BJT Current Sources

Dr. M. Shiple

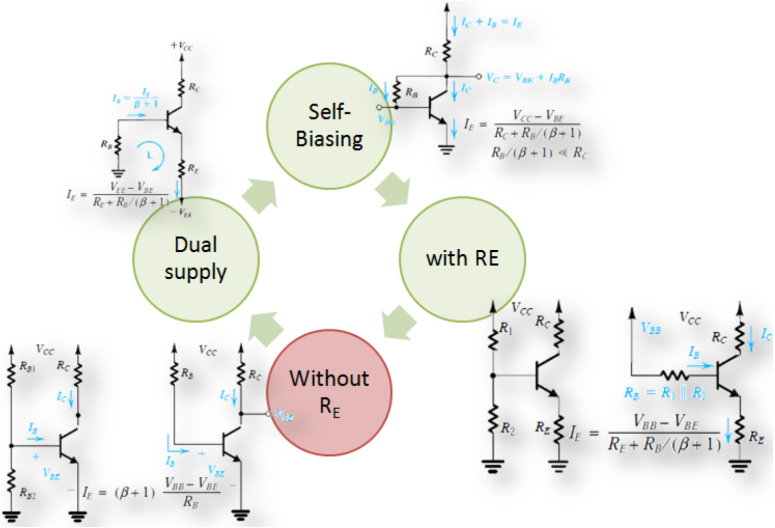
Advanced Electronic Circuits (EEI 184), 2018

Outline

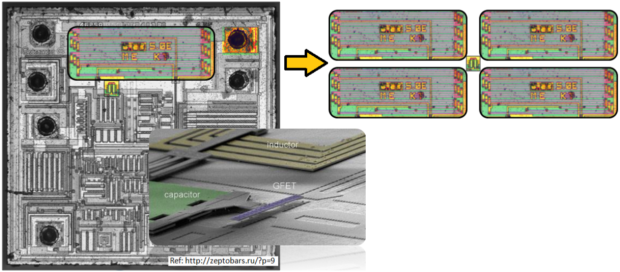
Introduction

Discrete Circuit Biasing

Independent on β



Purpose

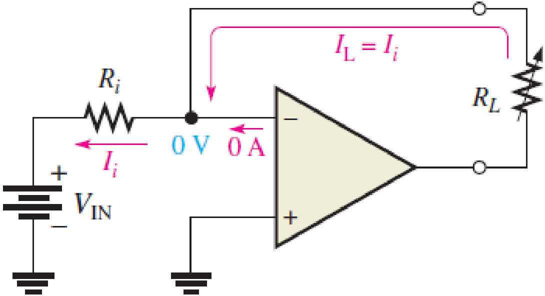


- Resistors require relatively large areas.
- Resistor biasing technique uses coupling and bypass capacitors.

Current Sources

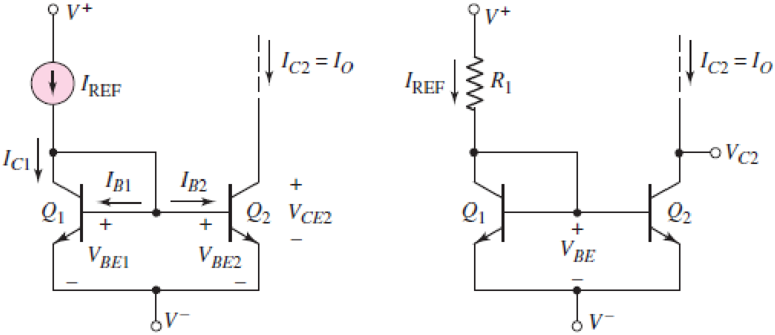
Problem Definition

Problem



Constant-current source delivers a load current that remains constant when the load resistance changes

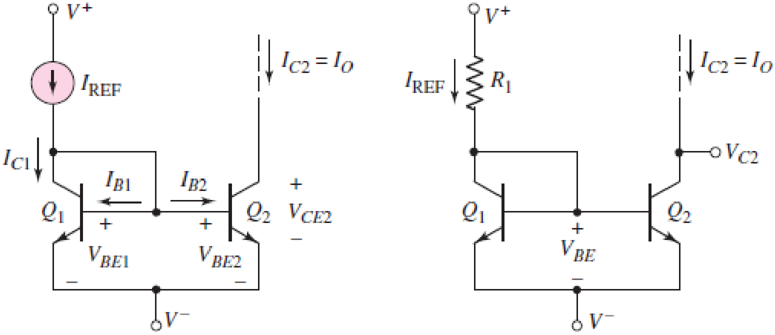
Two-Transistor Current Source



- Identical transistors Q1 and Q2.
- Operating at the same temperature.
- B-E voltage equal in Q1 and Q2.

$$I_{Ref} = \frac{V^{+} - V_{BE} - V^{-}}{R_1}$$

Cont.:Two-Transistor Current Source



According to matching transistor $I_{C2} = I_{C1}$

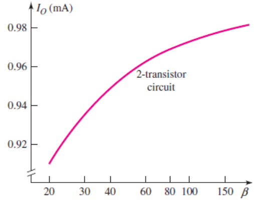
$$I_{Ref} = I_{C1} + 2I_B \qquad I_{B1} = I_{B1}$$

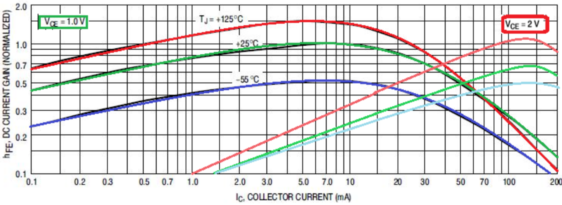
$$= I_{C2}\left(1 + \frac{2}{\beta}\right)$$

$$I_{C2} = \frac{I_{Ref}}{\left(1 + \frac{2}{\beta}\right)} \qquad I_{Ref} = \frac{V^+ - V_{BE} - V^-}{R_1}$$

β Dependence

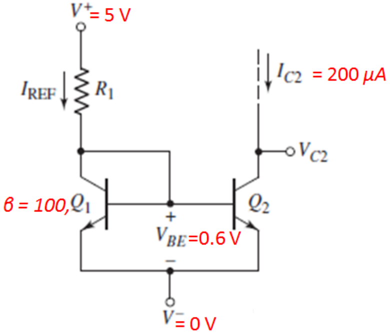
β Dependence





$$I_{C2} = \frac{I_{Ref}}{1 + \frac{2}{\beta}}$$

Design Example



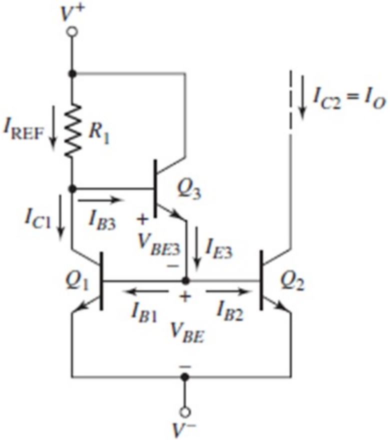
Find R_1

$$I_{Ref} = I_{C2}\left(1+\frac{2}{\beta}\right) = 204\mu A$$

$$R_1 = \frac{V^+ - V_{BE} - V^-}{I_{Ref}} = 21.6K\Omega$$

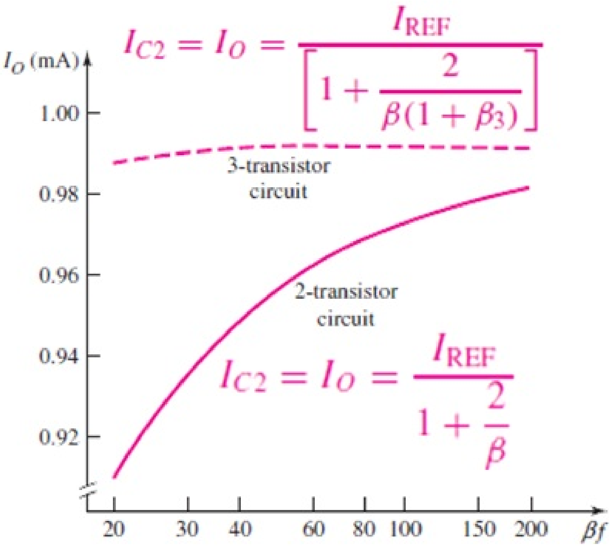
Three-Transistor Current Source

$$I_{Ref} = I_{C1} + I_{B3}$$
$$I_{E3} = (1+\beta)I_{B3}$$
$$I_{E3} = 2I_B$$
$$I_{C2} = \beta I_B$$
$$\therefore I_{Ref} = I_{C1} + \frac{I_{E3}}{(1+\beta)}$$
$$I_{Ref} = I_{C1} + \frac{2I_B}{(1+\beta)}$$
$$= I_{C1} + \frac{2I_{C2}}{\beta(1+\beta)}$$
$$= I_{C2}\left(1 + \frac{2}{\beta(1+\beta)}\right)$$



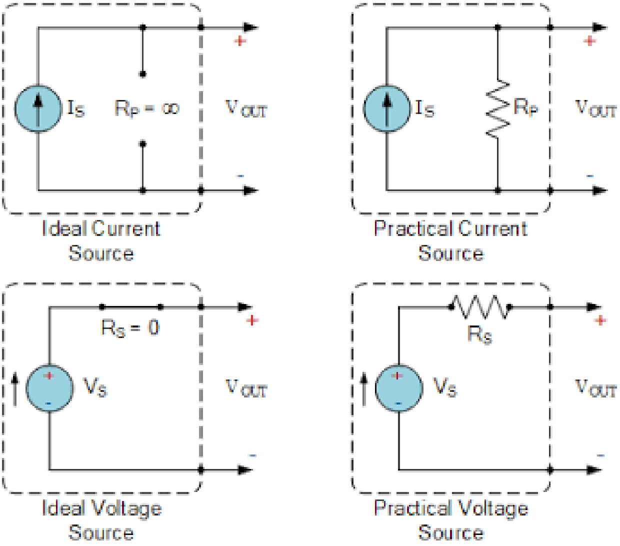
$$I_{C2} = \frac{I_{Ref}}{\left(1 + \frac{2}{\beta(1+\beta)}\right)}$$

β Dependence

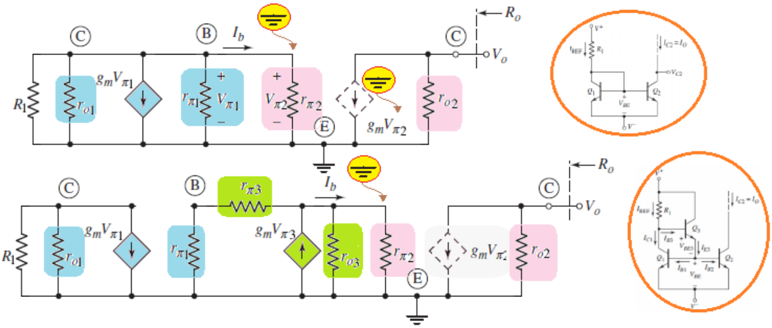


r_o Output Resistance

Output Resistance

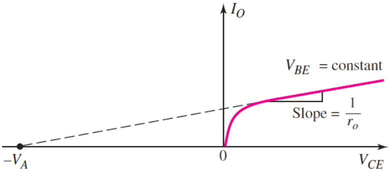


Output Resistance Two/Three transistors

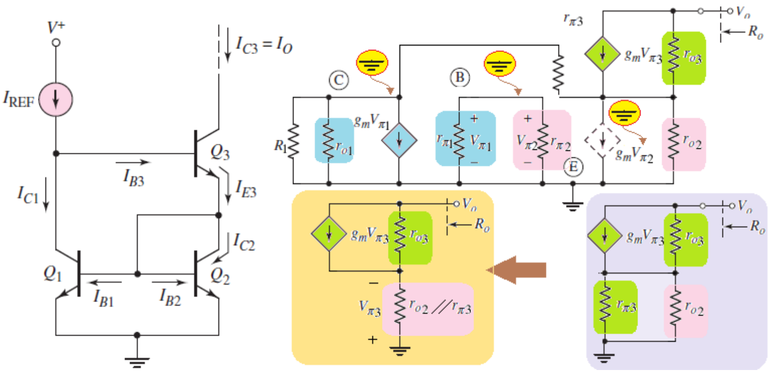


For constant biasing $V_{\pi 2} = 0$

$$R_o = \frac{V_o}{I_o} = r_{o2}$$



Wilson Current Source



For constant biasing $V_{\pi 2} = 0$

Wilson:Output Resistance

$$I_o = g_m V_{\pi 3} + \left(\frac{V_o - I_o (r_{o2} || r_{\pi 3})}{r_{o3}} \right)$$

$$\because V_{\pi 3} = -I_o (r_{o2} || r_{\pi 3})$$

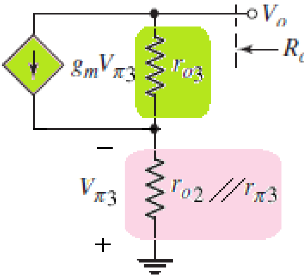
$$r_{o3} I_o = -r_{o3} g_m I_o (r_{o2} || r_{\pi 3}) + V_o - I_o (r_{o2} || r_{\pi 3})$$

$$\frac{V_o}{I_o} = r_{o3} + r_{o3} g_m (r_{o2} || r_{\pi 3}) + (r_{o2} || r_{\pi 3})$$

$$assume \quad r_{\pi 3} \ll r_{o2}$$

$$= r_{o3} + r_{o3} g_m r_{\pi 3} + r_{\pi 3} \approx 0$$

$$\cong r_{o3}(1 + \beta) \cong \beta r_{o3} \uparrow$$



Wilson Current Source

George R. Wilson

Wilson devised this configuration in 1967 when he and Barrie Gilbert challenged each other to find an improved current mirror overnight that would use only three transistors. Wilson won the challenge.

Wilson Current Source

$$I_{Ref} = I_{C1} + I_{B3}$$

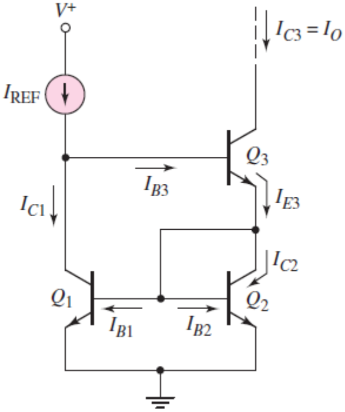
$$I_{E3} = I_{C2} + 2I_B = I_{C2}\left(1 + \frac{2}{\beta}\right)$$

$$= I_{C2} + 2I_B = I_{C2}\left(1 + \frac{2}{\beta}\right)$$

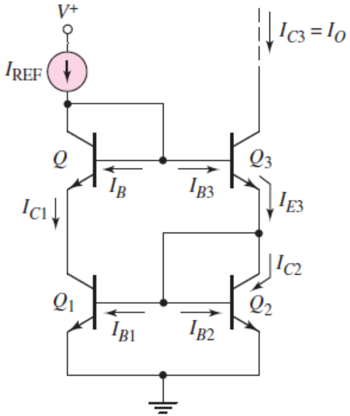
$$I_{C2} = \frac{I_{E3}}{1 + \frac{2}{\beta}} = \frac{(1+\beta)}{(2+\beta)} I_{C3}$$

$$I_{Ref} = \frac{(1+\beta)}{(2+\beta)} I_{C3} + \frac{I_{C3}}{\beta}$$

$$I_o = I_{Ref}\left(\frac{1}{1 + \left(\frac{2}{\beta(2+\beta)}\right)}\right)$$

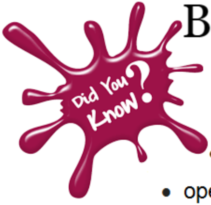


Further improvement (full Wilson Mirror)



Low output currents

Widlar Current Source

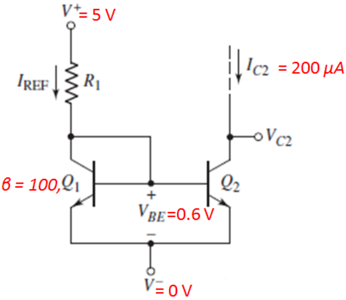


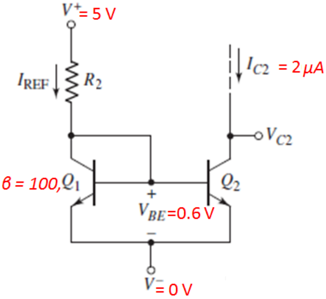
Bob Widlar

- Widlar current source
- bandgap voltage reference
- voltage regulator ICs (μA723)
- operational amplifier ICs (μA702, μA709)
- Active loads in the LM101A op amp (1967)

(1937 – 1991)

Problem





Find R_1 and R_2

$$I_{Ref} = I_{C2}\left(1 + \frac{2}{\beta}\right) = 204\mu A \qquad and \qquad 2.02\mu A$$

$$R_1 = \frac{V^+ - V_{BE} - V^-}{I_{Ref}} = 21.6K\Omega \qquad and \qquad \boxed{2.17M\Omega}$$

Widlar Current Source

$$I_o = I_S e^{\frac{V_{BE2}}{V_T}}$$

$$V_{BE2} = V_T ln\left(\frac{I_o}{I_S}\right)$$

$$I_{Ref} = I_S e^{\frac{V_{BE1}}{V_T}}$$

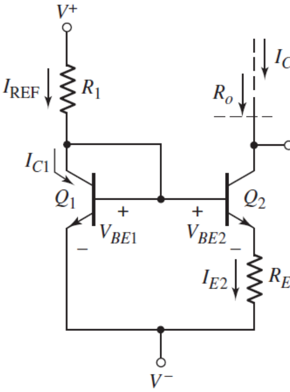
$$V_{BE1} = V_T ln\left(\frac{I_{Ref}}{I_S}\right)$$

$$V_{BE1} = V_{BE2} + I_o R_E \qquad \because I_o \approx I_E$$

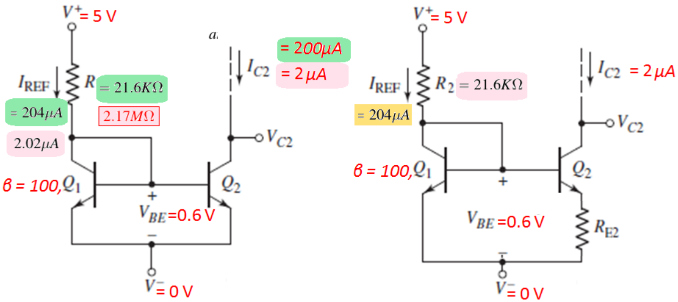
$$V_{BE1} - V_{BE2} = V_T ln\left(\frac{I_{Ref}}{I_o}\right)$$

$$\therefore I_o R_E = V_T ln\left(\frac{I_{Ref}}{I_o}\right)$$

$$R_1 = \frac{V^+ - V_{BE} - V^-}{I_{Ref}}$$



Example: Widlar Vs. Two Transistor

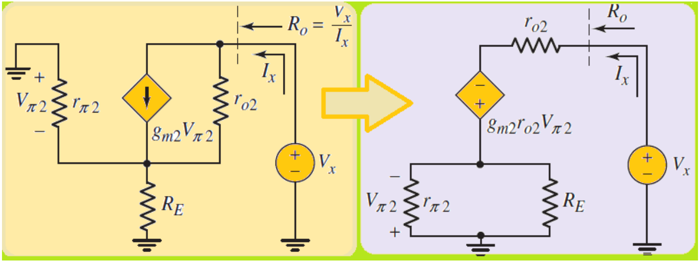


Find R_{E2} assume $R_2 = 21.6K$

$$R_2 = \frac{V^+ - V_{BE} - V^-}{I_{Ref}} \Rightarrow I_{Ref} = 203.7\mu A \approx 204\mu A$$

$$\therefore I_o R_E = V_T ln\left(\frac{I_{Ref}}{I_o}\right) \Rightarrow R_E = 60.1K\Omega \approx 60K\Omega$$

Widlar Output Resistor



$$R_o = \frac{V_x}{I_x} \Rightarrow V_x = I_x r_{o2} - g_{m2} r_{o2} V_{\pi 2} + V_{\pi 2}$$

$$V_{\pi 2} = I_x (R_E || r_{\pi 2}) \Rightarrow V_x = I_x \left(r_{o2} + g_{m2} r_{o2} (R_E || r_{\pi 2}) + (R_E || r_{\pi 2}) \right)$$

$$R_o = r_{o2} \left(1 + g_{m2} (R_E || r_{\pi 2}) + \frac{(R_E || r_{\pi 2})}{r_{o2}} \right)$$

$$\because (1/ro2) \ll g_{m2};$$

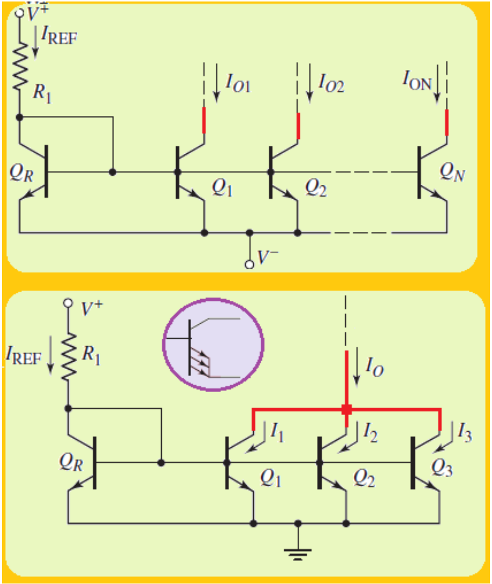
$\therefore R_o \approx r_{o2}(1 + g_{m2}(R_E||r_{\pi 2}))$ compare with $R_{O_2 tran} = r_{o2}$

Multi-transistor

Multitransistor Current Mirrors

$$I_{O1} = I_{O2} = I_{ON} = \frac{I_{Ref}}{1 + \frac{1+N}{\beta}}$$

$$I_O = N \frac{I_{Ref}}{1 + \frac{1+N}{\beta}}$$



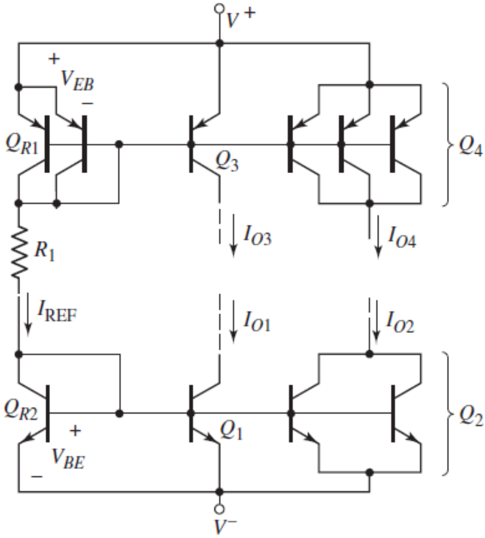
Examples: Multitransistor

$$I_{O3} = \frac{1}{2} I_{REF}$$

$$I_{O4} = \frac{3}{2} I_{REF}$$

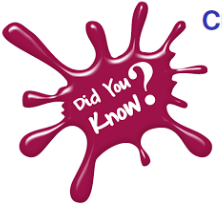
$$I_{O1} = I_{REF}$$

$$I_{O2} = 2 I_{REF}$$



Current Amplifiers

Current Amplifiers

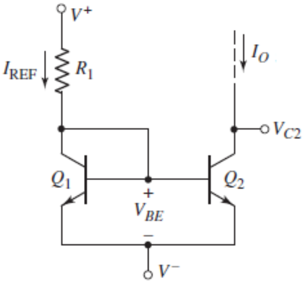


Current amplifiers

- Current amplifiers are occasionally used in analog systems.
- 1990s:analog designers promoted the notion of "current-mode circuits".

Mismatched Transistors

- The parameters I_{S1} and I_{S2} contain both the electrical and geometric parameters of Q_1 and Q_2.
- If Q_1 and Q_2 are not identical, then $I_{S1} \neq I_{S2}$.



$$I_{REF} = I_{S1} e^{\frac{V_{BE}}{V_T}}$$

$$I_o = I_{S2} e^{\frac{V_{BE}}{V_T}}$$

$$\therefore I_o = I_{REF} \left(\frac{I_{S2}}{I_{S1}} \right)$$

$$I_o = n \times I_{REF}.$$