EEE 51: Second Semester 2017 - 2018

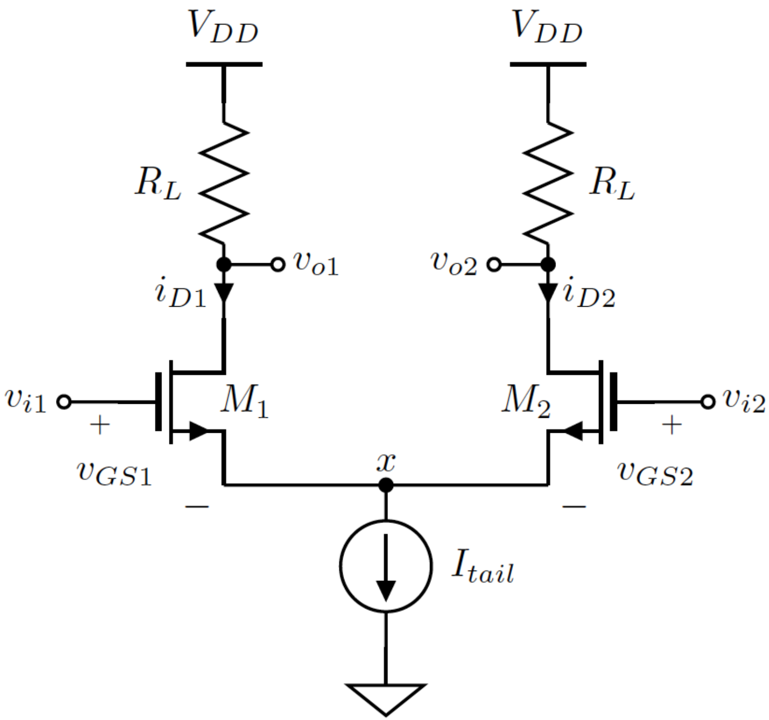
Lecture 10

Differential Circuits

Today

- MOSFET Differential Circuits

- Source-coupled pair: DC Analysis



KVL at the input loop: $V_{i1} - V_{GS1} + V_{GS2} - V_{i2} = 0$

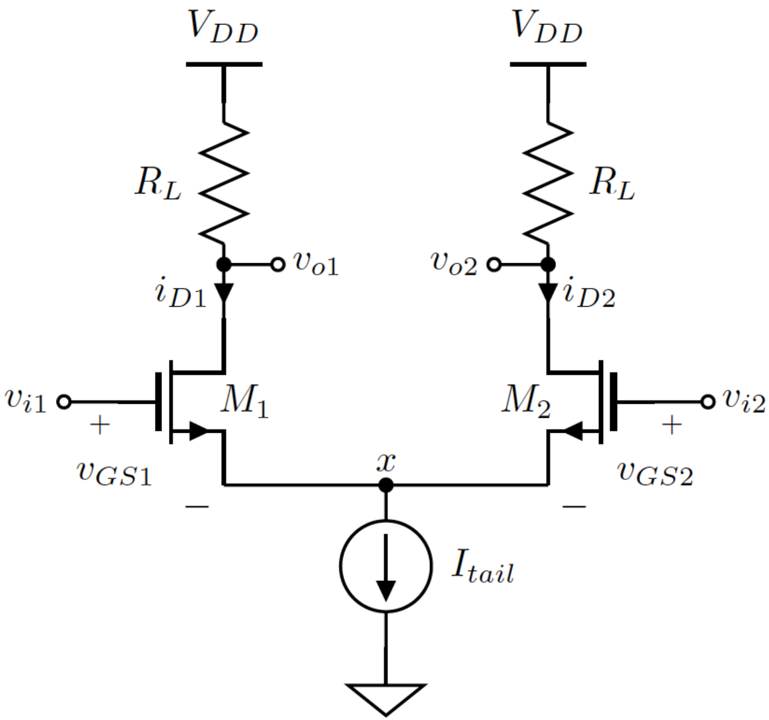
$$V_{i1} - V_{i2} = V_{GS1} - V_{GS2}$$

$$V_{id} = \left(V_{TH} + \sqrt{\frac{I_{D1}}{k}}\right) - \left(V_{TH} + \sqrt{\frac{I_{D2}}{k}}\right)$$

$$\boxed{V_{id} = \sqrt{\frac{I_{D1}}{k}} - \sqrt{\frac{I_{D2}}{k}}}$$

The MOSFET Differential Amplifier (2)

- Drain currents



KCL at node x: $I_{tail} = I_{D1} + I_{D2}$

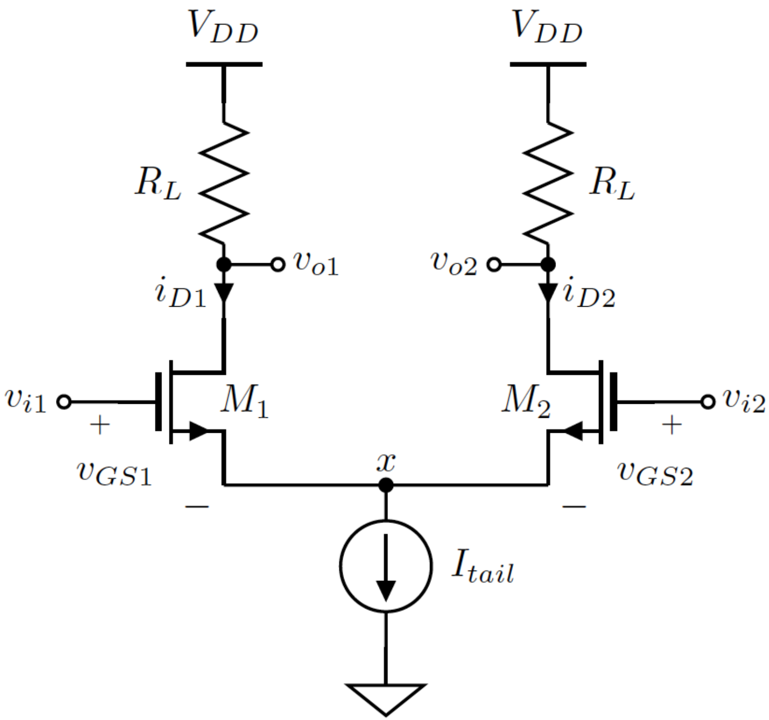
Recall: $\boxed{V_{id} = \sqrt{\frac{I_{D1}}{k}} - \sqrt{\frac{I_{D2}}{k}}}$

$$I_{D1} = \frac{I_{tail}}{2} + V_{id}\frac{k}{2}\sqrt{\frac{2 \cdot I_{tail}}{k} - V_{id}^2}$$

$$I_{D2} = \frac{I_{tail}}{2} - V_{id}\frac{k}{2}\sqrt{\frac{2 \cdot I_{tail}}{k} - V_{id}^2}$$

The MOSFET Differential Amplifier (3)

- Drain currents



$$I_{D1} = \frac{I_{tail}}{2} + V_{id}\frac{k}{2}\sqrt{\frac{2\cdot I_{tail}}{k} - V_{id}^2} = \frac{I_{tail}}{2} + \Delta I$$

$$I_{D2} = \frac{I_{tail}}{2} - V_{id}\frac{k}{2}\sqrt{\frac{2\cdot I_{tail}}{k} - V_{id}^2} = \frac{I_{tail}}{2} - \Delta I$$

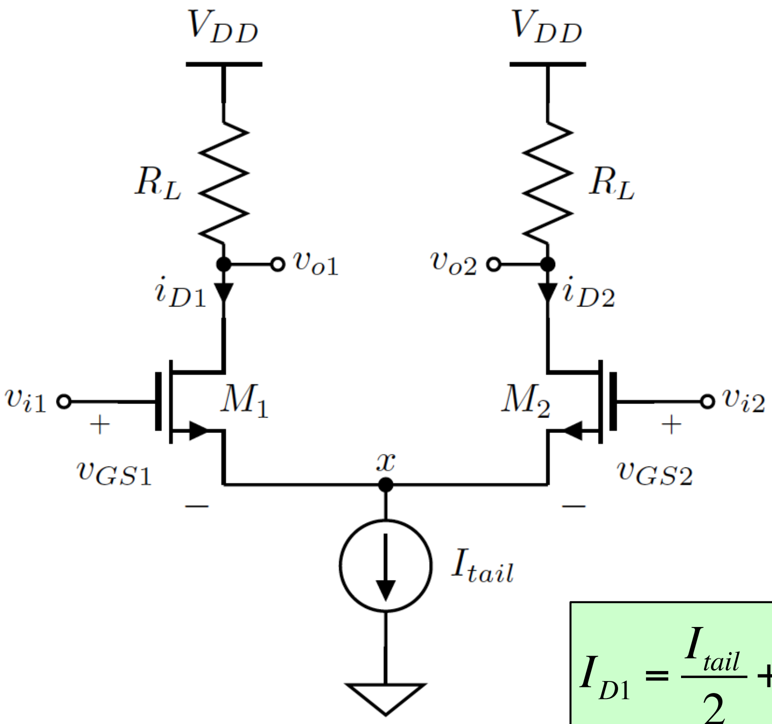
Note: $$\Delta I_{\max} = \frac{I_{tail}}{2}$$

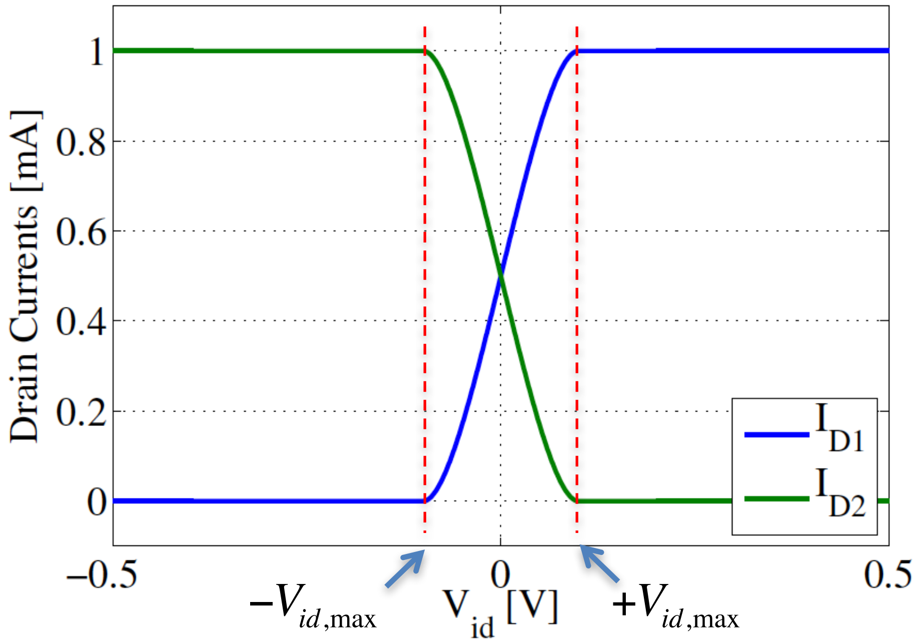
$$V_{id,\max} = \sqrt{\frac{I_{tail}}{k}}$$

Beyond this, all the tail current flows in one branch

The MOSFET Differential Amplifier (4)

- The source-couple pair



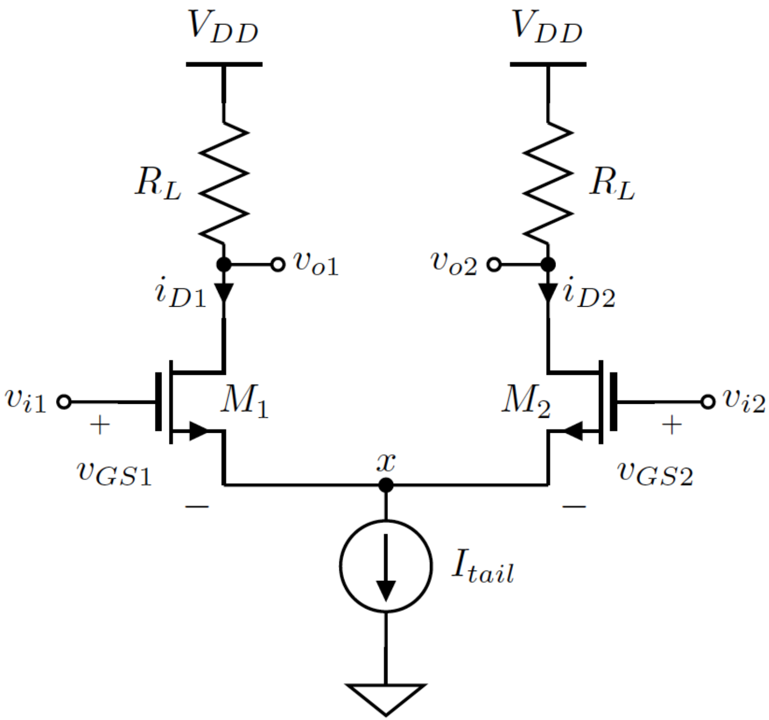


$$I_{D1} = \frac{I_{tail}}{2} + V_{id}\frac{k}{2}\sqrt{\frac{2 \cdot I_{tail}}{k} - V_{id}^2}$$

$$I_{D2} = \frac{I_{tail}}{2} - V_{id}\frac{k}{2}\sqrt{\frac{2 \cdot I_{tail}}{k} - V_{id}^2}$$

The MOSFET Differential Amplifier (5)

- Output voltage



KVL at the output loop: $V_{od} = V_{o1} - V_{o2} = R_L\left(I_{D2} - I_{D1}\right)$

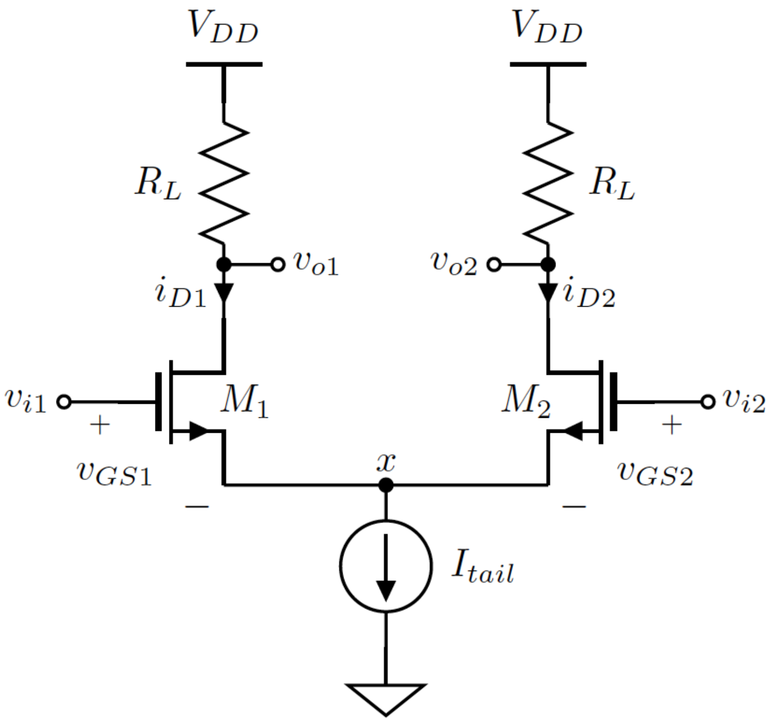
$$I_{D2} = \frac{I_{tail}}{2} - V_{id}\frac{k}{2}\sqrt{\frac{2 \cdot I_{tail}}{k} - V_{id}^2}$$

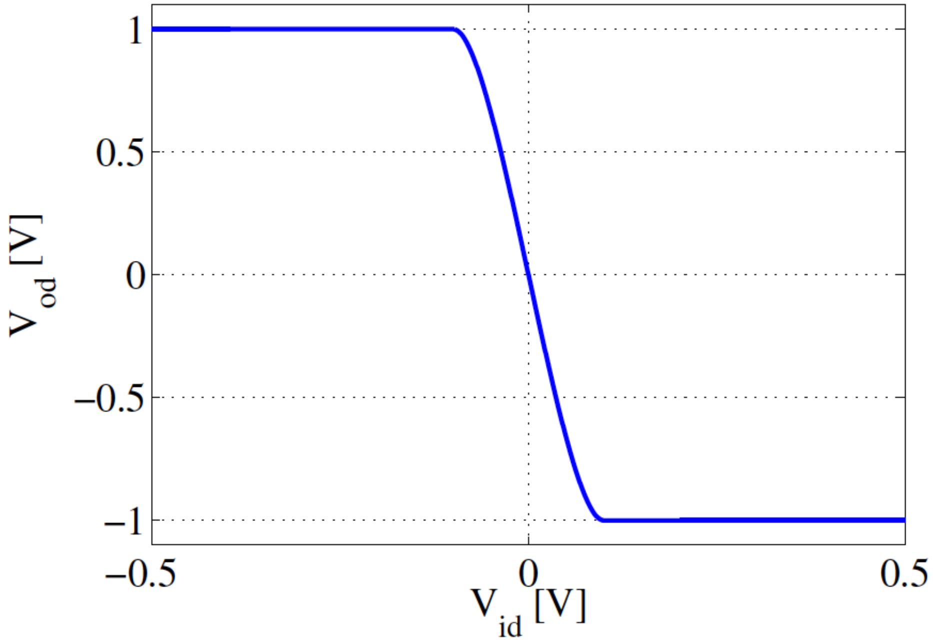
$$I_{D1} = \frac{I_{tail}}{2} + V_{id}\frac{k}{2}\sqrt{\frac{2 \cdot I_{tail}}{k} - V_{id}^2}$$

$$V_{od} = -R_L \cdot V_{id} \cdot k\sqrt{\frac{2 \cdot I_{tail}}{k} - V_{id}^2}$$

The MOSFET Differential Amplifier (6)

- Transfer characteristic

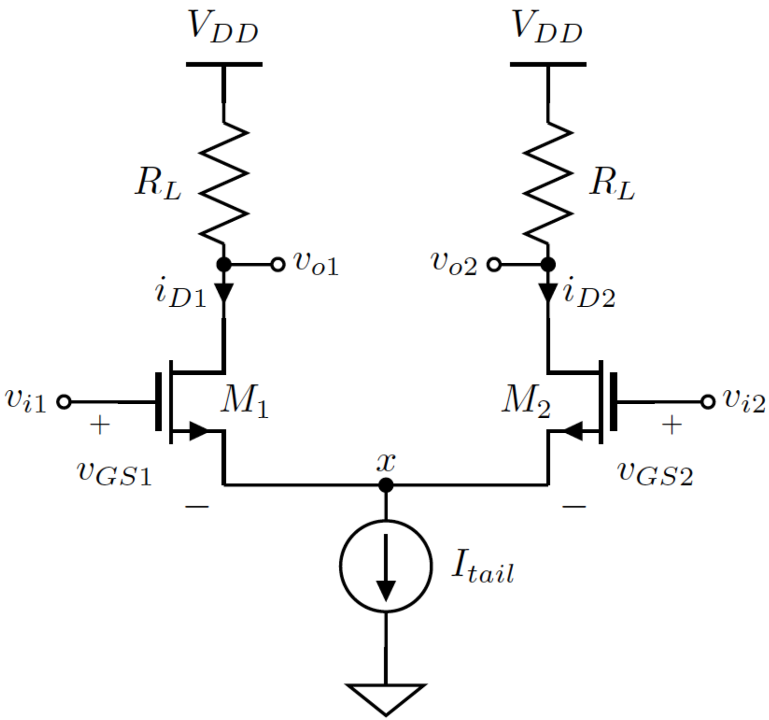




$$\boxed{V_{od} = -R_L \cdot V_{id} \cdot k\sqrt{\frac{2 \cdot I_{tail}}{k} - V_{id}^2}}$$

Common-Mode Input Range (1)

- MOSFET operating region?



Assume zero differential input

KVL: $V_{DS1} = V_{DD} - I_{D1}R_L - V_X > V_{GS1} - V_{TH}$

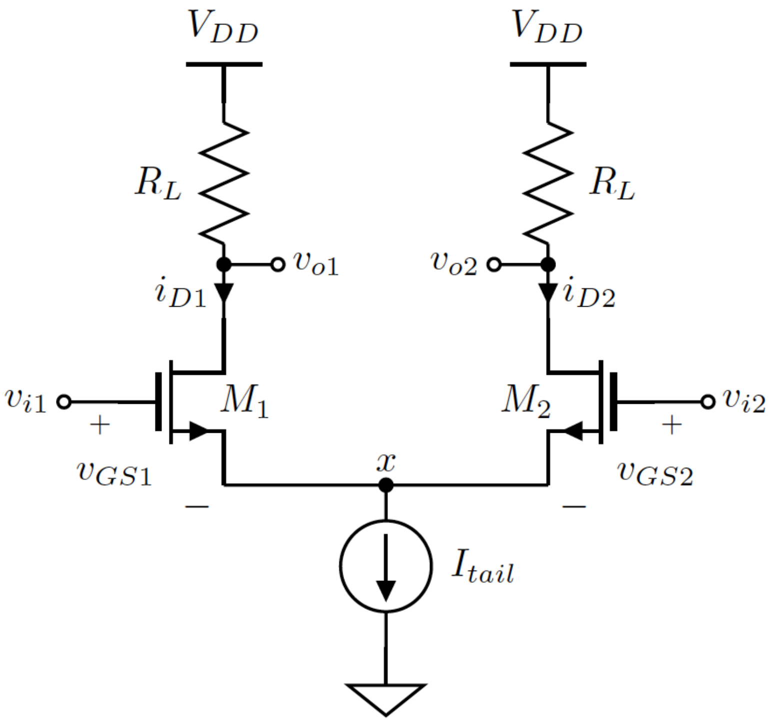
Note: $V_X = V_{I1} - V_{GS1}$

V_X is controlled by the input common-mode (DC input)!

$$\boxed{V_{DS1} = V_{DD} - I_{D1}R_L - V_{I1} + V_{GS1}}$$

Common-Mode Input Range (2)

- MOSFET operating region?



For zero differential input: $v_{ic} = V_{I1} = V_{I2} = V_{cm}$

$$I_{D1} = I_{D2} = \frac{I_{tail}}{2}$$

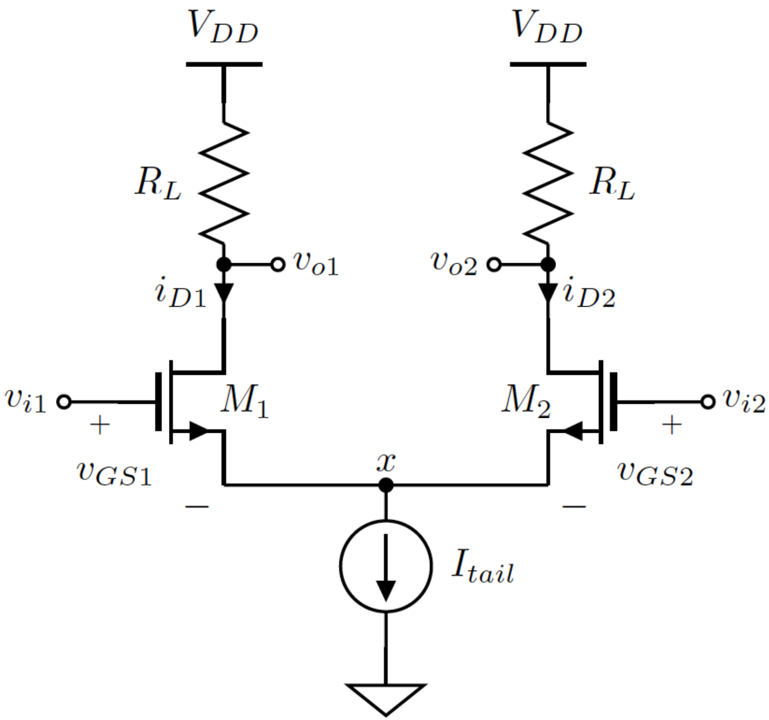
For a range of common-mode inputs!

$$V_{DS1} = V_{DD} - \frac{I_{tail}R_L}{2} - V_{cm} + V_{GS1}$$

$$V_{DS1} = V_{DD} - \frac{I_{tail}R_L}{2} - V_{cm} + V_{GS1} > V_{GS1} - V_{TH}$$

Common-Mode Input Range (3)

- MOSFET operating region?



$$V_{DS1} = V_{DD} - \frac{I_{tail} R_L}{2} - V_{cm} + V_{GS1} > V_{GS1} - V_{TH}$$

$$V_{DD} - \frac{I_{tail} R_L}{2} - V_{cm} > -V_{TH}$$

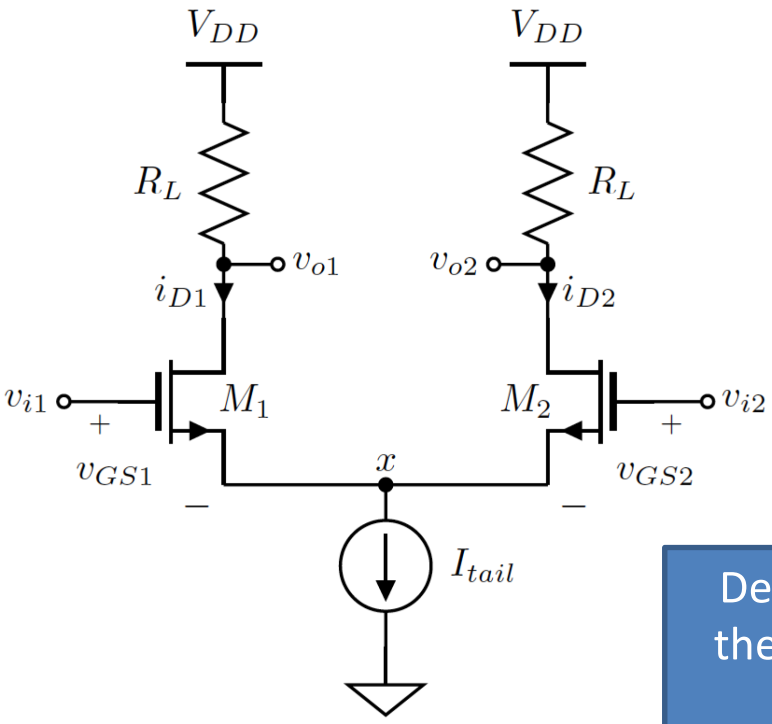
Maximum common-mode input voltage:

$$\boxed{V_{cm,\max} = V_{DD} - \frac{I_{tail} R_L}{2} + V_{TH}}$$

Common-Mode Input Range (4)

- MOSFET operating region?

If the tail current is not ideal → V_{min}



$$V_X = V_{I1} - V_{GS1}$$

$$= V_{I1} - V_{TH} - \sqrt{\frac{I_{D1}}{k}} = V_{cm} - V_{TH} - \sqrt{\frac{I_{tail}}{2 \cdot k}} > V_{\min}$$

$$V_{cm} > V_{\min} + V_{TH} + \sqrt{\frac{I_{tail}}{2 \cdot k}}$$

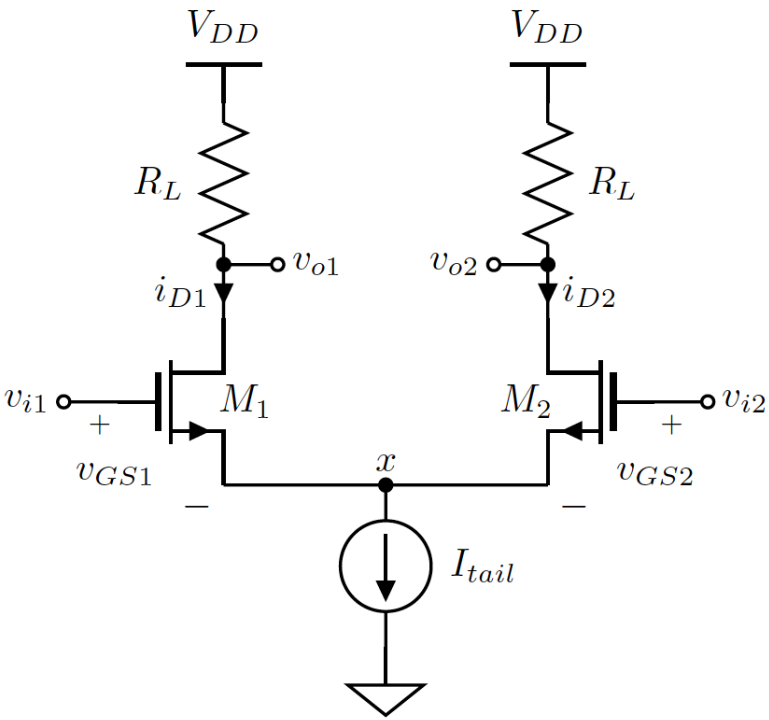
Minimum common-mode input voltage:

Dependent on the tail current source

$$V_{cm,\min} = V_{\min} + V_{TH} + \sqrt{\frac{I_{tail}}{2 \cdot k}}$$

Common-Mode Input Range (5)

- MOSFET operating region: also set by the input common-mode



$$V_{cm,\max} = V_{DD} - \frac{I_{tail} R_L}{2} + V_{TH}$$

Common-mode input range

$$V_{cm,\min} = V_{\min} + V_{TH} + \sqrt{\frac{I_{tail}}{2 \cdot k}}$$

Next Meeting

- Differential Circuit Small Signal Analysis
- Compound Amplifiers