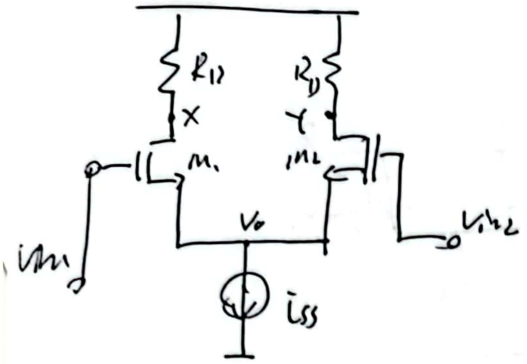
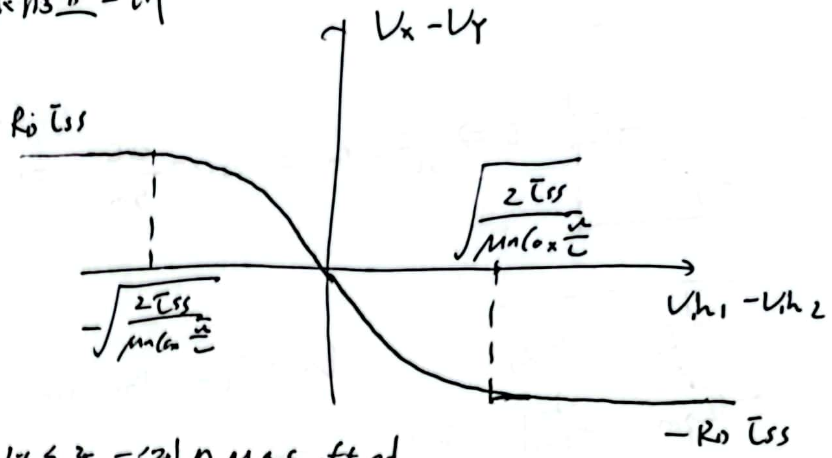
根据此一讲





$V_{in1} - V_{in2}$ 足够大/小，以至于一边MOS off时

假设 $V_{in1} - V_{in2}$ 足够大，M_2 off

$$V_{in2} - V_{TH} = V_P$$

$$\frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{in1} - V_P - V_{TH})^2 = I_{SS} \Rightarrow V_{in1} - V_P - V_{TH} = \sqrt{\frac{2I_{SS}}{\mu_n C_{ox}\frac{W}{L}}}$$

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

又有 $I_{D1} - I_{D2} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_{in1} - V_{in2})\sqrt{\frac{4I_{SS}}{\mu_n C_{ox}\frac{W}{L}} - (V_{in1} - V_{in2})^2}$

$$\Rightarrow V_X - V_Y = -\frac{R_D}{2}\mu_n C_{ox}\frac{W}{L}(V_{in1} - V_{in2})\sqrt{\frac{4I_{SS}}{\mu_n C_{ox}\frac{W}{L}} - (V_{in1} - V_{in2})^2}$$

If $(V_{in1} - V_{in2})^2 \ll \frac{4I_{SS}}{\mu_n C_{ox}\frac{W}{L}}$，即 接近 origin point 时

$$V_X - V_Y = -\frac{R_D}{2}\mu_n C_{ox}\frac{W}{L}\cancel{(V_{in}}\sqrt{\frac{4I_{SS}}{\mu_n C_{ox}\frac{W}{L}}}(V_{in1} - V_{in2})$$

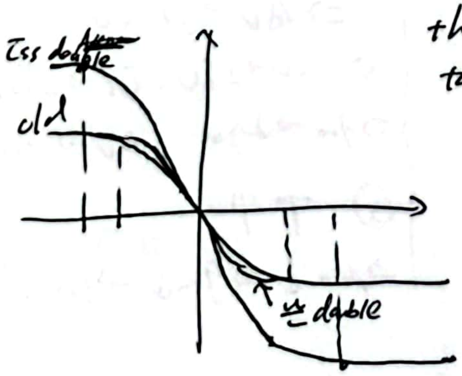
$$= -R_D \mu_n C_{ox}\frac{W}{L}\sqrt{\frac{I_{SS}}{\mu_n C_{ox}\frac{W}{L}}}(V_{in1} - V_{in2})$$

$$= -R_D\sqrt{\mu_n C_{ox}\frac{W}{L} I_{SS}}\,(V_{in1} - V_{in2})$$

when close to origin point, $k = -R_D\sqrt{\mu_n C_{ox}\frac{W}{L} I_{SS}}$

① I_{SS} is doubled. slope changes to $k = -\sqrt{\mu_n C_{ox}\frac{W}{L}2I_{SS}}\,R_D$

the circuit becomes more linear because it can take a larger input difference without "dying".

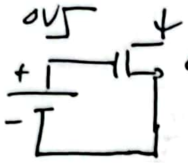


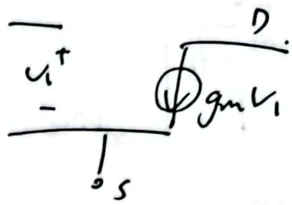
② $\frac{W}{L}$ is doubled.

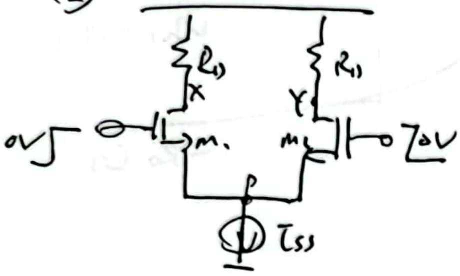
The circuit ~~is~~ becomes less linear, because it can take only a smaller input difference before it "dies".

Small-Signal Behavior of MOS Diff Pair.

- A few points.

① 

$\Delta I \Rightarrow \frac{\Delta I}{\Delta V} = g_m \Rightarrow \Delta V = \frac{\Delta I}{g_m} \Rightarrow$ 

② 

$V_X - V_Y = -R_D \sqrt{\mu_n C_{ox} \frac{W}{L} I_{SS}} \cdot (2\Delta V)$

$\Rightarrow \because V_X - V_Y = -R_D (I_{D1} - I_{D2})$

$\Rightarrow \begin{cases} I_{D1} - I_{D2} = \sqrt{\mu_n C_{ox} \frac{W}{L} I_{SS}} \, (2\Delta V) \\ I_{D1} + I_{D2} = I_{SS} \end{cases}$

$\Rightarrow I_{D1} = \frac{I_{SS}}{2} + \underbrace{\sqrt{\mu_n C_{ox} \frac{W}{L} I_{SS}} \, \Delta V}_{\Delta I}.$

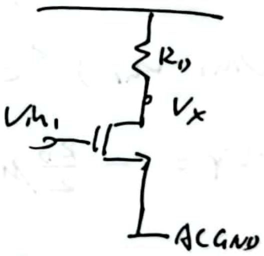
$\therefore \frac{\sqrt{\mu_n C_{ox} \frac{W}{L} I_{SS}} \, \Delta V}{g_m} = \Delta V \Rightarrow g_m = \sqrt{\mu_n C_{ox} \frac{W}{L} I_{SS}}$ [illegible]

$= \sqrt{\mu_n C_{ox} \frac{W}{L} 2 I_D}$

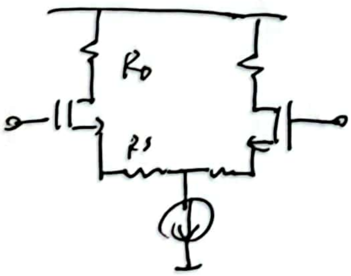
V_P doesn't change $\Rightarrow$ P is AC GND.

CS stage

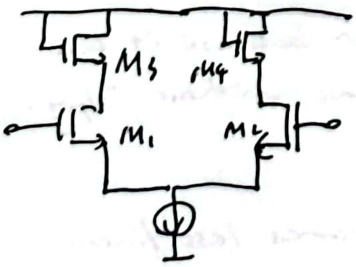
$\Rightarrow \frac{V_X}{V_{in1}} = -g_m R_D \Rightarrow \frac{V_X - V_Y}{V_{in1} - V_{in2}} = -g_m R_D$



Example



$\frac{V_X}{V_{in1}} = -\frac{R_D}{\frac{1}{g_m} + R_S}$ degeneration.



$\frac{V_X}{V_{in1}} = -\frac{\frac{1}{g_{m3}}}{\frac{1}{g_{m1}}} = -g_{m1} \frac{1}{g_{m3}}$

Observations

① $W \to 2W$.

$\Rightarrow g_m \to \sqrt{2} g_m$

$\Rightarrow A_V \to \sqrt{2} A_V$

② $W \to 2W$, $I_{SS} \to 2 I_{SS}$

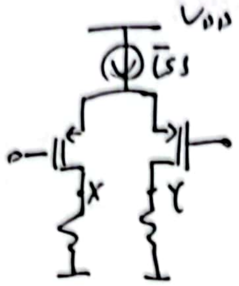
$\Rightarrow g_m \to 2 g_m$, $A_V \to 2 A_V$

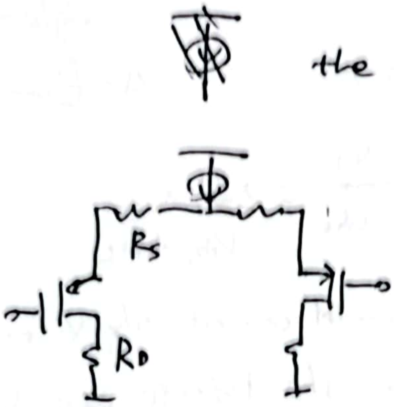
③ $T \uparrow$

$\Rightarrow \mu_n \downarrow \Rightarrow g_m \downarrow \Rightarrow |A_V| \downarrow$

P-Type Diff Pair

P

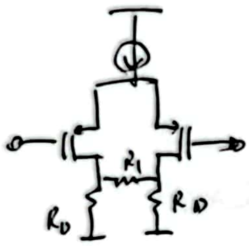




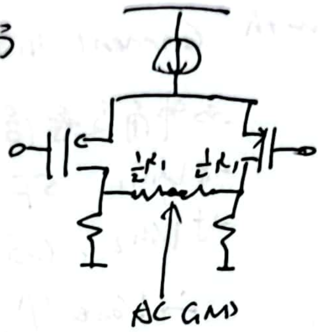
the same as N-Type

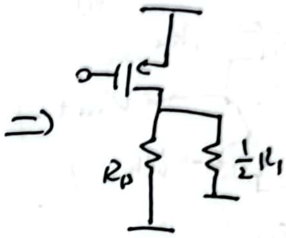
$$A_v = -\frac{R_D}{\frac{1}{g_m} + R_S}$$

Example



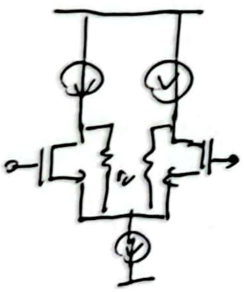
同样，平分





$$\therefore \frac{V_x}{V_{in}} = -g_m\left(R_D \parallel \tfrac{1}{2}R_1\right)$$

Diff. Pair with Current-Source Loads.

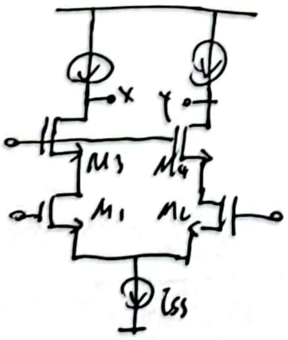


$A_v = -g_m R_D$. if we want a large A_v, we need a large R_D. That's why we use current-source.

In this case, the r_o can't be ignored.

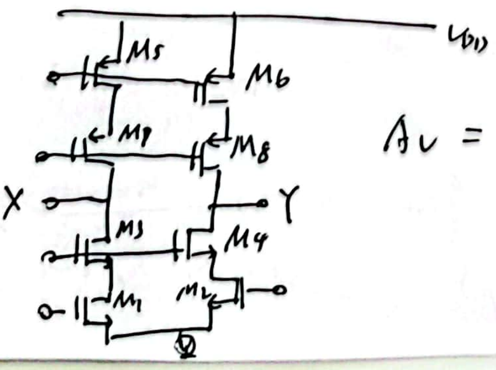
$A_v = -g_m r_o$.

Diff. Pair with Cascodes.



$$A_v = -g_{m1}\left[(1+g_{m3} r_{o3}) r_{o1} + r_{o3}\right] \simeq -g_{m1} g_{m3} r_{o3} r_{o1}$$

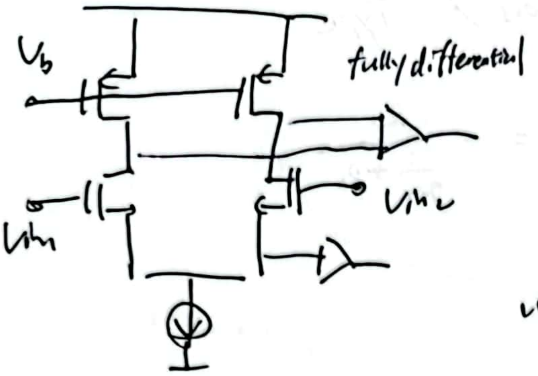
Let's implement the current sources.



"Telescopic Cascode"

$$A_v = -g_{m1}\left[(1+g_{m3} r_{o3}) r_o + r_{o3}\right] \parallel \left[(1+g_{m7} r_{o7}) r_{o5} + r_{o7}\right]$$

Diff. Pair with Active Load.

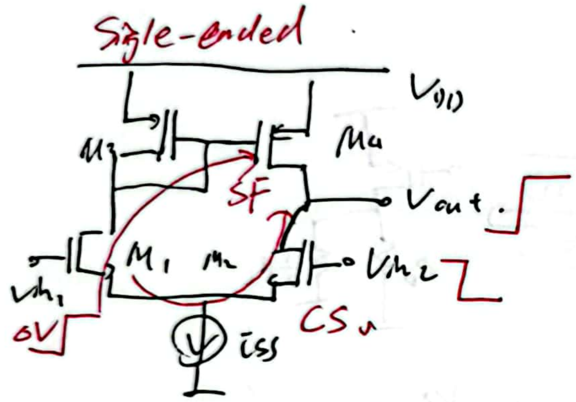


∴单放大. $\frac{V_x - V_Y}{V_{in1}-V_{in2}} = 2\frac{V_x}{V_{in1}-V_{in2}}$

single-ended.

We could connect only X to A and simply not use Y. the voltage gain is halved.

Single-ended.



with Current Mirror.

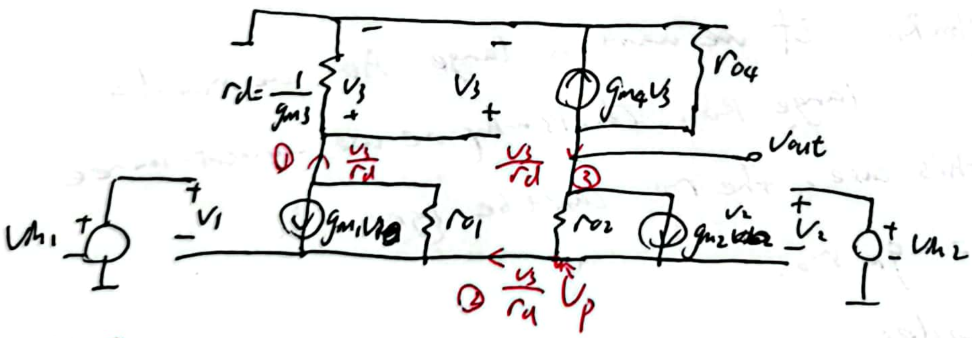
∴单角度看信号变化趋势.

对 V_{in1}, SF. V_{out} 同向变化.

对 V_{in2}, CS, V_{out} 反向变化.

∴ V_{out} ↑. ∴单级放大倍增强.

Draw Small-Signal model



3个节点. KCL

① $\frac{V_3}{r_d} + g_{m1}V_1 + \frac{V_3-V_p}{r_{o1}} = 0$

② $-\frac{V_3}{r_d} + g_{m2}V_2 + \frac{V_{out}-V_p}{r_{o2}} = 0$

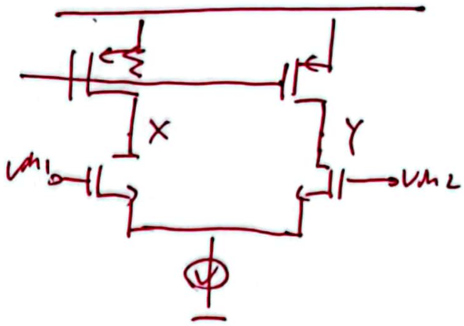
③ $g_{m4}V_3 + \frac{V_{out}}{r_{o4}} + \frac{V_3}{r_d} = 0 \Rightarrow V_3 = \frac{-V_{out}}{r_{o4}(\frac{1}{r_d}+g_{m4})} = -\frac{V_{out}}{r_{o4}\times 2g_{mp}}$

∵ $V_{in1} - V_{in2} = V_1 - V_2$

∴ 联立①和②得. $g_{mN}(V_{in1}-V_{in2}) + \frac{V_3 - V_{out}}{r_{oN}} + \frac{2V_3}{r_d} = 0$

$\Rightarrow \frac{V_{out}}{V_{in1}-V_{in2}} = g_{mN}(r_{oN} \| r_{op})$ ← $g_{mN}(V_{in1}-V_{in2}) = -V_{out}(\underbrace{\frac{1}{2g_{mp}r_{op}r_{oN}}}_{\text{negligible}} + \frac{1}{r_{oN}} + \frac{1}{r_{op}})$

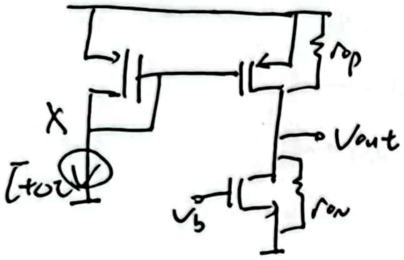
而在 fully differential 中.



$$\frac{V_X - V_Y}{V_{in1} - V_{in2}} = -g_{mN}(r_{oN} \parallel r_{oP})$$

单端放大达到同样的增益.

以下是一些 current 的思考

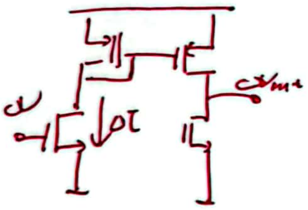


$$\Delta V_X = \Delta I \cdot \left(\frac{1}{g_m} \parallel r_o\right) \approx \frac{\Delta I}{g_{mp}}$$

$$\frac{\Delta V_{out}}{\Delta V_X} = -g_{mp}(r_{on} \parallel r_{op})$$

$$\Rightarrow \Delta V_{out} = -\Delta I(r_{on} \parallel r_{op})$$

据此关系也可~~直接推导~~理解单端放大公式.



$$\Delta V_{out} = -\Delta I(r_{on} \parallel r_{op})$$

ΔV_{in}

$$\Delta I = \Delta V \cdot g_{mN}$$

$$\therefore \frac{\Delta V_{out}}{\Delta V} = -g_{mN}(r_{on} \parallel r_{op})$$