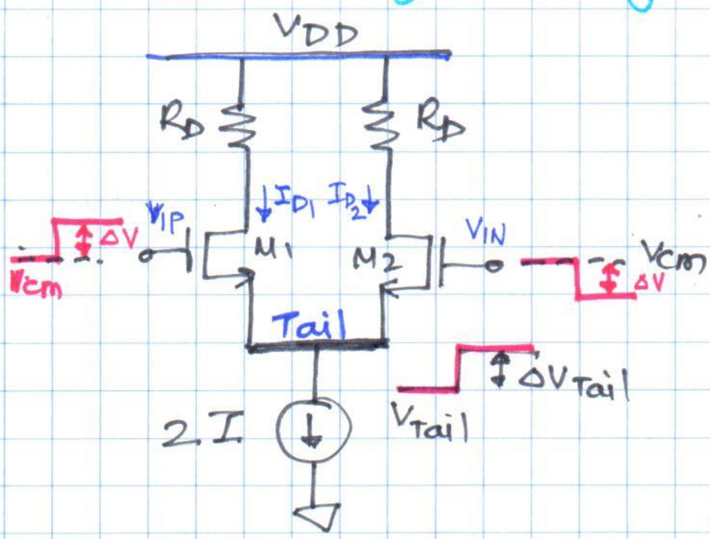
Concept of virtual ground @ tail.



Zoom in around $V_{IP}-V_{IN}=0$
Orig. $V_{IP}=V_{IN}=V_{cm}$.
Now apply $\Delta V \uparrow$ to V_P
$\Delta V \downarrow$ to V_N

assume V_{Tail} changes to $V_{Tail}+\Delta V_{Tail}$

since $I_{D1}+I_{D2}=2I$

$I_{D1}=I+\Delta I \qquad I_{D2}=I-\Delta I$

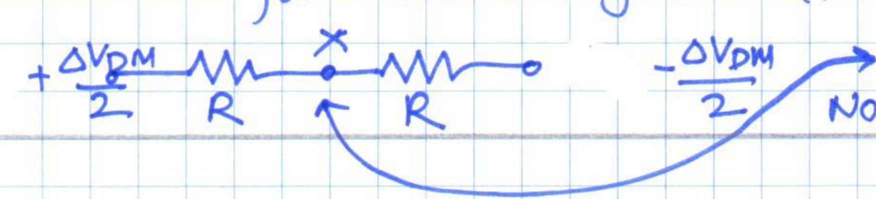
Transistors M1 & M2 behave like transconductors (ignoring r_o)

$$\Delta I_{D1}=\Delta I = g_{m1}(\Delta V_{IP}-\Delta V_{Tail})$$
$$= g_{m1}(\Delta V-\Delta V_{Tail})$$
$$\Delta I_{D2}=-\Delta I = g_{m2}(\Delta V_{IN}-\Delta V_{Tail})$$
$$= g_{m2}(-\Delta V-\Delta V_{Tail})$$

M1 & M2 identical $\quad g_{m1}=g_{m2}=g_m$

$$g_m(\Delta V-\Delta V_{Tail}) = -g_m(-\Delta V-\Delta V_{Tail})$$
$$\Rightarrow \Delta V_{Tail}=0$$

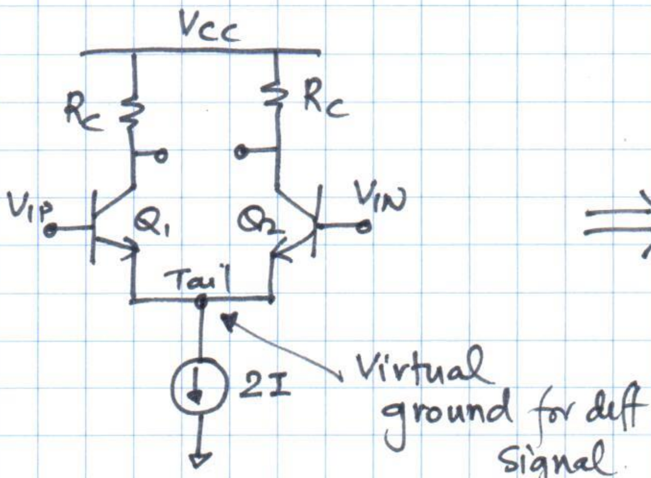
Hence "Tail" node acts like virtual ground "for small signal differential i/ps"



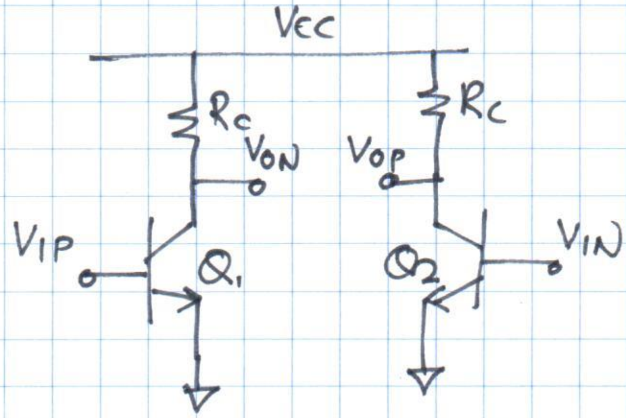
$\Delta V_X = 0$
Node X acts as Virtual ground

Same analysis is valid for BJT diff pair.

✲ Half circuit Concept



⟹



$$V_{ON} = -g_m R_C V_{IP} = -g_m R_C \frac{\Delta V_{DM}}{2}$$

$$V_{OP} = -g_m R_C V_{IN} = -g_m R_C \left(\frac{-\Delta V_{DM}}{2}\right)$$

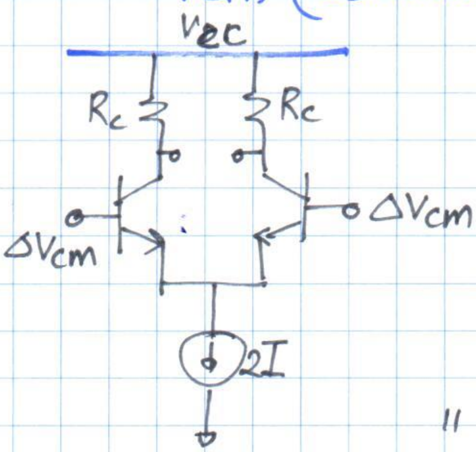
$$(V_{OP} - V_{ON}) = g_m R_C (V_{IP} - V_{IN})$$

Diff pair — diff voltage gain $= \dfrac{(V_{OP} - V_{ON})}{(V_{IP} - V_{IN})} = g_m R_C$

✲ g_m — Transconductance for each transistor.

$$g_m = \frac{I}{V_T}$$

✲ What happens when V_{cm} (common-mode) i/p voltage changes?



for ΔV_{cm} @ both V_{IP} & V_{IN}

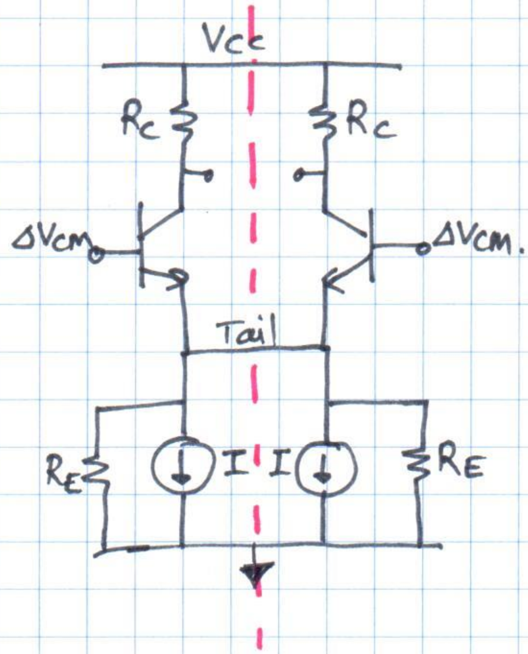
$$V_{OP} = V_{ON} = V_{CC} - I R_C$$

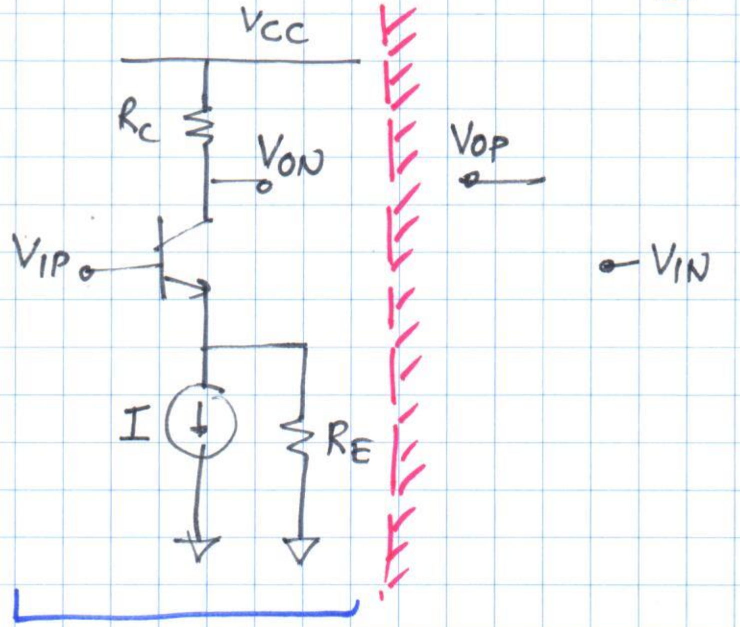
NO CHANGE

common-mode gain $= 0$

"ASSUMING CURRENT SOURCE IS IDEAL"

Consider current source (2I) with O/p resistance $\frac{R_E}{2}$





CE amplifier with Emitter Degen.
(L18 - page 1)

$$\frac{V_{OCM}}{V_{ICM}} = \text{Common-mode gain} = -\underbrace{\frac{g_m}{1+g_m R_E}}_{\text{Effective } g_m} \cdot R_C$$

Current source – large R_E → $g_m R_E \gg 1$

$$\frac{V_{OCM}}{V_{ICM}} \cong -\frac{g_m}{g_m R_E} \cdot R_C = -\frac{R_C}{R_E}$$

If Quality of current source is good "R_E very large"

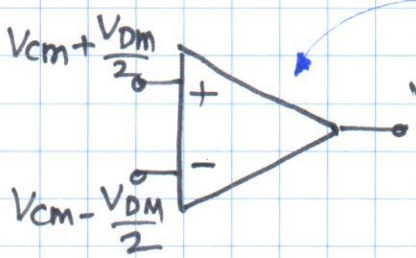
then $\left|\frac{V_{OCM}}{V_{ICM}}\right| \ll 1$

This is the reason we were trying to get current sources with high output R "cascoded mirrors"

★ Identical analysis is applicable to MOS Diff Pair Amplifier.

Concept: Common-mode Rejection Ratio (CMRR)

(Diff in Single Ended O/p)



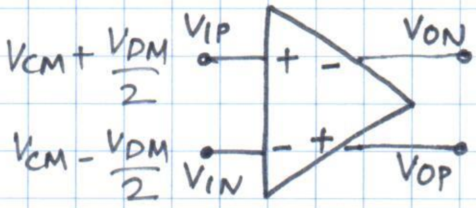
$$V_o = \underbrace{A_{cm} \cdot V_{cm}}_{\text{Undesired}} + \underbrace{A_{DM} \cdot V_{DM}}_{\text{Desired}}$$

$$CMRR = 20 \log \left| \frac{A_{DM}}{A_{CM}} \right|$$

"Ability to reject common-mode signals"

✱ Remember ECG example 50 Hz HUM.

For amplifier with "Differential Outputs" →



"DESIRED"

$$V_{ON} = A_{CM} \cdot V_{CM} + A_{DM}\left(-\frac{V_{DM}}{2}\right) + A_{CM\text{-}DM}(-V_{CM})$$

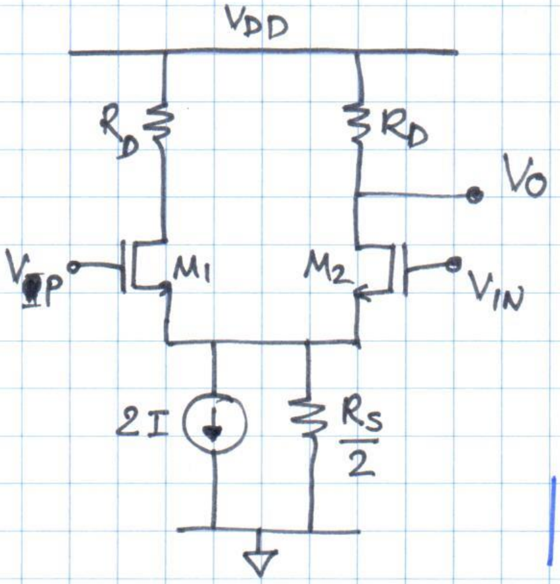
$$V_{OP} = A_{CM} \cdot V_{CM} + A_{DM}\left(+\frac{V_{DM}}{2}\right) + A_{CM\text{-}DM}(\cdot V_{CM})$$

$A_{CM} \cdot V_{CM}$:
- Rejected by next diff amp.
- Changes bias point — may impact small sig. gain
- Can limit O/p voltage swing

$A_{CM\text{-}DM}$ – Common-Mode to Diff-Mode Conversion
- Corrupts desired differential signal
- Can't be removed by next diff. amplifiers
- Due to circuit asymmetry due to "MISMATCHES"

CMRR Examples

Single-Ended Output



Note: we are only looking @ one o/p.

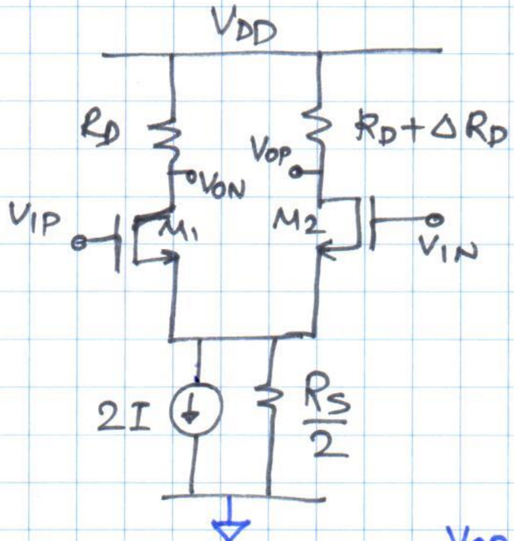
$$|A_{DM}| = \frac{g_m R_D}{2}$$ ← Since we are looking at one side only.

$$|A_{CM}| = \frac{R_D}{R_S}$$

$$CMRR = 20\log\left|\frac{A_D}{A_{CM}}\right| = 20\log\left(\frac{g_m R_D}{2} \cdot \frac{R_S}{R_D}\right)$$

$$CMRR = 20\log\left(\frac{g_m \cdot R_S}{2}\right)$$

Differential output



Consider only mismatch due to o/p resistor. (all other identical)

For common-mode i/p V_{CM} to both sides

$$\frac{V_{ON}}{V_{IP_{CM}}} = \frac{V_{ON}}{V_{CM}} = -\frac{R_D}{R_S}$$

$$\frac{V_{OP}}{V_{IN_{CM}}} = \frac{V_{OP}}{V_{CM}} = -\frac{R_D+\Delta R_D}{R_S}$$

$$\frac{V_{OP}-V_{ON}}{V_{CM}} = -\frac{\Delta R_D}{R_S} = A_{CM\text{-}DM}$$

common-mode to differential mode.

$$CMRR = 20\log\left|\frac{A_{DM}}{A_{CM-DM}}\right|$$

$$= 20\log\left|\frac{g_m R_D}{\Delta R_D / R_S}\right|$$

$$= 20\log\left|\frac{g_m R_S}{\Delta R_D / R_D}\right|$$

CMRR very high for Fully Differential circuits

$\frac{\Delta R_D}{R_D}$ → degree of Matching

→ < 1% easily achievable.

☆ You need to take into account mismatches due to other components as well (transistors)