臺灣科技大學 電子工程系 Introduction to Analog IC Design

112-1 期末考 試題卷

考試規則：

- Close book。可以使用計算機，但不能用手機或其他電子產品。請關閉手機。
- 考試時間: 13:20~15:10
- **沒有過程不給分** (題目未說明解題方式者，皆用小信號模型參數表示)

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Q1: (15%)

請寫出 Vout/Vin 的等效開迴路增益(A_{OL})、回授因子(Feedback factor, β)與閉迴路增益(A_{OL})。(15%)

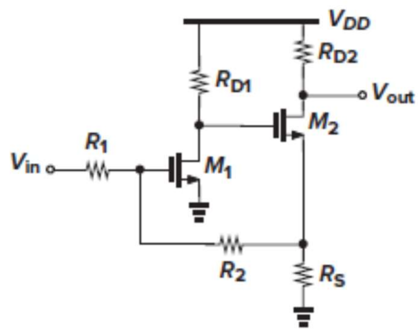


Fig. 1

Q2: (20%)

Suppose the open-loop transfer function of a two-stage op-amp is expressed as

$$H_{open}(s)=\frac{A_0\left(1+\frac{s}{\omega_z}\right)}{\left(1+\frac{s}{\omega_{p1}}\right)\left(1+\frac{s}{\omega_{p2}}\right)}$$

(a) 假如$\omega_{p2}=A_0*\omega_{p1}$ and $\omega_z=10\omega_{p2}$，請畫出$H_{open}(s)$'s bode plots for Magnitude and phase 並標示出 unit-gain frequency ω_u = ? Phase Margin (PM) 是多少? (10%)

(b) 一般的Two-Stage Opamp中，使用Miller電容跨接在第二級電路，其目的為何? 請解釋之。(10%)

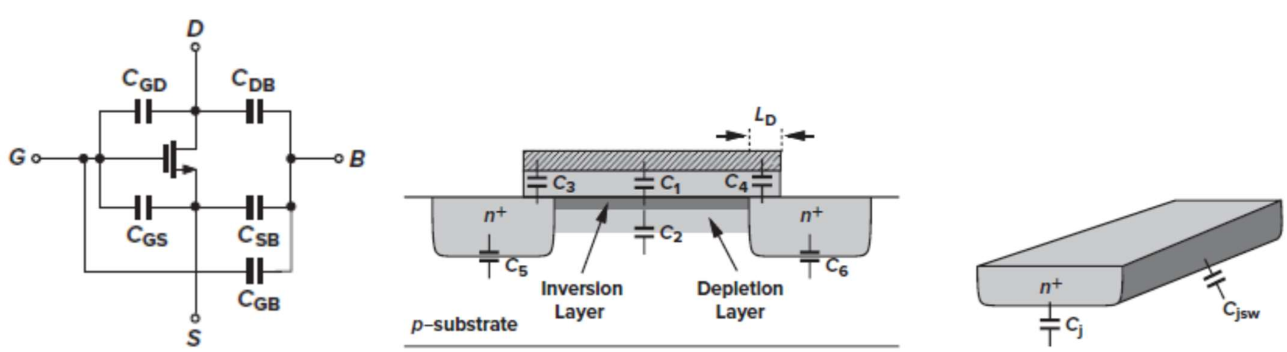
Q3: (20%)

假設 Fig. 3 是一個 nMOST，畫出來的電晶體模型為 Cox、通道寬度(W)、長度(L)與 Diffusion 寬度(E)。

(a) 請簡單解釋 Fig. 3(b)中的 C_1-C_6，其中 C_5 與 C_6 要用 C_j and C_{jsw} 表示。(10%)

(b) 寫出 Fig. 3(a)中，C_{GS}, C_{GD}, C_{DB}, C_{SB}，分別以 C_1-C_6 表示。(5%)

(c) 根據 Fig. 3(a)的小訊號模型(操作在飽和區)，簡單說明五個電容與其跨壓的關係(有關或無關)。(5%)



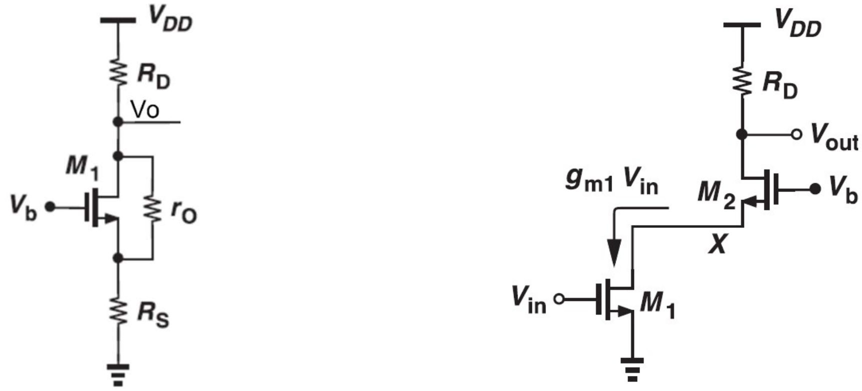
(a) (b) (c)

Fig. 3

Q4: (20%)

(a) 在 Fig. 4(a)中，請寫出此電路的輸入輸出轉換特性曲線與電壓增益(用小信號模型參數表示)。(10%)

(b) 在 Fig. 4(b)中，請寫出此電路的輸入輸出轉換特性曲線與電壓增益(用小信號模型參數表示)。(10%)

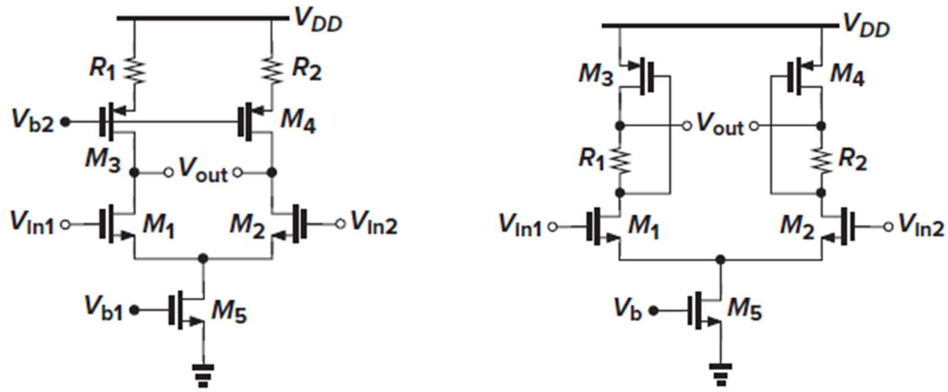


(a) (b)

Fig. 4

Q5: (10%)

假設Fig. 5中的所有電晶體都操作在飽和區且$\lambda \neq 0$，用小信號模型參數表示每個子電路中的小訊號差動增益 (Av=Vout/Vin>0)。



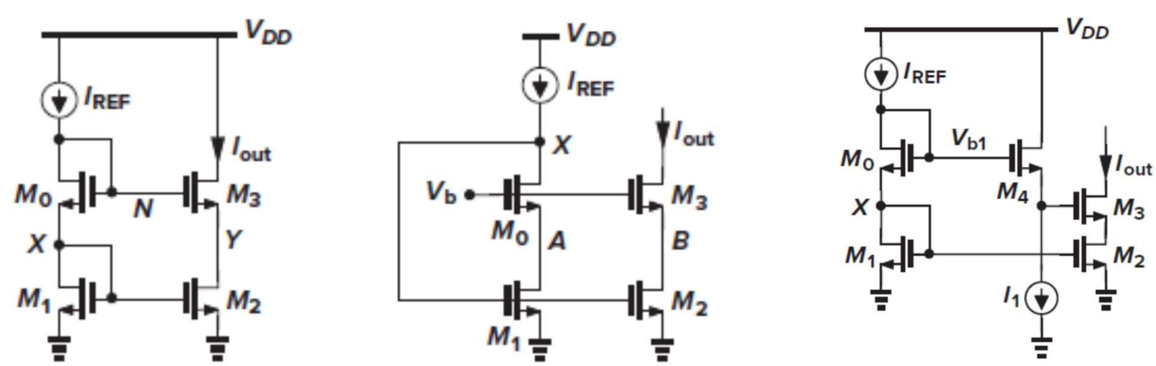
(a) (b)

Fig. 5

Q6: (15%)

(a) 在Fig. 6(a)中，相對於其他兩個電流源產生電路，其主要缺點為何? 請解釋之。(10%)

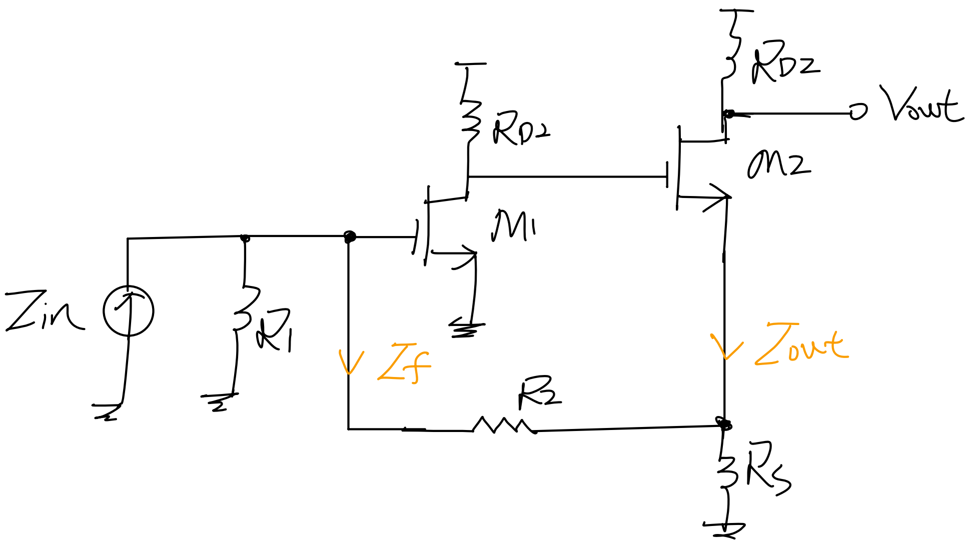
(b) 在Fig. 6(c)中，"M4與I1"的引入，其目的為何? 應該如何設計? (5%)



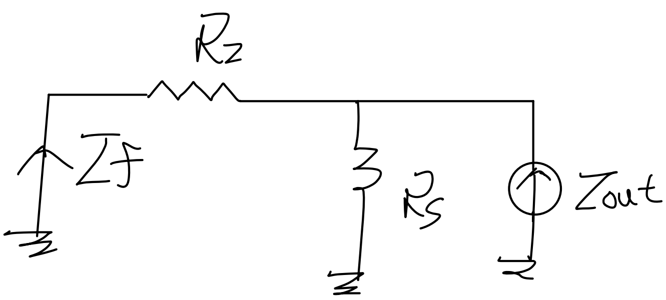
(a) (b) (c)

Fig. 6

Q1 2



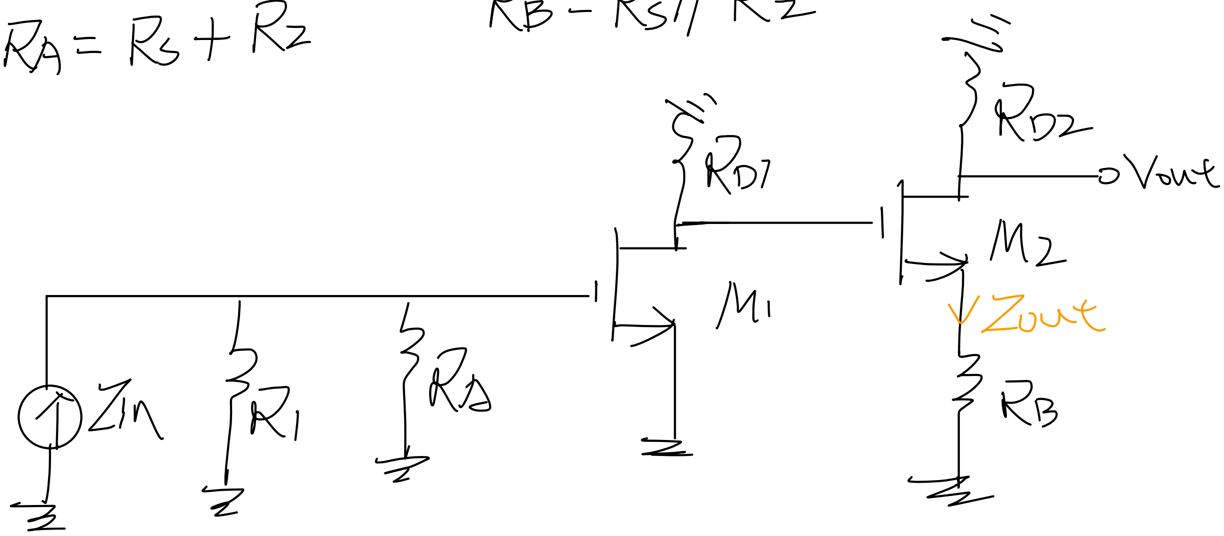
I-I feedback



$$\beta_I = \frac{I_f}{I_{out}} = -\frac{R_s}{R_s + R_2} \ \#$$

$$R_B = R_s // R_2$$

$$R_A = R_s + R_2$$



$$V_{g2} = I_{in}(R_1 // R_A) \times (-g_{m1} R_{D1})$$

$$I_{out} = G_{m2} V_{g2} = \frac{g_{m2} r_{o2}}{r_{o2} + (1 + g_{m2}' r_{o2}) R_B} \qquad g_{m2}' = g_{m2} + g_{m2b}$$

$$A_{I,OL} = \frac{I_{out}}{I_{in}} = -g_{m1} R_{D1} \times G_{m2} \times (R_1 // R_A)$$

$$\beta_I A_{I,OL} = g_{m1} R_{D1} \times G_{m2} \times (R_1 // R_A) \times \frac{R_S}{R_S + R_2}$$

$$\Rightarrow A_{I,CL} = \frac{A_{I,OL}}{1 + \beta_I A_{I,OL}} = \frac{-g_{m1} R_{D1} \times G_{m2} \times (R_1 // R_A)}{1 + g_{m1} R_{D1} \times G_{m2} (R_1 // R_A) \times \frac{R_S}{R_S + R_2}}$$

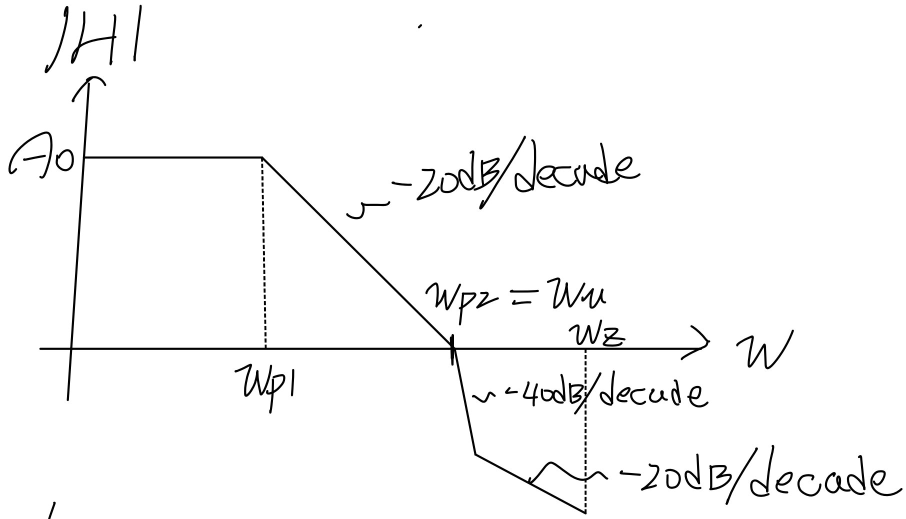
Assume $\beta_I A_{I,OL} >> 1$

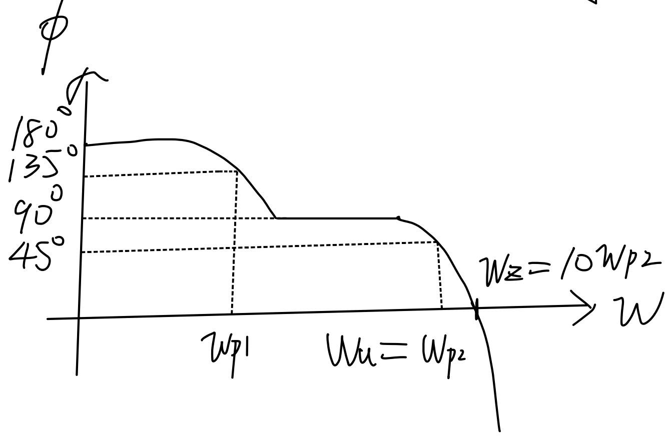
$$\Rightarrow A_{I,CL} \simeq \frac{R_S + R_2}{R_S} = 1 + \frac{R_2}{R_S}$$

$$\Rightarrow A_{V,CL} = A_{I,CL} \times \frac{R_{D2}}{R_1} = \left(1 + \frac{R_2}{R_S}\right) \frac{R_{D2}}{R_1} \quad \#$$

Q2

(a)





$$PM = 180^\circ - \tan^{-1}\left(\frac{W_u}{W_{p1}}\right) - \tan^{-1}\left(\frac{W_u}{W_{p2}}\right) - \tan^{-1}\left(\frac{W_u}{W_z}\right)$$

$$= 180^\circ - \tan^{-1}(A_0) - \tan^{-1}(1) - \tan^{-1}(0.1)$$

$$\simeq 180^\circ - 90^\circ - 45^\circ - 0 = 45^\circ \quad \#$$

或

$$PM = 180^\circ - 90^\circ - 45^\circ - 5.7^\circ \simeq 39.3^\circ \quad \#$$

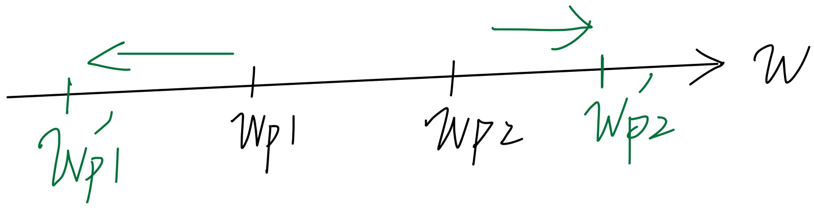
(b)

如果沒有使用Miller Compensantion的話

會使得 w_{p1} 及 w_{p2} 過於靠近，使得PM很差

因此透過 Miller compensantion 的技術

將 w_{p1} 及 w_{p2} 分離，使得PM變好!!



#

Q3

(a)

$C_1 = WLC_{ox}$ 表示 poly gate 與 oxide 間的氧化層電容

$C_2 = WL\sqrt{\frac{2\epsilon_{si} N_{sub}}{4\phi_F}}$ 表示 channel 與 substrate 間的空乏電容 送分!!

C_3、$C_4 = WL_D C_{ox} = WC_{ov}$

表示 poly gate 與 S/D 間的 overlap 氧化層電容

C_5、C_6 由 C_j 及 C_{jsw} 共同組成的空乏電容

$$C_5 = A_S C_{js} + P_S C_{jsw}$$

$$C_6 = A_D C_{js} + P_D C_{jsw}$$

其中 $A = E \times W$

$P = 2(W+E)$

或 $P = (W+2E)$

(b)

Assume 為飽和区

$C_{GS} = C_3 + \frac{2}{3} C_1$

$C_{GD} = C_4$

$C_{SB} = C_5$

$C_{DB} = C_6$ #

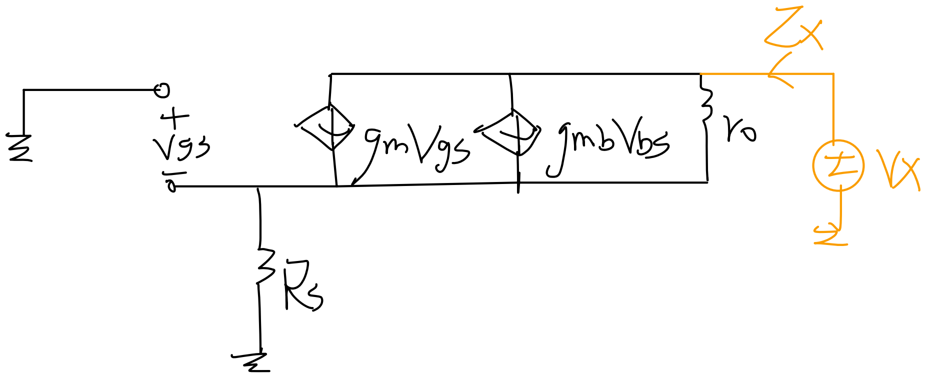
(c)

C_{GS} / C_{DB} C_{SB} 异电压有関

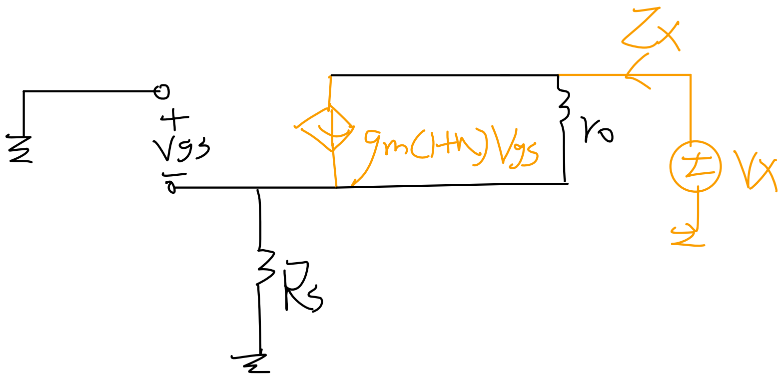
C_{GB} / C_{GD} 异电压無関 #

Q4

(a)



$$V_{bs} = V_{gs} \Rightarrow (g_m + g_{mb})V_{gs} = (1+n)g_m V_{gs}$$



$$V_{gs} = 0 - I_x R_s = -I_x R_s$$

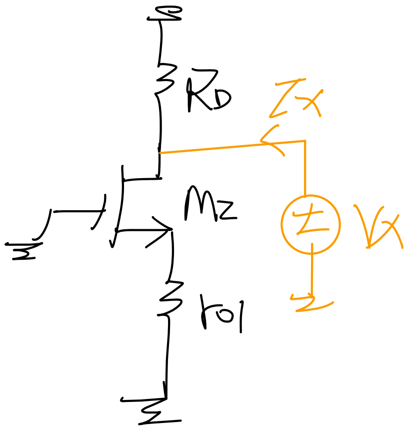
$$V_x = I_x R_s + I_x[(1+n)g_m R_s + 1]r_o$$

$$R_{out}' = \frac{V_x}{I_x} = R_s + [(1+n)g_m R_s + 1]r_o$$

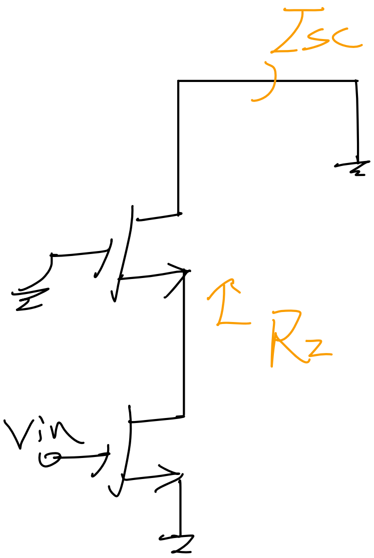
或 $R_{out}' = r_o + [(1+n)g_m r_o + 1]R_s$

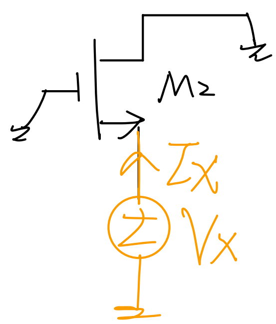
$R_{out} = R_D \,//\, R_{out}'$ #

(b)



$$R_{out} = R_D \,//\, \{ r_{o2} + [1+(g_{m2}+g_{m2b})r_{o2}]\, r_{o1} \}$$





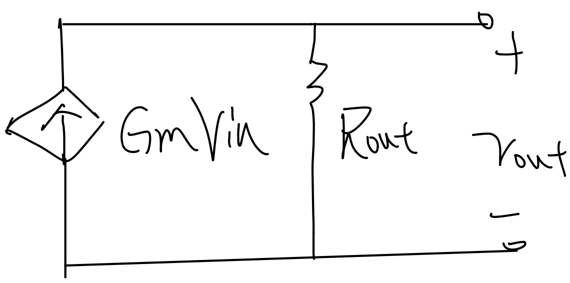
$$I_x = (g_{m2}+g_{m2b})V_x + \frac{V_x}{r_{o2}}$$

$$\Rightarrow R_2 = \frac{V_x}{I_x} = \frac{1}{g_{m2}+g_{m2b}+\frac{1}{r_{o2}}}$$

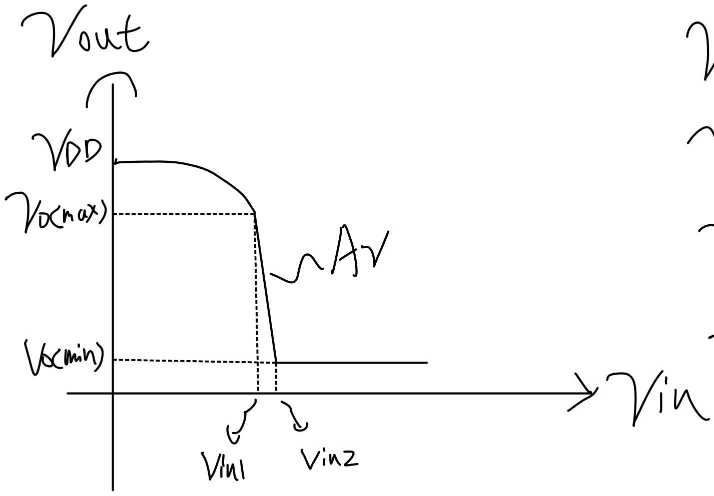
或 $$R_2 = \frac{r_{o2}}{1+(g_{m2}+g_{m2b})r_{o2}}$$

$$I_{sc} = -g_{m1}V_{in}\frac{r_{o1}}{r_{o1}+R_2} = -g_{m1}\frac{r_{o1}[1+(g_{m2}+g_{m2b})r_{o2}]}{r_{o1}+r_{o2}+(g_{m2}+g_{m2b})r_{o2}r_{o1}}v_{in}$$

$$G_m = \frac{I_{sc}}{v_{in}} = -g_{m1}\frac{r_{o1}}{r_{o1}+R_2} = -g_{m1}\frac{r_{o1}[1+(g_{m2}+g_{m2b})r_{o2}]}{r_{o1}+r_{o2}+(g_{m2}+g_{m2b})r_{o2}r_{o1}} \overset{(r_{o1}\gg R_2)}{\simeq} -g_{m1}$$



$$A_v = G_m R_{out} \ \#$$



$$V_{in1} = V_{th1}$$

$$V_{in2} = V_b - V_{GS2} + V_{th1}$$

$$V_{o(max)} = V_{DD} - G_m(V_{in1})\, V_{in1} R_D$$

大訊號的 G_m

$$V_{o(min)} = V_b - V_{th2}$$

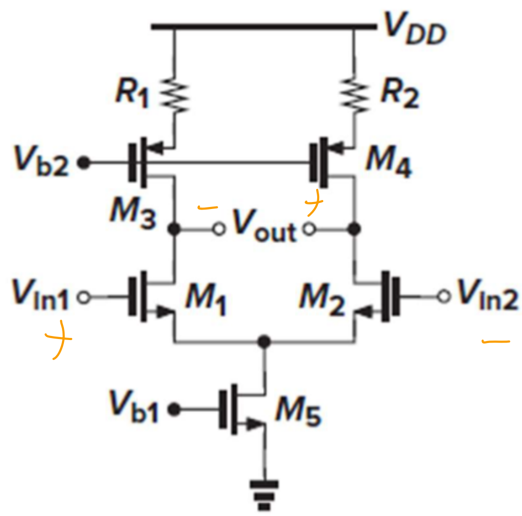
#

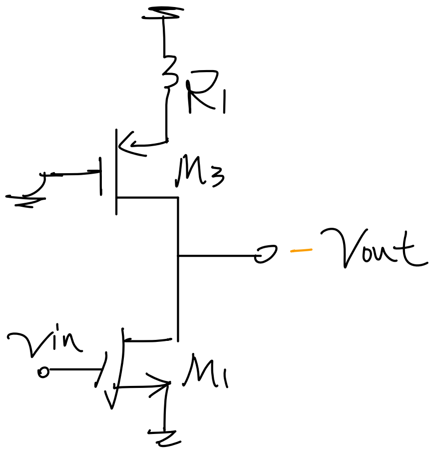
2b

Q5

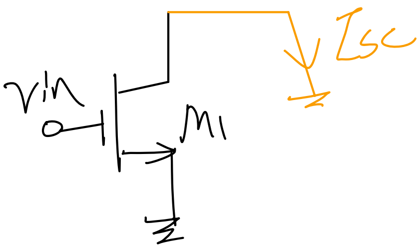
a.

利用差模等效半电路



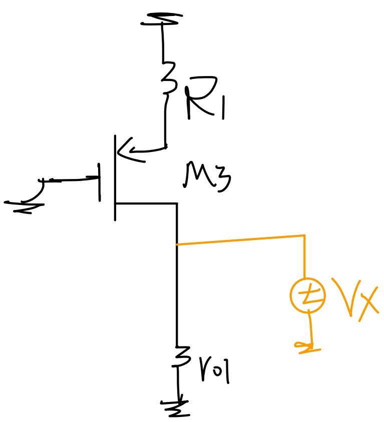


$$v_{in} = V_{in1} - V_{in2}$$



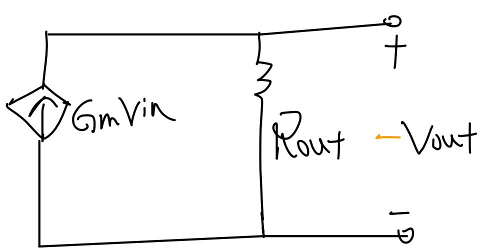
$$I_{sc} = -g_{m1} v_{in}$$

$$G_m = \frac{I_{sc}}{v_{in}} = -g_{m1}$$



$$R_{op} = r_{o3} + [1 + (g_{m3} + g_{m3b}) r_{o3}] R_1$$

$$R_{out} = r_{o1} \,//\, R_{op}$$

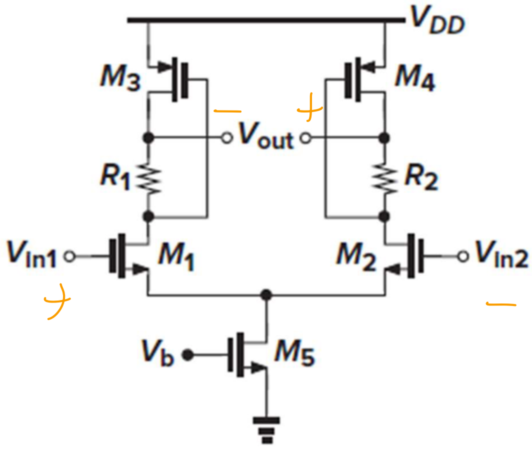


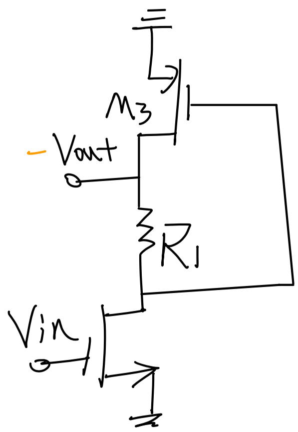
$$\frac{-V_{out}}{v_{in}} = G_m R_{out}$$

$$\frac{V_{out}}{v_{in}} = -G_m R_{out} \quad \#$$

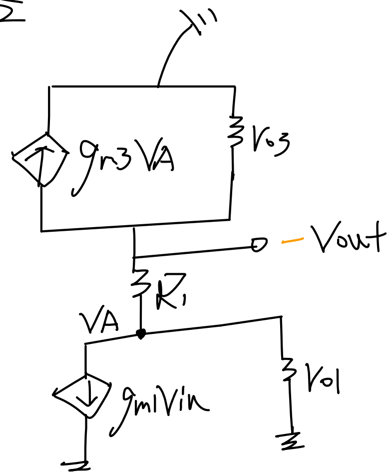
b、

利用差模等效半电路

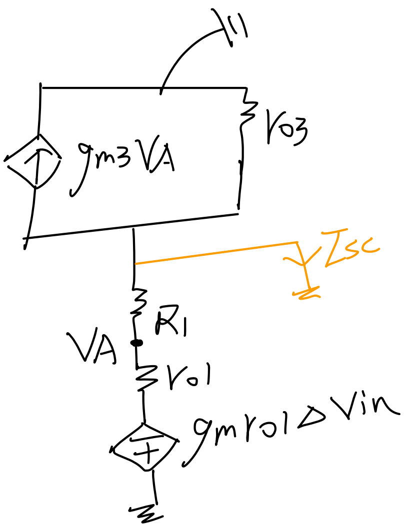




$\Rightarrow$



假設 $V_{in} = V_{in1} - V_{in2}$

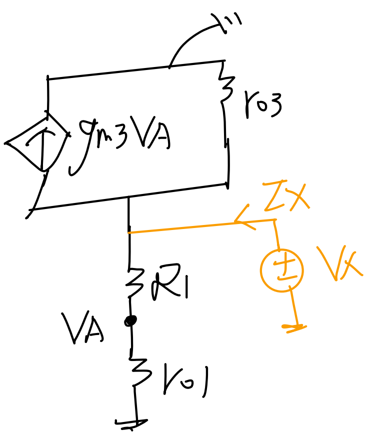


$$V_A = -g_{m1}r_{o1}V_{in}\frac{R_1}{r_{o1}+R_1}$$

$$I_{sc} = -\left[\frac{g_{m1}r_{o1}}{R_1+r_{o1}} - g_{m3}g_{m1}r_{o1}\frac{R_1}{r_{o1}+R_1}\right]V_{in}$$

$$\Rightarrow I_{sc} = \frac{-g_{m1}r_{o1}}{R_1+r_{o1}}\left[1-g_{m3}R_1\right]V_{in}$$

$$\Rightarrow G_m = \frac{I_{sc}}{V_{in}} = \frac{-g_{m1}r_{o1}}{R_1+r_{o1}}\left[1-g_{m3}R_1\right]$$

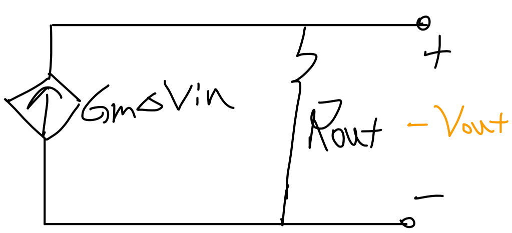


$$V_A = \frac{r_{o1}}{R_1+r_{o1}}V_X$$

$$I_X = \left(\frac{1}{R_1+r_{o1}} + \frac{1}{r_{o3}} + \frac{g_{m3}r_{o1}}{R_1+r_{o1}}\right)V_X$$

$$\Rightarrow I_X = \left(\frac{1+g_{m3}r_{o1}}{R_1+r_{o1}} + \frac{1}{r_{o3}}\right)V_X$$

$$\Rightarrow R_{out} = \frac{V_X}{I_X} = \frac{R_1+r_{o1}}{1+g_{m3}r_{o1}} \,//\, r_{o3}$$



$$\frac{-V_{out}}{V_{in}} = G_m R_{out}$$

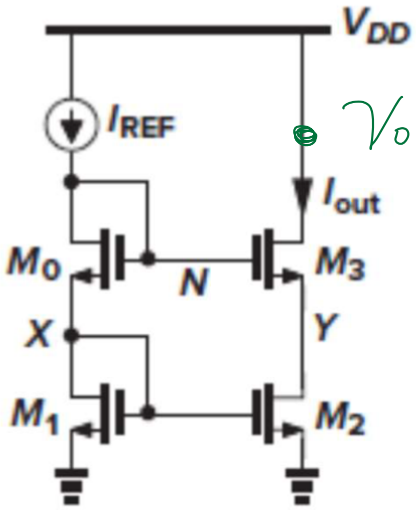
$$\Rightarrow \frac{V_{out}}{V_{in}} = -G_m R_{out} = \frac{g_{m1}r_{o1}r_{o3}(1-g_{m3}R_1)}{R_1+r_{o3}+(1+g_{m3}r_{o3})r_{o1}}$$

#

Q6

a.

Fig 6(a) 相比 (b)及(c) 所需的 $V_{o(min)}$ 較大



(a)

$$V_{o(min)} = V_{GS1} + V_{GS0} - V_{th3}$$
$$= 2V_{ov} + V_{th}$$

而 (b), (c)

$V_{o(min)} = 2V_{ov}$ #

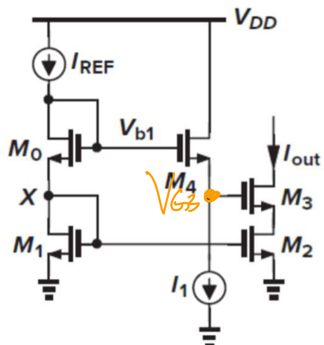
(b)

透過加入M_4及I_1來当作 level-shift

並且設計M_4具有較大的(W/L)使得V_{ov4}極小

讓 $V_{GS4} \simeq V_{th4}$

$$V_{o(min)} = V_{GS1} + V_{GS0} - V_{GS4} - V_{th3}$$
$$\simeq V_{GS1} + V_{GS0} - V_{th4} - V_{th3}$$
$$= 2V_{ov}$$ #



(c)

得到較小的$V_{o(min)}$