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

110-1 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: 13:20~15:20
- **沒有過程不給分**
-

表 **2.1** NMOS 和 PMOS 元件的第一層 SPICE 模型。

NMOS 模型			
LEVEL = 1	VTO = 0.7	GAMMA = 0.45	PHI = 0.9
NSUB = 9e+14	LD = 0.08e−6	UO = 350	LAMBDA = 0.1
TOX = 9e−9	PB = 0.9	CJ = 0.56e−3	CJSW = 0.35e−11
MJ = 0.45	MJSW = 0.2	CGDO = 0.4e−9	JS = 1.0e−8
PMOS 模型			
LEVEL = 1	VTO = −0.8	GAMMA = 0.4	PHI = 0.8
NSUB = 5e+14	LD = 0.09e−6	UO = 100	LAMBDA = 0.2
TOX = 9e−9	PB = 0.9	CJ = 0.94e−3	CJSW = 0.32e−11
MJ = 0.5	MJSW = 0.3	CGDO = 0.3e−9	JS = 0.5e−8

- V_{DD}=3V for all questions if not mentioned.
- $\varepsilon_0 = 8.85*10^{-14}$ F/cm ; $\varepsilon_{SiO2} = 3.9*\varepsilon_0$; $\varepsilon_{Si} = 11.7*\varepsilon_0$

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Q1: (10%)

Calculate the voltage gain (Av=Vout/Vin) of the circuit shown in Fig. 1.

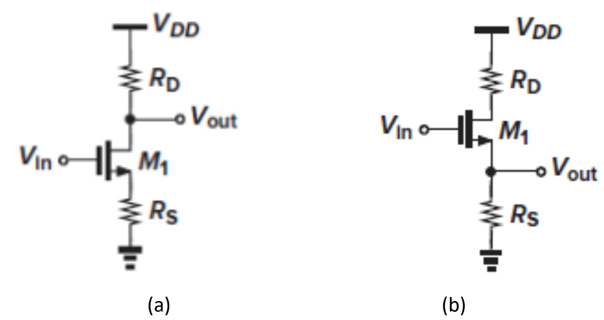


Fig. 1

Q2: (10%)

Assume the M3's drain node is the output (Vout) of the circuit shown in Fig. 2. Please show the minimum voltage of Vout using transistor parameters. The body effect is ignored. Hint: $M_i \sim (V_{THi}, V_{ovi}, g_{mi}, r_{oi})$

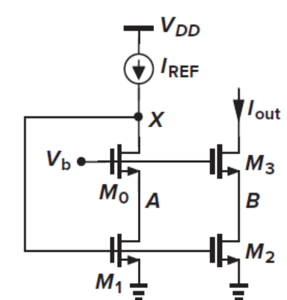


Fig. 2

Q3: (10%)

If ignore all other parasitic capacitors of MOSFETs, please calculate the equivalent input impedance of the circuits in Fig. 3. **λ≠0 for (a) and (b).**

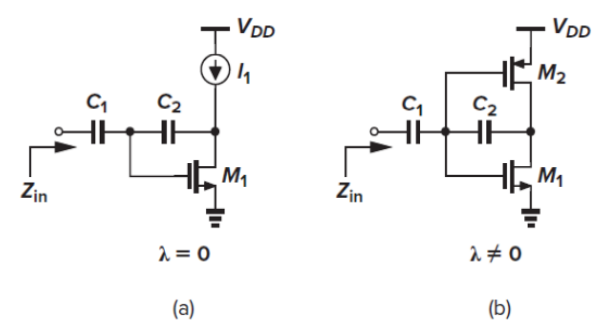


Fig. 3

Q4: (10%)
Calculate the input-referred thermal noise voltage and current of the circuit in Fig. 4. Assume that λ=γ=0.

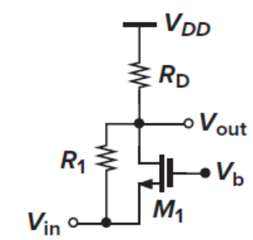


Fig. 4

Q5: (10%)
Calculate the close-loop input and output resistance ($R_{in,CL}$ and $R_{out,CL}$) using small-signal parameters.

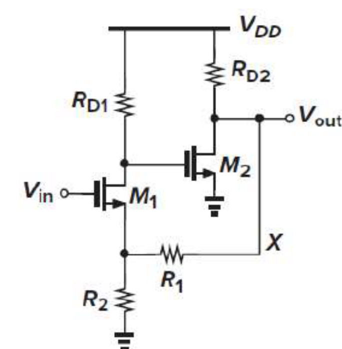


Fig. 5

Q6: (10%)
Assuming that $\lambda = \gamma = 0$, calculate the input-referred thermal noise voltage of the circuit in Fig. 6. Assume that $g_{m3,4} = 3/4{*}g_{m5,6}$.

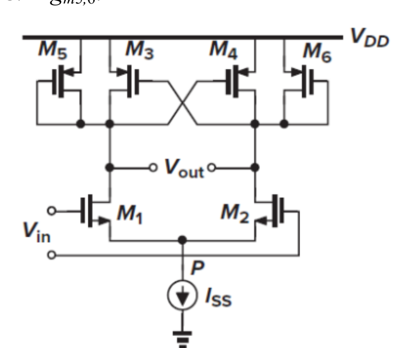


Fig. 6

Q7: (20%)

Suppose the amplifier of the circuit shown in Fig.7 has an open-loop transfer function $A_0/(1+s/\omega_0)$ and an output resistance R_0. Calculate the output resistance ($\mathbf{R_{o,CL}}$) and the voltage gain ($\mathbf{A_{V,CL}}$) of the closed-loop circuit.

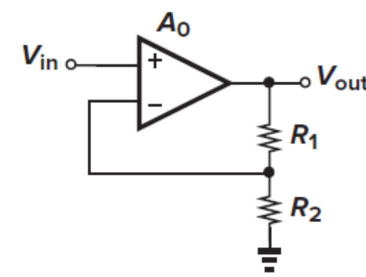


Fig. 7

Q8: (20%)

Consider the transimpedance amplifier shown in Fig. 8, where $R_D = 1$ kΩ, $R_F = 10$ kΩ, $g_{m1} = g_{m2} = 1/(100\Omega)$, and $C_A = C_X = C_Y = 100$ fF. Neglecting all other capacitances and assuming that $\lambda = \gamma = 0$, compute the phase margin of the circuit. (Hint: break the loop at node X.)

Fig. 8

Q1: (10%)

Calculate the voltage gain (Av=Vout/Vin) of the circuit shown in Fig. 1.

考慮 body effect

$G_m = g_m + g_{mb}$

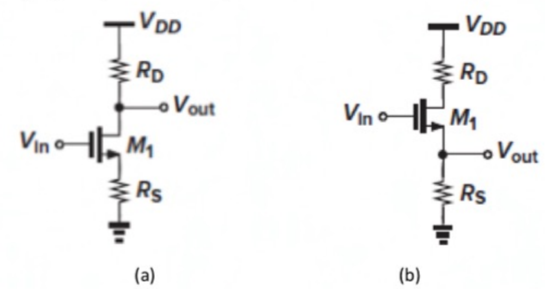
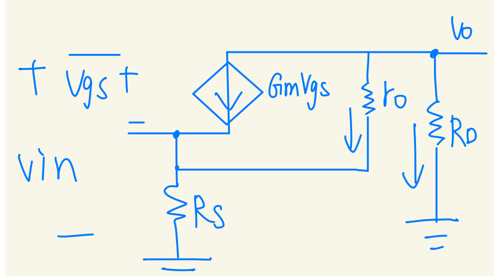


Fig. 1

(a)

$$\frac{V_{out}}{v_{in}} = \frac{-g_m R_D \cdot r_o}{(1+G_m r_o)R_S + r_o + R_D} \#$$



$$\frac{V_o + V_{gs}}{r_o} + G_m V_{gs} + \frac{V_o}{R_D} = 0$$

$$V_o\left(\frac{1}{r_o} + \frac{1}{R_D}\right) = -V_{gs}\left(\frac{1}{r_o} + G_m\right)$$

$$V_{gs} = \frac{-(r_o + R_D)\cdot V_o}{(1+G_m r_o)R_D} \cdots ①$$

$$v_{in} = V_{gs} + \frac{-V_o}{R_D} \times R_S \cdots ②$$

$$v_{in} = -V_o\left(\frac{r_o + R_D}{1+G_m r_o} + \frac{R_S}{R_D}\right)$$

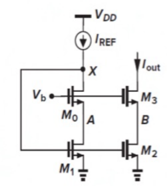
$$\frac{V_o}{V_{in}} = \frac{-(1+G_m r_o)R_D}{r_o + R_D + (1+G_m r_o)R_S}$$

(b)

$$\frac{g_m r_o R_S}{(G_m r_o R_S) + r_o + R_D + R_S} \# \text{ or } \frac{g_m}{g_m + \frac{1}{R_S} + \frac{R_D}{r_o R_S} + \frac{1}{r_o}}$$

Q2: (10%)

Assume the M3's drain node is the output (Vout) of the circuit shown in Fig. 2. Please show the minimum voltage of Vout using transistor parameters. The body effect is ignored. Hint: $M_i \sim (V_{THi}, V_{ovi}, g_{mi}, r_{oi})$



$$\frac{g_m}{I_D} = \frac{2}{V_{OV}}$$

Fig. 2

Q3: (10%)

If ignore all other parasitic capacitors of MOSFETs, please calculate the equivalent input impedance of the circuits in Fig. 3. **λ≠0 for (a) and (b).**

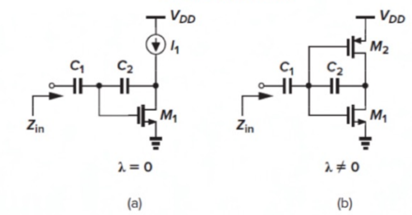


Fig. 3

Q2:

$$V_{out} = V_{ov2} + V_{ov3} \qquad I_{out} = I_{D3} = I_{D2} \qquad V_{GS2} = V_{GS1} = V_X$$

$$V_{ov2} = \sqrt{\frac{2 I_{out}}{U_n C_{ox} \frac{W}{L_2}}} \qquad V_{ov3} = \sqrt{\frac{2 I_{out}}{U_n C_{ox} \frac{W}{L_3}}} \qquad V_X - V_{TH1} = V_{OV1}$$

$$\Rightarrow \sqrt{2 I_{ref} \Big/ U_n C_{ox} \frac{W}{L_1}}$$

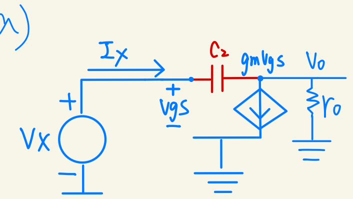
$$V_{ov2} = V_{GS2} - V_{TH2} = V_X - V_{TH2}$$

$$V_{ov3} = V_{GS3} - V_{TH3} = (V_b - V_{ov2}) - V_{TH3} \ \#$$

Q3:

(a)

先別看C1，後續再加



$$V_X = \frac{I_X}{SC_2} + (I_X - g_m V_X) r_o$$

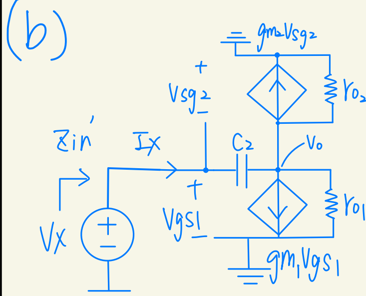
$$\Rightarrow V_X (1 + g_m r_o) = I_X \left(\frac{1 + SC_2 r_o}{SC_2}\right)$$

$$\frac{V_X}{I_X} = \frac{1 + SC_2 r_o}{(1 + g_m r_o) SC_2}$$

$$Z_{in} = \frac{1}{SC_1} + \frac{1 + SC_2 r_o}{(1 + g_m r_o) SC_2} \ \#$$

$$\text{or} \quad \frac{1}{SC_1} + \frac{\frac{1}{SC_2} + r_o}{1 + g_m r_o} \ \#$$

(b)



$$V_{gs1} = V_{gs2} = V_{gs} = V_X$$

$$I_X = (V_{gs} - V_o) \cdot SC_2 \ \dots ①$$

$$I_X = \frac{V_o}{r_{o1} // r_{o2}} + (g_{m1} + g_{m2}) V_{gs}$$

設 $r_{o1} // r_{o2} = R_o \quad g_{m1} + g_{m2} = g_m$

$V_o = I_X r_o - g_m r_o V_{gs}$ 代①

$$V_{gs} - I_X r_o + g_m r_o V_{gs} = \frac{I_X}{SC_2}$$

$$V_{gs}(1 + g_m r_o) = I_X \left(r_o + \frac{1}{SC_2}\right) \qquad \frac{V_X}{I_X} = \frac{r_o + \frac{1}{SC_2}}{1 + g_m r_o}$$

$$\text{而 } Z_{in} = \frac{1}{SC_1} + \frac{R_o + \frac{1}{SC_2}}{1 + g_m R_o}$$

↳可省略

$$\frac{1}{SC_1} + \frac{r_{o1} // r_{o2} + \frac{1}{SC_2}}{1 + (g_{m1} + g_{m2})(r_{o1} // r_{o2})} \ \#$$

Q4: (10%)

Calculate the input-referred thermal noise voltage and current of the circuit in Fig. 4. Assume that λ=γ=0.

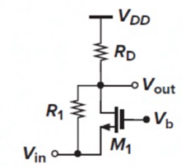
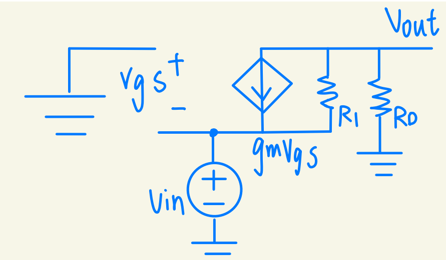


Fig. 4



$$\overline{V_{n,out}^2} = \left(4kT\gamma g_m + \frac{4kT}{R_D} + \frac{4kT}{R_1}\right)\left(R_1 // R_D\right)^2 \qquad A_V = \left(\frac{1}{R_1} + g_m\right)(R_D \| R_1)$$

$$\overline{V_{n,in}^2} = \overline{V_{n,out}^2} / A_V^2 = \frac{4kT\left(\frac{1}{R_D} + \frac{1}{R_1} + \gamma g_m\right)}{\left(\frac{1}{R_1} + g_m\right)^2} \; \# \qquad \overline{I_{n,in}^2} = \frac{4kT}{R_D} \; \#$$

Q5: (10%)

Calculate the close-loop input and output resistance ($R_{in,CL}$ and $R_{out,CL}$) using small-signal parameters.

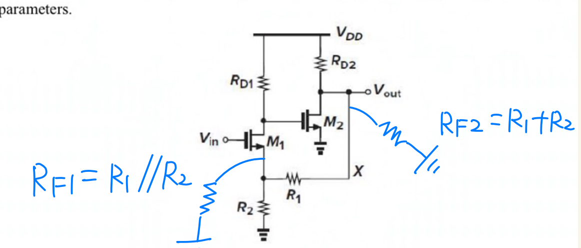


Fig. 5

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

$$R_{O,OL} = R_{D2} // R_{F2} // r_{O2}$$

$$V_F = V_X \cdot g_{m1} R_{D1} ; \; V_X = -g_{m2} V_t \cdot \frac{R_{D2} \cdot \left(R_2 // \frac{R_{D1} + r_{O1}}{1 + g_{m1} r_{O1}}\right)}{R_{D2} + \left[R_1 + R_2 // \frac{R_{D1} + r_{O1}}{1 + g_{m1} r_{O1}}\right]}$$

$$\frac{V_F}{V_t} = \frac{V_F}{V_X} \times \frac{V_X}{V_t} = g_{m1} R_{D1} * -g_{m2} \cdot \frac{R_{D2} \cdot \left(R_2 // \frac{R_{D1} + r_{O1}}{1 + g_{m1} r_{O1}}\right)}{R_{D2} + \left[R_1 + R_2 // \frac{R_{D1} + r_{O1}}{1 + g_{m1} r_{O1}}\right]}$$

$$= -g_{m1} g_{m2} R_{D1} R_{D2} \left(R_2 // \frac{R_{D1} + r_{O1}}{1 + g_{m1} r_{O1}}\right) \div \left[R_{D2} + R_1 + R_2 // \frac{R_{D1} + r_{O1}}{1 + g_{m1} r_{O1}}\right] = -A\beta$$

$$R_{in,CL} = \infty \times (1 + A\beta) = \infty \; \#$$

$$R_{out,CL} = \frac{R_{D2} // R_{F2}}{1 + A\beta} \; \#$$

Q6: (10%)

Assuming that $\lambda = \gamma = 0$, calculate the input-referred thermal noise voltage of the circuit in Fig. 6. Assume that $g_{m3,4} = 3/4 * g_{m5,6}$.

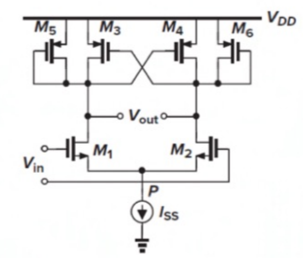


Fig. 6

ANS6 :

$$A_V = g_{m1,2} / (g_{m5,6} - g_{m3,4})$$

$$= 4\, g_{m1,2} / g_{m5,6}$$

$$\overline{I_{n,o}^2} = 4kT\gamma (g_{m3} + g_{m5} + g_{m1})$$

要X2

$$\overline{V_{n,in}^2} = 4kT\gamma (g_{m3} + g_{m5} + g_{m1}) / g_{m1}^2 \quad \#$$

$$= \overline{I_{n,o}^2} / g_{m1}^2$$

#

Q7: (20%)

Suppose the amplifier of the circuit shown in Fig.7 has an open-loop transfer function $A_0/(1+s/\omega_0)$ and an output resistance R_0. Calculate the output resistance (**$R_{o,CL}$**) and the voltage gain (**$A_{V,CL}$**) of the closed-loop circuit.

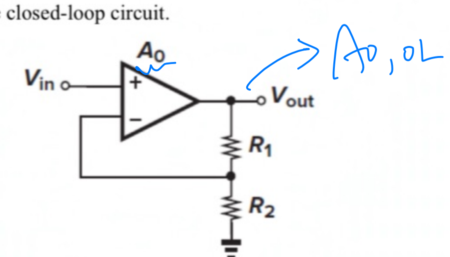


Fig. 7

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ANS7 (V-V Feedback)

assume by single-pole

$$R_{o,OL} = R_0 // (R_1 + R_2), \quad A_{0,OL} = A_0' = g_m(R_0 // (R_1+R_2))$$

$$(1+\beta A_{0,OL}) = 1 + \frac{R_2}{R_1+R_2} \cdot A_0'$$

$$R_{o,CL} = \frac{R_{o,OL}}{1+\beta A_{OL}} = \frac{R_0 // (R_1+R_2)}{1 + \frac{R_2}{R_1+R_2} \cdot g_m (R_0 // (R_1+R_2))} \cong \frac{R_0}{\frac{R_2}{R_1+R_2} \cdot g_m R_0} = \frac{1}{\beta g_m}$$

$$=$$

$$A_{V,CL} = \frac{A_0'}{1+\beta A_0'} = \frac{g_m (R_0 // (R_1+R_2))}{1 + \frac{R_2}{R_1+R_2} g_m (R_0 // (R_1+R_2))} \cong g_m R_{o,CL}$$

Q8: (20%)

Consider the transimpedance amplifier shown in Fig. 8, where $R_D = 1\ \mathrm{k\Omega}$, $R_F = 10\ \mathrm{k\Omega}$, $g_{m1} = g_{m2} = 1/(100\Omega)$, and $C_A = C_X = C_Y = 100$ fF. Neglecting all other capacitances and assuming that $\lambda = \gamma = 0$, compute the phase margin of the circuit. (Hint: break the loop at node X.)

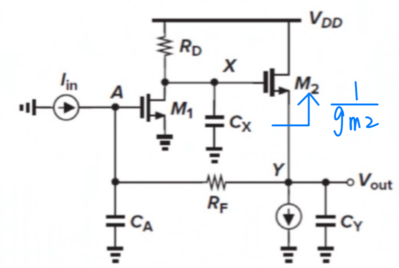

Fig. 8

ANS8: V-I Feedback

$$\underbrace{\beta}_{} \underbrace{A_0}_{} \cong \Big(\overbrace{R_F \cdot g_{m1} R_D}^{A_0}\Big)\Big(\overbrace{1/R_F}^{\beta}\Big) = g_m R_D = 10.$$

To break the loop after node X

We have three poles at nodes Y, A, X, ~~resulting three poles~~ labeled as ω_Y, ω_A, and ω_X

$$\omega_Y \cong 1/\big((1/g_{m2} \,//\, R_F)\, C_Y\big)$$

$$\omega_A \cong 1/(R_F \cdot C_A)$$

$$\omega_X \cong 1/(R_D \cdot C_X)$$

$\because\ R_F > R_D > 1/g_{m2}$, $C_X = C_Y = C_A$

$\Rightarrow\ \omega_A < \omega_X < \omega_Y$ $\left[\ \omega_A = \frac{1}{10}\omega_X = \frac{1}{100}\omega_Y\ \right]$

$$H(s) = \frac{\beta A_0}{(1+s/\omega_A)(1+s/\omega_X)(1+s/\omega_Y)}$$

$\omega_u = 10\,\omega_A \cong \omega_X$

$\Rightarrow\ PM \cong 45^\circ$

real is $\sim 40^\circ$ (by $\omega_Y = 10\,\omega_u$)