

Lecture 12

OUTLINE

- Current Mirrors

Reading: Chapter 9.2

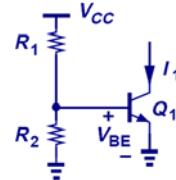
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Temperature and Supply-Voltage Dependence of Bias Current

- 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.



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

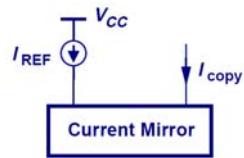
$$V_{BE} \approx \frac{R_2}{R_1 + R_2} V_{CC}$$

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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.



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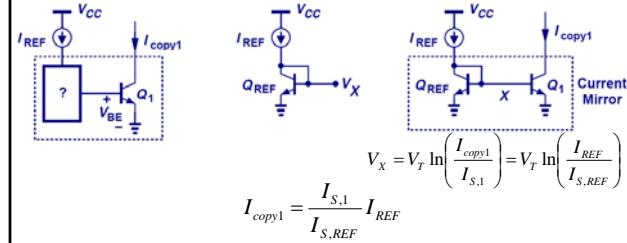
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Current Mirror Circuitry

- 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



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

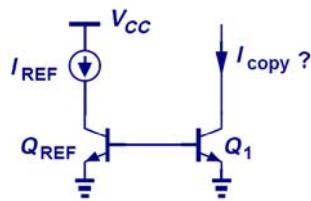
$$I_{copy1} = \frac{I_{S,1}}{I_{S,REF}} I_{REF}$$

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Bad Current Mirror Example I



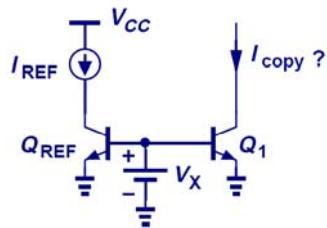
- Without shorting the collector and base of Q_{REF} together, there will not be a path for the base currents to flow, therefore, I_{copy} is zero.

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Bad Current Mirror Example II



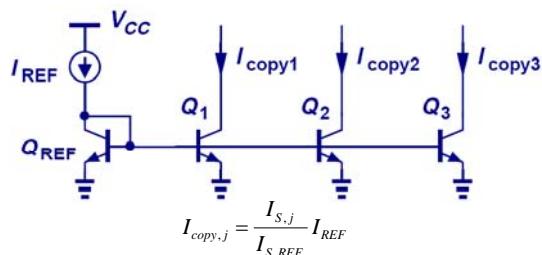
- Although a path for base currents exists, this technique of biasing is no better than resistive divider.

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Multiple Copies of I_{REF}



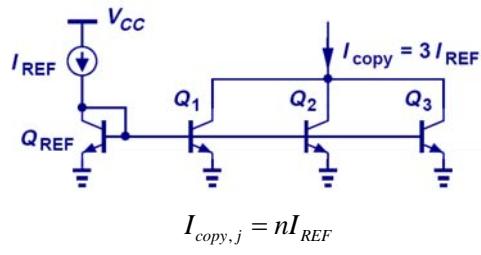
- Multiple copies of I_{REF} can be generated at different locations by simply applying the idea of current mirror to more transistors.

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Current Scaling



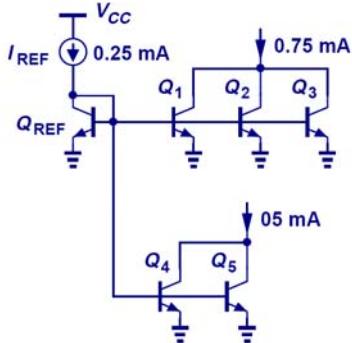
- By scaling the emitter area of Q_j n times with respect to Q_{REF} , $I_{copy,j}$ is also n times larger than I_{REF} . This is equivalent to placing n unit-size transistors in parallel.

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Example: Scaled Current



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Fractional Scaling

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

A circuit diagram showing a reference current source I_{REF} connected to a collector node. This node is connected to the bases of three transistors, Q_{REF1} , Q_{REF2} , and Q_{REF3} . The emitters of Q_{REF1} , Q_{REF2} , and Q_{REF3} are connected to a common node, which then connects to the collector of transistor X . The base of X is connected to the collector of transistor Q_1 . The collector of Q_1 is labeled I_{copy} . The collector of X is labeled $I_{copy} = I_S \exp\left(\frac{V_x}{V_T}\right)$. The collector of Q_{REF1} is labeled $I_{REF} = 3I_S \exp\left(\frac{V_x}{V_T}\right)$.

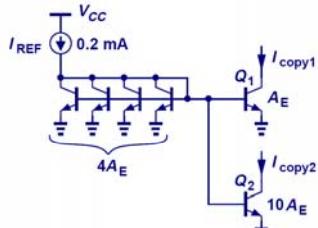
$$I_{copy} = \frac{1}{3} I_{REF}$$

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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 .

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Effect of Base Currents

A circuit diagram showing a reference current source I_{REF} connected to a collector node. This node is connected to the bases of three transistors: Q_{REF} , Q_1 , and Q_2 . The emitters of Q_{REF} and Q_1 are connected to a common node, which then connects to the collector of Q_1 . The base of Q_1 is connected to the collector of Q_2 . The collector of Q_1 is labeled I_{copy} . The collector of Q_2 is labeled nA_E . The collector of Q_{REF} is labeled $I_{C,REF} = \frac{I_{copy}}{n} \beta$. Red annotations show the base currents $I_{C,REF}$ and I_{copy} flowing through the base-emitter junctions of Q_{REF} and Q_1 respectively.

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

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

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

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

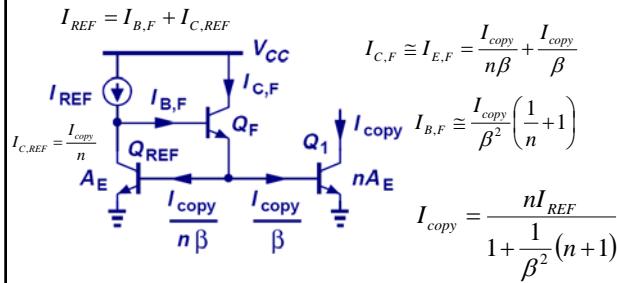
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Improved Mirroring Accuracy

- 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 .

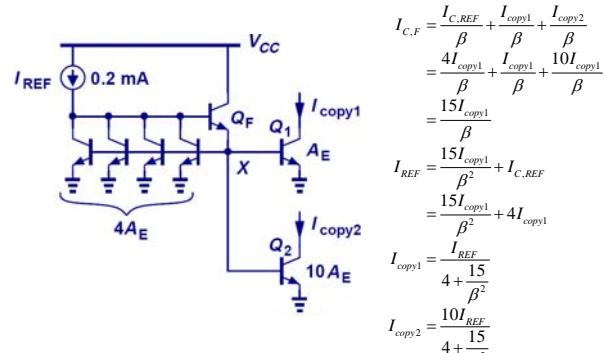


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Example: Different Mirroring Ratio Accuracy

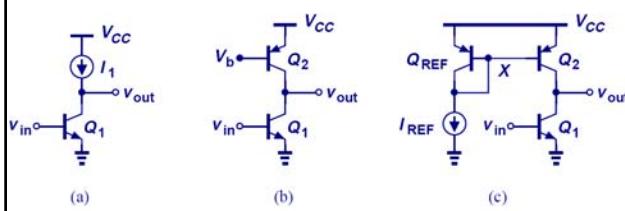


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PNP Current Mirror



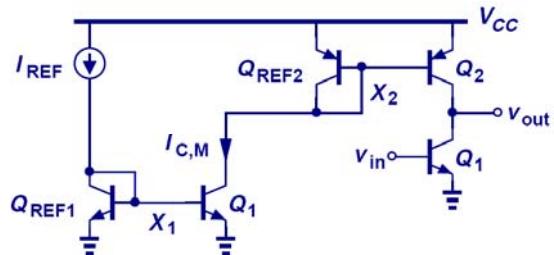
- PNP current mirror is used as a current source load to an NPN amplifier stage.

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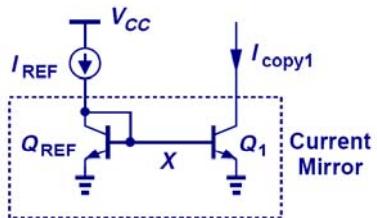
Generation of I_{REF} for PNP Current Mirror



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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.