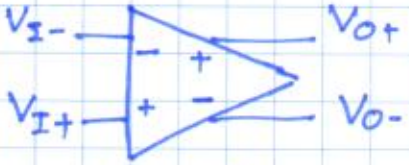
Standard Differential Amplifier (Lecture 7)

- → Differential i/p
- → Common-mode (i/p) is rejected by diff pair with current source
- → Single-Ended Output (DE to SE conversion) using mirror.

Std. Diff. Amplifier



Fully Differential Amplifier

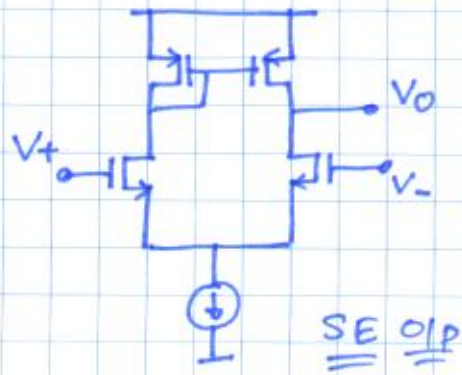
Fully. Differential Amplifier

- → Differential i/p, Differential O/p.
- → i/p common-mode is rejected by i/p diff pair
- → O/p common-mode set independently

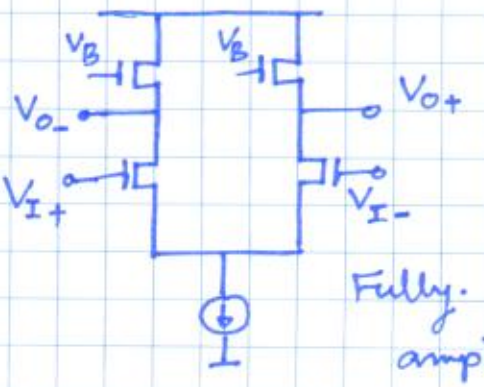
Why?

- ✡ Increased (double) O/p swing.
- ✡ Excellent Power Supply rejection
- ✡ Immune to noise coupling from any external sources.
- ✡ Improved freq. response ← NO DE2SE conversion

Simplest Example

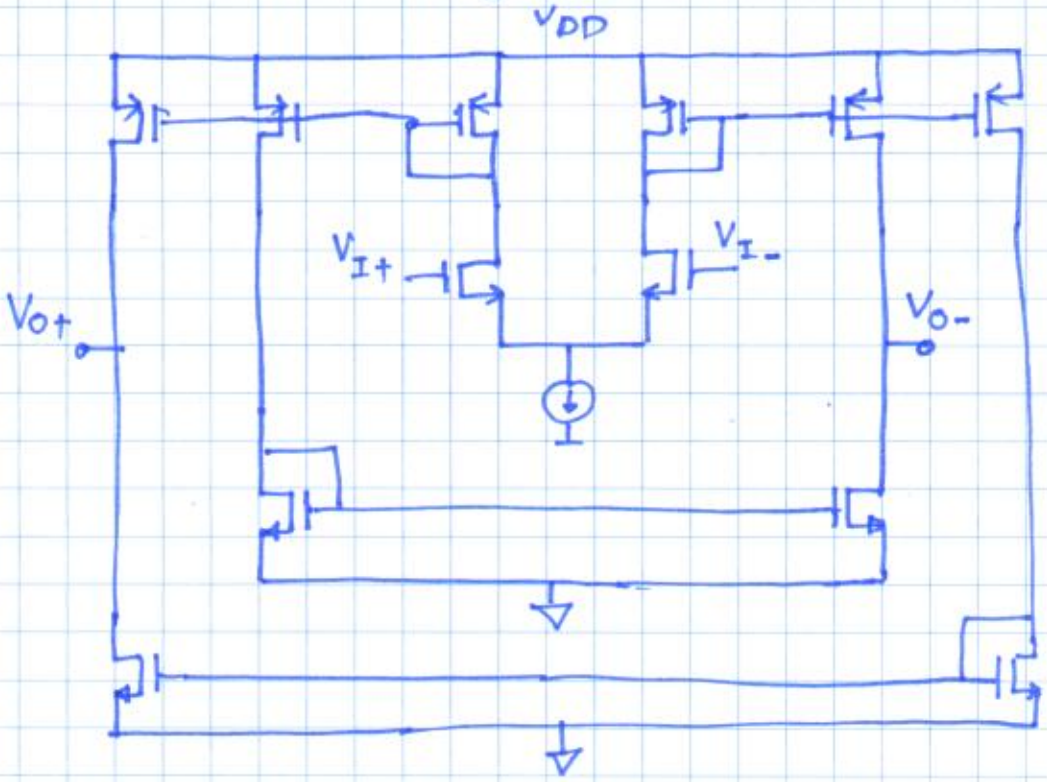


SE O/P

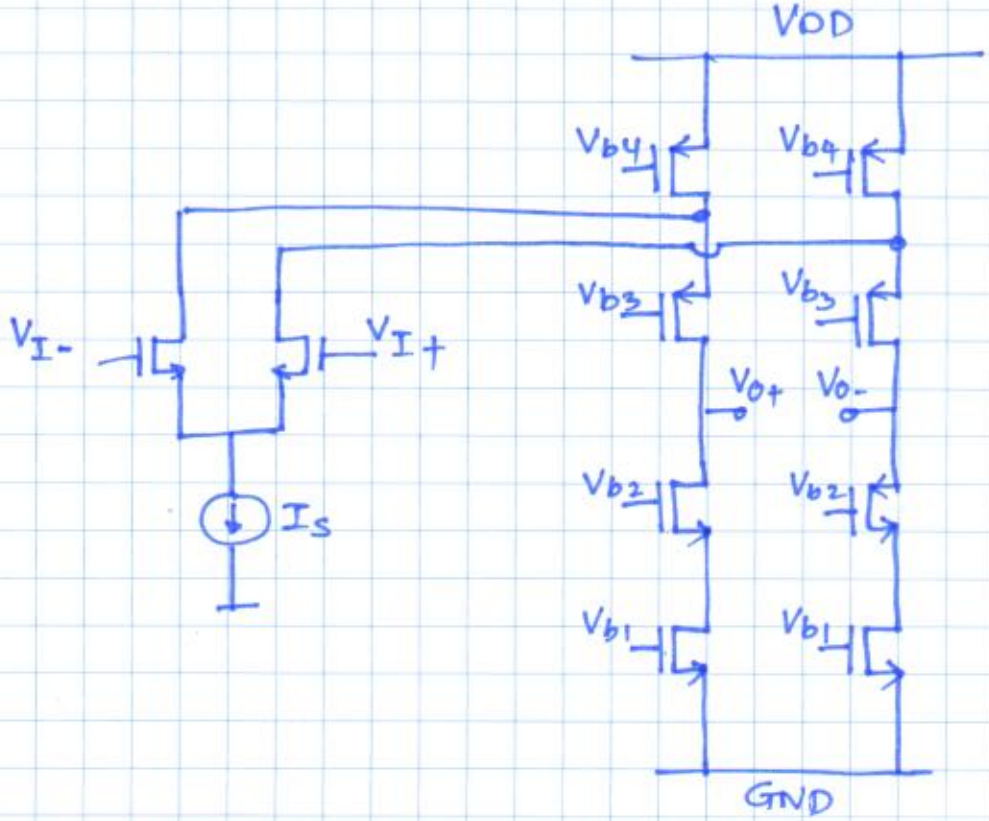


Fully. Diff. amplifier

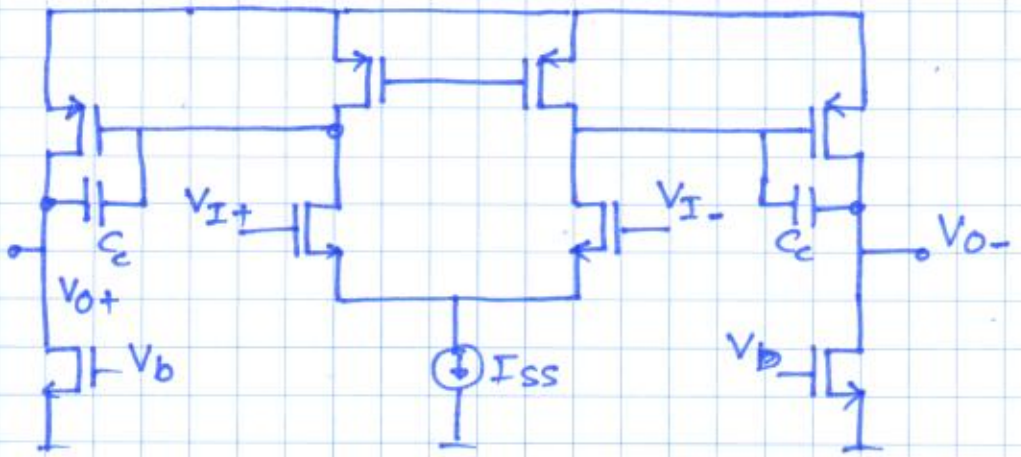
Examples of fully. differential Amplifiers



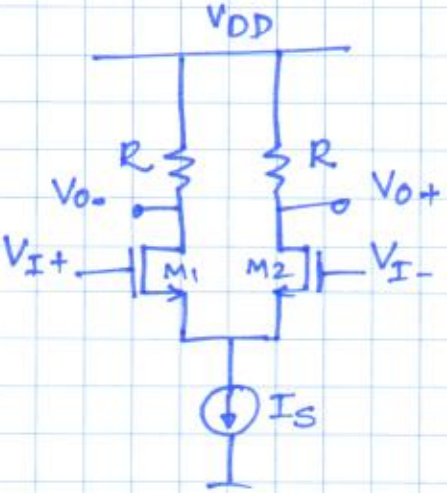
Fully Diff Folded Cascode Opamp



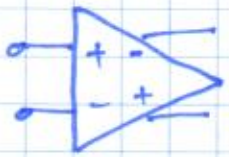
Fully-Differential Two Stage Opamp



Consider Simple diff pair with Rload. (fully diff)



$\Rightarrow$

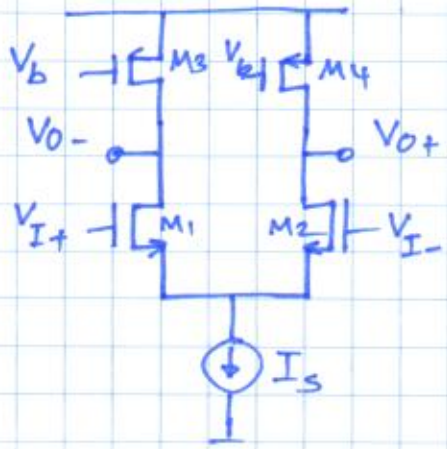


Assume: $V_{I+} = V_{I-} = V_{ICM}$.

M_1, M_2 sat.

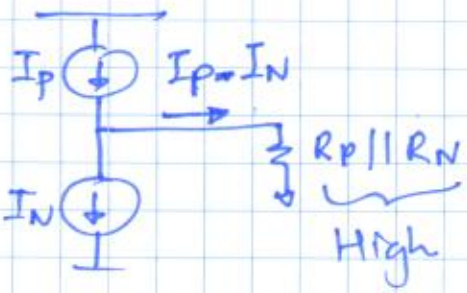
$V_{OCM} = V_{DD} - \frac{I_S}{2} R$ ← very well defined.

Current Source loading — High Gain



For common mode i/p V_{ICM}.

Assume all Transistor in Sat.



V_{OCM} undefined

I_P ; I_N are defined by process, temp, voltage
→ will change.
∴ → Even mismatches will impact V_{OCM}.

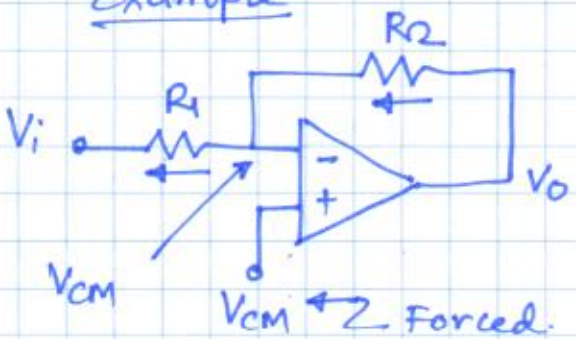
→ Tweeking I_P, I_N to get $V_{OCM} = V_{DD}/2$

→ DOESNOT work – V_{OCM} will keep changing with PVT & mismatches.

→ Need Feedback at o/p to stabilize output common-mode voltage.

→ Note: Differential feedback does not correct common-mode.

Example

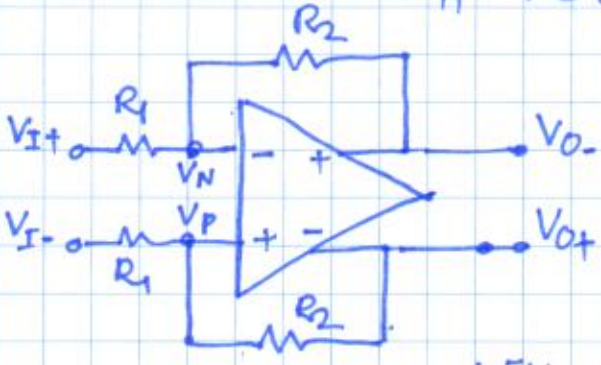


$$\frac{V_o - V_{CM}}{R_2} = \frac{V_{CM} - V_i}{R_1}$$

$$V_o = \frac{R_2}{R_1}(V_{CM} - V_i) + V_{CM}$$

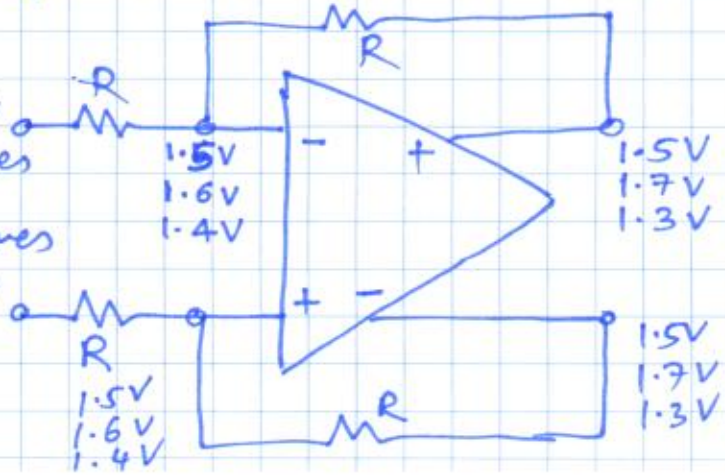
$$= -\frac{R_2}{R_1} V_i + \left(1 + \frac{R_2}{R_1}\right) V_{CM}$$

o/p DC (common Mode) very well defined.



Lets assume $(V_{I+}, V_{I-})_{CM} = V_{icm}$.
$= 1.5V$

$R_1 = R_2 = R$



V_P, V_N can take any values

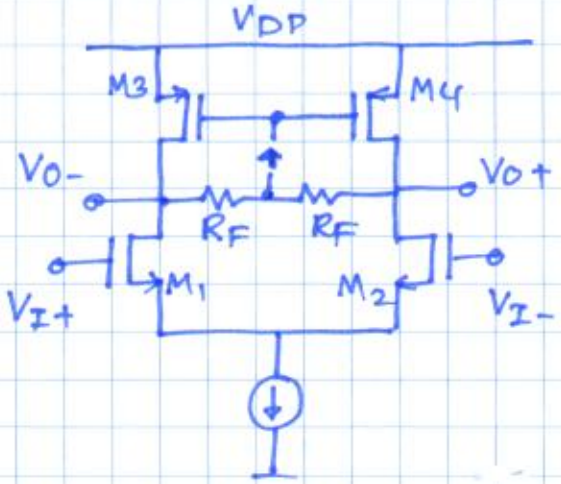
V_{op}, V_{o-} can take any values

o/p CM poorly defined

Need CMFB Common-Mode Feedback circuit

→ Required for high gain fully differential ckt.

Simple Example



Diff gain $g_{m_1}(r_{o_1} \| r_{o_3} \| R_F)$

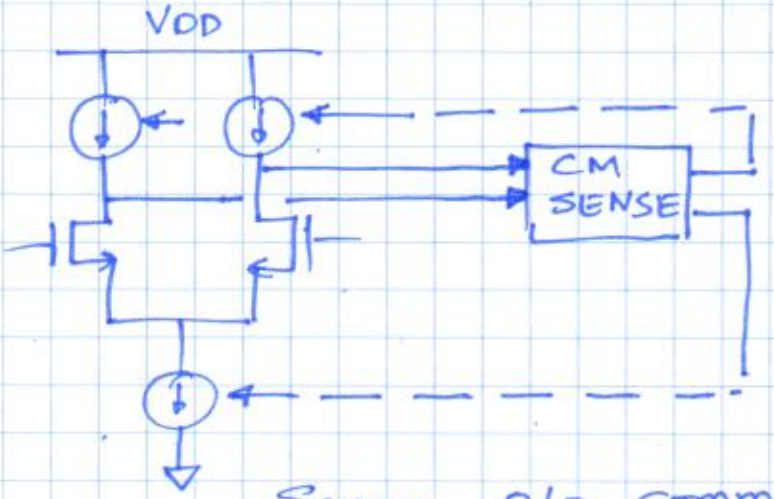
R_F → large.

O/p Common-mode

$$V_{OCM} = V_{DD} - |V_{GS_3}|$$

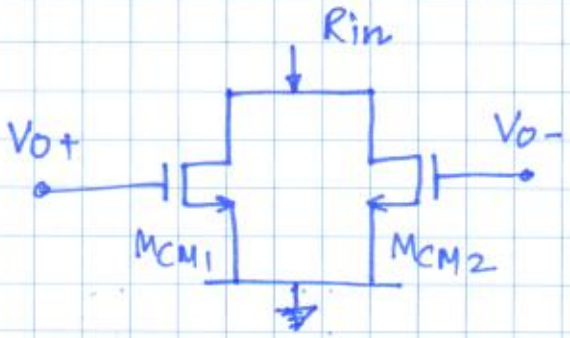
$$V_{DD\,min} = 2V_{dsat} + |V_{GS_3}| = 3V_{dsat} + |V_{T_P}|$$

Generic CMFB Strategy



Sense O/p common-mode voltage & adjust one of current sources.

CMFB using MOSFETs in triode region.



$$R_{in} = R_{CM1} \parallel R_{CM2}$$

↑ ↑

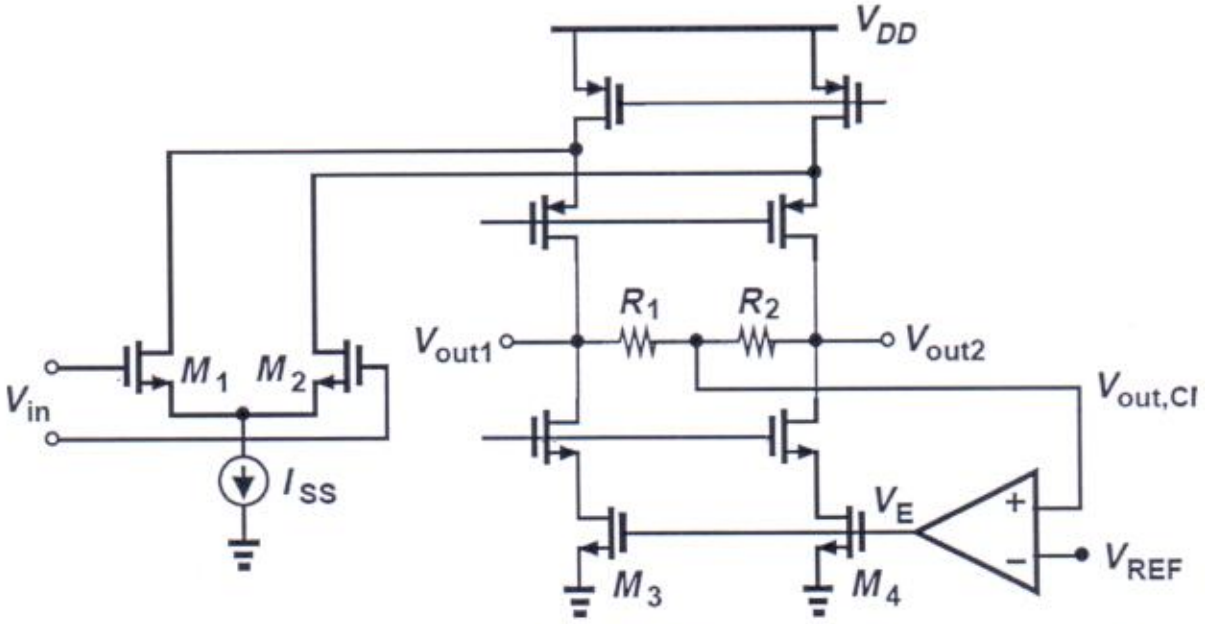
Triode region Resistance

$$R_{in} = \frac{1}{\mu_n C_{ox} \frac{W}{L}(V_{O+} - V_{TH})} \parallel \frac{1}{\mu_n C_{ox}\left(\frac{W}{L}\right)(V_{O-} - V_{TH})}$$

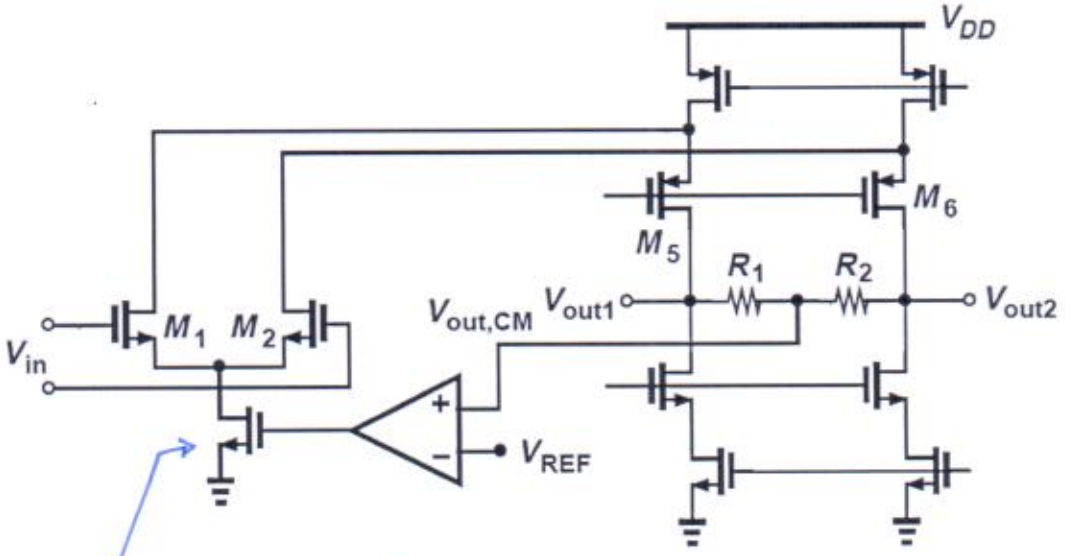
$$= \frac{1}{\mu_n C_{ox} \frac{W}{L}(V_{O+} + V_{O-} - 2V_{TH})}$$

$V_{O+} + V_{O-} \propto \frac{1}{V_{CM}}$ ← Independent of $(V_{O+} - V_{O-})$ (diff o/p voltage)

CMFB implementations (Folded-Cascode opamps)



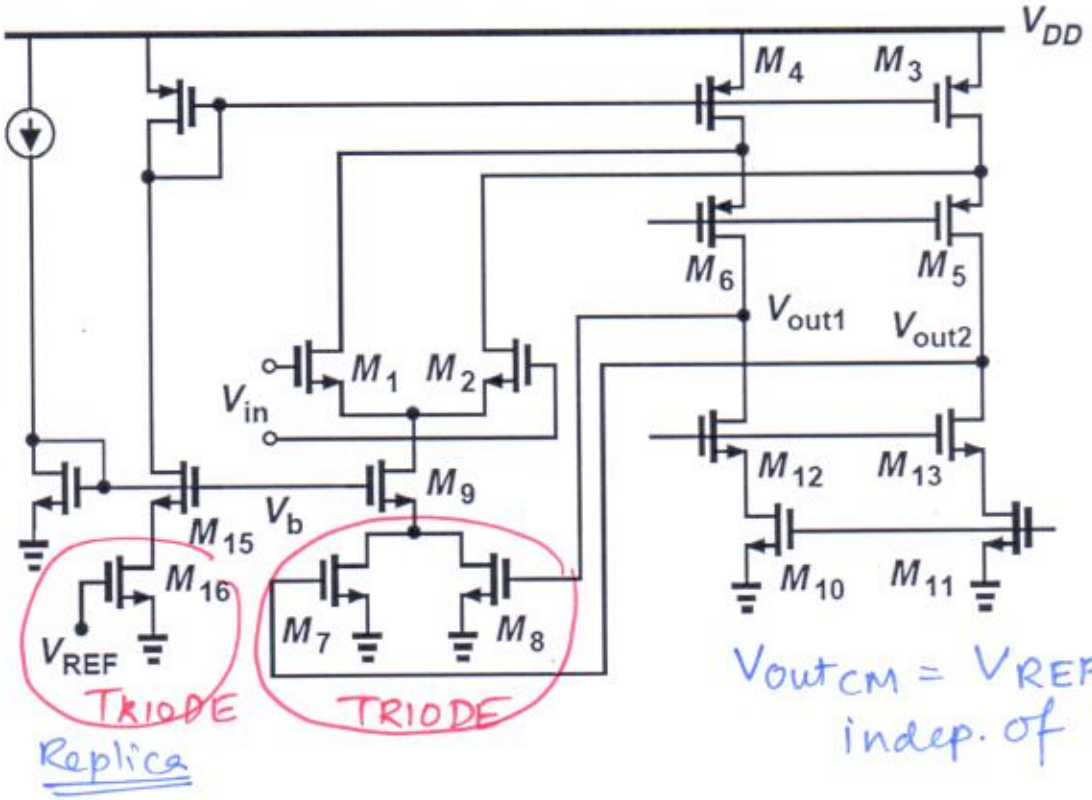
o/p current source control.



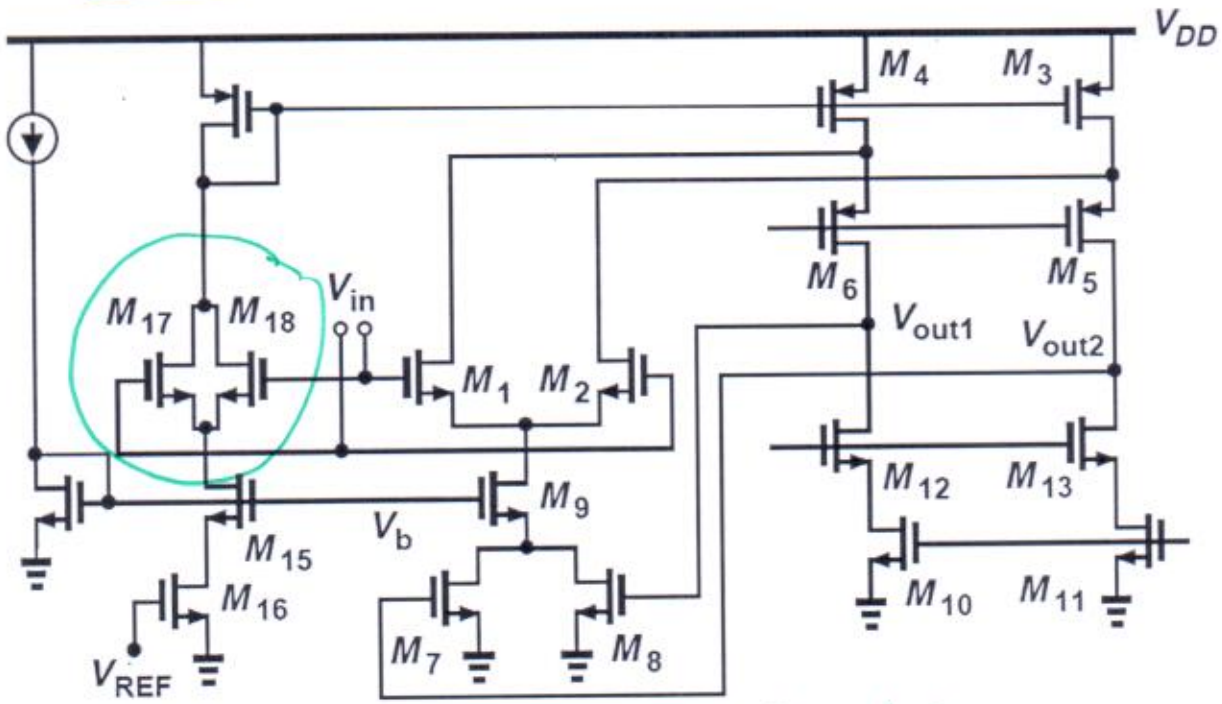
Diff pair tail current source control

Illustrations from Razavi Textbook

CMFB using triode region transistors



$V_{out_{CM}} = V_{REF}$ indep. of V_b.



M_{17} & M_{18} – Replica of diff pair

→ Make sure $V_{DS_{15}} = V_{DS_9}$

Indep. of Ch. length Mod?