High Swing Cascode Current Mirror

Introduction :-

→ High swing cascode current mirror is used instead of usual topology because the output impedance of cascoded current mirror is much higher than usual current mirror.

→ Ideally the output impedance of a current source should be "infinite".

→ Small signal model for usual and cascoded current mirror

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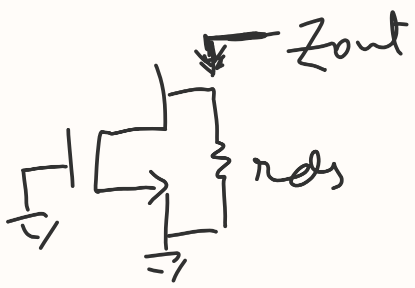
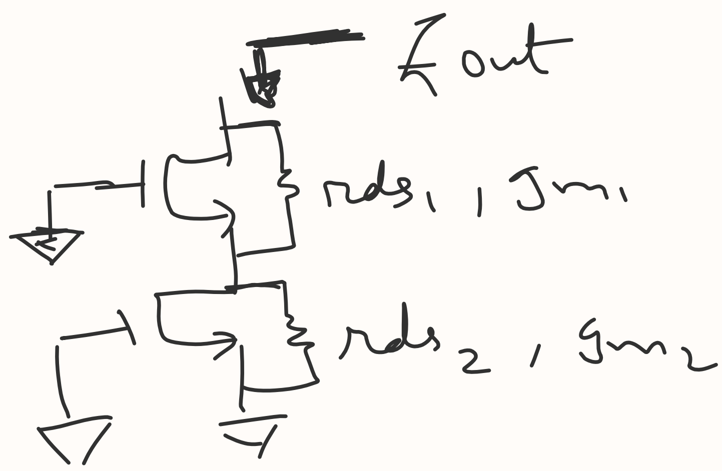


[Usual topology]

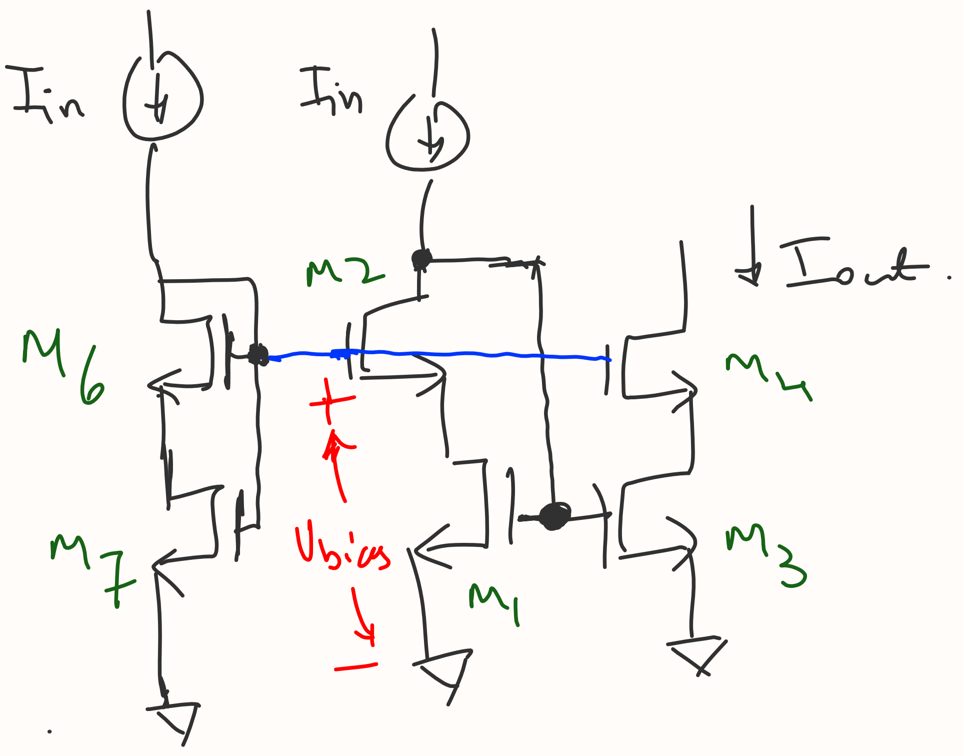
→ $Z_{out} = r_{ds}$



[Cascoded topology]

$$Z_{out} = (g_{m1} r_{ds_2} + 1) r_{ds_1} + r_{ds_2}.$$

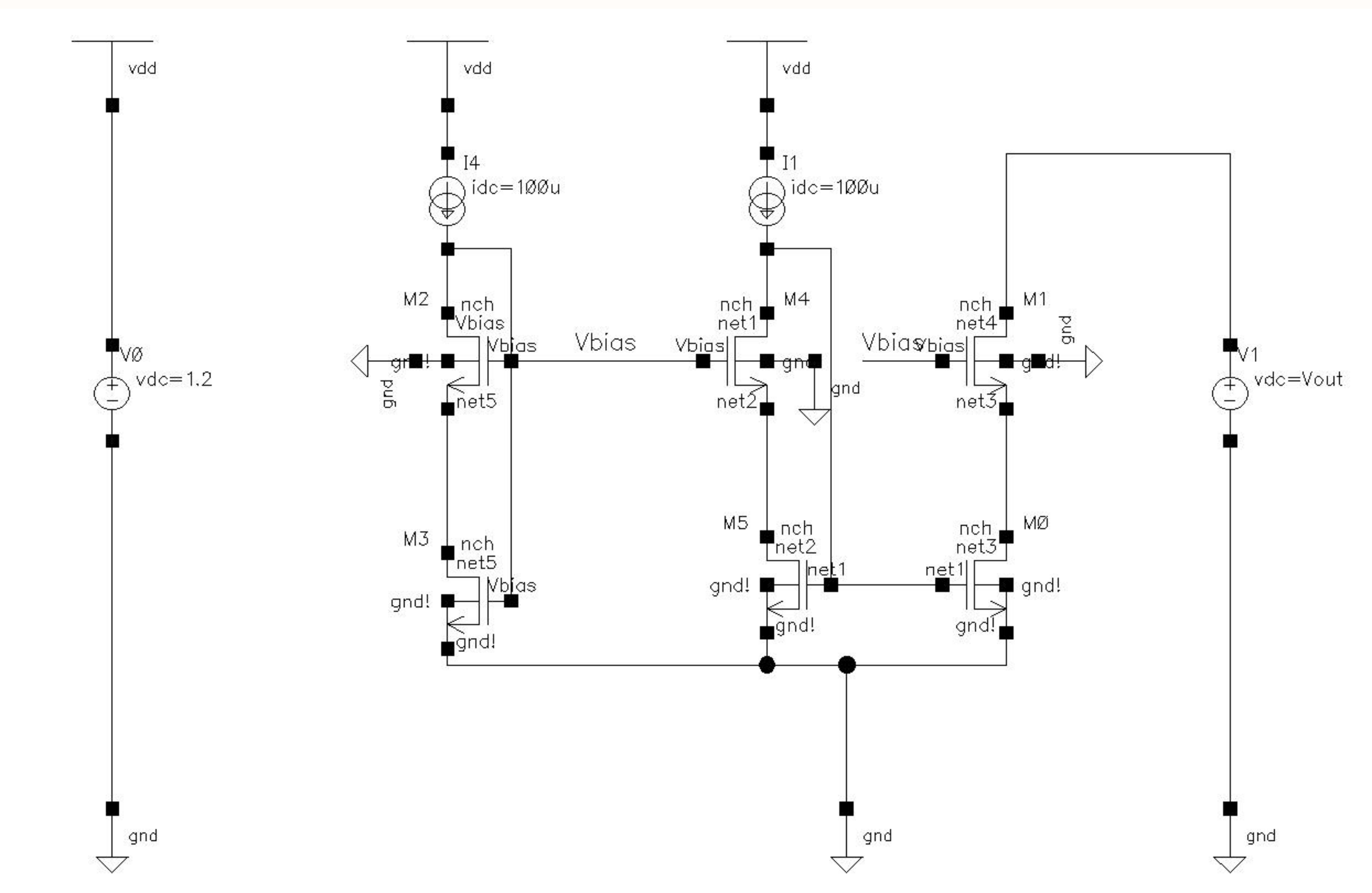
→ Schematic :-



→ The heart of the current mirror is formed by M_1 & M_3. The M_4 is cascode device M_4 will increase the output impedance. M_2 will ensure that V_{DS} of M_1 and M_3 is same so that mirroring is accurate.

→ About the bias ckt, M_6 will be in saturation and M_7 will be in linear region.

⇒ Schematic of Cadence :-



⇒ Design of Cascoded Current mirror :-

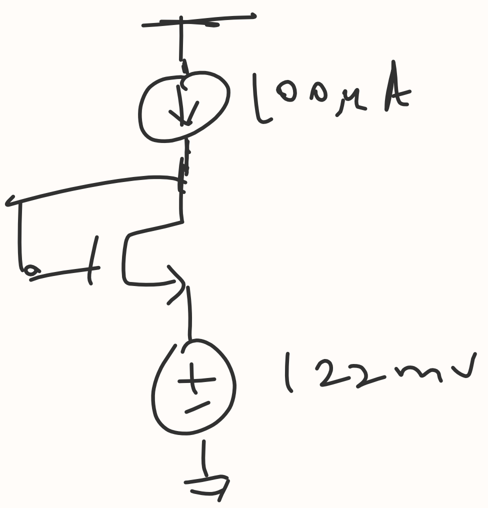
→ We will design current mirror for $I_{in} = 100\mu A$.

→ Let's take channel length of all transistors to be 500nm, so that we can avoid the channel length modulation effect majorly. Also take size of M_1, M_2, M_3, M_4 and M_6 equal.

→ We have choosen a $\left(\frac{g_m}{I_d}\right)_{1,3} = 20 \left(\frac{S}{A}\right)$, for this value of $\left(\frac{g_m}{I_d}\right)$ we found $V_{Dsat} = 72mV$. But the output resistance of Mosfet changes rapidly around V_{Dsat} so we will keep a little margin of say 50mV. Thus our $V_{DS_3} = \underbrace{72mV}_{V_{Dsat}} + \underbrace{50mV}_{\text{Margin}}$.

$\therefore \boxed{V_{DS_3} = 122mV.}$

→ For $\left(\frac{g_m}{I_d}\right) = 20$ we found $V_{gs_{2,4}} = 332.8203mV$ from $\left(\frac{g_m}{I_d}\right)$ Vs. V_{gs} graph. But the graph we plotted does not consider body effect, so due to body effect the actual $V_{gs_{2,4}}$ will be a little bit higher. The exact value of it was found by simulating the ckt in Cadence, The ckt was



→ Note that $I_{in} = 100\mu A$ is selected

→ From this we found the actual value of $V_{gs_{2,4}} = 351mV$

→ Thus $V_{bias} = V_{DS_1} + V_{gs_2}$

$\therefore V_{bias} = 122mV + 351mV$

$\therefore \boxed{V_{bias} = 473\,mV.}$

→ Now from $\left(\frac{g_m}{i_d}\right)_{1,2,0}$ vs $\left(\frac{i_d}{w}\right)$, we found w_1, w_2, w_3 & w_4.

→ $w_1 = w_2 = w_3 = w_4 = 64.943\ \mu m$.

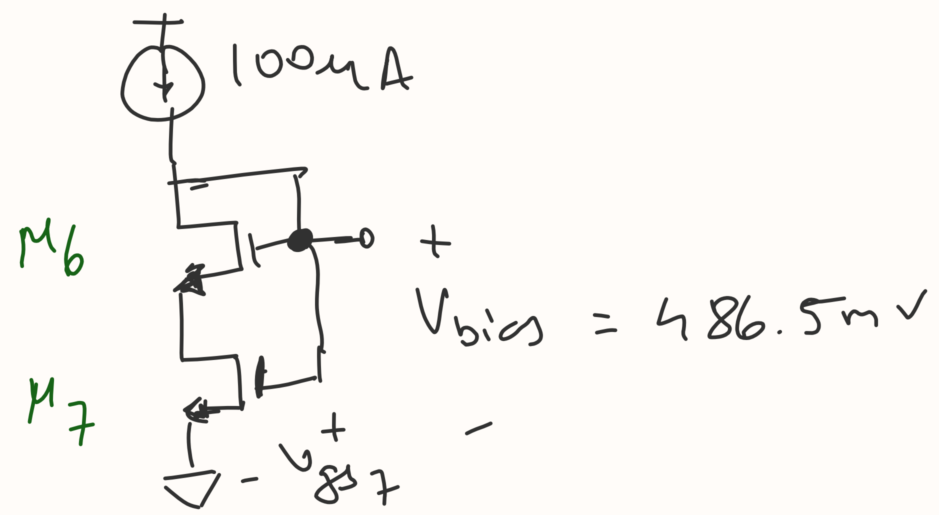
→ Also $M_6 = M_2$. so $L_6 = 500nm$ & $w_6 = 64.943\ \mu m$.

→ Now to find w_7 :-

→ As from ckt we know V_{bias} is set by V_{gs7}, thus from graph of V_{gs}. Vs. $\left(\frac{g_m}{i_d}\right)$, we found that for $V_{gs} = 473mV$ $\left(\frac{g_m}{i_d}\right) = 10.2767 \left(\frac{S}{A}\right)$. And from $\left(\frac{g_m}{i_d}\right)$ Vs. $\left(\frac{i_d}{w}\right)$, we can find w_7 for $\left(\frac{g_m}{i_d}\right)_7 = 10.2767 \left(\frac{S}{A}\right)$. The w_7 value turn out to be, $\boxed{w_7 = 8.771\ \mu m}$.

→ when we simulated the biasing ckt we found that $V_{gs7} = V_{bias}$ was 486.5 mV instead of 473mV.

→ The biasing ckt made in cadence is,



→ $w_6 = 64.93\ \mu m$

$L_6 = 500nm$.

→ $w_7 = 8.771\ \mu m$

$L_7 = 500nm$

→ Thus to reduce V_{bias} we increased the W_7 as by square law model, $I_D = \frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)(V_{gs}-V_{th})^2$.

I_D → Constant

$\frac{\mu_n C_{ox}}{2}$ → Constant

$(V_{gs}-V_{th})$ → Constant.

$\left(\frac{W}{L}\right)\uparrow \boxed{\Rightarrow} V_{gs}\downarrow$

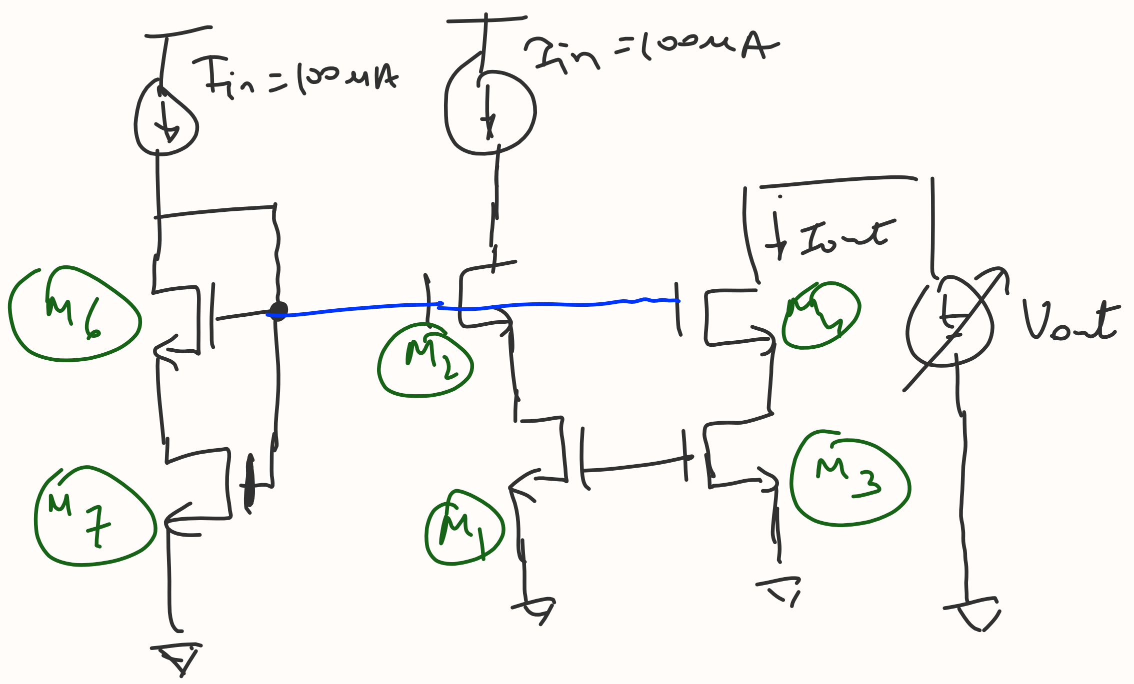
→ Although square law model is quite inaccurate but it is good enough to get the trends of different quantities for eg: if we increase $\left(\frac{W}{L}\right) \boxed{\Rightarrow} V_{gs}$ reduces.

→ From simulation it turn out that $W_7 = 10\,um$ gives $V_{gs7} = 475\,mV$ which is close enough to our required $V_{bias} = 473\,mV$.

→ Thus after getting all the values we will simulate the ckt in Cadence to know the swing and accuracy of our current mirror.

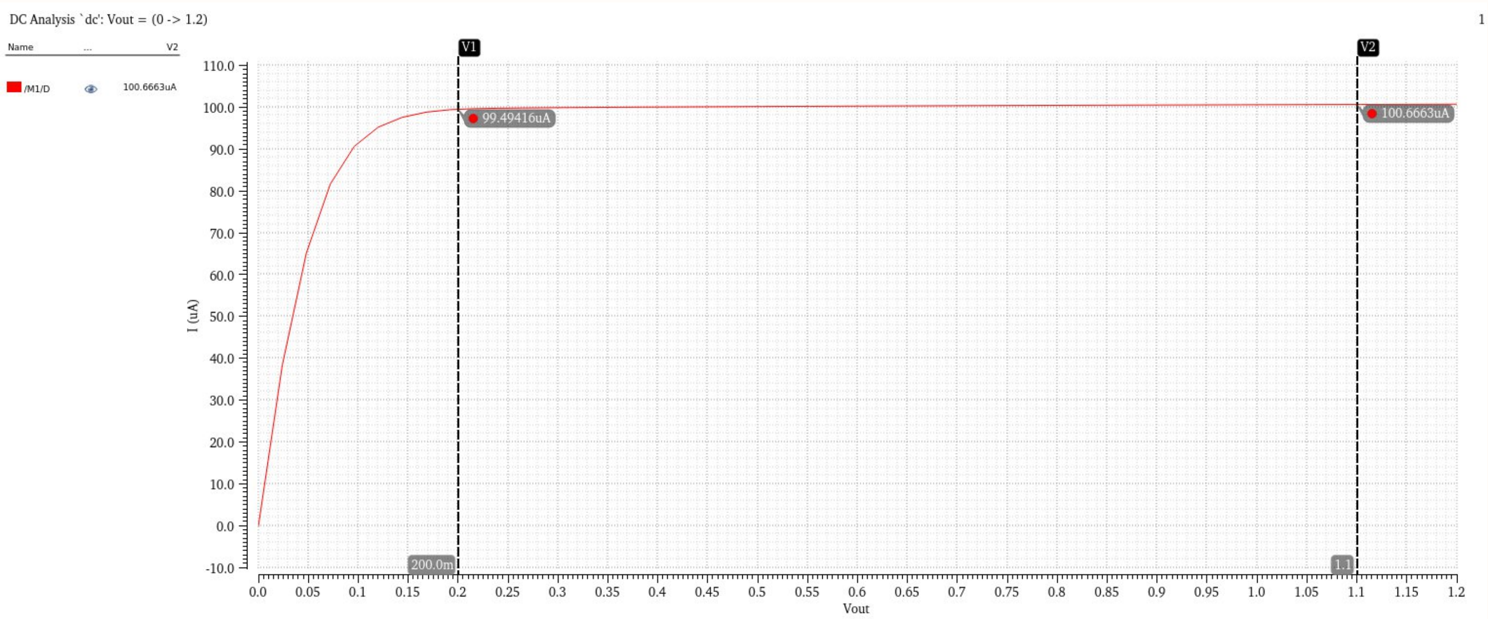
→ The setup is as shown below,

$\boxed{\Rightarrow}$



⇒ Simulation result :-

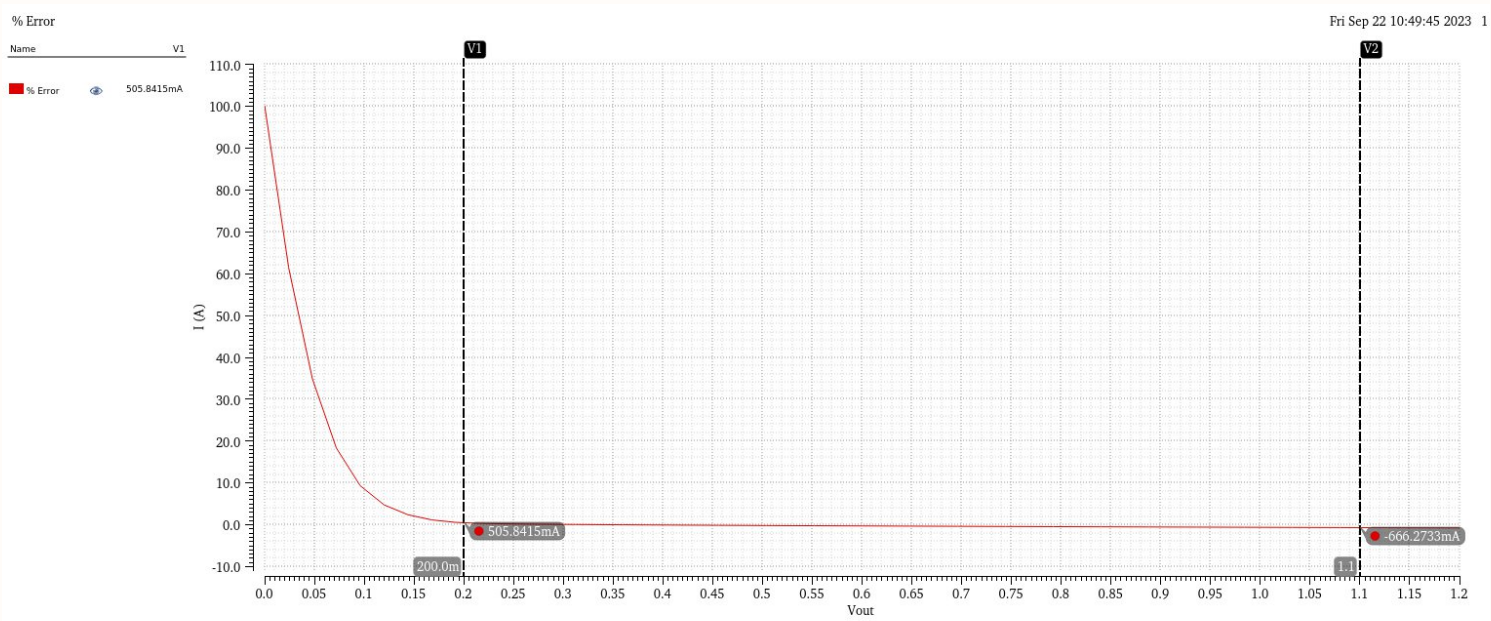
(a) I_{out} vs V_{out} :- {V_{out} is sweeped from 0 to $\underbrace{1.2V}_{V_{OD}}$}



(b) % Error curve :-

→ Here we plotted % Error vs. V_{out} curve for V_{out} being sweeped from 0 to 1.2V.

→ % Error is defined as, $\% \text{ Error} = \dfrac{100\mu A - I_{out}}{100\mu A} \times 100\%$.



Conclusion:

→ The minimum value of vout from graph is 200mV and after that we can see that almost negligible effect of variation of Vout is seen on Iout.

→ Also one important point to note is that minimum vout is decided on the value of Vbias and Vbias is

$$V_{bias} = \underbrace{V_{Dsat}}_{\text{Sat}^n \text{ Voltage of } M_3} + \underbrace{V_n}_{V_{margin}}$$

→ And V_{Dsat} depends on $\left(\frac{gm}{id}\right)_{1,3}$.

→ Thus minimum Vout is dependent on $\left(\frac{gm}{id}\right)$ value we choose and V_{margin} we choose.