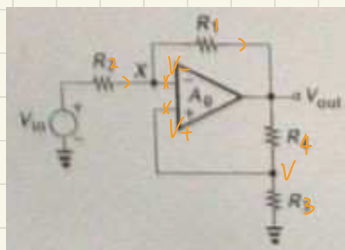


2013-A.

非理想型 Amp.

虚短虚断.



$$\begin{cases} V_+ = V_- \triangleq V & \textcircled{1} \\ \frac{V_{in} - V}{R_2} = I_X & \textcircled{2}, \quad \frac{V_{out} - V}{R_1} = I_X & \textcircled{3} \\ \frac{V}{R_3} = I_X & \textcircled{4}, \quad \frac{V_{out}}{R_3 + R_4} = I_X & \textcircled{5} \end{cases}$$

$$\textcircled{4}, \textcircled{5} \Rightarrow V = \frac{R_3}{R_3 + R_4} V_{out}$$

$$\textcircled{2}, \textcircled{3} \Rightarrow \frac{V_{in} - V}{R_2} = \frac{V_{out} - V}{R_1} \Rightarrow \frac{V_{in}}{R_2} - \frac{V}{R_2} = \frac{V_{out}}{R_1} - \frac{V}{R_1} = V \left(\frac{1}{R_2} - \frac{1}{R_1} \right)$$

$$\Rightarrow \frac{V_{out}}{R_1} = \frac{V_{in}}{R_1} + V \left(\frac{1}{R_1} - \frac{1}{R_2} \right) = \frac{V_{in}}{R_1} + \frac{R_3}{R_3 + R_4} V_{out} \left(\frac{1}{R_1} - \frac{1}{R_2} \right)$$

$$\begin{aligned} \Rightarrow V_{out} &= \frac{1}{R_2 \left(\frac{1}{R_1} + \frac{R_3}{R_3 + R_4} \left(\frac{1}{R_1} - \frac{1}{R_2} \right) \right)} V_{in} = \frac{1}{R_2 \left(\frac{1}{R_1} + \frac{R_3}{R_3 + R_4} \cdot \frac{R_1 - R_2}{R_1 R_2} \right)} V_{in} \\ &= \frac{R_1 R_2 (R_3 + R_4)}{R_1 (R_3 + R_4) + R_2 (R_1 - R_2)} V_{in} = \frac{(R_3 + R_4) R_1}{R_2 R_4 + R_1 R_3} V_{in} \end{aligned}$$

2. \

Flash
A/D

3. Flash 是 A/D C 中最快的
6 位需要电阻 $2^6 = 64$ 个. 比较器 $2^6 - 1 = 63$ 个.
直接得到 温度代码.

SNR

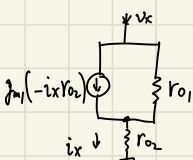
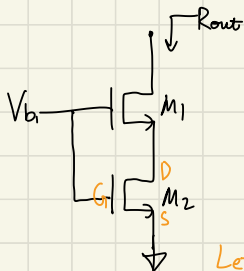
LSB

4. 10 bits. A/D C. $SNR = 6.02 \times 10 + 1.76 \text{ dB} = 61.96 \text{ dB}$.

$$V_{REF} \Rightarrow \text{LSB} = \frac{V_{REF}}{2^{10}} = \frac{V_{REF}}{1024}$$

5. 求 $R_{out} = r_{o1} (1 + g_{m1} r_{o2}) + r_{o2}$

Degeneration
|
 R_{out} .



$$V_{GS} = 0 \Rightarrow r_{o2}$$

Let $V_{b1} = 0$

$$\begin{aligned} r_{o1} (i_x + g_{m1} r_{o2} i_x) + i_x r_{o2} &= V_x \\ r_{o1} (1 + g_{m1} r_{o2}) + r_{o2} &= R_{out} \end{aligned}$$

6. \ 7. \

Diode 状态参数.

8. Diode $I_D = 10 \text{ mA}$. g_D (in small-sig. model) = $\frac{I_D}{V_T} = 0.38 \text{ S}$
 $V_T = 0.026 \text{ V}$

9. \

=

1. $\otimes$ NMOS: $V_I, I > 0$. PMOS: $V_I, I < 0$. Both: $g_o, r_o > 0$.

2. ?

Op. Amp. 工作区.

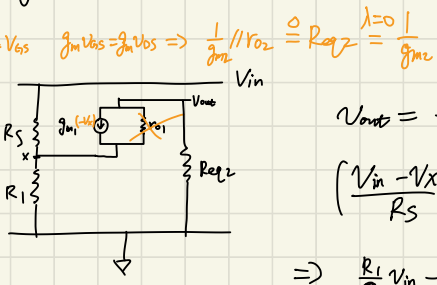
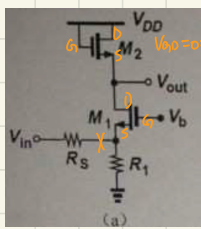
3. 负反馈状态 $\Rightarrow$ 线性区. 正反馈状态 $\Rightarrow$ 饱和区.

4. \

5. \

=

(i) 求 A_v . (in small-sig. model)



$V_{out} = +g_{m1} V_x R_{eq2}$

$\left(\frac{V_{in} - V_x}{R_S} - g_{m1} V_x \right) R_L = V_x$

$\Rightarrow \frac{R_L}{R_S} V_{in} - \left(\frac{R_L}{R_S} + g_{m1} R_L \right) V_x = V_x$

$\Rightarrow \frac{R_L}{R_S} V_{in} = V_x \left(1 + \frac{R_L}{R_S} + g_{m1} R_L \right)$

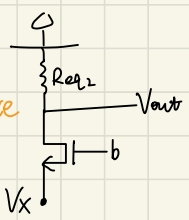
$\Rightarrow \frac{R_L}{R_S} V_{in} = \frac{V_{out}}{g_{m1} R_{eq2}} \left(1 + \frac{R_L}{R_S} + g_{m1} R_L \right) \Rightarrow A_v = \frac{R_L g_{m1}}{(R_S + R_L + g_{m1} R_L R_S) g_{m2}}$

Using known model:

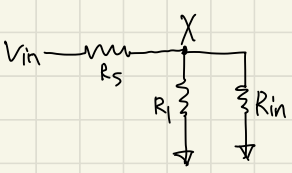
CG stage

with sig.

Source resistance



Looking up from X, $R_{in} = \frac{1}{g_{m1}}$ (CG stage).

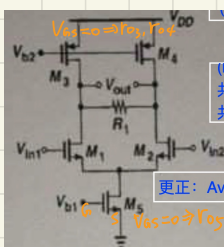
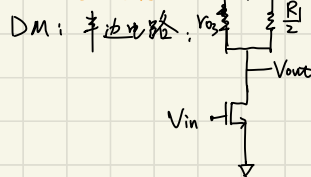


$V_x = V_{in} \frac{R_L \parallel R_{in}}{R_S + R_L \parallel R_{in}} = \frac{R_L \parallel \frac{1}{g_{m1}}}{R_S + R_L \parallel \frac{1}{g_{m1}}}$

(From CG stage again,) $\frac{V_{out}}{V_x} = g_{m1} R_{eq2}$

$\Rightarrow A_v = \frac{V_{out}}{V_{in}} = \frac{g_{m1}}{g_{m2}} \cdot \frac{R_L \parallel \frac{1}{g_{m1}}}{R_S + R_L \parallel \frac{1}{g_{m1}}}$

(2)

 $\lambda > 0$. 完全对称.

CS stage:

$$A_{DM} = -g_{m1} (r_{o1} \parallel (r_{o3} \parallel \frac{R_1}{2}))$$

CM: 半边电路. M_5 is split to 2 parts. Δ Perfect symmetry $\Rightarrow U_{R1} = 0 \Rightarrow R_1$ can be ignored.

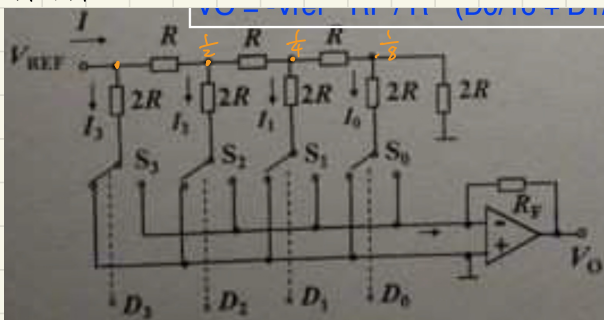
Degeneration with channel modulation eff.:

$$A_{cm} = \frac{-g_{m1} r_{o1} r_{o3}}{r_{o3} + r_{o1} + 2r_{o5} (1 + g_{m1} r_{o1})}$$

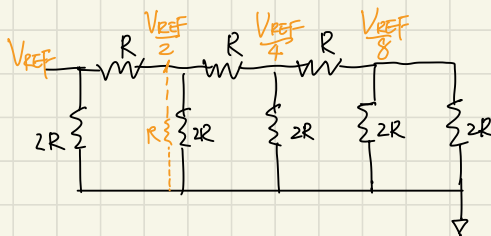
Perfect Symmetry $\Rightarrow A_{cm-DM} = 0$.

$$\Rightarrow CMRR = \frac{A_{DM}}{A_{cm} + A_{cm-DM}} = \frac{(r_{o1} \parallel r_{o3} \parallel \frac{R_1}{2}) r_{o1} r_{o3}}{r_{o3} + r_{o1} + 2r_{o5} (1 + g_{m1} r_{o1})}$$

六. DAC.

e.g. S_0 闭合, $2R$ 下端仍然接地. (虚地)

不影响各节点电压.

 $2R$ 作为这级反相输入模型中的输入电阻.放大倍数 $-\frac{R_F}{2R}$.放大的是 $2R$ 上方节点的电压. ($\frac{V_{REF}}{8}$)

$$\Rightarrow V_0 = -\frac{R_F}{2R} V_{REF} (D_3 + \frac{1}{2} D_2 + \frac{1}{4} D_1 + \frac{1}{8} D_0)$$

$$V_0 = -\frac{R_F}{16R} V_{REF} (2^3 \cdot D_3 + 2^2 \cdot D_2 + 2^1 \cdot D_1 + 2^0 \cdot D_0)$$

CS stage

Degeneration with channel modulation eff.

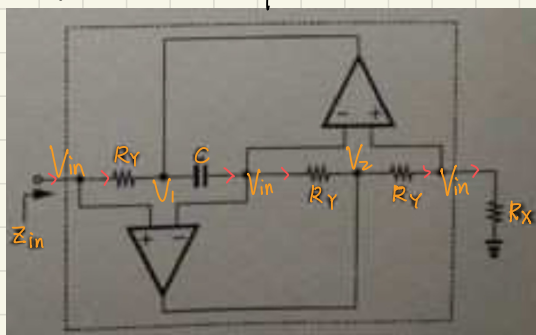
$$A_v = \frac{V_{out}}{V_{in}} = \frac{-g_{m1} r_{o1} R_D}{R_D + r_{o1} + R_S (g_{m1} r_{o1} + 1)}$$

CMRR

DAC

Op. Amp.

题做: ideal Amp. , $A \rightarrow +\infty$. 求 Z_{in} . 以及从右向左看该电路等效为何器件.



$$\begin{cases} \frac{V_{in} - V_1}{R_Y} = \frac{V_{in}}{Z_{in}} & ① \\ \frac{V_1 - V_{in}}{Z_C} = \frac{V_{in} - V_2}{R_Y} & ② \\ \frac{V_2 - V_{in}}{R_Y} = \frac{V_{in}}{R_X} & ③ \end{cases}$$

$$② \& ③: -1 = \frac{V_1 - V_{in}}{Z_C} \cdot \frac{R_X}{V_{in}} \Rightarrow \frac{V_1 - V_{in}}{V_{in}} = -\frac{Z_C}{R_X}$$

$$\& ①: Z_{in} = R_Y \frac{V_{in}}{V_{in} - V_1} = R_Y \frac{R_X}{Z_C} = \frac{R_X R_Y}{\frac{1}{j\omega C}} = j\omega R_X R_Y C.$$

相当于电感. (等效为 $j\omega L$ 的形式, 参数 $L = R_X R_Y C$.)

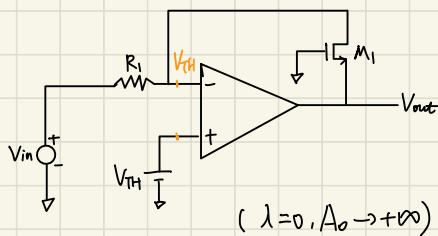
2015-A

1.

求传输函数:

开平方电路

(Sah eq. Op. Amp.)



$M_1: V_{GS} = V_{TH} - V_{out} \Rightarrow \text{Saturation Region.}$

$V_{GS} - V_{TH} = -V_{out} - V_{TH}$

$\Rightarrow I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (-V_{out} - V_{TH})^2$

$\frac{V_{in} - V_{TH}}{R_1} = I_D$

$\Rightarrow V_{out} = - \sqrt{\frac{2L(V_{in} - V_{TH})}{R_1 \mu_n C_{ox} W}} - V_{TH}$

2. \

3. 位数相同N 逐次逼近型 A/D 比 FLASH A/D 慢.

(不同) ADC 比较

前者完成一次转换所需的时钟周期数: N.

(参考 2013-A).

4. 14位 A/D C. $SNR = 6.02 \times 14 + 1.76 \text{ (dB)} = 86.04 \text{ dB}$

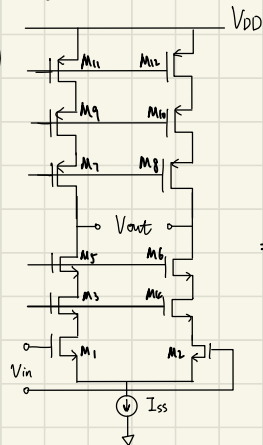
满量程 $V_{REF} \Rightarrow \text{LSB} = \frac{V_{REF}}{2^{14}}$

5. $R_{out} = ?$

差模. 看单端电路

$(V_{GS} = 0 \Rightarrow r_{o11})$

($\lambda > 0$)



$M_9, M_{11} \Rightarrow r_{o9} + r_{o11} + g_{m9} r_{o9} r_{o11} \approx r_{q+11}$

$M_7, (M_9, M_{11}) \Rightarrow r_{o7} + r_{q+11} + g_{m7} r_{o7} r_{q+11}$

$M_5, (M_7, M_{11}) \Rightarrow r_{o5} + r_{1+3} + g_{m5} r_{o5} r_{1+3}$

$r_{1+3} = r_{o3} + r_{o1} + g_{m3} r_{o3} r_{o1}$

$\Rightarrow R_{out} = (M_7, (M_9, M_{11})) // (M_5, (M_7, M_{11}))$

$= (r_{o7} + r_{o9} + r_{o11} + g_{m9} r_{o9} r_{o11} + g_{m7} r_{o7} (r_{o9} + r_{o11} + g_{m9} r_{o9} r_{o11}))$

$// (r_{o5} + r_{o3} + r_{o1} + g_{m3} r_{o3} r_{o1} + g_{m5} r_{o5} (r_{o3} + r_{o1} + g_{m3} r_{o3} r_{o1}))$

6.1 7.1.

Diode

8. $g_D = \frac{I_D}{V_T} = \frac{0.005 \text{ A}}{0.026 \text{ V}} = 0.19 \text{ S.}$

9. BJT. 有 4 个工作区. 分别是 截止区 饱和区 正向放大区 反向放大区

若 $V_{BE} > 0$ and $V_{BC} > 0$. 则其工作在 饱和区.

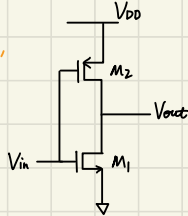
BJT

BJT

1. X $V_{CE} \uparrow, I_C \uparrow$. ($I_B \uparrow, I_C$ 不增大)
2. \
3. $\checkmark$ 运放在线性放大区, MOSFET 在饱和区; 运放在限幅区, MOSFET 在线性区.
4. \
5. \

Op.Amp. 中 MOSFET

三. (a) $\lambda > 0$, MOSFET in saturation region. $A_v = ?$



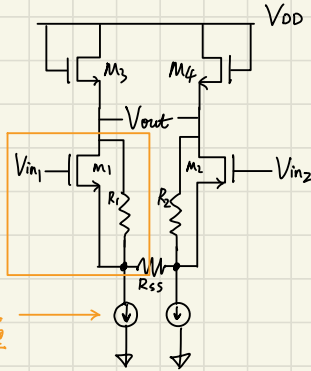
可看作 M_2, M_1 分别输入 V_{in} (在 G_1). $V_{GS} = 0 \Rightarrow V_O$.

叠加原理. $V_{out1} = V_{in} \cdot (-g_{m1}(r_{o1} \parallel r_{o2}))$

$V_{out2} = V_{in} \cdot (-g_{m2}(r_{o2} \parallel r_{o1}))$

$\Rightarrow A_v = \frac{V_{out1} + V_{out2}}{V_{in}} = -(g_{m1} + g_{m2})(r_{o1} \parallel r_{o2})$

(b) $\lambda = 0$. MOSFET @ saturation region. Perfect symmetry. $R_{out-DM} = ?$



$V_{GD} = 0 \Rightarrow V_{GS} = V_{DS} \xrightarrow{\lambda=0} \frac{1}{g_m}$

Half circuit:



$M_1(\lambda=0)$ and $R_1 \Leftrightarrow M_1(\lambda \neq 0)$ with $V_{G1} = R_1$

R_{out} for degeneration gives:

$R_{out} = \frac{1}{g_{m3}} \parallel \left(R_1 + \frac{R_{ss}}{2} + g_{m1} R_1 \frac{R_{ss}}{2} \right)$

电流源断路处理

六. 同 2013-A. DAC

选做. [2m]. Lemma. $A_v = -G_m R_{out}$. (见书).

2016

BJT

2. BJT. 有 4 个工作区. 分别是: 正向放大, 饱和, 截止, 反向放大

PNP

PNP管, $V_{BE} < 0$ 且 $V_{BC} < 0$, 则工作在: 饱和区.

3 A/D.C. 流水线型比 FLASH 慢

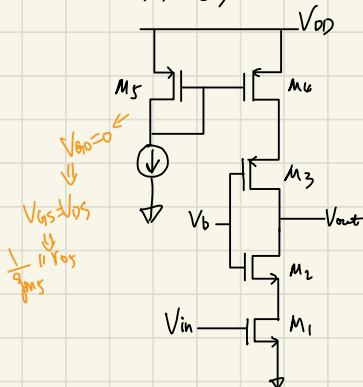
各种ADC.

N位逐次逼近型, 转换一次所需周期数 N .

FLASH. 比较器个数 $2^N - 1$. 溢出计数 $\rightarrow$ 二进制码.

5. $R_{out} = ?$
($\lambda > 0$)

Cascode



$i = 0$. $\Rightarrow (M_3 \& M_4)$ is cascode.

$$R_{out} = (r_{o3} + r_{o4} + g_{m3} r_{o3} r_{o4}) // (r_{o2} + r_{o1} + g_{m2} r_{o2} r_{o1})$$

(M_1, M_2 is cascode).

ADC

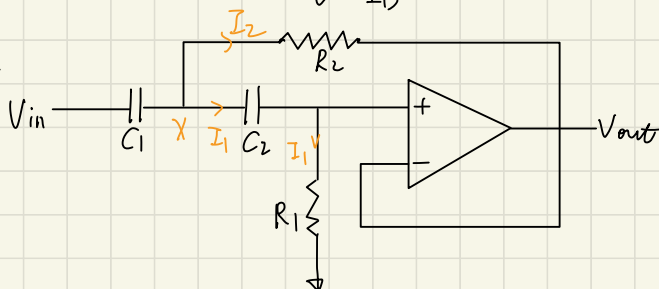
6. 10 bit ADC. $SNR = 6.02 \times 10 + 1.76 \text{ dB} = 61.96 \text{ dB}$

$$LSB = V_{REF} / 2^{10}$$

Diode

8. Diode. $I_D = 20 \text{ mA}$. $R_{eq} = \frac{V_T}{I_D} = 1.3 \Omega$.

9.



$V_{out} = ? V_{in}$

Op. Amp.

差分电路

$$V \triangleq V_+ = V_- = V_{out}$$

$$\frac{V_{in} - V_x}{Z_{C1}} = \dot{I}_1 + \dot{I}_2, \quad \frac{V_x - V_{out}}{R_2} = \dot{I}_2, \quad \frac{V_x - V_f}{Z_{C2}} = \frac{V_x - V_{out}}{Z_{C2}} = \dot{I}_1$$

$$\Rightarrow \frac{V_x - V_{out}}{Z_{C2}} = \frac{V_{out}}{R_1} \Rightarrow V_x = Z_{C2} \left(\frac{1}{R_1} + \frac{1}{Z_{C2}} \right) V_{out}$$

$$\frac{V_{in}}{Z_{C1}} - \frac{V_x}{Z_{C1}} = \frac{V_{out}}{R_1} + \frac{V_x}{R_2} - \frac{V_{out}}{R_2}$$

$$\Rightarrow \frac{V_{in}}{Z_{C1}} - \frac{Z_{C2}}{Z_{C1}} \left(\frac{1}{R_1} + \frac{1}{Z_{C2}} \right) V_{out} = V_{out} \left(\frac{1}{R_1} - \frac{1}{R_2} + \frac{Z_{C2}}{R_2} \left(\frac{1}{R_1} + \frac{1}{Z_{C2}} \right) \right)$$

$$\Rightarrow V_{out} \left(\frac{1}{R_1} - \frac{1}{R_2} + \frac{Z_{C2}}{R_2} \left(\frac{1}{R_1} + \frac{1}{Z_{C2}} \right) + \frac{Z_{C2}}{Z_{C1} R_1} + \frac{1}{Z_{C1}} \right) = \frac{1}{Z_{C1}} V_{in}$$

$$\Rightarrow V_{out} = V_{in} \frac{1}{Z_{C1} \left(\frac{1}{R_1} + \frac{Z_{C2}}{R_1 R_2} + \frac{Z_{C2}}{R_2 Z_{C1}} + \frac{1}{Z_{C1}} \right)} = V_{in} \frac{1}{\frac{Z_{C1}}{R_1} + \frac{Z_{C1} Z_{C2}}{R_1 R_2} + \frac{Z_{C2}}{R_2} + 1}$$

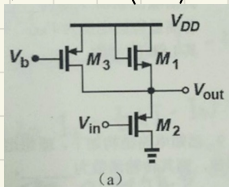
$$A = \frac{R_1 R_2}{R_2 Z_{C1} + Z_{C1} Z_{C2} + R_2 Z_{C2} + R_1 R_2} = \frac{R_1 R_2}{R_2 \frac{1}{j\omega C_1} + \frac{-1}{\omega^2 C_1 C_2} + R_2 \frac{1}{j\omega C_2} + R_1 R_2}$$

$$= \frac{-R_1 R_2 \omega^2 C_1 C_2}{j R_2 \omega C_2 + 1 + j R_2 \omega C_1 - R_1 R_2 \omega^2 C_1 C_2} = \frac{-\omega^2 R_1 R_2 C_1 C_2}{j\omega R_2 (C_1 + C_2) - R_1 R_2 \omega^2 C_1 C_2 + 1}$$

2. $\checkmark$ 饱和区. $V_{CE} \uparrow, I_{CE} \uparrow$

4. X.

7. (a) $A_v = ?$ ($\lambda > 0$)

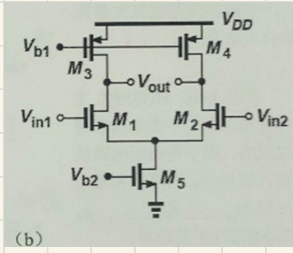


$$M1: V_{G0} = 0 \Rightarrow V_{GS} = V_{GS} \Rightarrow \frac{1}{g_{m1}} \parallel r_{o1} \Rightarrow R_{eq} = \frac{1}{g_{m1}} \parallel r_{o1} \parallel r_{o3}$$

$$M3: V_{GS} = 0 \Rightarrow r_{o3}$$

$$M2: \text{CD stage: } A_v = \frac{r_{o2} \parallel \frac{1}{g_{m1}} \parallel r_{o1} \parallel r_{o3}}{\frac{1}{g_{m2}} + r_{o2} \parallel \frac{1}{g_{m1}} \parallel r_{o1} \parallel r_{o3}}$$

(b) M_1, M_2 have $\lambda=0$. Others are $\lambda>0$. Perfect symmetry. CMRR=?

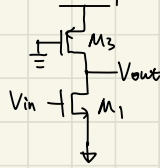


$$CMRR = \frac{A_{dm}}{A_{cm} + A_{cm-dm}}$$

$$\downarrow$$

$$A_{cm-dm}=0.$$

A_{dm} : Half-circuit.

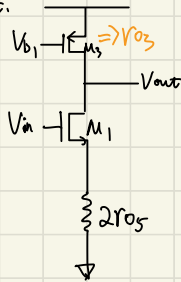


M_3 : $V_{GS}=0 \Rightarrow r_{o3}$.

M_1 : CS stage. ($\lambda=0$).

$$A_{dm} = -g_{m1} r_{o3}$$

A_{cm} : Half-circuit.



M_5 : $V_{GS}=0 \Rightarrow r_{o5}$

M_1 : Degeneration with $\lambda=0$.

$$A_{cm} = - \frac{r_{o3}}{\frac{1}{g_{m1}} + 2r_{o5}}$$

$$\Rightarrow CMRR = g_{m1} \left(\frac{1}{g_{m1}} + 2r_{o5} \right) = 1 + 2g_{m1} r_{o5}$$

六. 同 2013-A. DAC.

这题: 仍是 2013-A. $A_v = -G_m R_{out}$. 2013-A.

2019 A

Regeneration
($g_m r_o \gg 1$)

2. $R_{out} = (r_{o1} + R_S + g_{m1} r_{o1} R_S) // R_D$
 $R_S (g_{m1} r_{o1} + 1) + r_{o1} \xrightarrow{g_{m1} r_{o1} \gg 1} R_S g_{m1} r_{o1} + r_{o1} = (R_S g_{m1} + 1) r_{o1} \approx R_S g_{m1} r_{o1}$

3.

各种ADC比较

4. ADC. 高速低精度: FLASH A/D. 中速中精度: 流水线 A/D.
 现代高速高精度 ADC 的实现架构: 流水线 SAR A/D. ? ---

Diode

6. $R_{eq} = \frac{V_I}{I_D} = 2.6 \Omega$. $\frac{0.026}{0.01A}$

BJT

7. BJT. 4个工作区. 正向放大, 反向放大, 截止, 饱和.
 $V_{BE} > 0$ 且 $V_{BC} > 0$ (NPN by default?) $\Rightarrow$ 饱和区.

SNR, SNDR, ENOB

2. X. 信噪比对应 (A/D) 位数.
 $\frac{\text{信号}}{\text{噪声}} \rightarrow \text{有效位数}$
 $\frac{SNR}{ENOB}$

CM/DM
Acm-dm

3. X. Due to the imperfect symmetry, Acm-dm and Adm-cm exist.

ideal Amp.
of voltage
or current.

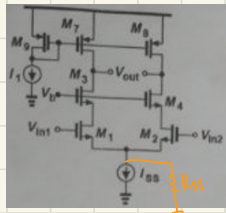
8. X 理想
 电压 Amp. $A_o \rightarrow +\infty$ $R_{in} \rightarrow +\infty$ $R_{out} = 0$.
 电流 Amp. $A_o \rightarrow +\infty$ $R_{in} = 0$ $R_{out} \rightarrow +\infty$

三. $\lambda > 0$.

(a). Perfect symmetry. $A_v = ?$

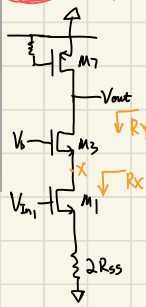
Dm/CM

(类似 2016, 一, 5)



$M9: V_{GS} = 0 \Rightarrow V_{GS} = V_{DS} \Rightarrow \frac{1}{g_m} // r_{o9}$

Acm: Half circuit:



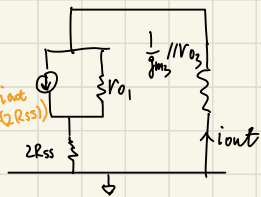
$M1: V_{GS} = 0 \Rightarrow V_{GS} = V_{DS} \Rightarrow \frac{1}{g_m} // r_{o1}$

$R_x = r_{o1} + 2R_{SS} + g_{m1} r_{o1} (2R_{SS})$

$R_y = r_{o2} + R_x + g_{m2} r_{o2} R_x$

$R_{out} = R_y // r_{o2}$

Gm: $V_{out} \rightarrow 0$. For M3, $V_{GS} = 0$.



$$- \left(\frac{1}{g_{m3}} \parallel r_{o3} \right) i_{out} - r_{o1} (i_{out} - g_{m1} (V_{in} - 2R_{SS} i_{out})) - i_{out} \cdot 2R_{SS} = 0$$

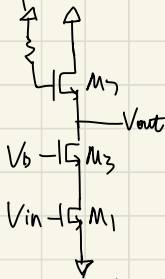
$$\frac{i_{out} (2R_{SS} + \frac{1}{g_{m3}} \parallel r_{o3} + r_{o1} + 2g_{m1} R_{SS} r_{o1})}{G_m} = r_{o1} g_{m1} \underline{V_{in}}$$

$$G_m = \frac{i_{out}}{V_{in}} = \frac{r_{o1} g_{m1}}{2R_{SS} + \frac{1}{g_{m3}} \parallel r_{o3} + (2g_{m1} R_{SS} + 1)r_{o1}}$$

By implementing the Lemma on the textbook, $A_{cm} = -G_m R_{out} = \dots$

For ideal current source I_{SS} , $R_{SS} \rightarrow +\infty \Rightarrow G_m \rightarrow 0 \Rightarrow A_{cm} \rightarrow 0$.

A_{cm} : Half Circuit. Using cascode model.

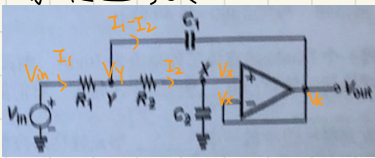


$$R_{out} = (r_{o3} + r_{o1} + g_{m3} r_{o3} r_{o1}) \parallel r_{o7}$$

$$G_m = \frac{g_{m1} r_{o1}}{r_{o1} + \frac{1}{g_{m3}} \parallel r_{o3}} \quad (\text{known answer of cascode.})$$

$$\Rightarrow A_{cm} = -G_m R_{out} = \dots$$

(b) 求传递函数.



$$I_2 = \frac{V_Y - V_X}{R_2} = \frac{V_X}{Z_{C2}} \Rightarrow V_Y = R_2 V_X \left(\frac{1}{R_2} + \frac{1}{Z_{C2}} \right)$$

$$I_1 - I_2 = \frac{V_Y - V_X}{Z_{C1}} = \frac{V_X}{Z_{C1}} \left(R_2 \left(\frac{1}{R_2} + \frac{1}{Z_{C2}} \right) - 1 \right) = \frac{V_X}{Z_{C1}} \cdot \frac{R_2}{Z_{C2}}$$

$$\frac{V_{in} - V_Y}{R_1} = \frac{V_X}{Z_{C1}} \frac{R_2}{Z_{C2}} + \frac{V_X}{Z_{C2}}$$

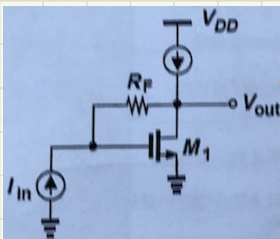
$$\Rightarrow \frac{V_{in}}{R_1} = \frac{R_2}{R_1} V_X \left(\frac{1}{R_2} + \frac{1}{Z_{C2}} \right) + \frac{V_X}{Z_{C2}} \left(\frac{R_2}{Z_{C1}} + 1 \right)$$

$$\Rightarrow V_{in} = V_X \left(1 + \frac{R_2}{Z_{C2}} \right) + \frac{V_X}{Z_{C2}} \left(\frac{R_1 R_2}{Z_{C1}} + R_1 \right)$$

$$(V_{out} = V_X) \Rightarrow V_{in} = \left(1 + \frac{R_2}{Z_{C2}} + \frac{R_1 R_2}{Z_{C1} Z_{C2}} + \frac{R_1}{Z_{C2}} \right) V_{out}$$

$$= \left(1 + jR_2 \omega C_2 - \omega^2 R_1 R_2 C_1 C_2 + j\omega R_1 C_2 \right) V_{out}$$

1. $\lambda > 0$.



Small-signal model:

$$\begin{cases} V_{b2} - I_n R_F = V_{out} \\ (I_n - g_{m1} V_{b1}) r_{o1} = V_{out} \end{cases}$$

$$\Rightarrow A = \frac{V_{out}}{I_{in}} = r_{o1} (1 - g_{m1} R_F)$$

$$R_{in}: i_x \quad V_X = i_x R_F + (i_x - g_{m1} V_X) r_{o1} = (R_F + r_{o1}) i_x - g_{m1} r_{o1} V_X$$

$$\Rightarrow V_X = \frac{R_F + r_{o1}}{1 + g_{m1} r_{o1}} i_x \Rightarrow R_{in} = \frac{R_F + r_{o1}}{1 + g_{m1} r_{o1}}$$

$$R_{out}: \text{For } M_1, V_{DD} = 0 (\because I_G = 0) \Rightarrow$$

$$R_{out} = \frac{1}{g_{m1}} \parallel r_{o1}$$

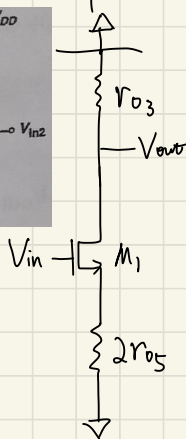
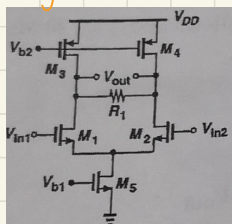
2020

1. $\lambda > 0$. Perfect symmetry.

1. $R_{out, C} =$

CM. Degeneration.

Half-circuit:



$$M_5: V_{GS} = 0 \Rightarrow r_{O5}$$

$$M_3: V_{GS} = 0 \Rightarrow r_{O3}$$

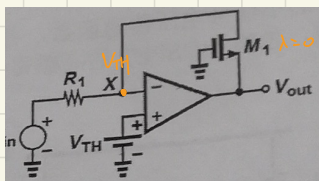
CM, Perfect symmetry $\Rightarrow U_{R1} = 0 \Rightarrow R_1$ can be neglected.

Degeneration: ($\lambda \neq 0$).

$$R_{out, C} = (r_{O1} + 2r_{O5} + 2g_{m1}r_{O1}r_{O5}) // r_{O3}$$

2 $A_v =$

(开平方电路?)



Big-signal model:

$$V_{out} = - \frac{\beta L (V_{in} - V_{TH})}{\sqrt{R_1 \mu_n C_{ox} W}} - V_{TH}$$

$$A_v = \frac{V_{out}}{V_{in}} = \dots \quad (\text{not constant}).$$

Small-signal model:

$$M_1: g_{m1} V_{GS} = -V_{out}$$

$$\frac{V_{in} - V_{TH}}{R_1} = -g_{m1} V_{out} \quad \text{In small-signal model, } V_{TH} = 0. \quad \rightarrow \quad \frac{V_{out}}{V_{in}} = - \frac{1}{g_{m1} R_1}$$

(↑一般指小信号; 忽略大信号解答).

6. Diode. $I_D = 1 \text{ mA}$.

Diode.

$$R_{eq} = \frac{V_T}{I_D} = \frac{0.026 \text{ V}}{0.001 \text{ A}} = 26 \Omega$$

7. BJT. 4个工作区. 正向放大, 反向放大, 截止, 饱和

$V_{BE} > 0, V_{BC} < 0, \Rightarrow$ 正向放大区 (NPN), 反向放大区 (PNP).

理想Amp中
输入, 输出的
 R_{in}, R_{out}
(4种).

二.

4. 跨阻放大器: I_{in}, V_{out} .
 $\downarrow \quad \quad \downarrow$
 $R_{in} \rightarrow 0 \quad R_{out} \rightarrow 0$

R.	V	I
I_{in}	$+\infty$	0
Out	0	$+\infty$

5. 线性电路的增益表达式为 $A_v = -G_m R_{out}$.

三. I_{SS} is an ideal source.

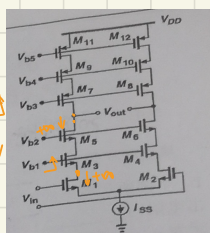
(1) M_1, M_2 have $\lambda=0$. $\lambda > 0$ for others. Perfect symmetry. $A_v =$

DM/CM

CMRR

$R_{op} \uparrow$

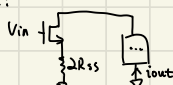
$R_{on} \downarrow$



A_{cm} : Ideal source $I_{SS} \Rightarrow R_{SS} \rightarrow +\infty \Rightarrow R_{on} \rightarrow +\infty$.

(Lemma) $\Rightarrow R_{out} = R_{op} < +\infty$.

G_m :



$R_{SS} \rightarrow +\infty \Rightarrow i_{out} = 0$.

$$G_m = \frac{i_{out}}{V_{in}} = 0$$

$\Rightarrow A_{cm} = 0$.

A_{dm} : Half circuit:

$M_1 \& M_{11}$: $R_{q,11} = r_{o1} + r_{o11} + g_{m1} r_{o1} r_{o11}$

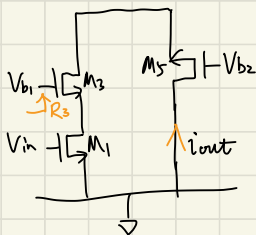
$M_7 \& (M_1 \& M_{11})$: $R_{op} = r_{o7} + R_{q,11} + g_{m7} r_{o7} R_{q,11}$

$R_{on} = r_{o5} + R_{1,3} + g_{m5} r_{o5} R_{1,3}$, where $R_{1,3} = r_{o3} + r_{o1} + g_{m3} r_{o3} r_{o1} \rightarrow +\infty$.

$R_{out} = R_{op} \parallel R_{on} \rightarrow R_{op}$.

Using the Lemma,

$V_{out} \rightarrow 0$.



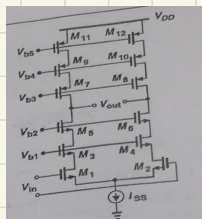
$M_3 \& M_5$: cascode. $R_3 = \dots$



$$i_{out} = g_{m1} V_{in} \Rightarrow G_m = \frac{i_{out}}{V_{in}} = g_{m1}$$

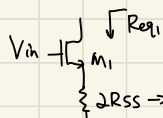
$A_{dm} = -G_m R_{out} = -g_{m1} R_{out} \rightarrow -g_{m1} R_{op}$.

(2) $\lambda > 0$ for all MOSFET. Perfect symmetry. $R_{out} = ?$ CMRR = ?



$R_{out,D} = R_{op} \parallel R_{on}$

$R_{out,C}$:



$R_{eq1} = r_{o1} + 2R_{SS} \parallel g_{m1} R_{SS} \rightarrow +\infty$.

$\downarrow$

$R_{on,cm} \rightarrow +\infty$. (Looking down from V_{out}).

$\Rightarrow R_{out,C} = R_{on,cm} \parallel R_{op,cm} = R_{op,cm} = R_{op} = \dots$

$A_{cm} = 0$. (Since ideal source I_{SS} .)

$A_{dm} = -G_m R_{out, D}$

$M_5 \Rightarrow \frac{V_{GS5}=0}{g_{m5}} \parallel r_{o5}$. For M_3 : $V_{GS3} = -(i_{out} - g_{m1}V_{in})r_{o1}$

$+i_{out}R_{eq5} + (i_{out} - g_{m3}V_{GS3})r_{o3} + (-V_{GS3}) = 0$.

$(R_{eq5} + r_{o3})i_{out} = (g_{m3}r_{o3} + 1)V_{GS3} = (g_{m3}r_{o3} + 1)(g_{m1}V_{in} - i_{out})r_{o1}$

$(R_{eq5} + r_{o3})i_{out} = -r_{o1}(g_{m3}r_{o3} + 1)i_{out} + g_{m1}r_{o1}(g_{m3}r_{o3} + 1)V_{in}$

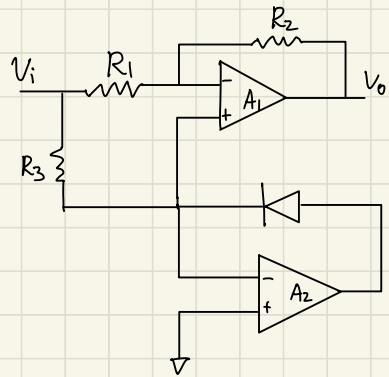
$\Rightarrow G_m = \frac{i_{out}}{V_{in}} = \frac{g_{m1}r_{o1}(g_{m3}r_{o3} + 1)}{r_{o1}(g_{m3}r_{o3} + 1) + r_{o3} + \frac{1}{g_{m5}} \parallel r_{o5}}$

$\Rightarrow A_{dm} = -G_m R_{out, D} = -G_m (R_{op} \parallel R_{on}) = \dots$

$A_{cm-dm} = 0 \Rightarrow CMRR = \frac{A_{dm}}{A_{cm}} = +\infty$.

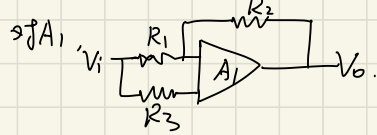
2020. 大部分原题. 新题如下:

五. 求: 传输特性曲线; $V_i = V_m \sin \omega t$ 时 V_o 的曲线. (这题, Diode 理想)



两种情况.

$V_i > 0$ 时, Diode 不导通.
 A_2 的虚短不成立. ~~忽略~~



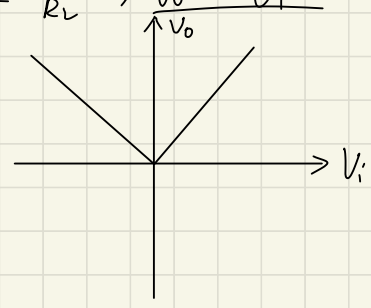
$I_+ = I_- = 0 \Rightarrow V_- = V_+ = V_i$
 $\Rightarrow I_{R1} = I_{R2} = 0 \Rightarrow V_o = V_i$

$V_i < 0$ 时, Diode 导通. 对 A_2 , $V_- = V_+ = 0$.

$\Rightarrow$ 对 A_1 , $V_- = V_+ = V_{-|A2} = 0$.

$\Rightarrow \frac{V_i}{R_1} = \frac{-V_o}{R_2} \Rightarrow V_o = -V_i$

$\Rightarrow V_o = \begin{cases} -V_i & (V_i < 0) \\ V_i & (V_i > 0) \end{cases}$
 $= |V_i|$



$V_i = V_m \sin \omega t \Rightarrow V_o = V_m |\sin \omega t|$



一. 填空.

2. 开平方电路 (图略), $\lambda > 0$. 求小信号增益. (易错)