EE223 Analog Integrated Circuits
Fall 2018

Lecture 13: Current Mirror Matching

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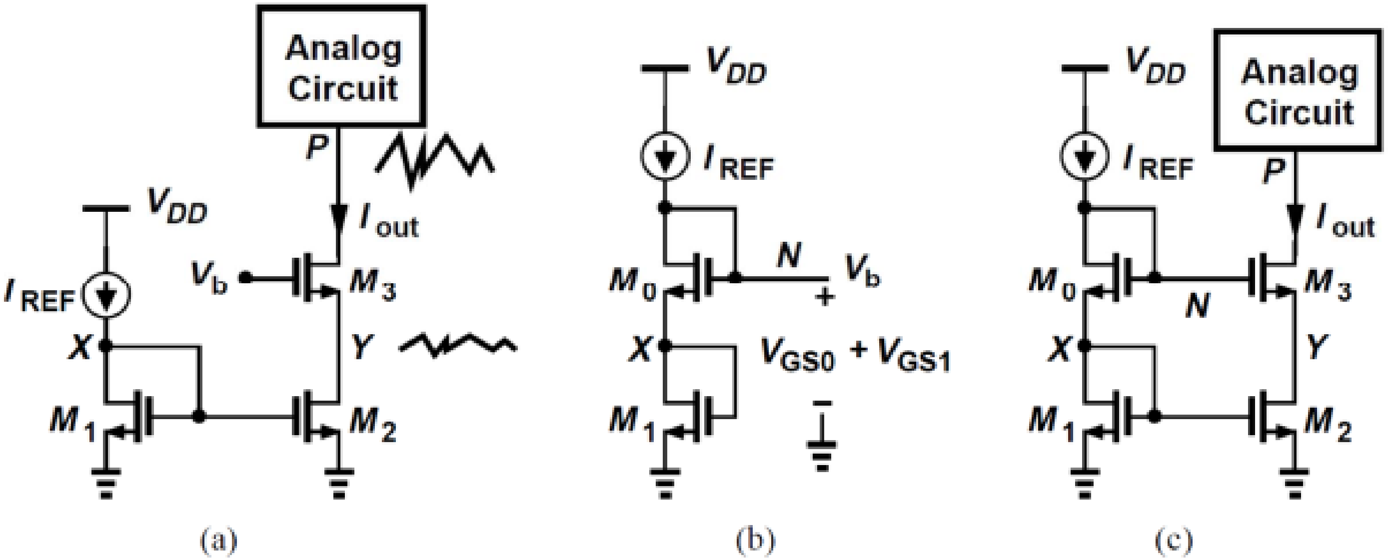
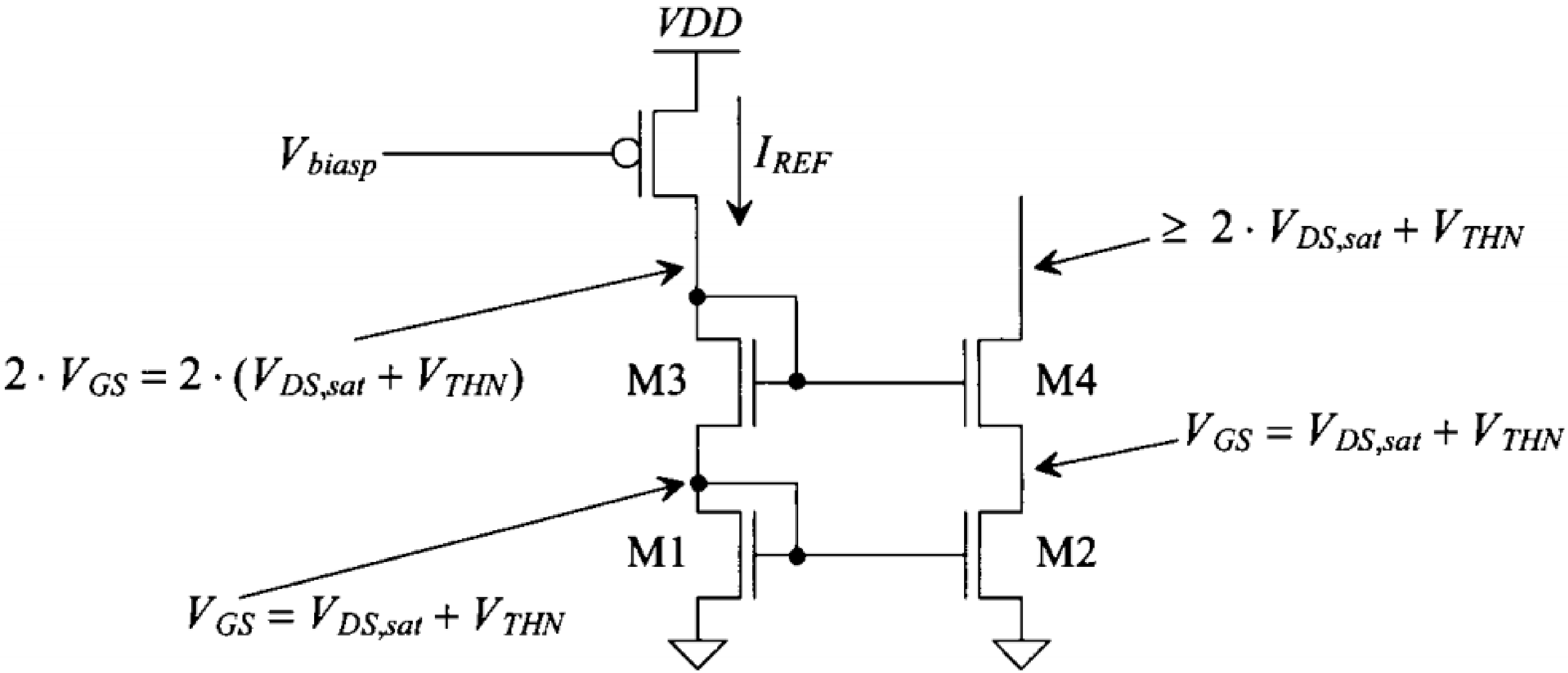
Cascode Current Mirror



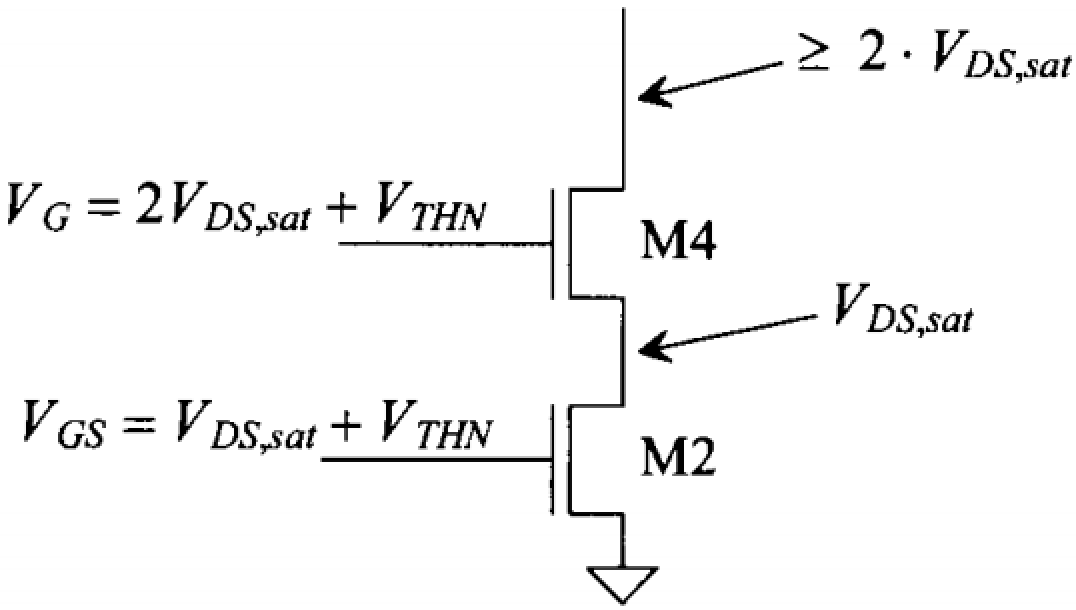
- A cascode device can shield a current source, thereby reducing the voltage variations across it.
- But, how do we ensure that $V_{DS2} = V_{DS1}$?
- We can generate V_b such that $V_b - V_{GS3} = V_{DS1}(=V_{GS1})$ with a stacked diode connected transistor

Cascode Current Mirror Compliance Voltage



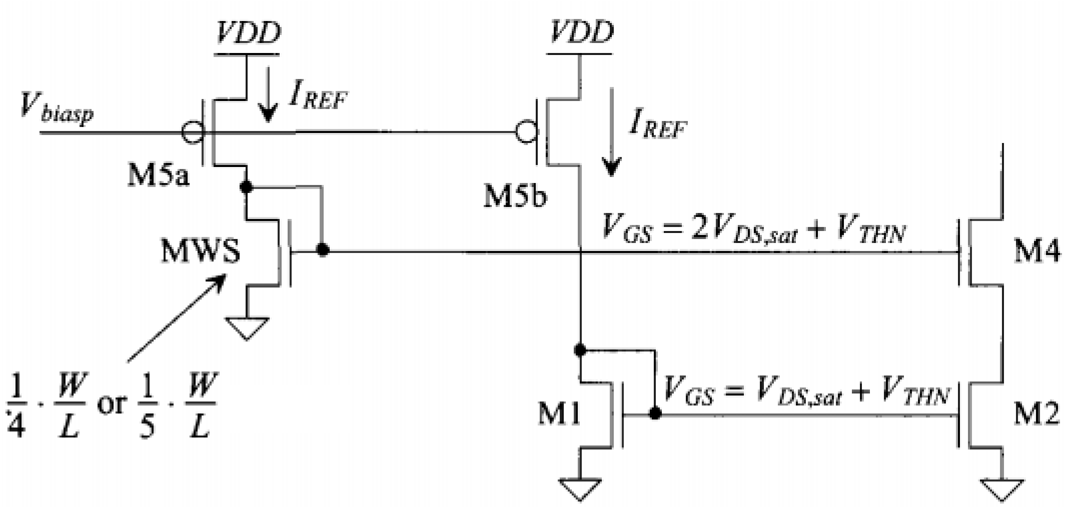
(a) Regular cascode structure

Wide-Swing (High-Swing or Low-Voltage) Cascode



(b) Low-voltage (aka wide-swing) structure

High-Swing (Wide-Swing) Cascode Current Mirror



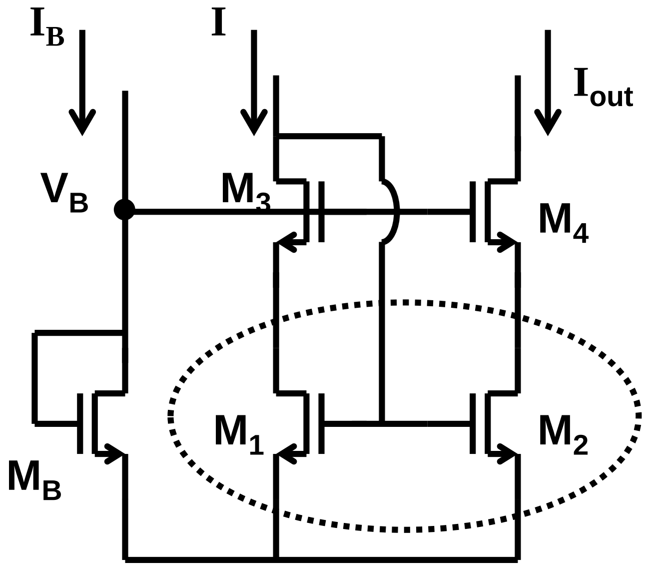
$$I_{REF} = \frac{KP_n}{2} \cdot \frac{W_{MWS}}{L_{MWS}} (2(V_{GS} - V_{THN}) + V_{THN} - V_{THN})^2$$

$$= \frac{KP_n}{2} \cdot \frac{W_{MWS}}{L_{MWS}} \cdot 4(V_{GS} - V_{THN})^2$$

$$= \frac{KP_n}{2} \cdot \frac{W}{L} (V_{GS} - V_{THN})^2$$

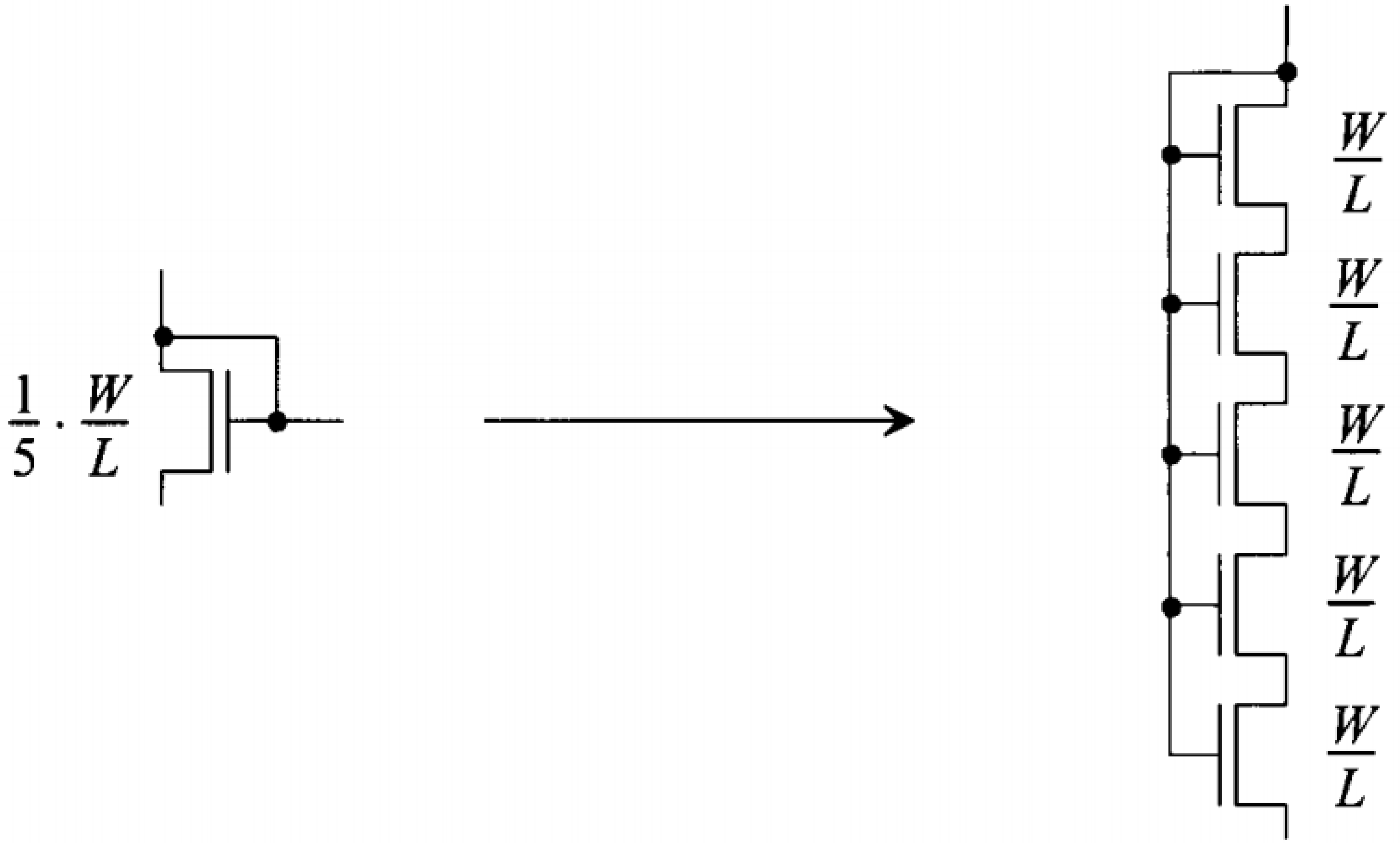
$$\frac{W}{L} = \frac{W_{MWS}}{L_{MWS}} \cdot 4$$

High-Swing (Wide-Swing) Cascode Current Mirror

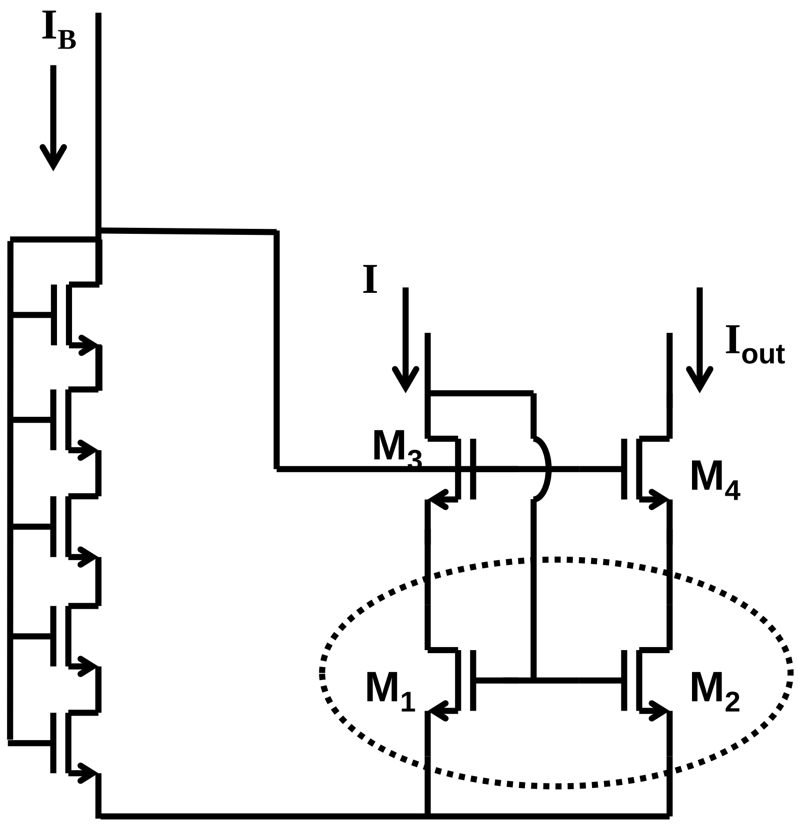


- $r_{out} = a / g_{ds2} = g_m\ r_{out}^2$
- $V_{out,min} = V_{dsat2} + V_{dsat4} = 2V_{dsat}$
- $(W/L)_B = ¼\ (W/L)_{1,2}$
  - Typically choose 1/5 ~ 1/10

Layout Consideration on High Swing Cascode Bias

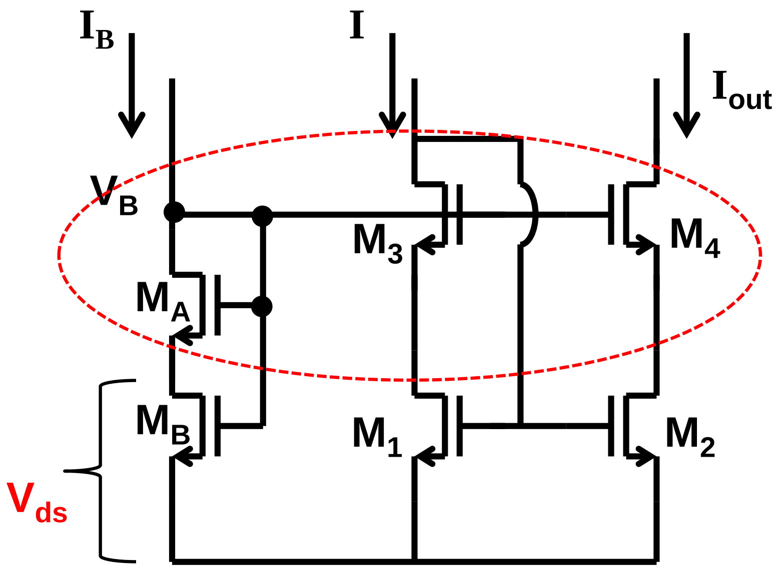


High-Swing (Wide-Swing) Cascode Current Mirror



Biasing High Swing Cascode Current Mirror

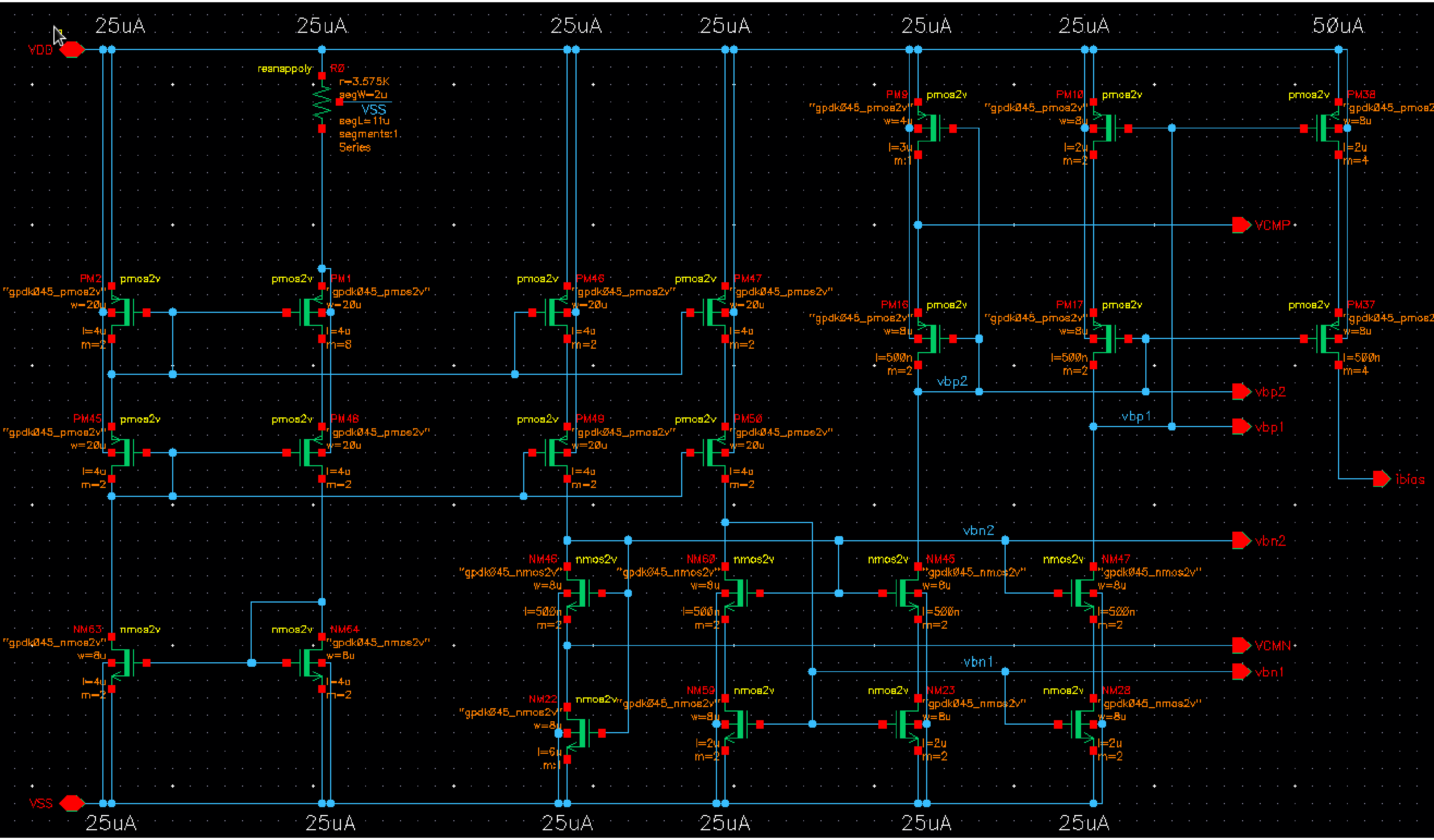
Practical approach for cascode biasing
→ Will use this biasing scheme extensively



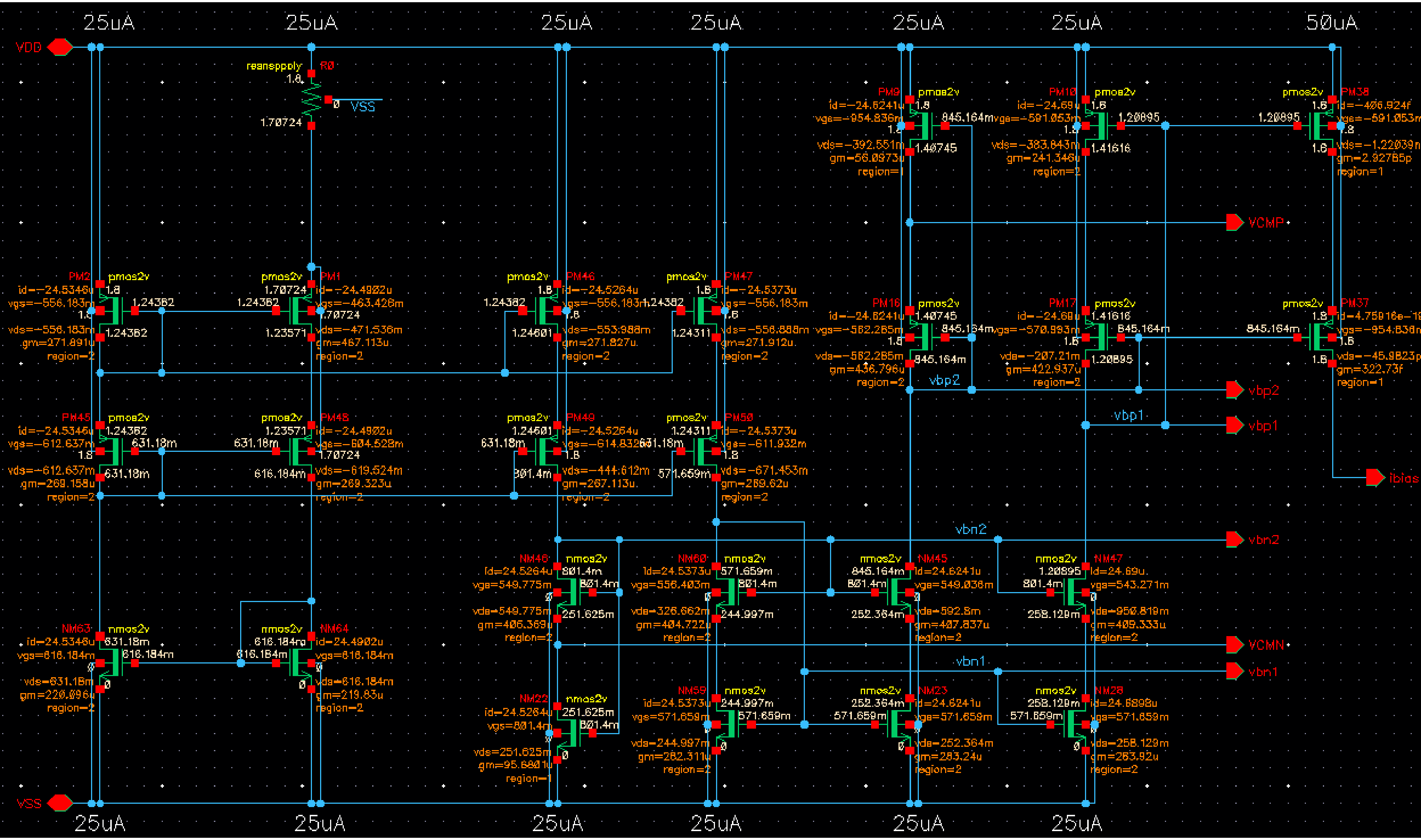
- M_A in Saturation
- M_B in Triode
- $(W/L)_A = (W/L)_3 = (W/L)_4$
- $(W/L)_B$ with large L
- Example:
  - $(W/L)_{A,3,4} = 5/0.18$
  - $(W/L)_B = 5/5$
  - Adjust L of M_B in Simulation to get the Vds you want

If you make the current densities of M_A, M_3 and M_4 are equal, V_{ds} of M_B will be copied over to V_{ds} of M_1 and M_2

Example Biasing High Swing Cascode Current Mirror

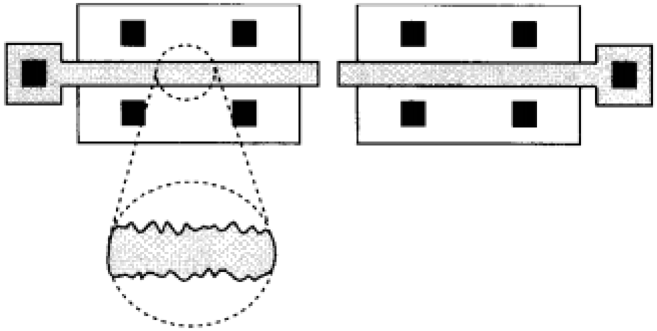


Example Biasing High Swing Cascode Current Mirror

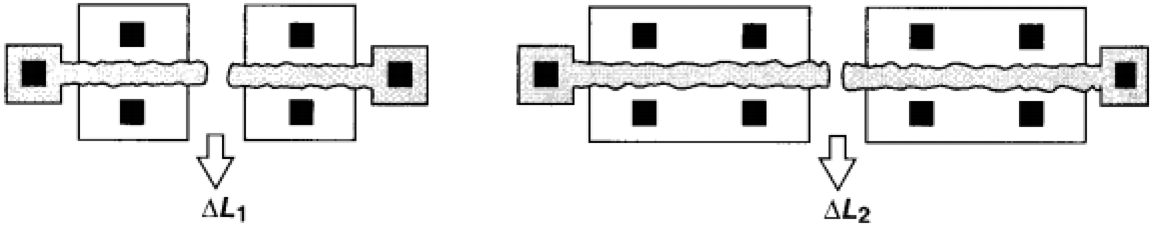


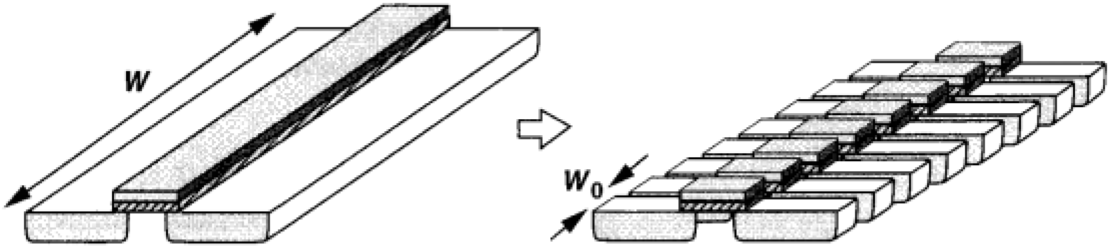
MOSFET Matching

Random Device Mismatch

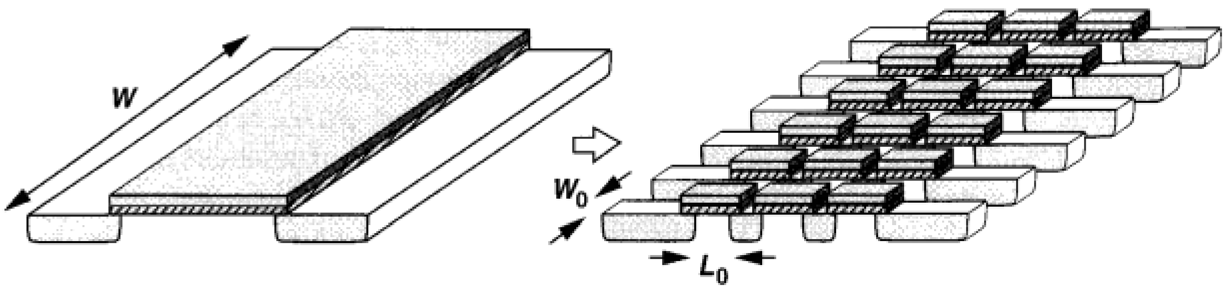


Mismatch Reduction with Large Device





Mismatch Reduction with Large Device



MOSFET Matching

IEEE JOURNAL OF SOLID-STATE CIRCUITS, VOL. 24, NO. 5, OCTOBER 1989 1433

Matching Properties of MOS Transistors

MARCEL J. M. PELGROM, MEMBER, IEEE, AAD C. J. DUINMAIJER,
AND ANTON P. G. WELBERS

Abstract —The ı
factor, and current factor of MOS transistors have been analyzed and measured. Improvements to the existing theory are given, as well as extensions for long-distance matching and rotation of devices. Matching parameters of several processes are compared. The matching results have been verified by measurements and calculations on several basic circuits.

A systematic study of mismatch between parameters of two identical MOSFETs.

Manufacturing devices with different W/L, distance, orientation to see how this affects matching.

MOSFET Matching Model

Matching of parameter, P, between two identically drawn devices

Area proportionality constant

$$\sigma^2_{\Delta P} = \frac{A_P^2}{WL} + S_P^2 D_x^2$$

Distance

Size

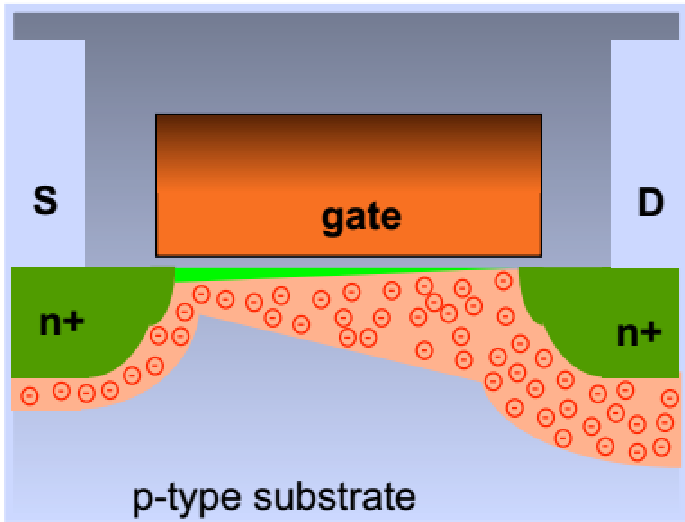
Variation with spacing

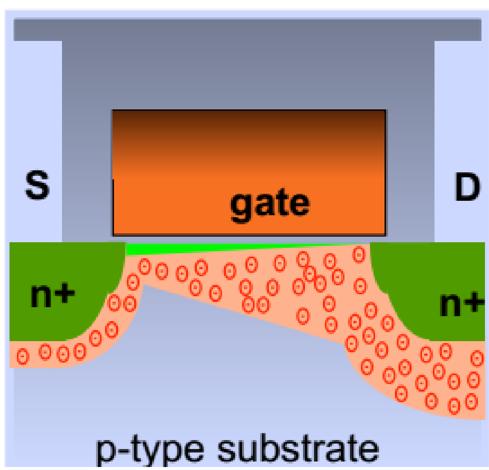
SpDx can be made small with good layout

Need to quadruple the area to reduce the mismatch by a factor of 2

MOSFET Matching and Technology Scaling

Impact of Technology scaling on Transistor matching?





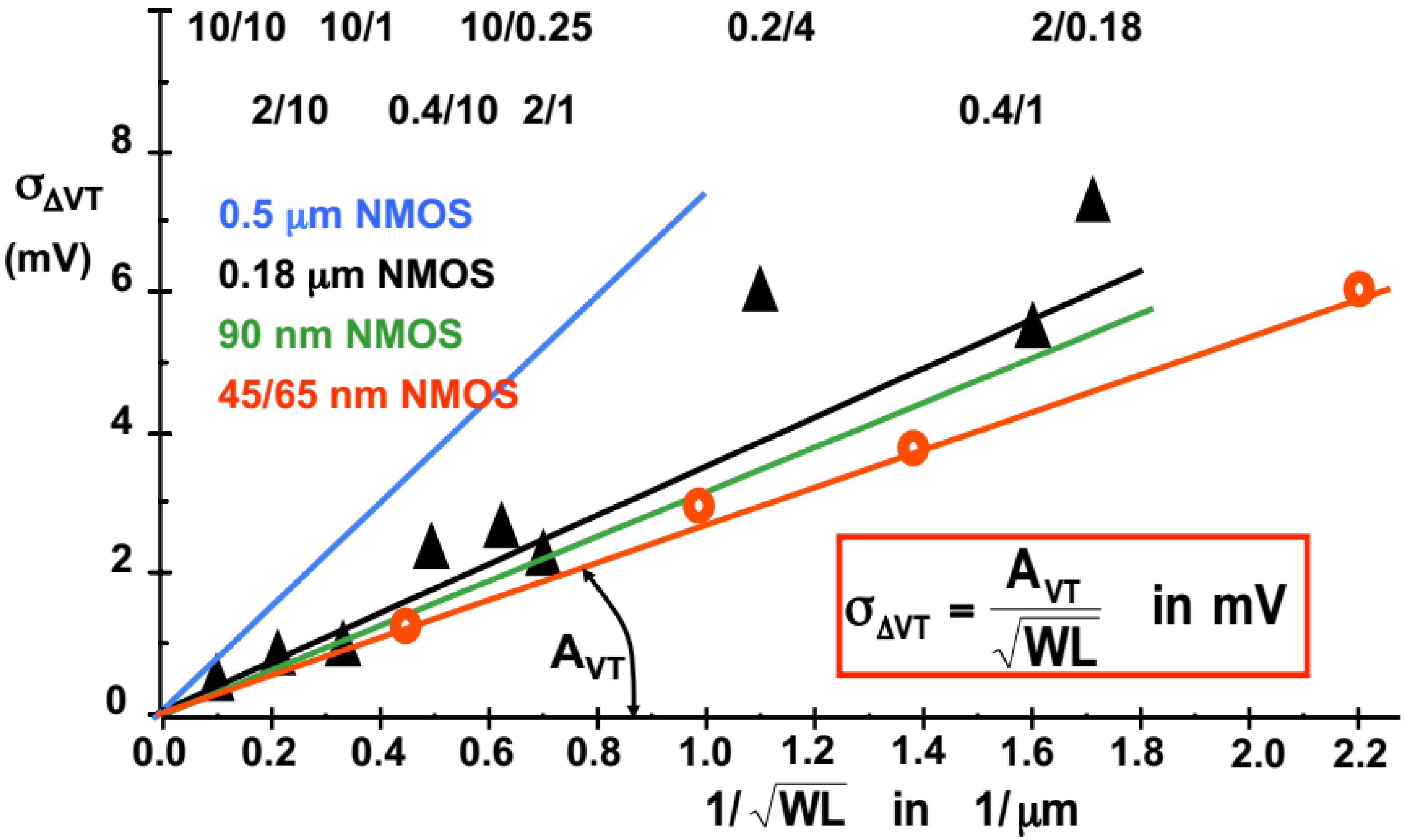
$$\sigma_{\Delta VT} \propto \frac{t_{ox}\sqrt[4]{N_a}}{\sqrt{W \times L}} = \frac{A_{VT}}{\sqrt{WL}}$$

$$t_{ox} \downarrow$$

$$\sqrt[4]{N_a} \uparrow$$

Hence: V_T matching improves for more advanced technologies

MOSFET Matching and Technology Scaling



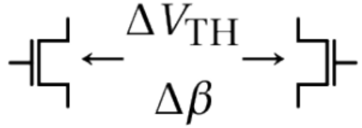
Ref: M. Pelgrom IEEE JSSC 1989 p. 1433, Tuinhout, Wils, and work by many others

Basic Rule of Matching

- Big devices match better. Randomness averages out more over a larger area.
- Big devices, more capacitance, more area.
- Reducing random mismatch comes at a cost.
- Important to know how much mismatch we can live with to avoid costly overdesign.

MOSFET Mismatch

- Mismatch between two identically drawn transistors.
  - Vth mismatch
  - Beta mismatch



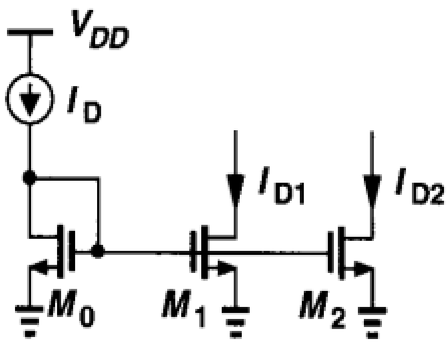
$$I_D = \frac{\mu_n C_{ox}}{2}\frac{W}{L}(V_{GS} - V_{TH})^2 = \frac{\beta}{2}(V_{GS} - V_{TH})^2$$

$$\Delta V_{TH} = \frac{A_{VTH}}{\sqrt{WL}}$$

$$\Delta\left(\mu C_{OX}\frac{W}{L}\right) = \frac{A_K}{\sqrt{WL}},$$

$$\boxed{\frac{A_{VTH}}{t_{ox}} \approx \frac{\mathrm{mV}\cdot\mu\mathrm{m}}{\mathrm{nm}}}$$

Current Mirror Mismatch



$$y = f(x_1, x_2, \ldots)$$

$$\Delta y = \frac{\partial f}{\partial x_1}\Delta x_1 + \frac{\partial f}{\partial x_2}\Delta x_2 + \cdots$$

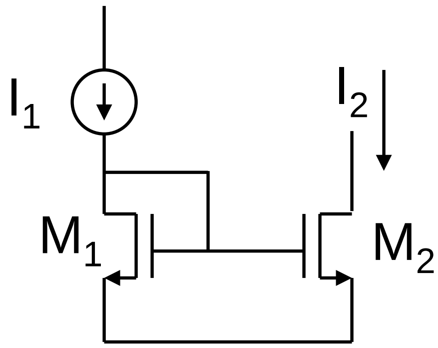
$$I_D = (1/2)\mu_n C_{ox}(W/L)(V_{GS} - V_{TH})^2$$

$$\Delta I_D = \frac{\partial I_D}{\partial (W/L)}\Delta\left(\frac{W}{L}\right) + \frac{\partial I_D}{\partial (V_{GS} - V_{TH})}\Delta(V_{GS} - V_{TH})$$

$$\Delta I_D = \frac{1}{2}\mu_n C_{ox}(V_{GS} - V_{TH})^2 \Delta\left(\frac{W}{L}\right) - \mu_n C_{ox}\frac{W}{L}(V_{GS} - V_{TH})\Delta V_{TH}$$

$$\boxed{\frac{\Delta I_D}{I_D} = \frac{\Delta(W/L)}{W/L} - 2\frac{\Delta V_{TH}}{V_{GS} - V_{TH}}}$$

Question on Current Mirror Mismatch



Current Mirror Mismatch

$$\frac{\Delta I}{I} \sim \frac{2\Delta V_{th}}{V_{GS}-V_{th}}$$

$$I_D = \frac{\mu_n C_{ox}}{2}\left(\frac{W}{L}\right)(V_{gs} - V_{th})^2(1+\lambda V_{DS})$$

$$\lambda \sim \frac{1}{L}$$

$$\Delta I_D = I_2 - I_1 = g_m \cdot \Delta V_{th} = \frac{2I}{V_{gs} - V_{th}} \cdot \Delta V_{th}$$

$$\frac{\Delta I}{I} = \frac{2\,\Delta V_{th}}{V_{gs} - V_{th}} \qquad \Delta V_{th} = \frac{A_{vt}}{\sqrt{WL}}$$

Mismatch Example Question for $I_1 = 10\ \mu A$ and $A_{vt} = 3\ mV \cdot \mu m$

Compare the current mismatch for the following 2 cases:

Case 1: $\frac{W}{L} = \frac{10\mu m}{10\mu m}$ Case 2: $\frac{W}{L} = \frac{100\mu m}{1\mu m}$