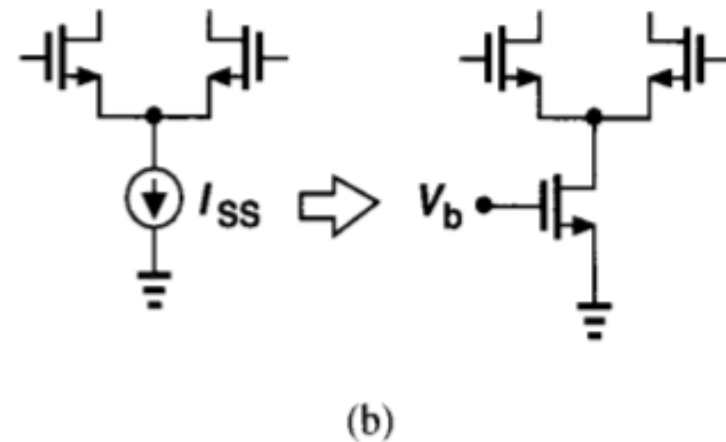
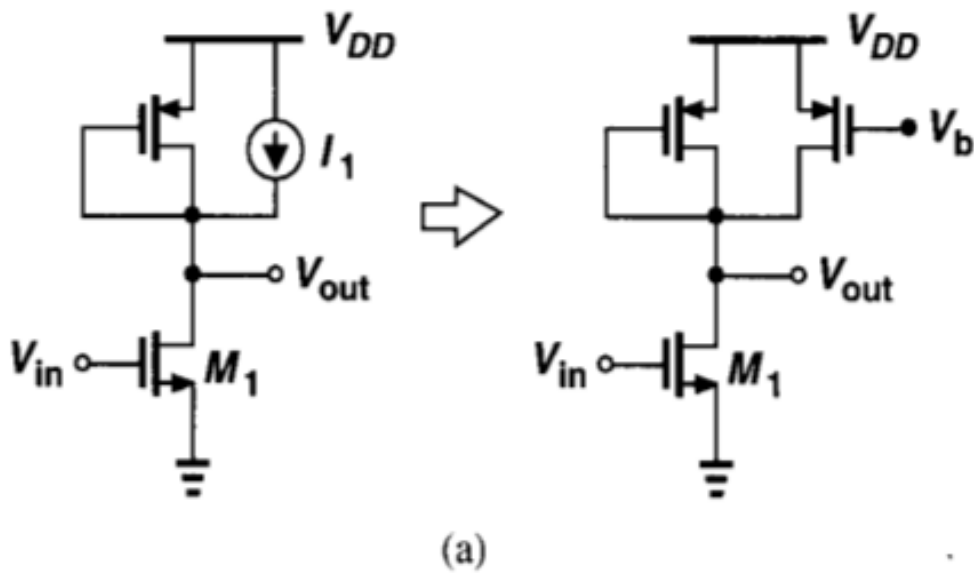


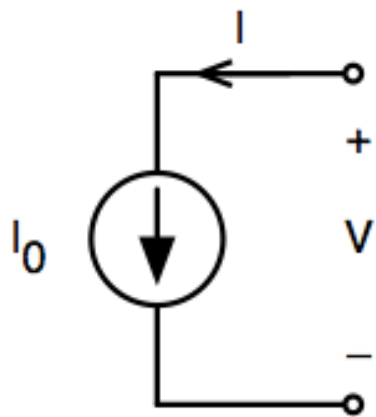


วงจรสะท้อนกระแส

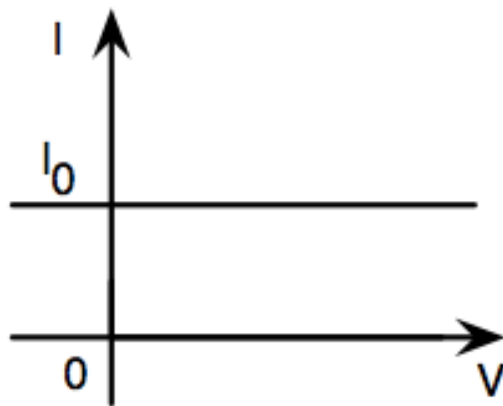
+ MOSFET as a current source



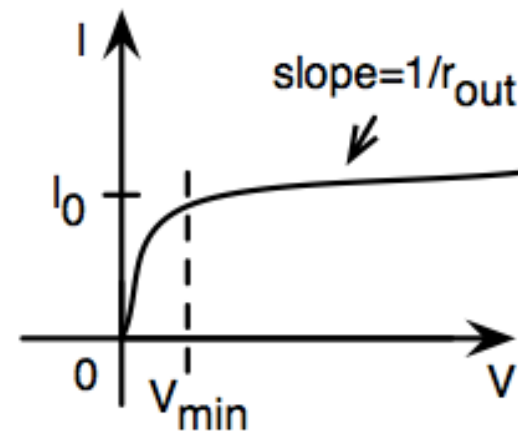
+ Ideal current source



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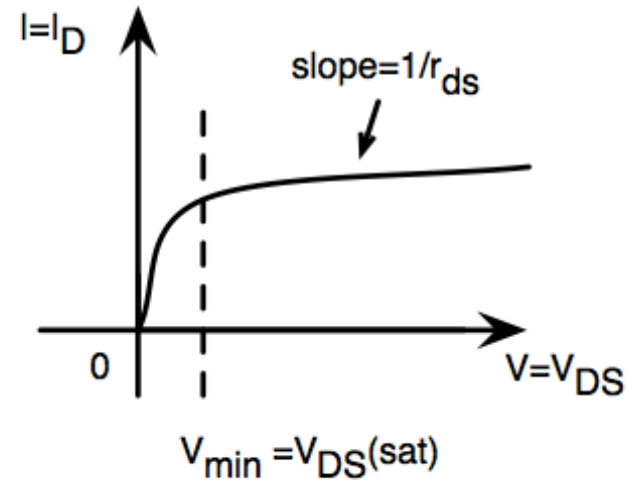
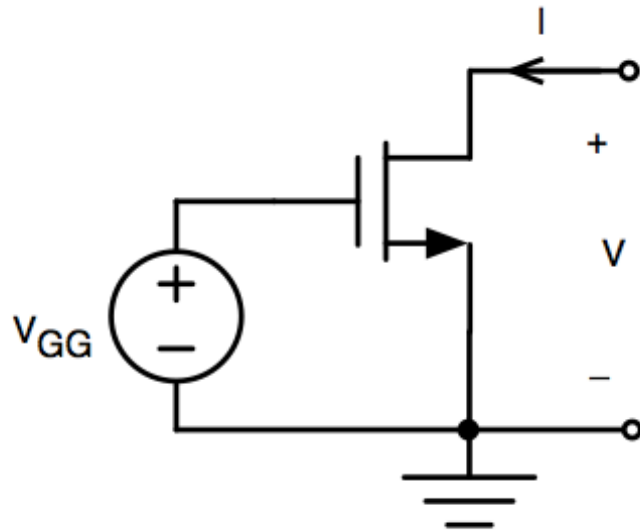


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+ Simple NMOS current source

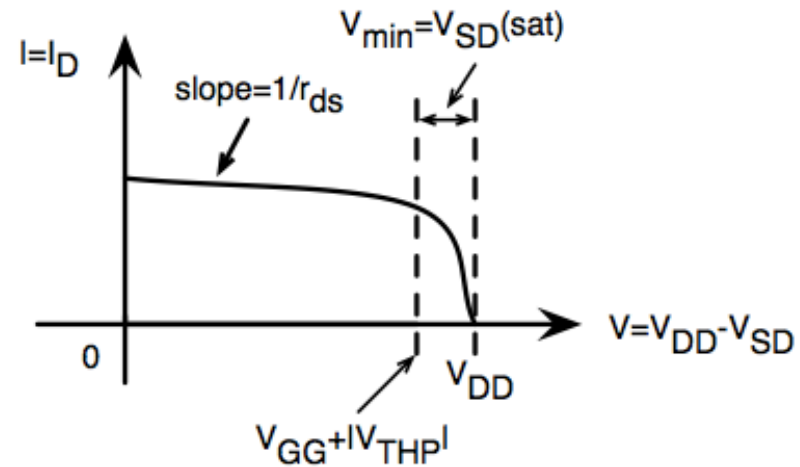
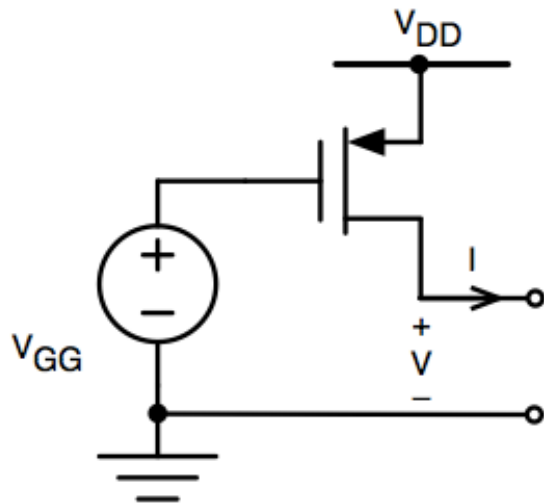


$$I_{out} = I_D = \frac{\mu_n C_{ox}}{2} \left(\frac{W}{L} \right) (V_{GG} - V_{THN})^2$$

$$r_{out} = r_{ds} = \frac{1}{\lambda_N I_D}$$

$$V_{min} = V_{DS}(sat) = V_{GG} - V_{TH}$$

+ Simple PMOS current source

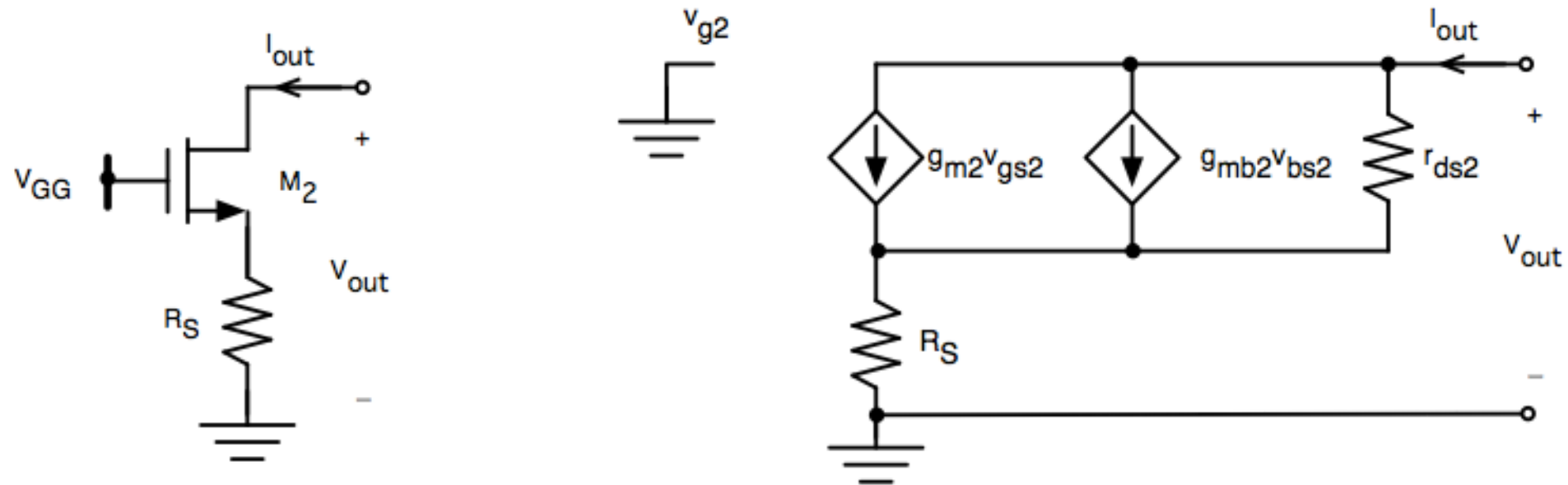


$$I_{out} = I_D = \frac{\mu_P C_{ox}}{2} \left(\frac{W}{L} \right) (V_{DD} - V_{GG} - |V_{THP}|)^2$$

$$r_{out} = r_{ds} = \frac{1}{\lambda_P I_D}$$

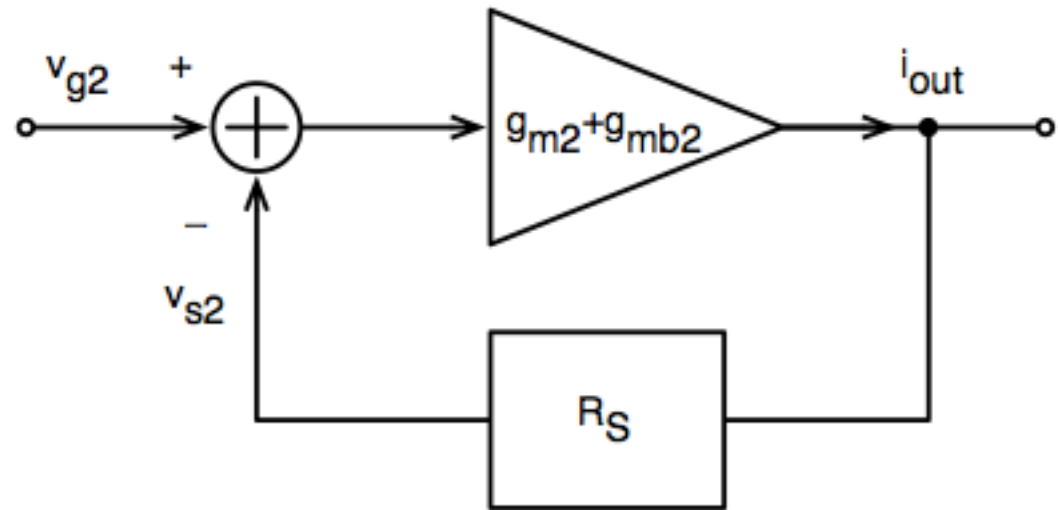
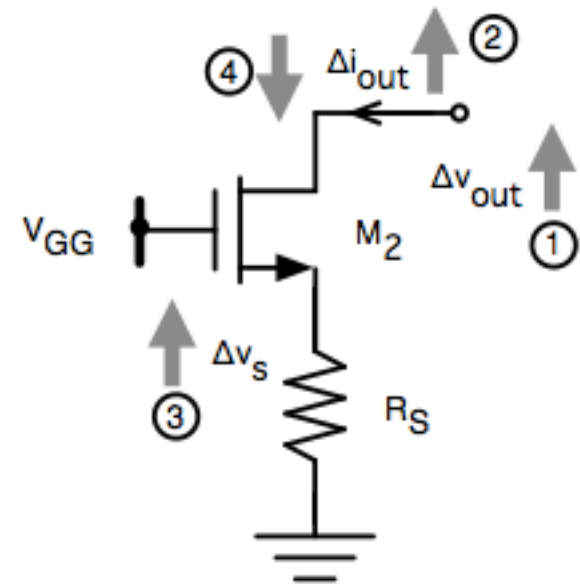
$$V_{min} = V_{SD}(sat) = V_{DD} - V_{GG} - |V_{THP}|$$

+ Increasing r_{out} with source degeneration technique

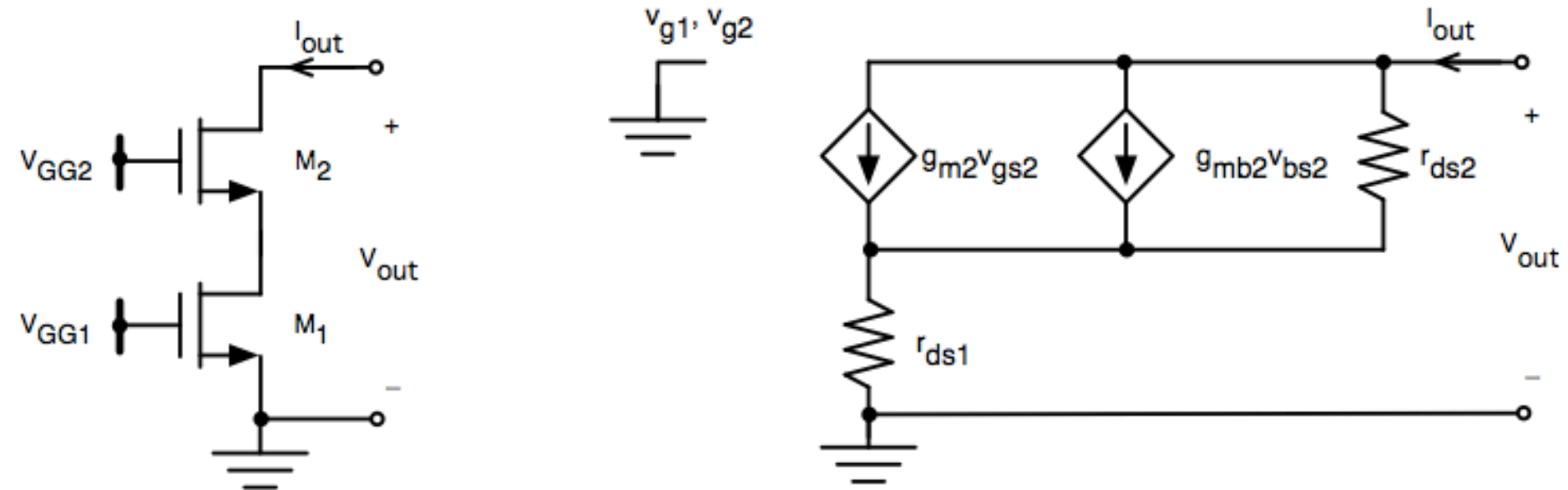


$$r_{out} = r_{ds2} + R_S [1 + (g_{m2} + g_{mb2}) r_{ds2}] \approx (g_{m2} R_S) r_{ds2}$$

+ Feedback model of source degeneration technique



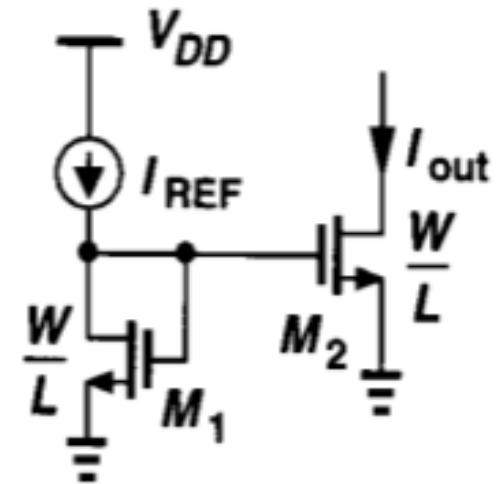
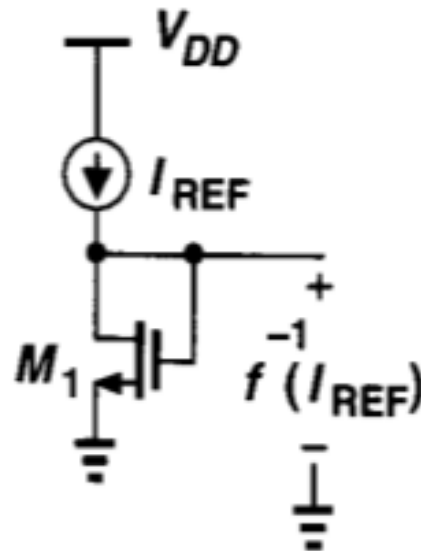
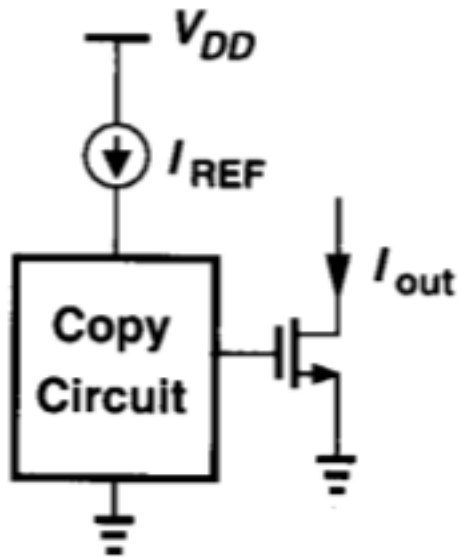
+ Cascode current source



$$r_{out} = r_{ds2} + r_{ds1} [1 + (g_{m2} + g_{mb2}) r_{ds2}] \approx (g_{m2} r_{ds2}) r_{ds1}$$

$$V_{min} = V_{DS1}(sat) + V_{DS2}(sat)$$

+ Current mirror

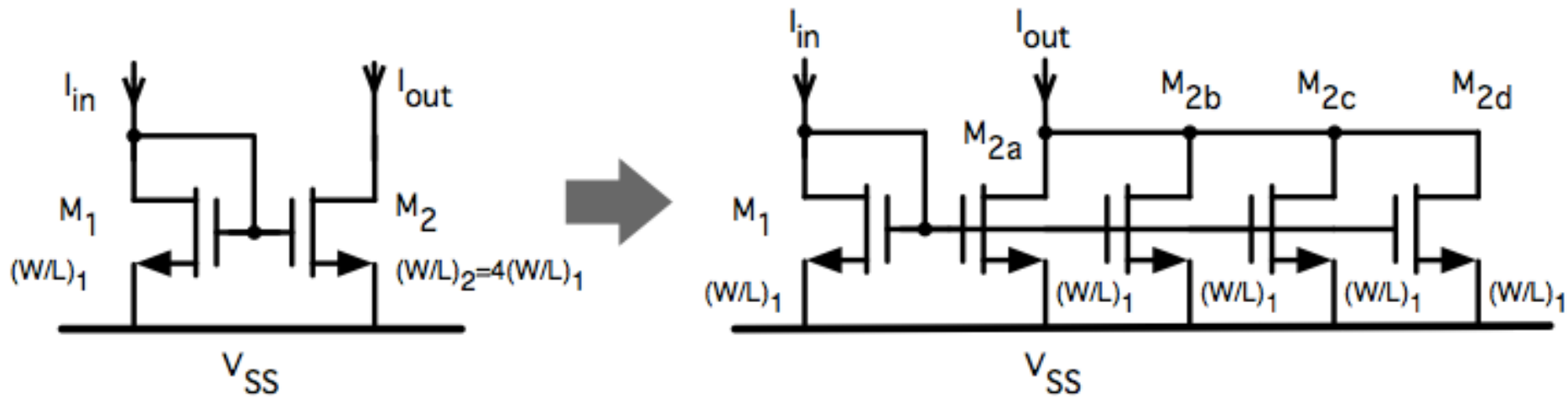


$$\frac{I_{out}}{I_{in}} = \frac{(\mu_n C_{ox})_2 (W/L)_2 (V_{GS2} - V_{TH2})^2 (1 + \lambda V_{DS2})}{(\mu_n C_{ox})_1 (W/L)_1 (V_{GS1} - V_{TH1})^2 (1 + \lambda V_{DS1})}$$

$$\frac{I_{out}}{I_{in}} = \frac{(W/L)_2 (1 + \lambda V_{DS2})}{(W/L)_1 (1 + \lambda V_{DS1})}$$

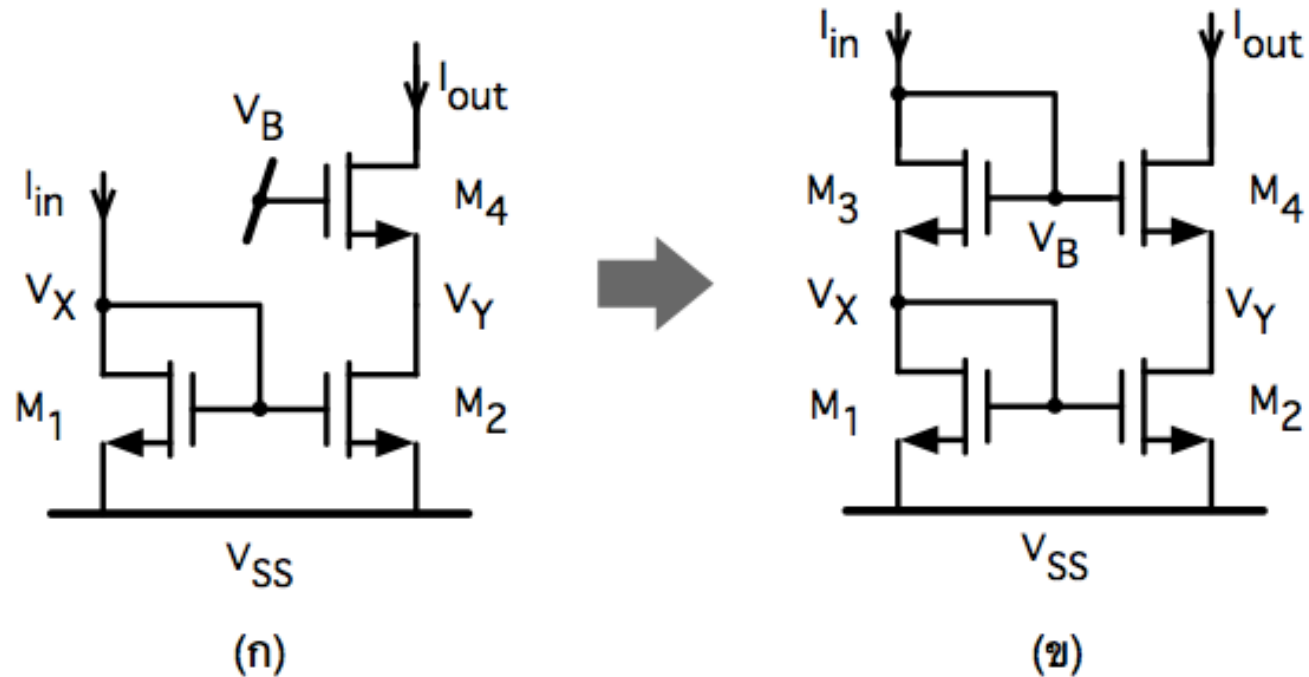
$$\frac{I_{out}}{I_{in}} = \frac{(W/L)_2}{(W/L)_1}$$

+ Accuracy improvement



$$\frac{I_{out}}{I_{in}} = \frac{W_2}{W_1} = \frac{4W}{W} = \frac{4(5 \pm 0.05)}{5 \pm 0.05} = 4$$

+ Cascode current mirror



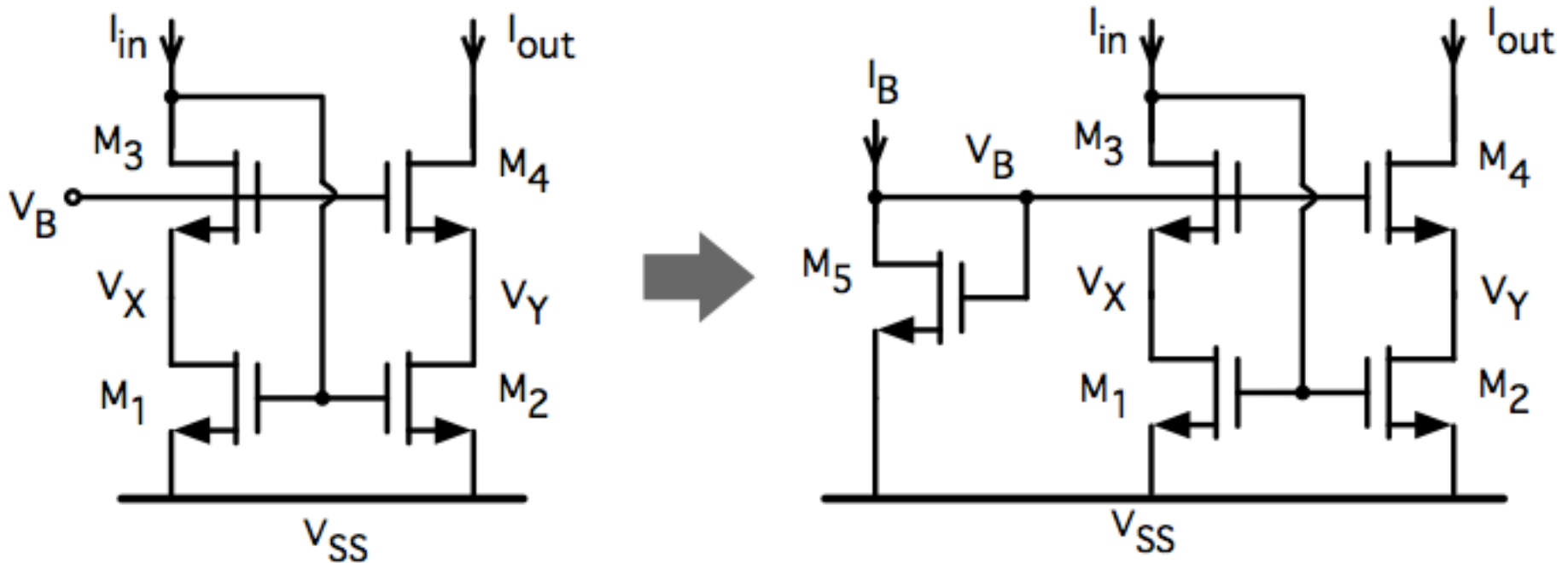
$$V_B \leq V_{out} + V_{THN}$$

$$V_{DS2} = V_{DS1} = V_{GS1}$$

$$V_{min} = V_{GS1} + V_{DS4}(sat) = V_{DS1}(sat) + V_{DS4}(sat) + V_{THN}$$

$$r_{out} = r_{ds2} + r_{ds4} + [(g_{m4} + g_{mb4}) r_{ds4}] r_{ds2} \approx g_{m4} r_{ds4} r_{ds2}$$

+ Low voltage cascode current source



$$V_B \geq V_{GS3} + V_{GS1} - V_{TH1}$$

$$V_B \leq V_{GS1} + V_{TH3}$$

$$V_{GS3} + V_{GS1} - V_{TH1} \leq V_B \leq V_{GS1} + V_{TH3}$$

$$V_{GS3} - V_{TH3} \leq V_{TH1} \text{ หรือ } V_{DS3}(\text{sat}) \leq V_{TH1}$$