN} = \frac{r_{\pi1}}{\beta_1 + 1} \approx \frac{1}{g_{m1}} \quad R_{out, OPEN} \rightarrow \infty$$

(Note : $R_{out} \rightarrow \infty$ because there is no current path :)

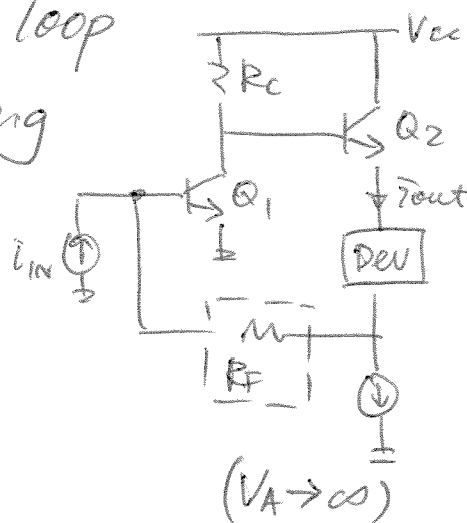
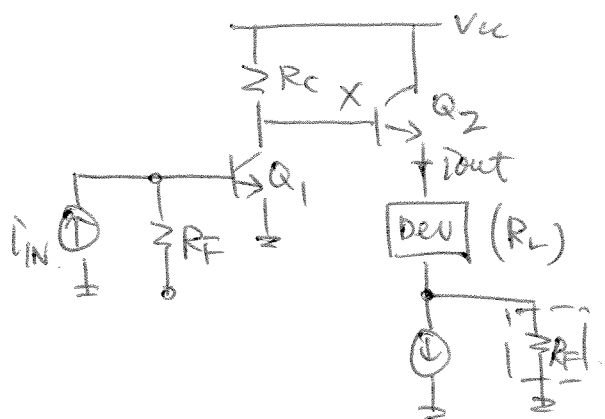
- Feedback factor k :



$$\Rightarrow A_{I, C.L.} = \frac{A_{I, O.L.}}{1 + A_{I, O.L.} \times K} = \frac{\beta_2}{1 - \beta_2}$$

$$R_{in, CLOSED} = \frac{1/g_{m_1}}{1 - \beta_2} \quad R_{out, CLOSED} \rightarrow \infty$$

58. Breaking the feedback loop results in the following circuit:



$$A_{I, O.L.} = \frac{i_{out}}{i_{IN}} = \frac{i_{out}}{U_X} \times \frac{U_X}{i_{IN}}$$

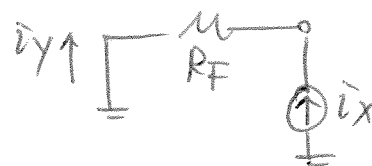
$$= \frac{g_{m2}(R_L + R_F)}{1 + g_{m2}(R_L + R_F)} \times \left[\beta_1 \times \left[R_C \parallel \left\{ r_{\pi 2} + (\beta_2 + 1)(R_L + R_F) \right\} \right] \right]$$

$$R_{in, open} = r_{\pi 1}$$

$$R_{out, open} \cong \frac{1}{g_{m2}} + R_F$$

- Feedback factor K :

$$K = \frac{\bar{i}_Y}{\bar{i}_X} = -1$$



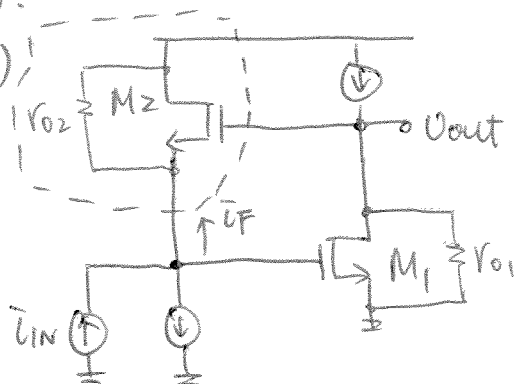
$$\Rightarrow A_{I, C.L.} = \frac{A_{I, O.L.}}{1 + A_{I, O.L.} \times K} = \frac{A_{I, O.L.}}{1 - A_{I, O.L.}}$$

$$R_{in, closed} = \frac{r_{\pi 1}}{1 - A_{I, O.L.}}$$

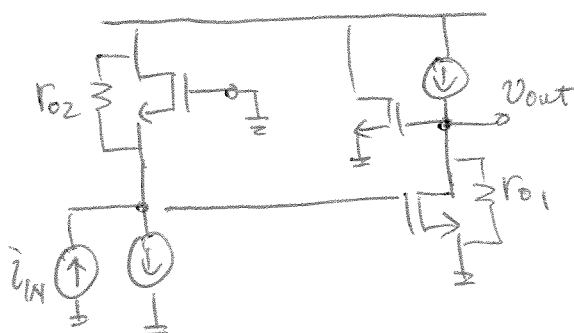
$$R_{out, closed} = \left(\frac{1}{g_{m2}} + R_F \right) (1 - A_{I, O.L.})$$

59.

(a)



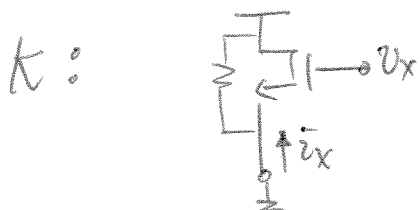
Breaking the feedback network results in the following:



$$R_{OL} = \frac{v_{out}}{i_{in}} = -(r_{o2} \parallel \frac{1}{g_{m2}}) g_{m1} r_{o1}$$

$$R_{in, OPEN} = r_{o2} \parallel \frac{1}{g_{m2}}$$

$$R_{out, OPEN} = r_{o1}$$



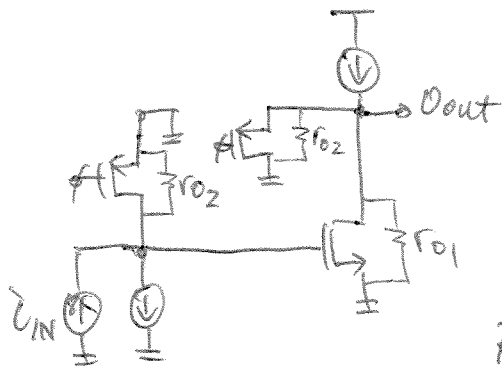
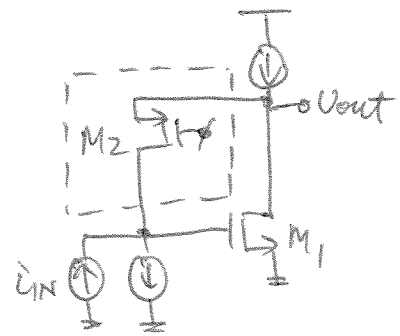
$$k = \frac{i_x}{v_x} = g_{m2}$$

$$\therefore R_{CL} = \frac{R_{OL}}{1 + R_{OL} k} = \frac{(r_{o2} \parallel \frac{1}{g_{m2}}) g_{m1} r_{o1}}{1 + g_{m1} g_{m2} r_{o1} (r_{o2} \parallel \frac{1}{g_{m2}})}$$

$$R_{IN, CLOSED} = \frac{(r_{o2} \parallel \frac{1}{g_{m2}})}{1 + g_{m1} g_{m2} r_{o1} (r_{o2} \parallel \frac{1}{g_{m2}})}$$

$$R_{out, closed} = \frac{r_{o1}}{1 + g_{m1} g_{m2} r_{o1} (r_{o2} \parallel \frac{1}{g_{m2}})}$$

(b) Breaking the feedback network results in the following:



$$R_{OL} = \frac{v_{out}}{i_{IN}}$$

$$= -r_{o2} \times g_{m1} [r_{o1} \parallel r_{o2} \parallel \frac{1}{g_{m2}}]$$

$$R_{IN, OPEN} = r_{o2}$$

$$R_{OUT, OPEN} = r_{o1} \parallel r_{o2} \parallel \frac{1}{g_{m2}}$$



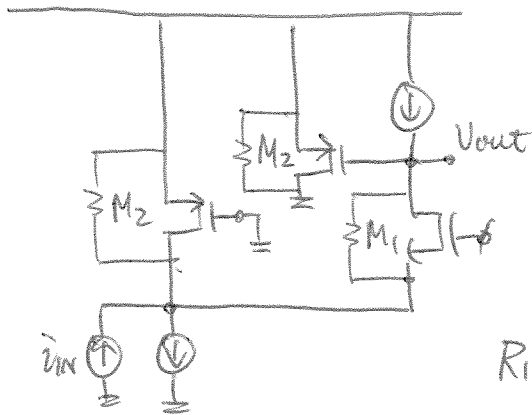
$$K = \frac{i_x}{v_x} = -g_{m2}$$

$$\therefore R_{CL} = \frac{R_{OL}}{1 + R_{OL} K} = \frac{-g_{m1} r_{o2} [r_{o1} \parallel r_{o2} \parallel \frac{1}{g_{m2}}]}{1 + g_{m1} g_{m2} r_{o2} [r_{o1} \parallel r_{o2} \parallel \frac{1}{g_{m2}}]}$$

$$R_{IN, CLOSED} = \frac{r_{o2}}{1 + R_{OL} K}$$

$$R_{OUT, CLOSED} = \frac{r_{o1} \parallel r_{o2} \parallel \frac{1}{g_{m2}}}{1 + R_{OL} K}$$

(c) Breaking the feedback network results in the following:



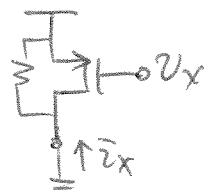
$$R_{OL} = \frac{v_{out}}{i_{IN}}$$

$$\approx \left(\frac{1}{g_{m1}} \parallel r_{o2} \right) (1 + g_{m1} r_{o1})$$

$$R_{in, OPEN} \approx \frac{1}{g_{m1}} \parallel r_{o2}$$

$$R_{out, OPEN} \approx r_{o2} + r_{o1} (1 + g_{m1} r_{o2})$$

K:

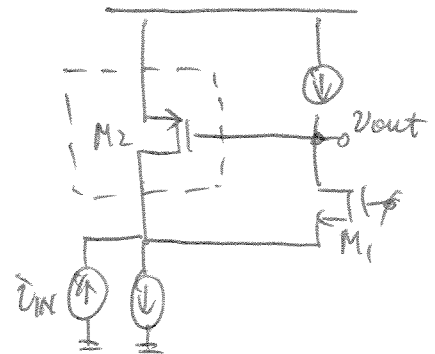


$$K = \frac{i_x}{v_x} = g_{m2}$$

$$\therefore R_{CL} = \frac{R_{OL}}{1 + R_{OL} K} = \frac{\left(\frac{1}{g_{m2}} \parallel r_{o2} \right) (1 + g_{m1} r_{o1})}{1 + g_{m2} \left(\frac{1}{g_{m1}} \parallel r_{o2} \right) (1 + g_{m1} r_{o1})}$$

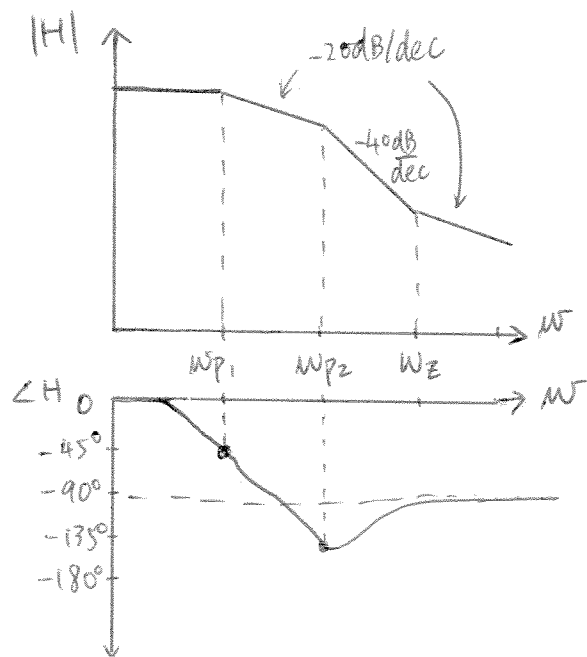
$$R_{in, CLOSED} = \frac{\frac{1}{g_{m1}} \parallel r_{o2}}{1 + R_{OL} \cdot K}$$

$$R_{out, CLOSED} = \frac{r_{o2} + r_{o1} (1 + g_{m1} r_{o2})}{1 + R_{OL} \cdot K}$$

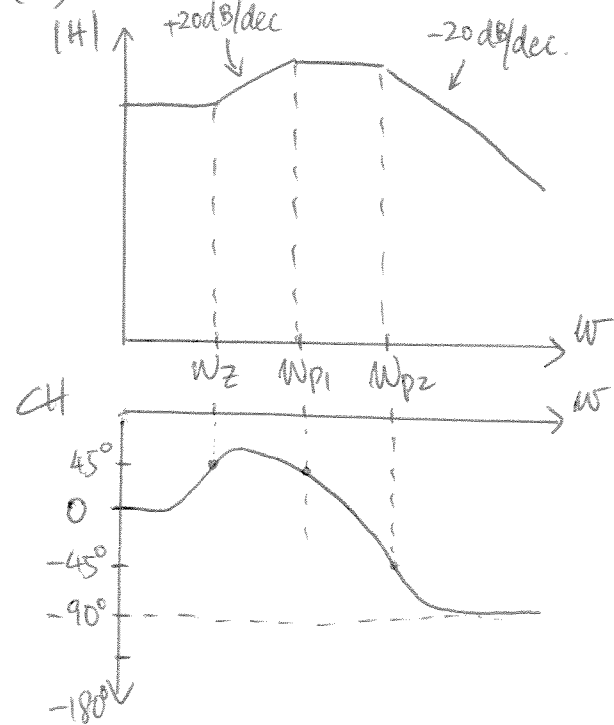


60.

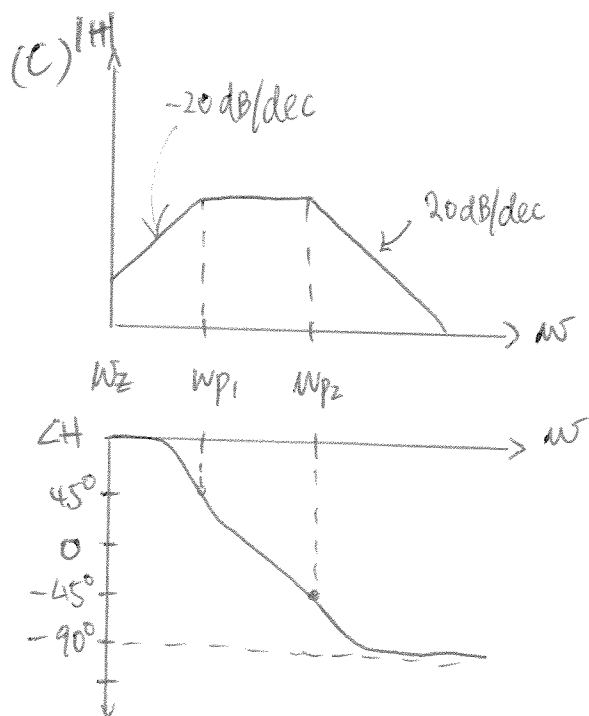
(a)



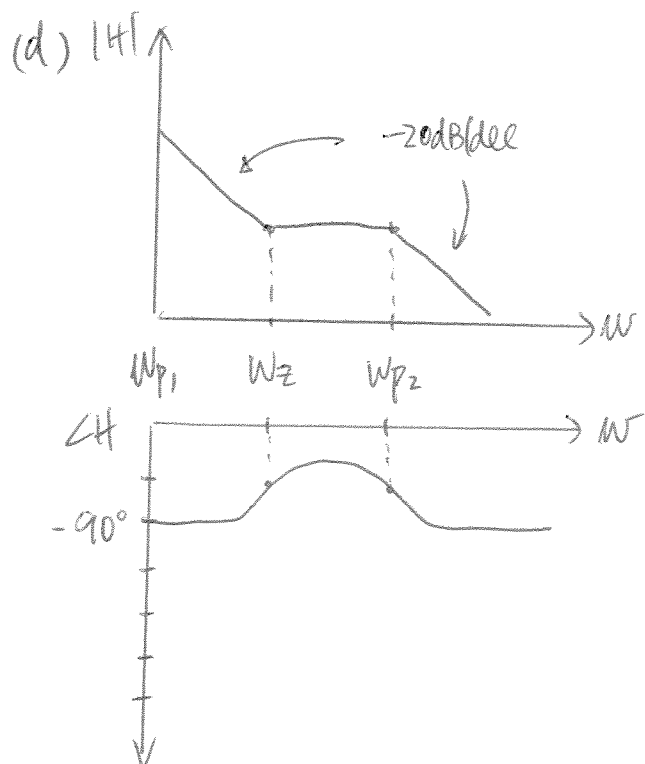
(b)



(c)



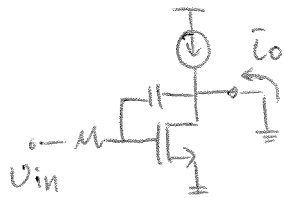
(d)



61. As ω_z comes closer to ω_{p1} or ω_{p2} , it cancels out the effect (i.e. -20dB/dec decrease) — pole-zero cancellation. It would appear as if nothing occurred at that overlapping frequency.

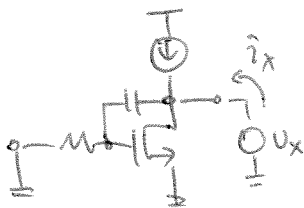
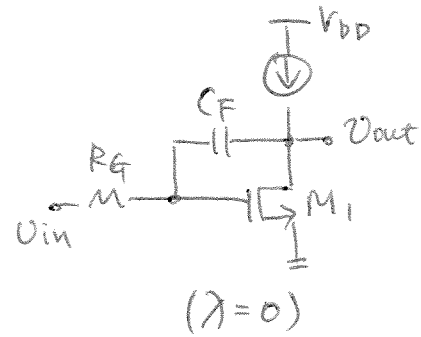
62.

Calculate $G_m(s)$ of circuit:



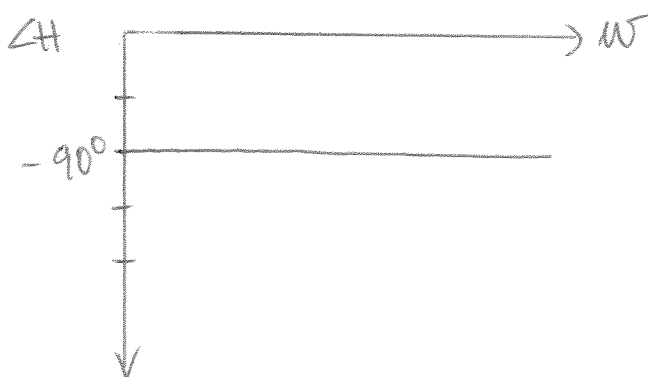
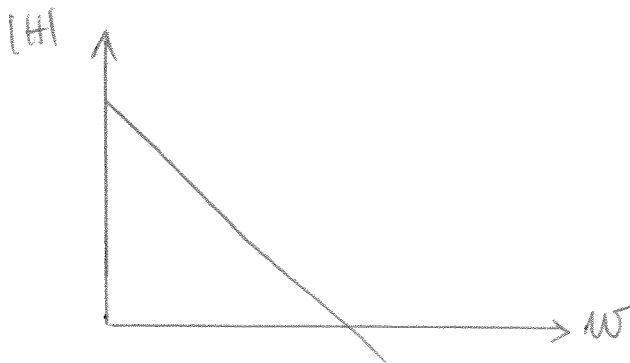
$$G_m = \frac{i_o}{v_{in}}$$

$$= g_{m1} \times \frac{1}{1 + sC_F R_G}$$



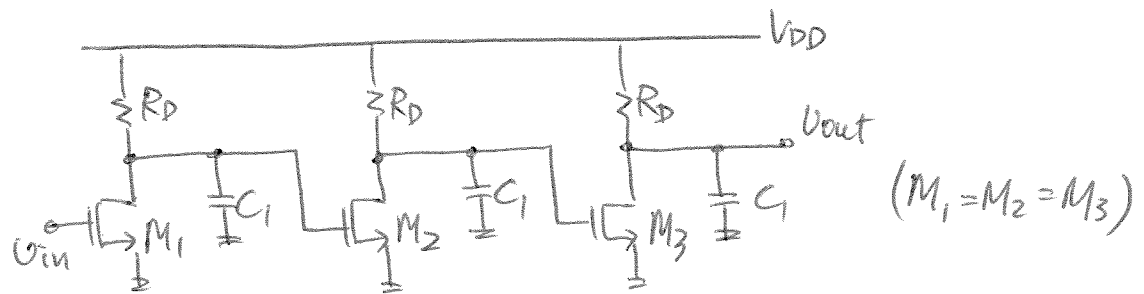
$$Z_{out} = \frac{v_x}{i_x} = \frac{1 + sC_F R_G}{sC_F \times (1 + g_{m1} R_G)}$$

$$\Rightarrow H(s) = G_m \times Z_{out} = \frac{g_{m1}}{g_{m1} R_G + 1} \times \frac{1}{sC_F} = \frac{1}{(g_{m1} R_G + 1) s \left(\frac{C_F}{g_{m1}} \right)}$$



63. By Nyquist Criterion, decreasing K ($K \rightarrow 0$) eventually leads to $|KH| < 1$ at $\angle H = -180^\circ$, which implies stability.

64.



$$H(s) = \frac{V_{out}}{V_{in}}(s) = \frac{(-g_m R_D)^3}{\left(1 + \frac{s}{\omega_p}\right)^3} \quad \text{where } \omega_p = \frac{1}{R_D C_1}$$

$$\begin{aligned} \Rightarrow \angle H(j\omega) &= \angle (-g_m R_D)^3 - \angle \left(1 + j\frac{\omega}{\omega_p}\right)^3 \\ &= 0 - 3 \tan^{-1}\left(\frac{\omega}{\omega_p}\right) \end{aligned}$$

$$\therefore \angle H \Big|_{\omega=0.1\omega_p} = -3 \tan^{-1}\left(\frac{0.1\omega_p}{\omega_p}\right) \cong -17.1^\circ$$

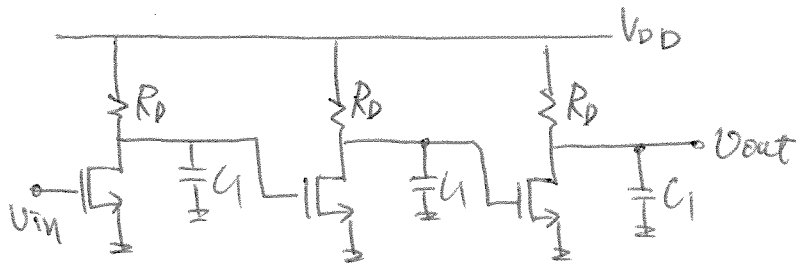
$$65. \quad H(s) = \frac{(-g_m R_D)^3}{\left(1 + \frac{s}{\omega_p}\right)^3} \quad (M_1 = M_2 = M_3)$$

$$\Rightarrow |H| \Big|_{\omega=\omega_p} = \frac{|g_m R_D|^3}{\left|(1+j\frac{\omega_p}{\omega_p})^3\right|} = \frac{(g_m R_D)^3}{(\sqrt{1+1})^3} = \frac{(g_m R_D)^3}{\sqrt{8}}$$

$$\begin{aligned} \Rightarrow 20 \log |H| \Big|_{\omega=\omega_p} &= 20 \log (g_m R_D)^3 - 20 \log \sqrt{8} \\ &\approx 20 \log (g_m R_D)^3 - (9 \text{ dB}) \end{aligned}$$

$\therefore |H|$ falls by 9 dB due to the three coincident poles.

6b.

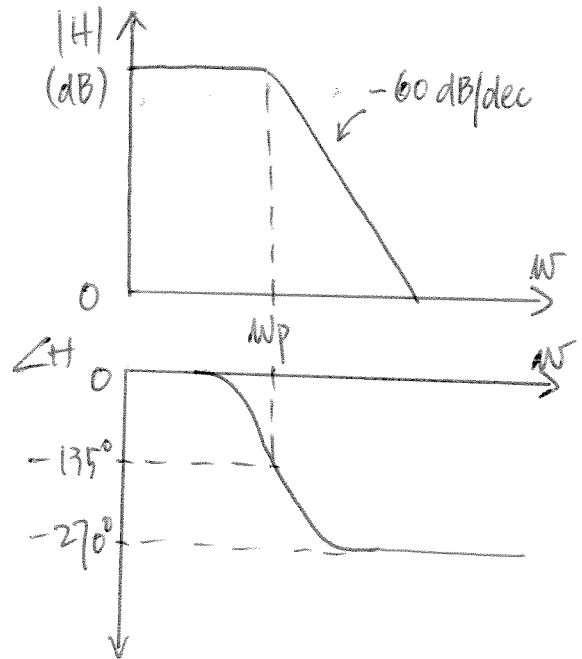


$$\omega_p = \frac{1}{R_D C_1}$$

$$k = 0.1$$

$$H(j\omega) = \frac{(-g_m R_D)^3}{(1 + j\frac{\omega}{\omega_p})}$$

$$\angle H = -3 \tan^{-1}\left(\frac{\omega}{\omega_p}\right)$$



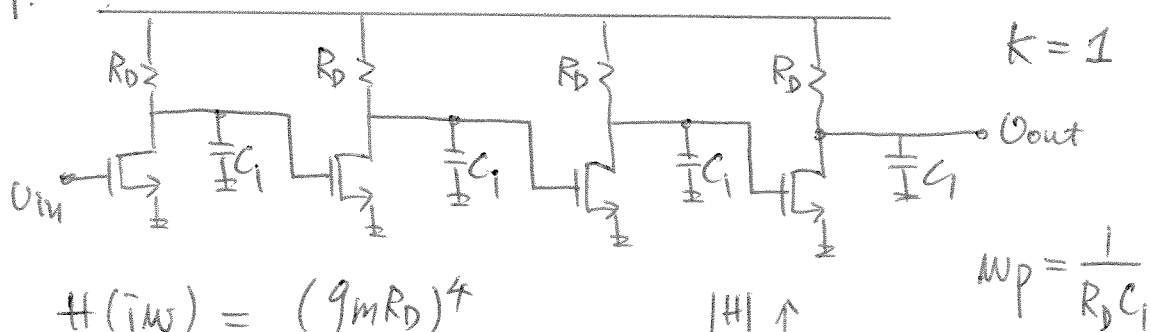
- Need to guarantee that $|KH| < 1$ when $\angle H = -180^\circ$:

$$\angle H = -180^\circ = -3 \tan^{-1}\left(\frac{\omega}{\omega_p}\right) \Rightarrow \omega = \sqrt{3} \omega_p$$

$$|KH(j\omega)|_{\omega=\omega_p\sqrt{3}} = \frac{(g_m R_D)^3}{(\sqrt{1+3})^3} \times 0.1 < 1$$

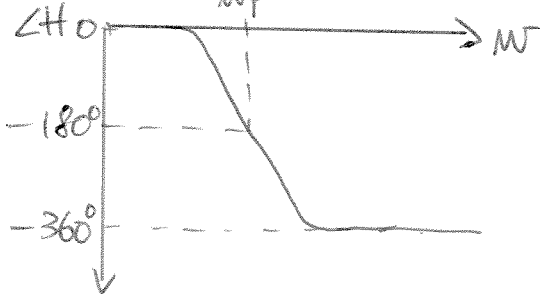
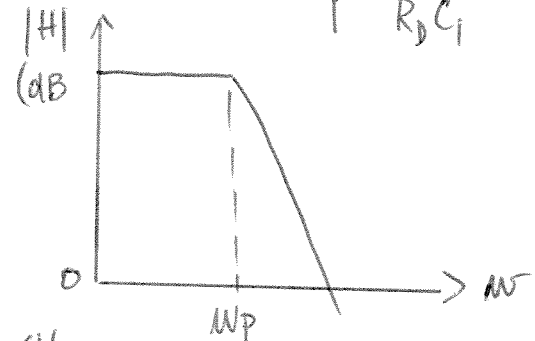
$$\Rightarrow g_m R_D < \sqrt[3]{80} \approx 8.94$$

67.



$$H(j\omega) = \frac{(g_m R_D)^4}{(1 + j \frac{\omega}{\omega_p})^4}$$

$$\angle H = -4 \tan^{-1} \left(\frac{\omega}{\omega_p} \right)$$



-To guarantee stability,

$$|KH| < 1 \text{ when } \angle H = -180^\circ$$

$$\angle H = -180^\circ = -4 \tan^{-1} \left(\frac{\omega}{\omega_p} \right) \Rightarrow \omega = \omega_p$$

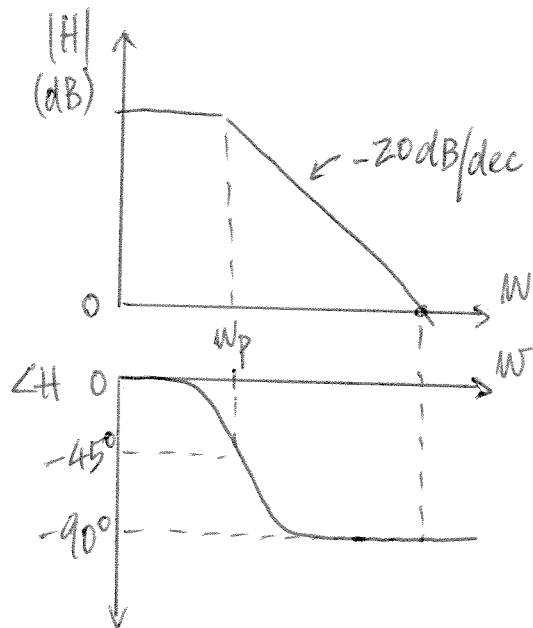
$$|KH| \Big|_{\omega=\omega_p} = \frac{(g_m R_D)^4}{(\sqrt{1+1})^4} < 1$$

$$\Rightarrow g_m R_D < \sqrt{2}$$

This four-pole system implies a lower upper-limit ($\approx \sqrt{2}$) on $g_m R_D$, which makes sense since $|H|$ drops faster here.

68. $H(s) = \frac{A_0}{1 + \frac{s}{\omega_p}}$

$k = 1.$

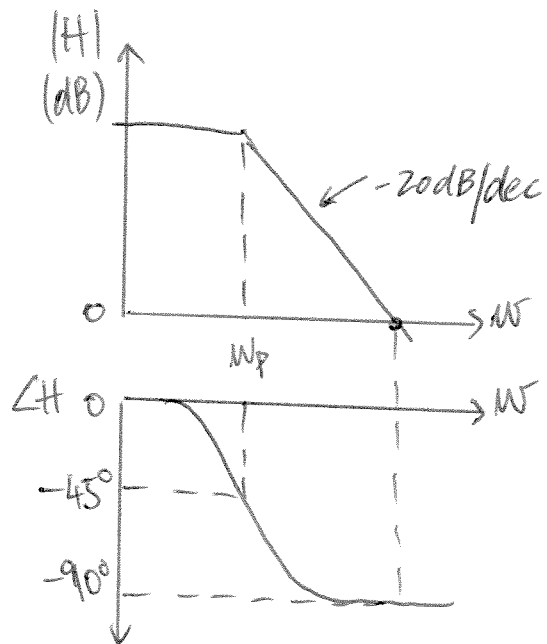


$\therefore$ Phase margin
 $= 180^\circ - 90^\circ = 90^\circ$

(i.e. system is stable.)

69. $H(s) = \frac{A_0}{1 + \frac{s}{\omega_p}}$

$K = 0.5$



Phase margin = 90°
(independent of K for one-pole systems.)

70. All three scenarios will become stable eventually (depending on how far w_{ax} is from w_{px} , & $w_{gx} < w_{px}$.)

71. In the $20 \cdot \log |kH|$ vs. $\log |w|$ plot, the magnitude plot decreases at a rate of 20 dB/dec . between w_{p1} & w_{p2} .

$$k=1 \Rightarrow 20 \log |H|$$

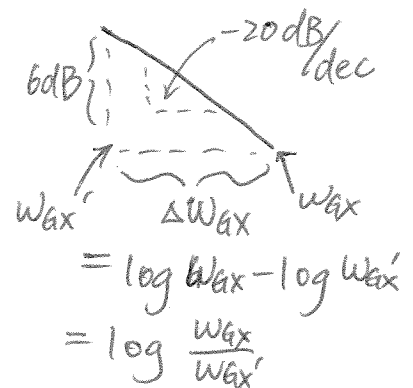
$$k=0.5 \Rightarrow 20 \log \left| \frac{H}{2} \right| = 20 \log |H| - 6 \text{ dB}$$

$\therefore k=0.5$ induces a 6 dB decrease on the magnitude plot at all frequencies.

$$\Rightarrow \Delta W_{ax} [\log] = \frac{6 \text{ dB}}{20 \text{ dB}} \approx -0.3$$

$$\frac{W_{ax}}{W_{ax}'} = 10^{\frac{6 \text{ dB}}{20 \text{ dB}}} \approx 0.5$$

$$\Rightarrow W_{ax}' = \frac{W_{ax}}{0.5} = 2 W_{ax}$$



$$\angle H = -\tan^{-1} \left[w \left(\frac{1}{w_{p1}} + \frac{1}{w_{p2}} \right) \right] \approx -\tan^{-1} \left(\frac{w}{w_{p1}} \right) \quad (w_{p2} \gg w_{p1})$$

$\Rightarrow$ Phase plot stays the same with $k=0.5$.

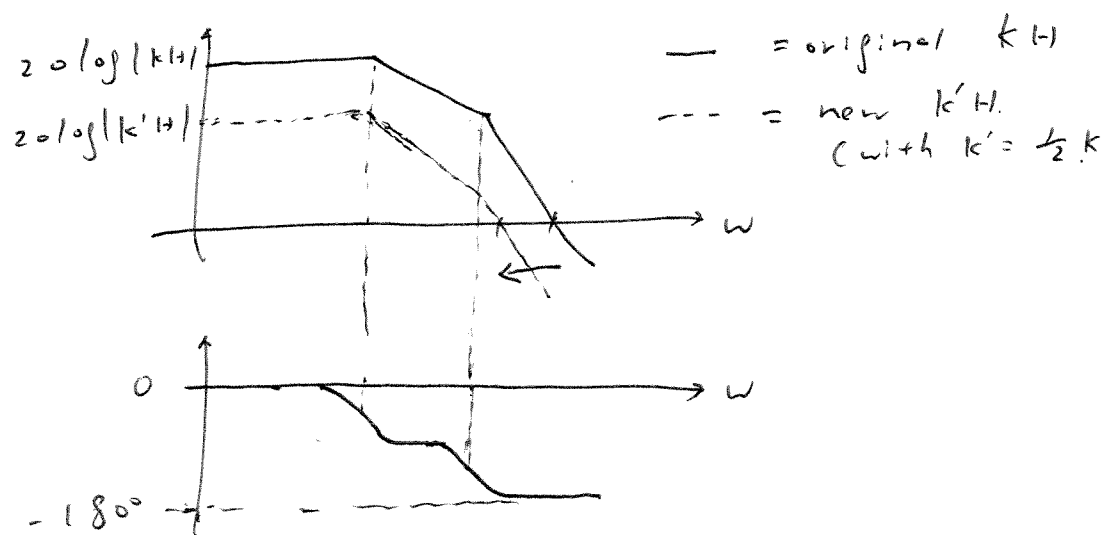
$$\text{In original example } \angle H(w_{p2}) \approx -\tan^{-1} \left(\frac{w_{ax}}{w_{p1}} \right) = -135^\circ$$

$$\angle H(w_{ax}') = \angle H(2w_{ax}) \approx -\tan^{-1} \left(\frac{2w_{ax}}{w_{p1}} \right)$$

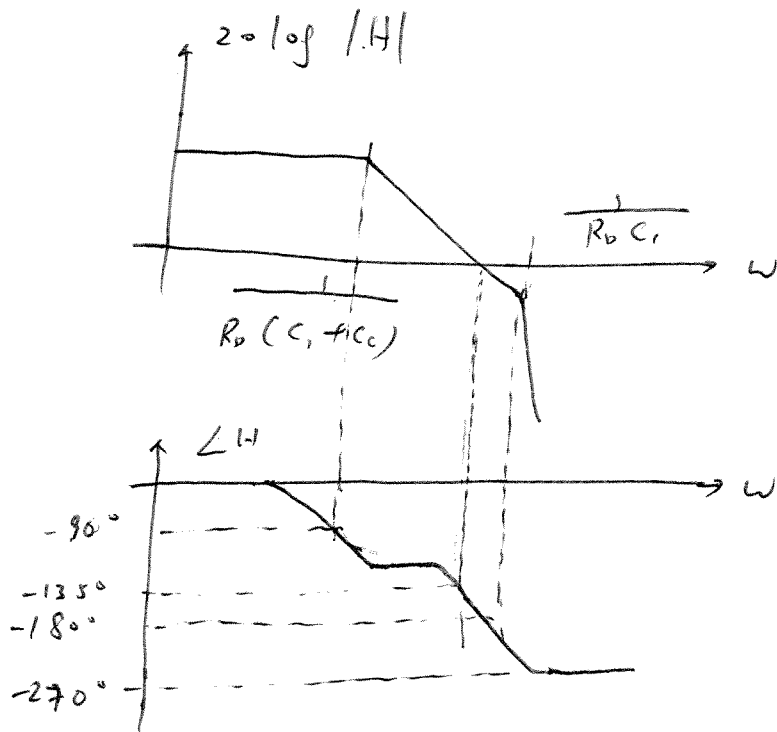
$$\Rightarrow \angle H(w_{ax}') = -\tan^{-1} [2 \tan 135^\circ] \approx -116^\circ$$

$$\Rightarrow \text{Phase Margin} = 180^\circ + \angle H(w_{ax}') \approx 63^\circ$$

(72) When k drops by a factor of 2, the phase margin improves. This is because a lower k corresponds to shifting the amplitude part of kH down by 6 dB. (The phase $\angle kH$ remains unchanged, since phase is only dependent on pole location and is independent of amplitude of kH .)
 Thus, the gain $|kH|$ drops to 0 dB at a lower frequency. This results in a larger phase margin.



(73) With the compensation capacitor C_c in place, the pole associated with C_c becomes dominant (i.e. at a lower frequency than the other 2 poles at $\frac{1}{R_D C_1}$).



(74)

Open-loop gain, $A_o = f_{mN} (r_{oN} // r_{op})$

$$= 50$$

$$\text{Closed-loop gain, } \frac{V_{out}}{V_{in}} = \frac{f_{mN} (r_{oN} // r_{op})}{1 + \frac{R_2}{R_1 + R_2} f_{mN} (r_{oN} // r_{op})}$$

$$= \frac{50}{1 + \frac{R_2}{R_1 + R_2} \times 50}$$

$$= 4$$

$$\therefore 4 = \frac{50}{1 + \frac{R_2}{R_1 + R_2} \times 50}$$

$$1 + \frac{50 R_2}{R_1 + R_2} = 12.5$$

$$\frac{R_2}{R_1 + R_2} = 0.23$$

Choosing $r_{o2} // r_{o4} = 5 \text{ k}\Omega$,

$$\text{i.e. } f_{mN} = 10 \text{ mS} //$$

$$\text{and } R_1 + R_2 \approx 50 \text{ k}\Omega,$$

$$\therefore R_2 = 0.23 \times 50 \text{ k}\Omega$$

$$= 11.5 \text{ k}\Omega //$$

$$\text{and } R_1 = 38.5 \text{ k}\Omega //$$

(75)

Open loop gain, $A_o = f_m R_D$

(assuming $R_1 + R_2$ is very large.)

$$\text{i.e. } f_m R_D = 10$$

$$\begin{aligned} \text{Closed-loop gain} &= \frac{f_m R_D}{1 + \left(\frac{R_2}{R_1 + R_2} \right) f_m R_D} \\ &= 2 \end{aligned}$$

$$\therefore \frac{10}{1 + \left(\frac{R_2}{R_1 + R_2} \right) \times 10} = 2$$

$$\frac{R_2}{R_1 + R_2} = 0.4$$

$$\begin{aligned} \text{Closed-loop input impedance} &= \frac{1}{f_m} \left[1 + \frac{R_2}{R_1 + R_2} \times 10 \right] \\ &= 50 \Omega. \end{aligned}$$

$$\therefore \frac{1}{f_m} \times 5 = 50$$

$$f_m = 0.15 //$$

$$\therefore R_D = 100 \Omega //$$

$$\begin{aligned} \therefore R_1 + R_2 &= 10 \times 100 \Omega \\ &= 1 \text{ k}\Omega. \end{aligned}$$

$$\therefore R_2 = 400 \Omega //$$

$$R_1 = 600 \Omega //$$

$$\textcircled{76} \quad \text{Open-loop gain} = R_{D1} (g_{m2} R_{D2})$$

$$= 10 \text{ k}\Omega$$

$$\text{Closed-loop gain} = \frac{10 \text{ k}\Omega}{1 + \frac{10 \text{ k}\Omega}{R_F}}$$

$$= 1 \text{ k}\Omega$$

$$\frac{10}{1 + \frac{10 \text{ k}\Omega}{R_F}} = 1 \text{ k}\Omega$$

$$\therefore R_F = 1.11 \text{ k}\Omega //$$

$$\text{Closed-loop input impedance} = \frac{1}{g_{m1}} (1 + 9)^{-1}$$

$$= 50 \Omega$$

$$\therefore g_{m1} = 2 \text{ mS} //$$

$$\text{Closed-loop output impedance} = \frac{R_{D2}}{10}$$

$$= 200 \Omega$$

$$\therefore R_{D2} = 2000 \Omega //$$

$$\therefore R_{D1} = 1 \text{ k}\Omega$$

$$\therefore g_{m2} = 5 \text{ mS} //$$

(77) Assuming R_F is very large,

$$\text{open-loop gain} = R_D (g_{m2} R_L)$$

$$= 10 \text{ k}\Omega$$

$$\text{closed-loop gain} = \frac{10 \text{ k}\Omega}{1 + \frac{10 \text{ k}\Omega}{R_F}}$$

$$= 1 \text{ k}\Omega.$$

$$\therefore R_F = 1.1 \text{ k}\Omega //$$

$$\text{closed-loop input impedance} = \frac{1}{g_{m1}} (1 + \beta)^{-1} = 50 \Omega.$$

$$g_{m1} = 2 \text{ mS} //$$

$$\text{closed-loop output impedance} = \frac{R_L}{10}$$

$$\therefore R_L = 2000 \Omega //$$

$$R_D = 1 \text{ k}\Omega.$$

$$\therefore g_{m2} = 5 \text{ mS} //$$

$$(78) a) \text{ open-loop gain} = R_c (f_{m2} R_m)$$

$$\approx 20 \text{ k}\Omega.$$

$$f_{m2} = \frac{I}{V_T}$$

$$\therefore f_{m2} = \frac{1 \text{ mA}}{26 \text{ mV}} = 38.5 \text{ ms}$$

$$\therefore R_c R_m = \frac{20 \text{ k}\Omega}{38.5 \text{ ms}}$$

$$\text{open-loop output impedance} = R_m \quad (\because V_o = \infty)$$

$$\therefore R_m = 500 \Omega //$$

$$R_c = 1040 \Omega //$$

$$b) \text{ closed-loop gain} = \frac{20 \text{ k}\Omega}{1 + \frac{20 \text{ k}\Omega}{R_F}}$$

$$= 1 \text{ k}\Omega$$

$$\therefore R_F = 1053 \Omega //$$

$$c) \text{ closed-loop input impedance} = \frac{\frac{1}{38.5 \text{ ms}}}{1 + \frac{20 \text{ k}\Omega}{1053}}$$

$$= 1.30 \Omega //$$

$$\text{closed-loop output impedance} \approx (500) \left(\frac{1}{20} \right)$$

$$= 25 \Omega //$$

79

Open-loop voltage gain

$$= \frac{R_{D1}}{\frac{1}{g_{m1}} + R_1 // R_2} \cdot [g_{m2} (R_1 // R_2)]$$
$$= 20 \quad \text{--- (1)}$$

$$\text{closed-loop gain} = \frac{20}{1 + 20 \left(\frac{R_2}{R_1 + R_2} \right)} = 4$$

$$\therefore \frac{R_2}{R_1 + R_2} = 0.2 \quad \text{--- (2)}$$

Open-loop output impedance = $R_1 + R_2$

$$= 2 \text{ k}\Omega$$

$$\therefore R_2 = 0.4 \text{ k}\Omega //$$

$$R_1 = 1.6 \text{ k}\Omega //$$

From (1),

$$\frac{R_{D1}}{\frac{1}{g_{m1}} + 2 \text{ k}\Omega} [g_{m2} \times 320 \Omega] = 20$$

$$\frac{g_{m1} R_{D1}}{1 + 2 \text{ k} g_{m1}} \times g_{m2} = 0.0625$$

$$\text{Setting } g_{m1} = g_{m2} = 20 \text{ mS} //$$

$$R_{D1} \approx 6400 \Omega //$$

To minimize power consumption, g_{m1} and g_{m2} should be minimized (and R_D maximized)

80

$$\text{Since } A_{OL} = \frac{f_{m1} \left(\frac{1}{f_{m2}} + \frac{R_1 // R_2}{\beta_2 + 1} \right)}{1 + f_{m1} \left(\frac{1}{f_{m2}} + \frac{R_1 // R_2}{\beta_2 + 1} \right)} \times f_{m2} (R_1 + R_2)$$

$$R_{out, closed} = \frac{R_1 + R_2}{1 + A_{OL} k}$$

$$\therefore A_{OL} = 2$$

$$\therefore 2 = \frac{A_{OL}}{1 + A_{OL} k}$$

$$\text{see } f_{m1} = f_{m2} = 50 \text{ mV}, \quad (R_1 + R_2) = 1 \text{ k}$$

$$A_{OL} = \frac{50 \text{ mV} \left(\frac{1}{50 \text{ mV}} + \frac{R_1 // R_2}{101} \right)}{1 + 50 \text{ mV} \left(\frac{1}{50 \text{ mV}} + \frac{R_1 // R_2}{101} \right)} \times 50 \text{ mV} (1 \text{ k})$$

$$\approx \frac{1 + 10^{-5} (R_1 // R_2)}{2 + 10^{-5} (R_1 // R_2)} \times 50$$

$$\approx 25$$

$$\therefore 2 = \frac{25}{1 + 25 k}$$

$$\therefore k = 0.46$$

$$[\therefore R_1 = 460 \Omega, \quad R_2 = 540 \Omega]$$

$$R_{out, closed} = \frac{1 \text{ k}}{1 + 25 \times 0.46}$$

$$= 80 \Omega //$$

$$\textcircled{81} \text{ open-loop gain } (A_{OL}) = -\beta_{m1} (R_F // r_{\pi 1}) / x \\ \left[R_C // [r_{\pi 2} + (\beta_2 + 1) R_F] \right]$$

$$A_{CL} = \frac{A_{OL}}{1 + A_{OL} \frac{1}{R_F}}$$

$$\therefore A_{CL} = 1000 \Omega$$

$$1000 = \frac{A_{OL}}{1 + \frac{A_{OL}}{R_F}}$$

$$R_{in, closed} = \frac{R_F // r_{\pi 1}}{1 + \frac{A_{OL}}{R_F}} = 50 \Omega$$

$$R_{out, closed} = \frac{R_F}{1 + \frac{A_{OL}}{R_F}} = 50 \Omega$$

$$\text{setting } R_F = 1200 \Omega$$

$$\therefore A_{OL} = 6000 \Omega //$$

$$\therefore r_{\pi 1} = 400 //$$

$$\beta_{m2} = 2.5 \text{ mV} //$$

$$\text{Assume } \beta_2 = 100, \text{ and } \beta_{m1} = \beta_{m2}$$

$$R_C = 8570 \Omega //$$