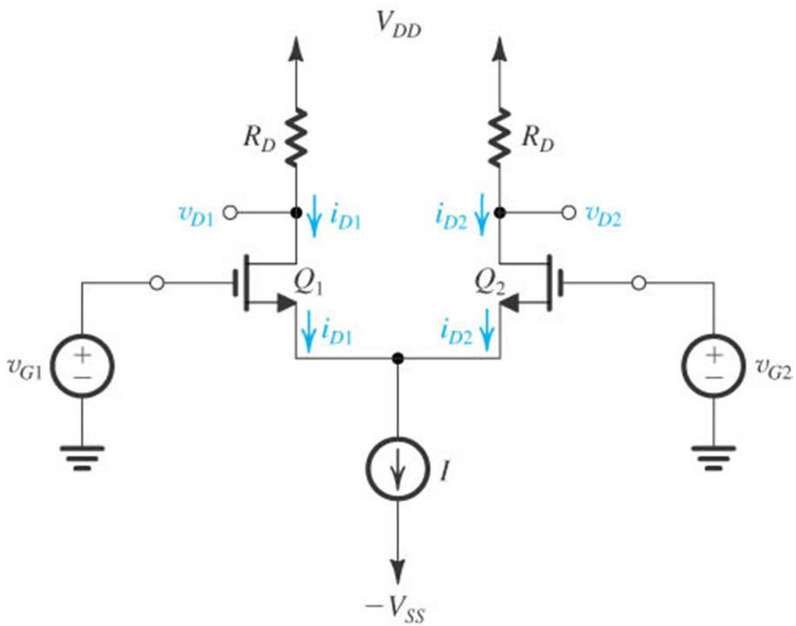
Lect. 9: Differential Amplifiers

Differential Amplifier



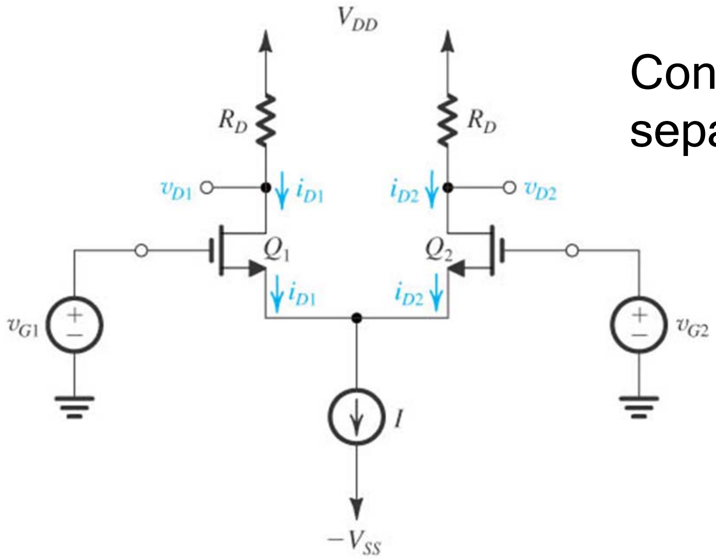
If $v_{G1} = v_{G2}$, $v_o = v_{D1} - v_{D2} = 0$

If $v_{G1} > v_{G2}$, $v_o < 0$

If $v_{G1} < v_{G2}$, $v_o > 0$

Non-zero output only for input difference
➔ Differential amplifier

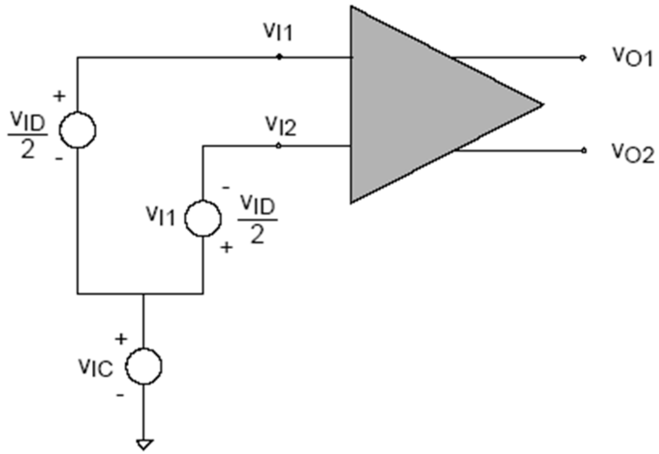
Lect. 9: Differential Amplifiers



Consider Common-Mode and Differential-Mode separately.

$$v_{G1} = V_{CM} + \frac{v_{id}}{2},\ v_{G1} = V_{CM} - \frac{v_{id}}{2}$$

$$V_{CM} = \frac{v_{G1} + v_{G2}}{2},\ v_{id} = v_{G1} - v_{G2}$$



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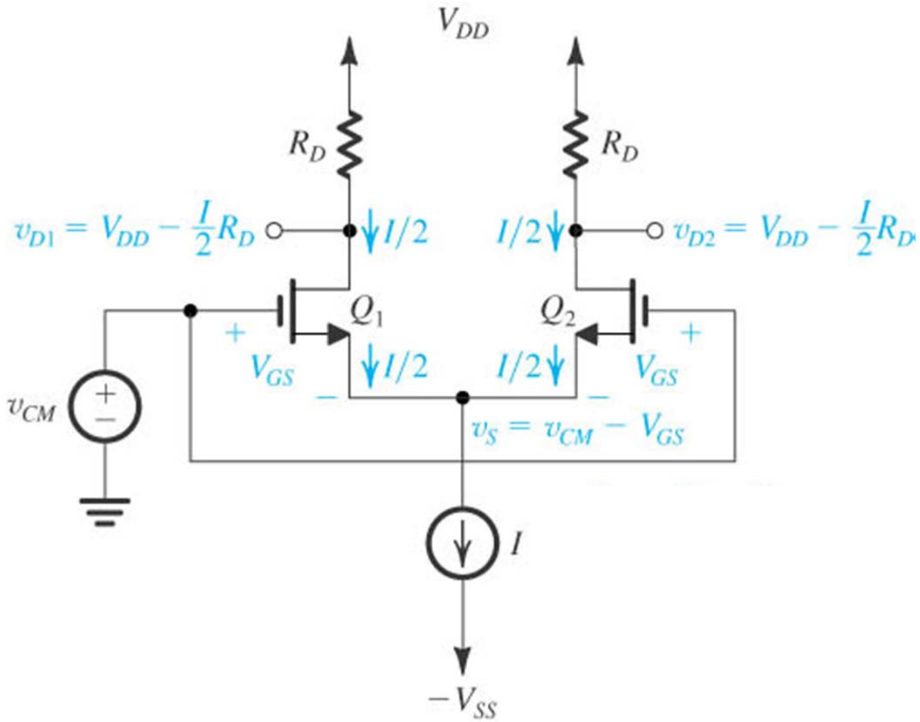
Common-Mode: $v_{G1} = v_{G2} = v_{CM}$



$$\upsilon_{D1} - \upsilon_{D2} = 0 \text{ (No CM output)}$$

$v_{CM,\ max}$?

$$v_{DS} \geq v_{GS} - V_{TH}$$

$$(V_{DD} - \frac{I}{2}R_D) - (v_{CM} - v_{GS}) \geq v_{GS} - V_{TH}$$

$$V_{DD} - \frac{I}{2}R_D + V_{TH} \geq v_{CM}$$

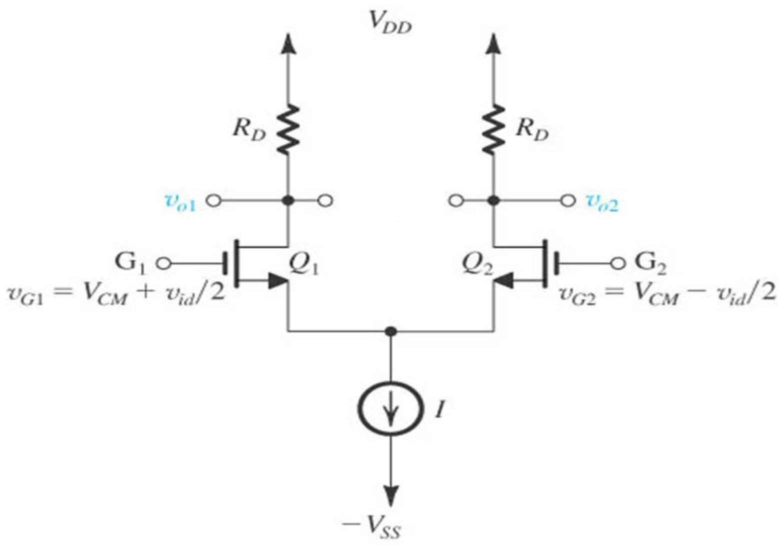
$$\therefore \upsilon_{CM,\max} = V_{TH} + V_{DD} - \frac{I}{2}R_D$$

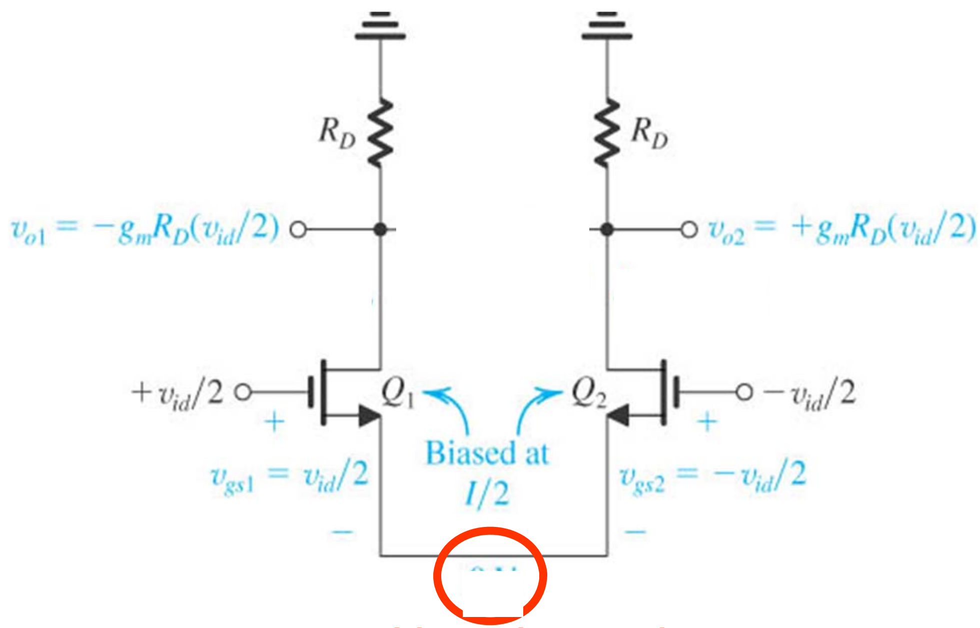
$v_{CM,\ min}$?

➔ Input common-mode range

Lect. 9: Differential Amplifiers

Differential-mode small-signal analysis





No voltage change since left and right are anti-symmetric

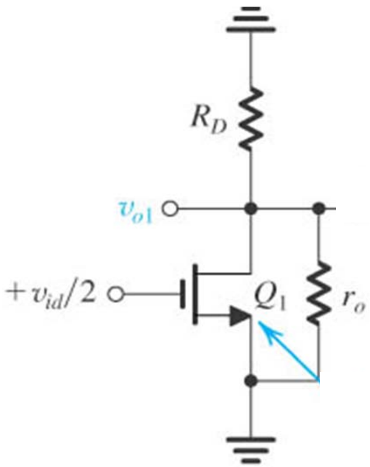
$$v_{od} = v_{o1} - v_{o2} = -g_m R_D \frac{v_{id}}{2} - g_m R_D \frac{v_{id}}{2} = -g_m R_D v_{id}$$

$$A_d = \frac{v_{od}}{v_{id}} = -g_m R_D$$

With r_o, $A_d = -g_m (R_D \parallel r_o)$

Lect. 9: Differential Amplifiers

Differential-mode small-signal half-circuit ➔ Consider only half circuit



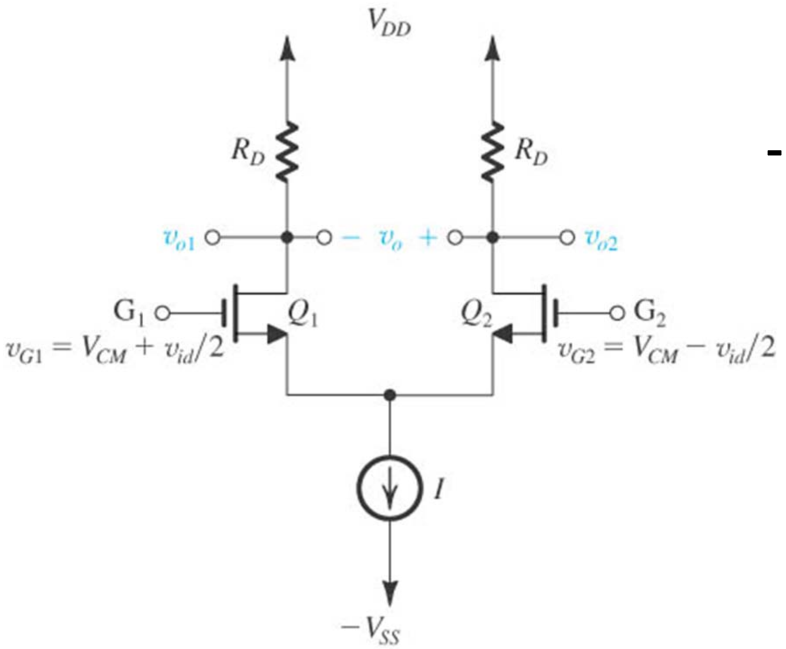
$$\frac{v_{o1}}{v_{id}/2} = -g_m(R_D \| r_o)$$

$$v_{o1} = \frac{v_{od}}{2}$$

$$\therefore \frac{v_{od}}{v_{id}} = -g_m(R_D \| r_o)$$

Differential pair acts as CS amplifier for input difference!

Lect. 9: Differential Amplifiers



Why a differential amplifier?

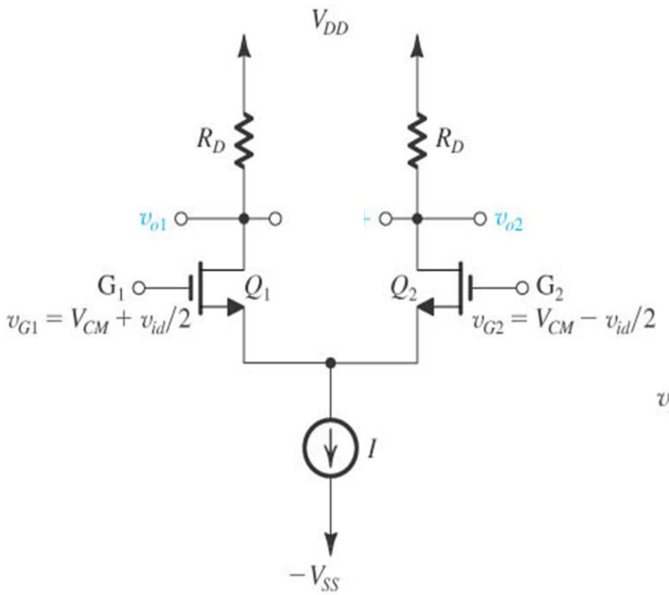
- Not sensitive to noises that are common to both input signals.

Common-Mode Rejection Ratio

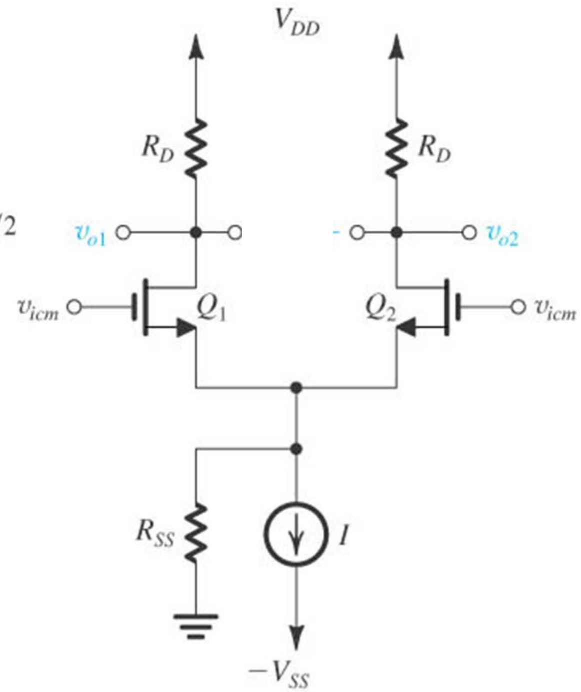
$CMRR = |A_d/A_{cm}|$

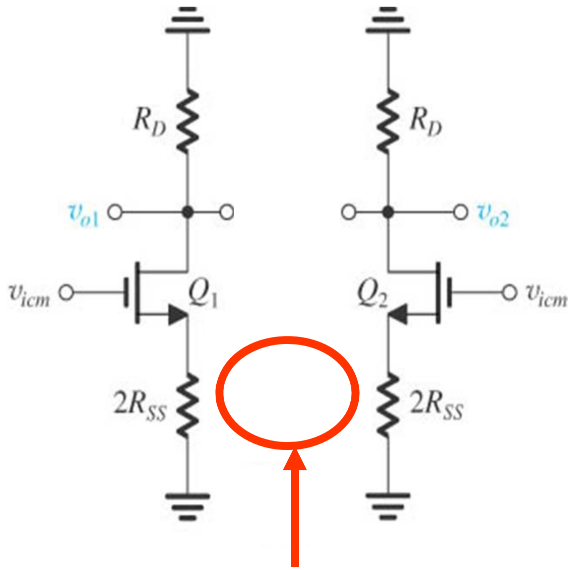
Ideally, infinite

What if the current source is NOT ideal?



Common-mode

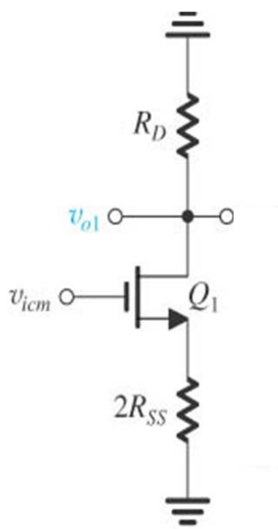




open circuit
(Left and Right are symmetric)

Common-Source with source resistance

Common-mode half circuit



$$\frac{v_{o1}}{v_{icm}} = ? \qquad v_{o1} = -g_m v_{gs} R_D$$

$$v_{gs} = v_{icm} - g_m v_{gs}(2R_{SS})$$

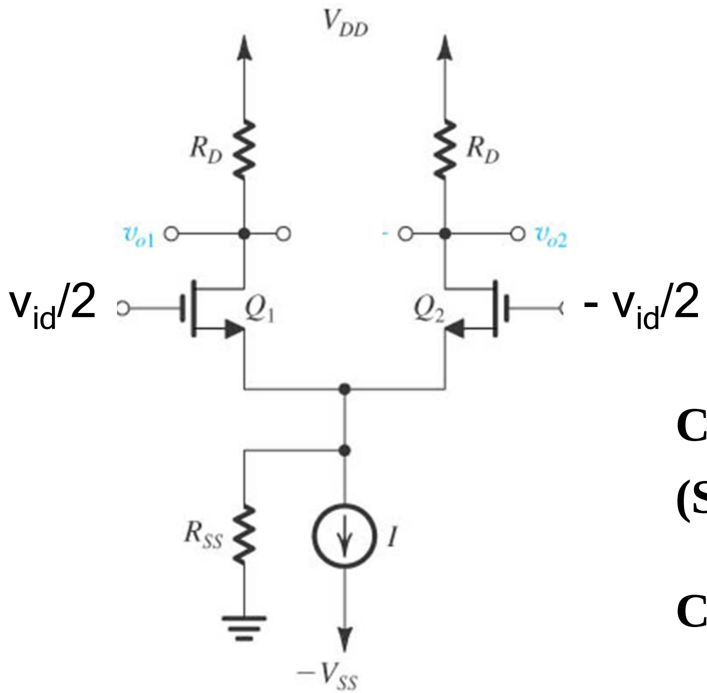
$$v_{gs} = \frac{v_{icm}}{1+2g_m R_{SS}}$$

$$\frac{v_{o1}}{v_{icm}} = -\frac{g_m R_D}{1+2g_m R_{SS}} \sim -\frac{R_D}{2R_{SS}}$$

➔ common-mode gain due to R_{ss} for single-ended output

Differential output ($v_o = v_{o1} - v_{o2}$), $v_o = 0$

What if the current source is NOT ideal? Differential-Mode



With anti-symmetric input,
the mid-point is still small-signal ground!

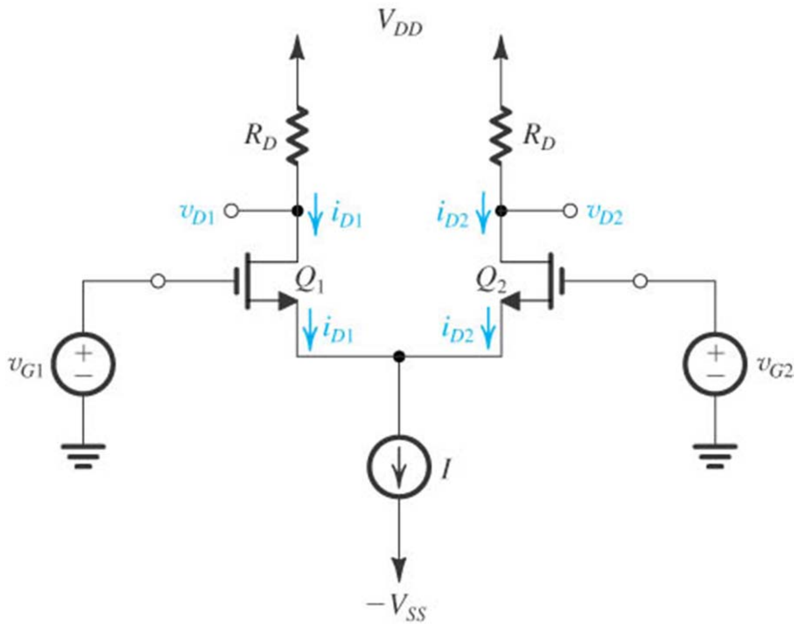
$$A_d = -g_m(R_D \| r_o)$$

CMRR: Common-Mode Rejection Ratio

(Single-ended output)

$$\text{CMRR}=\left|\frac{A_d}{A_{cm}}\right| \sim \frac{g_m(R_D \| r_o)}{\frac{R_D}{2R_{ss}}}$$

Lect. 9: Differential Amplifiers



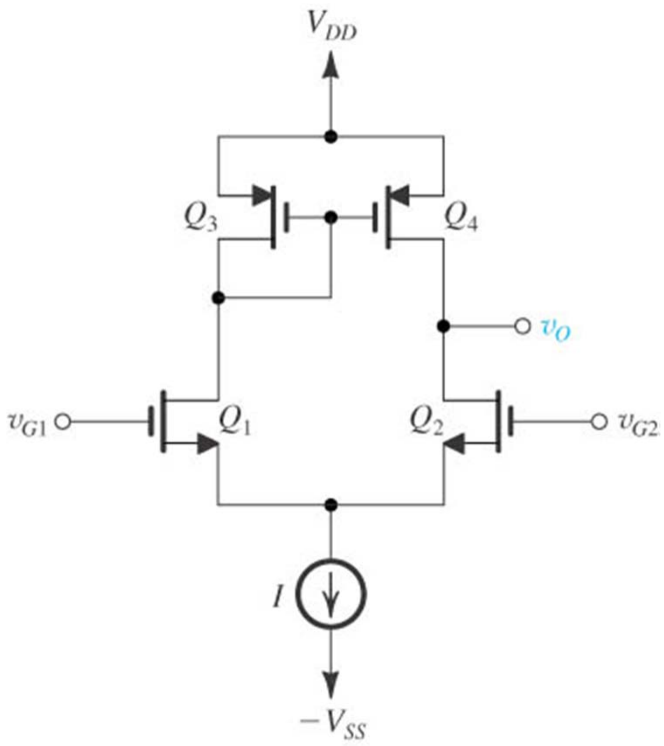
MOS differential pair is based on the symmetry

Anything that breaks the symmetry affects the circuit performance (CMRR, input offset)

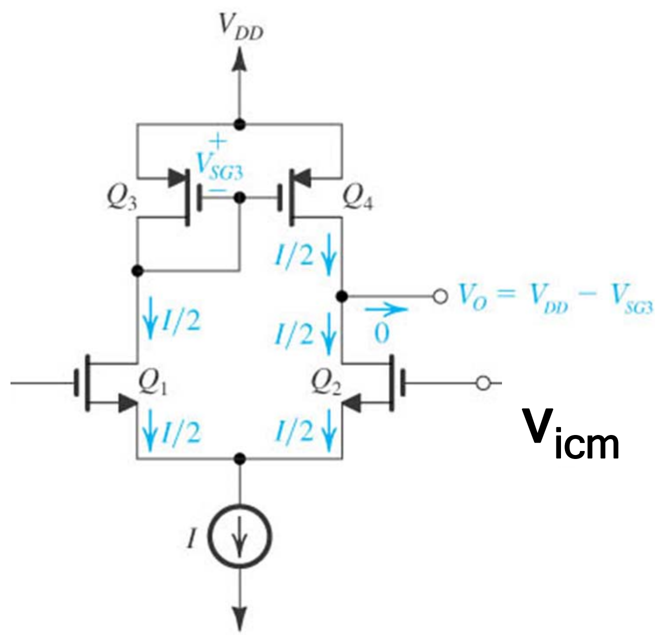
Device mismatches cause non-ideal performance ➔Eliminate R_D

Lect. 9: Differential Amplifiers

Active-loaded MOS differential pair
for single-ended output



Common mode



V_{icm} V_{icm}

W.-Y. Choi

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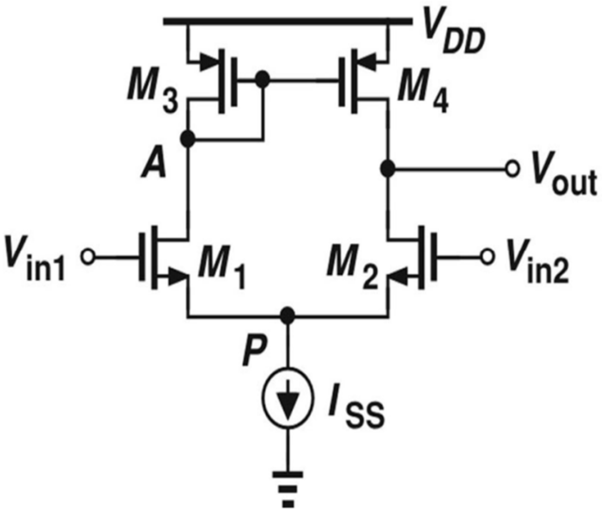
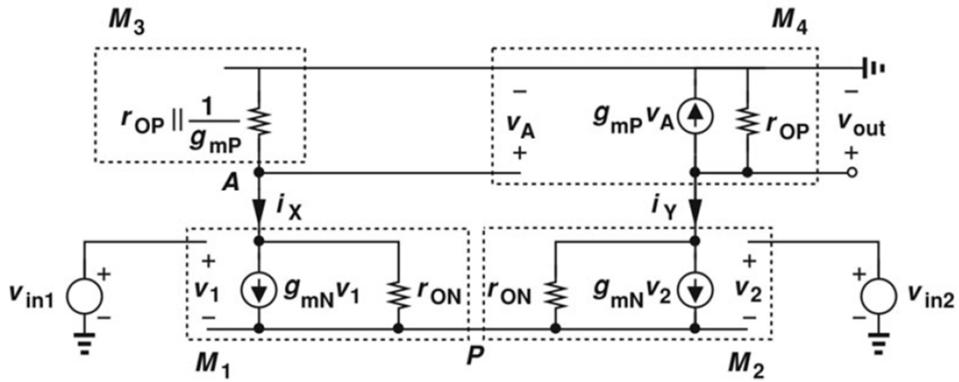
Differential mode small-signal analysis



Small-signal circuit



Applying half-circuit analysis,

$$\frac{v_{out}}{v_{in1}-v_{in2}}=\frac{g_{mN}(r_{ON}\,||\,r_{OP})}{2}$$

But the given circuit is asymmetric

➔ Half circuit analysis is not possible

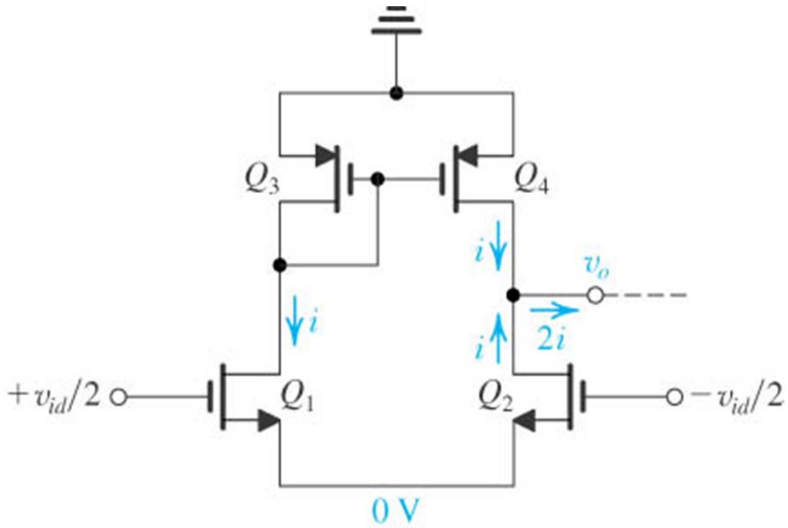
With complicated analysis (Razavi 10.6.2)

$$\frac{v_{out}}{v_{in1}-v_{in2}}=g_{mN}r_{ON}\frac{r_{OP}[1+g_{mP}(\frac{1}{g_{mP}}\,||\,r_{OP})]}{2r_{ON}+2r_{OP}}$$

$$\simeq g_{mN}(r_{ON}\,||\,r_{OP})$$

Factor of 2 difference!

Lect. 9: Differential Amplifiers



The current mirror action is not considered with half-circuit analysis

Current mirror doubles the transconductance

➔ Twice voltage gain!