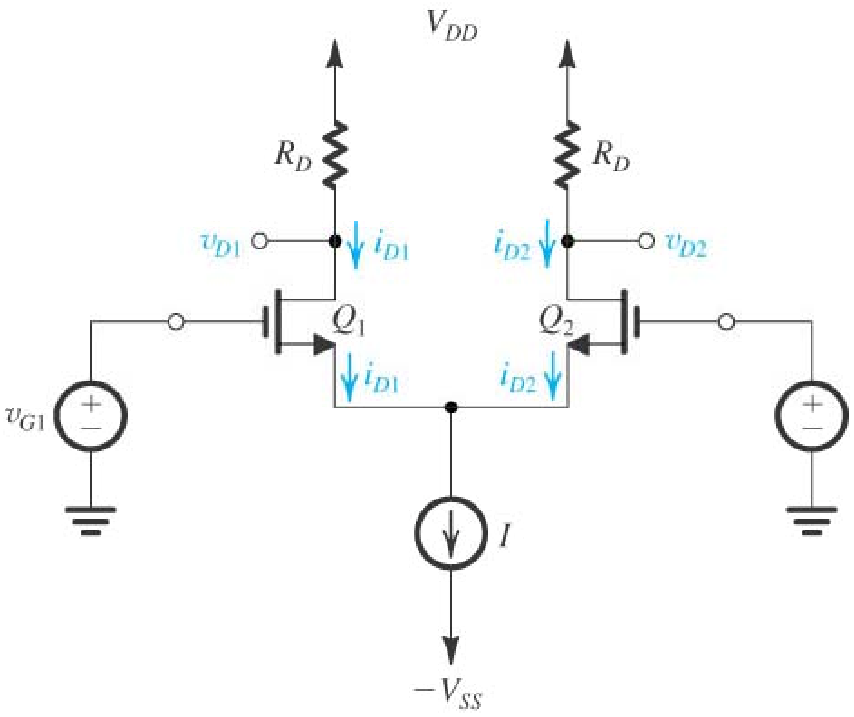
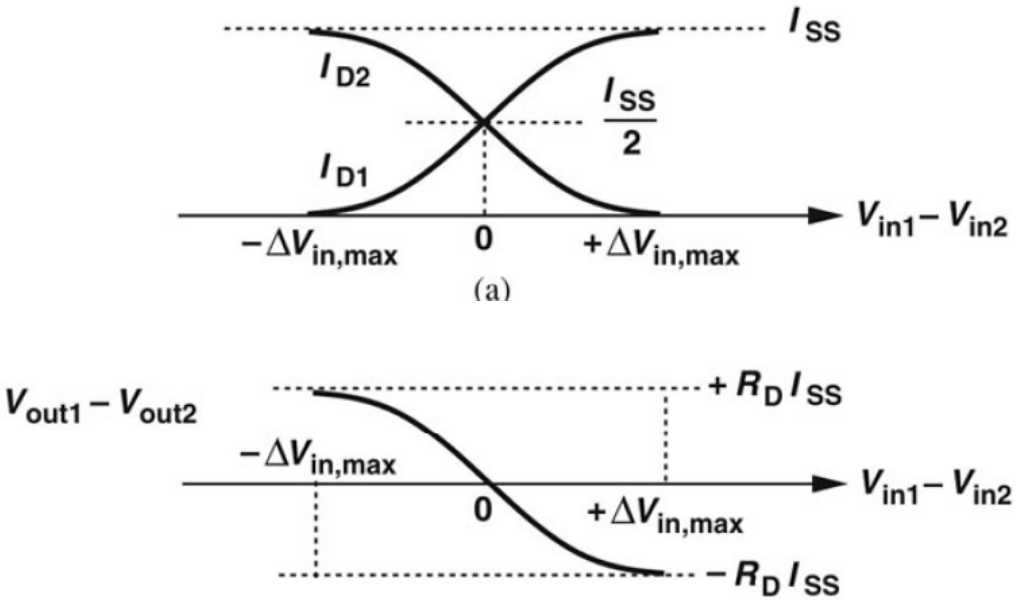
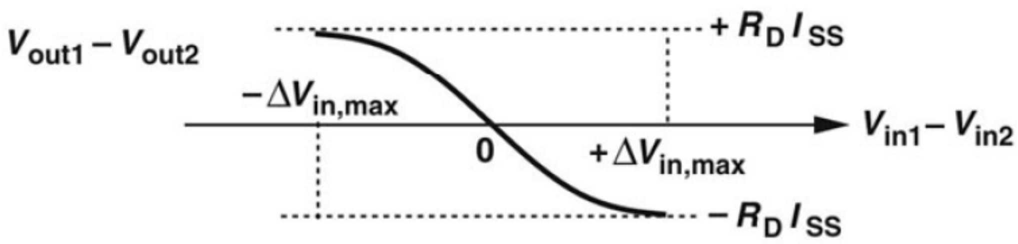
$(v_{out1}-v_{out2})$ vs. $(v_{in1}-v_{in2})$ ?

MOS Differential Pair

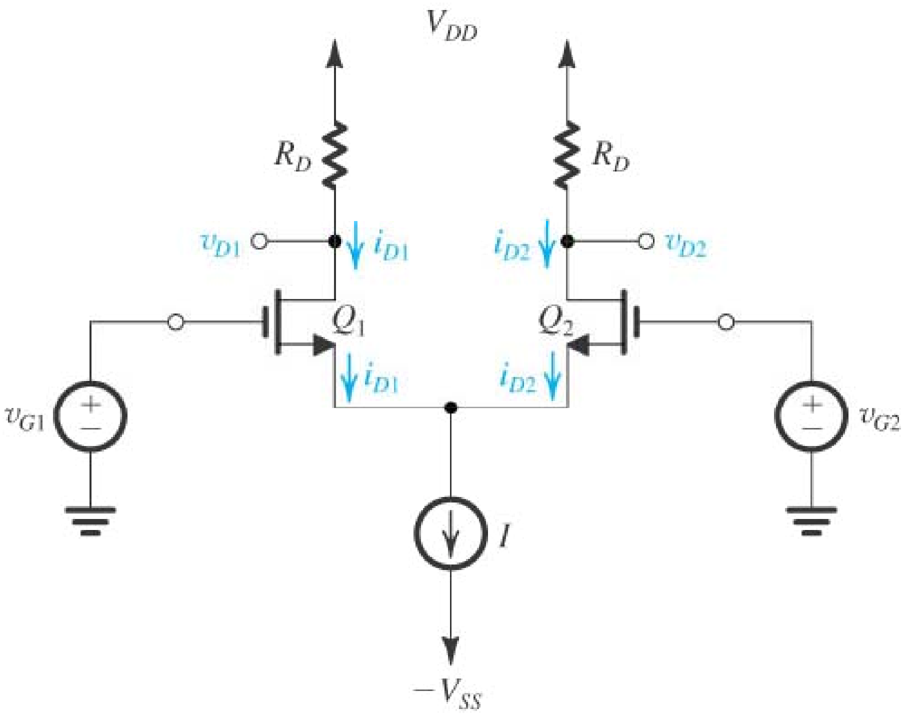


# Lect. 28: MOS Differential Amplifiers




MOS Differential Pair




What is $\Delta v_{in,max}$?

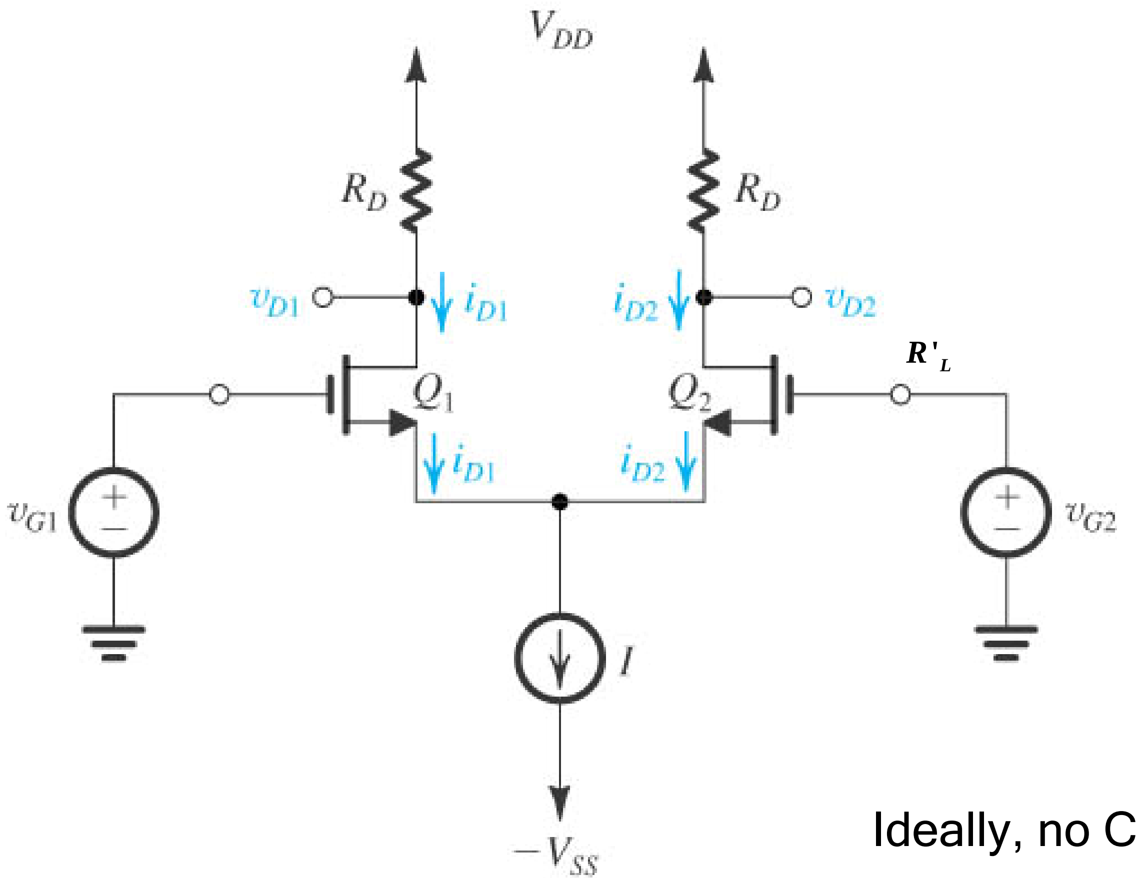
$$v_{G1} = v_t + \sqrt{\frac{2I_{SS}}{k\frac{W}{L}}}$$

$$v_{G2} = v_t$$

$$\Delta v_{in,max} = \sqrt{\frac{2I_{SS}}{k\frac{W}{L}}}$$

# Lect. 28: MOS Differential Amplifiers (Razavi 10.3)

MOS Differential Pair




$V_{CM}$: Common Mode

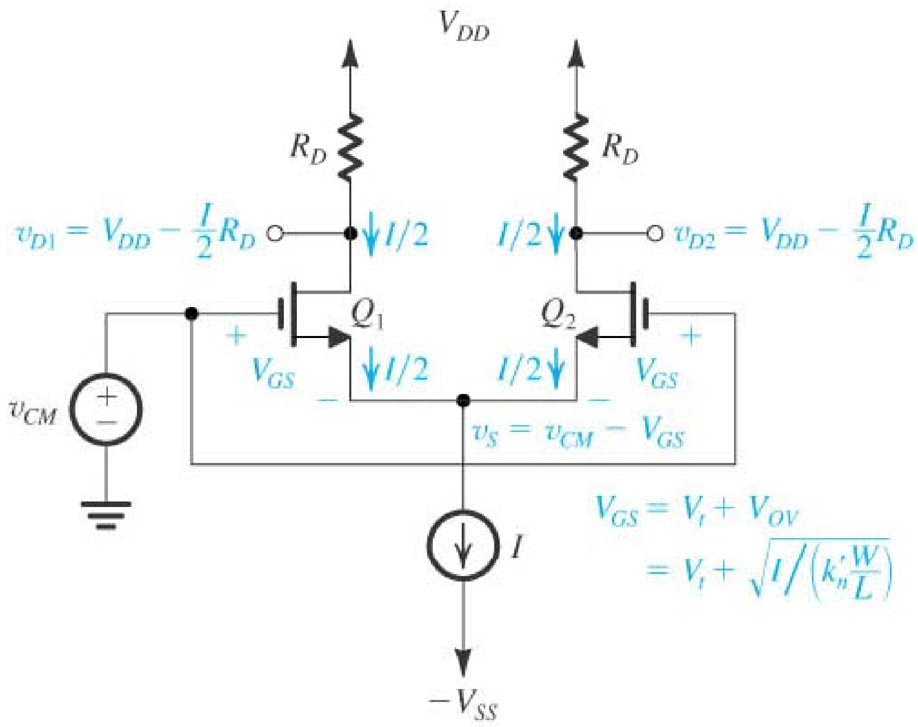
$v_{id}$: Differential Mode

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

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

Ideally, no CM response, large DM response

## Common-Mode




For identical $Q_1$ and $Q_2$

$$i_{D1} = i_{D2} = \frac{I}{2}$$

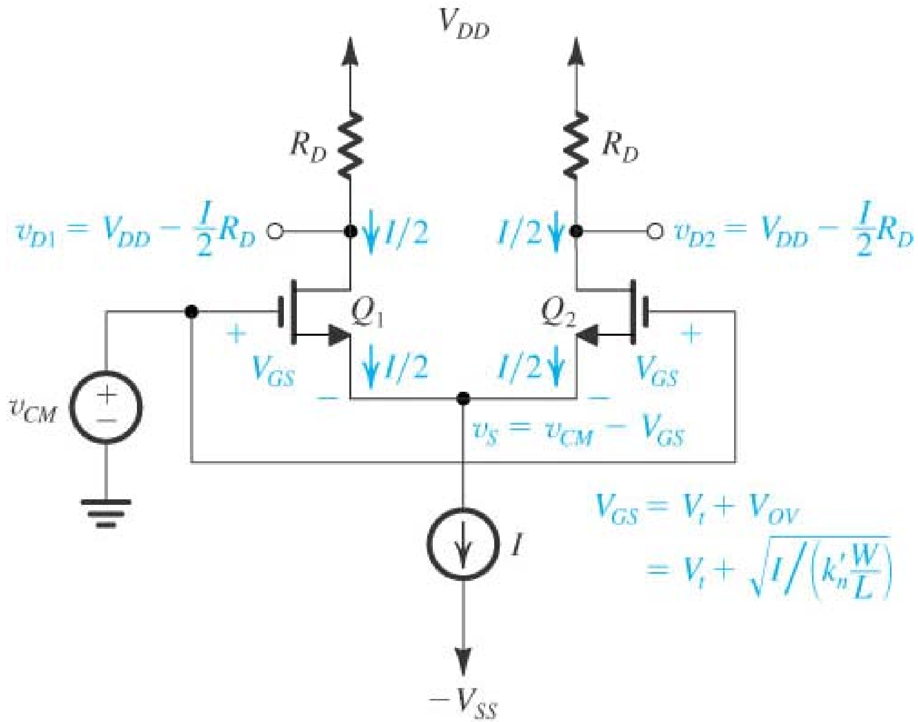
$$\upsilon_{D1} = \upsilon_{D2} = V_{DD} - \frac{I}{2}R_D$$

$$\therefore \upsilon_{D1} - \upsilon_{D2} = 0$$

==> **No CM output**

# Lect. 28: MOS Differential Amplifiers

Common-Mode




$V_{CM,\,max}$?

$$v_{DS} \geq v_{GS} - V_t$$

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

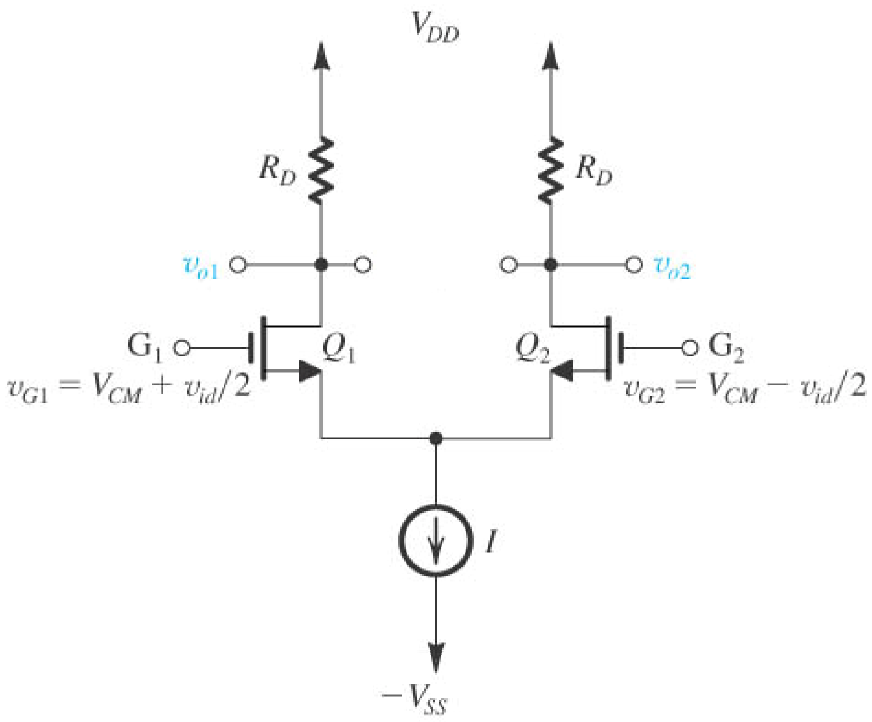
$$\therefore V_{DD} - \frac{I}{2}R_D + V_t \geq V_{CM}$$

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

$V_{CM,\,min}$?

# Lect. 28: MOS Differential Amplifiers

## Differential-Mode




If $v_{id} << V_{CM}$

Small-signal analysis can be used for differential-mode!

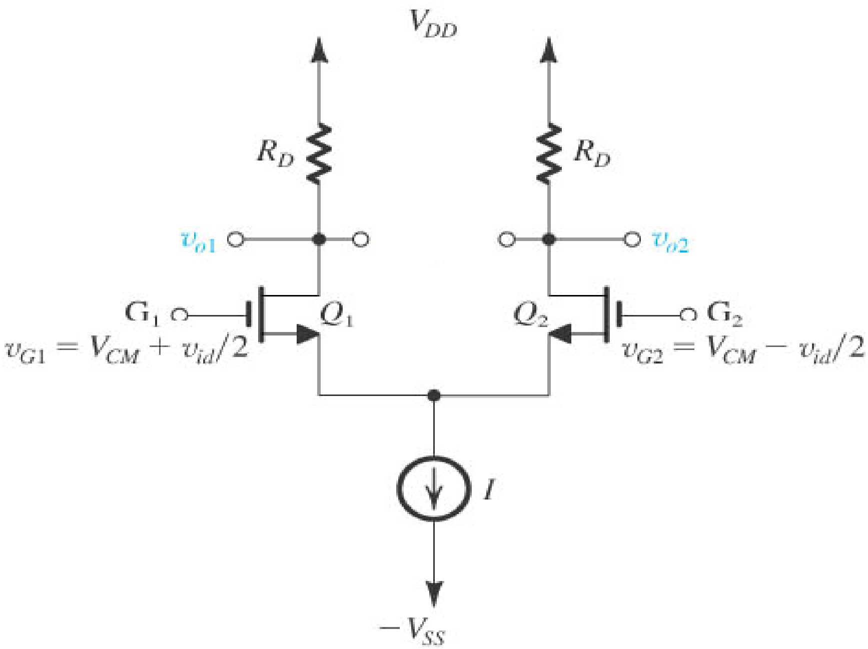
$V_{CM}$: Bias

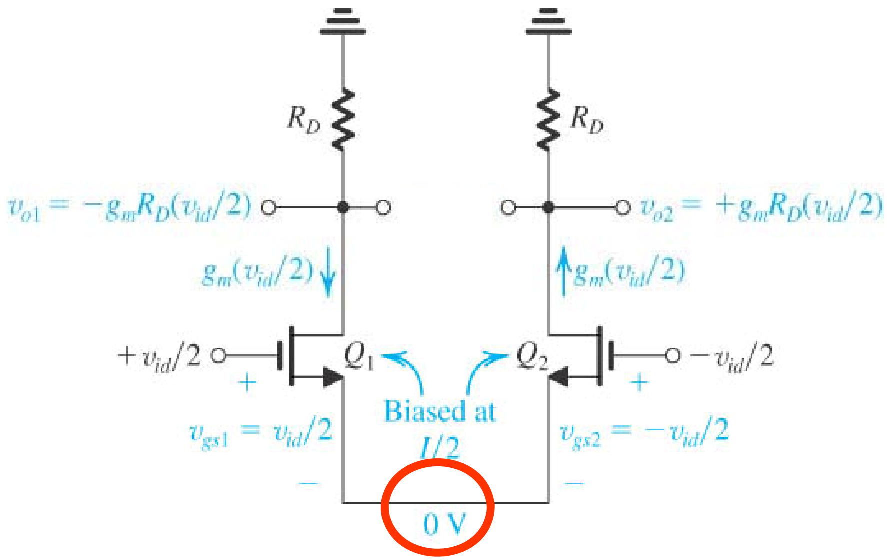
$v_{id}$: Small-signal input

➔ $v_{od}$: Small-signal output

# Lect. 28: MOS Differential Amplifiers

Differential-mode small-signal analysis

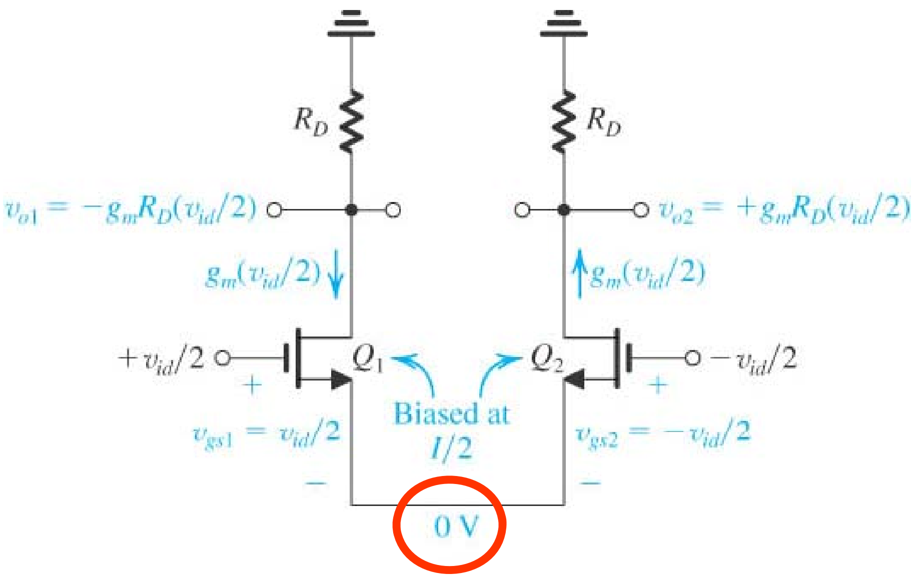


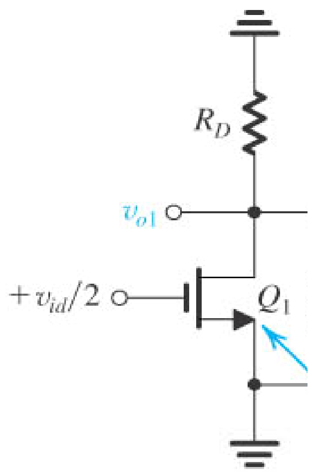




No voltage change
since Left and Right are
anti-symmetric (odd)

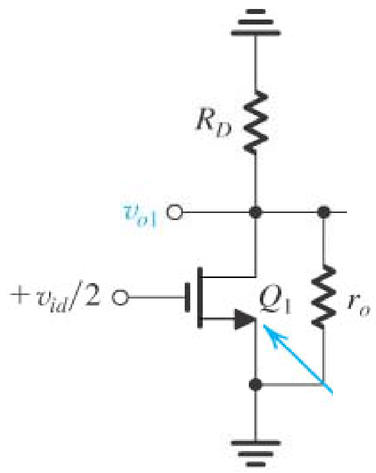
# Lect. 28: MOS Differential Amplifiers

Differential-mode small-signal half-circuit



Differential-mode small-signal half-circuit




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

For the total circuit

$$v_{od} = v_{o1} - v_{o2}$$

$$\text{But } v_{o2} = -v_{o1}$$

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

CS amplifier for input difference!

$$A_d = \frac{v_{od}}{v_{id}} = \frac{2v_{o1}}{v_{id}} = -g_m(R_D \parallel r_o)$$