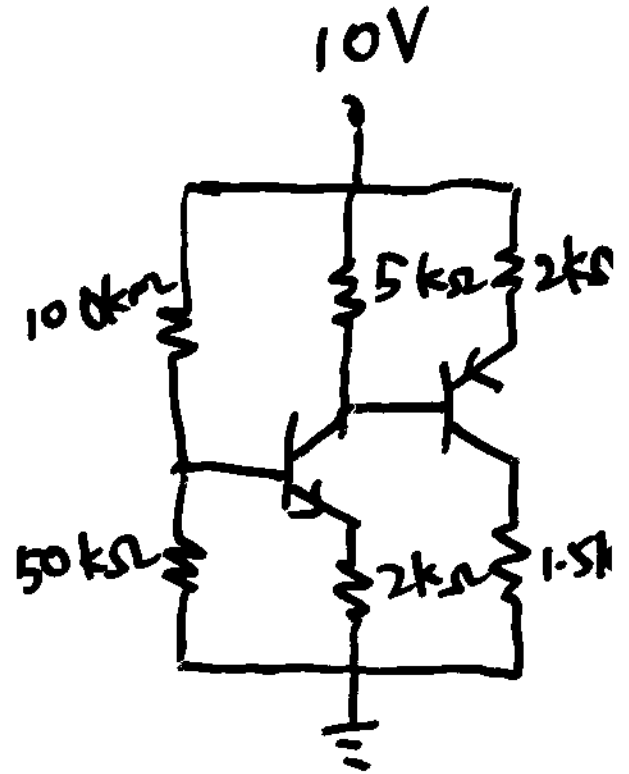
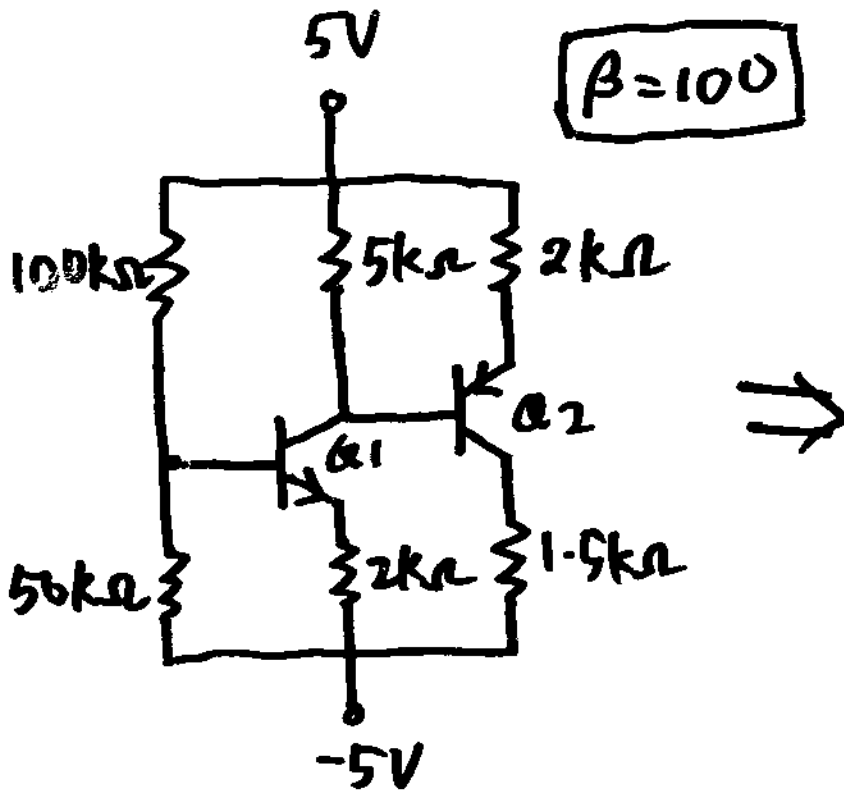


# Multi-Stage Circuits

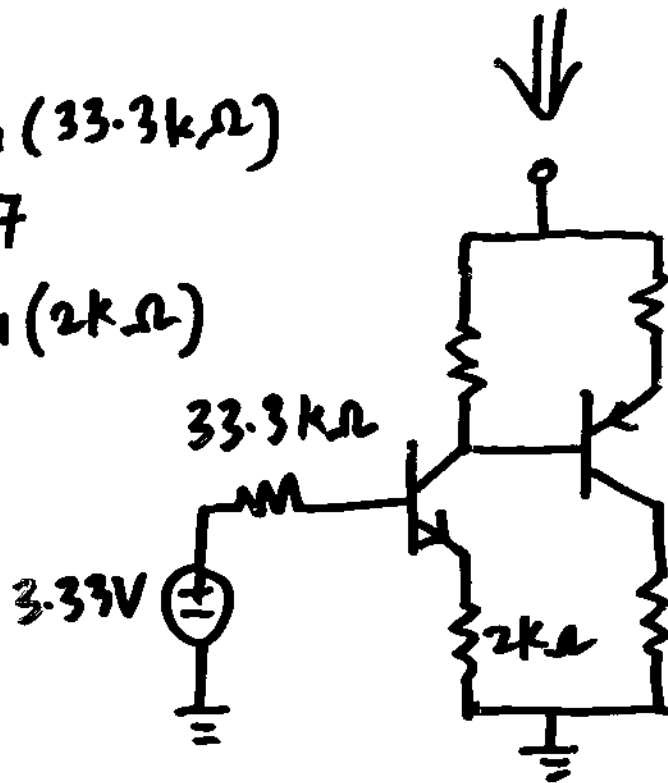


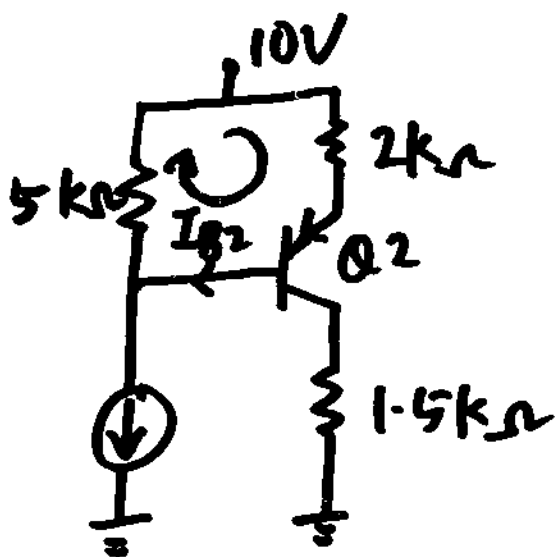
$$I_{B1} \Rightarrow 3.33V = I_{B1}(33.3k\Omega) + 0.7 + I_{E1}(2k\Omega)$$

$$\Rightarrow I_{B1} = 11.2 \mu A$$

$$I_{C1} = 1.12 \text{ mA}$$

$$I_{E1} = 1.13 \text{ mA}$$





$$-(\beta + 1)I_{B2} \cdot 2k\Omega - 0.7 + (1.12\text{mA} - I_{B2})5k\Omega = 0$$

$$\Rightarrow I_{B2} = 23.7\mu\text{A}$$

$$I_{C2} = 100 I_{B2} = 2.37\text{mA}$$

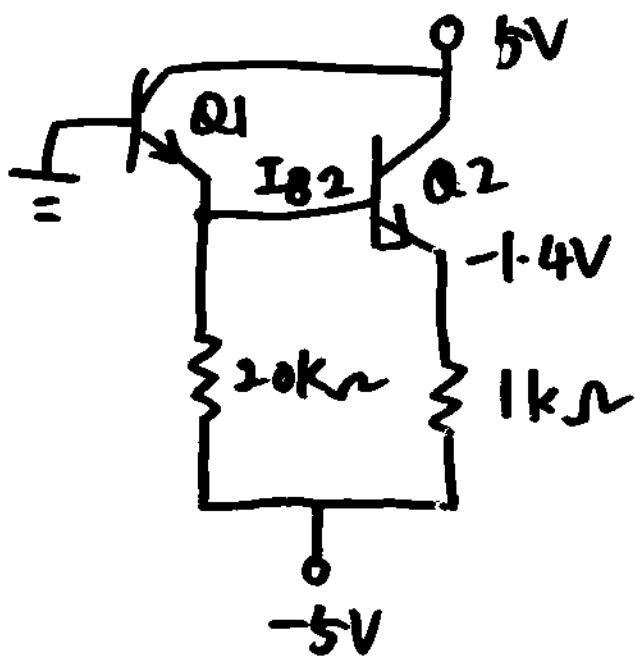
$$I_{E2} = 2.39\text{mA}$$

$$\text{Voltages: } V_{C1} = \boxed{5} - (1.12\text{mA} - 23.7\mu\text{A})5k\Omega = -0.481\text{V}$$

$$V_{E1} = \boxed{-5} + 1.13\text{mA} \cdot 2k\Omega = -2.74\text{V}$$

$$V_{E2} = \boxed{5} - 2.39\text{mA} \cdot 2k\Omega = 0.22\text{V}$$

$$V_{C2} = \boxed{-5} + 2.37\text{mA} \cdot 1.5k\Omega = -1.45\text{V}$$



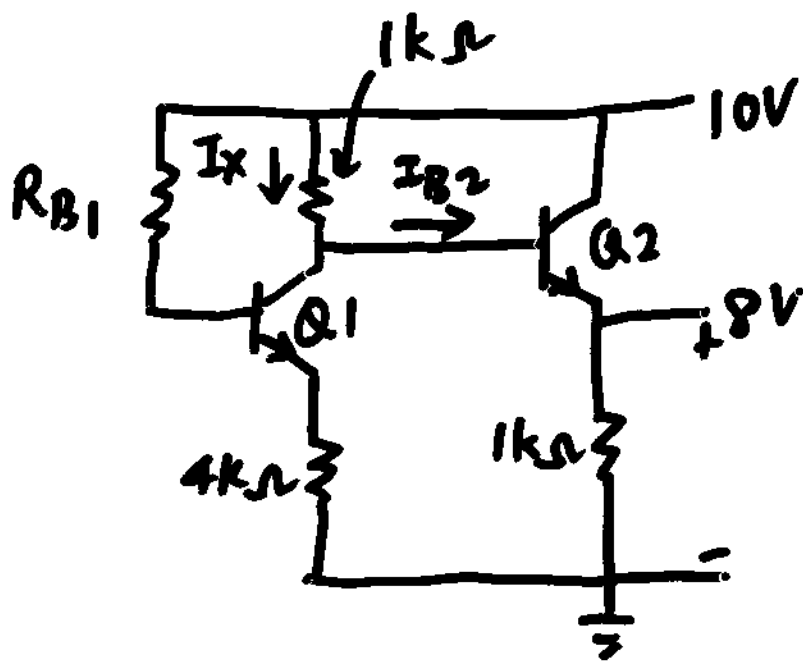
$$\beta = 80$$

$$V_{BE(ON)} = 0.7V$$

$$I_{E2} = \frac{-1.4V - (-5)}{1k\Omega} = 3.6mA$$

$$I_{B2} = \frac{3.6mA}{\beta + 1} = 44.4\mu A$$

$$I_{E1} = I_{B2} + \frac{-0.7 - (-5)}{20k\Omega} = 0.26mA$$



$$\beta = 100$$

$$V_{E2} = 8V$$

$$V_{BE(ON)} = 0.7V$$

$$\therefore V_{CB2} = 10 - (8 + 0.7) = 1.3V$$

$$I_{E2} = \frac{8}{1k\Omega} = 8mA$$

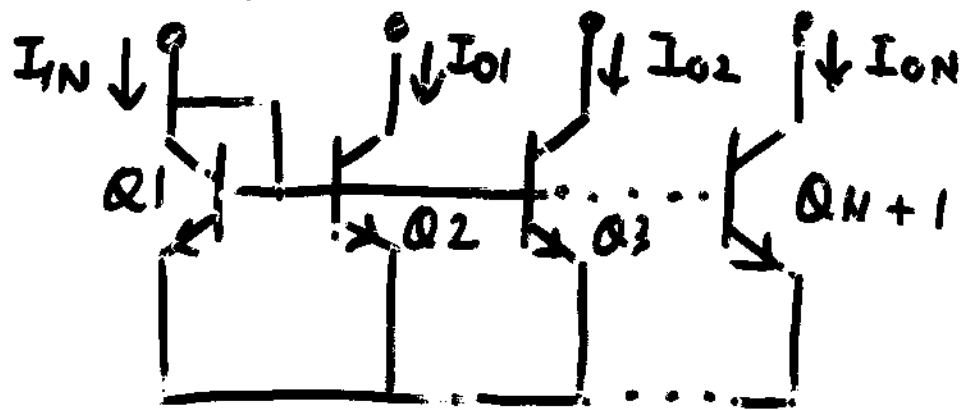
$$I_{B2} = \frac{8mA}{\beta + 1} = 79\mu A$$

$$V_{B2} = 8.7V$$

$$I_x = \frac{10 - 8.7}{1k\Omega} = 1.3mA$$

$$R_{B1} ?$$

# Multiple-Output Current Mirror



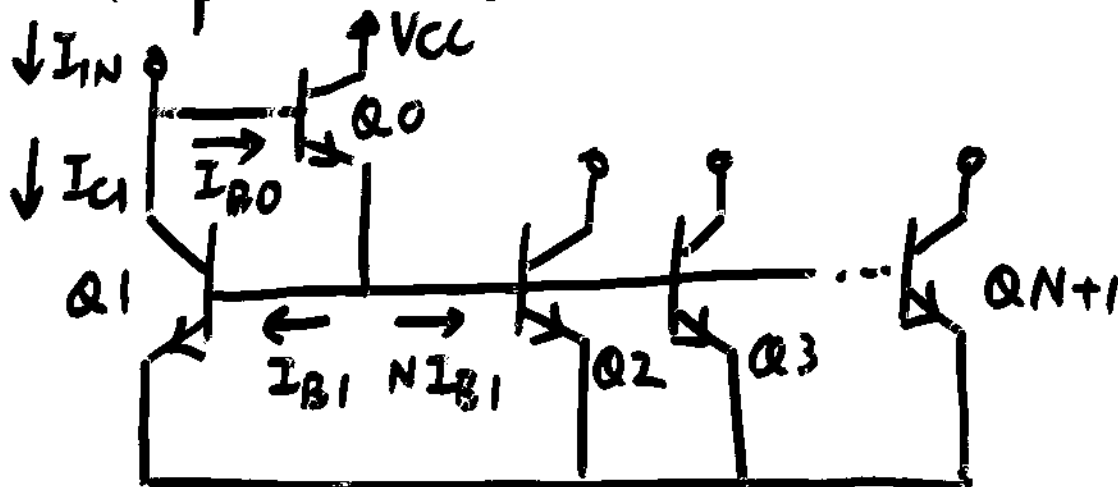
$$I_{IN} = I_{C1} + (N+1)I_B$$

$$= (\beta + N + 1)I_B$$

$$I_O = \beta I_B$$

$$= \frac{\beta}{(\beta + N + 1)} I_{IN}$$

## Improved version



$$I_{B0} = \frac{(N+1)I_{B1}}{\beta+1}$$

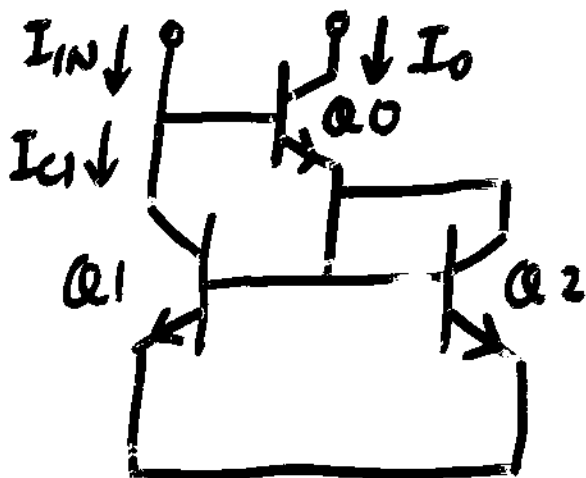
$$I_O = \frac{I_{IN}}{1 + \frac{N+1}{\beta(\beta+1)}}$$

# Early Effect

$$\begin{aligned}
 I_{IN} &= I_{C1} + 2I_B \\
 &= \beta I_B \left(1 + \frac{V_{CE1}}{V_A}\right) + 2I_B \\
 &= \left[2 + \beta \left(1 + \frac{V_{CE1}}{V_A}\right)\right] I_B
 \end{aligned}$$

$$\begin{aligned}
 I_O &= I_{C2} \\
 &= \beta I_B \left(1 + \frac{V_{CE2}}{V_A}\right) \\
 &= \frac{\beta \left(1 + \frac{V_{CE2}}{V_A}\right)}{\left[2 + \beta \left(1 + \frac{V_{CE1}}{V_A}\right)\right]} I_{IN}
 \end{aligned}$$

# Wilson Current Mirror



$$\begin{aligned}
 V_{CE2} &= 0 \\
 V_{BE1} &= V_{BE2} \\
 V_{CE1} &= V_{BE3} + V_{BE1} \\
 V_{CE2} &= V_{BE1}
 \end{aligned}$$

$$\frac{I_O}{I_{in}} = ?$$