EE223 Analog Integrated Circuits
Fall 2018

Lecture 11: CMRR and Beta_Multiplier

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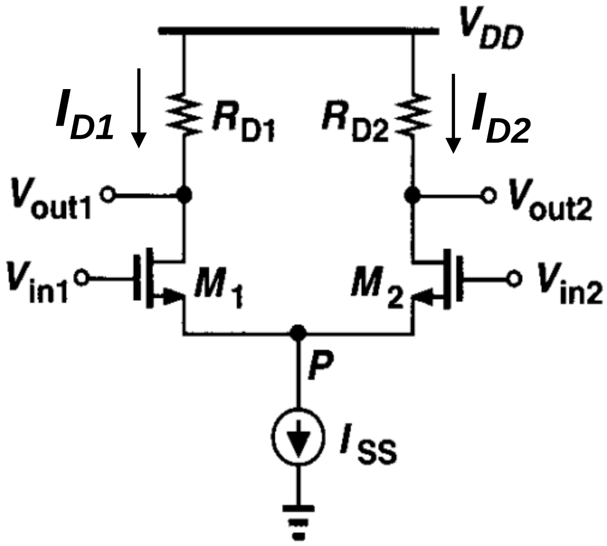
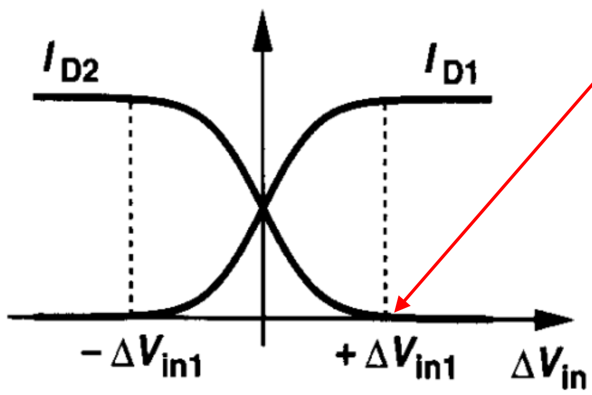
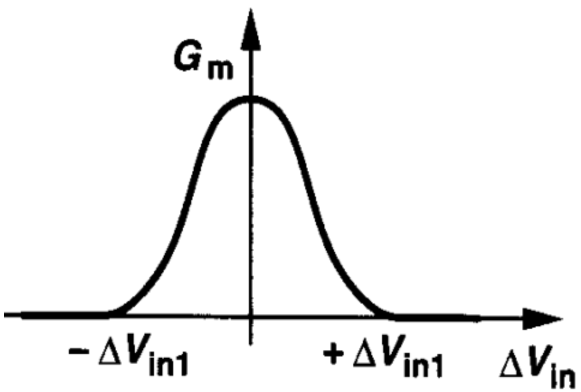
ENG-259

Large Signal Analysis of Differential Pair

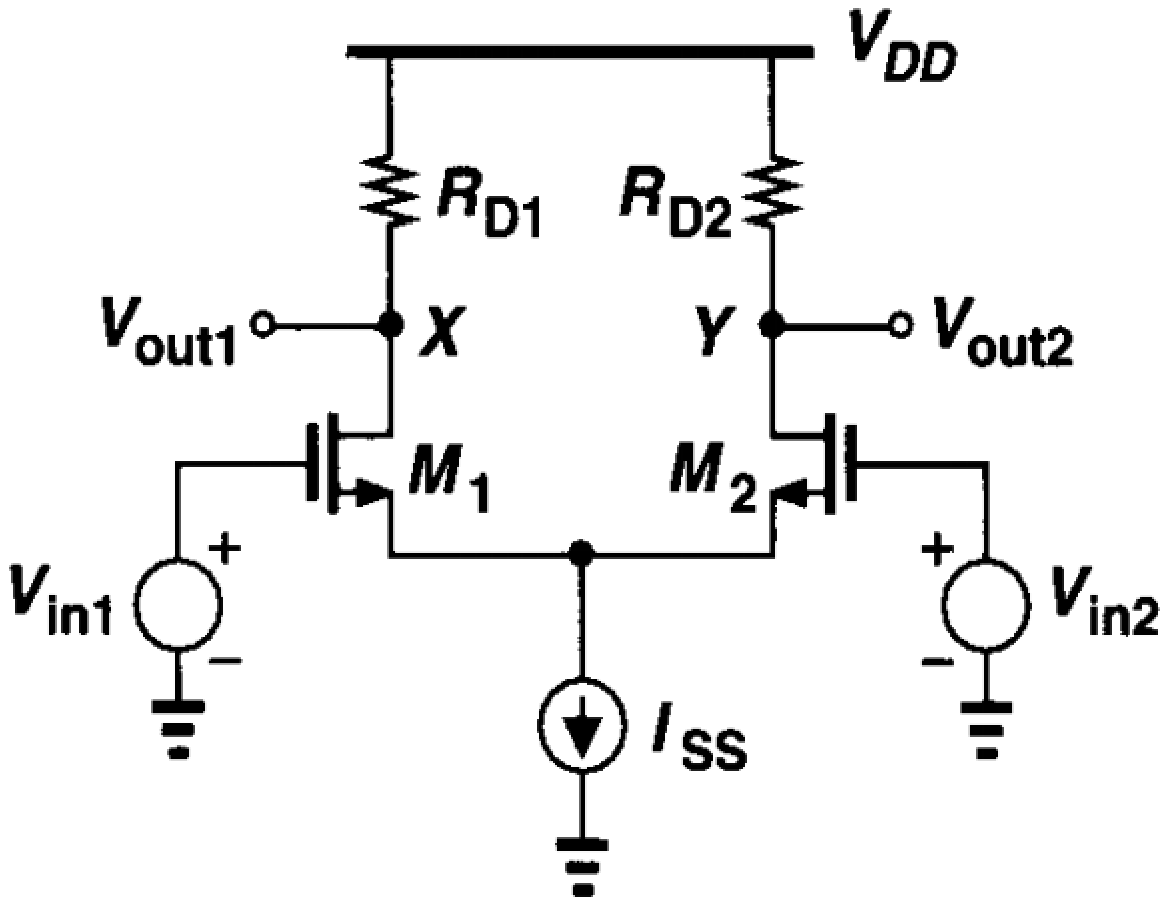


$\sqrt{2}\,V_{dsat}$ *of* M_1 *&* M_2 *in equilibrium*

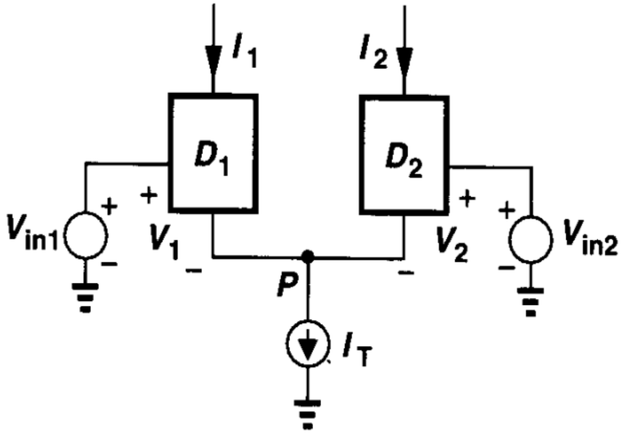


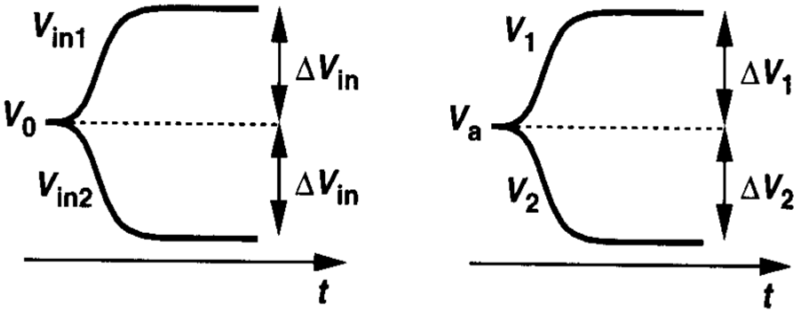


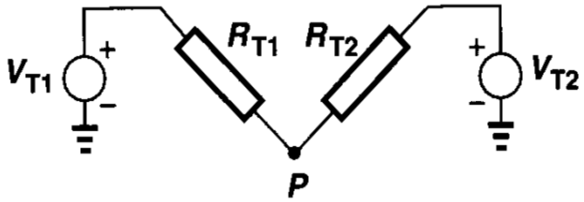
Small-Signal Behaviors of Differential Pair



Half-Circuit Concept

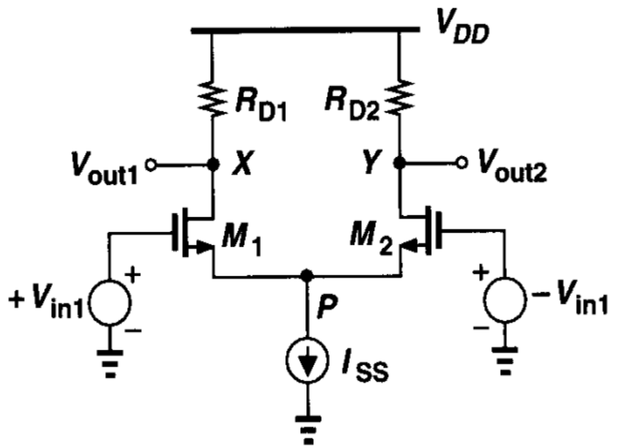


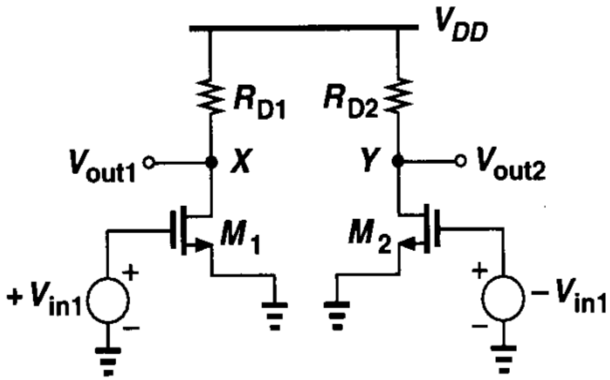


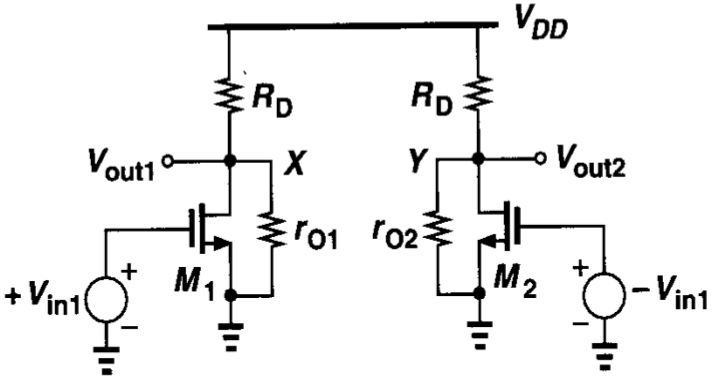


P is a virtual ground

Differential Gain Using the Half-Circuit







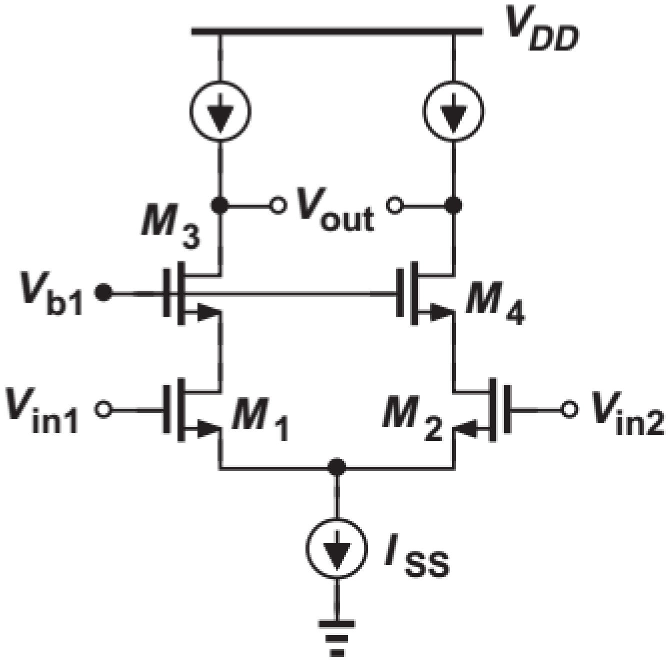
$$V_X/V_{in1} = -g_m(R_D \| r_{O1})$$

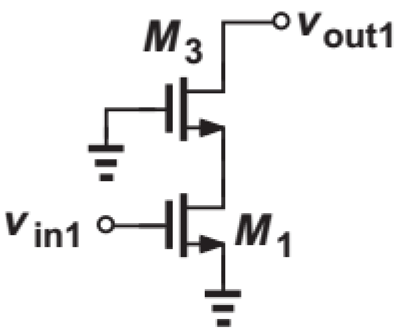
$$V_Y/(-V_{in1}) = -g_m(R_D \| r_{O2})$$

$$(V_X - V_Y)/(2V_{in1}) = -g_m(R_D \| r_O)$$

Differential Gain

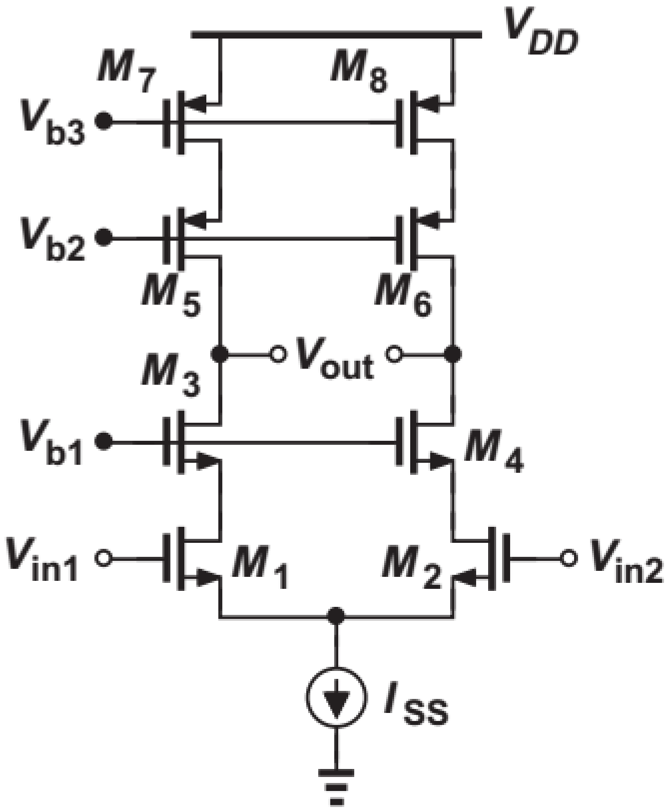
Cascode Differential Amplifier

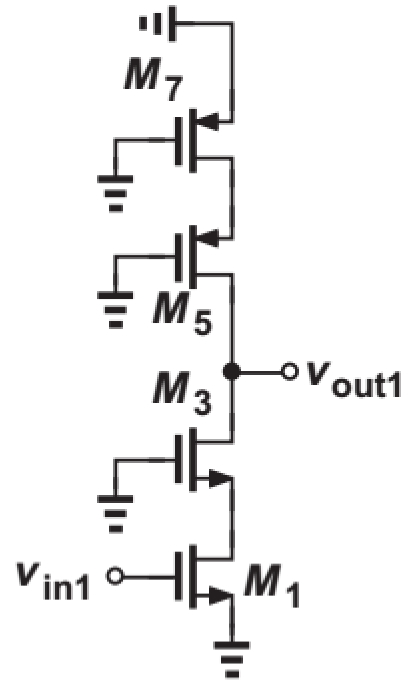




$$A_v \approx -g_{m3} r_{O3} g_{m1} r_{O1}$$

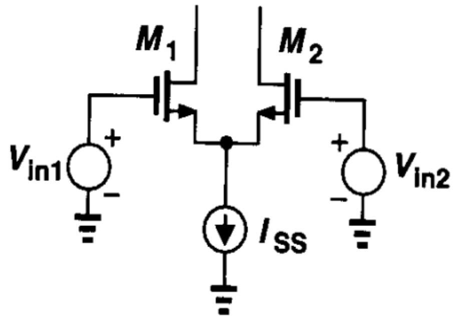
Telescopic Cascode Amplifier

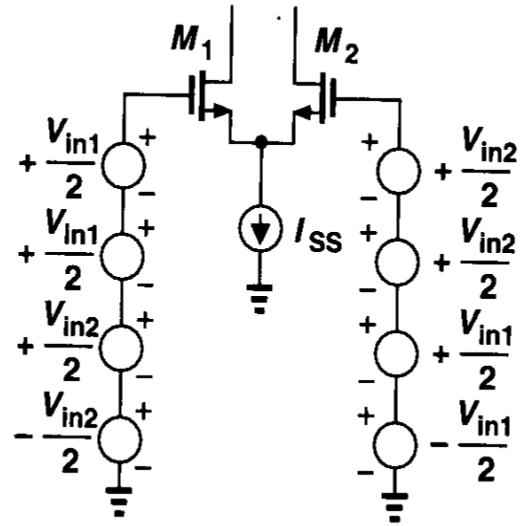


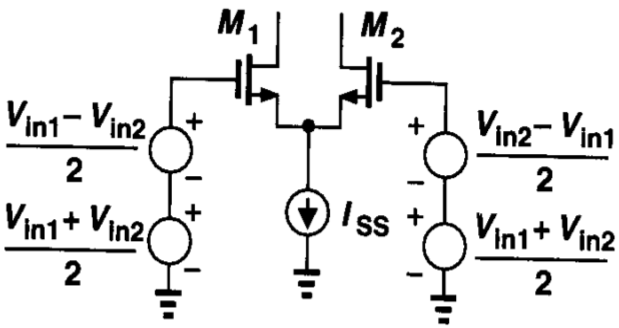


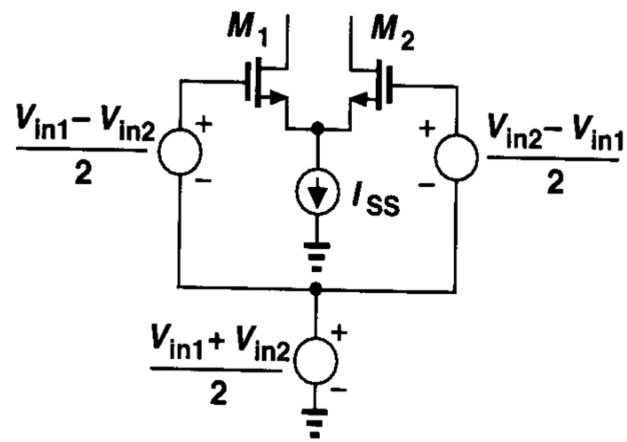
$$A_v \approx -g_{m1}[(g_{m3}r_{O3}r_{O1})||(g_{m5}r_{O5}r_{O7})]$$

Converting Arbitrary Inputs to Diff. & CM Inputs

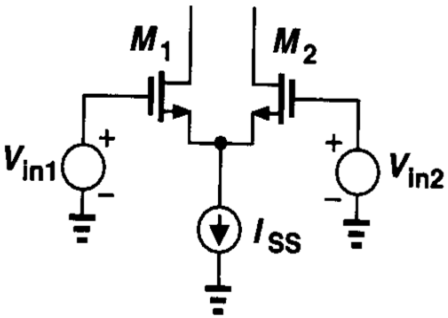


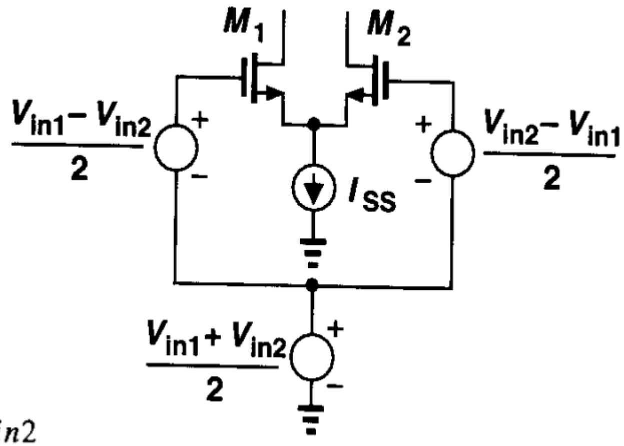






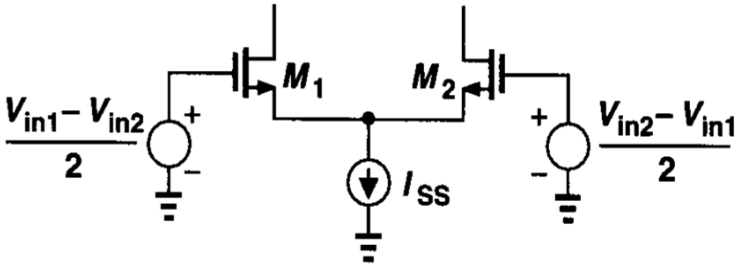
Superposition for Diff. and CM Signals

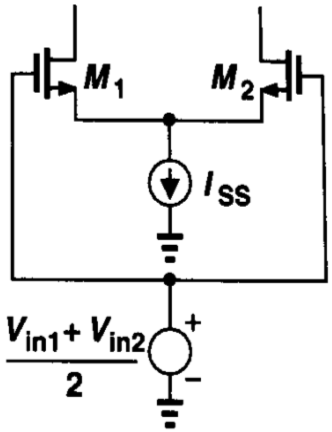




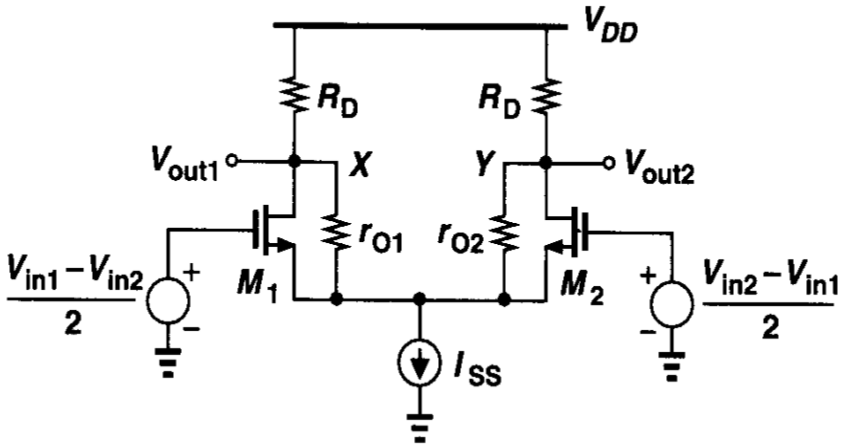
$$V_{in1} = \frac{V_{in1} - V_{in2}}{2} + \frac{V_{in1} + V_{in2}}{2}$$

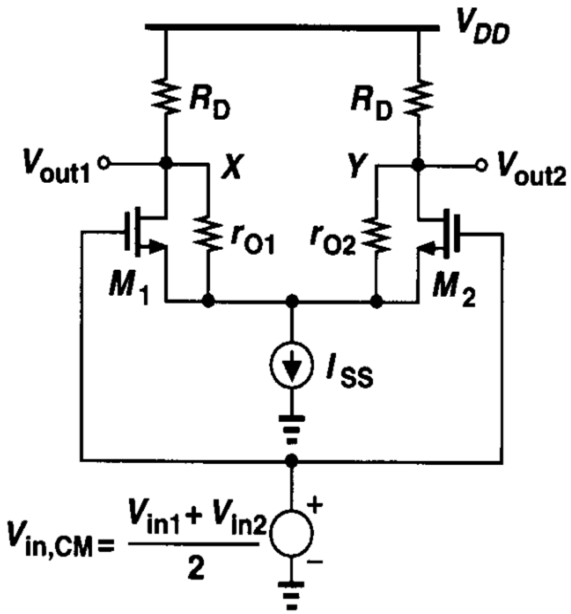
$$V_{in2} = \frac{V_{in2} - V_{in1}}{2} + \frac{V_{in1} + V_{in2}}{2}$$





Differential and Common-Mode Operation





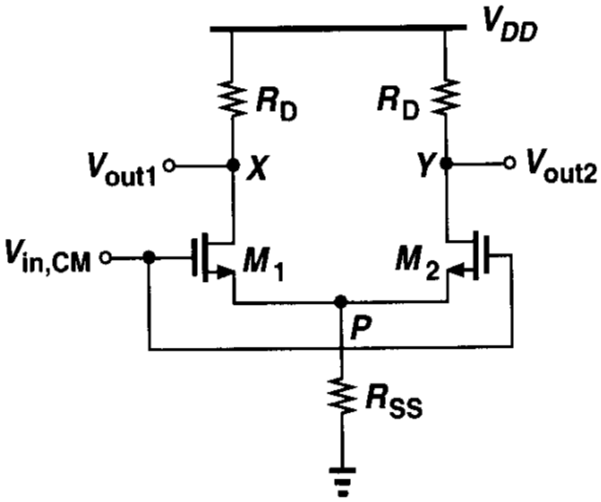
$$V_X = -g_m(R_D \| r_{O1})\frac{V_{in1} - V_{in2}}{2}$$

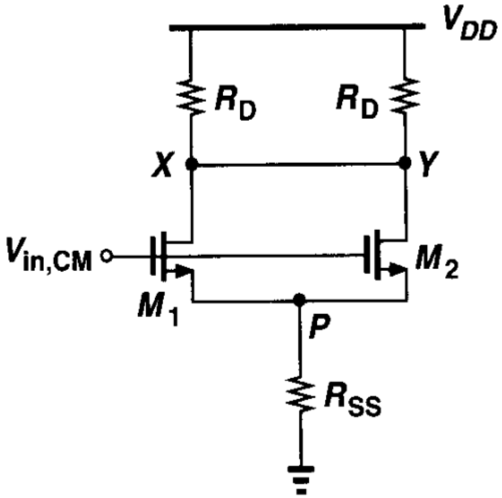
$$V_Y = -g_m(R_D \| r_{O2})\frac{V_{in2} - V_{in1}}{2}$$

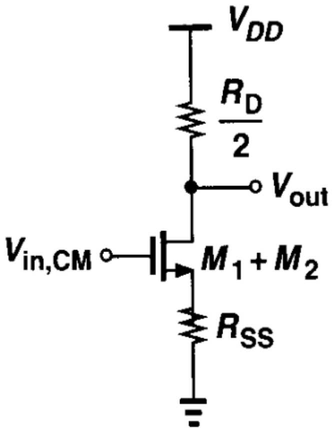
$$V_X - V_Y = -g_m(R_D \| r_O)(V_{in1} - V_{in2})$$

Differential Gain

Common-Mode Response



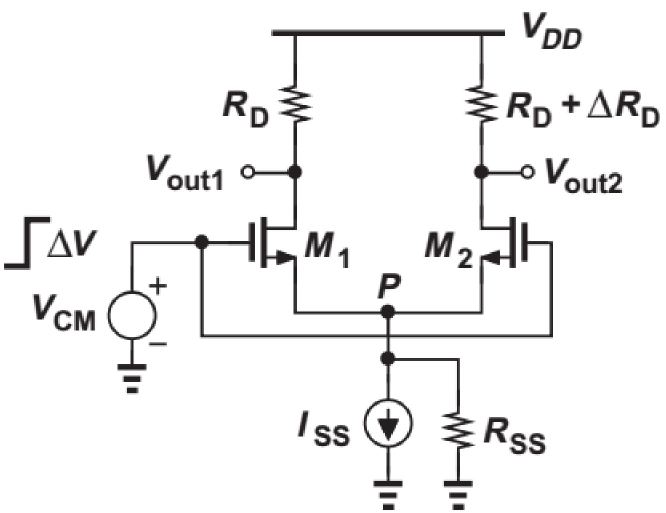




$$A_{v,CM} = \frac{V_{out}}{V_{in,CM}}$$

$$= -\frac{R_D/2}{1/(2g_m) + R_{SS}}$$

Common-Mode Rejection Ratio (CMRR)



$$\left|\frac{\Delta V_{out}}{\Delta V_{CM}}\right| = \frac{\Delta R_D}{\frac{1}{g_m} + 2R_{SS}} = \frac{g_m \Delta R_D}{1 + 2 g_m R_{SS}}$$

Common mode (CM) to differential mode (DM) conversion

→ Minimize this by maximizing R_{ss}

→ Cascode current source

→ Longer channel length

$$A_{DM} = -g_m R_D \qquad A_{CM-DM} = \frac{g_m \Delta R_D}{1 + 2 g_m R_{SS}}$$

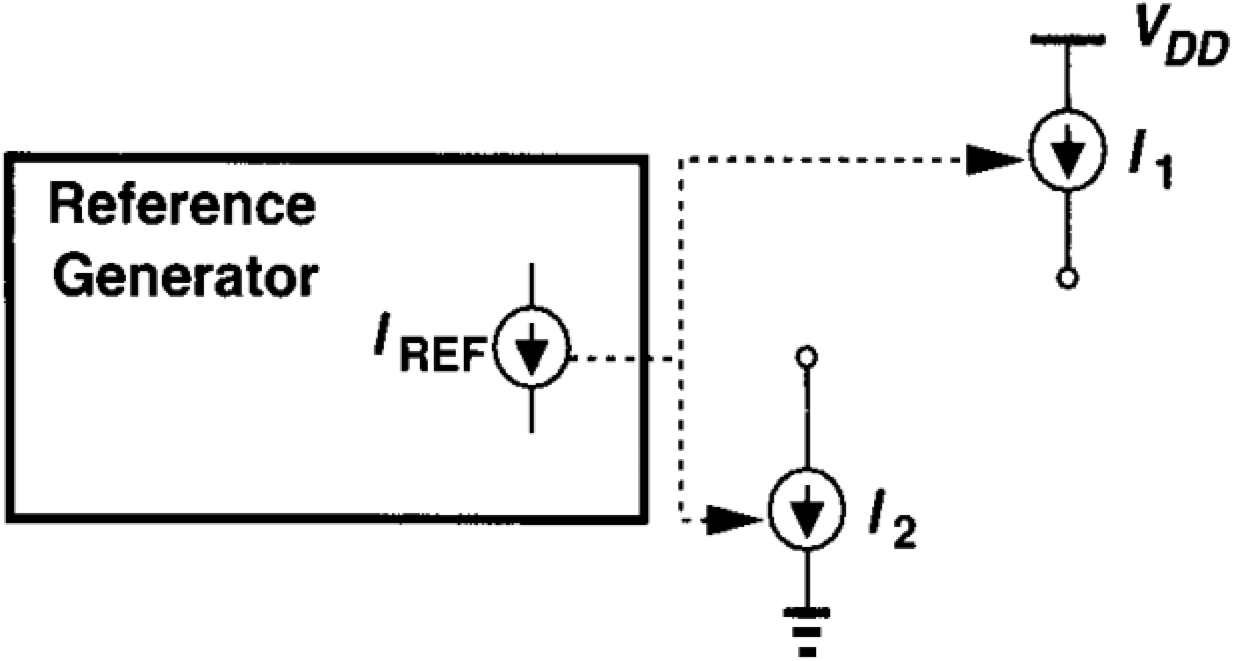
$$\text{CMRR} = \left|\frac{A_{DM}}{A_{CM-DM}}\right| = \left|{}^{-g_m R_D}\Big/{\frac{g_m \Delta R_D}{1+2 g_m R_{SS}}}\right| = \frac{R_D}{\Delta R_D}(1 + 2 g_m R_{SS})$$

For higher CMRR, increase Rss

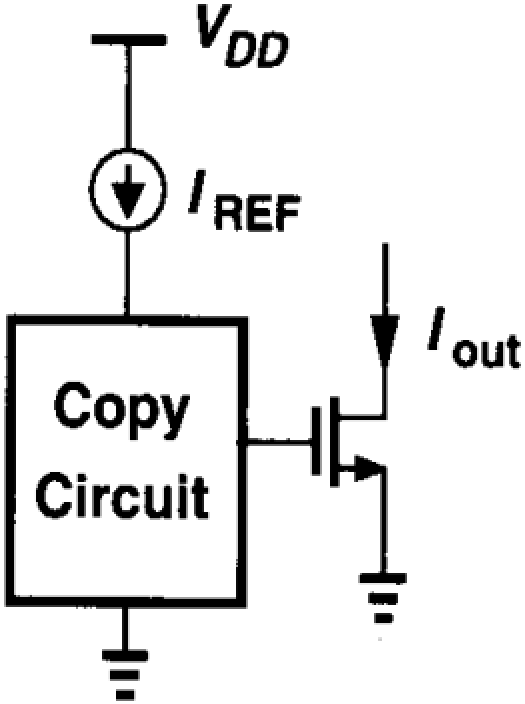
Current Reference Generator

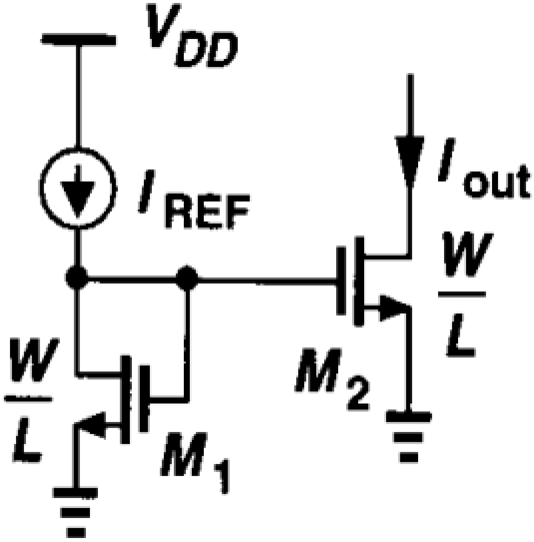
IC Biasing

- In IC design, we often assume that we have one precise current source somewhere in the IC and we copy its value to our circuits

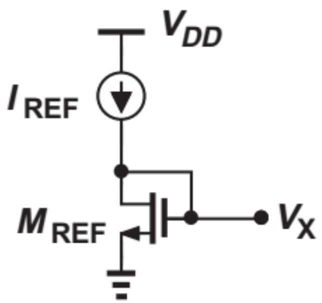


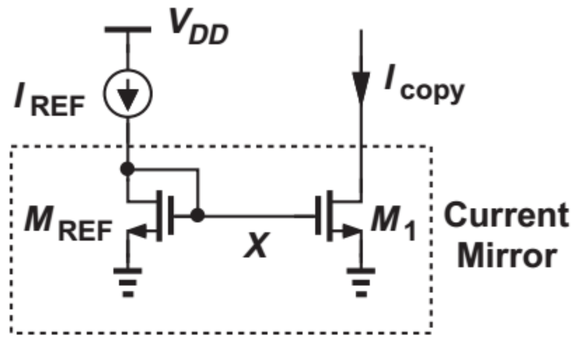
Current Copying





Concept of Current Mirror



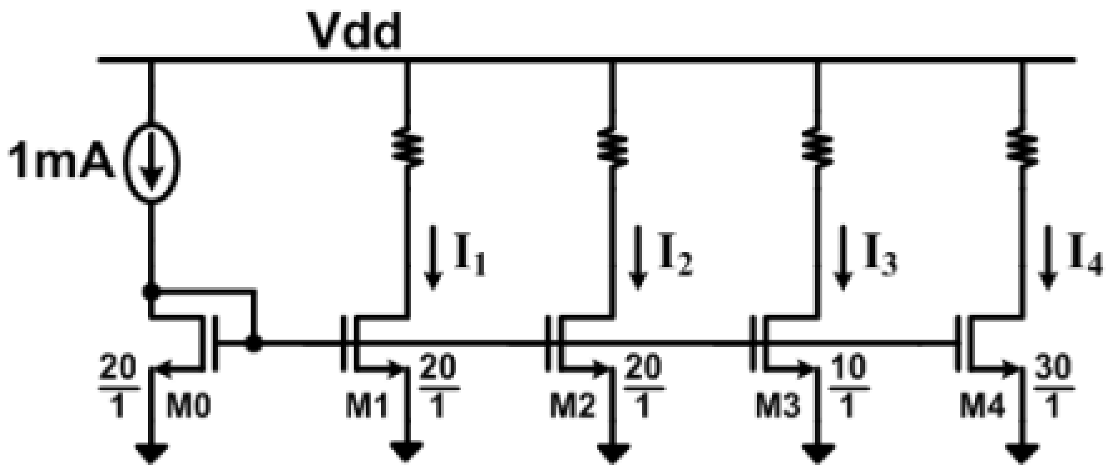


$$I_{D,REF} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_{REF}(V_X - V_{TH})^2 \quad \rightarrow \quad \frac{I_{D,REF}}{\left(\frac{W}{L}\right)_{REF}} = \frac{1}{2}\mu_n C_{ox}(V_X - V_{TH})^2$$

$$I_{copy} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_1(V_X - V_{TH})^2 \quad \rightarrow \quad \frac{I_{copy}}{\left(\frac{W}{L}\right)_1} = \frac{1}{2}\mu_n C_{ox}(V_X - V_{TH})^2$$

$$\frac{I_{copy}}{\left(\frac{W}{L}\right)_1} = \frac{I_{D,REF}}{\left(\frac{W}{L}\right)_{REF}} \quad \rightarrow \quad I_{copy} = \frac{\left(\frac{W}{L}\right)_1}{\left(\frac{W}{L}\right)_{REF}} I_{D,REF}$$

Ideal Current Mirror Example



I_1=1mA

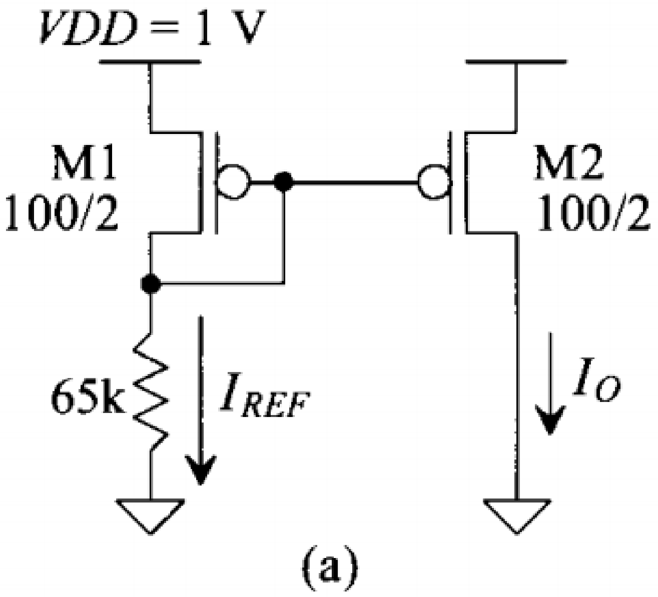
I_2=1mA

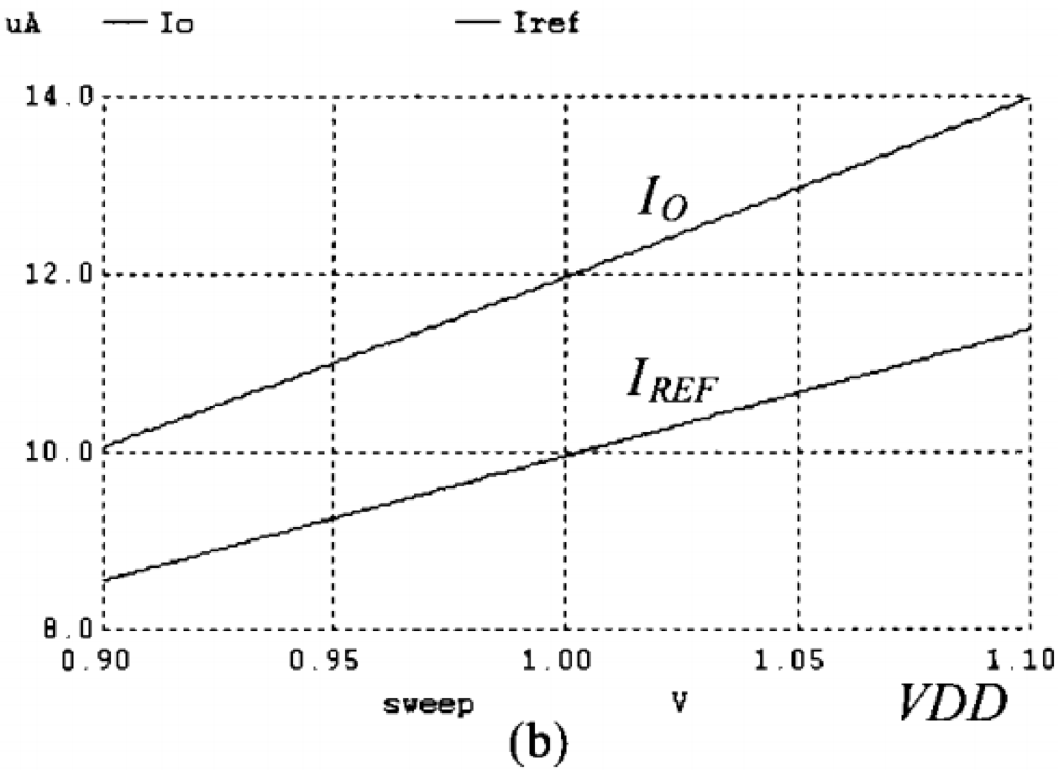
I_3=0.5mA

I_4=1.5mA

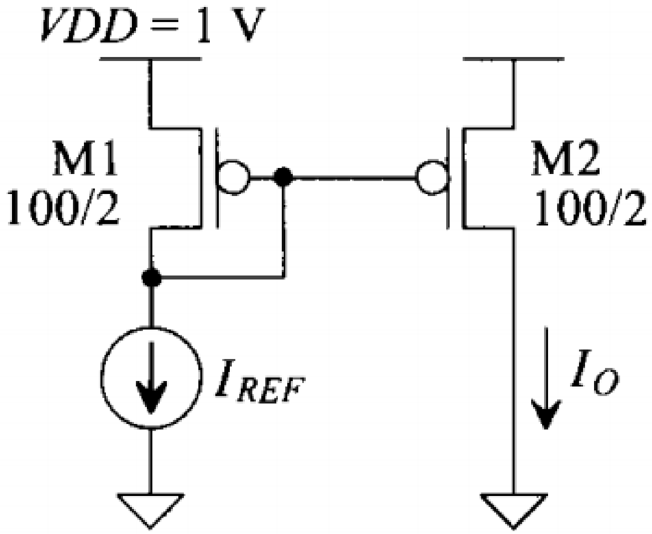
How do we generate Iref?

Biasing the Current Mirror with Resistor

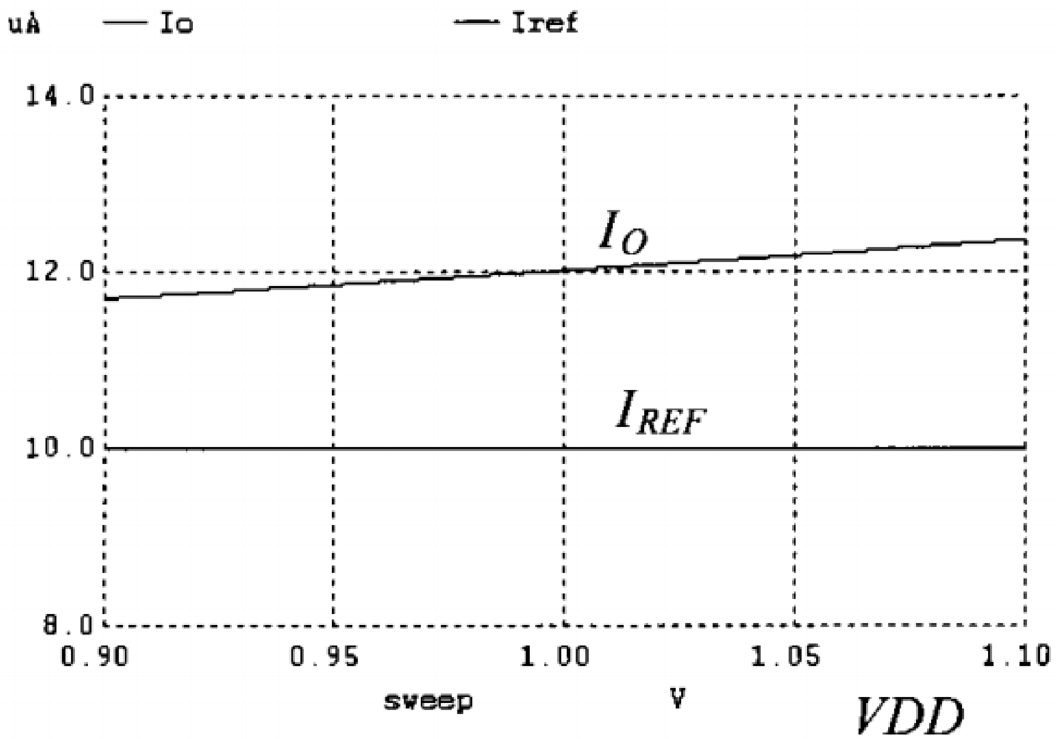




Biasing the Current Mirror with Current Source



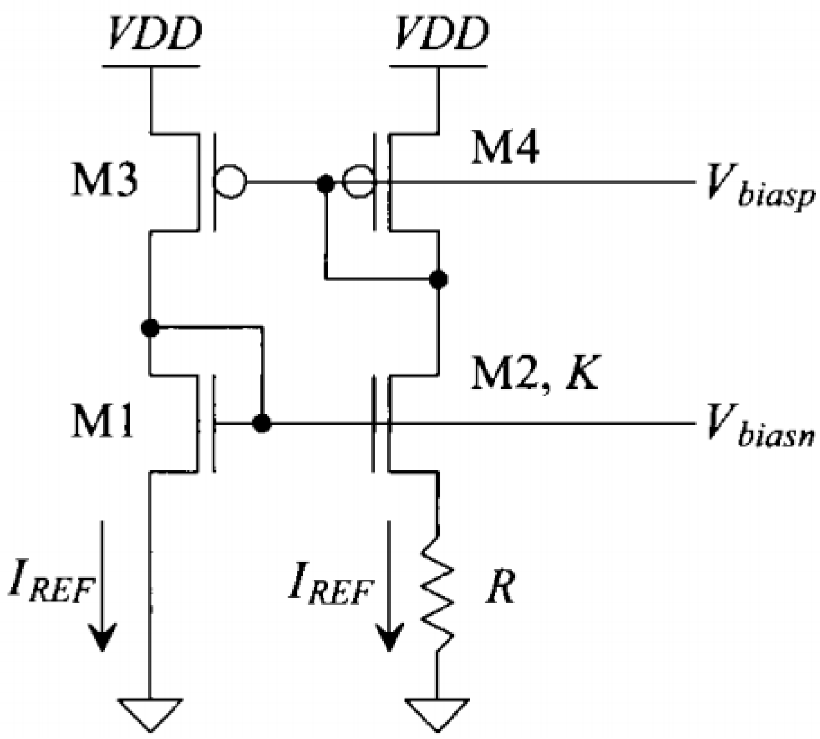
(a)



(b)

Supply Independent Biasing

Beta Multiplier Circuit



$$I_{REF} = \frac{2}{R^2 KP_n \cdot \frac{W_1}{L_1}} \left(1 - \frac{1}{\sqrt{K}}\right)^2$$

$$V_{GS1} = V_{GS2} + I_{REF} \cdot R$$

$$V_{GS} = \sqrt{\frac{2I_D}{\beta}} + V_{THN}$$

$$\left(\beta = KP_n \cdot \frac{W}{L}\right)$$

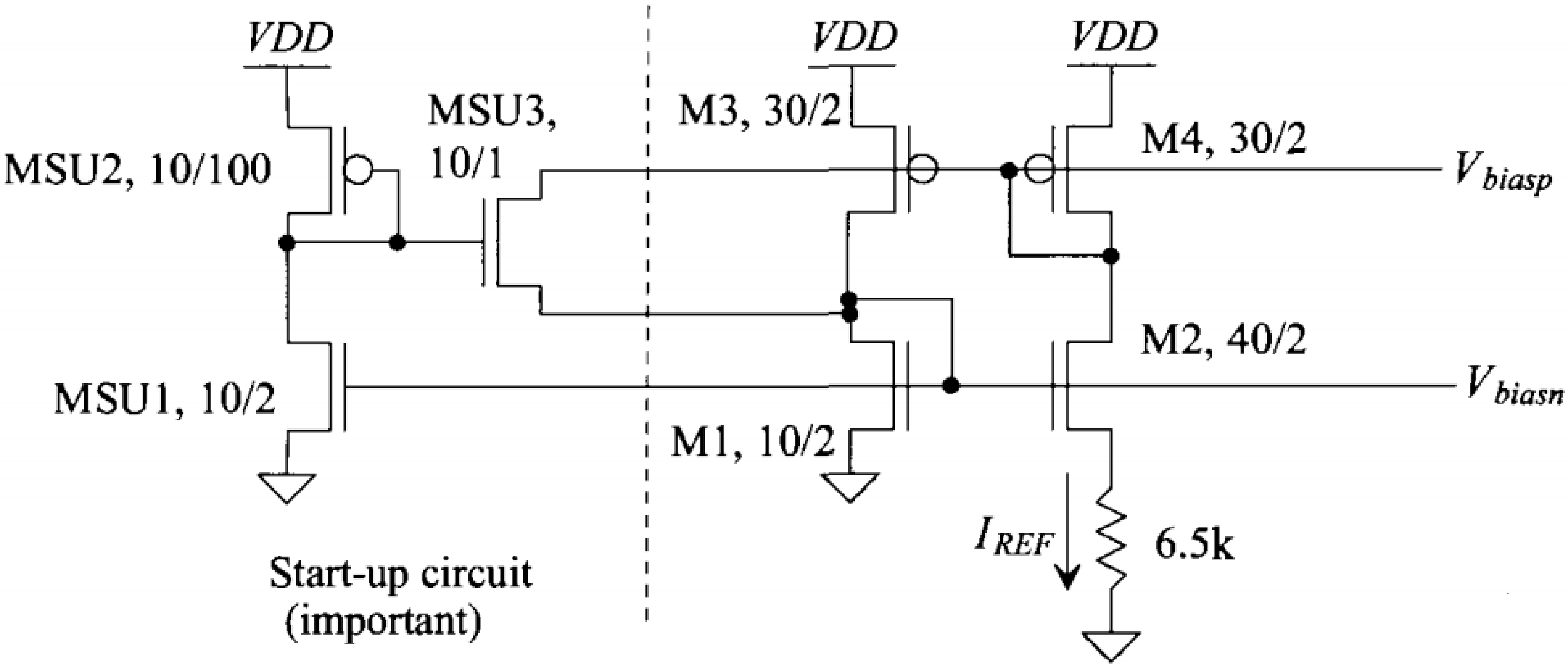
$$\beta_2 = K \cdot \beta_1$$

$$W_2 = K \cdot W_1$$

When K=4, g_m=1/R

⟶ Constant-g_m

Beta-multiplier Reference with Start-up circuit



Self-biased circuit has two possible operating points.
Zero current state should be avoided -> Need a Start-up