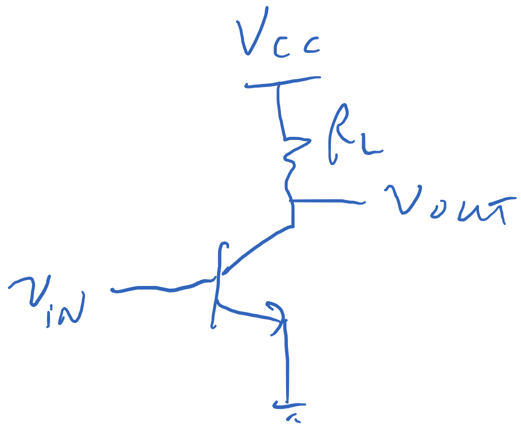
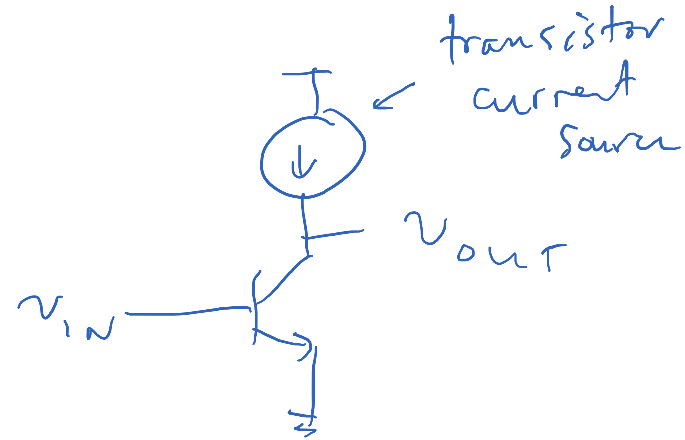
EEE 51: Second Semester 2017 - 2018

Lecture 7

Current Mirrors

- Current Mirrors

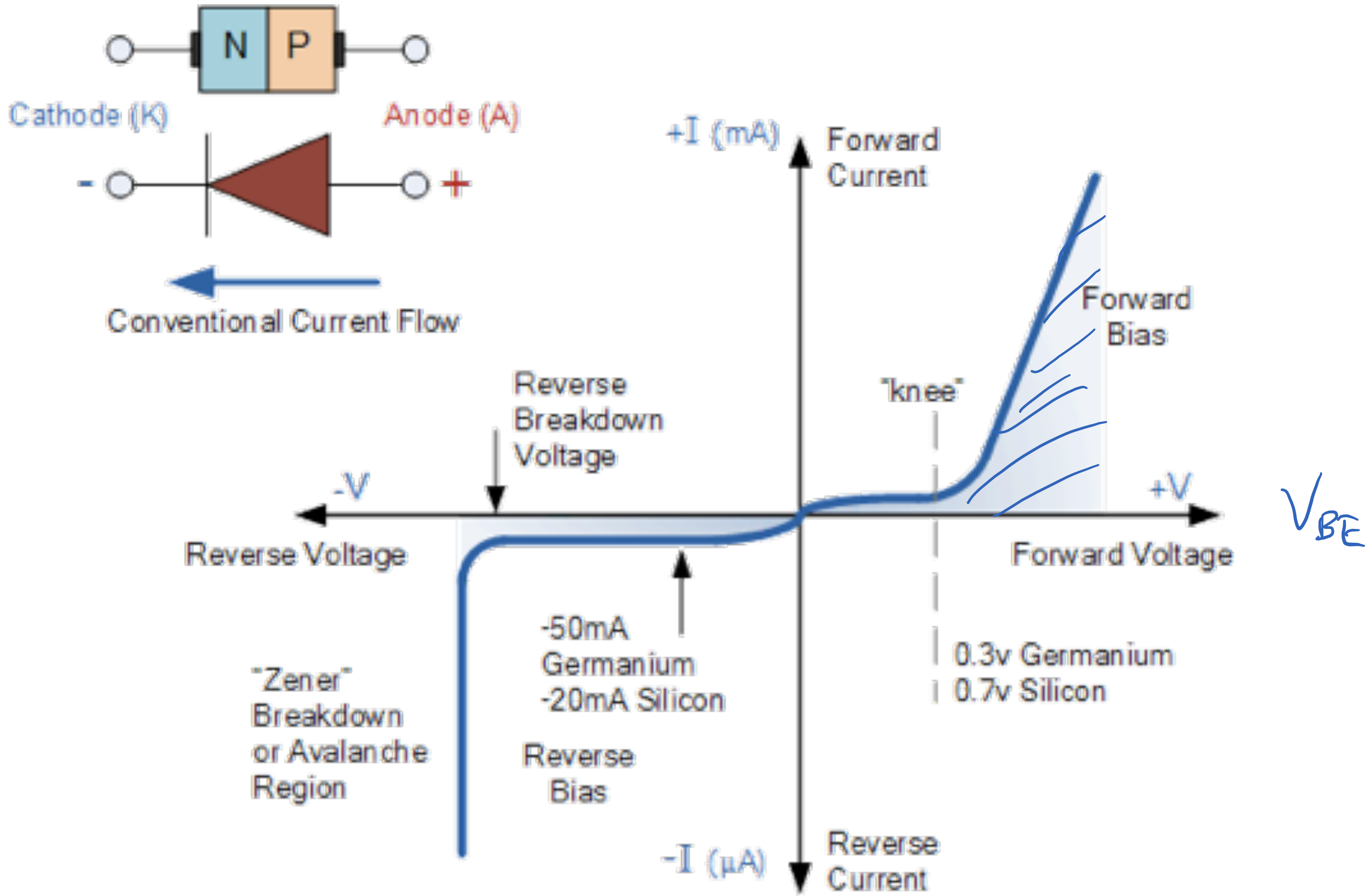




$$A_v = -g_m(r_o // R_L)$$
$$\approx -g_m R_L$$

$$A_v = -g_m r_o$$

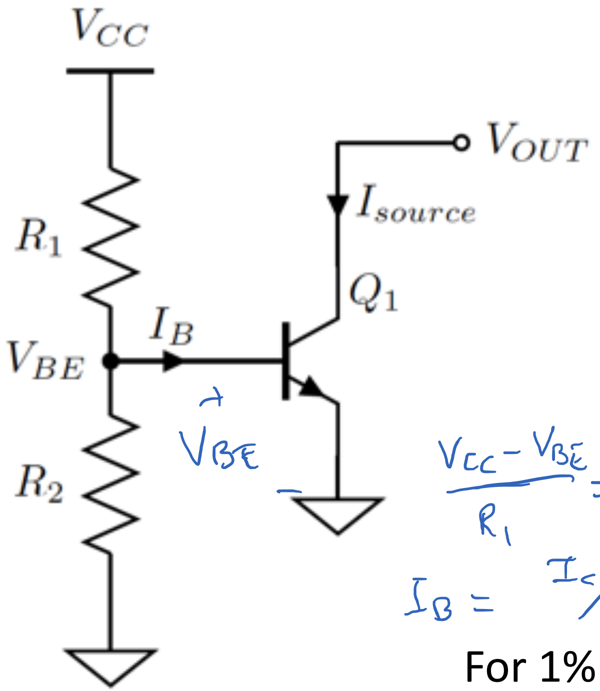
Practical Diode Characteristics



A Simple BJT Current Source

- Provide V_{BE} using a voltage divider

Forward Active: $I_C \approx I_S e^{V_{BE}/V_T}$



Example: what if we need 1mA?

$$V_{BE} = V_T \ln \frac{I_C}{I_S} = V_T \ln \frac{1\text{mA}}{2\times 10^{-16}\text{A}} = 0.7603\text{V}$$

Small changes in V_{BE}:

$$V_{BE} = 0.7703\text{V} \Rightarrow I_C = 1.5\text{mA}$$

Also, for V_{CC} = 5V and β = 200:

$$\frac{V_{CC}-V_{BE}}{R_1} = I_B + \frac{V_{BE}}{R_2}$$

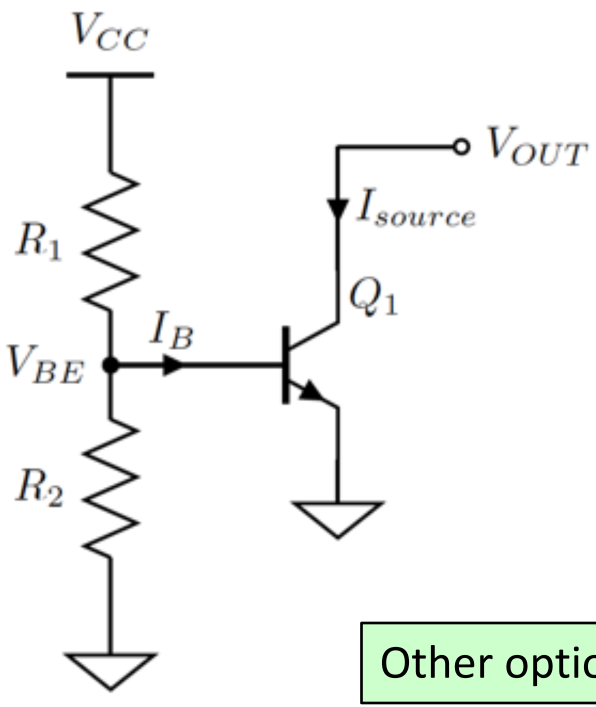
$$I_B = I_C/\beta$$

$$R_1 = 10\text{k}\Omega \Rightarrow R_2 = 1.8146\text{k}\Omega$$

For 1% error in I_C, ΔV_{BE} = 260μV $\Rightarrow$ $\beta = 200$ +/- 9

A Simple BJT Current Source

- Provide V_{BE} using a voltage divider



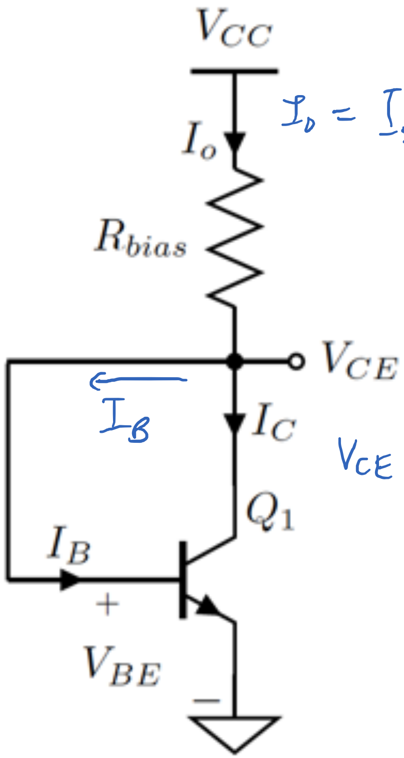
Main issues:

1. Need very precise resistor values
2. Need good β control

Expensive
(if possible at all)

Other options in generating V_{BE}?

The Diode-Connected Transistor (1)



$I_o = I_E$

$V_{CE} = V_{BE}$

Use R_{bias} to apply a current I_o into the BJT:

$$I_o = I_C + I_B = I_C \cdot \left(1 + \frac{1}{\beta}\right) \rightarrow I_C = \frac{I_o}{(1 + 1/\beta)}$$

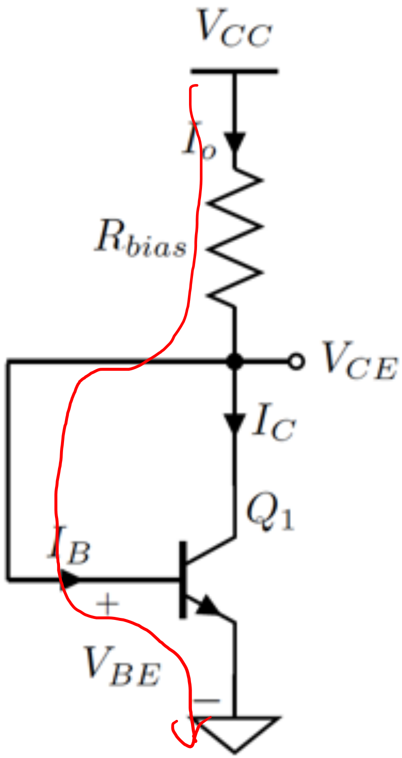
$$I_C \approx I_S e^{V_{BE}/V_T}$$

Solving for $V_{CE} = V_{BE}$ (assuming $V_A \rightarrow \infty$) :

$$V_{BE} = V_T \ln\left(\frac{I_C}{I_S}\right) = V_T \ln\left(\frac{I_o}{I_S} \cdot \frac{\beta}{\beta + 1}\right)$$

How do we generate I_o?

The Diode-Connected Transistor (2)



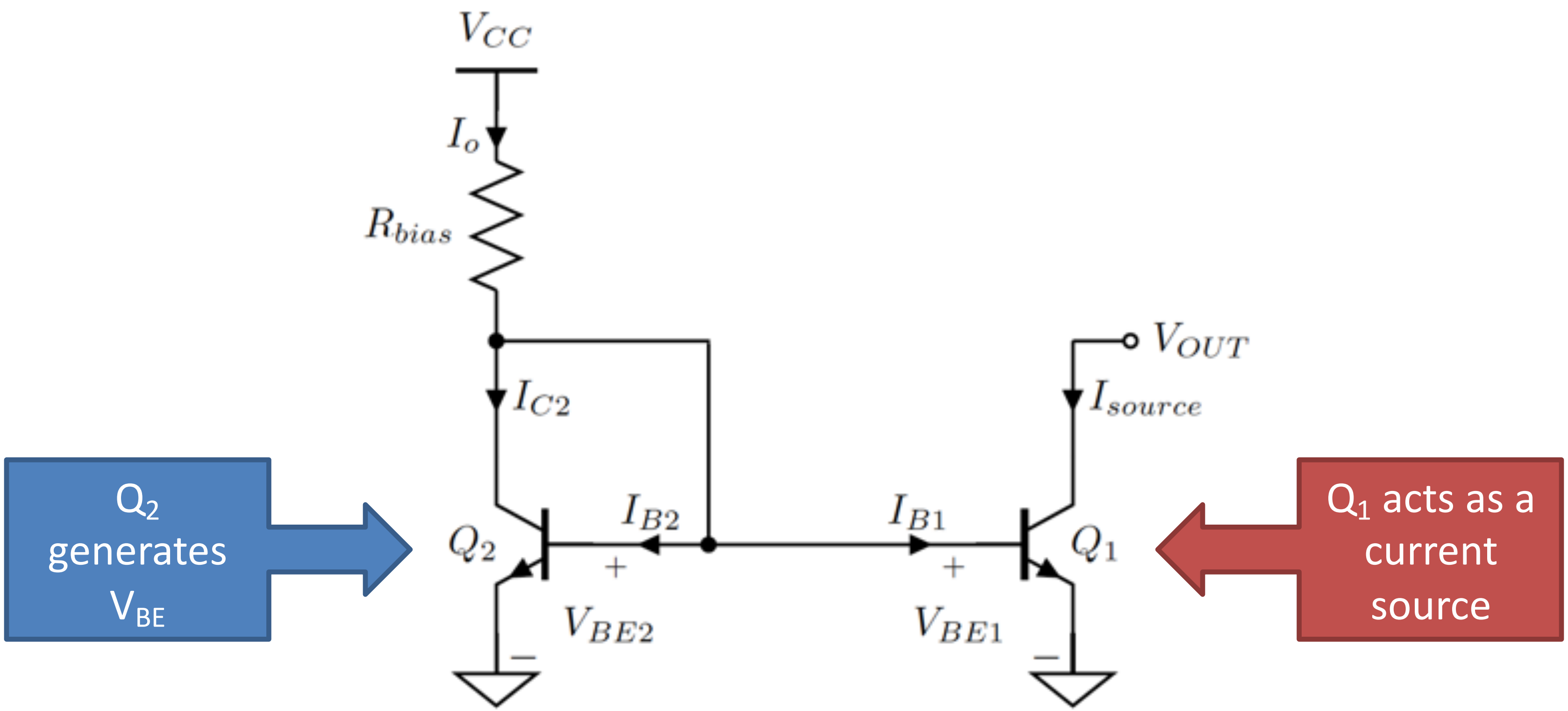
KVL at base loop:

$$V_{CC} - I_o R_{bias} - V_{BE} = 0$$

Thus,
$$\boxed{R_{bias} = \frac{V_{CC} - V_{BE}}{I_o} = \frac{V_{CC} - V_{BE}}{I_S \cdot e^{\frac{V_{BE}}{V_T}} \cdot \left(1 + \frac{1}{\beta}\right)}}$$

We can pick a resistor to generate V_{BE}

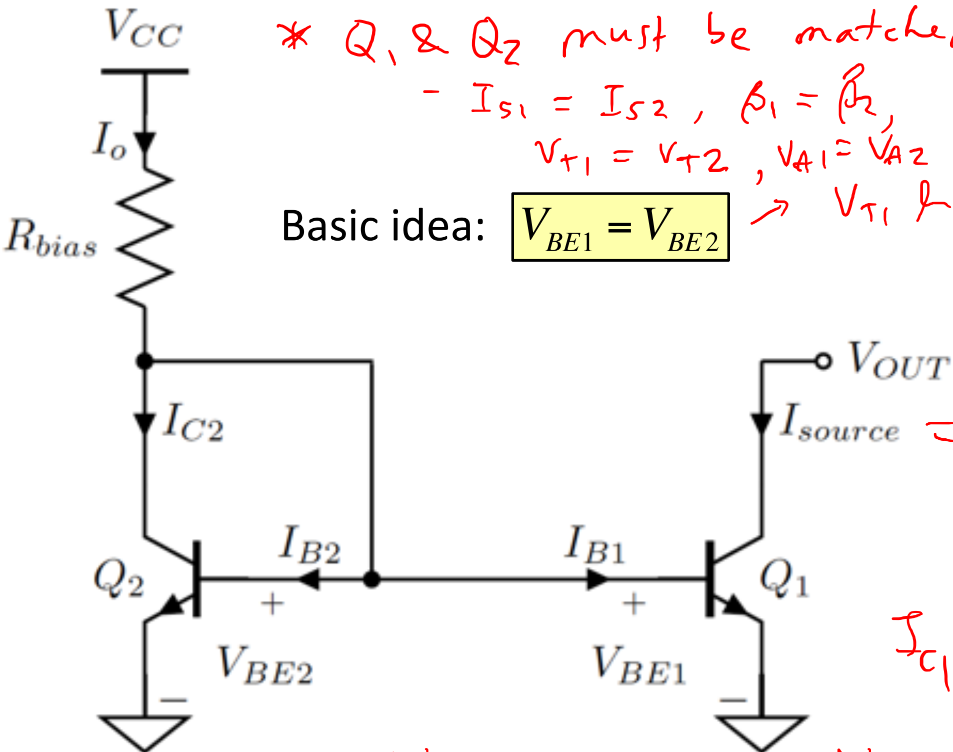
A Simple BJT Current Mirror (1)



A Simple BJT Current Mirror (2)

$I_C = I_S e^{V_{BE}/V_T}\left(1 + \frac{V_{CE}}{V_A}\right)$

* Q_1 & Q_2 must be matched
  - $I_{S1} = I_{S2}$, $\beta_1 = \beta_2$, $V_{T1} = V_{T2}$, $V_{A1} = V_{A2}$



Basic idea: $\boxed{V_{BE1} = V_{BE2}}$

$\rightarrow V_{T1} \ln\left(\frac{I_{C1}}{I_{S1}\left(1+\frac{V_{CE1}}{V_{A1}}\right)}\right) = V_{T2} \ln\left(\frac{I_{C2}}{I_{S2}\left(1+\frac{V_{CE2}}{V_{A2}}\right)}\right)$

Recall: $V_{BE} = V_T \ln\left(\frac{I_C}{I_S\left(1+\frac{V_{CE}}{V_A}\right)}\right)$

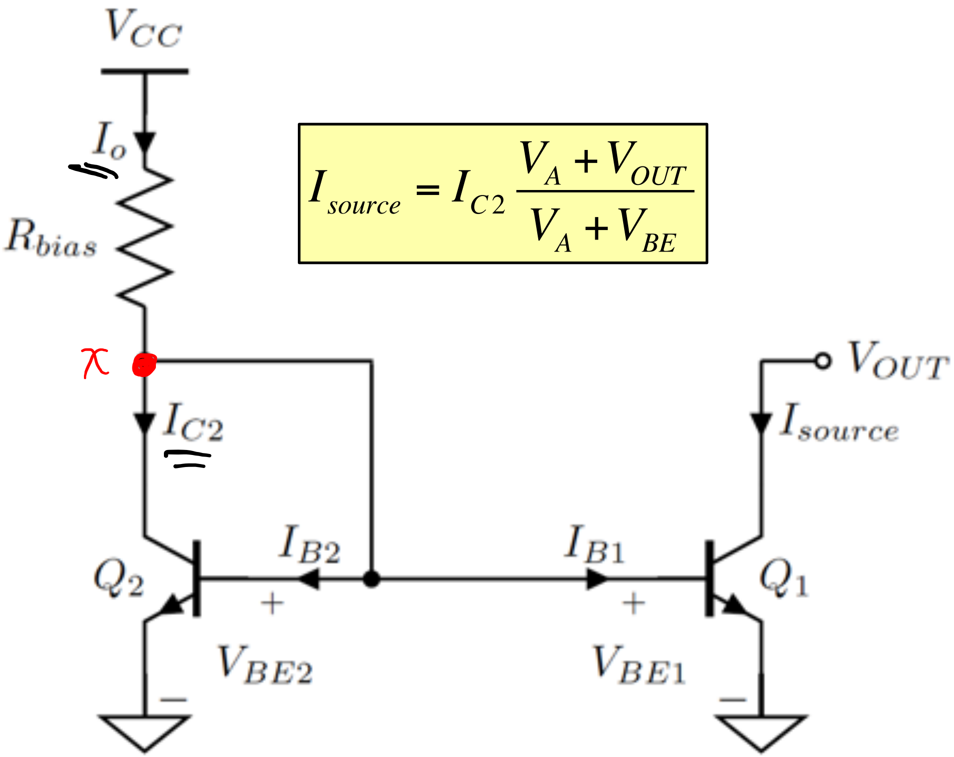
$$\frac{I_{C1}}{\left(1+\frac{V_{CE1}}{V_A}\right)} = \frac{I_{C2}}{\left(1+\frac{V_{CE2}}{V_A}\right)}$$

$I_{source} = I_{C1}$

$V_{CE2} = V_{BE2}$ $\quad V_{CE1} = V_{OUT}$

$$I_{C1} = \boxed{I_{source} = I_{C2}\frac{\left(1+\frac{V_{CE1}}{V_A}\right)}{\left(1+\frac{V_{CE2}}{V_A}\right)} = I_{C2}\frac{V_A + V_{OUT}}{V_A + V_{BE}}}$$

A Simple BJT Current Mirror (3)



$$I_{source} = I_{C2}\frac{V_A + V_{OUT}}{V_A + V_{BE}}$$

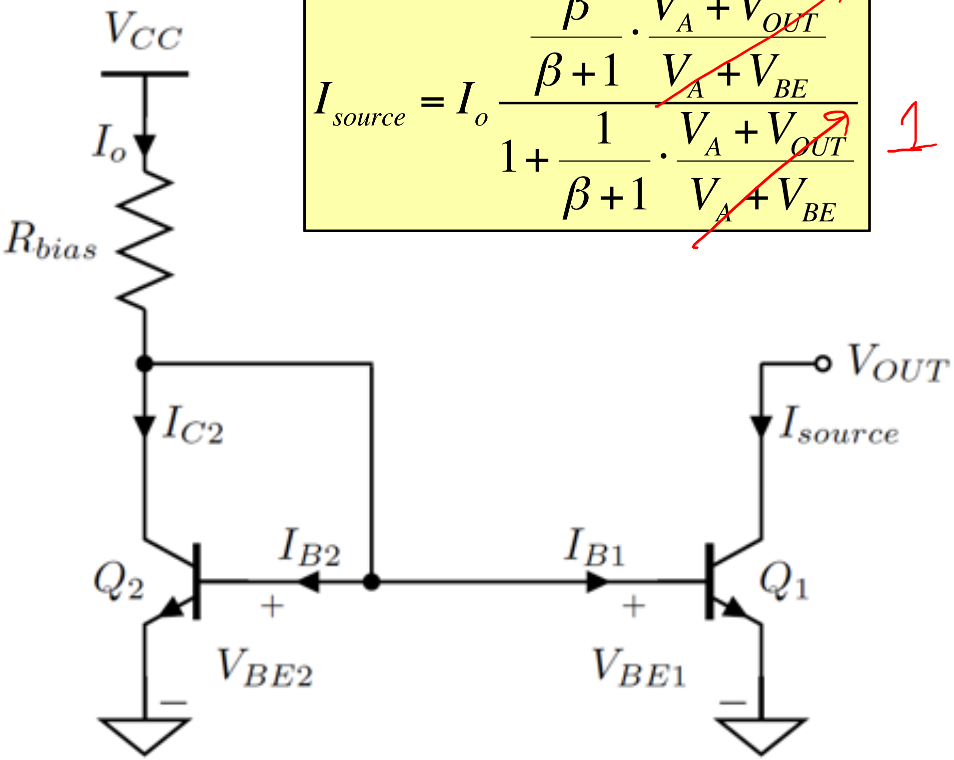
KCL at x :

$$\rightarrow\ I_{C2} = I_o - I_{B1} - I_{B2} = I_o - \frac{I_{source}}{\beta} - \frac{I_{C2}}{\beta}$$

$$= \frac{\beta}{\beta+1} I_o - \frac{I_{source}}{\beta+1}$$

$$I_{source} = I_o \frac{\dfrac{\beta}{\beta+1}\cdot\dfrac{V_A + V_{OUT}}{V_A + V_{BE}}}{1 + \dfrac{1}{\beta+1}\cdot\dfrac{V_A + V_{OUT}}{V_A + V_{BE}}}$$

A Simple BJT Current Mirror (4)



complete expression

$$I_{source} = I_o \frac{\frac{\beta}{\beta+1} \cdot \cancelto{1}{\frac{V_A + V_{OUT}}{V_A + V_{BE}}}}{1 + \frac{1}{\beta+1} \cdot \cancelto{1}{\frac{V_A + V_{OUT}}{V_A + V_{BE}}}}$$

Assume $V_A \rightarrow \infty$

$$I_{source} \approx I_o \frac{\frac{\beta}{\beta+1}}{1 + \frac{1}{\beta+1}} = \frac{I_o}{1 + \frac{2}{\beta}}$$

Assume $V_A \rightarrow \infty$ and $\beta \rightarrow \infty$

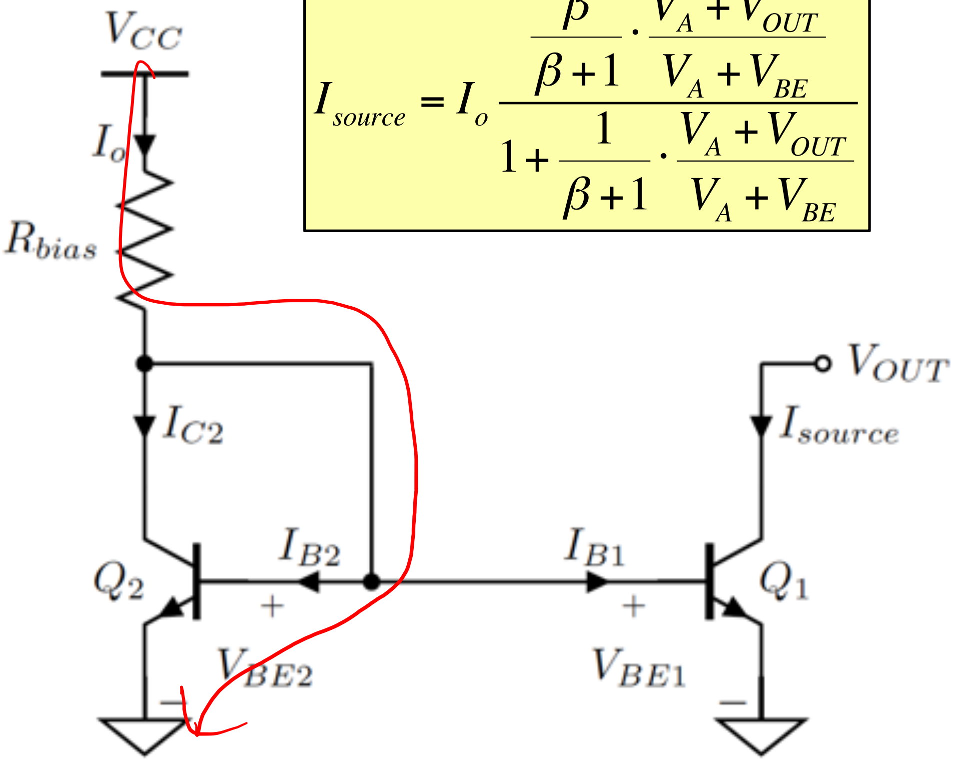
$$I_{source} \approx I_o$$

Mirror!

Mirroring Error:

1. Due to the base currents
2. Due to V_{CE} "mismatch"

A Simple BJT Current Mirror (4)



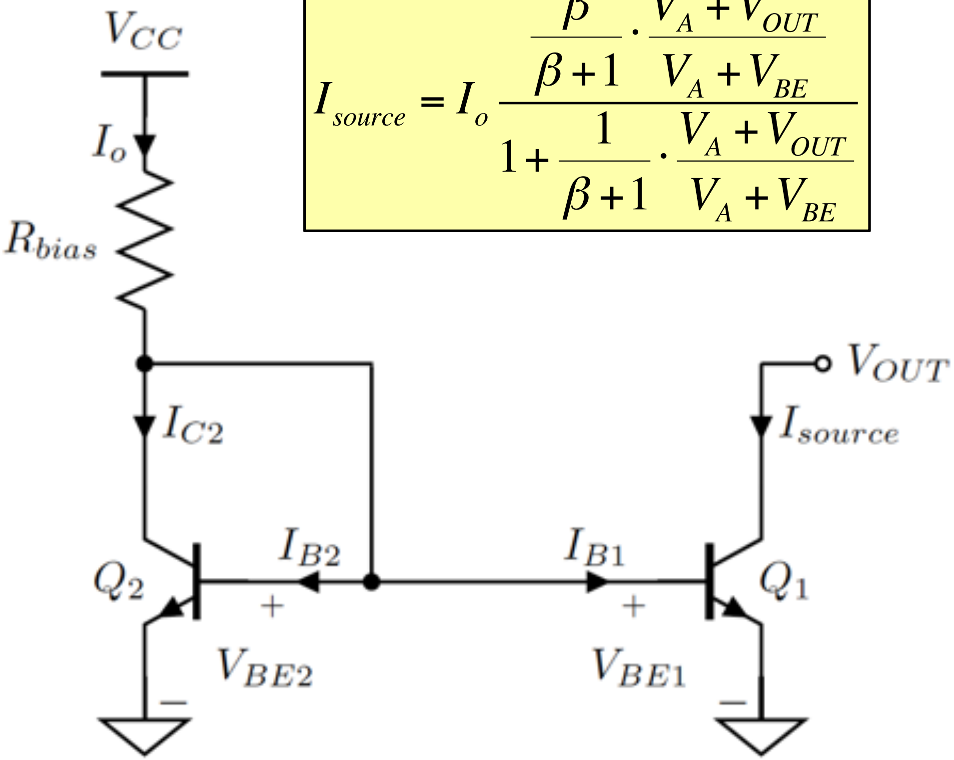
$$I_{source} = I_o \frac{\dfrac{\beta}{\beta+1} \cdot \dfrac{V_A + V_{OUT}}{V_A + V_{BE}}}{1 + \dfrac{1}{\beta+1} \cdot \dfrac{V_A + V_{OUT}}{V_A + V_{BE}}}$$

What about R_{bias}?

$$R_{bias} = \frac{V_{CC} - V_{BE}}{I_o}$$

R is **linearly** related to I_o and I_{source} (not exponentially!)

A Simple BJT Current Mirror (5)



$$I_{source} = I_o \frac{\frac{\beta}{\beta+1} \cdot \frac{V_A + V_{OUT}}{V_A + V_{BE}}}{1 + \frac{1}{\beta+1} \cdot \frac{V_A + V_{OUT}}{V_A + V_{BE}}}$$

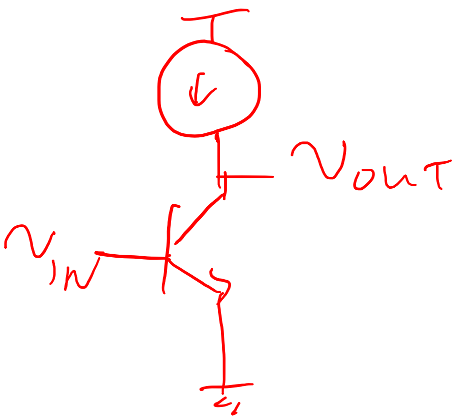
Assume $V_A \rightarrow \infty$

$$I_{source} \approx \frac{I_o}{1 + \frac{2}{\beta}}$$

Again, what if we need 1mA?

- We can tolerate β as low as 99 and still get only 1% error!

OUTPUT SWING



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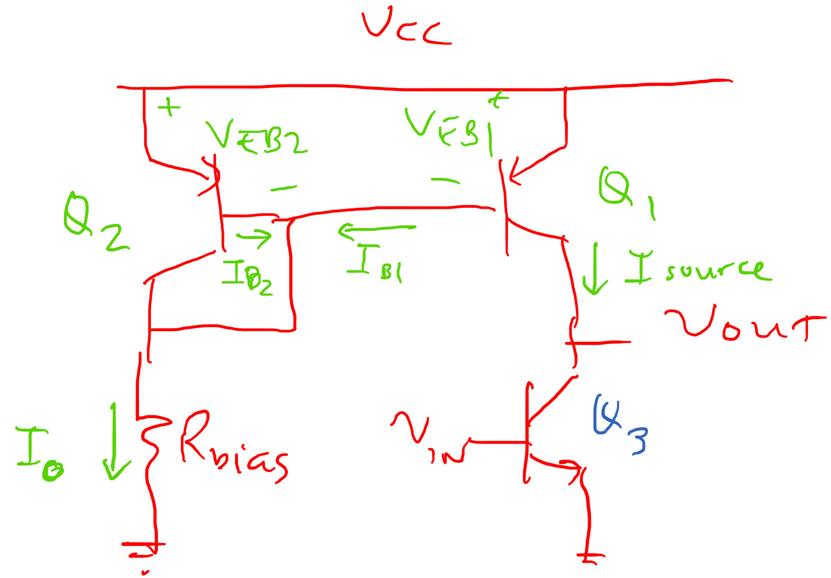
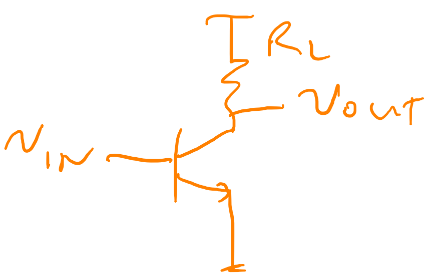




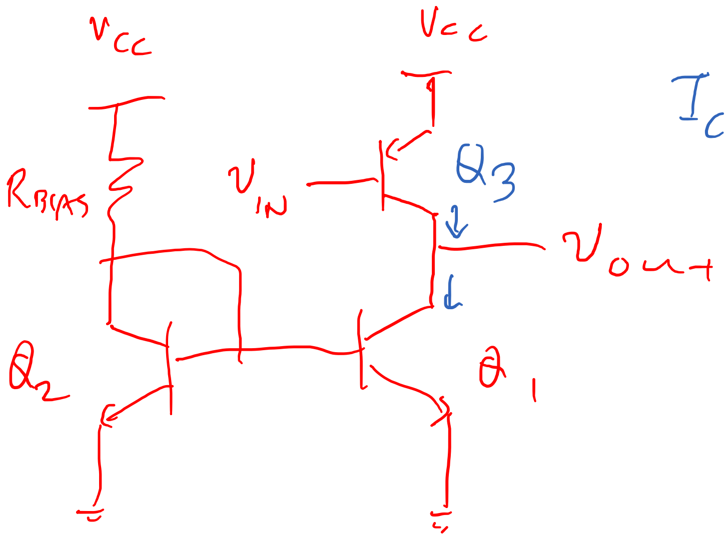
$V_{OUT,min} = V_{CE,SAT}$

$V_{OUT,max} = V_{CC}$

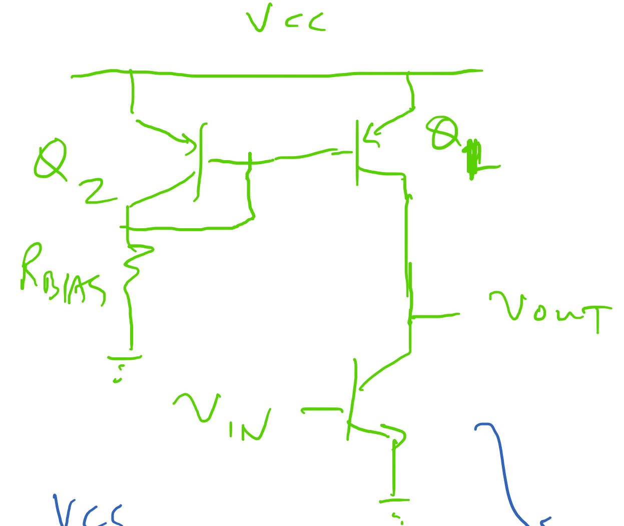
$V_{OUT,min} = V_{CE,SAT3}$

$V_{OUT,max} = V_{CC} - V_{EC,SAT1}$

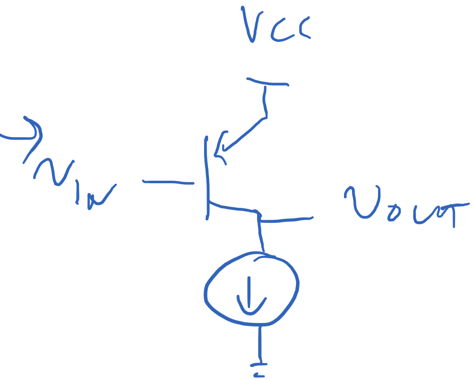
NPN CE w/ PNP simple CM

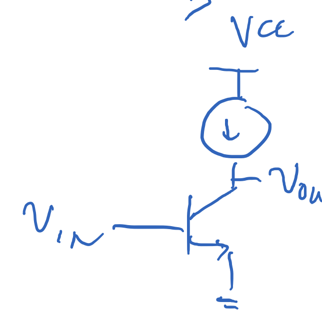


$I_{C1} = I_{C3}$



PNP CE w/ NPN simple current mirror





Next Meeting

- Biasing Amplifiers Using Current Sources
- Differential Circuits