CH8 Current source and bias circuit

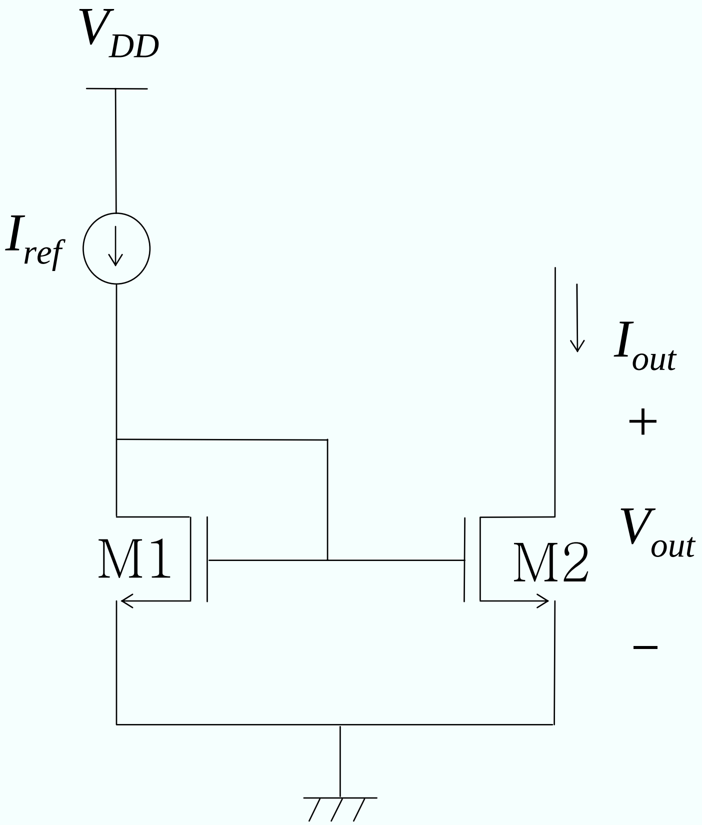
8.1 Current source

8.2 Bias circuit

8.1 Current source

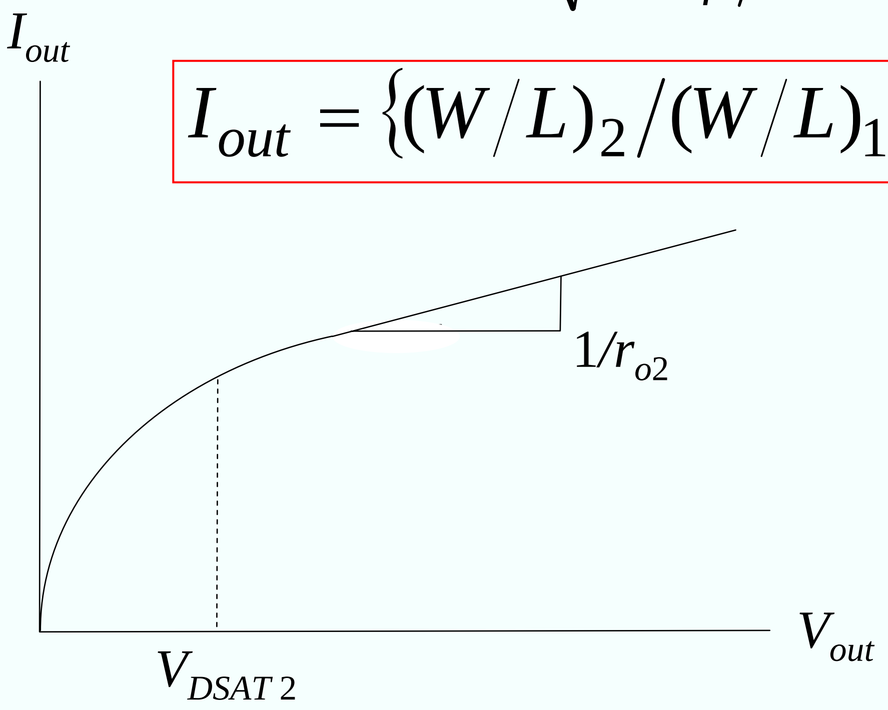
1. Current mirror current source
2. Cascode current source
3. Triple cascode current source
4. Multiple-output cascode current source
5. Wide swing cascode current sources 1, 2, 3

Current mirror current source



$$V_{GS2} = V_{TH} + \sqrt{2I_{ref} / \{\mu C_{ox}(W/L)_1\}}$$

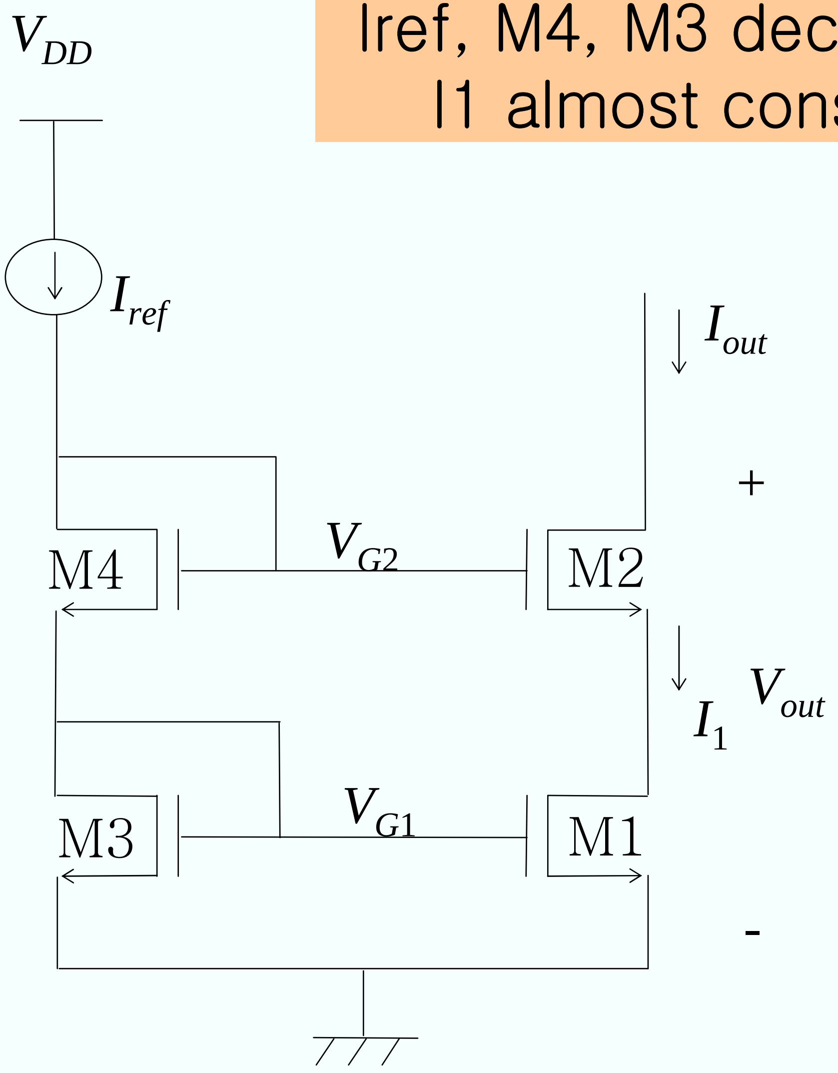
$$I_{out} = \{(W/L)_2/(W/L)_1\} \cdot I_{ref}$$

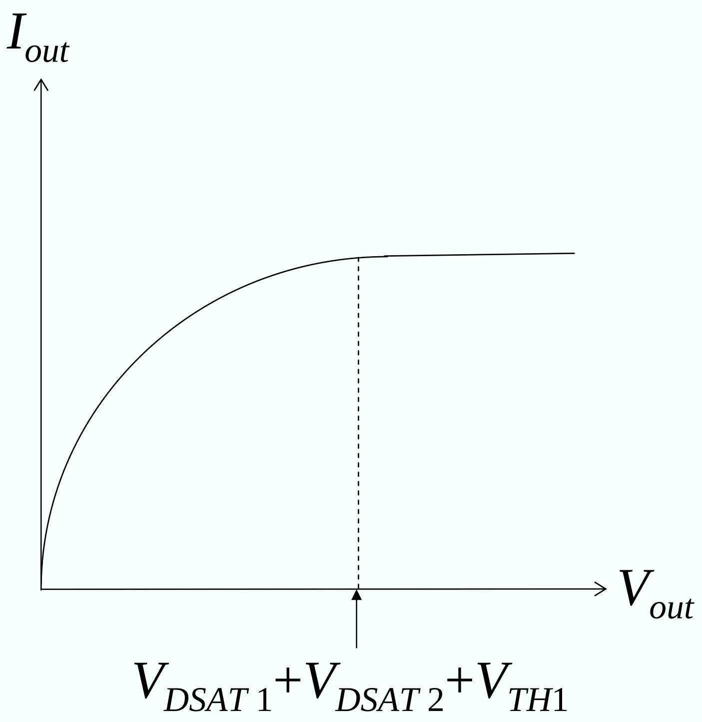


Iref and M1decide VGS1 (VGS2) ➔ VGS2 = DC voltage

8.1.2 cascode current source

Iref, M4, M3 decide VG2, VGS1 ➔ VGS2, VDS1 ➔ I1 almost constant ➔ high Rout



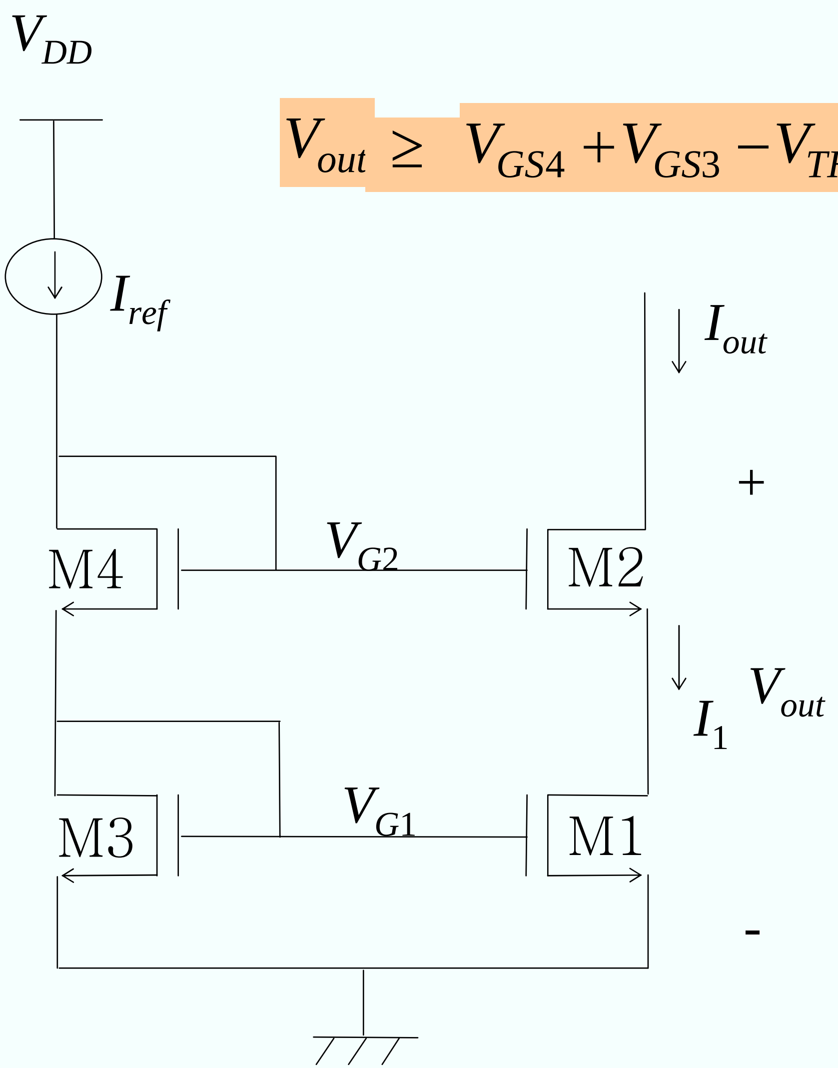


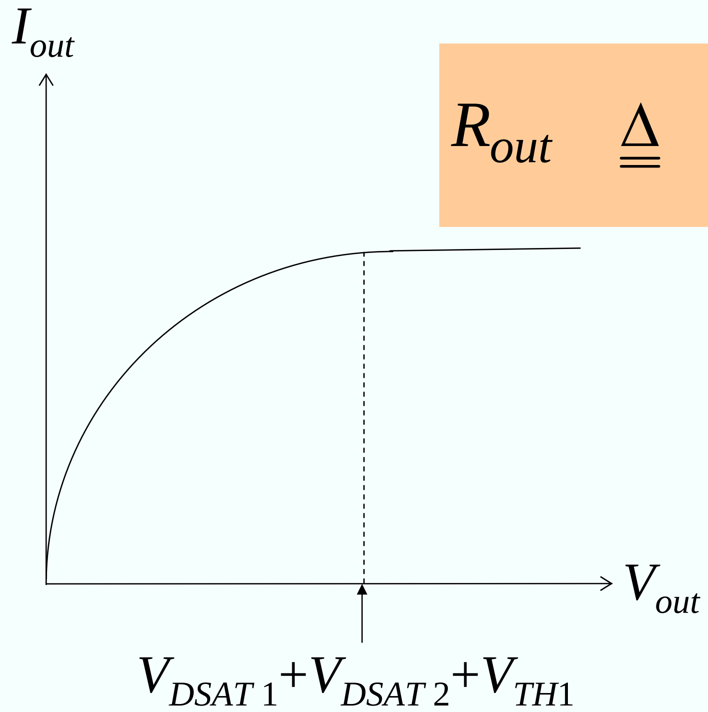
$$V_{DS1} = V_{GS4} + V_{GS3} - V_{GS2} = V_{GS3} = V_{GS1} > V_{GS1} - V_{TH}$$

M1 : saturation

$$V_{out} \geq V_{GS4} + V_{GS3} - V_{TH2} = V_{GS2} + V_{GS1} - V_{TH2} = V_{DSAT2} + V_{DSAT1} + V_{TH1}$$

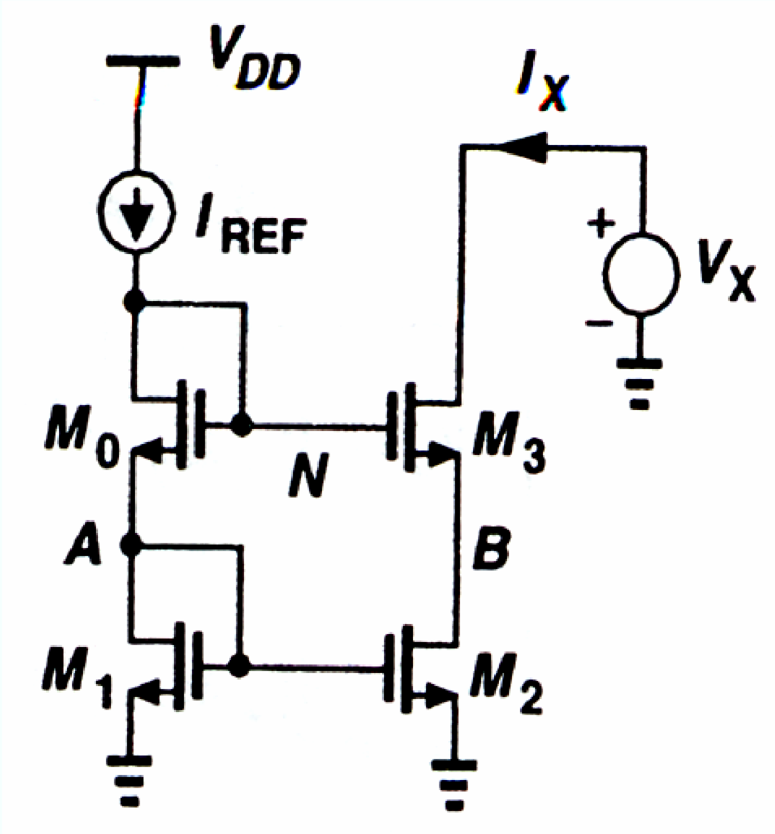
M2 : saturation

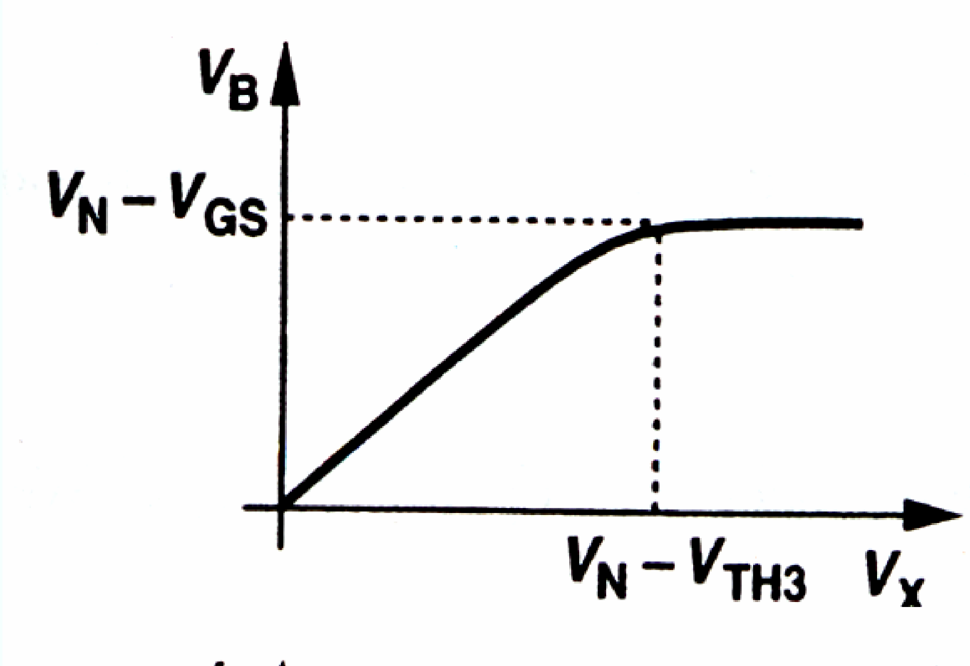


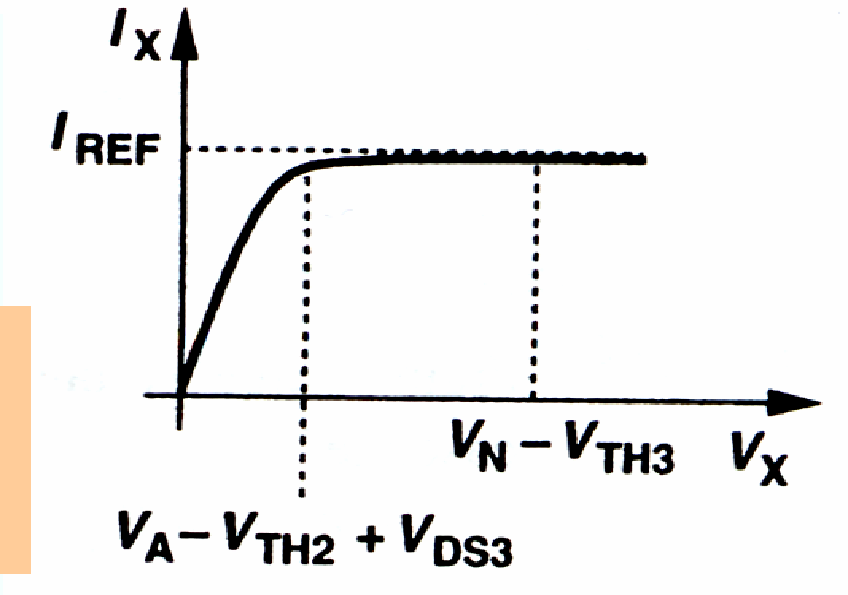


$$R_{out} \triangleq \frac{\Delta V_{out}}{\Delta I_{out}}$$

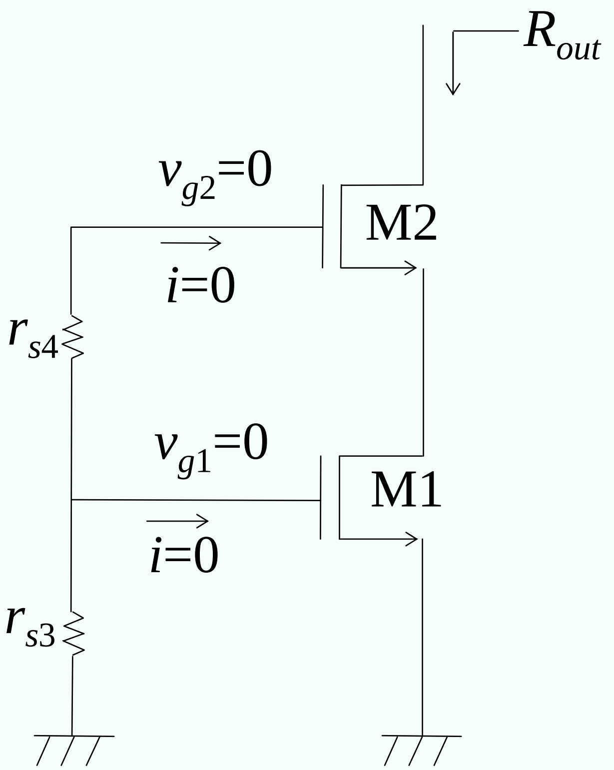
Cascode current source

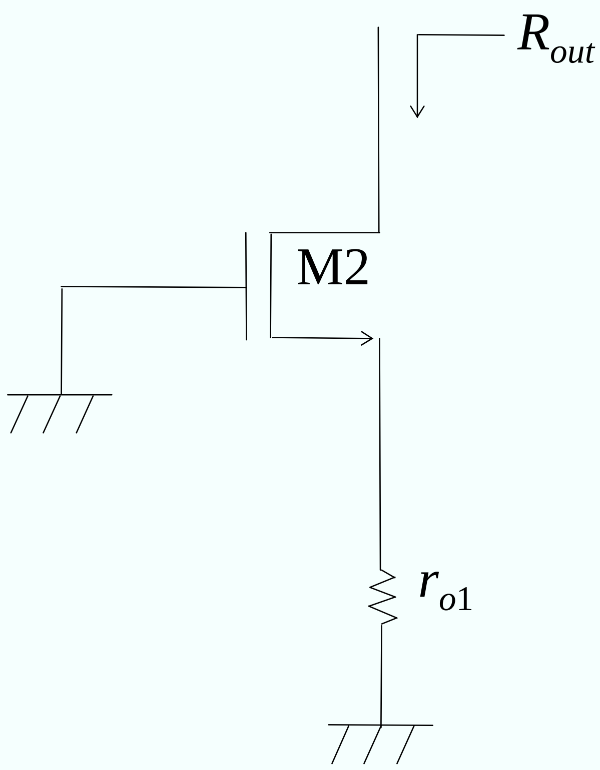






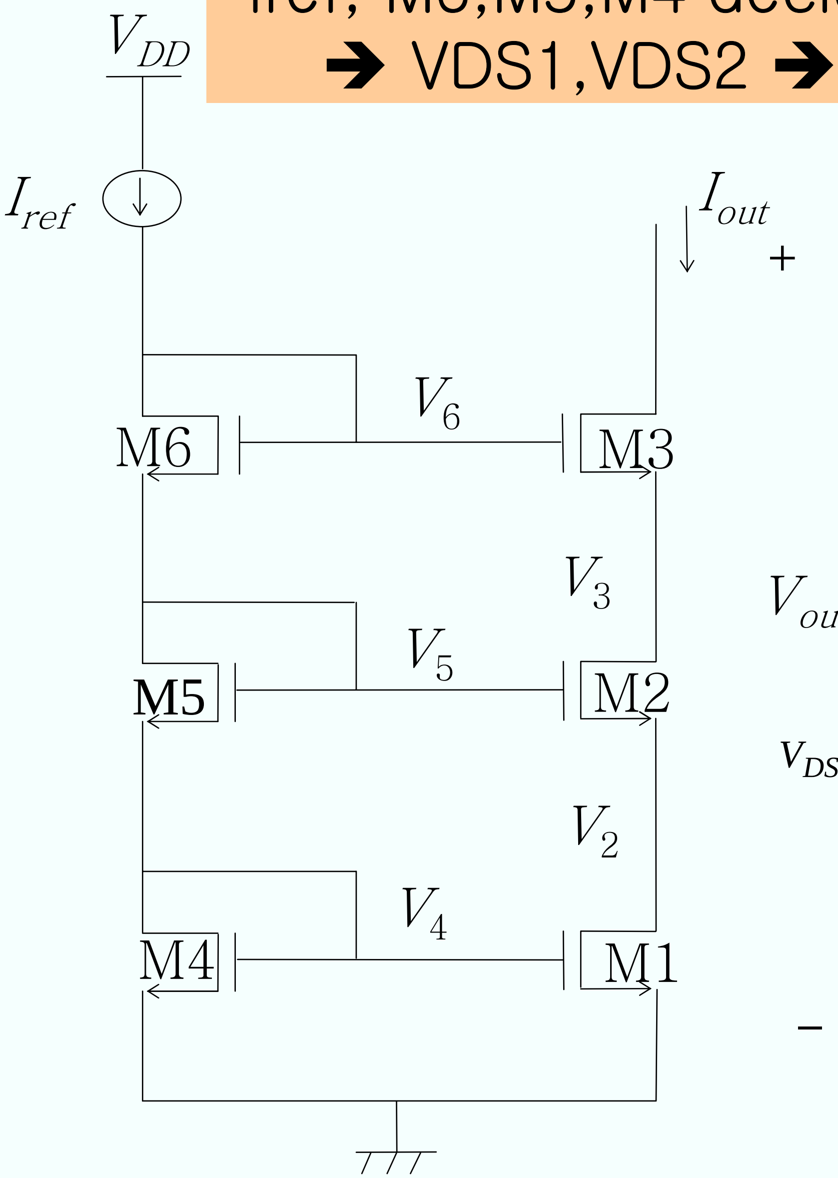
As Vx increases starting at 0,
M2 & M3 in triode initially,
M2 in saturation & M3 in triode, then
M2 & M3 in saturation.





$$R_{out} = g_{m2} r_{o2} \cdot r_{o1} + r_{o1} + r_{o2} \approx g_{m2} r_{o2} \cdot r_{o1}$$

Iref, M6,M5,M4 decide V6,V5,V4 ➔ VGS1 ➔ VGS2,VGS3 ➔ VDS1,VDS2 ➔ Iout almost constant ➔very high Rout



$$V_{DS1} = V_{GS5} + V_{GS4} - V_{GS2} = V_{GS4} = V_{GS1} > (V_{GS1} - V_{TH1})$$

M1 : saturation

$$V_{DS2} = V_{GS6} + V_{GS5} + V_{GS4} - V_{GS3} - V_{DS1} = V_{GS5} = V_{GS2} > (V_{GS2} - V_{TH2})$$

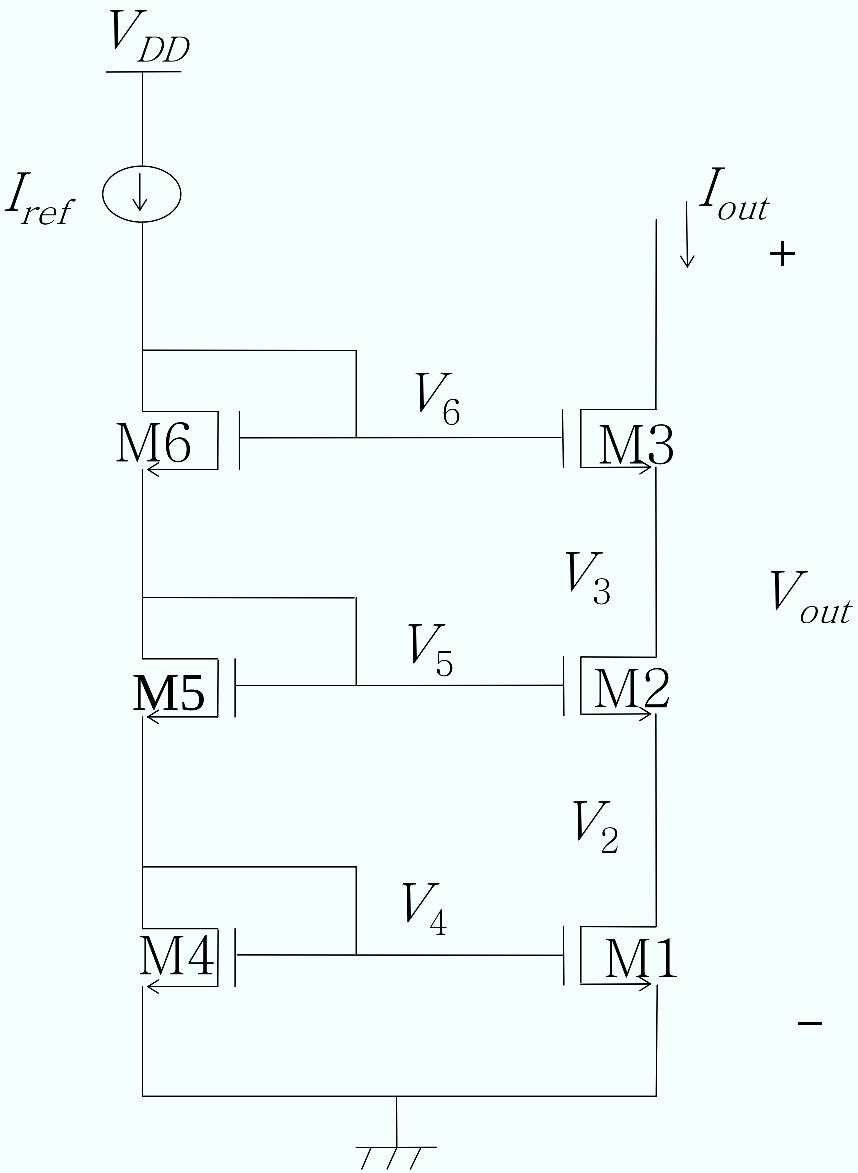
M2 : saturation

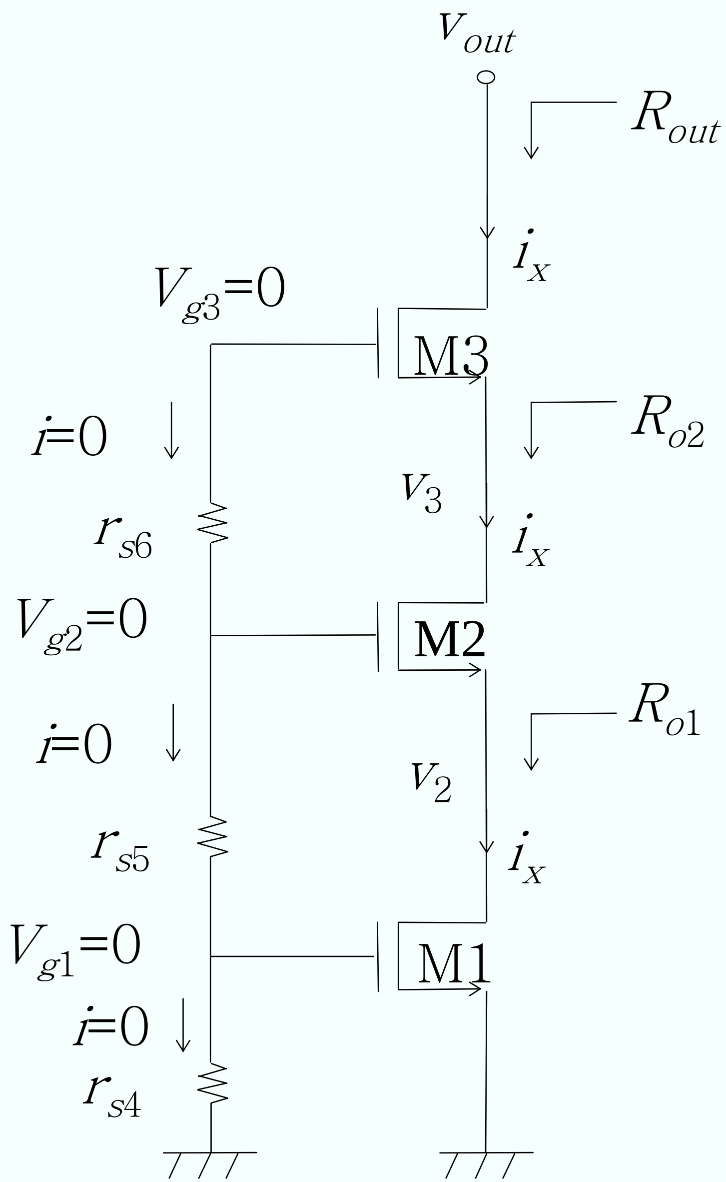
$$V_{out} \geqq V_6 - V_{TH3}$$

M3 : saturation

$$V_{out} \geqq V_{DSAT3} + V_{DSAT2} + V_{DSAT1} + V_{TH2} + V_{TH1}$$

Triple cascode current source



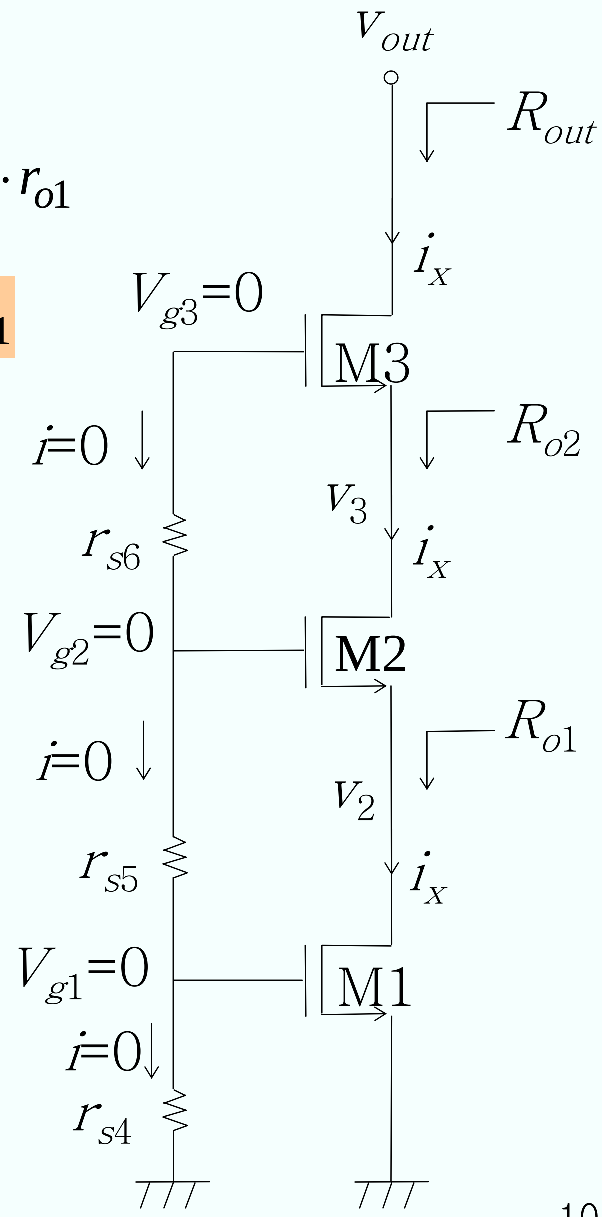


Triple cascode current source

$$R_{o1} = r_{o1}$$

$$R_{o2} = g_{m2}r_{o2} \cdot R_{o1} + R_{o1} + r_{o2} \approx g_{m2}r_{o2} \cdot R_{o1} = g_{m2}r_{o2} \cdot r_{o1}$$

$$R_{out} = g_{m3}r_{o3} \cdot R_{o2} + R_{o2} + r_{o3} \approx g_{m3}r_{o3} \cdot R_{o2} = g_{m3}r_{o3} \cdot g_{m2}r_{o2} \cdot r_{o1}$$



Triple cascode current source

$$v_{out} = i_x \cdot R_{out}$$

$$v_3 = i_x \cdot R_{o2}$$

$$v_2 = i_x \cdot R_{o1}$$

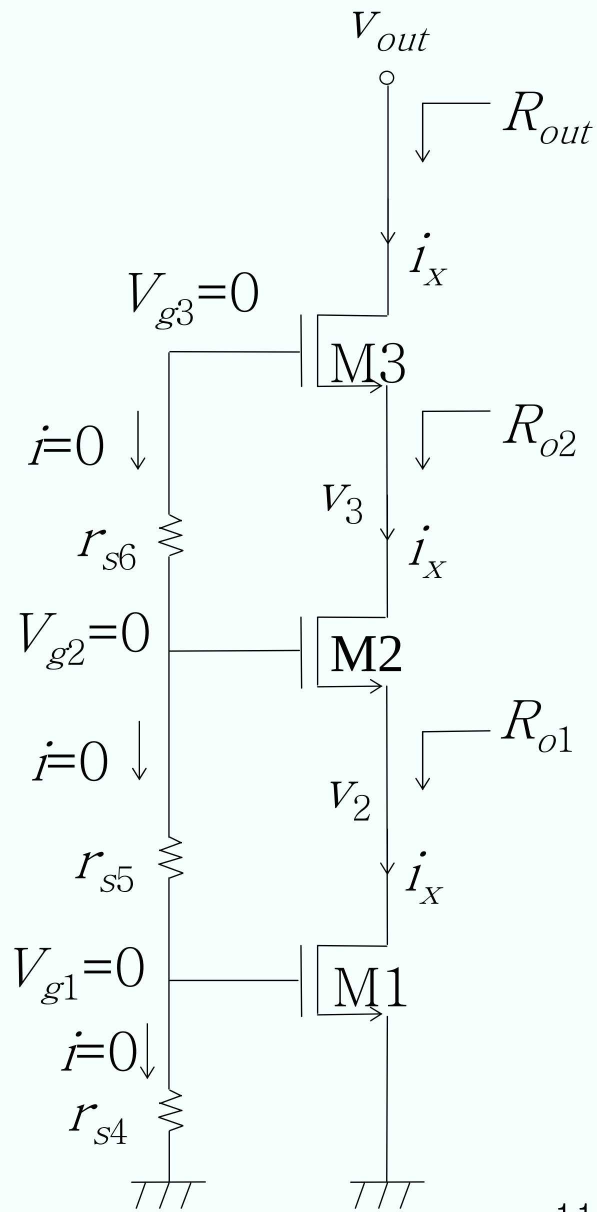
$$v_3 \approx \frac{v_{out}}{R_{out}/R_{o2}} = \frac{v_{out}}{g_{m3}r_{o3}}$$

Small, Cascode effect

$$v_2 \approx \frac{v_3}{R_{o2}/R_{o1}} = \frac{v_{out}}{g_{m3}r_{o3} \cdot g_{m2}r_{o2}}$$

Very small, Cascode effect

V3, V2 : almost DC voltage independent of vout



Iref,Mb0,Ma0 decide VGS,VDS of Ma1,Ma2,Ma3,Man
➔ VGS of Mb1,Mb2,Mbn ➔ Iout almost constant

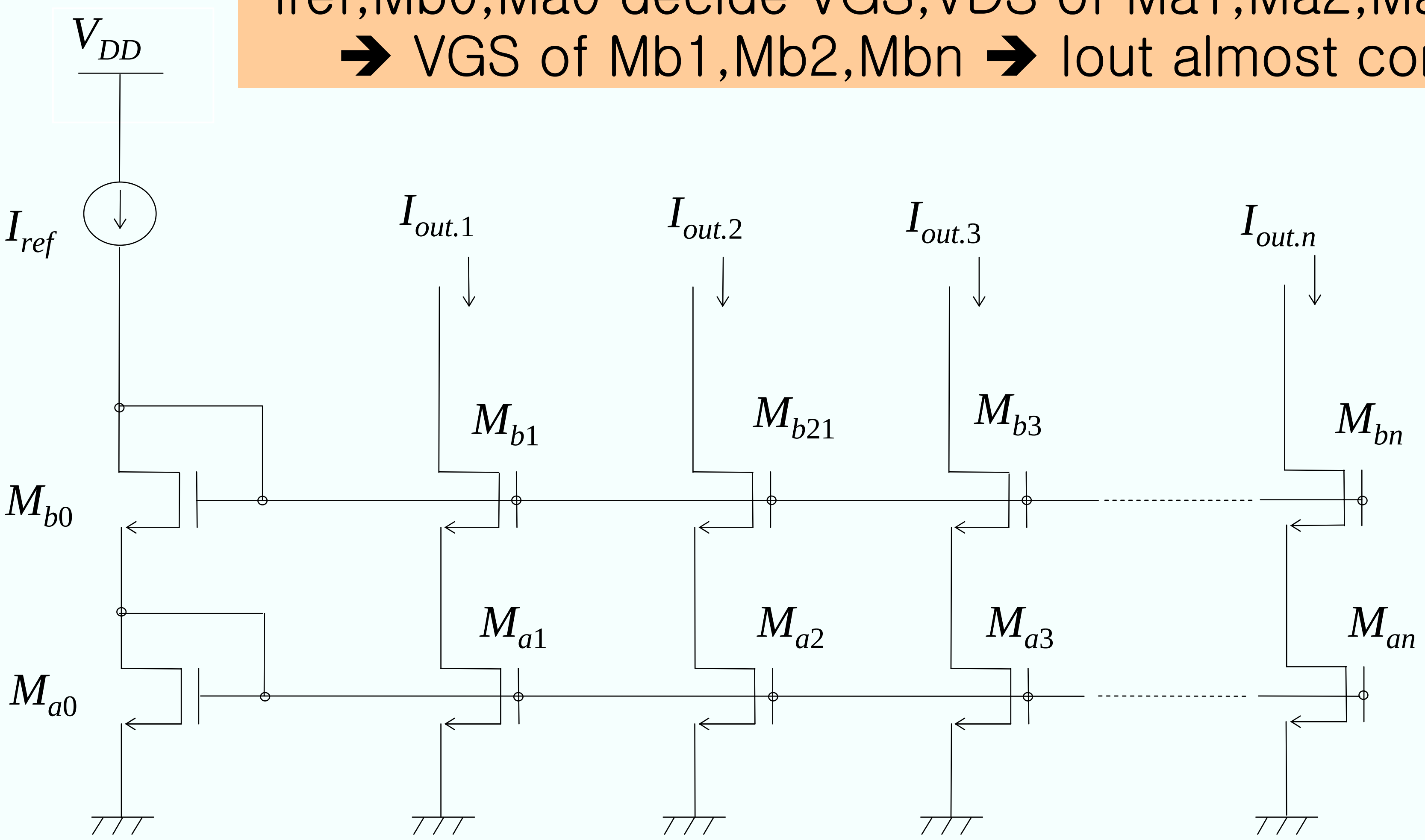
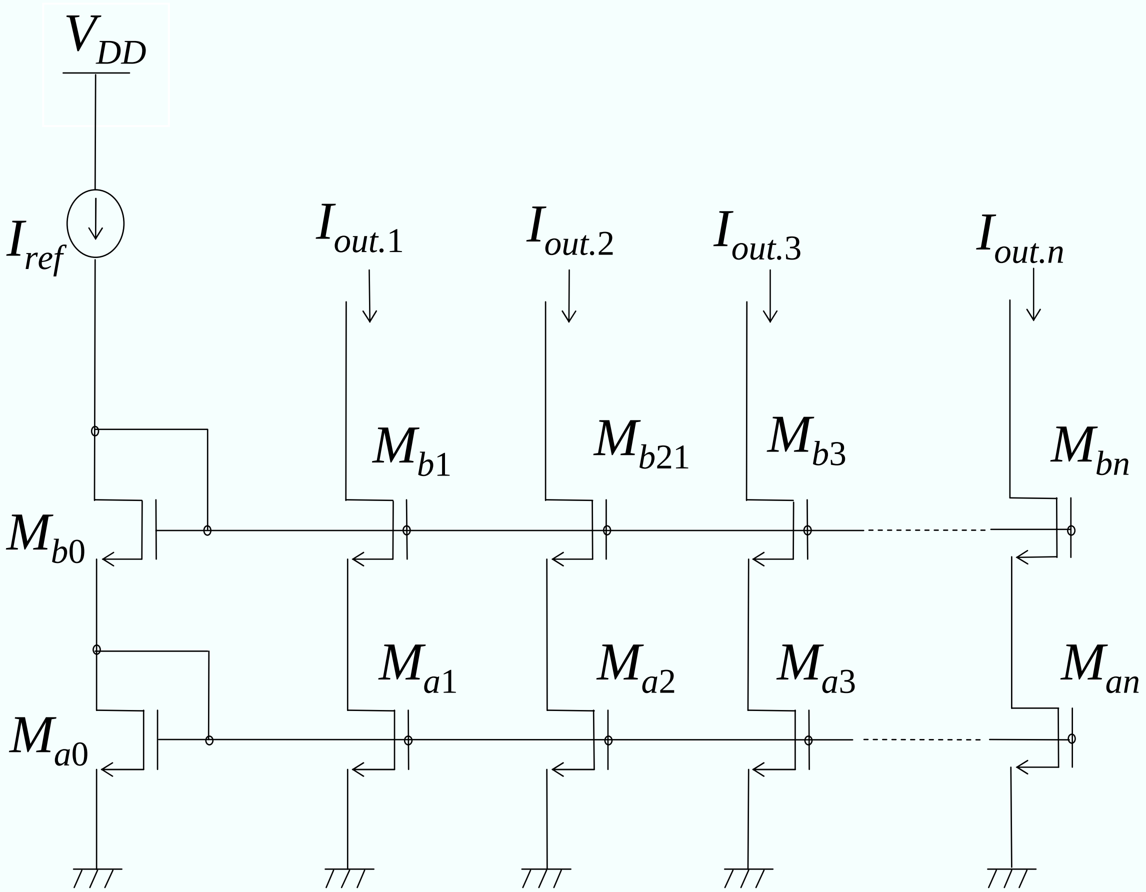


Fig8.1.4 Multi-output cascode current source

Multi-output Cascode current source



$$I_{out.1} = I_{ref} \cdot \frac{(W/L)_{Ma1}}{(W/L)_{Ma0}}$$

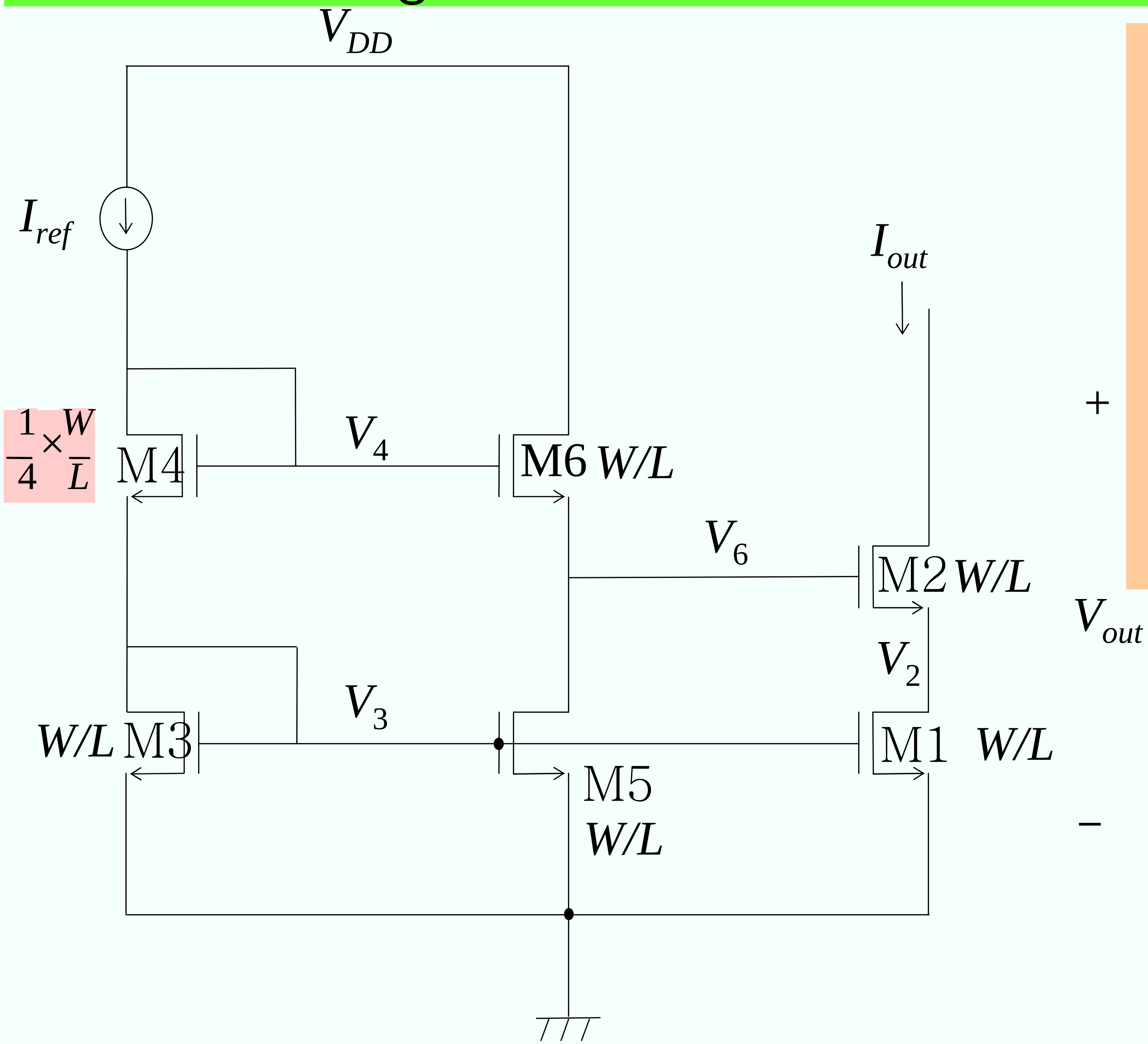
$$I_{out.2} = I_{ref} \cdot \frac{(W/L)_{Ma2}}{(W/L)_{Ma0}}$$

$$I_{out.3} = I_{ref} \cdot \frac{(W/L)_{Ma3}}{(W/L)_{Ma0}}$$

$$\vdots$$

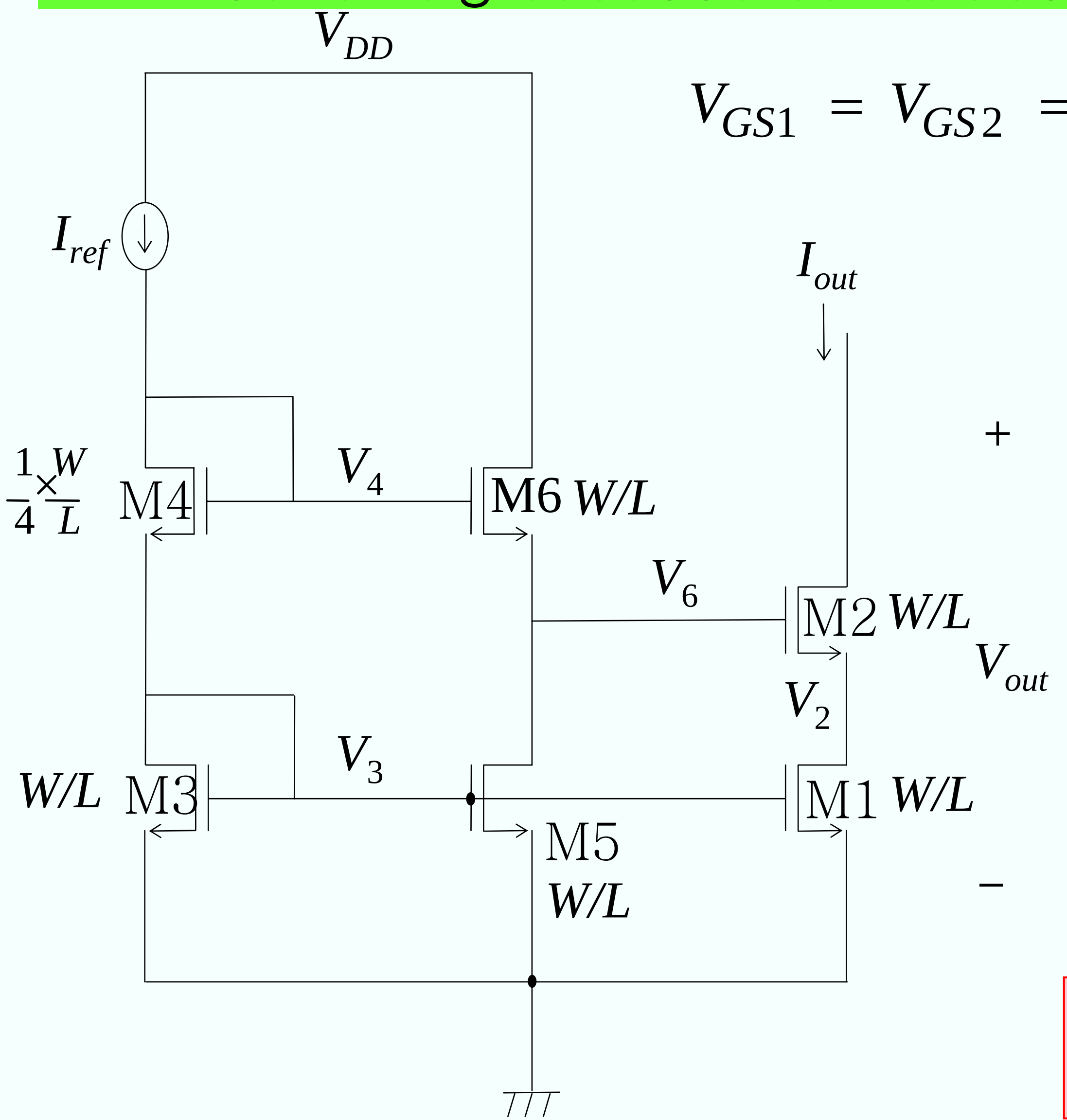
$$I_{out.n} = I_{ref} \cdot \frac{(W/L)_{Man}}{(W/L)_{Ma0}}$$

Wide-swing cascode current source: circuit 1



Iref,M3, M4
→ V3,V4
→ VGS of M5
→ VGS of M6,VDS ofM5
→ V6
→ VGS of M2, VDS ofM1
→ VGS, VDS ofM1:~=DC
→ Iout constant

Wide-swing cascode current source: circuit 1



$$V_{GS1} = V_{GS2} = V_{GS3} = V_{GS5} = V_{GS6} = V_{TH} + \Delta$$

$$V_{GS4} = V_{TH} + 2\Delta$$

$$V_3 = V_{GS3} = V_{TH} + \Delta$$

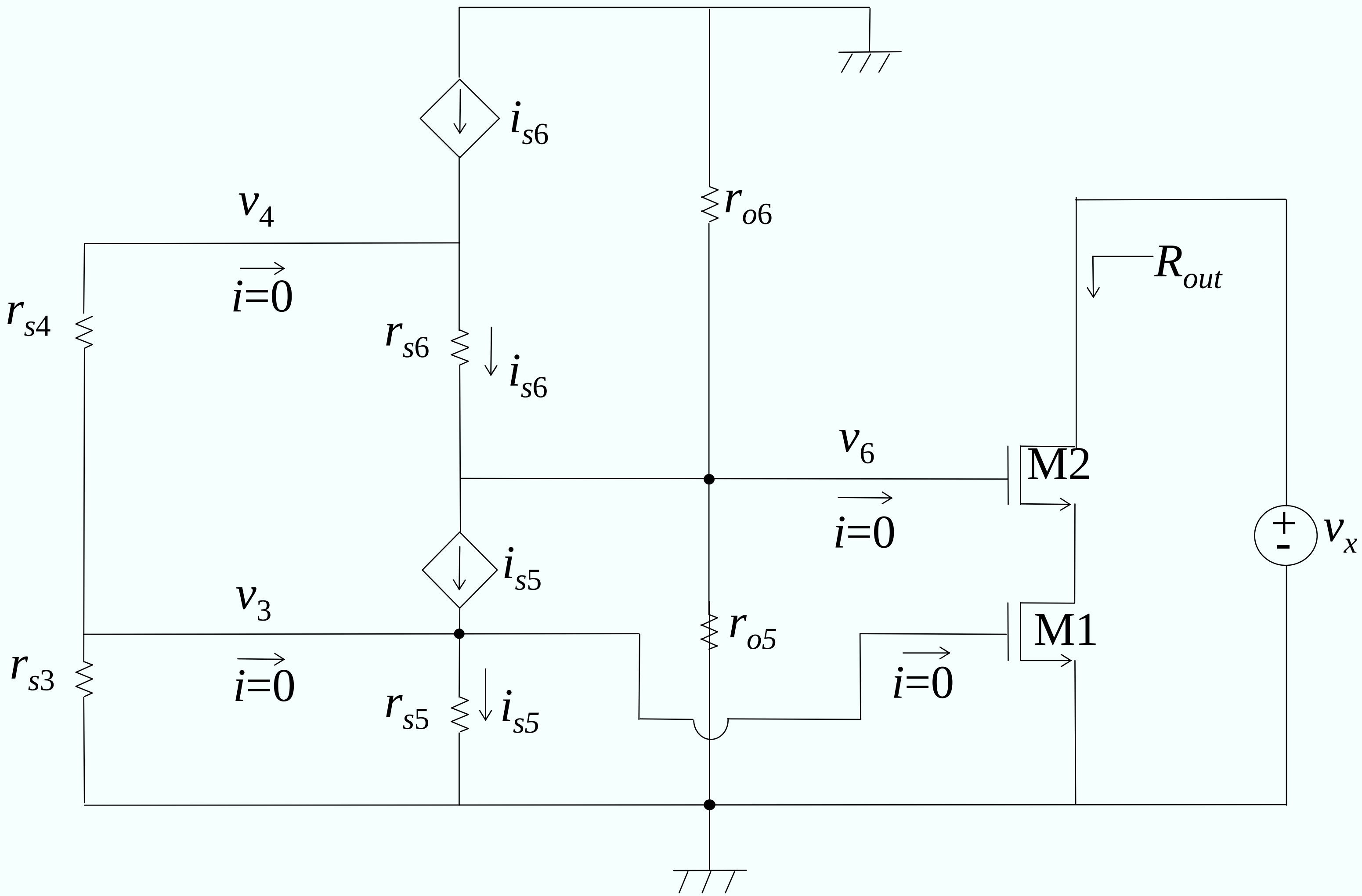
$$V_4 = V_{GS4} + V_3 = 2V_{TH} + 3\Delta$$

$$V_6 = V_4 - V_{GS6} = V_{TH} + 2\Delta$$

$$V_2 = V_6 - V_{GS2} = \Delta$$

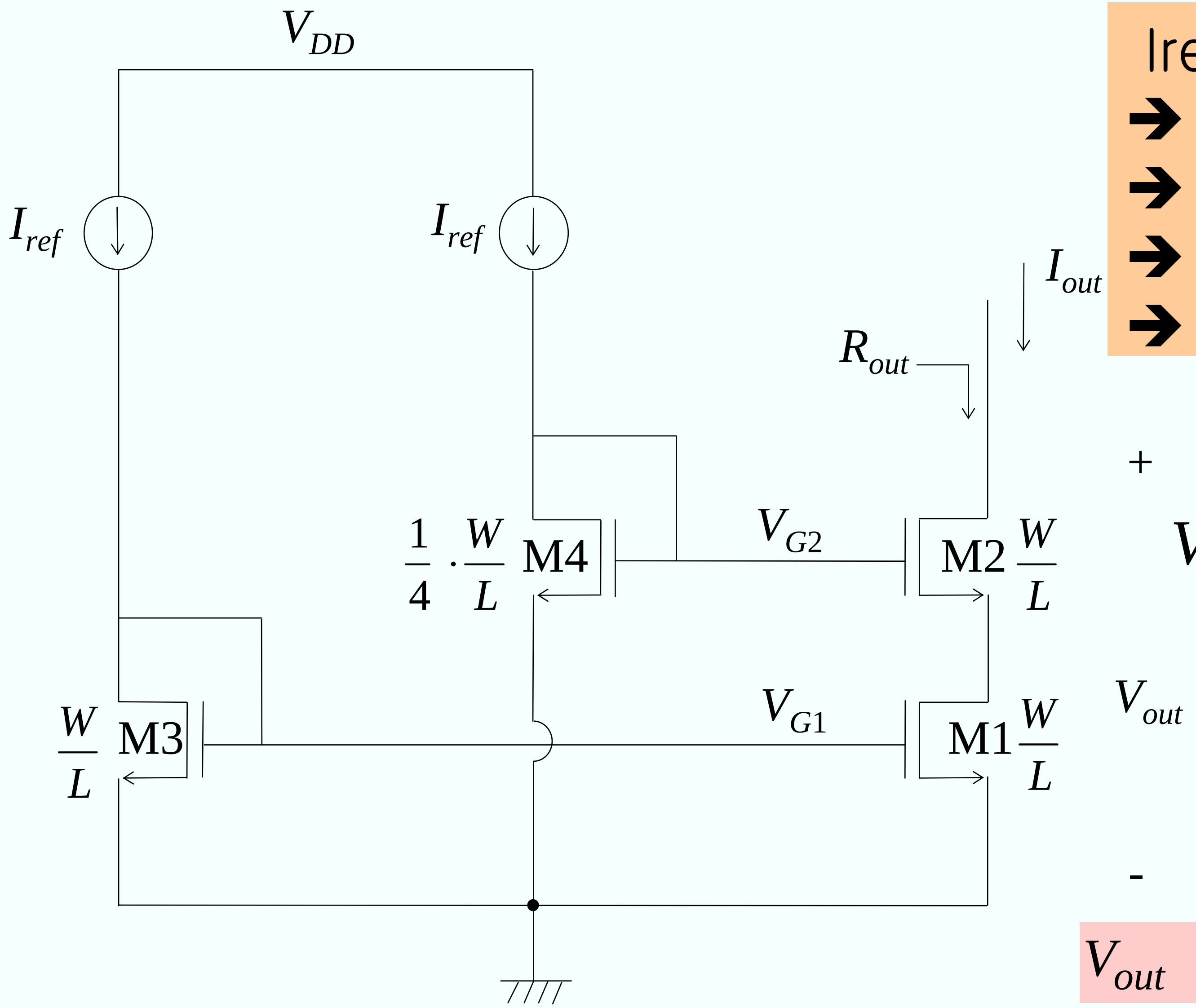
$$V_{out} \geq V_6 - V_{TH} = 2\Delta$$

Wide-swing cascode current source 1



$$R_{out} = g_{m2} r_{o2} \cdot r_{o1} + r_{o1} + r_{o2} \approx g_{m2} r_{o2} \cdot r_{o1}$$

Wide-swing cascode current source: circuit 2



Iref,M3,Iref,M4

- ➔ VG1,VG2
- ➔ VGS of M1
- ➔ VGS of M2, VDS of M1
- ➔ Iout almost constant

$$V_{DS1} = V_{G2} - V_{GS2}$$

$$= (V_{TH} + 2\Delta) - (V_{TH} + \Delta)$$

$$= \Delta$$

$$V_{out} \geq V_{G2} - V_{TH} = 2\Delta$$

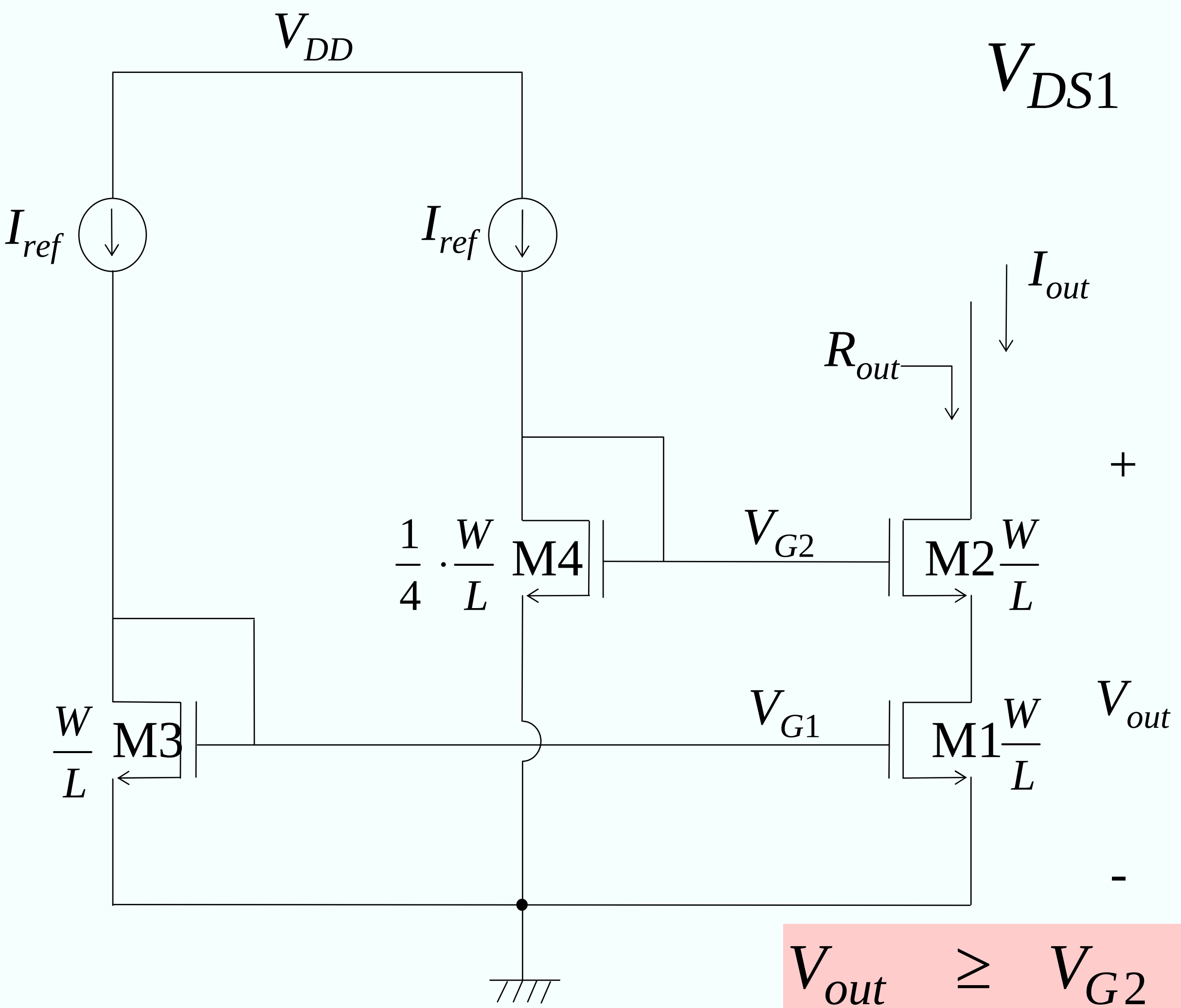
Wide-swing cascode current source 2

$$V_{G2} = V_{TH} + 2\Delta + V_{margin}$$

$$V_{DS1} = V_{G2} - V_{GS2}$$

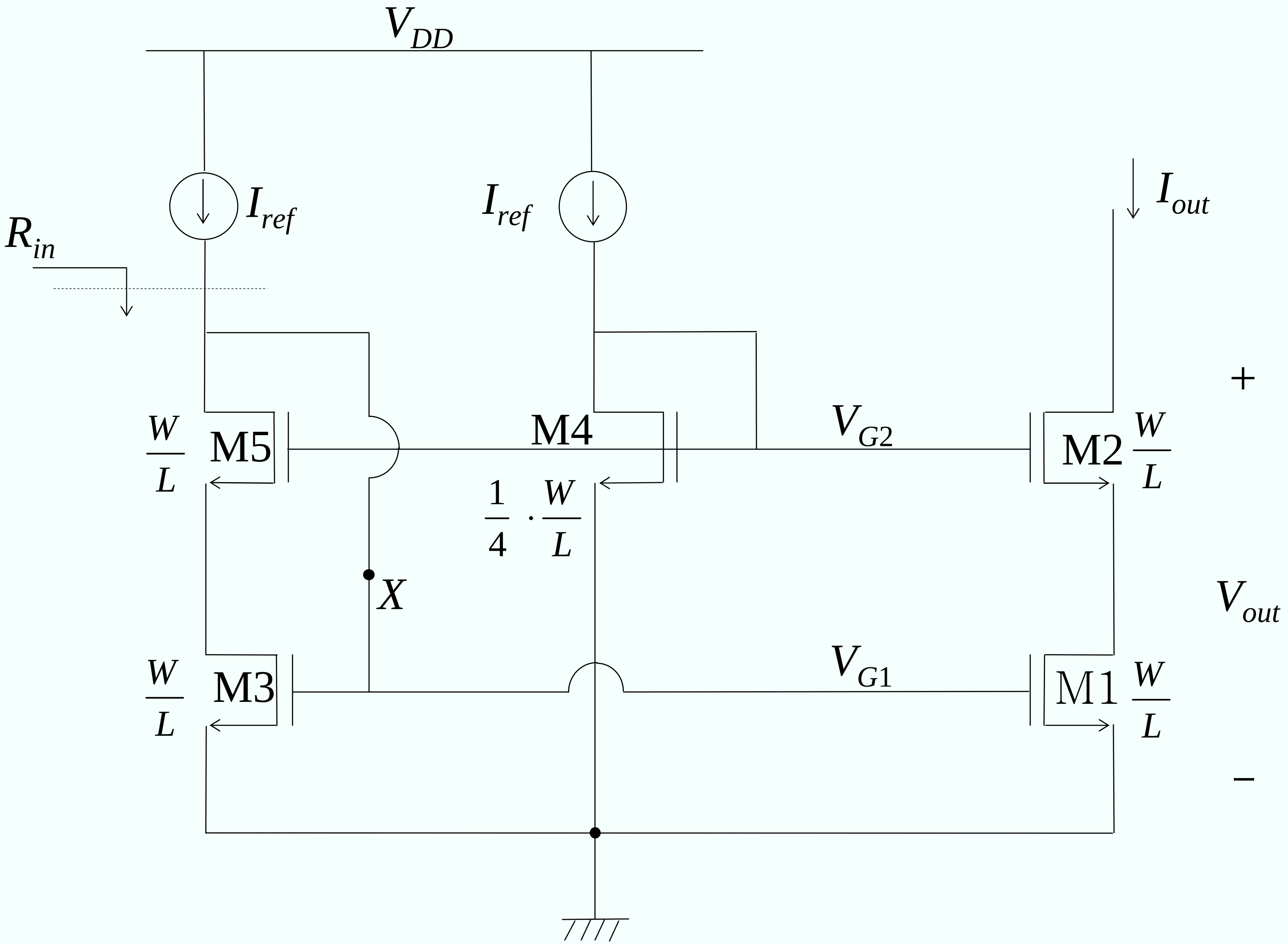
$$= (V_{TH} + 2\Delta + V_{margin}) - (V_{TH} + \Delta)$$

$$= \Delta + V_{margin}$$



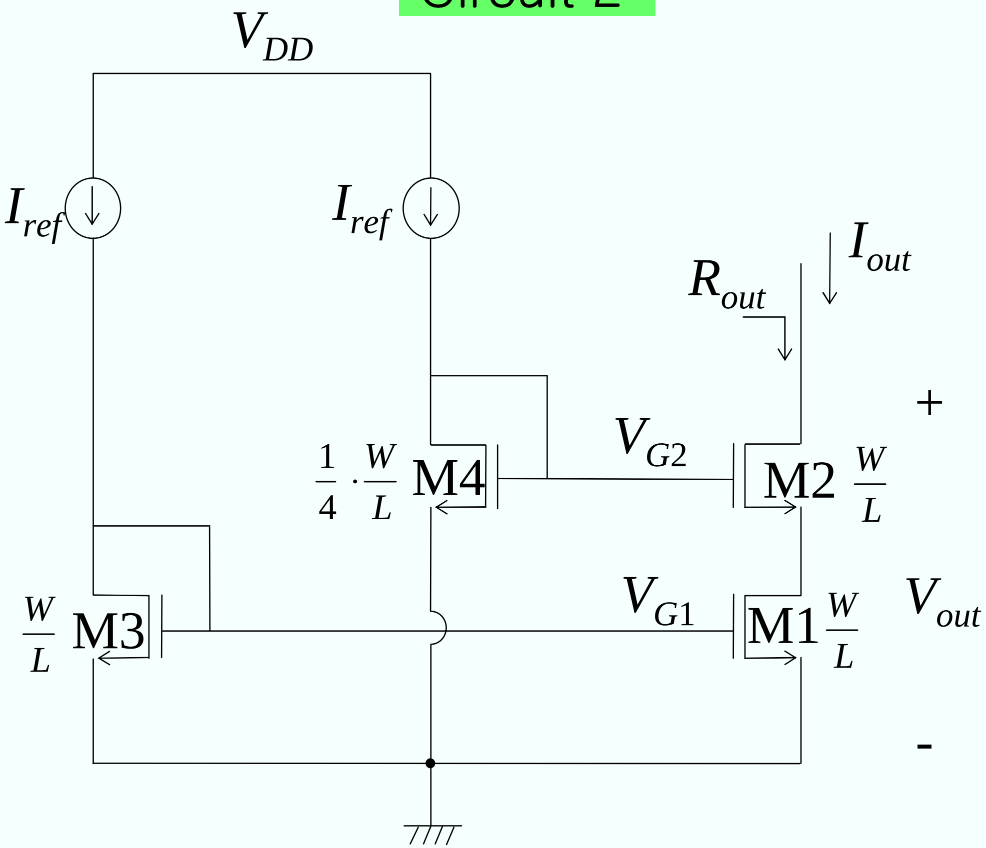
$$V_{out} \geq V_{G2} - V_{TH} = 2\Delta + V_{margin}$$

Wide-swing cascode current source: circuit 3

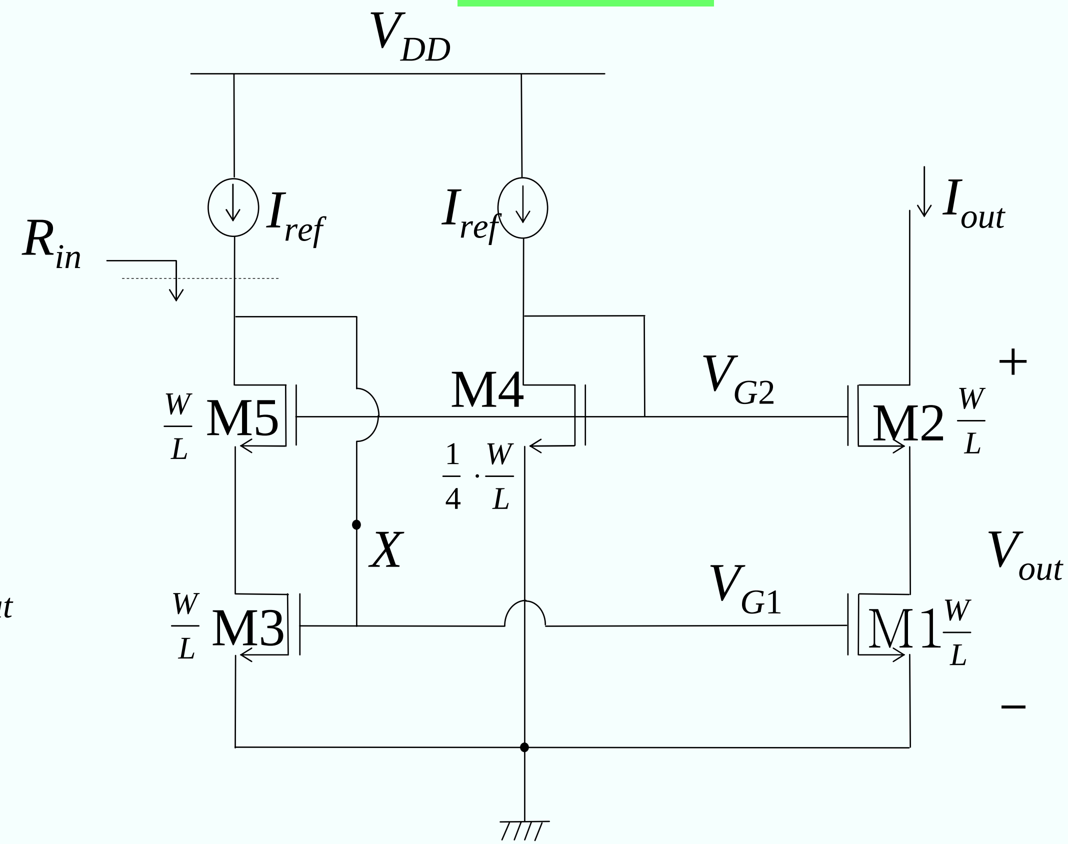


Wide-swing cascode current source 3

Circuit 2



Circuit 3



$$V_{DS1} = \Delta \qquad V_{DS3} = \Delta + V_{TH}$$

$$I_{out} < I_{ref}$$

Current gain < 1
Active load application

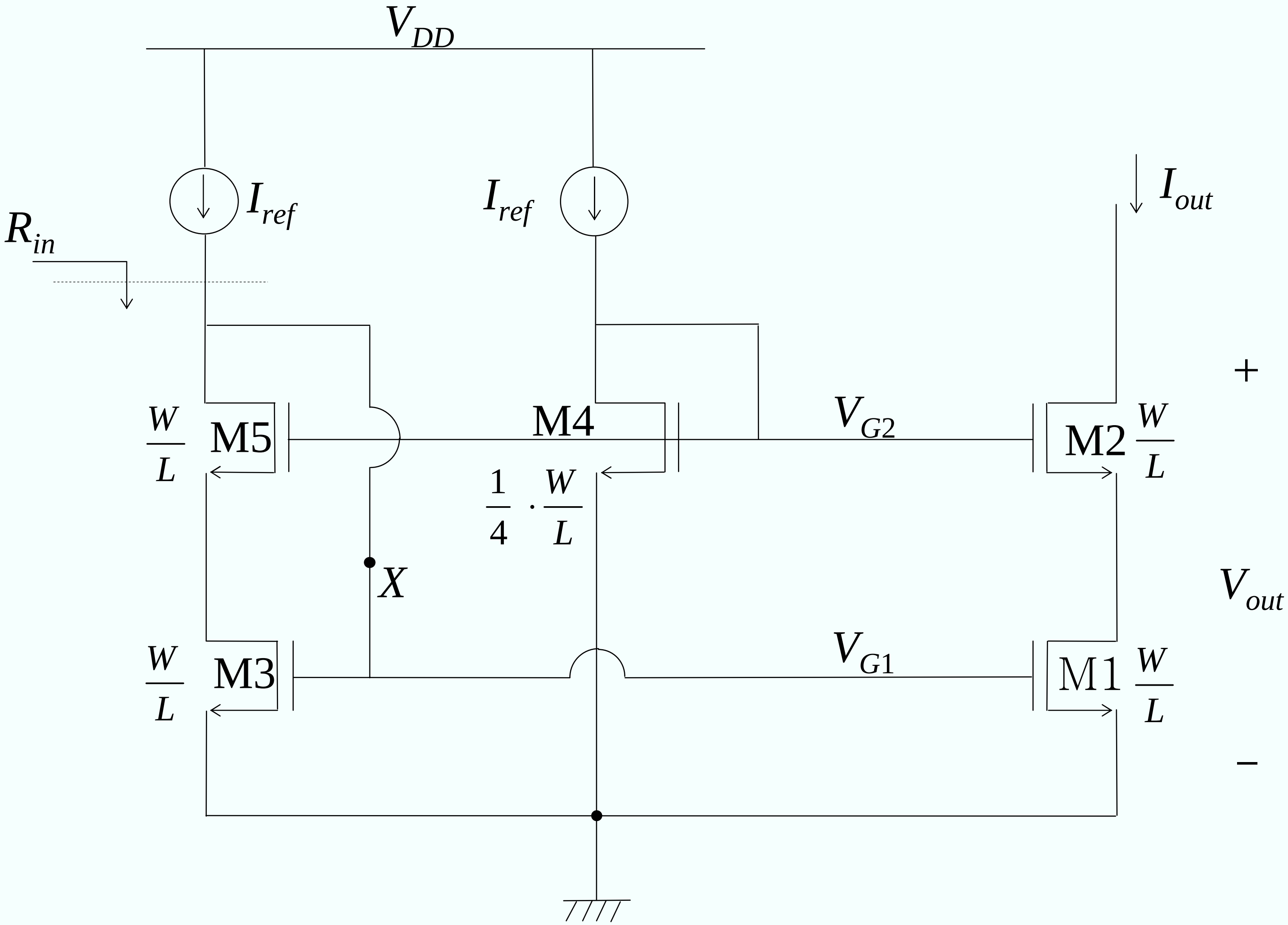
$$V_{DS1} = V_{DS3} = \Delta$$

$$I_{out} = I_{ref}$$

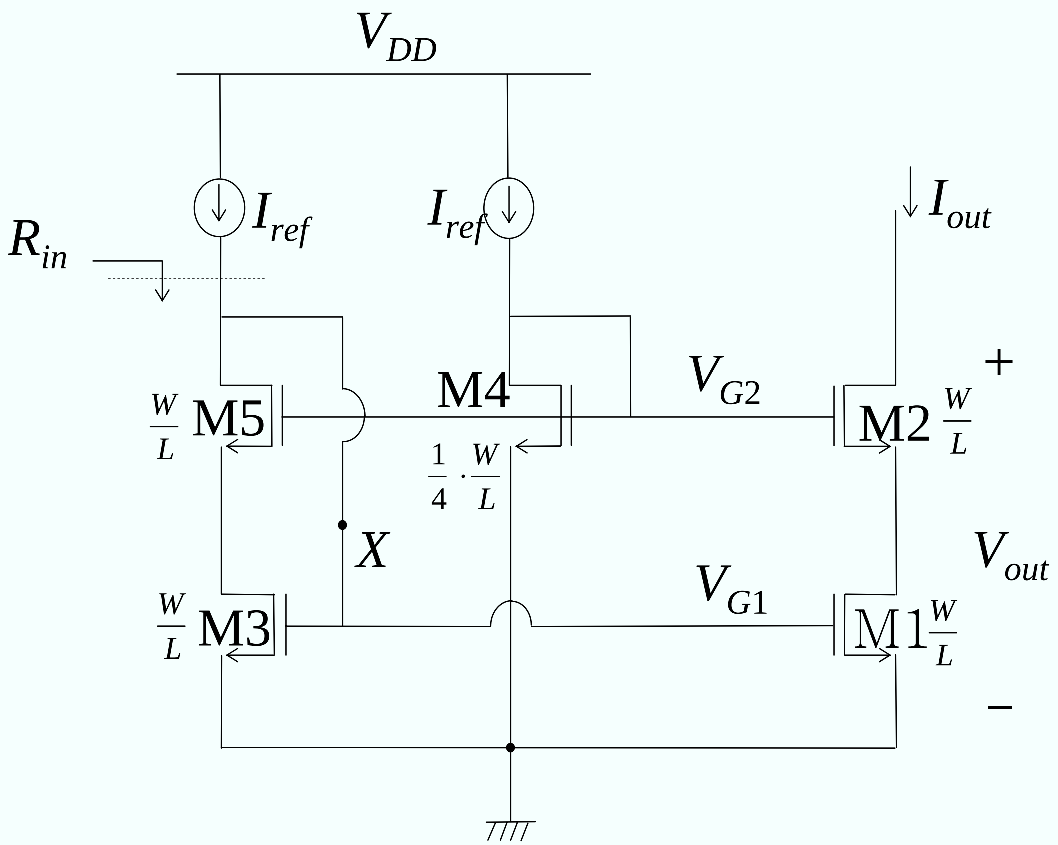
Current gain = 1

Wide-swing cascode current source 3

Iref,M4,Iref,M5,M3 ➔ VG1,VG2 ➔ VGS2,VDS1 ➔ VGS1,VDS1:constant ➔ Iout almost constant



Wide-swing cascode current source 3



$$V_{G2} = 2\Delta + V_{TH}$$

$$V_{G1} = \Delta + V_{TH}$$

$$V_{GS5} = \Delta + V_{TH}$$

$$V_{GS2} = \Delta + V_{TH}$$

$$V_{DS3} = V_{G2} - V_{GS5} = \Delta$$

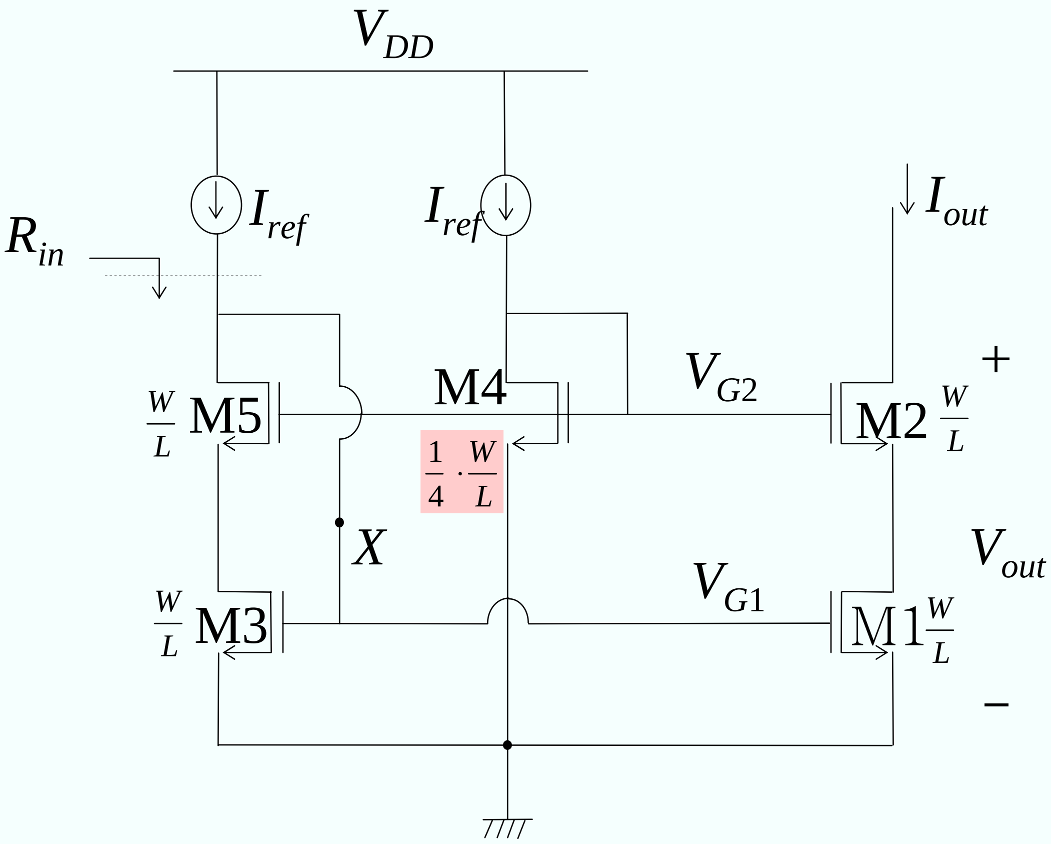
$$V_{DS5} = V_{G1} - V_{DS3} = V_{TH}$$

$$V_{DS1} = V_{G2} - V_{GS2} = \Delta$$

$$I_{out} = I_{ref}$$

Current gain = 1

Wide-swing cascode current source 3



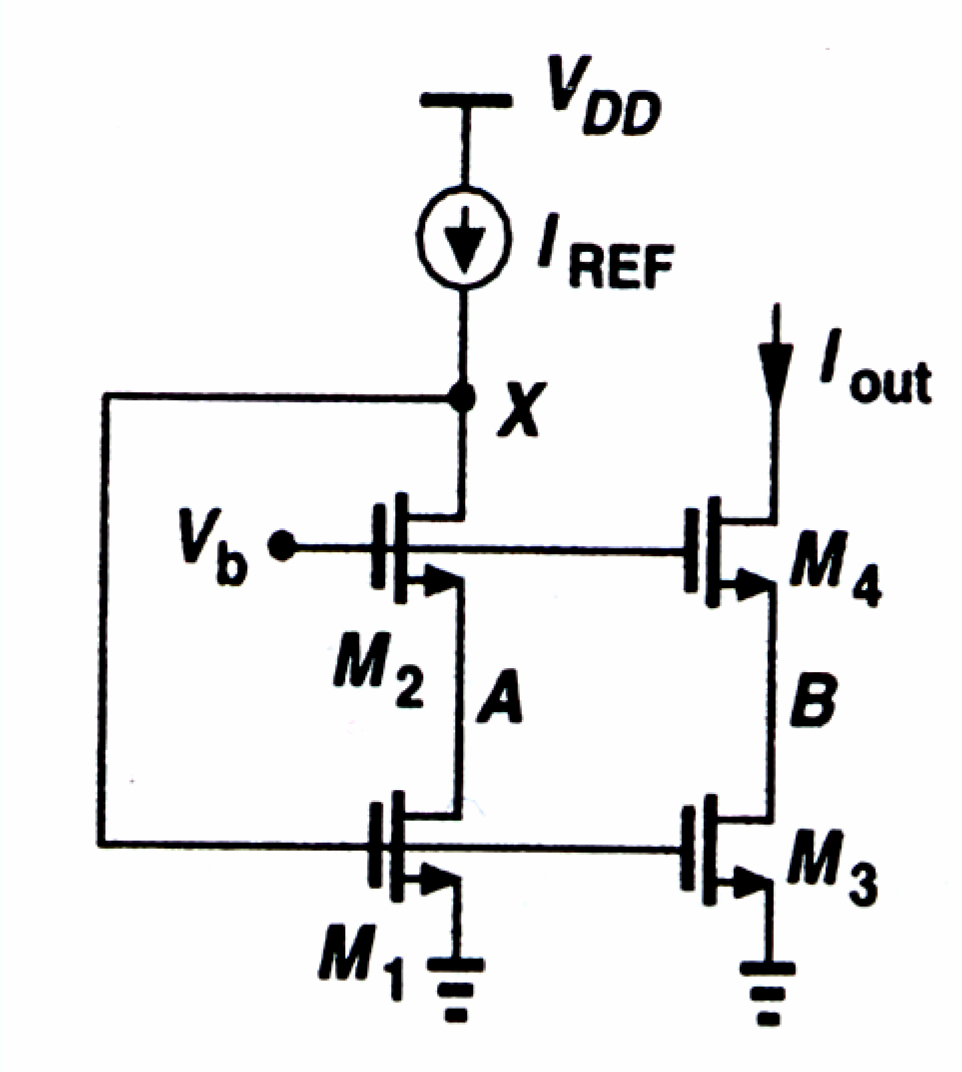
Negative feedback at M3, M5 (shunt)

$$V_{out} \geq V_{G2} - V_{TH} = 2\Delta$$

$$R_{in} = \frac{R_i}{(1 + loop\ \ gain)} \approx \frac{1}{g_{m3}}$$

$$R_{out} = g_{m2} r_{o2} \cdot r_{o1} + r_{o1} + r_{o2} \approx g_{m2} r_{o2} \cdot r_{o1}$$

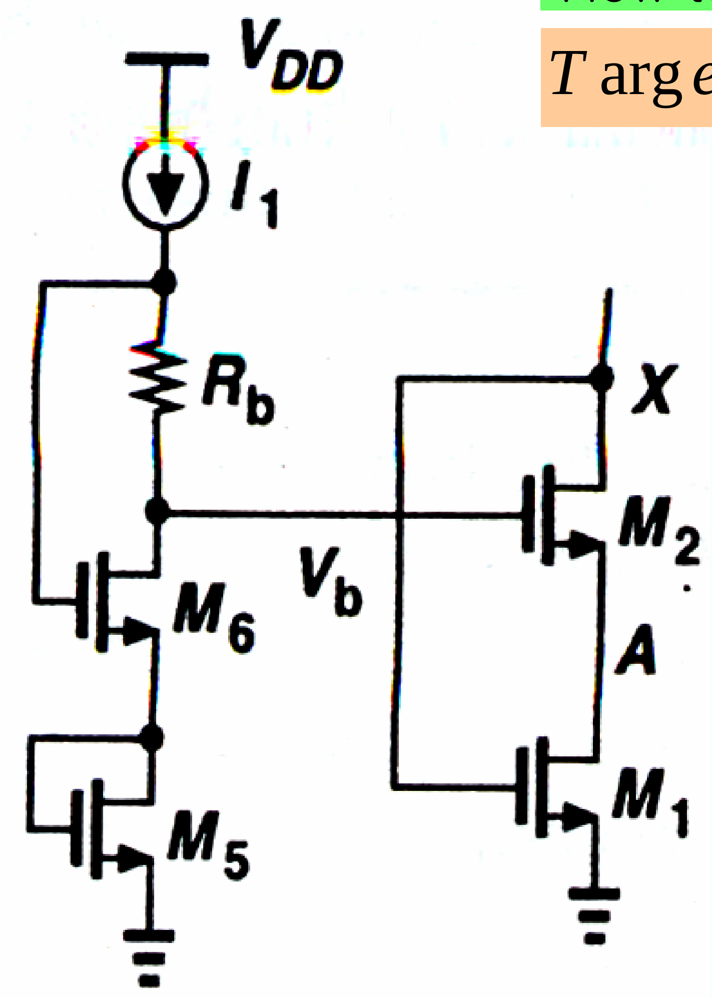
Wide-swing cascode current source 3

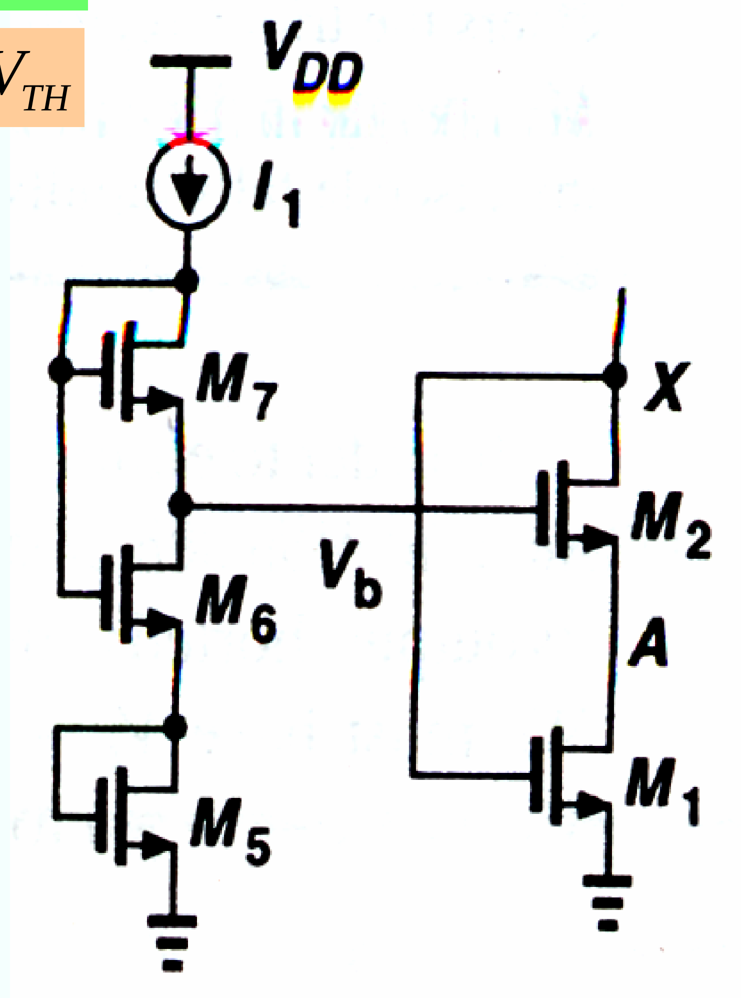


Wide-swing cascode current source 3

How to generate Vb

$$Target \quad V_b = 2\Delta + V_{TH}$$

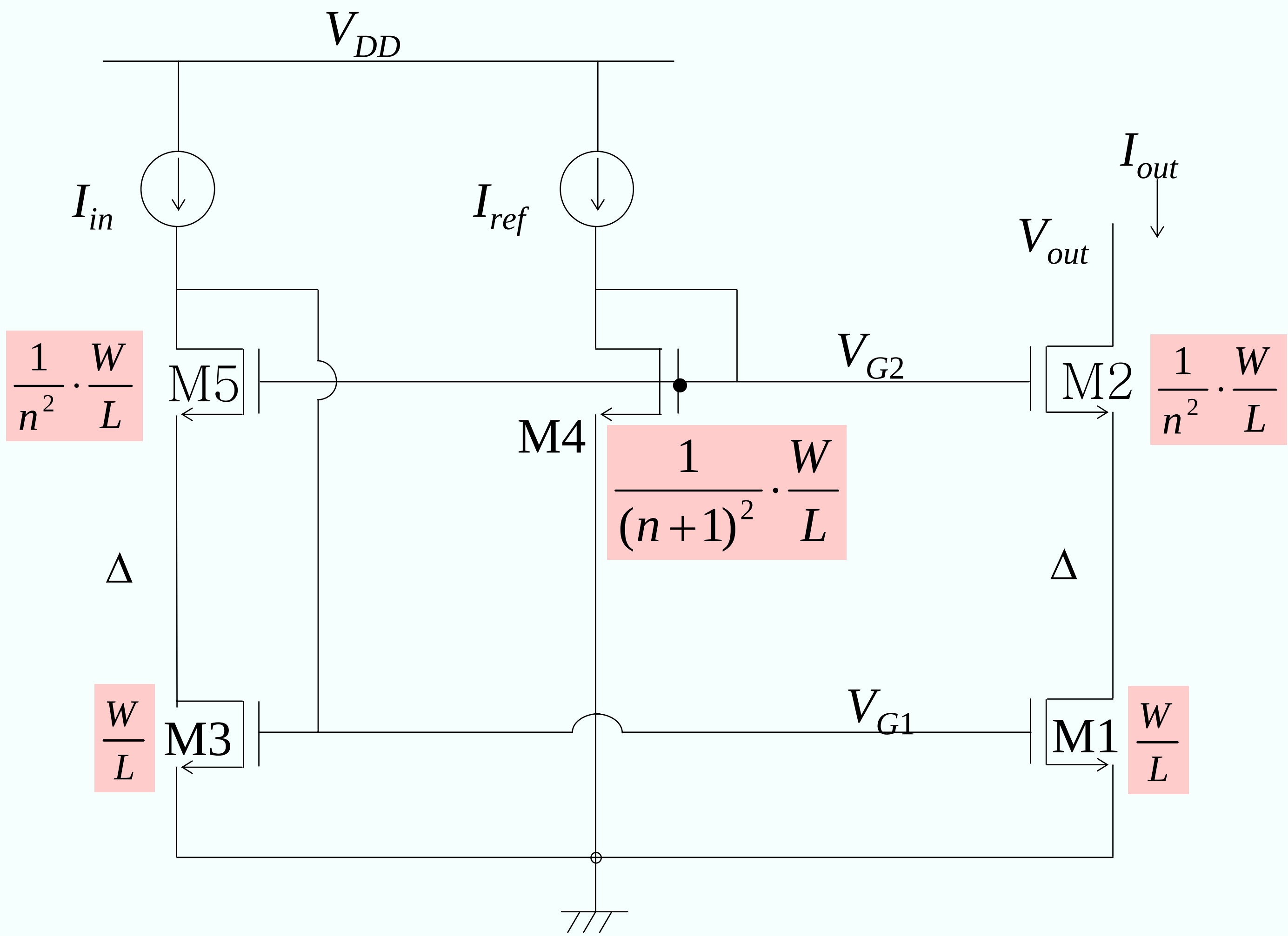




$$V_{DS6} = V_{GS6} - R_b I_1 \approx V_{GS1} - V_{TH1}$$

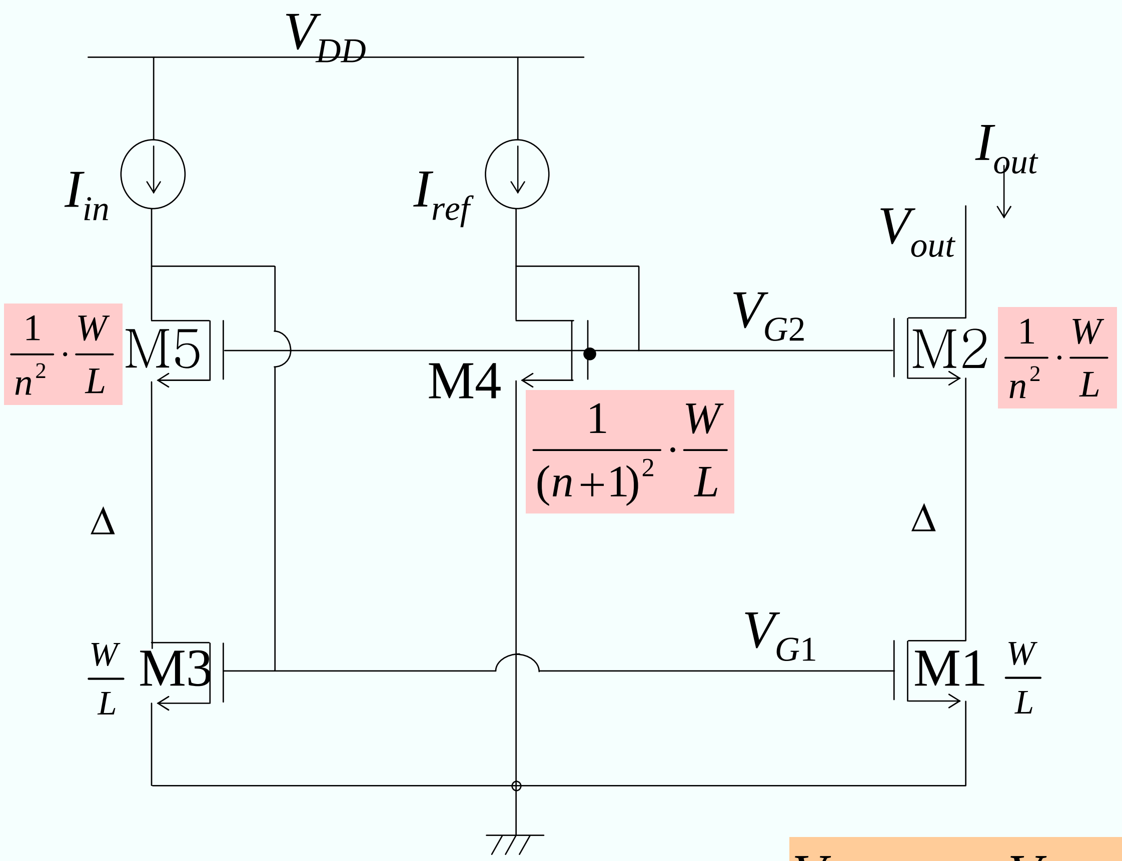
M_7 has a large W/L so that $V_{GS7} \approx V_{TH7}$

Wide-swing cascode current source 3



$$V_{out} \geq V_{G2} - V_{TH} = (n+1)\cdot\Delta\cdot\sqrt{\frac{I_{ref}}{I_{in}}}$$

Wide-swing cascode current source 3



$$V_{G1} = V_{TH} + \Delta$$

$$V_{GS5} = V_{TH} + n\cdot\Delta$$

$$V_{GS2} = V_{TH} + n\cdot\Delta$$

$$V_{G2} = V_{TH} + (n+1)\cdot\Delta\cdot\sqrt{\frac{I_{ref}}{I_{in}}}$$

$$V_{DS3} = V_{G2} - V_{GS5} = \Delta\cdot\sqrt{\frac{I_{ref}}{I_{in}}} + n\cdot\Delta\cdot\left(\sqrt{\frac{I_{ref}}{I_{in}}} - 1\right)$$

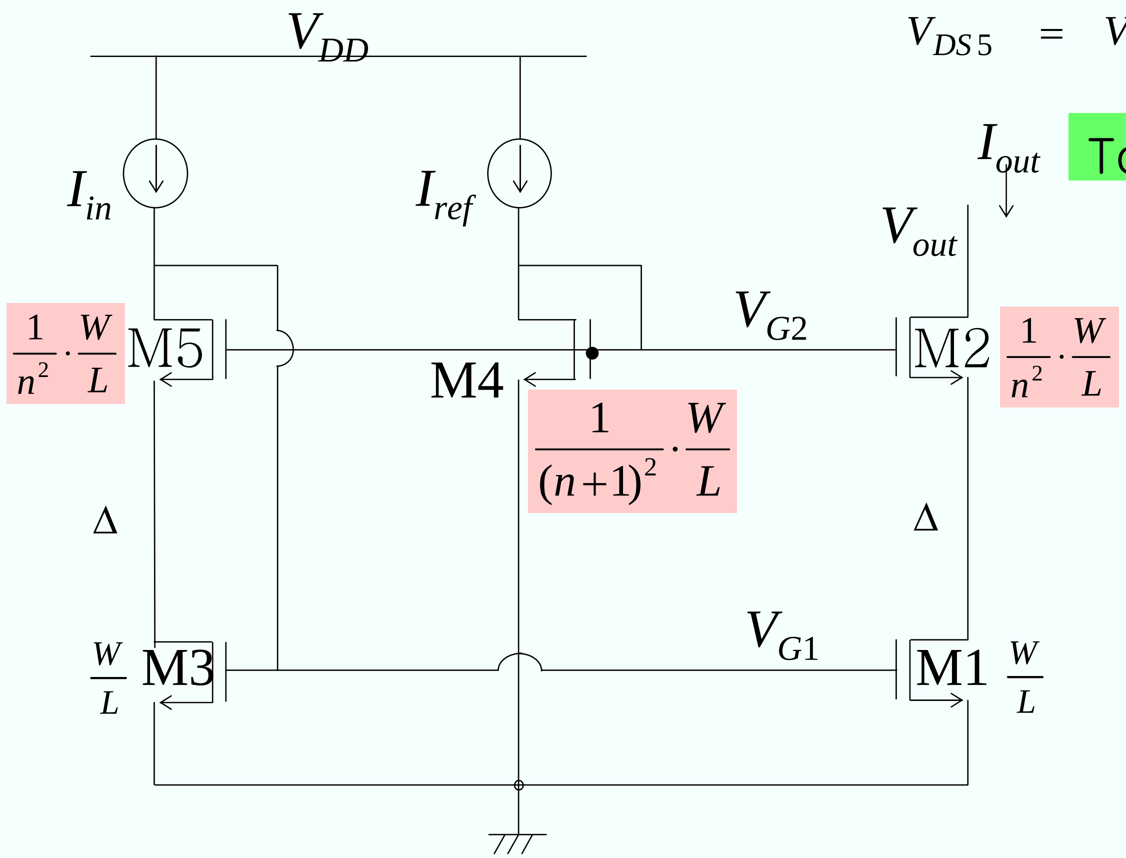
$$V_{DS1} = V_{G2} - V_{GS2} = \Delta\cdot\sqrt{\frac{I_{ref}}{I_{in}}} + n\cdot\Delta\cdot\left(\sqrt{\frac{I_{ref}}{I_{in}}} - 1\right)$$

Wide-swing cascode current source 3

$$V_{DS3} = V_{G2} - V_{GS5} = \Delta \cdot \sqrt{\frac{I_{ref}}{I_{in}}} + n \cdot \Delta \cdot \left(\sqrt{\frac{I_{ref}}{I_{in}}} - 1\right)$$

$$V_{DS1} = V_{G2} - V_{GS2} = \Delta \cdot \sqrt{\frac{I_{ref}}{I_{in}}} + n \cdot \Delta \cdot \left(\sqrt{\frac{I_{ref}}{I_{in}}} - 1\right)$$

$$V_{DS5} = V_{G1} - V_{DS3} = V_{TH} - (n+1) \cdot \Delta \cdot \left(\sqrt{\frac{I_{ref}}{I_{in}}} - 1\right)$$



To satisfy the following three conditions

$$V_{DS3} \geq \Delta$$

$$V_{DS5} \geq n \cdot \Delta$$

$$V_{DS1} \geq \Delta$$

➔

$$I_{in} \leq I_{ref}$$

$$n \leq \frac{V_{TH} + \Delta}{\Delta} \cdot \sqrt{\frac{I_{in}}{I_{ref}}} - 1$$