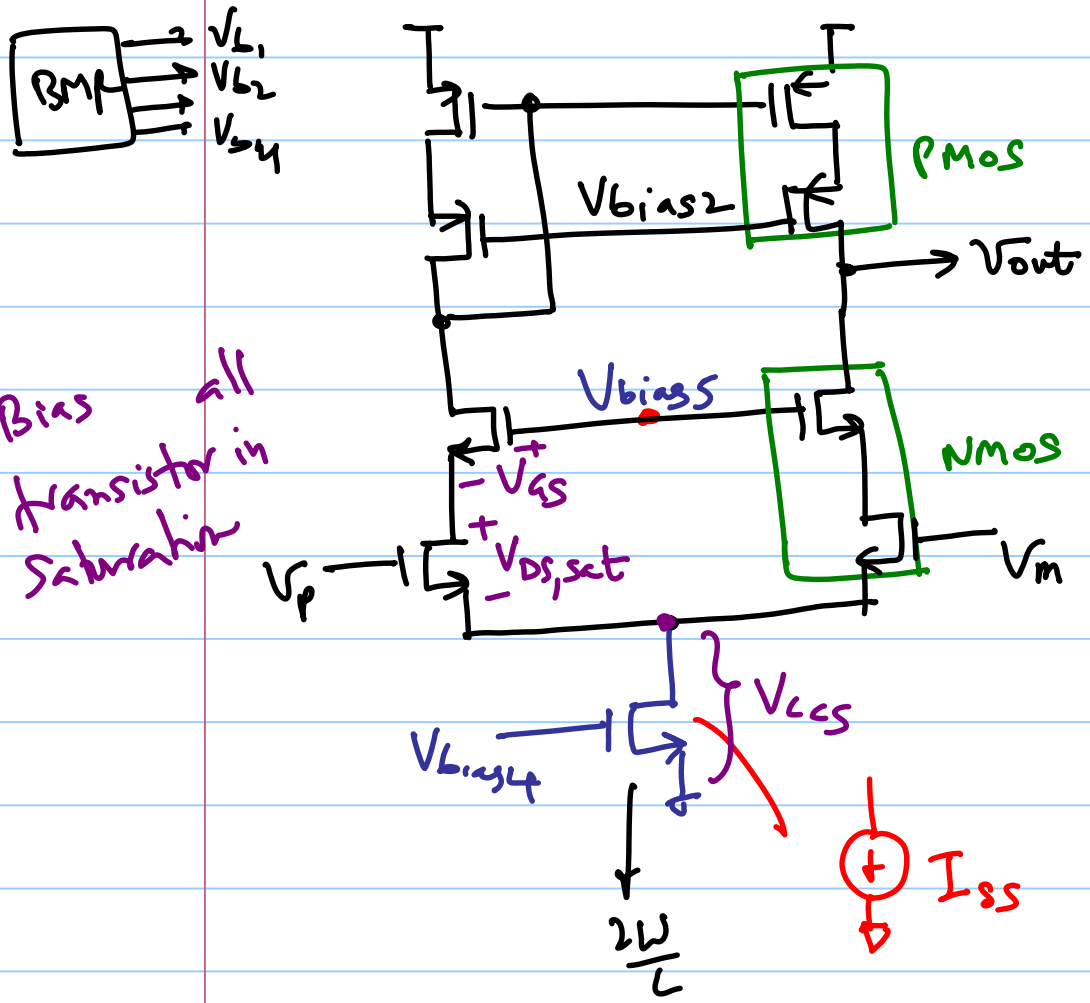
# ECE 511 – Lecture 23

Note Title 4/22/2014



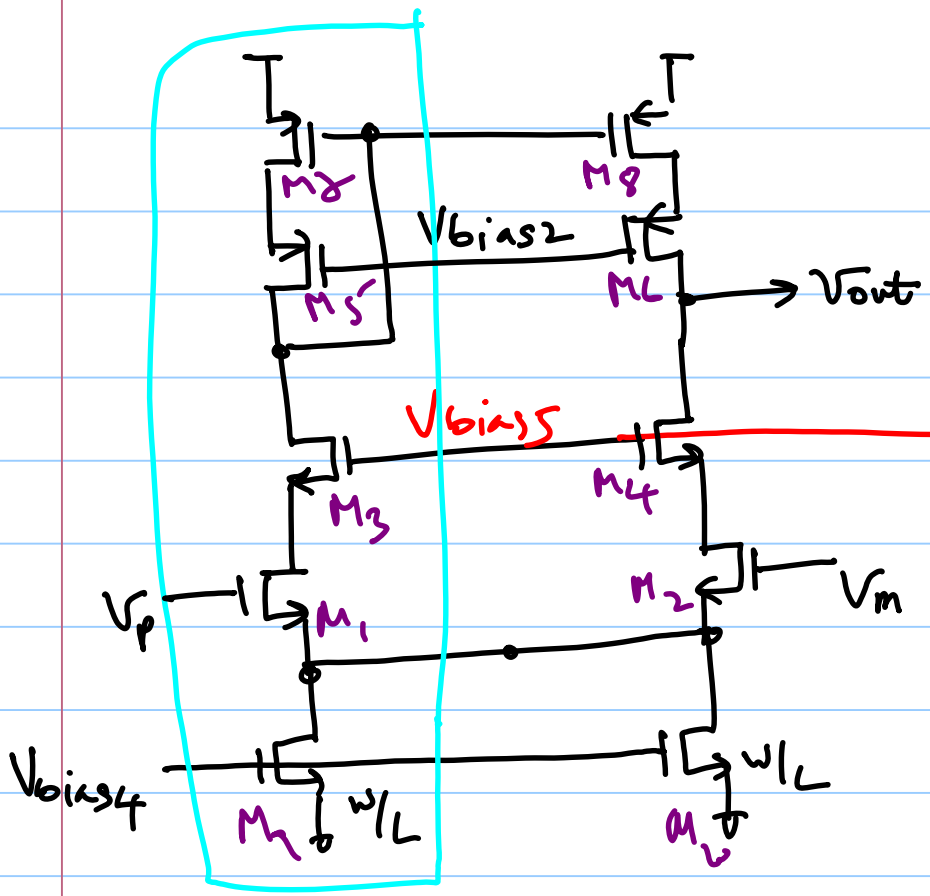

Bias all transistor in Saturation

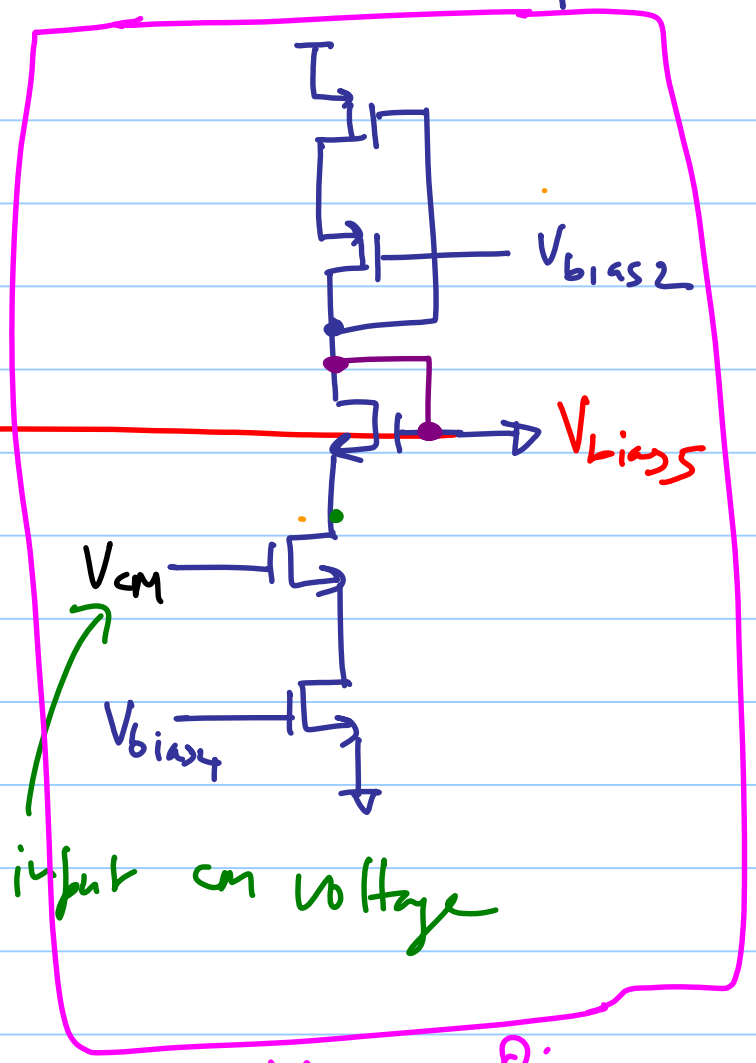
Telescopic

How to generate $V_{bias5}$?

↳ Replica Biasing.

Create a Replica circuit



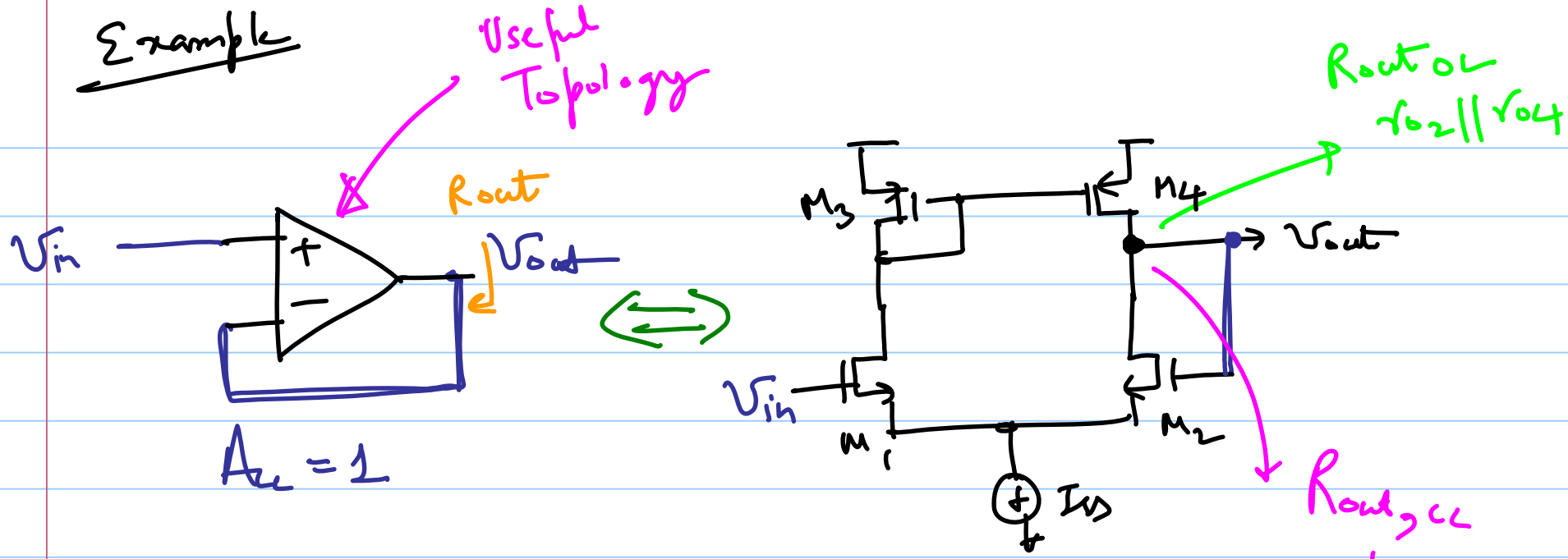




Vbias biases M3 & M4 in saturation while ensuring M1 & M2 are also in SAT.

Replica Bias Circuit

"Tracks PVT variations"

Example




closed-loop $R_{out} = \frac{1}{g_m}$ ← very low as desired

From feedback chapter

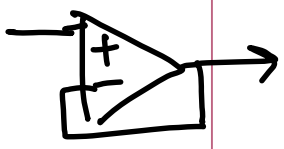
$$R_{out,CL} = \frac{R_{out,OL}}{1 + \text{loop-gain}} = \frac{r_{o2} \| r_{o4}}{1 + g_{m1,2}(r_{o2} \| r_{o4})}$$

$$\approx \frac{1}{g_{m1,2}}$$

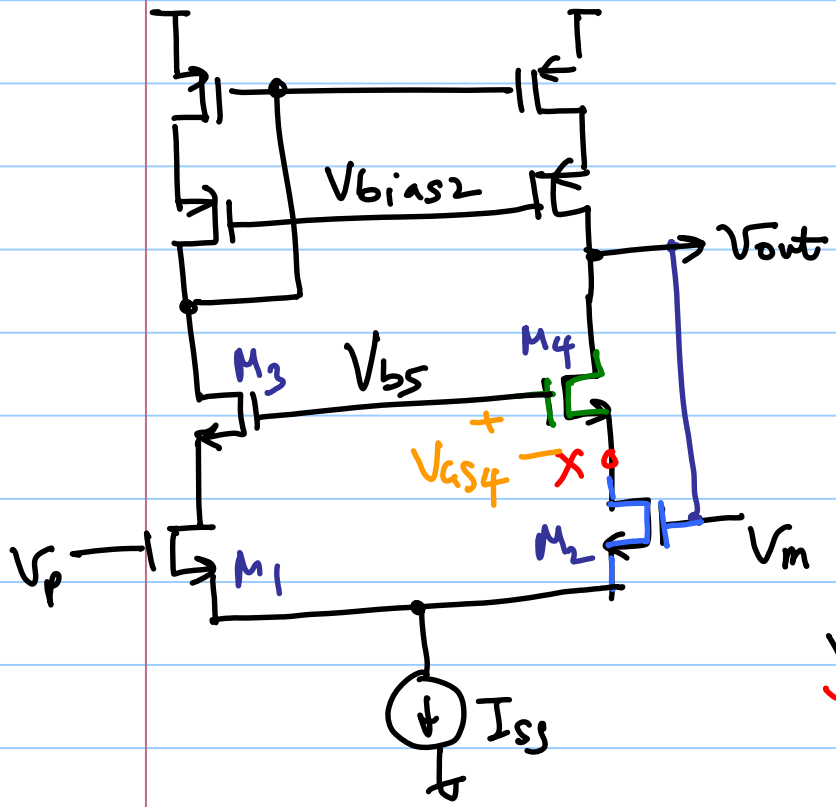
To be able to make unity-gain feedback connection:

output range should have good overlap with input CMR.

# Single-Stage Telescopic Amplifier:



* Both $M_2$ & $M_4$ must be in SAT




$M_2$ $\quad V_{out} \le V_x + V_{THN} \longrightarrow (1)$

$M_4$ $\quad V_{out} \ge V_{b5} - V_{THN} \longrightarrow (2)$

$V_x = V_{b5} - V_{GS4} \longrightarrow (3)$

$$\underbrace{V_{b5} - V_{THN}}_{V_{out,min}} \le V_{out} \le \underbrace{V_{b5} - V_{GS4} + V_{THN}}_{V_{out,max}}$$

$$V_{out,max} - V_{out,min} = 2V_{THN} - V_{GS4}$$

$$\simeq \underbrace{V_{THN} - V_{OV,4}}$$

This range is very small

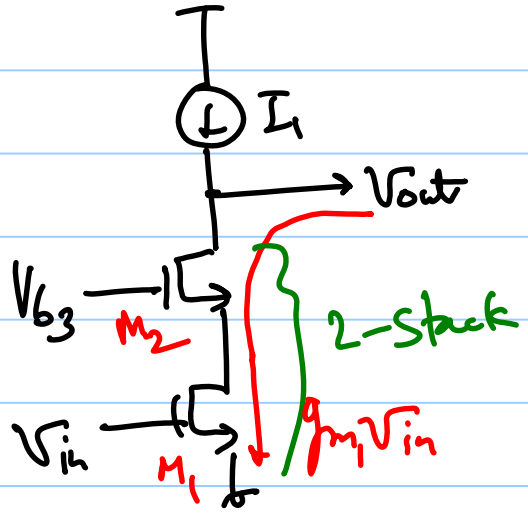
Main drawbacks of telescopic opamps

① Limited output swing

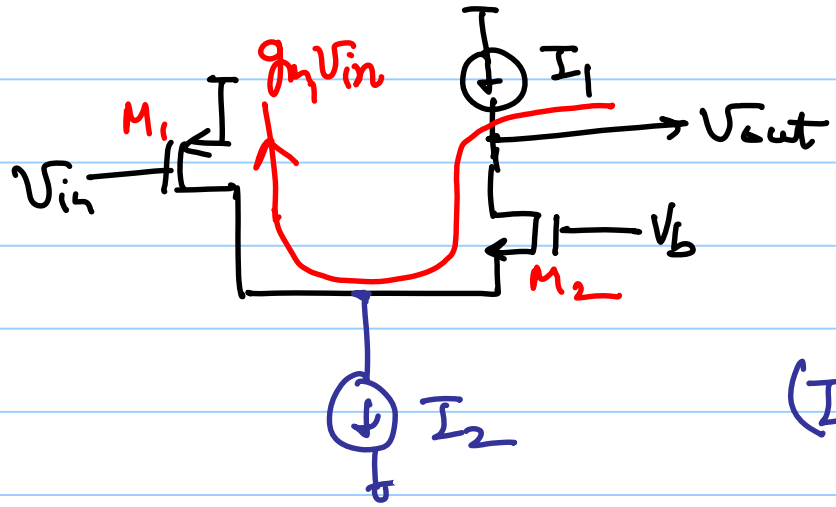
② difficulty in shorting input & output terminals

Folded Cascode to mitigate these problems

NMOS input device




PMOS input device

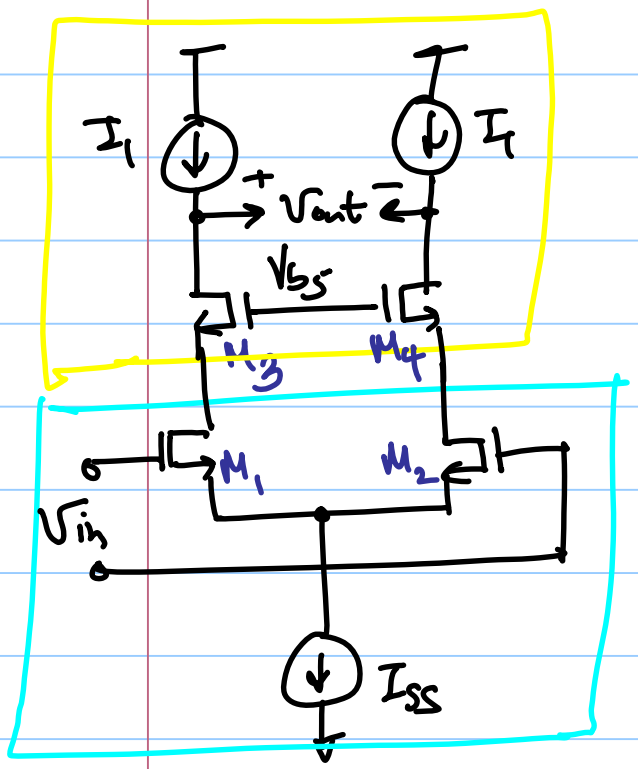


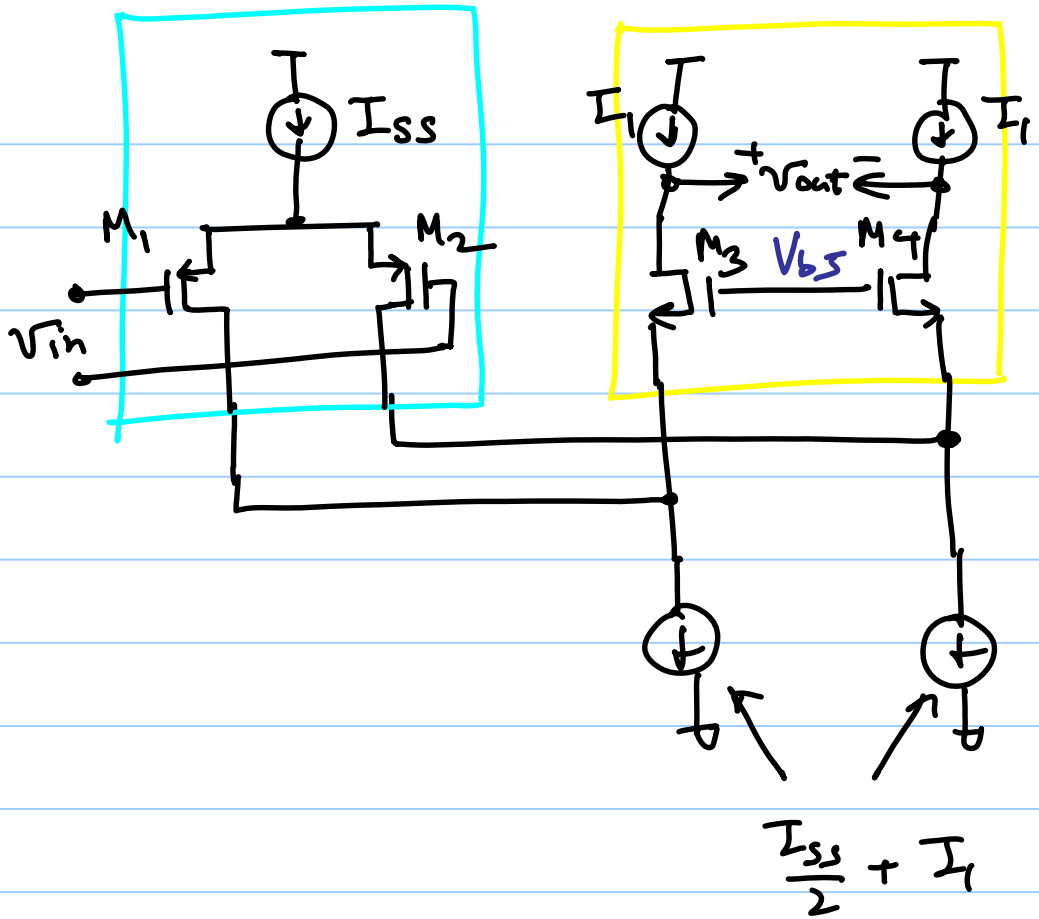

$(I_2 > I_1)$

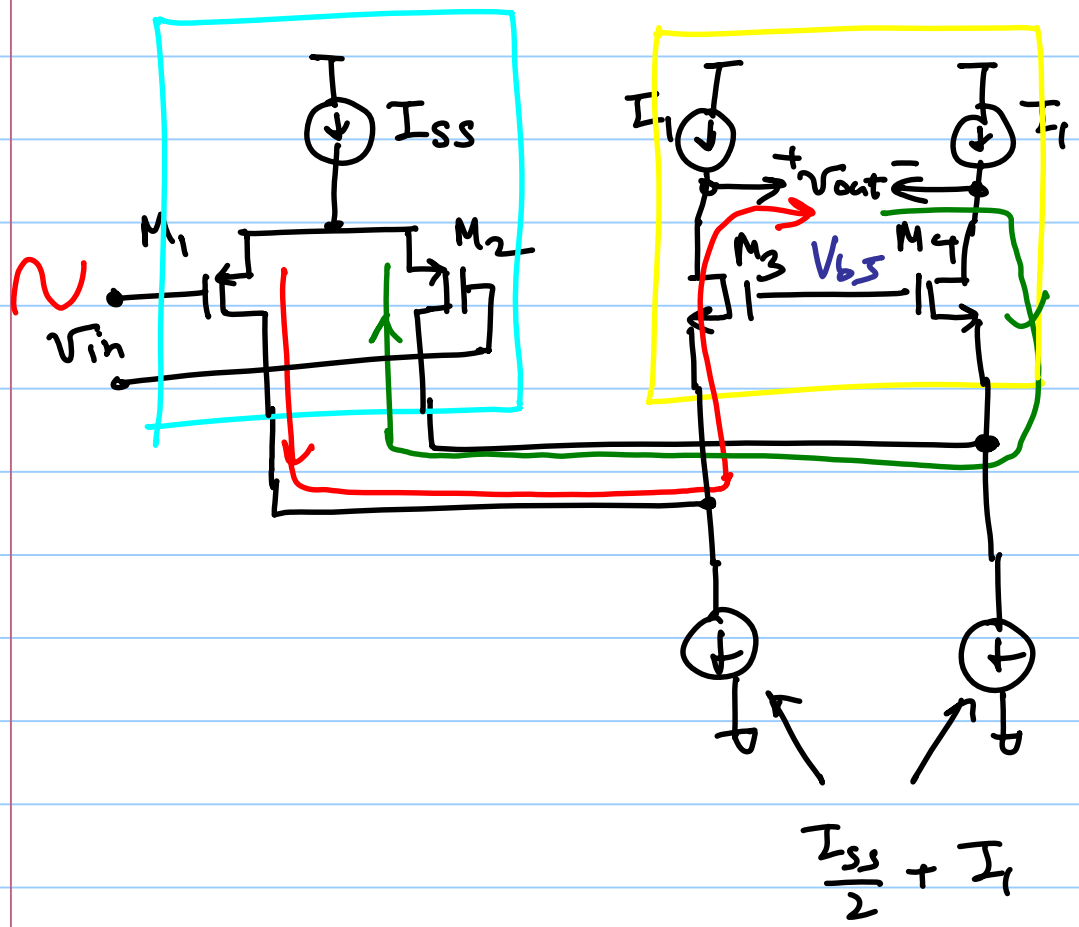
* input device replaced by opposite type
* $A_v = -G_m R_{out}$

$G_m = g_{m_1}$

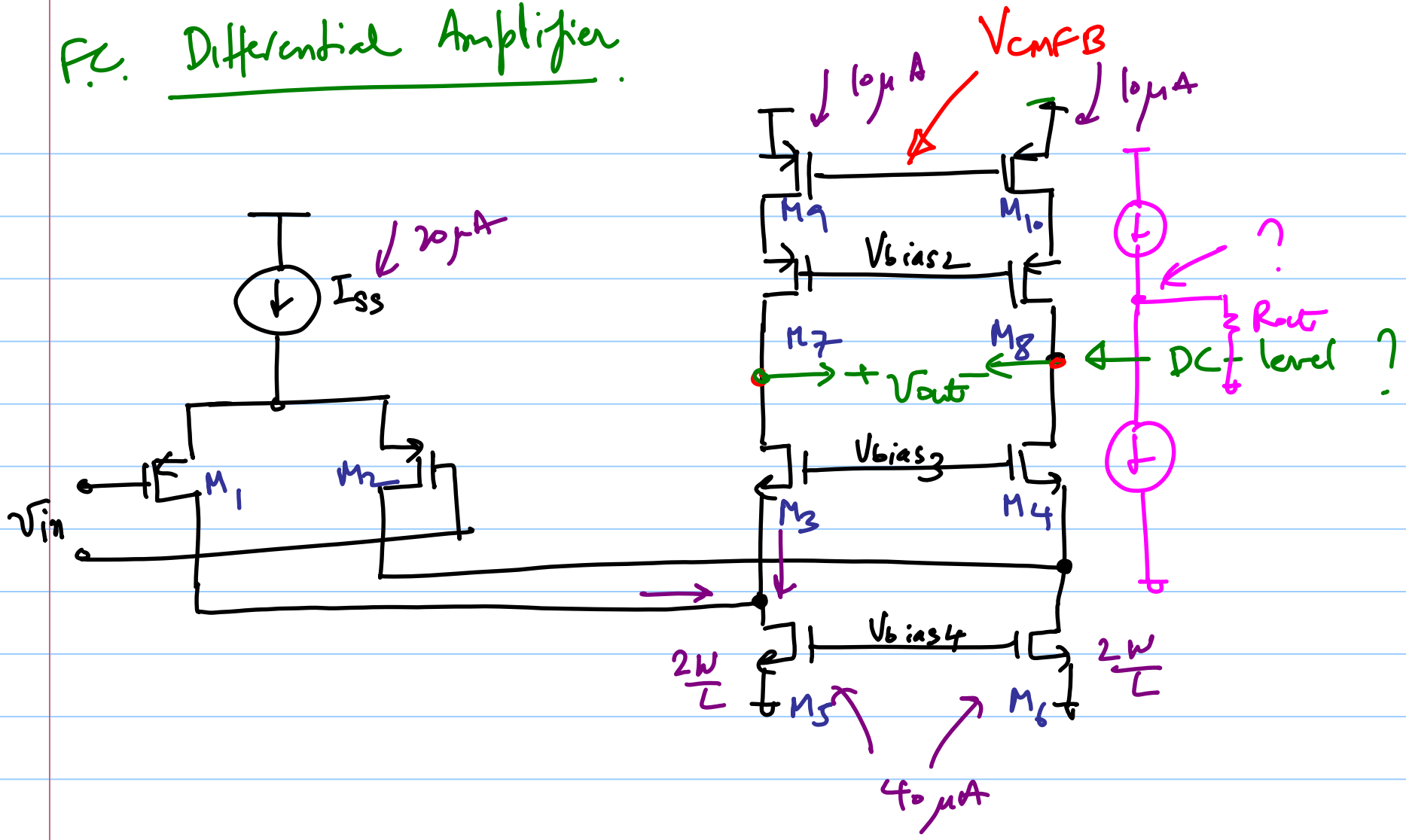
Regular Cascode Amplifier



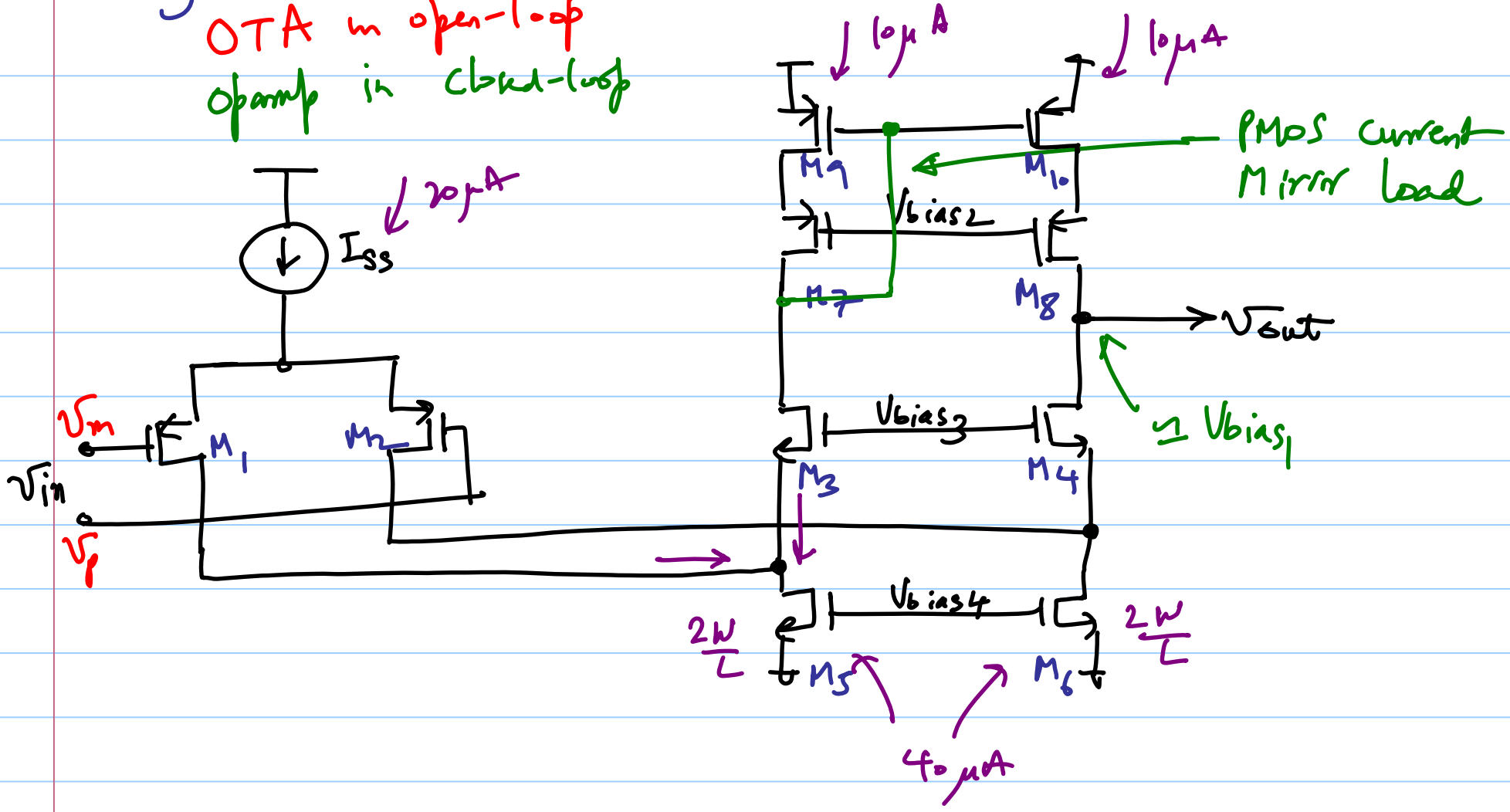

$I_{SS}$
$M_1$
$M_2$
$V_{in}$
$I_1$
$I_1$
$+V_{out}-$
$M_3$
$V_{GS}$
$M_4$
$\frac{I_{SS}}{2} + I_1$

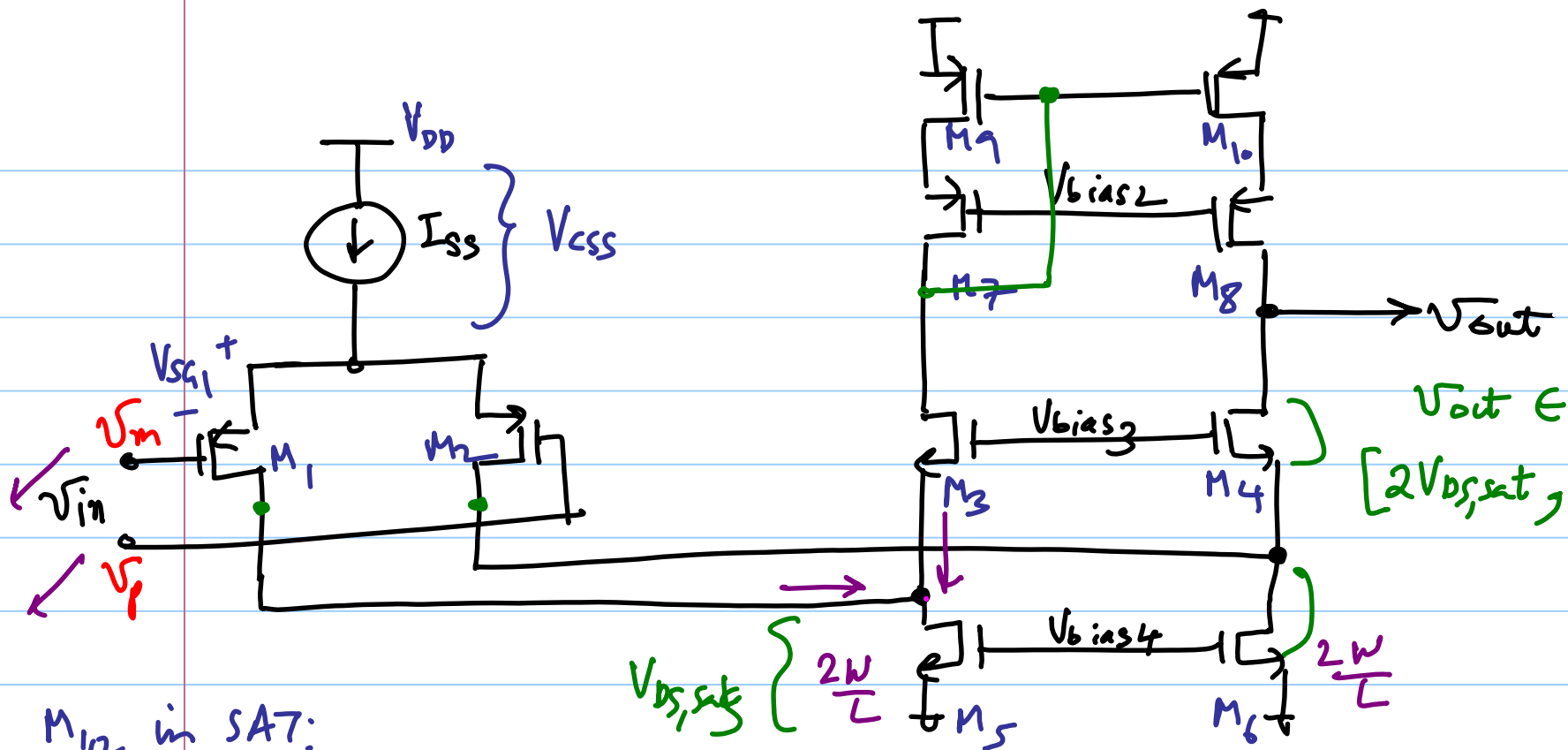
# F.C. Differential Amplifier



# Single-Ended folded Cascode Amplifier

OTA in open-loop
opamp in closed-loop






$V_{out} \in [2V_{DS,sat}, V_{DD} - 2V_{SD,sat}]$

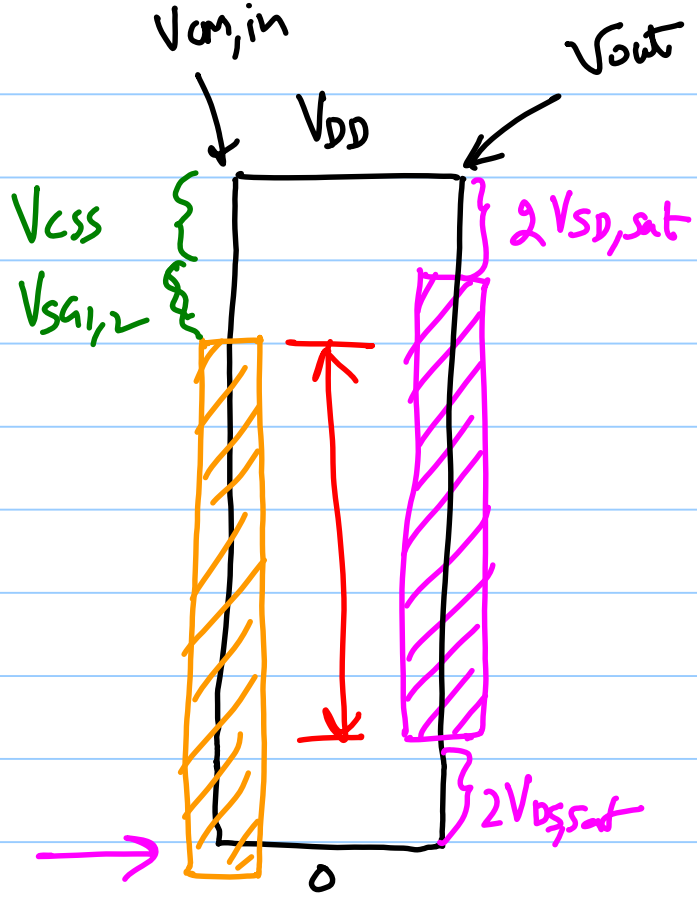
$M_{1,2}$ in SAT:

$V_{CM,in} \leq V_{DD} - V_{CSS} - V_{SG1,2}$

$M_{5,6}$ in SAT:

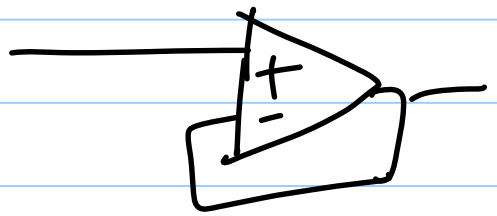
$V_{CM,in} \geq V_{DS,sat5} - V_{THP} < 0$ ⇐ input CMR accommodate the gnd rail.

$V_{CM,in} \in [V_{DS,sat} - V_{THP}, \; V_{DD} - V_{CSS} - V_{SG1,2}]$




Folded Cascode

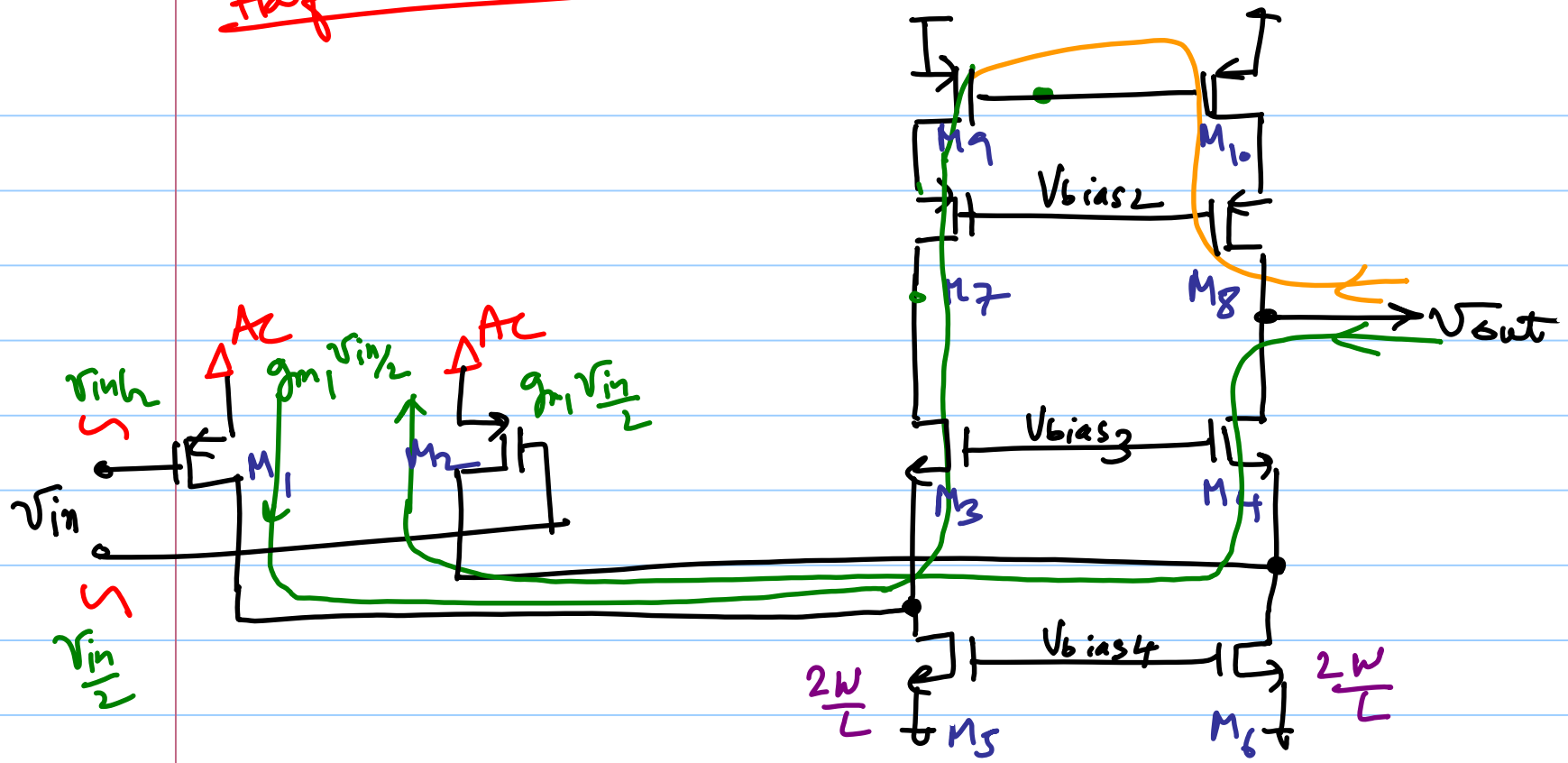
good overlap b/w $V_{in,cm}$ & $V_{out}$

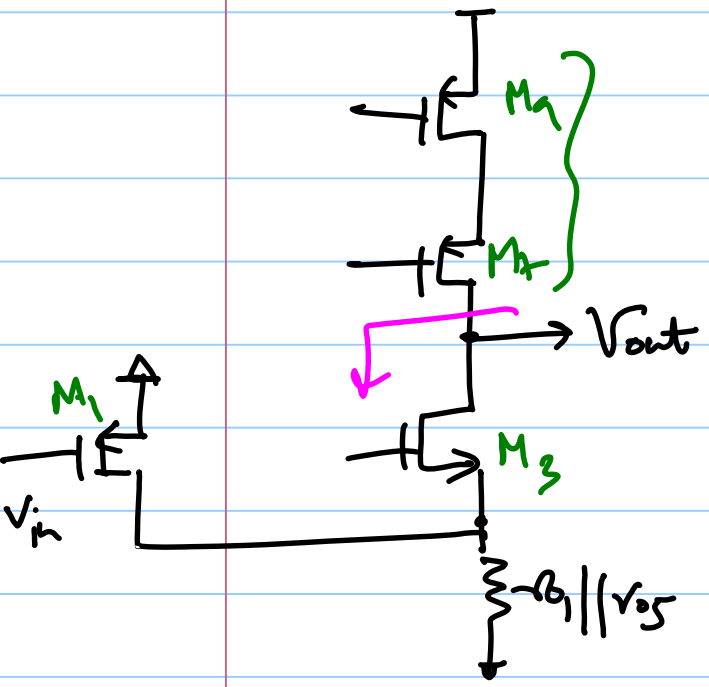



(−) Consumes more (~2x) bias current

↳ higher power consumption compared to Telescopic

# Half-Circuit Analysis





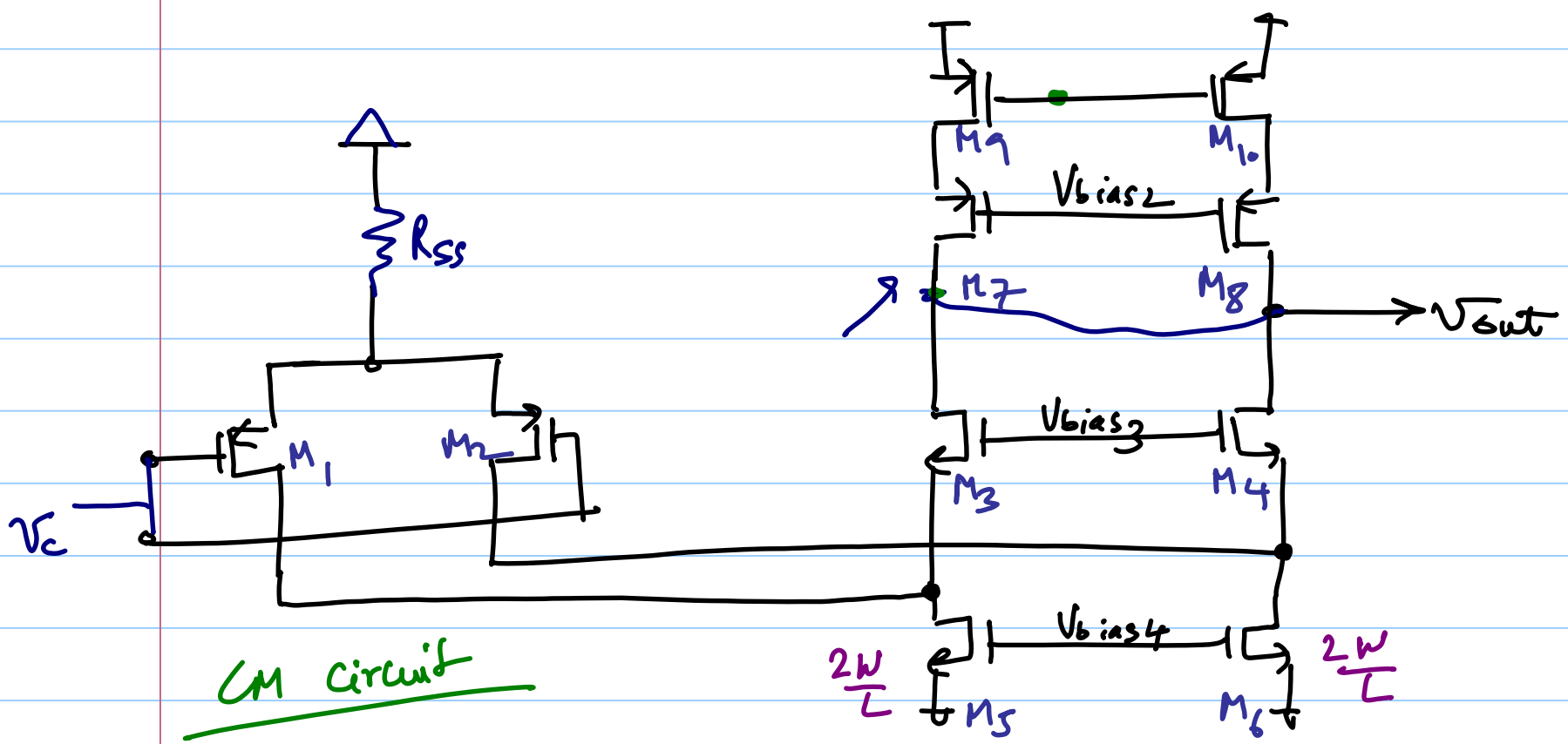

$$G_m \cong -g_{m1}$$

$$R_{out} \simeq \left(g_{m7} r_{o7} r_{o9}\right) \Big\| \left(g_{m3} r_{o3} \left(r_{o1} \| r_{o5}\right)\right)$$

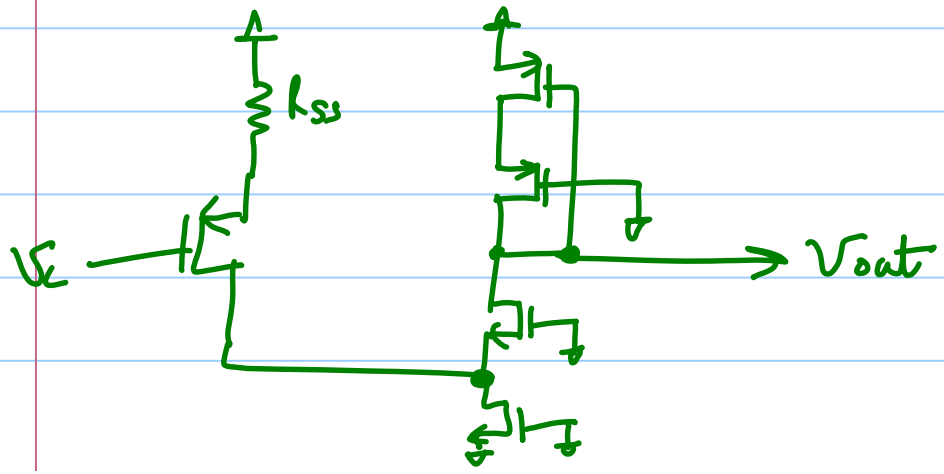
Half circuit gain $\Rightarrow -g_{m1} R_{out}$

$$A = g_{m1} \cdot R_{out}$$

$A_{v,cm}$




CM circuit




Apply GmRout method

$A_{v,cm}$

$$CMRR = \left| \frac{A_{v,dm}}{A_{v,cm}} \right|$$