

## Discussion 8

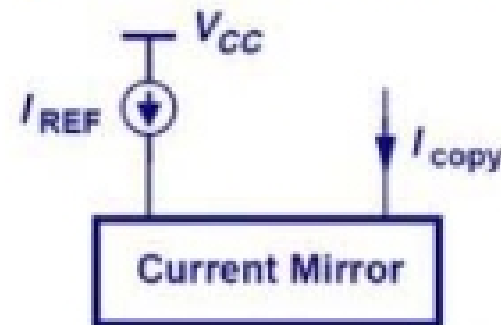
### Current Mirrors

#### 1. Motivation

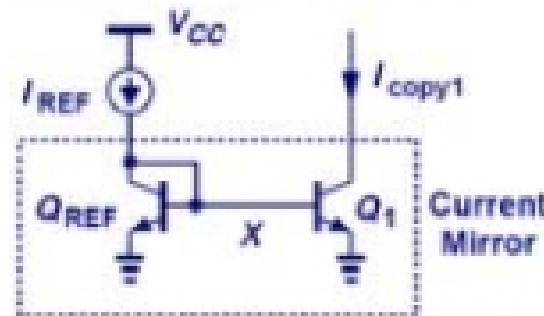
Typical biasing schemes introduced in Chapters 4 and 5 fail to establish a constant collector current if the supply voltage or temperature is subject to change. Although highly undesirable, these are unavoidable effects in transistor operating conditions. So how could we supply a constant current while avoiding supply and temperature dependence? The answer is using current mirrors.

#### 2. Bipolar Current Mirror

Assume that there is a “golden current”,  $I_{REF}$ , that is essentially independent of external conditions. Our goal is to produce  $I_{copy}$  that has same characteristics as  $I_{REF}$ .



In short, the black box could be realized as shown below.



Neglecting the base currents for now, note that  $Q_{REF}$  (diode-connected) and  $Q_1$  have equal  $V_{BE}$ . Therefore,

$$I_{REF} = I_{S, REF} \exp\left(\frac{V_x}{V_T}\right)$$

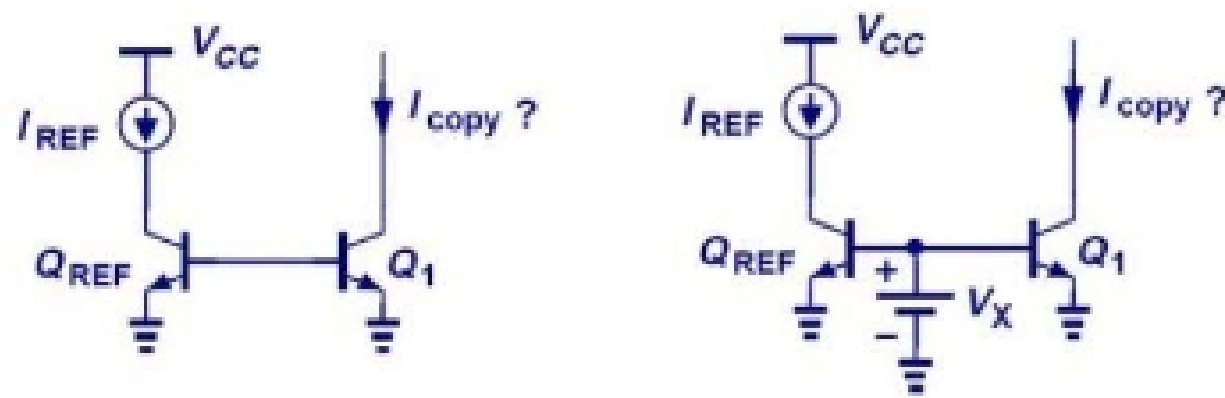
$$I_{copy} = I_{S, 1} \exp\left(\frac{V_x}{V_T}\right)$$

and hence,

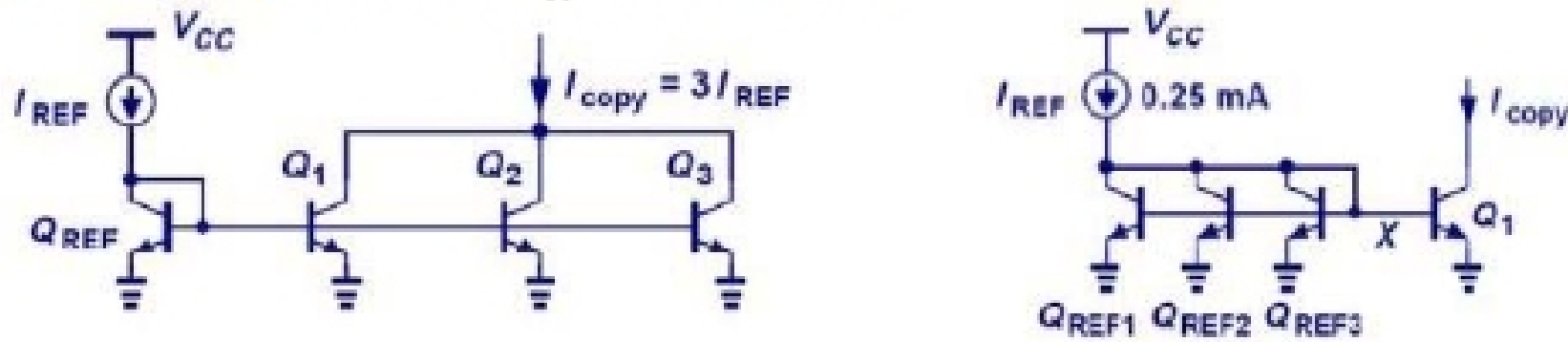
$$I_{copy} = \frac{I_{S, 1}}{I_{S, REF}} I_{REF}$$

If  $Q_{REF}$  and  $Q_1$  are identical ( $I_{S, REF}$  and  $I_{S, 1}$ ),  $I_{copy} = I_{REF}$ . Note that this holds true even though  $V_T$  and  $I_S$  vary with temperature.

Example) Explain why the following circuits are bad current mirrors.

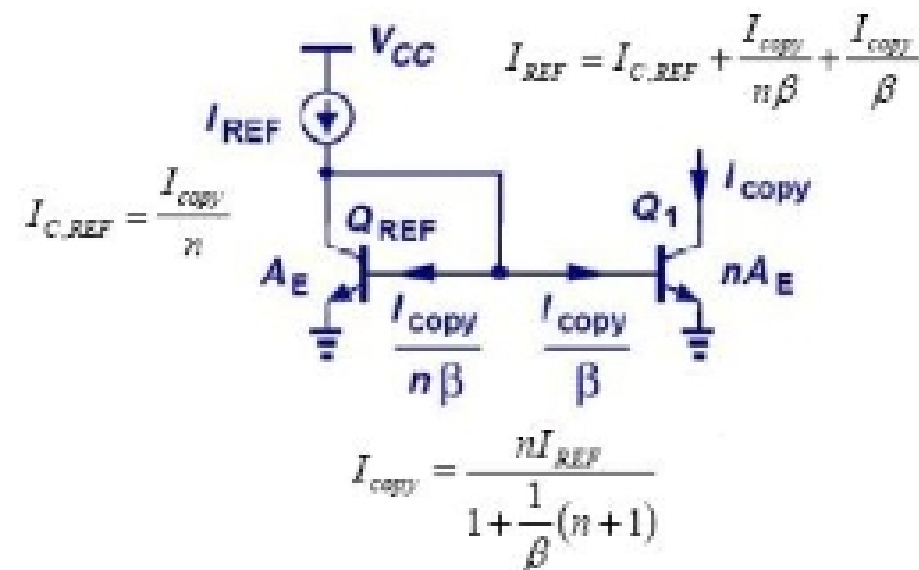


Example) Find the expression for  $I_{copy}$  in terms of  $I_{REF}$ .

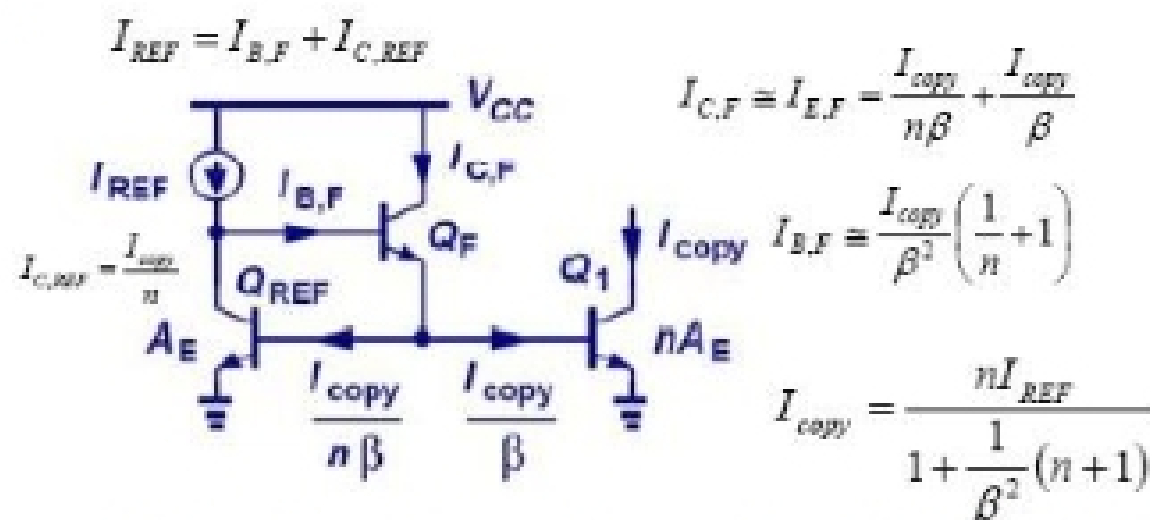


### 3. Effect of Base Current

Thus far, we have neglected the base current at node X by all transistors, an effect leading to a significant error as the number of copies increases. This error is due to a fraction of  $I_{REF}$  that through the base rather than the collector of  $Q_{REF}$ . Let us analyze the error with the following diagram.



For a large  $\beta$  and moderate  $n$ , the second term in the denominator is negligible and  $I_{copy} \approx nI_{REF}$ . However, as the number of copied current( $n$ ) increases, so does the error in  $I_{copy}$ . Let us try to suppress the error by introducing an emitter follower  $Q_F$  that is interposed between the collector of  $Q_{REF}$  and node X.



Note that we have assumed  $I_{C,F} \approx I_{E,F}$ . Now, we have reduced the effect of the base current by a factor of  $\beta$ . In other words, emitter follower allows room for more copied currents.

Example) [HW 7, Problem 1] Find the expression for  $I_{copy}$  in terms of  $I_{REF}$ .

