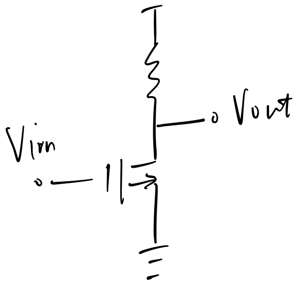
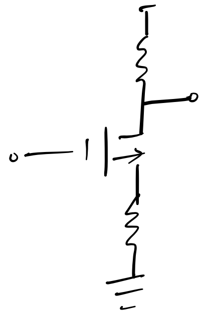
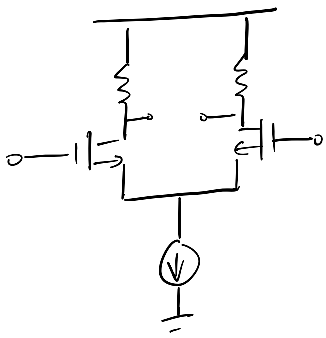
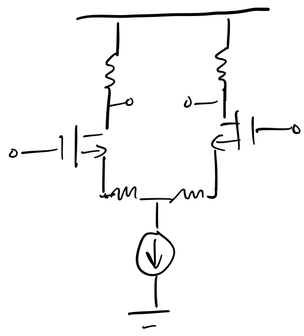
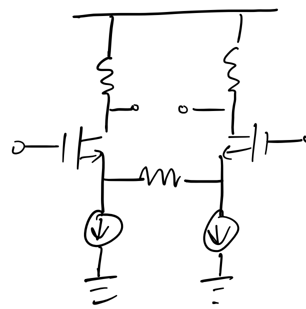
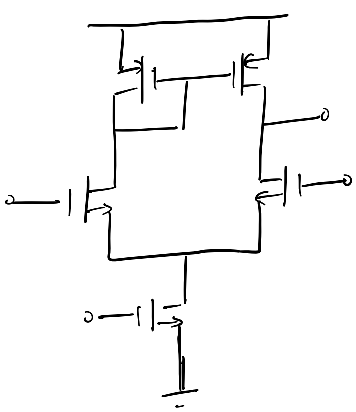


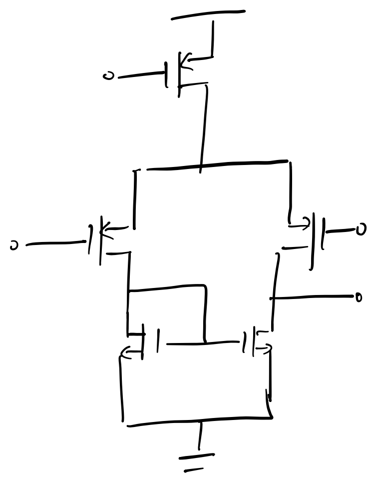


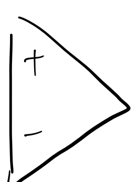












D

定性： $V_{out} - V_{in}$ 趋势

定量
- 大信号 —— A_v、SW（输入、输出摆幅）
- 小信号 —— A_v、R_{in}、R_{out}

CS

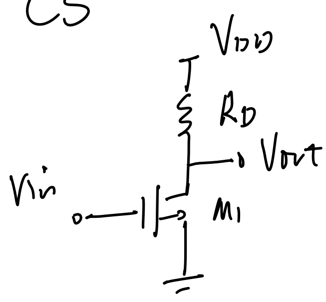
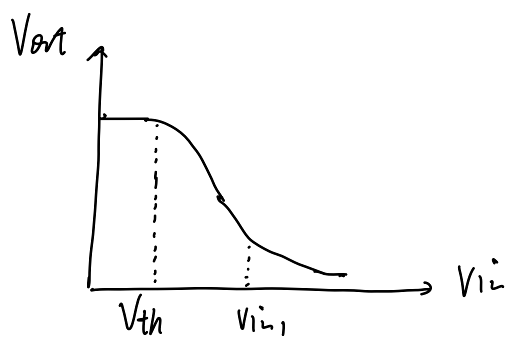


图 1

$V_{out} - V_{in}$



$$A_v = g_m R_D$$

CS (Rs)

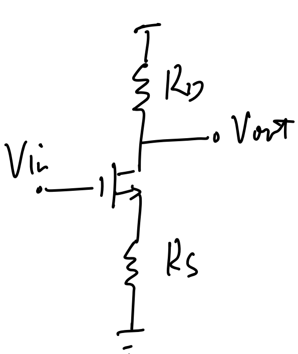


图 2

$$A_v = \frac{R_D}{R_s + \frac{1}{g_m}}$$

① 使输入器件更线性

② 增大 R_{out}

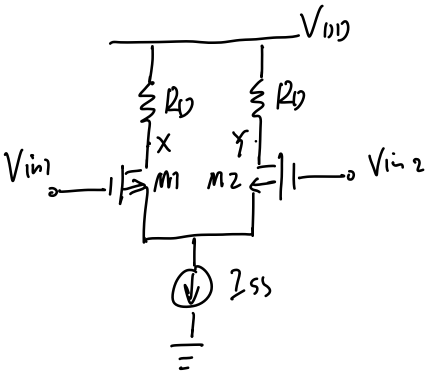


图3

相比起单边放大，能抑制共模噪声。

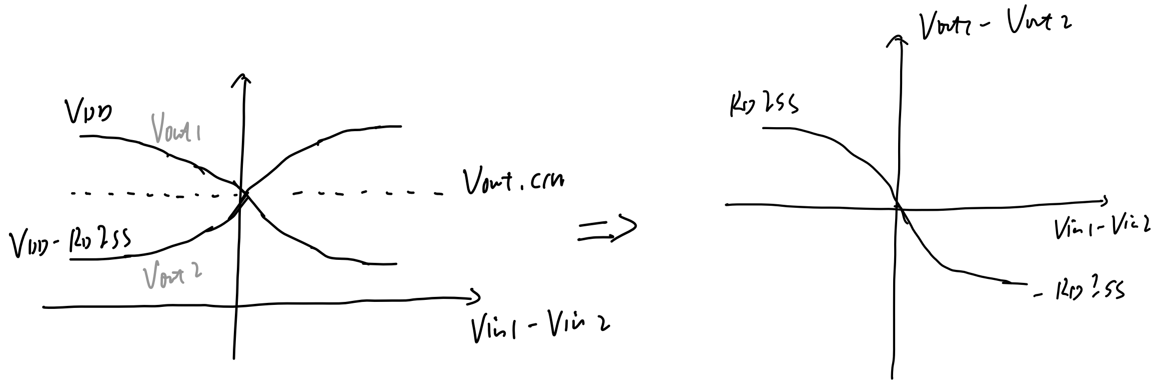
共模信号通常为电路偏置，比差模信号要大。

$\boxed{\text{(1) 定性分析}}$　　V_{out} — V_{in} $(-\infty \to +\infty)$

差模

$V_{in1} \ll V_{in2}$

- $V_{in1}=0$, $V_{in2}=V_{DD}$, M_1 off, M_2 triode,
  M_2相当于一个小电阻（R_{on}）
  $I_{D1}=0$, $I_{D2}=I_{SS}$, $V_X=V_{DD}$, $V_Y=V_{DD}-I_{SS}R_D$
- V_{in1}增大，V_{in2}减小、
  V_{in1}接近V_{thn}时，M_1逐渐导通并进入 sat.
  R_D有电流流过，$V_X=V_{DD}-I_{D1}\cdot R_D$
  且随着 $V_{in1}\uparrow$, $I_{D1}\uparrow$. $V_X\downarrow$
  $V_{in2}\downarrow$, $I_{D2}\downarrow$, $V_Y\uparrow$
- 当 $V_{in1}=V_{in2}$, $I_{D1}=I_{D2}$, $V_X=V_Y$
- V_{in1}继续$\uparrow$, V_{in2}继续$\downarrow$
  $I_{D1}\uparrow$, $V_X\downarrow$; $I_{D2}\downarrow$, $V_Y\uparrow$
- $V_{in1}=V_{DD}$, $V_{in2}=0$
  $V_X=V_{DD}-I_{SS}R_D$, $V_Y=V_{DD}$



共模

接单边输出看，和CS一样。

定量分析

大信号

差模：

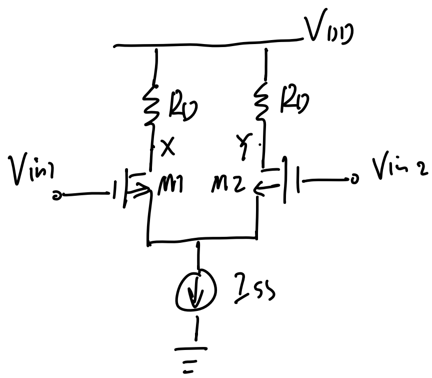


图 3

$$A_v = G_m R_{out}$$

$$G_m = \frac{\partial I_D}{\partial V_{in}}$$

$$V_{in2} - V_{in1} = V_{GS1} - V_{GS2}$$

$$V_{GS} = \sqrt{\frac{2I_D}{\mu_n C_{ox}\frac{W}{L}}} + V_{th}$$

$$V_{in2} - V_{in1} = \sqrt{\frac{2I_{D2}}{\mu_n C_{ox}\frac{W}{L}}} - \sqrt{\frac{2I_{D1}}{\mu_n C_{ox}\frac{W}{L}}}$$

……

$$\frac{\partial I_D}{\partial \Delta V_{in}} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\frac{\frac{4I_{SS}}{\mu_n C_{ox}\frac{W}{L}} - 2\Delta V_{in}^2}{\sqrt{\frac{4I_{SS}}{\mu_n C_{ox}\frac{W}{L}} - \Delta V_{in}^2}}$$

当 $\Delta V_{in} = 0$，$|A_v| = \sqrt{\mu_n C_{ox}\frac{W}{L}I_{SS}}\, R_D$

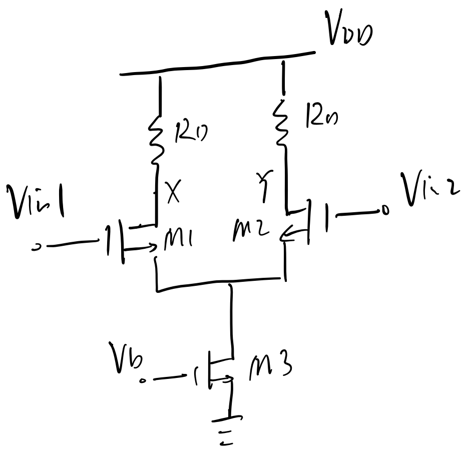
共模：

单端输出：$V_{out} = V_{DD} - I_D R_D$

$$I_D = \frac{1}{2}I_{SS}$$

摆幅 (SW)

- 输入摆幅 (共模)
- 输出摆幅 (差模)



$V_{in,cm}$ SW

$V_{GS2}+V_{GS3}-V_{th3} \le V_{in,cm} \le \min[V_{DD}, V_{DD}-\frac{I_{SS}}{2}R_D+V_{th}]$

当 MOS 在饱和区边缘

$V_{DD}-I_D R_D = V_{in}-V_{th}$

$I_D = \frac{I_{SS}}{2}$

$V_{in} = V_{DD} - \frac{I_{SS}}{2}R_D + V_{th}$

$V_{out,dm}$ SW

$V_{out,dm,max} = V_{DD}$

M_1, M_2 饱和区边缘: $V_X = V_{in}-V_{th}$

或 $V_Y = V_{in_2}-V_{th}$

$V_{in} = V_{in,cm} + V_{in,dm}$

$V_{in,cm} \gg V_{in,dm}$

故 $V_X(V_Y) \ge V_{in,cm}-V_{th}$

故输出摆幅有下限

$V_{in,cm}-V_{th} \le V_{out,dm} \le V_{DD}$

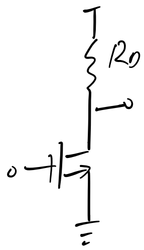
小信号

A_v {
叠加法 （电路不对称时亦可用）
半边电路法 （完全对称可用）

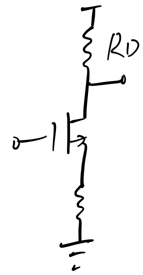
$$A_v = \frac{V_{x} - V_{y}}{V_{in2} - V_{in1}} = -g_m R_D$$

R_{in}、R_{out} 没研究过

进阶

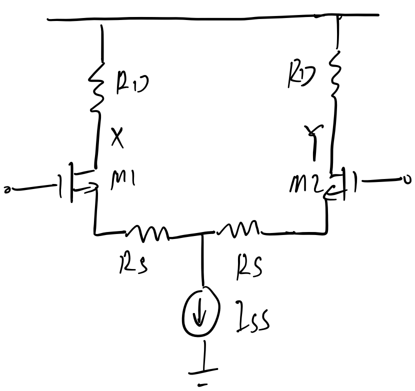


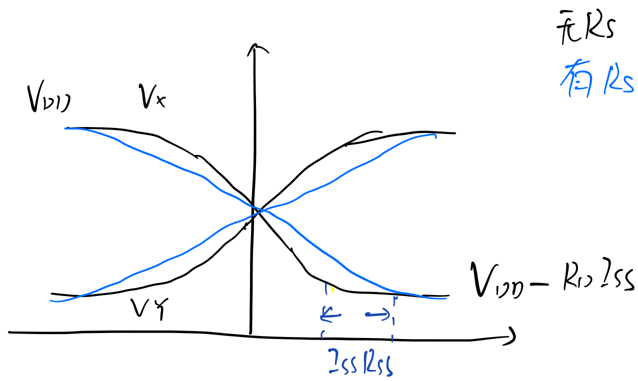
$A_V = -g_m R_D$



$$A_V = -\frac{R_D}{R_S + \frac{1}{g_m}}$$

更接近常数
更线性





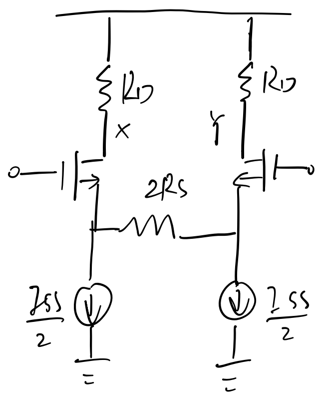
更线性

$$A_{v,dm} = -\frac{R_D}{\frac{1}{g_m} + R_S} \quad (A_v \downarrow)$$

SW

输入 $\pm R_S I_{SS}$
输入摆幅↑

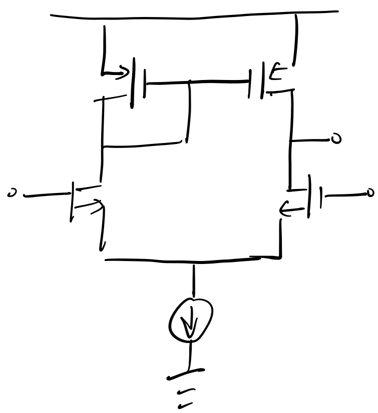
输出SW
$V_{in,cm} - V_{th} \le V_{out} \le V_{DD}$
$V_{in,cm} > \frac{R_S I_{SS}}{2}$
故输出摆幅减小 $R_S I_{SS}$



对共模信号，2Rs上无电流，

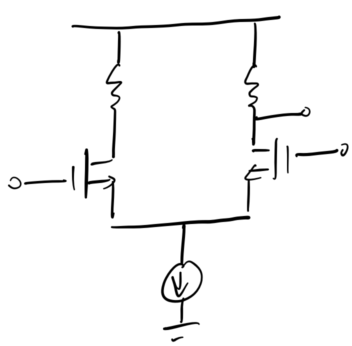
故输出摆幅不会被减小。

五管OTA

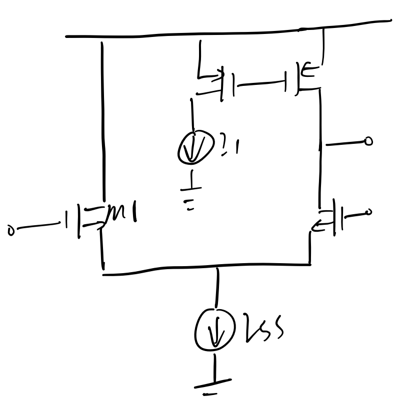


差分对双端输入 ⟶ 单端输出.

① 全差分取单边



增益减半, SW减半, 有共模噪声

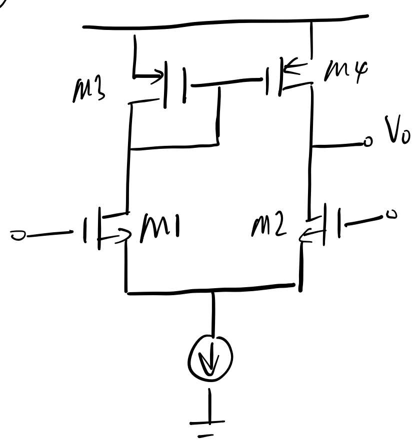
② 

I_{D1}被浪费了.

大信号

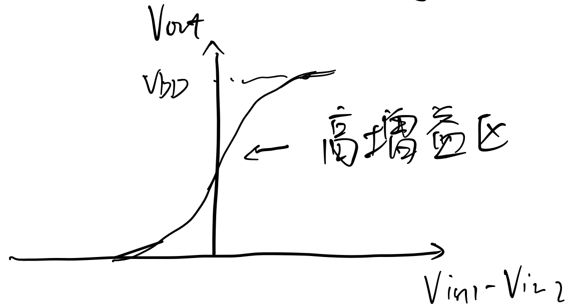
差模：

③



增益（小信号）

$$|A_v| = g_{m1}(r_{o2}\|r_{o4})\frac{2g_{m4}r_{o4}+1}{2(g_{m4}r_{o4}+1)}$$



电流镜偏置与输入相关.

Output sw： $\underline{V_{in,cm}}-V_{th} \le V_{out} \le V_{DD}$

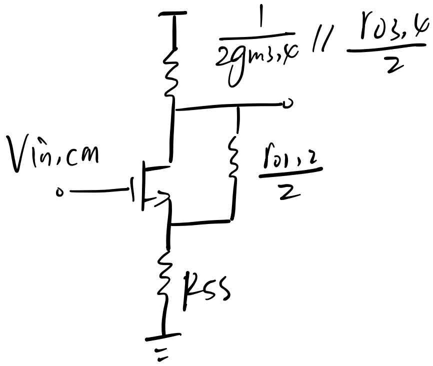
$V_{in,cm}$ 影响输出摆幅

input sw： $V_{GS1,2}+V_{DS5,min} \le V_{in,cm} \le V_{DD}-V_{thp}$

推拉加快电路瞬态.

将差动输入转换成大摆幅的单端输出.

共模:



$$A_{cm} = -\frac{\frac{1}{2g_{m3,4}} \parallel \frac{r_{o3,4}}{2}}{\frac{1}{2g_{m1,2}} + R_{SS}}$$

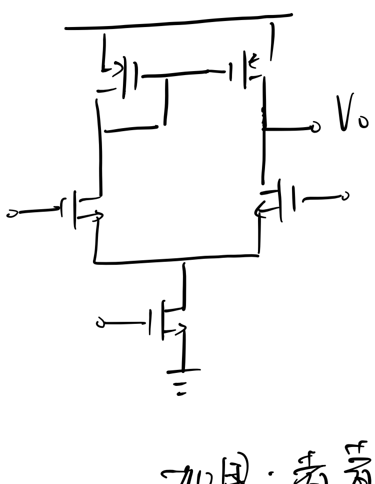
$$CMRR = \left|\frac{A_{DM}}{A_{cm}}\right|$$

$$= (1+2g_{m1,2}R_{SS})\,g_{m3,4}(r_{o1,2} \parallel r_{o3,4})$$

会有共模噪声.

有限的 CMRR

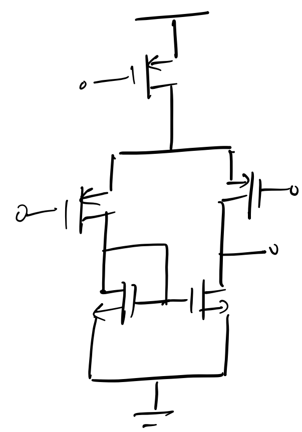
一般需要共模反馈后使用.



Nmos OTA 有下限

Pmos OTA 有上限

选择时看输入信号偏高或是偏低

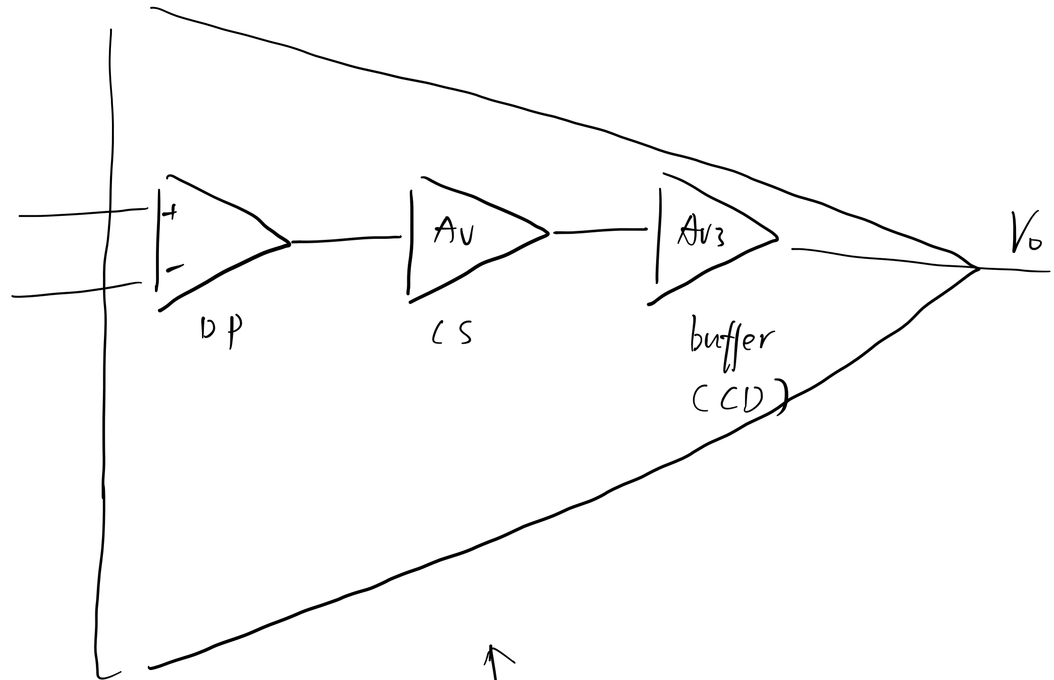


如果:看都可以.

通常 nmos 电子迁移率比 pmos 快, 同样速率下, pmos 尺寸比 nmos 大 2~3倍.

但 pmos 噪声小，更容易匹配（差分对对称）

电源越来越低，用 pmos 也越来越多。



差分对通常作输入级.