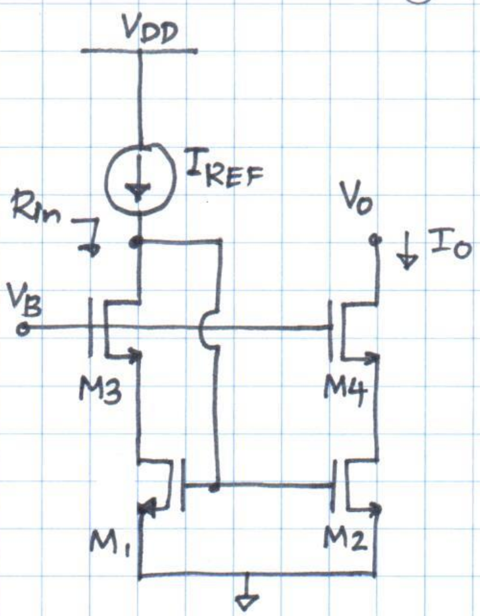
High Swing Cascode Current Mirror



Keeping all devices in saturation

$$R_{in_1} \cong \frac{1}{g_{m_1}}$$ (PROVE with small sig. analysis)

$$R_{out} = (g_{m_4} r_{o_4}) \cdot r_{o_2}$$

DC balance ✓

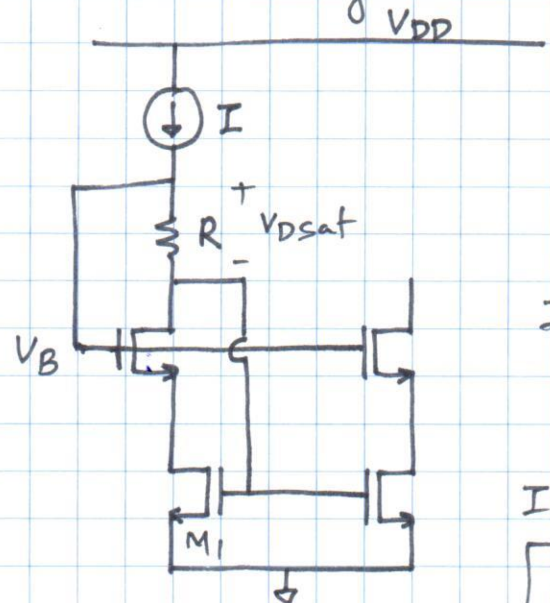
$$V_{DS_1} = V_{DS_2} = V_{dsat}$$

$$V_B = V_{GS_3} + V_{dsat}$$
$$= V_T + V_{dsat} + V_{dsat}$$
$$= V_T + 2V_{dsat}$$

$$V_{o\,min} = V_{dsat_4} + V_{dsat_2} = 2V_{dsat}$$

- Need to generate V_B.

Smart Biasing



V_B generated using I_{REF}.

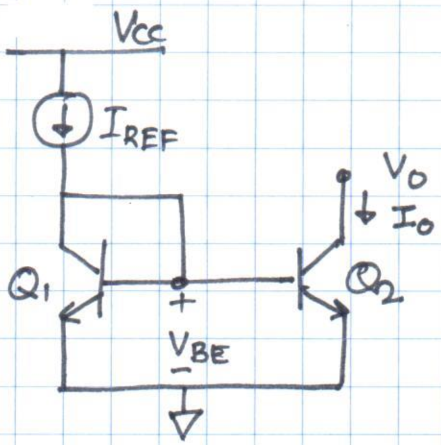
$$V_B = (V_T + 2V_{dsat})$$

$$IR = V_B - V_{GS_1}$$
$$= (V_T + 2V_{dsat}) - (V_T + V_{dsat})$$

$$IR = V_{dsat}$$

$$\boxed{R = \frac{V_{dsat}}{I}}$$

Bipolar Current Mirrors

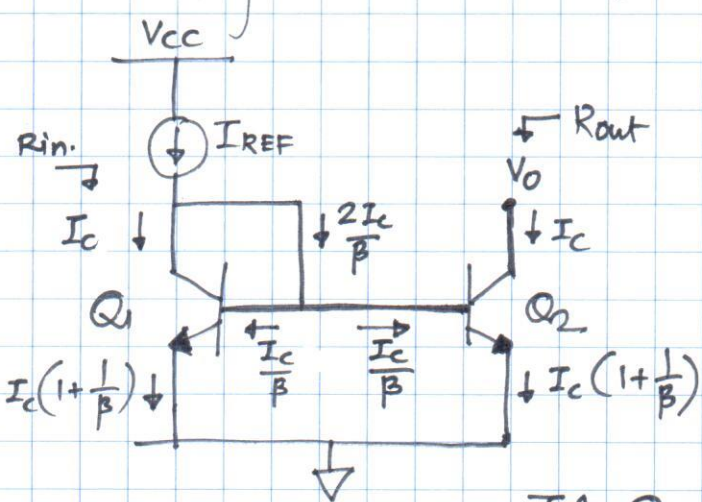


$V_O > V_{CEsat_2}$ (0.3 V)

$$\frac{I_O}{I_{REF}} = \frac{I_{S_2}}{I_{S_1}} = \frac{\text{Area of EBJ of } Q_2}{\text{Area of EBJ of } Q_1}$$

(Ignoring Base current $\beta = \infty$)

Effect of finite transistor β.



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

$$\frac{I_c}{I_{REF}} = \frac{1}{1+\frac{2}{\beta}}$$

If Q_2 area is m times bigger

then

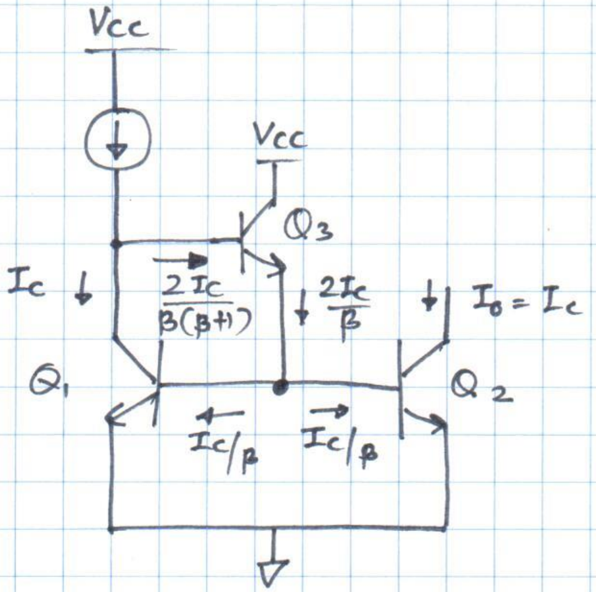
$$\frac{I_O}{I_{REF}} = \frac{I_c}{I_{REF}} = \frac{m}{1+\frac{m+1}{\beta}}$$

$$R_{in} = \frac{1}{g_{m_1}} \qquad R_{out} = r_{o_2} = \frac{V_A}{I_O}$$

Taking into account effect of finite r_{o2} (Early Effect)

$$\frac{I_O}{I_{REF}} = \frac{m}{1+\frac{m+1}{\beta}} \cdot \underbrace{\left(1+\frac{V_O - V_{BE}}{V_A}\right)}_{=1 \text{ when } V_O = V_{BE}}$$

Base Current Compensation



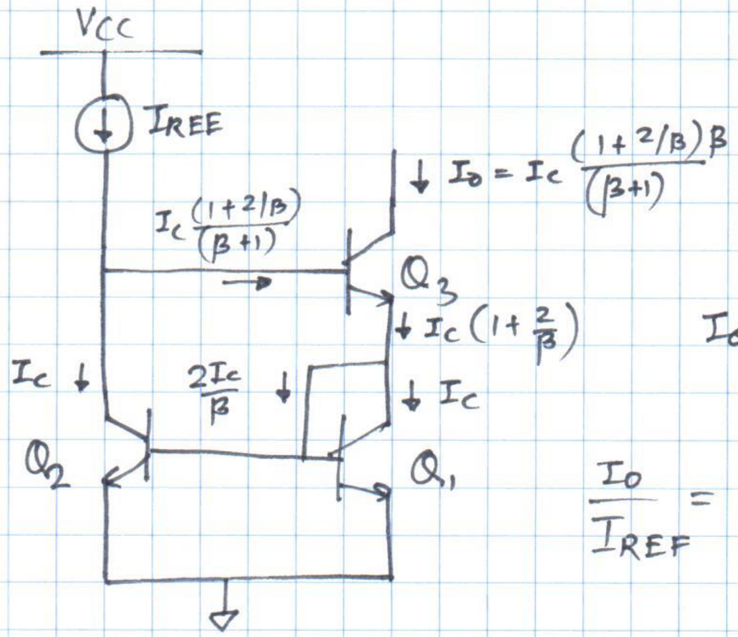
$$I_{REF} = I_c + \frac{2I_c}{\beta(\beta+1)}$$

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

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

$$\frac{I_o}{I_{REF}} \cong \frac{1}{1 + \frac{2}{\beta^2}}$$

Wilson Current Mirror



$$I_{REF} = I_c\left[1 + \frac{(1+2/\beta)}{(\beta+1)}\right]$$

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

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

$$= \frac{\beta+2}{\beta+2+\frac{2}{\beta}} \cong \frac{1}{1+2/\beta^2}$$

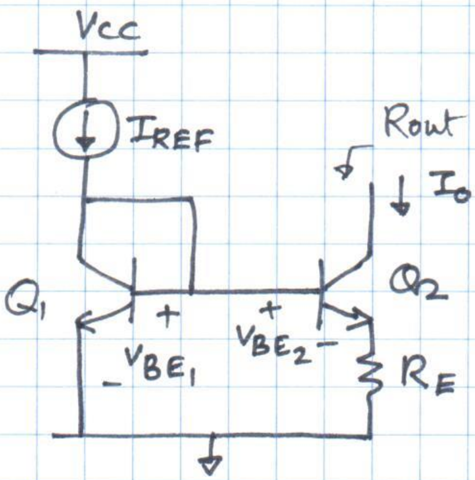
* $R_{out} = \frac{\beta_3 r_{o_3}}{2}$

Cascoding effect.

[Reference. – Sedra & Smith pp. 505]

The Widlar Current Source

(Bob Widlar)



$$V_{BE_1} = V_T \ln\left(\frac{I_{REF}}{I_S}\right)$$

$$V_{BE_2} = V_T \ln\left(\frac{I_o}{I_S}\right)$$

$$V_{BE_1} - V_{BE_2} = V_T \ln\left(\frac{I_{REF}}{I_o}\right)$$

$$I_o R_E = V_T \ln\left(\frac{I_{REF}}{I_o}\right).$$

* Allows generation of small current using relatively small resistors.

→ "ln" effect $\ln(100) = 4.6$; $\ln(1000) = \underline{\underline{6.9}}$

For example: to generate $10\,\mu A$ from $5V$.

$$R = \frac{5V - 0.7V}{10\,\mu A} = 430\,k\Omega \quad (\text{large area})$$

Using $I_{REF} = 1\,mA$; we can generate $I_o = 10\,\mu A$

$$10\,\mu A \times R_E = 26\,mV \cdot \ln\left(\frac{1\,mA}{10\,\mu A}\right)$$

$$R_E = \frac{26\,mV}{10\,\mu A} \times 4.6 = 11.96\,k\Omega$$

<u>Advantage</u>

$R_{out} = [1 + g_m (R_E \| r_\pi)]\, r_o$ <u><u>high</u></u>