

Lecture 12

OUTLINE

- Current Mirrors

Reading: Chapter 9.2

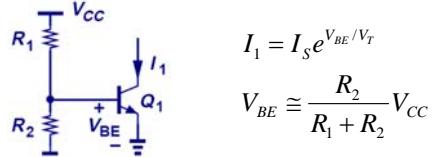
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Temperature and Supply-Voltage Dependence of Bias Current

- 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.



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

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

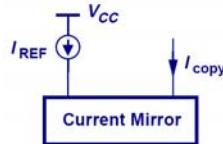
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Concept of a Current Mirror

- 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.



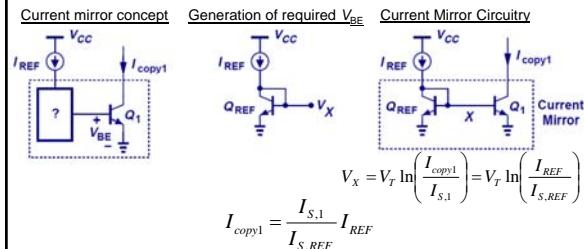
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Current Mirror Circuitry

- 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} .



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

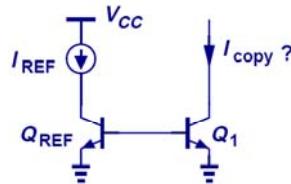
$$I_{copy1} = \frac{I_{S,1}}{I_{S,REF}} I_{REF}$$

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Bad Current Mirror Example I



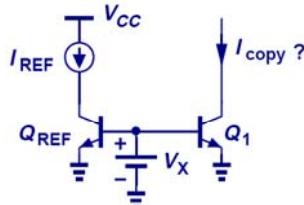
- Without shorting the collector and base of Q_{REF} together, there will not be a path for the base currents to flow, therefore, I_{copy} is zero.

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Bad Current Mirror Example II



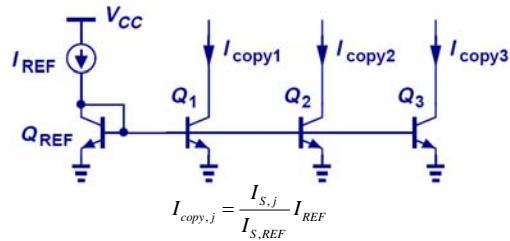
- Although a path for base currents exists, this technique of biasing is no better than resistive divider.

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Multiple Copies of I_{REF}



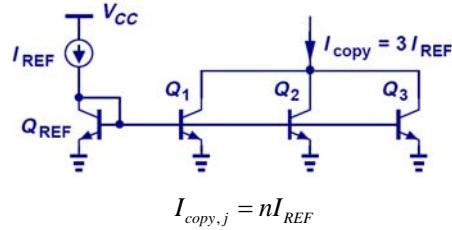
- Multiple copies of I_{REF} can be generated at different locations by simply applying the idea of current mirror to more transistors.

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Current Scaling



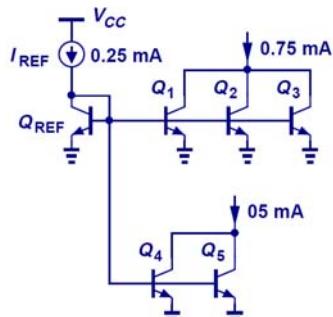
- By scaling the emitter area of Q_j n times with respect to Q_{REF} , $I_{copy,j}$ is also n times larger than I_{REF} . This is equivalent to placing n unit-size transistors in parallel.

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Example: Scaled Current



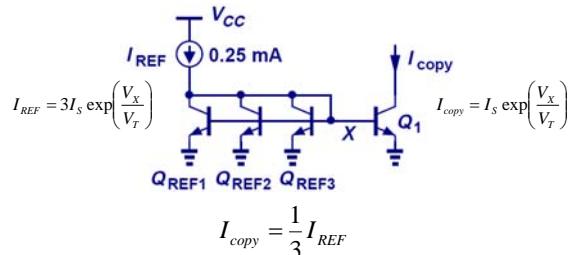
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Fractional Scaling

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

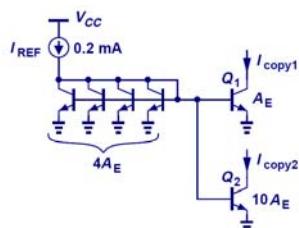


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Example: Different Mirroring Ratio



- 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

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

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

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

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

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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 .

The circuit diagram shows a current-controlled current source (CCCS) structure. A reference current source I_{REF} is connected to the base of transistor Q_{REF} . The collector of Q_{REF} is connected to the base of transistor Q_F , which has its collector connected to ground. The collector of Q_F is connected to the base of transistor Q_1 , which has its collector connected to the output node. The output node is also connected to the base of Q_F through a resistor $n\beta$. The collector of Q_1 is connected to the output node and to the base of transistor Q_E through a resistor nA_E . The collector of Q_E is connected to ground. The base of Q_E is connected to the output node and to the base of Q_F through a resistor $n\beta$. The collector of Q_E is connected to the output node and to the base of Q_1 through a resistor nA_E . The output node is connected to the collector of Q_1 and to ground through a resistor β .

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Example: Different Mirroring Ratio Accuracy

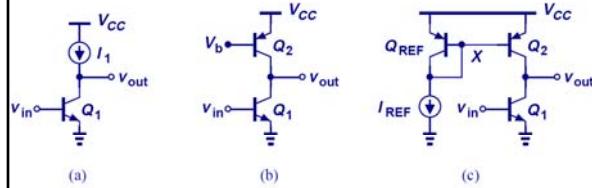
The circuit diagram shows a current-copying stage. A reference current I_{REF} of 0.2 mA flows through a resistor R_{REF} . This current splits into two paths. One path goes through a resistor R_X to node X. From node X, the current splits into two branches: one branch passes through transistor Q_F to ground, and the other branch passes through transistor Q_1 to node A_E . The current at node A_E is labeled I_{copy1} . The other path from node X goes through transistor Q_X to ground. From the collector of Q_X , the current splits into two branches: one branch passes through transistor Q_2 to ground, and the other branch passes through transistor Q_2 to node A_E . The current at node A_E is labeled I_{copy2} . The total current at node A_E is the sum of I_{copy1} and I_{copy2} . The current I_{copy1} is scaled by a factor of $4A_E$, and the current I_{copy2} is scaled by a factor of $10A_E$.

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PNP Current Mirror



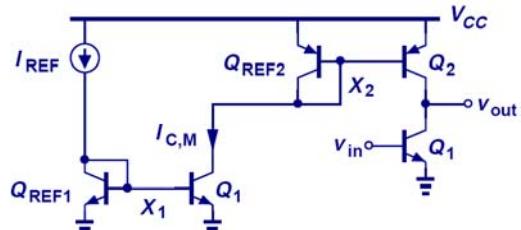
- PNP current mirror is used as a current source load to an NPN amplifier stage.

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Generation of I_{REF} for PNP Current Mirror

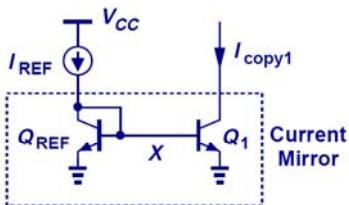


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Example: Current Mirror with Discrete Devices



- 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.

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