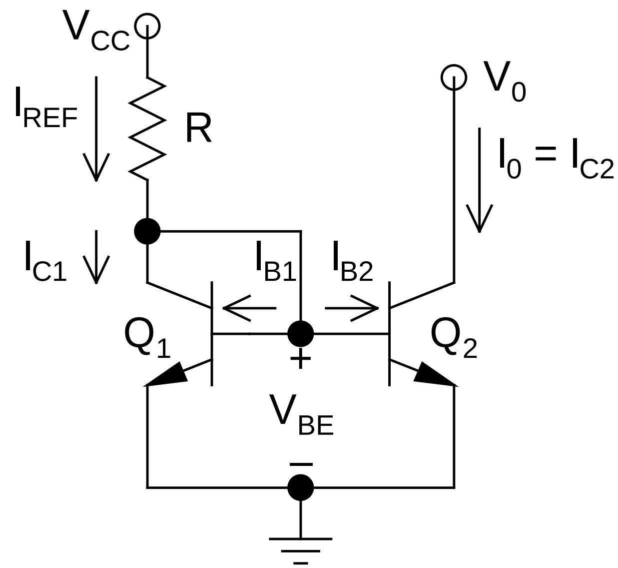
- ***Simple npn CM***:
  - Q_1 has its ***B and C shorted***
    - ***Can never saturate*** ($V_{BC} = 0$)
    - Known as ***diode-connected BJT***
  - Q_1 and Q_2 have ***same*** V_{BE}
  - I_{REF} = ***Reference Current***

    $= (V_{CC} - V_{BE})/R$
  - I_0 = ***Output Current*** = I_{C2}
  - V_0 = ***Output Voltage***
    - ***Variable***, ***depends on the load connected to it***



- ***General Analysis***:

$$I_{REF} = I_{C1} + I_{B1} + I_{B2} = I_{C1}\left(1 + \frac{1}{\beta_1}\right) + \frac{I_{C2}}{\beta_2}$$

- Now:

$$V_{BE} = V_T \ln\left(\frac{I_{C2}}{I_{S2}}\right) = V_T \ln\left(\frac{I_{C1}}{I_{S1}}\right)$$

$$\Rightarrow I_{C2} = KI_{C1} \quad \left(K = I_{S2}/I_{S1}\right)$$

- Thus:

$$I_{REF} = I_{C2}\left[\frac{1}{\beta_2} + \frac{1}{K}\left(1 + \frac{1}{\beta_1}\right)\right]$$

- ***Finally***:

$$I_0 = I_{C2} = \frac{I_{REF}}{\frac{1}{\beta_2} + \frac{1}{K}\left(1 + \frac{1}{\beta_1}\right)}$$

- This is the ***exact expression*** of I_0, ***without making any assumptions/approximations whatsoever***
- The ***only assumption*** so far is that we have ***neglected Early effect***, which we would include soon

- Now, we ***make approximations/assumptions***:

1. $\beta_1 = \beta_2 = \beta$:

$$\Rightarrow I_0 = \frac{KI_{REF}}{1 + \dfrac{1+K}{\beta}}$$

2. $I_{S1} = I_{S2} = I_S$ $(K = 1)$:

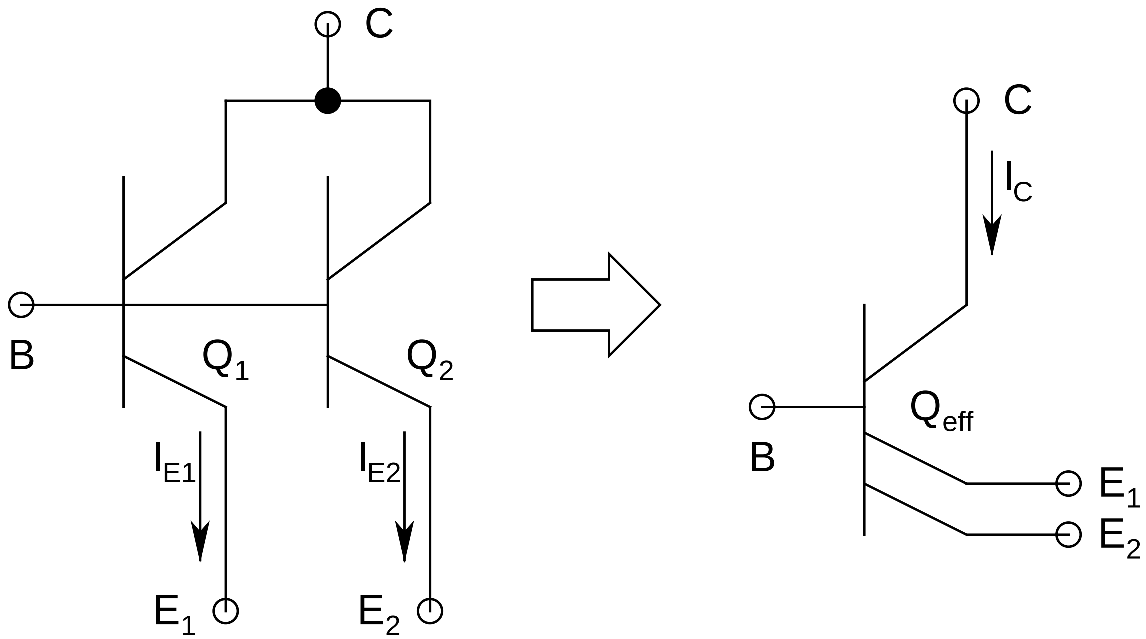
$$\Rightarrow I_0 = \frac{I_{REF}}{1 + 2/\beta}$$

3. And finally $\beta >> 2$:

$\Rightarrow I_0 = I_{REF} \Rightarrow$ ***Current Mirror***!

- For this to happen, Q_1 and Q_2 must have ***same β*** (***>> 2***), and ***same I_S***
- If two BJTs have ***same β, I_S, and V_A***, they are known as a ***matched pair***
- If $I_{S1} \neq I_{S2}$ and/or $\beta_1 \neq \beta_2$, then $I_0 \neq I_{REF}$
  - Leads to ***random error*** (***process induced***)
- If $\beta_1 = \beta_2$, but $I_{S1} \neq I_{S2}$, then $I_0 = KI_{REF}$
  - ***K or 1/K can only be integers***
    - ***I_0 and I_{REF} become integer multiples of each other***

- ***Multi-Emitter BJT***:



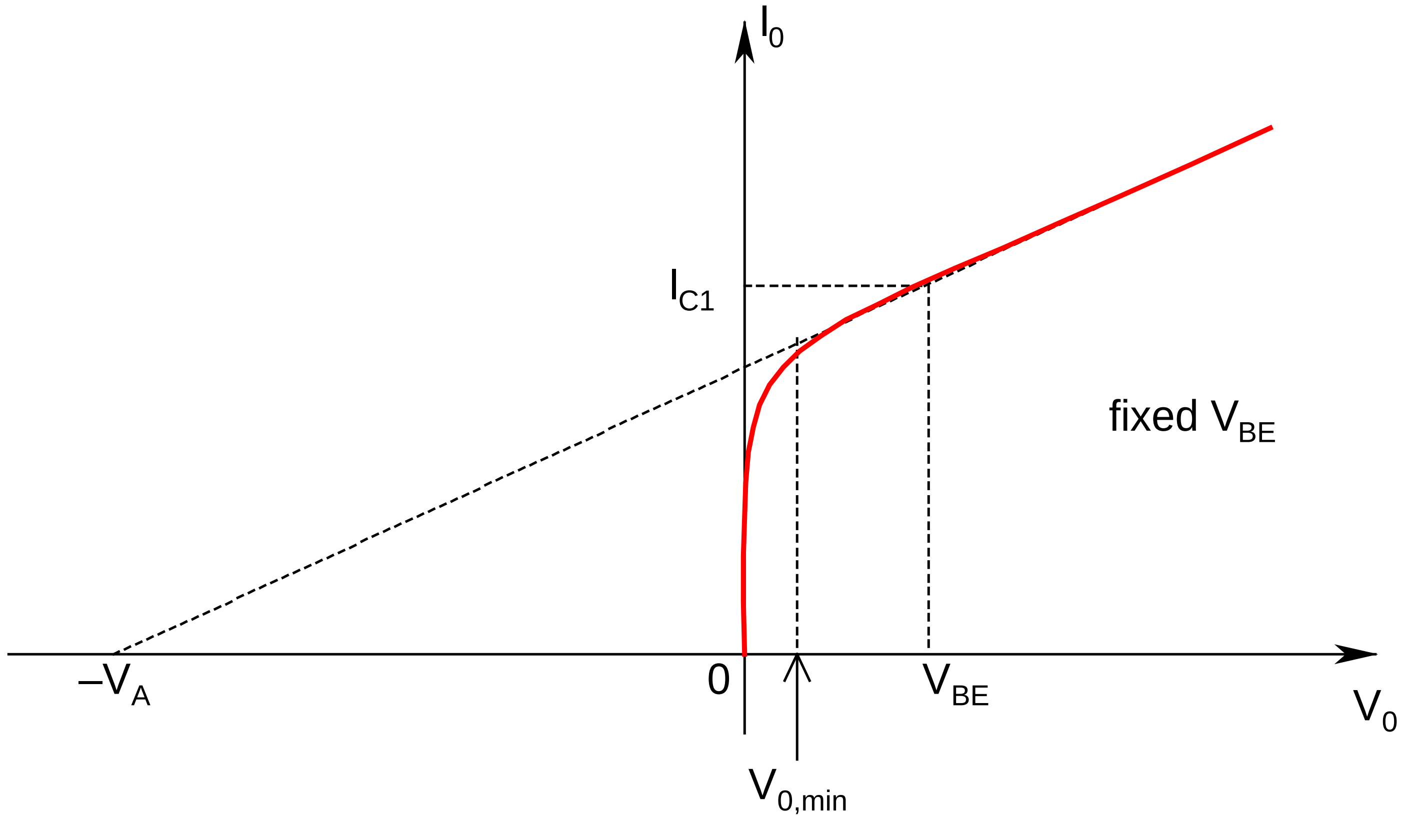
➢ $I_{S1} = I_{S2} \Rightarrow I_{E1} = I_{E2} = I_E \Rightarrow I_C \approx 2I_E$

- ***This does not imply that $\alpha = 2$**, **since there are two emitters***

- ***Systematic Error***:
  - ***Even if Q_1 and Q_2 are perfectly matched and $\beta >> 2$**, **still I_0 may not equal I_{REF}***!
  - ***Recall***:

    $$I_C = I_S[\exp(V_{BE}/V_T)](1 + V_{CE}/V_A)$$
  - ***Thus***:

    $$\frac{I_{C2}}{I_{C1}} = \frac{I_0}{I_{C1}} = \frac{1 + V_{CE2}/V_A}{1 + V_{CE1}/V_A} = \frac{1 + V_0/V_A}{1 + V_{BE}/V_A}$$
  - Therefore, ***$I_0 = I_{C1}$ only when $V_0 = V_{BE}$***



$V_{0,min} = V_{CE2}(SS) = 0.2$ V