Lecture 12

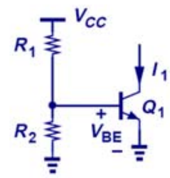
OUTLINE

- Current Mirrors

Reading: Chapter 9.2

Temperature and Supply-Voltage Dependence of Bias Current

- Circuits should be designed to operate properly over a range of supply voltages and temperatures.
- For the biasing scheme shown below, I_1 depends on the temperature as well as the supply voltage, since V_T and I_S depend on temperature.

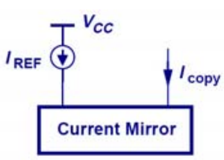


$$I_1 = I_S e^{V_{BE}/V_T}$$

$$V_{BE} \cong \frac{R_2}{R_1 + R_2} V_{CC}$$

Concept of a Current Mirror

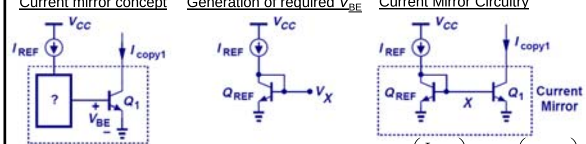
- Circuit designs to provide a supply- and temperature-independent current exist, but require many transistors to implement.
  - → "golden current source"
- A ***current mirror*** is used to replicate the current from a "golden current source" to other locations.



Current Mirror Circuitry

- Diode-connected Q_{REF} produces an output voltage V_X that forces I_{copy1} to be equal to I_{REF}, **if Q_1 is identical to Q_{REF}**.

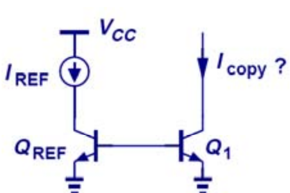
Current mirror concept | Generation of required V_{BE} | Current Mirror Circuitry



$$V_X = V_T \ln\left(\frac{I_{copy1}}{I_{S,1}}\right) = V_T \ln\left(\frac{I_{REF}}{I_{S,REF}}\right)$$

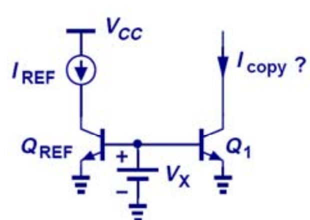
$$I_{copy1} = \frac{I_{S,1}}{I_{S,REF}} I_{REF}$$

Bad Current Mirror Example I



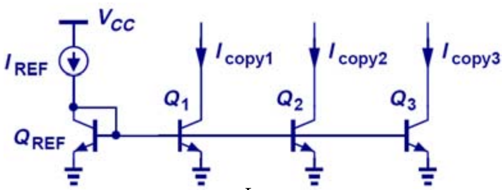
- Without shorting the collector and base of Q_{REF} together, there will not be a path for the base currents to flow, therefore, I_{copy} is zero.

Bad Current Mirror Example II



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

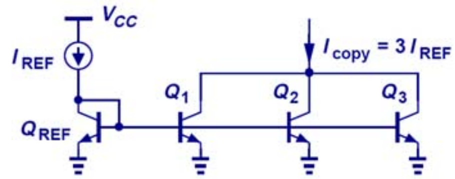
Multiple Copies of I_{REF}



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

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

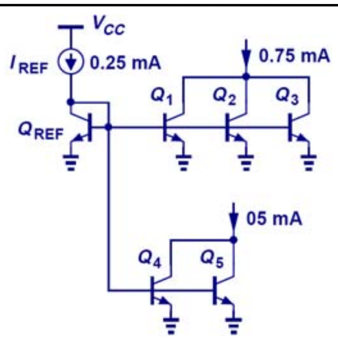
Current Scaling



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

- 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.

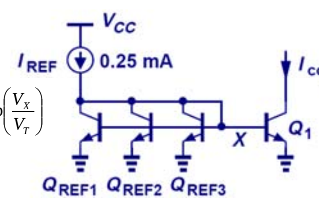
Example: Scaled Current



Fractional Scaling

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

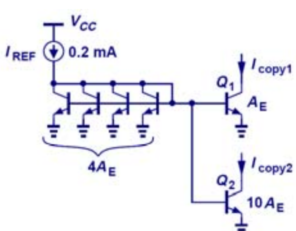
$$I_{REF} = 3I_S \exp\left(\frac{V_X}{V_T}\right)$$



$$I_{copy} = I_S \exp\left(\frac{V_X}{V_T}\right)$$

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

Example: Different Mirroring Ratio

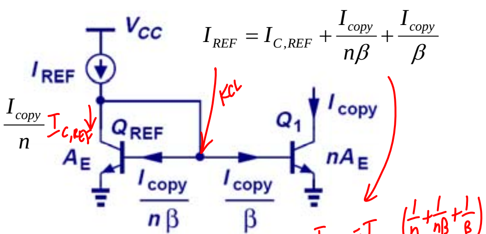


- Using the idea of current scaling and fractional scaling, I_{copy2} is 0.5mA and I_{copy1} is 0.05mA respectively. All coming from a source of 0.2mA.

Effect of Base Currents

$$I_{REF} = I_{C,REF} + \frac{I_{copy}}{n\beta} + \frac{I_{copy}}{\beta}$$

$$I_{C,REF} = \frac{I_{copy}}{n}$$

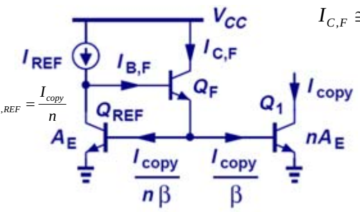


$$I_{copy} = \frac{nI_{REF}}{1 + \frac{1}{\beta}(n+1)}$$

Improved Mirroring Accuracy

- Use Q_F (rather than I_{REF}) to supply the base currents of Q_{REF} and Q_1, reduce the mirroring error by a factor of β.

$$I_{REF} = I_{B,F} + I_{C,REF}$$



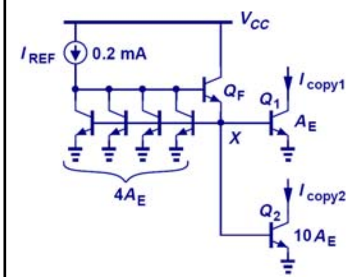
$$I_{C,REF} = \frac{I_{copy}}{n}$$

$$I_{C,F} \cong I_{E,F} = \frac{I_{copy}}{n\beta} + \frac{I_{copy}}{\beta}$$

$$I_{B,F} \cong \frac{I_{copy}}{\beta^2}\left(\frac{1}{n}+1\right)$$

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

Example: Different Mirroring Ratio Accuracy



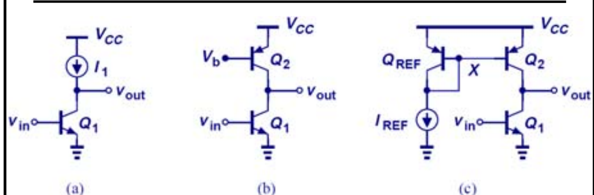
$$I_{C,F} = \frac{I_{C,REF}}{\beta} + \frac{I_{copy1}}{\beta} + \frac{I_{copy2}}{\beta}$$
$$= \frac{4I_{copy1}}{\beta} + \frac{I_{copy1}}{\beta} + \frac{10I_{copy1}}{\beta}$$
$$= \frac{15I_{copy1}}{\beta}$$

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

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

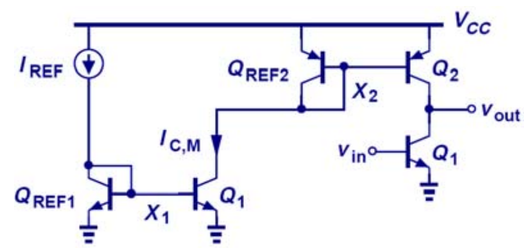
$$I_{copy2} = \frac{10I_{REF}}{4+\frac{15}{\beta^2}}$$

PNP Current Mirror

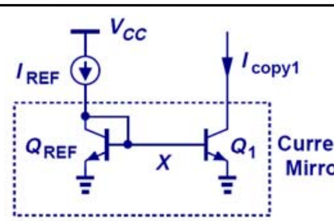


- PNP current mirror is used as a current source load to an NPN amplifier stage.

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.