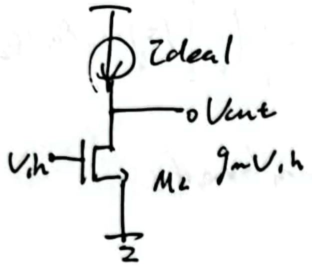
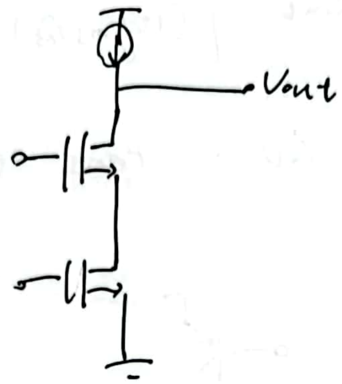
◦ Cascode Amp.

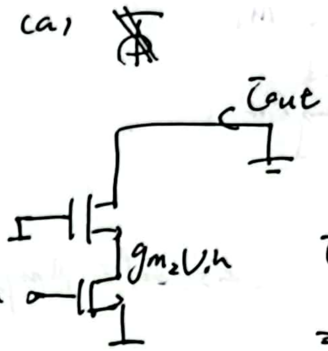


$\Rightarrow$



Use the method we describe just now

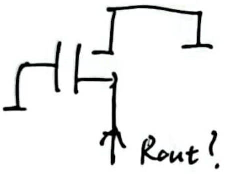
(a)



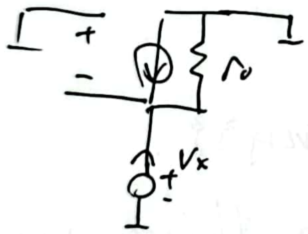
$I_{out} = g_{m2}V_{in}$

$G_m = g_{m2}$

Quiz:

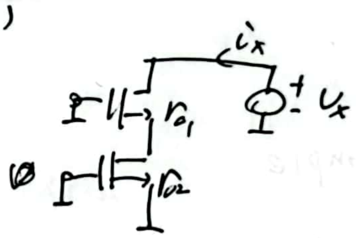


其实直接由二极管结论得出



$\Rightarrow \frac{V_x}{i_x} = \frac{1}{g_m} \| r_o$

(b)

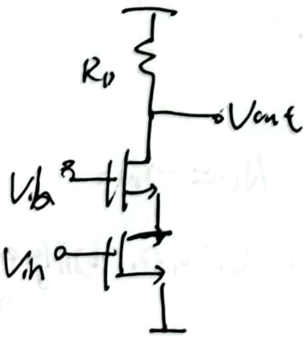


$R_{out} = \frac{V_x}{i_x} = (1+g_{m1}r_{o1})r_{o2} + r_{o1}$

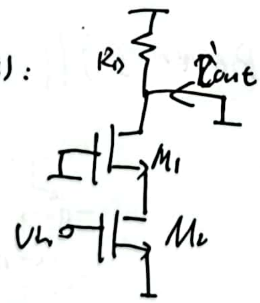
$\Rightarrow A_v = -g_{m2}[(1+g_{m1}r_{o1})r_{o2}+r_{o1}]$

$\approx -g_{m1}r_{o1} \cdot g_{m2}r_{o2}$.

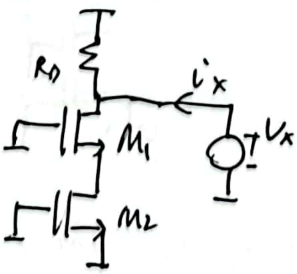
EXAMPLE



(a):



$\frac{i_{out}}{V_{in}} = \frac{g_{m2}V_{in}}{V_{in}} = g_{m2}$

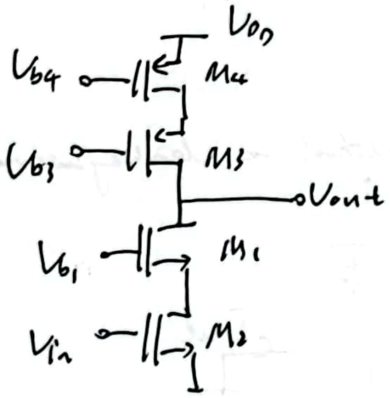


$\frac{V_x}{i_x} = [(1+g_{m1}r_{o1})r_{o2}+r_{o1}] \| R_D$

$\therefore A_v = -g_{m2}[R_D \| [(1+g_{m1}r_{o1})r_{o2}+r_{o1}]]$

$R_D \Leftarrow$  r_{o3}

Cascode Amp with Cascode Load

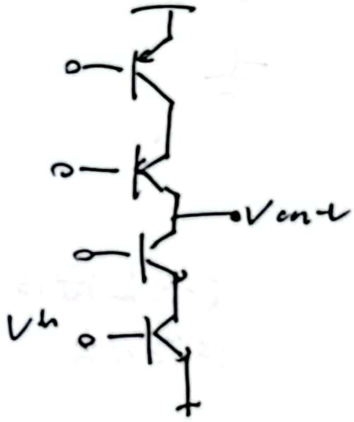


Cas $G_m = g_{m2}$

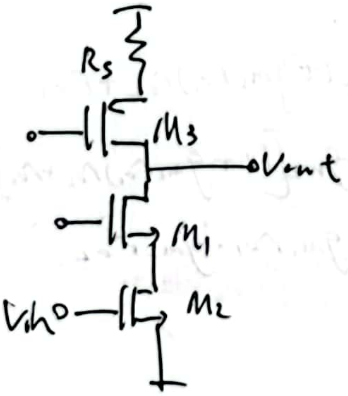
(b) $R_{out} = \{(1+g_{m3}r_{o3})\,r_{o4} + r_{o3}\} \,\|\, \{(1+g_{m1}r_{o1})r_{o2}+r_{o1}\}$

A_v : tens to hundreds

Bipolar Cascode Amps



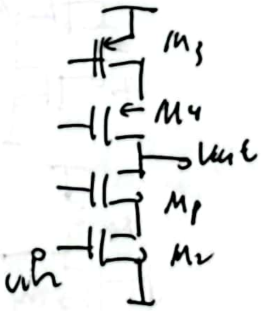
Example



远大于1，类似可以约等于.

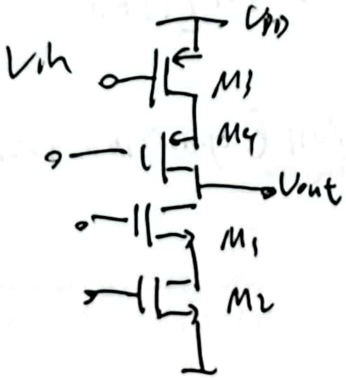
$$R_{out} = \left((1+g_{m3}r_{o3})R_s + r_{o3}\right) \| \left((1+g_{m1}r_{o1})r_{o2}+r_{o1}\right)$$

$$\approx (g_{m3}r_{o3}R_s + r_{o3}) \| (g_{m1}r_{o1}r_{o2})$$

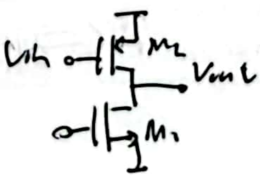


$A_v \approx -g_{m2}\left[(g_{m1}r_{o1}r_{o2}) \| (g_{m4}r_{o4}r_{o3})\right]$

Cascode Amp with P-Type Input

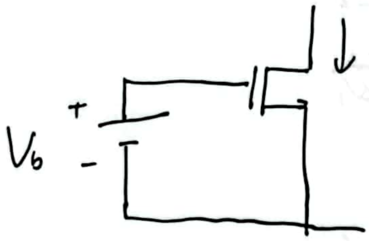


$$A_v = -g_{m3}\left[(g_{m1}r_{o1}r_{o2}) \| (g_{m4}r_{o4}r_{o3})\right]$$



$A_v = -g_{m2}(r_{o1} \| r_{o2})$

- Problem of Biasing Current Sources

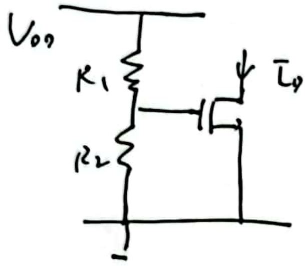


$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_b - V_{TH})^2$$

vary with temp

Issue #1

How to generate V_b:



$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left(\frac{R_2}{R_1+R_2}V_{DD} - V_{TH}\right)^2$$

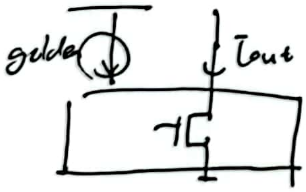
Issue #2 supply-dependant

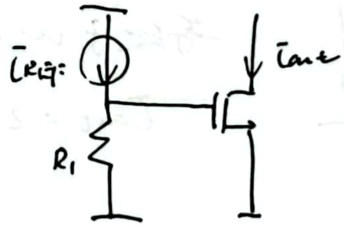
That's why we need a current ~~sour~~ mirror.

- Current Mirror

First, build one "golden" current source, using a "Bandgap" circuit.

Next, we "copy" this current source to build many others.





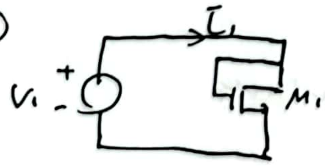
$$I_{out} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(R_1 I_{REF} - V_{TH})^2$$

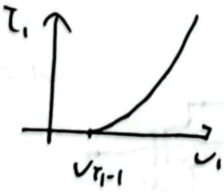
vary with temp

So, how to ~~go~~ copy a I_{REF}?

Observations.

①



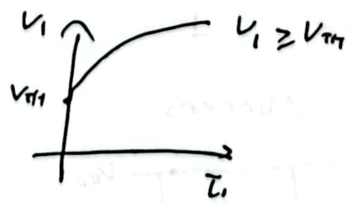


If M_1 is on, it is in sat.

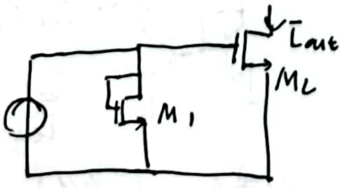
$$I_1 = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_1 - V_{TH})^2$$

②

$$V_1 = \sqrt{\frac{2 I_1}{\mu_n C_{ox}\frac{W}{L}}} + V_{TH}$$

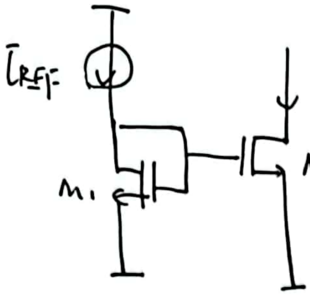


③



$$I_{out} = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}(V_1 - V_{TH})^2 = \frac{(\frac{W}{L})_2}{(\frac{W}{L})_1} I_1$$

Current Mirror



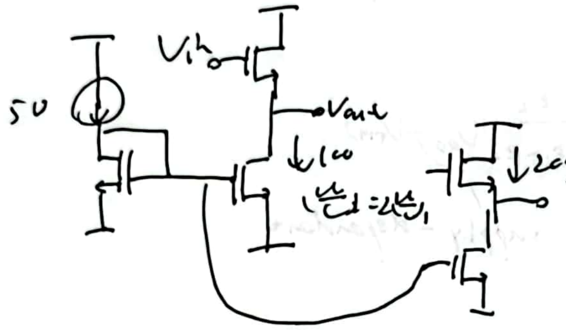
$$I_{out} = \frac{(\frac{W}{L})_2}{(\frac{W}{L})_1} I_{REF}$$

always $L_1 = L_2$

select $\frac{W_2}{W_1}$

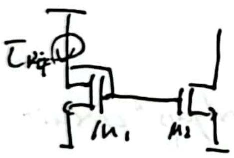
~~Also~~. Example

A circuit include two source followers biased at $100\mu A$ and $200\mu A$. We have a reference current of $5\mu A$.



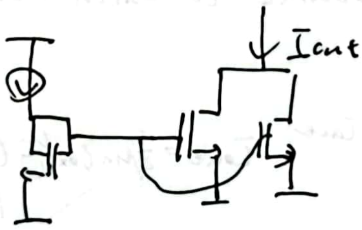
$(\frac{W}{L})_3 = 4(\frac{W}{L})$.

Alternative Perspective



$$\left.\begin{aligned} I_{D1} &= \frac{1}{2}\mu_n C_{ox}(\frac{W}{L})_1 (V_{GS} - V_{TH})^2 \\ I_{D2} &= \frac{1}{2}\mu_n C_{ox}(\frac{W}{L})_2 (V_{GS} - V_{TH})^2 \end{aligned}\right\} \Rightarrow I_{D1} = I_{D2} \times \frac{(W/L)_1}{(W/L)_2}$$

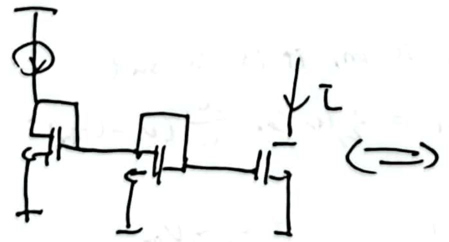
Example



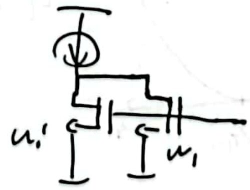
等效于 W double.

$I_{out} = 2 I_{REF}$

类似地，以及画等号编

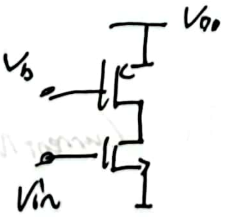


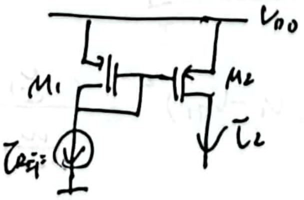
$\Longleftrightarrow$



$W = W_1' + W_1$

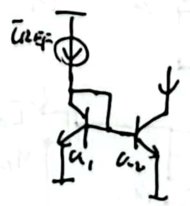
PMOS Current Mirrors.





$$I_2 = \frac{(W/L)_2}{(W/L)_1} I_{REF}$$

Bipolar Current Mirrors



$I_{C1} = I_{S1} \exp\frac{V_{BE}}{V_T}$

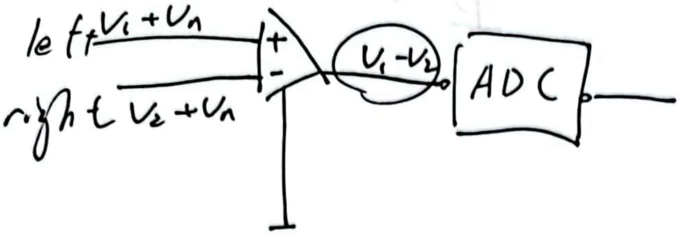
$I_{C2} = I_{S2} \exp\frac{V_{BE}}{V_T}$

$$\frac{I_{C2}}{I_{C1}} = \frac{I_{S2}}{I_{S1}}$$

但事实上，I_{C1}会偏小，因为基极有电流流入。

- Problem of Noise Coupling

from ECG



心电信号通常有 50Hz/60Hz noise . 通过差分消除.

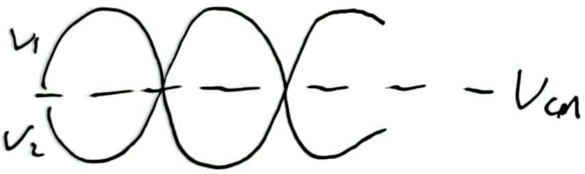
V_1-V_2 has no 50Hz/60Hz noise .

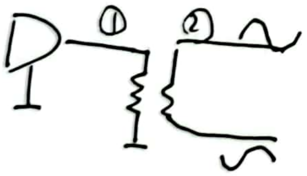
- Differential Signals.

(a) they vary by equal and opposite amounts

(b) they have the same average value

we call this the common-mode

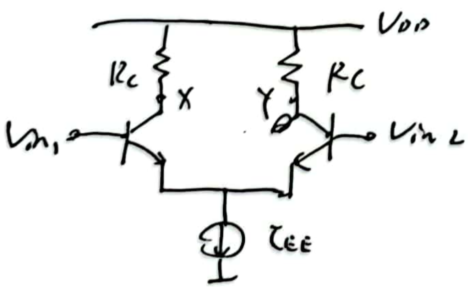


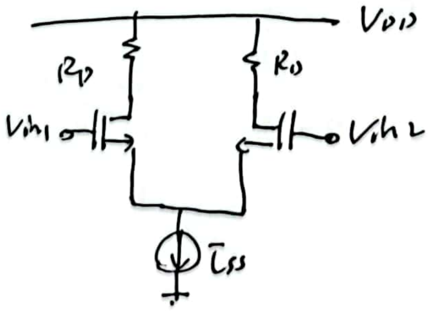


Generate the differential signals.

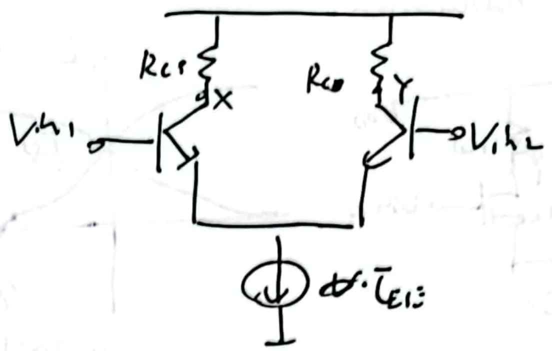
if the noise is added to the transmission lines ②,
the differential ~~p~~ can decrease it.
but if is added to the ①, no way.

- The Differential pair





- Bipolar Differential Pair.



Case I: $V_{in1} = V_{in2} = V_{cm}$

$$I_{C1} = I_{C2} = \frac{I_{EE}}{2}$$

$$V_X = V_{CC} - \frac{I_{EE}}{2} R_C = V_Y$$

The differential pair rejects perturbations in the input CM level

Case II:

$V_{in1} > V_{in2}$

考虑极端情况.

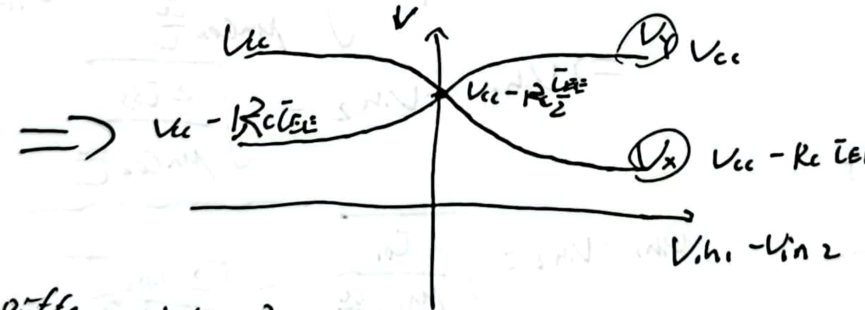
$V_{in1} - V_{BE} > V_{in2} \Rightarrow Q_2$ is off.

$\therefore \quad I_{C1} = I_{EE}, \quad I_{C2} = 0$

$V_X = V_{CC} - R_C I_{EE} \qquad V_Y = V_{CC}$

Case III: $V_{in1} < V_{in2}$ 同理: $I_{C1} = 0$. $I_{C2} = I_{EE}$. $V_X = V_{CC}$, $V_Y = V_{CC} - R_C I_{EE}$

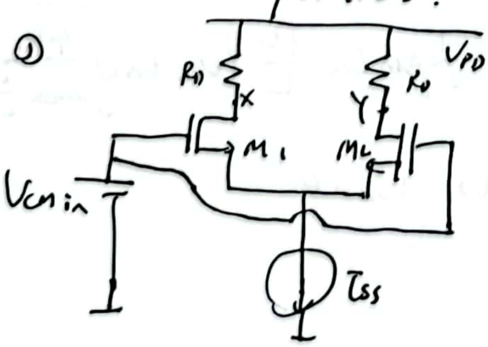
$\Rightarrow$



- MOS Differential Pair.

- General Properties.

①



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

$$V_X = V_Y = V_{DD} - R_D \frac{I_{SS}}{2}$$

$$V_{GS1} = \sqrt{\frac{I_{SS}}{\mu_n C_{ox} \frac{W}{L}}} + V_{TH}$$

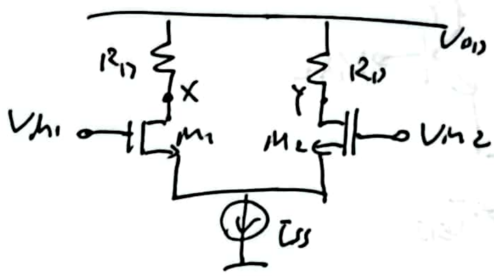
If $V_{in1} = V_{in2}$, the diff pair is in equilibrium

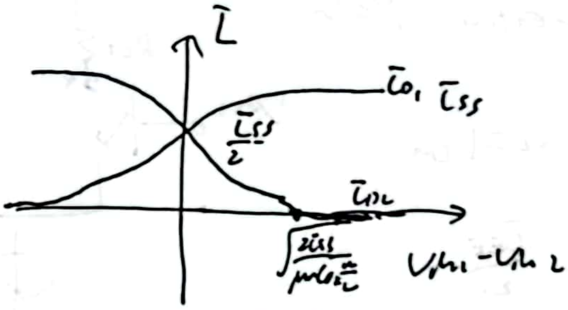
The equilibrium overdrive voltage:

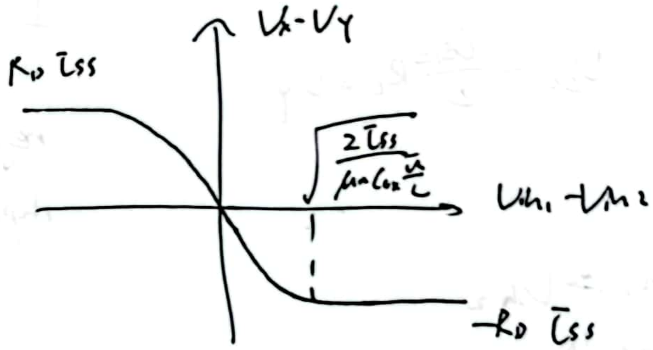
$$V_{GS1} - V_{TH} = \sqrt{\frac{I_{SS}}{\mu_n C_{ox} \frac{W}{L}}}$$

$V_{cm,in}$ change, nothing change

② Differential behavior.

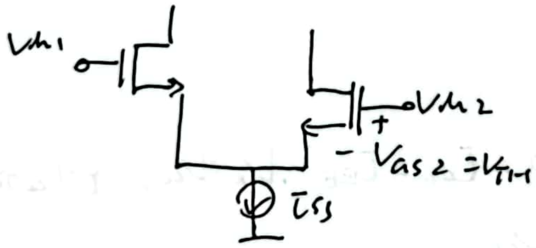






Example :

What's the minimum value of $V_{in1}-V_{in2}$ at which one transistor turns off ?



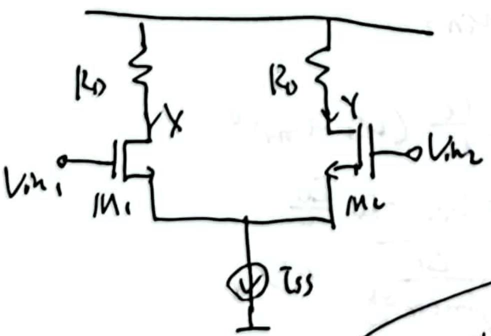
$\cancel{V_{in1}-V_{GS}=V_{in2}-V_{TH}}$

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

$$V_{GS1}=\sqrt{\frac{2I_{SS}}{\mu_n C_{ox}\frac{W}{L}}}+V_{TH}$$

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

Large-Signal Analysis



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

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

$$I_{D1}+I_{D2}=I_{SS}$$

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

① $I_{D1}-I_{D2}=0$ if $V_{o1}-V_{o2}=0$

②