Fundamentals of Microelectronics II

فصل ۹- طبقه کاسکود و آینه های جریان

(قسمت دوم- آینه جریان)

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- 9.2 Current Mirrors

Temperature and Supply Dependence of Bias Current

(a) (b)

$$V_{BE} = V_T \ln \frac{I_C}{I_S}$$

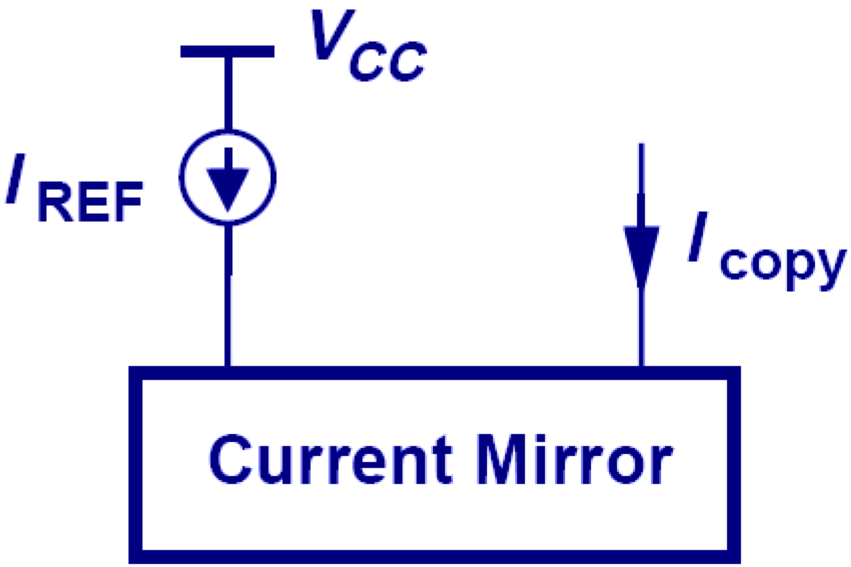
$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left(V_{GS} - V_{TH}\right)^2$$

$$R_2 V_{CC}/(R_1 + R_2) = V_T \ln(I_1/I_S)$$

$$I_1 = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left(\frac{R_2}{R_1 + R_2}V_{DD} - V_{TH}\right)^2$$

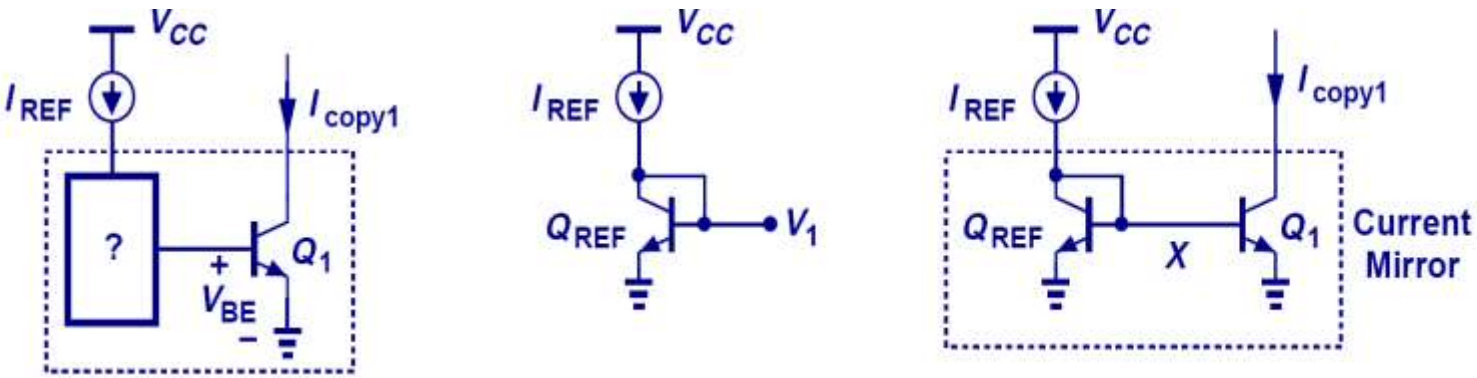
- **Since V_T, I_S, μ_n, and V_{TH} all depend on temperature, I_1 for both bipolar and MOS depends on temperature and supply.**

Concept of Current Mirror



- The motivation behind a **current mirror** is to sense the current from a "**golden current source**" and **duplicate** this "golden current" to other locations.

Bipolar Current Mirror Circuitry



(a) (b) (c)

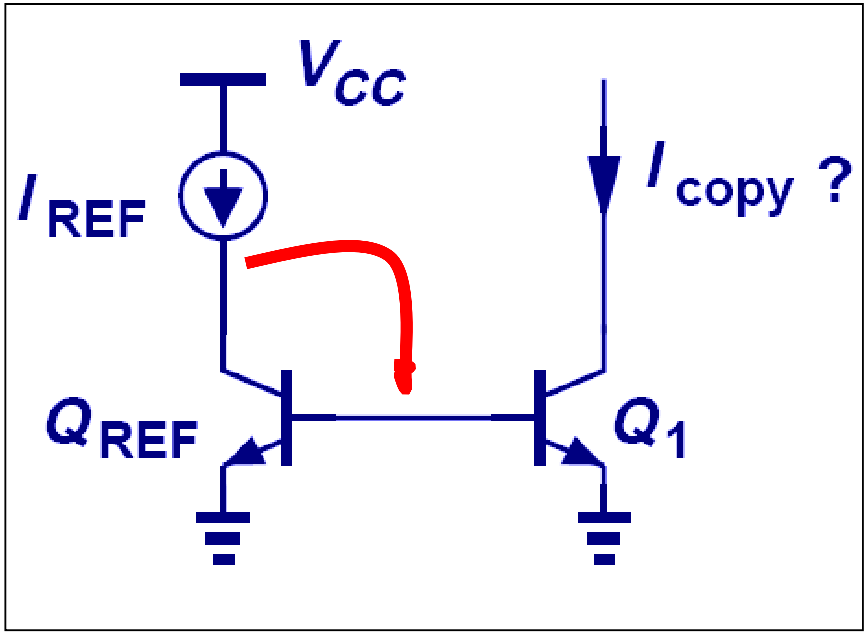
$$I_C = I_S \exp \frac{V_{BE}}{V_T}$$

$$V_{BE} = V_T \ln \frac{I_C}{I_S}$$

$$I_{copy} = \frac{I_{S1}}{I_{S,REF}} I_{REF}$$

- The diode-connected Q_{REF} produces an output voltage V_1 that forces $I_{copy1} = I_{REF}$, if $Q_1 = Q_{REF}$.

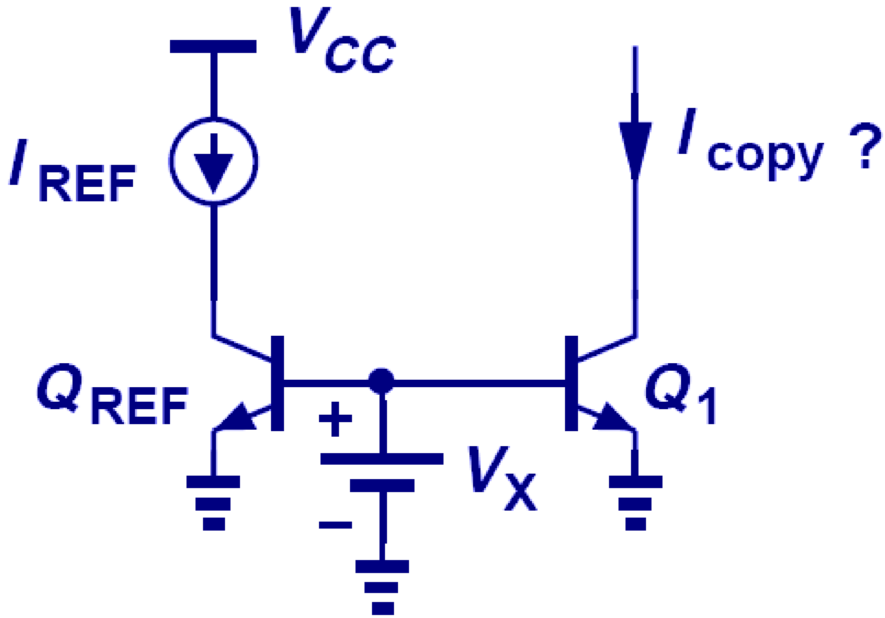
Bad Current Mirror (Example I)



$$\boxed{I_{copy} = 0???}$$

- **Without shorting the collector and base of Q_{REF} together, there will not be a path for the base currents to flow, therefore, I_{copy} is zero.**

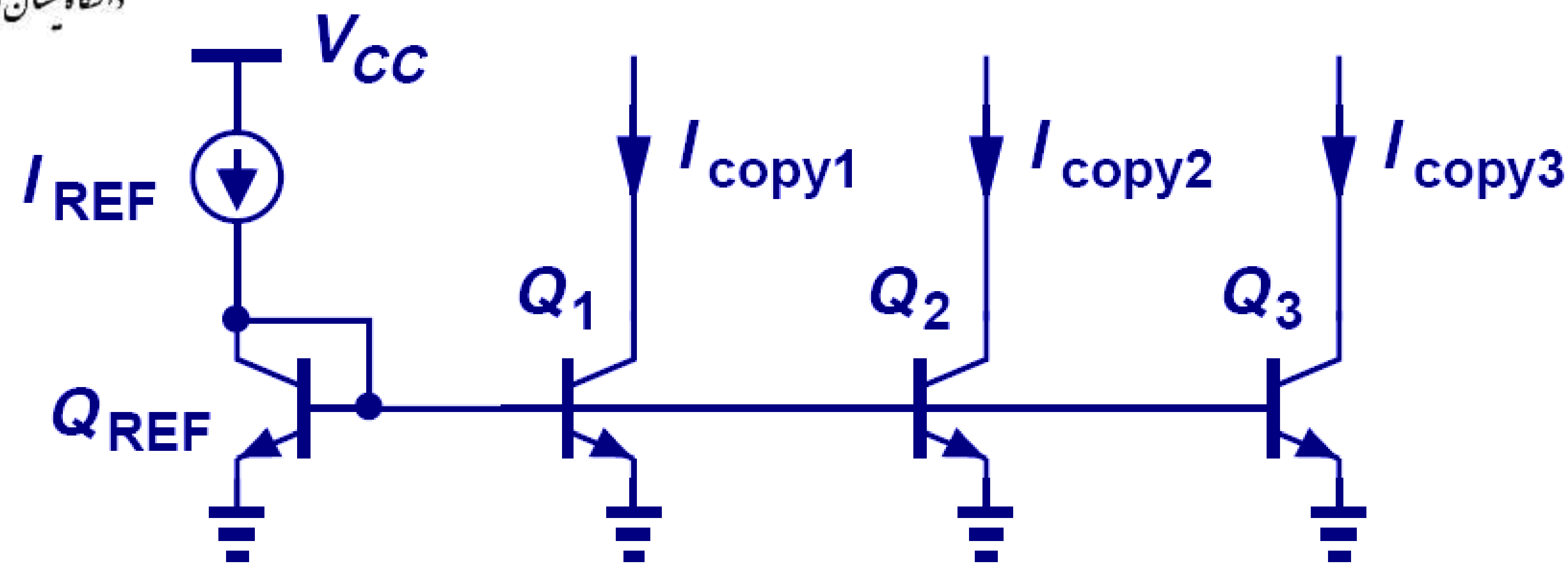
Bad **Current Mirror (Example II)**



$$I_{Copy} = I_{S1} \exp \frac{V_X}{V_T}$$

- **Although a path for base currents exists, this technique of biasing is no better than resistive divider.**

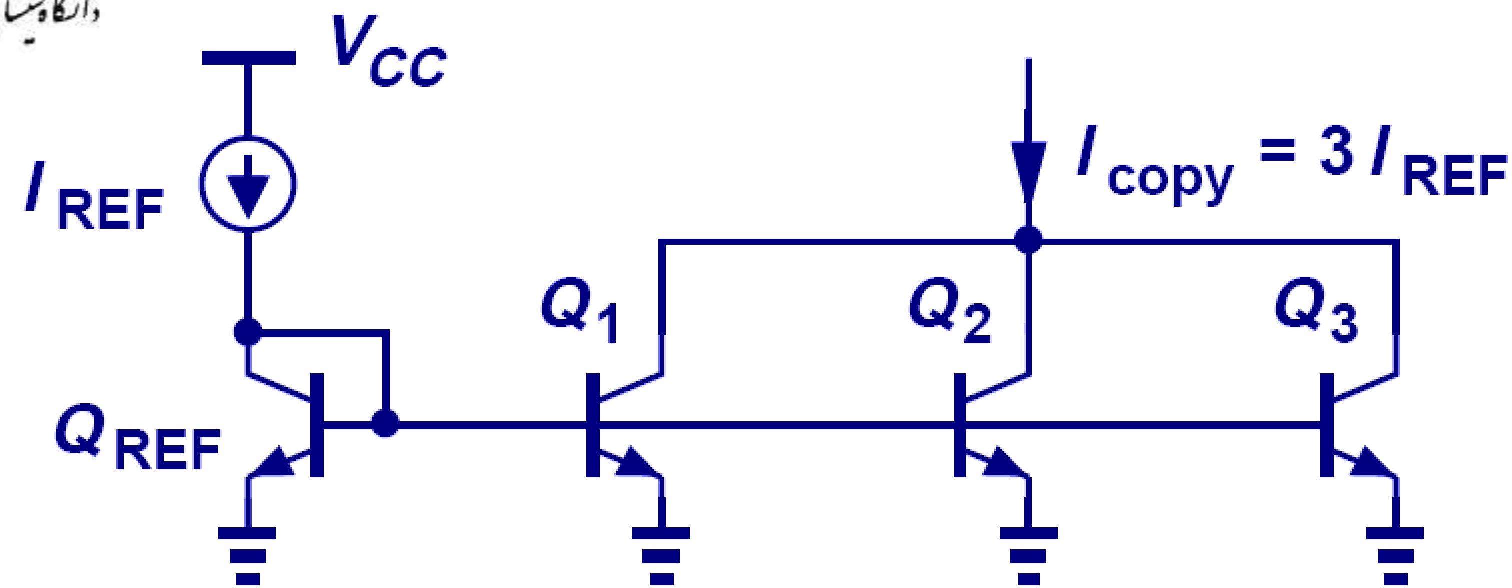
Multiple Copies of I_{REF}



$$I_{copy,j} = \frac{I_{S,j}}{I_{S,REF}} I_{REF}$$

- **Multiple copies of I_{REF} can be generated at different locations by simply applying the idea of current mirror to more transistors.**

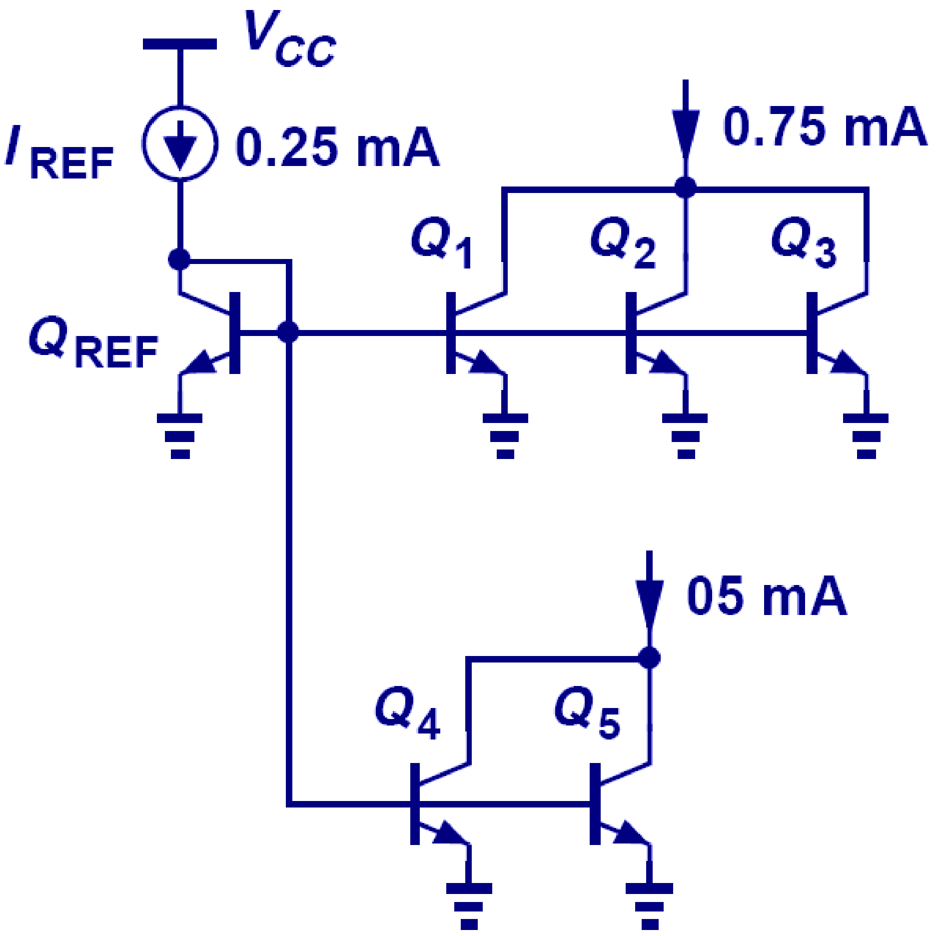
Current Scaling



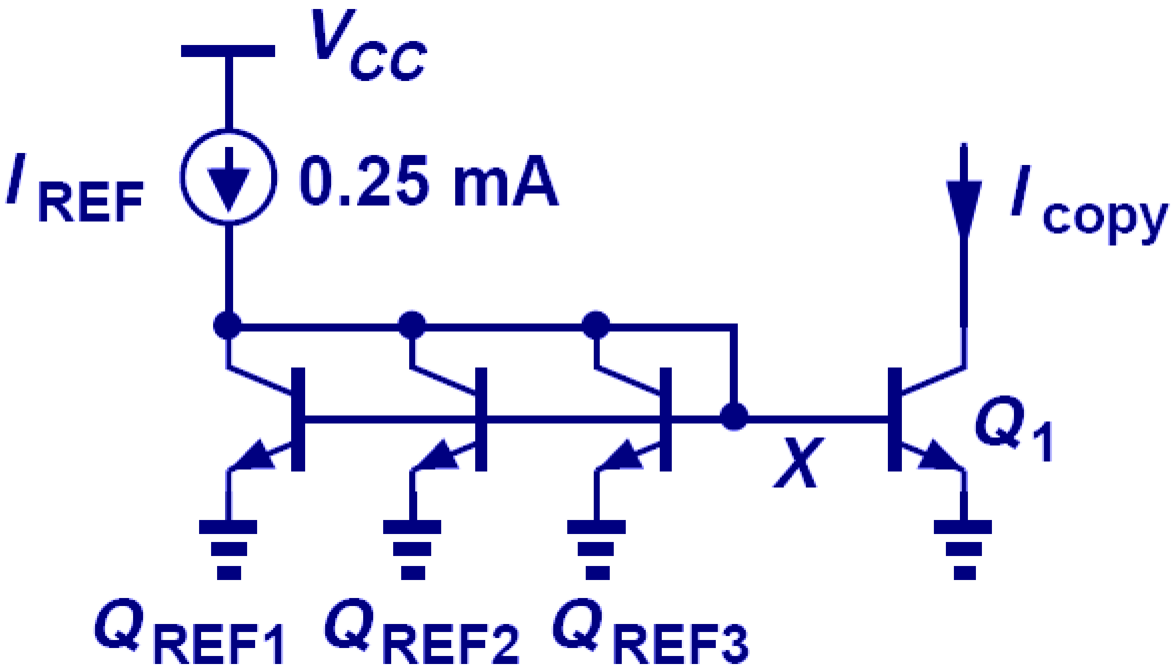
$$I_{copy,j} = nI_{REF}$$

- By scaling the emitter area of Q_j n times with respect to Q_{REF}, $I_{copy,j}$ is also n times larger than I_{REF}. This is equivalent to placing n unit-size transistors in parallel.

Example: Scaled Current



Fractional Scaling

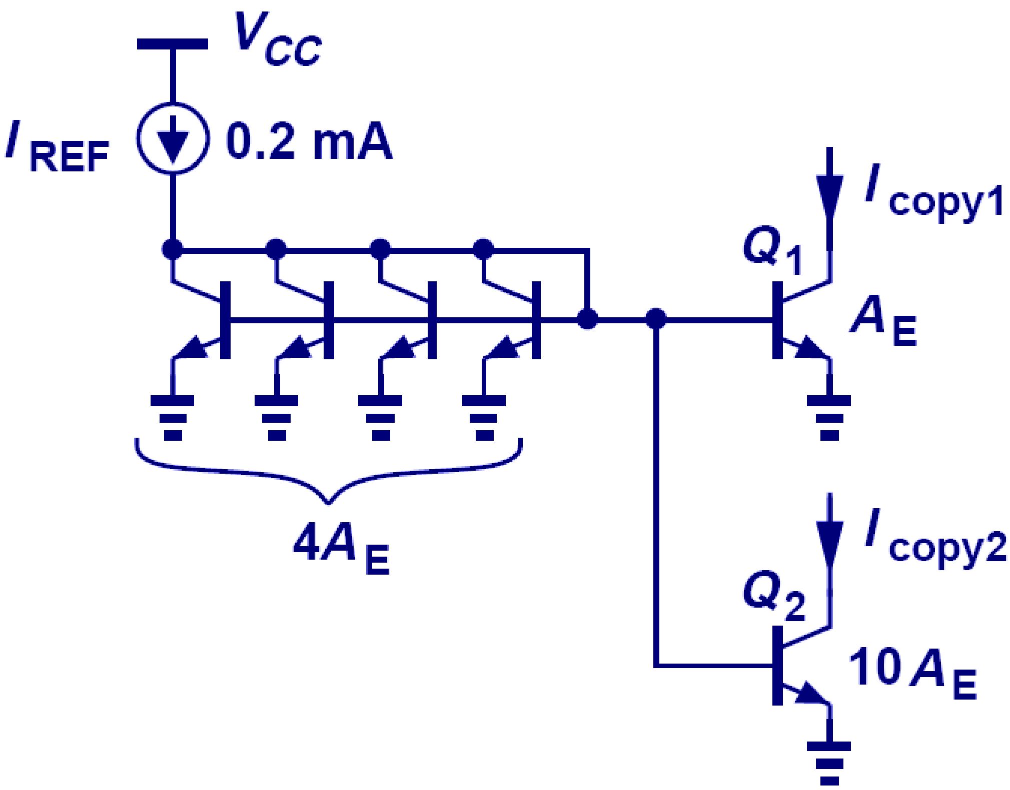


$$I_{copy} = \frac{1}{3} I_{REF}$$

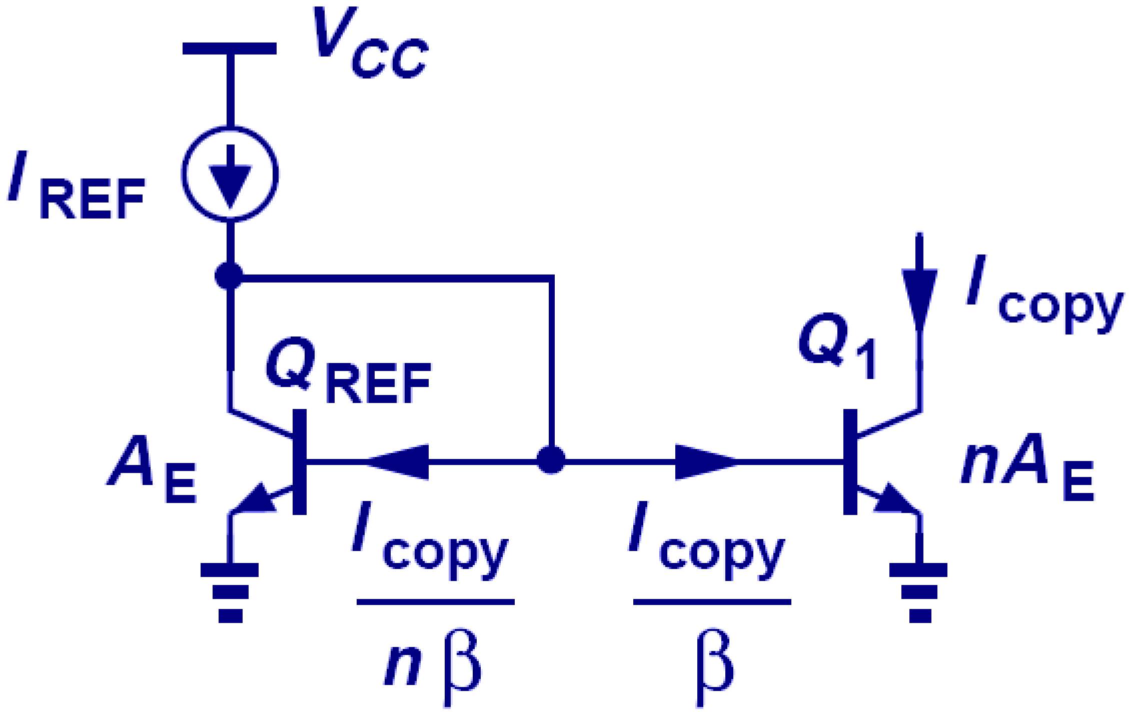
- A fraction of I_{REF} can be created on Q_1 by scaling up the emitter area of Q_{REF}.

Example: Different Mirroring Ratio

- Using the idea of current scaling and fractional scaling, I_{copy2} is 0.5mA and I_{copy1} is 0.05mA respectively.
- All coming from a source of 0.2mA.



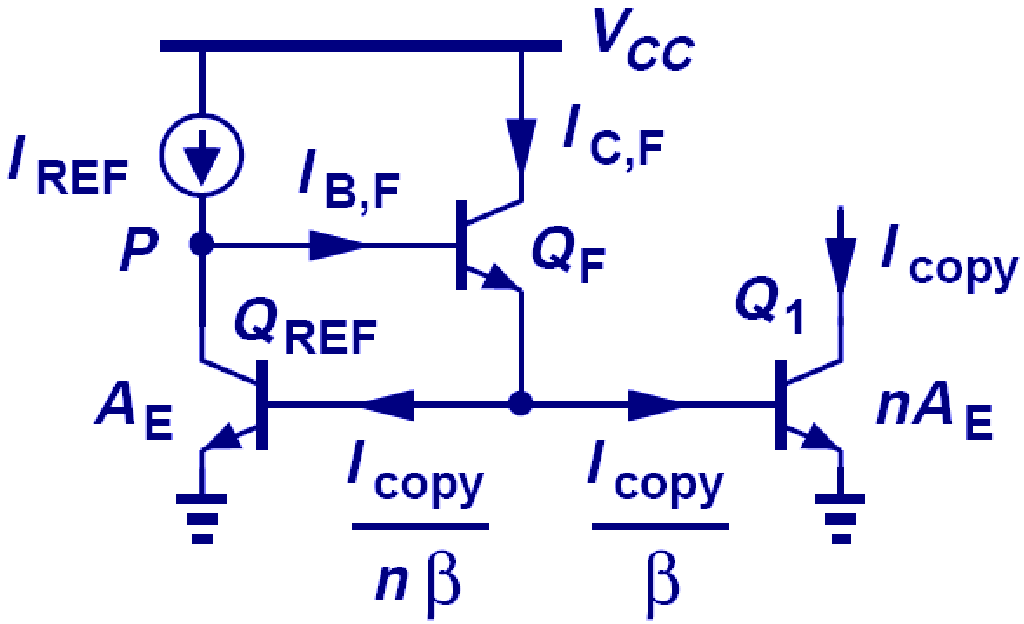
Mirroring Error Due to Base Currents



$$I_{copy} = nI_{C,REF}$$

$$I_{copy} = \frac{nI_{REF}}{1 + \frac{1}{\beta}(n+1)}$$

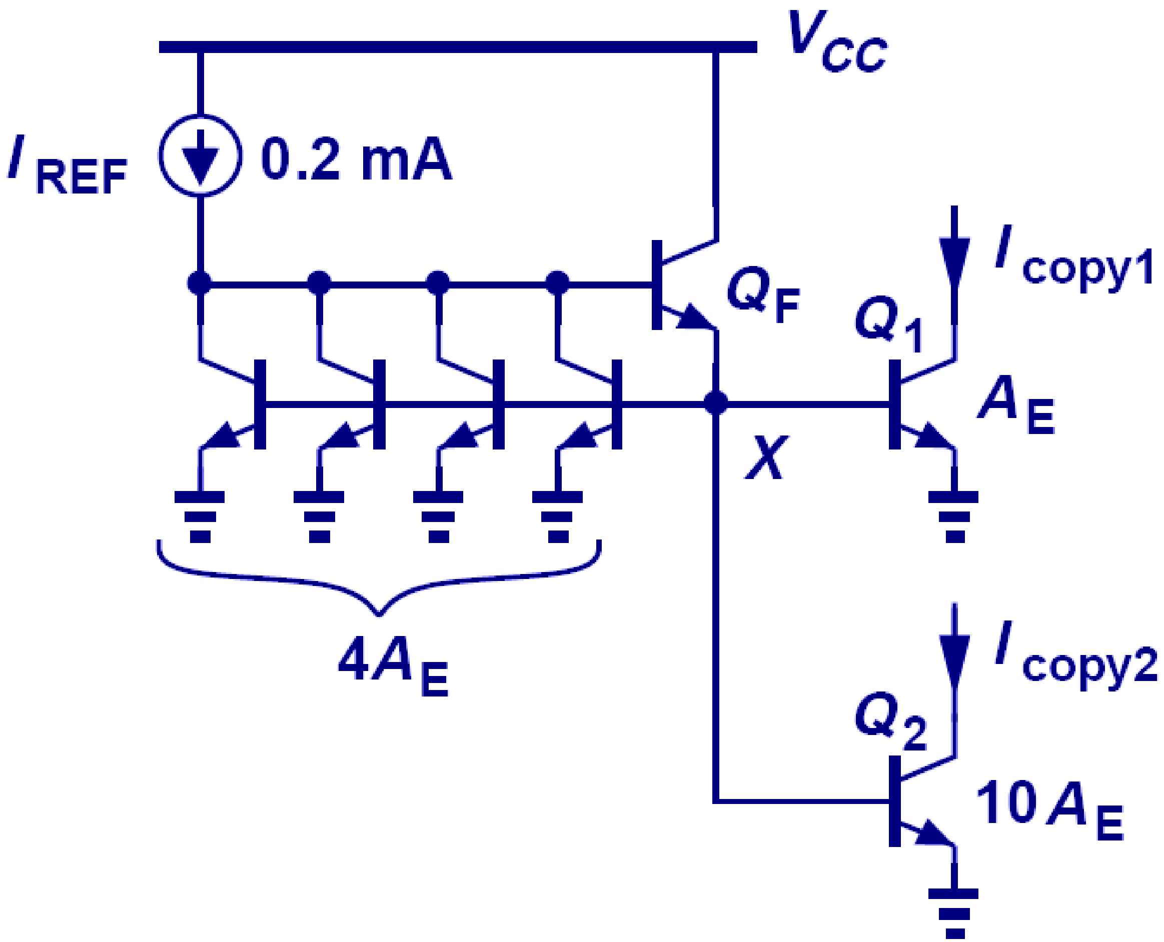
Improved Mirroring Accuracy



$$I_{copy} = \frac{nI_{REF}}{1+\frac{1}{\beta^2}(n+1)}$$

- Because of Q_F, the base currents of Q_{REF} and Q_1 are mostly supplied by Q_F rather than I_{REF}. Mirroring error is reduced β times.

Example: Different Mirroring Ratio Accuracy



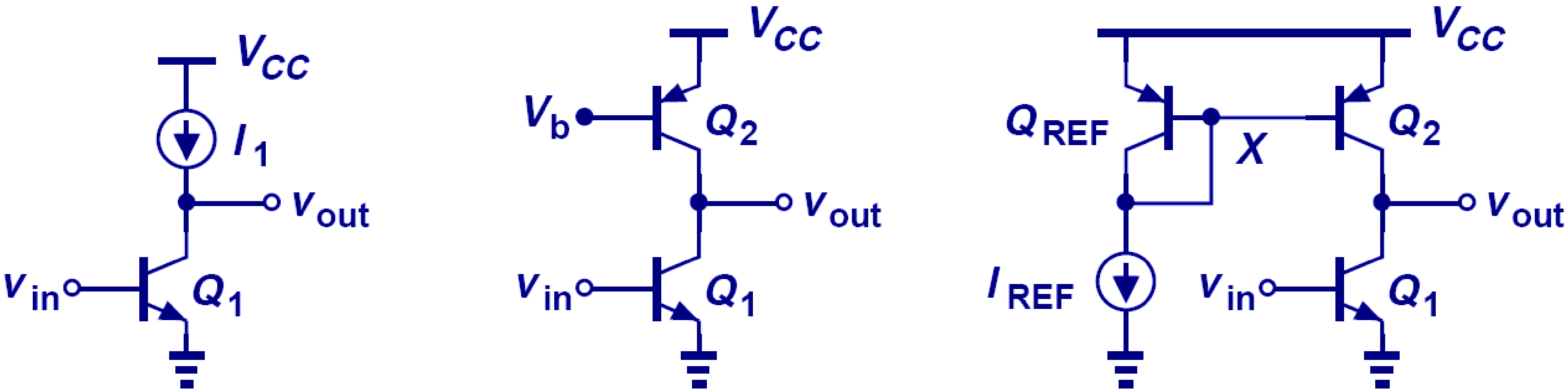
$$I_{copy,2} = 10 I_{copy,1}$$

$$Ic,_{REF} = 4 I_{copy1}$$

$$I_{copy1} = \frac{I_{REF}}{4 + \frac{15}{\beta^2}}$$

$$I_{copy2} = \frac{10 I_{REF}}{4 + \frac{15}{\beta^2}}$$

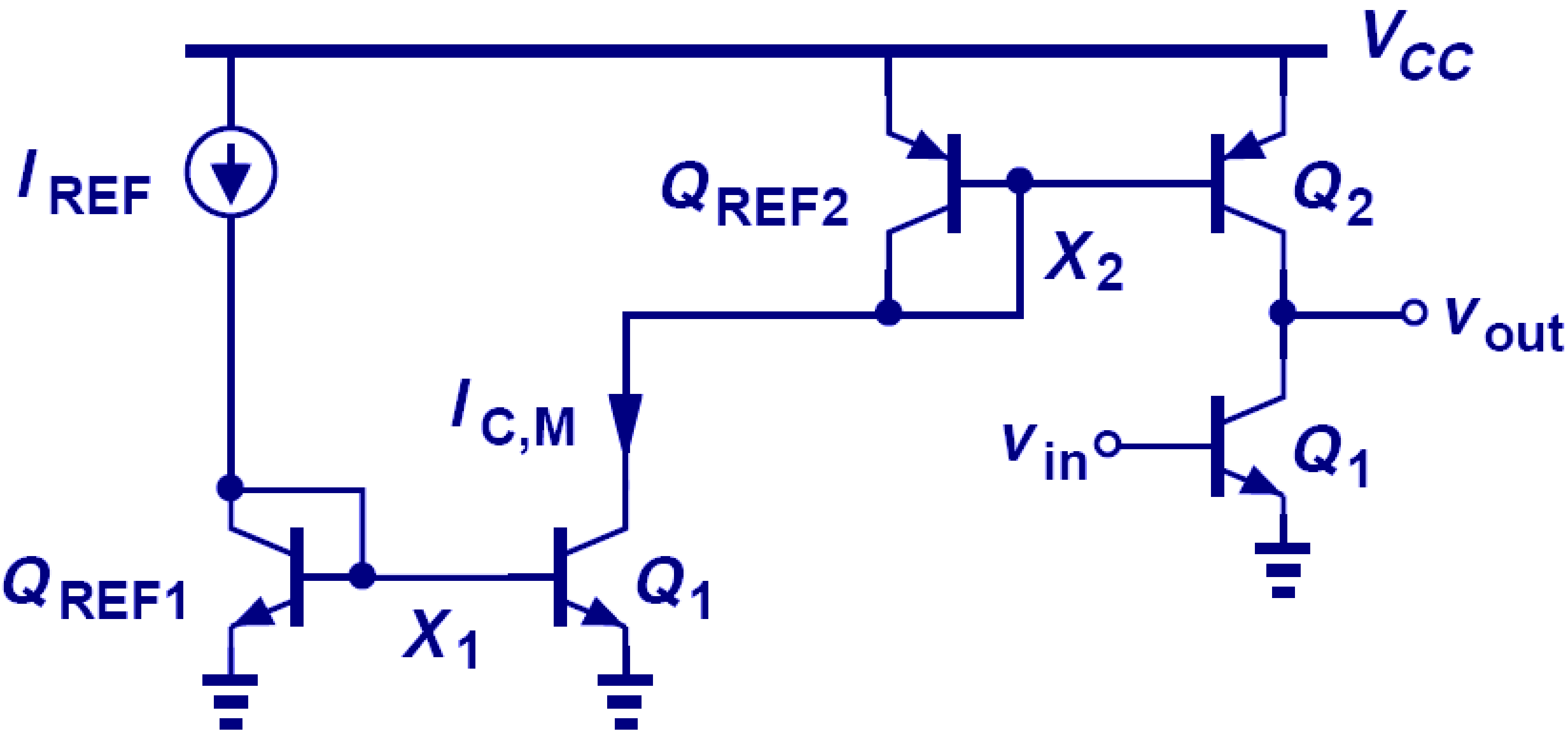
PNP Current Mirror



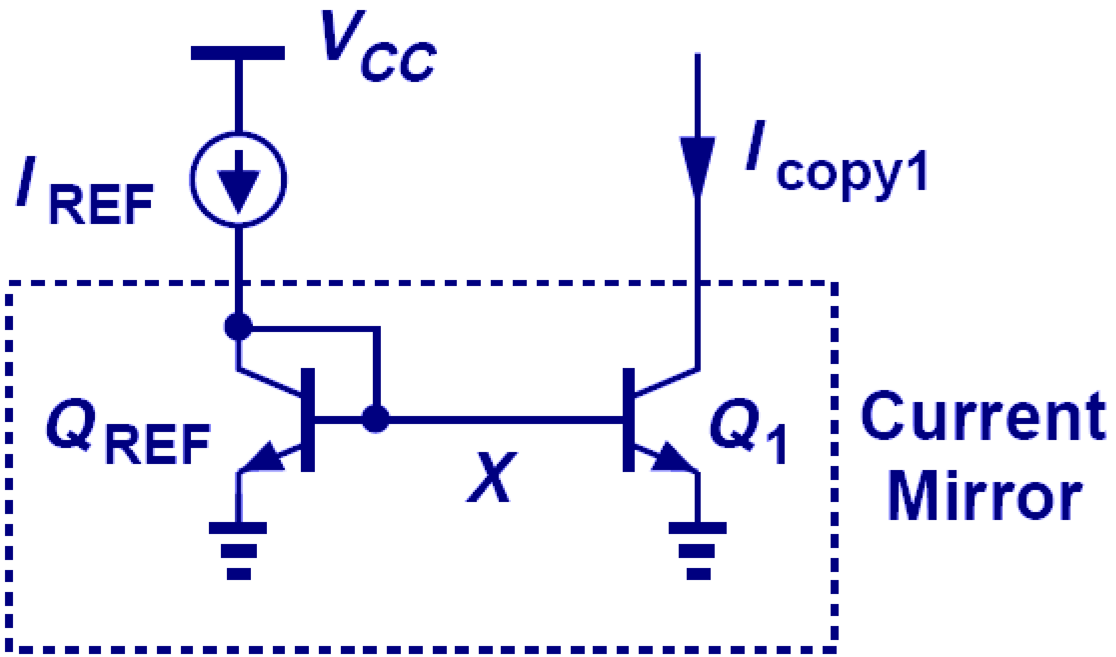
(a) (b) (c)

- **PNP current mirror is used as a current source load to an NPN amplifier stage.**

Generation of I_{REF} for PNP Current Mirror

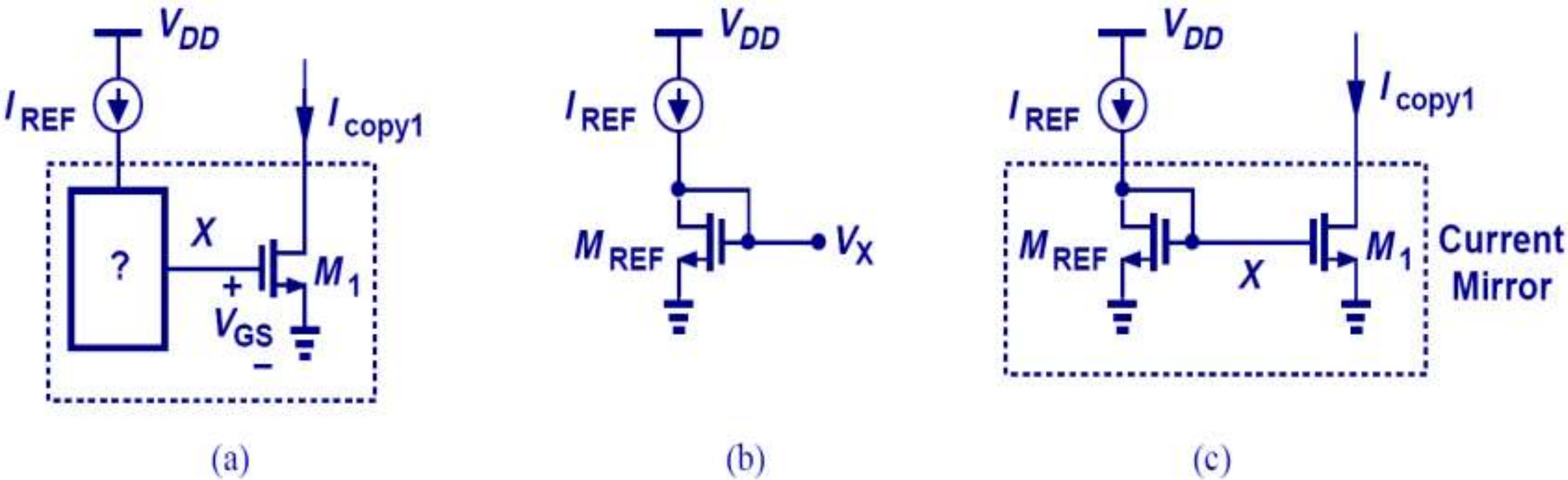


Example: Current Mirror with Discrete Devices



- Let Q_{REF} and Q_1 be **discrete NPN devices**.
- I_{REF} and I_{copy1} can vary in large magnitude due to I_S mismatch.

MOS Current Mirror



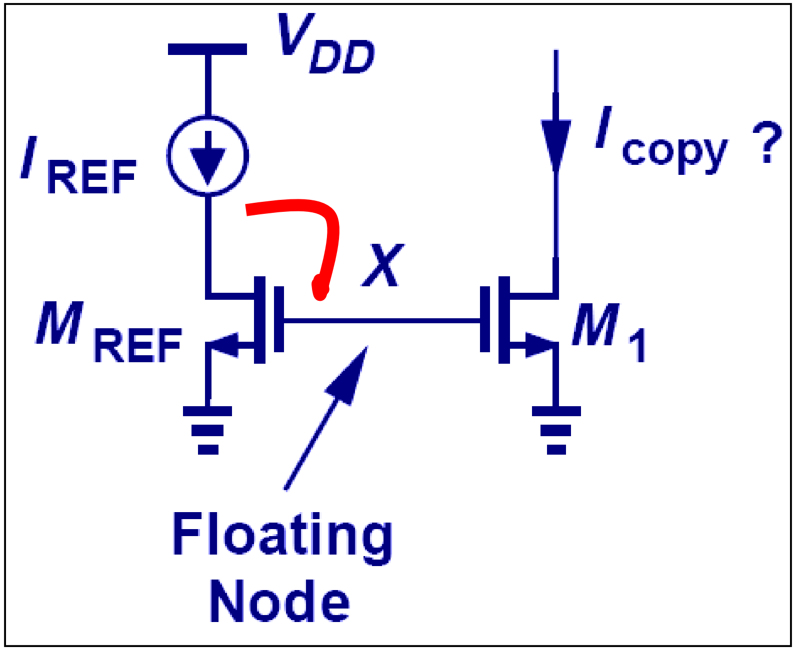
$$I_{D,REF} = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)_{REF}(V_X - V_{TH})^2$$

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

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

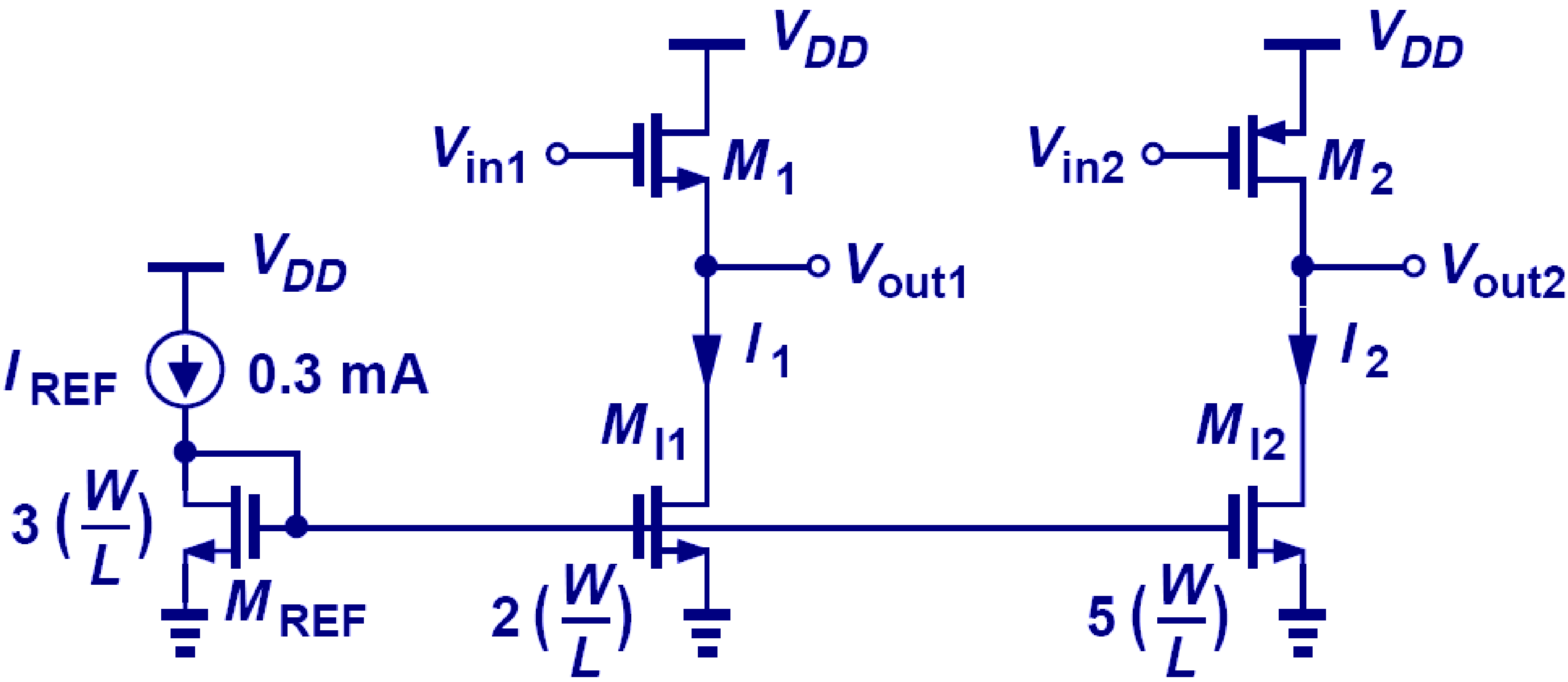
- **The same concept of current mirror can be applied to MOS transistors as well.**

Bad MOS Current Mirror Example



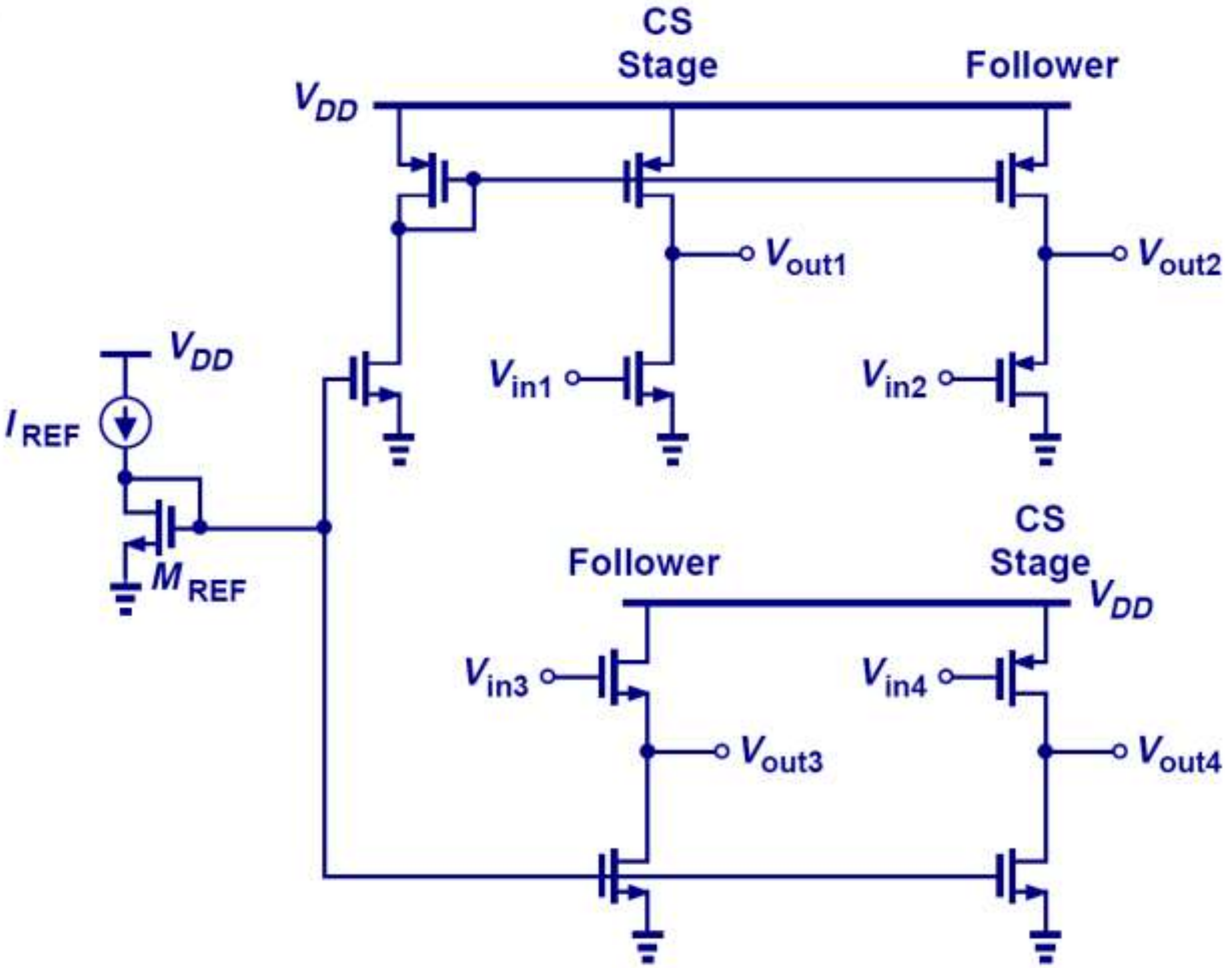
- This is not a current mirror since the relationship between V_X and I_{REF} is not clearly defined.
- The only way to clearly define V_X with I_{REF} is to use a diode-connected MOS since it provides square-law I-V relationship.

Example: Current Scaling



- **Similar to their bipolar counterpart, MOS current mirrors can also scale I_{REF} up or down ($I_1 = 0.2mA$, $I_2 = 0.5mA$).**

CMOS Current Mirror



- **The idea of combining NMOS and PMOS to produce CMOS current mirror is shown above.**